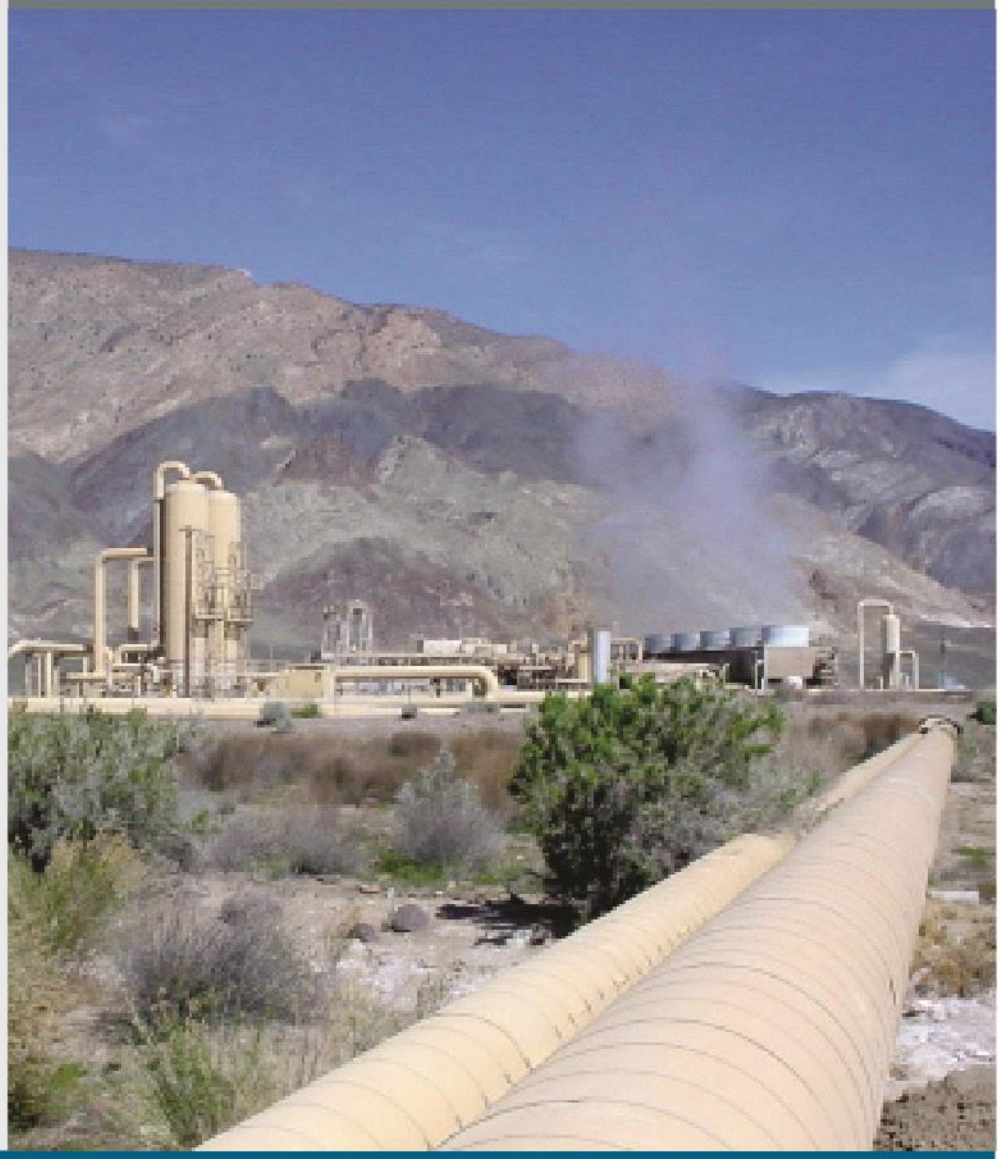
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

GEOTHERMAL TECHNOLOGIES OFFICE

2013 Peer Review Report

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Geothermal Technologies Office
2013 Peer Review Report

February 2014



The photo on the cover page is of the Dixie Valley, Nevada plant. Photo courtesy of the Geothermal Resources Council.

Geothermal Technologies Office

2013 Peer Review Report
February 2014

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Geothermal Technologies Office
2013 Peer Review Meeting
April 2013

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Chair
2013 Geothermal Technologies Peer Review Panel

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Executive Summary

Meeting Logistics

On April 22–25, 2013, the Geothermal Technologies Office (GTO, or the Office) within the Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy (DOE), conducted its annual program peer review in Denver, Colorado. In accordance with the EERE Peer Review Guide,[1] the review provided an independent, expert evaluation of the technical progress and merit of GTO-funded projects. Further, the review was a forum for feedback and recommendations on future GTO strategic planning. During the course of the peer review, DOE-funded projects were evaluated for (1) their contribution to the mission and goals of the GTO and (2) their progress against stated project objectives. Principal Investigators (PIs) came together in sessions organized by topic "tracks" to disseminate information, progress, and results to a panel of independent experts as well as attendees. Dr. Kate Baker served as the overall chairperson, with responsibility for overseeing the entire peer review process and providing guidance to reviewers to ensure consistency, transparency, and independence throughout the review process.

The 2013 GTO Peer Review Meeting was organized into the following tracks, with associated sessions:

- Track 1 – Co-Produced; Low Temperature; Supercritical Carbon Dioxide; Working Fluids; Innovative Exploration Techniques; Geophysics; and Geochemistry
- Track 2 – Enhanced Geothermal Systems Demonstrations; Fluid Imaging; Characterizing Fractures; Induced Seismicity; High Temperature Tools; Drilling Systems; Materials; Zonal Isolation; and Innovative Methods of Heat Recovery
- Track 3 – Systems Analysis; Data System Development and Population; Tracers; and Modeling.

Evaluation and Scoring Methodology

The following decision criteria were used by GTO to determine whether or not a project should be peer reviewed at the 2013 meeting: (1) project funding levels, (2) whether or not the project was presented the previous year, (3) its project management status, and (4) how the project performed based on reviewer feedback from the previous peer review. GTO also decided how the projects should be presented and evaluated at the peer review meeting. Projects could either be presented via oral presentation, which is subject to evaluation from expert reviewers; or they could be presented during a poster session, which is not subject to expert review and evaluation. At the 2013 Peer Review Meeting, 97 out of 112 projects were orally presented and reviewed by at least three expert reviewers, who provided both numeric evaluations and written comments. The remaining 15 projects were presented as posters at the review.

Reviewers provided comments and numeric scores in four areas: (1) relevance/impact of research, (2) scientific/technical approach, (3) accomplishments, results and progress, and (4) project management/coordination. Numeric scores were based on a ten-point scale, with qualitative descriptors given for the numerical scoring index. The table below illustrates the weighting of each criterion for each of the 12 geothermal technology areas. Scoring weight varies by technology area due to an effort by the Office to emphasize an alignment of areas of importance with the nature of the work performed. A more detailed explanation of the scoring rubric can be found in Section 2.1.

[1] *Peer Review Guide*, Office of Energy Efficiency and Renewable Energy (EERE), August 2004

Weighting of scoring criteria or metrics

Technology Area	Relevance /Impact of Research	Scientific /Technical Approach	Accomplishments, Results, and Progress	Project Management /Coordination
1. Co-Produced and Low Temperature	20%	30%	40%	10%
2. Data System Development and Population	15%	30%	30%	25%
3. Enhanced Geothermal Systems Demonstrations	20%	25%	40%	15%
4. Fluid Imaging, Characterizing Fractures, and Induced Seismicity	20%	30%	40%	10%
5. Geophysics and Geochemistry	20%	30%	40%	10%
6. High Temperature Tools and Drilling Systems	20%	30%	40%	10%
7. Innovative Exploration Techniques	20%	25%	40%	15%
8. Materials, Zonal Isolation, and Innovative Methods of Heat Recovery	20%	30%	40%	10%
9. Modeling	20%	30%	40%	10%
10. Supercritical Carbon Dioxide and Working Fluids	20%	30%	40%	10%
11. System Analysis	20%	30%	25%	25%
12. Tracers	20%	30%	40%	10%

For each project, a **weighted average score** was calculated (from the combined scores of individual reviewers) for each of the four aforementioned criteria. The following formula, where x = score and y = weight, was used to calculate the weighted average score:

Example Calculation:

$\{(x_1*y_1) + (x_2*y_2) + (x_3*y_3) + (x_4*y_4)\}$= total
{(10*.20) + (7*.40) + (9*.15) + (9*.25)} = total
{(2) + (2.8) + (1.5) + (2.25)} = 8.6 weighted average score

Additionally, reviewers were asked to provide qualitative feedback on the strengths, weaknesses, and suggested improvements for the projects they evaluated.

For the purposes of the 2013 Peer Review, GTO project portfolios were organized into four program areas: (1) Enhanced Geothermal Systems Demonstrations, (2) Hydrothermal Resource Confirmation, (3) Research and Development, and (4) Systems Analysis. Expert reviewers evaluated the overall performance of those program areas by providing qualitative feedback on three metrics: (1) Goals—how well the program area goals aligned to industry needs, (2) Projects— how well a program area formed an effectively balanced portfolio of projects that will contribute to achieving its goals and objectives, and (3) Communication and Collaboration—the degree and impact that program area interaction has on industry, universities, federal agencies, as well as comparable international actors and other stakeholders. Additionally, reviewers provided qualitative responses on program area strengths, weaknesses, and any recommendations for improvement.

Scores and comments were submitted by reviewers into an online database called the Peer Review Management Information System (P2RMIS), which allows real-time tracking of the review process. P2RMIS interfaces with external electronic application systems, facilities online meeting planning and logistics, and supports evaluations, reviews, and scoring.

Summary of Scoring Results and Analysis

The table below provides an overview of the weighted average scores of all of the projects based on technology area. The table includes the number of projects, the average number of reviewers to evaluate those projects, and the weighted average scores of all of the projects combined (average, maximum, and minimum) per technology area.

Summary scoring of projects by technology area

Technology Area	Number of Projects Reviewed	Average Number of Reviewers per Project	Average Weighted Average Score	Weighted Maximum Score	Weighted Minimum Score
Above Average Scoring Technology Areas/Panels					
Data Systems Development and Population	4	4	7.8	8.7	7.0
Modeling	12	3.9	7.6	8.4	6.6
Fluid Imaging, Characterizing Fractures and Induced Seismicity	10	4	7.5	8.7	6.6
Enhanced Geothermal Systems Demonstrations	5	4	7.5	8.4	6.3
Average Scoring Technology Areas/Panels					
Geophysics and Geochemistry	16	4	7.2	8.4	5.5
Tracers	3	4	7.0	7.8	6.0
Systems Analysis	6	3.8	7.0	8.6	5.6
High Temperature Tools and Drilling Systems	13	4	6.9	8.6	1.0
Innovative Exploration Techniques	9	3.4	6.8	8.6	4.4
Below Average Scoring Technology Areas/Panels					
Co-Produced and Low Temperature	10	4	6.1	8.4	3.2
Materials; Zonal Isolation; Innovative Methods of Heat Recovery	6	3.5	5.7	7.8	1.0
Supercritical CO2 and Working Fluids	3	4	5.6	6.5	5.0

For individual projects, a comprehensive list of reviewer comments, PI responses, and individual project scoring evaluations can be found in Appendix A.

Common Themes of the Analysis and Results

Common themes of projects with below average scores in accomplishments include:

(1) Hypotheses that were not confirmed by data
(2) An errant initial approach
(3) Causations that were assumed based on flawed correlations
(4) Slow progress
(5) A lack of investigations into novel findings
(6) Reviewer disagreement with the engineering or scientific methodology
(7) Issues with project management
(8) Little consideration for the feasibility of scaling up bench scale experiments
(9) A disconnect or a lack of experimental, field-tested, and/or real-world data
(10) A lack of novel methodology, approach, or accomplishments
(11) Questionable or lacking field testing, data validation/documentation, and/or site selection,
(12) A project scope that is inappropriate or has expanded detrimentally
(13) Insufficient project funding.

Reviewers in 2013 seemed to focus their comments on quality, comprehensive data reporting, and awareness of where projects fit in the current geothermal knowledge base. It should be noted that some projects received low scores in Accomplishments that, despite being on schedule, were not at a point where results were available. Other projects with positive results received low scores due to vague results where poor presentation or proprietary concerns impeded clear dissemination of data. Through this analysis, GTO observed that low scores by themselves do not always indicate low-performing projects. The comments must be examined to determine whether scores are low due to substantial structural issues in the project or if the scores are a function of surmountable barriers to project success identified by reviewers.

Common themes of projects scoring highly in accomplishments include

(1) Good collection, consolidation, correlation, and/or visualization of large data sets
(2) Sufficient review of existing literature, tools, methodology, and/or data
(3) Clear technology transfer efforts or capability
(4) Application of industry or project lessons learned
(5) Strong project management and/or technical team
(6) Strong project comprehensiveness or experiment methodology
(7) Accomplishments that obviously further the industry
(8) Ability to overcome barriers
(9) Novel project component
(10) Successful proof of concept development
(11) Systematic and iterative processes for coordination and methodology
(12) Focus on data validation
(13) Actively avoiding redundancy with other work.

The elements of the list above with the highest frequency are (5) a strong project management and/or technical team and (7) accomplishments that further the industry. This is congruent with the most common themes of low scoring projects where the usefulness of the results and the creativity of the project teams in solving problems were key attributes in reviewer scoring. Many of the high-scoring projects will provide results immediately useful to furthering the industry, whereas low-scoring project results were not as mature. is the Office anticipates that as the low-scoring projects' results progress toward maturity, their scores will improve. The utility of this analysis is to highlight attributes of both low- and high-scoring projects so that lessons learned can be applied by the Office to continually improve all projects in GTO's portfolio and to avoid common pitfalls.

Progress Noted by the Peer Review Panelists

GTO staff have demonstrated an intense dedication to the Office and its goals, and Project Officer (project manager) engagement with the PIs and other partners appears to be instrumental in the high level of progress made on issues vital to national and GTO goals.

The comments below, expressed by the 2013 GTO Peer Review Panelists, summarize the current state of and progress made by the various technology areas within the Office:

- GTO has made excellent progress in making its mission, goals, and progress known to stakeholders at all levels, both nationally and internationally.
- GTO leadership seems to present a united front.
- The Research and Development (R&D) portfolio is an excellent addition to the larger GTO portfolio.
- The Geophysics portfolio is making notable progress in a number of high-impact spaces. Highlights include innovative regional-to-prospect-scale exploration methods that take measures to quantify uncertainty and value of information, and preliminary efforts to develop comprehensive methodologies and models for reservoir development and operations.

- The projects assigned within the Systems Analysis portfolio offer a diverse collection of topics, both technical and non-technical. Each project has attributes that allow it to be distinguished within the greater goals of the GTO.
- Of the Systems Analysis projects reviewed, two have made excellent strides in reaching out to geothermal stakeholders: Geothermal Electricity Technology Evaluation Model and regulatory roadmaps.
- The construction of a national database is a useful goal towards improving widespread use of geothermal [energy]. Several geothermal databases have been developed that directly address the needs of industry, researchers, and the public.
- Targeting fundamental research in geothermal exploration is a strength of the program.

Potential Issues Identified by the Peer Review Panelists

The Peer Review Panel identified the following issues that they feel are worthy of discussion or consideration by the Office:

- The 400 MW of new power by 2014 is an unrealistic goal.
- Funding delays associated with GTO have been too frequent. Changes of course during a project (for a variety reasons) take too long to obtain DOE approval and the process is too cumbersome.

Specific Recommendations of the Peer Review Panelists

The Peer Review Panel believes that addressing the comments and recommendations below could add significant value to GTO and help achieve future successes:

- GTO should rebalance the EGS Demonstrations portfolio with a focus on engaging new Oil and Gas (O&G) industry experts. The R&D portfolio should also be rebalanced and refocused. More demonstration projects and engaging the O&G industry expertise is strongly encouraged.
- GTO should consider funding additional projects that measure fundamental thermodynamic data and phase relations needed for quantitative assessment of a geothermal system. The R&D program is strong, particularly in the area of simulation and modeling.
- Fluid-mineral interactions are key to understanding geothermal systems, and while not "new," these data are integral to success.
- Characterization of the materials that make up the reservoir is key to predicting the lifetime of the system, identifying the flow zones, and predicting the impact on the engineered systems.
- The Innovative Exploration Technologies portfolio should focus on the technical requirements to drill a 5,000-foot horizontal well with multiple stimulations.
- More comprehensive studies in Systems Analysis should be adopted, perhaps using the growing National Geothermal Data System database.
- GTO should call on more international expertise, in particular from countries with substantial geothermal power production, like Iceland, New Zealand, Indonesia, and Central American countries.
- GTO should press forward with plans for a comprehensive field experiment laboratory for conducting high-risk experiments that offer the opportunity to leapfrog current technology and reduce the levelized cost of energy.
- GTO is encouraged to work with other federal agencies to disseminate reliable resource data and to reduce technical, timeline, and financing uncertainties.
- Data resources should be presented at oil and gas conferences so that the data efforts can gain a more widespread audience.

1.0 Introduction to the Geothermal Technologies Office

The Geothermal Technologies Office (GTO or the Office) invests in innovative and transformative geothermal energy technologies to find, access, and economically use the nation's geothermal resources for power production. Through research, development, and demonstration (RD&D) efforts in Enhanced Geothermal Systems (EGS), Hydrothermal Resources, and Systems Analysis, GTO is working to advance geothermal as a cost-competitive source of domestic, clean, renewable baseload energy. GTO works in partnership with industry, academia, and DOE's national laboratories. GTO conducts multi-year RD&D on surface and subsurface opportunities for reducing the risk and cost of geothermal development and deployment.

GTO's current goal is to reduce the cost of geothermal energy to be competitive with conventional sources of electricity and accelerate the development of geothermal resources.

To achieve this goal, the Office's strategy is to:

- Accelerate near-term hydrothermal growth by
  - Decreasing exploration risks and costs
  - Accelerating the development of 30 GWe of undiscovered hydrothermal resources.
- Secure the future with EGS by
  - Demonstrating the capability to create and sustain a 5-MW Enhanced Geothermal Systems (EGS) reservoir by 2020
  - Accelerating the development of 100 GWe by 2050 (MIT).

Additionally, the Office has an increased focus on research to enable the identification of new geothermal prospects, regulatory roadmaps and streamlining, efforts to optimize and validate EGS, strategic mineral extraction, and increasing funding leverage.

GTO is currently organized into three program areas: (1) Enhanced Geothermal Systems, (2) Hydrothermal (which includes both Innovative Exploration Technologies and Low-Temperature and Co-produced Resources), and (3) Systems Analysis. The funding and budget history for the Geothermal Technologies Office is illustrated below in Figure 1-1. and Figure 1-2.

The Office has a total portfolio of more than 200 RD&D projects underway with academia, the national laboratories, industry, and other entities. The Office also supports some deployment activities designed to move advanced technologies into the market and conducts a broad range of systems analysis activities. It should be noted that management of the ground source heat pump portfolio is no longer part of GTO, but part of the Buildings Technologies Office in EERE.

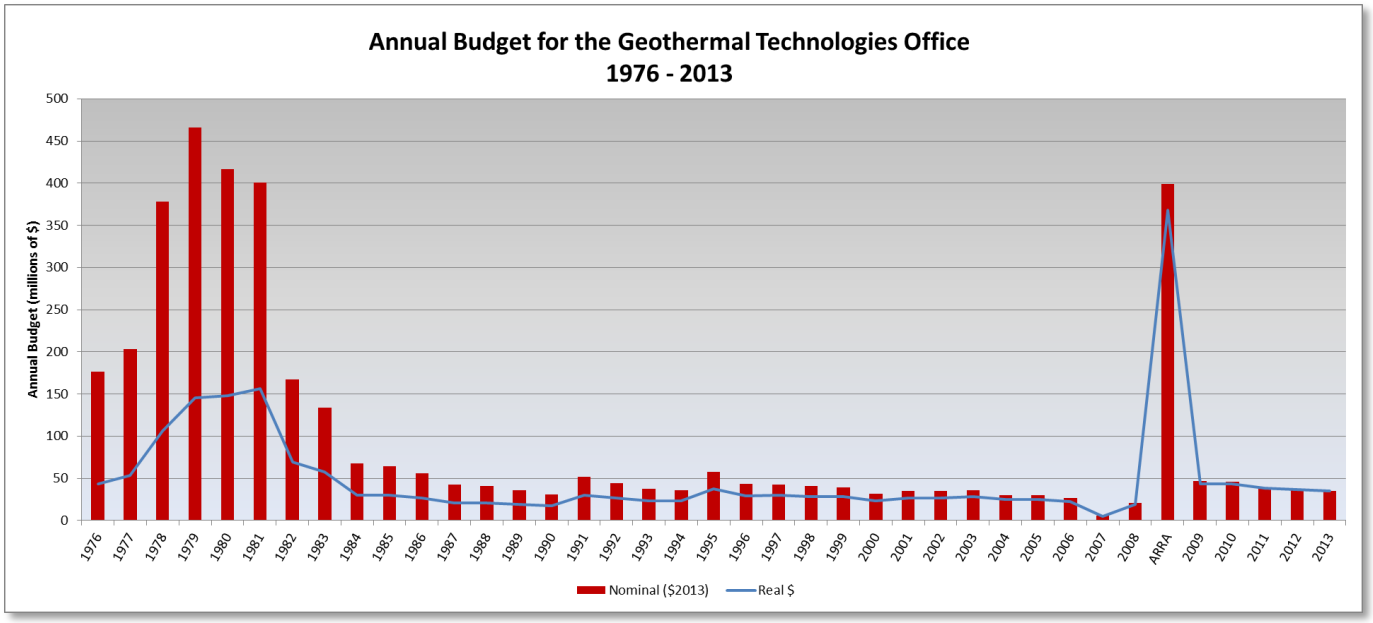


Figure 1-1. Geothermal Technologies Office funding history

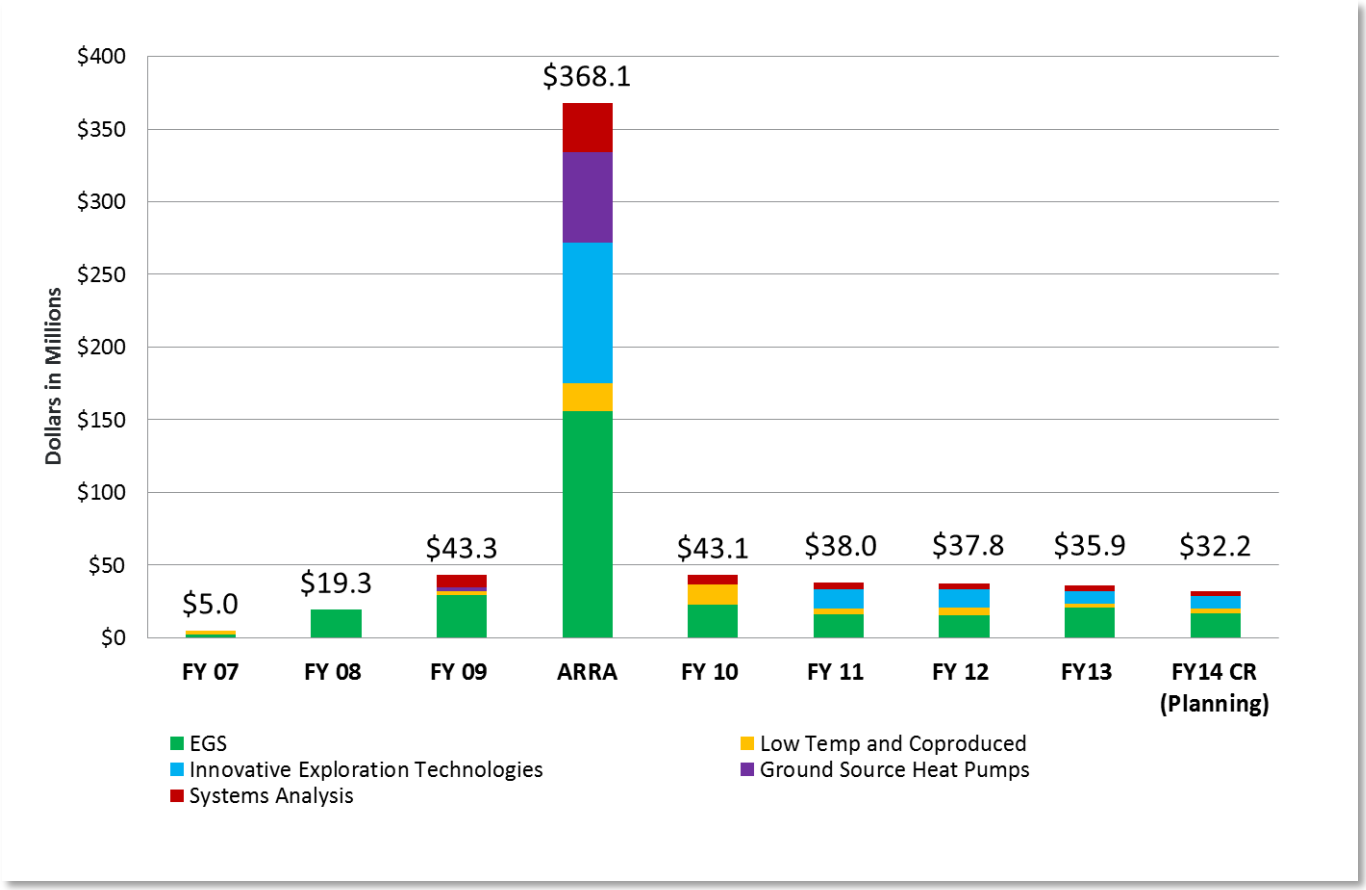


Figure 1-2. Geothermal Technologies Office budget history

2.0 Geothermal Technologies Office Peer Review Process

Peer review is a standard mechanism for assessing highly complex and/or technically challenging projects and programs, and is widely used by industry, government, and academia. Objective review and advice from independent experts provide DOE managers, staff, and researchers with a powerful and effective tool for enhancing the management, relevance, and productivity of government-funded projects. The 2004 EERE Peer Review Guide[2] defines a peer review as:

> *A rigorous, formal, and documented evaluation process using objective criteria and qualified and independent reviewers to make a judgment of the technical/scientific/business merit, the actual or anticipated results, and the productivity and management effectiveness of programs and/or projects.*

This definition is drawn from the DOE, the National Academy of Sciences (NAS), the White House Office of Management and Budget (OMB), the U.S. Government Accountability (GAO), and other federal agencies and institutions. It clearly distinguishes in-progress peer review from other types of peer review, such as merit review to select winners of competitive solicitations, or readiness (stage gate) reviews to determine when a technology is ready to move to the next phase of development, as well as from other management activities such as quarterly milestone reviews or budget reviews.

Peer review is based on the premise that the people best qualified to judge a program or project are experts in that or related fields of knowledge. Seeking advice from experts is useful for maximizing program management, as it adds an independent, qualified perspective and broadens the knowledge of a program director and program managers. Peer review is essential in providing robust, documented feedback to EERE leadership to inform program planning. Peer review also provides management with independent validation of the effectiveness and impact of its funded projects and program scopes. Knowledge about the quality and effectiveness of current projects and programs is essential in directing (or redirecting) new and existing efforts.

The Geothermal Technologies Office (GTO) conducted a rigorous, four-day peer review from April 22-25, 2013 in Denver, Colorado. The purpose of the review was to evaluate DOE-funded projects for their contribution to the mission and goals of the Office, and to assess progress made against stated project objectives. Expert reviewers also evaluated the merits of the technical and managerial approaches of the Principal Investigators (PIs). Additionally, reviewers were asked to evaluate the overall performance of four main program areas in GTO (Enhanced Geothermal Systems Demonstrations, Hydrothermal Resource Confirmation, Research and Development, and Systems Analysis).

PIs, representing a total DOE project investment of approximately $350 million, came together to report on progress and results. Peer reviewers included both unaffiliated, unconflicted PIs funded under EERE-GTO programs and experts in geothermal or related technologies who do not and have not received EERE-GTO project funding. In addition to the formal review, this event afforded an opportunity for the geothermal community to share ideas and solutions to address the challenges facing the geothermal industry.

The 2013 Peer Review meeting was organized into three tracks into which projects were grouped:

- Track 1 – Co-Produced; Low Temperature; Supercritical Carbon Dioxide; Working Fluids; Innovative Exploration Techniques; Geophysics; and Geochemistry
- Track 2 – Enhanced Geothermal Systems Demonstrations; Fluid Imaging; Characterizing Fractures; Induced Seismicity; High Temperature Tools; Drilling Systems; Materials; Zonal Isolation; and Innovative Methods of Heat Recovery
- Track 3 – Systems Analysis; Data System Development and Population; Tracers; and Modeling.

[2] *Peer Review Guide*, Office of Energy Efficiency and Renewable Energy (EERE), August 2004

2.1 Scoring and Evaluation Methodology for Projects Reviewed in FY2013

The decision criteria used by GTO staff to determine whether or not a project should be presented at a peer review meeting are: 1) project funding levels, 2) whether or not the project was reviewed the previous year, 3) its project management status, and 4) how the project performed, based on reviewer feedback from the previous peer review. GTO staff also decided how the projects should be presented and evaluated at the peer review meeting. Projects can either be presented via oral presentation, which is subject to evaluation from expert reviewers, or they can be presented during a poster session. Poster presentations are not subject to expert review and evaluation. In 2013, 97 out of 112 projects presented were reviewed by a minimum of three expert reviewers who provided both numeric evaluations and written comments. The remaining 15 projects were presented as posters at the 2013 Peer Review Meeting.

For those projects evaluated as part of the 2013 Geothermal Technologies Office Peer Review, reviewers were asked to provide comments and numeric scores on the following four metrics: 1) relevance/impact of research, 2) scientific/technical approach, 3) accomplishments, results and progress, and 4) project management/coordination. Each project was reviewed by a minimum of three expert reviewers who provided both numeric evaluations and written comments. Numeric scores were based on a ten-point scale, with qualitative descriptors given for the numerical scoring index. Additionally, reviewers were asked to provide qualitative feedback on the strengths, weaknesses, and suggested improvements for the projects they evaluated. Below is the explanation of the four criteria and the numerical scoring index.

Criterion 1: Relevance/Impact of Research

Projects were assessed on the importance of achieving the project's objectives relative to the broader Geothermal Technologies Office mission and goals. Projects were also evaluated on the extent to which the project addresses known, anticipated, and significant technical knowledge gaps or market barriers. Finally, projects were assessed on the impact the activities and results have on costs, performance, applications, markets, and other factors in geothermal energy development.

Relevance/Impact of Research Numerical Scoring Index			
10 – Outstanding. The project has made substantial progress and impact on the DOE's Geothermal Technologies Office missions and goals. Project has demonstrated outstanding advancement in addressing knowledge gaps and barriers. The project has exceptional impact on factors in geothermal energy development.	**7 to 9 – Good.** The project has made notable progress and impact on the DOE's Geothermal Technologies Office missions and goals. Project has demonstrated significant advancement in addressing knowledge gaps and barriers. The project has considerable impact on factors in geothermal energy development.	**4 to 6 – Fair.** The project has made modest progress and impact on the DOE's Geothermal Technologies Office missions and goals. Project has demonstrated some advancement in addressing knowledge gaps and barriers; impact is below what could be expected. The project has moderate impact on factors in geothermal energy development.	**1 to 3 – Poor**. The project has made little or no progress and impact on the DOE's Geothermal Technologies Office missions and goals. Project has demonstrated little to no advancement in addressing knowledge gaps and barriers; impact is below what could be expected. The project has marginal impact on factors in geothermal energy development.

Criterion 2: Scientific/Technical Approach

Projects were assessed on the quality of the technical approach and rated for the rigor and appropriateness of the employed technical approach (i.e., work elements, procedures and methods, instrumentation, equipment, staffing, etc.) to achieving the project's objectives with the available resources. This criterion covered both the design of the scientific/technical approach and how well the approach was executed in the project tasks.

Scientific/Technical Approach Numerical Scoring Index			
10 – Outstanding. The approach is sharply focused, excellent in design and centered on one or more key technical barriers to achieving the project's objectives. The execution of the approach is outstanding and has little to no room for improvement.	**7 to 9 – Good.** The approach is well thought out and effective in achieving the project's objectives. The project has good focus, with most aspects of the project contributing to significant progress in overcoming barriers/knowledge gaps. The execution of the approach is good and has minor room for improvement.	**4 to 6 – Fair.** Some aspects of the project may lead to progress in achieving project objective and overcoming barriers/knowledge gaps but the approach has significant weaknesses and noteworthy areas for improvement.	**1 to 3 – Poor.** The approach is unlikely to make significant contributions to the objectives and barriers/knowledge gaps. Significant flaws in the approach are identifiable with major areas for improvement.

Criterion 3: Accomplishments, Results and Progress

Projects were assessed on the technical accomplishments, results, and progress of the tasks. Additionally, projects were scored on the significance of these results in relation to project objectives and their technical targets/goals. Factors within this criterion centered around two areas: 1) quality – the quality of accomplishments, results, and progress made towards technical goals/targets and project objectives, and 2) productivity – the level of productivity in work underway considering accomplishments and the value of the accomplishments compared to the costs. This included achievements against planned goals and objectives, technical targets, awards, or other success measures presented.

Accomplishments, Results, and Progress Numerical Scoring Index			
10 – Outstanding. The accomplishments, results, and outcomes have been outstanding in relation to the resources expended and progress towards project objectives and technical targets/goals.	**7 to 9 – Good.** The accomplishments, results, and outcomes have been good in relation to the resources expended and progress towards project objectives and technical targets/goals. There is room for slight improvement.	**4 to 6 – Fair.** The accomplishments, results, and outcomes have been adequate in relation to the resources expended and progress towards project objectives and technical targets/goals. There is room for improvement.	**1 to 3 – Poor.** The approach is unlikely to make significant contributions to the objectives and barriers/knowledge gaps. Significant flaws in the approach are identifiable with major areas for improvement.

Criterion 4: Project Management/Coordination

Projects were assessed on how well technical, policy, schedule, business and staffing plans, and spend plans were carried out and on the quality of prospective future plans. Projects were also assessed on the inclusion of appropriate and logically placed decision points that affect the future direction of the work. Finally, projects were assessed on the coordination of activities with collaborators, stakeholders, and other entities (e.g., permitting officials).

Project Management/Coordination Numerical Scoring Index			
10 – Outstanding. Management of this project has been exceptionally effective and/or plans for future management are well-structured and include all the appropriate and logically placed management checks and controls. Any variances from original plans/schedule were corrected early and resulted in little to no impact on the overall project.	**7 to 9 – Good.** Management of this project has been very effective and/or plans for future management are well-structured and include all the appropriate and logically placed management checks and controls, however minor improvements are desirable. Any variances from original plans/schedule were corrected early and resulted in minor impact on the overall project.	**4 to 6 – Fair.** Management of this project has been weak and/or plans for future management are not well-structured and lack the appropriate and logically placed management checks and controls, numerous improvements are required. Any variances from original plans/schedule were delayed in correction and resulted in moderate impact on the overall project.	**1 to 3 – Poor.** Management of this project has been ineffective and has impaired the success of the project and/or future plans are poorly structured and missing the appropriate and logically placed management checks and controls; significant improvements are essential. Any variances from original plans/schedule were delayed in correction or not addressed and resulted in significant impact on the overall project.

The 97 projects that were presented at the 2013 Peer Review Meeting were evaluated by approximately 55 reviewers. The criteria were weighted differently across the 12 geothermal technology areas that were included in the 2013 Peer Review Meeting. Table 2.1 below illustrates the weighting of each criterion for each technology area. Scoring weight varies by technology area due to an effort by the Office to emphasize an alignment of areas of importance with the nature of the work performed.

Table 2.1. Weighting of scoring criteria or metrics

Technology Area	Relevance /Impact of Research	Scientific /Technical Approach	Accomplishments, Results, and Progress	Project Management /Coordination
1. Co-Produced and Low Temperature	20%	30%	40%	10%
2. Data System Development and Population	15%	30%	30%	25%
3. Enhanced Geothermal Systems Demonstrations	20%	25%	40%	15%
4. Fluid Imaging, Characterizing Fractures, and Induced Seismicity	20%	30%	40%	10%
5. Geophysics and Geochemistry	20%	30%	40%	10%
6. High Temperature Tools and Drilling Systems	20%	30%	40%	10%
7. Innovative Exploration Techniques	20%	25%	40%	15%
8. Materials, Zonal Isolation, and Innovative Methods of Heat Recovery	20%	30%	40%	10%
9. Modeling	20%	30%	40%	10%
10. Supercritical Carbon Dioxide and Working Fluids	20%	30%	40%	10%
11. System Analysis	20%	30%	25%	25%
12. Tracers	20%	30%	40%	10%

For each project, a **weighted average score**[3] was calculated (from the combined scores of individual reviewers) for each of the four aforementioned criteria.

In this manner, a project's weighted average score can be meaningfully compared to that of another project. The following formula, where x = score and y = weight, was used to calculate the weighted average score:

Example Calculation:

$\{(x_1*y_1) + (x_2*y_2) + (x_3*y_3) + (x_4*y_4)\}$= total
{(10*.20) + (7*.40) + (9*.15) + (9*.25)} = total
{(2) + (2.8) + (1.5) + (2.25)} = 8.6 weighted average score

Scores and comments were submitted by reviewers into an online database called the Peer Review Management Information System (P2RMIS), which allows real-time tracking of the review process. P2RMIS interfaces with external electronic application systems, facilities online meeting planning and logistics, and supports evaluations, reviews and scoring.

2.2 Methodology for Program Area Evaluations in FY2013

For the purposes of the 2013 Peer Review, GTO project portfolios were organized into four program areas: 1) Enhanced Geothermal Systems Demonstrations, 2) Hydrothermal Resource Confirmation, 3) Research and Development, and 4) Systems Analysis. Program area evaluation forms were introduced into the 2013 GTO peer reviewer process in order to capture feedback from expert reviewers regarding the overall performance of those programs areas (and their portfolio of projects). The program area evaluation forms were also hosted in P2RMIS, and expert reviewers who were evaluating projects in a specific program area were asked, but were not required to complete and submit an accompanying program area evaluation form.

Those reviewers who submitted the program area evaluation form provided qualitative feedback on the following three metrics: 1) Goals - how well the program area goals aligned to industry needs, 2) Projects - how well a program area formed an effectively balanced portfolio of projects that will contribute to achieving its goals and objectives, and 3) Communication and Collaboration - the degree and impact that program area interaction has on industry, universities, Federal agencies, as well as comparable international actors and other stakeholders. Additionally, reviewers provided qualitative responses on program area strengths, weaknesses, and any recommendations for improvement.

The qualitative analyses provided in this report are individual comments made by the reviewers. Comments were consolidated by the U.S. DOE for brevity and combined where recurrent, and do not represent consensus opinion on the subject matter.

[3] The weighted average score is an average in which each metric that is being averaged is assigned a weight. The weightings determine the relative contribution of each metric to the average. Weightings are the equivalent of having that many like items with the same value involved in the average.

3.0 Program Area Findings and Recommendations of the Peer Reviewers

While peer reviewers focused mainly on evaluating individual projects, they were also asked to provide a higher-level indication of strengths and barriers to execution within the following Geothermal Technologies Office (GTO) program areas: 1) Enhanced Geothermal Systems Demonstrations, 2) Research and Development (R&D), 3) Hydrothermal Resource Confirmation, and 4) Systems Analysis. The program area evaluation forms were new to the GTO peer review process in 2013, and were implemented to capture feedback from expert reviewers regarding the overall performance of those programs areas. The majority of the comments were collected via the program area evaluation forms that the expert reviewers completed in P2RMIS. Additionally, some comments arose during the peer review panel wrap-up sessions that were conducted at the 2013 Peer Review Meeting or that were captured by GTO staff during discussions at the meeting. The comments presented below are focused toward GTO program areas and not associated with individual projects. For individual projects, a comprehensive list of reviewer comments, PI responses, and individual project scoring evaluations can be found in Appendix A.

Enhanced Geothermal Systems (EGS) Demonstrations

- GTO has made excellent progress in making its mission, goals, and progress known to stakeholders at all levels, both nationally and internationally.
- Industry's needs are more closely aligned with discovery of hidden hydrothermal resources, as predicted by the U.S. Geological Survey (USGS), rather than development of EGS. However, this would change dramatically if the Department of Energy (DOE) were to meet the reservoir size and cost goals for EGS. In this context the goals are appropriate, and perhaps should be augmented by a quantitative reservoir lifetime goal along the lines of the one adopted in the MIT study.
- The industry goal of producing 5 MWs does not lend itself to hypothesis testing.
- The amount of useful information for future development of EGS depends on how well these projects can be managed to enhance understanding of reservoir creation at the same time as they are fulfilling their primary purpose of immediate generation increase in an existing field.
- GTO should focus more on Greenfield EGS efforts. This may not be attributed as a fault of the GTO, but rather to the fact that the hydrothermal potential in the U.S. is big enough and has not yet been exploited.
- The Geysers project is a true near hydrothermal demonstration of EGS and represents the best project in the portfolio.
- The Newberry project is a good greenfield project, but with the difficulties it is having with out-of-zone stimulation and the implications on EGS in general, it needs some help to make sure the causes, remedies, and understanding of that out-of-zone occurrence are understood so it can be remedied going forward.
- Recent developments on EGS demonstration projects, notably Desert Peak, have demonstrated that measurable progress is being made.
- There has been good involvement by experts from Universities and National Labs, working with the industry partners. Greater National Laboratory expertise in running demonstrations for controlled experiments is encouraged.
- GTO should rebalance the EGS Demonstrations portfolio with a focus on engaging new Oil and Gas (O&G) industry experts. More demonstration projects and engaging the O&G industry expertise is strongly encouraged. A field test site is a critical component.
- GTO should press forward with plans for a comprehensive field experiment laboratory for conducting high-risk experiments that offer the opportunity to leapfrog current technology and reduce the levelized cost of energy (LCOE). This approach has the best chance of allowing DOE to reach its EGS goals in a reasonable time.
- Demonstration projects have by and large succeeded with respect to obtaining critical field information about stimulation in an EGS system.

Research and Development

- The Research and Development (R&D) program is an excellent addition to the larger geothermal portfolio. GTO should consider funding additional projects that measure fundamental thermodynamic data and phase relations needed for quantitative assessment of a geothermal system. The R&D program is strong, particularly in the area of simulation and modeling.
- In the current risk adverse climate, funding safe activities like modeling is the easy and safe thing to do. Working closely with the companies that operate, drill and maintained fields, which involves more risk, has in the past lead to the discovery of techniques that improve operations and has highlighted problem areas that were not obvious from a distance. However, there appears to be too much emphasis on modeling and simulation in the R&D portfolio.
- Fluid-mineral interactions are key to understanding geothermal systems, and while not "'new" these data are integral to success.
- Characterization of the materials that make up the reservoir is key to predicting the lifetime of the system, identifying the flow zones, and predicting the impact on the engineered systems.
- The R&D program area goals are aligned with industry needs resulting in R&D projects that can bridge knowledge and technology gaps in a shorter time frame.
- The industry needs a strong GTO program which can compete with wind and solar and develop new geothermal resources.
    - Drilling Systems: a three times faster rate drilling is great, but the real question is, "how can we reduce deep drilling of geothermal wells by a factor of 3? Perhaps an even more open question is how can we produce deep geothermal resources > 25,000ft?"
    - Downhole Tools: 300C clearly separates geothermal from fossil energy. The target of 10km is good for the future of geothermal but may not be supported by existing conventional geothermal companies. Even so, the need for better sealing technology in conventional geothermal tools could benefit from a 10km requirement for high temperature tools.
- Much of the portfolio is characterized by strong collaborations, whether within or across institutions. There is a strong underlying theme of academic-industry and lab-industry partnerships. Some of these are more well-defined than others in terms of the buy-in from the industry partner and implications for near-term impacts on geothermal development.
- The Geophysics projects are making notable progress in a number of high-impact spaces and highlights include innovative regional- to prospect-scale exploration methods that take measures to quantify uncertainty and value of information, and preliminary efforts to develop comprehensive methodologies and models for reservoir development and operations.
    - The projects are mostly being completed by National Labs with some interaction with universities and little interaction with industry, other than to ask for material or cost share. This is a disconnect.
- GTO Innovative Exploration Technologies projects should focus on the technical requirements to drill a 5,000 foot horizontal well with multiple stimulations.
- A major weakness identified by one reviewer is the lack of a larger development program to focus DOE's technology effort; or a project similar to the Geodynamics project in Australia.
- There should be a means to bring Chevron or other major oil companies to work on the development of deep geothermal here in the U.S. Such an agreement will require increased DOE funding levels which are currently too low.

Hydrothermal Resource Confirmation

- GTO is definitely helping to accelerate hydrothermal growth by putting emphasis on new ways to find and develop blind resources. In the process of doing this, GTO has funded some ideas that seem to be pretty far out of the box, but it has also funded some carefully thought out schemes for locating and characterizing hidden prospects.
- Several project teams are developing innovative technology or are moving forward with field applications that have potential to demonstrate very useful technology.
- Innovative exploration methods for some reservoirs have been explored and, to a limited extent, demonstrated.
- The LCOE goal of $0.06 by 2020 might be achieved, but in light of rising costs of drilling, casing, and power plant construction, it will be a difficult target.
- The 30 GW of undiscovered hydrothermal power by 2020 is a good target but may not be realistic. Additionally, 400 MW of new power by 2014 is an unrealistic goal.
- Targeting fundamental research in geothermal exploration is a strength of the program.
- The focus of the Exploration projects should be in data integration, and a common modular platform for doing so needs to be developed.
- There appears to be a gap in encouraging the development of new conceptual models of geothermal resources. This would help the discovery of blind systems.
- The Low Temperature program was placed in a difficult position. By its nature, low-temperature production will add power in small increments. However, many of the projects reviewed did not appear to have great potential to demonstrate economic utilization of low-temperature resources for electrical generation.
- Projects in the Hydrothermal Resource Confirmation area have interacted well with academia, industry, and other agencies, but most of those interactions have been localized.
- It would be certainly an enrichment to call on more international expertise, in particular from countries with substantial geothermal power production, like Iceland, New Zealand, Indonesia and Central American countries.
- Underperforming management should be identified and roles tightly defined so meeting specific metrics, without which funding will not continue, can be easily measured. Portfolio balance seems sufficient, but strong emphasis on EGS may not result in meeting short-term goals.
- Funding delays associated with GTO have been too frequent. Changes of course during a project (for a variety of reasons) take too long to obtain DOE approval and the process is too cumbersome.
- More narrowly focused solicitations would also make it easier to evaluate proposals and utilize reviewers with proper capabilities.
- GTO definitely has a significant degree of awareness in the United States, and the impact on those entities actually working with GTO is strong. However, GTO may not have great international awareness or impact and this should be changed. Perhaps GTO could help fund projects being undertaken by American companies in places like Chile, Africa, Turkey, the Caribbean, and Central America. This would enhance the world-wide search for new energy while showcasing the DOE efforts to support this search.

Systems Analysis

- The Systems Analysis program area is quite strong in its diversified approach to analytical topics. There is a balanced distribution of technical and non-technical goals, which more often than not hinge on stakeholder interactions.
- The projects assigned within the Systems Analysis portfolio offer a diverse collection of topics, both technical and non-technical. Each project has attributes that allow it to be distinguished within the greater goals of the GTO. In several cases, however, the projects were not assessed or presented in a way which allows them to be related directly with the stated goals.
- The Systems Analysis goals focus on the collection and sharing of data to reduce risk across the industry. NGDS highlights the data collection efforts on a very broad scale, while projects such as the Regulatory Roadmap are targeted towards a more refined barrier area in permitting. Both broaden the collective knowledge of the industry.

Other goals are directed at bringing the industry together on shared topics of interest and utilizing inter-agency resources toward a collective goal.

- Of the projects reviewed, two have made excellent strides in reaching out to geothermal stakeholders: Geothermal Electricity Technology Evaluation Model (GETEM) and regulatory roadmaps.
- GTO has done an excellent job of devising goals for systems analysis that meet industry needs. The NGDS is particularly relevant in this regard. The foundation has been laid for future analyses that can be supported by an extensive database of past experience.
- Since the NGDS system is not yet fully complete it is difficult to say what the final impact will be. However, the projects themselves comprise an impressive array of participants from industry, academia, and government that appear to be collaborating well.
- The construction of a national database is a useful goal towards improving widespread use of geothermal. Several geothermal databases have been developed that directly address the needs of industry, researchers, and the public.
- Work with other federal agencies to disseminate reliable resource data and to reduce technical, timeline, and financing uncertainties needs to be expanded to include the oil and gas programs. Data resources should be presented at oil and gas conferences so that the data efforts can gain a more widespread audience.
- The big data projects do not have a follow-on architecture program that can continually evaluate the continuing data needs for the program. This project could also provide guidance for additional work that modifies or enhances the current achievements.
- More comprehensive studies in Systems Analysis should be adopted, perhaps using the growing NGDS database. An effort could be undertaken to evaluate the means of reducing drilling costs, the greatest deterrent to the widespread adoption of geothermal energy. Monte Carlo methods may be applied to predict success in hydrothermal exploration or EGS development, given variable natural conditions. This approach could serve as a valuable adjunct to GETEM.
- GETEM should be made more user friendly, and an ongoing effort should be supported to assure its costing algorithms are kept up to date.

4.0 Project Scoring Evaluation Analysis and Results

Overall Results

This section looks at trends and correlations among project scores and, tests for evidence of bias, and summarizes insights gleaned from reviewer comments about what distinguishes outstanding projects from poorly performing ones. For individual projects, a comprehensive list of reviewer comments, PI responses, and individual project scoring evaluations can be found in Appendix A.

Using the methodology described in Section 2.1, the weighted average score was calculated for each project. The weighted average score for all projects averaged 7.0. Figure 4-1 details the weighted average scores at the Technology Area level, as well as, presenting data for Technology Area funding and number of projects reviewed.

Technology Area (by score high to low)	Technology Area Score	Technology Area Funding Total and % of Review		Technology Area Projects Total and % of Review
	0 5 10	millions	0% 10% 20%	0% 10% 20%
Data System Development & Population	7.8	$ 41.6M	12%	4
Modeling	7.6	$ 11.4M	3%	12
Fluid Imaging; Characterizing Fractures; Induced Seismicity	7.5	$ 14.4M	4%	10
Enhanced Geothermal Systems Demonstrations	7.5	$ 77.8M	22%	5
Geophysics; Geochemistry	7.2	$ 16.4M	5%	16
Tracers	7.0	$ 3.7M	1%	3
Systems Analysis	7.0	$ 9.9M	3%	6
High Temperature Tools; Drilling Systems	6.9	$ 34.5M	10%	13
Innovative Exploration Techniques	6.8	$ 69.5M	20%	9
Co-Produced; Low Temperature	6.1	$ 57.2M	16%	10
Materials; Zonal Isolation; Innovative Methods of Heat Recovery	5.7	$ 6.1M	2%	6
Supercritical CO2; Working Fluids	5.6	$ 7.4M	2%	3
GTO 2013 Peer Review	--- Avg Score 7.0	$ 350.0M	--- Avg Funding $29.2M (8.3%)	97 --- Avg % of Projects 8% (8)

Figure 4-1. Technology areas sorted by average score with funding and number of projects data

For the 97 projects evaluated and scored, additional analyses of project scores were conducted to determine if correlations exist between the project scores and various project attributes. Project attributes considered for this analysis include: total project funding (including future commitments), project scoring metric results, technology area panel, reviewer profile (e.g. number of reviewers and reviewer affiliation), project duration, and standard deviations from averages. Project attributes were collected from Principal Investigators (PIs) and peer review statistics. Correlation between project scores and project attributes could be either positive or negative and are presented later in this section of the report.

Total project funding used for project score correlation pertains to the entire project duration and is not indicative of or limited to project spending in the fiscal year of the peer review. The projects reviewed in 2013 totaled nearly $350 million in total project funding, and as seen in Figure 4-1, there is a diverse distribution of project funding within the technology areas of the Geothermal Technologies Office (GTO). The total project funding shown in Figure 4-1 includes funding from the Department of Energy (DOE) as well as cost-share funding, and the statistics shown on the chart represent the aggregate of all the projects within a technology area. Further project funding analysis is shown in Figures 4.12 and Table 4.2.

For the weighted average score, Figure 4-2 shows a comparison of all projects. The projects are grouped by technology area and are ordered from lowest to highest score. While direct technology area comparisons should not be made due to slightly different weighting structures between areas, it can be seen that not all technology areas had projects score above average. In addition to showing project scoring, Figure 4-2 also shows the average score for Relevance for the review as a whole and for each technology area. Overall, reviewers accorded higher scores to project Relevance than the weighted average score, but between technology areas, there was a distribution observed with several technology areas having an average Relevance score that was significantly lower or higher than the overall program average for Relevance.

Reviewers ranked Data System Development & Population projects the highest in average Relevance (8.1), and these projects scored first or second in all metrics. These projects received approximately 12% of the total reviewed portfolio funding and represented approximately 4% of the projects reviewed. These scores and the reviewer comments received demonstrate how vital the compilation of standardized geothermal data is and will be to the industry.

As seen by the gray shading, approximately 70% of the projects scored between 5.6 and 8.4 (1 standard deviation from the 7.0 average) reflecting an overall favorable view reviewers had of the projects. Some projects fell outside of one standard deviation with fourteen projects below one standard deviation and eight projects above. Two projects scored more than two standard deviations below the mean of the weighted average score.

Projects scored in an evenly rising progression for all technology areas except for the following, which had clusters of low scoring and high scoring projects:

- Co-Produced; Low Temperature
- Systems Analysis
- Maters and Zonal Isolation; Innovative Methods of Heat Recovery

Reviewers consistently rated Relevance higher than the Weighted Average Project Score for all technology areas other than Innovative Exploration Techniques and Materials and Zonal Isolation; Innovative Methods of Heat Recovery. The greatest disparities where Relevance is higher than the weighted average project score are in the following technology areas:

- Data System Development & Population
- Geophysics; Geochemistry
- High Temperature Tools; Drilling Systems
- Supercritical CO2; Working Fluids
- Systems Analysis

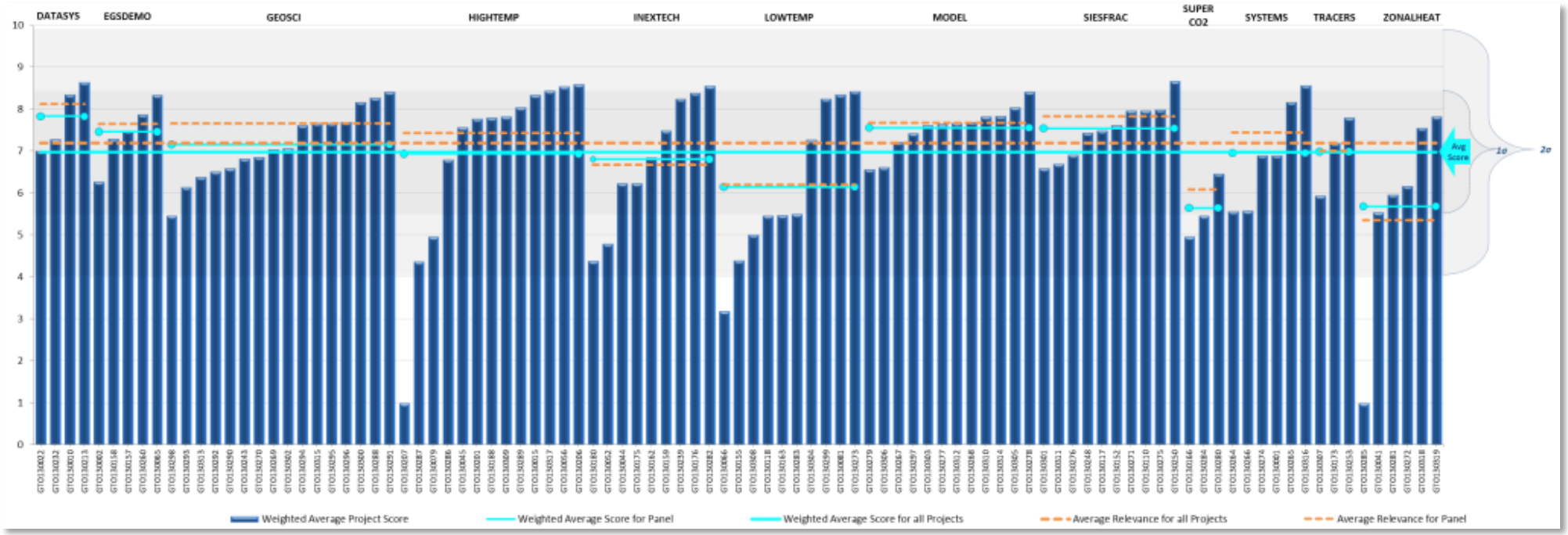


Figure 4-2. Weighted average scores – panel comparison*

**Please see Appendix B for the correlation of project ID numbers to project title and organization.*

Metrics Discussion

The charts in Figures 4-3 – 4-7 show the distributions of reviewer scores for each metric and the weighted average project score, respectively. The bar colors correspond to: Red – Poor (≤ 3), Yellow – Fair (4-6), Green – Good (7-9), and Bright Green – Outstanding (10). The left y-axis for all five charts corresponds to the bars and represents the percentage of reviewer evaluations for each score. The right y-axis corresponds to the curve, which represents the cumulative percentage of evaluations through the scoring range.

Figures 4-3 – 4-6 show narrow distributions around the top of the scoring range, where each of the four metrics were scored 7-9 (Good) or 10 (Outstanding) for 65% to 74% of all projects. It is seen that the Accomplishments, Results, & Progress metric and the Project Management & Coordination metric received more lower scores, which was reflected in the reviewer comments and recommendations. The DOE takes great care in project selection and accurate project reporting, so it is not surprising that, in general, projects were scored highly, especially for the Relevance and Impact of Research metric.

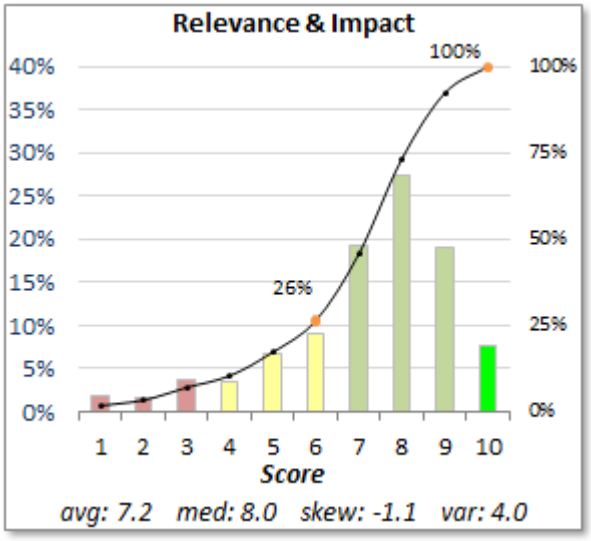


Figure 4-3. Relevance & impact of research

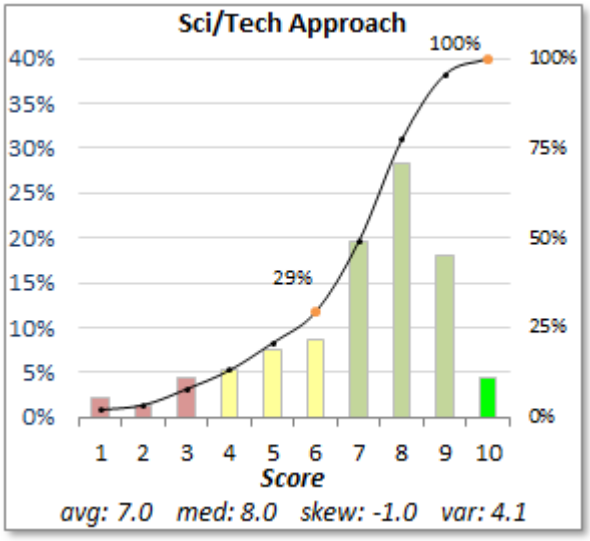


Figure 4-4. Scientific & technical approach

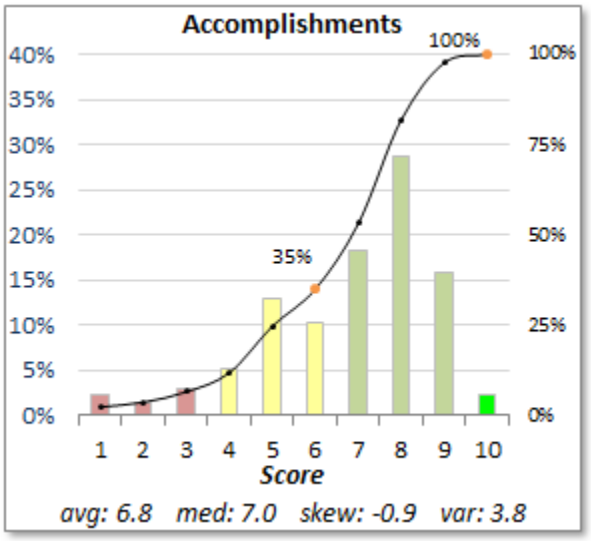


Figure 4-5. Accomplishments, results, & progress

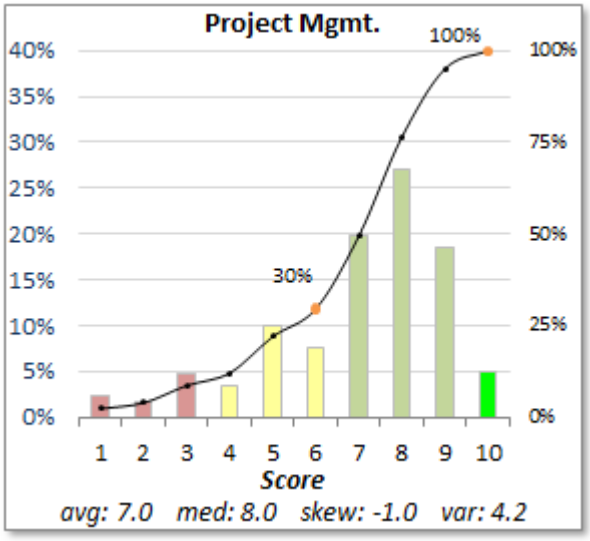


Figure 4-6. Project management & coordination

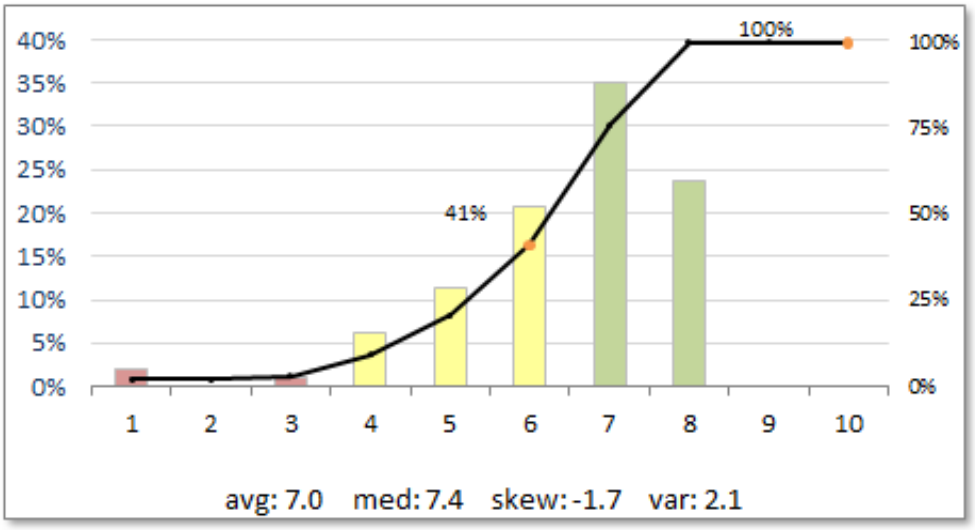


Figure 4-7. Weighted average project score

Figure 4-7 shows that roughly 60% of the projects were scored as "Good" or better. There were two projects that did not present, which were scored the minimum and thus skewed the overall results. Figure 4-7 shows that no projects achieved a weighted average score of nine or above, although some projects did score nine or above on certain metrics. This indicates that, while each individual project received high scores on certain metrics, it was uncommon for individual projects to score nine or above for all four metrics. Programmatically, this disparity of scoring metric results within individual projects offers potential opportunities to determine overall best practices and areas for improvement that could be shared with Principal Investigators to continually improve performance.

Analysis was conducted to compare how scores given by reviewers were correlated with respect to each other and to look at potential trends (Table 4.1). Given the care with which the original project portfolio is selected, one might expect a high score for Relevance to GTO mission and goals for all of the projects. Indeed, reviewers accorded most projects a significant degree of Relevance, but there are differences among the technology areas. High Relevance scores (>8 average scored by reviewers) are the norm in the Data Systems Development and Population projects and the High Temperature Tools and Drilling Systems projects (see Table 4.2). However, the Co-Produced and Low Temperature technology area had a relatively large fraction (6 of 10) of projects with Relevance scores only in the "Fair" range (an average score of 6 or less). High Relevance projects tend to be those for which reviewers can imagine tangible benefit or immediate application in an area of interest to themselves. In contrast, projects scoring low in Relevance had made little progress toward research goals with only site-specific or otherwise restricted application, or, more rarely, there were concerns about the underlying technical premises.

Table 4.1. Review metrics correlations

Correlation Matrix	Relevance Score	Approach Score	Accomplishments Score	Project Management Score	Weighted Project Score
Relevance Score	1.00	0.81	0.74	0.69	0.72
Approach Score	0.81	1.00	0.82	0.75	0.71
Accomplishments Score	0.74	0.82	1.00	0.79	0.73
Project Management Score	0.69	0.75	0.79	1.00	0.70
Weighted Project Score	0.72	0.71	0.73	0.70	1.00

Three-fourths of the reviewed projects scored better than "Fair" in Accomplishments, Results and Progress, with 60% scoring good or better. Only one of the projects presented before a review panel received a "Poor" score. As this is an R&D program, one might expect some percentage of failures in delivery. The ability to make progress toward and to deliver results correlates equally with Project Management and Technical & Scientific Approach scores, indicating that on average across the portfolio, strength in either or both of these is contributing to success. Reviewers found particularly robust delivery of results in the Data Systems Development and Population, Geophysics/Geochemistry, and the High Temperature Tools and Drilling Systems technology areas. Robust accomplishments seem especially challenging to deliver in the Supercritical CO_2, Materials, and Co-Produced and Low Temperature review areas. (100%, 67%, and 60% of reviewed projects scored ≤ 6 on average in Accomplishments, Results and Progress, respectively).

While the comments associated with the very highest and lowest scores may give bragging rights or encourage timely abandonment of unsuccessful efforts, the real value of the peer review comments to the program is in the mid-range, in which the reviewers offer detailed advice to nudge the project in directions likely to increase the success or value. The following exchange is typical:

Reviewer Comment: Other hypotheses for downward/upward migration include changing material props with depth, velocity strengthening/weakening and roles of temperature, downward migration of a cold dense tongue of water and soft inclusion for the chilled zone. Selecting features of the models that would discriminate between these various models could be useful – for example, a quenched soft inclusion model would shed stresses in the unquenched zone around the inclusion so seismicity might be equally likely above as below the zone – maybe possible to exclude based on that signature? Plotting data as a time-radius plot or time depth-plot might be useful in crafting hypotheses.

PI Response: Thank you for the thoughtful suggestions. We have made the time-depth plots and done more careful evaluation of the role of temperature gradient. We have thought some about velocity strengthening/weakening but that is mostly beyond the scope of this project.

Given the high value of constructive comments, quantitative analysis was used to perform a detailed comment analysis targeted at the projects scoring high or low for Accomplishments. The findings of this quantitative analysis support the existence of key elements that also influenced the scores for Approach and Project Management.

Common themes of projects with low scores in Accomplishments in order of descending frequency include (1) questionable or lacking field testing, data validation/documentation, and/or site selection, (2) issues with project management, (3) insufficient project funding or potential funding risks, (4) a lack of novel methodology, approach, or accomplishments, (5) a lack of investigations into novel findings, (6) missing key expertise on the project team or needing collaboration, (7) a disconnect or a lack of experimental, field-tested, and/or real-world data, (8) reviewer disagreement with the engineering or scientific methodology, (9) a lack of investigations into novel findings, (10) slow progress, (11) hypotheses that were not confirmed by data, (12) little consideration for the feasibility of scaling up bench scale experiments, (13) an errant initial approach, (14) permitting difficulties, and/or (15) a project scope that is inappropriate or has expanded detrimentally. Reviewers in 2013 seemed to focus on quality, comprehensive data reporting and awareness of where projects will fit in the current geothermal knowledge base. Low scores, by themselves, do not always indicate

poor projects. The comments must be examined to determine whether scores are low due to substantial structural issues in the project, or if the scores are a function of the commercial readiness level or surmountable barriers to project success identified by reviewers. For example, some projects received low scores for Accomplishments when, despite being on schedule, they were not at a point where results are available, and other projects with positive results received low scores due to poor presentation or proprietary concerns that impeded clear dissemination of data. Reviewers generally sympathized with the sensitivities surrounding intellectual property but noted ways in which PIs could better provide useful information to the geothermal community without compromising commercial interests.

Common themes of projects scoring highly in Accomplishments in order of descending frequency include (1) strong project management and/or technical team, (2) obvious technology transfer efforts or capability, (3) strong project comprehensiveness or experiment methodology, (4) sufficient review of existing literature, tools, methodology, and/or data, (5) positive collaborations, (6) strong potential for market transformation, (7) successful proof of concept development, (8) ability to overcome barriers, (9) a novel project component, (10) accomplishments that obviously further the industry, (11) systematic and iterative processes for coordination and methodology, (12) ability to overcome barriers, (13) application of industry or project lessons learned, (14) good collection, consolidation, correlation, and/or visualization of large data sets, and/or (15) a focus on data validation. Many of the high scoring projects will provide results immediately useful to furthering the industry whereas low scoring project results were not as mature or useful. As the low scoring projects progress towards maturity, their scores will improve. The utility of this analysis lies in identifying key challenges faced by low scoring projects independent of maturity and best practices of the high scoring projects so that lessons learned can be applied by the Office to continually improve all projects in the portfolio and avoid common pitfalls.

Reviewer Profile Discussion

Additional analysis was performed to test whether the reviewer profile affected project scores. The reviewer profile can include direct factors such as number of reviewers per project or reviewer affiliations, or the profile can include various external factors such as time of day of the project review or proximity to breaks in the review schedule. Cursory analysis of some external factors yielded no correlation to these factors and the resulting project scores. Figures 4.8 and 4.9 focus on direct factors and show the scatter plot of weighted average scores versus the number of reviewers on the panel of a specific project and the weighted average score versus reviewer affiliations, respectively. As required by the EERE Peer Review Guide, each project was reviewed by a minimum of three reviewers, and Figure 4-8 shows that the number of reviewers on a given project had little effect on the weighted average score. In all cases the distributions centered around an average of just under 7.0.

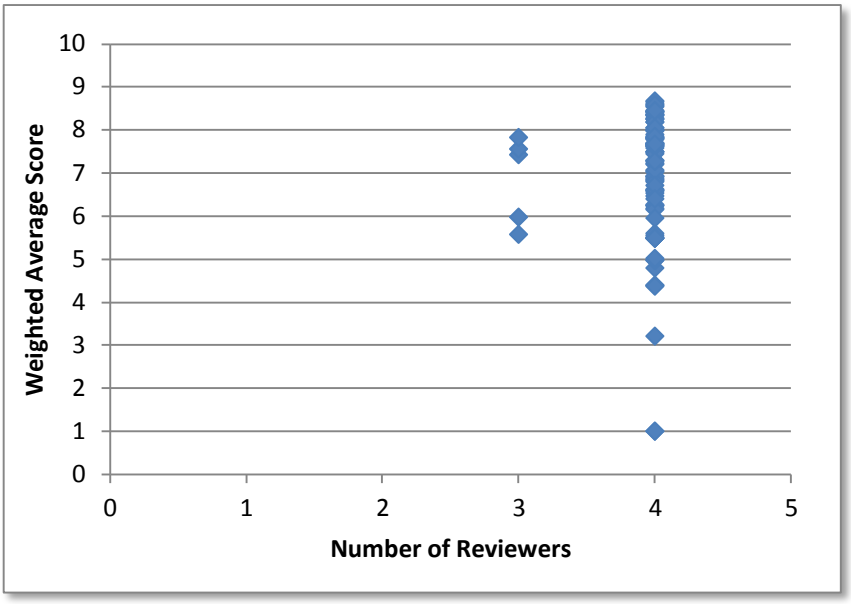


Figure 4-8. Weighted average score vs. number of reviewers

Figure 4-9 shows the scores from reviewers in four affiliation groups – Academia (86 total reviews performed), Government (21 total reviews), Industry (164 total reviews), and National Laboratory (112 total reviews) – presented in ascending order. Regarding the affiliations, nine National Laboratories were represented on the various panels, Government officials from local, state, and national organizations and agencies were included, and industry representatives from private companies, industry organizations, and consultants participated in review panels. Industry reviewers, who had the lowest average, scored about 60% of projects "Good" or better. Reviewers with an Academia affiliation scored projects the highest with an average of 7.43, which was only 0.07 higher than Government reviewer's average of 7.36. Industry and National Laboratory reviewers were slightly more critical, averaging 6.8 and 6.84 respectively, which is just below the "Good" threshold.

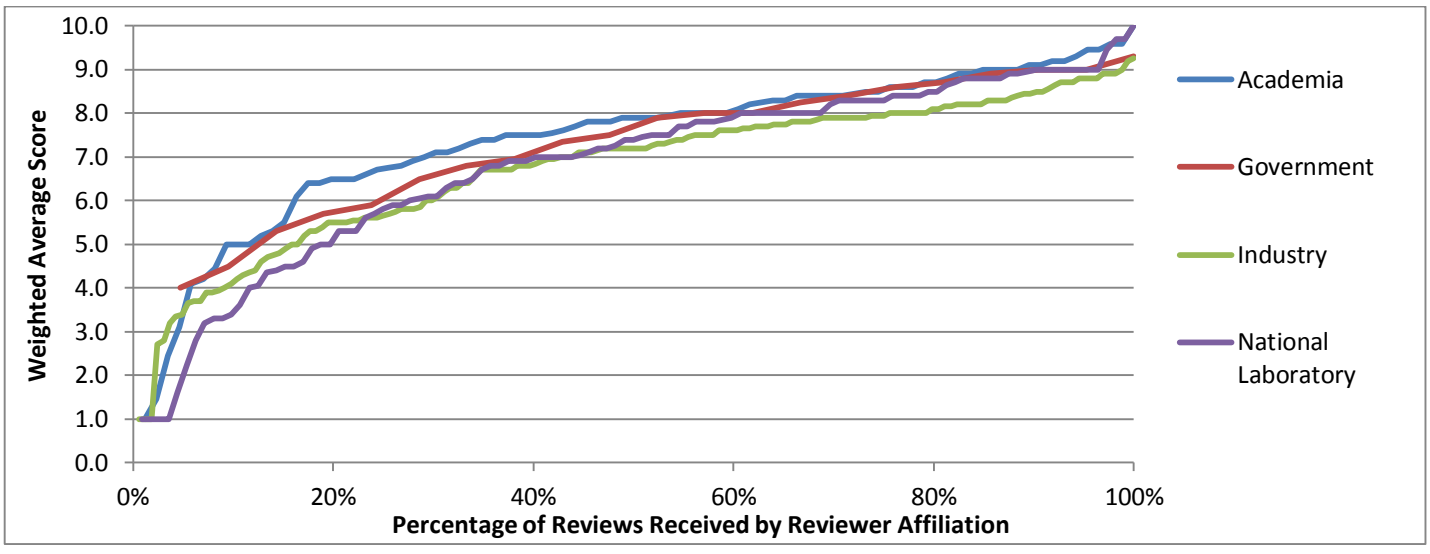


Figure 4-9. Weighted average score vs. reviewer affiliation

Additionally, a simple categorization of the PI affiliation into the same four groups of Academia (118 project reviews received), Government (12 project reviews), Industry (143 project reviews), and National Laboratory (110 project reviews) was performed. Despite similar numbers, there was substantial diversity in the affiliation groupings between PIs and reviewers. In fact, each PI-affiliated group was reviewed by all affiliation groups of reviewers except for the projects with Government PIs, which lacked any reviewers from Academia, likely due to the small number (4) of projects with a Government PI. Projects from National Laboratory PIs were the clear high performers with an average score of 7.52 and 74% of projects scoring "Good" or better. Nearly two thirds of Academia PI-directed projects scored "Good" or better, and that group had an average score of 7.06. Industry-led and Government-led projects had the lowest averages of 6.5 and 6.68 respectively, but over 50% of these projects were scored as "Good" or better.

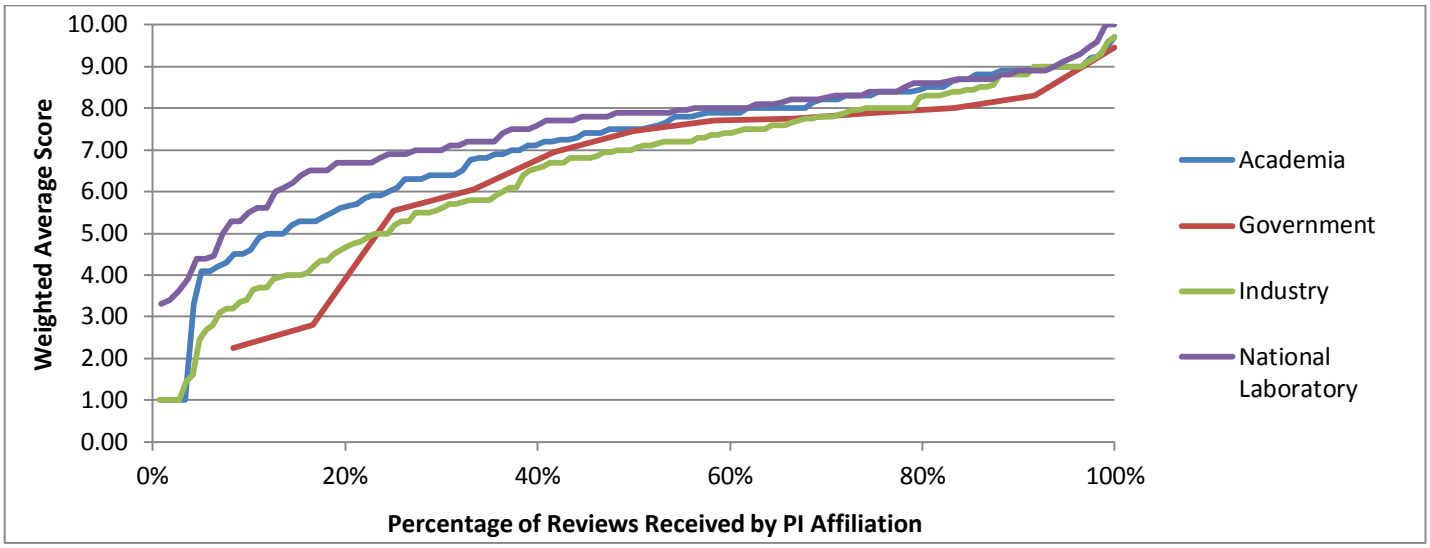
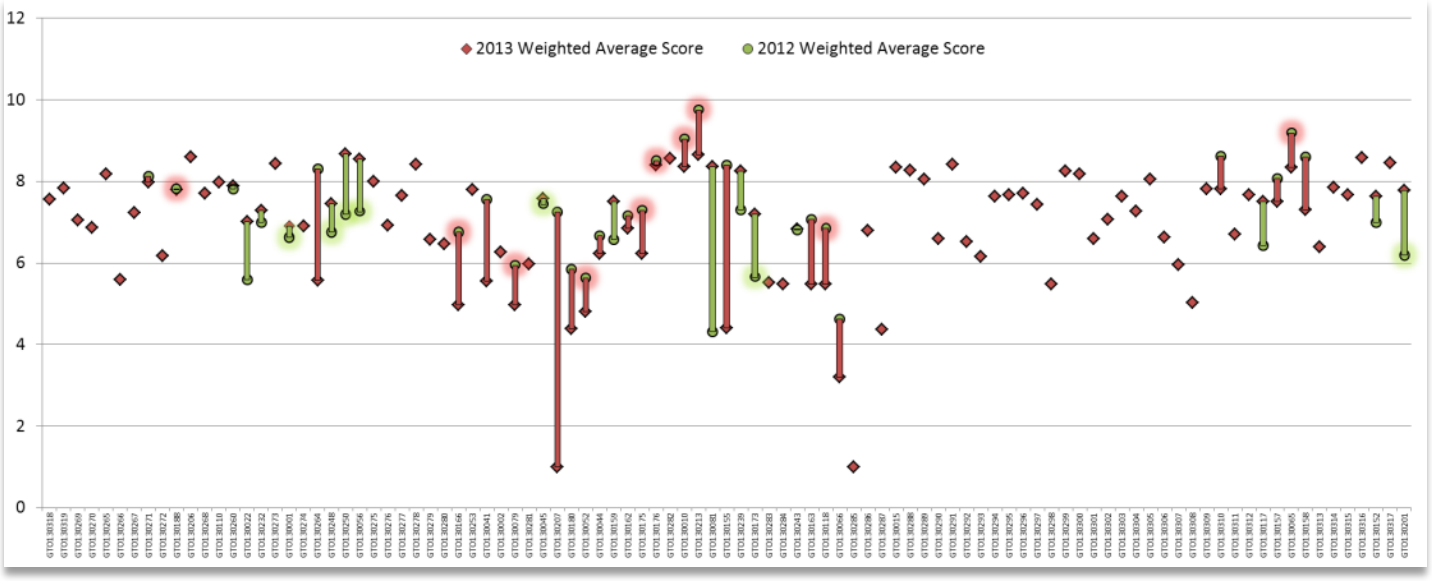


Figure 4-10. Weighted average score vs. PI affiliation

Figure 4-11 shows the year-to-year scores of projects in the GTO portfolio. Only 39 of the 97 projects were reviewed in both 2012 and 2013. These can be identified in Figure 4-11 as the projects that have a line between the two data points. Green lines indicate that a project's score rose from 2012 to 2013 whereas red lines indicate projects that received a lower score in 2013 than they had previously in 2012. Overall, the projects reviewed scored lower in 2013 than in 2012 with average weighted scores of 6.96 in 2013 and 7.15 in 2012 (scores for 2012 were adjusted from a 4-point scale to a 10-point scale). In 2013, there were 58 projects reviewed that were not reviewed in 2012, and in 2012 there were 76 projects that were not reviewed in 2013. The EERE Peer Review Guide requires that projects are reviewed every two years, so with EERE Programs that perform annual reviews it is common that some subsets of projects are reviewed every other year, while other subsets are reviewed every year with considerable migration between subsets as projects progress. Out of the 39 projects that were reviewed in both 2012 and 2013, 16 improved their scores by an average of 1.03 with a maximum improvement of 4.05. Twenty-three (23) projects saw a decline in their scores with an average difference of 1.38, with a maximum decline of 6.25.

As part of the peer review reporting process, GTO allows PIs to submit responses to reviewer comments. These are reported along with the reviewer comments in Appendix A. Anecdotally, it has been observed that this is an effective method of communicating questions and recommendations between PIs and reviewers. We investigated whether this exchange correlates with project improvement or not. The results are ambiguous. From the 2012 GTO Peer Review, 61 out of the 115 reviewed projects submitted responses. Of these 61 projects, 17 were reviewed again in the 2013 GTO Peer Review. Analysis was performed to determine whether submission of responses had an effect on the Weighted Average Score. Only seven of these projects received a higher score in 2013, but these projects improved by an average of 1.01,

while the ten projects with declining scores fell by an average of 0.87. These projects are identified on Figure 4-11 as the data points with either a red (decline in 2013) or green (ascension in 2013) glow surrounding the 2012 score. For the 2013 review, 67 of the 97 projects reviewed submitted responses.



**Please see Appendix B for the correlation of project ID numbers to project title and organization*

Figure 4-11. 2012 weighted average scores vs. 2013 weighted average scores*

Budget and Duration Discussion

Data System Development & Population was the top performing panel with all projects scoring above the Office average. These large-budget projects (average budget of $10.4M is the 2nd highest in the Office) were also the most highly rated for Relevance.

The following panels scored above average (>7.2) and represented 41% of program funding:

- Data System Development & Population
- Fluid Imaging; Characterizing Fractures; Induced Seismicity
- Modeling
- Enhanced Geothermal Systems Demonstrations

The following panels scored about average (6.8-7.2) and represented 39% of program funding:

- Geophysics; Geochemistry
- Tracers
- Systems Analysis
- High Temperature Tools; Drilling Systems
- Innovative Exploration Techniques

The following panels scored below average (5.6 – 6.1) and represented 20% of program funding:

- Co-Produced; Low Temperature
- Materials; Zonal Isolation; Innovative Methods of Heat Recovery
- Supercritical CO_2; Working Fluids

As shown in Table 4.2, the projects reviewed that received a majority of program funding (80%) scored at or above average.

Table 4.2. Overall panel scoring and budget information

Panel	Average Relevance & Impact of Research	Average Scientific & Technical Approach	Average Accomplishments, Results & Progress	Average Project Mgmt & Coordination	Average Weighted Average Project Score	Total Budget	% of Reviewed Project Budgets	Average Budget
Data System Development & Population	8.1	7.7	7.6	8.1	7.8	$41,564,210	12%	$10,391,053
Modeling	7.7	7.5	7.5	7.6	7.6	$11,355,453	3%	$946,288
Fluid Imaging; Characterizing Fractures; Induced Seismicity	7.8	7.8	7.3	7.4	7.5	$14,400,157	4%	$1,440,016
Enhanced Geothermal Systems Demonstrations	7.7	7.6	7.1	8.0	7.5	$77,838,992	22%	$15,567,798
Geophysics; Geochemistry	7.7	7.0	7.0	7.3	7.2	$16,419,511	5%	$1,026,219
Tracers	7.0	7.2	6.8	7.0	7.0	$3,738,474	1%	$1,246,158
Systems Analysis	7.4	6.9	6.8	6.7	7.0	$9,893,421	3%	$1,648,904
High Temperature Tools; Drilling Systems	7.4	7.0	6.7	6.8	6.9	$34,549,125	10%	$2,657,625
Innovative Exploration Techniques	6.7	6.7	6.8	7.1	6.8	$69,468,816	20%	$7,718,757
Co-Produced; Low Temperature	6.2	6.3	6.1	5.9	6.1	$57,187,769	16%	$5,718,777
Materials; Zonal Isolation; Innovative Methods of Heat Recovery	5.3	6.0	5.6	5.7	5.7	$6,123,083	2%	$1,020,514
Supercritical CO_2; Working Fluids	6.1	5.8	5.3	5.8	5.6	$7,442,228	2%	$2,480,743
AVERAGE	**7.1**	**7.0**	**6.7**	**6.9**	**6.9**	**$349,981,239**		

Further analysis on total project funding is shown in Figure 4-12. The x-axis represents a project's weighted average score and the y-axis represents a project's Relevance score. The intervals from the axes represent standard deviations from the average. The magnitude of the bubbles indicates the funding level of the projects. From Figure 4-12, we see that there is no obvious correlation between the weighted average score of the project, the relevance of a project, and the total funding for the project. It is seen that large budget projects are not more or less likely to perform well based on project evaluations. This trend also holds true for the relevance of a project. Project budget information was included in the review materials, and based on the equal distribution in Figure 4-12; it does not appear that budget information biased the scoring of the reviewers. While qualitative analysis of the trends in reviewer scores and comments is performed in the preparation of this report, this simple quantitative analysis further demonstrates the independent nature of the GTO peer review process.

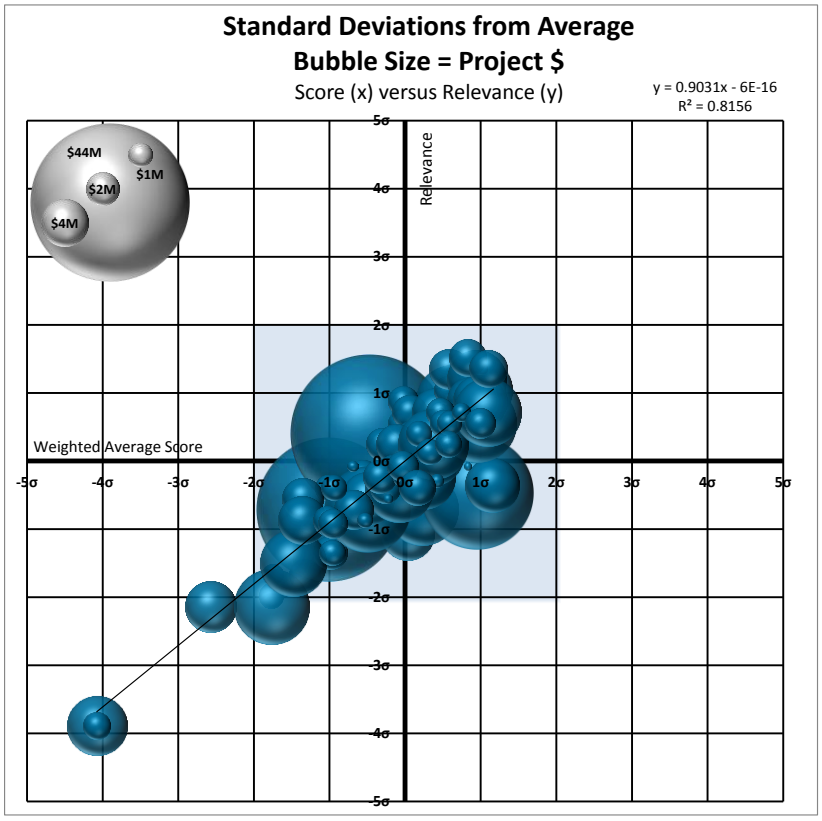


Figure 4-12. Weighted average score versus relevance – project funding

Like the total project funding chart in Figure 4-12, Figure 4-13 compares projects based on the age of a project to determine if there is potential for reviewer bias based on a project's duration. In 2011, a scatter plot of project life cycle was shown to indicate no correlation between the completion percentage of a project and the weighted average score. This was repeated in 2012 with similar results. Figure 4-13 uses the age of the project (computed as of the date of the peer review, 4/22/2013, minus the reported actual start date of the project) rather than budget for the bubble magnitude. Only one project in the 2013 review cycle was over 10 years old, 38 projects were 3-10 years old, 54 projects were less than 3 years old and 4 projects had not started or did not report a start date.

While Figure 4-13 does not show a strong correlation between project age and the Relevance or weighted average score of a project, it should be noted that, as in the 2012 review cycle, the oldest projects (largest bubbles) scored above the review average. It is not surprising that older projects tended to score slightly higher, as most projects with a long-standing period of performance are either projects with a demonstrated history of accomplishments or are long-term research projects with missions essential to furthering the geothermal industry.

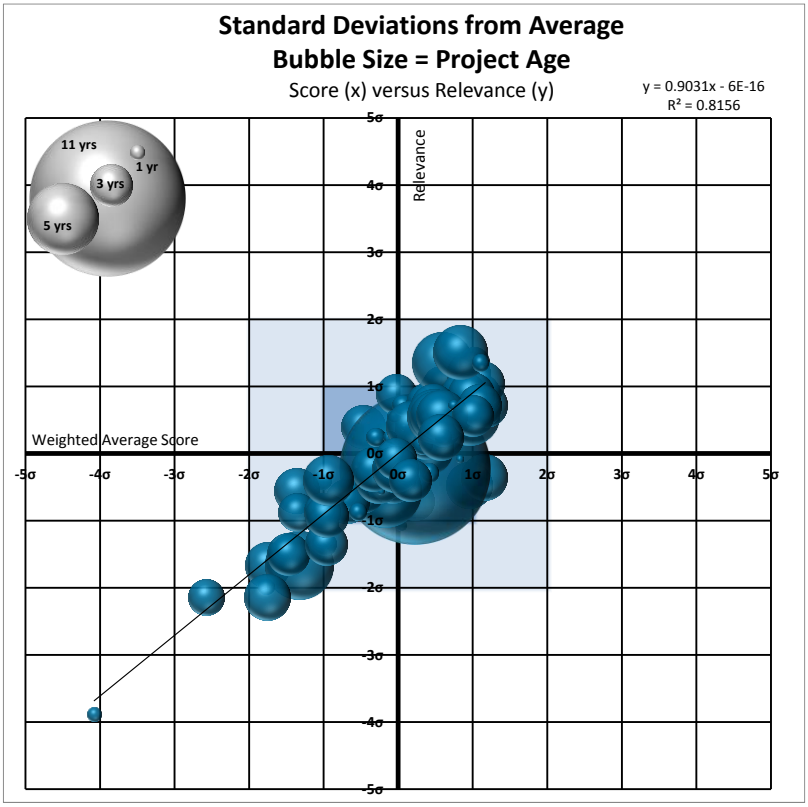


Figure 4-13. Weighted average score versus relevance – project age

The following subsections offer technology area overviews and describe the analysis of individual project scoring for each technology area included in the 2013 Peer Review. Also included in these subsections are callouts containing general or overview comments made by expert reviewers for each technology area. Detailed reviewer comments on individual projects and Principal Investigator responses to reviewer comments are included in Appendix A. Please see Appendix B for the correlation of project ID numbers to project title and organization.

4.1 Co-Produced & Low-Temperature

The Geothermal Technologies Office (GTO) works with industry and academia to develop and demonstrate new low-temperature and co-production technologies that will help the geothermal sector achieve widespread adoption of efficient and under-utilized, low temperature resources. The Co-produced & Low-Temperature technology area benefits from Office-wide component research and development to reduce capital and operating costs through improved efficiencies in working fluids, cooling systems, heat exchangers, and other system components. Additional capital and Operations and Maintenance (O&M) costs will be driven down by knowledge gained and technical advances made in both the demonstration projects and applied Research and Development (R&D).

Low-Temperature geothermal energy is defined as heat obtained from geothermal fluid at temperatures of 300°F (150°C) or less. These resources have typically been used in direct-use applications, such as district heating, greenhouses, fisheries, mineral recovery, and industrial process heating. However, some low-temperature resources can be harnessed to generate electricity using binary-cycle power-system technology.

Approximately 15-30 billion barrels of co-produced hot water is produced each year from oil and gas operations in the United States. Historically, this hot water has been an inconvenience and requires proper disposal; however, it is now being looked at as a resource to produce electricity for in-field use or to be sold to the grid. Co-produced geothermal resources have the potential to extend the economic life of oil and gas fields as well as engage the oil and gas sector in the geothermal market.

Projects funded by GTO in this technology area work toward a goal of achieving widespread production of low-temperature power through demonstration of economic power generation from low-temperature and co-produced fluids, data collection and dissemination, and increased collaboration between government and industry. GTO is working toward a goal of achieving widespread production of low-temperature power by 2020 through both surface and down-hole technology advances.

Table 4.1.1 provides a list of the Co-Produced & Low-Temperature projects that were included in the 2013 Peer Review Meeting and their scores. Overall, this technology review area had 10 projects reviewed. The 10 projects were scored by an average of 4 reviewers. The weighted average scores had an average, maximum, and minimum value of 6.1, 8.4, and 3.2 respectively. Please Refer to Table 2.1 for the weighting criteria used to determine the final scoring, and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

TABLE 4.1.1. Co-Produced & Low-Temperature projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Electric Power Generation from Co-Produced Fluids from Oil and Gas Wells; Electric Power Generation from Low to Intermediate Temperature Resources	William Gosnold University of North Dakota	8.8	9.0	8.0	8.3	8.4
Novel Energy Conversion Equipment for Low Temperature Geothermal Resources	Eric Minor Johnson Controls, Inc.	8.5	8.3	8.5	8.0	8.4
Hybrid Geothermal-Solar	Greg Mines Idaho National Laboratory	8.0	8.3	8.3	8.8	8.3
A Revolutionary Hybrid Thermodynamic Cycle for Binary Geothermal Power Plants	Adrian Sabau Oak Ridge National Laboratory	7.5	7.5	7.0	7.3	7.3
Fairbanks Geothermal Energy Project	Denise Brand Fairbanks North Star Borough	5.0	5.0	6.0	5.8	5.5
Kalex Advanced Low Temperature Geothermal Power Cycle	Cheryl Sandifer Technip USA	6.0	5.8	5.3	5.0	5.5
The Canby Cascaded Geothermal Development Project	Dale Merrick Modoc Contracting Company	5.5	5.8	5.0	6.3	5.5
Electric Power Generation Using Geothermal Fluid Co-produced from Oil and/or Gas Wells	Bernie Karl Chena Hot Springs Resort	4.5	5.0	5.5	4.5	5.0
Osmotic Heat Engine for Energy Production from Low Temperature Geothermal Resources	Nathan Hancock Oasys Water	4.5	4.8	4.8	2.8	4.4
Single-Well Low Temperature CO_2-Based Engineered Geothermal System	Alan Eastman GreenFire Energy	3.8	3.5	3.0	2.5	3.2

PROJECT SPOTLIGHT

Electric Power Generation from Co-Produced Fluids from Oil and Gas Wells; Electric Power Generation from Low to Intermediate Temperature Resources, *University of North Dakota*

Scoring Summary:
This project scored exceptionally high in both the Relevance and Impact of Research (8.8 out of 10.0) and Scientific and Technical Approach (9.0 out of 10.0) categories.

Key Reviewer Comments:
The quality of the research is excellent and the studies appear to have utilized many information sources, and the work completed is critical to reaching the objectives of the project. This appears to be the only co-production project that actually is operating on a working oil field.

4.2 Data Systems Development & Population

The Geothermal Technologies Office's (GTO) Data Systems Development & Population projects are part of the GTO Systems Analysis Data Provision Sub-Team. Additional Systems Analysis related projects are reviewed in Section 4.11.

GTO Data Provision and Data Stewardship activities include managing the geothermal informatics-related projects of the National Geothermal Data System (NGDS) as well serving the DOE's node on the NGDS, the DOE Geothermal Data Repository (DOE-GDR). As the design and testing of the National Geothermal Data System enter the final year, efforts shift to data stewardship and providing incentives to funding recipients to share high quality geothermal data.

Data and information collaboration within the geothermal community is greatly needed. The lack of data sharing between the geosciences disciplines presents barriers to geothermal development. Current national policy[4] supports data sharing to promote access to digital data sets resulting from federally funded research to allow companies to focus resources and efforts on understanding and exploiting discoveries. The policy supports increased access to federally funded published research and digital scientific data by directing federal agencies investing in research and development to have clear and coordinated policies for increasing such access.

Geothermal market analysts describe the need for data as a main geothermal development obstacle. "The rate-limiting step for all geothermal development is proving the resource – i.e., having sufficient geoscientific and exploration drilling data to be certain of a certain level of output."[5] While site-specific data gathering to identify and prove up a prospect is properly funded by the commercial venture seeking to exploit the resource, creation of reference sets of analog systems benefits the industry as a whole and represents appropriate encouragement of geothermal development through federal R&D.

In their Geothermal Risk Mitigation Strategies Report from 2008, Deloitte LLP identified the need for a national geothermal database to "provide developers and investors with a much-needed framework for investment evaluation," and the need for visualization tools that would rely on that data to "reduce the inherent risk in early stages of development and encourage an independent investment market."[3]

In order to help solve this problem, the U.S. Department of Energy's Geothermal Technologies Office (DOE GTO) has developed a plan, secured funds, and is supporting the development of the National Geothermal Data System (NGDS). The NGDS is being designed as a system of distributed nodes, all in communication with one another. Each node will collect data and provide access to the collected data to the other nodes. The DOE Geothermal Data Repository strives to be DOE's node on the NGDS.

Strategic Direction for Providing DOE Geothermal Linked Open Data
In its May 2011 Strategic Plan, the U.S. Department of Energy highlighted the importance of the success of their projects to include data reusability:

> *DOE's success should be measured not when a project is completed or an experiment concluded, but when scientific and technical information is disseminated. Beyond broad availability of technical reports, e-prints and multimedia, and publication in peer-reviewed journals, open access to experimental data and analysis codes is increasingly important in policy-relevant research areas. The Department will establish guidelines for use with both grants and contracts to ensure appropriate access to, and retention of, scientific data and analysis methods.*

[4] Memorandum For The Heads of Executive Departments and Agencies, "Increasing Access to the Results of Federally Funded Scientific Research", John P. Holdren, Director Executive Office of the President, Office of Scientific and Technical Information. 22 February 2013. Print.
[5] Bloomberg New Energy Finance, Q3 2012 Geothermal Market Outlook

In more applied areas, knowledge of what did not work can be of equal value with positive results, for that can prevent the misapplication of significant private resources (DOE Strategic Plan, May 2011.)

In line with DOE's strategic objectives, the DOE GTO is providing access to its geothermal project information through the Geothermal Projects Database[5] and the DOE-GDR. The DOE-GDR is intended to be one of many nodes on the National Geothermal Data System currently under development.

DOE's Node in the National Geothermal Data System (NGDS)

Figure 4-2-1 illustrates the current design of the NGDS as a system of distributed nodes, all in communication with one another. Each node will collect data and provide the other nodes access to the collected data. The DOE-GDR will be DOE's flagship node on the NGDS, and will be the submission point for all data generated by recipients of DOE GTO funds.

Figure 4-2-1. NGDS conceptual illustration showing DOE Geothermal Data Repository (GDR) node

Table 4.2.1 provides a list of the Data Systems Development & Population projects that were included in the 2013 Peer Review Meeting and their scores. Overall, this technology review area had 4 projects reviewed. The 4 projects were scored by an average of 4 reviewers. The weighted average scores had an average, maximum, and minimum value of 7.8, 8.7, and 7.0 respectively. Please Refer to Table 2.1 for the weighting criteria used to determine the final scoring, and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

TABLE 4.2.1. Data Systems Development and Population projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Heat Flow Database Expansion for NGDS Data Development, Collection and Maintenance	David Blackwell Southern Methodist University	8.8	8.5	8.3	9.3	8.7
State Geological Survey Contributions to NGDS Data Development, Collection and Maintenance	Lee Allison Arizona Geological Survey	8.5	8.0	8.8	8.3	8.4
National Geothermal Resource Assessment and Classification	Colin Williams U.S. Geological Survey	8.0	7.5	6.8	7.3	7.3
National Geothermal Data System Architecture Design, Testing and Maintenance	Harold Blackman Boise State University	7.3	6.8	6.8	7.5	7.0

PROJECT SPOTLIGHT

National Geothermal Data System Architecture Design, Testing and Maintenance, *Boise State University*

Scoring Summary:
This project received the lowest weighted average score for this technology area but addresses a critical need for the geothermal community.

Key Reviewer Comments:
Having a "one-stop" shop for geothermal data is a powerful thing. It should not only help the industry and geothermal community, but also be useful for people outside the community, and help educate the public.

4.3 Enhanced Geothermal Systems (EGS) Demonstrations

Enhanced Geothermal Systems (EGS) are engineered reservoirs created to produce energy from geothermal resources that are otherwise not economical due to a lack of water and/or permeability. EGS technology has the potential to unlock the vast amount of heat and energy located at depths accessible to current and future drilling technologies, regardless of natural permeability. This is a strategic domestic resource that can supply more than 100,000 MWe of clean baseload energy. The technical targets for this technology area are to demonstrate the ability to create a 5MW EGS reservoir by 2020, and ultimately lower the Levelized Cost of Electricity (LCOE) to 6 cents/kWh by 2030. While achieving cost-competitive electricity generation from EGS is a long-term goal, in the near-term, R&D and Demonstration projects will move industry along the EGS learning curve toward technological readiness. The Office supports RD&D activities through academia, national laboratories, and industry partnerships to advance EGS technologies.

Key EGS activities are currently focused on:

- Five EGS Demonstrations to validate reservoir characterization, creation, and operation via hydraulic, thermal, and chemical stimulation technologies in different geologic conditions;
- Many Research and development (R&D) projects funded by the American Recovery and Reinvestment Act (ARRA) and through a FY11 Funding Opportunity Announcement (FOA) - Key research areas include: zonal isolation, observation and monitoring tools, well completions, subsurface modeling, and induced seismicity;
- National Laboratory Annual Operating Plan (AOP) projects focused on key Office priorities and aligned with core lab capabilities; and
- Technology roadmapping.

The Office invests in both near-hydrothermal field and greenfield EGS Demonstration projects. The near-hydrothermal field EGS resource includes the areas around identified hydrothermal sites that lack sufficient permeability and/or in-situ fluids to be economically produced as conventional hydrothermal resources. Greenfield EGS is used to describe technology demonstration in geologic settings that have not been previously exploited as hydrothermal resources. Technologies of R&D solicitations have included: temperature-hardened submersible pumps; zonal isolation tools; smart tracers; high temperature, high pressure monitoring and logging tools; advanced seismic analysis for interpretation of fluid flow and induced seismicity; coupled models to predict reservoir development and performance; advanced mineral recovery from geothermal fluids; high temperature cements; directional drilling systems; measurement while drilling tools; well stimulation technologies; advanced fracture characterization technologies; and power conversion. While these technologies are vital to the success of EGS, they are cross-cutting technologies that are applicable in other geothermal resource types (e.g., hydrothermal systems). Recent successes include improved reservoir models and the expansion of the suite of high temperature downhole tools available for geothermal energy applications.

The Office's collective EGS RD&D efforts are currently focused on research and development of critical technologies for purposes of validation in the field-based demonstration projects. By the end of FY13, all five of the demonstration projects will have initiated (or even completed) well stimulation activities. In FY13, an EGS Field Laboratory effort was also launched, with continued preparation and development in FY14. The goals of this effort are to establish the technical and operational settings and parameters under which EGS can be commercially successful in a setting conducive to testing of potential high-risk, high-reward technologies.

Table 4.3.1 provides a list of the EGS Demonstrations projects that were included in the 2013 Peer Review Meeting and their scores. Overall, this technology review area had five projects reviewed. The five projects were scored by an average of four reviewers. The weighted average scores had an average, maximum, and minimum value of 7.5, 8.4, and 6.3 respectively. Please refer to Table 2.1 for the weighting criteria used to determine the final scoring, and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

TABLE 4.3.1. EGS Demonstration projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Demonstration of an Enhanced Geothermal System at the Northwest Geysers Geothermal Field	Mark Walters Geysers Power Company, LLC	8.0	7.8	8.8	8.8	8.4
Concept Testing and Development at the Raft River Geothermal Field, Idaho	Joseph Moore University of Utah	8.5	8.5	7.3	7.8	7.9
Feasibility of EGS Development at Brady's Hot Springs	Peter Drakos Ormat Nevada, Inc.	7.3	7.8	7.0	8.8	7.5
Desert Peak East EGS Project	Peter Drakos Ormat Nevada, Inc.	6.8	7.3	7.3	8.3	7.3
Newberry Volcano EGS Demonstration	Susan Petty AltaRock Energy, Inc.	7.8	6.8	5.3	6.3	6.3

PROJECT SPOTLIGHT

Demonstration of Enhanced Geothermal System at the Northwest Geysers Geothermal Field, *Geysers Power Company LLC*

Scoring Summary:
This project scored exceptionally high in both the Accomplishments, Results, and Progress (8.8 out of 10.0) and Project Management and Coordination (8.8 out of 10.0) categories.

Key Reviewer Comments:
The project (and EGS program) goal of showing 5 MW of EGS power production was essentially accomplished with tests indicating an increase in steam production from Prati 31 and Prati 25 as a direct result of the injection of cool water into Prati 32. An excellent stimulation experiment was performed. A field demonstration of this scope is producing the most valuable results from which understanding of geothermal reservoir mechanics can be obtained. This project has been well managed from the outset. The project staff from Calpine and from LBNL are all experienced in Geysers work, devised a well thought out project plan and implemented it well. This project contributed towards understanding induced seismicity, mitigation of non-condensable gas, and cold water stimulation methods.

4.4 Fluid Imaging, Characterizing Fractures, & Induced Seismicity

Mapping seismicity and subsurface fluid-flow pathways during stimulation and throughout the life of Enhanced Geothermal Systems (EGS) projects is critical from both a monitoring and reservoir management perspective; these data provide a means to identify the location of critically stressed fractures through both observation and modeling approaches. When collected over time, information on fracture location and orientation and the ability to predict fracture characteristics will promote an understanding of reservoir evolution and will lower EGS and Hydrothermal development costs by facilitating the drilling of preferentially oriented wells with a higher probability of success.

In general, the objectives of the Fluid Imaging, Characterizing Fractures, & Induced Seismicity technology area are to understand and predict the mechanical characteristics of a reservoir including the state of stress on existing or induced fractures in reservoir formations. Specifically, projects in this technology area seek to image natural or engineered fluid-filled fractures at depths of 1,000 meters or more in rocks of various compositions, and to monitor and record seismicity to sub-zero magnitudes with high reliability and a small location error. The Geothermal Technologies Office (GTO) is developing surface and borehole seismic methodologies using both compressional and shear waves for characterizing fractures in EGS. Additionally, GTO is developing high resolution, microearthquake (MEQ) tools and methods suited to monitoring EGS-induced microearthquakes.

Reservoir stimulation (hydraulic, thermal, and/or chemical) is an essential step in creating an EGS. Seismic imaging and monitoring MEQs, as well as fracture characterization, are critical R&D areas for EGS and have relevance to hydrothermal systems as well. The seismic energy released during reservoir stimulation provides the best means of locating and characterizing induced or reactivated fractures. The collection and interpretation of these seismic signals is thus crucial for understanding the geometry and quality of the reservoir created by the stimulation. Moreover, EGS risk and hazard assessment will benefit greatly from better MEQ predictions and simulation abilities currently under development.

Table 4.4.1 provides a list of the Fluid Imaging, Characterizing Fractures, & Induced Seismicity projects that were included in the 2013 Peer Review Meeting and their scores. Overall, this technology review area had 10 projects reviewed. The 10 projects were scored by an average of 4 reviewers. The weighted average scores had an average, maximum, and minimum value of 7.5, 8.7, and 6.6 respectively. Please Refer to Table 2.1 for the weighting criteria used to determine the final scoring, and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

TABLE 4.4.1. Fluid Imaging, Characterizing Fractures, & Induced Seismicity projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Fracture Network and Fluid Flow Imaging for Enhanced Geothermal Systems: Applications from Multi-Dimensional Electrical Resistivity Structure	Phillip Wannamaker University of Utah	8.3	9.0	8.5	9.3	8.7
Toward the Understanding of Induced Seismicity in Enhanced Geothermal Systems	Ronald Gritto Array Information Technology Inc.	8.0	8.3	8.0	7.3	8.0
Advanced 3D Geophysical Imaging Technologies for Geothermal Resource Characterization	Greg Newman Lawrence Berkeley National Laboratory	8.5	8.8	7.3	7.5	8.0
Full-waveform inversion of 3D-9C VSP data from Brady's EGS site and update of the Brady reservoir scale model	Lianjie Huang Los Alamos National Laboratory	8.5	8.5	7.3	8.3	8.0
Application of Neutron Imaging and Scattering to Fluid Flow and Fracture in EGS Environments	Yarom Polsky Oak Ridge National Laboratory	7.3	8.0	7.5	7.8	7.6
Monitoring and Modeling Fluid Flow in a Developing EGS Reservoir	Michael Fehler Massachusetts Institute of Technology	7.8	8.0	7.3	6.5	7.5
Characterizing Fractures in Geysers Geothermal Field by Micro-seismic Data, Using Soft Computing, Fractals, and Shear Wave Anisotropy	Fred Aminzadeh University of Southern California	8.3	7.3	7.5	6.3	7.5
Development of a Geological and Geomechanical Framework for the Analysis of MEQ in EGS Experiments (Geysers)	Ahmad Ghassemi University of Oklahoma	8.5	7.0	6.3	6.3	6.9
Use of Geophysical Techniques to Characterize Fluid Flow in a Geothermal Reservoir	Michael Batzle Colorado School of Mines	6.3	6.3	7.0	7.8	6.7
Sustainability of Shear-Induced Permeability for EGS Reservoirs – A Laboratory Study	Timothy Kneafsey Lawrence Berkeley National Laboratory	7.0	6.5	6.3	7.5	6.6

PROJECT SPOTLIGHT

Fracture Network and Fluid Flow Imaging for Enhanced Geothermal Systems: Applications from Multi-Dimensional Electrical Resistivity Structure, *University of Utah*

Scoring Summary:
This project tied for the highest score of this year's review, and scored exceptionally high in both the Project Management & Coordination (9.3 out of 10.0) and Scientific and Technical Approach (9.0 out of 10.0) categories.

Key Reviewer Comments:
Clearly, significant progress has been made towards stated project objectives. Theoretical methods and techniques were created and developed, codes were written and tested, and useful results obtained and delivered. Results presented convincingly demonstrate improved feature imaging resolution and enhanced algorithm efficiency and runtime speedup. The project's substantial accomplishments are, no doubt, a consequence of the research team's productivity in development, execution and application. This project's impact on subsurface reservoir imaging will be substantial.

4.5 Geophysics and Geochemistry

A primary objective of the DOE Geothermal Technologies Office (GTO) is to increase the U.S. geothermal resource base through the accelerated development of the USGS-estimated 30 GWe of undiscovered geothermal resources.[6] The discovery and confirmation of "blind" geothermal resources (i.e. no surface expression of a geothermal system) and the technical advancement of enhanced geothermal systems (EGS) are critical components of this U.S. geothermal resource expansion effort. High upfront costs and exploration risk are identified as key barriers to geothermal energy development. Thus, decreasing the levelized cost of electricity for undiscovered hydrothermal resources and EGS is being pursued through the advancement of geophysical and geochemical techniques in geothermal exploration.

The 2013 Peer Review Meeting Geophysics & Geochemistry projects address these needs in the following research areas, including:

- Integration of multiple geophysical, geological and/or geochemical techniques to reduce exploration risk;
- Utilization of new geophysical tools, techniques and processing methods not previously applied to geothermal exploration, development, and monitoring;
- Development of improved geothermometers, isotopic signature analyses, and geochemical methodologies;
- Modeling and prediction of fluid rock interaction and geochemical evolution of permeable fracture networks in enhanced geothermal systems;
- Developing geophysical tools and techniques to assess and monitor the sustainability and longevity of enhanced geothermal systems; and
- Improved constraint of fluid flow distribution in the subsurface for reservoir delineation as well as management of production/injection configuration at existing geothermal fields.

Table 4.5.1 provides a list of the Geophysics & Geochemistry projects that were included in the 2013 Peer Review Meeting, as well as their scores. Overall, this technology review area had 16 projects reviewed. The 16 projects were scored by an average of 4 reviewers. The weighted average scores had an average, maximum, and minimum value of 7.2, 8.4, and 5.5, respectively. Please Refer to Table 2.1 for the weighting criteria used to determine the final scoring, and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

[6] USGS. (2008). *Assessment of Moderate- and High-Temperature Geothermal Resources in the United States.* Retrieved October 17, 2013, from USGS Fact Sheet 2008-3082: http://pubs.usgs.gov/fs/2008/3082/pdf/fs2008-3082.pdf

TABLE 4.5.1. Geophysics & Geochemistry projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Identification of Hidden, High-Enthalpy Geothermal Systems in Extensional Regimes Through an Exploration Technology Paradigm Incorporating Magnetotellurics, Soil Gas Geochemisty and Structural Analysis	Phillip Wannamaker University of Utah	9.0	8.5	8.3	7.8	8.4
Monitoring EGS Stimulation and Reservoir Dynamics with InSAR and MEQ	Nicholas Davatzes Temple University	8.5	8.0	8.5	7.8	8.3
Effects of volcanism, crustal thickness, and large scale faulting on the development and evolution of geothermal systems: Collaborative project in Chile	Patrick Dobson Lawrence Berkeley National Laboratory	7.0	8.5	8.3	9.3	8.2
Novel Coupled Thermochronometric and Geochemical Investigation of Blind Geothermal Resources in Fault- Controlled Dilational Corners, Dixie Valley, Nevada	Daniel Stockli University of Texas at Austin	8.0	7.0	8.0	8.0	7.7
Methodologies for Reservoir Characterization Using Fluid Inclusion Gas Chemistry	Lorie Dilley Hattenburg, Dilley, and Linnell, LLC	8.0	7.0	7.8	8.8	7.7
Stochastic Joint Inversion for Integrated Data Interpretation in Geothermal Exploration	Robert Mellors Lawrence Livermore National Laboratory	8.3	7.8	7.5	7.0	7.7
Development of a low cost method to estimate the seismic signature of a geothermal field from ambient seismic noise analysis	Ileana Tibuleac University of Nevada, Reno (UNR)	8.5	8.0	7.3	6.3	7.6
The Viability of Sustainable, Self-Propping Shear Zones in Enhanced Geothermal Systems: Measurement of Reaction Rates at Elevated Temperatures	Susan Carroll Lawrence Livermore National Laboratory	7.8	6.3	7.0	8.5	7.1
Novel use of 4D Monitoring Techniques to Improve Reservoir Longevity and Productivity in Enhanced Geothermal Systems	Kelly Rose National Energy Technology Laboratory	8.3	7.0	6.5	7.0	7.1
Optimizing parameters for predicting the geochemical behavior and performance of discrete fracture networks in geothermal systems	Alexandra Hakala National Energy Technology Laboratory	8.0	6.3	6.5	8.0	6.9
Great Basin Center for Geothermal Energy (I\IV)	Wendy Calvin University of Nevada, Reno (UNR)	7.0	6.5	7.0	6.8	6.8

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Time-lapse joint inversion of GEOphysical Data and its application to geothermal prospecting – GEODE	Andre Revil Colorado School of Mines	6.8	7.0	6.3	6.5	6.6
Integration of Full Tensor Gravity and ZTEM Passive Low Frequency EM Instruments for Simultaneous Data Acquisition	Scott Wieberg Bell Geospace, Inc.	7.5	6.0	6.3	7.3	6.5
Improved Geothermometry Through Multivariate Reaction Path Modeling and Evaluation of Geomicrobiological Influences on Geochemical Temperature Indicators	Craig Cooper Idaho National Laboratory	6.8	5.8	6.8	6.3	6.4
Spectral SP: A New Approach to Mapping Reservoir Flow and Permeability	Donald Thomas University of Hawaii	6.8	6.3	5.8	6.3	6.2
Advances in Hydrogeochemical Indicators for the Discovery of New Geothermal Resources in the Great Basin, USA	Stuart Simmons Colorado School of Mines	6.5	6.0	4.8	4.8	5.5

PROJECT SPOTLIGHT

Identification of Hidden, High-Enthalpy Geothermal Systems in Extensional Regimes Through an Exploration Technology Paradigm Incorporating Magnetotellurics, Soil Gas Geochemistry and Structural Analysis, Phillip Wannamaker, *University of Utah*

Scoring Summary:
This project scored exceptionally high in both the Relevance & Impact of Research (9.0 out of 10) and Scientific and Technical Approach (8.5 out of 10) categories with an overall score of 8.4 out of 10.

Key Reviewer Comments:
This project speaks directly to GTO's goal of accelerating development of 30 GWe of undiscovered hydrothermal systems. Validating a new method with the potential to identify currently blind, regional-scale opportunities could have far reaching impacts. Bolstering models for a newly producing region in the McGinness Hills to grow production there in collaboration with Ormat could lead to near-term growth. Extending the model in Phase II to open up a new basin in the Black Rock-Kumiva Valley as a large and potentially favorable target is a class of discovery that only a small portion of the Office's portfolio can currently claim to address.

4.6 High-Temperature Tools & Drilling Systems

In order to effectively develop EGS reservoirs, the subsurface must be comprehensively characterized prior to, during, and after EGS stimulation. Therefore, the Office is working with partners to develop high temperature sensors and electronics for both transient and permanent downhole applications. This includes tools for reservoir characterization and tracking reservoir evolution; real-time downhole monitoring of temperature, pressure, fluid characteristics, and seismicity; tools for identifying and tracking fluid flow paths, pre- and post-stimulation; and tools, techniques, and technologies for drilling/well completion. The Office is also developing enabling technologies for reservoir creation and sustainable operation including high-temperature borehole packers and submersible pumps.

The American Recovery and Reinvestment Act of 2009 allowed the Office to support research and development of various High-Temperature Tools, Drilling Systems, and Zonal Isolation technologies tailored for use in harsh geothermal environments. High temperature tools and sensors are being designed for temperatures of 374°C and depths up to 10,000 m (supercritical reservoirs). In Drilling Systems, technologies are being developed that provide increased rates of penetration (3x the current rates of 10 ft/hr), reduced costs for drilling in hard rock environments, and 300°C tolerance with capabilities of reaching depths of up to 10,000 m. The Directional Drilling and Measurement-While-Drilling (MWD) technologies focus on tool development to guide directional drilling operations and facilitate characterization of the rock mass/reservoir during drilling, including telemetry methods to transmit data to the surface and design and development of high performance bottom-hole assemblies. The objectives of the Zonal Isolation efforts are to seal off unwanted flow regions using both physical and chemical diverters, and to facilitate multi-stage fracturing in high-temperature (>200°C) environments to increase power production per well.

Table 4.6.1 provides a list of the High-Temperature Tools & Drilling Systems projects that were included in the 2013 Peer Review Meeting and their scores. Overall, this technology review area had 13 projects reviewed. The 13 projects were scored by an average of 4 reviewers. The weighted average scores had an average, maximum, and minimum value of 6.9, 8.6, and 1.0 respectively. Please Refer to Table 2.1 for the weighting criteria used to determine the final scoring, and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

TABLE 4.6.1. High-Temperature Tools & Drilling Systems projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Gas Generator Development and Testing for Controlled Rapid Pressurization Using Liquid Propellants for EGS Well Stimulation; Energetic Materials for EGS Well Stimulation	Mark Grubelich Sandia National Laboratories	8.8	8.5	8.5	9.0	8.6
High-Temperature-High-Volume Lifting For Enhanced Geothermal Systems	Norman Turnquist GE Global Research	8.5	9.0	8.3	8.5	8.6
Evaluation of Emerging Technology for Geothermal Drilling Applications	Doug Blankenship Sandia National Laboratories	9.3	8.3	8.3	8.3	8.5
Directional Measurement-While-Drilling System for Geothermal Applications; High Temperature 300°C Directional Drilling System	Jochen Schnitger Baker Hughes Oilfield Operation, Inc.	9.0	9.0	7.8	7.5	8.4

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Rotation-Enabled 7-DOF Seismometer for Geothermal Resource Development	Darren Laughlin A-Tech Corporation	8.3	8.0	8.0	8.0	8.1
Well Monitoring Systems for EGS	Randy Normann Perma Works LLC	9.3	7.8	7.3	7.5	7.8
Technology Development and Field Trials of EGS Drilling Systems	David Raymond Sandia National Laboratories	8.8	7.8	7.5	7.3	7.8
Auto-Indexer for Percussive Hammers	Jiann Su Sandia National Laboratories	7.8	8.0	7.8	7.3	7.8
Complete Fiber/Copper Cable Solution for Long-Term Temperature and Pressure Measurement in Supercritical Reservoirs and EGS Wells	Kendall Waterman Draka Cableteq USA	8.3	8.0	7.0	7.3	7.6
Extreme Temperature (300 C) P/MWD with Energy Storage and Generation, Enabling Substantial Cost and Risk Reduction in Geothermal Exploration	Riccardo Signorelli FastCAP Systems Corp.	7.5	6.5	6.5	7.5	6.8
Microhole Arrays Drilled With Advanced Abrasive Slurry Jet Technology To Efficiently Exploit Enhanced Geothermal Systems	Kenneth Oglesby Impact Technologies, LLC	6.3	4.8	4.5	5.0	5.0
Deep Geothermal Drilling using Millimeter Wave Technology	Kenneth Oglesby Impact Technologies, LLC	4.0	4.0	4.8	4.8	4.4
Perforating System for Geothermal Applications	Moises Smart Schlumberger Technology Corporation	1.0	1.0	1.0	1.0	1.0

PROJECT SPOTLIGHT

Gas Generator Development and Testing for Controlled Rapid Pressurization Using Liquid Propellants for EGS Well Stimulation; Energetic Materials for EGS Well Stimulation, *Sandia National Laboratories*

Scoring Summary:
This project scored exceptionally high in both the Relevance and Impact of Research (8.8 out of 10.0) and Project Management & Coordination (9.0 out of 10.0) categories.

Key Reviewer Comments:
The project is bringing new expertise to bear on long standing problems. Initiating a near wellbore fracture network in the target zone may overcome some of the out-of-zone fracturing seen in the hydraulic stimulations.

4.7 Innovative Exploration Techniques

High exploration risks and costs are a major barrier to expanded development of the Nation´s hidden hydrothermal resources. To address this challenge, the Office is developing exploration tools and techniques to create a lower and more predictable risk profile for geothermal development projects. In addition to reducing exploration risk, exploration RD&D priorities include the following: increase the economic viability of exploration technologies, confirm new hydrothermal resources, and foster useful data for the National Geothermal Data System. Best practices are being developed for geothermal exploration that include geologic research, remote sensing, and surface and downhole geochemistry and geophysical techniques. These best practices will help establish technical and cost targets. Additionally, the portfolio of Recovery Act Exploration Validation projects has the specific goal of confirming 400 MWe of new geothermal resources by 2014.

Significant investment was made in R&D and validation of Innovative Exploration Technologies (IET) with the 2009 American Recovery and Reinvestment Act. A funding opportunity in 2011 further added to the portfolio of exploration technology development projects. GTO has also engaged in roadmapping efforts for the past two years. For more successful targeting of exploration wells technical advancement is needed in several areas: noninvasive geophysical techniques including improved data collection and interpretation of existing techniques; improved invasive measurement tools and techniques; improved geochemical techniques; high resolution remote sensing data and reliable automated processing methods; stress/strain data mapping; multidisciplinary conceptual models; 3-D modeling software; and the creation of case study examples of geothermal systems in different geologic settings. GTO is working in cooperation with industry, academia, and the National Labs to address many of these technology challenges.

Table 4.7.1 provides a list of the Innovative Exploration Techniques projects and their scores that were included in the 2013 Peer Review. Overall, this technology review area had nine projects reviewed. The nine projects were scored by an average of 3.4 reviewers. The weighted average scores had an average, maximum, and minimum value of 6.8, 8.6, and 4.4 respectively. Please Refer to Table 2.1 for the weighting criteria used to determine the final scoring and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

TABLE 4.7.1. Innovative Exploration Techniques projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Finding Large Aperture Fractures in Geothermal Resource Areas Using a Three-Component Long-Offset Surface Seismic Survey	William Teplow US Geothermal, Inc.	8.3	8.3	8.8	9.0	8.6
Comprehensive Evaluation of the Geothermal Resource Potential within the Pyramid Lake Paiute Reservation	Donna Noel MID Lake Paiute Tribe	8.5	8.3	8.5	8.3	8.4
Recovery Act: Detachment faulting and Geothermal Resources – An Innovative Integrated Geological and Geophysical Investigation of Pearl Hot Spring, Nevada	Daniel Stockli University of Texas at Austin	8.5	8.3	8.5	7.3	8.3
Merging High Resolution Geophysical and Geochemical Surveys to Reduce Exploration Risk at Glass Buttes, Oregon; Blind Geothermal System Exploration in Active Volcanic Environments; Multi-phase Geophysical and Geochemical Surveys in Overt and Subtle	Patrick Walsh Ormat Technologies Inc.	7.5	7.8	7.3	7.8	7.5

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Advanced Seismic data Analysis Program (The "Hot Pot Project")	Frank Misseldine Oski Energy, LLC	6.5	6.8	6.8	7.8	6.9
Innovative Exploration Techniques for Geothermal Assessment at Jemez Pueblo, New Mexico	Greg Kaufman Pueblo of Jemez	6.3	6.0	6.0	7.3	6.2
Validation of Innovative Exploration Technologies for Newberry Volcano	Albert Waibel Davenport Power, LLC	6.0	6.3	6.3	6.5	6.2
Direct Confirmation of Commercial Geothermal Resources in Colorado using Remote Sensing and On-Site Exploration, Testing and Analysis	F. Robinson Flint Geothermal LLC	4.8	4.5	4.8	5.5	4.8
El Paso County Geothermal Electric Generation Project: Innovative Research Technologies Applied to the Geothermal Resource Potential at Ft. Bliss	Jon Lear El Paso County	3.8	4.5	4.5	4.8	4.4

PROJECT SPOTLIGHT

Finding Large Aperture Fractures in Geothermal Resource Areas Using a Three-Component Long-Offset Surface Seismic Survey, *US Geothermal, Inc.*

Scoring Summary:
This project scored exceptionally high in both the Relevance and Impact of Research (8.3 out of 10.0) and Scientific and Technical Approach (8.3 out of 10.0) categories.

Key Reviewer Comments:
This project resulted in the design of an integrated exploration plan that should be replicable throughout the Basin and Range province. Because one of the primary GTO goals is to improve exploration efficiency while decreasing costs, this project can be considered to be highly relevant with a strong potential for positive impacts on the geothermal industry. The teams assembled and the accomplishments thus far attest to the rigor of this approach.

4.8 Materials, Zonal Isolation, & Innovative Methods of Heat Recovery

Non-drilling well construction costs represent a significant portion of overall well costs for conventional and EGS resources. Additionally, the incompatibility of wellbore materials in geothermal host environments or poor long term performance can result in catastrophic wellbore failure. GTO is investing in the development of specialized materials to reduce these costs, and/or extend functionality of materials into high temperature and harsh environments. Zonal isolation is essential for many EGS reservoir development activities. Packers and other zonal isolation methods are required to eliminate fluid loss, to help identify and mitigate short circuiting of flow from injection wells to production wells, and to target individual zones for hydraulic tests and/or stimulation.

In 2011, GTO released a competitive announcement entitled "Energy Production with Innovative Methods of Geothermal Heat Recovery (DE-FOA-0000336)." The objective of this announcement was: to promote geothermal heat recovery technologies that mitigate or preclude potential adverse environmental impacts of geothermal energy development, production or use; include innovative methods for extracting heat; and alleviate financial risks. The projects selected for award under this announcement were subject to a competitive downselection at the completion of Phase I, and because of this, were not reviewed at the 2013 Peer Review. However, one project being conducted at Louisiana State University was only award a Phase I scope of work and was reviewed in this track.

GTO's portfolio of cements is being developed to withstand extreme geothermal conditions. Materials that address the specific challenges of thermal fluctuations during EGS wellbore stimulation, on the order of 175° C change in temperature, and high-fidelity placement of cements in deep boreholes are being developed. Zonal isolation technologies are being developed to operate under 400 bars pressure differential in wellbores up to 10 5/8" in diameter at temperature greater than 300° C. Zonal isolation technologies and methods were identified as critical technologies for the creation and operation of EGS reservoir in the DOE's Technology Roadmap for Strategic Development of Enhanced Geothermal Systems.

Table 4.8.1 provides a list of the Materials, Zonal Isolation, & Innovative Methods of Heat Recovery projects that were included in the 2013 Peer Review Meeting and their scores. Overall, this technology review area had 6 projects reviewed. The 6 projects were scored by an average of 3.5 reviewers. The weighted average scores had an average, maximum, and minimum value of 5.7, 7.8, and 1.0 respectively. Please Refer to Table 2.1 for the weighting criteria used to determine the final scoring, and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

TABLE 4.8.1. Materials, Zonal Isolation, & Innovative Methods of Heat Recovery projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Multifunctional Corrosion-resistant Foamed Cement Composites	Toshi Sugama Brookhaven National Laboratory	7.7	8.0	8.0	7.0	7.8
Self-Degrading Temporary Cementation Sealers	Toshi Sugama Brookhaven National Laboratory	6.7	7.7	8.0	7.3	7.6
Self Consuming Downhole Packer	Mark Grubelich Sandia National Laboratories	5.8	7.0	5.8	6.3	6.2

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Development of an Improved Cement for Geothermal Wells	George Trabits Trabits Group, LLC	6.0	6.7	5.3	6.3	6.0
High Temperature, High Pressure Devices for Zonal Isolation in Geothermal Wells	Paul Fabian Composite Technology Development, Inc.	5.0	5.5	5.8	6.0	5.6
Geothermal Resource Development with Zero Mass Withdrawal, Engineered Convection, and Wellbore Energy Conversion	Christopher White LA State Univ.	1.0	1.0	1.0	1.0	1.0

PROJECT SPOTLIGHT

Multifunctional Corrosion-resistant Foamed Cement Composites, *Brookhaven National Laboratory*

Scoring Summary:
Brookhaven National Laboratory, principal investigator Toshi Sugama, had the two top rated projects within the Materials, Zonal-isolation, and Innovative Methods of Heat Recovery track. Both projects scored strongly in results and progress during the evaluation period.

Key Reviewer Comments:
The scientific approach to this work consisted of a series of laboratory tests to evaluate the material properties of a variety of composite cements. The cement that met all of the 13 criteria contains hydrogarnet, a hydro-ceramic phase (similar to zeolite), and a hydro-Al-oxide, all generated from refractory calcium aluminate cement, Class F fly ash, and sodium silicate. This composite cement exhibited sustained compressive strength when subjected to repeated heat-water quenching cycles, and also was shown to maintain a high shear bonding strength with carbon steel casing. An acrylic polymer was added to the cement to improve the corrosion resistance of carbon steel casing, and even adding 2% of the polymer reduced cathodic corrosion of the steel based on laboratory testing. A foaming agent was also evaluated to determine how much was needed to attain the specified cement density, while still retaining sufficient compressive strength.

4.9 Modeling

The objectives of GTO's predictive modeling efforts are to assess the productive capacity and longevity of potential EGS or conventional geothermal systems and to design the creation and exploitation of reservoirs. For both the initial native state of geothermal systems, and in response to alternative exploitation scenarios that may be considered, predictive modeling of geothermal systems primarily involves simulating thermal and hydrological transport and geochemical processes. However, prediction of mechanical rock response to enhancement activities is of particular importance for EGS. The objectives of GTO's reservoir/seismicity modeling efforts are to develop a computational test bed to produce realistic models of EGS stimulation-response scenarios, and to serve as a general guide for the geothermal developer to address induced seismicity issues.

Moreover, subsurface energy technologies associated with oil and gas development, geologic storage of carbon dioxide, and geothermal energy utilization can give rise to microseismic activity. Thus, coupled THMC capabilities are needed to predict such activity from perturbations induced by stimulation, production, and injection operations, and to identify and implement operational conditions that eliminate or limit the potential for large and/or numerous earthquakes.

Within the Modeling technology area, activities are focused on:

- Developing wellbore-to-reservoir-scale fully coupled thermal-hydrological-mechanical-chemical models;
- Developing joint geophysical inversion techniques;
- Quantitatively evaluating the viability of geologic environments for creating EGS;
- Developing methodologies for improving fracture and flow imaging using surface technologies; and
- Identifying geophysical methods with the highest value of information and refining how associated data are interpreted for identifying undiscovered geothermal resources.

Table 4.9.1 provides a list of the Modeling projects that were included in the 2013 Peer Review Meeting and their scores. Overall, this technology review area had 12 projects reviewed. The 12 projects were scored by an average of 3.9 reviewers. The weighted average scores had an average, maximum, and minimum value of 7.6, 8.4, and 6.6 respectively. Please Refer to Table 2.1 for the weighting criteria used to determine the final scoring, and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

TABLE 4.9.1. Modeling projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
THMC Modeling of EGS Reservoirs – Continuum through Discontinuum Representations: Capturing Reservoir Stimulation, Evolution and Induced Seismicity	Derek Elsworth Pennsylvania State University	8.0	8.5	8.5	8.8	8.4
Code Comparison Study	Tim Scheibe Pacific Northwest National Laboratory	8.3	8.0	7.8	9.0	8.1
Integration of Nontraditional Isotopic Systems Into Reaction-Transport Models of EGS For Exploration, Evaluation of Water-Rock Interaction, and Impacts of Water Chemistry on Reservoir Sustainability	Eric Sonnenthal Lawrence Berkeley National Laboratory	7.5	8.0	7.8	8.5	7.9

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Analysis of Geothermal Reservoir Stimulation using Geomechanics-Based Stochastic Analysis of Injection-Induced Seismicity	Ahmad Ghassemi University of Oklahoma	8.0	8.0	7.8	7.3	7.8
Coupled Thermal-Hydrological-Mechanical-Chemical Model and Experiments for Optimization of Enhanced Geothermal System Development and Production; Evaluation of Stimulation at the Newberry Volcano EGS Demonstration Site	Eric Sonnenthal Lawrence Berkeley National Laboratory	8.0	8.0	7.3	8.0	7.7
Use of a Reservoir Model to Predict Potential Effects of Fracturing Techniques	Ahmad Ghassemi University of Oklahoma	8.0	8.3	7.3	7.0	7.7
Integration of Noise and Coda Correlation Data into Kinematic and Waveform Inversions With Microearthquake Data for 3D Velocity Structure, Earthquake Locations, and Moment Tensors in Geothermal Reservoirs	Daniel O'Connell William Lettis & Associates, Inc.	8.3	7.8	7.3	7.8	7.7
Stimulation at Desert Peak and Brady's reservoirs: modeling with the coupled THM code FEHM	Sharad Kelkar Los Alamos National Laboratory	8.3	6.8	7.8	8.5	7.6
Innovative computational tools for reducing exploration risk through integration of water-rock interactions and magnetotelluric surveys	Joseph Moore University of Utah	7.3	7.0	7.7	8.0	7.4
FRACSTIM/I: An Integrated Fracture Stimulation and Reservoir Flow and Transport Simulator	Robert Podgorney Idaho National Laboratory	7.8	7.0	7.3	6.8	7.2
Reservoir-Stimulation Optimization with Operational Monitoring for Creation of Enhanced Geothermal Systems	Kenneth Carroll Pacific Northwest National Laboratory	6.3	6.8	7.0	5.5	6.6
Development of Advanced Thermal-Hydrological-Mechanical-Chemical (THMC) Modeling Capabilities for Enhanced Geothermal Systems	Yu-Shu Wu Colorado School of Mines	6.5	6.5	6.8	6.3	6.6

PROJECT SPOTLIGHT

Code Comparison Study, *Pacific Northwest National Laboratory*

Scoring Summary:
This project scored exceptionally high in both the Relevance and Impact of Research (8.3 out of 10.0) and Project Management & Coordination (9.0 out of 10.0) categories.

Key Reviewer Comments:
The proposed testing and comparison of numerical codes will result in higher confidence in predictions of numerical models, and ultimately help improve the quality of EGS reservoir engineering and management, and reduce the costs of geothermal exploration.

4.10 Supercritical Carbon Dioxide & Working Fluids

Since 2000, it has been suggested that Enhanced Geothermal Systems may be operated with supercritical carbon dioxide (CO_2) instead of water as the heat transmission fluid. Such a system would combine recovery of geothermal heat and energy with geologic storage of CO_2, a greenhouse gas. Research to date has indicated that under certain reservoir conditions, CO_2 outperforms water in its ability to mine heat from the subsurface. A major uncertainty remains about the nature and extent of the chemical interactions between injected CO_2, reservoir brine, host rock, and wellbore/surface materials. GTO ongoing research projects are focused on providing data and/or higher fidelity numerical simulation about these interactions.

Also, GTO has a limited portfolio of activities aimed at improvements to surface power conversion technologies. The hybridization of geothermal facilities with other renewable energy developments, most notably solar, is an idea that has potential merits. A main advantage of hybridization is the mitigation of power output decline during hot summer days - a period when solar output is the highest and geothermal output from air-cooled power plants is the weakest. The current, largely scoping studies are focused on identifying cost-efficient means of integrating these two renewable resources.

Table 4.10.1 provides a list of the Supercritical Carbon Dioxide projects that were included in the 2013 Peer Review Meeting and their scores. Overall, this technology review area had 3 projects reviewed. The 3 projects were scored by an average of 4 reviewers. The weighted average scores had an average, maximum, and minimum value of 5.6, 6.5, and 5.6 respectively. Please Refer to Table 2.1 for the weighting criteria used to determine the final scoring, and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

TABLE 4.10.1. Supercritical Carbon Dioxide & Working Fluids projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
An Integrated Experimental and Numerical Study: Developing a Reaction Transport Model that Couples Chemical Reactions of Mineral Dissolution/Precipitation with Spatial and Temporal Flow Variations in CO_2/Brine/Rock Systems	Martin Saar University of Minnesota	6.8	6.8	6.0	7.0	6.5
Advanced Heat/Mass Exchanger Technology for Geothermal and Solar Renewable Energy Systems (NV)	Miles Greiner University of Nevada, Reno (UNR)	5.8	5.8	5.3	5.0	5.5
Experiment-Based Model for the Chemical Interactions between Geothermal Rocks, Supercritical Carbon Dioxide and Water	Miroslav Petro PARC (Palo Alto Research Center)	5.8	5.0	4.5	5.3	5.0

PROJECT SPOTLIGHT

An Integrated Experimental and Numerical Study: Developing a Reaction Transport Model that Couples Chemical Reactions of Mineral Dissolution/Precipitation with Spatial and Temporal Flow Variation in CO_2/Brine/Rock Systems, *University of Minnesota*

Scoring Summary:
This project received a set of mixed scores from the reviewers, ranging from 8.0 to 5.0 for each of the evaluation categories. However, substantial reviewer and PI rebuttals can be found in Appendix A, which can be used to improve the execution of the remainder of this work.

Key Reviewer Comments:
The objective of this project is to experimentally determine spatial and temporal variations in pore/fracture geometries in CO_2/rock/water systems and develop semi-empirical correlations that can be used in multiphase flow simulators to adjust associated permeability and flow fields. Such correlations are of core importance to modeling long-term performance of EGS projects using CO_2 as a subsurface working fluid. Significant progress has been made through a series of core flood experiments and lattice Boltzmann numerical simulations.

4.11 Systems Analysis

The Systems Analysis technology area works to identify and address barriers to geothermal adoption in the U.S. and validate technical progress across the geothermal sector. The technology area takes a holistic analytical approach across the Office's technology portfolio to evaluate trends, conduct impact analyses, identify best practices, and provide resources and tools that will reduce costs and risk for geothermal developers. The technology area primarily conducts analyses in the following areas: environmental impacts of geothermal; policy and regulatory barriers to development and deployment; economic modeling and validation of geothermal technologies; as well as collecting and disseminating data for public use to spur geothermal development. Lessons learned resulting from these analyses are subsequently incorporated into the Office's Multi-Year Program Plan and either validate or refine the Office's overall strategic direction. The subprogram conducts these activities in partnership with the National Labs, federal agencies, academic institutions, and industry stakeholders.

In general, Systems Analysis is responsible for:

- Identifying technology, market, and industry barriers;
- Supporting informed decision-making;
- Analyzing the economic, environmental, and energy security benefits of geothermal development; and
- Demonstrating progress toward GTO goals and directing research efforts.

In addition, GTO's international partnerships aim to facilitate information sharing and leverage best practices across the geothermal sector. The Office participates in two major international efforts: the International Partnership for Geothermal Technology (IPGT) and the International Energy Agency's Geothermal Implementing Agreement (IEA-GIA). The IPGT's goals closely match those of GTO, and all IPGT collaborations are intended to the U.S. geothermal industry.

Table 4.11.1 provides a list of the Systems Analysis projects that were included in the 2013 Peer Review Meeting and their scores. Overall, this technology review area had 6 projects reviewed. The 6 projects were scored by an average of 3.8 reviewers. The weighted average scores had an average, maximum, and minimum value of 7.0, 8.6, and 5.6 respectively. Please Refer to Table 2.1 for the weighting criteria used to determine the final scoring, and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

TABLE 4.11.1. Systems Analysis projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Geothermal Regulatory Roadmap	Kate Young National Renewable Energy Laboratory	9.3	8.3	8.5	8.5	8.6
GETEM Development	Greg Mines Idaho National Laboratory	9.5	8.0	8.0	7.5	8.2
Estimation and Analysis of Life Cycle Costs of Baseline Enhanced Geothermal Systems	Uday Turaga Adi Analytics, LLC	7.0	7.3	6.0	7.3	6.9
Decision Analysis for Enhanced Geothermal Systems	Herbert Einstein Massachusetts Institute of Technology	6.8	7.0	7.3	6.5	6.9
Hybrid and advanced air-cooling	Desikan Bharathan National Renewable Energy Laboratory	6.5	5.8	5.0	5.3	5.6
Analysis of Low-Temperature Utilization of Geothermal Resources	Brian Anderson West Virginia University	5.7	5.3	6.0	5.3	5.6

PROJECT SPOTLIGHT

Geothermal Regulatory Roadmap, *National Renewable Energy Laboratory*

Scoring Summary:
This project scored exceptionally high in both the Relevance and Impact of Research (9.3 out of 10.0) and Accomplishments, Results, & Progress (8.5 out of 10.0) categories.

Key Reviewer Comments:
This project is strong in what it brings to industry in understanding and streamlining the permitting process. Open source publishing via OpenEI allows wide spectrum access and sharing of data.

4.12 Tracers

Tracers are important chemical tools for reservoir characterization and can be classified into two main groups including a) conservative, or chemically inert tracers and b) "smart", or chemically reactive tracers. Conservative tracers are established technologies that have been used to determine fluid path (well connectivity), fluid velocity, swept volume, and reservoir geometry. Smart tracers are a technology that is under development, and these tracers allow for additional measurements beyond those of conservative tracers, including but not limited to determination of surface area for heat exchange, fracture spacing, and reservoir temperature/pressure. This information facilitates the development of reservoir models with predictive capabilities through quantitative analysis of tracer and hydrologic data.

Interpretation of tracer data can be difficult and subjective, which can lead to differing interpretations of a given set of tracer data. Tracers, whether they are conservative or smart tracers, only directly contact a fraction of the geothermal reservoir. Thus, interpretation of the data collected is always conducted with many unknown parameters. As GTO proceeds with the tracer and tracer analysis/interpretation technology area in the future, the goal will be to use existing and new tracers coupled with data interpretation methods that are integrated with other geochemical, geophysical, and reservoir interpretation methods. The goal is to reduce the number of unknown variables and yield data that is essential to characterizing the geothermal reservoir, as any chemical reactor or heat exchanger would normally be characterized.

The Office is developing multidimensional geothermal tracer systems that offer great promise for use in characterizing fracture networks in EGS reservoirs. GTO is also providing integrated tracer and tracer interpretation tools to facilitate quantitative characterization of temperature distributions and surface area available for heat transfer. The Office is designing and analyzing laboratory and field experiments that would identify tracers with sorption properties favorable for EGS applications. Additionally, the Office is applying reversibly sorbing tracers to determine the fracture-matrix interface area available for heat transfer, and exploring the feasibility of obtaining fracture-matrix interface area from non-isothermal, Single-Well Injection-Withdrawal (SWIW) tests. Finally, GTO is also studying reservoir evolution following a successful EGS stimulation conducted in a field setting via a tracer study.

Table 4.12.1 provides a list of the Tracers projects that were included in the 2013 Peer Review Meeting and their scores. Overall, this technology review area had three projects reviewed. The three projects were scored by an average of 4 reviewers. The weighted average scores had an average, maximum, and minimum value of 7.0, 7.8, and 6.0 respectively. Please Refer to Table 2.1 for the weighting criteria used to determine the final scoring, and see Appendix A for detailed reviewer comments and rebuttals by the Principal Investigators for each individual project.

TABLE 4.12.1. Tracers projects

Project	PI Organization	Relevance & Impact of Research	Scientific & Technical Approach	Accomplishments, Results, & Progress	Project Management & Coordination	Weighted Average Scores for Projects
Quantum Dot Tracers for Use in Engineered Geothermal Systems	Peter Rose University of Utah	7.5	7.8	8.0	7.8	7.8
Novel Multidimensional Tracers for Geothermal Inter-Well Diagnostics	Yongchun Tang Power, Environmental and Energy Research Institute	6.5	7.3	7.5	7.3	7.2
Fracture Evolution following Hydraulic Stimulation within an EGS Reservoir	Peter Rose University of Utah	7.0	6.5	5.0	6.0	6.0

PROJECT SPOTLIGHT

Quantum Dot Tracers for Use in Engineered Geothermal Systems, *University of Utah*

Scoring Summary:
This project scored exceptionally high in the Accomplishments, Results, and Progress (8.0 out of 10.0) category.

Key Reviewer Comments:
Dr. Rose and his team have developed a new class of tracers designed to query the fracture and fracture surface properties in a geothermal system. These tracers avoid the cost and time required to conduct traditional tracer measurements. The development of an optical sensor system at different wavelengths presents many other uses beside geothermal tracers. The scientific approach of engineering nano-particles at 5 nm with specific fluorescence and charge is very innovative and illustrates a high degree of understanding of colloidal particle behavior and how to manipulate properties to act as tracers with a range of engineered properties.

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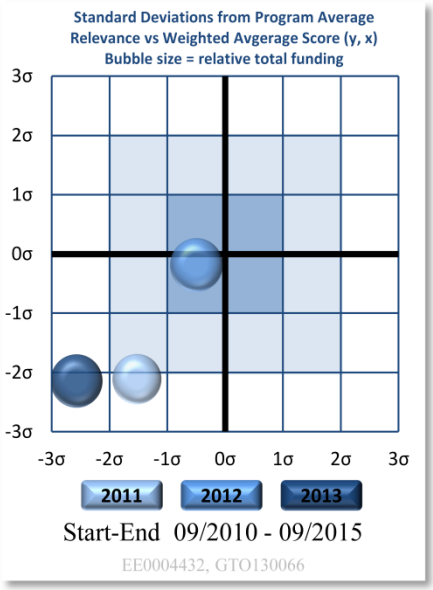
Appendix A: Detailed Reviewer and PI Rebuttal Comments

Co-Produced and Low-Temperature Reviewer Comments and Principal Investigator Rebuttals



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0004432
Project: Single-Well Low Temperature CO_2-Based Engineered Geothermal System
Principal Investigator: Eastman, Alan
Organization: GreenFire Energy
Panel: Co-Produced; Low Temperature

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23457

Score: 5.0

Comment: The project is intended to demonstrate the heat transfer properties of CO_2 using a relatively shallow, low-temperature well. At this time, the project is still in a "permitting" mode. Because of a lack of funds, it is unclear if the project will be carried to completion and what impact, if any, the work will have on Geothermal Office's mission and goals.

PI Response:

Reviewer 23456

Score: 2.0

Comment: This is a high-risk, long-term EGS project with, in my estimation, a relatively low payoff, even with success. This project goes from mathematical models to a full-scale, 6500 foot well, apparently with no bench-scale proof of concept. The economics of the project also need to be carefully defined. They apparently have made very little progress in the past year.

PI Response:

Reviewer 23478

Score: 5.0

Comment: This project seeks to satisfy the GTO objective of $0.06/kW by 2030 using a new and innovative technology, namely CO_2-EGS. It also needs to fill numerous knowledge gaps in the technical and marketing fields. There is no way to

assess the impact that this project has on industry development potential because very little field work has been done to date. The reason for the delay in project progress is said to be a dire need for funds. This is one of those projects that is relevant, but will not impact the industry for quite a few years, if it does work.

PI Response:

Reviewer 23532

Score: 3.0

Comment: The technology that the project proposes is of great interest to the development of a supercritical-CO_2 based low-temperature geothermal system and whether it requires stimulation (i. e. EGS) or has sufficient natural productivity for development. It should be noted that if there is sufficient natural permeability, there may be significant loss of CO_2 from the system.

The technology is a very interesting blend of supercritical-EGS and low-temperature resource development. However, see "weaknesses " for additional comments.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23457

Score: 4.0

Comment: The plan is to use a low temperature, shallow well in a huff-and-puff mode to demonstrate that CO_2 can be used to mine heat from reservoir rocks. Low temperature together with the planned huff-and-puff mode makes it unlikely that any significant amount of power will be produced. The project is unlikely to significantly increase scientific knowledge about the use of CO_2 instead of water in EGS.

PI Response:

Reviewer 23456

Score: 2.0

Comment: The desire to go to full drilling and large size production before any bench-scale proof of achievability of thermosyphon (does it work beyond modeling?) or supercritical CO_2 interactions with host rocks have been completed. Will mineralogic changes documented in the literature, which have the potential to plug fractures, occur under the P-T-scCO_2+/-H2O conditions likely to be encountered in the reservoir? The presentation states that the MOHC selection is in

progress and nearly complete, but the summary states that they have issued stop work orders to subcontractors. How is the work being done if the work has stopped?

The steps from the huff-puff experiments to installing and testing power generating equipment are not detailed. Will they plan to produce power in a huff-puff configuration? If this is EGS, they will need more than one well. They do not explain how a single-well thermosyphon will work. Do they have bench- or lab-scale tests to prove this concept?

PI Response:

Reviewer 23478

Score: 5.0

Comment: The project proponents plan to identify a drill site using micro-earthquake surveys seeking fractured zones in the St. John Dome, in AZ. Then, they want to drill to about 6,500 ft. (not to the 10,000 ft. needed to record 150C). They will log the hole, run CO_2 huff & puff tests, determine the recovery rates of CO_2, and if possible try to run a small binary cycle power plant to show that electricity production is possible.

Unfortunately, due to a lack of available funds, this project has barely begun, with MEQ surveys now under way. Accordingly, there is nothing upon which to base a reasonable score.

PI Response:

Reviewer 23532

Score: 3.0

Comment: I am not sure that the PI and some of the collaborators understand some (many?) of the technical obstacles to this project. First why don't they have a better idea of subsurface temperature? How will they be able to generate power from a single well system? Why have they gone to the expense of performing a seismic monitoring study at this early stage of the project?

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23457

Score: 3.0

Comment: Because of the inability to-date to raise sufficient funds, the project is seriously behind schedule. Assuming that sufficient funds are raised, the permitting will be completed in March 2015; field work will presumably start after that.

PI Response:

Reviewer 23456

Score: 1.0

Comment: Slide three of their presentation notes that the summary report is complete, but that the engineering design and cost estimate is only 25% complete and that the sensitivity test on design and cost estimates is 0% complete. Slide nine notes that they need to raise $2 million immediately. In the presentation, they stated that without this funding, the company will likely fail. They have issued stop-work orders to their subcontractors. They are achieving neither their goals and objectives nor their technical targets.

PI Response:

Reviewer 23478

Score: 2.0

Comment: The accomplishments to date are limited to 18 month's worth of micro-earthquake (MEQ) results, none of which have been documented in this presentation. The level of work underway is minimal and the value of the work can not yet be determined.

PI Response:

Reviewer 23532

Score: 6.0

Comment: They have made good progress on the project even though some of the important aspects of the project have not yet been investigated. They make a very good presentation of the project but I am somewhat doubtful that the project will be successful.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23457

Score: 3.0

Comment: Project work has been suspended pending the conclusion of efforts to raise the required funding.

PI Response:

Reviewer 23456

Score: 1.0

Comment: The presenter said that they are likely to be out of business within a few months (before the end of the fiscal year?), if they do not receive $2 million in private sector funding. They have, according to their summary, issued stop-work orders to their subcontractors. If management has led the company to failure and has stopped work on the project, they are not demonstrating management competence that, in my mind, is required for DOE grant continuation.

PI Response:

Reviewer 23478

Score: 2.0

Comment: There is very little to go on with respect to project management because, to-date, the only activity appears to be the starting of an MEQ survey. There has been coordination with project partners to get permits and the rights to some in-situ CO_2, but nothing else on which to base a score.

PI Response:

Reviewer 23532

Score: 4.0

Comment: The management of the project as it is put together is good. However I believe that the project team is lacking in sufficient earth science and/or geothermal experience to yield a successful outcome.

PI Response:

STRENGTHS

Reviewer 23457

Comment: Field project to test the possibility of mining heat using CO_2 instead of water from EGS.

PI Response:

Reviewer 23456

Comment: This concept is interesting.

PI Response:

Reviewer 23478

Comment: Project strengths are strictly hypothetical. It may be possible for CO_2-EGS to indeed be more efficient than water-based EGS, but this will have to be proven by this project, not just postulated.

If all works out with adequate down-hole temperatures, adequate heat transfer from rock to CO_2, and adequate permeability to allow influx of local CO_2, then it is possible the proposed system will work.

It is far too early in this project to cite any strengths exhibited.

PI Response:

Reviewer 23532

Comment: The only strength is that this is an interesting project from the standpoint of combining supercritical CO_2, EGS, and low-temperature electrical generation.

PI Response:

WEAKNESSES

Reviewer 23457

Comment: Insufficient funds have made the continuation of the project problematic.

Low temperature and huff/puff mode are not ideal for demonstrating the use of CO_2 in EGS.

PI Response:

Reviewer 23456

Comment: Serious project and management weaknesses identified last year have not been addressed. The PI provided no response to last years reviews, which suggests that the PI does not want to fully participate in this project.

There is the threat of the imminent failure of the company. This is a highly risky, unproven venture. They need bench-scale proof of concepts before any drilling. The concept that electricity can be produced from one well apparently using the huff-puff technique (if I am interpreting their paperwork correctly) means that no power can be produced while CO_2 is being injected, reducing power availability by half. Even if the thermosyphon works (and there will be no parasitic losses from pumping CO_2), what does this do to their economics? The PI, in the presentation, did not provide assurance that they will complete current phase before the company fails. What data have gone to the geothermal database? How will any data be transferred if the company fails?

The PI spent a fair amount of the presentation talking about potential uses for $scCO_2$, rather than directly addressing the issues that face this project (and were identified last year).

In slide 9, they note that they expect to take six months to raise funds for the company, which will be followed by 18 months of permitting. This means that the project, even if the company does not fail, is about to take a two-year hiatus. They do not address what other work they could be accomplishing during this time, such as refining their economics and proving their concepts.

PI Response:

Reviewer 23478

Comment: This project, as it now stands, still has all the weaknesses of an unproven theory. There are many unknowns on the technical side and on the marketing/economic side. Obviously, the primary weakness is a lack of funds. Until this project actually gets underway, it is fruitless to list other weaknesses.

PI Response:

Reviewer 23532

Comment: The project appears to have little understanding of the temperature gradient or bottom hole temperatures in the area of the project. They project a temperature of 150 C at 10,000 feet and suggest drilling to about 6,000 ft. Why? When asked about bottomhole temperature during the question period the PI was unable to provide any estimate. The project objectives state that the project is a single-well low temperature CO_2 project. It is extremely difficult to believe that a single well will be able to sustain any type of production of electricity! The use of injection and then flowback to estimate reservoir properties, however, is valid.

The project apparently is quite under-funded? Will this be remedied? DOE should have a closeout plan available for this project with a finite period of time available for project funding to be finalized.

PI Response:

IMPROVEMENTS

Reviewer 23457

Comment: The need additional funds to carry out a meaningful experiment (2 wells drilled sufficiently deep to access T > 150 degrees C) to demonstrate the use of CO_2 in EGS.

PI Response:

Reviewer 23456

Comment: Address weaknesses identified last year and this year.

PI Response:

Reviewer 23478

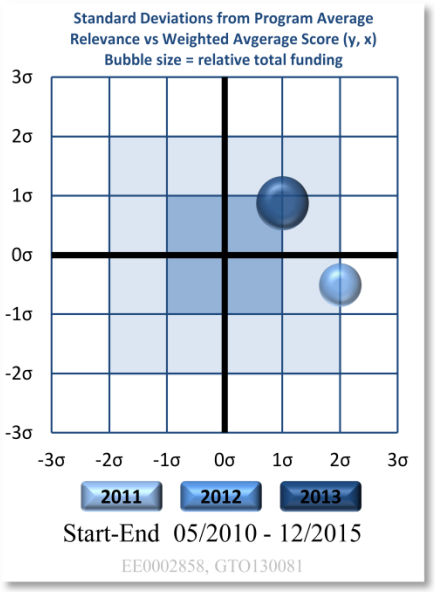
Comment: I can only suggest that every stone be turned so as to find funding and allow this work to proceed. The theory is good, but there is a long, expensive way to go.

PI Response:

Reviewer 23532

Comment: The project should consult with experts on subsurface temperature estimation to provide an estimate of the temperature with depth profile before expensive drilling is planned and executed.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002858
Project: Novel Energy Conversion Equipment for Low Temperature Geothermal Resources
Principal Investigator: Minor, Eric
Organization: Johnson Controls, Inc.
Panel: Co-Produced; Low Temperature

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23478

Score: 8.0

Comment: This project is definitely relevant to the GTO objective of inventing lower cost, higher efficiency low temperature power cycles. The proponent claims that in bench tests a 20% lower cost has resulted from their use of series, countercurrent cooling styles. This, combined with modifications to off-the-shelf chillers and new, improved working fluids and better heat cycle management, should easily meet the GTO stated standards.

Once the planned machine has been tested for several years at OIT and the claims verified, this unit could have very significant impact on the geothermal industry in light of the fact that so many thermal sites have relatively low temperatures.

PI Response:

Reviewer 23456

Score: 9.0

Comment: The purpose of this project is to develop, deploy, test and confirm that the electrical generation equipment designed under this project will lower costs by 20% compared with other generation cycles. If successful, the lowered costs could have a broad-based positive impact on development of geothermal power.

PI Response:

Reviewer 23457

Score: 8.0

Comment: The project seeks to develop a high-efficiency, low-cost ORC energy conversion for low temperature geothermal systems. If successful, the project will help meet GTO's goals to "develop low-cost, high efficiency energy

conversion technologies for EGS", and to "reduce the cost of electricity generation from low-temperature geothermal sources."

PI Response:

Reviewer 23532

Score: 9.0

Comment: The project is an interesting blend of improved heat exchanger utilization and perhaps an improved turbine (i.e. a turbine designed by Barber Nichols, a firm noted for innovations in geothermal technology). If the installation is properly instrumented so that thermodynamic data can be collected, the project might provide improved equipment and operational data for geothermal electrical generation.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23478

Score: 8.0

Comment: Because the project proponents are highly experienced with regard to the manufacture of chillers and turbines, the modifications to equipment and fluids have been easily accomplished. Tests have been run on a bench scale that show an average cost decrease of about 20% using input temperatures of 175-275F. A prototype binary generator has been built and is ready for installation at OIT in 2013.

All of this shows that the technical work undertaken is rigorous and appropriate and that the objectives have almost been achieved well within budget. After the field testing is completed in 2015, the approach will have been validated (or not).

PI Response:

Reviewer 23456

Score: 9.0

Comment: The scientific and technical approach has been successful, as the prototype has been constructed, and is awaiting installation at OIT. It is through the actual testing at OIT that cycle efficiencies will be fully demonstrated.

PI Response:

Reviewer 23457

Score: 8.0

Comment: A novel series counterflow arrangement is used to achieve greater thermodynamic efficiency than that possible with a parallel arrangement. At least a part of the claimed cost savings (> 20%) is attributed to the use of an existing chiller platform.

Serial arrangement is claimed to be more efficient than the parallel arrangement.

A 2-year data collection effort is planned to gather actual operating data.

PI Response:

Reviewer 23532

Score: 8.0

Comment: The approach is good. Johnson Controls is highly qualified to conduct this type of research and Barber Nichols makes superb turbine equipment. They appear to be making good progress relative to the stated objectives and available financial resources. The only delay appears to be due to OIT preparation of the site of the plant.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23478

Score: 8.0

Comment: Research by the proponents resulted in the building of two prototype generating units. Models of these machines showed that generation costs should be about 20% lower than they are for current state-of-the-art cycles. Bench-scale lab test results exceeded the modeled results. The essence of the innovation is the use of series, counter-flow cooling and brine handling schemes that improve efficiency of the generation cycle.

The next step will be long-term testing of the units at OIT. The site is not yet ready, but should be available in 2013.

PI Response:

Reviewer 23456

Score: 9.0

Comment: All goals, except installation and demonstration with data collection and analysis during operation, have been completed.

PI Response:

Reviewer 23457

Score: 8.0

Comment: The ORC units have been fabricated and will be shipped to OIT later this year for installation and testing.

The project is somewhat behind schedule due to the OIT installation site being not ready.

The project is within planned cost.

PI Response:

Reviewer 23532

Score: 9.0

Comment: The quality of accomplishments and engineering appear to be of high quality. The cycle that will be installed offers an innovative approach to geothermal binary electrical generation. Technical goals appear to be obtainable (optimized efficiency with 20% less cost).

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23478

Score: 8.0

Comment: The two proponent partners both have well proven track records of managing successful projects. They have completed all aspects of this scheme on time and under budget, thus attesting to the adequacy of the project management.

The only major delay is beyond the control of the partners and is due to conditions at OIT which have made the test site unavailable until the fall of 2013. At that time a two year data collection period will begin so as to confirm the generating characteristics of the new units.

PI Response:

Reviewer 23456

Score: 9.0

Comment: The demonstration unit has been constructed and is ready to install. The project is about to enter the final operation and data collection phase, after which further commercialization opportunities can be evaluated. The project fits well within the corporate structure, and the investigator interest in completing on-line testing seems very high.

PI Response:

Reviewer 23457

Score: 8.0

Comment: No management issues have been identified. Future plans include the collection of operational data over a 2-year period. Such data are vital for validating the cost savings.

PI Response:

Reviewer 23532

Score: 7.0

Comment: The project appears to be well managed. Engineering and technical development seem to have been rigorous and on time. The only program problem appears to be some delay in site preparation at OIT. This may indicate that scheduling was optimistic, there was some lack of coordination between PI and OIT or that OIT was compliant.

PI Response:

STRENGTHS

Reviewer 23478

Comment: The strengths of this project are 1) that the design of a revolutionary cooling and brine handling system has been successful, 2) that a generation cost reduction of 20% seems likely, and 3) that all the work to date has been completed under budget.

It seems likely that when the project is field tested in the Fall of 2013, the model and lab test numbers will be confirmed. If so, then this system could lead to widespread adoption and development of many new low temperature geothermal resources.

PI Response:

Reviewer 23456

Comment: The project has been successful to date. It is run well and close to on time. Delays are due to issues at OIT that appear to be well on their way to resolution.

PI Response:

Reviewer 23457

Comment: The use of serial counterflow arrangement is novel.

Testing to validate the claimed improvement in thermodynamic efficiency and claimed cost savings is planned.

PI Response:

Reviewer 23532

Comment: The project has designed and will install an ORC configuration that is novel to geothermal, as far as I know. The equipment that will be installed is from several well respected suppliers: chiller/heat exchangers from York, turbine from Barber Nichols, and generator from ABB. The equipment will also be installed at OIT where presumably the institution will have a vested interest in monitoring the equipment from an academic standpoint.

PI Response:

WEAKNESSES

Reviewer 23478

Comment: The only weakness to be cited is the delay in availability of the test site. This was beyond the control of the project proponents and should be remedied by Fall of 2013.

PI Response:

Reviewer 23456

Comment: The project is moving nicely along, so no real observations here.

PI Response:

Reviewer 23457

Comment: It is not apparent if the use of 2-units in series will be cheaper than a single larger unit.

Cost comparison with other binary equipment was not available.

PI Response:

Reviewer 23532

Comment: None observed.

PI Response:

IMPROVEMENTS

Reviewer 23478

Comment: I have no improvement suggestions. The execution of this project seems exemplary.

PI Response:

Reviewer 23456

Comment: Be sure to record and share lots of data. This will be helpful to others considering similar projects.

PI Response:

Reviewer 23457

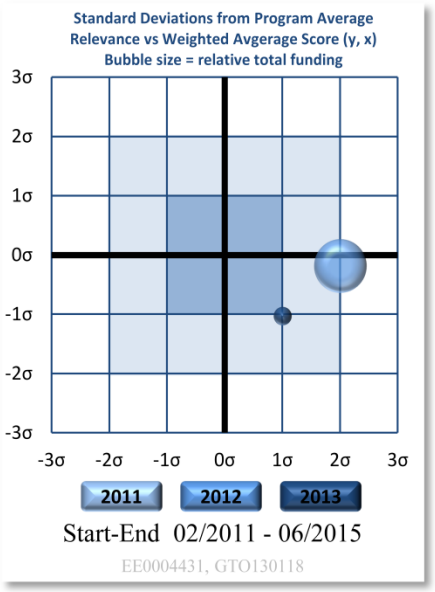
Comment: Include a cost comparison with a single larger unit.

PI Response:

Reviewer 23532

Comment: I suggest that DOE make sure that the equipment is sufficiently instrumented and data recorded so that the thermodynamic efficiency of all components can be determined.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0004431
Project: The Canby Cascaded Geothermal Development Project
Principal Investigator: Merrick, Dale
Organization: Modoc Contracting Company
Panel: Co-Produced; Low Temperature

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23478

Score: 5.0

Comment: This project plans to raise the bar for the use of low temperature resources by efficiently generating power in 50 kW increments and then cascading the power plant effluent downstream for use in space heating, greenhouses, and/or aquaponics before reinjection.

The focus will be on proving that such a system can be done on a stand-alone basis and that it can be economically viable.

The project proponents recognize the challenges to 1) finding resources of adequate temperature and permeability and 2) locating suitable, permeable injection well sites. In order to help in this exploration, a number of tools including MT, resistivity, air photo studies, and isotope analyses of produced waters will be used to the greatest extent possible.

Significant time and effort are also being put into education of the public regarding the scientific and economic merits of the project and to attract potential users of the cascaded waters to the Canby area.

If DOE wants to get 3GW on line by 2020, 50 kW projects like this will have to be replicated an awful lot of times!!

PI Response:

Reviewer 23456

Score: 5.0

Comment: This project has moderate local importance through its cascaded uses and district heating component. Much of the heat and all of the electric generation will be used, I gather, by the PI on his site. Geothermal district heating is well established; what is different here is the very low flow rates that seem to be working for heating. Other uses (greenhouses, generation of electricity) are established elsewhere. There is a suggested savings of about $100K per year on the district heating part of the program, and an overall economic benefit of about $271K per year. It is not clear to me how much of the economic benefit extends beyond the PI, other than the district heating. The concept of a cascaded system is nice, but it is not unique. In my judgment, this project is not developing data that will fill new technical knowledge gaps. Beyond the site specific applications, I remain to be persuaded that this project is likely to have broad impact on cost, performance, application or market penetration of geothermal energy development. The project has made modest progress, but the long-term impact to a broad audience is, in my mind, yet to be demonstrated.

PI Response:

Reviewer 23457

Score: 6.0

Comment: Cascaded use of a low temperature (~205 F) geothermal resource has the potential to make geothermal energy more competitive. If successful, the project will contribute to GTO's goal to "reduce the cost of power generation from low-temperature geothermal resources".

PI Response:

Reviewer 23532

Score: 6.0

Comment: The greatest technical interest and innovation of this project is the cascaded use of geothermal fluid for electrical generation and direct use. The project will also provide a test of the Electrotherm generation capability.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23478

Score: 5.0

Comment: Among the activities used by the proponents to prepare for drilling an injection well (ISO-3) and generating power, they have used isotope analyses of ground waters, MT and resistivity surveys, and review of data from many wells and springs in the interest area to guide them to a suitable injection well site.

They have improved the Injectivity Index of well ISO-2 from about 0.2 to about 2.1 gallons per minute/psi via the forceful injection of 500,000 gallons of water from ISO-1.

Additionally, they are carefully choosing the equipment to be used for power generation by matching conversion capabilities to the anticipated resource temperature and flow capacities.

As part of the overall plan, they are studying the heat and power balances on a seasonal basis.

Accordingly, their scientific and technical approaches seem to be adequate, but no better.

All of this work is in preliminary stages, so the rigor and appropriateness of the methods can not yet be accurately assessed.

PI Response:

Reviewer 23456

Score: 5.0

Comment: The low flow production and low intake injection well both suggest that the defined resource is less than prime on this site. A site for the next well has been selected, but there were not adequate data presented at the review for me to judge the likelihood of success in the well. Is this a case where the best resource may not be on property they now control, and a lower-quality resource is being settled for?

The PI stated that they have collected much data but there were few details provided in the presentation. What are their specific isotope results? Have these been published for general public review? Have these been submitted to any national databases? They state in their presentation that no data have been developed since the project is in its very early stages. Drilling a 3852 foot well that appears to have low permeability seems to me to be valuable data.

They also state that they have geophysical, geochemical, temperature and fracture analysis data. These data were not provided as part of the review, so I am unable to judge the likely success of the third well. I simply point out that their track record so far in targeting successful wells seems to be shaky.

They note that in CY 2014 they will have power plant operation with sales to recover the investment. But they also state that all the generated power will be consumed on site.

PI Response:

Reviewer 23457

Score: 6.0

Comment: It is planned to use 205 F water to generate 50 KW of electricity, and supply process heat for cascaded uses such as district heating and aquaculture.

At present, two low capacity production wells are available, and an injection well has yet to be drilled. Suitable generation equipment will need to be identified.

The capacity of the existing wells to supply the 50 kW power plant has yet to be demonstrated.

PI Response:

Reviewer 23532

Score: 7.0

Comment: There is little technical innovation in the engineering aspect of the project other than cascaded use of the resource. However, the project has used isotopic analysis of the geothermal fluids to assist in well location. If successful this tool will improve success in other similar geothermal exploration projects in northeastern California. It should be noted that utilization of the geochemical method was not included in the SOPO.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23478

Score: 4.0

Comment: Project accomplishments to date are few. In September 2011, well ISO-2 was drilled to a depth of 3,852 ft. and encountered temperatures up to 205F. Permeability was very low and well "development" was scheduled to begin in April 2012. This work comprised injection of 500,000 gallons of water from ISO-1 and resulted in an improvement of the Injectivity Index from 0.2 gpm/psi to about 2.1 gpm/psi. This is still very low permeability, but better than it was.

Also, financial projections were made, the result of which is reported to be that the project appears to be economically viable. This, of course, depends on the accuracy of the many assumptions made. This project has a long way to go.

PI Response:

Reviewer 23456

Score: 5.0

Comment: The quality of the work so far has been fair. Although they are making progress toward the objectives, I am concerned that the progress has been slow and relatively unsuccessful, beyond establishing the district heating system.
I am confused about the status of some elements of the program. On page 4 of their summary, they state that they will be using a MT system to look for faults. The next paragraph states, however, that the siting of the next well is complete. Is this a typographic error? I cannot sort out, from the presentation and writing, exactly where they stand.

PI Response:

Reviewer 23457

Score: 5.0

Comment: The site for an injection well has been identified.

Injection has been used to improve the injectivity of ISO-2 for 0.2 to 1.5 gpm/psi; however, it is still sub-commercial.

A Go-no-Go decision will be made in April 2013.

PI Response:

Reviewer 23532

Score: 6.0

Comment: It is difficult to determine how well the Canby project is progressing since initial dates for tasks and milestones have not been provided. However, the results seem to be reasonable and progress is moving forward.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23478

Score: 6.0

Comment: The most that can be said about the project management is that a great deal of thought and research has gone into this venture. The result of this is that necessary work has been cataloged in detail and challenges/hurdles are well known. There is no indication as to technical policies, staffing plans and budgeting plans are made or carried out. There is also little discussion of coordination with collaborators, stakeholders or other entities.

To date, apparently, required permits have been obtained, indicating satisfactory communications with environmental and regulatory agencies.

There appears to be only one go-no-go decision point built into the project. This is slated for April 2013 and it is assumed that this decision hinges on DOE approval of Phase II funding.

PI Response:

Reviewer 23456

Score: 5.0

Comment: On page one of their summary, they describe that the goal of this project is to create a "net-zero energy community." Do they intend to replace not just heating and electricity, but also all oil use in vehicles? And if all the electricity will be consumed on the PI's site, how will there be any for the rest of the community?

I suggest that much more detail needs to be done on a cost-benefit analysis, to assure that further investment will succeed in a program that has broad benefits beyond this specific site. I rate this project fair on management, as the presentation contains conflicting statements. They do rate high, however, for getting the community to work with them to install the district heating system.

During the presentation, the PI seemed reluctant to address significant opportunities that exist in nearby sites for geothermal water. Piping the water or generating power off-site may be more economic than continuing a low flow project. The goal, therefore, seems to be to bring geothermal on line, but only through developing resources on the PI's site. What will they charge themselves for the power?

The PI in their summary statement notes the prospect of connecting to the local grid. Later in the statement and during the presentation they directly contradicted this statement, suggesting that all the power will be consumed on site. I am discouraged by statements that directly conflict. This suggests either that they had not done their homework ahead of time to understand local institutional issues, or that they have not discovered an adequate resource to meet project objectives. It may also suggest that they are not doing careful management of this project.

PI Response:

Reviewer 23457

Score: 7.0

Comment: The project involves a large number of participants. However, no project management issues have been identified.

Key issues to be addressed are (1) the productivity of the wells, and (2) the economic feasibility. A resolution of these issues should be required for a "Go decision".

PI Response:

Reviewer 23532

Score: 7.0

Comment: Management of the project appears to be good although it is difficult to determine whether project timelines are being met. The future plans appear to be good, although the project faces some risk associated with drilling of the third well. However, the risk appears to be in line with risk in similar projects.

PI Response:

STRENGTHS

Reviewer 23478

Comment: The strength of this proposed project is that the concept is excellent and that the project would be an excellent model for other venues. The proponents seem convinced that the project will work and are working hard to cover all bases prior to learning whether or not the drilling and testing of a critical third well will be funded.

The concept of cascading uses of power plant underflows is not new, it just has not been widely implemented in the US. If this project is successful, it could inspire similar geothermal developments anywhere in the US where waters at 200F or so can be produced in amounts needed to generate power.

PI Response:

Reviewer 23456

Comment: Demonstration of district heating from low flow wells.

PI Response:

Reviewer 23457

Comment: Cascaded uses of low temperature resources may help in making their use economically feasible.

PI Response:

Reviewer 23532

Comment: The project has put effort into selection of a suitable site for an injection well. The project will demonstrate cascaded use of a low-temperature resource for electrical generation and direct use.

PI Response:

WEAKNESSES

Reviewer 23478

Comment: With this project about 5% completed, there are many unknowns yet to be quantified and many hurdles to overcome. It appears as if the project proponents are going to be 100% reliant of DOE funding of the drilling of ISO-3 to move forward. The absence of private funding (in the possible case of no DOE funding) is certainly a major project weakness.

The very small size of the project is also a weakness. Generation of only 50-100 kW of power has never been shown to be economic. The success of any greenhouse or aquaculture efforts will depend more on the market for whatever is grown or raised than the availability of "free" thermal energy. This is so because thermal energy costs rarely exceed 10% of the expenses in these agribusinesses.

PI Response:

Reviewer 23456

Comment: The lack of compelling resource productivity at the site, despite exploration and drilling, is cause for concern. There may be alternatives, such as using water from an adjacent, high production well or nearby hot springs, which should be investigated further before additional drilling is undertaken. Regulatory issues, although seeming daunting, may be solvable.

PI Response:

Reviewer 23457

Comment: It is unclear if the wells have sufficient productivity to supply the proposed power plant.

PI Response:

Reviewer 23532

Comment: Project presentation and summary did not provide dates for original milestones or state that the current milestone dates are identical with initial dates.

PI Response:

IMPROVEMENTS

Reviewer 23478

Comment: The only suggestion would be to think bigger. Increase the amount of power to be generated. Drill deeper to find a hotter resource and hopefully to intersect more permeable fractures. The economics of the entire venture would almost certainly be improved if this were to be done. The sale of excess power generated back to the local utility, if possible, might also greatly sweeten the economic scenario.

PI Response:

Reviewer 23456

Comment: There should be a complete economic analysis, including options of bringing water or power from off site. The economic analysis should be prepared so that other communities considering low-temperature cascaded geothermal will be able to assess the likelihood of success for their project.

External reviewers should look at existing geologic data and assess the likelihood of success in drilling the third well. All data gathered so far should be entered into DOE databases, beyond the web site that they plan to set up.

PI Response:

Reviewer 23457

Comment: Perform well tests to establish the productivity of wells.

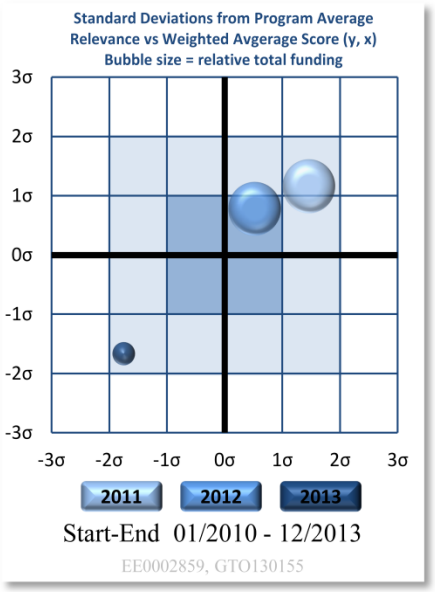
Carry out a financial analysis of the project.

PI Response:

Reviewer 23532

Comment: DOE should ensure that sufficient data on the thermodynamics of operation of the electrical generation system is collected in order to determine efficiency and operating parameters of the equipment.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002859
Project: Osmotic Heat Engine for Energy Production from Low Temperature Geothermal Resources
Principal Investigator: Hancock, Nathan
Organization: Oasys Water
Panel: Co-Produced; Low Temperature

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23478

Score: 4.0

Comment: This project is moderately relevant to the GTO objectives. It seeks to use very low temperatures (almost non-thermal) to drive an osmotic process so as to generate electricity. At this stage, there have been no estimates of the cost of power generated in this way and it has never been done (as far as I know).

Modest progress has been made to date and so there has been no impact on the geothermal industry. However, if this system works and can generate from 100F waters, innumerable geothermal sites could be developed (if the cost is adequately low).

PI Response:

Reviewer 23456

Score: 3.0

Comment: This is a tantalizing opportunity with major barriers. The company seems to be well suited for research and development of the necessary membrane, but poorly suited for working in geothermal settings. They state in their very brief summary that they stopped working in Q2 2012. There is no economic analysis in this project, so the cost of power that can be generated through PRO is not available and potential market penetration cannot be even very roughly estimated.

PI Response:

Reviewer 23435

Score: 2.0

Comment: No basic relationship between processes, inputs and electrical output are presented, so it is impossible to assess the potential contributions from this project. The presentation failed to establish and present a clear conceptual model

representing exactly how the conversion to electricity would occur. The use of a proprietary thermophysical database raises more issues regarding the broad utility of the work. This database is never described in terms of content or function. There are non net power calculations to show that the process is a a net power source. It is likely that working fluid geochemistry will cause operational difficulties.

PI Response:

Reviewer 23532

Score: 9.0

Comment: This scoring is dependent on acceptance of the revised SOPO. I believe that this study is a unique and very intriguing project, which could provide an extremely innovative power generation option. Continuation of the project beyond phase 1 is well worthwhile and it would be nice to see a prototype put into place if the current studies suggest that the technique is feasible and at least near economic. This is, of course, dependent on future funding.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23478

Score: 7.0

Comment: The scientific premise is that low temperature (104-212F) geothermal fluids can be used to recycle osmotic draw solutions in the bottoming cycles of conventional geothermal power plants. Six milestones have been proposed for this feasibility study and it can be assumed that each milestone constitutes a go-no-go decision point.

To date, partially because of the loss of the original project PI, there has been little documentation of the procedures, methods, instrumentation, equipment, staffing etc. used. Nor have there been given any indications as to how well the several milestone tasks have been executed.

Considering these constraints, a modest score must be given to the work as reported.

PI Response:

Reviewer 23456

Score: 2.0

Comment: The engineering concept seems potentially workable. While the scientific approach was strong at the beginning, stopping work on the project during Q2 2012 demonstrates that the approach has been very poorly executed. Rescoping will minimize both costs and benefits from this project.

PI Response:

Reviewer 23435

Score: 2.0

Comment: The geothermal fluid properties are key and yet they have not been determined. It is not clear that typical geothermal waters will even work with this system or the relationship between basic water quality metrics (such as total dissolved solids) and efficiency. This seems unusual since there was a significant effort to develop a proprietary database but it is not clear that the database will even be applicable as a function of water chemistry.

PI Response:

Reviewer 23532

Score: 8.0

Comment: Now that the project has been (or is being) rescoped, the quality of the work appears to be rigorous and well conducted. The phase 1 activities should be completed in a timely manner and hopefully will demonstrate accomplishments that would merit continued development by the company with or without DOE support. Execution appears to have greatly improved with the association of the new PI.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23478

Score: 7.0

Comment: Thus far, in 2012, progress was made on the following parts of the project:
1. Stripper and absorption optimization
2. Membrane development
3. Module development, and
4. Integration of the OHE into geothermal systems (bottoming cycle).

No details of any of these procedures have been given, so the quality or level of accomplishments relative to costs can not be assessed.

PI Response:

Reviewer 23456

Score: 3.0

Comment: While they have apparently succeeded in membrane development, much of the rest of the project is dramatically behind schedule, and they are looking toward dropping many components of their original proposal. The quality of their work looks good, but there seems to be no desire to carry this project through to completion. They have not met intermediate goals. The speaker noted that geothermal energy development is outside their area of emphasis.

PI Response:

Reviewer 23435

Score: 4.0

Comment: Very little prototype progress seems to have been made with respect to initial objectives. Rescoping will not improve prospects for utility of results.

PI Response:

Reviewer 23532

Score: 5.0

Comment: Execution of the project, results and progress are woefully behind schedule. However, the new PI and the SOPO under negotiation coupled with current results suggest that the Phase 1 project will be successfully completed. If the Phase 1 results suggest that the innovative technology is feasible, it is strongly hoped that additional development of the technology will take place.

The score represents progress and great delays of the project to date. if the delays are not included and only the technical results so far are considered I would score the project as 7.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23478

Score: 3.0

Comment: The management of this project appears to have been dealt a severe blow when the original PI left the company. The project was irretrievably behind schedule and so it is now being re-scoped to comprise only a feasibility study.

The company priorities do not include this project, but some company assets may still be available to the new project proponents.

It appears that DOE funding is critical to the continuation of this work, but to date, the required agreements have not been executed.

Because few of the assessment parameters have been documented for this project, scoring must necessarily be low.

PI Response:

Reviewer 23456

Score: 1.0

Comment: When the PI left the company, the project was apparently nearly abandoned. The corporate inability to recognize their contractual obligations to DOE does not demonstrate a commitment to carry through with this work. Based on the written summary and the presentation, I cannot judge the likelihood that they will be able to complete this project if it is rescoped to milestone 1 only.

They have so far provided no data to the public domain. Lack of outreach and lack of corporate commitment lead me to score this project very low.

PI Response:

Reviewer 23435

Score: 2.0

Comment: The loss of the PI is never a good sign. It looks like the rescoping effort is an attempt to justify much more modest results. It is notable and to DOE's credit that the budget seems to have been reduced.

PI Response:

Reviewer 23532

Score: 5.0

Comment: I am scoring based on the total project to date. Original PI and project rate a 1 but the reborn project and PI rate a 7. Strong technical results have been accomplished, however, scope and costs have not been well managed until recently.

PI Response:

STRENGTHS

Reviewer 23478

Comment: This could be a novel approach to beneficial use of low temperature fluids if it works and if costs are reasonable. There are abundant sites where low temperature geothermal resources exist and there are also opportunities to use the proposed system as a bottoming cycle on existing high temperature power plants.

This could be a strong project if the quantities of power able to be generated are significant (in the MW, not the kW, range).

PI Response:

Reviewer 23456

Comment: An interesting idea.

PI Response:

Reviewer 23435

Comment: None.

PI Response:

Reviewer 23532

Comment: The technology could provide a significant, novel method of electrical generation from low-temperature geothermal resources.

Although the company does not appear to be heavily invested in the use of membranes for other than water purification and low-temperature generation, this technology might be useful for reduction in non-condensable gases in the working fluid systems of geothermal binary power plants.

PI Response:

WEAKNESSES

Reviewer 23478

Comment: This project falls into the "thinking outside the box" category and as such has many unknowns. Also, even if a target of 7 watts/sq. meter is achieved (~100,000 sq. meters/MW), the system may be too large and unwieldy to manage and control in the field.

Considerable reorganization and renewal of efforts will be needed to get this project through the feasibility stage.

PI Response:

Reviewer 23456

Comment: Management has very low commitment to the project. There are no economic projections. Neither publications nor technology transfer have occurred.

PI Response:

Reviewer 23435

Comment: There is no real path to a prototype.

PI Response:

Reviewer 23532

Comment: Initial poor mangement and lack of company interest have left the project far behind schedule and unable to meet initial objectives. Unfortunately this will not allow the project to truly demonstrate the feasibility of the concept of electrical generation from low-temperature geothermal systems through the utilization of osmotyic energy.

PI Response:

IMPROVEMENTS

Reviewer 23478

Comment: Not knowing much about the workings of the proposed power generation cycle, I can make no suggestions for improvement.

PI Response:

Reviewer 23456

Comment: Unless there is a management increase in interest in this project, it should conclude.

PI Response:

Reviewer 23435

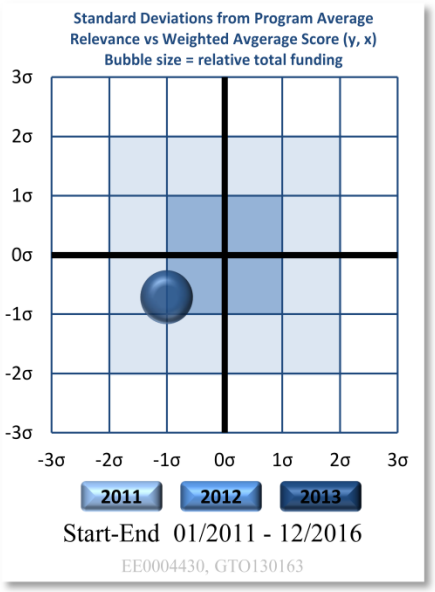
Comment: A more rigorous return on investment analysis would be useful.

PI Response:

Reviewer 23532

Comment: Figure out a way to continue the project into Phase 2 activities if the results from Phase 1 are promising.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0004430
Project: Kalex Advanced Low Temperature Geothermal Power Cycle
Principal Investigator: Sandifer, Cheryl
Organization: Technip USA
Panel: Co-Produced; Low Temperature

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23478

Score: 7.0

Comment: This project could lead to increased use of low temperature geothermal resources in the US thus making it relevant to the GTO stated objective of achieving 3 GWe by 2020.

In numerous ways, the project will address knowledge gaps and market barriers. Inasmuch as previous ammonia/water power cycles (Kalina) plants had marginal success, the proponents of this project are aware of the many gaps and problems to be solved.

It is claimed that this project could result in lowered power costs and lowered risk perceptions because wells might be shallower and less risky to drill. This projection will have to overcome the very high cost of the overall installation (currently > 8,000/kW).

PI Response:
The overall installation cost includes utility substation upgrades and the erection of transmission lines. The unit capital cost per kW is a strong function of power station output, i.e. the higher the power output the lower the unit capital cost.

Geothermal well drilling development is generally funded by high cost equity, whereas power plant and infrastructure are debt financed. By reducing the relative equity requirements in low temperature geothermal applications due to signifcantly lower well drilling costs, project economics permit a higher power plant and infrastructure capital costs, as this is generally debt financed at significantly lower interest rates.

Reviewer 23456

Score: 6.0

Comment: This project seeks to demonstrate an application of the Kalex ammonia-water cycle to generate electricity from 190-210 degree water. They have identified what appears to be an adequate resource in the Lower Klamath Lake (LKL) area, but have encountered permitting and eventual power sales issues. They are planning to investigate a second location in the Klamath Hills for potential resource development, should the LKL site not work.

Proof of the power-production technology in a low-temperature resource area will expand options for cycle design that could be applied in other geothermal areas. Proof will rely upon finding a suitable test site.

PI Response:
The Lower Klamath Lake (LKL) Project is currently sized at 5MW, whereas the Klamath Hills Project is sized at just under 10 MW. The geofluid temperatures at both sites are within a few degrees of each other; additional well testing investigations in the LKL area could possibly reveal higher flowrates, thereby yielding a high power output and improved economics. Site decision is expected by end 3Q 2013.

Reviewer 23435

Score: 4.0

Comment: The use of lower temperature resources as envisioned by this technology, could be useful in increasing geothermal electrical production. But there is very little presented to validate this assertion. There was no information given on the thermochemical properties or energy conversion ratios for the new working fluids versus Kalina cycle efficiencies. It is potentially useful to have such a focused attempt at using lower temperature resources, but this enthusiasm is tempered by the fact that no quantitative analyses verifying the improvements were provided.

PI Response:
Detailed heat and mass balances have been generated for the project. Vendor quotations for the heat exchangers, turboexpander and pumps have verified the energy conversion ratios of the various ammonia-water cycles. Such quantitative data and analyses will be made available in reports at the end of Phase 1. Depending on the selected configuration, Kalex Cycle efficiencies are generally higher or equal to the original Kalina Cycle. The current effort, as reported to the Peer Review meeting, is a concerted value engineering effort focused on improved performance at reduced capital cost.

Reviewer 23532

Score: 7.0

Comment: It is unclear just how this project will advance the technology of ammonia-water binary production. However, the project may develop better materials and performance relative to older Kalina cycles. It was noted that the current concept drops the regenerative heat exchanger of the original Kalina designs. This will simplify the system and reduce costs but will also result in decreased efficiency.

If nothing else, the project may provide current understanding of the energy flow through the system and the operation and thermal efficiency of the system if the power plant is suitably instrumented.

PI Response:
The cycle performance of ammonia-water systems has been well documented from projects in Japan, Germany and Iceland. The Kalina Cycle plant in Japan has proven that high reliability operations is achievable, however the plants in Germany and Iceland are not considered reliable by industry standards. One goal of the project is to demonstrate that high plant availability can be consistently achieved thereby increasing industry acceptance of the technology.

The project will incorporate lessons learned from previous projects, specifically focusing on materials of construction, the mixing of streams at different state points, and operational constraints.

The proposed Kalex SG-16 flowsheet does indeed drop the regenerative heat exchanger, however the operational performance of this flowsheet is equivalent to the original KCS-34 flowsheet.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23478

Score: 8.0

Comment: The more-than-adequate scientific/technical approach planned by the project proponents includes resource-related studies, creation of a power plant simulation model with sensitivity analyses, estimation of overall costs, conducting of environmental studies as required by regulatory agencies, analyses of grid interconnection requirements and acquisition of a Power Purchase Agreement, and the generation of financial pro-formas using existing power purchase prices.

These plans indicate that the proponents will rigorously and appropriately cover all aspects of the technical topics involved in the project.

To date, a few of the objectives have been addressed, but many are still to be initiated.

PI Response:

No comment.

Reviewer 23456

Score: 6.0

Comment: The staff and subcontractors seem capable of doing this project. They have taken a reasonable, staged approach to the project, with the exception of identifying institutional issues that may greatly impact their plans.

There are no scientific publications from this project yet. They identify that there will be reports to DOE, but they apparently do not have plans for wider dissemination of results.

Inverted temperature profiles in wells are briefly addressed, but the potential meaning of these inversions on long-term production is not addressed.

PI Response:
Scientific publications are planned once the power plant has been commissioned. The georesource's inverted temperature profiles will be incorporated into the reservoir engineering model to support long term operations of the geothermal power facility.

Reviewer 23435

Score: 4.0

Comment: The rigorous quantitative assessment of the new working fluid compared to other working fluids is lacking. There is an adequate amount of geohydrologic testing but no results were presented so there is no way to know how the resource contributes to the project success for the present or future.

The slide 4 schematic needed much more discussion and ties to quantitative efficiency improvement calculations. The Phase 1 activities seem like a coherent approach to establishing important aquifer and thermodynamic characteristics, but the data are only summarized, not presented, so evaluation as to their utility in analyzing site specific issues or generalizing to other sites is not possible.

PI Response:

The mixed component working fluids to be employed in this project will be ammonia-water. The relative percentage of ammonia in the mixture will likely differ from that employed in earlier power plants, for example, 94% current vs. 86% previous. The results of the project's geohydrological studies will be incorporated in reports at the conclusion of Phase 1.

Reviewer 23532

Score: 5.0

Comment: Minimal new science here. Little evidence of just what progress has been made other than an expression of success and completion of steps.

PI Response:

Process simulations, heat and mass balances, process flow diagrams and detailed process & instrumentation diagrams have been generated for this project. Non-confidential expressions of this technical information will be included in the Phase 1 reports.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23478

Score: 8.0

Comment: The following tasks have been completed:
1. an assessment of the Lower Klamath Lake resource viability
2. a flow test of well 12C
3. the drilling of well 9A; flow testing on hold
4. the grid impact has been studied
5. a draft of the EIS is under review
6. a preliminary cost estimate has been made for a 4.4 MWe gross power plant, and
7. an analysis of reliability, availability, and maintainability has been completed.

No figures have been reported regarding the outcomes of this work, so it is not possible to assess the quality, credibility, or adequacy of the work. Hopefully, this will be corrected during the Denver presentation and the subsequent Q&A session.

PI Response:

Reports at the conclusion of Phase 1 will detail work outcomes.

Reviewer 23456

Score: 5.0

Comment: The project has made reasonable progress on the power production side of this work. Their recognition that they may need to redo an exploration program, due to institutional issues, has come late and may delay their work. There may be a delay of 12-24 months in the LKL area due to economics of the plant. Beyond PPA changes, issues of economics are not detailed in their presentation.

PI Response:

State and Federal jurisdictional issues will indeed slow the development of LKL goethermal power project. The project will continue to develop the Klamath Hills geothermal power project, on private land 10 miles from the LKL area, as a viable backup.

Reviewer 23435

Score: 2.0

Comment: Significant progress was made in resource characterization, but the quantitative description of the resource is lacking. Most of the work seems to be oriented towards value engineering which is mainly a spreadsheet exercise. It could be argued that this is a low temperature resource development subsidy with the "Kalex" component thrown in to justify it as "research" and worthy of DOE funding. I do not understand how the financial model could be developed prior to the reservoir model, which should show sustainable production rates.

PI Response:

The value engineering efforts reported at this Peer Review Meeting represent the current work efforts. This work includes process simulations, flowsheet developments, equipment sizing, bulk material takeoffs, and detailed discussions with equipment vendors and construction contractors, and plant cost estimating to a plus/minus 10-15% level of accuracy.

The project will be demonstrate the commercial viability of mixed component ammonia-water working fluid systems based on Dr. Alexander Kalina's patents that have yet to achieve commercial working status in the United States. The technology holds promise for the exploitation of low temperature geothermal resources that are essential an untapped renewable energy opportunity in our country.

A conceptual reservoir model based on well flow testing data has been developed. This model will be refined as the power plant commences commercial operations, and the effects of continuous well drawdowns can be studied. The reservoir risk is considered acceptable based on data from nearby wells that have been operated at high production rates for the last 50 years.

The financial model has been developed to enable project developer decisions with respect to the commercial viability of the project, and continued equity investments.

Reviewer 23532

Score: 6.0

Comment: Progress appears to be acceptable except for environmental delays. Technical/engineering accomplishments apparently have been completed per schedule.

PI Response:

No comment.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23478

Score: 7.0

Comment: An indication of good management is the rational allocation of project responsibilities between the two project proponents according to their strengths. Plans for the future comprise 8 activities staged from 2013 through 2016. Go-no-go decision points are associated with each of these tasks.

Currently, the utilities serving the project interest area have met their required quotas of renewable energy supplies. Accordingly, power prices offered are quite low. The abundance of shale-gas and its low cost is also contributing to the low power prices. For this reason, some project activities have been slowed or delayed until power prices increase. Without higher power prices, it is doubtful if the project can be economically viable.

Under the circumstances, the project is being managed well with constraints being adequately addressed and flexibility being shown.

PI Response:

No comment.

Reviewer 23456

Score: 4.0

Comment: One issue with project management has been lack of recognition of institutional issues working on USFWS lands. Identifying these issues late into the project, such that they now are seeking to explore a second area, has the potential to delay the project by an unknown amount of time.

Project management seems competent in working on the power cycle side of the program. They apparently have all the licenses in place to use the Kalex cycle in geothermal applications.

The cell for “value of work completed to date” was not filled in during their presentation. They have identified a need for $36 mil to complete the project, but have not, in the presentation, identified the source of these funds beyond “cost share.” Will the funds be available?

BLM is not, by the way, the Bureau of Land and Mines, as they stated twice in their presentation. I assume they were talking about the federal agency The Bureau of Land Management.

PI Response:

Subsurface jurisdictional issues working on USFWS lands are divided between the Federal Government and the State of California. The project acknowledges the exceptional challenges of dealing with these institutions. The cost share to complete the project will be a combination of equity and debt financing. Yes, the BLM is indeed The Bureau of Land Management.

Reviewer 23435

Score: 4.0

Comment: The project management plan is scattered and not well sequenced. For example the financial model is completed before the resource model.

PI Response:

A conceptual reservoir model based on well flow testing data has been developed. This model will be refined as the power plant commences commercial operations, and the effects of continuous well drawdowns can be studied. The reservoir risk is considered acceptable based on data from nearby wells that have been operated at high production rates for the last 50 years.

The financial model has been developed to enable project developer decisions with respect to the commercial viability of the project, and continued equity investments.

Reviewer 23532

Score: 5.0

Comment: Project appears to be moving forward with an average degree of success, technical achievement and formulation of future plans.

PI Response:
No comment.

STRENGTHS

Reviewer 23478

Comment: The project strength may be due to the fact that so many of the mistakes and problems that plagued the Kalina Cycle power plants erected in the past have been recognized and reportedly can be overcome by the project proponents. They are certainly not starting from scratch, and this can be a strong advantage in achieving a more successful final product.

Another strength is the apparent flexibility of project management. They recognize that they may have to change venues if the resource is not adequate at Lower Klamath Lakes and they see the advantages of enlarging the first plant to ~9 MWe so as to improve economics.

PI Response:

No comment.

Reviewer 23456

Comment: Reviewer did not provide comments for this criterion.

PI Response:

N/A

Reviewer 23435

Comment: The resource seems to have been characterized adequately but reservoir modeling is still outstanding.

PI Response:

Agreed.

Reviewer 23532

Comment: Maybe this project will end the extremely long odyssey of placing and operating a Kalina cycle binary power plant on a U.S. geothermal resource!

PI Response:
No comment.

WEAKNESSES

Reviewer 23478

Comment: The most glaring weakness is the cost of this project. The overall budget is more than $37 million or more than 8,000$/kW. This is far from being competitive with gas, coal, or even "conventional" geothermal plants. If this price can not be lowered to the 3-4,000$/kW range, there is no chance that the cycle will be commercially salable.

PI Response:

Geothermal well drilling development is generally funded by high cost equity, whereas power plant and infrastructure are debt financed. By reducing the relative equity requirements in low temperature geothermal applications due to signifcantly lower well drilling costs, project economics permit a higher power plant and infrastructure capital costs, as this is generally debt financed at significantly lower interest rates.

Reviewer 23456

Comment: What is the source of cost share as the project moves forward? How long will it take to identify and permit a new site?

PI Response:

Cost share sources will be a combination of debt and project equity sourced by the project's developer. The new site at Klamath Hills has been identifed, and power plant permitting activities are in progress.

Reviewer 23435

Comment: There is no way to assess how the proposed work will be coupled to the resource.

PI Response:

Detailed resource reports are available, the main conclusions of which will be included in the Phase 1 reports.

Reviewer 23532

Comment: Limited development of new technology. This is using technology originally proposed to DOE in the 1980's and never implemented. If there is new technology related to material and efficiency, the presentation and summary documents do not provide much evidence to support the claims.

PI Response:

Phase 1 reports will include working fluid, material, and efficiency data.

IMPROVEMENTS

Reviewer 23478

Comment: I would suggest that the proponents focus initially on the identification of a satisfactory resource. There are several areas in the US where copious amounts of 190-200F fluids are known to exist and may be available. Neither the LKL or the Klamath Hills comprise such area (based on data to date).

Once the resource has been certified to be adequate, then the focus and the expenditures can shift to the issues listed in the proposal.

PI Response:

Additional market opportunities will be explored once this project is substantially completed.

Reviewer 23456

Comment: Need to obtain a clear commitment to a site.

PI Response:

Noted.

Reviewer 23435

Comment: None.

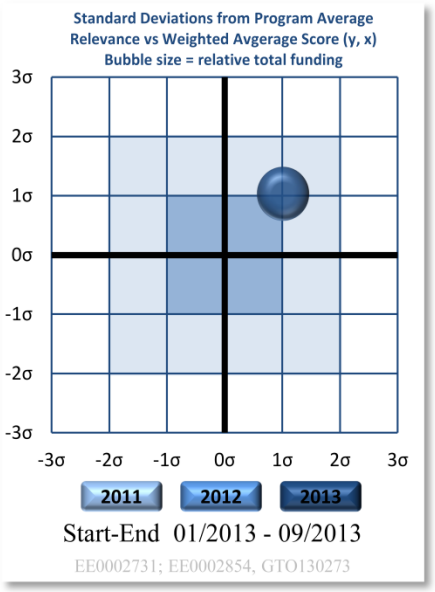
PI Response:

N/A

Reviewer 23532

Comment: DOE should make sure that the final equipment placed in to service is sufficiently instrumented to determine the thermal efficiency of the components and the system as a whole.

PI Response:
Noted and agreed.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002854
Project: Electric Power Generation from Co-Produced Fluids from Oil and Gas Wells; Electric Power Generation from Low to Intermediate Temperature Resources
Principal Investigator: Gosnold, William
Organization: University of North Dakota
Panel: Co-Produced; Low Temperature

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23478

Score: 7.0

Comment: These projects are relevant to some of the GTO objectives of 1) promoting more economical electricity generation using co-produced thermal fluids from petroleum wells and 2) generally utilizing low temperature fluids for power generation.

Also, these projects will create educational opportunities for college students as well as jobs and training that would be related to field development and power plant building and operation.

PI Response:

Reviewer 23456

Score: 10.0

Comment: This project addresses a potential use of a geothermal resource that is currently wasted. The project directly addresses a new market for geothermal electricity generation, which if proven attractive in the current oil boom of North Dakota, may have wide applications in other areas of the country. At this stage, the project also is doing very well in training new professionals for the field.

Successful demonstration in this project could lead to major new markets for geothermal development.

PI Response:

Reviewer 23457

Score: 9.0

Comment: The principal goal of these projects is to demonstrate the technical and economic feasibility of generating electricity from low temperature geothermal sources and from co-produced waters from oil and gas wells. A secondary goal is to educate the next generation of geothermal scientists and engineers.
Successful conclusion of these projects will support GTO's goals to promote the use of low-temperature geothermal sources and co-produced fluids.

PI Response:

Reviewer 23532

Score: 9.0

Comment: This project fully meets the objective of utilization of co-produced oil field waters for production of electricity. Additional impact of the project is a good working relationship with three electrical utilities in the Williston Basin and interest from a firm involved in cleanup of oil field water. Collection of operating data from the system as specified in the presentation and project summary will provide other operators in the Basin with data to base possible additional production modules in their fields.

The PI and collaborators are conducting a well thought out program looking at both the pros and cons of co-production. They are also sufficiently familiar with petroleum production so that they can provide a better understanding of the industry and how best to approach them with possible co-production options.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23478

Score: 8.0

Comment: The scientific/technical approach in these projects is limited to research undertaken to identify the most prolific thermal water bearing formations in the Williston Basin, to quantify oil and water production rates and the temperatures of produced waters.

This has been done for 4 formations, resulting in data that will enable estimation of power output at various ambient temperatures.

The quality of the research is excellent and the studies appear to have utilized many information sources. The work completed is critical to reaching the objectives of the project.

PI Response:

Reviewer 23456

Score: 10.0

Comment: This is a well-designed program that is being well carried out. The field test is all that remains.

PI Response:

Reviewer 23457

Score: 9.0

Comment: An evaluation of geothermal resources of the Williston basin was used to estimate the electrical generation capacity, and to identify suitable sites for demonstration projects.

A partnership has been established with Access Energy (manufacturer of ORC system) and Continental Resources Inc. (CRI) for the low-temperature generation project. Plans call for a similar partnership for the co-produced project. Operational experience with these projects will be helpful in establishing the economics of electricity generation from low-temperature and co-produced fluids.

PI Response:

Reviewer 23532

Score: 9.0

Comment: This project has a high quality approach utilizing students and drawing on expertise from five different academic disciplines and six different degree programs. A thorough and documented review of energy conversion equipment was made and a summary was provided to the peer reviewers. The project is also working with Aqua Advisory Group (AAG) to demonstrate their clean-up system for produced water. Cascading their system with a electrical production system would provide value to both systems.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23478

Score: 8.0

Comment: The results of the Basin study are concisely presented in tables and graphs that show the power output potential. Multiple fluid temperatures, ambient temperatures, and fluid flow rates are used to define power output ranges.

Additionally, diagrams of two proposed 125 kW ORC modules are shown together with selected specifications.

Prior to actual installation in the field, these are the accomplishments that are critical to the eventual success of the program.

The work has all been done well within the budget showing the cost-effectiveness of the effort.

PI Response:

Reviewer 23456

Score: 9.0

Comment: The program is making very good progress towards technical goals and project objectives. They are ready to install the test power plant and to begin to collect operational data. This final phase will help DOE gather real data about the cost of electrical generation from oil field waters.

PI Response:

Reviewer 23457

Score: 8.0

Comment: Successful establishment of a partnership with CRI and AE is a major accomplishment.

Twenty-five students have participated in these projects.

A better assessment of the geothermal resources of the Williston Basin has been carried out.

PI Response:

Reviewer 23532

Score: 7.0

Comment: The project was hindered by major delays with issues that the PI had little control over. However, since access to an operating field has been ensured, progress appears to be good. The project has done an outstanding job of looking at overall petroleum in the Williston basin and characterized the opportunities for co-production. They understand the limitations of utilizing individual stripper wells for electrical generation and wells with a low water cut. One of the stronger aspects of the projects is the cooperation between the research group, the oil field operator, the local utility and a waste water cleanup firm. All of these entities have an interest in utilizing electricity produced through co-production. Numerous presentations on this project have created a great deal of public awareness of the potential benefits of co-production

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23478

Score: 7.0

Comment: The project management has overcome obstacles comprising the loss of an initial partner and oil industry apathy. Management has demonstrated extraordinary perseverance and tenacity in enlisting new sponsors and working through pessimistic attitudes of some of the regional agencies.

All the management efforts and successes to date have been accomplished well under budget.

Future plans are to install a module in 2013, to assist in water clean-up activities, and to sign agreements with several interested electric co-operatives in the State. If the project stays on schedule, it will become a showcase that could attract investors. Obviously, the project economics (not detailed in the available documents) will have to make sense.

PI Response:

Reviewer 23456

Score: 9.0

Comment: The PI has persisted through many institutional barriers, and is close to having a power generation site in operation. There has been resistance from both oil companies, who are in a boom and don't want to consider how they might benefit from geothermal, and from local utilities who do not perceive of the way that geothermal can contribute to their supply (in an area of rapidly growing need). These barriers have apparently been overcome, and they are set to begin power production this year. The PI is also continuing outreach efforts to local oil and gas producers.

Information dissemination and workforce training have clearly been a successful emphasis of this project. This is what I would expect from university faculty.

PI Response:

Reviewer 23457

Score: 8.0

Comment: Despite many setbacks and challenges, the principal investigator has successfully established a working partnership to carry out a field test of electrical generation from low temperature sources.
No major project management issues have been identified.

PI Response:

Reviewer 23532

Score: 9.0

Comment: After some start-up difficulties the project appears to be well managed. Coordination with various stakeholders and other entities involved in the Williston Basin appears to be outstanding with cooperation between petroleum developers, utilities (3) and a service company. The technical work appears to have been carried out in a thorough manner.

PI Response:

STRENGTHS

Reviewer 23478

Comment: The project strength is the fact that the proponents intimately know the oil industry in North Dakota and they know where the optimum places are at which to build a co-production power plant. The big picture has been known for many years, but this group has narrowed down the target areas to a few and has obtained detailed information that should enable early power generation.

PI Response:

Reviewer 23456

Comment: Persistence, workforce training, and potential power impact are strengths.

PI Response:

Reviewer 23457

Comment: Establishment of a partnership to test the economic feasibility of electrical generation from low temperature sources is a positive.

Involvement of students in geothermal projects is good.

PI Response:

Reviewer 23532

Comment: This appears to be the only co-production project that actually is operating on a working oil field. The PI and colleagues have explored many aspects of oil production and have looked at how they can tie into co-production. They have considered normal producing wells, stripper wells, oil wells in water-flood operations and the water wells used in water floods as possible sources of warm water for power production. They have also reached out to several electrical utilities in the Basin and a service company who could use the generated electricity or cascade their operations with the electrical generation.

Numerous talks and papers generated by the project are serving as a great mechanism for getting the word out on co-production.

PI Response:

WEAKNESSES

Reviewer 23478

Comment: This project requires cooperation between oil industry operators and would-be power generators. Unfortunately, the industry attitude is one of apathy. They would rather stay with the status quo than be bothered with what they perceive as interference in their operations.

If this attitude can be mitigated, then the project should have a good chance to succeed on a modest scale in the near term future.

PI Response:

Reviewer 23456

Comment: Institutional barriers unforseen are potential weaknesses.

PI Response:

Reviewer 23457

Comment: Lack of a partnership for the field test for electrical generation from co-produced fluids could negatively impact the project.

PI Response:

Reviewer 23532

Comment: Initial delay in project startup. This appears to be symptomatic in the co-production arena since oil field operators are hesitant to utilize new technology and are also extremely busy with maximizing oil production during a period of high oil process and extremely rapid oil field development.

PI Response:

IMPROVEMENTS

Reviewer 23478

Comment: I really do not have any suggestions for improvements at this time.

PI Response:

Reviewer 23456

Comment: Keep on the good path to the demonstration, during which much valuable data will be collected. The viability of this resource use will be confirmed.

PI Response:

Reviewer 23457

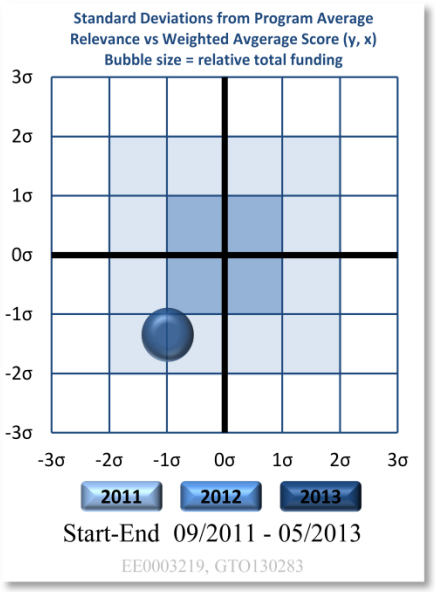
Comment: Engaging O&G companies will benefit this project.

PI Response:

Reviewer 23532

Comment: Make sure that the PI and project team continue to present an unbiased view of the potential for co-production.

PI Response:
We will continue to pursue the effort to develop co-produced geothermal power and are developing a detailed analysis to present the potential for co-production to all potential industry personnel.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0003219
Project: Fairbanks Geothermal Energy Project (Chena as a sub)
Principal Investigator: Brand, Denise
Organization: Fairbanks North Star Borough
Panel: Co-Produced; Low Temperature

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23478

Score: 3.0

Comment: This project is generally self-serving and not aligned in any major way with GTO goals and objectives. It may slightly increase the power output at Chena because fluid temperatures will be slightly higher and because more fluid will be available. Nevertheless, the expected power increases will not be great and the reduction of PM 2.5 is minimal with respect to the whole Borough.

The project may be somewhat in line with GTO objectives if the use of a screw expander instead of a turbine is considered to be important.

PI Response:

Reviewer 23456

Score: 8.0

Comment: This project is almost complete. There may be wider applications of the technology used in drilling and power production, even though all the power is going to be used on site.

PI Response:

Reviewer 23435

Score: 4.0

Comment: Geologic and geohydrologic details are missing, and, as a result, the substantiation of the potential contributions are difficult to assess. The project is a discussion of how much was learned by an inexperienced geothermal driller. The project clearly suffers from a lack of scientific oversight. DOE would have been much better served by requiring the involvement of a competent geohydrologist to acquire and organize the data. As a result of this lack of documentation, it is not likely that the results will be broadly applicable to other Alaska geothermal prospects.

PI Response:

Reviewer 23532

Score: 5.0

Comment: I do not see the value of deepening wells relative to the goals of the co-production program.
However, there is benefit to fully instrumenting the power system, and the use of the water hammer for drilling may prove useful in other geothermal drilling applications, particularly low-temperature applications.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23478

Score: 7.0

Comment: There is very little that is scientific or technical in this project. To date, they have deepened two wells and successfully penetrated fractures carrying thermal fluids at slightly higher temperatures than were previously recorded on the property.

The technical approach was to use a water hammer and button bit combination to penetrate hard granitic rocks. This is not really new or innovative technology.

One can say that the objectives were reached, thus attesting to the adequacy of the planning and execution of the drilling, but there is little else on which to rate this topic.

PI Response:

Reviewer 23456

Score: 8.0

Comment: The technical approach seems to have been a success, with both production and injection wells indicating a likelihood for long-term operation of the power plant. Further reservoir engineering studies could be helpful, but apparently are not included as part of this project.

PI Response:

Reviewer 23435

Score: 1.0

Comment: There is no attempt at anything approaching scientific hypothesis testing. The data are not presented in a manner amenable to scientific discussion. Basic data such as hydrogeologic cross sections are missing. There might some valuable data in this project but it is not well enough organized and the PI lacks the background to organize it to meet these objectives. Similarly, reservoir model development may be significantly hindered by the lack of rigorous data characterizing transients resulting from open holes and other poorly documented perturbations to the system. Basic reservoir engineering time series (drawdown with production and time, etc.) do not seem to be available. It is not even clear if this is porous media or fracture flow.

PI Response:

Reviewer 23532

Score: 4.0

Comment: There is some innovation in the use of a water hammer drill in this environment. However such drills are commonly used in the drilling of shallow holes in hard rock, i.e. the mining industry. The greatest science and technology impact will be the instrumentation of the power generation system which should provide information on the operation of low-temperature systems that could be of use in designing heat exchangers.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23478

Score: 6.0

Comment: The only two accomplishments were the successful deepening of two existing wells. This is good. They achieved their objectives and now plan to revise the model of the geothermal reservoir based on new information obtained while drilling.

All obstacles (cold weather) were overcome to finish the wells. Primarily, this was accomplished by terminating drilling until the weather warmed up in Spring.

This is not an earthshaking project. It is small and will benefit a tiny portion of Alaska. It could, however, encourage the initiation of several other projects located in Alaskan venues with geology and thermal indicia similar to those at Chena.

PI Response:

Reviewer 23456

Score: 8.0

Comment: The proposed work has been accomplished. One question that remains is what long-term thermal and production influences there may be from the injection well. Data related to production and injection temperature and amounts should be closely monitored.

PI Response:

Reviewer 23435

Score: 3.0

Comment: The primary accomplishment seems to have been how inexperienced drilling in combination with poor geologic modeling can result in problematic results. The potentially useful temperature profile data lack supporting data such as time after drilling (equilibrium profiles?). It is important to note that no economic data are presented suggesting that the PI is aware that on cost per kilowatt basis, this project is not viable and unfortunately, suggests that similar efforts are likely to be uneconomic. The most important contribution that this project could make to future efforts is the systematic acquisition of geohydrologically relevant data, but there appears to be no such data.

PI Response:

Reviewer 23532

Score: 7.0

Comment: The project appears to meeting the objectives of the SOPO.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23478

Score: 7.0

Comment: Inasmuch as all project objectives have been achieved, it can be opined that management was good. This was not a difficult project to undertake, and all parties to the work communicated, collaborated, and contributed as planned so that the project is close to budget.

There did not seem to be any decision points involved and the future of the project is limited to detailed characterization of new well flows, revision of the reservoir model, and the installation of a new power plant in 2013.

PI Response:

Reviewer 23456

Score: 8.0

Comment: According to the presenter, the project is on schedule to meet its end date of May 31, 2013. At this time, prior to the installation of the power plant, the project looks like it will be a success.

PI Response:

Reviewer 23435

Score: 3.0

Comment: The persistence of the project is commendable. The lack of technical and scientific perspective has resulted in unnecessary delays.

PI Response:

Reviewer 23532

Score: 5.0

Comment: The project is somewhat behind schedule. Otherwise, management of the project appears to be adequate for the objectives of this project.

PI Response:

STRENGTHS

Reviewer 23478

Comment: This project has been a success. Hotter water was discovered (albeit only a few degrees hotter) and the goal of finding a hotter fracture into which underflow can be re-injected was also achieved. There was nothing remarkable about this project and it may be replicable at the several hot springs emanating from granitic rocks that are known in Alaska.

The power output at Chena should increase and in so doing, less diesel will be needed and fewer particulates will be emitted.

PI Response:

Reviewer 23456

Comment: The project seems to be on track to produce power in the next few months.

PI Response:

Reviewer 23435

Comment: Persistence of the PI.

PI Response:

Reviewer 23532

Comment: The greatest strength of this project is that the power generation system will be fully instrumented so that a greater understanding of the entire power system from producing wells, to the power plant and on to the injection system will provide data of great value in understanding the operation and thermodynamics of a low-temperature electrical generation system.

PI Response:

WEAKNESSES

Reviewer 23478

Comment: The weakness in this project is that it is not at all novel or remarkable with respect to achievement of GTO goals. This is the type of project that should have been funded without use of DOE money. Private industry could have done this quite well.

PI Response:

Reviewer 23456

Comment: How well will this project transfer to other sites? I hope that the PI's enthusiasm will carry others to similar interest and developments.

PI Response:

Reviewer 23435

Comment: The presentation would benefit from more quantitative geohydrologic and systemtatic geologic data.

PI Response:

Reviewer 23532

Comment: The project offers little in the way of innovation. The instrumentation is not novel nor is the project developing technology, just using existing technology.

PI Response:

IMPROVEMENTS

Reviewer 23478

Comment: I have no suggestions to improve this project. It went well, on time (except for a weather delay), and is close to budget. It is not a complicated project.

I could however suggest that information from well logs and well testing be made public as well as detailed results of the performance of the new screw expander.

PI Response:

Reviewer 23456

Comment: Careful monitoring of power production, production and injection well flows and temperatures will help provide data useful to researchers and other developers of geothermal energy. It will be helpful to look at water chemistry through time, too.

PI Response:

Reviewer 23435

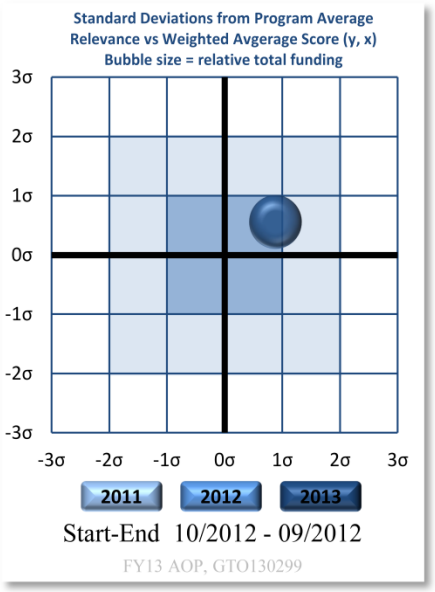
Comment: More scientific content in communications would be helpful. A quantitative cost per kilowatt analysis is needed.

PI Response:

Reviewer 23532

Comment: No suggestions for improvement for the remainder of this project.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: FY13 AOP
Project: Hybrid Geothermal-Solar
Principal Investigator: Mines, Greg
Organization: Idaho National Laboratory
Panel: Co-Produced; Low Temperature

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23478

Score: 9.0

Comment: This project represents an excellent attempt to overcome persistent problems plaguing binary power plants. These include initial fluid temperatures and flow rates less than design rates, temperature declines over time, flow rate declines over time, and efficiency declines due to rising ambient air temperature and humidity.

If successful, the use of CSP to supplement the geothermal fluid enthalpy could lower power costs, decrease perceived risk for investors, shorten project development times, and improve geothermal as an investment strategy.

PI Response:

No PI response necessary.

Reviewer 23456

Score: 7.0

Comment: This project addresses two issues: offsetting degrading resource productivity and mitigating resource risk. There may be some situations where adding solar to geothermal may make sense. It is a goal of this project to identify optimum conditions. This project is only directed toward modeling of appropriate conditions. No bench- or full-scale demonstrations are part of this work.

PI Response:

No PI response necessary.

Reviewer 23457

Score: 8.0

Comment: This project is to evaluate the feasibility of integrating concentrated solar power (CSP) with an air-cooled binary geothermal plant as a means of reducing the risks due to a decline in well productivity and/or geofluid temperature.

The project supports GTO's goal to reduce the risk associated with geothermal power development.

PI Response:

No PI response necessary.

Reviewer 23411

Score: 8.0

Comment: This is a good project evaluating the economic feasibility of development of a hybrid thermal-solar / geothermal system. This has particular relevance in many of the areas where good geothermal and solar resources intersect. This is the type of study that DOE should be funding and this should be brought to conclusion.

PI Response:

No PI response necessary.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23478

Score: 9.0

Comment: The proponents are approaching this task properly. First they are quantifying the effects of lower geothermal resource parameters on power output and the cost of electricity, and next, they are quantifying the mitigating effects of CSP with regard to the cost of drilling makeup wells, performance penalties, and risk reduction side-effects.

They will also estimate the size of the CSP array needed to create a positive effect on the LCOE.

All this is being done with carefully designed, flexible, detailed mathematical models (done by INL). Preliminary results are presented, preliminary conclusions drawn, and all well under budget.

PI Response:

No PI response necessary.

Reviewer 23456

Score: 7.0

Comment: The approach is well phased and so far has been moderately well executed. I would like to see more cooperation with industry, beyond the vague statements in the review that the researchers apparently have had some communication with industry, but they would not provide even generalities beyond that. What data can they gather from existing plants that might be relevant?

They state on page one of their summary that they are limiting their consideration to air-cooled plants, which "only occasionally operate at the design conditions." I would have appreciated more discussion of this point in their presentation.

I also note that the data in figure 3 or 4 in their summary, which are on slide 8 of their presentation, when combined with the lower figure on slide 9 of their presentation, seem to suggest that the CSP project they are proposing is largely confined to summer conditions, and will work best during the late stages of an air-cooled power plant's life. This result is valuable to DOE in assessing future proposals for hybrid systems.

PI Response:

The project team has had discussions with a potential industry collaborator that were conducted after the execution of a non-disclosure agreement. This agreement precludes any discussion during the peer review of those conversations.

Operating data that provides both process conditions and power generation with varying resource and ambient conditions would allow the projected performance benefits to be validated or revised. To establish an economic benefit, actual cost data is also required; industry frequently considers this data sensitive and is unwilling to provide.

Reviewer 23457

Score: 8.0

Comment: Binary power plant models in Aspen are used to develop regressions for the impact of off-design conditions (ambient, resource temperature, fluid supply) on power output. These relationships, along with CSP performance data from NREL's SAM model, are then used to estimate the hourly plant output with and without CSP augmentation.

The hourly plant output is required to ascertain the economic benefits (e.g. avoidance of PPA fines due to insufficient power generation and additional generation during summer days) of the hybrid design.

PI Response:

No PI response necessary.

Reviewer 23411

Score: 9.0

Comment: The team is approaching the project with a strong scientific approach without preconceived notions of what the outcome should be. Appears to be a robust study.

PI Response:
no PI response necessary

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23478

Score: 9.0

Comment: Simulations of plant output under various flow rate and temperature conditions have been run. These have been compared to results using the CSP hybrid models. The latter was done using a newly developed model that attempts to input multiple variable values and outputs power generation levels and LCOE estimates.

The quality of this work is very strong with credible results reported and graphed thus attesting towards tangible progress towards achievement of project objectives.

To date, very real progress has been made and the project has come a long way towards its goals. The fact that this has been done at remarkably low cost and under budget greatly enhances the work being done by the proponents.

PI Response:

No PI response necessary.

Reviewer 23456

Score: 8.0

Comment: This project is making adequate progress toward its goals and objectives. The staff is doing well in their analysis so far. It is important to recognize that even negative results that suggest this kind of CSP will not be economic in the early stages of a plant's life can be very important feedback to industry and regulatory and planning agencies. In discussing slide 12 during the presentation, they noted that they still have a negative NPV under all scenarios.

PI Response:

No PI response necessary.

Reviewer 23457

Score: 8.0

Comment: The evaluation model is operational, and can be used to compute hourly plant output for a variety of scenarios with or without CSP. This work will provide the necessary input for determining the economic feasibility.

PI Response:

No PI response necessary.

Reviewer 23411

Score: 8.0

Comment: The project appears to be progressing fine; it should be continued through conclusion.

PI Response:

No PI response necessary.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23478

Score: 9.0

Comment: Though relatively few INL and NREL staff are reportedly working on this project, the management has obviously been more than adequate, judging by the quality and quantity of work completed to date. There are some decision points within the process adopted, but the real decision point will be at the end of the project: is it economically viable or not and can there be a positive effect on the cost of electricity?

Again, the impressive work products produced to date show that there has been more than adequate communication, cooperation and collaboration between the partners and industry sources of input information.

It's hard to fault a project that is being managed so as to produce useful, tangible results, under budget, and on schedule!

PI Response:

No PI response necessary.

Reviewer 23456

Score: 8.0

Comment: The researchers are coming along well in this program. They are doing a good job of facing results that suggest the CSP as analyzed in this project may not be economic. As noted above, these results can be very important. They note in their presentation that the project is on or slightly ahead of schedule.

PI Response:

No PI response necessary.

Reviewer 23457

Score: 9.0

Comment: The project is on schedule. No management issues have been identified.

PI Response:

No PI response necessary.

Reviewer 23411

Score: 9.0

Comment: This is not a large project; it appears to be well coordinated

PI Response:

No PI response necessary.

STRENGTHS

Reviewer 23478

Comment: The strengths of this project lie in the considerable computer expertise at INL that allows for the creation of the models needed to simulate all aspects of this scheme. It seems very likely that all anticipated variations related to geothermal power production will be included in the models, and that many different sizes of CSP will be modeled so as to assess their mitigational effects on the results of declining geothermal fluid parameters.

It is expected that the NREL economic studies planned for 2013 and 2014 will be of similar quality and that the project outcome will be a reliable assessment of the economic viability of a CSP-Geothermal hybrid and if so, under what specific conditions.

PI Response:

No PI response necessary.

Reviewer 23456

Comment: A good project thoughtfully approached.

PI Response:

No PI response necessary.

Reviewer 23457

Comment: A rational model to evaluate the technical and economic feasibility of hybrid solar/geothermal project.

PI Response:

No PI response necessary.

Reviewer 23411

Comment: Strong and capable team.

PI Response:

No PI response necessary.

WEAKNESSES

Reviewer 23478

Comment: The documents reviewed did not include any detailed costs of CSP on a per kW basis and/or a per sq. meter basis. These would be helpful in assessing whether or not the eventual hybrid cost would be anywhere nearly realistic.

PI Response:

Comment has been noted and these metrics will be included in future project reporting as necessary.

Reviewer 23456

Comment: Potential for more cooperation with industry.

PI Response:

Opportunities to work with potential industry partners are being pursued to obtain data that will confirm that the model's estimates of the impact of variations in both ambient and resource conditions are representative of those experienced in operating plants. The ideal situation would be to reach an agreement with a partner who eventually incorporates the CSP and provides additional opportunity to validate the modeled projections of both cost and performance.

Reviewer 23457

Comment: Application to a "real case" as opposed to a "generic case" is not part of the project.

PI Response:

See previous response.

If the project team is able to obtain real data from an industrial partner, an analysis using real data rather than generic values would certainly be possible (and desirable) to perform.

Reviewer 23411

Comment: None.

PI Response:

No PI response necessary.

IMPROVEMENTS

Reviewer 23478

Comment: Please see the brief comment under "Weaknesses."

PI Response:

No PI response necessary.

Reviewer 23456

Comment: I suggest care in documenting assumptions about life cycles of reservoirs during long-term production. I also suggest that the researchers make well known that the economics of CSP may not be favorable during the early stages of a plant's life.

PI Response:

Comments noted and will be implemented in project reporting.

Reviewer 23457

Comment: Serious consideration should be given to incorporating data from an actual binary geothermal project.

PI Response:

The general plant design and rating models were developed using operating and equipment specification data from a commercial binary geothermal power plant. The plant models used in this analysis use modified resource and ambient conditions specific to the scenarios under investigation. However, the approach used for determining the corresponding plant specifications and off-design operating conditions have been retained from the models that were validated against commercial plant equipment specification and operating data that included conditions where both the resource and ambient temperature had varied from design.

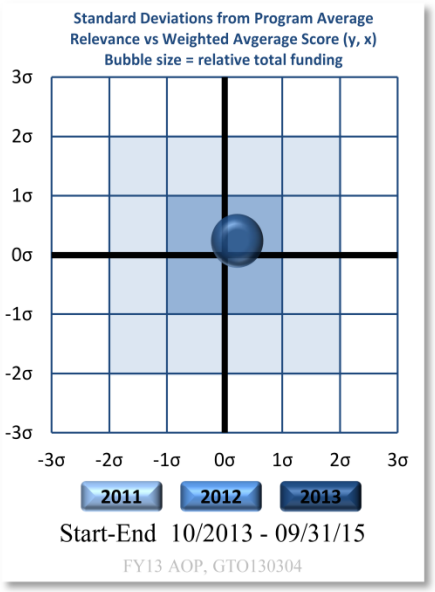
As indicated in previous response the project is pursuing obtaining data from facilities that have experienced a decline in both resource temperature and geothermal flow.

Reviewer 23411

Comment: N/A

PI Response:

No PI response necessary.



Review: 2013 Geothermal Technologies Office Peer Review
ID: FY13 AOP
Project: A Revolutionary Hybrid Thermodynamic Cycle for Binary Geothermal Power Plants
Principal Investigator: Sabau, Adrian
Organization: Oak Ridge National Laboratory
Panel: Co-Produced; Low Temperature

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23478

Score: 8.0

Comment: The proposed project is relevant to the achievement of the following three GTO goals:

1. Develop a low cost, high efficiency energy conversion system for EGS
2. Overcome the barriers related to low temperature energy conversion, and
3. Get 3 GWe on line by 2020.

To date this project has been addressing the identification of working fluids that can be used alone and in mixtures within a wide range of temperatures and pressures. The new fluids must meet a host of criteria to qualify for consideration and then must operate satisfactorily in simulators and lab tests.

If this project is successful, the increased efficiency of Binary power cycles could lower costs, allow expansion of existing plants and stimulate exploration and development of many new low temperature geothermal resources.

PI Response:

We agree with the reviewer.

Reviewer 23456

Score: 7.0

Comment: According to the materials presented to reviewers, the goal of this project is to assess a new thermodynamic cycle that has been developed by Harris Corporation to see if it has potential geothermal applications. They identify, on slide 2, a goal of a 15% improvement in brine effectiveness.

Their cycle diagram on slide 4 shows an input temperature of geothermal fluid of 330 degrees F. During the presentation, it was instead stated that the “sweet spot” for the cycle is 260 degrees F. The lower temperature will help the cycle apply to more resources.

PI Response:

The main goal of the project is indeed to deal with geothermal fluids of 330 F. During the presentation, our collaborator from Harris, Inc. intended to convey that the cycle would be applicable to lower temperatures than 330 F, using the expression of "sweet spot" of 260 F; a more accurate comment would have been that the cycle would be used at lower temperatures.

Reviewer 23457

Score: 7.0

Comment: The goals of the project are to (1) assess the applicability of a new thermodynamic cycle proposed by Harris Corp. to improve electricity generation from low-temperature geothermal sources, and (2) provide thermodynamic data for a mixture of working fluids.

The project will contribute to GTO's goal of developing low-cost, high-efficiency energy conversion technologies.

PI Response:

We agree with the reviewer.

Reviewer 23532

Score: 8.0

Comment: The project is looking at improving the technology for low-temperature applications of geothermal energy. They have revisited the power cycle by combining traditional ORC and a Brayton cycle. They are also investigating working fluids that at least have not been mentioned in the literature to my knowledge. However, the Brayton cycle may not be included in the prototype equipment under consideration.

PI Response:

Our original intention was to include Brayton-like compontents in the cycle as we have seen the potential to increase performance with a variety of new fluid mixtures. However, we noticed that it would be possible to proof some components of the cycle, as a first generation improvements, involving a single constituent fluid, such as R245fa. The Brayton-like components would be still considered.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23478

Score: 7.0

Comment: The proponents plan to execute their project in the following rigorous, and appropriate manner:
a) design new cycle components
b) design new cycle architecture (Rankine and Brayton)
c) identify new working fluid mixtures.
d) run thermodynamic simulations so as to understand the brine efficiencies and sizes of required new equipment.
e) determine costs, the size of the initial investment required, and the LCOE.

Thus far, the project is close to budget, however, to complete it, $700,000 more is going to be requested.

The computer expertise of the ORNL staff has been showcased in the several successful models created to date. There is no reason to expect that this excellence will not continue through the project conclusion (if new funds are available).

PI Response:

We agree with the reviewer.

Reviewer 23456

Score: 7.0

Comment: The work by Harris corporation seems like it has potential, as they apparently have constructed an appropriate test bed. The modeling work by ORNL should help define appropriate mixes of fluids to achieve both cycles.

PI Response:

We agree with the reviewer.

Reviewer 23457

Score: 7.0

Comment: The proposed cycle will use two loops to extract energy more efficiently from low-temperature geothermal sources.

The technical approach includes modeling of thermodynamic cycles to evaluate different working fluids. ORNL will conduct laboratory experiments to obtain thermodynamic data for mixtures of working fluids. A cost model for the new cycle will be developed.

PI Response:

We agree with the reviewer.

Reviewer 23532

Score: 9.0

Comment: The project appears to be using a sound technical approach while investigating the application of novel modifications of existing technology. The staff, facilities, and etc. appear to be of high quality. ORNL has partnered with a good industrial partner.

PI Response:

We agree with the reviewer.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23478

Score: 7.0

Comment: ORNL and Harris Corp have made very significant progress to date. Among the accomplishments are:
1. Identification of working fluid requirements.
2. Completion of a literature/IP survey.
3. 75% completion of the direct contact heat exchanger model.
4. A search for the required equipment by Harris Corp. is 20% done.
5. Specific Power simulations are 10% complete.
6. Harris Corp. has recommended the use of a Revolute turbine (vertical screw?).

There is no reason to think that the quality of the accomplishments is anything but high and all of the work listed above is very relevant to achievement of the project objectives. Thus far, achievements have been commensurate with expenditures, but additional funds are going to be requested in order to completer the work.

PI Response:

We agree with the reviewer.

Reviewer 23456

Score: 7.0

Comment: The project seems to be moving along well. Particularly the work by Harris, which according to the presentation, has resulted in a new turbine design and a first level test bed. The statement in their summary that there have been no publications or presentations so far is not encouraging.

PI Response:

There have been no publications intentionally as Harris aimed first at identifying intellectual property. There have been 8 patents filed. Harris is only now getting at a stage where aspects of this technology are being shared openly. In fact this peer review meeting was the very first open disclosure of this technology.

Reviewer 23457

Score: 6.0

Comment: A literature survey of hybrid technologies was completed. A model for estimating the size of heat exchangers has been developed. Equipment manufactures were contacted to assess the availability of hardware components.

PI Response:

The above compilation presented by the the reviewer does not reflect all the accomplishments presented during the review meeting. The accomplishments are listed in detail in our presentation on pages 5 through 10 and are listed here for the sake of completness: (1) complete the development of a thermodynamic model of the cycle conducted at Harris Corp., (2)

evolve the cycle design from an preliminary concept to a more advanced concept by conducting thermodynamic simulations at Harris Corp., (3) Harris Corp. has proposed the use of new turbine, named Revolute Turbine that requires less pressure drop between successive stages, and (4) identification of key properties of the working fluid for the hybrid cycle.

Reviewer 23532

Score: 8.0

Comment: The quality of the work appears to be relatively high and progress appears to be on schedule.

PI Response:

We agree with the reviewer.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23478

Score: 7.0

Comment: Project management appears to be adequate. Three major milestones/go-no-go decision points have been listed carrying through 2015 when project completion is now scheduled. The fact that $700,000 more is going to be needed to finish the work is somewhat disconcerting as it should have been budgeted originally. This is a negative testament to management.

It appears that there has been adequate coordination at all project stages undertaken to date by and between the collaborators, stakeholders and all other entities.

PI Response:

The reviewer carefuly observed the discrepancy between the total funding for FY2013 of $200K and the total buget request of $700K. For this type of proof-of-concept project, which was not awarded through a FOA, the proposal format did not allow for a detailed Scope of Work and budget for the entire project duration. However, we felt that we should provide as much info in the proposal for the larger Scope of Work rather than discussing only one FY effort; hence the $700K estimate. Basically, in the first FY the plan was assess the work done by Harris Corp. and make initial judgements on the potential of proposed concepts by Harris Corp. for power conversion. The effort for the next two FYs were envisioned to be dedicated towards hardware proofing, not just modeling and simulations.

Reviewer 23456

Score: 6.0

Comment: The project seems to be moving along, but not at a very fast rate. The outyear plans, as described in the SOW, such as graphs of brine effectiveness that are planned to take 1 1/2 years, do not seem to be responsive to nearer term program goals.

PI Response:

The reviewer rightly noticed that proofing a new thermodynamic cycle would not be fast. In this line of work, i.e. developing cost efficient and energy efficient new thermodynamic cycles, the keyword is cost as it is relatively easy to propose very efficient cycle without looking at component cost and initial investments. Thus, the work on this project has advanced on paralel fronts: (a) assessing the specific power generation of new cycle configurations and (b) identifying hardware OEMs and checking, if at all possible, the costs associated with the new proposed hardware. This thorough work on parallel fronts has hindered the progress in the first FY of this project but it would build a strong foundation for the next FY's effort. Basically, in the first FY the plan was assess the work done by Harris Corp. and make initial judgements on the potential of proposed concepts by Harris Corp. for power conversion. The effort for the next two FY's were envisioned to be dedicated towards hardware proofing, not just modeling and simulations.

Reviewer 23457

Score: 8.0

Comment: No project management issues have been identified.

PI Response:
N/A

Reviewer 23532

Score: 8.0

Comment: The project appears to be well managed as indicated by the coordination with the industrial partner and adherence to schedule and costs.

PI Response:

We agree with the reviewer.

STRENGTHS

Reviewer 23478

Comment: The project strength lies largely with the excellent reputations of both partners with respect to achievements within their respective fields of expertise. If a revolutionary binary cycle can be invented, with new and more efficient working fluid and a more efficient brine flow path, then the low temperature geothermal power industry will slowly benefit.

It is anticipated that several years will be required once the machine is commercially available for buyers to accept it and to buy it; it will take still more time to get the whole concept to become internationally popular.

So, it can be said that this is a potentially strong project, but only time will allow quantification of its strength.

PI Response:

We agree with the reviewer.

Reviewer 23456

Comment: The work by Harris in developing a new turbine and the test facility is good. The modeling by ORNL may help Harris identify brine combinations to try.

PI Response:

We agree with the reviewer.

Reviewer 23457

Comment: Experimental measurement of the thermodynamic properties of working fluid properties is important.

PI Response:

We agree with the reviewer.

Reviewer 23532

Comment: The project will likely advance the technology of electrical generation from low-temperature sources if the studies so far can be demonstrated during the development and operation of a prototype.

PI Response:

Agreed!

WEAKNESSES

Reviewer 23478

Comment: The weaknesses of this project lie in the fact that it proposes entirely new concepts in the revision of the tried and true ORC. There will, no doubt, be a period of de-bugging required (as with the Kalina Cycle in the past) and some major changes may be necessary until a machine without recalls is created.

The process and procedures being followed seem well thought out, so I can not now cite other weaknesses.

PI Response:

We agree with the reviewer. We are approaching this project with great respect for the tried and true ORC, and in this light we are simply attempting to see if improvements are possible. The technology will require de-bugging and hardware will comprise generational upgrades.

Reviewer 23456

Comment: Some statements in the presentation and summary are vague about exactly what has been accomplished so far (e.g., 75% of obtaining equations to implement a model estimating the size of heat exchangers). How many equations? Did they derive them? On slide 9, they state that "ORNL . . . made suggestions for improvement." Are these documented?

If they are important considerations, why have they not been published for the benefit of a wider audience? What exactly has ORNL done?

PI Response:

The reviewer asked very important questions. Consequently, our response here is extensive.

Before going into detail to answer the reviewer's concern, the following general considerations are made:

1) Some details that the reviewer is concerned with were covered in the accompanying Project Summary (the Word file) and we would like to ask the reviewer to read that document too. We also would like to remind the reviewer that there are severe page limitations and content limitations to both the presentation and the project summary. For example, excluding the slides on "relevance/impact", "scientific/technical approach", "future directions", "summary" and "project management" there will be only 6 slides that can be devoted to the accomplishments. We thus expect that reviewers would have very specific details unanswered.
2) ORNL or Harris effort: In order to give appropriate credit to Harris Corp., ALL the contribution and accomplishments stemming from Harris's effort were acknowledged by having Harris Corp. name associated with that contribution or accomplishments. Consequently, all the other contribution/accomplishments in the presentation and project summary that does not have Harris Corp. acknowledgement were solely accomplished at ORNL.

Our response to specific questions is given, as follows:

1) The model for direct-contact heat exchangers is quite evolved, following "Direct-contact heat transfer" by Kreith and Boehm and references therein. No new equations were developed by ORNL. The solution algorithm is being developed at ORNL. The number of equations (27) describing the critical jetting velocity, droplet size, nozzle velocity, number of nozzles, terminal velocity, flow rate ratio, holdup, superficial velocity, diameter of the column, length of column, and volumetric heat transfer coefficient.
2) Are the "ORNL … made suggestions for improvement" slide 9 documented, why they have not been published. There have been extensive communications between ORNL and Harris, as documented through bi-weekly minutes and internal reports written by either ORNL or Harris Corp. staff. The technology is all under NDA up until this first disclosure at the Peer Review. Harris Corp. has 8 patents on file and several others in the works. It is the intention of Harris Corp. to start making this technology and the supporting data open to a broader audience in the forseeable future. A project report will be issued at the end the FY.
3) What exactly has ORNL done? All contribution/accomplishments in the presentation and project summary that does not have Harris Corp. acknowledgement were solely accomplished at ORNL. These include: (1) identification of key properties of the working fluid for the hybrid cycle, (2) complete a literature and IP survey of related hybrid cycle technologies, (3) Implement a model for the direct-contact heat exchangers to estimating their size, (4) verify the results obtained from thermodynamic numerical simulations by Harris Corp. (5) assess the applicability of thermodynamic concepts considered at Harris Corp.

Reviewer 23457

Comment: Apparently, no prototype power plant will be built.

PI Response:

We are hopeful that a prototype plant will be built. A limited test bed has been built (for water and non-condensable gases). A new proposal is being writtent to build and test the Revolute Turbine and Mixer. Following the succesful lab scale testing of the cycle, it is envisioned that last step would be a full scale prototype plant.

Reviewer 23532

Comment: The only weakness is that the technology was glossed over a bit in the presentation and summary and the Brayton cycle appears to have been omitted in the prototype apparatus.

PI Response:

The presentation was very vague as the NDA with ORNL limited the disclosure of the technology. As the patents are now being published, and the technology is converting to hardware that is more representative of real world devices, the discloures and openness of the data will accelerate. The Brayton cycle component was not omitted from the apparatus, simply not communicated clearly.

IMPROVEMENTS

Reviewer 23478

Comment: The only improvement I can suggest is that a way to complete the project without using $700,000 in un-budgeted funds be found. Perhaps the money should be sought from private industry investors instead of relying on DOE money for the last parts of the project.

PI Response:

Much of the funds are coming from Harris Corp. There has been a subsatntial investment outside of the work with ORNL and DOE funds. It is fully intended that other commercial financing opportunities will be evaluated as part of the development process. Getting successful technoligies like these launched takes 10's of millions of dollars. This initial funding is simply a seedling fund to mature the technology and share ideas to insure that when it comes time for technology deployment we are all in more informed and defensible position to justify the larger investments.

Reviewer 23456

Comment: I am concerned that, although it is creative and shows some promise, the complexity of the overall system will inhibit its eventual use. I would like to be proven wrong, however.

PI Response:

We agree with the reviewer that complexity has its costs. That's why we are trying to reduce any unnecessary elements of complexity (and hardware) where ever it is possible. In this line of work, i.e. developing cost efficient and energy efficient new thermodynamic cycles, the keyword is cost as it is relatively easy to propose very efficient cycle without looking at component cost and initial investments. Thus, the work in this project has advanced on paralel fronts: (a) assessing the specific power generation of new cycle configurations and (b) identifying hardware OEMs and checking, if at all possible, the costs associated with the new proposed hardware.

Reviewer 23457

Comment: It is strongly recommended that components of the proposed cycle be tested in collaboration with binary power plant manufacturers (e.g. Ormat, TAS, etc.).

PI Response:

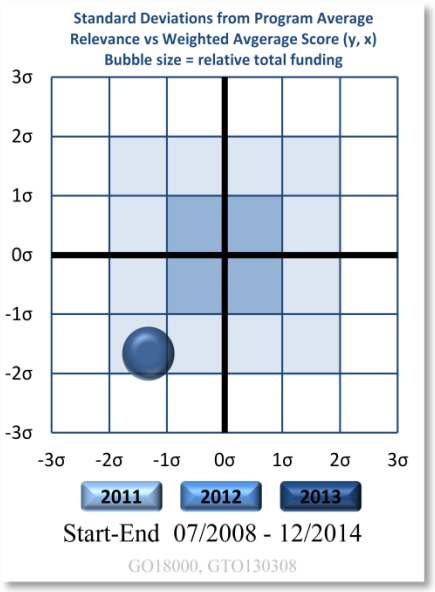
We agree with the reviewer. Harris Corp. has been in discussions with resources and suppliers of similar technologies as Harris Corp. have no intention of re-inventing anything that may already exist, which includes both hardware and technology methods.

Reviewer 23532

Comment: Definite inclusion of the Brayton cycle would be advantageous. However, the current funding level may not be sufficient.

PI Response:

Yes, it is intended to use a Brayton portion of the cycle. The testing in the next phase is intended to prove out the value in this combined arrangement of existing cycles.



Review: 2013 Geothermal Technologies Office Peer Review
ID: GO18000
Project: Electric Power Generation Using Geothermal Fluid Co-produced from Oil and/or Gas Wells
Principal Investigator: Karl, Bernie
Organization: Chena Hot Springs Resort
Panel: Co-Produced; Low Temperature

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23457

Score: 5.0

Comment: The goal of the project is to design, build and operate a low-temperature mobile geothermal power plant capable of operating with co-produced water from oil and gas wells.

The project contributes to GTO's goal of power production from low-temperature co-produced water.

PI Response:

Reviewer 23411

Score: 4.0

Comment: The project did an admirable job developing a portable version of a small ORC geothermal power plant and showed that a truck delivered power system is feasible. However, because of the lack of interest from an O&G partner, they have been forced to connect the system to a hot water well. Since the project was aimed at a demonstration of co-production, the relevance of the project is limited.

PI Response:

Reviewer 23641

Score: 6.0

Comment: The demonstration of low temperature power production using off the shelf technology was successfully conducted despite logistical problems. Transportability of the equipment and quick "plug and play" installation was demonstrated. There is incomplete access to and analysis of operational data due to UTC reorganization. The PI should be encouraged to obtain and analyze the data.

PI Response:

Reviewer 23532

Score: 3.0

Comment: This project has low relevance because it is not directed at electrical production from oil-field co-production. The project SOPO is related to co-production rather than generation from low-temperature, relatively low-salinity fluids. It will not answer questions such as dealing with oil-field brines or possible contamination of heat exchangers by entrained oil. It will also not provide demonstration of the technology for oil and gas operators.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23457

Score: 5.0

Comment: Installed Pratt & Whitney PureCycle model 280 ORC on two flatbed trailers. The mobile system was assembled at Chena Hot Springs in Alaska, and is now operating on 210 F water in Southwest Utah. Operational data will be obtained for a 2-year period.

PI Response:

Reviewer 23411

Score: 6.0

Comment: While the project has seen significant delays and setbacks from a lack of O&G interest, they have done a good job boot-strapping themselves to modify a power plant for "portable" operations.

PI Response:

Reviewer 23641

Score: 7.0

Comment: Technical approach was rigorous and appropriate.

PI Response:

Reviewer 23532

Score: 2.0

Comment: Little new science or technology since dealing with low-salinity, oil-free water using existing technology.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23457

Score: 5.0

Comment: Demonstrated that it is possible to install the 220 kW P&W power-plant on a mobile platform.
Power plant has been in operation since November 2012, and operational data are being generated.

PI Response:

Reviewer 23411

Score: 4.0

Comment: Similar to the issues regarding relevance, the project has seen successes in terms of developing hardware but has not accomplished the goal of a demonstration of co-produced power. It seems to be symptomatic that the O&G industry is not particularly interested in this technology, and this project has suffered from this situation. They have accomplished the goals they had control of, but unfortunately the project has not met fundamental program goals. It is particularly disturbing that data from the operating unit is not being gathered.

PI Response:

Reviewer 23641

Score: 7.0

Comment: The project successfully overcame siting obstacles to eventually install the equipment on a hot water source and generate power, achieving the project objectives. High value of accomplishment (demonstrating the viability of the modular geothermal power generation concept) for the cost.

PI Response:

Reviewer 23532

Score: 6.0

Comment: Project has accomplished what they are doing although it is not appropriate for the original SOPO.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23457

Score: 5.0

Comment: It has not been possible to find an oil and gas partner to host the power-plant. Hence the power-plant is being tested at a low-temperature water geothermal site. Thus the project will not meet its goal of generating power from co-produced water.

PI Response:

Reviewer 23411

Score: 3.0

Comment: The low score is largely based on events out of their control. In particular, the lack of interest of O&G has severely impacted the schedule. They have done the best they can from cards they were dealt.

PI Response:

Reviewer 23641

Score: 7.0

Comment: Project did a good job of adapting the plan through the search for a viable location. Once the location was defined, the demo was quickly and efficiently implemented.

PI Response:

Reviewer 23532

Score: 3.0

Comment: Project is well behind the original schedule. This is likely due to the delay in finding a suitable oil field operator. Did the original proposal include an operator who had agreed to the project?

PI Response:

STRENGTHS

Reviewer 23457

Comment: Demonstrated that it is possible to put small geothermal units on mobile platforms.

PI Response:

Reviewer 23411

Comment: Because of experience in the development of a low temperature system, the team was well qualified to execute this effort. They did the hardware work they committed to and provided a unit for operation.

PI Response:

Reviewer 23641

Comment: Real world applicability of modular small generation to geothermal.

Will encourage application of modular generation to more geothermal projects.

Supports development of a modular, distributed geothermal field development option.

PI Response:

Reviewer 23532

Comment: The only strength of this project is the utilization of a trailer mounted generation system. This is apparently of low technical difficulty.

PI Response:

WEAKNESSES

Reviewer 23457

Comment: Oil & Gas industry is apparently unwilling to host such geothermal units.

P&W is discontinuing the PureCycle.

PI Response:

Reviewer 23411

Comment: Weaknesses are obvious. Since this was intended to be a co-gen project and the unit is not performing that function - the goals of demonstrating power production at an O&G facility have not been realized.

PI Response:

Reviewer 23641

Comment: Incomplete analysis of operational data.

Unfortunate that the ultimate site is not a more substantial geothermal resource with development running room.

PI Response:

Reviewer 23532

Comment: The weakness of this project is that is does not include development at an oil and gas field which was the intent of the award as stated in the SOPO provided to the reviewers.

PI Response:

IMPROVEMENTS

Reviewer 23457

Comment: Such projects should only be funded on request from an O&G operator.

PI Response:

Reviewer 23411

Comment: Project is largely over; it would be good if data being generated was being stored for future use.

PI Response:

Reviewer 23641

Comment: Complete analysis of operational data and share the data and analysis with the geothermal community.

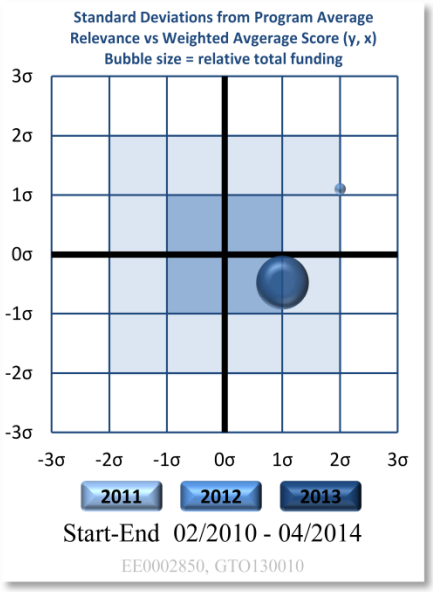
PI Response:

Reviewer 23532

Comment: This project is at a stage where there is no potential for improvement or adherence to the original SOPO.

PI Response:

Data System Development and Population Reviewer Comments and Principal Investigator Rebuttals



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002850
Project: State Geological Survey Contributions to NGDS Data Development, Collection and Maintenance
Principal Investigator: Allison, Lee
Organization: Arizona Geological Survey
Panel: Data System Development & Population

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23526

Score: 8.0

Comment: This is an important component of NGDS, and as a stand alone its value may be questioned. Taken as a whole the the value is paramount. The impact and relevance is directly connected to that of NGDS. This is very important to the Office and the community at large.

PI Response:
We view it the same way and are using the project as a centerpiece in the larger cyberinfrastructure arena to leverage other resources to enhance and support it.

Reviewer 23544

Score: 8.0

Comment: All relevant State data needs to be managed as a single unit. This will improve access to existing data and will set a standard for future data creation.

PI Response:
We're not sure entirely what is meant by managing all the State data as "a single unit." However, we see the State data (and in fact all data providers) as key elements of the integrated systems approach that has emerged as the global paradigm in part because of this project. We have demonstrated the viability of an distributed network as an effective replacement and improvement over the default centralized data bases everyone has struggled with for the past decades.

Reviewer 23511

Score: 8.0

Comment: Large amount of geothermal data has been accumulated and made available. Previously, this data was difficult to access. Should be very useful to industry in rapidly assessing new areas.

PI Response:
We agree and are committed to meeting and beating expectations for the final product.

Reviewer 23437

Score: 10.0

Comment: The volume and types of information being amassed as part of this project is of great potential value to the entire geothermal community. The focus on expressing these data in predictable, standards-based formats adds to the likely usefulness of the collection. Though the full NGDS, of which this project is part, has not yet been deployed it is clear that this project is contributing a large and valuable set to the total resources of NGDS, which by making increased knowledge available in useful forms is destined to play a part in the reduction of risks associated with geothermal development.

PI Response:
This is our vision and we believe we are track to meet the project goals.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23526

Score: 8.0

Comment: The approach is solid. The data quality/tier testing is a good approach. This will get the existing data into the system--the only drawback is that what happens as new wells are drilled--how will these data be qualified?

PI Response:
One of the challenges is to keep new data coming into the system. As part of our sustainability strategy, we are trying to make NGDS the default data integration framework for the state geological surveys, so they use it for all of their online data services. We envision NGDS as the basis for a Data Web. Just as everyone uses the World Wide Web for hosting on the Internet, we want USGIN-NGDS to serve that role for online data. This is why we are working so diligently to diversify data providers and users. We also hope to find other groups beyond DOE-GTO that find these data valuable and would consider funding their digitization or inclusion.

Reviewer 23544

Score: 8.0

Comment: The data approach was appropriate for the effort. The results are substantial.

PI Response:
Good to hear this validation.

Reviewer 23511

Score: 7.0

Comment: An appropriate approach has been taken and progress has been good on the database part of the work. My primary criticism is the new field data collect. Looking at the SOPO, new field data collect was one small part of one sub-task (2.4) yet this consumed (by my notes, if I understood correctly) about 4 million dollars (about 20% of the budget). On what basis were these sites and techniques chosen? Why these particular states and locations? The project objectives listed on page 1, section A of the SOPO are general and it is hard to see how drilling a few deep holes in a small part of Utah fits into the criteria. The data return on these wells is a tiny fraction of the data in the database.

PI Response:
The new data acquisition was an add-on to the project at the request of DOE-GTO about 5 months after the project began, as additional funds were unexpectedly available that needed to be allocated quickly or risk losing them. We worked with DOE to develop a solicitation to the project members to identify data gaps, and make the case for new data acquisition. The project's Science Advisory Board reviewed and ranked all proposals, which were then negotiated by the project management team and Management Advisory Board. DOE has representation on both boards.

The Utah proposal was one of the largest but also identified key data issues in an area of great geothermal potential. The initial results are particularly exciting and potentially significant.

There is no question that the amount of data from essentially an exploration program is smaller than that for the same amount of money spent on digitizing existing data. But the supplemental funding for new data acquisition was not intended to simply add more data points. In effect, it is a separate project, appended to the data project because of our ability to quickly develop and effectively implement a nation-wide program. The results of the add-on project are being incorporated into NGDS but that was not the driving factor for this task.

Reviewer 23437

Score: 9.0

Comment: The approach to assessment and incorporation of data assets from the various partners - 50 states, et al - is well thought out and is helping to ensure the data served by this system is of highest quality and interoperability. The loosely coupled approach being used helps ensure that the various project participants can proceed according to their own constraints without significantly impacting other participants.
Early work by this project on data sharing standards and protocols - in particular the approaches expressed in the USGIN framework - has stood the test of time and is working well for this project and as the 'glue' holding NGDS together.
Though this project appears to be a leader among the various NGDS-related projects in taking on the thorny issue of sustainability - keeping the NGDS alive, relevant and useful beyond the end of the NGDS projects - the concept still needs significant refinement to become a useful basis for moving forward.

PI Response:
We appreciate the recognition of the system design approach we are taking. This concept is gaining traction worldwide and we are seeing broad convergence. We agree there is much work to be done but we also believe the agile approach we are taking in development allows for continual adjustments and modifications to achieve project goals. The switch from Geoportal to CKAN is indicative of this, and demonstrates the fact that the system will always be a work in progress. Cyberinfrastructure is evolving quickly and what we have today is sure to be upgraded or replaced in short time frames. The system is effectively a collection of standards, protocols, procedures and modules to implement them. As new and better tools come along, we are able to fairly readily swap them out to keep the system fresh and robust.

We also recognize that the current project despite it size and scope, is not building everything users will want. This is a significant first step but much more needs to be done to take full advantage of the potential.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23526

Score: 9.0

Comment: Progress seems good and I believe the project will be successful.

PI Response:
We agree.

Reviewer 23544

Score: 8.0

Comment: The progress seems to be on line to finish with the end of the funding. The effort has been managed well.

PI Response:
We do feel confident we will meet or exceed goals and be on time. We've assembled both great technical and management teams for the project and the long time collaborations within AASG have contributed significantly to the teamwork among the participants.

Reviewer 23511

Score: 8.0

Comment: Good. Adequate progress has been made on each of the sub-tasks listed in the SOPO. In several cases, it appears to have expanded beyond the originally conceived results.

PI Response:
We have expanded the scope in a number of areas to take advantage of opportunities. One example is the MOU with the Western Regional Partnership to set them up as a node on the system. They will bring 10,000 GIS layers of land use and land management from 20 federal agencies for five western states. This is a valuable asset for the geothermal community users, it demonstrates the scalability of the system, and opens up opportunities to engage the WRP member agencies individually with NGDS.

Reviewer 23437

Score: 10.0

Comment: This project is on track to deliver all that is stated in their objectives.
- The accumulation of data from some states and other sources was delayed a bit but this delay has been accommodated by a no-cost extension.

- The quality and value of the data made accessible by this project is evident as one browses the content already in the repository.
- The project has made impressive progress on establishment of a repository to manage data resources and interfaces to search and access those data resources.
- The growing set of data interchange content models developed primarily by this project are becoming the foundational specification of data formats for all of NGDS.
The scope of this project is huge - gathering and integrating data from all 50 states - and the project is to be commended for 'herding cats' so well.

PI Response:
The initial delay was due largely to getting subawards set up with all of the states at a time when many of them were caught in financial turmoil of the recession. The project management team has worked closely with each of the participants to get them caught up. The Science Advisory Board reviews and accountability requirements has provided an effective management tool.

The project has filled in some of the gaps resulting from delays in the original Design-Build project.

The "cat herding" challenges have been ameliorated to a significant extent because of the long standing relationships among the state geological surveys. If we had to build a national coalition from scratch to do this project, it likely would not be anywhere nearly as successful. The lines of communication and the level of trust among participants has been instrumental.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23526

Score: 8.0

Comment: The coordination between this project and the NGDS framework project is critical for success. At the current stage, the project appears to be well managed.

PI Response:
The turn-around in coordination with the Design-Build project over the past year has been phenomenal and we are rapidly catching up from lost time. We feel that the synergy of being a subawardee on that project is finally paying off for both projects. The work on the State data project to train and integrate the 44 subawardees into the system is readily applicable to the BSU subs.

Reviewer 23544

Score: 8.0

Comment: The project has been successful because of the focus on managing it well. The states contribution efforts were well coordinated and have produced valuable data.

PI Response:

We put a lot of thought into the project management in the original proposal, recognizing at the time, that this aspect of it may be more challenging than the technical aspects. The Management, Science, and Technical advisory boards, the review, approval, and deployment processes for data have all worked largely as intended and been successful.

Reviewer 23511

Score: 8.0

Comment: Appears good and a substantial effort has been made in reaching potential collaborators. Thought has also been given to the next steps and sustainment. It may be difficult to manage all the proposed collaborations without losing focus.

PI Response:
You raise a valid concern about managing all of the collaborations and other sustainability activities. We already see that with many requests that we cannot completely fulfill or follow up with.

Reviewer 23437

Score: 9.0

Comment: The core project leadership team is small and high-functioning. Management of the numerous subcontractors is done very effectively, ensuring through various mechanisms, including the Science Advisory Board, that data assets being included are delivered timely and of highest quality. Well defined repeatable processes are in place to support the management of this diverse set of providers.
I have a concern that coordination among the NGDS-related projects, particularly in relation to sustainability of NGDS as a whole, has been neglected a bit in order to focus on more immediate needs. These projects are nearing completion and sustainability - post-deployment and post-project - must become a priority very soon.

PI Response:
We take accountibility and quality control very seriously in the project and are satisfied with the results and the recognition by the reviewers.

Ccoordination among the independent NGDS projects is a different challenge. Because AZGS is also a subcontractor on the BSU-led Design-Build project, and due to the excellent management now in place on that effort, we have been able to partner effectively and integrate most activities, procedures, and standards among all the participants on both projects. Sustainability is a task in the AZGS-led project as well as in the BSU project and we agreed during the past year to coordinate our planning in that area. However, there are numerous questions that have to be answered or resolved, some by DOE, some among the participants. Many of these are identified in a draft sustainability report (not a plan) delivered to BSU in May as part of that project, but which includes work done in this project.

We are now focusing more intently on creating a sustainability plan. Feedback from reviewers and DOE to the draft report is coming in piecemeal but helping to resolve issues and provide guidance on what options are viable. We anticipate having a sustainability plan to circulate in Fall 2013.

STRENGTHS

Reviewer 23526

Comment: Strong interactions with the states, and getting the data

PI Response:
A major focus for us.

Reviewer 23544

Comment: The modular approach has served the team well this year. The system will be functional for the users as the funding expires.

The data gathering efforts from the states was structured and organized. The preparing of the data will allow more uniform analysis across the United States.

The Open Source software approach will not require continuing fees as the program goes into the maintenance phase.

The project has been presented at multiple conferences and introduced to the commercial industry.

PI Response:
The project is largely progressing as planned. As the system becomes more data rich and user friendly, we plan on moving from largely seeking input from the user community to mostly demonstrating functionality.

Reviewer 23511

Comment: A clear sustainability plan has been developed and a large group of collaborations. A large amount of data has been accumulated.

PI Response:
The sustainability report is a precursor to the implementation plan. The growing number of collaborators is central to our strategy of making the USGIN-driven NGDS a widely deployed part of the nation's cyber-infrastructure that will be broadly based and supported.

Reviewer 23437

Comment: Strengths:

- Excellent management

- Skilled technical architects

- Domain expertise

- Data design/modeling skills

- Refined outreach

PI Response:
N/A

WEAKNESSES

Reviewer 23526

Comment: Perhaps some overlap with other projects, which may lead to either duplication or omission of data

PI Response:
This manifested itself early on with University of Nevada Reno being a participant on both the AZGS and BSU (Design-Build) projects, and worked with all the parties to delineate which data and functions were assigned to each project. The larger challenge has been to avoid duplication among all the projects overall, but especially AZGS and SMU projects because of the oil and gas well data. We have encouraged each of the States in our project to work directly with SMU to identify and avoid overall and gaps and facilitated many such reviews.

Reviewer 23544

Comment: The lack of a follow-on program or architecture support group or even another project means this system will at best be stable with a continuing slide to irrelevance.

PI Response:
This concern has been recognized since the original funding proposal was prepared. We are using open source, broadly supported software to ensure that there is robust community of developers behind the system. We took a modular approach, adopting existing components with their own sustainability mechanisms. We have worked diligently from the onset to broaden the appeal and use of NGDS to enlist a wide base of of contributers and users, again towards leveraging other projects and systems.
Reviewer 23511

Comment: Quality and integrity analysis. Although mentioned in SOPO, I did not find any additional references to it. Quality of data is essential for a useful database. Summary refers to http://www.stategeothermaldata.org/progress but I could not access it. As mentioned above, I thought that including data collection was a weakness.

PI Response:
We absolutely agree about data quality and integrity, and why we invest so heavily in it. We apologize that you could not find the documentation on the website. There are two pages that are particularly relevant:
http://www.stategeothermaldata.org/content/progress
http://www.stategeothermaldata.org/content/data_delivery

We have a formal process for metadata and data development, review, and approval, that is rigorously maintained. We have had 2-3 Geoinformatics Specialists in the Tucson office who work full time with each of the data providers, guiding and training them on project standards and procedures. They review each test data set and work with providers on quality

control issues. We review for competeness and data integrity based on the content model (correct data types, mandatory fields populated), but we can't review for scientific accuracy, reliability or even validity. [Our approach to that kind of quality has been to get the best documentation we can on the source of data, provide that to the user, and let them make a determination as explorers and scientists regularly do when gathering existing data.] Only when the Geoinformatics Specialists are satisfied, are data sets approved for deployment.

We believe data collection is one of the strengths of the project.

Reviewer 23437

Comment: Need refocused attention to issues surrounding a unified sustainability plan for NGDS.

PI Response:
We agree. The formal sustainability plan is scheduled for delivery in Fall 2013. We prepared a draft sustainability report in May 2013 under the BSU Design-Build project that incorporates much of the thinking and work done on the AZGS project. But we have been carrying out key elements of our sustainability strategy from the onset of the project, including leveraging resources from other projects, adding data providers to broaden the scope as well as increasing the amount of data in the system, and initiating collaborations that are intended to lead to wider adoption of the system framework.

IMPROVEMENTS

Reviewer 23526

Comment: Formalize some method to cross-check with other similar projects

PI Response:
That is a good idea, but probably needs more push by DOE on the projects to make it happen. It is our best interests to fully integrate all the projects as part of our goal of reaching a tipping point in its use. Some of other projects either do not recognize or value that concept.

We have strong integration of the AZGS and BSU projects, that have been more fully realized and effective since the redirection of the BSU project a year ago.

We drafted a Memorandum of Understanding between the AZGS and SMU projects but they never signed it. We have an informal working relationship to try to avoid duplication of data and to advise them on exposing their data as Web services.

The USGS is principally providing a geothermal assessment rather than contributing data, so this is a different interaction than with the other NGDS projects. However, there are vast amounts of USGS data we want accessible via NGDS. The NGDS is now searchable and accessible through the USGS National Map viewer. We are working with USGS at the Associate Director level and through the Community on Data Integration, to integrate data and services at the enterprise level across all of USGS.

Since the GDR moved to NREL last year, we have had a number of conversations and webinars on how to integrated GDR as a node into NGDS, on using NGDS content models, and on common standards. These have not yet led to GDR taking the actions needed to fully participate. A recent DOE-organized web conference seemed to dispel some misconceptions at NREL and may portend a new willingness to link the systems.

Reviewer 23544

Comment: The geothermal data efforts need a continuing focused effort after this current round of projects ends next year.

PI Response:
We agree and are putting significant time and resources into that effort. We reallocated approximately $250,000 of funds returned by subcontractors, to use in the sustainability effort. Note that we have one of four NGDS projects, so we need to convince the others of this need and get their cooperation create a coordinated system. We cannot mandate that so it either has to come from DOE in some manner, or we find incentives/inducements for the others to work with us.

Reviewer 23511

Comment: Evaluate use of the database. Who is using it and why? (hopefully, industry).

Implement quality control of the data.

PI Response:
As we move from beta test mode to operations of NGDS, it will be important to see who is using it and how, and continually survey what would make it more useful and valuable. We should incorporate that as part of the sustainability plan. Customer satisfaction is critical to success.

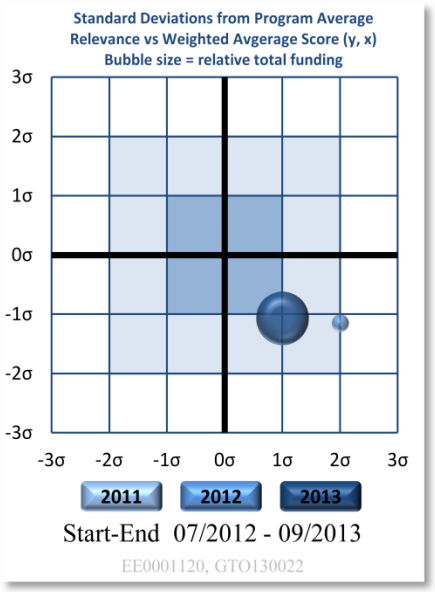
We believe we have a rigorous and comprehensive data quality program for data and metadata. Concerns about this appear to be misguided.

Reviewer 23437

Comment: Reach out to other NGDS-related projects, in particular the DOE-GDR, to assist them in ensuring that their data repositories conform to requirements as NGDS nodes. Coordinate with other NGDS-related projects to devise a unified approach to sustainability for all of NGDS.

PI Response:
We have made a number of approaches to DOE-GDR via NREL but until very recently, the response has been muted or mixed, apparently due to a lack of understanding of how NGDS works and how GDR could fit in. DOE-GTO recently organized a webconference among the groups to work out how to get all of us integrating our components. Initial reaction is that we seem to have moved beyond some misunderstandings and misperceptions, and that we may see tangible actions in the short term.

We heartily endorse a unified approach to sustainability of NGDS. AZGS and BSU are having discussions currently about their respective roles. We've made progress with NREL (DOE-GDR) collaboration in recent weeks that is promising. SMU and USGS have their own visions that are not as obvious, so we are not sure at this time what long term involvement we can expect from them.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0001120
Project: National Geothermal Data System Architecture Design, Testing and Maintenance
Principal Investigator: Blackman, Harold
Organization: Boise State University
Panel: Data System Development & Population

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23437

Score: 9.0

Comment: It is obvious that this project has undergone a significant and impressive transition in the last year. The project is now making significant progress in providing an architectural foundation and an accompanying user interface to provide federated access to a treasure trove of data resources that will be of immense value to researchers, explorers and developers within the geothermal community. In addition, through its data provision subs - OIT, EGI, Stanford, UNR - the project is adding a substantial collection of data resources to the overall content that will be accessible through NGDS.

PI Response:
No comment

Reviewer 23511

Score: 5.0

Comment: As originally proposed, highly relevant. Currently, implementation is incomplete. Other projects may have already superseded the work proposed here.

PI Response:
We are continuously engaging with related projects as we learn about them to avoid duplication of effort and coordinate activities where possible. Technology is evolving rapidly, so the best we can do is to develop a system designed to be adaptable. This is one reason for our focus on the content models and documented interchange formats. At completion, our instantiation of NGDS will meet our project plan as agreed to by DOE.

Reviewer 23526

Score: 8.0

Comment: The NGDS is long overdue. In my mind there is no question regarding the impact of relevance of the work, this is a must do project/program and will benefit the Office and the community at large for decades to come.

PI Response:
No comment

Reviewer 23544

Score: 7.0

Comment: This project has become relevant this year.

PI Response:
No comment

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23437

Score: 9.0

Comment: Quite a turn around.
No more lip service to agile practices, this project is now executing its development activities in a very solid agile manner, and is reaping the benefits of doing so.
Even more impressive is the fact that the design/development team is distributed among several entities, all of which seem to be collaborating well through this process. All of this speaks well of project management, Scrum management, good software engineering practices and development team members' commitment to a quality outcome.
The user centered design work has been thoughtful and thorough, with high quality results. Recent focus on getting domain experts to weigh in on the user interface design will most certainly help this capability meet the needs of the geothermal community.
The incorporation of an open source philosophy appears to be paying off.
It is also evident that the project's data provision tasks are now being worked in an effective manner, with solid work being done in the data inventory, assessment and acquisition activities.

PI Response:
No comment

Reviewer 23511

Score: 3.0

Comment: Three parallel paths are proposed: data assessment, software development, and sustainability. The data assessment has been completed. Software development is underway and, in terms of functionality, reasonably well-conceived and planned although likely too ambitious given the remaining time. In terms of sustainability, the approach is poor.

PI Response:
We're not sure what exactly is meant by the sustainability "approach is poor." Does this refer to the draft sustainability report itself, to the management and organization proposed, to the possible revenue streams, or something else? The

issue of sustainability is raised in multiple sections below in some cases with more specificity, so we hope we address the underlying concerns in one or more of those responses.

Reviewer 23526

Score: 7.0

Comment: The approach seems to be sound. Based the the presentation materials alone, it is somewhat difficult to understand how all the (sub) projects that supply data to the NGDS come together. The relationship between NGDS, State Data, SMU, and GDS needs to be clearly presented somewhere. The "node-in-a-box" concept is good, but somehow the data from a node needs to be mirrored somewhere to protect the long-term viability of the structure in general. Some assurance needs to be defined that if a node goes down the data will still be available.

PI Response:
We determined in our planning and prioritization process that mirroring between nodes with real-time fail over is out of scope at this stage of the system. We have been advocating virtualization of servers to enable imaging for backup and replication. A replication model for virtualized servers is being tested in the AASG project between hubs at Arizona and Nevada using the Hyper-V technology that comes with Windows Server 2012 out of the box, and are recommending such an approach for system mirroring. Fail over is still a manual process, requiring switching from the master to the replica and changing the Domain Name registration, but no data are lost. Technology for virtualizing servers and creating images of those for disaster recovery has become wide spread and provides a mechanism for such backup. Otherwise we emphasize that backup is an essential part of running any online data service. So at a minimum, with the help of "inter-human communication", this problem can be settled as well: In the case that an institute decides to shut down its node, it can export the data in the node so that it can be later imported into another node taking over that data. Since the community is not that big, it might be possible to solve the problem this way until some organization picks up the task to create a mirroring algorithm.

Reviewer 23544

Score: 8.0

Comment: The approach has been drastically changed since last year. There will be accomplishments, the goal is to finish as many sprints as possible. Funding/time may run out before all of the currently identified project areas are completed.

PI Response:
This is a certain risk. We have basics in place for a fully functional system as promised in the SOPO, but they need to be consolidated and stabilized. Considering this and other feedback, we will focus our activity of the remaining sprints on debugging, stabilizing and fixing. So, in short; we will complete our features by adding full-text indexing as the last new one and spend the remaining resources on fixing and documenting, as planned.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23437

Score: 9.0

Comment: Kudos for the quality work on the very appealing user interface, especially the dual map/library perspective represented. One can see that the team is listening to the needs of the geothermal developers and researchers, and others in the geothermal community. This is also being reflected in the various data formats as expressed in the NGDS content models.
The adoption of CKAN as a key architectural element is smart and is being executed effectively. Other open source elements are also being incorporated well.
Some highly valuable data assets have been assembled and incorporated.
One concern: The uncertainties about sustaining this system over time need to be resolved ... the project will end soon but the potential value of this system resides in it being available for the long haul.
Overall the project is now exhibiting impressive productivity.

PI Response:
We agree about the need to get uncertainties over sustainability resolved soon. We submitted a 99-page draft sustainability report to DOE for discussion in May, 2013. The report was not intended to be the implementation plan but rather identified a number of questions that need to be answered or resolved before a plan can be full proposed, adopted, and implemented. This includes who 'owns' NGDS; is continued operation of NGDS to be maintained by one or more of the current NGDS project managers (if so, which one) or is it open to any person or institution to take on; what restrictions or limitations will DOE have over the operational system; and others.

With DOE's concurrence, we are moving forward to set up a non-profit organization to host USGIN with NGDS as a major user ("client") of those services. We are organizing a one-day symposium in Washington DC to showcase NGDS as a mechanism for federal agencies to meet White House Open Data requirements (The USGS has agreed to co-sponsor this and provide a venue). We are holding end-user workshops around the country with data providers and the geothermal industry to guide further development priorities.

Reviewer 23511

Score: 3.0

Comment: Three parallel paths are proposed: data assessment, software development, and sustainability. The data assessment has been completed. Software development is underway and, in terms of functionality, reasonably well-conceived and planned although likely too ambitious. In terms of sustainability, the progress is poor. Little, compared to what was proposed in the SOPO, has been accomplished.

PI Response:
We probably are behind where we would like to be with a sustainability plan, for a variety of reasons. The redirection of the project a year ago led to reassigning duties for the sustainability plan along with other tasks. Although we had some catching up to do, this change has now resulted in very close collaboration with the State Geological Survey data project (AZGS) and their sustainability efforts. Despite the reviewer's concern that little has been accomplished, we are in fact, well situated, to complete a focused plan by Fall 2013 with an implementation process that is already underway.

Key aspects of the sustainability requirements have been in continuous development since the start of the project, including designing and building the NGDS as an operational open source modular framework that is scalable and transferable, rather than treating it like a research project. We have a long list of other groups asking to use the system around the world for geothermal applications, as well as for other uses in the US. This is a fundamental strategy this is central to our sustainability and we are incredibly successful already, even with NGDS in only beta test mode with limited user interface abilities.

The NGDS success influenced the White House Executive Orders on making federally funded research publicly available in open source, interoperable formats (February 2013) and a following mandata (May 2013) for all federal agencies to do the same for all their data. NGDS demonstrated that it can be done. It can be argued that NGDS is about to become the only operational data integration system in the country that meets the White House mandates. This puts us in remarkable position to capitalize on our capabilities, create a huge number of additional data providers and users, and implement a number of revenue streams as outlined in the draft sustainability report. We are incorporating plans to 'market' NGDS to federal agencies in Fall 2013 as a solution to the White House requirements.

Reviewer 23526

Score: 9.0

Comment: Progress seems excellent since the project was re-organized and the team refocused. I am confident the project will succeed, More detail on the "sprints" would have been helpful so the reviewers could access the the potential final capabilities and provide some input.

PI Response:
No comment

Reviewer 23544

Score: 6.0

Comment: The project was at risk last year. The reorganization of the effort was absolutely required. It is to be seen if the current set of sprints can be completed. There is a prioritized set of efforts so that a base capability will be achieved with the current funding and extended time restrictions.

PI Response:
No comment

PROJECT MANAGEMENT/COORDINATION

Reviewer 23437

Score: 9.0

Comment: As mentioned in the approach section application of agile practices of Scrum, including well-managed sprints, is paying off. In addition the project as a whole is now being managed well, with the various entities working well together.
Frequent decision points are built into the agile management process, and the project sponsor - DOE - and other stakeholders now have excellent visibility into this process and into technical progress through frequent meetings and project reporting.
As a result, despite previous evidence of stalled progress, this project is now on target to deliver an impressive product. One wonders what might have resulted had this project been managed in this way from the start.

PI Response:
No comment

Reviewer 23511

Score: 3.0

Comment: The poor progress reflects management, as far as I can tell, as no other reasons are provided.

PI Response:
No comment, please see other reviewer comments.

Reviewer 23526

Score: 10.0

Comment: The new management and organization team is top notch. I noticed there is now a 'team", as I noticed the contributors working/eating/talking together over the duration of the peer review. This indicates to me that they now are functioning effectively and working together. Good!

PI Response:
No comment

Reviewer 23544

Score: 8.0

Comment: A lot of productive work went into turning this project around. The new program manager should be complimented on the effort.

PI Response:
No comment

STRENGTHS

Reviewer 23437

Comment: What a difference a year makes. Kudos to project management and the project team for a remarkable turn around! After teetering on the brink of termination, the project is now a high performer.

Strengths include:
- User Centered Design approach
- Agile practices done well
- Incorporation of Open Source philosophy and architectural components
- Openness in project management
- Well-coordinated data assessment and incorporation
- Effective project management with a distributed and diverse team
- Great collaboration among team members

PI Response:
No comment

Reviewer 23511

Comment: Software design seems reasonable.

PI Response:
No comment

Reviewer 23526

Comment: Having a "one-stop" shop for geothermal data is a powerful thing. It should not only help the industry and geothermal community, but also be useful for people outside the community, and help educate the public.

PI Response:
No comment

Reviewer 23544

Comment: The single strength is that this project was able to be turned around. Results were already displayed at the conference during the presentation and at the web-site. The agile development process may be able to deliver a stable system before the funding/time runs out.

PI Response:
No comment

WEAKNESSES

Reviewer 23437

Comment: Primary concern is that sustainability plans remain murky. At this point I would expect some clarity in the alternatives and their trade-offs for sustaining the system into the future. Sustainability preparations should be a collaboration among all NGDS-related projects - coordinated by this team - to produce an integrated approach.

PI Response:

We agree the plan for sustainability is murky in some areas. Some of the decisions are dependent on determination from DOE about ownership, control, support, oversight, etc, but those are under intense discussion as this is written.

We appreciate the desire to examine the alternatives and their trade-offs. This was covered to some extent in the USGS-AASG report on stratetgic plan for USGIN which greatly influenced our draft sustainability report. However, in discussion with DOE and project monitors, we discovered that there were expectations from some of DOE's advisors that the deliverables might be packaged up and handed off to DOE, while a long term plan was developed. In fact, NGDS is more like the World Wide Web - a set of standards and agreements on how to move documents around the Internet. Much of the DOE funding is going to digitizing and serving data which are still owned and held by the data providers. The integration aspects of NGDS could be replicated by anyone who adopts and maintains the system standards and gets agreement from providers to participate, so part of the sustainability conversation has to involve what it is that is core to NGDS and what is generic that could be maintained by other cyberinfrastructure elements.

We agree that sustainability preparations be a collaboration among the NGDS projects. BSU and AZGS have fully integrated their sustainability efforts.

The USGS is principally providing a geothermal assessment rather than contributing data, so this is a different interaction than with the other NGDS projects. However, there are vast amounts of USGS data we want accessible via NGDS. The NGDS is now searchable and accessible through the USGS National Map viewer. We are working with USGS at the Associate Director level and through the Community on Data Integration, to integrate data and services at the enterprise level across all of USGS.

Since the GDR moved to NREL last year, we have had a number of conversations and webinars on how to integrated GDR as a node into NGDS, on using NGDS content models, and on common standards. A recent DOE-organized web conference identified the next steps needed to achieve that and should facilitate integrating the systems.

The recommendation that this team coordinates sustainability among all the NGDS projects makes sense, as the primary Design-Build project. We have implemented that in part through the joint BSU-AZGS sustainability planning. We are seeking buy-in from the other projects but do not have direct authority to mandate their participation. We need to convince the others of this need and get their cooperation to create a coordinated system. We will continue to work with DOE on sustainability of all the NGDS components.

Reviewer 23511

Comment: Poor progress to date on tasks listed in SOPO and unlikely to accomplish all by the end of the project. No clear sustainability plan.

PI Response:
In terms of sustainability, we submitted an extensive report that looked at numerous examples of how other data-focused systems are organized and funded. The report is not a plan but raised questions that have to be addressed by DOE and others before a actionable plan can be designed and implemented.

We provided recommendations from a panel of national experts who proposed that the NGDS framework be managed by an independent non-profit organization, that would provide for involvement by other end-users, thus broadening the base of data providers and system supporters. We identified a variety of revenue sources that could be used to support NGDS. We identified a growing list of potential customers and contributors, some of whom are eager to use NGDS now. Collectively, we have most of the materials and resources to finalize a sustainability plan by end of the calendar year. Some aspects of it are already being implemented now.

As previously stated we will deliver a fully functional NGDS system at the end of the project.

Reviewer 23526

Comment: The complexity of the isolated nodes, and potential lack of redundancy, may make the system vulnerable.

PI Response:
One of the motivations for the Node-in-a-box approach is to reduce the variability in the implementation of NGDS functionality, and facilitate maintenance because there is a community of users familiar with the technology. We have chosen to focus on getting content online and basic functionality implemented in order to bootstrap the system. As the system grows and becomes a part of common workflows, there will need to be more effort invested in durability and reliability.

Reviewer 23544

Comment: Most of the viable achievement have been developed since last summer. There is a list of sprints that will be beneficial to have but the late start puts the later efforts at risk.

PI Response:
Despite the late start we are confident that we will deliver a fully functional system. Things always take longer than you expect. Our current thinking is that we need to focus on testing and debugging the existing functionality rather than adding new features that may be buggy.

IMPROVEMENTS

Reviewer 23437

Comment: Attend to an integrated approach - among all NGDS-related projects - to NGDS sustainability. This project should lead that effort.

PI Response:
We agree that roles need to be clarifed and as mentioned in prior responses we will work toward resolving by the end of the project. This project is leading the sustainability planning effort, but with significant input and collaboration with the AAGS/AZGS State project.

Reviewer 23511

Comment: Currently, all effort seems to be focused on implementing as many features as possible (e.g. faceted search, etc). At this stage, regardless of whether a no-cost extension is approved, any software that is being developed up to the final minute will have unexpected features. An agile development system tends to favor software over documentation but the lack of documentation will hinder use and expansion by future open-source developers. Rather than adding more features, I think a focus on making a smooth transition to open-source would be better. In my opinion, a simple system with a limited number of features that works well is superior to more complicated system with bugs. Effort needs to put into sustainability otherwise it will be likely be completely useless in a few years, if not sooner. If it will be open source, then it should start now. Try to develop a user community now rather than simply posting the source at the end of the project. The current plan includes software to 'evaluate and analyze' (slide 15). I suggest that this effort should be kept to a minimum and that the focus is on developing a robust search capability.

PI Response:
The NGDS team acknowledges that there is a need to strike a balance between feature completeness and stability+documentation. At the time of this writing we consider NGDS features complete and will put all our effort into increasing stability, testing, debugging, documentation, and merging our additions to CKAN functionality back into the project. This is necessary to ensure the viability of the developed software as an open source project. We also intend to make the code publicly available as soon as all legal aspects involved with such an undertaking are covered.

Reviewer 23526

Comment: This comment goes to the "NGDS" concept overall, and this project in particular.

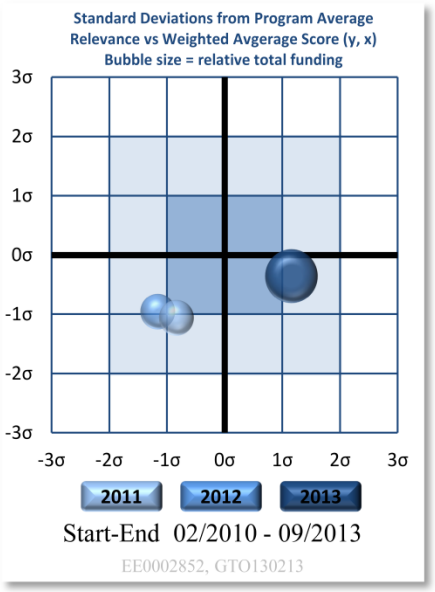
I think the one critical improvement is that the "node-in-a-box" software needs to include capabilities to mirror the data in at least two additional places. This would 1) ensure stability and longevity, and 2) enable search engine order (SEO) later. One of my biggest worries is that we can become dependent on a specific node, and have no assurance that the node will remain viable. This is especially true going into the future, when a community drive environment is envisioned. I would also recommend that as part of the GTO program, instead of asking for data plans, provide guidance and templates, and potentially the "node-in-a-box".

PI Response:
We are promoting the idea of virtualizing servers and using machine images and virtual machine replication to enable disaster recovery. Because the basic concept is a federated system, the individual data providers are responsible for their disaster recovery scenario. It may be worth exploring implementation of a data harvesting/archive resource in the system (GDR?); this would require a business model, perhaps based on a fee for service to provide the archival copying.

Reviewer 23544

Comment: The possible improvements have been made. The window of opportunity for this project is closing but it looks like there will be viable results.

PI Response:
No comment



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002852
Project: Heat Flow Database Expansion for NGDS Data Development, Collection and Maintenance
Principal Investigator: Blackwell, David
Organization: Southern Methodist University
Panel: Data System Development & Population

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23437

Score: 9.0

Comment: The subject data for this project are some of the most important data in support of geothermal development. The more heat flow and related data are made available to the geothermal community, the more confidence developers will possess as they pursue geothermal exploration and development activities. In concert with other data resources being made available through NGDS this collection has the potential to be a transformative influence within the geothermal community in the US and internationally.

PI Response:
Agreed.

Reviewer 23511

Score: 9.0

Comment: High and focused on the exploration needs of industry. Highly relevant.

PI Response:
Agreed.

Reviewer 23526

Score: 8.0

Comment: For me, the major impact of this particular NGDS project comes in the development/integration comes in the form of the combined Railroad Commission database. From personal experience in digging through proprietary oil and gas databases looking for analog wells, one cannot underestimate the value of bringing these data into a cohesive database.

PI Response:
Agreed.

Reviewer 23544

Score: 9.0

Comment: This project is producing high quality data for the geothermal industry. The de-duplicated efforts will bring positive feedback to the program as more industry analysts rely on this data for analysis. Increasing the quality of this data as it is integrated into the database is extremely important.

PI Response:
Agreed.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23437

Score: 9.0

Comment: There are three primary activities evident on this project: data collection, data transformation and software/system development. It is clear that this project carried out each of these activities in an appropriate manner. Considerable data have been accumulated from the various partners, and it appears this has been well coordinated. The partners in turn have helped to ensure that the data they provide are of the highest quality and ready for transformation and integration with the rest of the collection. To be commended is the work to cleanse and de-duplicate data and to otherwise ensure the highest quality data are incorporated.
The data store appears to have been properly managed and prepared to accept the incoming data. It sounds like the data transformation and load work was done well, and continues to adjust to the variations in the data received.
It is evident that the software development work has also been conducted well, and serves its purpose in providing data management, interpretation and visualization capabilities. Integration with the NGDS as a whole still remains to be completed. To the project's credit this integration will leverage NGDS standard mechanisms for catalog (CSW), data delivery (OGC services) and data structures (NGDS content models).

PI Response:
Agreed.

Reviewer 23511

Score: 8.0
Comment: Good. However, most of the current and upcoming MW produced by geothermal will be in CA, NV, UT, OR, HI. It would have seemed natural to focus more effort on these states. Texas, which has little geothermal, has a very high percentage of the data.

PI Response:
The focus was on collecting and integrating the disparate collections of the various participants from our project team, which include some large nationwide datasets. It is true that one of our team members contributed a massive collection of data gathered from the Texas Railroad Commission's proprietary systems, however the large quantity of Texas data does not imply that there is not also a significant amount of data from western states, including CA, NV, UT and OR. Indeed,

the heat flow data from Oregon alone contains over 1,430 entries and another 2,908 related files of information such as field notes, temperature depth curves, related publication references, etc.. California 1,524 has records of heat flow information and 540 pieces of related information. Utah has over 1,000 entries and Nevada has even more, with 2,874 records.

Additionally, please note that NGDS Design and Testing team led by Boise State University includes data-contributing participants from the western states mentioned by the reviewer: the Energy and Geoscience Institute at the University of Utah, the GeoHeat Center at the Oregon Institute of Technology, Stanford University's Geothermal Program, and the Nevada Bureau of Mines and Geology at the University of Nevada, Reno.

While it is true that the partners on our project team have relatively little information available from Hawaii at this time, our expectation is that the University of Hawaii would be contributing additional information as part of their sub-award to the collections gathered by the Association of American State Geologists (AASG) project managed by the Arizona Geological Survey. Indeed, the SMU led project was designed to leverage the extensive expertise of its participants; the complete coverage of the country is the responsibility of the AASG project.

Reviewer 23526

Score: 8.0

Comment: The approach is solid, and well defined. I would recommend continuing along the path to completion.

PI Response:
We appreciate the positive feedback. Thank you.

Reviewer 23544

Score: 9.0

Comment: The technical data approach for this project is first rate. The work is laid out in an understandable manner and the project has been extremely successful in improving the quality of the data.
PI Response:
Again, we appreciate the positive feedback. Thank you.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23437

Score: 8.0

Comment: The data incorporated in the SMU system is of impressive quantity, quality and relevance. The transformation work has paid off with what appears to be a well integrated collection of data that originated from multiple sources not originally designed to be integrated. The developed system appears to be handling all of this data well, and has been built in such a way that it can adapt to new incoming data.

Of special note is the work described to interpret and codify content coming from the Texas Railroad Commission - a valuable collection that was previously difficult for the community to assimilate and apply.
A key objective of the project is to contribute data to NGDS, and it appears much of this work remains to be done.
In addition, this project and the other NGDS-related projects are just now beginning to tackle sustainability - how NGDS will survive the end of these projects and continue to provide a growing and increasingly relevant knowledge base for the geothermal community.

PI Response:
At the time of the peer review only 1 of the 10 content models selected for delivery of WFS ('tier 3') data had been written. As of this writing, all 10 have been written and are in various stages of testing. The URL where these can be accessed is:

http://geothermal.smu.edu/geoserver/web/;jsessionid=A28A864F9A9087347C6D2F3563758DC7?wicket:bookmarkablePage=:org.geoserver.web.demo.MapPreviewPage

The support for CSW, the last remaining piece to participate as a full node on the NGDS, should be complete before the project conclusion date of September 30, 2013.

Reviewer 23511

Score: 8.0

Comment: Appear to have followed everything in SOPO. On budget and schedule. Clear plan for sustainment. However, I could not search online myself to test.

PI Response:
The DOE has been provided with a test userID on the interactive system available at http://geothermal.smu.edu and additional test userID can be issued as needed. We have experienced performance issues associated with the system that was created to load the data into the NGDS, which will hopefully be resolved soon. Even if these issues persist, the data will still be accessible via alternative paths, such as discoverable as a Web Feature Service through third party applications like Geothermal Prospector and/or through Catalog discovery (CSW).

Reviewer 23526

Score: 8.0

Comment: The data integration is a significant accomplishment, and the progress seems appropriate. This project, along with all the other NGDS projects, are at a critical juncture, and everything needs to come together in a relatively short period of remaining time.

PI Response:
Indeed. It will be a very busy final quarter as we work to complete our final objectives and validate the data collections. We are working intensively and extensively with Siemens to address the work left in the time left. The long hospitalization of a critical member of the Siemens team about a year ago and the departure of two of the original key members of the Siemens team in midstream have made a smooth completion more challenging.

Reviewer 23544

Score: 9.0

Comment: Look at the quality and quantity of data that is being made available. This project has continued to set the standard in geothermal data projects. The integration of the data across the many sources is very important for its future use.

PI Response:
The integration ('tier 3') has been one of the more challenging aspects of the project. We would love to have the opportunity to take the project to the next logical step by analyzing how the data integrated by this team correlates with data provided by the other NGDS project teams (AASG, EGI, and others).

PROJECT MANAGEMENT/COORDINATION

Reviewer 23437

Score: 10.0

Comment: This project appears to be managed in an exemplary manner. Coordination among the associated data providers has worked well. Data transformation and management has been planned and conducted successfully. Software development activities have also been well managed.

PI Response:
Thank you. The project team has functioned very well and the communication amongst the various sub-awardees is open and collaborative in nature. We would welcome the opportunity to leverage these working relationships though future project work together.

Reviewer 23511

Score: 9.0

Comment: Well-managed and good coordination between groups.

PI Response:
Thank you. Please see above response.

Reviewer 23526

Score: 8.0

Comment: The PI and project team seem well integrated and have a proven track record. Of particular importance is the knowledge capture from those in the industry who are "long in the tooth". I believe the PI mentioned something to this effect.

PI Response:
We agree. We believe there is still more to be learned from these seasoned team members in the next iteration of analysis of the data collected by the other project teams and believe we are well positioned to help in this effort.

Reviewer 23544

Score: 10.0

Comment: The project management of this work is an example of how it should be done. The project continues to be the basis for future exceptional analysis because of the proper approach and management.

PI Response:
Thank you!

STRENGTHS

Reviewer 23437

Comment: Project management, software development, data ingestion all quite strong. Very solid associated data providers are contributing and collaborating to ensure the highest possible quality data.

PI Response:
Thank you!

Reviewer 23511

Comment: Large amount of data collecting and with a clear and well-defined purpose with understanding of what industry needs. Considerable effort devoted to quality control. Clear and feasible sustainment plan (at least for a few years)

PI Response:
Thank you! Sustainability does remain an ongoing issue and while we are confident that the 'lights will be kept on' for the next few years, we do feel there is considerably more work that could be done to expand and improve the information as an ongoing project, incorporating the work of the other NGDS project teams, new oil and gas data, innovative drilling project results, etc..

Reviewer 23526

Comment: Capturing and making a significant amount of data available.

PI Response:
Yes, it is a significant amount of data. We believe it will be of high value to a variety of users for years to come.

Reviewer 23544

Comment: The integration of this high quality data will be a reason for this project to continue to be successful. There is funding for keeping the lights on after this project is complete. I am hoping that industry sees this as a major asset that needs to keep growing. If so, there will be a push for future funding.

PI Response:
Thank you! Sustainability does remain an ongoing issue and while we are confident that the 'lights will be kept on' for the next few years, we do feel there is considerably more work that could be done to expand and improve the information as an ongoing project, incorporating the work of the other NGDS project teams, new oil and gas data, innovative drilling project results, etc..

WEAKNESSES

Reviewer 23437

Comment: Concerned about lack of substantive sustainability plans, especially lack of coordination of sustainability among all NGDS-related projects.

Only other weakness to note might be what appears to be late attention to integration with NGDS, but coordination with NGDS now appears to be strong so this weakness may be sufficiently dealt with.

PI Response:
There are a number of teams which all need to coordinate their efforts in order to realize the objectives of a National Geothermal Data system: Design and Testing project managed by Boise State University, Database population by Association of American State Geologists (AASG) managed by the Arizona Geological Survey, SMU's heat flow database population work, and the Geothermal Data Repository currently led by NREL.

The SMU team has been highly participatory from the beginning in working with the Arizona team on the development of standard content models that could be used by any of the NGDS nodes for data submission or retrieval. Some of the design and testing decisions for the system as a whole were finalized after the SMU portion of the overall project was well underway, but SMU and Siemens have worked diligently to ensure compatibility.

Geothermal Prospector, as a 'consumer' of the data provided by the SMU Node (and other nodes of the NGDS), is a critical component of the overall success of the NGDS as well. SMU initiated involvement and coordination with the Geothermal Prospector team early on and both groups are positioned for interoperability testing in SMU's final quarter of the project. Ideally, the SMU project would conclude at the same time as this and other NGDS related projects, but the end dates of other projects is beyond our control and thus, plans are in place to complete our portion by September 30, 2013.

A key element of the SMU project sustainability is the capability to submit (or re-submit) data after the project conclusion. As new data becomes available in the future, or if testing activities indicate the need for corrections to previously submitted data, the researchers can upload this into the SMU Node themselves. This capability has been coded into the software but still requires additional testing with assistance from Siemens.

SMU has committed to maintain the system software, the hardware, the networking connectivity, and the physical and systems security for the SMU Node without additional support from the DOE for many years into the future. However, it

is true that after the project conclusion, SMU will not be in a position to make updates to the software or content models - just the data itself, and that will be on a best effort basis, given that there is no outside funding for such activities.

Reviewer 23511

Comment: Could not actually try to search database online. Not clear whether Alaska and Hawaii were included. SOPO says all 'onshore US'. Geothermal likely useful in both states.

PI Response:
The focus of this project team was on the contiguous US. There is relatively little data available from Hawaii, but what was available is integrated, as are an impressive offshore collection from the geopressured areas of the Gulf of Mexico assembled by Texas Tech University. One of SMU's PhD graduate students has been gathering and analyzing a significant amount of new data in Alaska made possible through financial support from the state of Alaska and the University of Alaska Fairbanks; that collection will be made available on the SMU Node of the NGDS. The SMU team would welcome the opportunity to incorporate the University of Hawaii's work as a sub-award on the AASG project as part of a future effort.

Reviewer 23526

Comment: The database integration for the Railroad Commission is impressive, but perhaps should have been focused on a state/regional with more demonstrated geothermal potential, perhaps beginning with the state with highest geothermal production, and working downward from there.

PI Response:
We believe Texas is well positioned for geothermal projects that make use of the naturally geopressured reservoirs along the Gulf of Mexico. Additionally, the large oil and gas infrastructure makes lower temperature coproduction opportunities worth pursuing. And, the extreme density of oil and gas data will help inform our understanding of sedimentary basins and their suitability for EGS geothermal projects throughout the country, in areas where hydrothermal resources are not prevalent. By including the Texas data collection, we have not neglected the western states. Indeed, the largest collection of scanned field notes, temperature-depth curves, and other related files of information in the SMU Node are from Oregon, California, Nevada, Utah, and other western states.

Reviewer 23544

Comment: The only weakness is the lack of direct support after this project is completed.

PI Response:
We would agree.

IMPROVEMENTS

Reviewer 23437

Comment: Work hard to resolve issues surrounding sustainability.

PI Response:
We have made arrangements to 'keep the lights on' for several years, which is difficult to accomplish without ongoing funding. Our preference would certainly be to have access to funding to support ongoing analysis and expansion and improvement of the collection, incorporating the data collected by the other NGDS project teams into our 'tier 3' services.

Reviewer 23511

Comment: Add Alaska and Hawaii (?). More focus on states with existing geothermal, as they are more likely to add MW in the near-term.

PI Response:
Alaska and Hawaii are not excluded from the project. Indeed, SMU graduate student Joe Batir recently traveled to Alaska where he collected a considerable number of new data points by working with mining companies and the oil and gas industry. The data were used to create a new heat flow map of Alaska. This data collection was made possible through financial support provided by the state of Alaska and the University of Alaska Fairbanks. The newly expanded Alaska data set will be made available through the SMU node of the NGDS, but additions like this require financial support and we are unaware of initiatives from the DOE to fund such basic data collection and interpretation going forward.

Reviewer 23526

Comment: See previous comment

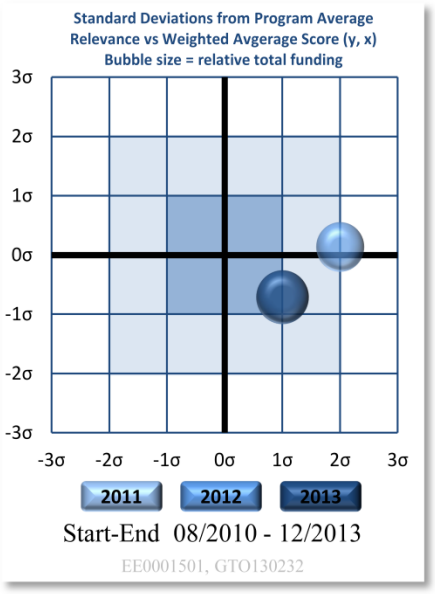
PI Response:
Response to previous comment from reviewer 23526 applies as well: We believe Texas is well positioned for geothermal projects that make use of the naturally geopressured reservoirs along the Gulf of Mexico. Additionally, the large oil and gas infrastructure makes lower temperature coproduction opportunities worth pursuing. And, the extreme density of oil and gas data will help inform our understanding of sedimentary basins and their suitability for EGS geothermal projects throughout the country, in areas where hydrothermal resources are not prevalent. By including the Texas data collection, we have not neglected the western states. Indeed, the largest collection of scanned field notes, temperature-depth curves, and other related files of information in the SMU Node are from Oregon, California, Nevada, Utah, and other western states.

Reviewer 23544

Comment: Get future funding!

PI Response:
We would be good stewards of future funding and have a number of projects we feel are worthwhile to pursue, using this project as a springboard. We appreciate the vote of confidence. We believe the continuation of basic resource data

collection and interpretation is paramount to geothermal project development. However, we are not aware of DOE initiatives to pursue such research on a broad scale.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0001501
Project: National Geothermal Resource Assessment and Classification
Principal Investigator: Williams, Colin
Organization: U.S. Geological Survey
Panel: Data System Development & Population

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23437

Score: 9.0

Comment: This project to refine the understanding of the geothermal resources of the US is clearly important work, relevant to the entire geothermal community. Improved assessments of the US conventional and unconventional geothermal resources will help set a sound basis for decision making in policy making, scientific research and resource development. Application of a well grounded and unambiguous resource classification system will further enhance the knowledge basis of this assessment and follow-on efforts.

PI Response:
Agree

Reviewer 23511

Score: 8.0

Comment: Relevant to hydrothermal, low temperature, and EGS.

PI Response:
Agree

Reviewer 23526

Score: 7.0

Comment: The project reported having 4 major goals, those being: developing a new resource classification standard, expand to all 50 states, improve EGS assessments, and work with NGDS. I think these all have relevance to the program and the nation and are worthwhile pursuits.

PI Response:
Agree

Reviewer 23544

Score: 8.0

Comment: This project attempts to improve the quality of existing geothermal data. Future energy producing site must be characterized so that more stations are productive from the first hole.

PI Response:
Agree

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23437

Score: 9.0

Comment: Though details provided were limited, the overall approach for the geothermal assessment and classification project appears sound. A mix of qualitative and quantitative methods have been used, along with field work for validation and for new data collection.
Perhaps as relevant data increase and become more accessible through NGDS the results of this project can be further refined.

PI Response:
Agree

Reviewer 23511

Score: 8.0

Comment: Not strictly a database project; blends analysis and contributing data.

PI Response:
Agree

Reviewer 23526

Score: 5.0

Comment: The project is very broad and from my perspective lacks a systematic approach and methodology. It was not communicated to me that standards are being developed, more like local exploration and assessments, but how do these define a system?

PI Response:
The breadth of the project is a challenge but reflects a fundamental requirement of assessment efforts at the present time. Ideally we would work on various geothermal assessments in a sequential fashion (e.g., first hydrothermal, then EGS, then sedimentary basins, etc.). This has been our approach in the past, but the interest in geothermal, as with other renewable resources, is intense right now and stakeholders are looking for information across the geothermal spectrum. Consequently, we are pushing forward with a number of assessment efforts in a nearly simultaneous fashion. Any future funding requests for new projects will be tightly focused and limited in scope.

Reviewer 23544

Score: 8.0

Comment: This project is more responsible for the creation of models to understand the geothermal opportunities. Moving the old data out of files and into spreadsheets allows for the reuse of significant past work. This project has the most science applied to the data that has been recovered and expended upon.

PI Response:
Agree

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23437

Score: 7.0

Comment: The results and conclusions, so far, from the assessment work appear to be of high quality. The reports and data will be of immense value when they are completed and disseminated. Progress appears to be hindered by factors associated with changes within the agency. It is to be hoped that the project will remain on track to complete by the already extended target date.
In the materials and in the presentation little was provided on the status of the classification work. It seems this is quite important and it would have been good - even if little has changed since the last peer review - to get an overview of the USGS classification system as it stands today, and a brief comparison between how USGS is treating classification vs. how other countries are dealing with it.

PI Response:
We will provide additional information on classification in the future.

Reviewer 23511

Score: 7.0

Comment: Some delays due to management and work revisions to keep on budget. Not all of the SOPO tasks have been addressed as far as I can tell (modeling evolution of systems).

PI Response:
System evolution modeling was completed by a postdoc and simply awaits final write-up and publication.

Reviewer 23526

Score: 5.0

Comment: This comes back to my previous comment--where I feel the approach is not well defined and justified, and so the accomplishments will, by their very nature, suffer. For instance, I don't see how conducting geophysical surveys at Pilgrim Springs, nor moving spring locations in a map, etc. helps with reaching the stated goals of the project. Likewise, for the EGS work, will developing site specific models "....that accurately anticipate reservoir performance..." really help with a generalize assessment methodology? It will likely only benefit one site in particular.

PI Response:
The main reason for doing site-specific studies is that we are only conducting studies that are targeted on systems/locations that can be considered representative in some fundamental aspects of a broader class of geothermal systems, thereby providing us with information that can be extended beyond those specific sites. In addition we are only working at locations where our expenses are leveraged by data from complementary studies.

Reviewer 23544

Score: 8.0

Comment: This project has a data assessment methodology that has been used to reassess the potential value of geothermal systems. This work will provide a wealth of geothermal data for directing our future geothermal development projects.

PI Response:
N/A

PROJECT MANAGEMENT/COORDINATION

Reviewer 23437

Score: 7.0

Comment: Perhaps due to changes within the agency, conduct of this project appears to be somewhat of a low priority. Insufficient attention appears to be given to ensuring the work is well-staffed and that milestones are met. In spite of this much has gotten done and the project may well meet objectives in the revised time frame.

PI Response:
We have been delayed by reassignments within USGS but the project definitely has a very high priority.

Reviewer 23511

Score: 7.0

Comment: Some delays due to management and work revisions to keep on budget. Good use of multiple collaborators.

PI Response:
N/A

Reviewer 23526

Score: 8.0

Comment: The project seems well managed both in terms of budgetary and with the meetings/etc.

PI Response:
N/A

Reviewer 23544

Score: 7.0

Comment: This project has been collecting data and may lack the funding to do the total envisioned project. The project management has produced good results with the funding that has been spent.

PI Response:
N/A

STRENGTHS

Reviewer 23437

Comment: Solid methods, and considerable experience within USGS in conducting assessments of geologic resources.

PI Response:
N/A

Reviewer 23511

Comment: USGS cost-share; provides a blend of analysis and data compilation. Multiple collaborators. Provides guidelines on EGS, which is a key point as EGS will be a key component in reaching GTO's goals in the future.

PI Response:
N/A

Reviewer 23526

Comment: Getting USGS reports into NGDS

PI Response:
N/A

Reviewer 23544

Comment: The geothermal community needs high quality data that can improve the odds for successful projects. This projects has delivered some of that needed data.

PI Response:
N/A

WEAKNESSES

Reviewer 23437

Comment: This project seems to be fairly deep into the priority list and appears to have suffered a bit as a result.

PI Response:
N/A

Reviewer 23511

Comment: It was difficult to tell exactly what the focus of this project was, as it included analysis, data assembly, and data collection.

PI Response:
See responses above on similar comments

Reviewer 23526

Comment: Lack of clear focus.

PI Response:
N/A

Reviewer 23544

Comment: The changes in management as the project was moving forward has limited the amount of data being developed. This may have developed from the budget cuts that were required.

PI Response:
N/A

IMPROVEMENTS

Reviewer 23437

Comment: Renew and strengthen focus on the objectives.

Place this project higher on the priority list.

Ensure that valuable new data and reports from this work are available through NGDS.

PI Response:
N/A

Reviewer 23526

Comment: For EGS estimates, have you considered something that follows along the lines of Doug Hollett's "play" approach? EGS is a recovery technique that can be applied to a number of different reservoirs/scenarios.

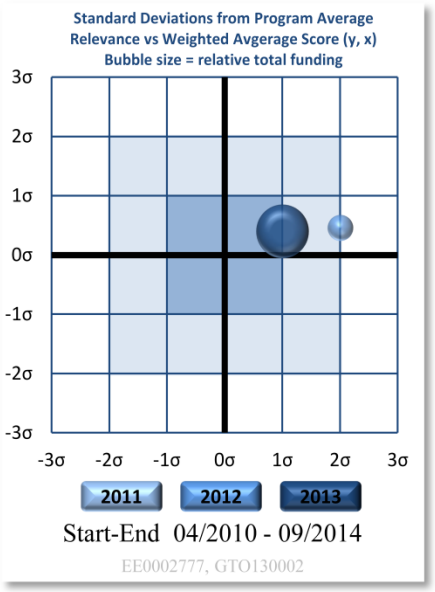
PI Response:
Yes, we are evaluating a very similar scheme.

Reviewer 23544

Comment: The technical approach is strong. Good data that is validated against theory is important. Having a new strong PI should help to put a finish on this effort.

PI Response:
N/A

Enhanced Geothermal Systems Demonstrations Reviewer Comments and Principal Investigator Rebuttals



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002777
Project: Newberry Volcano EGS Demonstration
Principal Investigator: Petty, Susan
Organization: AltaRock Energy, Inc.
Panel: Enhanced Geothermal Systems Demonstrations

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23533

Score: 4.0

Comment: Unacceptable "propritary"components, definitely affecting the benefits of transfer of new technologies.

PI Response:

Reviewer 24895

Score: 9.0

Comment: This project aims to establish an EGS style fracture system, demonstrating that
1. basic data can be gathered
2. used to design an EGS system
3. the design can be implemented
4. the implementation achieves the designed EGS system

PI Response:

Reviewer 23579

Score: 9.0

Comment: This project is arguably the most important of the current crop of EGS demonstrations, not only is it taking place in a very high-temperature greenfield area, but it is an expensive project and has very high visibility due to its support by Google; and it is a model of where EGS development might go for economic power generation. The success or failure of this project will have a significant effect on future investment, especially by the private sector, in EGS in high-temperature greenfield environments.

This project is in an area of considerable interest from a geological standpoint since the Cascades contain a number of active volcanoes and areas of silicic volcanic rock exposures. Broad areas are believed to be underlain by temperatures > 200C at depths reachable by EGS technology (MIT report, 2006). Due to its importance to the future of EGS, it is particularly important that this project be carried out in the best manner possible and brought to a successful conclusion. There is little room for error. In addition to testing the idea of using shear to open pathways for fluid circulation, the project is also researching and testing thermal zonal isolation materials. This TZIM technology, if it can be successfully developed and demonstrated, has the potential for significant contribution to controlling fluid flow in both EGS and hydrothermal reservoir development and operation. Another potentially valuable technology being deployed and tested is the simultaneous measurement of temperature at many depths in the borehole during stimulation to try to determine fluid exit zones.

PI Response:

Reviewer 23625

Score: 9.0

Comment: The capability for multi stage stimulation is critical for EGS. The use of TZIM's is a highly innovative and cost efficient way to achieve multi stage stimulation. Particularly attractive is the possibility to stimulate without the presence of a drilling rig, which has the highest impact on cost reduction.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23533

Score: 3.0

Comment: None of the goals were achieved, besides installing the expanded microseismic array:
The primary goal in this phase was to stimulate three different zones, relying primarily on the thermally degradable zonal isolation materials. In addition the multiple stimulation was conducted following a procedure based on some "proprietary" developed software.
The resulting microseismicity storngly suggest that these goals were not achieved, leading to the conclusions that: (i) the "proprietaray" diverter did not work, as expected; or, (ii) the "proprietary" model is not adequate.

In addition, flowback attempts could not be done due to weather conditions; and no attempts were made to heat the facility.
The principal investigator seemed to be surprised to have detected microseismic activity after shut-in?
Unable to understand shallow depth seismic noise

Strongly recommend that the data from the stimulations be critically reviewed before granting additional funds

PI Response:

Reviewer 24895

Score: 8.0

Comment: The project has a sound technical approach.
1. It collects all the design data,
2. Uses that data to design an EGS reservoir
3. Instruments the well and the surrounding area to collect information during the creation and to monitor and verify there are no adverse impacts of the creation.
4. Implements the design in the field
5. Then utilizes the created reservoir to demonstrate the viability of the EGS process.
   However, the project was not prepared to deal with the out-of-zone seismic activity nor did it have a robust analysis plan that could compare the gap between the planned stimulated reservoir and what actually happened.

PI Response:

Reviewer 23579

Score: 8.0

Comment: The project is well thought out and is being carried out by a competent technical team. Use of consultants and collaboration with several universities (UU/EGI, UOk) and national labs (INL, LBNL, LLNL, NETL) strengthen the project. The tasks are well planned and reflect a careful approach. The project is using a previously drilled well, NWG 55-29, drilled to TD at 3067 m at a BHT of 331 C. Thus, the heat source is proven, and what is needed is to show that a fracture system can be created in rock near the well bottom and a connection can be make to one or more production wells. The stimulation program carried out in late 2012 emphasized shear failure of the rock at depth with self propping to keep the fractures open. By successive use of zonal isolation materials, an attempt was made to separately stimulate three different zones at successively shallower depths in the well.

PI Response:

Reviewer 23625

Score: 8.0

Comment: All relevant scientific and technical expertise has been included in preparation of the stimulation test.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23533

Score: 2.0

Comment: See previous criterion comments

In summary, none of the predictions were achieved.
This reviewer strongly believes that maybe (?) one zone was stimulated and that the subsequent treatments resulted in extending the first treatment

PI Response:

Reviewer 24895

Score: 7.0

Comment: There were probably more permitting and equipment hurdles to overcome than expected, but they were overcome. The project may be a bit behind schedule, but the quality of the accomplishments has been good, as the permitting was accomplished and the stimulation done more or less to plan. The progress towards achieving the technical goals and objectives has also been good. While gaps have been discovered, such as the shallow seismic response, those can add to the understanding of EGS systems, if properly analyzed.
The possibility of the fracturing not meeting the plan should have been included in the analysis plan and data collection. The loss of the DTS makes the conclusions about the diversion suspect, as is it difficult to correlate the deep injection zones with the shallow seismic - It would not be expected that the diverter would travel 1000m through a fracture and then cause diversion, so attributing the seismic cloud movement to the diversion seems tenuous.

PI Response:

Reviewer 23579

Score: 6.0

Comment: It is evident that the project team has pushed forward this year in the face of adverse circumstances (i.e. winter weather). The well was stimulated, using zonal isolation materials to apparently stimulate three different zones from the bottom up. The microseismic array successfully recorded a number of events during stimulation. However, the location in space of these events is puzzling. Most of the events occurred at a depth of ~1,000 m, which is some 1,500 m above the lowest stimulated zone in the well. A few events were recorded near the well bottom, but these were confined to an area in the immediate vicinity of the bottom. The interpretation given by the project scientists is that either (1) soft, porous volcanic rocks make up an aseismic interval between the lower stimulated zone and the upper zone of seismicity, or (2) there may be one or more high-angle dikes conducting the injected water upward. An alternative explanation, felt to be unlikely when a question was asked in the presentation, is leakage of injected fluid upward around the well casing or near-vicinity of the wellbore, where it exited at the higher level, producing the upper seismic cloud. If this were to be the case, it would represent a significant setback in the project.

From the information given, it is hard to see that three different zones were stimulated. Perhaps clearer visuals would have helped. For example, a legend for the colors on the slide "Multizone Stimulation Results".

It is recommended at this point that an effort be undertaken to positively eliminate leakage around the casing before drilling a production well. If there is leakage, it would need to be mitigated and the stimulations repeated to achieve a successful project. As it is, the seismic occurrences do not yield a clear drilling target for a production well -- the upper seismic level is at lower temperature and the lower events are clustered around the injection well itself. The possibility of a casing leak may be contraindicated by the fact that the upper seismic cloud developed in somewhat separate areas for the three stimulations,and in a different area for the post-stimulation period (see cross sections in the Presentation), but this seems somewhat less than convincing. From the present seismic cloud, the claimed stimulated volume of ~1.5 cu km seems to be too large since the "cloud" has a cone shape with a large blank area between upper and lower levels of seismicity.

PI Response:

Reviewer 23625

Score: 6.0

Comment: Not all set goals have been achieved. But it has to be stressed, that this is not due to an inappropriate test but due to outer circumstances, in particularly bad weather. The failure of pumps is also unpleasant circumstances that can and do happen in such non-standard operations. It may be advisable to have spare pumps on site, although this is a relevant cost factor. Unfortunately critical results were not yet available at the presentation. There is only one mention, that no flow has been achieved, which would be very disappointing.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23533

Score: 5.0

Comment: DOE should definitely not accept that their funding be used to develop "proprietary" items as it does not allow reviewers to check their validity as well as their technical approach

PI Response:

Reviewer 24895

Score: 6.0

Comment: Not clear from the written materials how the coordination and delegation was done between the parties outside of primary investigator. Since the project progressed successfully, that speaks well of the management and coordination.

PI Response:

Reviewer 23579

Score: 6.0

Comment: This project has been managed with care. Go/no-go decision points have been incorporated at appropriate places. A significant effort was successfully concluded in a Finding of No Significant Impact for any induced seismicity caused by the project -- an important part of EGS projects and a potential show-stopper. The project team is to be commended for this achievement in such an environmentally sensitive area as this part of Oregon.

Use of consultants and collaborators appears to be appropriate.

One concern is the apparent lack of plans to positively eliminate the possibility that a leak around the borehole caused the somewhat unconventional and unanticipated pattern of seismicity during and after stimulation. Another concern is the criteria to be used at this point to select the well courses of the two proposed production wells.

PI Response:

Reviewer 23625

Score: 8.0

Comment: It is very difficult to evaluate the quality of project management and coordination from one short presentation. The fact that operations have been conducted without incidents and within the budget frame have to be appreciated. Not only in this project, but in general, most delays happen in the permitting process. It can be argued that more resources could have been allocated to the permitting process.

PI Response:

STRENGTHS

Reviewer 23533

Comment: Very disappointed with the analyses of the stimulation results which were totally unexpected. This site was one of the best prospect.

PI Response:

Reviewer 24895

Comment: Accomplished the major milestones: Got the permits, did the stimulation, tried diverters, monitored the departure from the wellbore, monitored micro seismic activity.

Getting permits for Newberry is a significant accomplishment.

Using centrifugal pumps and resolving the technical issues so long term stimulation could be physically accomplished at an economical price is a significant accomplishment.

Having reliable monitoring and location of the seismic events will allow analysis and interpretation of the results. The project measures all the data that has been thought to be critical to the design and successful implementation of reservoir creation. It measures the reservoir creation with flow and tracer testing. It has a reasonable plan to exploit and utilize that reservoir to demonstrate the viability of the EGS concepts.

PI Response:

Reviewer 23579

Comment: 1. This project has a good technical team and has been well carried out.

2. The development and testing of zonal isolation materials is a strength since the successful development of means to control fluid flow in the subsurface would be an important benefit not only to EGS stimulation but also potentially in hydrothermal reservoir development and operation. The whole topic of control of fluid flow in the subsurface by pumped pills of materials yet to be determined needs to be addressed by the DOE/Geothermal program. A variety of zonal isolation materials should be developed, ranging from those that do not degrade with time to those such as the ones being researched by this project, which are short-lived at high temperatures and have specific application to EGS stimulation.

3. The record of publication of project results is a significant strength of this program. Results have been presented at GRC and Stanford meetings since the project was initiated.

4. The microseismic array installed for this project appears to be particularly good, comprising 15 stations, 8 of which are borehole stations. (Note that the color codes on the Presentation slide titled "Mapping EGS with Microseismic Array" are reversed -- the yellow stations are actually the borehole stations). The recorded data should allow focal mechanism determination, a valuable addition to this EGS project in helping to understand the microearthquakes generated by the stimulation.

5. The use of a downhole distributed temperature measuring system to help determine zones of fluid uptake during stimulation is an interesting application and is to be commended.

PI Response:

Reviewer 23625

Comment: One of the key projects for greenfield EGS. Excellent use of an existing well to develop critical stimulation methods.

PI Response:

WEAKNESSES

Reviewer 23533

Comment: No obvious transferable technologies

PI Response:

Reviewer 24895

Comment: The failure of the DTS may make interpretation difficult

The project developed some data that raises questions that are not answered. There are pressure increases resulting from the diverting agents, but unclear whether new fracture systems were formed. The injection went out in the deeper part of the well, but most of the micro seismic activity is shallow. Whether the original stress assessment of the stimulation not model this correctly or if these inconsistencies have other explanations is not yet clear.

It assumes success of the modeling, seismic results and interpretation, moving directly to utilization with additional wells.

The project assumes that the micro seismic data will define the reservoir. While it provides for post analysis of the stimulation volume and location with tracer and temperatures, it does not include a plan to collect data to explain any gaps between the planned reservoir creations with the actual creation. There needs to be more time/money between Phase 2.1 and 2.2. We can learn more from the gaps than we can from what works as planned.

The out-of-zone seismic activity is a real problem for EGS and stimulation in general, because it implies that we cannot control the vertical growth of the stimulation, since the seismic activity is ~1000m higher than the casing shoe.

The possibility of the fracturing not meeting the plan should have been included in the analysis plan and data collection. The loss of the DTS makes the conclusions about the diversion suspect, as is it difficult to correlate the deep injection zones with the shallow seismic - It would not be expected that the diverter would travel 1000m through a fracture and then cause diversion, so attributing the seismic cloud movement to the diversion seems tenuous.

With the seismicity at 1000m instead of 2000+m, the temperature will be lower than expected in the created fracturing interval.

PI Response:

Reviewer 23579

Comment: It is not evident from the information presented that the possibility of a leak around the borehole during stimulation can be eliminated as an explanation of the unusual seismic 'cloud". It seems odd that the deep seismic events induced by the stimulation should lie so close to the well bottom with no development further away unless there is a low-resistance path upward very near the well bottom. The path upward could be due to permeable dikes or permeable volcanic layers, but it seems that a leak around the outside of the casing must be ruled out before the project continues. If leakage was indeed the cause, the stimulated region is almost certainly not optimum for an EGS development. In this case, the leak should be corrected, if possible, and the well stimulated again. This, of course, would add unanticipated costs to the project.

PI Response:

Reviewer 23625

Comment: To little contact with and involvement of commercial service companies of the oil&gas industry. Opening the project to service companies may allow to find alternative and competitive solutions.

PI Response:

IMPROVEMENTS

Reviewer 23533

Comment: Critally review all the field data and attempt to reach some justifiable conclusions. Disclose the proprietary items from a scientific point of view

PI Response:

Reviewer 24895

Comment: The project should include a plan that compares predicted EGS reservoir creation with actual creation and develop analysis of the gaps (modeling incorrect, data incorrect, execution problems, etc) which can then feed back into an improvement in the ability to plan and successfully create an EGS system. This is critical to resolve in this case, as the out-of-zone seismic activity is a real problem for EGS and stimulation in general, because it implies that we cannot control the vertical growth of the stimulation, since the seismic activity is ~1000m higher than the casing shoe. If the industry cannot explain the out-of-zone phenomena or propose an engineering explanation, it will make future permitting difficult.

PI Response:

Reviewer 23579

Comment: 1. Positively eliminate casing leak as an explanation for the seismic "cloud" before drilling a production well.

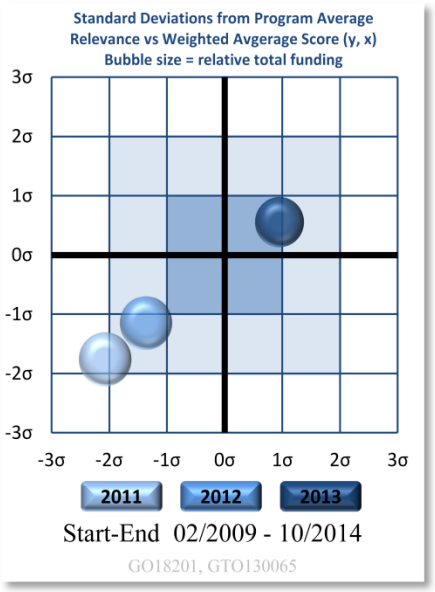
2. If leakage around the casing is eliminated, then plan the production well course carefully.

PI Response:

Reviewer 23625

Comment: Seek cooperation with commercial service companies of the oil&gas industry. Opening the project to service companies may allow to find alternative and competitive solutions.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: GO18201
Project: Demonstration of an Enhanced Geothermal System at the Northwest Geysers Geothermal Field
Principal Investigator: Walters, Mark
Organization: Geysers Power Company, LLC
Panel: Enhanced Geothermal Systems Demonstrations

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23533

Score: 8.0

Comment: Investigators recognized the importance of thermal effects in stimulating the Geysers (i.e. not pressure)
Only EGS project where borehole "suction" occurs
Strong evidence of shear re-activation
Highest temperature conditions
Very good preliminary data analyses

PI Response:
N/A

Reviewer 23568

Score: 10.0

Comment: Demonstrating that thermal stress fracturing produces significant reservoir volume would provide major operational advantages for reservoir management. Distinguishing between shear stimulation and thermal fracturing would be essential to the research.

PI Response:
N/A

Reviewer 23579

Score: 8.0

Comment: Northwest portions of The Geysers geothermal field are known to be underlain by the High-Temperature Reservoir (HTR), which is composed of highly metamorphosed graywacke having very low porosity. Oxygen isotope analysis shows HRT rocks to have never been exposed to connate water. Temperature gradients in the HTR are typically 10 F/100 ft, and temperatures in the lower portions of the wells are ~400 C. The HTR is believed to be due to an underlying very young intrusion whose temperature perturbation is propagating upward. Above the HTR is the so-called

Normal Temperature Reservoir (NTR) which is highly porous due to fracturing and which produces dry steam at ~325 C. This project seeks to determine whether cool water injected into the (HTR) at low pressure will cause thermally induced fracturing sufficient to allow steam to be recovered at nearby wells, i.e., can an EGS be formed with injection of cool water in the HTR. Another objective is to determine whether the high NCG and chlorine content of the HTR and of portions of the NTR above the intrusion, presumably due to off-gassing of the recent intrusion, can be mitigated by injection.

The project is highly relevant and important since success would potentially facilitate recovery of an enormous amount of heat in the HTR and extend the life of The Geysers field appreciably.

PI Response:
The whole-rock oxygen-18 analysis shows that the rocks HTR in the EGS Demonstration area have not been exchanged by meteoric water. However, the produced native steam may be connate water which has exchanged with the rocks and increased its concentration from 0 per mil SMOW (when the graywacke sediments were deposited) to as much as +3 per mil SMOW when the rocks were heated by a Recent granitic intrusion.

Reviewer 23625

Score: 6.0

Comment: Stimulation of deeper low permeability zone below a well known and developed hydrothermal field is a valuable attempt to extend a field. In this respect the project is relevant as a "Field Extension EGS", but not for "Greenfield EGS". Stimulation by thermal fracturing is a well known method in hydrothermal fields for a long time in the Geysers field and is not new.

PI Response:
Stimulation by thermal fracturing in the EGS Demonstration is, in fact, new at The Geysers as discussed in the presentation. The major difference between ALL previous injection at The Geysers and the EGS project is that the injection is directed toward the HTR by a liner to avoid injection into the hydrothermal NTR. Isotopic evidence was presented in the presentation that the HTR (unlike the NTR) is not a hydrothermal reservoir and is hot dry rock (HDR). Typically HDR stimulation is by hydraulic fracturing which the NW Geysers EGS Demonstration purposely avoided by relativley low rate and low pressure injection. Therefore the conceptual model Calpine demonstrated (as at the HDR reservoir in Hiijori, Japan) is that a "cloud" of thermally-induced fractures rather than a single set of hydraulically-induced fractures is possible in a HDR. What does the reviewer mean by Greenfield EGS? Stimulating an HDR below the NW Geysers is much more than a "field extension" of The Geysers because an HDR below the NTR at The Geysers (at Prati 32) was previously unknown.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23533

Score: 8.0

Comment: Investigators considered many different aspects and approaches to reach a consensus in the acquired field data

PI Response:
N/A

Reviewer 23568

Score: 7.0

Comment: The approach is to use a combination of field observations of MEQs and logging with thermal-hydrologic-mechanical modeling. That is fine as far as it goes, but the really diagnostic experiment is to do a controlled experiment in which you stimulate once with reservoir-temperature fluid and in a different, but similar well, with cold fluid. I can understand that this might not be done for cost reasons, but that would be the right experimental design rather than depend on modeling to test the hypothesis.

PI Response:
N/A

Reviewer 23579

Score: 9.0

Comment: The project is being undertaken by Calpine staff with significant participation by LBNL. Calpine is the largest operator in The Geysers field and has a competent and well experienced staff, particularly suited for this project. The technical approach has been to deepen and recomplete two existing wells, Prati 32 and Prati State 31, into an injection-production pair, with P 32 being the injection well, followed by stimulation through The injection/stimulation portion of the project was carried out in 2011 and 2012, and succeeded in producing fracturing of the tight rocks in the HTR and connection of the fracture system with PS 31 and, to a lesser extent, to nearby P 25.

The original planning for this project included the all necessary elements to generate sufficient data for evaluation of results and demonstration that project goals had or had not been met. of and EGS a complete package of (1) succesful access to the HTR through P 32 and PS 31stimulation, microseismic project has been executed substantially according to the original plan. The wells have been repeatedly logged, stimulation has been carried out at a variety of flow rates -- 400 gpm, 700gpm and 1000 gpm.

PI Response:
N/A

Reviewer 23625

Score: 7.0

Comment: Appropriate approach to extend a producing field into adjacent low permeability zones.

PI Response:
N/A

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23533

Score: 9.0

Comment: Excellent work, very good critical assesment of field data. Might encounter a slight delay due to corrosion, requiring some repairs at producing well. Developed a multiphase reservoir production model.

PI Response:
N/A

Reviewer 23568

Score: 8.0

Comment: An excellent stimulation experiment was performed. A field demo of this scope is producing the most valuable results from which understanding of geothermal reservoir mechanics can be obtained. The oxygen isotope characterization of how much of produced fluid was injected fluid is very high quality. The result that seismicity migrated downward with time is another quality result with important implications for reservoir management.

PI Response:
N/A

Reviewer 23579

Score: 9.0

Comment: 1. The project goal of showing 5 MW of EGS power production was essentially accomplished with tests indicating an increase in steam production from Prati 31 (3.75 MW) and Prati 25 (1.75 MW) as a direct result of injection of cool water into Prati 32. (The increased steam is not actually used in a power plant, but it could be).
2. Isotopic analyses show that the increased production potential in the two wells comes from the water injected into Prati 32. This is also demonstrated by the increase in static well-head pressure in the production wells during injection with the corresponding decrease in static well-head pressure during periods of no injection. These data demonstrate that a connected fracture system has been created in hot, tight rocks between injection and production wells.
3. Data indicate that NCG content of the injection derived steam is markedly lowered, an important result for future geothermal development in the area. However, chlorine content was not lowered, indicating that other measures will be needed to either lower chlorine content of the steam or deal with the corrosion issues it causes.
3. A high quality MEQ system was installed and operated successfully. Microseismic activity shows a clear correlation with injection, as is true of both production and injection in other parts of The Geysers field. As injection continued, the average and maximum depths of induced seismicity slowly migrated downward, with events occurring as deep as 17,000 ft (the injection interval was 7800 ft to 11,143 ft). Seismic events occurring at depths greater than the injection depth have also been documented at other fields. The maximum event was M = 2.84, and was no cause for concern to the operation or to nearby communities.
4. A program of public outreach was successfully conducted during this project and a Calpine visitors center was opened. Significanlty, community support for this project was forthcoming.

PI Response:
N/A

Reviewer 23625

Score: 9.0

Comment: The microseismic monitoring array has been improved. The well head pressure in the adjacent producer has significantly increased. This is a real accomplishment, showing that the method, although not new, is appropriate in this setting.

PI Response:
N/A

PROJECT MANAGEMENT/COORDINATION

Reviewer 23533

Score: 8.0

Comment: Very efficient, seem to know what they are doing.

PI Response:
N/A

Reviewer 23568

Score: 10.0

Comment: The integration of the LBNL seismicity and flow modeling results with the Calpine field operation was nicely done.

PI Response:
N/A

Reviewer 23579

Score: 9.0

Comment: This project has been well managed from the outset. The project staff from Calpine and from LBNL are all experienced in Geysers work, devised a well thought out project plan and implemented it well. A problem with corrosion near the top of PS 31 has temporarily halted the project until it can be repaired later in 2013. After that, production of steam from the well will allow determination of the actual increase in steam generation as a result of injection into P 32.

Coordination between Calpine and LBNL has apparently been smooth -- the team appears to have reached a comfortable working relationship to everyone's benefit.

PI Response:
N/A

Reviewer 23625

Score: 8.0

Comment: The project has been conducted to regular industry standards by a professional team familiar to work in this field of expertise.

PI Response:
N/A

STRENGTHS

Reviewer 23533

Comment: Considered many aspects to fully understand reservoir behaviour.

PI Response:
N/A

Reviewer 23568

Comment: The field demo data are the most valuable.

PI Response:
N/A

Reviewer 23579

Comment: 1. The research results from this project are directly applicable to development of the HTR in The Geysers field. The data developed by this research and the success of the project to date should facilitate such development and perhaps eventually allow the very large heat resource of the HTR to be economically used, extending the life of the field significantly. The injection method tested here, low flow with thermal stimulation of the reservoir rock, has been a success, and may be applied at other fields.

2. The original planning has proven to have been well done. The project has been carried out substantially as planned, and where problems arose, the project team has had the resources needed to solve them.

3. The project team, comprising scientists and engineers from Calpine and LBNL, is highly competent and is backed up, should problems arise, by the considerable resources and experience of Calpine at The Geysers. The long-standing good relations and data sharing between Calpine and LBNL has allowed LBNL to continue and expand work at The Geysers, particularly in research into induced seismicity and coupled reservoir modeling and 3D visualization. The involvement of a national laboratory guarantees that results will be published and placed in the Geothermal Data Repository for the benefit of the entire geothermal community.

4. Public outreach has been a significant and important part of this project. The displays at the Visitors Center in Middletown and the information on the web site Geysers.com have been upgraded. The outreach has succeeded in winning community approval of the project.

PI Response:
N/A

Reviewer 23625

Comment: A technical success, with a large upside potential in the Geysers fields.

PI Response:
N/A

WEAKNESSES

Reviewer 23533

Comment: None

PI Response:
N/A

Reviewer 23568

Comment: I am not sure there was a definitive observation of thermal stimulation.

PI Response:
N/A

Reviewer 23579

Comment: No specific weaknesses were identified.

PI Response:
N/A

Reviewer 23625

Comment: Successful project, but no commercial use by the lack of a PPA. (Not the fault of the PI).

PI Response:
N/A

IMPROVEMENTS

Reviewer 23533

Comment: None

PI Response:
N/A

Reviewer 23568

Comment: Reviewer did not provide comments for this criterion.

PI Response:
N/A

Reviewer 23579

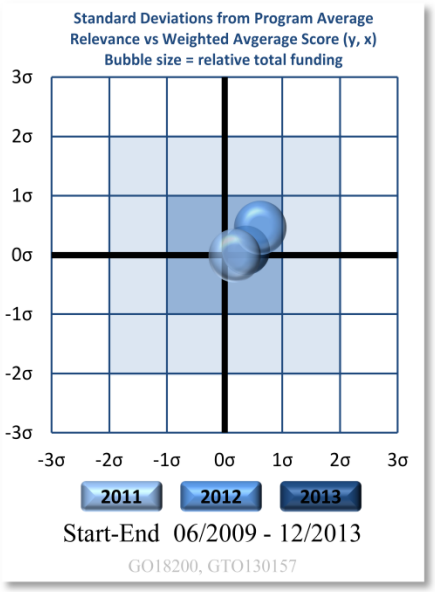
Comment: No specific suggestions for improvement are identified.

PI Response:
N/A

Reviewer 23625

Comment: Correct approach for the task. Implementation of a microseismic monitoring with an extended early warning traffic light system, may further improve community relations.

PI Response:
N/A



Review: 2013 Geothermal Technologies Office Peer Review
ID: GO18200
Project: Feasibility of EGS Development at Brady's Hot Springs
Principal Investigator: Drakos, Peter
Organization: Ormat Nevada, Inc.
Panel: Enhanced Geothermal Systems Demonstrations

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23533

Score: 7.0

Comment: The advantage of this project is that it relies on lessons learned from the Desert Peak project. One of the goals of pre-conditioning the well is to achieve self propping by shear stimulation displacements...just speculation at this time; in addition how will this be proven? Decision tree developed from Desert Peak is used to direct procedures for Brady.

PI Response:

Reviewer 24895

Score: 6.0

Comment: This project is more aimed and conventional geothermal systems than EGS. However, this project has some benefit to the EGS program. It aims to establish an EGS style fracture system that connects an existing well to the natural fracture system that supports the current commercial development at Brady, demonstrating that
1. basic data can be gathered
2. used to design a stimulation plan to connect back into a natural fracture system
3. the plan can be implemented
4. successful implementation demonstrates the ability to predict and control directionality or volume to intersect an existing fracture system
5. if successful, this would demonstrate the subsequent wells do not have to intersect an established hydrothermal system, but can be targeted so the stimulation of subsequent wells will intersect the original hydrothermal reservoir. Whether this can be extended to EGS reservoirs will depend on the modeling done prior to stimulation concerning fracture volume and comparisons made of the actual to theoretical after the stimulation
6. this creates a larger potential reservoir

PI Response:

Reviewer 23579

Score: 8.0

Comment: Success with this project would help show the feasibility of using tight in-field wells in hydrothermal convection systems by connecting them to the producing parts of the field. Many (most?) operating hydrothermal fields today have one or more wells that have low or no productivity, and can not be used either for production nor injection even though they may be within the thermal anomaly. This project seeks to perform stimulation of an interval in well 15-12 ST1 in a staged program beginning with low-pressure, low flow-rate pumping to activate shear failure and self propping of fractures. Stimulation pressure and flow rate would be increased in a series of steps, culminating in hydraulic fracturing, similar to the plan carried out at Desert Peak by the same team. The merits, methods and geological environments appropriate for shear stimulation vs hydraulic fracturing are being debated in the geothermal community, with no consensus having yet been reached. Thus, the relevance of the current project. Data and experience generated by this project will benefit EGS projects as well as hydrothermal projects

PI Response:

Reviewer 23625

Score: 8.0

Comment: For the broad GTO goals, it would be a relevant objective to achieve an improved hydraulic connection to the producing field. Just to improve productivity/injectivity of well 15-12 ST-1 is relevant for economics but not relevant to EGS. The well is located in such a position, that either a connectivity may be achieved to the producing field or to well 88-11 to the south- west. That would be a real achievement for EGS.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23533

Score: 8.0

Comment: Guided by lessons learned from Desert Peak. Investigators have (?) evaluated a number of Geomechanical Numerical models, claiming that 'some of them' provide realistic hydraulically induced fracture geometries...but nothing was disclosed. What is the critical injection rate for reaching fractures beyond shear movement? Effects (i.e. advantages?) to use 180 degrees injection fluids was not discussed in details.

PI Response:

Reviewer 24895

Score: 7.0

Comment: The project has a sound technical approach.
1. It collects all the design data,
2. It builds on the success at Desert Peak. If Brady can demonstrate a repeat of the success at Desert Peak, it will help verify the repeatability of the method
3. Uses the design data and the Desert Peak data to design a stimulation treatment
4. Instruments the well and the surrounding area to collect information during the creation and to monitor and verify there are no adverse impacts from the stimulation and to monitor the extent of the stimulation.
5. Implements the design in the field
6. Has tentative plans to make on the fly decisions using the model as the stimulation is in progress

The plan is to demonstrate that a non-productive well can be connected to an existing natural fracture system. Doing some reservoir creation modeling and post stimulation comparison would make the data more useful to a wider range of projects.

PI Response:

Reviewer 23579

Score: 8.0

Comment: The technical approach is similar to that used at Desert Peak, with lessons learned at DP being incorporated in the plans for this project. The area has undergone thorough geological and geomechanical studies to form a good geologic model of the field and to determine the mechanical properties and state of stress of the rocks at depth. This information is important for good planning of the stimulation program. A 13-station microseismic array with real-time data analysis has been installed and is operating well. A minifrac test indicated that the chosen well has very low injectivity, 0.047 gpm/psi and is appropriate for stimulation. Log analysis indicates a series of fractures through the stimulation interval.

The stimulation program reflects lessons learned from Desert Peak. Specifically, the initial shear stimulation is cut to 10 days since the corresponding portion of the work at DP shows that most of the gain in injectivity was achieved early on. This will be followed by 10 days of mixed-mode hydro and shear stimulation, and then 4 days of high pressure hydrofracturing. Tracers will be injected at appropriate steps in each phase of the stimulation. At the end of this work there will be a stage-gate go/no-go decision.

PI Response:

Reviewer 23625

Score: 8.0

Comment: Commendable approach. Interesting well location. It is understandable that experience from well stimulations at Desert Peak will have to flow into the procedures at Brady's.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23533

Score: 8.0

Comment: Encouraging

PI Response:

Reviewer 24895

Score: 8.0

Comment: There were probably more permitting and hurdles to overcome than expected, but they were overcome. The project may be a bit behind schedule, but the quality of the accomplishments has been good, as the permitting was accomplished and the stimulation plan completed. Setting a precedent for the permitting process is an important accomplishment.

PI Response:

Reviewer 23579

Score: 7.0

Comment: Progress on the technical aspects of this project have been limited through no fault of the project team. After some consideration, the BLM decided to do a full downhole EA for the project. Considerable effort was required by the team with backup from DOE, but the result was a success with the finding of no significant impact. This is an important accomplishment since it is the first EGS project in Nevada to be permitted, and there is, naturally, a learning curve for most BLM employees in geothermal resources, and particularly in EGS development. One hopes this EA and FONSI will be a model for future EGS development in Nevada and elsewhere.

PI Response:

Reviewer 23625

Score: 5.0

Comment: 1. The quality of the accomplishments to date is very good.

2. None of the key operations (Phase 2): shear stimulation, mixed-hydro shear stimulation, nor high-rate puls stimulation have been carried out so far.

According to the presented schedule this should be in Q2/Q3 this year. Delays in the program may be attributed to an inefficient BLM permitting process.
For this reason I would prefer to abstain from assigning a score. (However the template does not accept this, therefore a 5)
It is not clear, when these operations are going to be carried out.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23533

Score: 9.0

Comment: Excellent progress compared to Desert Peak.

PI Response:

Reviewer 24895

Score: 9.0

Comment: Since the project progressed successfully, that speaks well of the management and coordination. Using decision tree process and data developed at Desert Peak for decision making speaks well of the project management, Successfully implementing a decision tree process that incorporates all the various participants outside Ormat is important to the success, but the other participants should be asked to confirm that they were able to effectively participate in that process.

PI Response:

Reviewer 23579

Score: 8.0

Comment: The decision-tree project management system in place is the same as was used for Desert Peak, where it proved to be useful. There are appropriate go/no-go decision points in place. Coordination of the efforts of a large group of participants is always a problem, and there are plans for quarterly project meetings as well as daily communications as necessary. Whether or not the funding will prove to be adequate is a question. Planning seems to be complete for the up-coming stimulation.

PI Response:

Reviewer 23625

Score: 9.0

Comment: The project has been conducted to industry standards by a professional team which is familiar to carry out such operations.

PI Response:

STRENGTHS

Reviewer 23533

Comment: Based on experience acquired from Desert Peak project.

PI Response:

Reviewer 24895

Comment: The project measures all the data that has been thought to be critical to the design and successful implementation of connecting the well to the existing reservoir. It is building on the knowledge from Desert Peak and, to the extent it can replicate the results; it will help confirm what happens when this method is used. The initial stimulation testing at Desert Peak fell short of the goal, so it is an opportunity to build and expand on that experience.

PI Response:

Reviewer 23579

Comment: 1. The R&D being done both here and at Desert Peak is important for spurring work in other known geothermal fields to extend field productivity and longevity through application of EGS techniques to marginal wells within the thermal anomaly.

2. The project team, with the experience at Desert Peak, is a strength for this project.

PI Response:

Reviewer 23625

Comment: Project builds up on experience from similar projects (Desert peak). Results will have an impact on the economic development of the field.

PI Response:

WEAKNESSES

Reviewer 23533

Comment: Some recent developments (see above) need to be disclosed in more details for the reviewers to be fair.

PI Response:

Reviewer 24895

Comment: Long open hole interval may limit the options for stimulation. While it project plan provides for post analysis of the stimulation volume and location with tracer and temperatures, it does not include a plan to establish the expected results prior to doing the stimulation and then explain any gaps between the planned reservoir creations with the actual creation. There needs to be more time/money spent on gap analysis. We can learn as much from the gaps as we can from what works as planned, if we can extend the knowledge into other resource areas that do not have existing hydrothermal systems to connect into.

PI Response:

Reviewer 23579

Comment: No specific weaknesses are identified.

PI Response:

Reviewer 23625

Comment: So far obviously the permitting process. I cannot assess why such a process should take a year.

PI Response:

IMPROVEMENTS

Reviewer 23533

Comment: Need to tighten up some details (see above).

PI Response:

Reviewer 24895

Comment: The project should include a plan for pre and post stimulation analysis that measures actual reservoir creation. It should then compares predicted EGS reservoir creation with actual creation and develop analysis of the gaps (modeling incorrect, data incorrect, execution problems, etc) which can then feed back into an improvement in the ability to plan and successfully create an EGS system. Assuming the fracturing stay within zone, being able to explain why would be an added advantage.

PI Response:

Reviewer 23579

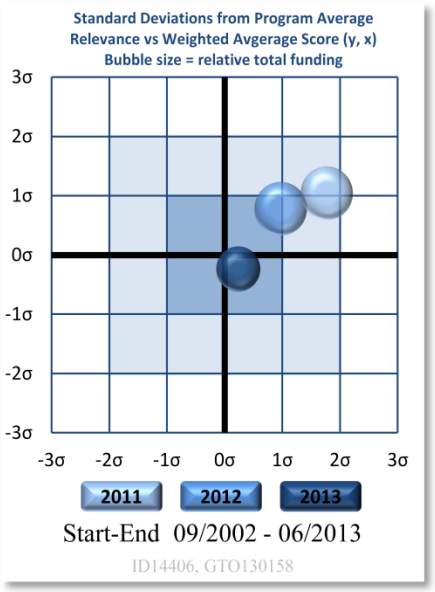
Comment: No specific improvements are identified. The main point should be to get on with the project as soon as the go/no-go decision is made.

PI Response:

Reviewer 23625

Comment: Not being familiar with permitting issues in the U.S., it may be advisable to allocate more resources to this process. From our experience we advise a proactive cooperation with the regulators.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: ID14406
Project: Desert Peak East EGS Project
Principal Investigator: Drakos, Peter
Organization: Ormat Nevada, Inc.
Panel: Enhanced Geothermal Systems Demonstrations

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23533

Score: 7.0

Comment: The goals for this project (similar to Brady's) was to improve injectivity as well as hydraulic connection with an existing naturally fractured reservoir; resulting in enhancing power generation. The advantage of this project was that an operating power generation plant was available on-site. The project consisted in anumber of phases, ranging from shear stimulation to chemical (i.e. mud acid), controlled hydro-fract, pulse stimulation, and finally traditional hydraulic fracturing. The final result was an injectivity increase from 0.8 gpm/psi to 2.1 gpm/psi; hence, some of the goals were achieved. However, seismic magnitude went from 0.8 to 1.6 on the Richter scale

PI Response:

Reviewer 24895

Score: 6.0

Comment: This project is more aimed and conventional geothermal systems than EGS. However, this project has some benefit to the EGS program. It will demonstrate that
1. basic data can be gathered
2. used to design a stimulation plan to connect back into a natural fracture system
3. the plan can be implemented
4. successful implementation demonstrates the ability to predict the results of a stimulation system

PI Response:

Reviewer 23579

Score: 8.0

Comment: Success with this project helps show the feasibility of using tight in-field wells in hydrothermal convection systems by connecting them to the producing parts of the field either for production or for injection. Many (most?) operating hydrothermal fields today have one or more wells that have low or no productivity, and can not be used either

for production nor injection even though they may be within the thermal anomaly. This project has performed stimulation of a selected interval in well 27-15 in a staged program beginning with low-pressure, low flow-rate pumping to activate shear failure and self propping of fractures and ending with high-pressure hydrofracturing. The merits, methods and geological environments appropriate for shear stimulation vs hydraulic fracturing are being debated in the geothermal community, with no consensus having yet been reached. Thus, the relevance of the current project. Data and experience generated by this project will benefit EGS projects as well as hydrothermal projects.

PI Response:

Reviewer 23625

Score: 6.0

Comment: Commendable approach in a stepwise improvement of the injectivity of a injector into a poorly permeable formation. Relevant to the geothermal industry how to stimulate a well. However of limited relevance for EGS development.

The well location lies outside the path of operating injection and production wells. The goal to improve hydraulic connection to the producing field cannot be achieved from this location.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23533

Score: 7.0

Comment: Incremental progress in injectivity. The question to be raised is: "were the different stages necessary to achieve the final goal?"...or "would the final stage (i.e. standard hydrao-frac) be sufficient, or even result in a better result?", i.e. no waste of resources or pumping energy? PETREL does not predict location of microseismic activity associated with the stimulation; hence, what is its use? Re-completion will access two additional zones....goal(s) unclear.

PI Response:

Reviewer 24895

Score: 6.0

Comment: The project had a sound technical approach during the first phase.
1. It collects all the design data,
2. Uses that data to design a sequence of stimulation treatments

3. Instruments the well and the surrounding area to collect information during the creation and to monitor and verify there are no adverse impacts from the stimulation.
4. Implements the design in the field

During the first set of stimulations, the project demonstrated that a non-productive well can be connected to an existing natural fracture system, showed what worked and what did not work and achieved 80% of its injection goal.

The second phase of cleaning out the well to total depth should have included a re-evaluation of the injectivity after the clean out. There was an increase from 0.8 gpm/psi after completing the upper zone stimulations to 2.1 gpm/psi after completing the stimulation of the combined well, but no information on how much was there after the clean out and before the second stimulation and no data on where the second stimulation went (how much went into the upper zones and how much into the lower zones), making conclusions about what happened and what was successful in the deepening and stimulation.

PI Response:

Reviewer 23579

Score: 7.0

Comment: The technical approach for this project has been well thought out, based on geological, rock mechanics, well log and other studies. Noteworthy is the attention paid to generating a good geologic model of the field in order to help plan the stimulation program. The initial attempt at stimulation, carried on in 2010-11, fell a little short of project goals of increasing injectivity to 0.8 gpm/psi of injection pressure. Problems developed when the chemical stimulation caused well-bore instability, and much of 2011-12 was spent is stabilizing the well bore and removing a cement plug and mud to gain access to TD at 5809 ft. The latest, highly successful stimulation used this longer interval, and one wonders if the entire interval from 3000 to TD should not have been included in the stimulation plan from the outset.

PI Response:

Reviewer 23625

Score: 9.0

Comment: Excellent approach to increase injectivity of a well in well considered steps. Commendable technical approach.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23533

Score: 7.0

Comment: The use and selection of numerical models remains unclear to this reviewer.

PI Response:

Reviewer 24895

Score: 8.0

Comment: On the plus side, good progress was made on meeting the planned objectives and technical targets. The well achieved 80% of its target with the shallower completion and 2 time the target with the deeper completion. On the negative side, there was a false start on the first well that ate up some of the funds. The quality may have been affected by the technical approach, but met the intent of the program plan, which was to connect the well to the existing fracture system and resolve the injection limitation at the power station.

PI Response:

Reviewer 23579

Score: 7.0

Comment: An initial shear stimulation increased the injectivity by a factor of 10; chemical stimulation failed to increase injectivity and, indeed, caused well-bore damage; medium flow rate hydroshear resulted in a 4-fold increase in injectivity; high flow-rate stimulation and pulse stimulation added marginally to the injectivity, which stood at an uneconomic 0.8 gpm/psi at the beginning of 2012. Much of 2012 was spent in work-over and recompletion of well 27-15. Previous stimulation had been done only on the interval 3035 to 3500 ft, with the lower portion of the well filled with high-viscosity mud capped by cement. The cement plug was drilled out and the mud removed to give access to TD at 5809 ft for the high flow-rate stimulation in early 2013. This high-flow rate, high pressure stimulation finally pushed the injectivity to 2.1 gpm/psi, a value twice the target injectivity. The conclusions from this work are that initial shear stimulation was an effective first step in the program, intermediate stimulation was also effective, and the final high-rate stimulation pushed the injectivity further upward. The role played by the much longer stimulation interval in the borehole for the final stimulation will presumably be discussed in pending reports. These results are being used to help plan the stimulation program at Brady's Hot Spring, a companion project. The stimulation was shown to increase the output of the power plant by 1.7 MW, so this project was successful in meeting its goals for increased power production.

The microseismic monitoring system functioned well, recording some 300 events with a maximum magnitude of 1.7, a non-threatening figure. Analysis showed consistency with the known stress field, so there were no surprises. Tracer tests were successful and showed a strong connection of well 27-15 with the production field.

An important take-away lesson from the chemical stimulation is that the injected chemicals should have been pushed further into the formation by follow-up water injection and should have been done at a later time when more permeability had been developed. Another conclusion is that the majority of injectivity gain in the initial shear stimulation phase of the project was attained early on, and a much shorter period of shear stimulation would have been adequate.

PI Response:

Reviewer 23625

Score: 7.0

Comment: The project goals were only partly achieved:
Increase permeability of well 27-15 to commercial levels was achieved.
Improve the hydraulic connection to the producing field. Could not be demonstrated.
Demonstrate enhance power generation: Goal achieved not by improving the reservoir porosity. Only through increase of injection capability. The power production was so injection limited, now it is production limited. This is economically a significant progress.
The contribution to the creation of man made reservoirs is however not significant.
Deploy cost-effective techniques for other EGS projects. This goal was achieved.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23533

Score: 9.0

Comment: Very good, improved with addition of Geothermex.

PI Response:

Reviewer 24895

Score: 7.0

Comment: While it was not clear from the written materials how the coordination and delegation was done between the parties outside of primary investigator, the presentation indicated this was an evolving process that culminated in using decision-tree decision making that all participants could participate in. How satisfactorily this worked should be independently checked with the participants for confirmation though. Since the project progressed successfully, that speaks well of the management and coordination.

PI Response:

Reviewer 23579

Score: 8.0

Comment: The project team was managed by Ormat and Geotherm-ex, but included consultants and collaborators from a number of other institutions, including LBNL, TerraTec, the USGS, the University of Utah, Temple University, and people from British and German companies, among others. Interfacing of each organization's personnel and responsibilities was a complex task that required special planning. A decision-tree analysis was used to help keep everyone informed and to decide on the next steps at each stage of the project. This management tool was deemed to be successful and to be critical to making good decisions. It is also being implemented on the Brady's project.

The project began in 2002, and has been underway for a long time. The well originally picked for stimulation was deemed, after thorough study, to be unsuitable. This required further studies and ultimate selection of the present well. The ultimate success is the reward for persistence!

PI Response:

Reviewer 23625

Score: 9.0

Comment: The project has been conducted to industry standards by a professional team which is familiar to carry out such operations.

PI Response:

STRENGTHS

Reviewer 23533

Comment: Good attempts in trying to understand field data.

PI Response:

Reviewer 24895

Comment: Accomplished the primary goal of increasing the well’s injectivity within the budget and project plan, although, since the budget was exhausted and there was still work to be completed, it is not clear if this will remain a strength

PI Response:

Reviewer 23579

Comment: 1. The thorough preparation for this work is a strength, including development of a good geological model of the field, thorough core analyses to determine mineralogy (especially of alteration minerals) and mechanical properties, installation of a MEQ system, use of a wide variety of consultants and collaborators, and development of a decision-tree management system.

2. A highly competent team performed the work.

3. Project results have been reasonably well reported at GRC and Stanford meetings (with the caveat that it is not known what data and information Ormat considers to be proprietary and will not be published.)

PI Response:

Reviewer 23625

Comment: Systematic and cost-effective procedure to achieve economic levels of injectivity.

PI Response:

WEAKNESSES

Reviewer 23533

Comment: Elaborate on modelling used and critiques.

PI Response:

Reviewer 24895

Comment: Not clear what the effect of removing the cement plug versus the stimulation did after the cement plug was removed, or where the stimulation went (into the upper stimulated zone or into the bottom of the well or ?). It appears that the baseline was not reestablished after removing the cement plug.

Not clear how the effects of the different methods will be separated from one another – did the sequence control the results? How will the various techniques be separately evaluated to help future EGS projects optimize the techniques used.

PI Response:

Reviewer 23579

Comment: 1. The project is reportedly 90% complete while the entire allocated budget has been spent. Apparently more DOE money will be needed to complete the data analysis and reporting for the project.

2. Selection of the 3000 to 3500 ft interval for stimulation was done at the outset based geological, rock mechanics and other studies and the well was presumably plugged back to the 3500 ft level. A large part of the project effort in 2012 was spent in opening the rest of the well to TD at 5809 for the final, high-pressure, high flow-rate stimulation in early 2013. One wonders whether stimulation of the full length of available hole at the outset would not have changed the results and allowed earlier achievement of the project goals. Would shear stimulation have worked in the lower interval?

PI Response:

Reviewer 23625

Comment: Does not show EGS relevant reservoir connectivity improvement. The well location lies outside the path of operating injection and production wells.

PI Response:

IMPROVEMENTS

Reviewer 23533

Comment: See above

PI Response:

Reviewer 24895

Comment: Depends on the success that the project has in being able to analyze the results and feed back into the design criteria. It is clear that the best parts of the methodology will be extended into the stimulation at Brady, but the robustness of the evaluation results will have an influence on how well it can be applied generally. With the budget exhausted, it is not clear if the additional work necessary to get a clearer picture will be done – is there evidence that the fracture stayed in-zone during both treatments and some reasons why. How much new volume should have been created and how much was created? With the focus on improving the injection capacity at Desert Peak, there may have been a lost opportunity to make the data more broadly useful.

PI Response:

Reviewer 23579

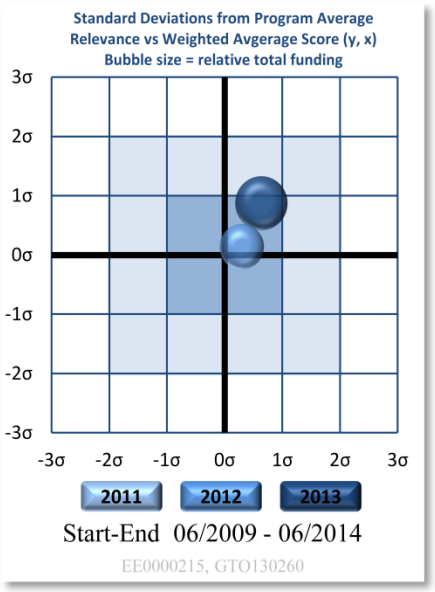
Comment: No specific improvements to this nearly complete project are identified.

PI Response:

Reviewer 23625

Comment: Select a location between operating injection and production wells, if the improvement of hydraulic connection to the producing field is a goal.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0000215
Project: Concept Testing and Development at the Raft River Geothermal Field, Idaho
Principal Investigator: Moore, Joseph
Organization: University of Utah
Panel: Enhanced Geothermal Systems Demonstrations

RELEVANCE/IMPACT OF RESEARCH

Reviewer 24895

Score: 7.0

Comment: This project is more aimed and conventional geothermal systems than EGS. However, this project has some benefit to the EGS program. It aims to establish an EGS style fracture system that connects an existing well to the natural fracture system that supports the current commercial development at Raft River, demonstrating that
1. basic data can be gathered
2. used to design a stimulation plan to connect back into a natural fracture system
3. the plan can be implemented
4. successful implementation demonstrates the ability to predict and control directionality or volume to intersect an existing fracture system
5. if successful, this would demonstrate the subsequent wells do not have to intersect an established hydrothermal system, but can be targeted so the stimulation of subsequent wells will intersect the original hydrothermal reservoir
6. this creates a larger potential reservoir

In addition, this project plans to separately test and evaluate stimulation methods, which should help identify which of these methods will provide the most advantageous outcome in future projects.

PI Response:

Reviewer 23568

Score: 10.0

Comment: The goal is to develop techniques to improve injectivity at the old Raft River geothermal field. This project is run by a really experienced PI who knows all the knobs and how to turn them to stimulate an EGS reservoir.

PI Response:

Reviewer 23583

Score: 10.0

Comment: GTO's EGS program goals will significantly advance when project objectives are achieved, because an engineered reservoir will have been created using thermal and hydraulic stimulation techniques in an existing, non-productive well. Moreover, since there are many more potential hydrothermal systems with the same moderate temperature (about 150°C), significant impact is anticipated in lowering market barriers to EGS as more operators and developers discover the economic benefits. In addition, because the project's goal is to increase injectivity in this low-permeability completion by either increasing flow in existing producing wells and/or, at a minimum, providing more injection capacity, knowledge gaps such as thermal breakthrough risk will be reduced in the current injection scheme potentially resulting in more power delivered to the grid. Finally, all important permitting and bureaucratic barriers have been addressed and the project is poised to perform the stimulation.

PI Response:

Reviewer 23625

Score: 7.0

Comment: The preconditioning of the well with a thermal frac is an appropriate method, but not new.
The relevant contribution of this project may be the validation of the thermal stimulation models with the results of the thermal frac.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 24895

Score: 7.0

Comment: The project has a sound technical approach.
1. It collects all the design data
2. Uses that data to design a staged set of stimulation treatments
3. Instruments the well and the surrounding area to collect information during the creation and to monitor and verify there are no adverse impacts from the stimulation.
4. Implements the design in the field
5. Monitors performance between the different stimulation treatments

The project then plans to demonstrate that a non-productive well can be connected to an existing natural fracture system. One potential negative was the out-of-zone injection that occurred over a substantial vertical interval. While the cause was identified as a leaking port collar, the small vertical extent of a port collar and the large vertical extent of the cooling anomaly leave some risk that the cement job is not intact or that the barrier between the target zone and upper intervals is not competent. This leaves some risk that the stimulation could go out of zone.

PI Response:

Reviewer 23568

Score: 10.0

Comment: The approach is to understand and integrate the geologic setting and the reservoir properties into a stimulation plan. The approach is very comprehensive, i.e., petrology, geochemistry, rock mechanics and geophysics for the geology, and hydraulic testing and seismic monitoring for the reservoir.

PI Response:

Reviewer 23583

Score: 9.0

Comment: Vast majority of analyses performed in Phase I were conducted by high-quality, external research teams and successfully managed and coordinated by the PI. The overall quality of these technical approaches was excellent providing evidence that the scientific method was successfully and efficiently implemented throughout the project's many characterization tasks. The techniques employed were current, high quality, O&G industry techniques or new and innovative geothermal-based technology. Specifically, water chemistry interpretation as displayed on the NW-SE cross-section was particularly effective in delineating the general subsurface fluid flow patterns that were critical to the interpretation of the potential impact of the stimulation on other production/injection wells. However, some difficulties were encountered. In particular, the interpretation of the MT data suffered due in part to the scatter in, and seemingly semi-random distribution of, resistivity anomalies. The resistivity maps were presented did not display sufficient and coherent information to allow for improvement in the understanding of the reservoir structure nor were they effectively interpreted. The assembled research team is top-notch with experienced geothermal experts, contractors and operators as well as collaborators from several other universities and national laboratories.

PI Response:

Reviewer 23625

Score: 8.0

Comment: Accurate scientific evaluation and analysis of available data. Full scale investigation of petrology, geochemistry. Comprehensive use of geophysical and petrophysical data sets.
The application of a thermal frac for preconditioning of the well is regarded as the appropriate approach.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 24895

Score: 8.0

Comment: The permits have been acquired and the stimulation is ready to progress. It appears that permitting delays are a common cause of project delays in the EGS demonstration program. There were some unexpected problems with the well and there are some risks associated with it.

PI Response:

Reviewer 23568

Score: 8.0

Comment: All the tasks for geologic and reservoir characterization were achieved. Also, a significant amount of modeling was accomplished to evaluate thermal stimulation.

PI Response:

Reviewer 23583

Score: 8.0

Comment: From the beginning, funding, permitting, and logistical delays as well as technical difficulties with borehole drilling and casing have hampered the project and slowed down technical progress, e.g., actual start date was delayed 10 months. However, after recent Phase I approval, it is estimated that original completion date can be met and the project is back on track. Throughout the course of Phase I, several scientific studies have been conducted with very interesting yet complex and difficult to interpret results. In fact, how these results inform the stimulation plan and shed light on the long-standing reservoir flow path and source uncertainty has been slow to materialize. In addition, there has been a paucity of results integration, particularly with respect to understanding the subsurface reservoir flow structure. A very positive exception to note is the interpretation of the geochemical and geologic analyses presented as a cross-section. A careful scientific integration of all these studies to produce a better model of the reservoir is key to interpreting stimulation results and in managing the stimulation. That being said, the injectivity testing as well as the borehole televiewer results were successfully implemented and effectively interpreted, becoming, in the end, major drivers to the current stimulation plan. An important question is what were the individual contributions from each of the studies to both the overall uncertainty reduction in the subsurface reservoir flow/source model and the stimulation plan? Is it possible that certain studies did not contribute to informing the plan and reservoir model? The answer would be very beneficial to the program and future EGS endeavors.

PI Response:

Reviewer 23625

Score: 5.0

Comment: The main target to improve the well injectivity has not yet been achieved. According to the presentation the project appears to be on track (in time and intermediate targets).
However 78% of the funds are used up and it is not clear whether the remaining funds of $1.8M will be sufficient to carry out the outstanding stimulation program.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 24895

Score: 7.0

Comment: Good progress has been made, with the exception of having problems with the recompletion of the well. It is clear from the presentations which of the collaborators was responsible for what piece of the overall plan. The decision making process, trading off technical goals and budget has worked, but would need to be confirmed by the other collaborators. Evaluation of the overall performance is based on how well the project has accomplished it goals and budget – relatively successful, with the exception of the cost/timeliness of the well repair, but not unexpected.

PI Response:

Reviewer 23568

Score: 10.0

Comment: This project required a significant management effort to coordinate all the individual tasks. This was carried out successfully.

PI Response:

Reviewer 23583

Score: 8.0

Comment: Effective project management in implementing the technical and logistics plans as well as providing leadership were noticeable. Evidently, early-on challenges with drilling equipment and well completions were managed effectively because well was successfully competed and is now ready for stimulation. Decision points are placed to allow for project review prior to each stage and the Go/No-Go decision to proceed with actual stimulation has been approved. Coordination

between several external entities to perform technical work was evidently effective given the numerous work products presented at the preview for this project. Project has published and presented at annual Geothermal Resources Council (GRC) and Stanford meetings. The project is also communicating with the National Geothermal Data Repository to make project results public.

PI Response:

Reviewer 23625

Score: 6.0

Comment: Scientifically driven project. This is valuable in terms of the analytical approach to achieve results. The important operational part is however still missing.

PI Response:

STRENGTHS

Reviewer 24895

Comment: Gathered all the data required for Phase I and evaluated it to produce a stimulation plan. The project includes a plan to test different methods of stimulation. The effectiveness of each method is evaluated before proceeding to the next method.

PI Response:

Reviewer 23568

Comment: The comprehensive set of data from geochemistry, geology, and rock mechanics combined with injectivity and other field stimulation data are most valuable for scientific study of EGS.

PI Response:

Reviewer 23583

Comment: GTO's EGS program goals significantly advance when project's objectives are realized, significantly lowering market barriers to EGS adoption as well as reducing existing knowledge gaps resulting in more EGS grid power delivered. The majority of the analyses performed in Phase I were conducted by high-quality, external research teams and successfully managed and coordinated by the PI. The overall quality of the technical approaches employed was excellent. The techniques employed were current, high quality, O&G industry techniques or new and innovative geothermal-based technology. The assembled research team is top-notch with experienced geothermal experts, contractors and operators as well as collaborators from several other universities and national laboratories. And it looks like the original completion date can be met and the project is on track.

PI Response:

Reviewer 23625

Comment: Accurate scientific approach, producing valuable models that will be tested with the stimulation program.

PI Response:

WEAKNESSES

Reviewer 24895

Comment: Not clear that the well/formations above the target zone will withstand the stimulations without an out-of-zone event. Not clear how the evaluations will feed back into a gap analysis. How will the evaluations be used to evaluate differences between the expected results and the actual results and determine if the gaps are a result of data problems, modeling problems or execution problems?

PI Response:

Reviewer 23568

Comment: Thermal stimulation in my mind is only circumstantially evidenced by the modeling. A controlled experiment using different fluid temperatures is required to prove thermal stimulation.

PI Response:

Reviewer 23583

Comment: Several scientific studies have been conducted and how these results inform the stimulation plan and shed light on the long-standing reservoir flow path and source uncertainty has been slow to materialize. In addition, there has been a paucity of results integration, particularly with respect to understanding the subsurface reservoir flow structure. A very positive exception to note is the interpretation of the geochemical and geologic analyses presented as a cross-section. A careful scientific integration of all these studies to produce a better model of the reservoir is key to interpreting stimulation results and in managing the stimulation. That being said, the injectivity testing as well as the borehole televiewer results were successfully implemented and effectively interpreted, becoming, in the end, major drivers to the current stimulation plan. An important question is what were the individual contributions from each of the studies to both the overall uncertainty reduction in the subsurface reservoir flow/source model and the stimulation plan? Is it possible that certain studies did not contribute to informing the plan and reservoir model? The answer would be very beneficial to the program and future EGS endeavors.

PI Response:

Reviewer 23625

Comment: Some peliminary studies are not relevant to the achieve the objectives.

PI Response:

IMPROVEMENTS

Reviewer 24895

Comment: Some monitoring of the competency of the completion and cement/formation should be included in the stimulation plan, so there is assurance that the stimulation will be confined to the zone of interest. Include plans to do a gap analysis and a feedback plan to improve the understanding of the data required, modeling effectiveness and/or execution effectiveness.

PI Response:

Reviewer 23568

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23583

Comment: The interpretation of the MT data needs more work and would benefit from a joint integration with other subsurface models. Multiple data sets and interpretations need to be integrated into the best model of the subsurface and then incorporated into a THM model. Stimulation decisions need to be justified by tests and analyses performed. The most important activity for Phase II is the stimulation, importantly, several other technical activities associated with monitoring the stimulation or determining its extent are also planned. The PI needs to schedule most of these other activities before the stimulation and this could be a challenge depending on when the stimulation occurs and the individual schedules of the other research teams involved.

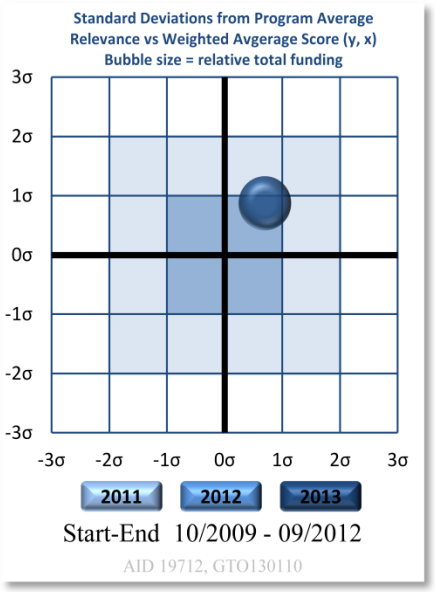
PI Response:

Reviewer 23625

Comment: Focus on objective to improve injectivity of the well. Geophysical studies may be relevant to understand the system, but they are not relevant to to achieve better injectivity/productivity.

PI Response:

Fluid Imaging, Characterizing Fractures, and Induced Seismicity Reviewer Comments and Principal Investigator Rebuttals



Review: 2013 Geothermal Technologies Office Peer Review
ID: AID 19712
Project: Full-waveform inversion of 3D-9C VSP data from Brady's EGS site and update of the Brady reservoir scale model
Principal Investigator: Huang, Lianjie
Organization: Los Alamos National Laboratory
Panel: Fluid Imaging; Characterizing Fractures; Induced Seismicity

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23583

Score: 8.0

Comment: Project objectives are aimed at developing innovative approaches to modeling and imaging EGS reservoirs. These objectives are highly relevant to broader GTO mission and goals. I agree with research team's claims that this work will "...help optimize the operation of injection and production wells and the placement of new wells...", and in that sense their project addresses several EGS subsurface imaging knowledge gaps such as reservoir characterization, fracture monitoring and reservoir modeling. The impact of the successful achievement of these project objectives will be a better understanding of the subsurface fracture permeability to better inform and improve reservoir heat extraction strategies. In the long run this will lower costs and LCOE.

PI Response:
Thank you.

Reviewer 23446

Score: 9.0

Comment: Addresses constraint in the subsurface using geophysics coupled with realistic models of mechanical, fluid and thermal response/state.

PI Response:
Thank you.

Reviewer 23579

Score: 8.0

Comment: Microseismic data will be available from essentially every geothermal reservoir and from every EGS development or demonstration for the foreseeable future. This is because monitoring and studies of induced seismicity are required for geothermal utilization to proceed. MEQ equipment typically deployed at geothermal areas continues to improve, and it is increasingly typical to use downhole multi-component sensors at multiple stations and to telemeter the data for analysis in real time. Development of new and improved methods for analysis, visualization and geological interpretation of this wealth of data is an area in which the DOE geothermal program can make a significant contribution to the geothermal community worldwide and to the US industry in particular. Development of a full-waveform inversion method to achieve a better picture of the distribution of both P-wave and S-wave velocities in space and time is a worthy endeavor.

PI Response:
Thank you.

Reviewer 23479

Score: 9.0

Comment: This is an imaging project aimed at the Brady's Hot Spring EGS site. The power plant at Brady's currently produces 12 MW and the intent is to increase production to 15 MW. This project is part of a suite of projects aimed generally at guiding and enhancing EGS-type experiments at Brady's and nearby Desert Peak.

The overall project design is excellent and well-integrated, and aims to better understand the relationship between changes in fluid pressure (and temperature), the resulting changes in stress and strain, and consequent changes in permeability. This is the paramount issue in EGS reservoir creation, and the project team is sufficiently diverse and talented to make real progress.

PI Response:
Thank you.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23583

Score: 7.0

Comment: It is difficult to assess quality of the scientific/technical approach because very little information was presented ('fat-ray' double difference tomography needs a lot more explanation before I can comment). That being said, research team is top notch with a good track record and results look definitely interpretable. The two results shown were impressive but does not allow me to comment on this project's scientific/technical approach. Not all results were shown and it makes one wonder if, maybe, they weren't so good and they only showed the best results. If that is the case, then maybe the technical approach did not succeed as planned, however, there are other explanations. As stated the technical approach looks appropriate and the methodology followed is standard for developing a reservoir model.

PI Response:

We can only use the MEQ data available before the stimulation at Brady's EGS field, and we have shown all the results. Because of the limited number of slides, we could not show the technical detail of the method. We will publish the method in a journal paper.

Reviewer 23446

Score: 9.0

Comment: Uses time lapse geophysics to invert for behavior. Attempt is to define perm tensor and to solve for fluid flow and temperature within reservoir. Uses 3D data and awaiting data from Brady's. Couples analysis to FEHM at LANL. Uses "fat ray path" that solves for region within a tunnel of half wavelength between source and receiver.

PI Response:
Thank you.

Reviewer 23579

Score: 9.0

Comment: The research scientists performing this work are known for their experience and innovation -- they are leaders in the field. They are backed up by the support of the considerable capabilities of LANL for this project. Phase I of the project has been finished, and results at least partly published. Besides these scientists, a diverse group of collaborators from other national laboratories, the academic sector and the private sector was formed for Part I of the project. Part I has been completed as 09/30/2012 on schedule and on budget. For Part II, the research will entail applying the newly developed elastic-waveform inversion method to 3D-9C VSP data from Brady's EGS site to obtain a quantitative, high-resolution image of the reservoir. The data will be obtained under the direction of LBNL and Hi-Q Geophysical in 2013 and passed to LANL for analysis. No problems are foreseen in completing Part II.

PI Response:
Thank you.

Reviewer 23479

Score: 9.0

Comment: Please see comments elsewhere.
PI Response:
Thank you.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23583

Score: 6.0

Comment: Probably the most significant technical accomplishment was building, running and validating a 3D, discrete reservoir THM model for Brady's Hot Springs including discrete fractures based on the core analyses, borehole logs and seismic velocity estimates. Comparison of model results with cumulative injection/production data was very impressive and is rare in this industry, however, reservoir model efficacy could have been better demonstrated if all validation results were shown including temperature, pressure and flow rate, not cumulative flow rate. Moreover, technical quality of the accomplishments is hindered by the lack of results. For example, results of their "...novel elastic-waveform inversion method..." that calculates "...time-lapse seismic data to obtain accurate estimates of EGS reservoir changes", were not shown, so I can't comment on that accomplishment except to say that I am curious as to why they did not show results. In addition, their "provide a quantitative, high-resolution image of Brady's EGS reservoir" milestone is still awaiting data collection by another team. All in all, a couple of excellent results were shown but not enough to say that this project's productivity was high and it left me with a sense that if results they didn't show were as good as what they did show, then why didn't they show them; maybe they weren't so good is one possible answer that I cannot ignore.

PI Response:
During this review, what we showed are the results obtained after the previous year's review. We already presented elastic-waveform inversion results during the project reviews in previous years.

Reviewer 23446

Score: 8.0

Comment: Has provided constraint for one site. And imaged for distributions of properties within that site. Awaiting data from another project (Brady's) to complete. Has matches between flow rates in wells for the site analyzed but it is not clear how unique this constraint is or what parameters are co-inverted to make the fits.

PI Response:
A distrete fracture model was used to conduct simulation to match the well data.

Reviewer 23579

Score: 8.0

Comment: The objectives of Part I of the project have all been met and the total budget for Part I has been expended. Although this has been an expensive project, the accomplishments have been considerable. Part II of the project will be completed in 2013, and is expected to result in an improved model of seismic properties in the reservoir area.

A question that remains is how the geothermal industry will be able to take advantage of the techniques and software developed on this project. Project researchers have issued a request for collaboration with industry partners having microseismic data sets and a desire to have them analyzed by the methods developed by this project.

PI Response:

Thank you. We look forward to collaboration with industry.

Reviewer 23479

Score: 7.0

Comment: It is somewhat premature to evaluate this particular element of the overall project because it is just underway and, more importantly, still lacks the "quantitative, high-resolution VSP image" that will be the primary basis for analysis.

The seismic imaging, originally scheduled for October 2012, is now apparently scheduled for May 2013.

PI Response:
We will commence the work as soon as the data are available. It is a great challenge to acquire VSP data within the geothermal well.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23583

Score: 9.0

Comment: Project management data is spot on and looks like scope, schedule and budget are being managed well. The only slip to schedule is out of the hands of the PI. Not a lot to say here, except it is a large team effort and coordination and communication could have been a real problem.

PI Response:
Thank you.

Reviewer 23446

Score: 9.0

Comment: Ok. Project is completed.

PI Response:
Thank you.

Reviewer 23579

Score: 8.0

Comment: This project has apparently been carried out as planned, with the budget for Phase I being spent and the goals for Phase I met. Future plans await delivery of a set of 3D 9-component data from a VSP survey to be delivered by LBNL and Hi-Q Geophysical later in 2013. When available, the researchers will perform a full-waveform inversion on the data

and report the results. This project, by nature, has to be carried out in its entirety. Intermediate decision points are not applicable. Coordination with all stakeholders has apparently been well done.

PI Response:
Thank you.

Reviewer 23479

Score: 7.0

Comment: Please see comments elsewhere.

PI Response:
Thank you.

STRENGTHS

Reviewer 23583

Comment: GTO's broader mission and goals will be advanced by successful completion of this work and several EGS subsurface imaging knowledge gaps are addressed. The impact of successful achievement of these project objectives will be a better understanding of the subsurface fracture permeability to better inform and improve reservoir heat extraction strategies. The technical approach looks appropriate and the methodology followed is standard for developing a reservoir model. Probably the most significant technical accomplishment was building, running and validating a 3D, discrete reservoir THM model for Brady's Hot Springs. Comparison of model results with cumulative injection/production data was very impressive and is rare in this industry. Project management data is spot on and looks like scope, schedule and budget are being managed well. This is a large team effort and coordination and communication could have been a real problem but evidently were not.

PI Response:
Thank you.

Reviewer 23446

Comment: Important topic and a team that is capable of completing the task. Initial results already received. Using up-to-date seismology to define response.

PI Response:
Thank you.

Reviewer 23579

Comment: This project has been carried out be a very highly competent staff from LANL supplemented with collaborations from a number of other institutions. The researchers are at the top of their field, indicating that reliable results should be expected.

PI Response:
Thank you.

Reviewer 23479

Comment: Please see comments elsewhere.

PI Response:
Thank you.

WEAKNESSES

Reviewer 23583

Comment: Because very little information was presented and not all results were shown, it is difficult to accurately assess quality of the scientific/technical approach. Another consequence of the paucity of results, is a lack of confidence in the technical approach. In addition, reservoir model efficacy could have been better demonstrated if all validation results were shown including temperature, pressure and flow rate, not just cumulative flow rate. The only slip to schedule is out of PI's hands.

PI Response:
We can only present the results after previous year's review. We did present the other results during the project reviews in previous years.

Reviewer 23446

Comment: Not clear to me what correlations mean and what data are co-inverted to give the observed subsurface maps. A common issue with all such projects is closing the loop to define what is really in place and how this relates to the inversions. This is not a single issue for this project alone but is a common difficulty. The desire to invert for the permeability tensor – not clear what method is used for this and how robust these estimates may be.

PI Response:
We look forward to further studies in collaboration with industry.

Reviewer 23579

Comment: 1. A considerable amount of software has been developed on this project, and it is not apparent how scientists and engineers in the geothermal industry can best take advantage of these new developments. The project scientists have issued an invitation to the industry to work on available data sets, and perhaps the best way to get the new methods into use is for the researchers to substantially do the analysis. During the extended and continuing development of the

TOUGH codes by LBNL, a series of workshops were made available for potential users. No similar plans were mentioned for this project, but they should be considered.

2. The map of Vs for the Brady area, showing much lower velocity on the west side of the fault(s) than on the east side, is very interesting and appears to be a significant result. Yet the presenter apparently did not know how the map corresponded to the geothermal field, i.e. the geological interpretation of these results. It is very important in research supported by the DOE geothermal program that the implications for application to actual field situations be identified and discussed. The best way to accomplish this is for the researchers to work closely with the field geoscientists and together interpret the results.

PI Response:
Yes, we discussed with James Faulds University of Nevada, Reno who would help us interpret the results.

Reviewer 23479

Comment: The PI's oral presentation showed a certain lack of familiarity with the field context of the work. For instance, two of the slides presented for review showed shear-wave velocities at Brady's based on a "fat-ray double-difference tomography method". These data revealed a pronounced low-velocity zone. Yet the PI was not able to relate the low-velocity anomaly to reservoir geometry. Further, FEHM model results were presented in the absence of any spatial context. Increased communication with other members of the overall project effort – many of whom are intimately familiar with the field situation at Brady's – would enhance the effectiveness of this particular project element.

PI Response:
Agree.

IMPROVEMENTS

Reviewer 23583

Comment: More results should be shown to substantiate claimed accomplishments and reservoir model efficacy could have been better demonstrated if all validation results were shown including temperature, pressure and flow rate, not cumulative flow rate.

PI Response:
Agree if time allowed during the project review.

Reviewer 23446

Comment: Important for all inversion projects to lay-out the forms of the correlations between parameters that are used – as this is crucial to define veracity of outputs. And also to objectively present outputs with appropriate error bars – this is clearly an important problem and a difficult one. Is it possible to use focal mechanisms from events to further constrain behavior?

PI Response:
Thank you.

Reviewer 23579

Comment: The LANL scientists on this project should work closely with the Ormat staff and with Ormat's Brady's Hot Springs project team to achieve an interpretation of the research results in terms of the field geology, geochemistry and geophysics.

PI Response:
Agree.

Reviewer 23479

Comment: The main progress to date – in the absence of the anticipated VSP image – is (1) the development of the "fat-ray double-difference tomography method" and (2) the development of a "permeability tensor" from core images. I am not competent to evaluate (1) but have a few comments and suggestions with respect to (2).

First, "permeability tensor" is a bit of an overstatement. What the team did was map lots of fractures in drill core, and then use that data to infer the principal directions of the permeability tensor. There was no quantitative assessment of permeability, nor any attempt to distinguish hydraulically conductive versus non-conductive fractures. Nor was there any effort to relate mapped fracture orientation to principal stress directions (which I assume are known for this system).

Thus, to, date, little real use has been made of these core-scale data. However, they exist, and could be made useful. There is real interest in the question of how well core-scale information can represent field-scale behavior. It would be interesting to:

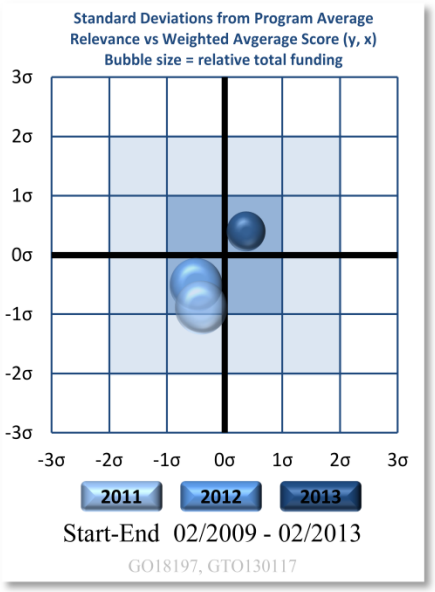
(1) Consider the completed core-scale mapping versus the state-of-stress, a la Colleen Barton, Mark Zoback, and others (Geology, 1995).

(2) Consider the core-scale mapping (and state-of-stress) versus whatever is known about the directionality of permeability on the field scale, which must be considerable, given the existence of numerous wells.

(3) Compare the core-scale and field-scale inferences re directionality of permeability to the more regional-scale fault modeling done by structural geologists.

Such an effort could be of both scientific and practical benefit, and help to inform the ongoing reservoir-modeling effort.

PI Response:
Agree and thank you.



Review: 2013 Geothermal Technologies Office Peer Review
ID: GO18197
Project: Monitoring and Modeling Fluid Flow in a Developing EGS Reservoir
Principal Investigator: Fehler, Michael
Organization: Massachusetts Institute of Technology
Panel: Fluid Imaging; Characterizing Fractures; Induced Seismicity

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23579

Score: 8.0

Comment: Development of reliable methods to map and visualize the flow of fluids in the subsurface in both space and time from remotely sensed data is an urgent need in all forms of geothermal energy utilization. Microseismic data sets are available from essentially every operational geothermal field since the potential for inducing damaging earthquakes has spurred regulations requiring monitoring of MEQ activity. This project seeks to develop improved methods to locate microseismic events and to relate them to injection of fluids and to stress states and rock properties in the subsurface. Such studies have application to geothermal field management and also to EGS field development, where the question is "what can microearthquake locations in space and time tell us about movement of fluids injected for stimulation or for operation?"

PI Response:
Acknowledged

Reviewer 23434

Score: 6.0

Comment: The proposed project "Monitoring and Modeling of Fluid Flow in a Developing Enhanced Geothermal System (EGS) Reservoir" is an ambitious proposal that has a high level of relevance to the understanding of EGS system.This task proposed to "improve our ability to predict performance of an EGS reservoir over time by relating, in a quantitative manner, microseismic imaging with fluid and temperature changes within the reservoir" through the means of analyzing microsiesmic data to infer fracture geometry, changes, and affect on flow properties from field data, and then modeling the reservoir to aid in the planning of the reservoir.

Unfortunately the work that was presented at the peer review did not directly address this original research topic, instead recasting the project objective as "Use Chevron’s high-quality data from a long-term injection in the Salak geothermal field to better understand stress changes and permeability development during the fracture growth stage of an EGS development", which is similar to the originally proposed work, but much less ambitious and with a lesser impact to the geothermal community as a whole.

PI Response:
The goal of the project was to better understand the development of an EGS reservoir. Perhaps there is some confusion because it was not the intention of the proposal that thework would be to look at the long-term operation of a reservoir.

The proposal was to use the Chevron dataset to evlauate the questions in quotes in the second paragraph from the reviewer. The dataset does not allow one to look at the long-term operation of a reservoir.

Reviewer 23446

Score: 9.0

Comment: Project is exploring the linkage between stress changes and fluid flow (permeability) using the Salak field as an analog. The constraint of permeability is one of the crucial components in the viability of EGS and in prospecting.

PI Response:
Acknowledged

Reviewer 23479

Score: 8.0

Comment: The goal is to explain the downward migration of seismicity below zones of fluid injection in geothermal reservoirs. This behavior seems to be widespread (The Geysers, Fenton Hill, Hengill, Rosemanowes, Salak, etc.) and poorly understood. There is practical significance in terms of understanding reservoir behavior and the potential for long-term pressure support and production enhancement.

PI Response:
Acknowledged. While downward growth is widespread, it is not generally acknowledged as a significant factor in the development of EGS reservoirs. Most reservoirs do not echibit this behaviour (e.g. Soultz, Hijiori Ogachi, Cooper Basin).

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23579

Score: 9.0

Comment: The research work used the considerable microseismic data set from the vicinity of well AWI-18 in the Salak field on the island of Java in Indonesia. This field is operated by Chevron, and Chevron technical staff are participants in the project. AWI-18 is a well in which there has been long-term injection. It lies somewhat outside the western boundary of the field. Observations of microseismicity from the Hot Dry Rock experiment at Fenton Hill, New Mexico and from the Hengill field in Iceland indicated that seismicity migrates downward with time and can occur well below the level of fluid injection. This effect has been observed at other fields as well, including at The Geysers. Part of the current research has to explain this effect and to determine under what conditions it will be observed. To this end, some 1168 microseismic events at Salak were analyzed.

PI Response:
Acknowledged

Reviewer 23434

Score: 6.0

Comment: The primary method used in the project "Monitoring and Modeling Fluid Flow in a Developing EGS Reservoir" was to use seismic interferometry to better locate micro seismic events from a set of data from the Salak geothermal field. This did indeed prove to be a useful method for improving the confidence in micro seismic event locations, as shown on slide 11 of the PI's peer review presentation. But this is not a new result, as the PI points out in "Comparison of micro earthquake locations using seismic interferometry principles" Melo, G., Malcolm, A., and Fehler, M., SEG Technical Program Expanded Abstracts 2012: pp. 1-5. doi: 10.1190/segam2012-1371.1

Even if this is not a new technique, the data presented at the peer review was worthwhile in that it attempted to link the occurrence of micro seismic activity determined from the project into a fundamental understanding of why seismicity migrates downwards during injection events. By coupling the mohr columb stress criteria with basic facts about how principle stresses change with depth and temperature some insights into why seismic events migrate downward were presented. Again, not 100% novel, but interesting and good to see the descriptions.

PI Response:
Acknowledged. We are trying to interpret the evaluated data to provide a model to help understand why and where downward growth of seismicity may occur.

Reviewer 23446

Score: 9.0

Comment: Analysis of catalog of events and observed trends in data with time. Observed migration of seismic zone downward with time and hypotheses of this behavior. Attempt to use seismic interferometry to understand behavior.

PI Response:
Acknowledged

Reviewer 23479

Score: 8.0

Comment: Please see comments elsewhere.

PI Response:
N/A

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23579

Score: 9.0

Comment: Progress on this research has been substantial and will be of interest to anyone analyzing microseismic events in geothermal studies. Study of possible mechanisms for the observation that microseismic activity has been seen to move downward from the level of injection of fluids in geothermal reservoirs has led to interpretation of the phenomenon as Mohr-Coulomb shear failure. In areas where the maximum and minimum principal stresses have different gradients with depth, the differences between these two stresses increases with depth until shear failure occurs. This mechanism was invoked by Pine and Batchelor at the Cornwall, England hot dry rock experimental site, but has not received much emphasis in geothermal studies since. One significant accomplishment of the project has been the incorporation of a Mohr-Coulomb model into the LANL FEHM coupled reservoir simulator model to allow the study and prediction of shear failure in microseismic analyses.

At Salak, improved location of microseismic events shows the events to be located closer to the injection well than previously thought, and to extend downward in a planar shape parallel to a known fault zone. Interferometry studies of the microseismic events has shown that it is possible to estimate the time of flight between two microseisms and help test the consistency of event parameters.

The project is essentially complete, with report and paper writing being the main tasks left to do.

PI Response:
Agreed. One or more papers will result from this project. We have refined out interpretation since the review and that has been presented at a geothermal energy meeting and was well received.

Reviewer 23434

Score: 5.0

Comment: Unfortunately, when the presented work is compared to the proposed work the accomplishments, results and progress do not appear stellar.

Of the four proposed deliverables, it appears that only phase 1 and phase 2 were completed. An initial model with seismic locations was developed, and this model was then refined to improve the locations of the seismic events.

The phase 3 deliverable (Detailed information about the fracture geometry from seismic data will be provided along with a paper describing the methodology for defining the geometry and describing the results and limitations of application of the method. An initial approach for combining geophysical data into a geomechanical model will be outlined) was not mentioned in the peer review, nor does there appear to be anything in the literature that would suggest this was completed. The phase 4 deliverable (one or more peer-reviewed papers describing our methodologies for analysis of geophysical data and integrating it into the geomechanical model. Papers will also describe the resulting geomechanical modeling and results of the modeling along with applications of the results to EGS systems.) has understandably not been completed either, as the modeling has not yet been performed. The PI addressed the lack of modeling in this project as a major short coming, and expressed hopes that they would be able to complete some of that in collaboration with LANL, even though the project ended in February of 2013.

The progress when compared to the proposal is not great, though this may be a case of a too ambitious proposal.

PI Response:
The proposal was ambitious and we were delayed a year in getting the data due to intellectual property issues between Chevron and MIT. We accept that the item 3 was an ambitious part of the the project and that we did not make as much progress on that as we had hoped. The proposal presented some ideas for this work. We evaluated our proposed methods and found that they could not be reliably applied.

Reviewer 23446

Score: 8.0

Comment: Defining models for migration of seismicity with time – related to fluid behavior but also driven by stress regime. Two hypotheses – increasing deviatoric stress with depth or thermal reduction in stresses with time by quenching.

PI Response:
Acknowledged

Reviewer 23479

Score: 7.0

Comment: The PIs first convinced themselves that the downward migration was in fact "real" by evaluating or reevaluating hypocenter locations. They have advanced alternative hypotheses to explain the phenomena in terms of preexisting stress gradients and enhanced potential for shear failure. These hypotheses remain to be tested.

PI Response:
Acknowledged

PROJECT MANAGEMENT/COORDINATION

Reviewer 23579

Score: 8.0

Comment: This project has apparently been carried out as planned and is now nearly complete. Staffing was excellent. The data sharing agreement was acknowledged as a challenge which was successfully navigated -- kudos to Chevron and to the researchers. There were no intermediate decision points -- the project had to be performed as proposed or not done at all.

PI Response:
Acknowledged. Thank you.

Reviewer 23434

Score: 3.0

Comment: Due to the fact that roughly half the project was not completed (i.e. the linkage to a reservoir model with improved understanding of the fracture flow properties from the seismic measurements) and the money has been spent, I would say the project was poorly managed. Though, again, this could be a case of an overly ambitious proposal.

PI Response:
This is a matter of interpretation. We believe that we obtained useful knowledge from the project even if it was not exactly what was expected at the outset. That is the nature of research.

Reviewer 23446

Score: 8.0

Comment: Ok.

PI Response:
Acknowledged

Reviewer 23479

Score: 7.0

Comment: This is a focused and well-designed study that has made significant progress towards its objectives. It is nearly complete in terms of funds expended but has some remaining resources, including ongoing student efforts.

PI Response:
Acknowledged

STRENGTHS

Reviewer 23579

Comment: A highly competent research team carried out this project on a real data set furnished by Chevron for the Salak field in Indonesia.

PI Response:
Acknowledged. Thank you.

Reviewer 23434

Comment: The PI and his co-researchers are high quality geophysicists, and having their insights into the geothermal realm is important.

PI Response:
Acknowledged.

Reviewer 23446

Comment: Using interesting data set with interesting observations and attempting physics-based models. Models are probably appropriate for the lever of constraint for the site. Not clear what other data are available for the site in addition to the seismicity – presumably also information on injection rates and temperatures and structural and perm data inferred from the site that could also be wrapped into the project.

PI Response:
Acknowledged

Reviewer 23479

Comment: Please see comments elsewhere.

PI Response:
N/A

WEAKNESSES

Reviewer 23579

Comment: One potential weakness, easily corrected, is that most research results to date have been published in journals and venues perhaps not usually read by some in the geothermal industry. At least one paper on the results of this research should be given at either the GRC or the Stanford annual meeting. A 2010 paper at Stanford dealt with an analysis of microseismicity at Soultz, but the project has produced interesting and significant results since that time.

PI Response:
We intend to publish one or more papers about the project.

Reviewer 23434

Comment: The weaknesses of this project seem to stem from an attempt to do too much with micro seismic data. The goal of obtaining "Detailed information about the fracture geometry from seismic data ..." and "... methodology for defining the geometry and describing the results and limitations of application of the method" is a very lofty goal, one which the PI gave no indication was solved over the course of this project. If this project had been initially cast as an examination of

micro seismicity location techniques along a path to improve the state of the science, then I think the progress could have been listed as good and the task could be thought of as a success.

I think that the lack of any modeling hurts this project as well. Since fluid modeling is literally in the title of the proposed task, no modeling results of any kind are a definite weakness in how this project was evaluated.

PI Response:
Agreed. We were hurt by a lack of fluid modeling itself. We are still hoping to do some to complete the work even though the project is complete. We do believe that the conceptual model of stess gradients along with temperature gradients is an important step that has value beyond any model of a single reservoir because the conceptual model can be more widely applied.

Reviewer 23446

Comment: Were results of the more elegant processing methods given in the talk?

PI Response:
We were limited in the talk by time and the required elements for the presentation given that it was a project review andnot necessarily a tchnical presentation. Also, some advances came between the time that the talk was prepared and the time the talk was given. Unfortunate but not review is perfect.

Reviewer 23479

Comment: The primary objective listed in the Project Summary, with specific reference to the Salak field, is to "predict stress changes and permeability development" as a consequence of injection. This objective has not been met – there has been no work on permeability development – but I think that it still can be. As noted elsewhere, it might be useful to take a somewhat more generic approach, rather than focusing only on Salak.

PI Response:
The projects goal was to focus on Salak due to the high quality dataset.

IMPROVEMENTS

Reviewer 23579

Comment: Publish a summary of research results at either the GRC or Stanford annual meeting, as noted above.

PI Response:
Acknowledged

Reviewer 23434

Comment: A stricter adherence to the original plan, in conjunction with a more realistic plan from the outset, would make projects of this nature more successful and provide better data to the community.

PI Response:
Acknowledged

Reviewer 23446

Comment: Other hypotheses for downward/upward migration include changing material props with depth, velocity strengthening/weakening and roles of temperature, downward migration of a cold dense tongue of water and soft inclusion for the chilled zone. Selecting features of the models that would discriminate between these various models could be useful – for example, a quenched soft inclusion model would shed stresses in the unquenched zone around the inclusion so seismicity might be equally likely above as below the zone – maybe possible to exclude based on that signature?

Plotting data as a time-radius plot or time depth-plot might be useful in crafting hypotheses.

PI Response:
Thank you for the thoughtful suggestions. We have made the time-depth plots and done more careful evaluation of the role of temperature gradient. We have thought some about velocity strengthening/weakening but that is mostly beyond the scope of this project.

Reviewer 23479

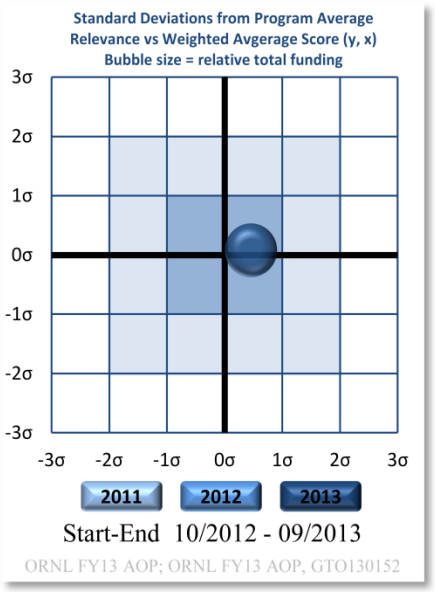
Comment: Looking at this phenomenon from a hydrogeologic perspective, my first question is: "Where is the water going?" It seems likely that it is moving downward, consistent with the seismicity, because the pressure in the deep injection zones is typically less than local cold-water hydrostatic pressure. Cooling and cracking (and seismicity) would seem to be natural consequences of downward migration of cold water. Perhaps much of the failure is tensile rather than shear; are the seismic data diagnostic in this regard?

THM modeling is a natural way to explore the various hypotheses. Because downward migration seems widespread, it might be useful to do generic modeling conditioned on several of the known examples, rather than emphasizing the specifics of a particular field. What can we say about expected fluid-flow directions based on the pressure and saturation regimes at various reservoirs?

The injection-related seismicity seems possibly analogous to certain seismicity in unexploited hydrothermal systems. Consider for instance the early work by Clive Lister on downward migration of a cracking front at the mid-ocean ridge, where cold recharge encounters sufficiently hot rock. Or the recent work by Janik and McLaren on the Lassen hydrothermal system (JVGR, 2010). At Lassen, seismicity is inferred to be concentrated at the roots of the hydrothermal system, where cool meteoric recharge water mines heat from hot rock across a thin conductive boundary layer.

I am glad that this project has some resources remaining because there are excellent opportunities to do a bit more work and bring the project to a fully satisfying conclusion.

PI Response:
I have a post doc who is now preparing to do waveform inversion to look at focal mechanisms of a few events. This was planned for earlier but was not completed by the end of the project. We will look more carefully at your other well thought out suggestions when we attempt to do a little THM modeling.



Review: 2013 Geothermal Technologies Office Peer Review
ID: ; ORNL FY13 AOP
Project: Application of Neutron Imaging and Scattering to Fluid Flow and Fracture in EGS Environments
Principal Investigator: Polsky, Yarom
Organization: Oak Ridge National Laboratory
Panel: Fluid Imaging; Characterizing Fractures; Induced Seismicity

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23479

Score: 8.0

Comment: The PI's presentation and submitted documents make a strong case for the importance of lab-scale experiments in the context of EGS. Drilling is extremely expensive; we are not going to be able to drill dozens of holes; and it is important to understand the physiochemical behavior as fully as possible prior to drilling. Both lab experiments and modeling can contribute to this understanding, and the results of lab experiments can be used to test numerical models.
Neutron imaging can be used to "see" into materials at EGS-like conditions.

PI Response:
Agreed.

Reviewer 23434

Score: 3.0

Comment: The project 'Application of Neutron Imaging and Scattering to Fluid Flow and Fracture in EGS Environments' is really two separate projects that are utilizing similar equipment, but are actually different.

The fluid flow in fractures portion of the study makes the case that an improved understanding of how fluid moves through fractures is needed to improve reservoir modeling performance. While this is true, there are numerous works in the literature (from Tsang 1984 to Piri et al 2012) that do an excellent job of describing flow through fractures. What is desperately needed is a way to upscale the results from these small scale studies to something meaningful above the core scale.

The strain measurement portion of this study makes the case that understanding the stress regime around a propagating fracture in a geologic sample is critical to better understanding of 'hydraulic fracturing' processes. As the majority of fracturing that is desired in EGS systems is of the shear-slip variety, I don't feel that this is a very strong argument. I think there is a need for this type of research, but I think that the hydraulic fracturing processes related to fracking of shale gas wells is more applicable to the research that the PI is proposing.

PI Response:
While we agree that upscaling is important, we believe that the there is a siginifcant gap between theoretical study and experimental validation of fluid flow through fractures as stated in our documentation. The Tsang 1984 reference that the reviewer alludes to, for example, is a computational study with the conclusion that tortuosity has a potentially large effect on fluid flow rate. In a later publication (1987) in which Tsang extends this work into a 'channel model' of fracture flow, it is specifically stated that "validation of this conceptual models by experiments is crucial, since we have made a vareiety of simplifying assumptions in our approach…". This need is what our work aims to address.

Concerning the reviewer remark on shear-slip as the primary mechanism for permeability enhancement for geothermal, while this has been the historically prevalent view, it is not unanimous. Furthermore, much of the community now believes that permeabilty enhancement will be achieved through a combination of shear destabilization and tensile fracture. Understanding both phenomena is crucial to EGS success since geothermal activities are unlikely to follow the path of Shale Gas development which was largely empirical and involved thousands of fracturing operations to perfect methods. Thus experimental tools that shed insight on fundamental fracture mechanisms are crucial.

Reviewer 23446

Score: 10.0

Comment: Understanding flow-transport processes at all scales and their interaction with stress is important for EGS. The project explores that feasibility.

PI Response:
Agreed.

Reviewer 23579

Score: 8.0

Comment: This is an interesting and innovative project whose ultimate relevance and impact on the geothermal industry remain to be determined. The use of neutron imaging to examine and quantify processes inside cores offers a new window onto such processes. There has been little or no work in this area. There is, of course, a question of how well observed processes inside a 1 in X 6 in piece of core represent processes in nature and inside simulation model grid blocks, which are typically meters to tens of meters on a side. However, a significant gap exists in our knowledge of the mechanics and controls on fluid flow in the subsurface under geothermal conditions. Observations, even at scales that are very small compared with reservoir scales can be instructional and relevant. This research has the potential to open a new window in such processes.

PI Response:
Agreed. This capability is expected to also be a tool for validating CFD simulations, which can then be applied to facilitate improvement of more commonly applied Darcy flow based reservoir models. 'Ground Truth' is required at some point if simulations are to be trusted.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23479

Score: 10.0

Comment: The PI clearly understands the EGS context of the ongoing experiments, including the distinction between those processes likely to be significant during initial reservoir creation versus long-term reservoir operation. Experiments are underway that apply to both contexts – mainly "hydromechanical" in the context of reservoir creation, "hydrochemical" in the context of long-term operation.

PI Response:
N/A

Reviewer 23434

Score: 3.0

Comment: The PI and group have a very unique system that enables them to visualize processes that are difficult, if not impossible to view with other methods. Unfortunately they do not seem to have much of a geologic, reservoir engineering, or geothermal background, so some of the methods they are using seem questionable.

Fluid flow. The only 'fracture' that was shown for the fluid flow portion of this task was a piece of sandstone that had been cut in half and shimmed up with aluminum spacers. While it is interesting and novel to be able to visualize fluid flow within this sample, the results are less interesting than the early 1980's work of multiphase flow in Hele-Shaw cells, which showed that a high velocity more viscous fluid displacing a less viscous in place fluid would move in a stable (non-fingering) fashion. Not surprisingly, this is what was observed in the test.

The ability to visualize fluid flow this quickly within the opaque rock sample is impressive, but I see no novel work that will come from this with the current guidance.
There also was no discussion of quality checking the thresholding of the precipitation on the rock face as shown on slide 10. Since the 3D model appears to be an AVISO software rendering, I'm assuming that the standard AVISO threshold was used. Mentioning the details of these processes would provide some more confidence in the quality performance of the task.

Strain measurement. This is a unique measurement technique, but there appears to be a long way to go before meaningful measurements that are relevant to the geothermal community can be taken. The ability to measure strains within sandstone and granite within a uniformly stressed sample is good, but the amount of variation in the measured values leads one to think that small variations in the strain field during a fracturing event may be missed. But perhaps more importantly, the PI gave no indication of how actual fracturing strains will be measured. Phrases like 'stress concentration features' and 'incipient hydraulic fracture conditions' make me think that the approach is not 100% formulated yet, about two years into the project.

PI Response:
The PI has both a commercial and research focused geothermal and oil & gas background. The reviewer seems to have missed the point of the work to date. We are at this stage still trying to establish the feasibility of flow and strain field quantification using neutron-based techniques (although we believe that feasibility has been demonstrated for the strain measurement capability). The 'proof-of-principle' experiments are necessarily simplistic in order to validate the

measurements made against accepted results. Part of our work plan involves the definition of an experimental progression that addresses pressing reservoir flow and rock mechanics questions. The next set of experiments planned for the strain measurement thrust for example will attempt to shed light on discrepancies between theoretical and measured breakdown pressures in hydraulic fracture experiments reported at the most recent American Rock Mechanics Association symposium.

Reviewer 23446

Score: 10.0

Comment: Using neutron imaging to illuminate process-based experiments. Feasible to view flow processes by particle image velocimetry (piv), to look at dynamic displacement of fluid interface fronts and to image stresses. Imaging of stresses is an exciting addition to these methods.

PI Response:
N/A

Reviewer 23579

Score: 9.0

Comment: This project appears to be staffed by competent researchers and to have the considerable resources and knowledge base of Oak Ridge National Laboratory to support it. Instrumentation is appropriate for the task, and presumably could be supplemented if needed. The technical approach, i.e., to build a pressure vessel to contain core samples and to subject them to conditions of temperature and pressure similar to those at depth in geothermal areas, and then to use neutron beams to look through the containment vessel and into the core, is well thought out. It should add new data and insights to fluid flow and mechanical processes in cores and, presumably, to the subsurface. The results achieved to date indicate that the method works as predicted. The research team is now in a position to use the method on a variety of geological samples.

PI Response:
N/A

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23479

Score: 8.0

Comment: The PIs have successfully demonstrated the neutron-imaging method – typically applied on engineered materials – on representative media. They have also demonstrated the ability to image fast-moving fronts.

The PI describes the liquid-liquid imaging results to date as only partially successful (though I found them impressive!) and expressed optimism that they might be improved by particle-imaging velocimetry, which is imminent. (A naïve

question: The PI seemed troubled by evidence of mixing in the liquid-liquid experiments. But, won't most real hydrothermal fluids be miscible? Perhaps I am missing the point…)

PI Response:
N/A

Reviewer 23434

Score: 4.0

Comment: I'm unsure of how long this project has been ongoing, but the SOW provided to reviewers indicates there was FY11 funding, so I will assume roughly two years.

The progress does not seem to be that great for two years into the project.

There are several publications out there (i.e. "APPLICATION OF NEUTRON IMAGING TO INVESTIGATE FLOW THROUGH FRACTURES FOR EGS" & "DEVELOPMENT OF A NEUTRON DIFFRACTION BASED EXPERIMENTAL CAPABILITY FOR INVESTIGATING HYDRAULIC FRACTURING FOR EGS-LIKE CONDITIONS", both from the 2013 Stanford geothermal workshop with the PI as the lead author) that show that the system is slowly developing, but no results that are relevant to geothermal activities.

Even if the project accomplishes all of it's stated goals, the progress towards improved geothermal reservoir simulations will most likely be limited because there is apparently little thought into how this data will be up-scaled in meaningful way. This makes any result that is obtained diminished from the outset.

PI Response:
While the first year of the project was admittedly slow, the second has been extremely productive. We completed the design and construction of the experimental setup, have performed three different roughoy week long experiments at two different neutron scattering facilities and will try to complete at least one more experiment before the end of the FY. We also belive that we will obtain results directly 'relevant to geothermal activities' in the next set of strain experiments and hopefully by the end of the next FY for the flow investigations.

Reviewer 23446

Score: 9.0

Comment: Have completed initial experiments for proof of concept to define the response in candidate samples involving artificial (1.5mm) fracture. Has defined feasibility of defining stresses in systems where crystals are present (i.e. significantly heterogeneous). Initial results for precipitation experiments.

PI Response:
N/A

Reviewer 23579

Score: 9.0

Comment: This project has progressed as planned. The pressure vessel has been successfully designed and tested on actual core samples. It appears to work well. The problem of lack of resolution of fluid fronts is being addressed and should be solvable. Tests to determine whether or not mineral strain can be measured in core samples have yielded encouraging results. This capability should be of considerable interest in helping to model such variables as the effect of mineral grain size on inducing fracturing in rock.

Demonstration of the ability to see deposition of minerals on fracture surfaces has been a success. The actual test mineral deposited, boric acid, was used to demonstrate only the principal. Studies of deposition or dissolution of precipitates of interest in geothermal reservoir studies would likely take a long exposure to the circulating fluids (weeks or months) under reservoir temperature and pressure conditions, but this should be possible given the equipment as designed. Maintaining the core and container at geothermal temperatures and pressures for extended periods of time was the topic of a question by one reviewer, and was deemed to be no problem by the presenter.

PI Response:
N/A

PROJECT MANAGEMENT/COORDINATION

Reviewer 23479

Score: 8.0

Comment: Please see comments elsewhere.

PI Response:
We were actually considerably underspent in year 1 due to manpower limitations. Year 2 spending was on track and the reviewer is correct that there was significant cost associated with the development of the experimental setup. This cost is largely one-time, although the setup continues to evolve, and subsequent funds are largely spent on the research effort.

Reviewer 23434

Score: 5.0

Comment: The project management seems OK. The final slide of the peer review is a bit confusing for this project, but I think this is because this is an annual operating plan (AOP) project and funding levels change year to year.

The project management does seem to be over looking some of the literature that is out there on fracture flow and is repeating experiments that were performed decades ago. Albeit these new experiments are measured with neutrons rather than CT or visual methods, but none of the 'fluid flow in fracture' results seem as though they will be revolutionary.

The costs seem high for the products being developed, but I think that is in large part due to the expensive nature of the equipment needed to perform the tests.

PI Response:
N/A

Reviewer 23446

Score: 10.0

Comment: ok.

PI Response:
N/A

Reviewer 23579

Score: 8.0

Comment: The project has been well managed, as indicated by the progress to date and by the plans for the rest of 2013. No decision points were presented, but this is not deemed to be problematic for this particular project as it really must be carried out to the currently planned end point before a decision is made to proceed with further use of the technique. To date there are apparently no collaborators, but as the research continues beyond the current project, earth scientists involved in actual development of geothermal fields as well as researchers having much more experience in the geothermal environment than the current research staff should be involved if the full potential of this new method is to be achieved. Formation of an advisory committee for this project should be considered soon.

PI Response:
N/A

STRENGTHS

Reviewer 23479

Comment: There is good communication between the PIs group at ORNL and the code-comparison team centered at PNNL, such that at least one of the code-comparison test cases is expected to be based on the ORNL mapping of strain fields at incipient fracture.

PI Response:
N/A

Reviewer 23434

Comment: The PI and research team are attempting to use a novel technique for visualizing fluid and fracture behavior within a laboratory setting under elevated pressure and temperature settings.

PI Response:
N/A

Reviewer 23446

Comment: Attempting to recreate reservoir conditions and to conduct experiments under these relevant environmental conditions is important. The ability to image stresses and link this with other measurements is exciting as many of the important processes in EGS reservoirs have a stress control. Dynamic imaging is important (not clear what the scan/refresh time for this imaging is and in what detail the imaging is feasible).

PI Response:
N/A

Reviewer 23579

Comment: This project will likely result in a new tool for use in geothermal reservoir studies, both for development of data for use in reservoir models and for testing and calibration of various simulation models. The ability to use neutron imaging to look inside cores under geothermal conditions of pressure and temperature and to measure certain physical and chemical processes will be unique.

The project has apparently been carried out as planned and budgeted, and is on track for development of a new tool for studying core samples.

The investigators have demonstrated a good publication record (for such a new project) in literature easily accessible to the geothermal industry (the Stanford workshops).

PI Response:
N/A

WEAKNESSES

Reviewer 23479

Comment: There was some ambiguity about the temperatures achieved (or achievable) in the experimental apparatus. The SOW and Project Summary refer repeatedly to temperatures up to 350C, but experiments to date seem to have been at much lower temperatures (<100C?). I trust the PIs verbal assurance that high-temperature experiments are feasible and imminent. This is of course important because of the influence of temperature on rheology and chemical reactions.

PI Response:
Good point. We have a plan for how to achieve the higher temperatures but have not focused resources on the implementation to date because we have been more focused on honing and validating the strain and flow measurement techniques.

Reviewer 23434

Comment: The researchers do not appear to be very knowledgeable about fracture flow in general, and are thus making some unusual choices in what to study i.e. air-water flow through a manufactured fracture, even as a proof of concept is very limited in it's relevance. Even showing how flow in a rough fracture could be visualized would have been more relevant to the topic. The boric acid precipitation test is very confusing. Why? As a proxy for other precipitation/dissolution tests?

There appears to be much planning left to do,and for a project that has been ongoing for at least two years that seems worrying. From the presentation alone

- "One method demonstrated for temperatures up to 100°C. Concepts developed for higher temperatures (slide 6)" - PI stated in review that the system is rated up to 300, but then on slide 13 "High temperature (>250 deg C) heating arrangement will be designed and tested for pressure cell" I may be confusing the pressure cell with the 'flow cell', but there is no explicit mention of two different cells in the presentation, so I don't think so

- "Need to improve fluid injection scheme" to reduce blurring of doped single phase flows.

- "Baseline experiments to address fundamental modeling and simulation issues will be defined" It seems awfully late in the game to still be defining what the baseline experiments will be for determining things like surface roughness and tortuosity within fracture flow samples.

The strain measurement portion of the project is similarly fraught with questions about the fundamental direction of the project. While proof of concept with the simple loading schemes has been shown in the presentation, there is was no real insight given into how hard it will be to expand these analysis to more meaningful situations. The PIs use of a hole in the sample to mimic a stress concentration does not indicate to me that the studied test will in fact be similar to an EGS fracturing situation.

PI Response:
Many of the reviewers comments were addressed in preceding responses. We will reiterate that the experimental progression selected for all thrust areas is intended to ensure that the quality of measurements performed is high and that the measurements are accurate. The presentation material for example described the need to perform strain measurements during uniaxial load tests in order to both validate the ability to measure strains associated with mineral lattice components and to calibrate the measurements in order to infer macroscopic stress levels. These procedures in themselves are fairly standard for diffraction based strain measurement and are followed per good practice. The flow thrust by contrast has no experimental precedent that we are aware of. We are essentially developing the critical techniques from scratch, although we are able to use some standard imaging tools related to image capture and processing. We believe that if these techniques are fully realized they will be extremely useful to the geothermal community at large conerned with fracture flow. It is also emphasized that the ORNL research team is actually quite enthusiastic about collaborating with other researchers in the application of these methods, even if others only want to use our equipment.

Reviewer 23446

Comment: Always limited by resolution. An order of <100 um is quite low. Always this conflict between small sample size in scanner to reach required resolution (at least this is the possibility in x-ray CT) and having to have a relevant sample size for the process – such as REV for fracture. Current fracture aperture of close to 2mm is quite large. For perm of ~1e-14 m^2 typical for stimulated reservoirs and with a 10 m spacing between fracture the aperture is order 0.1mm – i.e. at limit of 100um pixel.

PI Response:
It is agreed that the resolution is low at the moment. The gage volume of measurement is also larger than we would like. However, the nature of evolution of neutron scattering facilities is such that these sort of specifications are constantly improving due to source flux increases and measurement improvements. For example, the PI is aware of a project that will begin in FY14 with the objective of decreasing the measurement gage volume of the Vulcan strain measurement instrument at SNS by one order of magnitude using coded aperture techniques. If successful, this project would enable strain measurements at sub-cubic millimeter gage volumes.

Reviewer 23579

Comment: The greatest weakness in the project to date is an apparent lack of interfacing with experts from the geothermal industry, other national laboratories or the academic sector to help determine project directions or predictions of ultimate utility of the technique. This is somewhat understandable since the tool under development must be shown to work as planned before it can see much actual application. A project of this kind, being carried out by scientists who apparently have limited knowledge of geothermal resource development, would be well served by establishing an advisory committee of a few colleagues with extensive experience in geothermal geology, geochemistry and reservoir engineering.

PI Response:
The assembly of an advisory committee is a good idea and will be pursued.

IMPROVEMENTS

Reviewer 23479

Comment: One question regarding future plans – cooling and consequent tensile failure are likely to be ubiquitous and important in EGS systems. Will there be any experiments aimed specifically at this issue?

PI Response:
This might be tricky to do due to the length of time needed for measurements (minutes) since thermal shock occurs over very short time scales but the feasibility will be explored.

Reviewer 23434

Comment: Detailed literature review of existing works.

I would recommend focusing on the strain measurements. If beam time is limited this seems a slightly more promising avenue.

Attempt to capture effluent samples if/when geochemical flow through tests are performed.

A better link with the geothermal community needs to be made for this work to be more relevant.

PI Response:
There project team will continue to make more of an effort to engage the broader geothermal community.

Reviewer 23446

Comment: No suggestions. Interesting project.

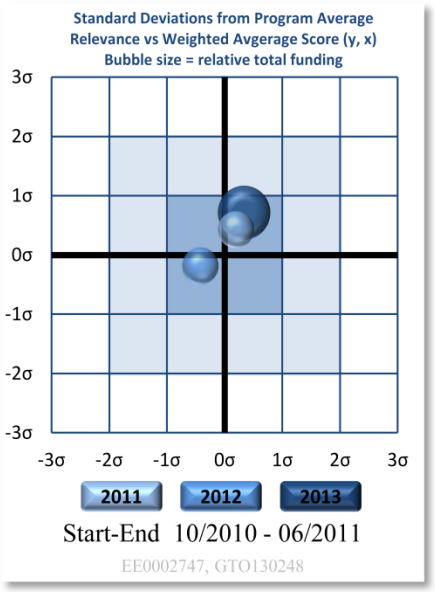
PI Response:
N/A

Reviewer 23579

Comment: Establish and foster collaboration with scientists from such groups as: (1) LBNL, who are working on coupled reservoir simulation models and on fracture mechanisms for microseismic studies, (2) LLNL, who are working on geothermal reservoir geochemistry, (3) the USGS, who are working on both of the preceding topics, and (4) EGI/University of Utah, who have access to a comprehensive storage library of core from geothermal areas and who have examined cores and cuttings from most of the world's geothermal areas. These organizations are only a sample of those that might be recruited for collaboration or for an advisory committee.

Reach out to researchers not necessarily involved in the geothermal industry who are working on subsurface fluid flow problems. One such person who could be recommended is Dr. Paul Meakin at the Idaho National Laboratory.

PI Response:
Great feedback. We appreciate the specificity and will follow up.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002747
Project: Characterizing Fractures in Geysers Geothermal Field by Micro-seismic Data, Using Soft Computing, Fractals, and Shear Wave Anisotropy
Principal Investigator: Aminzadeh, Fred
Organization: University of Southern California
Panel: Fluid Imaging; Characterizing Fractures; Induced Seismicity

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23533

Score: 8.0

Comment: Could improve the efficiency of using microseismic data
Considers change with time
Using fractals, able to distinguish induced vs. triggered events
Using geostatics, able to enhance resolution

PI Response:
Thanks for the positive comment. As mentioned by this reviewer, we tried to use microseismic data in an efficient way to extract as much information from them as possible. We demonstrated how such data can be used to characterize the fracture network over 5 years times period, thus providing a better understanding of the fracture network geometry, connectivity, and density. Our technical analysis of microseismic data involves extracting the information content about the events, such as their size, relationship to other events, attributes, using both geostatistics, tomographic inversion, and fractal geometry.

Reviewer 23526

Score: 7.0

Comment: The general technical area of characterization of fractures is highly relevant and has the potential to be impactful.

PI Response:
Thanks for the positive comment. We are also hopeful that this critical insight allows the EGS develpoment plan to be refined and stimulation treatment to be optimized. Our methodology also provides useful tools for long-term improvements to the well spacing plan, the well planning design, and the completion design.

Reviewer 23446

Score: 10.0

Comment: Linking reservoir properties to volumetric imaged data is important. Recovering a full suite of parameters from these data are important to EGS development – especially if these include moduli, densities, porosities, permeabilities and apertures for fractures.

PI Response:
We thanks for the positive and supportive comment and the perfect score.

Reviewer 24862

Score: 8.0

Comment: Although obvious for the reviewer, the presentation did not establish a clear connection between the project achievements and the GTO's goals and mission (as identified in Multi-Year Research, Development, and Demonstration Plan (MYRD&D).

PI Response:
Thanks for the positive comments. We did our best to overview the new acheivments after the last meeting. Although we put some supplementary slides to cover the previous goals and acheivements. In our presentation, we clearly mentioned the acheivemnts for autopicker, fractal analysis, velocity modeling, rock and fracture property mapping, and ansitropy mapping.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23533

Score: 9.0

Comment: Use multiple approaches, sometimes overlapping to improve accuracy
Poor oral presentation, difficult to follow the logic, at least for this reviewer

PI Response:
We did our best to cover lots of results in the limitted available time. This was made more challenging by the diversity of both the technical disciplines covered and the experince and technical background of the reviewers. In the future, we will try to improve upon both the content and the delivery of the presentation. As mentioned by this reviewer, the successful integration of different methods helped us clarify our hypothesis. Thishelps reduce the errors that may arise in locating the fractured areas and may help us target the stimulated area for future development plans.

Reviewer 23526

Score: 4.0

Comment: The approach, as presented, applies/developed an autopicker and analysis of MEQ data, then attempts to develop velocity maps and then relates them to rock/fracture properties. I wasn't convinced that the proposed methodology provides any correlates measure of reservoir performance or parameters,

PI Response:
I wish I clarified this better during the presentation. Figure on slide 9 shows that regions with higher fracture density anomalies (such as low VP and low shear moduli as discussed) correlate with higher steam production with relatively low water injection levels. This finding is consistent with our hypothesis and theory from the preceding discussions in our annual report. We are also able to use bulk and shear moduli distribution to identify the fluid types and a degree of fluid saturation as discussed in the presentation. It should be emphasized that as we discuss further below, most of the modeled properties are only indicative and at best and can be used qualitatively.

To elaborate further, the geomechanical properties have been modeled based on well defined theoretical models. The issue, however, is the difficulty in-applying some of the defined models (such as stress relationships) for a complex "non-sedimentary" system which makes up the Geysers field. The possible solution is to use effective media theory to redefine the relations by taking presence of fractures (and their impact on properties) into account. Variability in density was modeled using geostatistical approaches and the impact of said variability on the elastic properties was identified as insignificant. While this concept may be investigated in the future, due to the limited resources (we have been in no cost extension mode for several quarters), looking into the effectice media theory or other methods would be beyond the scoope of this project.

Reviewer 23446

Score: 9.0

Comment: Using MEQ data from Geysers. Use these data form zoned regions to extract relevant data. Using fuzzy methodology to define azimuthal velocities and constrain velocities and use these velocities to link to other parameters of density, porosity, permeability, etc.

PI Response:
Thanks for useful comment. We are hopeful that opertors use this understanding and methodology as a tool for EGS develpoment, long-term improvements to the well spacing plan, the well design, stimulation and the completion design.

Reviewer 24862

Score: 7.0

Comment: Staffing shortage was acknowledged by the PI.

PI Response:
Thanks for the understanding of the fact that we are on a no cost extension mode and most of the accomplishments for this quarter were under-funded.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23533

Score: 9.0

Comment: Good, even though was unable to attract post-doc

PI Response:
Thanks for the understanding of the fact that we are on a no cost extension mode and most of the accomplishments for this quarter were under-funded. At the time of writing this, we have secured a post doc with strong seismology and geothermal background. Obviously, she will play a role in future projects to be proposed to extend some of our results with the necessary enhancements.

Reviewer 23526

Score: 4.0

Comment: The accomplishments seemed largely overstated in comparison to their actual content. The analysis seems to rely on a number of constitutive relations and ad hoc observations, to produce maps of physical properties. For example, a number of the relations presented rely on the density. Is the subsurface all of a uniform density? What is the density of a fracture? How do you honestly provide a volume averaged measure of fracture aperture? No presentation is given relating the qualitative and constitutive calculation back to measurable fluid flow measurements.

PI Response:
Just as the velocities that have been predicted at any discrete location within the study area are an averaged estimate of a predefined volume (based on inversion parameters), the elastic properties that are estimated can also be considered averaged values of said grid volumes. Fractures and variations in microstructures that might be expected within sandstone reservoirs and/or fractured metamorphic or crystalline deposits have an impact on the computed elastic properties due to variations in said structure and to the presence of different fluid types within the pore space. Theoretical models on the effect of fractures–including their anisotropy–have been studied over the years and are available, including many studies on effective medium theories (EMT), which deal fractures in non-porous media. However, due to the absence of good estimates of fracture properties and anisotropy within the study area, using complicated theoretical models that map such affects is not possible. For a detailed discussion of elastic wave propagation in cracked media, refer to a recent monograph titled Mechanics of Crustal Rocks; 2012 (Leroy and Lehner, 2012).

Therefore, within the confines of inaccuracies due to inversion schemes, data quality, effect of rock fabric anisotropy, fractures, and so forth, the elastic properties should be usable for qualitative analysis and interpretations made in this project. Future work should look into more complex models based on data availability and some work needs to be conducted to find the optimal model and the specific properties required to apply said EMT models.

To define the elastic moduli in the medium, we integrate P-wave and S-wave velocity volumes with each other and with density volumes created from lithology logs. Figure in slide 8 shows the created 3D density volume at the NW GGF.We identify five major rock types in this area which are color coded, then assign constant density to each type of rock. Notably, There are two major uncertainties in this assumption: First, each rock type has a range of recorded density with respect to its location and condition; for instance, the grain densities of the graywacke have a median value of 2.71 and a weighted average of 2.72, with a standard deviation of 2.5 percent. Second, geologic features–such as intrusion of bottom formation into the top– create higher degree of uncertainty in locating different rock types. The latter enables the presence

of other rock types in the known formation that was detected from limited lithology logs. Because of these uncertainties, we carry out statistical simulation runs to generate an adequately large number of density realizations to test the effect of the variability ofdensity in the computation of elastic properties that make use of density values as per defined relations. For this purpose, we test our methodology on the horizon located at 1.2 km below sea level 6. This depth corresponds to the location of the normal temperature reservoir (NTR) where most of injection and production wells have steam entries. There are two rock types in the NTR: crystalline ”felsite” with a density of about 2.63 g/cc, and metamorphic graywacke, with a density around 2.7 g/cc. According to the available lithology logs, felsite density is only in the southern portion of our study area. The uncertainties in density estimates made by using lithology logs are deemed insignificant in the horizon of interest due to the high presence of graywacke formation, which is known to have a nearly constant density of around 2.7 gr/cm3 (Satik et al., 1996; Gunderson, 1992). This horizon is affected by felsite intrusion; hence, lithology variations, including crystalline felsite of lower density with the metamorphic graywacke is the main reason for density uncertainty in this horizon.

We use Sequential Gaussian Simulation to generate 1000 density realizations for our study area.. From our results from all density-dependent properties–we observe that substantial changes within the range of interest in density values over the spread of the horizons do not create major changes in the actual elastic moduli values. Moreover, even with substantial variations in density, qualitative interpretations from the results should be reasonably accurate. We submit that the variations observed with the target properties are in the same order of magnitude as those observed with density variability. This finding indicates that errors due to density variations should not have a substantial impact on the final property maps for qualitative–and some degree of quantitative–evaluation due to the lower impact of density (degree of 1) compared to phase velocities (degree of 2) as well as relatively small density variability (2:1%).

To further validate the relatively small property variation as a result of varying density maps, we have computed difference maps for the mapped properties. We observed from results that as expected, the difference maps follows the same trend as the density realization (because the second density used in computation is a constant baseline map). Also, the maximum difference observed for the all of properties stays below 5%. Thus using constant density for a major portion of the horizon of interest should allow us to make a qualitative interpretation.

Reviewer 23446

Score: 8.0

Comment: Provided maps of these parameters over the full extent of the site.

PI Response:
Thanks for the positive comment, we are hopeful that opertors use this understanding and methodology as a tool for EGS develpoment, long-term improvements to the well spacing plan, the well design, stimulation and the completion design.

Reviewer 24862

Score: 9.0

Comment: Considering the shortage of staff, a high level of productivity is shown. The quality of work appears to be high.

PI Response:
Thanks for good comment and high score. We are hopeful that opertors use our acheivments as a tool for EGS develpoment, long-term improvements to the well spacing plan, the well design, stimulation and the completion design.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23533

Score: 6.0

Comment: Unable to comment, but very little collaboration was evident

PI Response:
We expect to show increased collaboration (especially with our partner Calpine) during the next period.

Reviewer 23526

Score: 3.0

Comment: For the amount of funding awarded, the project doesn't seem to have produced much of value. I see the DOE share of $1,500K, and cost share of another $650K, and only two full time students being supported. Where are all these funds going, given that LBNL and Calpine are unfunded collaborators? Are we to believe that the three listed USC team members work in this full time? If so, I'd expect much more than what was presented.

PI Response:
Some clarification on the staffing is in ordre. As the project proposal indicates and our budgeting follows, the project included several gradutes students, two faculty members (Prof. Sahimi and Prof. Sammis, who contributed to the frcatl analysis, and b-value analysis) and the PI who did the coordination and contributed to virtually all the technical accomplishments. The funding for the post-doc was used for additional faculrt (David Okaya) and others. Out of $1500K DOE funding $150K was subcontrcated. Most of the cost sharing from Calpine was in the form of provision of data. The rest includes cost share work to be reported in the next meeting. From the $1350K Doe funding, after university ovehead of 65%, about $480K went to actula resercah for both the faculty and students for about two years. (Roughly $240K/year). The university overhead is partially counted on the cost share (some of it in the form of tution for the students). As a few of other reviewers correctly point out, the volume of the accomplishments far exceeds the actual funds used on the project.

We have develpoed the new autopicker that use noise based classification for fuzzy segmentation and hybrid Neuro-fuzzy autopicking. It has improved applicability and efficiency over current technology.

We offered an innovative method for monitoring the fracture movement in different stages of stimulation that can be used to optimize the process. We applied fuzzy logic concept in clustering the microseismic data to find the fracture network areas. Fuzzy cluster centers may represent centers of the connected fracture network which are ideal for reservoir creation and for enhancing production.

We offered an effective way to obtain the fractal dimension of microseismic events and identify the pattern complexity, connectivity, and mechanism of the created fracture network. This results indicate that the spatial distribution of hypocenters of microseismic events provide deeper insight into the structure of the fracture network of large-scale porous media. In addition, the results indicate that by calculating the fractal dimension of a microseismic cloud we may identify whether stimulated microseismic data are triggered (tectonic) or induced. Hence, we may find an explanation for changes in observed fracture behavior or determine if those changes might be caused by the presence of nearby faults (tectonic) or by contact with the fracturing treatment (induced). Determining the fractal behavior of microseismic event clouds in

different stages of stimulation and their dimensions, allows us to assume that the fracture network at the underlying unconventional reservoir is self-similar (scale independent), and thus that its structure, mechanical, and transport properties are best described by using fractal geometry.

With significant results from Geysers, we claimed that b-values of microseismic events can ascertain if the those that are stimulated have been triggered or induced. In other words, we can differentiate fracture-related events from fault-related ones in real-time; a microseismic cloud with b-value larger than 1.2 is induced and not tectonic, and higher b-values mean lower stress.

We offered an improved procedure to create compressional and shear velocity models as a preamble for delineating anomalies and map structures of interest and to correlate velocity anomalies with fracture swarms and other reservoir properties of interest. We also demonstrated how integrating with production = injection data and fuzzy clustering can help us clarify our hypothesis, which relates the velocity and stress anomalies to the propagating fracture network. Moreover, we demonstrated that integrating the passive seismic tomography with density information allows us to detect the space-time dependency of elastic properties and stress in response to local variations of fluid pressure or fracture creation.

Reviewer 23446

Score: 9.0

Comment: ok

PI Response:
Thanks for postive comments.

Reviewer 24862

Score: 7.0

Comment: Seems to be reasonably managed

PI Response:
Thanks for positive comments.

STRENGTHS

Reviewer 23533

Comment: Covers many aspects and scientific approaches

PI Response:
Thanks for positive comments. Indeed given the complexity of the probkems we tackle, we did need to cover many different components of the problem using different tools and approaches.

Reviewer 23526

Comment: Based on what was submitted and presented, I don't find many strengths to this project

PI Response:
The work provides some novel processing and interpretation workflows to maximize the amount of usable information from local MEQ surveys. For geothermal systems (which are highly dependent on passive monitoring), the new workflows provide relatively easy ways of identifying geomechanical anomalies which in turn allows for improved reservoir modeling as well as well/ field design and development. New autopicking workflow should enable improved phase detection and should be useful in optimizing the overall "data collection - processing - inversion" cycle and improve our understanding of the observed seismicity.We have develpoed the new autopicker that use noise based classification for fuzzy segmentation and hybrid Neuro-fuzzy autopicking. It has improved applicability and efficiency over current technology.

Reviewer 23446

Comment: Volume filling measurements of key parameters of permeability and apertures are necessary attributes for geothermal reservoirs of all types and EGS reservoirs in particular. Able to show changes in behavior over a 5 year period as a time lapse response for the site. Correlations of seismic “b” value and fractal dimensions are interesting.

PI Response:
Thanks for the positive comments, As it is correctly pointed out the ability to highlight changes in the reservoir behavior with time, based on the MEQ data is an important aspect of this poject.

Reviewer 24862

Comment: A validated auto-picker will significantly improve quality and timeliness of MEQ locations. Relating MEQ velocities to rock properties and fractures provides much needed information on the details of the reservoir development.

PI Response:
Thanks for the comments. As you mentioned, our new autopicker-use noise based classification for fuzzy segmentation and hybrid Neuro-fuzzy autopicking- has improved applicability and efficiency over current technology.

Just as the velocities that have been predicted at any discrete location within the study area are an averaged estimate of a predefined volume (based on inversion parameters), the elastic properties that are estimated can also be considered averaged values of said grid volumes. Fractures and variations in microstructures that might be expected within sandstone reservoirs and/or fractured metamorphic or crystalline deposits have an impact on the computed elastic properties due to variations in said structure and to the presence of different fluid types within the pore space. Theoretical models on the effect of fractures–including their anisotropy–have been studied over the years and are available, including many studies on effective medium theories (EMT), which deal fractures in non-porous media. However, due to the absence of good estimates of fracture properties and anisotropy within the study area, using complicated theoretical models that map such affects is not possible. For a detailed discussion of elastic wave propagation in cracked media, refer to a recent monograph titled Mechanics of Crustal Rocks; 2012 (Leroy and Lehner, 2012).

Therefore, within the confines of inaccuracies due to inversion schemes, data quality, effect of rock fabric anisotropy, fractures, and so forth, the elastic properties should be usable for qualitative analysis and interpretations made in this project. As you mentioned, future work should look into more complex models based on data availability and some work needs to be conducted to find the optimal model and the specific properties required to apply said EMT models.

WEAKNESSES

Reviewer 23533

Comment: No validation with core lab measurements

No validation with in-situ stress measurements

PI Response:
It is true that validation with cores or in-situ stress measurements were not made as access to said data was absent. Moreover, the current project did not envision such validatory tests as part of the proposed work. Finally, the number of sample points required for a reasonable correlation between predicted and actual in-situ properties is very high and a detailed program will be required to develop such a correlation. Due to perturbations within the reservoir (continuous fluid injection & production), the geomechanical properties are subject to considerable change and therefore, such a study will be very holistic and will require adequate planning and resources.

We used lithology logs, laboratory measurement of rock properties in integration with effective medium theories, and production/injection rates to better understand the fracture network evolution and to locate regions with potentially higher fracture density. We used core measurment at the Geysers which were analyzed by Boitnott in 2003. We used them as fundumental understanding and validation for our results. His core measurements at The Geyers shows that VP negatively correlates to porosity. Notably, different lithologies demonstrate dissimilar trends. Some with a wide range of velocities are confined to a narrow range of porosities, whereas some have a wide range of porosities are confined to a narrow range of velocities, and some show a strong correlation of velocities to porosities. They also illustrates that seismic velocities are insensitive to pressure, persisting to high effective pressures.

Core measurment also confirmed the apparent signature of saturation on bulk and Shear modulus. Saturation effects include an increase in Bulk modulus and a reduction in Shear modulus. Shear modulus reduces due to rock-water interaction. Our results and interpretation have been validated using these observation. Unfortuantley, there is no in-situ stress mearuemnt available for validation. Thanks for your comments again.
Reviewer 23526

Comment: See the previous comments, seems largely based on qualitative measure and gross, over simplified parameter estimates. No quantitative or predictive capabilities.

PI Response:
We were able to quantitavley measure the fracture apperture, Bulk, Shear, and Young moduli. These values also confirmed with some laboratory measurements and CT scan of core measurement performed by Stanford which will be peresented in final report. In addition, we quantify the compelxity of the fracture newtork at the Geysers using fractal analysis. If fractures nucleate and grow more or less at random in a highly heterogeneous medium, such as large-scale porous formations, then they should form a network of interconnected fractures that resembles what is called a percolation cluster (Stauffer and Aharony, 1994; Sahimi, 1994), i.e. a cluster of (more or less) randomly distributed interconnected fractures that percolates between two widely-separated planes. To describe this phenomenon in more intuitive but physically understandable basis, we appeal to the critical path analysis (CPA) first developed by Ambegaokar et al. (1971) and confirmed by many sets of simulations. They argued that transport processes in a highly heterogeneous medium can be reduced to one in a percolation system at or very near the percolation threshold. The idea is that in a medium with broadly distributed heterogeneities, a finite portion of the system possesses a very small conductivity, hence making a negligible contribution to the overall conductivity or other effective flow or transport properties. Therefore, zones of low

conductivity may be eliminated from the medium, which would then reduce it to a percolation system. Ambegaokar et al. (1971).

Described a procedure by which the equivalent percolation network, called the critical path, is built up. They showed that the resulting percolation system is at or very near its percolation threshold. When applied to heterogeneous fractured rock (Sahimi, 2011), CPA suggests that the fracture network must have the connectivity of a percolation cluster because, for example, the fractures are the main conduits for fluid flow in rock as their permeabilities or hydraulic conductances are much larger than those of the matrix in which they are embedded. Using the procedure of Ambegaokar et al. (1971), one finds that the fracture network of rock must be at, or very near, its percolation threshold.

Our estimates of the fractal dimensions listed in presetation deviate from that of the sample-spanning percolation cluster by, at most, 4%, well within the estimated errors, but not close to that of the percolation backbone. Thus, the seismicity induced by cold water happens on a fracture network that is similar to the 3D samplespanning percolation cluster, whereas the tectonic events occur on the backbone of the fault network. The reason is that when cold water is injected into the GGF, the path the fluid takes within the porous formation and the fractures that it generates within the rock are, due to the heterogeneity of the formation, random. Even if the path is not random but contains extended correlations, the structure of the cluster at the largest length scale should still resemble that of a percolation cluster. The cold water generates some fractures that are dead-ends, because the growth of such fractures stops only when the pressure of the water cannot overcome the resistance offered by the rock. As a result, the network generated by the injection contains both dead-end as well as multiply connected fractures, i.e., the sample-spanning percolation cluster. This knowledge can, therefore, be used for realistically modeling a fracture network of the GGF.

We are also really hopeful that opertors to use our acheivments as a tool for EGS develpoment, long-term improvements to the well spacing plan, the well design, stimulation and the completion design.

Reviewer 23446

Comment: Not clear if the loop-is-closed on prediction versus comparison with field data. Time lapse view shows changes but not clear what the absolute fidelity of the conversion from raw data to distributed parameters is.

PI Response:
Indirect comparisons with field data have been made through the known production/ injection data from the wells within study area. While these observaitons were used to validate observed changes in the observed properties, a more holistic approach involving in-situ data has not been used. A major source of uncertainty comes from the inversion workflow itself (which includes intrument issues, phase arrivals errors, inversion errors, algorithmic limitations, etc. to name a few). To add to these errors, we also have prediction errors from geostatistical estimation workflow. We calculate the effective normal stress , confining stress, Poisson's ratio, Bulk modulus, Young's modulus, and Shear modulus volume to fully characterize the fracture network. These distributed paramerters are better representative of fracture network properties than raw velocities.

Most induced fractures in tight reservoirs are either created through an hydraulic fracturing process, such as shale reservoir, or through a thermal contraction process, such as The Geysers. At The Geysers, water is not pumped into the reservoir under pressure, but "free falls" down the well bore to the reservoir level. Limited reservoir pressure results from the development of a standing water column near the base of the well, but is generally insufficient to initiate fracturing. Stark (1990) reported that most seismicity in The Geysers geothermal field is related to cold water injection due to a thermal contraction process. The cold fluid injectate interacts with hot rock causing contraction at and near fracture surfaces. Rutqvist et al. (2006) reported that evaporation cooling with contraction reduces both effective stress, and static

friction, triggers slip along planes of weakness, and results in the slight opening of fracture. We can use the effective normal stress as an index for fracture opening, which is essential to fluid movement and production.

Saturation effects include an increase in Bulk modulus and a reduction in Shear modulus. Shear modulus reduces due to rock-water interaction. The low frequency Biot-Gassmann theory (Biot, 1956; Boitnott, 2003) explains the changes in Shear modulus as due to void geometry with resolution control of the stress field at the void space scale. Berge et al. (2001) used the same theory to predict the dry Bulk modulus for rocks with different void ratios. Increasing the void ratio significantly reduces the Bulk modulus especially for thin cracks or fractures. Moreover, Barton (2006) stated that a set of moduli decreased because of micro displacements of the fractures. In partly saturated fractures, this reduction is more significant. He also reported that Young's modulus in fractured rock decreased exponentially with fracture density.

Reviewer 24862

Comment: The effect of temperature on rock property correlations doesn't seem to be considered. Most likely, site-specific correlations will have to be developed. Also, independent verification of the velocity model (i.e. passive seismic) will lead confidence as well as providing a reliable starting point. A discussion of resolution/accuracy would help interpret the model results.

PI Response:
The effect of temperature on rock property estimates have not been considered and was not part of the original DOE workplan and associated deliverables. However, it will be looked into in our future work. In order to independently verify the observed phase velocities, sonic logs would be requierd which were not made available for any of the available wells.

IMPROVEMENTS

Reviewer 23533

Comment: Technique relies only on velocity measurements; how do we switch from dynamic properties to static properties?

PI Response:
The geomechanical properties modeled in the study were based on both dynamic and static property estimates (phase velocities, densities, etc.) and as such are dynamic themselves. The elastic proeprties within the "perturbed" zone varies with time (with water injection/ steam production). We obtain seismic velocity models from microseismic data. Therefore, we consider inherent dynamic changes through time, using microseismic data created from fracture network.

Reviewer 23526

Comment: Not sure what to say here. Reviewer suggests bringing the analysis back to measurable parameters such as pressure or temperature.

PI Response:
We will definitely consider that for any possible future work.

Reviewer 23446

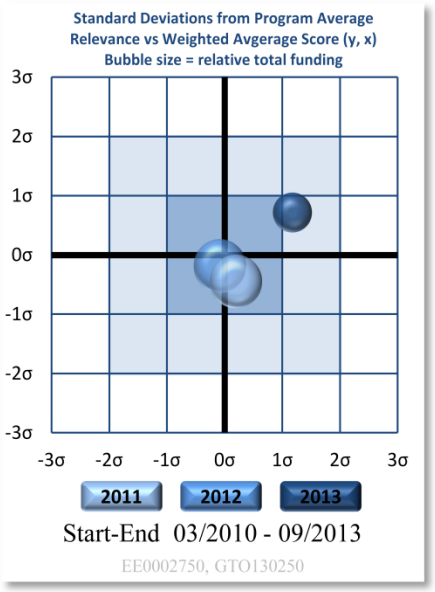
Comment: Comparison with field data in as rigorous a way as possible would be useful. For example, predictions of permeability and aperture together with core view of fracture spacing could be used to link predicted permeabilities and predicted apertures independently of the correlations used. The need to compare final results with what is in place may have been done but was not presented.

PI Response:
A comparative study involving field data has not been conducted at this stage. The project team will look into designing sain comparative study in the future to independently validate the predicted geomechanical properties. We will definitely consider that for any possible future work. This value also confirmed with some laboratory measurments and CT scan of core measurement performed by Stanford which will be peresnted in final report.

Reviewer 24862

Comment: Relate with other ongoing EGS projects. The effect of temperature on rock property correlations should be addressed. Independent verification of the velocity model (i.e. passive seismic) will lead confidence as well as providing a reliable starting point . A discussion of resolution/accuracy would help interpret the model results.

PI Response:
We will definately consider that for any possible future work.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002750
Project: Fracture Network and Fluid Flow Imaging for Enhanced Geothermal Systems: Applications from Multi-Dimensional Electrical Resistivity Structure
Principal Investigator: Wannamaker, Phillip
Organization: University of Utah
Panel: Fluid Imaging; Characterizing Fractures; Induced Seismicity

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23479

Score: 7.0

Comment: This is a focused technology-development effort by a capable team at the University of Utah/EGI. The goal is to develop an improved 3D topographic-correction model for resistivity data.

PI Response:
N/A

Reviewer 23434

Score: 9.0

Comment: The project "Fracture Network and Fluid Flow Imaging for Enhanced Geothermal Systems: Applications from Multi-Dimensional Electrical Resistivity Structure " is a highly relevant project with a potentially large impact on the future of geothermal energy exploration. By improving electrical resistivity measurements, a more accurate understanding of subsurface structure can be developed, which will eventually lead to improved success rates of green and brown field development.

PI Response:
N/A

Reviewer 23446

Score: 8.0

Comment: Electrical resistivity mapping is one way to probe reservoirs for high perm zones and to conduct active experiments in time lapse. Showed example of how topographic corrections are necessary and are a significant effect on the resulting constraint of the (low) resistivity zones.

PI Response:
N/A

Reviewer 23583

Score: 9.0

Comment: For the most part I agree with project's major premise that "Electrical resistivity is one of the prime indicators of geothermal processes...", though I don't agree with the word "prime", I definitely agree with the statement that "...the imaging problem is ill-posed, inflexible in representations, and has been slow and costly". I could add other problems with electrical methods such as, the uniqueness of solutions and lack of a believable uncertainty estimates, but that is another research topic. That being said, there is no doubt that achieving project's objectives of addressing technical barriers for electrical methods, reducing costs for implementations and analyses, and improving accuracy, scalability, speed and spatial resolution, is in every aspect perfectly aligned with GTO/EGS's broader mission and goals.

PI Response:
N/A

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23479

Score: 8.0

Comment: The PI notes that dramatic increases in computational power have made feasible the use of direct (non-iterative) solvers, and that direct solvers have certain advantages in terms of stability(?) and accuracy.

The PIs will exercise the improved model on resistivity data from Cove Fort, Utah, and Kahara-Telega Bodas, Indonesia. These two cases are strategically selected to represent a wide range of rock and fluid types and (in both cases) dramatic topography.

PI Response:
The two systems we will analyse is pending final decision.

Reviewer 23434

Score: 9.0

Comment: The project utilizes important developments outside of what might be thought as the traditional geothermal/geophysical realm. First, by developing algorithms and solution techniques that are specifically optimized for today's reasonably priced personnel 'super computers' (i.e. a multi-core personnel computer with high level of RAM and processors) professor Wannamaker and his research team are improving the chance of success with the high-fidelity models that they are using. The high-fidelity finite edge with deformable grids is another technical approach that is highly intelligent. By linking the grid structure to the sub-surface structure solutions to the resistivity can be generated that are less likely to have spurious errors from a disconnect between the grid and the sub surface structure. Both of these approaches are well reasoned and appropriate.

PI Response:
N/A

Reviewer 23446

Score: 9.0

Comment: Develop a computational tool to allow the effects of topography to be included – this includes structured meshes with grading between element sizes and topologies and finite element rather than finite difference protocol. PI notes that it is mainly a technology/tool development.

PI Response:
N/A

Reviewer 23583

Score: 10.0

Comment: The technical approach is both innovative and scientifically rigorous, but, best of all, it is imminently applicable with useful results at Coso and Raft River. The technical approach was highly successful due to the excellent team of PI Wannamaker leading Kordy, and Maris. Results presented clearly made the case for improved imaging resolution and algorithm efficiency and speedup. This is due to, I believe, a topnotch research team with a unique combination of skills, knowledge and expertise in new multi-core direct solvers, deformable hexhedral elements, and Gauss-Newton direct parameter solvers. Execution of the research approach as well as methods employed were of the highest scientific caliber, achieving and demonstrating significant, practical and valuable results.

PI Response:
N/A

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23479

Score: 8.0

Comment: A series of convincing examples demonstrates (1) the distorting effect of topography when ignored and, using a series of synthetic examples (2) the abilities of the model under development.

PI Response:
N/A

Reviewer 23434

Score: 8.0

Comment: Accomplishments: The development of the code to this point is a definite accomplishment, but I think there will be many more higher profile accomplishments in the very near future as this code is put to greater use. The flexibility of the code and potential for improved understanding of subsurface resistivity under extreme surface topologies will warrant revaluation of multiple sites where data has already been collected.

Results: To date, the results are impressive. The results of the code performance in the parallel environment it was developed for are very good to see. The improved measurements of synthetic data are impressive. Again, I would like to see the results in a couple of months, as I think this project is on the edge of fully blossoming.

Progress has been good. There appears to have been a fairly major setback early on in the project when the focus was on using the Loki-3D platform, but that has been overcome and it appears that the rapid progress in the last couple of months will continue to the end of this project at the end of FY13.

PI Response:
N/A

Reviewer 23446

Score: 8.0

Comment: Has developed/is developing the promised software.

PI Response:
N/A

Reviewer 23583

Score: 10.0

Comment: Clearly, significant progress has been made towards stated project objectives. Theoretical methods and techniques were created and developed, codes were written and tested, and useful results obtained and delivered. Results presented convincingly demonstrate improved feature imaging resolution and enhanced algorithm efficiency and runtime speedup. The project's substantial accomplishments are, no doubt, a consequence of the research team's productivity in development, execution and application. This project's impact on subsurface reservoir imaging will be substantial.

PI Response:
N/A

PROJECT MANAGEMENT/COORDINATION

Reviewer 23479

Score: 9.0

Comment: Please see comments elsewhere.

PI Response:
N/A

Reviewer 23434

Score: 10.0

Comment: The project management of "Fracture Network and Fluid Flow Imaging for Enhanced Geothermal Systems: Applications from Multi-Dimensional Electrical Resistivity Structure " by Phillip Wannamaker seems excellent. The research time seems bright and capable, the goals are being achieved even when hardship is encountered and the research is on track to be completed within budget by the end of the year.

PI Response:
N/A

Reviewer 23446

Score: 9.0

Comment: ok

PI Response:
N/A

Reviewer 23583

Score: 9.0

Comment: PI's leadership and research team's prowess contributed importantly to the project's success. Schedule and scope were carried out within budget and on track with the original plan. This is especially noteworthy when one considers the 3 month project start date delay. Early on in the project, around June of 2012, the research team had a decision point as to which forward model approach to use, either EFD or Loki, but neither were selected and they decided instead to pursue edge E finite elements. In hindsight, this decision was significant because it had a very favorable impact on successful of the final outcome. Coordination of activities with stakeholders was obviously a success in view of the fact that results obtained were incorporated in at least one of the demonstration projects as one of their "significant results".

PI Response:
N/A

STRENGTHS

Reviewer 23479

Comment: The PIs are capable and are making good progress. This project will yield significant papers and a useful new tool for community use.

PI Response:
N/A

Reviewer 23434

Comment: I feel a real strength of this research is how forward thinking it is. In thirty years it is likely resistivity measurements will be performed from the air, whether that is from multiple drone aircraft or more standard air vehicles. This research is providing the groundwork for the algorithms and techniques that will be used to accurately process the data obtained by these air measurement systems.

But, while the thoughts are to the future, the ability to improve the reconstructions of measurements that were taken in the past is also a possibility. This research is very strong.

PI Response:
N/A

Reviewer 23446

Comment: ok.

PI Response:
N/A

Reviewer 23583

Comment: Project's objectives are perfectly aligned with GTO/EGS's broader mission and goals. The technical approach is both innovative and scientifically rigorous and was highly successful due to the excellent research team. Results presented showed improved imaging resolution and algorithm efficiency and speedup with significant progress made towards stated project objectives. This project's impact on subsurface reservoir imaging will be substantial. Schedule and scope were carried out within budget and on track with the original plan and a critical decision made early on, had a very favorable impact on the success of the final outcome. Coordination of activities with stakeholders was handled well, given that results obtained were incorporated in at least one of the EGS demonstration projects as one of their "significant results".

PI Response:
N/A

WEAKNESSES

Reviewer 23479

Comment: This is a useful project. However, improved topographic corrections for resistivity data are arguably a second-order issue in terms of the future of geothermal resources and EGS; lack of such a tool is probably not what inhibits EGS development. For instance – the Coso example featured in the review presentation was done without any topographic correction at all (flat-Earth inversion), yet yields clears and interesting correlations between resistivity, temperature, and seismicity. Although the topography at Coso is perhaps not "drastic", most potential EGS sites probably don't have much more topography than Coso.

PI Response:
The second phase of Coso collection (by contractor Geosystem for TerraGen) goes over much more severe topo to the west. But I agree, many factors go into a successful EGS system.

Reviewer 23434

Comment: I couldn't see any, but this is not my strongest area.

PI Response:
N/A

Reviewer 23446

Comment: Improvement of this particular finite element (FE) model over finite difference (FD) models with ragged edges not apparent to the casual viewer but may be important.

PI Response:
The EE example of scattering from a rough wire model was a clear example of potential problems.

Reviewer 23583

Comment: None.

PI Response:
N/A

IMPROVEMENTS

Reviewer 23479

Comment: Please see comments elsewhere.

PI Response:
N/A

Reviewer 23434

Comment: Expanding this to more than two geothermal fields would be nice to see. One thing that was mentioned in the review was doing a fairly flat site to ensure that the new code is replicating the same reconstructions when topology is not critical. I think that would be a grand idea.

PI Response:
We plan to check against flat models. Pending support, we have several other systems in mind worth re-examining. Apart from the topo capability, the high accuracy of direct solutions motivates our development.

Reviewer 23446

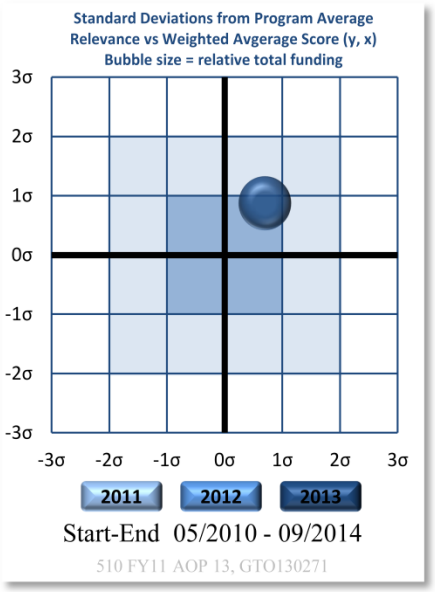
Comment: ok

PI Response:
N/A

Reviewer 23583

Comment: None.

PI Response:
N/A



Review: 2013 Geothermal Technologies Office Peer Review
ID: 510 FY11 AOP 13
Project: Advanced 3D Geophysical Imaging Technologies for Geothermal Resource Characterization
Principal Investigator: Newman, Greg
Organization: Lawrence Berkeley National Laboratory
Panel: Fluid Imaging; Characterizing Fractures; Induced Seismicity

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23583

Score: 9.0

Comment: The overall premise of this project, that effective geothermal resource characterization is critical in furthering both hydrothermal and EGS development has strong alignment with GTO's broad mission and goals. Specifically, the purpose of this project, to develop improved geophysical imaging methods to identify subsurface structure, fluid locations, and characterizing fractures, if successful, will advance resource characterization technology and directly address this key technical knowledge gap. Applying this new method to four sites: Krafla, Hengill, Krysuvik fields in Iceland and Coso in the United States increases the likelihood of adoption and partnering with industry, academia and the national laboratories improves the probability of a successful commercialization.

PI Response:
Acknowledged

Reviewer 23434

Score: 9.0

Comment: The improvement of geophysical imaging is critical for the characterization of subsurface structure, and this project is linking together an improved methodology to do just that.

PI Response:
Acknowledged

Reviewer 23479

Score: 8.0

Comment: This project aims at joint inversion of seismic and electromagnetic data in order to image subsurface conditions.

PI Response:
That is correct aim of the project, but we further seek to use the results to produce a geophysical tool that can be useful in predicting geothermal fluid concentrations and be used for identifying economical geothermal drilling targets.

Reviewer 23579

Score: 8.0

Comment: This project seeks to use joint inversion of microseismic data and electromagnetic data to sharpen the subsurface picture of seismic velocities and electrical resistivities, which can then be better related to the geology and geochemistry of a geothermal occurrence. The joint inversion of various types of data sets is a promising area for research which has been supported for a number of years. That support should continue. Inversion schemes are generally difficult mathematically and can require long computer runs on the best machines. Joint inversion of two data sets is an even bigger problem. The ability to run more and more complex models has been growing with the memory size and computational speed of computers, and this shows no signs of slowing in the near future.

Ideally we are ultimately working toward the capability of using geological, geochemical, geomechanical, temperature and other constraints to jointly invert multiple sets of remotely sensed electrical, seismic, magnetic, gravity and other types of data, along with visualization techniques to display the results and work with them in real time. No doubt such a capability would materially enhance our ability to pick drill targets, design stimulation programs, avoid damaging induced seismicity, and solve many other problems in geothermal development and utilization. At the moment, it might sound grandiose to envisage the joint inversion of, perhaps, five data sets, but we should aim high.

PI Response:
While we are currently focusing mostly on the joint inversion of seismic and electromagnetic data, we are also aware of other datasets and interpretations that will help us better understand our results. Understanding of these datasets is being provided by the group of collaborators that we have on the project and who have intimate knowledge of the geothermal fields that we are studying. By engaging in meetings with the field operators, we are gaining access to their expertise to expand our interpretation of our results. In addition, in some cases, we are adding additional data to our analysis. As an example, we are currently modeling observed deformation in the Krysuvik region using the constraints imposed by the joing seismic/electromagentic inversion.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23583

Score: 8.0

Comment: The key technical innovation for this project is development of a coupled imaging methodology exploiting unique strengths of MEQs and magnetotelluric (MT) data to reinforce the joint inversion image. If it works the combined image is vastly improved compared to separate, individual images. The approach combines a multi-step technique where at each step the coupling between data step is increased with a cross-gradient, constraining technique that preserves spatial similarity and ignores signal amplitudes. This is not a new joint inversion idea but the specific application is novel. Finally, because the method will be developed and tested using field data from four sites applicability and tech transfer are enhanced. The quality of this renowned, international, multi-institutional team is top notch and the approach is both scientifically rigorous and technically practicable.

PI Response:
While we are using exising methodologies for coupled imaging, we are also developing 3D full wave form elastic wave field simulation and imaging capabilities so to provide enhanced coupling of seismic attributes with eletrical attributes. Because of time limitations we could not discuss these results in depth at the review. The use of a structural coupling between the attributes is a natural starting point for joint imaging in the geothermal context. However we are open to other means of coupling the geophysical attributes though rock property relationships, but such relationships from active geothermal fields are often not that reliable.

Reviewer 23434

Score: 8.0

Comment: The proof of the combined analysis used in the PIs approach is in the pudding, or rather the improved resistivity cubes that are being produced that sync up incredibly well with known sub-surface phenomena. All indications are that this approach is providing some of the best inversions available.

PI Response:
Acknowledged

Reviewer 23479

Score: 10.0

Comment: This is a true joint inversion – not merely a comparison. As I understand the process, resistivity and velocity are mapped independently. Then the analyst selects the higher-resolution map and uses it as a constraint on inversion of the other data set. This is a computationally intensive process, and the overall project cost is high (>$3M).

PI Response:
Costs are on track according to the budget that was approved for this project. The cost of the project arises from the multiple institutional involvment, computational requirements, labor, a significant data acquistion campagin in Iceland. However, the project is strongly leveraged with financial support, exclusive of DOE funding, for project scientists from Iceland and Sweden. Multiple data sets have been provided by industrial collaborators, including Terra Gen Power for Coso, the Icelandic Power companies that operate Krafla, Krysuvik and Hengill fields, and MEQ, MT, geochemical and geomechnaical data provied by ISOR and Iceland Meterological Office (IMO).

Reviewer 23579

Score: 9.0

Comment: To perform this research, a team of scientists from the LBNL and MIT, in collaboration with Terra Gen, Iceland GeoSurvey, the University of Reykjavic and the University of Uppsala, has been formed. These scientists are all at or near the top of their field. The procedure is to develop methods to jointly invert microseismic and magnetotelluric data, and to apply the new methods to four sites, the Krafla, Hengill, Krysuvik fields in Iceland and the Coso field in the United States. An underlying assumption is that seismic velocity, rock density and electrical resistivity are at least partly determined by the same geological attributes, so that subsurface models derived from the geophysical data will reflect geological conditions and their variations in 3 dimensions. This assumption should be true to varying degrees in different geothermal fields. By comparing the geophysical models with the subsurface geology and geochemistry in well-known

fields, an assessment of the method can be obtained and conditions under which joint inversion of the particular combination of data sets can be evaluated.

PI Response:
Acknowledged

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23583

Score: 5.0

Comment: I am concerned that not enough progress has been made considering the time and resources spent, though the team has better than a year to wrap things up. I am not sure why project progress has been hampered and why the accomplishments have been slow coming but a lot of work is needed in the final year to complete the lengthy list of future FY14 tasks. Even FY13 has several very important milestones that have not been completed and half of the year is over. I am concerned because the quality of the ideas and work products is high but productivity has been low.

PI Response:
Data collection and preparation of data for analysis has been a large effort. During the data collection phase, we have been improving and testing our methods for joint inversion. While it may appear that we are behind schedule, we believe that the final year of the project will be quite productive as we harness the groundwork that we have laid with the datasets from the four geothermal fields.

Reviewer 23434

Score: 9.0

Comment: Excellent progress, continual movement forward in the analysis of the four sites identified in the initial proposal, award winning papers, working codes, new field data being obtained, and international collaborations. This project is doing quite well as far as progress and accomplishments are concerned.

PI Response:
Acknowledged

Reviewer 23479

Score: 8.0

Comment: The spectacular example from Krysuvik, Iceland, which is featured in the 2013 review material, demonstrates the potential benefit of joint inversion.

PI Response:
Acknowledged

Reviewer 23579

Score: 7.0

Comment: Progress on the SOW and goals of this project has been good. At Krafla, Inversions of the MT data using methods developed independently by 4 different research groups show commonalities in the resistivity structure at depth, as would be expected. Much of the dissimilarity in the electrical inversions was attributed to near-surface effects and different starting models, which seems reasonable. Interpretation of neither the electrical data nor the microseismic data by themselves yielded evidence of the known partial melt at the base of the IDDP borehole, which famously encountered magma. However, when the electrical data were used as a constraint on inversion of the microseismic data, a sharp increase in Vp/Vs was seen in a small region near the borehole, and interpreted as a drop in Vs due to the presence of magma. Although the images shown in the presentation do not afford clear-cut evidence of this interpretation, it can be viewed as definite encouragement for the methods employed. The big question is, however, if magma were not known at this shallow depth and all one had was the geophysics, would a partial melt have been predicted? This is a question perhaps best addressed by geologists and geophysicists who have experience in the Krafla field.

More microseismic data are being collected in the Krysuvik area, and interpretation of extant data is continuing. Anomalously low Vp and Vs occur in regions that roughly coincide with microearthquake occurrences, and a large high resistivity zone is shown at depth in the same region. Further work is needed to clarify the picture here.

The work done on this project at Coso was not covered in the presentation at this peer review, but is documented in reports referenced in the Project Summary. This work appears to be complete.

From the results so far, it is evident that very careful interpretation of the inversions will be needed in conjunction with experts in the geology and geochemistry of each of these fields in order to yield reliable results.

PI Response:
That is correct, joint imaging does not releave the interpreter of careful analysis of the coupled images of the seismic and electrical attributes. To help along in this process we are incorporating other types of geological, geochemical and geomechanical data in the analysis. Nevertheless, we believe we are showing the enhanced possbilities of better understanding complex geothermal systems through coupled/joint imaging analysis with our imaging and modeling approaches. During the review we cited our combined analysis at Krafla and Krusuvik as examples.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23583

Score: 3.0

Comment: The project management information presented in the review documents is confusing. The authors state that the DOE contribution is 2/3 and the cost share is 1/3, however, under the Planned and Actual Expenses to Date column only DOE's portion of the total budget is shown. Then under Value of Work Completed box, a DOE + Cost Share number is shown. Finally, under the Funding Needed to Complete Work only the DOE portion is shown. In addition, the schedule is confusing. Project started in May 2010 and received DOE funding in FY10 of $750,000 in FY11 $175,000 and in FY12 $830,000 was sent. However, no milestones or results materialized until March of FY13. What happened?

Looks like nothing got done in FY10, 11 and 12. Something is missing here, but from what is presented, the project has not been managed very well.

PI Response:
The project is on task and within scope. There was some delay in achieving target milestones and project scheduling because of a funding lag in FY11, where we received only 175K out of the 925K request. This caused some delays and resulted in an extension of the project by one year to complete it as planned. As documented, DOE is providing 2/3 of the cost for the project with the other 1/3 from our partners, including funds for labor, contribution of previously acquired data as well as new data acquistion in the Hengill and Krysuvik geothermal areas. In our reporting over the duration of the project, we provided DOE the yearly milestones and budget request with cost share so we unsure why this information was not available to the referee.

Reviewer 23434

Score: 10.0

Comment: Complex project with many actors. For the project to be on task and accomplishing as well as it has been the management must be spot on.

PI Response:
Acknowledged

Reviewer 23479

Score: 9.0

Comment: Please see comments elsewhere.

PI Response:
Acknowledged

Reviewer 23579

Score: 8.0

Comment: This project appears to be well managed and coordinated among the various participants. The project is on schedule for an ending in 2014, and expenditures have been made as planned. There are apparently no go/no-go decision points, and none would be expected in a project of this type, where the project has to be carried out pretty much as planned before decisions can be made on the applicability of the method.

PI Response:
Acknowledged

STRENGTHS

Reviewer 23583

Comment: The overall premise of this project has strong alignment with GTO's broad mission and goals. If successful, this project will advance resource characterization technology and directly address a key technical knowledge gap. Applying this new method to four sites increases the likelihood of adoption and partnering with industry, academia and the national laboratories improves the probability of a successful commercialization. If their idea works, the combined image is vastly improved compared to separate, individual images of the subsurface. The quality of this renowned, international, multi-institutional team is top notch and the approach is both scientifically rigorous and technically practicable.

PI Response:
Acknowledged

Reviewer 23434

Comment: Strong knowledge in the processes combined with state of the art analysis techniques and a broad system to obtain new data, this project has many strengths.

PI Response:
Acknowledged

Reviewer 23479

Comment: This is a well-run, scientifically rigorous project which will certainly yield significant publications and may contribute to the siting of planned deep wells in Iceland.

PI Response:
Acknowledged

Reviewer 23579

Comment: Development of improved inversion techniques, especially joint inversion of two or more data sets, is important because of the potential to sharpen the picture of the subsurface. Since microseismic data are or will be available from virtually all moderate- and high-temperature geothermal reservoir operations and from EGS development sites, it is an important data set with which to work along with other data sets from remote sensing technologies.

Very strong research team.

Field data are being used from geothermal areas whose geology is quite well known. The result should be a good assessment of the potential utility of joint inversion of microseismic and magnetotelluric data in geothermal exploration and development.

PI Response:
Acknowledged

WEAKNESSES

Reviewer 23583

Comment: This is not a new joint inversion idea and I am concerned about low productivity. The project management information presented in the review documents is confusing with no milestones or results materializing until March of FY13. Something is missing here, but from what is presented, the project has not been managed very well.

PI Response:
We disagree. As we have already mentioned acqusiton and analysis of new data is time consuming and has required a large effort. While it may appear that we are behind schedule, we believe that the final year of the project will be quite productive as we harness the groundwork that we have laid with the datasets from the four geothermal fields. We would also like to make aware that our project received two best paper presentations at the GRC meeting in 2011. An internatational project of this scope is always difficult to manage because of its complex character, including ongoing data acquisiton in Iceland, the far flung locations of project scientists (US, Iceland, Sweeden and China), meeting coordination, complex scheduling and effective communicaiton. Yes project management has been a challenge, we are trying, and will resolve to do better at it over the remaining duration of the project.

Reviewer 23434

Comment: The PI does not explain the total depth of the project well in the peer review, leaving the reviewer to his own devices to find out the depth of the work done. But that isn't a downside to the project, just the PIs presentation at the peer review.

PI Response:
The peer review format for the presentation requires many broiler plate slides to address DOE reporting requirements. Sorry, but this reduces the time to present detailed technical acomplishments of the project and explain in sufficient detail the complex and collborative nature of this project. Because there is a strict time limt for the presentation it is not possible to provide an in depth review requested by the referee. Please do not blame the presenter, it is the required format of the peer review. This is a large project with many activities and that means that making a short presentation about the project requires some decisions to be made about what to present and what not to present.

Reviewer 23479

Comment: The PIs are dedicated and energetic and the project is scientifically compelling. However, it is not clear that the method can ever attain the resolution implied in the Statement of Work, which seems to refer to a potential to map (individual) fluid-bearing fractures. ("[A] coupled imaging process using micro-earthquake recordings and electrical resistivity surveys to map fluid bearing fractures.")

The spectacular example from Krysuvik, Iceland, which is featured in the 2013 review material, demonstrates the potential benefit of joint inversion. However the imaged anomaly – which is inferred to represent magma and an overlying plume of magmatic volatiles – is several km on a side. The Coso work featured in the 2012 review material – which I have not seen – may have been a more compelling example of field-scale application.

PI Response:
When we finish the technical analysis,which will include techncial publications, for all the fields, we will be able to make a determination on the resolution attained and the potential of the technolgy to image fluid bearing fractures through joint geophysical imaging analysis.

Reviewer 23579

Comment: It is not apparent from the presentation or information submitted for review that there is geological, geochemical or geomechanical input from those working in the particular geothermal fields being studied. One would hope that the geophysical interpretations are not being made without discussion with the geological staffs working in the study areas. This is a critical interface for methods such as those being carried out in this project, where the research is based on mathematical development and computer implementation for analysis of remotely sensed field data sets. How well or how poorly do the interpretations correspond with known subsurface conditions?

Not perhaps a project weakness, but the Project Summary contains a number of instances of grammatical problems. It appears to have been written in a rush and not well checked.

PI Response:
We are working with the field operators who are providing additional subsurface ground truth. Also, collaborators like Knutur Arnason from ISOR bring considerable geological expertise about the Icelandic geothermal fields under investigation. Arnason has also allowed access to critical geochemical, temperature and uplift data that are being integrated into the project interpretations.

IMPROVEMENTS

Reviewer 23583

Comment: The only thing the researchers can do at this point is to put more effort on this project and complete what they had originally said they would do. Given past performance I am not sure that is a likely outcome. The ideas are great and the preliminary results are promising but the majority of the work has yet to be accomplished.

PI Response:
We repeat that data collection and preparation of data for analysis has been a large effort. During the data collection phase, we have been improving and testing the methods for joint inversion. While it may appear that we are behind schedule, we believe that the final year of the project will be quite productive as we harness the groundwork that we have laid with the datasets from the four geothermal fields.

Reviewer 23434

Comment: NA

PI Response:
N/A

Reviewer 23479

Comment: I admire the science that is being accomplished under this project and can appreciate its significance. However, in light of the overall objectives of the program I would encourage:

(1) Increased attention to the issue of field-scale application and

(2) Critical assessment of which "fluid" properties are more likely to be imaged by joint inversion, e.g. porosity, salinity, hydrothermal alteration, or permeability (most interesting, but unlikely). Non-uniqueness may be inevitable, but ambiguity in such interpretations has been a perennial challenge (could be clay or saline fluid or magma…). Can the PIs perhaps suggest diagnostic field- or lab-scale experiments based on their experience?

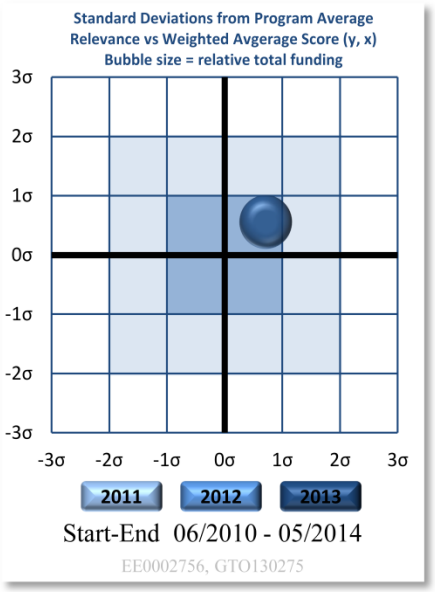
And a final question: The Statement of Work emphasizes the importance of data quality. Will the Iceland and Coso data be sufficiently good to achieve the goals of this study and if not, why not?

PI Response:
With all due respect (1) this is a field driven project so we do not understand the comment of increased attention to the issue of field-scale application; that is what we are doing primarily. We consider evidence for direct imaging of fluid properties to be an important technical bench mark for the project. This bench mark is callanging, but coupled analysis at Krafla does indicate promise that we can improve our ability in predicting fluids. Still this is just one field example and we will have to complete our analysis of the other field data sets for a complete assesment of methodology for enhanced mapping of geothermal fluids.

Reviewer 23579

Comment: Enlist the participation of geologists and geochemists working in each of the fields to help in the assessment and interpretation of the inverted maps and profiles. Document their assessment of whether or not and to what extent the geophysical interpretations add important insight to the subsurface picture. This will be the critical test of whether the method is likely to be embraced by those exploring for geothermal fields or managing the operations of existing fields.

PI Response:
Agreed and that is what we are doing, using the resources and expertise provided by K. Aranson and colleagues at ISOR. We have several publications in the works regarding the assessment and interpretation of our imaging results. We note once more that our results are being compared and contrasted with independent geological and geophysical information that was discussed above.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002756
Project: Toward the Understanding of Induced Seismicity in Enhanced Geothermal Systems
Principal Investigator: Gritto, Ronald
Organization: Array Information Technology Inc.
Panel: Fluid Imaging; Characterizing Fractures; Induced Seismicity

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23480

Score: 8.0

Comment: The project addresses a very important aspect of EGS development: induced seismicity. Earthquakes resulting from that development could affect the future use of EGS as a viable geothermal energy alternative. EGS projects must be able to deal with the potential occurrence of induced seismicity and predict the size and frequency of events with confidence. If successful, this project will reach definitive conclusions about regional stress evolution and the likelihood of large induced events. The study is bound to The Geysers, a location whose stress characteristics and responses may not reflect those of other geothermal provinces.

PI Response:
See response to reviewer 25419 below.

Reviewer 25419

Score: 5.0

Comment: This project seems very site specific, and the presenter could not explain how it could be adapted outside the Geysers Field. The seismic monitoring system at the Geysers is not actually owned/run by the operator; it is owned and operated by LBNL, which raises the question regarding successful adoption by the industry of the monitoring and thereby its process/analysis, unless required by law.

PI Response:
As stated in the project description and in the presentation at the DOE GTP Review Meeting, the goal of the project is to develop technology to gain better understanding of the interaction between water injection and water and/or steam production from the reservoir and the observed seismicity. To that effect we have chosen to use the pleathora of earthquakes at The Geysers as a proxy for the deveopment of our technology. We do not intend to apply the understanding of the earthquake physics at The Geysers to any other geothermal reservoir but rather the techniques we have developed. It is correct that the network at The Geysers is operated by LBNL and not the operator. However, the current "Protocol of Induced Seismicity" by the DOE GTP states that operators of new EGS development are required to collect a baseline of earthquake data prior to and during EGS oprerations to assess the impact of the operations on induced seismicity. Furthermore, Array IT, the prime contractor of the current project, has teamed with Jarpe Data Solution, Inc. to offer inexpensive seimsic data collection, analysis and interpretation solutions. These services will be available to any operator of geothermal reservoirs at much reduced cost compared to current rates.

Reviewer 23446

Score: 9.0

Comment: Understanding seismicity as related to geothermal production and linkages with causality (triggering and event magnitudes and mechanisms) is an important issue in the success of EGS.

PI Response:
N/A

Reviewer 23583

Score: 10.0

Comment: This project, "Towards the Understanding of Induced Seismicity in Enhanced Geothermal Systems" is extremely relevant to GTO's broader EGS mission and goals and highly focused on addressing significant, identified technical knowledge gaps such as, understanding the physical connection between reservoir creation, monitoring and operations and seismicity, better knowledge of MEQ's role in delineating fracture extent, fracture type and flow pathways and what to do to avoid impactful seismicity in places where population density is high. Greater understand of these critical seismic topics will have significant impact on furthering EGS development.

PI Response:
N/A

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23480

Score: 7.0

Comment: This project draws on many years of experience and uses the latest analytic tools in attempting to obtain answers to this problem. The approach seems thorough and comprehensive. The considerable seismic monitoring data at The Geysers field have been used. Though data are available dating back to the early 1980s, only post-2003 data are being used in this study. Given that induced events were correlated as far back as the 1980s, and large-scale fluid injection began in 1997, why were earlier datasets not used? Arriving at conclusions about induced seismicity might be more readily made if data from the early experience at The Geysers were compared with later data, post pipeline injections. The project's tasks are well thought out and include state of art techniques as well as internal tests of performance.

PI Response:
Comparing pre-2003 with post-2003 data is complicated by the fact that the networks at The Geysers have been continuously changed throughout time. Not only have the type of sensors changed, but also their number and locations. With such variation in sensors it will be impossible to deduce statistically significant results about temporal changes in seismicity correlated to injection and production activities. For instance, with the increase in sensor density over time, the

magnitude of completeness at The Geysers has continuously dropped to currently ~ 1.0. However, prior to 2003 the magnitude of completeness was larger and thus it would be scientifically incorrect to make inferences between the increase in microseismicity and injection/production operations in the reservoir.

Reviewer 25419

Score: 7.0

Comment: There was no mention of a sensitivity analysis to determine if: 1) the seismic station coverage was adequate or 2) if fewer stations could be employed to get the same results. The seismic system is surface installed and there appears to be no plans to look at borehole seismic monitoring, which will likely be necessary in volcanic and thick soft rock/unconsolidated rock regimes due to signal attenuation.

PI Response:
For our tomography study we conducted several resolution tests to determine whether the results are resolved by the geometry of earthquake and sensor locations. Similarly our seimsic moment tensor analyses employed jacknife tests to determine the statistical significance of the results with fewer stations and station variations. Both results were presented during the review. While the concept of network sensitivity is very intersting, it was not part of our proposed work. Our emphasis was to develop technology for analysis of MEQ in geothermal reservoirs, which in itself contains a lot of tasks. Technology for network sensibility analysis for induced seismicity in geothermal reservoirs, however, is readily available through other researchers and research institutions (i.e., Kraft et al., 2013).

Reviewer 23446

Score: 9.0

Comment: Using a very large and long-lived data set to understand process for the Geysers and in particular for the injection experiments. Attempting to link reservoir operations and seismicity. Using seismicity with coupled modeling of deformation and stress changes to understand regions of increased seismicity. Using moment tensors to define event types (deviatoric vs isotropic). Examine strong motion behavior from rate-state modeling of rupture.

PI Response:
N/A

Reviewer 23583

Score: 10.0

Comment: It is very exciting and gratifying to see application of earthquake and explosion monitoring state-of-the-art seismic techniques applied to EGS seismic data. A greater understanding of physical connections between MEQs and reservoir creation, monitoring and operations is essential to determining MEQ's role in delineating fracture extent, fracture type and flow pathways. Clearly, there is significant information in MEQ data collected at places like The Geysers over decades that has not been mined until now and the potential of discovering these relationships is very exciting. As mentioned before the scientific/technical approach is of the highest quality and the technical team is world-class. The techniques and algorithms selected for this analysis, namely, 4-D double difference tomography, Vp/Vs-Ratio, Vp and Vs velocity structure, full waveform moment tensor analysis, Hudson plot, reservoir stress evolution, and finally, estimation

of seismic hazard and potential ground motion, are a perfect match for addressing posed problems. Work elements are logical, detailed and extremely thorough. From the results obtained the execution of the approach looks flawless. All in all, this project is a timely, state-of-the-art approach, implemented by world experts on a rich, highly valuable data set.

PI Response:
N/A

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23480

Score: 7.0

Comment: Interesting results have been achieved, including the relationship of Vp/Vs changes to degree of fluid saturation in the reservoir. These results are consistent with the injection of waste water into the field. Progress on most tasks has been noteworthy, and the results are well-documented. Some task results remain to be completed due in part to the lag in bringing the work team together. While the work is progressing, the degree to which the tasks can be completed and useful results for analysis/prediction of induced seismicity remain problematic at this point. Will analysis be done looking at spatio-temporal occurrences of small M<3 EQ and their relationship to larger M>3 events? Stress relaxation phenomena?

PI Response:
As our SOPO states, we are developing technology to understand the relationship between larger magnitude events (M>3) and reservoir activities. Our emphasis is on earthquakes that have the biggest impact on the public and which may jeopardize the continued operation of the geothermal reservoir.

Reviewer 25419

Score: 6.0

Comment: The quality of the work appears to be adequate; however, the productivity is low. Based on the Project Management slide, the project is project is slightly over budget (CV = -$7k) and considerably behind schedule (SV=-$267k). The SOPO indicated 9 tasks (excluding project management) to be completed by 5/31/14, most other tasks/subtasks are started, but only a small number of tasks and subtasks (i.e., 1.1, 2.1, 3.0, and 6.0) are completed, and ~77% of the budget has been spent. This project should be closely monitored.

PI Response:
N/A

Reviewer 23446

Score: 9.0

Comment: Analyzed 1.2M events to define form of events and understand deviatoric vs isotropic modes. Events form into broad cluster as deviatoric with small dilational component. Initial coupled modeling results constrained by subsidence measurements are also available.

PI Response:
N/A

Reviewer 23583

Score: 10.0

Comment: The quality of results, sheer number of achievements, and productivity of the research team so far is exceptional. Of particular note are results of double-difference tomography where a low Vp/Vs-ratio structure was imaged. Also, The Geysers events as a population deviate significantly from Northern California events showing bias towards volumetric sources. The research team has successfully created a 3-D geomechanical model and conducted model calibrations. In addition, they have modeled 15 years of injection and production with total subsidence, pore pressure and stress changes with varying injection/production rates. Finally, they developed four different approaches to calculate seismic hazard. Interpretation of results are astonishing to say the least: Vp/Vs-ratio appears to be uncorrelated to Vp and Vp/Vs-ratio appears to be anti-correlated to Vs so, for The Geysers, traditional poroelastic theory does not appear to be applicable.

PI Response:
N/A

PROJECT MANAGEMENT/COORDINATION

Reviewer 23480

Score: 7.0

Comment: The multinational project staff appear to be well-coordinated, and the work plan is well-conceived. The project is on schedule and within budget after a no-cost extension. The 3-D hydromechanical model will be the key to deriving conclusions about induced seismicity; much work remains and the available resources may not be adequate within the project's remaining 4 weeks.

PI Response:
After our no-cost extention was granted the project will continue through 5/31/2014.

Reviewer 25419

Score: 6.0

Comment: As mentioned, the project is over budget (slightly) and considerably behind schedule.

PI Response:

N/A

Reviewer 23446

Score: 9.0

Comment: Large multicomponent and international project. Ok.

PI Response:
N/A

Reviewer 23583

Score: 7.0

Comment: This projects scores high on coordinating activities between project participants including a major university and an international collaborator as well as integration with GEISER and the close collaboration with Calpine. However, the project scores lower on keeping scope, schedule and budget due to a six months due late funding start and delays in finding and hiring a post doc and selecting a graduate student and delayed research that was scheduled to build on each task. Nonetheless, DOE has granted a no-cost extension through May 31, 2014. Finally, appropriate and logically placed decision points were included.

PI Response:
N/A

STRENGTHS

Reviewer 23480

Comment: Exceptional effort has been undertaken to analyze the extremely large events database from The Geysers.

PI Response:
N/A

Reviewer 25419

Comment: The project is trying to address the right set of questions with regard to induced seismicity.

PI Response:
N/A

Reviewer 23446

Comment: Well integrated project looks at existing data in a sophisticated way (full waveform) and attempts new interpretations to define modes of events and to ultimately define causality.

PI Response:
N/A

Reviewer 23583

Comment: Project is critically relevant to GTO's broader EGS mission and goals and highly focused on addressing significant, identified technical knowledge gaps. The scientific/technical approach is of highest quality with a world-class technical team. Techniques and algorithms selected for this analysis are a perfect match for addressing posed problems. Work elements are logical, detailed and extremely thorough. From the results obtained the execution of the approach looks flawless. All in all, this project is a timely, state-of-the-art approach, implemented by world experts on a rich, highly valuable data set. The quality of results, sheer number of achievements, and productivity of the research team so far is exceptional. This projects scores high on coordinating activities between project participants including a major university and an international collaborator as well as integration with GEISER and the close collaboration with Calpine and appropriate and logically placed decision points were included.

PI Response:
N/A

WEAKNESSES

Reviewer 23480

Comment: Pre-2003 seismic data appear to be neglected in the analysis.

PI Response:
See comment to reviewer 23480 under Scientific/Technical Approach.

Reviewer 25419

Comment: The project is: 1) possibly too site specific and lacking adaptability outside the Geysers; and 2) relies on a preexisting seismic network and data, which many geothermal fields do not have, bringing into question is adoptability by industry.

PI Response:
See comment to reviewer 25419 under Relevance/Impact of Research.

Reviewer 23446

Comment: None apparent.

PI Response:
N/A

Reviewer 23583

Comment: This project scores lower on keeping scope, schedule and budget.

PI Response:
N/A

IMPROVEMENTS

Reviewer 23480

Comment: Reviewer did not provide comments for this criterion.

PI Response:
N/A

Reviewer 25419

Comment: Ensure that a sensitivity analysis is done.

Ask the hard questions about adaptability and adoptability.

Consider the implications of surface versus borehole seismic measurement.

PI Response:
Until 2013, there was only one borehole station installed at The Geysers and we did not have access to these data.

Reviewer 23446

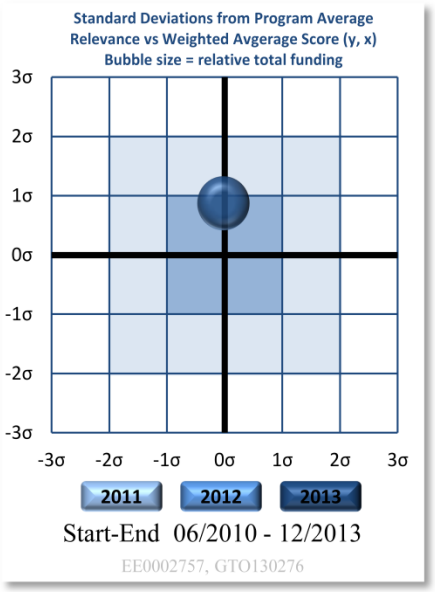
Comment: Binning data pre-and post- the 2005 gray-water injection project or relative to other major changes in operations would make sense in further defining causality for the seismicity.

PI Response:
This suggestion is included in our research plan.

Reviewer 23583

Comment: PI will have to pay more attention to managing scope, schedule and budget over the next year.

PI Response:
N/A



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002757
Project: Development of a Geological and Geomechanical Framework for the Analysis of MEQ in EGS Experiments (Geysers)
Principal Investigator: Ghassemi, Ahmad
Organization: University of Oklahoma
Panel: Fluid Imaging; Characterizing Fractures; Induced Seismicity

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23480

Score: 7.0

Comment: The study looks at predicting reservoir response to stimulation, with emphasis on induced seismicity. This is one of the key issues affecting widespread adoption of EGS for energy extraction. The ability to understand and predict the size and location of induced events will go a long way in gaining acceptance for EGS techniques in the geothermal industry. Greater understanding of these events will serve to assuage the concerns of nearby residents and the public about the chances for damaging induced events.

PI Response:
N/A

Reviewer 25419

Score: 9.0

Comment: This is basic science that is necessary to better understand the root causes of induced seismicity. It is a ground-up approach that can also reduce uncertainty modeling.

PI Response:
N/A

Reviewer 23446

Score: 9.0

Comment: Defining linkage between MEQs and rock-type, structure and permeability evolution is a key issue in EGS.

PI Response:
N/A

Reviewer 23583

Score: 9.0

Comment: This project is focused on solving one of the most critical and technically challenging EGS knowledge gaps—a better understanding of the relationship between MEQ events and fracture attributes of interest, such as extent, interconnectedness, overall distribution and type. The project's objectives are to develop a framework for investigating processes that contribute to the occurrence of MEQs at EGS sites. This is quite a ambitious undertaking. This framework incorporates laboratory measurements from Newberry and Geysers EGS demonstration experiments. In the end, researchers aim to remove barriers for prediction of reservoir's response to stimulation. If met, significant technical knowledge gaps will be reduced thus broader GTO mission and goals will definitely advance. If MEQs can be utilized to better create and control fractures as well as monitor their propagation in realtime, then costs and performance will be impacted and the range of potential applications will significantly expand.

PI Response:
N/A

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23480

Score: 5.0

Comment: The project uses a geomechanical approach to study the response of rock core to stimulation, attempting to relate those responses to the behavior of natural fractures. The approach is versatile, allowing the variation of rock porosity/permeability under confining stress along with the effects of fluids to be studied. However, the means proposed to scale the core results to reservoir behavior is not obvious. And the core in large part is standardized rock samples (e.g., Westerly granite) rather than core from geothermal wells. The study needs to relate large-scale activity (slide #11) with the poroelastic measurements. How does the observed AE relate to what is going on at the core sample scale? What about effect of stress rate and magnitude? Don't need to exceed fracture stress to generate AE.

PI Response:
The problem of scaling from core to reservoir is an interesting one from core testing view point. The PIs have ideas they are currently implementing to solve this problem that will be made public in due course. However, within the framworks of the current project, core testing is useful to get needed data for input inot numerical models for analyzing seismicity and also to better describe the reservoir from lithologic and geomechanics view points.

We would like to point out to the Reviewer that the data on Westerly granite was used to dvelop a testing protocol via comparison with existing data which is for Westerly granite. The PIs have done test on various types of tuffs, including samples from the Newberry Volcano relevant to the EGS demonstration project there, but not all results were fully availabel at the time the slides were prepared.

The observed heteogenity in AE is related to reservoir geomechancis heterogenity as was suggetsed in the presentation and Q&A. Experimental results clealy show that certain rock intervals are aseismic. The stress heterogenity is in fact ralted to this lithological heterogeneity. The point is that numerical models that can account for such factors need input data that must, in the first place be obtained from lab data as in this porject.

Exceeding fracture stress is not alwayes needed to generate AE by slip, but it certainly is needed to generate AE by new rock failure. Moreover, fracture surface properties control the AE generated by fracture slip and this is the subject of this project, in fact we have pusblished results (Li, Jung, Ghassemi, 2012. Mechanical Properties of Jointed Welded Tuff from Newberry Volcano.46th US Rock Mechanics / Geomechanics Symposium held in Chicago, IL, USA, 24-27 June 2012-) on these, and our data show broad correlation of rock type, fracture surafce properties and observed AE. Furthermore, the cores tested from Newberry are in the vicinity of MEQs generated during the stimulation activities during October to December, 2012, thus providing the potential for deriving correlations between lab measurements and in situ behavior of the same or equivalent rocks.

Reviewer 25419

Score: 8.0

Comment: The approach is solid and robust.
It is focused on only two sites with different geologies.

PI Response:
Yes, we are working with data we have and the general framwork that will be develoep dcna be applied to other sites. But in the process, we could certainly consider other cites if additiona funding and data were to be made available.

Reviewer 23446

Score: 9.0

Comment: Petrophysical analysis of samples form Geysers and from Newberry. Failure experiments with acoustic emission (AE) monitoring and determination of strength parameters and ultimately coupled with measurements of permeability.

PI Response:
N/A

Reviewer 23583

Score: 6.0

Comment: In most cases, the formation's response to EGS stimulation is MEQs, but does that always mean increased fracture permeability? This is a possible question that motivates this work. Another important related question is, what are the causal mechanisms for MEQs and are there predictable changes in rock mass properties that can be observed? The research team has developed an ambitious, comprehensive and, I believe, potentially effective approach integrating geological and geomechanical measurements from laboratory experiments and field measurements to tackle these thorny questions. The quality of the research team is first-rate. Their combined understanding is comprehensive in both

knowledge and skill sets and they have extensive experience. I believe that their innovative approach could achieve their objectives but not within available resources allocated. This is an ambitious, major technical challenge that will require many additional projects like this before final answers are discovered. It is my opinion, that the results of this work will most likely not provide definitive answers to these questions but rather provide a framework for subsequent R&D.

PI Response:
One would be foolish to claim a definitive answer to all of these questions within one project. We hope to build a solid foundation while answering some very imprtant questions. Surely, additional projects are needed.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23480

Score: 5.0

Comment: Results have been obtained with laboratory core analyses. The rock mechanic attributes of the core have been measured, including those of core from the Newberry field. Marrying those results to field-scale observations remains to be done. The field correlations presented look interesting, but the results from the core do not appear linked with the observed seismicity. (Core locations are described as magenta diamonds, but there is no such symbol on the figures.)

PI Response:
There is corresposdence between rock type and observed AE. Clay rich, ductile rocks tend to show less AE. More brittle rocks show significant AE. We postulate field AE reflects this fact. More log analysis is needed to be conslusive and integraction of the characterization of natural fractures in core is on-going.

Also, there appears to be some confusion. On slide 12 in the presentation, the positions where cores were obtained for the analysis of natural fractures are in fact plotted along the well path on the plot of MEQ activity. The same positions are plotted on the geophysical logs, but as yellow squares along the left panel. As of the time of this presentation, work to refine MEQ locations via advanced relocation techniques had not yet been completed and so the spatial resolution to correlate MEQs with the geophysical logs is not yet available. We note that such relocations will not have even relative spatial accuracy, let along absolute location accuracy, on the scale of the thin layers evidenced in the natural gamma ray, resistivity, velocity, and porosity logs. However, we will work to establish such a correlation. We note that zones exhibiting fluid flow, and thus likely susceptible to fluid pressure rise accompanying stimulation, and their lithologic correlation can be made as a proxy for lithologic correlations between MEQs and the geologic and rock deformation analyses. In addition, the issue of mineralogy as documented in core (by cuttings, thin section, and XRD analysis) and rock mechanical properties from triaxial tests with in situ physical properties revealed in the geophysical logs and MEQ locations is a high priority

Reviewer 25419

Score: 8.0

Comment: The quality of the work is more than adequate.
The project is behind schedule, but under budget. A significant amount of work has been completed, and it would appear that the project can be completed on-budget and near to on-time.

PI Response:
N/A

Reviewer 23446

Score: 9.0

Comment: Experiments largely completed. Observed different velocity strengthening/weakening behaviors in different samples. Permeability experiments not yet completed?

PI Response:
N/A

Reviewer 23583

Score: 3.0

Comment: Some progress has been made but not enough considering the time and resources spent. Clearly, the project has not been the top priority of this top notch team; I know they can be more productive. Site core or equivalent rock samples were collected and characterization has been initiated, but a lot more work is needed to build a framework. Selected lithological units pertinent to stimulation were selected from the sites and characterized using both geomechanical and petrophysical tests. Quality of the work is high but productivity has been low. There exists a lack of useful conclusions and the framework is not in place. On the positive side, preliminary results suggest that observed reservoir heterogeneity with regards to brittle versus ductile behavior helps understand the distribution of observed MEQs. Work continues on compiling the set of geological and geomechanical conditions that are responsible for generation of MEQ, and to help identify fracturing type, permeability structure and style. However, the future activities list is quite ambitious especially if they continue at the current rate of progress and accomplishments have been meager, to say the least.

PI Response:
We strongly disagree. The reviewer appears not to have an appreciation for the nature of experimental work and geologic data collection as well as for what has been achieved to date. Clearly s(he) is relying on the powerpoint and limited project summary which by nature cannot provide a detailed history of all accomplishments. Equipement set up and calibration, student prepration, core acquisition, plug extraction and selection for testing, plug characterization and preparation, basic rock mechanicsl properties determination, porosity, permeability, mineral composition, geological characterization, establishing procedure for consistent, quantitative fracture properties measurements and performing and analysing tests all have been completed. Establishing procedures and protocols for measuring poroelastic properties and performing AE tests have been on-going.This is a significant portion (and expensive) of the project that has been nearly completed. What remains is inejction experiments and integration of geological, geomehanical with AE data from the field. The latter is now just becoming fully available for integration into a self-consistent framework. The budget expenditure corespond to the activities were planned, and the results of the supported activities are significant.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23480

Score: 5.0

Comment: The project is behind schedule, but apparently additional funds are not needed. The proposed future work is very ambitious, given only eight months remain and some work has lagged.

PI Response:
We will ask for a no-cost extension. At worst, the project will take an extra 6-8 months. This is a University type project that involved students.

Reviewer 25419

Score: 9.0

Comment: Coordination appears strong, given that one of the co-investigators (from another institution) was able to step in at the last minute to give the presentation for the PI and competently answered all questions, as the the project is being moved from one university to another.

PI Response:
N/A

Reviewer 23446

Score: 9.0

Comment: ok.

PI Response:
N/A

Reviewer 23583

Score: 2.0

Comment: Clearly, project management has not been effective in controlling costs, keeping on schedule and getting the work done. 75% of the budget is spent and the majority of the work is still to come. As mentioned before in the previous section, some progress has been made but not enough considering the time and resources spent, useful conclusions have not been put forward and the framework is not in place. Finally, the list of future activities list is quite long and ambitious to say the least especially if they continue at the current rate of progress. Decisions points, if there are any, were not discussed. Looks like the project started late by 2.5 months but is also behind schedule by 5 months. So the original project for three years is now 3.5 years. It looks like the majority of the essential work will be done in the last six months with only 25% of the budget.

PI Response:
We are not sure where the reviwer gets the impression that "the majority of work is still to come". The tasks to be perfomed are clear for us. We have compelted 70-75% of the tasks and 30-35% (including Tempel budget) remain along with about 30% of the budget. The five months delay in the schdule is not due to the lack of management. The PI moved to a different institution in Jan 2013 and ample notice was give and a no-cost extension was requested (Oct. 2012). However, the project transfer has not materialized.

STRENGTHS

Reviewer 23480

Comment: The project team is exceptional, and access to core from Newberry gives the project immediate relevance in DOE's near-term goals for EGS.

PI Response:
N/A

Reviewer 25419

Comment: Basic science that is necessary for enhanced understanding of induced seismicity.

Integration of many lines of evidence that leads to robustness and reduction in uncertainty.

PI Response:
N/A

Reviewer 23446

Comment: Important topic. Full linkage between petrophysical/structural analysis for samples, including origins of pre- and post-porosity and permeability development and constrained with acoustic data in final analysis. Full suite of observations may have implications for anomalous seismicity at Newberry.

PI Response:
N/A

Reviewer 23583

Comment: The potential impact of this research and relevance to GTO's broader goals are high. If project objectives are met, significant progress will be made in reducing technical knowledge gaps. The scientific rigor of this project is solid and logic is sound. The technical approach is reasonable and could achieve significant and impactful results. The quality of the research team is first-rate with their combined understanding is both comprehensive in knowledge and skill sets and extensive in experience. Some progress has been made and a few preliminary results have been put forward.

PI Response:
N/A

WEAKNESSES

Reviewer 23480

Comment: The project seeks to draw general conclusions about MEQ behavior from analysis of rock mechanical properties of core samples. Such conclusions would only seem valid from a statistically significant sample size, involving many core from a number of different geothermal sites. The lack of such a database will limit the extent to which conclusions will be applicable beyond Newberry.

PI Response:
N/A

Reviewer 25419

Comment: None.

PI Response:
N/A

Reviewer 23446

Comment: None apparent.

PI Response:
N/A

Reviewer 23583

Comment: This is quite a ambitious undertaking and a major technical challenge and most likely results of this work will not provide definitive answers to these questions but rather, at best, provide a framework for subsequent R&D. Not enough progress has been made considering results to date contrasted with significant time and resources spent. Useful conclusions have not been put forward and the framework is not in place. The future activities list is quite ambitious especially if they continue at the current rate of progress and accomplishments have been meager, to say the least. Clearly, project management has not been effective in controlling costs and keeping on schedule. It looks like the majority of the essential work will be done in the last six months with only 25% of the budget.

PI Response:
Again, we are sure how the reviewer is reaching the conslusions. We have completed:

Core collection, preparation rock mechanical testing; Petrophysical characterization of representative library core; mineral composition, thin section preparations and analysis; porosity, permeability measurement, quantified the variation

in porosity and pore geometry as a function of distance from the slip surface; quantified textural evolution via thin section analysis, quantified the correlation between natural fracture roughness and dilation history, characterized the dependence of fracture dilation, fluid flow history, and strength on the stage of fault development.

Multi-stage compression test on tuff samples and analysis of data (20 samples). Development of elastic and failure properties for core plugs from N2-4281, 4219 ft and high-resolution scanning of some samples to be tested for exploring pore volume structure before and after failure.

Measurement and studies of poroelastic properties of tuff.

Measurement of joint properties in triaxial test and quantification of tuff joint properties; performed poroelastic tests on tuff samples and determines poroelastic properties.

Collection of X-Ray-CT scans of core samples containing natural fractures from the Newberry Geothermal field.

Development of algorithms for automated (a) image analysis and (b) XRay-CT analysis of open, healed, and skeletal porosity; Digitized archived geophysical property logs from GEO-N2 that will be used to (a) assess measurements of in situ porosity, (b) rock strength, (c) refine a local stress model. Compilation of 2D and 3D core measurements of porosity as well as in situ porosity from geophysical logs forming a database that allows the correlation of the three distinct data sets.

Developed AE monitoring protocol and conducted triaxial test with AE monitoring andhave perfomed test on granite, ss, and tuff.

Established preliminary correlation between rock type and properties and observed MEQ.

Collected and sug-cored additoinal core. Performed additions tets to study ductile vs behavior of various tuff.

We are not sure where the reviwer get the impression that the above work is not essential. The tasks to be perfomed are clear as are the extensive list of completed tasks. We have compelted 70-75% of the tasks and 30-25% remain along with about 30-35% of the budget (including Temple's). The fact that the remaning work is important does not mean the work completed to date has not been important. Performing injection experiments prior to the above completed work would not have been very meaningful.

IMPROVEMENTS

Reviewer 23480

Comment: Reviewer did not provide comments for this criterion.

PI Response:
N/A

Reviewer 25419

Comment: Look into expanding the project or funding a follow-on project to include rock types and stress regimes found at other existing sites, since in-/near-field EGS is the first target horizon.

PI Response:
N/A

Reviewer 23446

Comment: Correlations of laboratory observations with field studies should be feasible now that field data are available. How do these observations provide improved constraint to breakout analysis in boreholes?

PI Response:
N/A

Reviewer 23583

Comment: The only thing the researchers can do at this point is to put more effort on this project and complete what they had originally said they would do. Given past performance I am not sure that is a likely outcome.

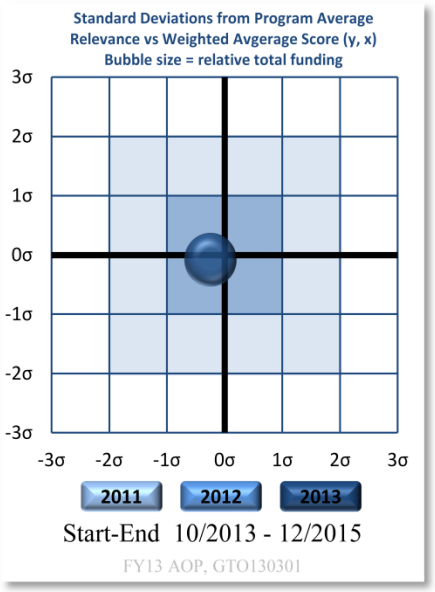
PI Response:
As previously addressed in response to comments by the same reviewer (e.g., p. A-9), this reviewers perspection on the project accomplishments is highly inaccurate. The quarterly reports, publications, and summary within the powerpoint all prove the project has made significant accomplishments in proportion to the expenditures. We do realize that if the reviewer is relying solely on the very limited material able to be represented in the powerpoint (out of all of the materials provided) to support his/her criticisms, especially in regard to the scientific results that focus only on the most recent elements, that they might gain a misimpression.

The project objectives included:

(i) Petrophysical analysis; Determine the rock mechanical properties on library core, etc . (ii) Deformation at fracture walls & dilatancy ; geological analysis of core area ; (iii) Analysis of core to characterize mechanisms of porosity formation conditions; (iv) Investigate rock mech. props dependencies ; (v) Injection experiments using library and core samples; Investigate acoustic emissions and permeability structure ; (vi) Investigate MEQ/porosity/permeability in injection experiments; (vii) Develop integrated geological/geomechanical framework for MEQ.

At this point in the project, we have not done part of (v) that is injeciton experiments, and have not fully completed (vii), which is the final element incorporating all data sets.

Work on (vii) has continued and we are waiting for project transfer to complete (v) and finalize (vii).



Review: 2013 Geothermal Technologies Office Peer Review
ID: FY13 AOP
Project: Sustainability of Shear-Induced Permeability for EGS Reservoirs – A Laboratory Study
Principal Investigator: Kneafsey, Timothy
Organization: Lawrence Berkeley National Laboratory
Panel: Fluid Imaging; Characterizing Fractures; Induced Seismicity

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23533

Score: 8.0

Comment: Worthwhile project, but too early to review - still in the "shake-down" phase of newly developed testing procedures.
Will provide important information on fractures sustainability over time.
Interesting and unique pressure cell.

PI Response:
We agree.

Reviewer 23526

Score: 6.0

Comment: The impact and relevance of this project does come across as being strong. I don't believe that this is the most pressing need before GTO

PI Response:
Because of the importance of fractures in EGS and conventional geothermal systems, understanding fracture sustainability and how to optimize reservoir development with respect to sustainability could have substantial impacts and is worth investigating.

Reviewer 23446

Score: 9.0

Comment: Understanding changes in permeability that occur post-stimulation in EGS reservoirs is important in defining longevity of the reservoir with regard to both permeability (transmission) and heat-transfer area and thermal efficiency.

PI Response:
We agree. Thank you.

Reviewer 24862

Score: 5.0

Comment: The relation of the proposed work to GTO's mission and goals in the current time frame are not identified. The topic is relevant to long term sustainability of an established EGS system, but the GTO is struggling with establishing a short term demonstration project. Thus this is diverting efforts that could be better utilized to address the current problems.

PI Response:
The mission and goals of the project are to understand fracture sustainability with respect to rock type and conditions. Although applicable to EGS, such an understanding can be more generally applied as well, thus the project is timely.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23533

Score: 7.0

Comment: Unfortunately the maximum load limited of 3,000 psi may not be sufficient to shear asperities.
Good data analyses plans.

PI Response:
Thank you for the comment. During the timeframe of the GTO review, my colleague found an error in the engineer's detailed design. This required some additional thinking resulting in an increase in maximum force applied (thus maximum stress on the asperities). Additional thinking and a minor change in the experiment design will allow increasing the maximum stress another factor of almost 2 (new maximum stress >7,000 psi).

Reviewer 23526

Score: 5.0

Comment: The approach seemed poorly thought out. For instance, the configuration of the experiments gives no control over the wetted area for flow, making the results less that quantitative. Also, the pressures that system will operate at seemed rather low for something targeted at EGS. One other thing I had in my notes was a question, and I honestly don't recall why, but it was "Is this a Geysers project in disguise?"

PI Response:
In the approach to the experiment, we had to balance a number of factors including wetted area (desire to maximize), load (desire to maximize), flow rate (control range to appropriate - low), temperature (specific range), rock type, method of force application, fluid collection, chemical and isotope analysis, materials, temporal aperture quantification, flow controls, data collection, and project safety among others. We considered several methods of flowing fluid through fractured rock under stress. All of them result in varying flow paths and velocities in the fracture, thus the local Damkohler number is location dependent. All of the methods also rely on averaging the flow and chemistry (collecting a sample that has flowed across the sample through the ensemble of flowpaths) thus forcing us to view the sample fracture as a unit that would be quantified by surface measurements. All techniques would result in fast flow paths, and slow flow

regions. We do have the capability to go to much higher stresses in a typical Hassler-type setup, but currently don't think we can accurately quantify temporal fracture aperture changes in such a system. A scientifically intriguing set of experiments would include observing the processes near an asperity contact at the small (~micron) scale, simultaneously observing the chemistry and mechanics. This is more basic research however and is not in our current workscope.

I cannot provide an explanation of your note about whether this is a Geysers project in disguise. Perhaps the comment was written for another presentation.

Reviewer 23446

Score: 9.0

Comment: Develop a cell to measure perm changes in artificial fracture concurrent with mass balances on reactive species and deformations.

PI Response:
We agree.

Reviewer 24862

Score: 5.0

Comment: The design limits on load (~3000 psi) and time frame of the experiments (~ 2 months) does not fully address the conditions expected in EGS. Has a design been considered incorporating sufficient lead-throughs into the vessel to the specimen to allow important measurements like strains, acoustics etc?

PI Response:
As addressed above, we will be able to test samples to over 7,000 psi. The estimate of 2 months came from a literature review, and was acknowledged as an estimate. For the sake of being able to test many samples, we hope the reasonable timeframe is ~ 2 months, but nature will govern that. As explained in the presentation or the question and answer session following, strains will be measured. We currently measure accoustic emmission on another geothermal laboratory project and plan to use the same equipment in this project (rated to above 300C). This data will be invaluable in our data interpretation. In our designs, we tend to limit feed-throughs to the minimum number as they often significantly complicate the design, manufacture, and operation of the vessel (pressure rating, leaks, available space).

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23533

Score: 9.0

Comment: Project was able to build a pressure cell at and incredibly cheap cost.

PI Response:
We agree.

Reviewer 23526

Score: 3.0

Comment: This only based on the presentation of the experimental setup, which I felt was lacking. Please see my previous comment. The similar project presented the following day at the review seemed better thought out.

PI Response:
This review came very early in process. In addition, the presentation was submitted well in advance of the review, and the requested presenation structure is not optimal for all projects at all stages as it is focused on the big-bullet issues and not the very important details. In that the reviewer felt that the presentation of the experimental setup was lacking, I would agree that the presentation was lacking but would strongly disagree that the project approach and equipment design are lacking. As the presenter, partly as the result of the requested presentation structure, I did not present the trade-offs and balances that are required to create a system to quantify fracture sustainability. Had I done so, I believe that the reviewer's opinion might be significantly different. I can assure the reviewer and the GTO that the in the design many criteria and hopefully the most important criteria were considered, and the system presented in the review was the more optimal of the two concepts that resulted from the evaluation.

As to the similar project presented on the next day mentioned by the reviewer, it would be nice to have a direct reference that identifies the specific project and the criteria the reviewer was considering to justify the comparison relative to the individual project goals, objectives, and approaches. Without that, I have no basis to interpret the comment.

For reference, my response to the reviewer's last comment (presumably from Scientific/Technical Approach) is presented below.

In the approach to the experiment, we had to balance a number of factors including wetted area (desire to maximize), load (desire to maximize), flow rate (control range to appropriate - low), temperature (specific range), rock type, method of force application, fluid collection, chemical and isotope analysis, materials, temporal aperture quantification, flow controls, data collection, and project safety among others. We considered several methods of flowing fluid through fractured rock under stress. All of them result in varying flow paths and velocities in the fracture, thus the local Damkohler number is location dependent. All of the methods also rely on averaging the flow and chemistry (collecting a sample that has flowed across the sample through the ensemble of flowpaths) thus forcing us to view the sample fracture as a unit that would be quantified by surface measurements. All techniques would result in fast flow paths, and slow flow regions. We do have the capability to go to much higher stresses in a typical Hassler-type setup, but currently don't think we can accurately quantify temporal fracture aperture changes in such a system. A scientifically intriguing set of experiments would include observing the processes near an asperity contact at the small (~micron) scale, simultaneously observing the chemistry and mechanics. This is more basic research however and is not in our current workscope.

Reviewer 23446

Score: 8.0

Comment: Cell being constructed. Early in project. No results to date.

PI Response:
We agree.

Reviewer 24862

Score: 5.0

Comment: The project is at a very early stage - this review was premature

PI Response:
We agree. We hope that in the next review we are able to improve the reviewer's perspective of the project.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23533

Score: 8.0

Comment: Impossible to comment at this stage

PI Response:
We agree.

Reviewer 23526

Score: 5.0

Comment: Seemed OK so far, not much to report.

PI Response:
We agree. We hope that in the next review we are able to improve the reviewer's perspective of the project.

Reviewer 23446

Score: 9.0

Comment: ok.

PI Response:
We agree.

Reviewer 24862

Score: 8.0

Comment: The project is in very early stages but seems to be underspent - perhaps more effort could lead to a superior design.

PI Response:
We agree.

STRENGTHS

Reviewer 23533

Comment: Was able to build a unique testing facility within the few first months and within budget

PI Response:
We agree.

Reviewer 23526

Comment: None at this point

PI Response:
No response.

Reviewer 23446

Comment: An important topic. An interesting and innovative cell designed from scratch with appropriate constraint on deformation, and mass and fluid fluxes – and capable of high ambient temperatures (300C). Stress limit at ~20 MPa is on the low range for EGS. Careful attention to sterility of geochemical fluids (gold and titanium) and attempted small volumes for collector system. Innovative seals (graphite) addresses a difficult problem of seals at high temperatures.

PI Response:
We agree.

Reviewer 24862

Comment: The types of measurements proposed are in short supply and will contribute to understanding long term reservoir performance.

PI Response:
We agree.

WEAKNESSES

Reviewer 23533

Comment: Limited normal loads capability

PI Response:
We agree and have taken steps to improve this weakness. We have reaised the maximum stress to over 7,000 psi.

Reviewer 23526

Comment: Appears poorly thought out experimentally.

PI Response:
We disagree. As addressed in previous responses, there are trade-offs that are required in the design of any experimentals system. The researchers involved are acutely aware of this and have seriously considered and evaluated what we believe to be the most significant parameters resulting in what we believe is an optimal system to accomplish our goals.

Reviewer 23446

Comment: No significant weaknesses. Stress range is at low end for EGS but processes-based view of behavior will be important. May need to be careful with seal friction and calibrating to remove that.

PI Response:
We agree. We have increased the maximum stress. We are also concerned with seal friction and this has been a serious concern so far.

Reviewer 24862

Comment: The design does not address the range of overburden expected in EGS reservoirs or the time frames of interest (years instead of months?).

PI Response:
We have increased the maximum applicable stress by a factor of about 2.4 putting our test apparatus in the appropriate stress range. Our timeframe has been estimated using a review from the literature. Experiments will determine the actual timeframe required.

IMPROVEMENTS

Reviewer 23533

Comment: Also consider the case of an inclined fracture which would allow a shear component to be induced on the fracture plane.

PI Response:
Using an inclined fracture would be very interesting and will certainly be considered.

Reviewer 23526

Comment: Redesign the experimental apparatus so you have better control. The radial flow setup is just too difficult to quantify the flow patterns. Perhaps you could design the outflow side with more detail so that you could measure distinct intervals along the circumference.

PI Response:
Thank you for this suggestion. In fracture flow (and fracture flow experiments), the fracture geometry and laws of physics govern the flow. This is true in this test as well. There will be regions of slow flow or even nearly stagnant regions, and regions that flow more rapidly. The only way to control the flow is to control the fracture geometry or somehow use the laws of physics to optimize flow (I'm not sure how to do this.). Controlling the fracture geometry is an option that although interesting, I believe would be difficult for the community to accept. We have considered collecting samples from distinct intervals along the outflow circumference. One concern is in collecting enough sample in a timely manner for analysis. We will certainly keep this option open as we continue.

Reviewer 23446

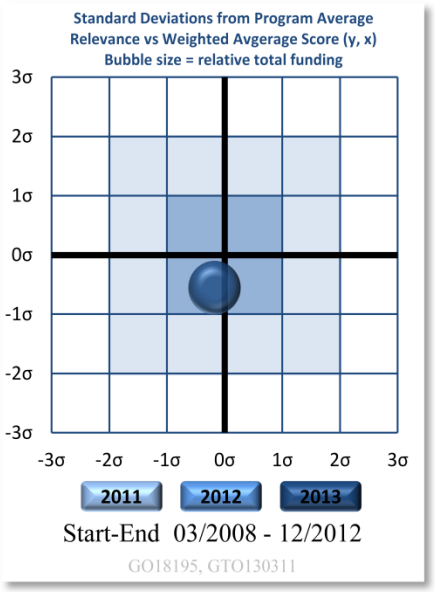
Comment: Measurement of stresses will be important and the external load cell may potentially be augmented with in cell load cell that could be accommodated in the current design. Radial flow geometry is a reasonable compromise but may have issues of sample tilt/rock that give significantly preferred flow directions – see Iwai thesis with Witherspoon from c. 1978 for example. Maybe using longer cores can stem this issue.

PI Response:
Thank you for these comments and the reference. An in-cell load cell would certainly help to quantify effects of friction at the seal and tell us what we really want to know. We have considered using one and hope to implement one. Flow direction is a concern. In a fracture, there will always be faster and slower flow regions. We will undoubtedly see that here as well. Work has been done looking at permeability anisotropy for linear offsets; we don't know how our slight rotational offset will affect permeability.

Reviewer 24862

Comment: Give consideration to how feed-though could be included so that variables such as strains, resistivity, acoustic signals can be monitored. Consider designing chemically benign markers so the flow-though areas can be identified. Consider using polymers at the end of the test to obtain fracture molds. Consider incorporating the ability to apply shear on the fractures

PI Response:
These are wonderful suggestions. A benign marker early in the test and another later could add to the data to tell a very interesting story as to changes in flow path. Although I really like the idea of using polymers, I am concerned about our ability to quantify some of the chemical and mineralogical changes if we do that. We are hoping to use fracture profiles to tell us the same story. That technique, although conceptually easy, has its troubles as well. We agree that shear is important, and are considering two techniques to apply shear in the current setup.



Review: 2013 Geothermal Technologies Office Peer Review
ID: GO18195
Project: Use of Geophysical Techniques to Characterize Fluid Flow in a Geothermal Reservoir
Principal Investigator: Batzle, Michael
Organization: Colorado School of Mines
Panel: Fluid Imaging; Characterizing Fractures; Induced Seismicity

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23579

Score: 6.0

Comment: Education of the next generation of graduates to enter the geothermal community is important for the vitality of the industry and of its supporting research scientists and engineers. The Colorado School of Mines has long been known for excellence in education, especially in the earth sciences. However, based on the presentation made, it is uncertain whether or not the students involved received a quality experience in this particular class. The score given for this element reflects the importance of the task to the geothermal community rather than an assessment of the overall project.

PI Response:

Reviewer 23434

Score: 8.0

Comment: This project is relevant, but not to expand the science of geothermal fluid imaging innovations. The project is relevant in improving the work force of future geophysical professionals and for improving the community understanding of what geothermal is and how researchers develop their understanding of where geothermal resources are.

In the broad context of the program, this type of project does a great service.

The relevance is bolstered by the production of new seismic readings around the Princeton Hot Springs area, which indicates that it seems highly probable to produce a meaningful amount of heat from new regions in this area.

PI Response:

Reviewer 23479

Score: 6.0

Comment: This project – now complete – was to use combined inversion of geophysical data to image geothermal reservoirs, while also training students. My impression is that the latter objective may have been more fully achieved than the former.

PI Response:

Reviewer 23583

Score: 5.0

Comment: This work has average relevance to GTO's overall program goals. Joint inversion of geophysical data to image subsurface structures of interest to geothermal exploitation is certainly relevant but techniques were tried-and-true technology and not innovative. The training aspect is noteworthy but did not directly address major technical barriers to discovering hidden resources or developing EGS sites. In fact, I am hard pressed to find a technical barrier that this research addressed. The impact on the greater geothermal community of this work will be negligible. Local developers will benefit.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23579

Score: 5.0

Comment: It goes without saying that field experience is very important to earth science students. The field can't be replaced by a book or a computer. Doubts about the field experience offered in the project are discussed in the next section, and will not be repeated here. These doubts, however, are reflected in the score for this element.

PI Response:

Reviewer 23434

Score: 9.0

Comment: Professor Batzle and his students used multiple geophysical measurement techniques to evaluate the Mt Princeton Hot Springs, Chaffee County, Vail Hot Springs and Pagosa Springs areas. The resistivity measurements and deep seismic readings gave students insight into both high tech and (fairly) low tech methods of subsurface evaluation. These approaches were absolutely appropriate for the scope of this project.

PI Response:

Reviewer 23479

Score: 6.0

Comment: Please see comments elsewhere.

PI Response:

Reviewer 23583

Score: 5.0

Comment: Given that the particular, technical approach employed was not described in these reports in sufficient detail to properly evaluate, nonetheless, the very brief joint inversion technique description supplied as "Gauss-Newton algorithm", which is a very old technique, leaves this reviewer cold. In fact, it looks like all they did was use different data sets to heuristically develop a structural model consistent with each data type, but the "joint" aspect is down-played. In fact, this technique for joint inversion was used 40 years ago by this reviewer. Noting new has been added. This does not look like research but rather a field exploration/exploitation demonstration with little advancement in geothermal R&D.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23579

Score: 4.0

Comment: The field camps were apparently well attended and provided a varied exposure to geothermal geophysics. The productivity of this project seems to have been quite good. However, if the quality of the presentation is a reflection of the quality of the field camps, considerable question can be raised. This is the basis for the rather low score. Specifically:

1. There was no information given about the instrumentation or field procedures for the data obtained, leaving one to hope that modern instrumentation was available and best field practices were observed for all data collected.

2. There was no information given on the specific types of data reduction and interpretation techniques applied to the field data, even though the title of this project is "Joint Inversion.....".

3. The figures shown in the presentation were hard to relate to one another so that a coherent picture of the work in the Mount Princeton area could be assessed. Specifically, the SP profile, whose interpretation was done in terms of a Gauss-Newton inversion, is not located on the map of the area. The slide does not show any of the values of the parameters used in the inversion -- fluid-flow characteristics, etc. On the Gravity/Magnetic/ Seismic Integration slide, the treatment of the magnetic data is not indicated (was a regional gradient taken out?) and it is not indicated whether or not terrain corrections were applied to the gravity data (they would be needed in this area of rugged terrain). Was any regional gravity gradient removed before the profile was interpreted? How did the gravity and mag contribute to the interpretation? What equipment was used for the seismic work, how was it reduced and interpreted, etc., etc. How was the joint gravity/mag/ seismic inversion done? Is any geologic data available? and what does it show?

4. The slide titled the "2009 E-W Seismic Line" shows an interpreted fracture-flow geothermal system and an interpreted EGS system, and the next slide shows a proposed drill hole to test these interpretations. There is no mention of any supporting data for these interpretations, and perhaps there is none. If so, the slides and interpretation should be identified as strictly speculative. On what basis were these interpretations made? Most importantly of all, one would hope that the students did not come away from the course with the impression that this is all there is to generating a geothermal drilling target!

5. The "Development Plan" slide was also quite speculative, and one hopes that the students knew this and that it was meant strictly as a bare-bones illustration of some of the considerations that need to be included in any real geothermal development. There was no way to judge this from the presentation and written material submitted.

Attempts were made to access the field reports listed in the Project Summary to help clear up some of the confusion indicated above and to better assess the quality of the field courses. These attempts failed due to an error 404 message that the report was not on the server listed. Attempts to look for the reports by exploring the CSM web site led to "not authorized" messages.

In short, the presentation and written material submitted were not comprehensive, were non-technical and carried little information that could be used to justify a higher grade. It is hoped that the field courses were much better than the impression that could be gained from the presentation.

On the positive side, the presenter appeared to be a dynamic and very likeable character, whose leadership of a field course would have enlivened the experience significantly.

PI Response:

Reviewer 23434

Score: 9.0

Comment: Accomplishments: All milestones, deliverables and desired outcomes for this project were accomplished. A full success.

Results: Can be measured in two ways. New measurements of subsurface structure were taken in the greater Mt Princeton Hot Spring region which indicate potential new regions for geothermal development. Also, multiple students were trained and an extensive community outreach was performed which assists the geothermal community as a whole.

Progress: The project is complete (at least the portion funded this time). This is the type of work that Professor Batzle will obviously continue as long as he can. The passion that he must have instilled in his students is another unmeasurable benefit of this project.

PI Response:

Reviewer 23479

Score: 6.0

Comment: I recall being excited about this project when it was first proposed, but the end results seem slim in light of the rather large $1.2M investment.

One problem, in my view, is that the particular geophysical methods that were employed are not readily integrated. For instance, the most intensive study area was Mount Princeton, in the upper Rio Grande Rift. There, Self-potential (SP) data showed interesting results. But the SP data reach ~700 m depth in the best case. They cannot contribute to identifying the deep (~2 km) drilling targets identified on the basis of seismic data.

The Project Summary indicates "structures and targets for EGS well defined"; it is not clear that this is the case. In fact, the proposed EGS target at Mount Princeton is speculative, and seems to be defined almost entirely on the basis of standard seismic imaging.

Further, the applicability of this study to EGS in general seems tenuous, in that the work focused almost entirely on areas with vigorous natural hydrothermal circulation. (For instance, the large hot springs at Mount Princeton flow at ~40 L/s.) If EGS is to become a significant factor in the overall US energy picture, it needs to extend beyond hydrothermal environments.

Does this study yield any lessons about geophysical prospecting for EGS in non-hydrothermal environments?

PI Response:

Reviewer 23583

Score: 9.0

Comment: This project had several, very practical accomplishments and by any measure of results was very successful. Field measurements were made, students trained, results interpreted, a model developed that pointed to new exploration targets—all-in-all a very successful project. The quality of the products is adequate and the productivity is acceptable.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23579

Score: 7.0

Comment: Field courses were held every year from 2008 to 2012, and the project is considered to be complete. The field courses seem to have been well organized from a logistics viewpoint, and worthwhile, as judged by the crop of students who participated each year and the number of areas studied. It's not easy to organize and execute a good summer field course for several dozen students. During the presentation, one slide showed an impressive list of organizations and people with whom the project had interfaced over the years, so one can speculate that the project coordination with collaborators was successful.

This project is considered to be complete, so no future plans were discussed. There was possibly a soft decision point at the end of each field year, but these were apparently not significant nor exercised.

PI Response:

Reviewer 23434

Score: 10.0

Comment: The project was well managed. Student labor was utilized to collect data, which offset costs. All milestones were met by the completion of the project, which was on time. No issue with data collection in adverse conditions was sited. All in all this project appears to have gone off without a hitch.

PI Response:

Reviewer 23479

Score: 5.0

Comment: Please see comments elsewhere.

PI Response:

Reviewer 23583

Score: 9.0

Comment: From the data presented, project management was highly effective and kept the scope and schedule while keeping within the budget.

PI Response:

STRENGTHS

Reviewer 23579

Comment: 1. This project exposed some 240 students to geophysical field techniques and data reduction and interpretation methods in several known geothermal areas in Colorado. Ensuring the availability of well qualified students is important to the geothermal industry, and is to be commended. Field techniques can best be illustrated through actual practice in the field -- reading about them is not enough to ensure that high quality field data are obtained. This is the importance of field camps.

2. Reports were apparently written for each field season (but seemingly can't be easily accessed).

PI Response:

Reviewer 23434

Comment: One of the primary goals of this project was to expose students to multiple geophysical data collection techniques and have them analyze the data to attempt to find undiscovered (or under utilized) geothermal resources. This engages the 'next generation' of geothermal professionals.

Student development was accomplished, with over 240 students from around the world engaged. In my personal experience it is not difficult to get students excited about geothermal projects, the topic is perceived as quite sexy. But, this project did a greater service to the community by engaging the students in such a manner that they were collecting and analyzing real data, showing them both the hardships and rewards of working with geothermal data.

Another large strength of this project was the community outreach. Professor Batzle and his students engaged with a wide and diverse mixture of people from the community. The potential benefit of this type of outreach is hard to quantify, but I wonder if an offhand remark that Professor Batzle made during his review is related. In regards to the new geothermal development that was underway outside the Mt Princeton Hot Springs area he remarked that he was surprised at the progress made thus far. It would not surprise me in the least if the advancement of new geothermal prospects in this area and the student/professor community outreach were related.

PI Response:

Reviewer 23479

Comment: The more interesting aspects of this study have to do with student and community engagement. The long list of partners is truly impressive. It is notable that, despite these many partnerships, the PIs indicate that “local resistance to development” remains a primary challenge to any actual resource development.

The number of students educated (240) is also impressive. Although that education must necessarily have been cursory – perhaps equivalent to a brief field camp – all of these students were at least exposed to geothermal resources, resource assessment, and community interaction.

Among the geophysical surveys, the Self-potential (SP) surveys stand out as having been well-executed, well-analyzed, and thoroughly presented in the peer-reviewed literature.

PI Response:

Reviewer 23583

Comment: Accomplishments and management were very strong components of this project. Training and resource discovery are given high marks. techniques applied were tried-and-true technology, not well described but results were okay.

PI Response:

WEAKNESSES

Reviewer 23579

Comment: The presentation at the Peer Review was not adequate to determine the quality of the education imparted to the 240 students over the course of several summer field excursions. The presentation itself gave the impression that the work may not have been done with the care needed for reaching conclusions and making recommendations for drill testing and installation of a utilization system in real-world geothermal development efforts. Specifics for this criticism are listed above.

PI Response:

Reviewer 23434

Comment: Perhaps the project and the work would have benefited from a wider involvement of geophysical professionals early on, but I'm not convinced of that.

PI Response:

Reviewer 23479

Comment: With the exception of the SP-based work by Andre Revil and colleagues, the publication legacy of the study is limited.

My overall impression that this effort was not well-integrated and this was, unfortunately, reinforced by the style of the presentation and subsequent Q&A. Despite the emphasis on the Mount Princeton area, the PI seemed unable to address fundamental questions about geothermometer temperatures and conductive heat flow in that area.

Please see also my comments under "Accomplishments…"

PI Response:

Reviewer 23583

Comment: Program relevance, scientific merit and impact and technical approach were of mediocre value.

PI Response:

IMPROVEMENTS

Reviewer 23579

Comment: It might be worthwhile for Colorado School of Mines to convene a meeting of a limited number of industry representatives to provide advice on what would be most useful to them in a summer field program.

For presentation of this project to an audience knowledgeable about geothermal energy, the following suggestions are made:

- Present a field map showing the locations of all surveys and survey lines.
- Summarize the known geology, geochemistry, geophysics, and other pertinent data for the study area.
- List the field techniques used for field data collection, the equipment used and the data reduction methods applied.
- Discuss the interpretation methods applied to individual techniques, the data sets that were subject to joint inversion, the joint inversion methods themselves and the results.
- Indicate the extent of the exposure of the typical student to the various methods, i.e. how many students operated which equipment, were they required to do the data reduction, etc. for each data set, how were they involved in the interpretation.

A presentation such as this should be possible within the DOE requirements for written and oral project presentation.

PI Response:

Reviewer 23434

Comment: Not really applicable as the project is over.

PI Response:

Reviewer 23479

Comment: It is notable that, despite many local partnerships, the PIs indicate that "local resistance to development" remains a primary challenge to any actual resource development. It would be useful to learn more about the nature of the partnerships and reasons for resistance, and to capture any advice about community relations that the PIs might have to share.

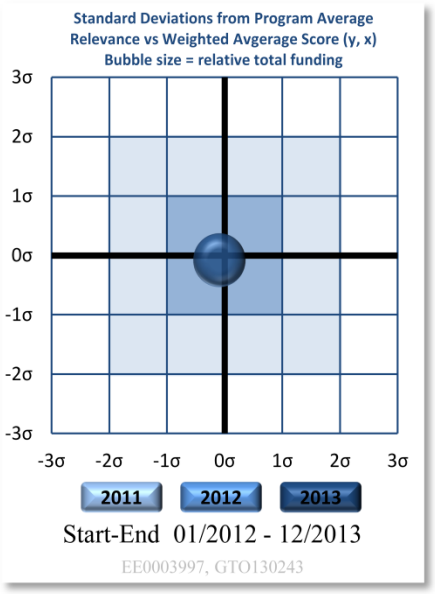
PI Response:

Reviewer 23583

Comment: NA

PI Response:

Geophysics and Geochemistry Reviewer Comments and Principal Investigator Rebuttals



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0003997
Project: Great Basin Center for Geothermal Energy (I\IV)
Principal Investigator: Calvin, Wendy
Organization: University of Nevada, Reno (UNR)
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23417

Score: 8.0

Comment: The GBCGE has undertaken significant amount of geothermal research in the Basin and Range over the past 10-12 years and this has contributed substantially not only to the understanding of hydrothermal systems in extensional environments but also to geothermal systems in general and, in particular, to new geothermal exploration techniques.
The new approach of shorter research programs and seed grants is very appropriate and the types of projects currently being funded is good, particularly in the InSAR, GPS and remote sensing fields which are technologies that will aid the discovery of blind systems.
The relevance of these research projects remains current and it is refreshing to see the GBCGE step outside of the Basin and Range. However research topics seem to be spread over a wide range of disciplines and for a institution of this size it could be that more focus is needed.

PI Response:

Reviewer 23641

Score: 9.0

Comment: GBC activities are strongly aligned with GTO goals in developing a future workforce for geothermal and in research on geothermal systems.

PI Response:

Reviewer 23612

Score: 7.0

Comment: This is a unique project with very broad objectives and potential reach. Growing the strength and competitiveness of academic institutions in the heart of geothermal country, supporting cutting-edge research, educating

future scientists, and building collaborations across agencies and other organizations all support GTO's goals. In that sense, relevance is high. Six PI-led R&D projects funded by the center began September 2012, so results are generally still preliminary and it is hard to infer potential impacts. The diversity of the projects is notable (reservoir modeling, seismology, well data, remote sensing, geochemistry, E&M), expressing breadth of expertise at UNR and DRI. Some insights into potential impact could have been better illuminated as described in the specific comments for each sub-project below.

PI Response:

Reviewer 23450

Score: 4.0

Comment: The question of relevance has several aspects: are geothermal dollars to be spent on R&D or training students? Both are worthwhile activities. The focus on small projects for training student for the geothermal industry seems appropriate to the stated GBC objectives. The retention rate in the geothermal industry should be higher. The lack of reservoir engineering expertise or perspective undercuts the potential relevance of the Center.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23417

Score: 7.0

Comment: Wide range of projects presented which makes reviews somewhat difficult. Summarizing:

1. THMC – useful but a number of other DOE projects being funded in this area.
2. Downhole Geophysics – very important area.
3. InSAR/GPS – these types of projects are critical to improving the success rate of geothermal exploration particularly in the Basin and Range.
4. Noble gasses and isotopic analysis.
5. Crustal attenuation (velocity models) – really critical for B&R.
6. Exploration in the Pacific NW – critical but no information.
7. 3D modeling of fairway mapping.
8. Remote Sensing – critical for finding blind systems.
9. 2-m Temperature mapping – useful but further research is probably not needed.

It is a positive move that GBC is moving outside of the Basin and Range province. However the presenter seemed to indicate that their internal project solicitation process did not require specific topic areas for project proposals. It would be more valuable if broad topic areas could be specific - such as the Pacific Northwest. That would result in a more focused program rather than one that was scattered. Some of the topics currently being funded have become established techniques and do not need further research funding.

PI Response:

Reviewer 23641

Score: 9.0

Comment: Strong technical capabilities; doing high quality research.

PI Response:

Reviewer 23612

Score: 7.0

Comment: All of the sub-projects seem to have an adequate approach, with some details that would make evaluating this component easier listed below under specific comments. One question that came to mind was whether the seed funding process could have been more competitive. Other NV institutions of higher education were informed of the opportunity, but no interest was expressed and no applications were received. Is there an understanding of why the solicitation was not more successful, or how this could be improved in the future? The approach included shifting focus to smaller competitive grants to seed future faculty research. But, the very high success rate questions the competitive nature and trends towards a subsidy for UNR and DRI faculty. Is this justified?

PI Response:

Reviewer 23450

Score: 3.0

Comment: The scientific approach is to provide seed grants, technical staff support, fellowships and outreach (as stated on the slide). This isn't science, has no obvious focus and one wonders how projects are selected, vetted, and funded?

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23417

Score: 7.0

Comment: Since the presentation covered multiple projects covering multiple disciplines it is difficult to assess individual accomplishments. However the quality of the researchers at GBCGE has always been very high, and the new type of approach being used to fund research and outreach, in the reviewers opinion, should be supported by funding.

PI Response:

Reviewer 23641

Score: 9.0

Comment: High quality projects, high quality graduates entering the geothermal workforce. High productivity on the GTO investment.

PI Response:

Reviewer 23612

Score: 7.0

Comment: More clarity on the success metrics for GBCGE would help in addressing accomplishments. There are two aspects here: 1) what has been accomplished in the past decade relative to the baseline prior to 2002, and 2) how did the new efforts under the scope of the current award foster progress with respect to the preceding period? The former will presumably be clarified in the pending decadal report due 9/2013. For the later there are plans to require seed grantees to include plans for applying for outside support in their project final reports. Is there any plan to further track improvement in faculty success in securing external funding due to these seed grants?

Specific comments and questions based on limited details regarding each project. These remarks were not used in scoring the overall project:

- Reeves, THMC Modeling: If the models are used by proponents of Brady's to guide the EGS stimulation, this is a very valuable contribution. To what extent has the collaboration with Ormat been developed, such that these results might inform field efforts? Is this work duplicative of modeling underway by LANL, and if so is there a plan to collaborate and/or compare approaches and results?
- Tibuleac, Attenuation: Is there a plan to compare the value of each method for measuring attenuation, and if so how? The ambient noise approach for characterization in absence of or in between major seismic events could add real value.
- Louie, Downhole Geophysics/New Zealand: The educational opportunity sounds rich, but what is the plan for evaluating the value of shear-wave splitting?
- Hammond, InSAR/GPS: Over what time period did the preliminary InSAR data show ~5cm subsidence near Stillwater? What are the rates? Will GPS be used to quantify uncertainty associated with InSAR, and is this relevant here given the large signal? Can you still calibrate and then apply the methodology to sites with slower deformation rates?
- Cooper, Noble Gas: Was March/April 2013 sampling conducted as scheduled, and if so are there any preliminary thoughts on how the data may inform the conceptual models? What are the major features of the preliminary model that can be tested?
- Cashman, EM/ReMi: These techniques have been around for more than a decade (ReMi; Louie, 2001). What is new here? Is there a plan to more robustly quantify uncertainty of each method based on LiDAR and water samples?
- Calvin, Graduate Fellowships: This year 4 GBCGE graduate fellows will finish. The historical average for the program since 2002 is 3/year. Other students are also working on faculty-funded research. Will some of them graduate as well? Are total graduates this year higher than other years because of some change in the program? If not, a more interesting question is how the record of the past decade compares to that before the center was funded.

- Calvin, GBCGE Communication: Have new funding sources within and outside of DOE been identified as planned? What plans are there to pursue these opportunities? What is the status and prospects for the NSF I/UCRC? Has the seed funding already opened any doors to securing additional support, especially outside of DOE? If this isn't the ultimate impact, would those dollars be better spent by DOE on open competitions?

PI Response:

Reviewer 23450

Score: 5.0

Comment: The projects listed are interesting and provide training and application of geophysics, seismology, geochemistry, and structural geology to geothermal problems.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23417

Score: 7.0

Comment: Managing multiple projects at multiple facilities requires time and budget. GBCGE has always managed projects effectively on limited resources. They also have placed a significant amount of data in the public domain and made it readily and easily available for public use. This has not always been the case with many other institutions working on DOE-funded projects.

PI Response:

Reviewer 23641

Score: 9.0

Comment: Appears to be a well managed institution doing quality work for reasonable cost.

PI Response:

Reviewer 23612

Score: 7.0

Comment: What are the results of and plans going forward resulting from the collaborations indicated – the NSF US-New Zealand workshop, the EPRI workshop on EGS, and the USGS UAV collaboration? What about plans and prospects for the NSF I/UCRC? The establishment of collaborations outside of NV are commendable, but more details on the status and impacts of these opportunities would help in evaluating this piece.

PI Response:

Reviewer 23450

Score: 4.0

Comment: Funds expended to date seem to have supported a range of projects with good R&D payback metrics (individuals supported/seeded, papers published, etc). Reviewer does not think it is appropriate to spend taxpayer monies on reservoir engineering projects in New Zealand when we have the Stanford Geothermal Program and other domestic reservoir engineering professionals. This is especially noteworthy as the GBC has no reservoir engineering expertise.

The reviewer is not fond of congressional earmarks as it circumvents the administrative and R&D oversights and places other researchers at funding disadvantage for limited R&D funds.

PI Response:

STRENGTHS

Reviewer 23417

Comment: 1. Excellent, very high quality researchers with extensive experience in Basin and Range geothermal settings.

2. Continuing development and training of students for employment in the geothermal industry, particularly in Nevada. This is a very important industry need.

3. The concept of "seed grants" is an excellent approach to a varied and diverse range of projects.

4. Venturing outside of the Basin and Range is a positive move.

PI Response:

Reviewer 23641

Comment: Location at the heart of US geothermal industry. Good mix of skills for a relatively small program. Enthusiastic and well trained graduates.

PI Response:

Reviewer 23612

Comment: The project is strong in the breadth of research it is supporting across the geothermal spectrum. The seed-funding mechanism is a good concept and could add real value if it helps to inject geothermal R&D into other support streams.

PI Response:

Reviewer 23450

Comment: Geoscience focus and integration of different disciplines on the various projects.

31% geothermal retention rate in the industry.

PI Response:

WEAKNESSES

Reviewer 23417

Comment: 1. While a varied research program is a credible goal, there does seem to be rather a disjointed or unfocussed platform on which these projects are based.

2. The question was asked if working with overseas institutions was something reasonable for DOE funded projects - the response was that GBCGE could only respond to proposals submitted. It should be possible to provide some set of internal guidelines that outlines the research topic areas that would allow a more focused approach.

PI Response:

Reviewer 23641

Comment: Heavy focus on Nevada research (due to its status as state entity). Opportunities to apply research to geothermal outside Nevada.

PI Response:

Reviewer 23612

Comment: The seed-funding process was not particularly competitive.

PI Response:

Reviewer 23450

Comment: Lack of reservoir engineering expertise.

PI Response:

IMPROVEMENTS

Reviewer 23417

Comment: 1. A stronger focus on specific areas - such as focusing on the Pacific North West - would provide a more organized program.

2. Some of the existing research areas, such as 2-m probes, do not need further support. This is a technology that is relatively straight forward and has been fully developed as a research topic.

3. Although not fully relevant to this review, the reviewer would like to see additional funding go to the National Geothermal Academy. Many queries are received from overseas for training programs. The US lags behind in providing such programs and these are the types of activities that will promote the development of new ideas and technologies by association with overseas geothermal projects. GBCGE is an ideal place for foreign geothermalists to come and study, especially if a broader program were developed in Reno. This would require the development of researchers experienced in geothermal systems exploration in volcanic environments.

PI Response:

Reviewer 23641

Comment: Keep up the good work.

PI Response:

Reviewer 23612

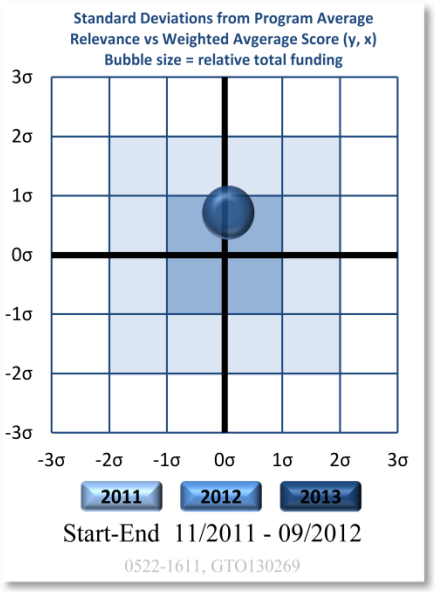
Comment: Additional details on metrics and methodology for evaluating impacts of the center would add a lot of value and help in demonstrating the opportunity that a center approach affords DOE and the community.

PI Response:

Reviewer 23450

Comment: If the Center is to provide technically trained people for the geothermal industry, it would be helpful to include reservoir engineering, either directly or in collaboration with a domestic university (Stanford, Colorado School of Mines, U of Texas, etc).

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: 0522-1611
Project: Novel use of 4D Monitoring Techniques to Improve Reservoir Longevity and Productivity in Enhanced Geothermal Systems
Principal Investigator: Rose, Kelly
Organization: National Energy Technology Laboratory
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23417

Score: 7.0

Comment: Identifying and characterizing fluid pathways during the life of an EGS system will be one of the most difficult barriers for geothermal (EGS) developers to overcome. For that reason alone this is an important project. However not much information regarding this project was provided either in the documentation or during the presentation. The reviewer was left uncertain as to how monitoring was actually going to be accomplished. (See Technical Approach)

PI Response:
Appreciate the feedback. We'll endeavor to improve the clarity of our documentation and presentations in the future. Ultimately, the monitoring is conducted through a combination of continuous geophysical measurements (EM/MT/gravity) and specialty acquisition of key geophysical parameters (e.g. the surface portable SAR system) designed to coincide with key events such as stimulations and flow of the EGS reservoir. To-date, continuous MT profiling was carried out pre- and syn- stimulation, a monitoring effort that continued into post-stimulation (December 2012 - February 2013), and is resuming in August 2013. The 3D MT monitoring over the entire stimulation zone and surrounding areas took place before stimulation, and a subset of sites were repeated during stimulation. Post-stimulation redeployment of the array is currently being scheduled. Similarly gravity data were obtained over the area pre-stimulation, although field conditions and the smaller signal levels anticipated from smaller volumes of injected fluids than originally anticipated led us to suspend gravity monitoring syn-stimulation. Both ground-based and satellite based radar data was collected pre-stimulation and leading up to the first phase of stimulation. Ground-based radar data collection was terminated with winter conditions mid-stimulation, but satellite InSAR data has continued to be collected.

Reviewer 23641

Score: 8.0

Comment: High relevance/impact research aimed at remote monitoring of subsurface reservoir behavior over time.

PI Response:
Appreciate the feedback.

Reviewer 23612

Score: 10.0

Comment: The project addresses a critical and to date poorly studied component of EGS development – system operations. Reducing costs and improving performance beginning with stimulation activities and ultimately running through the production lifetime are key to EGS success, so starting to develop techniques around this goal could be high impact. There is a real opportunity for lessons learned not only technically, but in terms of logistics associated with long-term and comprehensive instrument deployment, data acquisition, and analysis campaigns. The methodology is begin developed and applied to EGS at Newberry volcano, but aspects of the approach may also be relevant to traditional hydrothermal field management, especially with respect to monitoring (and mitigating, through in-field EGS) long-term fluid and/or heat drawdown.

PI Response:
Appreciate the feedback. It is also our hope that once we understand which geophysical parameters or combination of parameters are of use at the Newberry EGS site that the resulting approach may be transferrable to other subsurface resource systems such as conventional geothermal, hydrocarbon, CO_2 storage etc. So the reviewer's comments are appreciated and align well with our intent.

Reviewer 23450

Score: 8.0

Comment: The project stated goal is to improve low cost monitoring capabilities using surface based techniques. If this can be done, then this would be a highly relevant advance in surface measurements of subsurface fracture creation and propagation. While the project is focusing on EGS resources, the proposed techniques, if field demonstrated, would be useful in conventional geothermal and petroleum stimulation monitoring and analysis and changes over time. The multiple and rich data sets provide constraints for uncertainty analysis.

PI Response:
Appreciate this feedback. This aligns well with the comment directly above and our response.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23417

Score: 5.0

Comment: Despite the importance of monitoring EGS reservoirs as they are produced, neither the presentation nor the project summary seemed to present how this was going to be achieved. Phrases such as "advanced geophysical techniques" were frequently used without much accompanying detail. Some of this detail may have been presented in earlier reviews. It is difficult for the reviewer to visualize how MT/CSEM or the other geophysical tools described could characterize or monitor fluid movement through individual, discrete fractures at depths up to 10,000 feet or more and over horizontal (or subvertical) distances of 1000's of feet. Unless there have been some substantial development of equipment, the techniques described, in the reviewer's opinion, are just not sensitive enough to accomplish this goal to the degree of accuracy that would be required by an EGS operator.

It would seem important to have some model of what an EGS system may look like in the subsurface - spacing and fracture apertures, permeability/interconnectivity etc. If such a model existed it should not be difficult to evaluate the applicability of these techniques to be able to characterize the system.
Integration of such datasets is still an important objective and will certainly aid in the development of systems, but the reviewer does not believe they can achieve what is being suggested. There is also no indication as to how the geochemical datasets are actually going to be incorporated into the modeling.

PI Response:
We appreciate the reviewer's perspective but would like to offer a few recently published peer-reviewed references that help illustrate why we believe, and others in the technical community as well, that the various geophysical tools utilized in our approach do have sufficient sensitivity to be appropriate for the monitoring proposed in this study. Utlimately, however, that is the goal of this work, to assess and evaluate the effectiveness and appropriateness of these tools for the monitoring proposed.

Vasco, D., Rutqvist, J., Ferretti, A., Rucci, A., Bellotti, F., Dobson, P., Oldenburg, C., Garcia, J., Walters, M., and Hartline, C., 2013, Monitoring deformation at the Geysers Geothermal Field, California, using C-band, and X-band interferometric synthetic aperture radar., Geophysical Research Letters, vol. 40., pgs. 1-6.

Peacock, J., Thiel, S., Reid, P., and Heinson, G., 2012, Magnetotelluric monitoring of a fluid injection: example from an enhanced geothermal system, Geophysical Research Letters, vol. 39, pgs 1-5.

Peacock, J., Thiel., S., Heinson, G., and Reid, P., 2013, Case History, Time-Lapse Magnetotelluric Monitoring of an Enhanced Geothermal System, Geophysics, vol. 78, pgs B121-B130.

Specific details about the field operations alluded to be this reviewer have been addressed in our response to the first reviewer's question above.

Reviewer 23641

Score: 8.0

Comment: Strong and innovative technical approach.

PI Response:
Thank you, the feedback is appreciated.

Reviewer 23612

Score: 7.0

Comment: As the project is early in the deployment phase and pre-analysis, the laboratory and numerical feasibility assessments are of interest. Some results are shown for MT/CSEM predictive modeling, but more details would help in evaluating the care with which experiments were designed for the other techniques. There were competing changes in dynamics with respect to the initial stimulation plan/expectations: less volume by half was injected, but seismicity occurred shallower than anticipated. So, deformation is still anticipated to have occurred at the detection threshold (<cm for ground radar, ~cm+ for InSAR), but was an updated sensitivity analysis done profiting from the new information? There was “numerical and laboratory-based assessment of the … radar” that produced predictive models, but with what

method and results? They "anticipate changes with EGS stimulation" in gravity measurements, but of what order and are they resolvable? They say that "combined MT and CSEM can achieve deep penetration and finer scale resolution." What scales and how deep, and how does this impact the project?

The stated method is to "reduce ambiguity by overlaying complementary data sets." What techniques will be used to integrate the data? Will a component of this be embedded in the "new software"? What are its intended component parts and capabilities? A small technical question is whether radar reflectors on trees move more than the ground itself. Could this be an issue for the ground-based radar, and can it be mitigated through the use of InSAR and its lower sensitivity to horizontal motions?

In the field, the team seems to have executed well given scheduling and weather hardships, which were beyond their control. What impact will the decision not to proceed with gravity work and the deployment of only 29 of the originally planned 75 MT stations in the syn-stim phase have on the results?

PI Response:
We definitely agree that our results presented at this review were limited to and impacted by the unexpected results of the field stimulation. However, in highly exploratory settings such as the Newberry system, these types of unexpected results are common and the team has and continues to work to adapt while maintaining the goals of our specific project which is the development of a new approach and method for monitoring the health and longevity of an EGS reservoir.

As this is a new approach, the team is responding to the challenges presented by the unexpected initial field data and is also awaiting the second phase of field data collection, due summer/fall 2013. However, ultimately we will be assessing the value and results of the different geophysical datasets, and potentially geochemical as well, to assess the utility of each individually as well as combinations that may prove more effective for monitoring of the subsurface fluid migration pathways over time. Ultimately, we anticipate providing a recommended approach, what combination of geophysical tools and potentially layouts etc. that an operator could implement at other EGS sites. The software mentioned above is intended for use in the interpretation and analysis of the individual datasets.

With regards to the reduced gravity and MT data collection in the 2012 field season, the continuous monitoring stations are anticipated to provide a correlation between the pre-stim fuller geophysical dataset and the reduced monitoring dataset that will help reduce and mitigate the loss of data. In addition, given that stimulation appears to have migrated largely out of the target zone meant that the MT and gravity sensors and design may not have been appropriate to capture the shallower water migration regardless. Essentially, those surveys were designed for the deeper, ~10,000 feet below surface, reservoir target, and not the shallower, ~4,000 feet below surface, stimulation that appears to have occurred. We are addressing this by implementing firmware modifications to our MT instrumentation to allow us to collect higher frequency (4 kHz sample rate) data (previously 1 kHz was the maximuk sample rate), and we are planning to redeploy these instruments to obtain a higher resolution nearer surface electrical conductivity image that may help delineate posited shallower fluid flow paths than originally planned by AltaRock Energy.

Reviewer 23450

Score: 8.0

Comment: Field testing of the portable interferometric radar and the ability to detect sub-centimeter ground deformations and relate to fracture creation and propagation would be an advance in surface measurements and the ability to relate to subsurface hydraulic stimulation. If it can be performed in a cost effective manner, it is useful for mapping the region or volume impacted by the stimulation. Further integration with gravity, MT/CSMAT can be used to map productive regions and bounding clay rich caps to a geothermal system.

PI Response:
Appreciate this comment. It is related to comments and responses above as well.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23417

Score: 5.0

Comment: Because of the delay in Alta Rock's field operations, not much has been achieved so far in this project. Various meetings and permits have been completed with some deployment of equipment. Phase 1 report was submitted in September 2012 but the reviewer did not have access to that document, so it was uncertain as to what was included. There has been data collection but no results have yet been presented.

PI Response:
Appreciate the comment. Does not appear to warrant a PI response other than to note there has been a very substantial field data acquisition phase, and that more than 1/3 petabytes of electromagnetic time series data, as well as a rich gravity and radar data set have been acquired as part of this ongoing field and analysis campaign.

Reviewer 23641

Score: 8.0

Comment: Accomplishments of high quality and productivity despite sIte access limitations.

PI Response:
Appreciate this comment. Seems related to responses above as well.

Reviewer 23612

Score: 7.0

Comment: Productivity is good given scheduling and weather constraints, but again perceived impacts of modifications in field deployments is a bit unclear on some accounts (gravity, MT). The use of InSAR to augment radar and the plan to engage LBNL on geochemical modeling to fill in for lack of flowback fluid samples sounds like good adaptations. How well are the two radars working in tandem and what is the state of the LBNL collaboration?

PI Response:
Thank you. Please see the journal references included in a response above as they may be useful for this commnent as well.

Pertaining to the LBNL coordination, we have reached out to that group on a number of occassions but with no success. We plan to utilize Altarock and our EERE Program Manager to try and rectify this issue once the next field phase at Newberry is completed, fall 2013.

The two radar day sets are currently being processed and it is difficult to answer this question adequately at this time. What we do know is that the ground based radar is more sensitive to horizontal motion and satellite InSAR is more sensitive to vertical motion so the two systems are complimentary in determining the complete surface deformation vector at each common point. Since the ground radar is on-demand, it can fill in gaps in data coverage between repeat pass InSAR orbits. However, in our case given the distance to the stimulation zone is 6 km away from the Paulina Peak antenna position which reduces the East-West (azimuth) resolution, isolating point targets is more difficult and requires more advanced processing and experimental processing techniques than originally anticipated.

Reviewer 23450

Score: 6.0

Comment: Project is too early for significant accomplishments. Proof of concept numerical studies and the Newberry example show promise for integration and mapping of these multiple geophysical data sets.

PI Response:
Appreciate the feedback.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23417

Score: 6.0

Comment: Project management tasks seem to have been completed in an efficient manner. Adequate meetings between Team members. With regard to budget approximately 50% of the Phase 2 budget has been expended with little data or results.

PI Response:
Appreciate the feedback. As was intended in the original project proposal, schedule, and plan, results and products should be forthcoming as we move into year 3 of this study. As is the case with many field based projects, field and data acquisition costs are a substantial portion of the budget and schedule, with results and interpretations resulting in the latter 1/3 to 1/4 of these types of studies. Previous comment responses have noted the large volume of data thus far collected in this project.

Reviewer 23641

Score: 8.0

Comment: Resourceful in adapting to site access issues.

PI Response:
Appreciate the feedback.

Reviewer 23612

Score: 8.0

Comment: The team seems to have accomplished much of their intended scope despite external complications. Coordination with primary stakeholder AltaRock and subcontractors to enable field deployment and acquisition under difficult conditions shows logistical competence, and technical competence is high. It's not clear exactly what decision points were in place to address changes in plans, though. Is this being done in an ad hoc manner, or are there clear contingencies in place? This would go for post-stim efforts as well as work to date.

PI Response:
Appreciate the feedback. With regards to the decision process in place to address changes in field operations etc., our main tools are administrative controls and processes. Specifically, our team holds regular biweekly coordination calls. In addition, we regulalry coordinate with the Altarock team, and during field operations we were on the distribution list for the daily operations and drilling report. Finally, as issues such as the lower volume of water injected and the likely stimulation of the shallower zone have emerged, we have coordinated and worked with our EERE GTO Program Manager to evaluate our approach and various changes in schedule, approach etc. as appropriate.

Reviewer 23450

Score: 6.0

Comment: Project costs seem appropriate for work completed to date. There does seem to be a lot of players to coordinate schedules and activities.

PI Response:
Appreciate the feedback.

STRENGTHS

Reviewer 23417

Comment: 1. The monitoring of EGS projects is going to be a very critical issue for the future of the geothermal industry. Newberry is by far the best prospect the US has for a true EGS project, so if monitoring research can work in this setting then hopefully other sites can benefit.

2. Alta Rock certainly is one of the most active in EGS development and as a consequence the best and most knowledgeable people available are working on this project.

PI Response:
We have definitely benfitted from good interaction with, and the knowledge of the Altarock folks. Appreciate the reviewer's comments.

Reviewer 23641

Comment: Innovative reservoir monitoring approach. Relatively low cost, non-invasive method.

PI Response:
Appreciate the feedback.

Reviewer 23612

Comment: The approach is hugely important to current and future EGS successes, and the team and techniques are of the highest level. Development, testing, and validation (through the use of InSAR) of an innovative ground-based radar interferometry system adds real exploratory value to the project.

PI Response:
Appreciate the feedback.

Reviewer 23450

Comment: The combination of multiple and diverse geophysical data sets to for detection of conductive and resistive regions.

Application of these methods at an active geothermal exploration site for testing and refinement.

Adaption to field conditions as weather changed.

PI Response:
Appreciate the feedback.

WEAKNESSES

Reviewer 23417

Comment: The reviewer does not have any comprehensive understanding of what the outcome of this project will be primarily because no substantial information were presented. For example during operations of an EGS project, an anticipated problem could well be temperature decline in the producing well - how will the data collected as a result of this research program be able to provide the developer information as to why such declines are occurring?

PI Response:
Appreciate the feedback. As noted in a comment/responses above, we will work harder in future presentations to communicate the anticipated outcomes and results of this project more clearly. See response above pgs 1 and 2, for additional discussion.
Reviewer 23641

Comment: None identified.

PI Response:
Appreciate the feedback.

Reviewer 23612

Comment: Since many of the field results are still pending, the sensitivity analyses hold the key to verification of thoughtful experimental design and expectations on success. Details on the methods and results here were lacking.

PI Response:
Appreciate the feedback. As noted by the reviewer, details on the results were lacking but these will be forthcoming over the next year and we'll endeavor to communicate these in future presentations.

Reviewer 23450

Comment: Project dependence on operator support and susceptibility to weather issues (mostly unavoidable).

PI Response:
Appreciate the feedback.

IMPROVEMENTS

Reviewer 23417

Comment: Given the quality of the researchers, more data can be provided and a much clearer discussion on how CSEM data collected at the surface can provide sufficiently sensitive data useable to monitor fluid flow and temperature in an operating EGS system. Engineering such as EGS system is one thing, but monitoring an operating system and resolving flow and temperature problems in reasonable, economic time frame is another.

PI Response:
Appreciate the feedback. Please see the response above on page 3 which addresses this comment and provides several recent journal publication citations that help support our approach.

Reviewer 23641

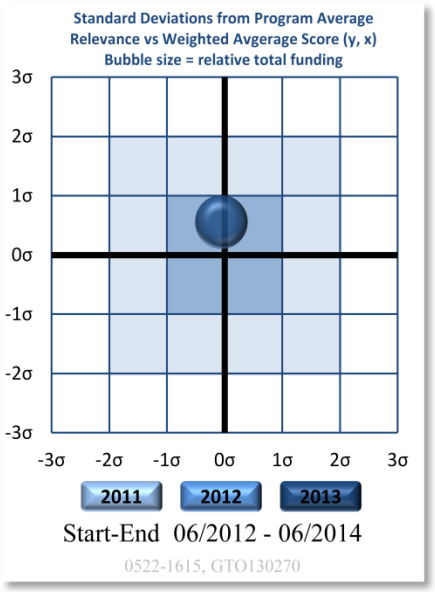
Comment: None identified.

PI Response:
Appreciate the feedback.

Reviewer 23612

Comment: Added clarity on the feasibility studies for each method, along with updates that reflect the latest data from the field (e.g. volume injected) would help. In addition to calibrating expectations for the current project, if done thoughtfully this work could also serve as a gauge for the utility of each method for EGS going forward.

PI Response:
Appreciate the feedback. We'll endevor to communicate more clearly in future presentations methods used, approach, and results to address this concern.



Review: 2013 Geothermal Technologies Office Peer Review
ID: 0522-1615
Project: Optimizing parameters for predicting the geochemical behavior and performance of discrete fracture networks in geothermal systems
Principal Investigator: Hakala, Alexandra
Organization: National Energy Technology Laboratory
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 25423

Score: 9.0

Comment: This project can have direct impact on development of geothermal resources by providing information on behavior of fractures in geothermal systems.

PI Response:
This is a primary goal for the project.

Reviewer 23444

Score: 7.0

Comment: Two objectives are stated: (1) to use reactive transport modeling with fracture flow models to predict changes in fracture transmissivity due to chemical reactions, and to verify predictions with lab experiments; and (2) to demonstrate the application of specific isotope systems as indicators of fracture flow pathway-specific fluid-rock geochemical reactions in EGS reservoir samples. There is no doubt that the ability to predict and quantify changes in fracture aperture and transmissivity due to fluid-rock interactions in EGS systems is critical to identifying and sustaining the life of the system and its productivity. Fluid-rock reactions have the potential to significantly alter flow paths not only in the rock but also in the engineered system. If results from these small-scale experiments can be up scaled and generalized to the field scale, an important outcome would be realized. Consequently, the relevance of this portion of the research is high, if these goals can be achieved. It is less clear that the second objective will have widespread applicability or impact, in part because these isotopic systems (Sr, O, C) have been studied for decades and bulk fluid geochemistry cannot be unambiguously related to fracture transmissivity.

PI Response:
A primary goal with the use of the isotopic systems is to determine whether isotope variations in through-flowing fluids can be linked back to specific mineral reactions occurring at fracture surfaces. To better understand these interactions, the isotope compositions of different minerals and bonding environments in the core material are being measured, and these data will be compared to experimental fluids. This will provide the basis for application of additional, less common metal isotope systems as tracers for dissolution and ion exchange.

Reviewer 25419

Score: 9.0

Comment: This project is conducting basic research on the behavior fracture networks created as a result of EGS development, which is important to EGS reservoir sustainability.

PI Response:
This is the focus of the project.

Reviewer 25040

Score: 7.0

Comment: This project is still in its early phases, but its fundamental goal of investigating permeability evolution during fluid flow in fractures is a critical one for evaluating the lifetime of EGS stimulated fracture and the factors controlling that lifetime, with a view toward optimizing the development and management of EGS systems. This tool will probably remain heuristic in nature rather than predictive because of the great complexity of natural systems and fluid-rock interactions. However, this does not diminish its value in anticipating chemical reactions that may impact EGS systems.

PI Response:
The results from this work are anticipated to lead towards an ability to develop inputs for broader reservoir planning associated with EGS systems.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 25423

Score: 8.0

Comment: The project is well executed for the limited amount of data obtained to date. Moving forward, the PI is going to have the keep the project and co-investigators on track if she's going to accomplish her objectives, especially with respect to the experiments. My suggestions for improvement in the experimental program are:
1) Clearly elucidate the conceptual model for what the experiments are to accomplish. The PI did not do this in her presentation, but she did allude to it later in the Q&A. This conceptual model may exist; if it does it needs to be front/center and ever present in the PI's thinking the next year. If it does not exist, one needs to be developed. It should include elements such as source of fluid for fractures that are being studied: is it recycled production fluids, in-situ but untapped geothermal fluids, meteoric waters first entering the system?
2) Stay clear on the geochemical processes of interest and analyses needed to elucidate these processes. For example, if stable carbon and oxygen isotopes won't work because of the geochemistry, then don't do them. Another example: one or two short experiments with DI water are allowable for methods development, but don't get bogged down here or the year will go by without appropriate progress.
3) What are the criteria for deciding when an experiment is done? Steady state concentrations of specific inorganic parameters? Steady state permeability? Permeability threshold below which the experiment cannot proceed? These criteria need to be clearly defined and enunciated.

PI Response:
We are identifying the types of fluids that will need to be used for the experimental work that best relate to potential field operations. Per comments made during the peer review discussion, the project team decided to investigate the effect of alternative fluids through the use of batch experiments. Results from the batch/static experiments will be used to inform reactive transport models and flow-through experimental work. We will clearly identify the parameters for completion of an experiment, and the technical reasons behind choosing those parameters, after the completion of reactive transport modeling to help predict what may occur during the flow-through experimental runs.

Reviewer 23444

Score: 5.0

Comment: Based on the material supplied, the technical approach involves a combination of predictive numerical modeling on reactive flow through fractures with fluid-rock experiments on stressed core, characterization of natural samples via X-ray CT imaging, and bulk rock data, and stable isotopic analyses of fluids with the goal of relating isotopes to fluid-rock reactions. From the discussion, it was less clear that an appropriate conceptual model had been developed for the system in its entirety in order to guide the experiments and the modeling.

There is a vast literature on fluid-rock interactions, and the isotopic signatures of these reactions, beginning in the late 70's, which does not appear to have been consulted. Much of the proposed work has been completed by previous workers, perhaps with different rocks but largely applicable. It appears that minimal, if any, literature search had been done prior to beginning the modeling or experiments. A few references were given in the SOW, the earliest 1998 (by one of the collaborators). With the current thermodynamic data, rates, and isotopic fractionation factors, one could predict the likely chemical reactions that would occur in the rock samples. Isotopic indicators are not going to give fracture transmissivity - isotopes may identify likely mineral reactions which can then potentially be inferred to give transmissivity. Transmissivity is a derivative property and requires spatial information.

The experimental method is sound but there are logic leaps in the data gathered. The starting materials and final materials appear to be well characterized for chemistry and starting fracture/porosity. Bulk fluid chemistry is not going to provide information on transmissivity – rather it may record specific fluid-mineral reactions (see above). The flow-through experiments appear to be appropriate. However, starting with a ‘pure’ fluid flowing through the rock will cause large amounts of dissolution because the fluid is far from equilibrium. Most fluids in EGS systems are not far-from-equilibrium. It is unclear how these pure fluid experiments will relate other than to constrain the isotopic analyses.

There are numerous open-source image processing routines available, it is unclear why code needs to be developed for processing data from XRCT (e.g. U TX CT lab) – perhaps this refers to developing the routine needed to convert CT data to use in crunchflow?

The combination of fluid flow experiments with CT is useful for producing the temporal framework. It was difficult to assess how the XRCT data was being incorporated into the reactive flow modeling from the material provided and if ‘Crunchflow” has options for modeling a discrete fracture or discrete fracture networks.

How this study will be up-scaled presents a challenge to the researchers that was not clearly addressed.

PI Response:
The geochemical information obtained from solids and fluids prior to, during, and after the experimental runs will be used in combination with the imaging results to inform the reactive transport codes. Routine development for the modeling was necessary in order to translate the CT-mapped fracture surfaces into a format suitable for use as a reactive surface in Crunchflow. We are using known reaction kinetics and thermodynamics as input parameters for the pre-experimental reactive transport modeling. The experimental work (including imaging and geochemical/isotopic analysis) will result in identification of phases involved in the reactions, the extent to which these phases exchange/dissolve/precipitate at fracture surfaces, and how the reactions in specific locations affect flow across the fracture. As noted above, the pure water starting material allows knowledge of initial geochemical reactions to be combined with spatial imaging during the experiments, and informs follow-on experiments with more complex fluids.

Reviewer 25419

Score: 6.0

Comment: The technical approach is complex.
The techniques/methodology has the potential to be easily transferred to all geothermal fields (i.e., it is not site specific).
The approach is flawed because it is only looking at a single species of mineral evolution at a given moment, when in actuality multiple mineral species can be grown at once and/or can evolve over time.

PI Response:
We will be considering the complex mineralogy across the fractured core surface during the flow-through experiments through inverse modeling of the evolving fluid chemistry and isotopic composition.

Reviewer 25040

Score: 6.0

Comment: This project has a very ambitious but well-rounded technical scope. It is highly advantageous to have in-situ CT scan capability so fracture topography can be identified under downhole T-P conditions, without introducing artifacts from having to remove the core from the holder. Fluid chemistry and isotopes will be critical tools for remotely monitoring fluid-rock interactions in the subsurface.

A limitation to the direct utility of these studies to EGS systems is that the flow-through experimental apparatus is limited to a maximum of 149 deg C. Most EGS systems will probably be developed in higher temperature systems. For example, the temperature of rocks considered for EGS stimulation at Bradys Hot Spring is about 200 deg C. If the system was built specifically for studying EGS systems with DOE GTO funding, the experimental apparatus should have been designed to achieve temperatures of at least 200 deg C if not 250 deg C. The current apparatus design seems better suited to oil and gas applications.

The complexity of the mineralogy (chlorite, silica polymorphs, sericite, iron oxides, carbonate) of the Brady Hot Springs rock chosen for study will make experiments hard to interpret. It might be advantageous to do initial runs with a rock much simpler in mineralogy, even monomineralic. The results of these experiments would still be useful while permitting the team to get experience in running the experimental system and modeling the results.

PI Response:
We are leveraging an existing experimental apparatus that was originally developed for oil and gas operations, and are aware that the upper temperature limit of the unit is low relative to field temperatures in EGS systems (the system was not built specifically for EGS systems). We understand that the mineralogy of the Brady Hot Springs rock is complex; however, we intend to leverage prior knowledge of experimental work performed with simpler rocks/monomineralic rocks to aid in experimental design and interpretation of results. Our prior experience with similar experiments on carbonate and sandstone cores has given us confidnce in our ability to operate the experimental system effectively.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 25423

Score: 7.0

Comment: Looking past the checklist of milestones, the project has made only modest progress to date. Part of the problem is probably due to delays in getting funding in place for the large number of teamed institutions, or even getting the project kicked off to start. Another part of the problem is the National Lab bureaucracy; an ever present problem outside the control of the PI. The PI's team needs to stay focused and on task this next year. I believe the team will make up for lost ground and can do the things they say the can. However, they will have to be diligent in their efforts, given the limited time that is available.

PI Response:
The reviewer observations of challenges associated with receipt of funds and allocation to team members is correct. We have added research support to the project team to aid with the experimental work and help the team to make up for lost time.

Reviewer 23444

Score: 6.0

Comment: Acquisition of cores with subsequent mineralogical and chemical characterization appears to be good. Minerals are identified and whole rock geochemistry (XRF) was completed, although complete chemical analyses were not presented and it is unclear as to why this data was obtained. Selected portions of samples have been characterized for stable isotopes. XRCT is an excellent tool for characterizing spatial variations in mineralogy and identifying vein structures, but this only works with the minerals have sufficient density differences. The development (building?) of experimental flow-through system and development of routines to incorporate imaging data into numerical model appear to be on target. Preliminary results were minimal but these types of projects have significant lead time. The preliminary results elucidated important issues. Modeling could be underway.

PI Response:
We appreciate these comments. The preliminary results and modeling are helping to guide us in the flow through experimental design.

Reviewer 25419

Score: 6.0

Comment: There should be concern about the little budget that is left for NETL to complete its portion of the work (all contracts are obligated at this time).
As a first step the project is good, but the results are not necessarily the final step, because the experiments did not address multiple-mineral speciation.

PI Response:
At this point the amount of budget left for NETL is for PI salary support. The funds allocated to URS and the university subcontracts will be used for necesssary laboratory materials and fluid chemistry measurements.

Reviewer 25040

Score: 7.0

Comment: Good progress was made on team building, CT imaging, translation to permeability and porosity maps, incorporation into CrunchFlow and demonstrating the ability to model the flow, especially considering the project started in June 2012.

The project encountered problems typical of doing things for the first time, such as problems with using isotopic signatures to track fluid-rock interaction, and problems with the CT pressure vessel and the construction of the flow-through experimental system.

Perhaps the PI could reconsider abandoning the isotopic research, and determine the isotopic characteristics of each mineral rather than bulk rock isotopic signature. The bulk rock signature will not be useful in tracking mineral dissolution/precipitation reactions occurring during flow.

It was not clear how the spatial distribution of fracture mineralogy is going to be mapped onto the 2D image of the fracture as input to the modeling. This information is critical to interpreting what mineral reactions are responsible for observed changes in fracture topography detected by CT post-mortem analysis of the core.

Why is GeoTek's multi-elemental composition core logger (XRF) being used to quantify the bulk rock composition? Would XRF be able to detect the changes in major element chemistry from fluid-rock alteration along the fractures?

It would be useful in future presentations to track the monies spent from the subcontracts rather than the total value of the subcontracts. This would allow evaluation of progress vs. burn rate.

PI Response:
We are going to focus efforts on mineral-specific isotopic signatures, understanding that the bulk-rock characterization is merely a necessary starting point for mass balance efforts. The mineralogy information is currently being input into the 2D fracture image for reactive transport modeling. The XRF information was collected to obtain bulk information about the cores as an additional piece of baseline information for designing the experiments. In the future we will work with our contractor to identify progress versus burn rate of the subcontracts.

PROJECT MANAGEMENT/COORDINATION

Reviewer 25423

Score: 10.0

Comment: Organizational charts and flow diagrams suggest an integrated approach that is well managed. If anything, the PI may have gone a bit overboard in her adherence to management paradigms.

PI Response:
We focused on clear structure for performing the work in order to ensure that all project components would be coordinated appropriately.

Reviewer 23444

Score: 8.0

Comment: The project has a large number of participants and appears to be well coordinated with the various parties interacting and cooperating. The technical components appear to be in place and sufficient personnel are involved to move the project to completion.

PI Response:
We focused on clear structure for performing the work in order to ensure that all project components would be coordinated appropriately.

Reviewer 25419

Score: 7.0

Comment: The project has a complex teaming structure.
The PI presented a workflow diagram that suggests adequate project management structure is in place, but small delays could have a significant impact on budget and schedule.

PI Response:
We focused on clear structure for performing the work in order to ensure that all project components would be coordinated appropriately. Due to how we developed the project structure, any additional delays will be accounted for, and at this time future delays should have minimal impact on budget.

Reviewer 25040

Score: 7.0

Comment: Assembled a large team with varied skill sets from a variety of institutions.

Seem to be missing team member(s) with experience in geothermal geology and fluid-mineral interactions and with knowledge of EGS field conditions to properly constrain experiments.

PI Response:
We will focus on collaborating/interacting with experts in the geothermal community to help guide us with future components of this work.

STRENGTHS

Reviewer 25423

Comment: The strengths of the project include the following:

1) Synergy of expertise (isotope geochemistry, reactive transport modeling, etc. from partner institutions; analytical, experimental, and modeling expertise and equipment in house)

2) Collaborations with local universities

3) Doing the work that NETL is good at. It would be a mistake to compete against other National Labs or Universities, the PI has done a good job of meshing strengths of her institution and affiliated partner institutions.

PI Response:
We appreciate the positive comments.

Reviewer 23444

Comment: Strengths of the proposed research are in its focus on important issues of fluid-mineral interactions in EEGS systems. Other strengths include: (1) the use of actual fracture apertures as input into the reactive transport model; and (2) the study of alteration as a function of mineralogy and fluid chemistry. RCPT is a useful tool for identifying fractures and their connectivity. The majority of techniques in use here are not new but have been widely tested. Discrete fracture network calculations are difficult, both from meshing the fractures and from the numerical standpoint of the calculations. Connecting the RCPT images to reactive transport modeling could be a major advancement in modeling these systems.

PI Response:
We appreciate the positive comments. One intent with this project is to combine existing known techniques in a new format to address questions related to reactivity across fractures.

Reviewer 25419

Comment: Qualified research team.

PI Response:

We appreciate the positive comments.

Reviewer 25040

Comment: Multidisciplinary team. In-situ micro-CT imaging of cores.

PI Response:
We appreciate the positive comments.

WEAKNESSES

Reviewer 25423

Comment: I am not sure how the results will be disseminated. According to the Funding Opportunity Announcement for this Financial Assistance award, the recipient must provide data to the DOE Geothermal Data Repository (DOE-GDR). I did not see this aspect addressed, not in the presentation or in the associated documents. This needs to be addressed.

The only mechanism that was described for sharing data is writing reports of results. The PI is going to have to make sure that the results of the report reach a broad audience, and DOE reports tend to fade into obscurity within the archives.

PI Response:
We will need to work with the DOE-GDR points of contact to identify the best format for reporting of data from these experiments. We also will develop peer reviewed manuscripts for technical journals, and will present results at conferences.

Reviewer 23444

Comment: See above. The lack of understanding of the background work that had been done on this topic makes it seem that many known facts are being rediscovered. This limits the new data obtained, versus redoing what is already known (but unknown to the researchers). Predictions about what should be observed could be made, then measured, then modeled again. The approach of using far-from-equilibrium fluids for the flow through experiments does not mimic most EGS systems, either in fluid chemistry nor reactions. Most EGS systems show that minerals are in close equilibrium with fluids - or that fluids are rock buffered.

PI Response:
We plan to add experiments through batch/static experimental systems to complement the flow-through experiments. The batch experiments will allow us to understand how the use of different fluids can affect the reactions anticipated to occur in these systems. We have been searching the literature for known information about mineral reactions, and are using this information in our reactive transport modeling. Results from the reactive transport models will be used to define the experimental parameters, and experimental results will be re-modeled to evaluate differences between the predicted and actual results.

Reviewer 25419

Comment: Complex research program and project management structure.

Lack of research in multi-mineral growth.

PI Response:
We have a team structure in place that allows us to address the complex research program. We will address the issue of multi-mineral growth with the experimental work.

Reviewer 25040

Comment: Limitation of experimental apparatus to a maximum of 149 deg C.

Starting experiments with a core with complex mineralogy.

PI Response:
We are leveraging prior knowledge in flow-through experiments using geologic cores, obtained through other research performed at NETL (e.g., through CO_2 storage and oil and gas-related research). We acknowldge the limited temperature range of our experimental apparatus, however we are unable to upgrade the unit within the timeframe of this project.

IMPROVEMENTS

Reviewer 25423

Comment: Determine a mechanism for distributing project results, one better than report writing. Suggestions include: a) presentation at Stanford Geothermal Workshop, or similar venue,

b) presentation at AGU or other relevant meeting,

c) publication of results in scientific journals.

Option "a" is acceptable but not optimal. It's acceptable because, in addition to a talk, a written record is generated that is widely circulated and available to the general public. However, the written record is a conference paper that is not peer reviewed. Option "b" is an acceptable step along the way, but it is not sufficient to fulfill my recommendation as there will not be a permanent public record. Option "c" is preferred as being the most permanent of records. I realize that it is difficult to publish in the National Lab environment. That said, one strategy is to present at the Stanford Geothermal Workshop, or similar venue, and use the conference paper as a draft for a journal article

Experimental aspects: conceptual paradigms, procedures, protocols, etc. Details provided in my previous discussion of Scientific/Technical approach.

PI Response:
We appreciate the suggestions for broader dissemination of results, and will be exploring the avenues presented in this comment.

Reviewer 23444

Comment: By conducting a complete literature search on fluid-rock interactions, their isotopic consequences, and understand past fluid-rock experiments, new contributions could be identified, steps could be skipped and much could be learned. This, in turn, allows researchers to provide new, useful data. Develop a conceptual model for the system in keeping with the goals of the project, such that the data obtained answers that questions posed. Minerals react with fluids at their surfaces, therefore one needs to know the mineralogy of the fracture surface rather than bulk chemistry (as obtained from XRF and XRD). Consider completing predictive calculations on reactive transport to determine the optimal experiments to undertake. Evaluate the impact of using 2D XRCT data vs. 3D data for determining actual flow paths. Determine how to upscale the experiments on a single core to the field scale.

PI Response:

We have been conducting a literature search on fluid-rock interactions and related isotope behavior, and are using this information to inform reactive transport models to aid in identifying the appropriate experimental parameters for the flow-through experiments. We will be performing an analysis of the fracture surface to understand parameters prior to experimentation.

Reviewer 25419

Comment: Closely watch project for schedule slippage.

Consider re-directing to include multi-mineral growth analysis.

PI Response:
We are aware of potential schedule slippage and will also consider multi-mineral growth analysis.

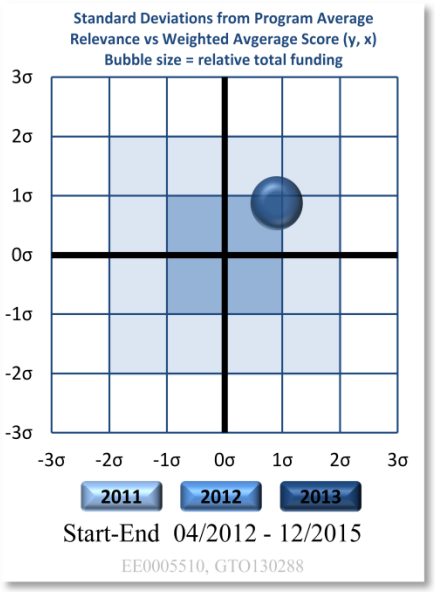
Reviewer 25040

Comment: Ensure that the team has strong ties with person(s) with experience in geothermal geology, fluid-mineral interactions, and knowledge of field conditions to properly constrain experiments (e.g. fluid flow rates, residence times).

Review DOE-funded previous experiments of a similar nature (e.g. Carlson, LLNL) and Penn State (Elsworth) plus other rock-water experiments in literature to discover potential pitfalls and avoid previously recognized deficiencies in experimental design and interpretation, reaching out to these people if feasible.

Suggest running reactive transport models (Task 4) before and during flow-through experiments (Task 3) to identify the data needed to setup and constrain the models, potentially gain better insight into what might happen during the experiments, evaluate the magnitude of changes and the ability to detect them with the experimental setup, and so on.

PI Response:
We will be reaching out to collaborators with experience in geothermal geochemistry, and the associated literature. We will be running reactive transport models prior to, during, and after the flow-through experiments to evaluate changes and deviations from expected results.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005510
Project: Monitoring EGS Stimulation and Reservoir Dynamics with InSAR and MEQ
Principal Investigator: Davatzes, Nicholas
Organization: Temple University
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23417

Score: 8.0

Comment: This is a very relevant research program carried out by a group of experienced scientists. The need to develop techniques that will allow monitoring of fluid flow within EGS systems is essential for all future EGS projects. Currently we have no known primary techniques to be able to track this type of flow other than seismic and surface deformation measurements. In particular, fluid loss will be a major issue for EGS and will limit the number of projects that can be developed. Being able to understand these types of parameters will not only reduce drilling costs but allow EGS operations to be managed effectively over the life of the project.

PI Response:
N/A

Reviewer 23641

Score: 9.0

Comment: Innovative, relevant, and high impact research to map the evolution of the stimulated zone and pore pressure distribution in reservoir during stimulation and production phases of EGS.

PI Response:
N/A

Reviewer 23612

Score: 8.0

Comment: The project proposes to develop a methodology to improve EGS performance from the start of stimulation activities through production. The targets include seismicity, which is an essential constraint for any EGS project; and InSAR, which is readily attainable without the need for costly or logistically difficult field instrumentation campaigns. This makes for a potentially highly transferrable toolbox that could be reapplied at many sites. The methodology is being developed and applied to the Brady's EGS project, but the approach may be broadly applicable for reservoir management across geothermal settings. The PIs claim the potential to increase productivity per well and thereby reduce LCOE, though this is a long-term aspiration that is hard to directly validate from the actual project scope. The primary product of the research will be open-source software tools that operate on a "semi-automated work flow" to presumably guide field

operators. Are these tools ultimately intended for industry consumption, and what format will they take under the scope of the project?

PI Response:
These tools are intended for industrial and research applications. They will streamline the workflow necessary to use these data sets to investigate reservoir structure. The development of the toolbox is ongoing and we are coordinating with our industrial partners at ORMAT to design a workable format. In part, these tools will link and guide steps in the analysis and modeling. The project goals and design clearly include developing of a prototype toolbox to be turned over to ORAMT for use in on-going reservoir analysis and management.

Reviewer 23450

Score: 9.0

Comment: The monitoring of the dynamic response of a geothermal reservoir with inSAR and MEQ is highly relevant for reservoir characterization and drainage volume. Brady Hot Springs has a long production history and good geoscience data set.

PI Response:
N/A

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23417

Score: 8.0

Comment: The PI has significant experience in geothermal research, as does his team. The approach uses InSAR and seismic monitoring as tools to evaluate stimulation scenarios and to track and monitor fracture development. The technical approach is well thought out and sounds reasonable. However the question seems not to have been asked as to whether:
1. Can existing tools effectively locate the MEQ's sufficient to be able to accurately evaluate where individual fractures are being generated?
2. Can interpretation of new InSAR data separate the deformation caused by injection into a single well from deformation resulting from other development activities within an existing operating geothermal field?
3. Are the tools sensitive enough to be able to resolve both temperature and fluid flow problems as they arise in an operating EGS project, i.e. monitoring, and can this be achieved in a timeframe that would be economically reasonable for an operator?

The technical approach used in this project is will hopefully answer such questions. The research certainly needs to be done, but the reviewer is uncertain as to how it would be possible to evaluate the success of this project.

The reviewer believes that this approach, i.e. InSAR/GPS with seismic, is a better approach than using electromagnetic techniques such as MT/CSEM to understand fluid flow in an EGS reservoir.

PI Response:

The reviewer identifies excellent questions for research, but we disagree that these questions have not been considered. In fract, they were part of the thought process that went into the development and design of the proposal. This project provides an important opportunity to address these questions. We (hopefully) expect the on-going research to answer these questions.

Reviewer 23641

Score: 9.0

Comment: High quality technical approach integrating multiple tools and methods.

PI Response:
N/A

Reviewer 23612

Score: 7.0

Comment: The SOPO includes informing metrics for minimum distances stimulations must extend. How will this be quantified and explained by the project results? Will the volume of rock affected with respect to the volume/surface area of the fluid pathways be considered? The workflow looks like a forward-only approach. Is there already or are there any plans to incorporate inverse methods?

PI Response:
A. The SOPO provides a goal of assessing: (1) the position of the pre-stimulation reservoir with respect to EGS demonstration well 15-12, (2) the change due to stimulation including the shape of any connection the established reservoir due to stimulation. The hydraulic volumes accessed by wells deform in response to injection or production. The location, timing, and characteristics of seismic energy release and InSAR monitoring of surface deformations, which will include aseismic deformation provide the opportunity to infer the volume deformation at depth and thus the corresponding fluid pressure perturbation.

B. MEQ and the surface deformation provide potential measurements to constrain pressurized volume and some information about surface area. This will be a topic of on-going research, the results of which will be shared with the partners in the EGS project, which includes additional measurement techniques, to address this issue.

C. With regard to inverse methods:
- Formal inversion is a useful and potentially viable approach to explore, and our research team is both capable and interested in such methods, but would require additional resources.
- Our project workplan clearly outlines an iterative forward modeling approach to the research questions that has the benefit of assessing sensitvity of the misfit between model predictions and observations to model parameters. The iterative analysis of the reservoir behavior seeks to minimize the misfit of the model prediction to observable deformation responses and thus has a similar result to formal inversion.

Reviewer 23450

Score: 8.0

Comment: The coupling of large scale inSAR data with local MEQ information provides data integration across several scales. Production and injection cause changes in the pressure field and it is shown that it can be monitored using the two data sets for surface deformation and region of influence. The workflow data analysis and best-fit model is helpful to identify probable from improbable subsurface models of flow and permeability structure.

PI Response:
We agree.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23417

Score: 8.0

Comment: Accomplishments and results are good as far as the project has progressed. Efforts have focused on data gathering and interpretation of data gathered to date, so there is little to comment at this stage. However, the project seems to be moving forward and appropriate data has been collected. Stimulation of BR15-12ST1 is key to the project and that has been delayed.

PI Response:

Due to the series of delays in the stimulation schedule, we have been acquiring InSAR data at the high rate of one acquisition every 11 days in each of three frames since summer 2012, when the stimulation was originally planned. This preparatory data acquisition is unavoidable to achive the maximum resolution to characterize the stimulation; and such a long period was not part of the original budget design. The cost of high-frequency acquisitions is roughly $2340 (USD) per month.

Reviewer 23641

Score: 9.0

Comment: Making excellent progress. High quality, high productivity.

PI Response:
N/A

Reviewer 23612

Score: 8.0

Comment: The finding that most of the surface deformation at Brady's is aseismic (with MEQ energy release too small to account for it) shows the potential utility of the combined seismic/deformation approach to fully capturing dynamics. The implication that primary surface deformations may be related to dominant matrix permeability is an interesting result. Further testing this theory throughout the project could add to our understanding of permeability heterogeneity and influences on productivity. The preliminary results for the Brady reservoir could inform the course of the demonstration. What role are these results playing in decision making processes?

PI Response:
The project team is engaged in data/results exchange and logistical coordination with the EGS Demonstration Project. Results to date have been presented at Demonstration Team Workshops during which stimulation design was being developed.

The project team regularly meets with the ORMAT partners, including the key personel guiding the EGS demonstration. In addition, PI Davatzes is a member of both project teams, participating in the EGS analysis, preparations and design, in which he has presented the up-to-date project results.

Reviewer 23450

Score: 9.0

Comment: The data set presented and interpretation is internally consistent and insightful. I especially like presenting geoscience models of a dynamic flow system in terms of probability or uniqueness.

PI Response:
N/A

PROJECT MANAGEMENT/COORDINATION

Reviewer 23417

Score: 7.0

Comment: There appears to be thorough documentation of Tasks and timelines to date. Future directions are well laid out with appropriate milestones.

PI Response:
N/A

Reviewer 23641

Score: 9.0

Comment: Appears to be a well managed project.

PI Response:
N/A

Reviewer 23612

Score: 10.0

Comment: The project has been well managed. Challenges appear to have been addressed thoughtfully, from adjusting the acquisition rate of SAR images to reconcile with scheduling delays to deriving a new velocity model to counter poor MEQ locations. This is a talented and resourceful team that is likely to make a substantive impact on EGS field operations capabilities.

PI Response:
N/A

Reviewer 23450

Score: 5.0

Comment: Project uses researchers from three organizations, and the project is providing results on schedule.

PI Response:
N/A

STRENGTHS

Reviewer 23417

Comment: This is a good project with many strengths:

Strength 1. An excellent research team with extensive experience in both EGS and conventional geothermal site evaluation.

Strength 2. A thorough SOPO that addresses the fundamental need of an EGS project, i.e. characterizing and monitoring development of a geothermal EGS reservoir.

Strength 3. A good data set with which to work.

PI Response:
N/A

Reviewer 23641

Comment: Strong research team and dedicated field operator:

–Benefits from a 20-year record of reservoir deformation in the shallow subsurface (<1-2 km) and pumping records

–Is integrated with an EGS demonstration project

–Uses multiple mechanisms for monitoring fluid migration, change in stress, and deformation during EGS reservoir management including pre-, syn-, and post- stimulation behavior of the stimulated volume

–Independently evaluates the relationship between MEQ and stimulation

–Provides a database documenting these effects in response to both EGS stimulation and reservoir management practice

–Provides rapid development of technology to monitor and guide stimulation during development of an EGS including evaluation of the longevity of the EGS flow pathways

–Provides an integrated reservoir model with higher resolution than can be achieved from monitoring well responses alone

–Technology transfer is ensured by development of a prototype at the operating Brady's geothermal field & open-source code development

PI Response:
N/A

Reviewer 23612

Comment: The problem relevance and team quality are high. The progress on data compilation and quality of the preliminary results are very good and could provide new insights into field development and operations.

PI Response:
N/A

Reviewer 23450

Comment: Choice of Brady HS and the historical geoscience data set.

Very interesting data integration across several distance scales (inSAR and MEQ).

Refinement of velocity model.

PI Response:
N/A

WEAKNESSES

Reviewer 23417

Comment: The reviewer is uncertain as to whether any type of surface monitoring could really monitor in detail either fracture characterization/development and fluid movement in those fractures from depths that will likely be in the 8000 - 10,000 feet depth range for most EGS systems. None of the EGS projects reviewed has demonstrated this ability. If such techniques are really possible they would probably have already been used extensively in the conventional hydrothermal systems where one would expect higher flow volumes in fractures with larger apertures and therefore easier to detect and monitor.

PI Response:
The InSAR data show that Brady clearly has a short and long wavelength deformation related to reservoir activities and which indicate an impact on subsurface fluid pressure at different depths. The overall viability of this tool set, its potential for integration into a signle approach, are the subject of the research. We do note that, similar to the Brady analysis, successful results related to EGS have also been obtained at the Geysers. Similarly, InSAR reveals localized surface deformations in other geothermal fields such as Dixie Valley, Coso, Salton Sea with success, Iceland, has have analysis of producing gas fields in the Oil and Gas industry.

Reviewer 23641

Comment: Long project (through 2016).

PI Response:
The length of the project is linked to the development of the EGS Demonstration Project, and despite changes in the timeline we are operating on budget with a high degree of productivity.

Reviewer 23612

Comment: Details on the methodology are hard to extract from the presentation materials. This goes both for the modeling results obtained so far and for plans to develop the proposed open-source software tools.

PI Response:
N/A

Reviewer 23450

Comment: No reservoir engineering analysis integrated with the other results.

PI Response:
We are working with our ORMAT partners to honor reservoir engineering constraints, which are part of ORMAT operation and thus are not formally conducted within this project team and budget. In addition, this entire data set is available to the project team via ftp access

IMPROVEMENTS

Reviewer 23417

Comment: No general overall improvements. Perhaps the use of tiltmeters to monitor deformation could be considered. Otherwise this research should be continued to evaluate whether such tools are applicable and how they could be used commercially. It is a question that needs to be resolved.

PI Response:
Tiltmeters have been previously considered and are a good suggestion. They provide very fine temporal and deformation resolution and have been shown to be useful in monitoring hydraulic fracturing. However deploying shallow subsurface monitoring arrays with sufficient spatial resolution, a key need for the project objectives, is costly and time consuming. Given sufficient support, they could compliment our existing workflow and add value to the project.

Reviewer 23641

Comment: None identified.

PI Response:
N/A

Reviewer 23612

Comment: More details on how the work will be integrated with decision making for the Brady project, and how portable the code will be for future application (i.e. who are the target users and how will it be structured to facilitate uptake?) would add value.

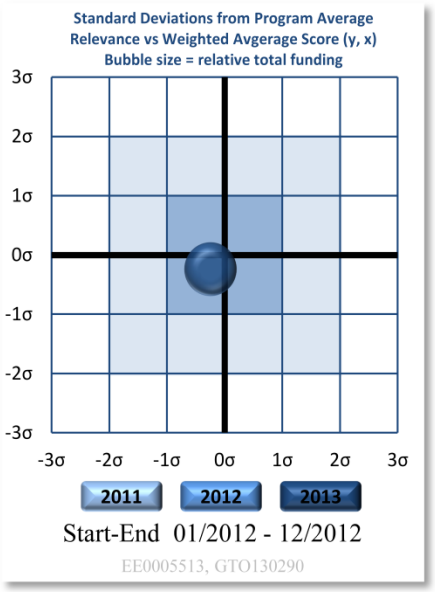
PI Response:
A. We currently work with the members of the EGS demonstration project team to exchange research results, logistics. This exchange takes place both through in person meetings and active participation in EGS analyiss and Design in both projects by PI Davatzes.

The target users of the technology being developed are clearly identified as researchers and reservoir operators. This is evident also in that a final product of this project will be a proto-type turned over to ORMAT ensuring technology transfer.

Reviewer 23450

Comment: Need to integrate reservoir engineering information (well tests, models, PTS survey data) with the rest of the geoscience data set.

PI Response:
We currently are using such data directly and via collaboration with our partners at ORMAT and through collaboration with the EGS demonstration project. In addition, this entire data set is available to the project team via ftp access through the EGS project.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005513
Project: Time-lapse joint inversion of GEOphysical Data and its application to gEothermal prospecting - GEODE
Principal Investigator: Revil, Andre
Organization: Colorado School of Mines
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23417

Score: 5.0

Comment: This was a confusing presentation and the reviewer is still not certain exactly what the project is going to include. Assumption is that it will be joint inversion of primarily MT-seismic data only. However there is discussion of including heat and fluid flow as characterized by resistivity, SP, and in-situ temperature.
There are a number of research projects focused on joint inversion of MT and seismic data, so there is not necessarily any new innovation in this approach. There is little else, other than generalities, in the project summary to describe how this joint inversion of all the data is going to be accomplished.

PI Response:
The joint inversion of MT and seismic data using an image guided inversion has never been undertken in the literature. This is a completely new topic and apparently the referee miss this point. So with all the respect due to the referee, we find his comment unjustified. We got amazing results using the image guided inversion applied to the inversion of resistivity data using GPR data to guide the inversion. This was clearly stated and demonstrated bothn in the presentation and in the Phase 1 report. A submitted paper (now accepted for publication) was provided to the referees in the phase report. We just finished the image guided inversion of MT data and our results are going to be included in the quaterly report in July 2013. Having the time constrains for the DOE presentation, it was not possible to provide more details on the methodology in the oral presentation. The math and novelty of our approaches were clearly explained in the phase report that was provided to the referee.

Reviewer 23641

Score: 7.0

Comment: High relevance research into better predictive geophysical exploration techniques for hydrothermal systems and EGS monitoring.

PI Response:
We agree and this is reflected by a high interest of a lot of players in the field for our research. Especially very few people have developed inversion algorithms for the self-potential data in terms of ground water flow pattern and we already published several highy cited papers showing such potential (no pun intended) of this method for geothermal targets at a depth of several kilometers.

Reviewer 23612

Score: 7.0

Comment: Bringing multiple types of data to bear to quantitatively constrain exploration targets and field operations meets a broad array of GTO goals. A real strength of the approach is in the partnership with Ormat, presumably with the potential to directly influence and positively impact development and operations at Jersey Valley. This potential is only tempered by a lack of clarity on what the products of the work will look like, such as what kinds of constraints the models will deliver and how they will be leveraged at the target site(s).

PI Response:
We agree. The application to the field will be devlooped in the second phase of the project. We are lso working on set of 5 new papers showing applications to geothermal targets.

Reviewer 23491

Score: 8.0

Comment: This and other programs seek to merge a wide variety of geophysical data which is often the only way to identify hidden system targets. Improved exploration technologies which raise likelihood of a successful drilling program are desperately needed to will lower the cost of geothermal exploration. This project if successful will provide another tool for exploration.

PI Response:
Actually such objective can only be achieved through the merging of the information (geophysics, geology, hydrogeology) and the use of probablity theory. We are also developping an approach to use various geophysical data and to develop "geothermal attributes" to narrow down the presence of a geophysical target. We demonstrated in our presentation the validity of this approach with the coal seam fire problem: using different geophysical method and developping a joint interpretation approach was useful to identify the burning front. The same can be used for geothermal targets as both problems share similar characteristics.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23417

Score: 4.0

Comment: The approach appears to be strongly influenced by methodologies used in the oil and gas industry.
Relevance of SP data is uncertain as this technique cannot look sufficiently deep to be relevant to geothermal systems. Similar comment for DC resistivity.
The reviewer is uncertain as to the relevance of research on active volcanoes outside of the US. (Stromboli). This does not seem to be a consistent approach when attempting to characterize geothermal systems such as Jersey Valley.

The Project Summary states "... perform time-lapse geophysical monitoring during EGS stimulation". There does not seem to be a reference to EGS in any other parts of the document. Is this an error?

PI Response:
With all the respect due to the referee, these statements are not correct: the self-potential method is a passive method and it has been shown to be sensitive to ground water flow in geopthermal targets at depths of several kilometers. Published examples by us and other groups include: Jardani, A., and A. Revil, Stochastic joint inversion of temperature and self-potential data, Geophysical Journal International, 179(1), 640-654, doi: 10.1111/j.1365-246X.2009.04295.x, 2009; Byrdina S., D. Ramos, J. Vandemeulebrouck, P. Masias, A. Revil, A. Finizola, K. Gonzales Zuniga, V. Cruz, Y. Antayhua, and O. Macedo, Influence of the regional topography on the remote emplacement of hydrothermal systems with examples of Tiscani and Ubinas volcanoes, Southern Peru, Earth and Planetary Research Letters, 365, 152-164, 2013. Many other references from the older literature can be found in these two papers. So the first statement made by the referee is not suported by a close inspection of the literature. This point was also discussed both in the oral presention and in the report in which a copy of the second paper cited bove was provided to the referees.

The referee is making a similar statement about the DC resistivity. With all the respect due to the referee, this is also statement that is not correct. Many example of deep DC (galvanometric) resistivity have been performed and published on geothermal targets and faults to depth down to 4 kilometers. In Jardani, A., and A. Revil (Stochastic joint inversion of temperature and self-potential data, Geophysical Journal International, 179(1), 640-654, doi: 10.1111/j.1365-246X.2009.04295.x, 2009), a DC resistivity section is shown on the Cerro Prieto geothermal field down to 3 km. The work of Storz, H., Storz, W. and Jacobs , F. (2000, Electrical resistivity tomography to investigate geological structures of the earth's upper crust, Geophys Prospect 48(3), 455–471) shows a deep DC resistivity tomography in Germany down to 4 kilometers. There are many other examples. Therefore the statement made by the referee is not supported by a close inspection of the available literature. In addition, the determination of resistivity by induction (MT or CS-AMT) suffers from the poor knowledge of the resistivity in the shallow part of the system (let sy less than 400 meters). Therefore DC resistivity tomography, even at a depth of 200-600 m, can help to identify deep geothermal targets by improving MT or CS-AMT data inversion. We are working on this topic as well.

From the comment of the referee, it is unclear if he is not happy to see some investigation on foreign volcanoes (which was done at no cost for DOE) or if the application of our target to the geothermal systems of active volcanoes is not relevant to other types of geothermal (basin and range) targets. In both cases, we disagree with him. Stromboli is a perfect target to test our method because of its size, because it has been well-studied, and because of its strong activity. There are no target with such a combo in the US. The second point is kind of curious. Geothermal targets associted ith volcanoes are relevant (see for instance the targets in Hawaii funded by DOE in the same call).

Regarding EGS targets, we agree with the referee. Jersey Valley is not an EGS sites. That said, we believe that our methodology, especially the time lapse aspects, is relevant to EGS sites and this is the wish of the PI to see such an application in the next few years.

Reviewer 23641

Score: 8.0

Comment: Strong technical approach fusing petrophysics, geophysics, geology and reservoir modeling.

PI Response:
Thanks for the comment.

Reviewer 23612

Score: 8.0

Comment: The team brings experience of diverse applications of their techniques, from O&G to volcanology to geothermal settings. This exposure is very beneficial for the small geothermal sector. The authors mention similarities between geothermal and EOR applications, and if approaches and techniques could be leveraged from the latter it could have significant impact on GTO's goals. The broad approach shows through in the project goals that include exploration and operations, applicable to both traditional hydrothermal and EGS settings.

The sample collection and analysis plan sounds extensive. A more detailed plan outlining personnel, facilities, and schedule, would help in evaluating this component.

PI Response:
Regarding EOR, we agree wth the referee. Regarding the sample analysis and collection, we have recently finished this component of the project and we plan to have a submitted paper by the end of the summer.

Reviewer 23491

Score: 8.0

Comment: This project with its approach to the multiple data sets shows a reasonable scientific/ technical approach. A step by step approach of integrated multiple data sets in small number seems much more reasonable than taking on a large number of data sets all at once. There may be a better approach, yielding perhaps quicker results, but it is not obvious at the outset.

PI Response:
We thank the referee for his comment. We see value in both approaches. We can indeed start with a coase investigations of a potential geothermal target and then use survey design to plan additional surveys to refine the sensivity of the next set of measurement with respect to potential targets. We don't plan to work on survey design in the course of this proposal but his could be an intresting avenue to explore later on.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23417

Score: 5.0

Comment: The Presentation reports five of the Tasks in Phase 1 are completed but does not present or discuss any of the results as they pertain to geothermal site characterization. Neither do any of the published papers that are presented as accomplishments seem to show any connection to geothermal.
Tasks 9 and 12 indicate that DC resistivity, SP and CS-EM surveying will be completed in the Jersey Valley as part of Phase 2. It is uncertain as to what relevance these data sets will have in helping to define the reservoir. Currently DC-resistivity and SP methods are not generally used in geothermal exploration because of their limited depth of investigation. CS-EM is sparingly used normally in concert with MT surveys.

Testing of equipment in the Upper Arkansas Valley and at Stromboli seems to be unnecessary and it would have been more valuable to test such equipment in known geothermal areas - Mt Princeton is not a recognized geothermal system as yet, but there are many others that could have been used.

PI Response:
An important effort has been to develop the codes and the strategy to jointly invert the geophysical data. This is a huge task that has been acocmplished in a short period of time (merely one year). Not only we used strategies already proposed in the literature (like the cross-gradient approach) but by proposing also our own strategies like the active time constrain approach for time lapse inversion and the image guided inversion for the joint inversion of seismic and EM data. Several of the papers show the applications of ur methods to geothermal targets associated with volcanoes. We pare writing a new set of 5 papers with more direct applications to geothermal systems.

Regarding the second and third comments, the resistivity and self-potential methods are complementary methods to detect geothermal targets and to identify the patterm of ground water flow in these targets. We devoted an important part of our proposal to support this point. We are therefore quite surprise by this statement. As mentionned above, DC resistivity and self-potential have a depth of investigations of 4 kilometers, which is good enough for geothermal exploration. There are MANY published papers on that topic and this was clearly discussed in our proposal and in phase report, so the referee comment is not correct. There is therefore a misconception by the referee of what can be accomplished with these methods and a lack of knowledge of the relevant literature. MT survey are NOT sensitive to ground water flow. The way MT data are inverted is still extremely primitive by comparison with the methods developed elsewhere, for instance in hydrogeology for data fusion. Tikhonov type regularization of the inverse problem is still the standard in the inversion of MT data while it is considered as dead science elsewhere. There are many other ways to regularize the inverse problem and I hope that the referee will read some of our future papers on the subject.

Using other targets: why not. We are definitively open to ideas here but this has a cost. The Upper Arkansas Valley is in our backyard and is our playground becaue of a previous DOE project. This means low costs for DOE and low cost for us as well. The Upper Arkansas Valley has been the subject of numerous research for geothermal energy and drilling there has only been slowed down because of the economical crisis. The State of Colorado is very interested to start a drilling program there.

Reviewer 23641

Score: 8.0

Comment: Four of six tasks completed.

PI Response:
The two other tasks have been completed since. We were especially late in getting the samples from Jersey valley but this task is now done and a paper should be finished by the end of the summer. Same for the MT equipment: we just collected new data that will be discuss in the quaterly proposal at the end of july.

Reviewer 23612

Score: 6.0

Comment: Accomplishments are a bit difficult to judge. Did the project begin 9/30/11 or 1/1/2012, as both dates are listed? In either case, it's not clear whether the papers that are listed and profiled in the presentation pertain to this project or rather display the great body of supporting and related work that the PIs have undertaken. The PI states that the team will be publishing more papers on geothermal applications, which is good. Since the team is supported through non-DOE sources for volcanology work, it would help to have a clarification of what work was performed under the DOE scope. Aside from permitting on the list of milestones, it is not clear what has been accomplished beyond perhaps some characterization work at Jersey Valley. What is the status of the modeling effort with respect to this project?

PI Response:
The projct was supposed to start in 9/30/11 but we got the DOE funding only in the beginning of 2012 and we could only hred students and postdocs at this time. This explains this discrepancy between the two dates. Again, to be successful, a huge amount of code development was undertaken. New algorithms and inversion strategies were developed and tested in a single year. We plan to publish in the forthcoming year five papers showing the applications of these algorithms to geothermal targets. The field works on volcanoes was done with no DOE support. The DOE support came for the development of the codes (all of them will be released free of charges to the community and we started to implement this strategy by publishing two papers in Computers and Geosciences with their codes). Therefore the DOE funding came for the forward and inverse modeling used on identifying the geothermal targets on these volcanoes. Clearly, as stated in our initial proposal, we needed a variety of case studies to validate our codes and we went directly to the easiest one. We hope this will be understood by the referees and the DOE.

Reviewer 23491

Score: 6.0

Comment: This task seems to have started quite late and there's a lack of intermediate milestones, with a large number of the milestones being completed on the 1st of January, I question if that is really the case. The quality of the work seems quite good with rather detailed results in the cases presented. I would like to see a more detailed timeline of the progress.

PI Response:
A detailed timeline of the progress was formulated and sent to the referee in June 2013 via DOE. It will not be repeated here.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23417

Score: 4.0

Comment: The Project Management presentation was also somewhat difficult to understand. The tasks accomplished slide was clearly laid out with appropriate milestones as was the tasks to be accomplished in Phase 2.
Much of the field work was stated as being completed by subcontractors but no subcontractors were mentioned unless they were either ORMAT or subcontractors hired by ORMAT. It would be helpful to know how these datasets were being collected in order to assess the quality of the data. The budget slide was confusing and the dollar amounts did not seem to add up . There was also a reference to a Phase 3 which did not appear in either the Presentation or the original SOPO.

PI Response:
We apologize for the presenttion of the Project Management. We will do a better job next year. The field work at Jersey valley was mostly done by contractors working for ORMAT. We do not the budget to have contractors on our own, this is why we did not mentionned further the contractors in our report. Regarding data quality: we check the data quality of the gravity data by collecting our own survey that is both complementary of the existing one and that overlap the one provided by ORMAT for quality control. The data were found reproducible. At this point, we have no idea of the quality of the CS-AMT data available for the site. We plan to collect our own dataset to do a job similar to the one done with the gravity data. There is no Phase III, but Phase II is divided in two parts, one for year 1 and one for year 2. We apologize for the error.

Reviewer 23641

Score: 8.0

Comment: Appears to be a well managed project.

PI Response:
Thanks

Reviewer 23612

Score: 7.0

Comment: Partnership with Ormat is a strength of the project. Are there clear plans to implement the modeling tools and results in Jersey Valley? What is the operational schedule there, and how do the project plans align with it?

Leveraging field work at Stromboli and insights from a volcanic setting are a plus for the project. Who supports this work, NSF? Is there more of an opportunity here to bridge gaps between agencies and research communities, given the many parallels between modern, geophysics-rich volcanology and geothermal?

In addition to Stromboli and Jersey Valley, the team will test CS-AMT at two other locations. Are similar data not available at Jersey Valley for calibration to that site, or are these tests just additive to NV work?

PI Response:
The work at Stromboli was supported by funding from the itlian government and the work in Peru by french funding from, both to our two scientific partners: Anthony Finizola in the first case and Svetlana Byrdin in the second case. As explained above, the DOE funding was used to develop the code and we used these opportunities to test the codes on real data.

Reviewer 23491

Score: 7.0

Comment: Judging by the large number of datasets and cases examined in this program I can only assume that there was a large amount of coordination that had to be accomplished to the the project to its current state. The strange milestones

completion date lead me to believe that the project management component has not been carried out in a particularly judicious manner.

PI Response:
We have done a lot of work in a very short period of time and submitted a huge amount of paprs that were ALL accepted for publication. This also demonstrate the high quality of the work done here as the imact factor of the journals in which we published our work is quite high. We are glad this has been recognized by the refereee. We recognize that things are not perfect but the codes have been developed, some of them already released, and we are now ready to publish more case studies on geothermal fields.

STRENGTHS

Reviewer 23417

Comment: The concept of what is trying to be accomplished with this project is reasonable, and the reviewer is certain what has been accomplished has been done in a scientific manner. However, as yet, no evidence has been presented that links this work to the geothermal industry.

PI Response:
Our first goal in phase 1 was to develop the codes using new strategies for time-lapse inversion and joint inversion. This is now done. These codes have been validated on some geothermal targets of active volcanoes as proposed in our initial plan. Also the coal seam fire application is clearly not a geothermal target BUT it has the flavor or the parfum of a geothermal target and we believe that this was a superb opportunity to test the joint inversion code for resistivity and SP and the use of joint attributes for the interpretation of multiple geophysical datasets. This study gave us new ideas for the use of multiple geophysical data and attributes to refine the interpretation of these data in localizing geothermal targets before drilling. In the second phae of the project, we plan to bring more results to geothermal fields. We are working hard in this direction.

Reviewer 23641

Comment: Forward modeling geophysical response exploration:
• New joint inversion algorithms for exploration
• New fully coupled inversion algorithms for monitoring
• Forward modeling for reservoir temperature monitoring
• Test of the inversion at Stromboli
• Acquisitions at Jersey Valley (Nevada)
• New acquisitions Upper Arkansas Valley (CO)
• Field camp at Pagosa Springs (CO)
• New method of time lapse geophysics
• New method to monitor fracking

PI Response:
And all of these results in 1 year or so. We think we got quite a lot of results and we are ready for phase 2 to publish a good number of publications dedicated to geothermal fields.

Reviewer 23612

Comment: The team has significant experience in applications complementary to geothermal. Adapting technologies and methods from other sectors could have great benefit. Prolific publishing in the peer-reviewed literature in the style demonstrated in the presentation materials would also be a boon.

PI Response:
We thank the referee for his comments.

Reviewer 23491

Comment: The real strength of this program is it's apparent ability to handle a large number of survey results from different tools in a way that allows each of the results to inform the others. This sort of wide band approach will be necessary to more efficiently select drill targets.

PI Response:
We agree with this comment.

WEAKNESSES

Reviewer 23417

Comment: Simply put, the project seems to be somewhat "jumbled" with no clear direction or purpose.

There is much reference back to the oil and gas industry, and there appears a lack of any solid understanding of the geothermal industry from the scientific team members. The reviewer believes that a greater understanding of hurdles and barriers that face geothermal can only really be understood by knowing the industry and how geothermal systems are explored and discovered.

There is a sense in reviewing this project that there may be other motivations rather than simply understanding geothermal systems and how to find them.

PI Response:
The overall goal is to develop methodologies to fuse the information in helping the industry in improving its definition of geothermal targets before drilling and to get a better idea of the plumbing system during the production of a geothermal field. As mentioned in our project, such a task cannot be done with 630,000 dollars and our funding is coming from various sources because the development of such a set of codes would benefit to many people outside the realm of the geothermal world (one include CO_2 sequestration for instance). We have started to work on geothermal systems before this proposal (as documented by our published papers) and we will continue after the end of this project. We are quite disapointed by the last statemnt of the referee: for us, there is no barriers between different fields and this is why we are working with many different partners for many different applications. We are truly interested and motivated by developing new approaches that could help the geothermal industry in reduing their upfront cost in terms of drilling. We are sorry that this is not obvious to the referee.

Reviewer 23641

Comment: Some of the examples are at very shallow depth (tens of meters.) I would like to see more examples at typical geothermal depths.

PI Response:
We fully agree with this comment and some of the applicatiosn were only used to validate the codes with real data that could be easily gathered at low cost. We are now focusing in publishing papers using data from typical geothermal depths.

Reviewer 23612

Comment: It is difficult to extract the work being accomplished under the scope of the DOE award from that derived from other efforts, even if they are related.

PI Response:
We are sorry if this was not clear. The goal was to develop, in Phase 1 of this project, a set of geophysical tools to perform the joint time-lapse inversion of geothermal targets and to start to prepare Phase 2 for some applications to Jersey Valley and other test sites.

Reviewer 23491

Comment: The weakness of this project is that it is extremely complex, and that complexity could lead to the project not being fully completed, when in actuality a 90% solution would do for most cases. The investigators need to keep in mind that a good solution to this and other problems like it is what is needed. Perfect solutions are not possible and might not be worth waiting for.

PI Response:
Good comment and we agree with the referee. Actually our goal is also to setup a variety of strategies that can be used depending on the amount of information available. We are presently preparing a set of 5 papers all directly applied to geothermal systems showing how deterministic or stochastic inversion algorithms can be used to solve real-life geothermal problems.

IMPROVEMENTS

Reviewer 23417

Comment: The reviewer believes it is important to have someone with a good perspective on geothermal exploration conditions included on the team. Maybe that should be a role for ORMAT but there does seem a lack of recognition of what is normal for exploration in the Basin and Range.

More focus on demonstrating the applicability of the techniques being developed to known geothermal environments rather than on other environments in other parts of the world.

PI Response:
Actually phase 2 of the project involves much more collaboration with ORMAT at Jersey Valley. We will focus on more US targets in Phase 2 but there were real opportunities, again at no cost for DOE, to tests our methods on these volcanoes.

Reviewer 23641

Comment: Some of the examples are at very shallow depth (tens of meters.) I would like to see more examples at typical geothermal depths.

PI Response:
We fully agree and the next 5 papers will address geothermal targets.

Reviewer 23612

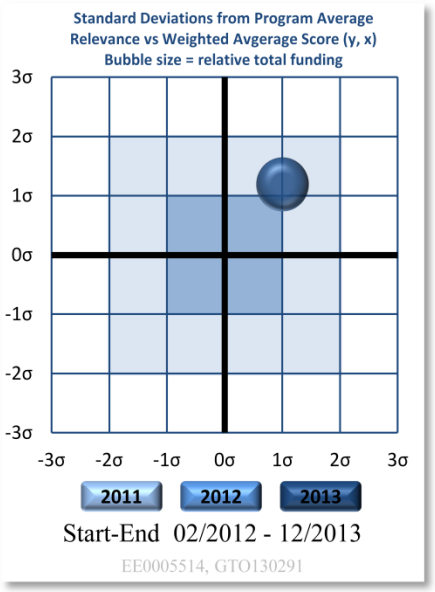
Comment: A clearer delineation of PI efforts and how related studies are being leveraged specifically towards progress on the DOE scope would help. Potential for contributions to greater Jersey Valley development would also add value.

PI Response:
We agree and the focus on Jersey Valley is really the target of Phase 2. We hope that the referee will be able to review our next phase report.

Reviewer 23491

Comment: A much clearer explanation for the non technical would be of great advantage. In most cases the selection of a drill site and the development of a geothermal prospect requires that the selection be presented to more non-technical persons that technical one. Another question that bears inspection is could the DOE fund the development of one modular program that would by sharing a common data structure and programming style allow a researcher to employ a variety of different solutions to inverse problems. It is my feeling that the efforts in this broad area of data analysis are rather scattered.

PI Response:
We have done a lot of presentations to non-technical persons (Denver, Upper Arkansas valley, Pagosa Springs,middle school students) and from the feedbacks we received, we can say that we were successful there. In was our understanding that the presentation to DOE for the review process was a technical one. The second point is interesting but all efforts in this direction have failed in the past. I think the novelty we proposed is that all our codes are available free of charges including the source codes. In some groups I know, the students working in some project are not allowed to have access to the source codes for the forward models (there are considered to be top secret). Our philosophy is clearly at the opposite of such practices.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005514
Project: Indentification of Hidden, High-Enthalpy Geothermal Systems in Extensional Regimes Through an Exploration Technology Paradigm Incorporating Magnetotellurics, Soil Gas Geochemisty and Structural Analysis
Principal Investigator: Wannamaker, Phillip
Organization: University of Utah
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23417

Score: 9.0

Comment: This is an excellent, well conceived, well thought-through research project. It is premised on the occurrence of electrically high conductive zones reaching into shallow crustal areas as evidenced from a regional MT transect. These types of studies have two noteworthy attributes: i) they maximize geothermal resource identification in areas where there are fairly abundant low to moderate enthalpy systems (i.e. the Grat Basin) and ii) they take significant step forward in identifying areas where blind systems may exist. If demonstrated to be viable, these technologies will be valuable in the further exploration of the Basin and Range.
It is also conceivable that the technologies can be used in volcanic terrains, specifically where larger volcanic systems with a known shallow heat source where the most favorable portion of a large volcanic edifice can be selected for initial exploration.

However, none of the three techniques outlined in this program are new to geothermal and all have been used in exploration to various degrees. The approach is excellent, but there is no real discussion as to how this joint interpretation will be completed. If the approach proves to be a successful one, then the assumption is that multiple regional MT transects in the Basin and Range would be valuable to identify other high level magmatic systems.

PI Response:
To a large extent, the thrust of the project was to confirm that these newly-recognized MT structures were related to recent magmatic activity in the deeper crust, and that associated high-T fluids were finding pathways upward to connect into geothermal systems. McGinness in part was meant to prove the MT by showing that deep-seated (e.g., 3He bearing) fluids were in the system and permissible pathway structures existed at both shallow and deeper scales. Those were borne out, showing that Dixie Valley, the first instance where the three indicators also converged, was no accident.

It is true that additional MT data should be acquired to uncover new geothermal districts off the existing transect, which in a sense was a data set of opportunity. These should not be sited casually but determined based on reconnaissance examination of structural setting, geodesy, volcanism, heat flow, to name a few indicators. The layout would not necessarily be as transects but perhaps sometimes instead as footprints where warranted.

Reviewer 23641

Score: 8.0

Comment: Highly relevant research into combined geophysical, geochemical and structural techniques for hydrothermal exploration.

PI Response:
N/A

Reviewer 23612

Score: 10.0

Comment: This project speaks directly to GTO's goal of accelerating development of 30 GWe of undiscovered hydrothermal systems. Validating a new method with the potential to identify currently blind, regional-scale opportunities could have far reaching impacts. Bolstering models for a newly producing region in the McGinness Hills to grow production there in collaboration with Ormat could lead to near-term growth. Extending the model in Phase II to open up a new basin in the Black Rock-Kumiva Valley as a large and potentially favorable target is a class of discovery that only a small portion of the Office's portfolio can currently claim to address.

PI Response:
N/A

Reviewer 23450

Score: 9.0

Comment: Exploration for hidden, high quality, geothermal resources is difficult. Integrating diverse geoscience datasets (electrical methods, geochemistry, and structural geology) in new and different ways to look for relationships is always welcome. High enthalpy geothermal systems are rarer in the geothermal resource base and will require the integration of diverse data sets. Thus, efforts to integrate increasingly diverse geoscience data sets is relevant to understanding how geothermal systems look from different geoscience viewpoints.

PI Response:
N/A

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23417

Score: 7.0

Comment: The technical approach is innovative but there is a question of scale that is not addressed when searching for blind systems. Given that the MT transect identified the anomalous shallow crustal heat source areas, then it is assumed that these anomalous areas would cover reasonably large areas. MT surveys, to be effective, cover relatively small areas - say 10 - 30 sq. miles and it is not explained how specific drill targets will be generated using these techniques on a

regional scale as would be required for evaluation of blind systems. Both soil gas and regional structural surveys are not particularly designed for specific drill target selection, although they certainly can be used for such purposes.
The relationship between magmatic heat source, its depth, and the shallow fluid (geothermal) system is not clearly explained. Phrases such as "fluidized fault zone" are used. Reviewer is not sure the relationship between faults and magmatic intrusion in to the shallow crust is adequately discussed. While zones of crustal weakness clearly exist and can act as preferred pathways the concept of of shallow magma movement being controlled by existing fault zones does not seem probable.

PI Response:
First, to scale: I would not necessarily agree that MT surveys must cover small areas to be effective in our context. For the future, in areas with no previous data, surveying to establish a new district may be of order 200 sq mi or more. With modern inversion exploiting all 12 data points/frequency/site, resolution of a 100 site survey should be within 1 km. This P.I. is not sure DOE research should be operating at a scale that will provide someone with the next drillable target but rather should establish clear fairways within which a second, focused step could lead to production.

Second, to deep-shallow connections: this is not familiar territory to us either. We don't have a firm notion of the direct contribution by magmatic components to the resource. Mass balance in the 3He suggests only of order 10%. On the other hand, we don't want to second-guess the hydrology of noble gasses in particular. The magmatic components may in part indicate that there has been extra vigorous extension that has allowed both emplacement of magmatism and substantial permeability for deep circulation. We also view the delineation of such structures as representing a large, next generation, potentially supercritical T resource base.

Reviewer 23641

Score: 9.0

Comment: Exploits recently-recognized opportunities in individual techniques. Combines highly independent methodologies to curtail non-uniqueness. Brings district-scale geophysical concepts into exploration. Strong cooperation with geothermal industry.

PI Response:
N/A

Reviewer 23612

Score: 9.0

Comment: The scientific approach and project design are excellent. The team presents a clear hypothesis for high-enthalpy system development and geography, and justifies the four-component approach (MT, soil gas, and geochemistry, and structure) both in terms of connecting the dynamic chapters in their proposed story and in curtailing non-uniqueness. The team is of the highest quality and execution so far follows suit. Mostly qualitative coupling of the different methods and datasets is planned – i.e. selecting strong structural features from the geologic model and constraining them in the MT inversion. Some effort to develop quantitatively coupled methods and/or develop uncertainty estimates would add value to the approach.

PI Response:
N/A

Reviewer 23450

Score: 9.0

Comment: The initial selection of two districts for evaluation using large-scale (crustal) low resistivity features that can be identified with known geothermal features with smaller scale data sets is sound. It benefits from correlating crustal scale features with more localized indicators of geothermal resources. Such integration of diverse geoscience data sets across differing physical scales is very promising to understanding how geothermal 'fairways' occur and how to explore on a large scale rather than chasing hot springs.

PI Response:
N/A

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23417

Score: 8.0

Comment: Currently true blind systems have not been tested. To the reviewers understanding, geothermal systems such as McGuinness Hills and Blue Mountain were originally identified by shallow drilling for mineral exploration. In the search for true blind systems it will be necessary to evaluate much larger areas, 100-200 sq miles, with absolutely no surface indications. How does a developer/exploration company reduce that area to a manageable size?
McGuinness Hills is a good start but can it be a true test case if so much surface disturbance and well casing exist in the main portion of the reservoir?

PI Response:
We agree that larger areas will need to be evaluated to establish new districts. It may well be that a two-stage investigation is appropriate, with the second focusing on structural upwellings identified but not exploitably pinpointed in stage one. As for surface development versus data quality, this is not so much an issue with the MT at least given modern methods of remote referencing. For example, we lost only about a 200 m wide patch of detailed continuously profiling at Dixie Valley when we surveying right under the main transmission line. Development should not affect structural geology inferences and probably not gas flux more than ~100m from the well pad.

Reviewer 23641

Score: 9.0

Comment: Excellent progress in a challenging discipline: regional trend analysis to identify hydrothermal fairways.

PI Response:
N/A

Reviewer 23612

Score: 8.0

Comment: Progress on the components of the effort that have advanced seems good. This includes the MT survey and model, and mapping. The gas and geochemistry efforts are in a premature stage. Reconnaissance gas flux results are couched as promising, but these aren't presented very clearly so it is hard to judge. What are these preliminary results? Still, the lag on this component is apparently due to funding delays and so should not reflect poorly on team progress. At the current early stage, it's still hard to gauge the likelihood of success, as would be met by "a recommendation forward to pursue new enthalpy potential in the McGinness Hills field." But, progress meets with established milestones.

PI Response:
N/A

Reviewer 23450

Score: 8.0

Comment: Project is on schedule except for weather related delays. Collected data is under review and analysis. The information on structural characterization, with the 2D MT inversion, is very interesting and should excite explorationists.

PI Response:
N/A

PROJECT MANAGEMENT/COORDINATION

Reviewer 23417

Score: 8.0

Comment: Very thorough explanation of costs to date. This is a relatively small budget for an important research program. If Phase 2 is completed, it would be important to test the results with some type of drilling program, although none is in the budget. Any such drilling program should not be part of a developers exploration program, and all data should be available to the public for review.

PI Response:
It is true that drilling would be well outside the current budget but would be of high interest in the Phase II area.

Reviewer 23641

Score: 9.0

Comment: Appears to be a well managed project. Integration of disciplines well done.

PI Response:
N/A

Reviewer 23612

Score: 9.0

Comment: The plan is good and seems to have been executed smoothly, save the delay in soil gas flux measurements. Collaboration with Ormat, from data sharing, to field access, to well sampling is a real strength of the project. The potential for positive results of the study to translate readily into new geothermal development seems very tangible due to this relationship.

PI Response:

N/A

Reviewer 23450

Score: 5.0

Comment: Cost, schedule, and accomplishments are appropriate.

PI Response:
Not sure why we scored only 5/10 given that our management was deemed appropriate.

STRENGTHS

Reviewer 23417

Comment: 1. Extremely high quality researchers knowledgeable in exploration associated with all types of geothermal systems.

2. Simple use of a combination of previously proven techniques, so no new equipment development or other barriers to expanding the approach to other areas or environments

PI Response:
N/A

Reviewer 23641

Comment: Exploits recently-recognized opportunities in individual techniques. Combines highly independent methodologies to curtail non-uniqueness. Brings district-scale geophysical concepts into exploration. Strong cooperation with geothermal industry.

PI Response:
N/A

Reviewer 23612

Comment: The potential to place more blind hydrothermal real estate into a reserves category has outstanding impact potential, and the hypothesis-driven approach is a model for the program. The strength of the team members and preliminary results lend confidence.

PI Response:
N/A

Reviewer 23450

Comment: Integration of diverse geoscience data sets across different physical scales.

Identification of favorable structural and thermal regime settings.

EGI long history of geothermal research .

PI Response:
N/A

WEAKNESSES

Reviewer 23417

Comment: 1. Scale issues need further clarification - both relating to areal size of the resistivity anomalies associated with the shallow magmatic systems and the depth relationship between the magma and a potential geothermal system.

2. Can McGuinness Hills with geothermal wells, power plant, and etc. be accurately characterized from an EM standpoint without very noisy data.

3. Strongly biased technique towards Basin and Range projects. It would be helpful to see how this combination of methods would work in volcanic settings. Would the isotopic data be sufficiently discriminating in larger volcanic settings?

PI Response:
1. Agreed, this is at an early state. Often, two-stage investigations with the second having more focus would be appropriate. 2. We have worked in much noisier environments (e.g., Coso) and obtained very good to excellent data with appropriate remote reference processing. 3. Yes, but B&R prospects have been perhaps the most enigmatic and represent a very large area. Still, the approach should be applicable to Snake River Plain prospects at least. Arc volcanic settings are a different beast but targetable MT structures still are definable in terms of high-temperature alteration and clay destruction at depth.

Reviewer 23641

Comment: None identified.

PI Response:
N/A

Reviewer 23612

Comment: It would have helped to have seen even a brief interpretation of the promising preliminary soil gas results to better gauge progress there.

PI Response:
N/A

Reviewer 23450

Comment: Perhaps include other geoscience data sets.

PI Response:
N/A

IMPROVEMENTS

Reviewer 23417

Comment: Assuming this EM approach defines prospective areas in the 50 - 100 sq mile range, what techniques would be available to reduce the evaluation area to a size that could be explored by detailed MT, soil gas and structural analysis?

PI Response:
Likely needs a two stage approach, but as I say a 100 site survey over a 200 sq mi area should provide resistivity voxels with lateral resolving scales < 1 km.

Reviewer 23641

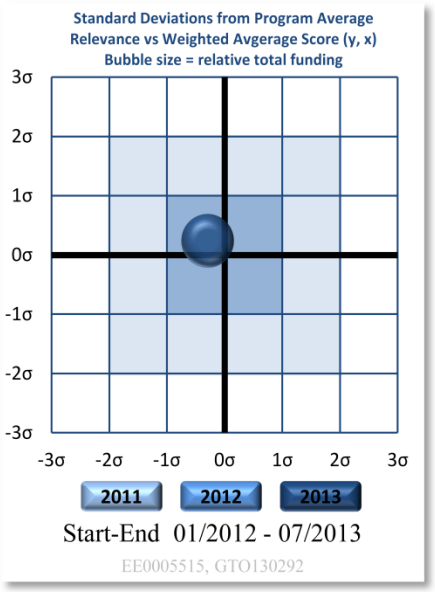
Comment: None identified.

PI Response:
N/A

Reviewer 23612

Comment: The project could benefit from additional thoughts on rigorous coupling of datasets and quantification of uncertainty in results.

PI Response:
N/A



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005515
Project: Integration of Full Tensor Gravity and ZTEM Passive Low Frequency EM Instruments for Simultaneous Data Acquisition
Principal Investigator: Wieberg, Scott
Organization: Bell Geospace, Inc.
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23417

Score: 9.0

Comment: This type of project is critical to the future of geothermal development if we are to look for and discover blind systems. Currently we have techniques capable of generating good drilling targets if we have prospect areas in the range of approximately 10 -20 square miles. Such techniques are usually surface based with only a few aboveground – such as remote sensing. If we are searching for blind deposits we need to be looking at prospect areas of 100-200 square miles, and that can only be achieved by aerial techniques. For that reason alone we need projects like this that attempt to adapt proven land-based surveys. The passive ZTEM system has to be able to demonstrate both aerial effectiveness, which it has in other natural resource areas, along with a useful depth penetration.

PI Response:
The use of AirFTG and ZTEM aerial systems for large scale surveys is done extensively in hydrocarbin and mineral exploration.

Reviewer 23641

Score: 7.0

Comment: Relevant research to combine two of the most advanced airborne geophysical methods onto one platform.

PI Response:
N/A

Reviewer 23612

Score: 7.0

Comment: The project seeks to improve prospect exploration efficiency by combining two advanced airborne methods onto a single platform. This should lead to lower costs, and/or more data at the same cost and therefore higher value. If proven to reduce uncertainty over the standard methods applied individually, the impact could be good. The project doesn't clearly address the engineering to impact transition – who will use the technology and what are the prospects for cost reduction? Ormat's potential uptake via McGinness Hills as a "calibration field," to see if the methodology is useful

as a blind exploration tool, could add significant value to the approach. The team has experience conducting large (80,000 line km) surveys, so assuming the same scales can be applied with the current application the opportunity for regional prospecting could be impactful.

PI Response:
N/A

Reviewer 23491

Score: 7.0

Comment: This project is indeed relevant to the problems seen in the geothermal exploration. The ability to do two different types of surveys with one overflight would improve exploration efficiency. It appears to me that integrating the various geophysical testing regimes that are available is probably one of the few ways that we can really improve geothermal exploration.

PI Response:
N/A

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23417

Score: 7.0

Comment: The technical approach is good but I would modify Part 3 and 4 of the technique. Testing such a new method over a known system such as McGuinness Hills makes a lot of sense. This is a new geothermal system with not too much surface disturbance or distortion of the system signature. However, that is just one type of system – what is needed is a demonstration that this technique is applicable to other types of geothermal environments, such as Imperial Valley or the Pacific North West. Also McGuinness Hills generally has low elevation variations – making it a useful initial test. However we need more rugged test sites to evaluate the sensitivity to elevation changes and the impacts of compromises necessary for the two different sensing tools.

PI Response:
Most AirFTG surveys are typically done in much more rugged terrain and remote areas. Additional test areas were not within the scope of this project.

Reviewer 23641

Score: 8.0

Comment: High quality technical approach. Resourceful in addressing tow cable performance issue.

PI Response:
N/A

Reviewer 23612

Score: 4.0

Comment: It's hard to evaluate the scientific approach as little is said about how data will be analyzed, what existing data is available to the team at the Phase I site for validation (is this well-log data from Ormat, MT, etc.?). The planned analysis methods are also unclear. Will the "higher confidence geophysical model" be validated in some quantitative manner, such as comparing the integrated model to one developed from a single dataset?

The technical effort has struggled. Despite the team's experience in this space, three design iterations for the TZEM tow cable have failed. The PI also seems uncertain as to how to effectively solve the engineering issues except through the current incremental approach. So, it's difficult to have confidence that "tow cable issues can be resolved." How and when? This risk seems to compound in the face of airplane noise impacting ZTEM acquisition. The proposed solution is a longer tow cable, which at face value sounds like it could further complicate the primary failure mode.

PI Response:
Separately, the AirFTG & ZTEM both are proven technolgies. Provided gravity gradient and electromagnetic data sets are applicable to geothermal deposit characterization the existing data should prove to match. These systems may well show higher detail than previously identified by current methods.
The incremental approach to solving the tow cable issues is a result of evaluating the unexpected failures and applying engineered solutions.

Reviewer 23491

Score: 5.0

Comment: The technical approach seems to me to be a bit lacking, the inability of this project to prove the viability of these two sensors together has been limited by problems with the tow cable. It would seem that a proper, reasonable, technical approach to the tow cable problems should have solved this technical difficulty prior to the present.

PI Response:
The original tow cable was never identified as a high risk item as it has been utilized on multiple BT-67 aircraft where the only difference was the actual shape and size of the antenna being deployed. Additionally, the tow cable has been utilized on a Grand Caravan aircraft with the same antenna being deployed, but a slight different tow cable routing due to the smaller aircraft size. The extended period to solve this issue is being driven by the availabilty of the survey aircraft for testing.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23417

Score: 8.0

Comment: To date most of the research seems to have focused on equipment redesign. This appears to have been completed in a very professional manner by skilled Bell Aerospace engineers. Challenges resulting from flying two birds

on one aerial platform, to the reviewers knowledge, has not been completed in many cases. For that reason alone this is a very viable project.

PI Response:
Clarification: The AirFTG is mounted within the aircraft and does not require any external components during survey. The towed antenna is utilized by the ZTEM system only.

Reviewer 23641

Score: 8.0

Comment: Good progress and resourceful at addressing tow cable performance issue.

PI Response:
N/A

Reviewer 23612

Score: 4.0

Comment: There are two primary results so far. The first is integration and installation of the system. Does this simply refer to onboard acquisition electronics and controls?

The second is acquisition of FTG alone over the target site, given ZTEM tow cable challenges. This is not particularly novel given that the project was targeting a method that explicitly advances upon FTG alone. Did it make sense to fly gravity alone, or will the cost incurred hamper later flights if and when the engineering challenges are overcome? There are also concerns about the FTG due to increased altitude, presumably to satisfy ZTEM safety constraints. Is there a fundamental issue with the proposed combination of FTG and ZTEM, in that quality will degrade for one of the methods in order to accommodate the other? The team states that while optimal altitude for gravity is 250 ft, and they have to fly at 500 ft to tow the bird at 250 ft, they can still acquire high-quality FTG at higher altitudes (and this is common, e.g., for overwater surveys). So, while this may be surmountable, an impact analysis for the geothermal setting would add credence.

PI Response:
The risks identified are actual scope requirements for the project. The primary outcome is to evaluate the impacts of each system on the other due to the competing flying requirements. Part of this evaluation is to fly each system individually, at the respective optimal alitude, so flying the FTG only was a required component of Phase I.

Reviewer 23491

Score: 5.0

Comment: It is my belief that this project has not made the accomplishments that it should have given the funding and time that has been available to the project . The real work of this project is to attempt to integrate the data from the two sensors and that hasn't even started yet, due to problems with the tow cable. It's my belief that a good aerodynamics

engineer along with some help from perhaps mechanical, electrical and civil engineers should be able to solve the tow cable problems quite readily. Which would get this project to the real objective.

PI Response:
The primary driver for the delay in the technical issues is NOT due to the lack of educated and experienced engineers working on the project. The availability of the survey aircraft is very limited as each project is allocated a production window which results in extended periods of time between each window of testing.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23417

Score: 7.0

Comment: This Project seems to be very well managed both time wise and budget wise. Problems that have been encountered appear to have been addressed and resolved in a very timely manner with no serious loss of schedule.

PI Response:
N/A

Reviewer 23641

Score: 8.0

Comment: Well managed project.

PI Response:
N/A

Reviewer 23612

Score: 6.0

Comment: FTG acquisition was completed a year ago. Has all of the ensuing year been spent trouble shooting the ZTEM tow cable? How much of the DOE investment has been spent during this phase? The PI does present a fairly rigorous approach to diagnosing and progressively upgrading the tow cables. Ground-based testing seems to make sense, but has not proven successful. There aren't many details about how the collaborators are working together. In fact, it's not clear who has responsibility for which portions of the engineering work, how difficulties have been managed, who is liable for the lost ZTEM instrument, who is paying for the continued tow line testing, etc. A more detailed management plan would help in keeping track of progress and mitigation plans.

PI Response:
The availability of the survey aircraft is very limited. As each iteration of the tow cable completes ground testing, the project is essentially suspended until the next test window becomes available.

Reviewer 23491

Score: 8.0

Comment: The project management and coordination appears to have been carried out quite well given the problems with the tow cable. I'm certain that a good deal of interaction between the various parties has had to be scheduled on quite short notice in order to progress this program.

PI Response:
N/A

STRENGTHS

Reviewer 23417

Comment: 1. A very competent and experienced engineering company working with an experienced and well respected developer.

2. A critical project to assist the industry in searching for blind geothermal systems

PI Response:
N/A

Reviewer 23641

Comment: Well qualified PI with necessary skills and experience to combine two of the most advanced airborne geophysical methods onto one platform.

PI Response:
N/A

Reviewer 23612

Comment: Successful collaboration with Ormat at McGinness Hills to demonstrate utility and create opportunity for broader uptake of the technique would be a strong outcome. The mitigation effort for ZTEM cable issues, especially ground-based testing, seems thoughtful.

PI Response:
N/A

Reviewer 23491

Comment: I think this project has a real strength in the fact that the possibility of integrating data almost real time from the two different sensors should be the result. This could be a real advance in geothermal exploration. Further with the integration of both ZTEM and FTG accomplished as a result of this project adding other data to these parameters should be simplified. All of this would lead eventually to lower cost geothermal.

PI Response:
N/A

WEAKNESSES

Reviewer 23417

Comment: 1. Some uncertainty as to how this technology will get into the public domain.

2. Would like to see a more variety of testing on known geothermal systems.

PI Response:
Both the AirFTG and ZTEM systems are used individually in commercial surveying. The combination already has significat interest in other surveying applications, such as mining and petroleum exploration, as well as geothermal studies. Expanding or additional surveys to further test/prove the comnbination are not within the scope of this project, but could be accomidated as additional projects.

Reviewer 23641

Comment: None identified.

PI Response:
N/A

Reviewer 23612

Comment: Despite significant effort to address tow cable issues and a declaration that they can be resolved, the plan for doing so is unclear. What confidence is there that the next iteration will succeed where attempts 1-3 have failed?

PI Response:
The current iteration has passed the ground testing and is being used on the original ZTEM Grand Caravan installation with no issues to date.

Reviewer 23491

Comment: The striking weakness of this program is the inability to manufacture a proper working tow cable. It seems to the reviewer that the proper engagement of aerodynamic ,mechanical, civil, and strength materials engineers should have able to solve this problem quite readily.

PI Response:
The tow cable issues have NOT been a result of the lack of proper engagement of appropriately educated and experienced engineers.

IMPROVEMENTS

Reviewer 23417

Comment: There would be a considerable value in looking at how this technique would help in geothermal environments outside the Basin and Range. For example testing in areas such as the Pacific North West where topography is more severe and potential systems will likely be deeper.

PI Response:
Steeper topography and deeper systems would work well together. The steeper topography forces a higher mean altitude clearance, but the deeper targets would be effected less by the higher cleranaces.

Reviewer 23641

Comment: None identified.

PI Response:
N/A

Reviewer 23612

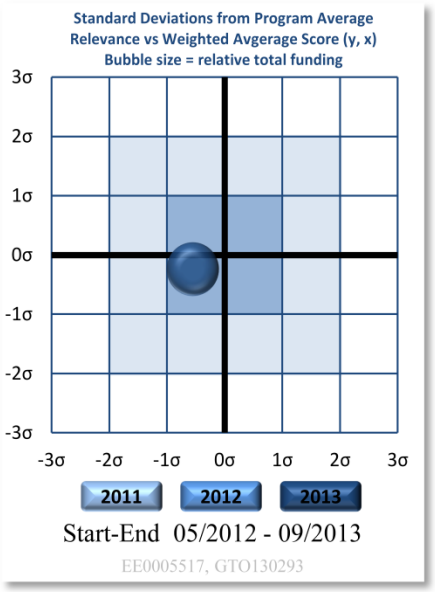
Comment: Are there comparable Bell Geospace or other industry experiences/case studies that could be used to suggest validated pathways for resolving tow cable issues?

PI Response:
The size and flying characteristics of the ZTEM antenna are unique. The instatllation has pulled from known industry systems which included the ZTEM on a smaller aircraft, but these are not the only areas are being evaluated by the project.

Reviewer 23491

Comment: There are two improvements that need to be made to this project, the first is to engage the proper engineering support to solve the tow cable problem. The second improvement that could be made is to attempt a parallel path to acquire the two data sets and begin to work to integrate them into a single product.

PI Response:
N/A



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005517
Project: Spectral SP: A New Approach to Mapping Reservoir Flow and Permeability
Principal Investigator: Thomas, Donald
Organization: University of Hawaii
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23417

Score: 4.0

Comment: The importance of understanding fluid flow regimes within active geothermal systems is of critical importance. Many techniques have been tested but none have so far been tested successfully. The approach used in this project is stated as being new and innovative, but there is no detailed discussion of this new approach either in the presentation, Executive Summary or the SOPO. If there is a new data processing approach that can characterize fluid flow in geothermal reservoir conditions, then it could have a profound impact on the industry.

PI Response:
We apologize for not being able to present a detailed discussion of the planned approach: with the time and space constraints placed on our presentations and submittals, it is difficult to do justice to an extremely complex and challenging topic. We appreciate this opportunity to rectify that omission.

At the time of the peer review meeting we had completed Phase I data acquisition at the Kilauea Summit. Data were acquired in synchronized fashion over long duration. These data can be correlated with DI events (short duration cyclic deflation followed by re-inflation of the summit) at the Kilauea Summit, as well as other geophysical measurements routinely collected by the USGS. As magma drains from the main magma chamber of Kilauea and travels down the conduit, the heat source induces excitations of the hydrothermal fluid that translate into perturbations of the electric and magnetic fields. Depending on the depth of the source, we expect the signals to appear at differing frequency/time ranges.

The procedure for processing and analysis of the data acquired in Phase I is outlined as follows: the synchronization over long acquisition times provides the precise transfer function that can be used to predict effectively the fields at one site from those measured at another site. Subtraction of the predicted fields from the measured fields yields a residual field that is highly sensitive to anomalous signals local to the site, and those are the signals of interest in our approach.

Egbert's (1997) multivariate statistical approach is used for producing the residuals. This method is very useful for better understanding of signal and noise characteristics, and for separating coherent signals of differing spatial scales, and distinguishing anomalies present in both the electric and magnetic fields, from those present in only one field type. The frequency-independent changes are likely due to near surface distortion, whereas frequency-dependent changes are more likely related to deeper changes in subsurface conductivity. The spectral density matrix (SDM) is a multivariate structure of the EM data which contains information about the dimensionality of signal and coherent noise. It has been shown previously that the dimension, or number of non-zero eigenvalues, of the SDM will be 2 in the absence of coherent noise. This corresponds to the case where the MT plane wave assumption holds perfectly. One may expect that if EM fields were being produced by some other process, such as hydrothermal/heat flow processes, that these signals would not be coherent

with the solar wind or sferic signals, and as such would be present as a separate principal component. We recognize, however, that EM noise will be a significant challenge in extracting the signals of interest. We subject the SDM to an eigenvalue decomposition, and typically consider only the first five principal components, since the higher components usually correspond to signal levels below the system noise floor.

Analysis of signals extracted in this manner provides the locations of regions of varying permeability and a possible location of a potential geothermal resource since these signals would appear only in regions where a mechanism for creating these signals exists. As part of Phase II we plan to treat the data in a more rigorous way, incorporating inversion of the MT data for subsurface resistivity and, if the SSP signals are large enough, we will couple the SP signal with subsurface flow properties using TOUGH2 code (Pruess et al., 1999).

Although some elements of the proposed data processing and analysis have been historically applied to processing of MT data, including array measurements of MT signals, suppression of extraneous signals through development of transfer functions among sites, and numerically modeling the computed flows using the resistivity distribution defined by the MT analysis, the application of the combined techniques to the development of a detailed map of the permeability distribution within a geothermal field has not been attempted.

Reviewer 23641

Score: 9.0

Comment: Relevant research into use of spectral SP to map fluid movement in the subsurface in an active volcanic terrain.

PI Response:
Thank you. In addition to the relevance of this research in volcanic terrain, it will have broader applicability since we are investigating fundamental processes that are inherent to hydrothermal activity whether of volcanic origin or associated with deep fluid circulation as occurs in environments like the Basin and Range.

Reviewer 23612

Score: 9.0

Comment: The project aims to develop a new geophysical survey method to map fluid flow using time-dependent self potential (SP) and MT. While a number of methods can be used to remotely infer temperature and fluid saturation, imaging fluid flow and ultimately permeability is a holy grail of geothermal prospecting. Developing a new methodology for this could have a significant impact on lowering development costs through better targeting of wells.

PI Response:
Thank you; this is the overall objective of the research and the hoped for outcome.

Reviewer 23450

Score: 5.0

Comment: The project objective is to map fluid flow around geothermal prospects using resistivity and hydrologic flow modeling coupled with expert systems. It is unclear how this is greatly different than other geothermal projects. How will

the expert systems capture the expertise of experts from LBNL, and what about industry expertise? Proof of principal and demonstrated improved exploration drilling success rate is needed.

PI Response:
The characterization of the project objective is not quite correct; our objective is to develop a method of inferring fluid flow in the subsurface using a novel method of analyzing the time-dependent or spectral spontaneous potential signal collected during an MT survey. The extraction and analysis of the SSP signals will lead to a proxy for permeability and a possible location of a potential geothermal resource since these signals would appear only in regions where a mechanism for creating these signals exists. In a more rigorous way, the MT data sets will be inverted to obtain subsurface resistivity structure; SSP data sets will be analyzed and numerically modeled with the recovered resistivity structure (from the MT analysis) to develop a 2-D, or 3-D where possible, model of subsurface flows responsible for the observed SSP signal. While we recognize that noise will be an inescapable component of the signals, if the SSP signals are large enough and show a good correlation with the resistivity structure, the ultimate goal of this research is to couple the SP signal with subsurface flow properties using a simulator code such as TOUGH2 (Pruess et al., 1999). The latter is a numerical simulator for nonisothermal flows of multicomponent, multiphase fluids in three-dimensional porous and fractured media, that would lead into estimates of true permeability. That is the key objective of this work;we note, however, that achieving that objective would take the TRL of this technology well beyond those for which this FOA was intended.

The development of an expert system is a secondary objective of the work that is intended to make the analysis of the combined MT and Spectral SP data more accessible to the exploration/drilling community; it is also important to understand that development of the expert system is part of the second phase of the proposed work that has not been initiated, and can't be initiated, until the go/no-go decision is made. Hence, it was considered inappropriate to incorporate discussion for this in this project review. We fully concur that proof of principal is needed; however, proposals for research drilling (to prove out the concept) were prohibited from being included or considered in the responses to the solicitation for the present work: "For Topic Area 5, DOE will NOT accept or review applications proposing the development of existing shallow temperature surveys/tools (2 meters) and TEMPERATURE GRADIENT/SLIMHOLE/PRODUCTION WELL DRILLING (caps added)."

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23417

Score: 3.0

Comment: There are a number of technical issues with the approach:
1. Kilauea summit is not a good analog for geothermal systems in Hawaii and particularly not for worldwide systems. It would seem that most geothermal systems are not adjacent to active vent areas and are considerably deeper than that found at Kilauea.
2. The summit system is almost certainly shallow, very permeable due to recent volcanism and primarily a volcanic feature probably with heating of shallow groundwater. Permeability within such a system is not representative of developed hydrothermal systems. .
3. SP is not generally recognized as a tool in geothermal exploration because of it depth limitation (00’s of feet at best rather than 000’s of feet.)

The reviewer was left with the question as to why characterization was being completed in settings that would never be used to develop actual geothermal projects. Phase 2 of the project is reported to be located on the Mauna Kea Rift Zone but no rationale or detailed location was presented as to why that was picked.

PI Response:
There were practical considerations in the selection of the Kilauea Summit as one of the sites for consideration in the present work: one of the requirements for the Phase I proposal was that the research team focus on technologies that were in the Technology Readiness Level 2 and 3 and that the work be undertaken in the laboratory and/or computational environments (see FOA guidance: "Phase I – Proof of Concept shall include activities that analyze the proposed technology's specifications, performance requirements, design optimization, and refinement of cost targets. The objective of Phase I is to complete a robust feasibility assessment of the proposed technology. Activities within Phase I shall be limited to the laboratory and/or computational environment(s). Applicants must propose technologies in Technology Readiness Levels (TRLs) 2 and 3 for Phase I (see Appendix D). Only technologies in TRLs 2 and 3 are eligible for Phase I funding.") An existing data set was available for the Kilauea Summit region that, with supplementation by a limited additional field survey, would enable us to focus on that aspect of the work. The Kilauea summit offers the advantage of having a broad range of other geophysical data sets being simultaneously collected along with the MT survey data; this is as close to a "laboratory" test of the concept in a field setting as we could hope to access. We would also note that the Kilauea summit was not the only place that we intend to collect data; we have a KGRA on the lower Kilauea East Rift Zone (KERZ) where we are currently collecting MT/SP data which will be included in the analysis.

Further, the characterization of Kilauea's summit as having only a shallow heat source is more than simplistic; there are a diversity of heat sources below the summit region that extend to depths of several kilometers and that offer an opportunity to work with SP sources spanning an equally broad depth range. The assertion that the entire summit region is underlain by permeable lavas is equally ill-informed: drilling has demonstrated that the summit and rift zones have conditions that range from permeable subaerial lavas to extremely impermeable intrusives and ash beds. We would argue that there are few locations on the planet that have such a diversity of subsurface conditions in such a limited area and where we will be able to observe such contrasts in fluid flows. With respect to SP having not been usefully applied to geothermal exploration due to depth limitations: our objective here is not to apply conventional SP analysis, but to develop an approach using SSP signals, which, depending on the depth of the source, would appear at a different frequency/time ranges, that will let us apply it to deeper sources.

With respect to the Mauna Kea west flank, this is a largely unexplored region of Hawaii Island and it was our intent to conduct surveys over this region based on geologic and other geophysical evidence for the presence of a rift zone. That work will be made possible by the State-funded matching resources that were supplied to the project for resource assessment. Once a prospect area is identified, we will apply the Spectral SP survey methods and analysis to that area. Again, the intent here was to meet the guidance from DOE that we conduct the second phase work in an area of less known hydrothermal conditions rather than the KERZ where conditions are known.

Reviewer 23641

Score: 8.0

Comment: Rigorous and appropriate scientific approach.

PI Response:
Thank you.

Reviewer 23612

Score: 8.0

Comment: The approach includes instrument development, software development, field deployment and data acquisition, and processing and presumably interpretation and modeling. This is a comprehensive approach to developing and validating the methodology. It sounds like progress has been made in augmenting the commercial MT system to improve fidelity. How much higher resolution are the afforded measurements, and what kind of features can now be imaged that wouldn't previously have been resolvable? A significant strength of the project is that the method is being developed in the field laboratory that is the Kilauea Summit area. The significant prior characterization and existing instrumentation there provides a strong basis to ground truth the new work. Such criteria for field site selection should be a model for other exploration methods development projects. The details behind the method are not presented. Are new algorithms being developed to process the data? What is the interpretation process? The summary states that MT surveys "are, to a degree, treated as black-box surveys." The technical approach here is also presented in a bit of a black-box manner. It would help to have a clearer description of the methodology.

PI Response:
Thank you for these insightful comments. We agree that the Kilauea Summit provides us with an outdoor laboratory that gives us the opportunity to utilize other geophysical data and measurements to ground truth our results. Due to improved noise performance of the new MT acquisition system we are able to collect much smaller signals than previous generation of MT systems allowed for. Multivariate multi-station processing is the other important component that improves data fidelity. We are still in process of analyzing the data, and we don't have yet a quantitative measure of this improvement. At the time of the Peer Review meeting, we had only accomplished the Phase I data acquisition at the Kilauea Summit. This left the data analysis to take place after the reporting process had already occurred. Data analysis is now underway. Our data acquisition scheme of long term synchronized acquisitions at multiple sites provides a spatial array of measurements which is used to separate the fields of a 'local' SSP source from the natural EM fields that are coherent over hundreds of kilometers. The methodology separates the fields using a multivariate statistical approach. Utilizing the transfer functions previously mentioned, it is possible to predict the fields at one site from those measured at another site. Subtracting the predicted fields from the measured fields yields a residual field that is highly sensitive to anomalous signals local to the site. These are the signals of interest in our approach. Analysis of the residual fields will lead to a proxy to permeability and possible locations of geothermal resources. Further details of our proposed methodology have been included in prior responses to other reviewer comments above.

Reviewer 23450

Score: 6.0

Comment: The data set collected at Kilauea is certainly of value, it is unclear how analogous this data will be to Basin and Range or other exploration areas with different thermal and structural regimes. The project is heavy on software and hardware development for the East Rift Zone environment, how is this useful to exploration elsewhere?

PI Response:
As noted in an earlier response, we are currently working on development of a technology at the TRL of 2 to 3; our strategy is to define the concept in a field laboratory that offers strong signals at a range of depths and then move out to more conventional geothermal resource areas. If we can prove out the concept and apply it successfully in a KGRA, we can then proceed - at a later date - to an untested location and determine whether we can successfully define fluid flows at geothermally relevant depths in as-yet-unproven geothermal areas in Hawaii. If that effort is successful, we would then plan to apply it in continental environments; however, the latter steps are those associated with technologies at TRLs of 6 through 8 and are, according to the DOE GTO guidance, far beyond the stage of proposals that would have qualified for this FOA.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23417

Score: 5.0

Comment: Summit surveys were completed during the review period, but no data was presented. New surveys are being completed on the ERZ but it is not known what is the target of this survey and no location map was presented. It appears that MT equipment was purchased for the project and a contractor developed visualization software. Both of these items are readily available commercially.

PI Response:
Data plots were presented at the review meeting as was a map showing the locations of the stations; however, there were severe constraints placed on both the time available for the presentation as well as in the number of optional slides that could be presented in the Powerpoint. A much more complete presentation was desired by the PI but, in respect to the logistical challenges for DOE GTO in performing a review of so many projects in a reasonable amount of time, much important detail had to be sacrificed.

I am not at all clear on the second comment: we are trying to advance the current state of the art of geothermal exploration technology because the current SOTA can't provide all the information required to optimize siting of exploration wells or to optimize field development. Both milestones - acquisition of the equipment and development of the software - are steps in the process, not endpoints.

Reviewer 23641

Score: 6.0

Comment: High quality and high productivity. Timing delays out of PI control due to Kilauea volcanic activity.

PI Response:
I would agree, working in the Kilauea summit region is a challenging endeavor due to the sensitivity of the environment, the dynamism of the geology, and the Federal oversight of the lands, but it provides a unique natural laboratory in which to test the Spectral SP concept and to begin to unravel the relationships among fluid flow and electric fields generated by the interaction of both steam and hot water with the variety of geologic conditions existing at varying depths beneath the summit region.

Reviewer 23612

Score: 7.0

Comment: The team has deployed 18 MT stations at Kilauea Summit and collected high quality data. This is a logistical feat and seems likely to provide new insights over Kilauea. Is this the first such MT survey on this part of the volcano? A couple of time series are shown, but it would help to see more of a high-level overview of data acquired and characterization of quality and potential insights. Signals are seen that correlate with deflation/inflation events, and these have been inferred to represent “obvious hydrothermal activity,” or “steam flow within the rift due to changes in magma

transport." The team can distinguish this from magmatic signatures due to differences in signal strength, and they are working on how to constrain depth for shallow vs. deep flow sources. Presumably this will also afford matching up signals with known spatial constraints on hydrothermal vs. magmatic systems. This seems like a good approach to tuning the technique. It is still difficult to envision how the PI intends to extract quantitative permeability information from the data. While analysis has just begun, a planned work flow could help to clarify the likely value to come.

PI Response:
This is not the first magnetotelluric survey on the Kilauea Summit. But it is the first since the recent summit vent activity has begun, and the first using instrumentation to allow for more precise transfer function estimates. It is correct that we have met challenges and obstacles, and collecting MT data in this environment is a logistical feat. At the time of the review we had only finished acquiring data at the Kilauea Summit. We are now in the midst of processing and beginning to perform a detailed analysis of the data collected to provide a proof of concept. The time series data do show, in some cases, correlation with D/I events at Kilauea. We hope to capitalize on this as they indicate timing for excitation of the hydrothermal system. Detailed descriptions of the methodology are presented in responses to reviewer's coments elsewhere. In general, the workflow consists of traditional processing of the MT data. This is followed by application of multivariate statistical analysis tools to generate a predicted field at each MT station. Differencing the measured field from the predicted field yields a residual field due to SSP signals that provides a proxy to permeability, as it is associated with local subsurface processes. If the SSP signals are strong enough, and can be isolated from noise signals effectively, in Phase II we intend to employ numerical simulation codes (TOUGH2 (Pruess et al., 1999) as an example) to couple the SSP signals with resistivity models, generated by the MT data and predicted fields, to estimate true permeability.

Reviewer 23450

Score: 5.0

Comment: Progress to date is limited to issues specific to the Kilauea site (strong SP signals, natural and man-made noise, new equipment, land access and subsurface trespass issues, and etc.), which have hampered the project schedule.

PI Response:
Project startup has been much more challenging than anticipated. We have strong local support for our effort but, at the same time, we have a dense regulatory network and intense oversight on any field activity in Hawaii. Nonetheless, the execution of the fieldwork is essential in developing this new technology; other locations on the Continent might have encountered less challenging conditions, but would not have offered the same opportunities to incorporate multiple data streams into our analysis of the SP sources in the Kilauea summit region and in the Kilauea East Rift Zone.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23417

Score: 5.0

Comment: Project management seems to be adequate, although, no indication was given as to how the field work is being staffed and who are running the equipment.

PI Response:
The field surveys are being conducted "in house"; we have a field team who has been trained in the instrument deployment and an experienced Post Doctoral researcher who is overseeing the data collection and processing.

Reviewer 23641

Score: 8.0

Comment: Well managed. Complex access issues well handled.

PI Response:
Thank you. We have met some complex issues in terms of equipment procurement, access to MT sites on public lands and related logistics. We find , but aren't surprised, that what ought to be straight forward logistical issues, often demand an inordinate amount of time to resolve.

Reviewer 23612

Score: 8.0

Comment: Working in and around Volcanoes National Park is logistically challenging, as the PI well knows. The team has clearly been able to use its experience and connections to develop support for implementing the project, from government, to private industry, to community leaders. That said it seems a little surprising that such a team was as bogged down by land access issues and coordination with USGS. Given past experience could these hurdles have been more accurately planned for? Was the original schedule too ambitious? There have also been cost overruns. By how much, and are these attributed to permitting or other efforts?

The working relationship with the MT system manufacturer KMS Technologies to improve commercial instrumentation is an added collaboratory benefit. Is there a potential for these developments to go back to KMS in any commercial sense, or is this just a custom application?

The project has also generated additional funding outside of DOE associated with the geothermal prospecting goals. This is real value added and makes direct and possibly near-term impact of the methodology on the Big Island seem that much more attainable.

PI Response:
We appreciate the observations by the reviewer. The unfortunate reality that we are dealing with is that all of us are operating in a progressively risk averse environment. The National Park perception is that it benefits minimally from the research being conducted while its exposure to litigation is nearly constant and only increases when they allow anyone into the restricted areas. They have placed extremely restrictive conditions on access that transfers much of the burden for supporting this (and other earth sciences research) onto the USGS which has neither the charter nor staff to fulfill. Arguably, one could have planned for a longer review/logistics process; however, it is difficult to achieve engagement from the relevant gatekeepers until a project has received funding and many of the obstacles encountered didn't materialize until said gatekeepers fully engaged with the request for access and the details of that access. In hindsight, the schedule was too ambitious; however, the larger part of the delay was associated with challenges associated with procurement of the equipment. Funding to make acquisition, rather than rental, of equipment was not available at the time we developed the schedule; further, the delays in execution of the contract - of nearly six months - caused disruption of the schedules for our research partners that further delayed project progress. Some of these delays were unavoidable and were certainly unknown at the time that the schedule was being prepared.

Our relationship with KMS is entirely collaborative; the improved equipment design modificatons specific to this project are available to them for use as appropriate for their commercial customers. That is certainly the hoped-for outcome of any technological advances we can facilitate through this research.
We agree that the synergistic interaction between the research/technology development effort and geothermal exploration state-wide is a major benefit of the ongoing work. Having the technological capability and required equipment in Hawaii for regional evaluation of prospective geothermal areas was a significant motivation behind purchasing the equipment (and taking on the inherent challenges associated with procurement) and will produce, we believe, a value added component to this research effort that will benefit the State and industry developers in the State.

Reviewer 23450

Score: 4.0

Comment: Project is highly specific to the general Kilauea site, and no back-up site or plan was established; the project is a year behind schedule.

PI Response:
The reasons for selection of the Kilauea summit site as our primary/most desirable research location to initiate the work have been detailed above; it provides many advantages not available at any single location in the in the continental US that is even marginally accessible or available for similar research. The back-up site/plan was the Lower Puna region on the Kilauea East Rift Zone where we have strong support from the local landowners and the existing geothermal industry - where and with whom we are currently working. Nonetheless, the advantages of working in the Kilauea summit region justified the effort and time invested in conducting the surveys there. It is also relevant that the entirety of the delay was not the logistics of access to Kilauea but was also associated, to a significant degree, with navigating the procurement process. Although this process required much more time than would have been required for rental of the field equipment, the greater flexibility that ownership offers, by allowing us additional field time for data collection, when and where needed, more than compensates for that added time.

STRENGTHS

Reviewer 23417

Comment: Research to date should provide substantial data for assisting in the interpretation of volcanic systems found in the Hawaiian chain.

PI Response:
The basic processes that we are investigating and characterizing - the spectral self potential (SSP) fields generated by fluid flow - occur not only in a volcanic environment, but also within most hydrothermal systems of interest to the geothermal development community. For example, fault-bound fluid flow in the Basin and Range environment will also involve the same mechanisms that generate these SSP fields. The assertion that these processes only occur in Hawaii, or in volcanic environments, is not supported. We have elected to pursue this research where we believe that it has the greatest potential for succeeding and where the nuances and challenges can more easily be investigated.

Reviewer 23641

Comment: Unique, dynamic environment in which to test the concept: electric field data show large variability over time in areas of elevated hydrothermal activity. Well positioned to undertake the detailed data analysis and modeling tasks required to reach the Go/No Go decision point. Strong local support, logistical and financial, has been provided by all sectors of Hawaii including government, private industry, and community leaders. Land access obtained for phase I of project will help further accessibility for phase II. Strong interest in the results of the project as they relate to both local and industry-wide success of geothermal projects.

PI Response:
Thank you; we agree that the Kilauea Summit area and KERZ provides an ideal outdoor laboratory for our research, and believe that we are well poised for future Phase II efforts due to our level of interaction with government, community and industry. We are currently undertaking the processing and detailed analysis of our data in addition to furthering our data collection. We will continue to pursue these as project goals.

Reviewer 23612

Comment: Exploiting new signatures to constrain fluid flow in hydrothermal systems would be a big leap for exploration and characterization efforts. Developing and validating new methodology in a well-characterized setting is a model approach. Winning outside investments in spite of difficulties with land access is a great result and shows good management.

PI Response:
Thank you. We are fortunate to have access to such a unique field laboratory and are hopeful that this work will produce both technological and scientific insights that will be broadly applicable to other environments.

Reviewer 23450

Comment: New technology and concepts applied to SP monitoring.

Better understanding of temporal changes in the E field around active magma chambers.

PI Response:
I think this reviewer misses our objective: the actvie magma chamber itself is not the subject of our study. A dynamic magma chamber is serving as the initiating source for changes in fluid (water and steam) flow in the subsurface. That this magma chamber extends to depths of several kilometers, makes it ideal for accessing the depth relationships of importance to analysis of the spectral self potential signals.

WEAKNESSES

Reviewer 23417

Comment: 1. Project Summary states that an objective is to develop geophysical technology using MT and SP applications to map fluid flow around geothermal systems. The reviewer does not believe that this is technically possible.

2. The discussion of technical barriers does not seem to recognize the existing current technology used to site production wells.

3. It may be that the research project is focusing solely on systems in Hawaii which case there will be limited applicability of the results.

4. No indication as to where Phase II work in the Mauna Kea Rift will be located.

5. It seems to the reviewer that much of the work being completed is not directly related to geothermal exploration technology.

PI Response:
1. Perhaps this reviewer's opinion is correct; I would feel obliged to give it more weight if s/he offered a substantive argument as to why it is not possible. The basic physical processes that generate the SP signals are recognized and demonstrated in the scientific literature; our literature review has not identified any prior, unsuccessful, efforts to apply our proposed analysis process to these signals and, hence, there is no supporting evidence for the reviewer's assertion. Natural EM fields are coherent over hundreds of kilometers. Our data acquisition scheme of long term synchronized acquisitions at multiple sites provides a spatial array of measurements which may be used to separate the fields of a 'local' SSP source from the natural EM fields of the Earth. Therefore removal of the natural fields can be done by differencing between sites. Since the electric fields are vectors and are governed by the subsurface conductivity distribution they are not the same at separated sites but they are linearly related through a tensor transfer function. Using a precise transfer function obtained from long runs of the array data, it is possible to effectively predict the fields at one site from those measured at another site. Subtracting the predicted fields from the measured fields yields a residual field that is highly sensitive to anomalous signals local to the site, and those are the signals of interest in our approach. Further details of our proposed methodology are included above. If no one attempts to conduct detailed investigations of the physical processes, and their associated measureable effects, relevant to fluid flow in the subsurface, then the only guaranteed outcome is that there will be little advancement in our capabilities to map those flows.

2. Given the space limitations, we were unable to provide a complete dissertation on the exploration and well siting strategies that are presently in use in the geothermal industry; however, having recently watched a well-respected geothermal producer spend in excess of $10 million on an unsuccessful production well - due to less than adequate formation permeability - it is clear that there is room for improvements in our current capabilities.

3. As noted earlier, we are investigating the utility of signals produced by processes that, with the possible exception of hot dry rock formations, are occurring in all active hydrothermal systems. These processes are not unique to Hawaii and to argue that the results of this research are applicable only to Hawaii seems to misapprehend processes that are fundamental to active hydrothermal systems worldwide.

4. Reconnaissance surveys, using State-funded resources, will be initiated in the near future that are expected to guide us in selection of prospective research areas on Mauna Kea.

5. It is important that the reviewers recognize the fundamental processes that this work is investigating. Our work is approaching a technology that is currently at a TRL 2 or 3; an investigation of the relevant processes and a proof of concept is a necessary first step in advancing the technology to a higher TRL that can be applied to geothermal exploration efforts.

Reviewer 23641

Comment: None identified.

PI Response:
Thank you.

Reviewer 23612

Comment: Not many details were provided describing the methodology.

PI Response:

We agree that at the time of the GTO project review we did not provide enough details of the methodology. This was, in part an oversight, but also the result of time and space limitations imposed by the review process that limited our ability to discuss a very complex analysis process. We have included much more detailed discussion of the methodology in responses to all reviewers above and in the next section that we hope will alleviate this deficiency.

Reviewer 23450

Comment: Project seems to be highly specific to active volcanic geothermal environments; applicability to other geothermal environments is unclear.

PI Response:
We are investigating processes that occur in a broad range of hydrothermal systems - whether water dominated or steam dominated. The only high-temperature environment where these processes may be of marginal relevance is in the exploration for hot-dry-rock systems; however, if successful, the technology will be highly relevant even to those systems during a development effort if they can enable better/more precise 1) mapping of fluid pathways generated by enhancement processes applied to the system; and 2) assessment of the evolution of those pathways as the heat extraction network matures. As noted above, we have selected an active volcanic system for study because this system provides a more dynamic and robust expression of fluid flow processes, and their SP effects, than we are likely to find in more steady-state environments. This was done intentionally: the signal to noise contrast will be greater and will enable us to more easily define the signal characteristics and nuances. Insights derived from this effort can then be applied to characterizing the same effects in a less dynamic environment.

IMPROVEMENTS

Reviewer 23417

Comment: It is the reviewer's opinion that this project needs much clearer objectives that are related to geothermal system exploration at depths of 5000+ feet - the normal depth of geothermal systems. It may need radical re-focusing if it is to have value to geothermal development.

PI Response:
I don't believe that this reviewer's expectations of this research effort are consistent with the guidance and constraints placed on it by the FOA under which the research was funded. That guidance specified the TRL of the research that was eligible for funding at a Phase I level; had we proposed to conduct work that was ready to be applied directly to geothermal exploration and development, it would NOT have met the requirements of FOA. We would certainly agree that the ultimate objective of the technology development effort is to have a method that can be broadly applied to geothermal exploration at depths of 2 km or more; but this work is a necessary first step in achieving that goal. We would further suggest that this reviewer's expectations for transitioning our pursued technology from a TRL of 2 or 3 to one of 7 or 8 in a year or two is perhaps unrealistic considering that development of the current state of the art for MT has consumed more than 50 years.

Reviewer 23641

Comment: None identified.

PI Response:
Thank you.

Reviewer 23612

Comment: More clarity on the proposed methodology for developing permeability estimates from the acquired data would help in evaluating the potential outcomes of the project, including how this can be translated into software tools with utility for outside users.

PI Response:
Thank you for your comments and thoughtful review. We have included a much more detailed discussion of the methodology in responses to all reviewers above, and believe that the proposed methodology has now been more clearly explained. We do not wish to be repetitive in our responses, but will state here, one additional time, the outline of the proposed methodology.

A spatial array of measurement sites is necessary in order to separate the fields of a ‘local’ SSP source from the natural EM fields of the Earth. Natural EM fields are coherent over hundreds of kilometers, so removal of the natural fields can be done by differencing between sites. Since the electric fields are vectors and are governed by the subsurface conductivity distribution they are not the same at separated sites but they are linearly related through a tensor transfer function. Using a precise transfer function obtained from long runs of the array data, it is possible to predict effectively the fields at one site from those measured at another site. Subtracting the predicted fields from the measured fields yields a residual field that is highly sensitive to anomalous signals local to the site, and those are the signals of interest in our approach. A heat source or a fluid flow are some of the mechanisms that would produce these fields. Depending on the depth of the source, these signals would appear at a different frequency/time range. Egbert’s (1997) multivariate statistical approach is used for producing the residuals. This method is very useful for better understanding of signal and noise

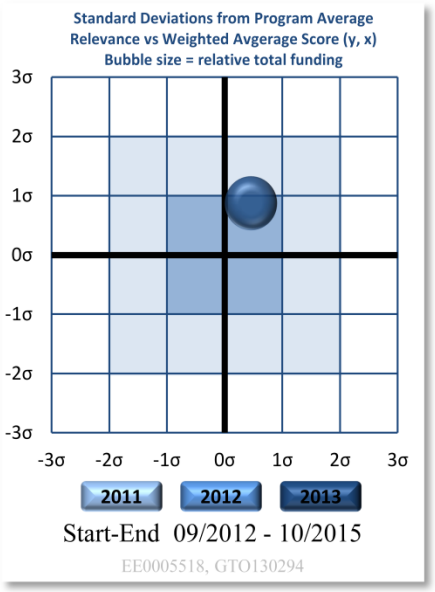
characteristics, and for separating coherent signals of differing spatial scales, and distinguishing anomalies present in both the electric and magnetic fields from those present in only one field type. The frequency-independent changes are likely due to near-surface distortion, whereas frequency-dependent changes are more likely related to deeper changes in subsurface conductivity. The SDM is a multivariate structure of the EM data which contains information about the dimensionality of signal and coherent noise. It has been shown previously that the dimension, or number of non-zero eigenvalues of the SDM will be 2 in the absence of coherent noise. This corresponds to the case where the MT plane wave assumption holds perfectly. One may expect that if EM fields were being produced by some other process, such as hydrothermal/heat flow processes, then these signals would not be coherent with the solar wind or sferic signals, and as such would be present as a separate 'principal component'. We subject the SDM to an eigenvalue decomposition, and consider only the first five principal components, since the higher components correspond to signal levels below the system noise floor.

Analysis of extracted signals will lead to a proxy for permeability and a possible location of a potential geothermal resource since these signals would appear only in regions where a mechanism for creating these signals exists. In a more rigorous way, the MT data sets will be inverted to obtain subsurface resistivity structure; the SSP data sets will be analyzed and numerically modeled with the recovered resistivity structure from the MT analysis to develop a 2-D, or 3-D where possible, profile of subsurface flows responsible for the observed SSP signal recovered. If the SSP signals are large enough and show a good correlation with the resistivity structure, we will couple the SP signal with subsurface flow properties using a numerical simulator such as TOUGH2 (Pruess et al., 1999). The ultimate goal of the work is to make estimates of the true formation permeability through the use of a simulator for nonisothermal flows of multicomponent, multiphase fluids in three-dimensional porous and fractured media.

Reviewer 23450

Comment: The project should expand its data collection to include other geothermal environments to test the new equipment and software algorithms.

PI Response:
I agree; we have selected Kilauea and other Hawaiian hydrothermal systems in which to test the basic concepts and demonstrate that this approach to mapping subsurface fluid flow has potential. Once that milestone has been achieved, we would propose to apply it more broadly in other hydrothermal systems nationwide. However, that would be a technology at a TRL of 7 or 8 and would have to come under a separate FOA than the one to which we responded.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005518
Project: Development of a low cost method to estimate the seismic signature of a geothermal field from ambient seismic noise analysis
Principal Investigator: Tibuleac, Ileana
Organization: University of Nevada, Reno (UNR)
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23417

Score: 7.0

Comment: Seismic reflection has been used extensively for geothermal exploration in the Basin and Range and there are indications that it may be useful in a number of other geothermal areas. One of the limiting problems of such surveys is the dependence of the technique on the availability of seismic velocity models. A method of developing models passively would significantly improve the quality of reflection data interpretation and accurate definition of structure. The reviewer is not certain that this will "improve discovery of blind geothermal systems" as suggested in the Project Summary since there is no direct correlation between seismic velocity and geothermal occurrences, however, it will "improve data interpretation to minimize ambiguous geophysical signals."

PI Response:
We thank the reviewer for this comment. It is generally accepted that seismic data alone is insufficient to characterize geothermal favorability. It has been demonstrated, however, that reflection surveys could identify faults, and could result in estimates of compressional seismic velocity models. The velocity models and faults, which we aim to identify, are correlated with geothermal systems.

Also, using active source reflection surveys is cost-prohibitive for large areas. If, as we are trying to demonstrate, our project will allow cost-effective preliminary ambient noise surveys, with similar results as the active surveys, this technique would be applied in more areas, possibly improving the probability of geothermal system discovery.

Reviewer 23641

Score: 9.0

Comment: Highly relevant research into potentially low cost application of ambient seismic noise analysis for geothermal exploration, to identified faulted structures.

PI Response:
We thank the reviewer for this comment.

Reviewer 23612

Score: 10.0

Comment: One of the barriers to reducing geothermal development risk is sufficient utilization of robust non-invasive exploration techniques. Logistical and cost constraints both contribute to this. The proposed method is cost-effective (several times cheaper than an active survey conducted by partner Magma Energy) and can be conducted under casual use provisions on federal lands. If the method proves to have good characterization value, it could make real contributions to cutting costs (both by reducing exploration costs up front and by minimizing dry well costs and excess drilling) while accelerating the development of geothermal energy.

Another significant benefit of the project is that it brings cutting-edge seismic methods that are at the forefront of basic research to bear on geothermal exploration. This kind of technology transfer from academia (or other industries such as O&G) to the geothermal industry is critical to growing success. If done more broadly across the GTO portfolio such efforts could have vast impact.

PI Response:
We thank the reviewer for this comment.

Reviewer 23450

Score: 8.0

Comment: The concept of using passive monitoring of ambient seismic noise has been around for over 30 years. It is interesting to see if modern instrumentation and data processing can detect and resolve seismic signatures as an exploration method. If demonstrated, it offers a low-cost method of reconnaissance exploration in frontier areas by essentially listening. Project relevance is demonstrated by an industry collaborator.

PI Response:
We thank the reviewer for this comment. In this project we use seismic interferometry, which is a novel experimental technique. We agree that passive monitoring of ambient seismic noise has been investigated before. Early seismic experiments found that the ambient seismic noise was larger in amplitude and had a lower frequency content above some geothermal fields, however, exceptions were also found. Although the theoretical basis of seismic interferometry has been developed more than 30 years ago, the field "exploded" in 2004-2005, when ambient noise -extracted inter-station Green's Functions (GF) with main component surface waves were first inverted for shear velocity structure. Crosscorrelations of ambient seismic noise at two stations were beamed over a long period of time to extract GF's. This was an innovative approach, and so far only few groups have applied it for seismic exploration. We are also one of first groups to use autocorrelations to extract the reflection component of the GF's beneath a station, which provides supplementary information for building the seismic velocity model.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23417

Score: 7.0

Comment: Objective 3, (Task 6) statistical methods to integrate geophysical data and the Phase II evaluation of new areas both seem to be unnecessary. Using geophysical Favorability maps to assess productive geothermal reservoirs suggests that the approach does not take into account or appreciate data from other sources, such as geochemistry. All data needs to be assessed prior to drilling and it is only the drilling of wells that can indicate a productive geothermal reservoir.

Geophysical exploration techniques should focus on identifying good drilling targets. In a related comment, Objective 4, Phase II should demonstrate project success by including a well in the new area.

PI Response:
We thank the reviewer for finding a problem with the formulation of our scope in regard to drilling. We meant to recommend locations with drilling favorability from the seismic perspective. Choosing drilling locations is a complex decision, which is beyond the scope of our project. We plan, however, to relate "favorable" parameters from other geophysical studies and our seismic results, and statistically assess correlations. This is the objective of Task 6.

In Task 6 we will make two statistical comparisons: first, a comparison of our results and the active survey results in the area, and second, a comparison of estimated seismic properties to other existing geophysical data, to find whether correlations exist in the areas favorable for geothermal exploration. We plan to use a large Soda Lake database which was made available to UNR by Magma Energy. This database includes data from all the past geothermal exploration studies at Soda Lake. In order to assess the usefulness of the existing, and new seismic parameters and their correlations to other geophysical estimates we need Task 6. Our approach in Task 6 will be similar to the study of Iovenitti et al.,2012.

With the statistical knowledge from Phase I, after we have established an optimal method, we would apply the technique to a new area in Phase II. This exercise is necessary because we aim to develop a transportable method. We are considering two new locations for the Phase II study (Desert Queen, NV and Dixie Valley, NV). Well, and, to our knowledge, other geophysical and geological information is avalable for each of these locations, except for the seismic information.

REFERENCE

Iovenitti, J.L., Blackwell, D.D., Sainsbury, J.S., Tibuleac, I.M., Waibel, A.F., Cladouhos, T.T., Karlin, R., Kennedy, B.M., Isaaks, E., Wannamaker P.E., Clyne, M.T., Ibser, F.H., Callahan, O.C., 2012, Towards Developing a Calibrated EGS Exploration Methodology Using the Dixie Valley Geothermal System, Nevada. Proceedings, Thirty-Seventh Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 30 - February 1. 15 p.

Reviewer 23641

Score: 9.0

Comment: Strong and rigorous technical approach.

PI Response:
We thank the reviewer for this comment.

Reviewer 23612

Score: 8.0

Comment: The project approach is high value. For $120k/yr the project brings together academic, state, and industry partners with graduate and undergraduate student involvement. The lineup of tasks – including velocity model development, field deployment and data acquisition, analysis of new geothermal seismic signatures, integration with existing geophysical data, and model assessment – is good given the resources. The use of IRIS/PASSCAL resources is

also commendable. Such science-community-driven facilities should be taken more advantage of by the geothermal sector.

More details on the proposed SP-SC-A parameters would be of interest. Is this technique adopted from other settings, and if so are there some hypotheses for what is anticipated for this application? The statistical favorability component is also unclear. What kinds of geophysical data will used and what is the methodology?

What are the best sources for ambient noise for this application, and does this suggest any regional preferences for best utility of the method? How does working in or near operating geothermal fields that produce their own categories of noise, at the surface and at depth, affect the method? Can you expect the same return in greenfield exploration efforts where these noise sources are absent? It sounds like there is sufficient noise everywhere, and greenfield settings may actually be easier to the extent there are fewer sporadic anthropogenic sources (cars, etc.).

A big plus in the approach is that the method is being developed and calibrated at an existing and well-characterized geothermal field. If a successfully validated model can be applied to a second site in Phase II, it could be even more impactful.

PI Response:
We thank the reviewer for the comments and questions. We provide below more details on the reasons we believe the SP_SC_A parameters would be of use. The main hypothesis in proposing a study of these parameters is that the effects of crustal heterogeneity on seismic waves are observable as attenuation, spectral content variations or measurable as stochastic parameters. We also mention below references to projects which inspired our proposal.

The statistical favorability approach will use an extensive database of all the quantifiable geological and geophysical information available from Magma Energy at Soda Lake, and will be: (1) Develop favorability maps (structures and patterns) for all the geophysical data; (2) Use statistical techniques appropriate for pattern identification across multi-dimensional datasets to quantify the inter-geophysical data relationships using geostatistic methods. Similar to innovative statistical analysis of on-going studies by Iovenitti et al., (2012), we will use geophysical data available at Magma Energy Corp. (Echols et al., 2011) and the new seismic data such Vp, Vs, Vp/Vs, Vp*Vs, density, attenuation (Qp, and Qs), stochastic and spectral waveform properties, and other available indicators from production fluids and springs and compare with well - derived information. This variable resolution data will be measured, modeled (or calculated) or inferred. We will test application of methods such as linear correlation analysis, multivariate analysis, chi-square tests and Classification and Regression Tree (CART) to estimate the possibility of predicting the location of a productive reservoir from the available data. Some of the questions we seek to answer are: Is the new seismic exploration method a valid, inexpensive application? Should this method be used preliminary or alternative to active surveys?

Re: The noise sources questions. We are aware that our extracted Green's Functions (GF's) will depend on the noise quality. Any seismic noise, as long as it is not unidirectional and/or monochromatic is useful for our study. A field "illuminated" by cultural noise is very desirable, and we intend to estimate whether we can use the cultural noise to shorten the duration of the experiment. If no cultural noise would be recorded, and the noise field would be random, that would actually be the ideal setting for an ambient noise experiment, and good quality, perfectly symmetrical GF's would be extracted.

REFERENCES

Echols, J., D. Benoit, M. Ohren, G. Oppliger, and T. Van Gundy, 2011. Integration of a 3D-3C reflection seismic survey over a known geothermal resource: Soda Lake, Churchill County, Nevada, GRC Transactions, 35 (this volume)

Iovenitti, J.L., Blackwell, D.D., Sainsbury, J.S., Tibuleac, I.M., Waibel, A.F., Cladouhos, T.T., Karlin, R., Kennedy, B.M., Isaaks, E., Wannamaker P.E., Clyne, M.T., Ibser, F.H., Callahan, O.C., 2012, Towards Developing a Calibrated EGS Exploration Methodology Using the Dixie Valley Geothermal System, Nevada. Proceedings, Thirty-Seventh Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 30 - February 1. 15 p.

Reviewer 23450

Score: 8.0

Comment: The approach is innovative, with the method first tested against known structures for data processing and calibration. It will be interesting to learn if modern digital equipment and improved processing can identify a geothermal signature remotely. First, identifying the attributes of a geothermal signature in a known field and structure before attempting in an unknown environment is prudent. The research project has a number of specific tasks for method development, feasibility, and validation. The proposed tasks are logical and sequential.

PI Response:
We thank the reviewer for this comment.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23417

Score: 5.0

Comment: Only Tasks 1-3 have been completed, so this is early stage of the project.

PI Response:
We thank the reviewer for this comment.

Reviewer 23641

Score: 9.0

Comment: Reasonable progress after surmounting permitting issues.

PI Response:
We thank the reviewer for this comment.

Reviewer 23612

Score: 8.0

Comment: The team accomplished permitting and successfully acquired large amounts of data. Some of the preliminary results successfully replicate active survey results from the same profiles. Resolution is lower, despite higher station density, due to lower signal energy. Longer acquisition times are planned to realize similar fidelity. Are the logistics of

this accounted for, such as the instrument availability constraints that hampered the initial campaign? The results are good considering deployment delays and the very low cost of the experiment to date.

PI Response:
This type of seismic survey has been never before conducted for more than three days. Our preliminary analyses were also for three days and had promising results. Beamforming is equivalent to a low-pass filter, and longer surveys may improve the high frequency content of the beams, and thus may result in better seismic model resolution. We aim to estimate the optimal survey length and the optimal number of sensors in Phase I.

Re. constraints which hampered the initial campaign. High frequency geophones with "Texan" digitizers are easily available from IRIS, however, because of delays in starting the project, we changed the experiment date three times and thus the sensor availability became a problem. Also, in consultation with IRIS personnel, we changed the type of sensors (to three-component), the digitizers and the batteries, to accommodate a longer deployment. These sensors were in high demand for other experiments and that also created sensor availability problems. We will use the logistics experience in Phase I to avoid the same challenges in Phase II.

Reviewer 23450

Score: 7.0

Comment: The project is on schedule with data acquisition completed and processing in progress. Future activities are designed to enhance the data acquired and processed.

PI Response:
We thank the reviewer for this comment, this is correct.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23417

Score: 6.0

Comment: Good, very experienced project team. Some contradiction between the Project Summary and Presentation as to which GTO goals this project is satisfying.

PI Response:
We thank the reviewer for this comment. The project outcomes/deliverables are summarized below: (1) Testing and evaluation of a novel seismic exploration method based on analysis of body-waves and surface-waves extracted from ambient seismic noise; (2) Development of a cost-effective technique, consisting of statistical integration of inexpensive seismic analysis techniques with other geological and geophysical data. (3) An assessment of whether or not this new technique allows reliable geothermal reservoir characterization; (4) Estimation of a drilling favorability map - from a seismic perspective - for Soda Lake.

Reviewer 23641

Score: 8.0

Comment: Appears to be a well managed project.

PI Response:
We thank the reviewer for this comment

Reviewer 23612

Score: 6.0

Comment: The project began 9 months late. Was this due to permitting delays or other hurdles? What were the obstacles, and how were they circumvented?

Plans for Phase II are still underway. The team is currently considering a site near Fallon, NV. Plans include assessing the "success of the method in drilling target identification." Presumably this means conducting Phase II also at a site that is already drilled. Is this on or near the Naval Air Station, and if so is there any intent to collaborate with the Navy GPO given their knowledge and interest in the area?

PI Response:
Some of the obstacles were prompted by the Magma Energy Corp. decision to close its office in Reno. As a result of this crisis, Jim Echols from Magma Energy, who would have been in charge with record section interpretation on our project, lost his position with Magma. He was also not be able to cost-share on Phase II. Dr. Mariana Eneva from Imageair has cited personal reasons for breaking the Imageair sub-contractor commitment to Task 5 completion: Statistically Assess Geothermal Reservoir Favorability. The Task 5 approach was to: 1) Develop initial geothermal reservoir favorability maps for each available geophysical dataset; 2) Use geostatistics methods for pattern identification across multi-dimensional datasets to develop a final favorability map; 3) Assess the possibility of predicting productive geothermal reservoir favorability. By leaving the project, Imageair freed $32,400 (without 0.41% fringe). The change in the industrial partners did not affect Phase I of our project, since we have assembled a new team. The experiment site was unchanged and approved, and we had the support of the Alterra personnel at the Soda Lake plant, which is still operating. To replace Jim Echols and to ensure data interpretation, we have a new industrial partner and subcontractor, Optim Inc. The PI has collaborated with Optim Inc. for a similar experiment at Pyramid Lake. Our collaboration resulted in a synergy of codes and file formats for fast processing which will benefit the project. Optim will process and interpret the newly acquired seismic data, and will assist in the active-passive survey comparison. To replace Imageair we used UNR resources. Dr James Faulds, from the Nevada Bureau of Mines, participates as essential personnel in the project. All the existing Soda Lake geophysical information was handed by the Magma Energy scientists to Dr Jim Faulds. Dr. Faulds is an expert in the Soda Lake geophysical properties. He, and his graduate student, who is writing a thesis on the Soda Lake geothermal area, will help on all aspects of Task 5. Dr Tibuleac has the required statistics background, and is familiar with geo-statistical methods, since she is involved into a similar task on an on-going DOE - funded study conducted by Altarock Energy Inc in Dixie Valley. She will conduct the geostatistical analysis at Task 5.

We were also required to obtain deployment approval from numerous entities, including private persons, the Bureau of Land Management and Alterra Corp, prior to the start of the project. We had additional constraints related to borrowing the sensors from IRIS. The above activities took a long time and changed the experiment logistics.

We are negociating with the DOE and with the US Navy a deployment in Dixie Valley, NV. Another possible location is Desert Queen, Nevada. Dr Faulds' opinion will be decisive in choosing the new location.

Reviewer 23450

Score: 5.0

Comment: Costs and accomplishments seem appropriate.

PI Response:
We thank the reviewer for this comment

STRENGTHS

Reviewer 23417

Comment: 1. Fulfills an important need to develop good seismic velocity models.

2. Uses an existing geothermal system to test the applicability of the new technique.

PI Response:
We thank the reviewer for this comment

Reviewer 23641

Comment: Innovative aspects of this research:

- Demonstration and validation of a relatively inexpensive seismic exploration technique, using ambient seismic noise, as opposed to active sources recorded at arrays and reflection lines.

- The method has the potential to provide knowledge of existing fault dips using ambient seismic noise processing.

- The method has the potential to estimate a preliminary shear velocity model which, unlike the P-velocity model, is not yet satisfactorily accomplished by conventional seismic reflection surveys and which has the potential to provide important independent information.

- Investigation of supplementary seismic indicators (attenuation, spectral content and stochastic properties) of geothermal reservoir favorability;

- Statistical evaluation, integration and synthesis of seismic and other geothermal favorability parameters.

PI Response:
We thank the reviewer for this comment

Reviewer 23612

Comment: A low-budget technique that promises returns equivalent to much more costly and environmentally sensitive survey methods could have significant impacts on exploration risk reduction, especially if the technique is adopted where seismic methods would have otherwise simply been omitted or underutilized. Adapting cutting-edge methods from the basic research community to the geothermal setting should be one of the basic development models for GTO.

PI Response:
We thank the reviewer for this comment

Reviewer 23450

Comment: Revisiting an old passive exploration technique with new technology (hardware and software).

Validating geothermal signature with a know geothermal field.

PI Response:
We agree that the theoretical basis of our method was developed in the past, however, seismic interferometry is a new experimental approach to estimate velocity models between pairs of stations. We trust that even if the only merit of our method were the new hardware and software , we would be able to attain our goals, and provide a reliable and cost - effective exploration method, and potentially useful new seismic parameters to be considered for geothermal exploration.

WEAKNESSES

Reviewer 23417

Comment: Development of drilling favorability maps using only integrated geophysical data is a major floor in this project, although seismic velocity model generation is the most important component of the project.

PI Response:
We thank the reviewer for this comment. The main goal of this project is to statistically assess the geothermal exploration favorability based on the seismic data, which is intended as one of the parameters used in a drilling location decision. We need to relate our results to other geophysical parameters in order to know when we estimate potentially interesting seismic parameters in the study area. We are aware that a complex set of variables is necessary for estimation of a drilling location and our formulation related to "estimation of drilling favorability" was too general and should be reformulated adding "from the seismic analysis perspective".

Reviewer 23641

Comment: None identified.

PI Response:
N/A

Reviewer 23612

Comment: Delays led to necessarily cutting corners on the instrument deployment and associated data acquisition. Responsible factors and the approach to mitigating them here and in the future weren't clearly presented.

PI Response:
We believe that we may avoid some of the problems related to sensor availability because the sensor request will be made after the project has started and we will have a predictable experiment date. We have presented above some of the challenges when starting this project. We have learned valuable experiment logistics lessons and we intend to use this knowledge to ensure the success of a second experiment.

IMPROVEMENTS

Reviewer 23417

Comment: Since seismic characteristics do not specifically respond to geothermal properties, the value of favorability maps are limited. It would be important to evaluate this technique by testing it in a greenfield environment where velocity models have been generated from previously run seismic reflection surveys. If an area can be selected where a successful exploration well was drilled based on reflection data, then processing noise data would be valuable to see if the well would have been located in the same location. Favorability maps as discussed in Task 6 indicate that only geophysical data are to be included. Geochemistry, structural data, remote sensing all must be included in predicting reservoir locations.

PI Response:
We thank the reviewer for this comment. We are testing the method in a well-calibrated area at Soda Lake, for which all the geophysical and geological data mentioned by the reviewer exists. We will consider this advice in choosing the location for Phase II. Our team would only recommend reservoir locations, based on the comparison between our data and other geophysical information, however, we would leave the final drilling decision to an experienced geologist.

Reviewer 23641

Comment: None identified.

PI Response:
N/A

Reviewer 23612

Comment: The SP-SC-A parameter component sounds interesting. This is scheduled for completion this summer, so it would have been interesting to be able to comment on additional details of the methodology here.

PI Response:
The approach will be to investigate the usefulness of stochastic heterogeneity, of spectral properties and of attenuation variations for detecting productive geothermal reservoirs, and faults. The most important effect of random heterogeneity on seismic waves is scattering caused by fluctuations in density and seismic velocity. Thus, information about underground stochastic heterogeneity may be of use in exploring for geothermal resources. We will research possible fault indicators related to seismic scattering, such as: a) stochastic (Pullammanappallil et al., 1997) parameters (Hurst number, characteristic length) of the ambient noise autocorrelations and crosscorrelations; b) ambient-noise spectral energy differences above the fault, compared with spectral energy measured at positions away from the fault for frequency intervals such as 1-3.5 Hz or 1-6 Hz. The last investigation is inspired by observations of microtremor spectral anomalies in the range of 1-6 Hz associated with "partially saturated" hydrocarbon reservoirs (Saenger et al., 2009; Schechinger et al., 2009). We will investigate variations in the seismic noise spectral content in a geothermal reservoir area, like in Georgsson et al., (2000). Attenuation affects passive experiments more than affects active source experiments. To explore the possibility for attenuation estimation, we will modify our codes to retrieve surface wave travel times and amplitudes and to recover the amplitude decay with distance of the GFs using a procedure described by Prieto and Beroza (2008). The expected outcome of this task will be an assessment whether a set of new seismic parameters have the potential to provide information important for identification of production fields. We will also assess whether the existing active surveys could provide useful and sufficient information on SP-SC-A parameters of a production geothermal field. The milestone of this task will be an assessment whether additional, useful seismic information can be extracted using other properties than only seismic velocity of the waveforms recorded above a production geothermal field by array and line-type surveys. Some of the questions we seek to answer are: What other useful spectral and stochastic information isrelated to fault or geothermal reservoir presence and could be extracted from ambient-noise processing? What is the best way to characterize attenuation?

REFERENCES

Prieto, G. A., and G. C. Beroza, 2008. Earthquake ground motion prediction using the ambient seismic field, Geophys. Res. Lett., 35, L14304, doi:10.1029/2008GL034428.

Pullammanappallil, S., A. Levander, S. Larkin, 1997. Estimation of crustal stochastic parameters from seismic exploration data, J. Geophys. Res., 102, 15,269-15,286

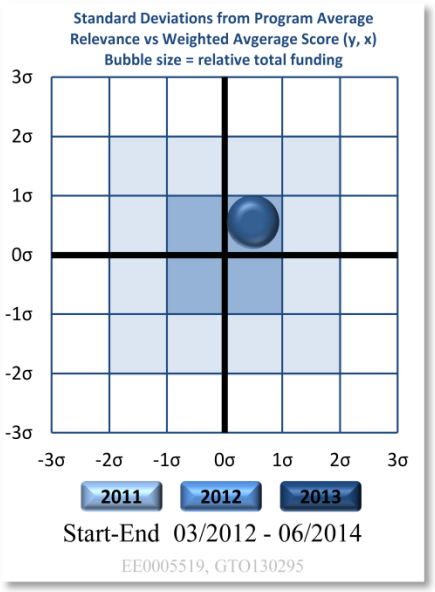
Saenger, E. H. & M-A. Lambert & T. Nguyen & S.M. Schmalholz, 2009, 71st EAGE Conference & Exhibition — Amsterdam, The Netherlands, 8 - 11 June 2009.

Schechinger, A. Goertz, B. Artman, 2009. Extracting subsurface information from ambient seismic noise – an example from Germany, 79th Soc. of Expl., Geoph. Int. Exp. and An. Meet. 2009, Houston, Texas, USA, 25 - 30 October 2009, 1617-1621

Reviewer 23450

Comment: Consider validation on additional geothermal fields with differing structural styles and thermal regimes (Basin and Range, magmatic, back-arc, crustal thinning).

PI Response:
We thank the reviewer for this suggestion. We agree that the upper 1-2 km of the crust need to be evaluated in relation to the composition and properties of the underlying material, and that geothermal favorability should be assessed also looking at the interactions between the very shallow and the deeper crust charateristics in different tectonic regimes. We will try to follow this advice, while also trying to optimise the experiment costs, by choosing an area easily accessible and as close to Reno as possible. For example, one of the proposed Phase II experiment locations is Dixie Valley, within the Basin and Range, in an area charaterized by crustal thinning and high heat flow.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005519
Project: Methodologies for Reservoir Characterization Using Fluid Inclusion Gas Chemistry
Principal Investigator: Dilley, Lorie
Organization: Hattenburg, Dilley, and Linnell, LLC
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 25423

Score: 8.0

Comment: This project can have direct impact on development of geothermal resources by providing a semi-quantitative tool to help locate fractures and permeable zones. Sharing the data with the national database will help disseminate the information to other interested parties.

PI Response:

Reviewer 23444

Score: 8.0

Comment: The overarching goal of this research direction is to use fluid inclusion signatures (FIS) as a guide to locations of faults and permeable zones that could be targeted for production of geothermal fluids. The approach has been applied to specific geothermal fields but needs to be generalized for more widespread applicability. If successful, targeting areas for drilling could reduce cost and facilitate geothermal well development. FIS data has been used in several cases to help target zones This proposal is focused on the continued analyses of large datasets that have been generated to date, thus bringing that data to fruition.

PI Response:

Reviewer 25419

Score: 9.0

Comment: Fluid inclusion geochemistry is a fairly novel approach to reservoir characterization; because of this, the causes of/influences on fluid composition still needs to be better understood.
Developing a better understanding of fluid inclusion geochemistry with regard to geothermal systems has the potential for a significant impact in our understanding of reservoir distribution and evolution.

PI Response:

Reviewer 25040

Score: 7.0

Comment: Fluid Inclusion Stratigraphy (FIS) seems to be a tool that has been accepted by and used in industry with the aid of a consultant who specializes in FIS. The PI cited cases in which FIS studies have benefited companies. The work in the project will make FIS methodologies available to industry so they will be able to conduct the initial data interpretation themselves. Tasks 1 and 2 in particular will compile 10 years of research and data compilation of work in this area and fill data gaps such that the DOE Geothermal Data Repository has a full record of a decade of research in this area.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 25423

Score: 7.0

Comment: The project is well executed for the data obtained to date. Two scientific issues need to be addressed. First, there needs to be some work done to related the bulk FIS data to data obtained from individual fluid inclusions. Cuttings should be available to go back and analyze individual inclusions from the same sample intervals. I understand the PI won't be able to analyze all sample intervals. I also understand that the PI cannot individually analyze all inclusions within any one sample interval. Finally, I also understand that the mass balance won't add up; that is, there's no way to obtain the exact same signature by analyzing individual fluid inclusions vs analyzing bulk sample. But some effort must be made in this regard. It's an important scientific step to understand what is contributing to the bulk signature developed for the FIS. The PI can take several approaches, I leave it up to her. Options include random selection of some sample interval, targeting sample intervals that yield anomalous results, and/or intervals that yielded expected, routine results. If some fluid inclusions work on individual inclusions has been performed by someone else, the PI could leverage this data. Or perhaps a simple collaborative effort can be developed with another party such as EGI at UU. Second, some attempt needs to be made to determine whether the organic molecules are indeed within the fluid inclusions or whether these organic results represent some type of contamination issue, from drilling fluids for example. Efforts expended on my first point can contribute to this point. If in fact it turns out that the organic signatures are real, the PI should continue efforts to relate the organic molecules to gas compositions in an effort to develop ideas as to the source and meaning of these constituents.

PI Response:

Reviewer 23444

Score: 7.0

Comment: The primary approach is relies on crushing bulk-rock drill core(?) samples (chips?), collecting the fluids released from mineral inclusions, determining fluid chemistry (volatiles)by a mass spectrometer (completed by commercial company), and finally analyzing the chemical species in the fluids obtained as a function of depth within the

well. The PI is well established and has successfully demonstrated this technique to work well. The commercial analyses are high quality and span the chemical spectrum. To date, a number of samples and wells have been analyzed resulting in a large amount of data. The procedure and methods for obtaining the raw data appear to work well.

Because the entire sample is crushed, fluids from primary and secondary inclusions are analyzed together. The assumption is that the fluids only record the geothermal event, which may or may not be the case.

This specific funding is focused largely on continued analysis of data generated to date in order to develop methodologies that place FIS in context and to share this data with the larger geothermal community. How these data are to be evaluated to extract meaningful relationships is not well articulated e.g. what procedures will be used for evaluating the relationships between FIS signatures, their controls, rock type, etc. Methods for determining meaningful relationships among parameters in a multicomponent system are not addressed. Due to the number of potential parameters, this could be a daunting task but should be considered. A multicomponent or chemographic analyses should be completed because the focus of the research is on analyzing the large datasets acquired to date. Also, the FIS approach presents a challenge, to take data unique to a specific geothermal system (each system appears to be unique) and to generalize these data for widespread use by the industry.

PI Response:

Reviewer 25419

Score: 8.0

Comment: This project is taking a systematic approach to data collection and analysis.
The project is incorporating results from multiple geothermal fields.
There are some concerns about the applicability of the technique as it is regarding low temperature systems.

PI Response:

Reviewer 25040

Score: 6.0

Comment: The assumption is made that the chemistry of the fluids obtained by crushing a bulk rock sample provides information that can be used to identify fractures and geothermal processes. From a purely scientific viewpoint, it is troubling that data from all the primary and secondary fluid inclusions are gathered and used for interpretation, whereas only primary inclusions should maintain the true chemical and physical signatures of geochemical processes. Throughout about ten years of working on FIS, the PI has apparently not sought to address this issue. Although the scientific underpinning has not been established, the approach appears to have worked for identification of permeable fractures. The use of bulk rock fluid inclusions for identifying specific geothermal processes, as proposed in Task 3, seems much more problematic.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 25423

Score: 9.0

Comment: The PI has made excellent progress with respect to stated objectives and goals. It's difficult to say any more; the PI has clearly identified progress and upcoming dates very clearly in her powerpoints and the current state of the project and where it is going is very obvious.

PI Response:

Reviewer 23444

Score: 7.0

Comment: The quality of the data generated is excellent. However, analyses of the data appear to be less thorough and could be improved.

The enormous quantities of raw data have been compiled into spreadsheets and with several overarching parameters. These have been submitted for uploading into the National database.

New data has been analyzed in the context of specific wells. Selected species ratios appear to be informative and correlate with other data. The results and accomplishments to date suggest that the study is on target and that results generated to date will be shared with the broader community.

This work has been an ongoing research project for about a decade. It appears that more data has been generated, but advancement of the method or its utility appears to be incremental. The controlling factors do not appear to have been identified, which limits the ability to generalize the results for more widespread application.

PI Response:

Reviewer 25419

Score: 8.0

Comment: The project is slightly behind schedule, but appears to be under spent.
The results thus far are encouraging, but it is clear that the performers are still struggling with what the results are telling them.

PI Response:

Reviewer 25040

Score: 7.0

Comment: PI has shown that FIS is economical and that FIS has been used by industry.

Good progress was made in compiling data collected to date for the Geothermal Data Repository and filing in gaps in data from a variety of geothermal fields.

Results were achieved at a low cost.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 25423

Score: 10.0

Comment: The project is well managed. The PI is to be commended for adherence to schedules, milestones, and general execution of project as written.

PI Response:

Reviewer 23444

Score: 9.0

Comment: There is a small team working well and largely on schedule. Excellent working relationships appear between the PI and the commercial company that generates data such that data analyses is quick and efficient.

There do not appear to be decision points.

PI Response:

Reviewer 25419

Score: 9.0

Comment: The project is very streamlined, which makes it easy to manage; delays in schedule are understandable and should be easy to overcome.

PI Response:

Reviewer 25040

Score: 7.0

Comment: Good collaboration with geothermal industry to collect samples from multiple fields.

PI Response:

STRENGTHS

Reviewer 25423

Comment: The strengths of the project include the following:

1) Integrates fluid inclusion work within context of wells and well history

2) Wide variety of fields, host rocks, etc. are studied

3) Geochemical evaluation of data is thorough and integrated (e.g., uses standard diagrams for geothermal waters and integrates FIS data within this context)

4) Efficient and timely manner of completing the proposed work.

PI Response:

Reviewer 23444

Comment: This work is largely one-of-a-kind and the PI has an excellent reputation for producing high quality FIS data. Results to date suggest that FIS can locate permeable zones, or FIS changes occur between zones that may have geothermal potential. The massive amounts of data have been submitted to the national database such the they are accessible to the broader geothermal community for data mining. The cost of the research is moderate.

PI Response:

Reviewer 25419

Comment: Novel tool.

Potential to provide large amounts of data about geothermal reservoirs at a relatively low cost..

Simple research approach/structure.

PI Response:

Reviewer 25040

Comment: FIS has been designed to be easy to implement by industry.

PI Response:

WEAKNESSES

Reviewer 25423

Comment: The weaknesses are more of a "to do" list of things to address; the first two I list have already been covered in Scientific/Technical Approach assessment:

1) Some effort at ground truth for bulk analyses to analysis of individual inclusions.

2) Determine whether the organic molecules are indeed within the fluid inclusions or whether these organic results represent some type of contamination. This is especially important before any kind of attempt at "organic geothermometry" can be attempted.

3) The correlation coefficients and trend lines in slide 12 are tenuous at best. That data is pretty scattered, I'd shy away from presenting data in this regard unless/until my previous point is addressed.

4) For future presentations: don't simply read your slides; geochemistry charts are clear but well logs are difficult to read because of the amount of information being presented. I don't know how to improve the latter, it's a difficult task but perhaps the PI can come up with a better graphic for future presentations.

PI Response:

Reviewer 23444

Comment: Most of the research is directed toward compiling the 10 years of data and more analyses rather than identifying the controlling factors for FIS. Analyses of bulk samples limit the ability to track fluid inclusion generations or the impact of mineralogy on the fluids produced. The research appears to be incremental and lacking thorough data interrogation. A plan for generalizing these location specific (even well specific) FIS profiles to the larger geothermal industry is lacking but would greatly benefit the industry.

PI Response:

Reviewer 25419

Comment: Interpretation of results is poorly constrained at this time.

PI Response:

Reviewer 25040

Comment: Bulk rock FIS results do not seem to have been correlated with results from studies of single fluid inclusions which have historically and successfully been used to define the geochemical and physical processes that occur in a geothermal system. How do the findings from FIS/bulk rock fluid inclusions compare to the findings from single fluid inclusions? The comparisons could shed light on the strengths and limitations of FIS.

PI Response:

IMPROVEMENTS

Reviewer 25423

Comment: My recommendations for improvements have already been covered in Scientific/Technical Approach assessment and Weaknesses sections.

PI Response:

Reviewer 23444

Comment: Conduct a multicomponent analyses of the multicomponent system. Interrogate the data more thoroughly, develop a plan for data analyses to identify key features. Perhaps work with a statistician. Relate the fluid inclusion chemistry to the mineralogy as that is one key factor that controls fluid inclusions, i.e. one would not expect to see fluid inclusions in a zone of clay minerals, for example. How do these issues factor into the overall FIS? Develop a methodology to determine if, and when, these signatures are broadly applicable to what types of geothermal systems, or if they are. These are interesting data, but what more information can be gleaned from this massive, high-quality dataset?

When developing slides for presentation, make the axes labels of sufficient size as to be readable i.e. change the default axes label font size. Having readable labels reduces the frustration of the viewer and communicates the information more readily.

PI Response:

Reviewer 25419

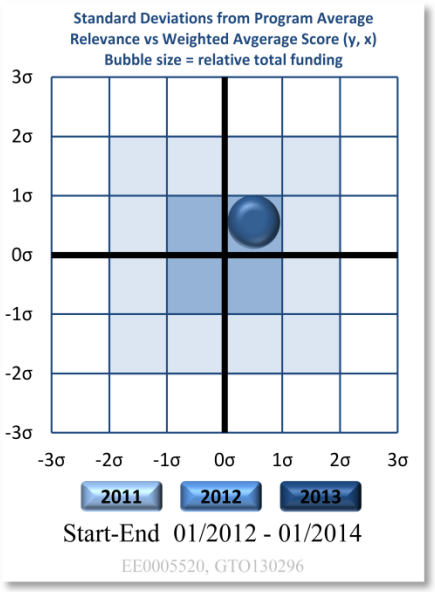
Comment: Consider if adding an additional geologic (i.e.,. mineralogical/petrographic) or geometrical tool/analysis may improve interpretation of results (i.e., can additional data collection better constrain interpretation?).

PI Response:

Reviewer 25040

Comment: If the project proceeds to Task 3 and Phase 2, the PI should team with noted expert(s) in fluid inclusion studies (single vs. bulk rock) to better define the relationship between bulk rock FIS results and information from single fluid inclusions, and what information, if any, bulk rock FIS can provide regarding the evolution of geochemical and physical processes over time.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005520
Project: Novel Coupled Thermochronometric and Geochemical Investigation of Blind Geothermal Resources in Fault- Controlled Dilational Corners, Dixie Valley, Nevada
Principal Investigator: Stockli, Daniel
Organization: University of Texas at Austin
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 25423

Score: 7.0

Comment: This project can directly impact understanding and development of geothermal resources by synthesizing aspects of structural geology, fluid alteration mapping, conventional thermochronometry, and soil gas geochemistry. Sharing the data with the national database will help disseminate the information to other interested parties.

PI Response:
We agree with the comments and are very much planning to share the data with the community. None of the data will be proprietry and all results will be published or made available throught he national database. We would like to emphasize, however, that this project has significant impact both in terms of integration of novel data and the first-time appliaction of non-tradiational 4/3He thermochronometry.

Reviewer 23444

Score: 8.0

Comment: The stated goals of this research are to: (1) test a novel application of integrated low-temperature thermochronometry and soil-gas geochemistry in a detailed structural context; (2) demonstrate that this approach (although the approach is not specified) is an effective research tool for locating blind geothermal systems; (3) evaluate the importance of fault interactions…for fluid circulation and maintaining fracture permeability; (4) apply He isotopes to recover thermal histories of samples; (5) use soil gas and noble gas surveys to track geothermal gassing to explore for blind systems; and to (6) train renewable energy scientists.

Developing new and novel methods for locating blind geothermal resources is directly relevant to the geothermal program's mission. To increase the use of geothermal energy requires new resources to be located and developed. New exploration tools that locate these systems could potentially reduce cost and risk and enhance the market share of renewable geothermal energy. As such, the potential impact of the research is high, if this succeeds. The relevance of application of He isotopes to recover thermal history is interesting but its direct relevance is less obvious.

PI Response:
No comment.

Reviewer 25419

Score: 9.0

Comment: This project is developing an integrated tool for geothermal system delineation that combines geologic and geochemical techniques. It is also implementing thermochronometry (claims for the first time in geothermal exploration) to determine the timing of geologic events that may provide additional insight into geothermal systems. The likelihood of finding a geothermal exploration "silver bullet" akin to 3D seismic in oil and gas exploration is slim; however, the integration of multiple lines of evidence into a single tool holds promise to get close. The approach highlighted in this project is promising and potentially easy to implement in other geologic settings.

PI Response:
We agree with the reviewer that the existence of "silver bullet" is unlikely and we, by no means, claim to be able find or invent this proverbial "silver bullet. However, we do believe that our integrated techniques and the implentation and testing of new and novel methodologies and approaches will help further understand the processes and scenarios associated with the occurrence of geothermal prospects and plays. We agree with the reviewer that the appraoch highlighted in the is project is promising and relatively easily implemented and thus might have the potential to lower exploration costs.

Reviewer 25040

Score: 8.0

Comment: It is of great importance to fully and accurately characterize the structural evolution of the Stillwater Range and the resulting fracture patterns to better identify potential exploration targets and to better understand exploration and production results to date.

PI Response:
No comments.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 25423

Score: 8.0

Comment: The project is well executed for the data obtained to date. The approach is rigorous and of high quality. Specific question: the PI made the statement that “focused flow on structural re-entrants has probably reset the ages”. There was no discussion of what the rocks looked like… were they also visually altered or altered in thin section? Lightly or heavily altered, especially in comparison to amount of reset on the ages? What minerals were altered? Providing this information would have helped, but I must admit we ran out of time in the Q&A session, otherwise I would have asked the question.

PI Response:

No comments.

Reviewer 23444

Score: 6.0

Comment: A classic geothermal (and structural) area provides the basis for this study. Structural mapping provides the basemap for samples selected for thermochronologic studies and soil gas surveys. Faults are mapped and their offsets reinterpreted based on this new mapping. Thermochronology and soil gas samples are collected in a geologic context and according to well-developed protocols. Target areas were reinterpreted after initial results were returned. All aspects of the project quality appear to be high.

It is unclear how goal (1) relates to geothermal energy development in that thermochronology and structures elucidate uplift and geologic history and soil gas potentially provides fault information but this is not an approach, in itself, that leads to an exploration tool. It is detailed mapping and uplift histories, important components in the regional geologic history of a field ,but it is hard to directly relate to exploration. These mapping and geochronologic tools cannot provide data on maintenance of fracture permeability. Indirect information on permeability can be obtained if He values are elevated in a fault zone but how does He data provide this information. It is unclear how thermal histories of samples relate to blind geothermal systems. From the material provided, there seems to be a disconnect between data gathered and the desired outcomes for geothermal exploration.

This is an excellent study that will produce more refined structure and geologic maps, as well as thermochronologic data for the area, but the direct linkage to the broader geothermal industry is a bit obtuse. Locating subsurface fractures is important, but only one component to locating a geothermal field.

Students associated with this project will have experience in structural mapping, thermochronology and He isotopes as they relate to geothermal, but training ‘renewable’ energy (solar, wind, etc.) scientists is a far greater topic than addressed here and as such, training cannot be achieved by this study alone.

PI Response:
It appears to be unclear to this reviewer (not the others) how our integrated approach applies to the geothermal energy development. The Stillwater Range and Dixie Valley system are one of the best-studied geothermal systems, but the structural evolution of the area and the strucutral control on geothermal resources remain only poorly understood and it appears to be difficult to use subsurface strucutral observations to predict the occurrence of geothermal resources. Understanding the geothermal system in terms of the structural controls, fluid pathways, permeability evolution, and thermal evolution (both conductive and advective) are critical to elucidating occurrence models and finding geothermal resources. As one of the other reviewers pointed out, the proposed method and novel methodology are easily tranported to new areas and are thus not site specific, but really rather process specific. Our approach aims to be more hollistic in addressing the various ingredients of geothermal anomalies. The lack of strucutral constraints or misguided tectonic models for the area has forces us to spend more time than anticipated redoing and/or refining the strucutral background work that might not be as critical to geothermal exploration overall, but key to the integration of the different methodologies. The same is true for more traditional enegry exploration. Similarly, while we agree that the student and postdoc training is not perfect and the exposure to traditional geothermal exploration (whatever that might mean) is somewhat lacking, we are trying hard to expose them to the concepts of geothermal exploration, the problems, and the challenges, but at the same time also to train the next generation in terms of novel approaches to geothermal exploration. I think the same thing is occurring in oil and gas exploration at the moment with the influx of new blood and new ideas and approaches into the field.

Reviewer 25419

Score: 7.0

Comment: The technical approach is sound, except for possibly the soil gas sampling which is showing ambiguous results (a better understanding of local hydrology may be necessary to interpret the soil gas results). Another concern would be the ability to develop thermochonologic history if an area of suitable or adequate samples for dating cannot be found. Are there other techniques/tools that could be used to overcome, or at least reduce the uncertainty, in the soil gas results? Are their other dating techniques that could fill gaps, if they exist, in sampling?

PI Response:
We agree that the soil gas survey shows ambiguous results and has not been as well-integrated as hoped. This is partly to blame on the timing (dry season only) and the needed revisions ot the existing structural model. This existing model guided the first soil gas deployment, but really needs to be redone in light of the new structural findings. Regarding the second concern (lack of suitable or adequate samples). This is not an issues in most of the current stusy area (ample apatite and zircon), but our laboratory at UT is working hard on expanding the repertoire and developing new, non-traditional thermochronometers (e.g., magnetite or calciate He dating) to expand the applicability to other rock types and geological enviorments as well as other thermal sensititivity windows.

Reviewer 25040

Score: 7.0

Comment: Detailed field mapping, combined with conventional and new thermochronometric techniques are a great combination of tools for establishing the structural evolution of the area, and determining potential origins of permeability required for a commercial geothermal system. Project has already developed a landmark concept for the structural model of the Stillwater Range.

Statements were made that the project is a novel, integrated “geochemical” approach to exploration for blind resources, and will establish the “fluid evolution” of dilational fault corners. These seem to be overstatements. I do not see that this project will accomplish these goals given the stated work tasks. The alteration mineralogy will be mapped but there is no mention as to how this information will be translated to an interpretation of fluid evolution.

The statement was also made that thermochronometry “pin-points” the heat in a present-day geothermal system. However, wouldn't thermochronometry help to determine the thermal evolution of the area, rather than its current thermal state? The only link to the current geothermal system would be the soil gas analysis, which is a fairly weak tool in the search for blind geothermal resources, although one of the limited number of tools now available.

PI Response:
We have taken this comments to heart. We agree that we are lagging behind in terms of the integration of fluid rock interaction work and our ability to interpret fluid evolution. As a results, we have refocused some of the postdocs efforts in that direction, but more importantly we have hired an additional Ph.D. student (at 50% effort) to investigate these issues. His focus is on diagenesis and fracturing or in our project on fracturing and alteration, borth interms of alteration and mineralization. We are very forunate to have him at UT as he has a strong background in geothermal exploration. Student interactions with him have also augemented our exporsure and training in the more applied geothermal aspects. He is spending part of this summer in Dixie Valley mapping fractures and alterations and will over the Fall and Spring semesters investigate the geochemistry and thermal impact of altererations and their detailed structural contexts.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 25423

Score: 9.0

Comment: The PI has made excellent progress with respect to stated objectives and goals. It's difficult to say any more; the PI has clearly identified progress and upcoming dates very clearly in his powerpoints; the current state of the project and where it is going is very obvious.

PI Response:
No comments.

Reviewer 23444

Score: 8.0

Comment: Results and accomplishments to date appears to be on track and of high quality.
The component of field work resulted in sample collection, remapping and reinterpreting the structures in this classic area. This data then lead to the development of an updated structural model for Dixie Valley, in part based on age constraints determined by this work. As such, this work could have a major impact on other studies in the Dixie Valley area. The work, both field and analytical, appears to be of high quality and the PIs are productive. Progress has been made during the granting period. It is unclear to this reviewer if the data obtained can produce the outcomes desired.

PI Response:
No comments other than that we are trying hard and have redirected some of our efforts in lights of the comments and discussions at the peer reivew meetings (see above).

Reviewer 25419

Score: 7.0

Comment: The quality of the work is good, despite some ambiguous results.
The project appears to be on schedule, but budgeting is unknown. The PI failed to provide a project management slide.

PI Response:
The presentation did contain all mandatory slides, bu the management slide was made obscured but additional information on the project management.

Reviewer 25040

Score: 8.0

Comment: Good progress on structural mapping and interpretation. Great addition to our understanding of the Stillwater Range and development of a new concept for geothermal exploration, which might be used to explain the presence and absence of productive hydrothermal areas along the range.

PI Response:
No comments.

PROJECT MANAGEMENT/COORDINATION

Reviewer 25423

Score: 9.0

Comment: The project is well managed. The PI is to be commended for adherence to schedules, milestones, and general execution of project as written.

PI Response:
No comments.

Reviewer 23444

Score: 9.0

Comment: The team had kick off meetings, appears to be well coordinated and is working well together. Appropriate staffing is in place and all are experts in their fields.

Excellent integration of the team and expertise of universities and lab personnel.

This is a phase one project only, no decision points are necessary.

PI Response:
No comments.

Reviewer 25419

Score: 7.0

Comment: The project team appears to be working together and making steady progress, however, there should be concern about budget as nothing was reported.

PI Response:
No comments.

Reviewer 25040

Score: 7.0

Comment: Seems to need to add geochemical expertise to team.

PI Response:
I think this has been a major outcome and redirection of our efforts in response of the peer-review meeting. This partially also underscores the tremendous usefullness of these meetings. I wish other agencies, e.g., NSF would do the same. As stated above, we are aware of the need for more geochemical and especially alteration (fluid rock alteration) experties. We therefore have hired a Ph.D. student and redirected some of the postdoc focus to better address the fluid flow history and the fracture-alteration interactions.

STRENGTHS

Reviewer 25423

Comment: The strengths of the project include the following:

1) Integrating disparage geologic disciplines (structural geology with CO_2 and noble gas geochemistry as well as conventional thermochronometry)

2) Collaborations between UT, Kansas, and LBNL

3) Presentation was delivered in a professional manner. The PI was on time and on target with the level of his discourse.

PI Response:
No comments.

Reviewer 23444

Comment: The team of researchers is strong and capable of performing the proposed work. The classic geothermal area selected, with the depth and breadth of previous knowledge concerning this system, should facilitate interpretation of the newly generated data. Soil gas data and He appear to be useful, at least to some extent. The new field data could significantly improve prospecting and evaluation of reservoirs. The new thermochronologic and geologic data developed will add a new dimension to this well-studied area. If the approach here can be broadened to be widely applicable to the discovery of new fields, a significant impact could result.

PI Response:
No comments.

Reviewer 25419

Comment: Integration of multiple tools and techniques to develop a more robust tool for geothermal system discovery and delineation that has the potential to be widely applicable and cost effective.

PI Response:
No comments.

Reviewer 25040

Comment: The core of the project is basic but sound and apparently much needed - structural mapping and use of new thermochronometic techniques to unravel the structural evolution of the region.

PI Response:
No comments.

WEAKNESSES

Reviewer 25423

Comment: The weaknesses of the project include the following:

1) The quality of the slides needs to be improved. It may have been a Mac to PC translation issue, but it is incumbent on the PI to address these issues in advance…why would you want to show reviewers sloppy text and reversed images, among other issues? This weakness reflects poorly on the PIs for a second reason. I've read the Project Summary. It's a data rich document (complements to the PIs), but I couldn't follow everything without maps and illustrations to help guide me. I referred back to the figures in the powerpoint presentation, but their poor quality did not help. It's the visuals that bring home the impact of this study, the PI needs to make sure his visuals are of proper quality. Given the importance of the visual aspect of the data, it would have been helpful to provide illustrations in the Project Summary.

2) The CO_2 surveys would have had more impact if their locations were presented on the same map. Also on this map, proposed future transects should have been plotted.

PI Response:
I very much agree and whole-heartedly apologies. It has become rare for Mac to PC traslations to become an issue to the improved compatibility. This is no excuse although I double checked and looked at the uploaded slides carefully. Font incompatibility and figure inversions are typical undesired outcomes. My sincere apologies to the reviwers and the audience. I think it's also an excellent recommendation by the reviewer to add all figures to the Project Summary, so that reviewers do not have to go back and forth between the Summary and the ppt (esp. with corrupted ppt figures). I have to admit that as a reviewer I have found that very helpful myself (embedded figures in Project Summary). Regarding the CO_2 survey - I also agree with the reviwers that either an overview map or an insert map should be added.

Reviewer 23444

Comment: There needs to be a more integrated assessment of how the data gathered in this study (He, and Th/He geochron) will help target blind resources. In addition, these data alone cannot establish temperature and fluid evolution of specific structures. Large leaps of logic and data are involved in making these connections. What are the components to be evaluated? How does thermochronology help target blind reservoirs? It provides uplift histories and the detailed mapping provides structural information but a better integration for exploration is needed. He and soil-gas data have numerous confounding factors, some of which have been explored, but a more rigorous analysis is necessary. The presentation was a bit unfocussed on the relationships between data gathered and its relationship to geothermal exploration. This is an expensive project that appears to be only peripherally related to geothermal exploration.

PI Response:
Excellent suggestion. It would be good to more clearly illustrate the conceptual integration of the data. We have worked on this, but our efforts have not come to complete fruition and were aparently not clear the reviewer. The deta themselves will undoubtedly help this efforts as the get integrated, but we agree that the conceptual intgeration and the communication of these efforts graphically are critical.

Reviewer 25419

Comment: Soil gas data ambiguity.

Reliance on the presence of certain mineral to develop thermchonology.

Project management/budget transparency.

PI Response:
Some of these weaknesses have been addressed in previous comments. To reiterate here. Yes, the soil gas survey yielded ambiguous data and was not as well integrated as it was executed prior to revision of the pre-existing model. This is unfortunate and will be remedided during the second deployment this Fall. We are painfully aware of this and admittedly also somewhat discouraged by the results. The relience on certain minerals of thermochronometry have not been an issue. We have recovered ample apatite and zircon from the rocks, however, as pointed out before/above, the UT laboratory is working hard to develop new thermochronometers to expand the applicability to other geological/lithological environments and other thermal sensitivity windows.

Reviewer 25040

Comment: The geochemistry and fluid evolution aspects of the project seem to be, by far, the weakest aspects of this project. The impact of the project as a combination of "thermal history (heat) and fluid flow and chemistry in an unprecedented fashion" is exaggerated.

PI Response:
Yes, we agree. As pointed out above, we concur with this assessement and thus have put renewed emphasis on this aspect with the addition of a Ph.D. student and refocusing some aspects of the efforts of the post-doctoral scholar. Fluid rock interaction and the relationship to fractures is clearly a critical aspect that has so far not received sufficient attention. Partly to blame for this has been the required focus on revising and refining the basic geology of the area.

IMPROVEMENTS

Reviewer 25423

Comment: My recommendations for improvements have already been covered in Scientific/Technical Approach assessment and Weaknesses sections.

PI Response:
No comments. We are grateful for the excellent comments and suggestions and believe that we have addressed these recommendations in the previous sections.

Reviewer 23444

Comment: Focus on collecting data that answers the questions posed - exploring and discovering blind geothermal systems. At a minimum, a clearer connection to the stated goals of the project needs to be made. Consider the impacts of biological processes, seasonal variations, etc. on results of the soil gas survey. He data also has several confounding factors that need to be explored and their impact on the resulting data discussed. Develop a data collection plan that minimizes other confounding impacts. More clearly articulate the rationale for obtaining thermochronological data in the search for geothermal resources (understanding structural geology, is clear).

PI Response:
No comments. We are grateful for the excellent comments and suggestions and believe that we have addressed these recommendations in the previous sections.

Reviewer 25419

Comment: Develop a better understanding of what could cause the ambiguity in the soil gas results.(i.e., consider local hydrology, rocks, vadose zone interactions, etc).

Explore different age-dating techniques

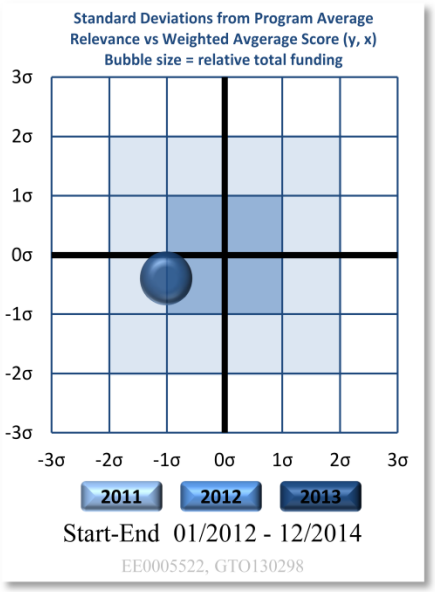
Look into how this could be applied to improving the understanding of known geothermal systems (i.e., reservoir development [possibly for in/near field EGS applications] and management).

PI Response:
No comments. We are grateful for the excellent comments and suggestions and believe that we have addressed these recommendations in the previous sections.

Reviewer 25040

Comment: Ensure that someone with established expertise in fluid-rock interaction and the study of geothermal alteration assemblages is on the team if one of the goals of the project is to establish the fluid evolution of dilational fault corners.

PI Response:
No comments. We are grateful for the excellent comments and suggestions and believe that we have addressed these recommendations in the previous sections.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005522
Project: Advances in Hydrogeochemical Indicators for the Discovery of New Geothermal Resources in the Great Basin, USA
Principal Investigator: Simmons, Stuart
Organization: Colorado School of Mines
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 25040

Score: 6.0

Comment: The project's goal is to develop and improve hydrogeochemical indicators for geothermal exploration, which would be an important tool for finding blind systems in the Great Basin, especially if the effects of individual processes such as boiling and mixing could be isolated from the total signature. These tools might also be useful as remote indicators of fluid-rock interactions occurring in EGS systems. To date, the project has focused on making standard fluid-rock equilibria calculations for Great Basin geothermal systems (Task 1), and beginning 2D simulations of the Desert Peak system (Task 2).

PI Response:
Fluid mineral equilibria had to be assessed as a starting point. In phase I, no new data could be obtained via field work, hence existing data sets had to be utilized.

Reviewer 25423

Score: 8.0

Comment: This project can have an indirect impact on our understanding of geothermal resources by providing improved understanding of fluid-rock interactions. An improved reactive transport model, one of the two major goals, can also help with understanding how fluid-rock interactions affect EGS. Sharing the data with the national database will help disseminate the information to other interested parties.

PI Response:
None.

Reviewer 25419

Score: 5.0

Comment: Why fund geothermometer research that is only seeking an incremental improvement in the technique, when the technique is good enough as is? This project has little relevance or impact as it is planned.

PI Response:
At the start of this work, there was a widespread industry perception that traditional chemical geothermometers are poor indicators of resource temperature in the Great Basin. The absence of any systematic regional study, which involved rigorous evaluation of fluid-mineral equilibria simply reinforced the industry perception.
We demonstrated that fluid-mineral equilibria is a valid, widespread control on geothermal fluid chemistry for a range of different fluid compositions and that feldspars, clays, calcite, and quartz-chalcedony are important mineral phases, irrespective of local geology. This is a new outcome, never before addressed on a province-wide basis. Additional testing, through incorporation of existing and new data will be conducted in Phase II. Some might say that this is not so surprising, but then you have to deal with the problem of why chemical geothermometers failed to provide reliable results.

Had there been a different outcome (i.e., one which showed that fluid-mineral equilibria had little influence on geothermal fluid chemistry), then the proof of concept would have failed and cancellation or redirection of the project would be essential.

Reviewer 23444

Score: 7.0

Comment: From the supplied materials, two goals were associated with Phase I (2012) of project: (1) to define fundamental controls on fluid-mineral equilibria in six geothermal systems in order to derive data that could be used to develop a 'new' geothermometer, and (2) to quantify the effects of the various fluid processes that influence fluid compositions. Phase 2 was the formulation of 'additional geothermometers based on new indicator species with reaction transport modeling used to check their validity. Slightly different objectives were provided on the SOW – model reactive transport processes that affect fluid chemistry, understand chemical signatures of permeability, and develop geothermometers. New fundamental knowledge on fluid rock interactions was to occur. If successful, this project would provide new geothermometers to understand reservoir temperatures which could potentially lower risks and costs for development and exploration, in line with geothermal's mission.

Fundamental controls on fluid-mineral equilibria are largely well known (e.g. work by Helgeson and others), so this work would be specific to the six geothermal systems noted.

PI Response:
The work was not just specific to 6 geothermal systems, but 6 geothermal systems that represent the diversity of geothermal activity within a province with considerable geothermal resource potential. Helgeson and others formulated a methodology for assessing fluid-mineral equilibria, but they never proved it existed in Great Basin hydrothermal fluids.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 25040

Score: 6.0

Comment: PI's first step was a logical one- study thin sections and use XRD to identify minerals that would control fluid chemistry in the subsurface. It would have been useful to see an example of why he came to this conclusion from these studies, even though the assemblage itself was not unexpected.

The PI then used fluid chemistry data from wells from six geothermal systems to calculate fluid-mineral equilibriums in standard fashion and tested established geothermometers. A provisional new Na-K geothermometer was proposed. It would have been useful to compare it to existing geothermometers, for which different intercepts and slopes on a (log Na/K)/(1/T) diagram have been proposed (e.g. Truesdell, Fournier) for reference and comparison. The work to this point was very basic, but an essential starting point.

The 2D TMC model of the Desert Peak system in Task 2 will be interesting and hopefully heuristic. Work on this task is still in its early stages.

The PI proposes to study hydrothermal alteration of fractured crystalline rocks from Coso and Steamboat as a proxy for an EGS resource. This is a full research project in itself, and one that appears to have been conducted previously by other researchers who have completed extensive core studies detailing multiple generations of vein and alteration assemblages and determined their probable origins. It is unclear how the PI's proposed work will build on or complement these prior studies.

PI Response:
The work will remain focussed on Tasks 1 and 2 as originally proscribed. Work on Coso and Steamboat Springs will not be pursued.

Reviewer 25423

Score: 8.0

Comment: As described in the project documents and in the presentation, the approach is sound. Collaboration between fluid-rock experts and numerical modeling experts is solid.

PI Response:
None.

Reviewer 25419

Score: 6.0

Comment: The study is focused geothermometry measurements made on brine samples from geothermal wells (in operating geothermal fields). It appears to not include shallow wells (thermal or otherwise), springs, and other surface manifestations, because the mixing complicates measurements/results. This would seem to make the tool only applicable to determining the temperature of the deep heat that feeds the geothermal reservoir, and has little bearing on reservoir management (which can be done with thermal couples on wellheads) and geothermal system discovery (i.e., blind system finding).

PI Response:
For each system, we tried to find 3 to 10 fluid analyses that could be shown representative of the state of the reservoir (with all its inherent spatial variability) at a specific point in time. The data from the hottest deepest well is desired because the fluid composition best reflects the deep upflow. That's the condition that needs to be evaluated.

For reference, I know of no major producing geothermal field where the reservoir is managed by well head temperature measurements, because the well head condition is not the same as the reservoir condition.

Reviewer 23444

Score: 4.0

Comment: Based on the materials supplied, a poorly defined approach was used to determine fluid-mineral equilibria. Fluid chemistry was compiled primarily from the literature for the six wells (< 25 analyses) with no metadata or quality control information. The mineralogy of the wells was to be determined via XRD and petrography (50 samples total ~ 8/well). The relationship of the mineral data to the fluid chemical data is unclear/unknown, yet it is fundamental to identifying mineral-fluid equilibria. How representative these samples are to variations in mineralogy as a function of depth is unspecified. Fluid chemistry is speciated via two computer codes (all which rely on thermodynamic data for minerals, aqueous species and complexes - with errors). Activity-activity diagrams were constructed to display selected fluid chemistries in equilibrium with minerals but the one a-a diagram shown was incomplete (no saturating phase given, no phase components, no Cl concentrations, no specific mineral chemistry, etc.).

This approach lacks rigor. Minerals in these systems are not pure but solid solutions, activity-compositions relationships were not evaluated but can dramatically impact speciation and fluid-mineral equilibrium. Activity-composition relationships should be taken into account. Minerals change as a function of depth within a well, how is their relationship to fluid chemistry determined? Were the systems rock buffered? How was the approach to equilibrium determined? Empirical relationships are identified between species to develop a new thermometer but these relationships largely lack a thermodynamic underpinning or identification of controlling phases. Reaction path models are run to determine changes in mineral abundance – all of which rely on thermodynamic data. These data are subject to errors.

An uncertainty analyses must be done to establish the utility of a geothermometer and its controlling factors must be identified for it to be widely applicable. To develop a completely empirical, robust relationship requires far more than 25 analyses and far more data analyses.

Numerical modeling of a selected reservoir is done to 'match' observed mineral abundances and test fluid-mineral equilibria using Toughreact. This is a well known code widely used for reaction path modeling and appears appropriate.

PI Response:
The scope of this project is simultaneously broad and detailed in the way we are evaluating the controls on geothermal fluid chemistry across a large, geologically diverse province like the Great Basin. We have to deal with the fact that each geothermal system is unique, with differing histories of natural flow and subsequent fluid production. There is also variability in the quality and availability of relevant datasets, which permit satisfactory achievement in desktop interpretation. Certain elements are necessarily blurred because we are looking for provincial controls on fluid chemistry to develop generic tools for exploration. At the same time we are trying to address site-specific controls through careful modeling of Desert Peak, using TOUGHREACT, a state of the art reaction path simulator. Importantly, we have tried to strike a balance in terms of needs and directions of research

We disagree strongly that rigor or data analysis are lacking. Data analysis has been rigorous.

For each system, we tried to find 3 to 10 fluid analyses that could be shown representative of the state of the reservoir (with all its inherent spatial variability) at a specific point in time. The data from the hottest deepest well is desired because the fluid composition best reflects the deep upflow. We believe the quality of the data was sufficient to address all

the milestones and metrics for proof of concept. These analyses represent a range of compositions for different reservoir temperatures in different geo-hydrological settings

The use of silica polymorphs and pure alumino-silicates follow previous studies, showing these provide a satisfactory first order means of assessing fluid-mineral equilibria control on fluid compositions in terms of chemical geothermometry in geothermal reservoirs (e.g., Fournier, 1985; Giggenbach, 1988, 1991; Arnórsson, 2000). This has guided our rationale and methodology in Phase I, and it is supported by the Phase I outcomes.

No "corrections" are required as all the thermal waters are dilute (considerably less than seawater salinity). A correction for mineralogy has yet to be identified, and will be evaluated in Phase II. If such a mineral correction proves essential, then this could obviate the effectiveness of a chemical geothermometer as it would be impossible to know the reservoir mineral assemblage in advance of drilling an exploration well.

Preparation of phase diagrams is not a limiting step in our work. Understanding the geochemical data set, speciation calculations, and integration of the results, however, involves considerable investment of time. We produced a number of phase diagrams relevant for evaluating mineralogical controls on major cations, silica polymorphs, and calcite. These were included, described, and discussed in Appendix A of the Phase I report, and here is the list of what we interrogated:

Fig 1. SiO2 vs temperature with quartz, chalcedony, & cristobalite solubilities

Fig 2. Log [Ca2+][HCO3-] vs temperature showing saturation levels of calcite

Fig 3. Log [Na+]/[H-] vs log [SiO2] for 150°C, 200°C & 250°C

Log [K+]/[H-] vs log [SiO2] for 150°C, 200°C & 250°C

Log [Ca2+]/[H-]2 vs log [SiO2] for 150°C, 200°C & 250°C

Log [Mg2+]/[H-]2 vs log [SiO2] for 150°C, 200°C & 250°C

Fig 4. Log [Na+]/[H-] vs log [K+]/[H-] at quartz saturation for 150°C, 200°C & 250°C

Fig 5. Log [K+]/[H-] vs temperature at quartz saturation

Fig 6. Log [Na+]/[K+] vs temperature

Fig 7. Log [Mg2+]/[K+] vs temperature

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 25040

Score: 5.0

Comment: The PI did not show much evidence of progress during his presentation or in his peer review materials. The PI was not prepared to discuss progress on Task 2.

It is good to confirm, but not surprising, that fluid-mineral equilibria control water chemistries in the Great Basin.

PI claims various achievements, which seem to be related to Task 2 but are not supported by work conducted to date. For example,
"showed the modeling provides a test bed for assessing time dependent changes in hydrothermal fluid compositions",
"showed the application of multicomponent chemical geothermometers on modeled thermal waters closely match model temperatures", and
"proved the viability of TOUGHREACT… for assessing time-dependent changes in fluid-mineral equilibria and their effects on the evolving compositions of hydrothermal fluids…."etc.
However, the 2D modeling results shown seemed to be so preliminary (system still heating up to a maximum of 80 deg C) that these goals could not yet have been achieved. They may in the future, but this task has not yet progressed far enough to demonstrate anything.

The Task 2 modeling results show the precipitation of quartz even though the reservoir had only reached a maximum of 80 deg C. The accomplishments state that the 2D model incorporated reaction kinetics. If so, it seems a silica polymorph such as chalcedony would have precipitated in place of quartz.

PI Response:
We demonstrated that fluid-mineral equilibria is a valid, widespread control on geothermal fluid chemistry for a range of different fluid compositions and that feldspars, clays, calcite, and quartz-chalcedony are important mineral phases, irrespective of local geology. This is a new outcome, never before addressed on a province-wide basis. Additional testing, through incorporation of existing and new data will be conducted in Phase II. Some might say that this is not so surprising, but then you have to deal with the problem of why chemical geothermometers failed to provide reliable results.

Yes, the TOUGHREACT modeling is preliminary. We acknowledged this.

Reviewer 25423

Score: 5.0

Comment: For the total budget of this project (~$1M) and the funds spent to date ($368K), remarkably little has been accomplished. The PI has a world-class reputation; one would have thought that he would have produced more than a table of 21 analyses, a few phase diagrams, and a questionable proposal for a new geothermometer. Perhaps significant time was spent on evaluating mineralogy of the well cuttings and the PI was not able to convey the amount of work performed on this (or some other tasks), but I don't know because this information was not provided. The coPIs have developed the basis of a numerical model for Desert Peak, but when asked the PI was unable to address simple questions about the model, such as quartz vs calcite precipitation. The PI presented a paper at the Stanford Workshop and has an associated proceedings paper; with this the PI has demonstrated a successful start to his SOPO commitment to disseminate information.

The basis for the claim that "A linear trend in Na/K versus temperature permits formulation of a new empirical geothermometer" is tenuous at best. The PI has written that the proposed geothermometer has yet to be tested or proven, both in project documents and in the Stanford Workshop proceedings paper. While this written qualification is acceptable, the PI could not adequately answer direct questions from the panel about the existing uncertainties of the data (uncertainties with respect to data underlying the thermometer and on potential errors associated with the regression). I

realize that the hypothesized geothermometer requires further work, but it is also true that the PI should have thought through these aspects before standing before a review panel.

PI Response:
We reject this judgment on the basis our achievements as defined by the SOPO. We also worked within our budget.

The identification of a potentially new Na/K geothermometer is a significant outcome, and the most important result for industry. We have emphasized that verification and validation is a high priority for Phase II work, requiring new analytical results of production fluids from additional geothermal fields. We have published a paper reporting this provisional result to make it accessible to industry (Simmons, 2013).

A second significant outcome is the evidence that deep thermal waters, much deeper than the reservoirs of producing fields, are in equilibrium with albite and K-feldspar at 250 °C. The possibility that such hot temperatures might exist illuminates the role of our work in adding new knowledge of Great Basin geothermal systems and their resource potential.

We satisfied the metrics and milestones of our SOPO. For Task 1, we extended the number of fields studied from 5 to 6, and we extended the number of mineralogical analyses from 50 to 80. For Task 2, deficiencies with respect to progress in developing a final model of Desert Peak are acknowledged and will be overcome in Phase II.

We want to dispel the notion that the aspects of Phase I could be executed quickly and leave much free time to explore other activities. This is not the case, and very significant efforts and time commitments were required to evaluate the data available to us.

Quarterly reports of progress were supplied on time as required. For Phase II, perhaps it could be useful for the PI and DoE to have regularly scheduled phone conversations to discuss progress.

Reviewer 25419

Score: 6.0

Comment: The quality of the work appears good, but errors induced by sampling, analytical equipment and human/operators do not appear to be accounted for in the derivation of new geothermometer equations. This skews the results presented to indicate that the error on the equation is small, when it potentially is not.

PI Response:

We are remiss in not documenting in our progress report the main sources of uncertainty and error in the interpretation/calibration of chemical geothermometers. They include:

- thermal and chemical structure at the time analyzed fluids were sampled
- permeability structure and natural fluid flow paths
- homogeneity/heterogeneity of reservoir fluids sampled at the wellhead
- feed point temperature(s)

- production effects owing to interactions involving re-injected water
- role of reaction kinetic effects.

All the above could have important effects for reliable formulation and application of chemical geothermometers. Pertinent information are, however, difficult to obtain for asssessment. Analytical errors on species reported water analyses were assumed to be <5%.

Reviewer 23444

Score: 3.0

Comment: The accomplishments appear to be minimal. Nearly all of the stated accomplishments have been reported previously in the literature. To date, accomplishments include (1) determining that the partial to full mineral-fluid equilibrium exists in the 6 systems, and (2) determining the equilibrium mineral assemblage. Rock samples were X-rayed to determine mineralogy – although this appears to have been only partially completed as generic minerals are listed rather than specific identifications that would be forthcoming from XRD work. For examples, what is K-mica? Muscovite, illite, biotite, a mixed layer clay?; What is K-feldspar -microcline? orthoclase? i.e. its structural state; Was no epidote found in the samples, a mineral common in these types of systems, or is it less than detection i.e. observed from petrography? The mineral assemblages reported are generic, widespread and well–known in geothermal systems.

Additional stated accomplishments and results related to geothermometry include that quartz/chalcedony solubility is most reliable, that the Na/K ratio represents equilibration T and that ratio with T is a new geothermometer. "Discovered unexpected Na/K vs. T trend formulated into an empirical chemical geothermometer". These 'accomplishments' are not new. A literature search would have revealed the relationship between Na-K and T in thermal waters, as was observed by White, 1957; Ellis and Mahon, 1964; and later expanded to include Ca by Fournier and Truesdell, 1973. The three diagrams developed in this study were incomplete. Consequently if this work is a major advancement over previous geothermal studies (not mentioned), it could not be ascertained.

Without an error analyses, the validity of the 'fit' is uncertain.

A 2D numerical model for Desert Peak was developed and run using TOUGHREACT – a legacy code that is widely used in the industry. Consequently this study/work was not necessary to ‘prove’ the viability of using this code. Preliminary calculations provide maps of mineral dissolution and precipitation for one system.

PI Response:
See other comments.

PROJECT MANAGEMENT/COORDINATION

Reviewer 25040

Score: 3.0

Comment: Needs to better manage, understand, and integrate the work of collaborators carrying out Task 2.

PI Response:
Ok

Reviewer 25423

Score: 5.0

Comment: The project and the PI appear to have adhered to schedules, milestones, and general execution of the project as written. When asked, the PI was unable to answer questions on the data provided by his coPIs (question on the numerical models).

PI Response:
Untrue. In response to a question during the presentation, I asked if I could defer to the person who did the TOUGHREACT modeling and the reply was no. The PI has sufficient understanding of what was accomplished.

Reviewer 25419

Score: 8.0

Comment: The project is progressing as planned.

PI Response:
N/A

Reviewer 23444

Score: 3.0

Comment: Project management and coordination was not addressed in the materials supplied. This score is based on the lack of substantial progress toward the goals.

PI Response:
N/A

STRENGTHS

Reviewer 25040

Comment: The PI has vast geothermal experience and management of U.S. geothermal systems to bring to the study. LBNL collaborators are excellent.

PI Response:
N/A

Reviewer 25423

Comment: The strengths of the project include the following:

1) Fundamental assessment of existing datasets, including aqueous data and examination of drill cuttings. Sometimes it takes a fresh look at a well-studied geologic terrain through the lens of the fundamentals; this project (Task 1) provides this perspective.

2) Collaborations with recognized experts in numerical modeling.

PI Response:
N/A

Reviewer 25419

Comment: Experienced PI.

PI Response:
N/A

Reviewer 23444

Comment: The potential to provide a new empirical geothermometer for geothermal conditions.

PI Response:
N/A

WEAKNESSES

Reviewer 25040

Comment: The PI's presentation and presentation materials suggested that the PI had made little progress. I had to go back to his paper at the 2013 Stanford conference to get a better sense of what had been accomplished. It would be helpful to see more representative results during the next review.

Seems like a half-hearted effort from a talented and experienced person.

There is a lack of familiarity with Task 2 work.

PI Response:
Apologies for this.

Reviewer 25423

Comment: The weaknesses of the project include the following:

1) Presentation was lacking. PI spent an inordinate amount of time on an introduction to fundamental geochemistry; he needed to get to the point much quicker and provide the reviewers with more time on meaningful discourse. PI did an exceedingly poor job of staying on time and of balancing his presentation between scientific review/reminders (e.g. quick summary of relevance of fluid-rock geochemistry) and respect for the scientific intelligence of the review panel.

2) Communication and integration between PI and his modeling collaborators.

3) The issues already discussed in the Accomplishments, Results, and Progress section.

PI Response:
Will try to improve next time.

Reviewer 25419

Comment: Lack of relevance.

Lack of error prorogation.

Only source of samples are from geothermal wells in active fields; the tool is only useful to determine ultimate deep reservoir temperature, not for blind system discovery or reservoir management.

PI Response:
We did exactly what we said we were going to do and we achieved our SOPO milestones and metrics agreed upon in advance of Phase I with DoE.

Reviewer 23444

Comment: This is an expensive project that to date has realized little new, fundamental or transformative information. The apparent lack of a thorough literature search prior to this study largely resulted in what is already known. To evaluate a new geothermometer requires precise data that is well-characterized. To date, the approach appears to lack rigor and is general at best. Specific fluids must be linked to mineral assemblages. Uncertainties in the data need to be evaluated. The presentation was ineffective which decreased the potential significance of this study. Time is valuable, therefore spending the first 10 minutes of the presentation on irrelevant topics significantly impacted the information that could be communicated. The followup questions, attempting to fill in the gaps, were not answered adequately nor professionally. This is an expensive study with little new in results.

PI Response:
The reviewer poorly appreciates the time expended to integrate several aspects of thi sproject. We disagree with most of the conclusion, but also acknowledge that perhaps time was a bit too short to cover all the aspects that would have satisfied this reviewer, who seems to have very high expectations after just 1 year of desktop study.

IMPROVEMENTS

Reviewer 25040

Comment: See weaknesses.

PI Response:
N/A

Reviewer 25423

Comment: My recommendations for improvements have already been covered in the Scientific/Technical Approach assessment and Weaknesses section.

PI Response:
N/A

Reviewer 25419

Comment: Consider redirecting research to investigate better geothermometery techniques/equations that could be used to discover blind geothermal systems or enhance reservoir management.

PI Response:
N/A

Reviewer 23444

Comment: See also Scientific Approach/Technique.

Rigorous analyses of fluid-mineral equilibria is essential, answering the following questions: How do fluids relate to minerals observed? What temperature are they recording? How uncertain is the T? What are the sources of uncertainty? What are the criteria for selecting the data in the numerical models? What are the exact compositions of the minerals and how does solid solution or structural state impact the phase equilibria i.e. the study needs to incorporate activity-composition relationships into modeling and data regression.

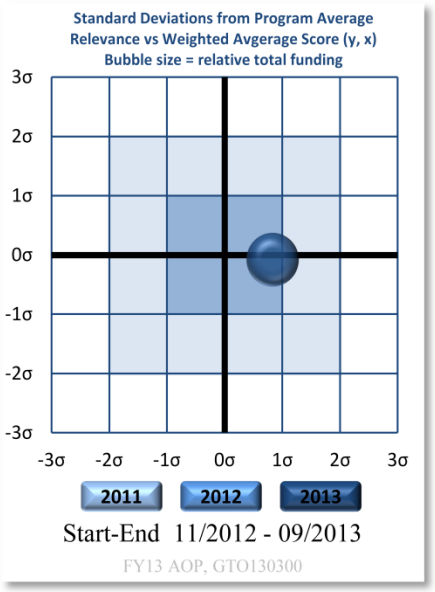
Uncertainly quantification must be done to understand the sources of the error, including those inherent in the thermodynamic database(s) utilized. The sources of error in the analyses must be understood and evaluated. Develop a summary presentation that is informative and professional. Thoughtfully answer questions asked by the reviewers. Much more information could have been communicated with a focus on science and data.

PI Response:

We agree rigorous analysis is essential. The thermodynamic database is the least of our problems. There is much greater inherent error other aspects such as:

- thermal and chemical structure at the time analyzed fluids were sampled
- permeability structure and natural fluid flow paths
- homogeneity/heterogeneity of reservoir fluids sampled at the wellhead
- feed point temperature(s)
- production effects owing to interactions involving re-injected water
- role of reaction kinetic effects.

This is a broad based study for a geologically diverse province. We have to gloss over some details to make progress.



Review: 2013 Geothermal Technologies Office Peer Review
ID: FY13 AOP
Project: Effects of volcanism, crustal thickness, and large scale faulting on the development and evolution of geothermal systems: Collaborative project in Chile
Principal Investigator: Dobson**,** Patrick
Organization: Lawrence Berkeley National Laboratory
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 25040

Score: 7.0

Comment: 3He/4He isotopic ratios are currently used in the exploration for geothermal resources. However, we need to be able to get more information from the measurements other than stating that some mantle (magmatic) component is present. This study, though limited in scope to the impact of crustal thickness on 3He/4He ratio, begins the process of elucidating the controls of 3H/4He ratios. We need more of this type of study to be able to glean more information from 3He/4He measurements. Please keep thinking of other ways to test processes that impact isotopic ratios, and ways to estimate the relative contribution of multiple variables (e.g. crustal thickness) on isotopic ratios.

PI Response:
N/A

Reviewer 25423

Score: 8.0

Comment: This project can have indirect impacts on the development of geothermal resources by improving the veracity of an exploration tool. Sharing the data with the national database will help disseminate the information to other interested parties.

PI Response:
The data from this study will be published (initial results were presented at the 2013 Stanford Geothermal Workshop) and will be submitted to the NGDS at the conclusion of the project.

Reviewer 25419

Score: 6.0

Comment: Based on the review, it is hard to determine the impact the work being done in Chile will have on the U.S. geothermal industry. The relevance of He isotope measurements have regarding the U.S. geothermal industry is not well understood, and seems to be a more academic pursuit.

PI Response:
The PIs have submitted a new AOP proposal that would apply the results of this study to the use of He isotopes for evaluating geothermal resources in the Cascades and the Snake River Plain. While these areas have high heat flow and recent volcanism, they do not have any developed geothermal resources. The use of He isotopes in conjunction with other geochemical signatures might help in elucidating volcanic vs. hydrothermal signatures for hidden geothermal systems.

Reviewer 23444

Score: 7.0

Comment: The primary focus of this research is to analyze He isotopes in specific regions along the Andes in Chile, with the stated goal of improving the use of He isotopes as guides for geothermal exploration. Developing widely applicable and unique exploration tools that target geothermal resources has considerable potential to reduce cost and risk, and locate new resources. However, it is unclear that the signal in the He isotopes can be sufficiently deconvoluted to produce the desired results.

PI Response:
One of the objectives of this study is to use the local variations in He isotopes within a geothermal system to identify upflow vs. outflow zones, as this would assist in targeting of exploration wells. We are still awaiting the results of our most recent sampling to further evaluate this concept.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 25040

Score: 9.0

Comment: Fantastic idea to use the Chilean Andes as a test bed with its variations in crustal thickness, volcanism, multiple geothermal systems, faulting, and multiple sampling sites.

Excellent collaborations and leveraging of resources.

PI Response:
The financial, logistical, and scientific support from our colleagues at the University of Chile has been critical to the success of this project.

Reviewer 25423

Score: 9.0

Comment: The project is well executed for the data obtained to date. I have one scientific question that I did not have time to ask at the meeting. Slide 9 depicts two anomalies in the northern half of the study area. One anomaly is two

squares (CVZ volcanic) at low Rc/Ra. The second is three blue diamonds (CVZ hydrothermal) at higher Rc/Ra. Are these anomalies real or some artifact? If real, do the PIs have a hypothesis as to the underlying cause? Do the PIs have plans to sample these areas to investigate further?

PI Response:
In presenting values from the liturature, I deliberately didn't screen out values. The two volcanic values with low Rc/Ra values were from Hoke et al. (1994) from Volcan Olca and Volcan Ollague. A more recent analysis from Volcan Olca by Tassi et al. (2011) yielded a value of 6.11, well within the volcanic field. Two of the three high hydrothermal values were collected by Hoke et al. (1994) from Surire. This area was also sampled by Tassi et al. (2010), who reported values that fall within the hydrothermal field (2.73 and 2.79 Rc/Ra), but unpublished data from Unocal appear to confirm the elevated He ratios reported by Hoke et al. There is no volcanic edifice adjacent to this system, so one possible explanation for these high values could be a shallow young intrusion. The third high Rc/Ra hydrothermal value from the CVZ was also from Hoke et al. (1994); this sample (from Caico) had a large amount of air contamination, as the actual R/Ra was only 3.63.

Reviewer 25419

Score: 7.0

Comment: The approach is sound, but sampling methodology for different settings/surface manifestations could be improved so that data distribution would be better.

PI Response:
Given the limited budget for this project, we were limited to sampling locations where researchers from the University of Chile were working. We hoped to collect additional samples at Tinguiririca, but we did not realize that getting to the fumarole area would require obtaining more permissions and arranging for guides to reach these remote features.

Reviewer 23444

Score: 9.0

Comment: The scientific and technical approach appears to be well thought out, logical and progresses in series commensurate with testing the hypothesis. A literature review provided the necessary background prior to field work. Field work was well coordinated with colleagues in the US and Chile. The target areas for sample collection and analyses were selected, in part, to evaluate the impact of crustal thickness, volcanism, and faults on the He signature obtained, and in part, to leverage funds from other on-going research in the area. Conceptual models were used to help target locations. Sample collecting and analysis were rigorous and appropriate, and within well-defined protocols. The approach is well executed.

It is less clear that the areas selected for analyses were optimal for targeting up flow and outflow zones.

There does not appear to be methods developed for deconvoluting the He signature processes and/or determining the cause and effect in this multicomponent system, a non-trivial task. Perhaps these could be assessed.

PI Response:

The use of a conceptual model for the two systems where more detailed sampling was conducted (Tolhuaca and El Tatio) is critical for deciphering the He isotopic signature. We were able to obtain a well sample from the Tolhuaca system, which will allow us to compare the surface feature compositions with that obtained from the actual geothermal reservoir (once the analyses have been run).

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 25040

Score: 8.0

Comment: Interesting scientific findings regarding dependence of 3He/4He isotopic signatures on crustal thickness and variation with shallow processes.

Good progress has been made considering diverse and widespread team, and at low cost.

PI Response:
N/A

Reviewer 25423

Score: 9.0

Comment: The PI has made excellent progress with respect to stated objectives and goals. It's difficult to say any more; the PI has clearly identified progress and upcoming dates very clearly in his powerpoints and the current state of the project and where it is going is very obvious.

PI Response:
N/A

Reviewer 25419

Score: 7.0

Comment: Progress of the project appears to be adequate.
Due to reported sampling difficulties the results may have bias, or be incomplete.

PI Response:
This study relies heavily on published data in addition to the samples that we collected in the field to provide a sufficient sample size needed to properly draw conclusions. Due to laboratory problems with the mass spectrometer, we are still awaiting the results of our most recent sampling visit.

Reviewer 23444

Score: 9.0

Comment: Accomplishments and results are of high quality and progressing appropriately. Significant background data has been compiled and evaluated. A thorough literature review allowed the accomplishments in this study to build on previous work. Samples have been collected from two spatially separated but well-characterized areas within the Andes, differing in crustal thickness and with different locations related to large scale faults. One sample area includes the geothermal system at Tolhuaca. Conceptual models were utilized to target sampling locations and test hypothesis of upflow zone. Fluid samples have been analyzed for stable isotopes and noble gases. The quality of the results (data) is excellent and progress toward the goals/milestones is on track.

The complications of the geologic setting in the location of the sampled He conspire to make interpretation of results less than straightforward. Consequently, moving these results into the broader geothermal realm will be challenging.

PI Response:
We agree that the interpretation of He isotopes can be challenging, and thus must be made in the context of the geologic setting, utilizing all available geologic and geochemical data.

PROJECT MANAGEMENT/COORDINATION

Reviewer 25040

Score: 9.0

Comment: Great coordination among multiple parties in different countries.

PI Response:
N/A

Reviewer 25423

Score: 10.0

Comment: The project is well managed. The PI is to be commended for adherence to schedules, milestones, and general execution of project as written. The PIs are also to be commended for the leveraging they've accomplished; that is, the collaborative work with the University of Chile is very beneficial to the project and a cost-effective way of getting work done.

PI Response:
N/A

Reviewer 25419

Score: 8.0

Comment: This appears to be adequately addressed.

PI Response:
N/A

Reviewer 23444

Score: 10.0

Comment: Project management and coordination appear to be excellent. There is integration of numerous scientists across universities and laboratories as well as international cooperation among universities and the laboratory. Data gathering and analyses are on time.

PI Response:
Unfortunately, we are now a bit off schedule now due to the delays in analyzing the most recent samples caused by problems with the mass spectrometer at LBNL.

STRENGTHS

Reviewer 25040

Comment: Excellent leveraging of financial and logistical support from other sources.

Establishment of collaborative relationships with South American scientists, top university researchers and geothermal industry that made this study feasible.

Top tier researchers.

Data acquisition outside of US in unique geologic environment.

Data acquisition in a most-cost effective fashion; highly opportunistic (in a positive sense).

PI Response:
N/A

Reviewer 25423

Comment: The strengths of the project include the following:

1) Leveraging the existing dataset of aqueous geochemistry for the area.

2) Collaborations with local university, especially with respect to developing some new aqueous data.

3) Presentation was very professional. The PI did an excellent job in balancing his presentation between scientific review/reminders (e.g. noble gasses in geothermal systems) and respect for the scientific intelligence of the review panel.

PI Response:
N/A

Reviewer 25419

Comment: Minimal cost to GTO to provide support for study.

Fosters collaboration with international partners.

PI Response:
N/A

Reviewer 23444

Comment: The tight focus of the research with the well-developed plan for achieving the goals is a strength of the research. This research will provide new data for He in this region and has the potential to contribute to the use of He isotopes for geothermal exploration. The PIs are excellent and are commended for their presentation that was clear, thorough, and to the point as were answers to the reviewer's questions. Perhaps one of the primary strengths of the proposal was the leveraging of funds from various sources to minimize cost of this research.

PI Response:
N/A

WEAKNESSES

Reviewer 25040

Comment: None noted.

PI Response:
N/A

Reviewer 25423

Comment: The one weakness is more of a "to do" list of things to address: according to the Funding Opportunity Announcement for this Financial Assistance award, the recipient must provide data to the DOE Geothermal Data Repository (DOE-GDR). I did not see this aspect addressed, not in the presentation or in the associated documents. This needs to be addressed.

PI Response:
The results of this work will be published (initial results were already published in the Stanford Geothermal Workshop), and the resulting data will be submitted to the NGDS at the conclusion of the project.

Reviewer 25419

Comment: Not clear how the research benefits the U.S. and the geothermal industry.

Inability to collect samples at some locations.

PI Response:
The goal of this project was to utilize a geologic setting with very significant differences in crustal thickness and proximity to active volcanism (Chile) and then use these results to develop an interpretive framework that could be applied to other settings. The PIs have just submitted a new AOP proposal to extend this work to the Cascades and the Snake River Plain. Sample collection was limited in part by where our colleagues at the University of Chile were conducting field work.

Reviewer 23444

Comment: There appears to be a large gap between analyses gathered in this project and the goal of improving the use of He isotopes as an exploration tool. It is unclear how this gap is to be addressed, and if it can be overcome. He isotopes have been measured for about 30 yrs, and their utility has yet come to fruition. From the material presented, it appears that there is an incomplete evaluation of the impacts of various geologic processes on He isotopic values measured.

PI Response:
The plot for the CVZ provided some contrast between the He isotopic signatures for features associated with hydrothermal systems and those linked with active volcanoes. The work on using He isotopes to identify upflow zones within a single system is still ongoing, but the samples from Tolhuaca appear to be consistent with a previously developed conceptual model for the system.

IMPROVEMENTS

Reviewer 25040

Comment: No comment.

PI Response:
N/A

Reviewer 25423

Comment: My recommendations for improvements have already been covered in Scientific/Technical Approach assessment and Weaknesses sections.

PI Response:
N/A

Reviewer 25419

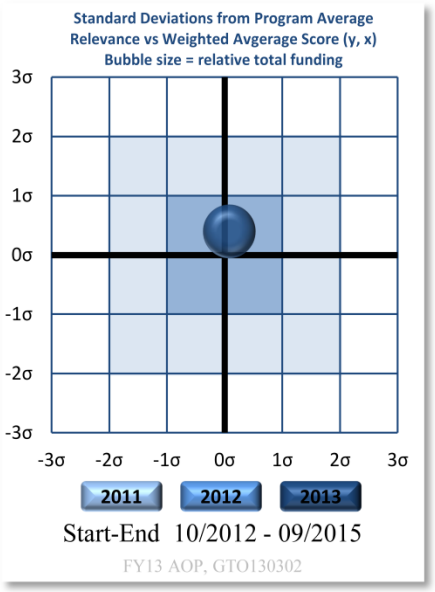
Comment: Develop better sampling devices/techniques to ensure adequate sampling distribution.

PI Response:
N/A

Reviewer 23444

Comment: Developing a more thorough analyses of cause and effect on He isotope systematics would be useful. What other parameters, in addition to crustal thickness, volcanism, faults, upflow zones/fluids influence the signature obtained? Is crustal thickness relevant to application of He isotopes in geothermal systems? How does one discriminate which influence is most important? What predictions could one make to more rigorously test the outcomes obtained here? Are their other related fluid-rock signatures that could be combined with He work to improve its utility?

PI Response:
We also collected water and condensed steam samples and measured D/H and 18O/16O ratios to evaluate the extent of water-rock interaction and the possible contribution of magmatic "fluids' to the geothermal system. These data will be used in developing more integrated interpretations of our He isotope results.



Review: 2013 Geothermal Technologies Office Peer Review
ID: FY13 AOP
Project: The Viability of Sustainable, Self-Propping Shear Zones in Enhanced Geothermal Systems: Measurement of Reaction Rates at Elevated Temperatures
Principal Investigator: Carroll**,** Susan
Organization: Lawrence Livermore National Laboratory
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23552

Score: 7.0

Comment: The main objective of the project by Caroll and her team is to expand low- to moderate-temperature mineral-specific geochemical kinetic database relevant to EGS shear stimulation zones up to 300°C. The primary motivation comes from the need for sustained longer-term (30 year) permeability in deep hot rocks through reactivation of fractures. However, laboratory-based experimental data has shown that chemical reactions may fracture permeability in a dramatic fashion at temperatures well below EGS target temperatures. Such dramatic reductions in long-term fracture permeability clearly undermines the long-term heat transfer capabilities and undermines the economic feasibility of EGS. The chemical reactions and mineralogical processes operating in open fractures in EGS are only poorly understood and this project tries to address these issues by obtaining important new kinetic data for fracture relevant minerals at EGS temperatures necessary. There is no question that this kind of research is important and ultimately will not only impact EGS, but other natural and induced fracture permeability reservoirs. The laboratory-dervied kinetic data are essential input parameters for more accurate modeling and more realistic long-term risk assessment. However, measuring dissolution rates and deriving rate equations for fracture minerals will only help to better understand one aspect of the problem and require realistic testing and case studies to demonstrate the validity of the extrapolated and "simplistic" laboratory data.

PI Response:
The PI agrees with the reviewer and did propose to conduct fractured core experiments on from shearzone rock from current EGS demonstration projects to further constrain geochemical models used a specific EGS demonstrations. Together with GTO, we decided to focus on the fundamental rate data and conduct EGS specific calibration experiments using fractured core pending avialable budget. Currently there is no data for key fracture filling minerals proposed in our study.

Reviewer 23444

Score: 7.0

Comment: The primary objective of this research is to experimentally determine kinetic data for selected minerals found in EGS systems. The focus is on ‘shear zone minerals’ although these are also low temperature alteration phases found in many EGS (and other) systems. Such data could be used in kinetic models for reaction-path modeling of mineral-fluid equilibria to determine dissolution and preciptation rates for secondary minerals. Most rate data is measured at higher temperatures (due to slow reaction times) and then extrapolated to lower temperatures/pressures. Such a technique is

associated with large uncertainties. Potentially the data developed here could reduce risk of development and improve the longevity and sustainability of the EGS system by providing better constrained values with which to evaluate and model such systems.

PI Response:
Mineral phases selected for study span the appropriate temperature space in terms of their stability and were identified by previous XRD/SEM analysis as being key mineral phases in the shear zone. One possible exception might be smectite which was identified at EGS sites with lower temperture footprints.

Reviewer 25419

Score: 9.0

Comment: The work provides basic data/understanding necessary to understand closer rates of fractures created during EGS development.

PI Response:
We agree.

Reviewer 25423

Score: 8.0

Comment: This project can have direct impact on development of geothermal resources by providing kinetic information on common fracture-filling minerals. Sharing the data with the national database will help disseminate the information to other interested parties.

PI Response:
We agree.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23552

Score: 3.0

Comment: The scientific and technical approach is subdivided into to main categories: (1) measurement of dissolution rates for fracture minerals up to 300°C and (2) Development of rate equations for mineral dissolution. The primary objective is to constrain the dissolution rates for biotite, chlorite, illite, plagioclase and smectite as a function of pH and temperature ranging from 100 to 300°C in mixed flow reactors. While this is certainly a valuable and very basic contribution, the project summary description is less than satisfactory. There is no discussion about fundamental aspects, such as the interaction between minerals, the role of dissolution vs precipitation or re-precipitation. There is no mention of fluid-rock interaction data or academic kinetic and thermodynamic databases, etc. The approach as described appears very simplistic! What is the natural basis for the minerals and mineral reactions chosen? Have the PIs looked at any core to show that the mineral chosen are the relevant minerals? Yes, geochemical alterations and their rate information are important parameters that enter into computational models, but where is the mineralogically realistic and relevant or textural context. What about re-precipation or reaction armoring of minerals? Simple dissolution in a batch reactor is not hard, but more is needed to improve the situation. Is pH is the only rate controlling factor? What about grain size, O2

fucacity, etc. The team will incorporate the resulting mineral rate equations "directly into modeling efforts to fully assess the impacts of geochemical alteration on long-term fracture permeability for EGS" .... without any further testing or mineralogical evidence!

PI Response:
I apologise for not fully providing this reviewer with enough background information. I have about 30 years of expertise conducting rock-water experiment designed to constrain reactive-transport models for radioactive waste disposal, contaminant transport, geologic carbon storage, and geothermal systems. I fully understand the complexity and the difficulties surrounding rock-water interactions. I also fully understand how modelers employ rock-water interactions to assess impact. They rely on dissolution rate data that is tied to mineral solubility to assess the major impacts of chemistry. As this reviewer pointed out the relevance section – calibration experiments are needed to constrain the importance of dissolution/precipitation, mineral coatings, etc. Together with GTO, we decided to focus on the fundamental rate data and conduct EGS specific calibration experiments using fractured core pending avialable budget. Currently there is no data for key fracture filling minerals proposed in our study.

Reviewer 23444

Score: 6.0

Comment: The approach is to use standard and well-established experimental techniques for measuring dissolution rates in fluids as a function of pH and temperature. Appropriate characterization of the silicates, prior to and after reaction, allow for maximum utility of the data. Information on the composition of the various solid solution minerals was not given and these data are critical to determining the activity-composition relationships and reaction rates. Plagioclase is a complicated mineral phase - potentially with numerous exsolution features, microporosity, and intergrowths that could significantly alter the reaction rate; yet these features do not appear to be taken into account. Such features could produce uncertainties on the same order as those derived from extrapolation. Characterization of materials was not described in the materials presented but was addressed, somewhat, during the questions. Parameters needed for the rate equations are measured by standard techniques - although large errors exist in surface area measurements. Data resulting from experiments will be combined with measured mineral data to develop a rate equation. The approach appears to be well executed although in the early stages. No integration with previous work on rate equations has been done or appears to be planned, it should be. It is also unclear that a complete literature search was completed prior to this work, there are few to no references to previous solubility work on these minerals (e.g. Oelkers, etc.) There is no uncertainty quantification presented which should be done. There are potentially large errors associated with several aspects of this data i.e. surface area measurements as well as errors from temperature, pressure, fluid and mineral composition etc. Smectite is not stable at 300C – it is unclear why these conditions are being selected for measurement. It is well known that laboratory measured rates do not match field rates, and that these rates are typically different by orders of magnitude (e.g. see Brantley's work). No discussion of this is presented – although this is on the order of magnitude as the likely differences suggested from high to low T extrapolation.

PI Response:
I apologise for not fully providing this reviewer with enough background information. The reviewer provides many comments that will help the final product and that we will adopt. These include:

- Appropriate characterization of silicates before and after reaction. This a standard part of our experimental protocol, although not stated in the backgroune information.
- Develop and discuss limitation of the rate equations as they apply to various compositional and textural characteristics of a given mineral system. We routinely employ high-resolution TEM to evaluate the phases before and after reaction. The solution chemistry is a most effective tracer of secondary reactions that can not be evaluated even with state of the art imaging techniques.

- Although high uncertainty in mineral surface area continue to plaque the geochemical community, I note that different labs have yield similar rate data using BET, meaning that rates measured against BET can be collectively pooled intro reactive transport simulators. Use of Monte Carlo techniques would allow the uncertainty in the available surface area to be assessed when measured against calibration experiments (which we would really like to do) and field data. We employed this technique in our recent publication in ES&T (Carroll SA, McNab WW, Dai Z, Torres SC (2013) Reactivity of Mount Simon Sandstone and the Eau Claire Shale under CO_2 storage conditions. Environmental Science & Technology 47(1):252)., as was pointed out by review 25419 below.
- We will integrate previous data, as we did in Smith et al (2013) to derive comprehensive rate equations.
- We conducted literature search as part of our previous GTO project and did not include it as a specific task for this project.
- Smectite in fracture filling minerals may see high T fluids as they travel back to the surface.

Yes, there are large differences between laboratory and field experiments. This is one reason we feel that calibration experiments using rock core from EGS sites are needed.

Reviewer 25419

Score: 8.0

Comment: The technical approach is sound and reproducible. The project is expensive given the work being done.

PI Response:
We are porposing to close the kinetic data gap for geothermal EGS within in three years. This is a significant effort. The budget in the review included conducting the calibration experiments. If we do only the kinetic experiments the budget would be 25% less.

Reviewer 25423

Score: 8.0

Comment: The project is well executed for the data obtained to date. The PI recognizes the importance of mineral composition and reactive surface area to kinetic studies. There's really nothing I can add regarding the scientific/technical approach, the PI is well versed in this kind of study and her postdoc is very competent. My next comment addresses an issue that is beyond the scope of the funded project: from the perspective of broader impacts, it would be good for this data to be employed in an analysis similar to the PI's recent publication in ES&T (Carroll SA, McNab WW, Dai Z, Torres SC (2013) Reactivity of Mount Simon Sandstone and the Eau Claire Shale under CO_2 storage conditions. Environmental Science & Technology 47(1):252). I hope the PI has plans for an analysis along these lines, to be performed after this project concludes. Also, I would have liked to see an effort towards addressing the "Viability of Sustainable, Self-Propping Shear Zones in Enhanced Geothermal Systems", as the title implies. However, the PI is performing the proposed work as funded. Thus my desire is directed more towards "next steps" that are beyond the scope of this project.

PI Response:
Thank you. Again we would be all to happy to conduct calibartion experiments and quantify the chemical variability so that more accurate assessments of geochemical impacts could be made for a given EGS site.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23552

Score: 5.0

Comment: This relatively new project is still in the initial phases of the project, but has already conducted 13 new experiments that have mainly dealt with chlorite dissolution between ~100 to 300°C and a pH range of 3 to 10.In there initial results chlorite rates appears to show show classic dependence on pH. The results are intriguing and I look forward to seeing more in the future and hopefully also more realistic approach.

PI Response:
Again we would be all to happy to conduct calibartion experiments and quantify the chemical variability so that more accurate assessments of geochemical impacts could be made for a given EGS site. We are currently not funded to do this. Kinetic data are necessary first step.

Reviewer 23444

Score: 6.0

Comment: Conducting experiments can be fraught with unexpected problems but these appear to be minimal in this work. The project is in its early stages. New data appears to be chlorite dissolution data measured in CO_2 and a CO_2-brine mixture (but this appears to be related to another project?). Although one milestone was marked as complete - biotite dissolution (written materials), no data was presented. The quality of the data produced to date appears good but no modeling had been completed to date to evaluate the data. Productivity is difficult to access. Although two papers have been published on chlorite dissolution, those must have been related to another project because this work is only a few months old. Therefore the productivity of this project is questionable. This is a very expensive project to determine these data, with few new results, to date.

PI Response:
We did not show all data collected with the presentation because the presentation was required two months before the review and because there is a substantial delay to have the solutions analyzed (however the quality of the data are worth wait). As the reviewer noted one does run into unexpected delays. One included that neutral to alkaline solutions required longer reaction times and required a good number of the experiments to be repeated. We did not bring this up at the review because it was resolved internally.

Reviewer 25419

Score: 8.0

Comment: The project has just begun so assessment of this metric is not necessarily valid. The project appears to be on schedule and budget

PI Response:
Thanks

Reviewer 25423

Score: 9.0

Comment: The PI has made excellent progress with respect to stated objectives and goals. It's difficult to say any more; the PI has clearly identified progress and upcoming dates very clearly in her powerpoints and the current state of the project and where it is going is very obvious.

PI Response:
Thanks

PROJECT MANAGEMENT/COORDINATION

Reviewer 23552

Score: 7.0

Comment: This is a relatively new project and the project management/coordination appears on track so far. The number of experiments conducted so far appears to suggest a well coordinate program.

PI Response:
Thanks

Reviewer 23444

Score: 9.0

Comment: The technical staff is sufficient to complete the project and appears to be on time and well coordinated.

PI Response:
Thanks

Reviewer 25419

Score: 8.0

Comment: Again this cannot be properly evaluated do to the recent start of the project,

PI Response:

Reviewer 25423

Score: 10.0

Comment: The project is well managed. The PI is to be commended for adherence to schedules, milestones, and general execution of project as written.

PI Response:
Thanks

STRENGTHS

Reviewer 23552

Comment: Collection of basic data.

PI Response:
Thanks

Reviewer 23444

Comment: The PI has expertise in experimentally determined rate equations. The research is focused, and there is ample time to complete the necessary experiments. Potentially useful data will result from the project that can be integrated into the various reaction path modeling programs currently available.

PI Response:
Thanks

Reviewer 25419

Comment: Basic research that enhances understanding of geochemical processes that will effect EGS reservoir maintenance.

PI Response:
Thanks

Reviewer 25423

Comment: The strengths of the project include the following: 1) Use of existing facilities, equipment, personnel, and expertise to perform the work. In other words, the PI and her staff are good at what they do and have the equipment to do it. With this project they are using the equipment and personnel to perform valuable work. 2) Presentation was very professional. Susan did an excellent job.

PI Response:
Thanks

WEAKNESSES

Reviewer 23552

Comment: Despite the valuable data to be collected, the approach seems very simplistic and is ultimately in need of real mineralogical benchmarking in cores. See other comments above.

PI Response:
The PI agrees with the reviewer and did propose to conduct fractured core experiments on core from current EGS demonstration projects to further constrain geochemical models used a specific EGS demonstrations. Together with GTO, we decided to focus on the fundamental rate data and conduct EGS specific calibration experiments using fractured core pending avialable budget. Currently there is no data for key fracture filling minerals proposed in our study.

Reviewer 23444

Comment: A thorough review of the literature needs to be completed and data derived from this project needs to be compared and integrated with previous data. Discussion of errors associated with the data and uncertainty quantification needs to be completed. Dissolution rates vary dramatically with microstructural aspects of minerals such that the variability in mineral structures may overwhelm the PT effects. The magnitude of the change in dissolution rate should be discussed. It would be helpful to address what the differences in reaction rates mean in terms of the lifetime of an EGS system - they may be meaningless. When preparing presentations, all figures need to have figure captions that adequately explain the figures. Proofing should be done to minimize errors, e.g., missing minus signs on rate values. The project is expensive for the type of data to be produced. What is the actual impact of the project?

PI Response:
We will consider all comments from this reviewer as was discussed above as we move forward with the project. Calibration experiments are needed to begin to assess system variability and implications for EGS.

Reviewer 25419

Comment: Expensive considering any university could have completed this work.

PI Response:
We are proposing to fill the kinetic data gap for EGS at elevated temperture for fracture filling minerals. The advantage of doing this work at LLNL is that we have the relevant equipment and we are experts in the field. We also have access to range of sophisticated analytical and model tools, should we need them.

Reviewer 25423

Comment: None

PI Response:

IMPROVEMENTS

Reviewer 23552

Comment: Need for more realistic approach and comparison to natural examples. Incorporation of all available data. Consideration of dissolution and (re-) precipitation in a more holistic system.

PI Response:
The PI agrees with the reviewer and did propose to conduct fractured core experiments on core from current EGS demonstration projects to further constrain geochemical models used a specific EGS demonstrations. Together with GTO, we decided to focus on the fundamental rate data and conduct EGS specific calibration experiments using fractured core pending avialable budget. Currently there is no data for key fracture filling minerals proposed in our study.

Reviewer 23444

Comment: Error propagation must be completed and sources of uncertainties discussed. Previous work needs to be taken into account. In order to adequately compare dissolution rates from different studies, they need to be equivalent systems (Fig. 1 on summary) and that needs to be indicated. A discussion of using lab determined rates in field settings should be evaluated with respect to the difference in high/low T data. How to upscale these data to an EGS system and what it means in terms of the system's lifetime should be addressed.

PI Response:
We will consider all comments from this reviewer as was discussed above as we move forward with the project. Calibration experiments are needed to begin to assess system variability and implications for EGS.

Reviewer 25419

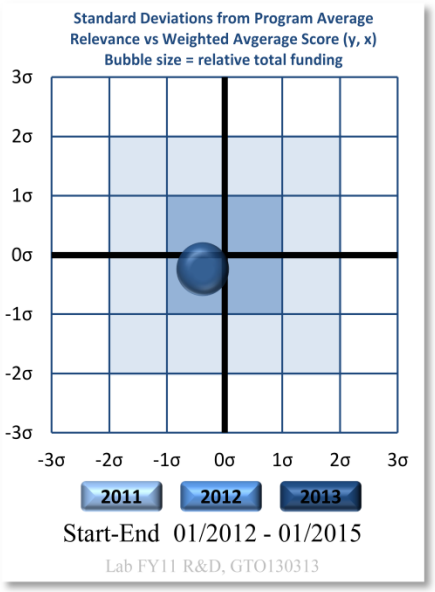
Comment: Consider awarding project to less expensive institution.

PI Response:
We are proposing to fill the kinetic data gap for EGS at elevated temperture for fracture filling minerals. The advantage of doing this work at LLNL is that we have the relevant equipment and we are experts in the field. We also have access to range of sophisticated analytical and model tools, should we need them.

Reviewer 25423

Comment: My recommendations for improvements have already been covered in the Scientific/Technical Approach section.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: Lab FY11 R&D
Project: Improved Geothermometry Through Multivariate Reaction Path Modeling and Evaluation of Geomicrobiological Influences on Geochemical Temperature Indicators
Principal Investigator: Cooper**,** Craig
Organization: Idaho National Laboratory
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 25423

Score: 7.0

Comment: This project can have a direct impact on the development of geothermal resources by providing a geothermometry modeling tool to assist exploration.

PI Response:

no comment

Reviewer 23444

Score: 9.0

Comment: The proposed objective of this research is to develop geothermometric techniques – a geothermal modeling tool (GMT) - that can predict reservoir temperatures to +/- 30C and make these commercially available to the industry. Such an accurate geothermometer would lower risk and cost of geothermal reservoir development and is in line with the programs mission. If such a GMT could be developed, it would be spectacular in that determining accurate temperatures is difficult. Typically minerals are the only method.

It is unclear how such a tool would accelerate development of undiscovered hydrothermal resources (a stated purpose) as it does not appear to be an exploration tool.

PI Response:
It is an exploration tool in that we can predict the hydrothermal reservoir temperature using our modeling tool. It is true that a water sample is needed that gives an expression of a hydrothermal resource and we need to know something about the geology of the hydrothermal resource (based on large scale geologic maps), but the resource itself can be 'undiscovered'. We expect the tool to answer the question that we often receive at the laboratory "I have a well with warm water, if I drill deeper will I get hotter water?"

The development and testing of the multivariable geothermometry inverse modeling tool and the associate microbial and laboratory activities will assist in assessing the temperature of deep geothermal systems that have not been evaluated using traditional drilling methods and the measurement of the bottom hole temperatures.

Reviewer 25419

Score: 7.0

Comment: In general, geothermometry is of relatively minor impact in geothermal exploration and field management; therefore, developing a new, more accurate geothermometer suggests minimal impact.
The incorporation of microbiology into geothermometer development is novel and may improve the technique.

PI Response:
Using Multivariable geothermometry, we should be able to get a more accurate assessment of a hydrothermal system prior to conducting an expensive drilling program. Such assessments should provide improved estimates of production enthalpy but could provide guidance to a drilling program.

Reviewer 25040

Score: 4.0

Comment: There is continued need to develop new and improved geothermometers for geothermal exploration, and the inverse simulation work addresses this need. However, the lab experiments and microbial activity tasks seem much less relevant and important to DOE's goals and the critical needs of the geothermal industry.

PI Response:
The laboratory experiments provide a methodology to test and validate the multivariate reaction path modeling tool. The microbial task examines another variable that could influence the observed chemistry of the water sample and will provide, at the very least, a screening tool to identify water samples that may have been impacted and may not be as useful for geothermometry.

The contradictory comments on impact of the laboratory by reviewers 25419 and 25040 as well as comments by other reviewers suggests to us that the proposed laboratory portion of the project is needed to help build consensus among the geothermal community on the limitations and accuracy of geothermometry approaches.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 25423

Score: 7.0

Comment: Moving forward, the PI is going to have the keep the project and the co-investigators on track if he's going to accomplish his objectives, especially with respect to the experiments. The PI will recall that several panel reviewers asked pointed questions about the experimental protocols and plans as well as the geochemical modeling. An experimental matrix was provided by the PI to two panel reviewers, who in turn shared the matrix with the rest of the panel. I have several suggestions with respect to the experimental program; my suggestions are provided in the Improvements section.

PI Response:
We will examine the Improvement section, thank you.

Reviewer 23444

Score: 5.0

Comment: The approach utilized here is to combine a commercial reaction-path modeling program (Geochemists Workbench (TR), GWB) with an inversion optimization approach (PEST) to develop the GMT. This method is complemented by fluid-rock experiments at appropriate conditions to compare those results with the results from the modeling approach at conditions relevant for two geothermal areas. The effect of S cycling on geochemistry will be assessed by genetic probes for S microbes and their impact on geochemistry evaluated.

While the goal is to develop a GMT from user input solution chemistry and assumed mineral assemblages, many factors - in addition to temperature – affect fluid chemistry and the resultant calculated T. The mineralogy of the samples, the approach to equilibrium, other cations/anions in the fluid phase, etc. all influence the fluid chemistry. If the mineralogy of the samples is unknown or the mineral chemistry of the samples is assumed and solid-solution components are not specifically identified, the resultant T could be off by more than 30C. Solid solution in minerals and their equilibrium fluid compositions can dramatically impact the T, or vice versa. The approach suggested to determine a GMT seems to be a bit naïve or at minimum lacking in an understanding of the thermodynamics of the system. The underlying feature of the GWB is the thermodynamic database(s) utilized in all of the calculations. GWB is only as good as the thermodynamic data. Most of these values have substantial uncertainties (especially in H-enthalpy and G-free energy). In addition, one needs to consider the activity – compositions relationships that are to be used for minerals and fluids, their validity for the PTX (where X = composition) conditions of the system, and the speciation models for fluids. These complexities were not addressed in the presentation or the materials supplied. There are known problems with GWB with respect to speciation of Al and Mg at low T-P conditions that lead to erroneous mineral assemblages and likely fluid compositions. How are these to be assessed? It is unlikely that any of the thermodynamic data is known to within 30C.

While one can solve for the solution saturation state with respect to the minerals (if they are known) and PEST varies T to react the optimal solution, it is unclear what this numerical solution will record. It seems like there will be a precise answer, the accuracy of which is unknown.

There has been no rigorous uncertainty analysis (error propagation) that is needed prior to verifying that calculated T's are within 30C. The errors cited in the presentation, i.e. 1-4C, do not take into account the other sources of uncertainty in the system.

Little information was presented on the experimental approach making it difficult to evaluate. However, it appeared appropriate. Three geothermal fields are to be evaluated. It is unclear how the accuracy of the new technique will be assessed.

Genetic sequencing was in line with protocols for that system.

PI Response:
The successful application of any geothermometer to a given geologic setting is based on the assumption that the water sample had achieved equilibrium with an assemblage of minerals at reservoir temperatures and that any changes to the water composition between its leaving the reservoir and its sampling location can be accounted for. The accuracy of the approach taken in this study (as in all geothermometry) relies upon the suitability and the accuracy of the thermodynamic data used in the inverse modeling calculations as well as the quality (e.g., accuracy) of the water chemistry data used. As the reviewer identifies, uncertainties in the thermodynamic data as well as the lack of explicit accounting for solid solutions can contribute to uncertainty the inverse method. While we recognize these limitations, our goal is to develop a generalized, improved methodology for geothermometry. We do not plan to alter thermodynamic databases nor delve into

the intricacies of solid solution theory for which there is often a lack consensus (as well as data) in the geochemical community. Nonetheless, the approach we are taking readily accepts new thermodynamic data as it comes available and could, in principle, incorporated aspects of solid solution theory. In addition, the approach allows us to check the saturation states of other minerals (those not included in the optimization) thereby aiding us in proposing alternative hypotheses for mineral controls. The GWB model is fully capable of predicting the equilibrium with mineral assemblages at a given PT condition from water composition. Uncertainties in computed equilibrium conditions are not an inherent problem with GWB but with (as the reviewer notes) uncertainties in the thermodynamic data as well as in the compositional analysis of the water and limitations in the activity coefficient models employed. GWB allows for the selection of several databases and allows users to modify the thermodynamic data. We certainly agree that the uncertainties the reviewer discussed can result in erroneous estimates of reservoir temperatures. An approach being used and tested in the project is to identify from a review of the literature of geothermal/hydrothermal field locations reoccurring sets of alteration mineral assemblages common to geothermal systems. The inverse modeling will be conducted using several of the identified assemblages allowing the comparison among predicted temperatures and providing an assessment of the robustness of the approach.

The examples presented at the review meeting were manual simulations based on synthetic data sets and were intended to illustrate the approach. The reported errors largely represent the error associated with the manual numerical approach; the full optimization approach results in much smaller errors. By coupling PEST to GWB, the developing GMT includes uncertainty estimates for temperature of an individual water sample and mineral assemblage. However, these errors should not be considered as the overall uncertainty of the approach. Testing literature reported water data from known geothermal field against multiple mineral assemblages (as describe above) will provide additional insight into the uncertainty in the temperature measurements.

Reviewer 25419

Score: 7.0

Comment: Mixing with ground and/or surface waters with geothermal fluids does not appear to be explicitly addressed in study. The lab studies/experiments are technically sound. The use/applicability of certain software (i.e., Geochemists workbench) to do the analysis is debatable and other software may be better.

PI Response:
Mixing is included in the PEST inversion as a dilution mechanism. At this time, we are assuming that the geothermal water is of a much higher TDS that the water it mixes with such that we can assume that the mixing water has no dissolved minerals. The approach is sufficiently general that dilution can be accomplished using water of a specified composition.

At the start of the project, it was decided that GWB would be used. The program has many features that make worthy of consideration. The approach that we are developing can certainly be adapted to other programs that have simple If the results using GWB are successful, the modeling approach can be easily be applied to another geothermal model.

Reviewer 25040

Score: 4.0

Comment: There is value in the project's attempt to reduce uncertainty in temperature estimates using their inverse simulation approach. This approach depends on the ability to adequately predict rock-water interactions at temperature and simulate changes in solution composition owing to mixing, cooling, volatile loss, etc. This ability has been tested and largely proven in a huge number of laboratory and modeling studies in recent years. The established use of

geothermometry in geothermal exploration and to monitor reservoir performance also demonstrates that we have this capability, although improvements can be achieved. Thus, I do not understand why it is asserted that lab experiments are required to "determine the relative importance of …minerals to define solution composition" and to determine the influence of various processes on water composition. This element of the project does not fill a gap in the geothermal knowledge base.

It is asserted that sulfur microbial activity could impact geothermometer predictions (e.g. major element fluid chemistry) and significant effort (and cost?) seems to have been expended towards the development of a sulfate-reduction gene assay without first having demonstrated the potential magnitude of such microbial activity. Would sulfur oxidation affect silica solubility and the silica geothermometer, or the Na-K geothermometer? How much could it impact inverse modeling? The project used Geochemist's Workbench software for its inverse modeling, and GWB has a module for sulfur microbial activity that might have been exploited. The consequences of sulfate reduction on geothermometer predictions should have quantified before beginning the assay work.

PI Response:
As a first step in assessing the potential implications of microbial activity on geothermometry, we developed and tested a quantitative assay for genes specific to sulfate reducing bacteria and archaea. We applied it to water samples collected from a "blind" geothermal system in southeastern Idaho and obtained evidence indicating that these samples did indeed harbor sulfate reducing microorganisms. In particular, samples from a very S rich site (Sulfur Springs) exhibited both high biomass and high concentrations of sulfate reducing genes. These results indicate that this is an environment conducive to sulfur metabolizing activity, and thus microorganisms may play an important role in mediating water chemistry at this site. The inverse modeling calculations for geothermometry could not resolve a temperature solution without including sulfide in the geochemical calculations at levels $\geq$ 5 mM, and the resulting temperature prediction for Sulfur Springs (81 ℃) was significantly lower than predictions using the chalcedony (93 ℃) and quartz (121 ℃) geothermometers. These observations provide preliminary evidence suggesting that microbial sulfur metabolism may influence geothermometry predictions in the Soda Springs system, and indicate that further investigation is merited. Future work will include the development of quantitative assays for other functional genes involved in sulfur cycling, and application of the assays in laboratory and/or field studies of microbial sulfur transformation and impacts on geothermometric predictions.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 25423

Score: 7.0

Comment: From the presentation it looks as if the project is on schedule and on task, as presented in slides 13 and 14. Looking past the checklist of milestones, the project has made modest progress to date. Much has been accomplished in the geochemical modeling, little in the experiments (which are the most time consuming part). Part of the problem is probably due to delays in getting funding in place for the large number of teamed institutions, or even getting the project kicked off to start. Another part of the problem is the National Lab bureaucracy; an ever present problem outside the control of the PI. Finally, the switch in project management did not help things. The PI's team needs to stay focused and on task this next 1-2 years. They will have to be diligent in their efforts, given the limited time that is available, and critically assess the need for their various project elements, especially experiments as discussed below. But if the PI keeps his team on course the project has a high probability of success.

PI Response:
Agree. Point taken

Reviewer 23444

Score: 8.0

Comment: From the materials provided, the project is in its initial stages. The combined methodology/approach has been developed and prototyped by a few specific idealized cases with results presented at the Stanford Geothermal conference and at an AGU meeting. The assertion that multicomponent geothermometry has been demonstrated needs more rigorous testing and benchmarking.

Experiments have commenced to determine the role of the primary and secondary minerals in controlling equilibrium of the geothermal fluid. Secondary minerals are a result of fluids interacting with primary minerals, so this portion of the research is a bit unclear.

Microbial genetic markers have been determined, although it is unclear why this was done prior to analyzing the likelihood of these microbes occurring in the system's analyzed.

Results to date are in line with the modified plan.

PI Response:
The markers developed identify the presence and abundance of the the microbes giving us indicators for potential activity. Our project goal was to develop assays that could be used time and again for geothermometry predictions. Use of a 16S ribosomal DNA library could have been constructed to identify the presence of many of total microorganisms present in this specific system, however depending on several the biases of the library and PCR it may or may not have identified the sulfur reducers/oxidizers. Likewise sulfur redox gene-specific libraries could have been generated to identify the presence of sulfur cycling microorganisms but this approach would have provided data limited to the Soda Springs system and would not have been nearly as effective at demonstrating potential activity as does the quantitative PCR approach that we took. These alternative approaches would have been expensive and due to budget constraints we determined from project initiation to use the more direct approach to develop the apply qPCR assays that quantify sulfur metabolizing microorganisms.

Reviewer 25419

Score: 7.0

Comment: The project is on schedule but over budget given the value of work completed to date.
Given the remaining budget and workload, the goals should be able to be met.

PI Response:
no comment

Reviewer 25040

Score: 5.0

Comment: Good progress was made on the inverse modeling, and a sulfate-reduction gene assay was developed. Two papers were presented at the 2013 Stanford conference which is highly commendable.

The Stanford paper on the INL multicomponent equilibrium models revealed what seemed to be inconsistencies. For example, the researchers cite Bethke's (2008) input of 3 molal Cl, but it is obvious that this was a typographical error and should have been 0.3 molal. Table 2 in their Stanford paper suggests that they actually used 0.3 molal, but 3 molal was still cited in the text. Also, from their prediction of about 210 ppm SiO2 (Table 2) it appears that they allowed dissolved silica to re-equilibrate during cooling, unless 210 ppm actually refers to Si instead of SiO2? This data is then used to claim that the Fournier silica geothermometers do not work as well as inverse modeling, whereas the silica geothermometers are based on the assumption that major element chemistry is preserved as the fluid ascends to the surface (e.g. no precipitation). More care should be taken in future publications because errors/inconsistencies/misprints such as these make the validity of the work suspect.

PI Response:
We resolved the Si issue about a week after the Stanford conference and addressed the issue in a revised paper. The problem was related to the activity coefficient model used in the calculations. Correcting for this, one obtains much improved estimates from the Fournier silica geothermometers but still not as close as the value obtained in the optimization. We suspect that the primary reason is the inconsistency of the thermodynamic data used in the database versus that used by Fournier. With regard to the reported concentrations, we will certainly attempt to be better in the future. We plan on publishing in a peer reviewed journal correct these issues prior to publication.

PROJECT MANAGEMENT/COORDINATION

Reviewer 25423

Score: 8.0

Comment: The new PI was put in an awkward situation with the recent departure of the original project PI. I trust the DOE Program Manager will make suitable allowances.

PI Response:
No response

Reviewer 23444

Score: 7.0

Comment: Collaboration with other scientists working on similar projects is commendable.

With the original PI leaving the lab, it is questionable why the project continued to be funded or who is taking over as lead. The need for a geochemist that understands thermodynamic data as well as experimental approaches is critical to the success of this project.

PI Response:
We agree that a geochemist is critical to the project. The project has two geochemists on the team; Dr. Carl Palmer and Dr. Robert Smith, who will be directing the geochemistry work of the project.

Reviewer 25419

Score: 6.0

Comment: The project performers did not anticipate issues with software incompatibility, which was shortsighted. The Project documentation indicates that this is a new area of research for the performers, which suggests that GTO is paying, in part, for line-of-business development with FOA dollars.

PI Response:
The term "software incompatibility" is misleading. Combining the existing compiled version of GWB with the compiled version of PEST required developing some additional programs, creating templates, and transferring data between the applications. Some difficulties were encountered but the issues have been overcome and the suite of programs now work together and calculate for a given water chemistry what the temperature, CO_2 fugacity, and mass of water that needs to be added (or subtracted) for the water to have been equilibrated with a user-specified mineral assemblage. Issues were anticipated, they just took longer to resolve than we would have liked.

Reviewer 25040

Score: 4.0

Comment: INL must find qualified PI to lead the project now that original PI has left the project.

According to the presentation materials, the project is expected to be completed within the budget by 1/1/15. However 47% of the total project funding ($472k) has already been expended during the first 15 months on the inverse calculations and the development of a gene assay. Planned "future work" includes costly lab experiments that have not started, more assay techniques, completion of the inverse simulation task, and the study of data acquired from two geothermal sites, so there appears to be a major shortage of funds needed to complete the planned work.

PI Response:
The project was front loaded. The inverse model is complete. The laboratory experiments are underway at the University of Idaho with an excellent post-doc researcher. Review of the budget using Microsoft Project suggests that budget is tight but manageable.

STRENGTHS

Reviewer 25423

Comment: The strengths of the project include the following:

1) Collaborations with the local university,

2) Information is being presented in public forums with the papers at the Stanford Workshops

PI Response:
No response

Reviewer 23444

Comment: The potential approach will have widespread utility if uncertainties in the data can be quantified and an appropriate algorithm developed. The importance of determining temperatures in both EGS and "traditional" geothermal systems cannot be understated as temperature is a first order control on the viability of the system. Using a commercial software package, GWB, is both good and bad. It is readily available but expensive. Thermodynamic data in the program has variable quality, as do all databases. Incorporating biological activity into modeling programs potentially provides a more realistic assessment of the system.

PI Response:
We agree that GWB is expensive; however, it has many features that are useful geochemical calculations. The methodology can be extended to less expensive geochemical software but that is currently beyond our scope.

Reviewer 25419

Comment: The inclusion of geomicrobiology is a strength; however, the application may not be fully exploited (see weaknesses).

PI Response:
See Weaknesses Section for how it has been initially used to evaluate a system.

Reviewer 25040

Comment: Potential for improved temperature predictions through coupling GWB and PEST and advancing the concepts behind saturation index-temperature diagrams to include provisions for the impacts of volatile loss.

Coupling GWB and PEST allows for evaluating uncertainty in analytical data as well as uncertainty in thermodynamic data, which have not been investigated adequately to date.

PI Response:
No response.

WEAKNESSES

Reviewer 25423

Comment: The weaknesses of the project is that according to the Funding Opportunity Announcement for this Financial Assistance award, the recipient must provide data to the DOE Geothermal Data Repository (DOE-GDR). I did not see this aspect addressed, not in the presentation or in the associated documents. This needs to be addressed.

PI Response:
We will work with the DOE-GDR to ensure that all published papers/reports are submitted to the GDR.

Reviewer 23444

Comment: Determining an accurate temperature in fluid-rock systems requires that the system be as carefully characterized as possible. Calculated temperatures vary due to a variety of reasons including mineral chemistry, assumed equilibrium, and etc. Weaknesses include the lack of incorporating activity-composition relationships in determining mineral-fluid equilibrium, the lack of error propagation or an understanding of the sources of uncertainty in this approach, and the simplifying assumptions inherent in this approach. At the very least, if one is to assert that temperatures can be determined to +/- 30C, one must provide a rigorous error analyses of all system components. The stated errors are simply one part of the system. How is the accuracy and precision of this system going to be benchmarked? A precise geothermometer that is inaccurate is not advisable.

This project is quite expensive for combining two commercial packages. Additional comments are included in the previous section on scientific approach.

PI Response:
I believe we addressed this comment in our response to your comment in the Scientific/Technical Approach

Reviewer 25419

Comment: Geothermometer development is of minimal impact.

Mixing of surface and/or groundwater with geothermal fluids does not appear to be considered.

This is basic research being done largely by a national lab, with an aim towards business development.

The use/applicability of certain software (i.e., Geochemists workbench) to do the analysis is debatable and other software may be better.

PI Response:
We believe that geothermometry can play an important role in resource develop as do several of the other reviewers. Mixing is included as discussed previously. We have partnered with a university which is doing the experimental work. We will continue to use GWB for the time being. The inversion approach can be fairly straight forward applied to other geochemical software packages.

Reviewer 25040

Comment: Resources were spent on gene assays prior to completion of a preliminary assessment of the potential impact of microbes.

Microbe work is limited to magmatic systems.

Some questionable geochemical data and results were presented in Stanford paper on multicomponent geochemical models.

PI Response:
As a first step in assessing the potential implications of microbial activity on geothermometry, we developed and tested a quantitative assay for genes specific to sulfate reducing bacteria and archaea. We applied it to water samples collected

from a "blind" geothermal system in southeastern Idaho and obtained evidence indicating that these samples did indeed harbor sulfate reducing microorganisms. In particular, samples from a very S rich site (Sulfur Springs) exhibited both high biomass and high concentrations of sulfate reducing genes. These results indicate that this is an environment conducive to sulfur metabolizing activity, and thus microorganisms may play an important role in mediating water chemistry at this site. The inverse modeling calculations for geothermometry could not resolve a temperature solution without including sulfide in the geochemical calculations at levels ≥ 5 mM, and the resulting temperature prediction for Sulfur Springs (81 ℃) was significantly lower than predictions using the chalcedony (93 ℃) and quartz (121 ℃) geothermometers. These observations provide preliminary evidence suggesting that microbial sulfur metabolism may influence geothermometry predictions in the Soda Springs system, and indicate that further investigation is merited. Future work will include the development of quantitative assays for other functional genes involved in sulfur cycling, and application of the assays in laboratory and/or field studies of microbial sulfur transformation and impacts on geothermometric predictions.

Microbe comment, the upper limit of microbial activities are at temperatures of ~<120C. Regardless of the source of the microbes (underlying rocks or mixing with surface waters) they can metabolically change water chemistry.

The "questionable" data and results issue has been previously addressed. The issue has been resolved. Nonetheless, the multicomponent approach with more up-to-date thermodynamic data used in this project appears to provide better estimates than the Fournier quartz geothermometer.

IMPROVEMENTS

Reviewer 25423
Comment: I realize that it is difficult to publish in the National Lab environment, but these data must find their way into the refereed scientific record. One strategy is to present at the Stanford Geothermal Workshop, or similar venue, and use the conference paper as a draft for a journal article.

Recommendations for the experimental program:
1) Clearly define and elucidate a conceptual model for what the experiments are to accomplish. The PI did not do this in his presentation, and was not able to successfully address this in the Q&A. The Project Summary does a better job of this. It's my understanding that other project documents exist that contain even more detail. Finally, a conceptual model is nicely provided in the Stanford Workshop paper (Cooper et al., 2013). As the project moves forward, a conceptual model needs to be front/center and ever present in the PI's thinking. The experiments must be mapped to this conceptual model. The conceptual model needs to be the metric against which all experiments are evaluated, modified, or even removed from the program.

2) Is the full suite of experiments needed and necessary? Also, during the panel review, questions arose as to whether all of the proposed experiments were needed. The PI and project team should evaluate their experimental matrix in light of progress, goals and achievements to verify that all experiments are in fact needed.

3) The experimental matrix lists duration of experiments as 128 days. Hopefully the project documents that were unavailable to the review panel explain why this duration is needed. More importantly, the experimental plans hopefully provide alternate criteria for deciding when an experiment is to be terminated. For example, achieving steady state concentrations of specific inorganic parameters may be more important than running for 128 days.

4) The stated purpose of the lab experiments is to validate the numerical simulations and GMT. The project should also conduct a literature search to see if other experimental data is available, or if field data is available, to provide additional validation.

PI Response:
1) We agree that we need to publish in peer review journals
2) We can review the experimental portion of the project.
3) Samples are to be taken during the testing to evaluate if equilibrium has been reached. The 128 days was based on previous work by the investigators and is only used to help assist the project scheduling.
4) A literature search is currently underway evaluating the mineral assemblages and water chemistry.

Reviewer 23444

Comment: There has been no estimation of errors or rigorous error analysis (error propagation) that is needed prior to verifying that these T's are within 30C. At a minimum, uncertainly quantification must be done for all portions of the system and an understanding of the underlying thermodynamic data used to calculate these temperatures must be completed.

Benchmarking the temperatures determined by an independent technique would add validity to the approach proposed here.

PI Response:
We have discussed how to proceed with error propagation and have conducted a test to demonstrate the uncertainty generated by typical analytical error (Cooper et al., 2013). We will conduct similar tests to demonstrate the impact of uncertainty in the thermodynamic data.

Reviewer 25419

Comment: Consider the effects/impacts of surface and ground, and geothermal fluid mixing on results.

Quantify and include sampling, analytical, and mixing error.

PI Response:
See previous comments about how mixing has been incorporated.

Reviewer 25040

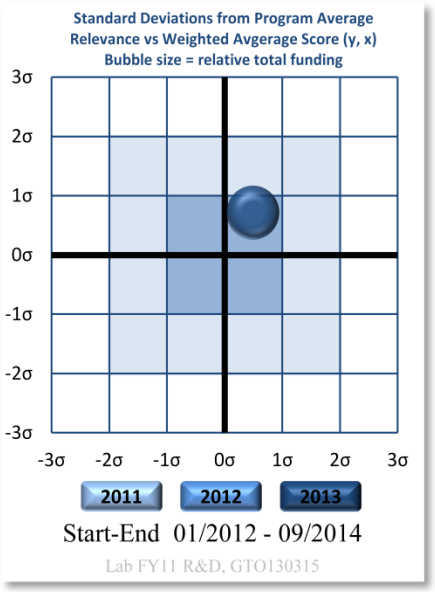
Comment: DOE should review the necessity of planned lab experimental program.

Development of additional microbial assay techniques should be delayed until evidence of the importance of sulfate-reducing microbes in natural systems to geothermometers has been demonstrated.

PI Response:
Laboratory experiments at reservoir-relevant temperatures and pressures are being conducted to provide "surrogate" water samples that have well characterized initial conditions (e.g., temperature, pressure, water composition, etc.) and have been subjected to defined physical (boiling, cooling, fluid mixing, etc.) processes. These "surrogate" samples will be used to test the accuracy and robustness of predictions of reservoir temperature and conditions using the inverse multivariate reaction-path geothermometry approach. The specific objectives of these experiments are to;

- Assess the relative importance of primary and/or secondary (alteration) mineralogy in defining equilibrium solution composition at elevated temperatures and pressures.
- Determine the influence of different cooling mechanisms (e.g., equilibrium isenthalpic phase separation vs. conductive cooling and steam flashing), volatile loss, and fluid mixing histories on final water composition.
- Evaluate the limitations of laboratory experiments for approximating field geochemical conditions during the development of enhanced geothermal systems.

Microbial assay are being developed to assess the potential magnitude of microbial activity and if this microbial activity can explain the discrepancies in the geothermometry predictions of different minerals such as those observed at Soda Springs.



Review: 2013 Geothermal Technologies Office Peer Review
ID: Lab FY11 R&D
Project: Stochastic Joint Inversion for Integrated Data Interpretation in Geothermal Exploration
Principal Investigator: Mellors, Robert
Organization: Lawrence Livermore National Laboratory
Panel: Geophysics; Geochemistry

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23417

Score: 6.0

Comment: This project is relevant to geothermal exploration and the discovery of new geothermal systems because it is one of the few research projects that recognizes the need to incorporate all datasets available during exploration and not just geophysics. However, it was also recognized in the Project Summary that fluid flow and temperature are almost always only known following some type of drilling, which may lessen the value of the research since subsurface data will have been collected. As a consequence this research may be more applicable to early phase development projects rather than exploration.

PI Response:
Yes, the project is expected to applicable to early phase development as well.We would consider thermal gradient wells and slim hole exploration wells as part of the exploration phase and hence some sub-surface information would be available. The Superstition Mountain prospect used as an example is in the exploration phase and not early phase development. Jennejohn, [2009] considers exploration continuing until the first production well is drilled successfully. In many cases, analog or other regional information or data (nearby boreholes, etc.) may be available to support exploration activities; these, too, should be incorporated in analyses as much as they can.

Jennejohn, D. Research and development in geothermal exploration and drilling, 2009, GEA, 25 p.

Reviewer 23641

Score: 8.0

Comment: Relevant research to interpretation of geothermal prospects by identifying useful temperature and flow fields at depth.

PI Response:
N/A

Reviewer 23612

Score: 10.0

Comment: This is a critically important project with an approach that stands to have significant impact on exploration, prospect evaluation, and well targeting. The overall claim that the work can reduce exploration cost and time will likely bear out over time, but the clear near-term benefit is the prospect of robust uncertainty quantification. The geothermal community has chronically struggled to quantify drilling risk, with massive implications for drilling success rates and financing difficulties, for example. This is a model approach to breaking down some of these significant barriers to development.

While this isn't mentioned, the method holds the potential for testing sensitivity of results to different data types by "withholding" data and evaluating the impact on inverted models and probabilities. Such a method for quantifying exploration value added of specific techniques could improve efficiency and advance industry uptake of the most impactful methods, meeting the overall goals of cost and time reduction. The team has thought about this component and the value of information approach, which is great.

Is there a long-term vision of applying this methodology to field operations? Could microseismicity be added as a data type to move into the EGS realm? Adapting the approach to 4D for such applications could have exciting implications, and would also promote the importance of one of the goals of moving to reduced-order forward methods.

PI Response:
Yes, the methodology could certainly be broadened for use in field operations. We would like to do so, of course, but need to prove it first. In theory, microseismicity, as well as other types of data, such as geochemical information, could be added but we do not have immediate plans for that as we are keeping it at the exploration stage now.Sensitivity analysis, reduced order methods, and value of information are on our list of methods to try.

Reviewer 23450

Score: 9.0

Comment: The project is highly relevant to the exploration of blind or hidden geothermal prospects. Current geothermal development projects are largely leftovers from the exploration efforts over 30 years ago. A new exploration paradigm is needed to find large, high temperature resources. The integration of hydrologic flow modeling with various geophysical measurements is a powerful tool to test likely combinations that could occur to mimic the conditions measured.

PI Response:
N/A

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23417

Score: 7.0

Comment: The approach requires permeability and flow to be modeled prior to inversion. The example used, Superstition Mountain has a relatively simple structure. The flow regime can be simply interpreted using the NUFT. However most geothermal systems exhibit complex fracture dominated flow patterns not easily understood even at geothermal sites with numerous wells. I believe this type of modeling is useful but may be more valuable in development fields rather than at

the exploration stage. Unlike other natural resource industries, very little is known about a geothermal prospect prior to drilling. It would be almost impossible to describe temperature and fluid flow distribution prior to drilling.
It is also uncertain as to what is being modeled with the resistivity data and what will be modeled with MT data. Are these intended to be representations of fluid flow or boundaries to the geothermal system? Variations in resistivity data in geothermal environments reflect a number of widely differing subsurface characteristics

PI Response:
These points are well taken and are, in part, a basis for the original project concept. We agree that the task is challenging and especially when considering complex fracture-flow scenarios (NUFT can handle both porous and continuum-based fracture flow set ups). The purpose of the stochastic approach is to estimate a range of possible solutions constrained by as much (seemingly disparate or dicsonnected) data as possible. The idea is to gain a broad understanding of what might be possible rather than a detailed answer. Usually, explorationists have a conceptual idea of a prospect and this is intended as a way to check this concept. Nevertheless, if the approach works for early development this would be a welcome benefit. Ideally, the result will provide constraints on both fluid flow and boundaries but we recognize that variations in resistivity may be due to a wide range of causes. But adding additional constraints (e.g., types and forms of data, such as geochemical information or geostatistical representations of fracture permeability variations) to the inversion we hope to provide additional quantitaive constraints on the various characteristics.

Reviewer 23641

Score: 8.0

Comment: Technically rigorous approach.

PI Response:
N/A

Reviewer 23612

Score: 9.0

Comment: The approach is very logical and appropriately incremental. Initial focus on synthetic data and comparison of results to a pre-defined geologic model enables necessary tuning and confidence building. MCMC is a top-rate computational method and the broad expertise of the project team spanning inversion and key data types are a strong complement.

What challenges are envisioned when transitioning from synthetic to real data? How are these and their solutions being anticipated?

Some emphasis is placed on computational intensiveness. The time necessary for compiling data, creating initial prospect models, etc. is surely significantly more intensive than the ~10 hr inversion. Improving efficiency of numerical models is always attractive, but it's not clear how much of a priority this should be. Is the intent to develop and open-source and/or portable, semi-automated tool that others (industry?) could operate on desktop-class workstations? Is this even feasible given the amount of expert tailoring necessary to incorporate disparate data types? I agree with the authors that current compute time certainly "is not impractical" and would encourage the development of additional capabilities at the expense of more computing, given the value in reducing risk prior to expensive (and even more time intensive) drilling.

PI Response:
We have tested real data and anticipate no significant technical challenges other than a broader solution space. Yes, we would like to eventually have a tool that others can use but our focus now is on proving the usefulness. Yes, we agree that there is a belief underlying this approach that the investments in (and benefits from) compiling data into multiple conceptual models and executing subsequent MCMC analyses are more competetive than more direct drilling and/or limited types of existing exploration activities. The current work is, of course, proceeding at a measured pace, not only so that we can evaluate incremental performance, but also to consider how to best translate the concept into more practical arenas.

Reviewer 23450

Score: 7.0

Comment: The technical approach is sound and relies greatly on numerical methods and many realizations. The numerical intensity of the problem is likely the greatest technical challenge to develop better algorithms, numerical sifting, or methods to reduce. The use of hydrologic modeling to place constraints on the other geophysical measurements is sound.

PI Response:
A trade-off exists between the numerical needs and the range of possible unknowns tested. We are exploring the bounds of this trade-off. For example, despite the increasing costs accrued when adding complexity in the models or number of MCMC inversion stages, it still remains possible to use more intensive computational analyses, outside of the MCMC loops, once the MCMC process has narrowed the configuration space to a more reasonable or managable level.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23417

Score: 7.0

Comment: The project appears to have achieved many of its initial modeling goals. However, it is not possible to judge any of those achievements as there was no data presented. This is not the fault of the research team but serves to illustrate that, as research projects develop, reviewers have to trust that work done prior to the period of review (usually the past year) has been completed appropriately. This supports the value of a single review team for the life of the project.

PI Response:
Data, and a possible model, were presented for a real prospect at Superstition Mountain, CA. The time available prevented any more discussion or details of this information.

Reviewer 23641

Score: 8.0

Comment: Reasonable accomplishments with two of three technical milestones completed.

PI Response:

Reviewer 23612

Score: 9.0

Comment: Productivity is high, as demonstrated by the on-schedule status despite a late start due to funding delays. Is the forward MT code under development as part of this project, at LLNL, or independently? If the later, is progress on target to feed into this project or are there any concerns about timely availability?

PI Response:
We are adapting another forward MT code and therefore we do not have significant concerns in that area.

Reviewer 23450

Score: 6.0

Comment: The synthesis/inversion of a data set at Superstition Mtn. is interesting. Can this be replicated under different geologic and hydrologic conditions and provide improved exploration success? An improvement in exploration success rates and reduction in project costs is needed, and this project needs some direct evidence as a useful tool for exploration. Project is somewhat hampered by the numerical intensity of the stochastic inversion.

PI Response:
Testing the algorithm in other areas is a goal of the third year of the proposal and we are actively seeking areas. Currently, we are not hampered by the numerical intensity of the inversion.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23417

Score: 6.0

Comment: Although the project started late, a significant amount of work has been accomplished.

PI Response:

Reviewer 23641

Score: 8.0

Comment: Appears to be a well managed project.

PI Response:

Reviewer 23612

Score: 9.0

Comment: The LLNL-based team seems to collaborate very effectively, as demonstrated by the on-time, on-budget course. Coordination with the Navy GPO on an actual prospect potentially adds value to the effort. Does GPO have any plans to incorporate results from this project into their development plan? This would make for a superb near-term impact.

PI Response:
We are in contact with GPO but have not yeat reached the stage where results can be incorporated into development.

Reviewer 23450

Score: 5.0

Comment: Costs and scope seem appropriate.

PI Response:

STRENGTHS

Reviewer 23417

Comment: 1. Strong technical team. 2. A new approach to modeling geothermal systems that has not been tried before.

PI Response:

Reviewer 23641

Comment: Providing automated method to evaluate prospects and provide errors estimates; decrease evaluation time and reduce number of wells. Using MCMC inversion combined hydrothermal and geophysical forward modeling codes to constrain geothermal prospect. Flexible and robust; yields error estimate based on top 10% of acceptable models.

nversion tested with synthetic data set (temperature, resistivity) based on an actual prospect and reproduces original model. Initial tests with real data.

PI Response:

Reviewer 23612

Comment: The project is a first step in taking a rare stab at addressing exploration value of information, making it a crucial effort in GTO's portfolio. The team is top notch and collaborating especially effectively.

PI Response:

Reviewer 23450

Comment: Coupling of hydrologic flow modeling with temperature, heat flow, and MT data provides a rich data set to test the numerical methods.

The numerical testing of thousands of realizations and ranking with associated uncertainty provides a large amount of data for exploration probabilities.

PI Response:

WEAKNESSES

Reviewer 23417

Comment: 1. Needs significant amount of data to build initial models. This is rarely available in greenfield exploration projects.

2. Saturation to the surface is also rarely the case but it prompts a comment that the varied geologic and hydrologic settings of geothermal systems needs to be addressed. The simple fluid flow model shown in Figure 3 may be appropriate for Superstition Mountain but it is not typical of most geothermal systems.

3. Computational time seems to be a significant problem that needs to be addressed in some way.

PI Response:
We agree that the accuracy of any model will depend on the supporting data. Projects with less data will generally have less accuracy, but it may still represent an improved understanding of the prospect. One of the broader ideas in this project is to see how well disparate types of data (which may, in fact, be individually sparse) can be collectively combined and interpreted to gain insights and understanding about a prospect that would otherwise not be possible. Yes, currently we assume that fluid saturations extend to the surface – this was one of several choices made for computational simplicity in the early phases of the project. It is our intention to address more realistic saturation distributions once the MT inversions on real data are completed. We are keenly aware of the computational versus model complexity trade-offs that exist and are working to identify practical modeling and operational paradigms to address these issues (see other comments and responses).

Reviewer 23641

Comment: None identified.

PI Response:

Reviewer 23612

Comment: Nothing notable.

PI Response:

Reviewer 23450

Comment: Need another test case. Can't model the SP response of the mixing of fresh water and brine.

PI Response:
We have considered including SP but decided it was lower priority. We are considering other cases as well.

IMPROVEMENTS

Reviewer 23417

Comment: It would be valuable for this, and many other modeling projects, to have a set of geothermal reservoir settings so that the variability can be understood by modelers. The predominance of fracture flow needs to be recognized.

PI Response:
This is a good point. We are working on ways to address fracture permeability.

Reviewer 23641

Comment: None identified.

PI Response:

Reviewer 23612

Comment: Further exploration of the value of information approach is highly encouraged. If the work can continue to help define a pathway for validating contributions to meeting critical metrics, such as drilling success, it would be extremely valuable.

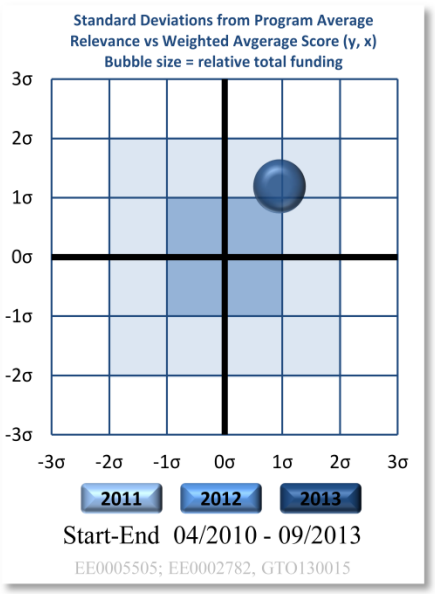
PI Response:
Yes, this is in our project plan.

Reviewer 23450

Comment: Integration of additional geophysical data sets may improve solution uniqueness and help constrain the realizations.

PI Response:
We agree.

High Temperature Tools and Drilling Systems Reviewer Comments and Principal Investigator Rebuttals



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005505; EE0002782
Project: Directional Measurement-While-Drilling System for Geothermal Applications; High Temperature 300°C Directional Drilling System
Principal Investigator: Schnitger, Jochen
Organization: Baker Hughes Oilfield Operation, Inc.
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23433

Score: 10.0

Comment: This is a very worthwhile project. Experience in the petroleum sector over the last few years has shown the importance of directional drilling, and the subject will only become more important as geophysical and other techniques get progressively more capable of locating targets of interest. The Geothermal Industry is bound to follow this direction, so the development of directional drilling and navigation tools is clearly of great importance. The decision to combine the MWD and Directional Drilling components into one project makes excellent sense. The projects are broken down into their important components. On the drilling side, this includes the development of drill bits and motor components not only for high temperature service, but also capable of standing the high levels of shock and vibration expected while drilling hard rocks. In both cases, the development of metallic components (notably metallic seals and bearing materials, and in the case of the motor, replacing the usual elastomeric motor stator by a metal one) is highlighted. The development of a suitable drilling mud is not forgotten. Concerning the MWD unit, the project is again divided into a set of complementary and important components (sensors, supporting electronics, power system and telemetry unit). All components are well described and areas requiring work are clearly identified. If the project is successful, it may be hoped that the project will deliver a complete Directional Drilling System, ready to go.

PI Response:

Reviewer 23454

Score: 8.0

Comment: There are several distinct questions involved in scoring this project. First, two separate tools are being developed and, although they are clearly being designed to work as a system, either could be used independently of the other. Second, even if both tools work perfectly and meet program goals, there is no estimate of how much impact that success will have on the geothermal industry. There is also little information on the gap between the goals for these tools and the state of existing technology. I have scored this as an 8, because both tools appear likely to meet Program goals, but this may have little relevance to their industry impact.

PI Response:

Reviewer 23527

Score: 9.0

Comment: This is a high value effort that should result in the production of otherwise unavailable drilling equipment that will be useful to the geothermal industry. It will hopefully address a number of critical issues that currently affect the transition of mature O&G technologies to high temperature environments. The market should be significant and key barriers look like they are being addressed. Cost-related aspects of the technology are difficult to evaluate at this point in time, but one cannot even reasonably do this if the needed technology does not currently exist. This project takes a significant step towards this end as directional drilling in geothermal is concerned.

PI Response:

Reviewer 23447

Score: 9.0

Comment: Drilling is the foundation of geothermal project success and 80% of geothermal project investment is spent on well drilling/completion. Often geothermal operators have to spend additional funds/time to reach their target due to harsh geothermal environment and still have to settle for less than ideal results due to limitations of current geothermal drilling systems. Successful completion of both projects (directional drilling system -DDS and directional measurement while drilling system –MWD) will produce a complete set of drilling tools to be used in harsh geothermal conditions, aligning with GTO's goals of up to 300 ℃ downhole temperature and 10km depth with 3 times the drilling penetration rate of current systems. This project advances previous work (200 ℃) so actual field use of these tools should be available in a relatively short timeframe. The components this project can provide include: drill bit, steerable motor, drilling fluid/equipment, telemetry device, power module, downhole electronics and navigation instrument.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23433

Score: 9.0

Comment: The technical approach is excellent. The entire project has been seen as a whole, with a view to delivering a complete system, ready to go. Thus, while the main emphasis is laid on the major work elements (drill bits, motor and electronics package), more peripheral concerns are not forgotten. These include, for example, the development of a suitable drilling mud. The contracting company (Baker-Hughes) has long and extensive experience in the development of drill bits, motors and directional drilling equipment, so one can have a high degree of confidence that a successful outcome will be achieved, if at all possible. The reviewer also notes that each sub-project has been given progress targets, with suitable go/no go decision points.

This is an ongoing project, for which much progress has been made, but for which some issues remain to be solved. These include hopes for further improvements in bit life, and the evaluation of the performance of the all-metallic motor at high temperature. More work is required on the MWD unit, since achieving 300C capability will either require increasing the thermal capability of the electronics package, or the provision of a better cooling system for the available 200C electronics. More work is required on seals. None of these issues appears insurmountable. The reviewer notes that there are no sub-contractors, and that all work is done in-house. This is generally a good approach from the point of view of keeping control over costs and times.

PI Response:

Reviewer 23454

Score: 9.0

Comment: Technical approach is excellent. Work has been well planned, research efforts have been in proper priority, and reasonable decisions have been made among alternatives. Equipment and staffing have been first-rate.

PI Response:

Reviewer 23527

Score: 9.0

Comment: The approach is methodical and well thought out. I reviewed this project last year and don't have anything new to add given that the plan is essentially unchanged, with the exception of schedule.

PI Response:

Reviewer 23447

Score: 9.0

Comment: The project approach is sound, thorough and logical. As an experienced geothermal drilling service company, the team paid great attention to details such as each of the components of the two systems and how to test their interaction along with identifying waste disposal of cuttings. In addition to scientific and technical concerns, environmental concerns appeared to be a high priority to the team.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23433

Score: 9.0

Comment: Progress so far has been excellent. Not only has the project been well divided in terms of the technical components (Bits, motor, mud, MWD components) but each technical component has been divided in terms of time, with periodic reviews and go/no go decision points. This is an ongoing project, with substantial progress reported so far. Further work will include : Fabrication and testing of drill bits, testing of the motor under high-temperature conditions, and further development of the MWD system. In the latter case, some significant issues remain, in particular as to whether an electronics package can be developed that will stand the 300 C environment, or whether it will be necessary to use the 200 C electronics but with additional cooling and insulation. If the 300 C package cannot be developed, it appears that the 200 C fall-back option will still deliver an acceptable system. Productivity seems to be good, insofar as it is possible to judge productivity in a research environment where the difficulty of achieving a particular outcome is, in the nature of things, unknown. Again, as noted above, the team comes from a company with an excellent record in innovation and project management, so one can expect a good outcome. Four publications have been presented.

PI Response:

Reviewer 23454

Score: 9.0

Comment: Accomplishments have shown significant progress, and are of high quality. The directional system is much further advanced than the MWD, but both projects are close to schedule. Several of the innovations achieved so far can be applied to other technologies.

PI Response:

Reviewer 23527

Score: 5.0

Comment: The project seems to have fallen behind compared to the plans described during last years peer review. While there has been progress made with regard to design and prototype fabrication tasks it looks like there is a roughly 6 month delay in task activities. With respect to what has actually been accomplished, it would be useful to receive a more rigorous and complete description of the results associated with prototype testing. This is particularly important as regards understanding whether or not performance targets are likely to be met. There was brief description of such testing in the provided documentation but the details were scant. More data on the motor and bit testing in particular would be useful. The progress of the MWD tasks was even more difficult to gage since much of the work seems to be conceptual at this stage although there was mention of component selection.

PI Response:

Reviewer 23447

Score: 8.0

Comment: Both projects are slightly behind schedule although much has been accomplished. The DDS project has been progressing over three years and is almost complete. The MWD project just got underway the middle of last year. The DDS project is in the fabrication phase. Nine 8-1/2" diameter tri-cone hybrid (PDC and roller cone) bits rated to 300°C, three 6-3/4" metal to metal directional motors rated to 300°C and drilling fluid rated to 300°C is expected to be completed in August and tested at Baker Hughes Houston test facility in September. The MWD project is in development/design phase resolving technical hurdles involving various high temperature components in the system. The active cooling system component was developed in Germany and was tested at 250°C for 50 hours. Telemetry and power supply issues are being resolved.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23433

Score: 8.0

Comment: Project management has been good. As noted above, the global project has been logically decomposed in terms both of the differing technical tasks that must be addressed, and also in terms of the time-development of each technical component. Activities being carried out in the US (Houston) and in Germany (Celle) appear to be well connected. Again, as noted, the fact that all of the work is carried out in-house, without need for sub-contractors, means that it is easier to keep things running together, and to identify activities that need to be given additional support. The reviewer notes that in one area, the prospect of potential failure to deliver up to original specification has been identified, and a fall back line of activity is being considered (This is the possibility that the electronics package will only be able to stand 200 C, thus requiring an enhanced cooling system). All other current difficulties look as if they are soluble by the project termination date.

PI Response:

Reviewer 23454

Score: 9.0

Comment: Management and coordination are excellent. Decisions have been logically made, and the costs for results achieved are reasonable. Decision points have been appropriate so far and appear to be so for the remainder of the project.

PI Response:

Reviewer 23527

Score: 5.0

Comment: There appears to have been a roughly 6 month delay in the schedule of the project. Is there an explanation for this. Tasks otherwise appear to be on track with respect to completion, if not timeliness. The decision points and planning of the project is good in general. My opinion on this aspect of the project has not changed significantly since last year.

PI Response:

Reviewer 23447

Score: 8.0

Comment: Overall management of both projects is good. DDS project has been underway for almost three years and is almost complete with sound results. MWD project is making some progress and has longer to go to meet proposed objectives. PI is on top of issues and finds solutions. Patent work seems to be causing some delays.

PI Response:

STRENGTHS

Reviewer 23433

Comment: Major strengths of this project are:
1. The project addresses a central need in geothermal drilling, namely the requirement for an effective high temperature Directional Drilling system.
2. The project includes work on all aspects of the required system, including the combination of bit, motor and MWD package. The latter includes the necessary sensors, electronics, power supply and the data-transmission unit. Success of the project should allow the deployment of a complete system.
3. The project is being carried out by a company that has a recognized record of success in the development and supply of equipment of this type.
4. Project management is facilitated by the work all being carried out in-house, without sub-contractors (although it is divided between activities in the USA and Germany).
5. Problems, to the extent that they have arisen and been recognized, are addressed, and fall-back actions are available.
6. If successful, commercialization of the directional Drilling System should be straightforward as Baker Hughes already has an ongoing sales and marketing organization that carries out Directional Drilling work for the petroleum and other sectors.
7. If the project is only partially successful, most successful components will themselves be of value even if other parts are not. For example, the development of a high temperature bit style will be of value even if the high temperature motor cannot be developed up to the required temperature, and both of these will be of value even if the MWD package does not perform as expected (directional drilling may still be carried out using direction and inclination measurements taken by wireline deployed tools, although this is a less efficient method.

PI Response:

Reviewer 23454

Comment: Both components of the project have been well planned and executed. Accomplishments to date are impressive. It seems likely that that the project will meet Program goals, within budget. Personnel and facilities for the work are very good.

PI Response:

Reviewer 23527

Comment: Project team has strong background in technology area and resources needed to accomplish objectives.

PI Response:

Reviewer 23447

Comment: Project could produce much needed high temperature DDS and MWD systems to reduce drilling costs in addition to better realizing geothermal target objectives. Since this project is being conducted by a highly respected company experienced in drilling system design, these systems should be available commercially in a relatively short time frame.

PI Response:

WEAKNESSES

Reviewer 23433

Comment: The reviewer finds few weaknesses in the project. The project personnel have identified a number of issues that remain to be addressed. These include difficulties with the design and operation of the high-temperature test facility for the motor, and the possibility that it may not be possible to find a metallic coating for the rotor/stator pair that has the required combination of thermal stability and abrasion resistance. There is also the risk that it will not be possible to obtain or develop the various components of the MWD electronics package to have a genuine 300 C temperature capability (i.e. without active cooling). Metal-to-metal seals also pose problems, but there is much experience in the design and use of such components, although replacement of polymeric seals by metallic ones will require some minor design changes (from radial to face - type seals).

It was noted above that one of the merits of the project is that all the work is being carried out in house without the use of sub-contractors. It is not known to what extent help is being sought from external sources regarding the issues raised above. Based on previous experience, the reviewer believes that the project team will have this possibility in mind.

PI Response:

Reviewer 23454

Comment: The only criticism is not of the project , but the process. As noted above, even if the tools work as designed, there is no way to know what the impact on industry will be.

PI Response:

Reviewer 23527

Comment: The motivation of the organization to successfully complete the work is not a given and is essential to project success (no offense intended). This is the reality of work involving large Oilfield Services companies. If there attention is redirected internally these projects tend to fail. Hopefully that will not happen in this case.

PI Response:

Reviewer 23447

Comment: Weaknesses are minor, try to minimize project delays.

PI Response:

IMPROVEMENTS

Reviewer 23433

Comment: Several alternative lines of work are proposed if the preferred or initially-selected options are not successful. These options include, for example,

alternative approaches to designing the electronic components (200 C plus active cooling vs. 300 C uncooled chips), the selection of a suitable power supply (high-temperature battery vs. an alternator), conversion from polymeric to metallic seals. etc. Some of these alternatives, if adopted, will require substantial redesign. If additional funds can be made available, it may be worthwhile to allocate some funds to allow more active investigation of these alternatives, so that if one or other of the primary choices proves unsuccessful, the project is not held up unduly since alternative approaches will have already been under consideration.

PI Response:

Reviewer 23454

Comment: None

PI Response:

Reviewer 23527

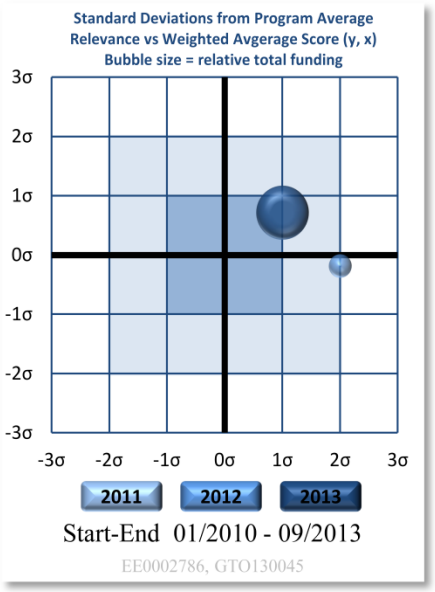
Comment: Is there a way of engaging Baker Hughes management in the administration or monitoring of progress for this project? It seems that there has already been at least one PI change. That might be a useful way of keeping everything on track if it can be done with being too onerous and obtrusive.

PI Response:

Reviewer 23447

Comment: Continue progress with MWD and look to partner with geothermal operators willing to use DDS and MWD systems for field trials.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002786
Project: Complete Fiber/Copper Cable Solution for Long-Term Temperature and Pressure Measurement in Supercritical Reservoirs and EGS Wells
Principal Investigator: Waterman, Kendall
Organization: Draka Cableteq USA
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23409

Score: 7.0

Comment: The ability to sense a Geothermal Well's temperature and pressure conditions is a critical capability in Geothermal Energy endeavors. The project team has made advances in the design of the optical fiber and cable described in this system, but have had setbacks in production of the cable. It is not clear that commitments have been made by the cable manufacturer that these issues to resolve these issues in a timely manner.

PI Response:
The project includes several new materials and manufacturing process. Some of the more significant setbacks are the result of weaknesses not becoming evident until combined with a subsequent development. Personnel changes have also impacted the project management effectiveness. Nonetheless, the company remains committed to resolving the manufacturing issues.

Reviewer 23521

Score: 10.0

Comment: The Geothermal Industry, and especially the Enhanced Geothermal Systems, is in great need of cabling solutions that can withstand the harsh environment conditions characteristic to these specific reservoirs. Temperature, pressure and corrosiveness are the main adverse factors for cabling solutions. This is a well-thought project and addresses these three main factors. Additionally, the investigators of this proposal are addressing some other problems related to optical fiber, like hydrogen ingression and H2O degradation, and also problems related to self-supporting deployment in the well.

PI Response:
Agree.

Reviewer 24895

Score: 8.0

Comment: There is currently a gap in the measurement capabilities for continuous temperature measurement, which this project addresses. Its target temperature 375C would cover almost all anticipated EGS project temperatures and all conventional geothermal temperatures. The 375C target was not reached, but the 300C cable that was achieved will be a significant improvement. The long term monitoring (over years) is not possible, but short term monitoring during stimulations, etc will be a necessary tool in the interim. There is still a need for a tool that can operate reliably over a 5+ year period. There are other ways to continuously monitor pressure, so while a good addition, the pressure is not absolutely necessary in terms of there being an existing gap.

PI Response:
Agree

Reviewer 23567

Score: 8.0

Comment: The development of a high temperature fiber/copper cable system will not only enable high speed communication link, but also allow deploying a network of fiber-based sensors which will allow distributed monitoring of multiple well parameters in an economical fashion. It is still not clear if all-fiber based approach is going to become a dominant solution for EGS, but it will definitely provide a viable solution for optical readout from traditional sensors increasing fidelity and bandwidth of data transmission, which will become more challenging as depth and temperature of geothermal wells is expected to increase. This is an important project with a clear benefit to geothermal industry provided solution is not excessively expensive to the end user.

PI Response:
Agree

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23409

Score: 7.0

Comment: The approach is well thought out and effective in achieving the project's objectives. The project has good focus, with most aspects of the project contributing to significant progress in overcoming barriers/knowledge gaps. The execution of the approach was good for Phase 1, but the cable manufacturing has experienced substantial problems in Phase 2. It is jot clear from the documentation whether the cable manufacturing problems will be resolved.

PI Response:
Several prototypes have been manufactured, including one long length for long-term well testing. Knowledge was gained from each prototype manufactured and corrective actions have been taken.

Reviewer 23521

Score: 10.0

Comment: The scientific/technical approach of this project seems to cover critical issues present in Enhanced Geothermal Reservoirs related to cable for powering downhole sensors and tools and for temperature/pressure measurements. The team is investigating two sides: (1) optical fiber development, and (2) electrical cable development. For the optical fiber side of the project, the tasks are well defined and cover two main aspects: fiber development, and coating development, each with its own subtasks that cover glass chemistry and new materials to scale up and testing/validation of the final coating/fiber combination. The main issue addressed in the 'electrical cable development' side of the project is related to the development of insulation for copper conductors.

PI Response:
Agree

Reviewer 24895

Score: 8.0

Comment: The approach was well thought out and the scope of the problem was well defined. There is some question about the staffing after the reorganization of the company and the project. There is also some question about the choice of the pressure capability target, as it is much too low for anticipated EGS depths. However, during the presentation and questions, it did not seem that there was really any pressure limitation. However the PI was only recently put in the job, so may need more chasing. More seriously, the project ended up targeting a lower temperature (300C). An explanation for the change was not in the written material, but during the Q&A in the presentation, it appears the hurdles are too large to go to 375C. The data would indicate that long term monitoring at 300C will also exceed the cables expected life. There is some question as to why this was not anticipated in the original project plan.

PI Response:
The original project plan included a 220 bar pressure rating. Current tubing encapsulated cable (TEC) technology offers cables with pressure ratings significantly greater than 220bar. The final cable design for this project uses a 0.25inch diameter 0.035inch wall tube with a 1380bar pressure rating.
Early in the project it became evident that the fiber polyimide coating and extrudable insulation materials were limited to 300°C operation. A partner has manufactured metal coated fibers to evaluate hydrogen resistance at high temperature. The metal coated fiber may provide a solution for operating temperatures greater than 300°C, but the technology is not ready for consideration in a cable.

Reviewer 23567

Score: 7.0

Comment: The approach of unique glass chemistry by substituting Ge core with Fluoride seems to be very promising based on the experimental data as hydrogen darkening has been not completely, but significantly suppressed in the latter case. A large portion of the development is devoted to fabricating and testing the fiber/copper cable in both lab and field environments. Field testing will be very important as lab tests not always recreate all conditions precisely and it will be especially needed for testing mechanical integrity of the fiber/copper assembly and reinforcement approach to prove the concept. The cost of the solution however is not known yet and hopefully could be made affordable.

PI Response:
Agree. The project focus is now on deploying a cable in a well. The project is intended to provide an improved cable technology and the improvements will add cost. Costs of the products developed are expected to be proportional to the value.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23409

Score: 6.0

Comment: The accomplishments, results, and outcomes have been adequate in relation to the resources expended and progress towards project objectives and technical targets/goals. There needs to be a greater showing that the cable development manufacturing issues will soon be resolved.

PI Response:
Agree. The project includes several new material developments and manufacturing processes, combining the developments into one cable system has been a challenge.

Reviewer 23521

Score: 8.0

Comment: According to the team, the 'key objectives' of this project were already achieved. Also, they list some additional important accomplishment that were not part of the original plan. However, due to some unforeseen problems, the downhole trials are behind schedule.

PI Response:
Manufacturing problems prevented delivery of cable to the planned test site. Missing this opportunity coupled with the manufacturing problems has delayed the downhole trial.

Reviewer 24895

Score: 7.0

Comment: Considering the technical hurdles and the company reorganization, great progress was made. They did not reach the target temperature or the life needed at the lower 300C temperature, but maybe that was too much of a stretch. There is still verification testing and more hurdles, but the quality of the accomplishments and the productivity in working around the hurdles has been good.

PI Response:
Agree.

Reviewer 23567

Score: 7.0

Comment: All fiber components were addressed with an adequate amount of details and novel approaches and solutions were developed in cases where gaps were identified. These include novel gel and coating development as well as new fluoride-based glass chemistry developed and tested in the lab environment. The only concern is the manufacturability of the cable which seemed to pose difficulties and delays in the recent trial cable preparation. The process yield and manufacturing process maturity may have an impact on the cable system cost. Overall good progress has been demonstrated although with deviation from the original schedule. Field test still needs to be performed to conclude success of the approach in a real geothermal well environment to allow observe mechanical and chemical effects on the cable performance, strength of the sheaf in real application as well as effect of H which has not been fully tested in the H2 lab tests.

PI Response:
Downhole field testing is needed to validate the lab tests and evaluate all elements of the cable system.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23409

Score: 7.0

Comment: Need better coordination with cable manufacturer.

PI Response:
Agree.

Reviewer 23521

Score: 8.0

Comment: In terms of the project management/coordination side of the project, the team seems to handle it appropriately, with the exception of the scheduling of the project. However, major challenges were identified and appropriate solutions are formulated.

PI Response:
Agree.

Reviewer 24895

Score: 7.0

Comment: Some issues with the reorganization, but difficult to separate management/coordination issues from technical hurdle problems, as far as the project being slightly behind schedule. In the end, a usable test cable has been produced and will be ready for testing. While behind schedule, it still got done.

PI Response:
Agree.

Reviewer 23567

Score: 7.0

Comment: The reviewer understands difficulties encountered by the research team during the company buyout turmoil. And as company reorganization and ownership changes have been completed, the team has been able to gain better control of the schedule. The project seems to be well managed provided mentioned circumstances and the only concern left is a highly compressed timeline packed with many milestones left in the remainder of the project plan for finishing work by the end of the year. The execution of such plan will require a very high degree of coordination and may not be able to tolerate any additional delays or setbacks.

PI Response:
Agree.

STRENGTHS

Reviewer 23409

Comment: Strengths are that the project team has developed a highly resistant glass chemistry that is resistant to H2. The polymer developed is also a good coating for the fiber so as to withstand and sense higher temperatures (>300 degrees).

PI Response:
Agree.

Reviewer 23521

Comment: I like the fact that the team is proposing a combination of optical fiber/electrical cable that can withstand adverse conditions characteristic to Enhanced Geothermal Systems. Usually I see these as separate solutions in past projects. The proposed work is extremely well thought, with well-defined tasks covering pretty much all the problems one can think of.

PI Response:
Agree.

Reviewer 24895

Comment: A cable good to 300C has been developed and produced for testing. There was a good plan with two phases running in parallel to minimize time and cost. The project leveraged existing technology and utilized the strengths of the team. A usable (testable) cable that will operate for 400+ hours at 300C has been manufactured, overcoming hurdles of reorganization, problems with the spacer material and manufacturing problems.

PI Response:
Agree

Reviewer 23567

Comment: Approach for design and manufacturing of the cable is solid. Critical components of the cable assembly have been demonstrated with the final test scheduled to prove the concept in the field.

PI Response:
Agree

WEAKNESSES

Reviewer 23409

Comment: Clearly, the cable manufacturing is a weakness of the project. Problems in cable manufacturing have caused delays in the project and has decreased the overall productivity of the project. At the time of the oral presentation, the cable problem had not yet been resolved.

The PI that made the oral presentation was new to the project. Looks like the project has had a change in the PI in the last month. The new PI was not apprised of some of the history of the technical issues when questioned by the reviewers.

PI Response:
A long-length of cable has been completed for use in the downhole trail. Problems encountered manufacturing this cable and other earlier prototypes have been addressed and changes will be incorporated the next cable manufactured. The most significant unresolved problem is related to the fiber coating process. Problems with the fiber coating are not easily detected and can cause problems during subsequent manufacturing processes, such as installing the fiber in the metal tube.

Reviewer 23521

Comment: As mentioned previously, falling behind schedule is the major weakness of this project.

PI Response:
Agree.

Reviewer 24895

Comment: The target temperature, 375C was good, as it met or exceeded current temperatures, but the revised target is lower than many of the existing projects. This limits where it can be used and its limited life expectancy at 300C will impact its use for long term monitoring.

The project under targeted the pressure required. EGS wells are targeted for 15,000 to 25,000 feet and would have pressures of 400 to 800 bar, but the project only targeted 220 bar. According to the PI during the talk, higher pressures should not be a problem, but some definition on the limits needs to be made.

PI Response:
Current tubing encapsulated cable (TEC) technology offers cables with pressure ratings significantly greater than 220bar. The final cable design for this project uses a 0.25inch diameter 0.035inch wall tube with a 1380 bar pressure rating.

Reviewer 23567

Comment: The proof of high temperature reliability and manufacturability of fiber/copper assembly are shifted very close to the end of the project which may not allow enough time for adjustments if needed. However, the reviewer recognizes project resources limit.

PI Response:
Agree.

IMPROVEMENTS

Reviewer 23409

Comment: Greater attention needs to be placed on resolution of the cable manufacturing task. Corrective Action plan needs to be designed and documented for resolving the cable manufacturing problems.

PI Response:
Agree.

Reviewer 23521

Comment: Reviewer did not provide comments for this criterion.

PI Response:
N/A

Reviewer 24895

Comment: The written material discusses what was done, but not what was learned. What was the failure in the high temperature testing and what would need to be done to extend the operating temperature higher? What are the gaps in getting to higher temperatures and longer operating reliability at lower temperatures? What hurdles were discovered and how might they be overcome? Can the learning's on the fill material be extended to higher temperatures? Did the weld failure on the test cable identify other opportunities for improvement?

PI Response:
During the material development work it became evident that 300°C was a limitation for both the fiber coating and extrudable electrical insulation. The fiber coating life was projected using Arrhenius plots of thermal gravimetric tests. To achieve operating temperatures significantly greater than 300°C a metal coated fiber may be needed.

The extrudable insulation developed for this project has a 320°C melt temperature. The Underwriters Laboratories long-term aging method described in UL 2556 was used to determine the material suitability for use at 300°C. The insulation developed increases the operating temperature of Fluoroplastic insulation materials from 260°C to 300°C. Further development work would be needed to achieve minor incremental improvements of 5°C to 10°C. To achieve operating temperatures significantly greater than 300°C a mineral insulation such as mica may be needed.

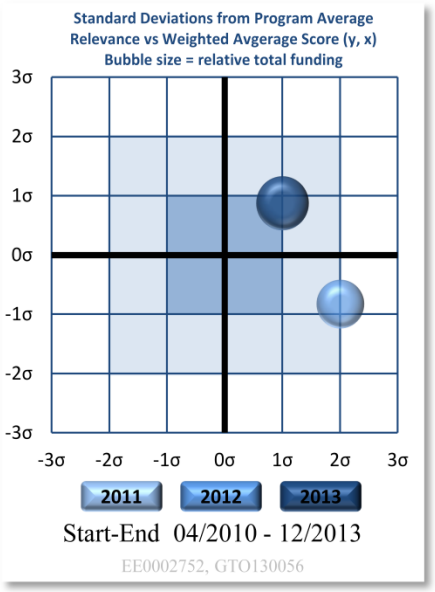
The supplier of material used as a gel alternative in the metal tube claims the material is suitable for continuous use at 350°C. With the other materials in the cable limited at 300°C, we have not evaluated the gel alternative for use at temperatures greater than 300°C.

The weld failure was an unfortunate and avoidable problem that was caused by poor dimensional control of the cable being installed in the tube. Corrective action has been taken to prevent reoccurance.

Reviewer 23567

Comment: Need to make sure that all novel technologies of gels, glass chemistry and coatings developed in the course of the project will be commercialized at a reasonable cost for a successful product offering.

PI Response:
Agree.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002752
Project: High-Temperature-High-Volume Lifting For Enhanced Geothermal Systems
Principal Investigator: Turnquist, Norman
Organization: GE Global Research
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23409

Score: 10.0

Comment: The design of this pump is a breakthrough in Geothermal industry; it is designed to operate at a higher temperature (300 degrees C) than conventional pumps (250 degree C), and is purported to extend to wells as deep as 10 km. Pump is also high volume and able to move 80kg/s water.

PI Response:
None.

Reviewer 23521

Score: 10.0

Comment: The Geothermal industry, especially the Enhanced Geothermal Systems can benefit a lot from an improved High-Temperature High-Volume Lifting solution. The research team is proposing the development of new motor technology that can withstand high temperatures characteristic to EGS systems.

PI Response:
None.

Reviewer 23500

Score: 6.0

Comment: High temperature capable artificial lifting systems are a key enabling technology for EGS applications. Current pumping systems cannot operate, or have reduced lifetimes in the high temperature environments planned for EGS systems. GE's project addresses this gap in downhole pumping technology with a detailed engineering plan to bring a product to market. While if successful, this technology will enable production from some high temperature EGS resources, it may not by suitable for all projects. Given that the stated power consumption for this pump is 4-5MW, a cost analysis will have to be done for each project to ensure electricity can be produced on a cost effective basis with this amount of parasitic load. Also, until a cable system that can deliver 4-5MW in a 300C downhole environment is developed, this pump may not be able to be deployed in resources that approach its upper temperature limit.

PI Response:
The proposed ESP system's modular design is intended to enable suitability to a wide range of EGS applications. The 4-5 MW load is for the most extreme applications. The design intention is for the ESP system to be customized for each application using pump and motor modules that can be added or removed as appropriate. Additionally, the high temperature design will help enhance reliability for lower temperature application and thus reduce operating costs and increase energy production. It is acknowledged that high power, high temperature cabling will be required and that this is beyond the scope of the current project. The team has elected to focus on what they believe is the most challenging technical hurdle, which is the motor. Once the motor can be made to operate reliably, the team is confident that a cable system can be developed as well.

Reviewer 23567

Score: 8.0

Comment: This project is addressing a gap in high volume high temperature geothermal artificial lift pump. Lifting the fluid to the surface is important to achieve optimal efficiency and increase production from a given geothermal well. Not all the wells will have sufficient pressure to be economically feasible and this work will be significantly relevant for deeper and hotter resources. As current state of the art systems do not meet required performance specs in terms of power and lifting volume, the project is high/medium impact even with risks associated with required power budget and high temperature reliability that have to be addressed beyond the executed scope.

PI Response:
None.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23409

Score: 10.0

Comment: The Scientific/Technical approach is sound following a standard design process of Requirements Definition, Conceptual Product Design, Detailed Product Design, modeling and simulation of components and subsystems, and fabrication and testing (thermal, strain, etc.) of components. A formal Design of Experiments was done to support the scientific approach for development.

The approach is to take a standard GE pump and motor and replace the components with high temperature components.

PI Response:
While the prototype demonstrator pump is essentially a modified version of a production pump, the pump to be used in the EGS application is a new design based on a detailed Design of Experiments. Both the prototype motor and the actual EGS motor are of an entirely new design that employs both high temperature materials and a novel construction that promotes thermal management.

Reviewer 23521

Score: 10.0

Comment: The scientific/technical approach is sound and consists of three main phases:
1. Background investigation
2. Develop technology and materials
3. Lab-scale prototype development.
All phases and the different components taken into account are well-thought and of great importance to the tool development.

PI Response:
None.

Reviewer 23500

Score: 9.0

Comment: This project employs a well thought out systems engineering approach to the problem of developing a high temperature downhole pump. The team divided the project into a requirements definition phase, a subsystem development phase, and a testing phase. During requirements definition the team appears to have performed their due diligence by consulting with experts in EGS systems as well as evaluating all possible pump technologies before settling on a final candidate design. The development phase of the project not only included designing the motor and pump, but also evaluation and testing of individual components (seals, bearings, windings, etc..) to ensure their survival at temperature exceeding 300C. The testing phase, while not yet complete, also appears to be well planned. The addition of an extra test to examine the thermal performance of the motor is a very good idea to identify and address any design issues before the full system flow loop testing. GE's thermal test stand and flow loop are appropriate for evaluation of the motor and prototype subscale high temperature pump.

Overall this project represents one of the best planned technical approaches to a GTO funded engineering development project that I have seen.

PI Response:
None.

Reviewer 23567

Score: 7.0

Comment: The project is well defined to achieve a particular goal of building a high temperature motor for artificial lift systems. The focus of the resources on this task once it was identified as a critical roadblock during designs evaluation stage does make sense. However, there are a couple of other major risks which could have been addressed with a higher degree of detail and could have been included in the plan. These should address power requirements for cabling system and deeper study of reliability of components at high temperatures. Given the challenging power rating of the motor, cables are expected to support high voltage, be it DC or AC, and when coupled with high temperature, the potential for reliability degradation of electrical components could be tremendous. Again, given the high potential impact of the project, the outcome is a great learning step and the score was not reduced significantly.

PI Response:
As mentioned above, it is acknowledged that high power, high temperature cabling will be required and that this is beyond the scope of the current project. The team has elected to focus on what is believed to be the most challenging technical hurdle, which is the motor. The three-year operating life of the equipment under high-temperature conditions is challenging, and accelerated degradation tests of the relevant materials have been conducted to the best of the team's ability given the resouce constraints of the program.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23409

Score: 9.0

Comment: Project has progressed at a steady rate. Slight project delay/extension so that additional thermal testing of components could be undertaken; but overall, a well progressed project. Pump fabrication is now complete at the time of the oral presentation at the Peer Evaluation Meeting. Motor evaluation is almost complete and is on-schedule. Motor is in final stages of assembly. All of components are readying for thermal tests.

Thermal tests will be done where motor is subjected to operating conditions in a 300 degree environment.

PI Response:
None.

Reviewer 23521

Score: 8.0

Comment: Not very clear what the timeline of the project is. The accomplishments, results and progress seem to be in line with expectations. A no-cost extension was requested and approved.

PI Response:
Project is to be completed in December, 2013.

Reviewer 23500

Score: 9.0

Comment: The quality of the results presented to date is excellent. All the planned technical goals appear to have been met. System component selection, development and testing at temperatures exceeding the target operating temperature of the pump are a positive indication that the prototype system should operate well in the motor thermal testing and flow loop testing.

PI Response:
None.

Reviewer 23567

Score: 7.0

Comment: The program is well on track for achieving set goals. As PI indicated, the scope has been created as the project was started and a great focus was given to the delivering on the high temperature pump. There seems to be a very strong support from GE Artificial Lifting Systems with a great potential for the final product to be available commercially. However the downside is in potentially overlooked complete system shortfalls resulting in a lower than expected maximum operating temperature which could be possible to achieve and under-utilization of the motor capacity if cabling and lifetime are limited. There is still existing opportunity for improvements.

PI Response:
While high temperature cabling is acknowledged as an additional and sizeable technical challenge, the team, with support from GE Artificial Lift, decided to focus on the motor and pump because it was felt that these were the most technically challenging system components and the program budget did not allow for the additional scope of the cable. Also, given the potential for a shortfall in other system components at high temperatures, it can advantageously stated that the motor would be more reliable than ever before thus making the overall system for applications <300C (which is the majority of applications) more robust and reliable.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23409

Score: 10.0

Comment: No subcontractors for the project. All work is being done at GE. So, project management appears smooth and seamless. Project is on-schedule and on-budget.

PI Response:
None.

Reviewer 23521

Score: 8.0

Comment: Project Management/Coordination seems to be well performed. However, an unforeseen no-cost time extension was necessary for the project to be brought back on track. This moves the end of the project to December 2013.

PI Response:
The program budget allows for the build of only one motor of this type with no precedence, and the need to get it right the first time. As this was a first-time build, the team encountered some manufacturing and material compatibility challenges that required time for resolution, thus causing the delay.

Reviewer 23500

Score: 8.0

Comment: This project is currently on target, in terms of both schedule and budget, to reach the extended end date of December 31, 2013. The only issue that may cause a delay in the schedule is if any problems with the motor design or materials selection are discovered during the motor thermal testing. However, any delays are unlikely given the thorough work during the design phase of the project.

PI Response:
None.

Reviewer 23567

Score: 8.0

Comment: The project is well managed; milestones and deliverables are clearly set. Execution is on track with adjusted schedule as some delays were encountered. PI has used the opportunity to access vast company resources to reduce risks and development costs. As the main focus of the project on the development of the high temperature pump and development of the high temperature flow loop test setup is close to completion, there is still some room to attempt for a short feasibility study to address open questions for a more complete answer focused on the needs of EGS.

PI Response:
None.

STRENGTHS

Reviewer 23409

Comment: Well designed product that includes proper modeling/simulation and laboratory testing. GE has also decided to field test the device at a geothermal once the project is complete, at no cost to DOE.

GE leveraged their existing materials database so that experimental materials characterization did not need to be done for many component materials (e.g., permanent magnet properties were already well known by GE).

PI Response:
GE has NOT decided to do a geothermal test once the project is complete. A possible Phase 4 of the program could include a field test, but this is not yet established.

Reviewer 23521

Comment: Good scientific/technical methods, with broad investigation of several different approaches.

PI Response:
None.

Reviewer 23500

Comment: The thorough technical approach and quality results shown to date are both major strengths of this project.

PI Response:
None.

Reviewer 23567

Comment: A solid design developed for the high temperature artificial lift motor developed. GE Artificial Lift Systems seem to support this project which is important for carrying it over into a real product.

PI Response:
None.

WEAKNESSES

Reviewer 23409

Comment: None

PI Response:
None.

Reviewer 23521

Comment: -

PI Response:
None.

Reviewer 23500

Comment: The main weakness for this project is the 4-5MW load. A load this large could limit the use of this pump to all but the most productive geothermal systems.

PI Response:
The intention is to modularize the system to make it applicable to a wide range of EGS applications, with the most extreme needing power in this high 4-5 MW range for the 80 Kg/s flow at 300 degree C and 300 bar pressure.

Reviewer 23567

Comment: It is well understood that the project had to focus on the high temperature motor development, but there is a need to look at a bigger picture and do a back-of-the envelope estimates for the rest of the lifting system components.

PI Response:
A possible follow-on effort could include development of the system components not developed under the current effort.

IMPROVEMENTS

Reviewer 23409

Comment: It will be interesting to observe if the actual cooling system continues to operate as expected over time given the high heat conditions.

PI Response:
None.

Reviewer 23521

Comment: -

PI Response:
None.

Reviewer 23500

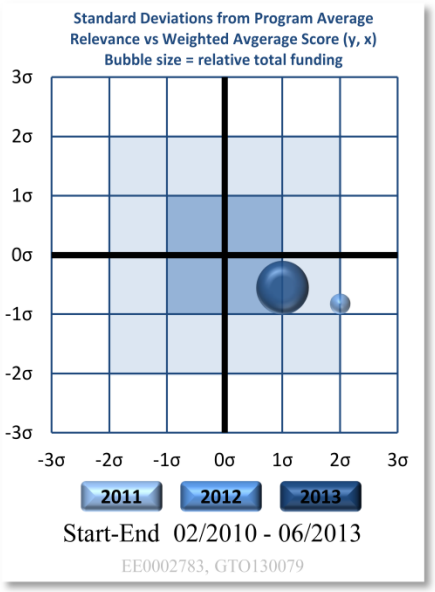
Comment: This project is nearing the final testing phase and therefore, I have no suggested improvements. However, any future work involving downhole pump development should look at technologies to reduce overall power consumption of the system.

PI Response:
None.

Reviewer 23567

Comment: Need to talk to cable companies. The final design of the motor/pump could be great during short duration lab tests, but may end up being used as a scaled down version at shallower depths and lower temperatures suited more for Oil and Gas applications. Team may have enough expertise now to possibly gauge if motor/pump challenging requirements could be overcome by a distributed pump system. Outstanding feasibility questions could be addressed to put at ease concerns for this work to highlight a solid solution for artificial lifting in geothermal wells.

PI Response:
None.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002783
Project: Microhole Arrays Drilled With Advanced Abrasive Slurry Jet Technology To Efficiently Exploit Enhanced Geothermal Systems
Principal Investigator: Oglesby, Kenneth
Organization: Impact Technologies, LLC
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23433

Score: 7.0

Comment: One of the problems in extracting heat from typical geothermal source rocks is that of obtaining adequate contact between the heat transfer fluid (water) and the rock mass. Natural fractures are important in this respect, but they tend to be either infrequent and/or oriented mostly parallel with one another. This results in inadequate contact and, if large fractures are present, a tendency for short-circuits to occur. It is thus attractive to be able to provide multiple pathways for the transfer fluid to flow between injection and production wells. This might be done by, for example, detonating explosives at the bottom of injection and/or production wells, but results may be ill-controlled. More attractive would be to be able to place supplementary boreholes that, for example, lie perpendicular to the run of the main natural fractures. Hence the attractiveness of the drilling system proposed in the present project. This allows the drilling of small drain- or injection holes that kick off from a main hole (probably drilled by conventional means). The drain holes are to be oriented mostly perpendicular to the lie of the natural fractures, allowing cross connection. Drilling of such holes requires a fairly sharp kick-off from the main borehole, but does not require the hole itself to be of large diameter. For both of these reasons, drilling by conventional means is less than ideal. The proposed method is to drill the holes by jet erosion, in which a slurry of abrasive particles is blasted from a jet nozzle. In the present embodiment, it is proposed to use a supercritical fluid such as carbon dioxide (preferred), steam or nitrogen as the propelling fluid. It is proposed to convey the drilling slurry to the nozzle on coiled tubing. This should allow relatively easy deployment and allow the drilling of relatively small diameter holes (around 4" in diameter). In parallel, a modeling approach aims to discover the effectiveness of different arrays of injection and drain holes in rock masses of different types (number and orientation) of natural fractures.

PI Response:
Agree with description.

Reviewer 23480

Score: 6.0

Comment: This work could eventually prove highly relevant to the Office's goal of supporting EGS development. The project is still in the very early stages, and much engineering/technology development remains before the micorbore system can be deployed. The ability of the system to be fully operational by 2020, a key goal year for EGS demonstration, is problematic. Basically, this work is two projects in one: (1) use of microholes to develop EGS reservoirs; (2) use of ASJ to drill the microholes. Of the two, use of microholes is most relevant to the GTP's needs and

goals. Microholes have the potential to improve heat extraction from EGS reservoirs with perhaps only marginal increases in cost. The study does not address this point adequately. ASJ still has a long way to go before the technology has practical application for geothermal.

PI Response:
Agree with description and analysis.

Reviewer 23478

Score: 6.0

Comment: This project is relevant to the GTO objectives because it addresses the goal of improving reservoir rock contact so as to obtain greater heat transfer. Also it may create more efficient EGS projects by eliminating the need for as many large diameter holes, thus lowering costs and improving the LCOE. Because EGS has not been proven commercially, it is not possible to accurately asses the impact this project could have on eventual EGS costs and efficiency. Theoretically, it could be a very positive effect , but everything claimed still has to be confirmed.

PI Response:
Agree with comments and analysis.

Reviewer 23447

Score: 6.0

Comment: Innovative wellbore completion technology using microhole arrays drilled with FLASH abrasive slurry jetting (ASJ). The concept is to drill microhole (>4") arrays (40-200) directionally in a downward slope from the primary vertical EGS wellbore to better intersect fractures and mine the heat of the geothermal system with fewer wells thus lowering the overall cost of the EGS project. Technology is in infancy and very complex. Development of tools for actual field use might be available many years from now. Even if successful this technology has limited applications: 1) work based on a vertical primary well bore (not for deviated/horizontal wellbore) and 2) work basically assumes new wellfield completions since technique does not have a way to track where microholes go (necessary information for infill drilling and re-entering existing wellbore for sidetrack).

PI Response:
Microholes (drilled by any methods and not just FLASH ASJ) can be kicked out of an exiting wellbore, vertical or directional. Agree that there is no way now to track where they go as being drilled (except an external detector), thus a broad target would be desired. Some capabilities of logging directional path after drilling completed. It is envisioned that this can be an existing or new field development. The FLASH ASJ drilling technique will take years to get it to the deep well commercial level.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23433

Score: 4.0

Comment: The technical approach has some merit, insofar as it should allow the rapid drilling of a large number of small (4" diameter) drainholes from a main bore. The approach is novel, and therefore a considerable amount of early work needs to be done before the feasibility of the technique can be established. This necessarily requires laboratory work to test jet nozzles, abrasive materials and the propelling fluids. Much of this work has been done. In parallel, modeling work has established, in principle at least, that a more efficient and complete recovery of heat may be obtained from a rock mass by the use of suitable arrays of drain holes. This is a good and systematic approach. Several issues remain to be resolved, however. Most fundamentally, it is clear that efficient drilling requires a sufficient pressure drop across the jet nozzle to accelerate the abrasive particles against the rock to be drilled. As the hole depth increases, the bottom hole (ambient) pressure inevitably increases, leading to loss of effectiveness. It also appears that increase in bottom hole pressure may result in loss of super-criticality in the gas stream. The resultant presence of liquid may decrease the efficiency of the nozzle. Supposing that these issues can be resolved, there remain some further possible disadvantages to the system. One is the question of the fate of the abrasive particles. No information was given concerning the ratio of volume of abrasive particles to rock mass removed, but it is unlikely to be less than one. This means that there is the risk of plugging some of the natural fractures that the drill traverses with cuttings and abrasives. Directional control of the drainhole is also likely to pose problems. With all stand-off drilling methods, the diameter of the hole can be very variable. In general, however, conservatism requires that the average hole diameter must be substantially larger than the drill diameter, to avoid getting stuck in "tight spots". This then leads to the drill nozzle and following tubing to droop, or possibly to be deviated in some arbitrary direction if the rock has a strong anisotropy in abrasion resistance. Previous experiments with water jet drilling systems have shown that this is a significant problem, not easy to deal with. Finally, there is no possibility to steer the drill as it advances, and no logging method available to find the direction and inclination of the resultant hole. Since development of these devices is not included in the project, knowing where the drainholes are will be difficult to establish. In turn, comparison of the field results with reservoir modeling will necessarily be very difficult, since the positions of the drainholes will not be known.

PI Response:
The reviewer has hit on several key points- modeling has shown benefits to use of microhole arrays; FLASH ASJ drilling requires a pressure loss across the nozzle which requires higher injection pressures and/or the bottom hole pressure to be kept low while drilling (gas lift or pump); supercritically of the gas is not a huge concern as Nitrogen can be used at the depths considered; injected abrasive particles and rock cutting disposal important with current thinking to separate in the wellbore and temporatily store in the large wellbore rathole (below zones of interest); directional control limited-agreed but estimatable; and variable hole size is a given unless the rock is known and uniform.

Reviewer 23480

Score: 3.0

Comment: The approach involves a combination of paper studies and bench-scale equipment development and tests. The paper studies may not have achieved the depth of analysis needed to guide subsequent tests adequately. The degree to which microbore and especially Flash ASJ technology has achieved success outside a laboratory setting is not presented in the project materials. Issues related to drilling many small legs from a single wellbore and controlling simultaneous flow through those legs are not adequately addressed. Neither the EGS or ASJ portions of the study appear to have been

evaluated with techno/economic feasibility studies which would help to confirm the expected benefits and help in the consideration of improvements to the technology. This project tries to do too much with a constrained budget.

PI Response:
Agreed. Challenges in the FLASH ASJ testing has limited progress in that portion of the project..

Reviewer 23478

Score: 6.0

Comment: The project had two basic scientific objectives in Phase I: Show the ability to actually drill microholes under high temperature conditions and then to estimate the potential benefits of the system.

Towards these ends, the proponents have conducted bench scale cutting, boring and slicing experiments, they have designed equipment that is necessarily very complex and expensive, they have overcome severe nozzle erosion challenges, and they have learned that their system works best in pressure regimes of 5,000 psi or less. Because hydrostatic pressures of 5,000 psi may be found at depths of "only" 11,520 feet, the limitation may cause problems in deeper EGS prospects.

Because of these obstacles, the project is behind schedule and over budget compared with the work accomplished. Accordingly, the score is lower than it would otherwise be.

PI Response:
Understand

Reviewer 23447

Score: 6.0

Comment: Scientific/technical approach is fair. Perhaps project is more complex than anticipated. Many issues have been considered, not all have been addressed. The modeling using TOUGH2 gave some good theoretical comparisons on various microhole array configurations to conventional EGS systems. However, perfect placement of microholes in a reservoir simulator most likely won't be duplicated in actual geothermal field conditions with varying lithologies, reliability of pumps and other surface equipment, encountering possible loss circulation zones or water interference with nozzle, etc. The work plan to design, bench test and redesign nozzle and slurry components was reasonable and carefully thought-out.

PI Response:
Agree

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23433

Score: 5.0

Comment: Significant progress has been achieved in laboratory and modeling work. Problems have arisen with generating the required slurries and handling the carrying fluids (steam, carbon dioxide and nitrogen), but good progress has been made. Nozzle development has also made progress, but more work needs to be done. Abrasion damage remains a problem but it appears to be soluble. Of greater concern is the translation of the laboratory work done on surface to deep hole conditions. It was reported that field drilling results have been less than expected at this time, but the reasons why were not discussed. Remaining concerns that have been identified but not yet resolved include understanding the behavior of the drilling system at depth. It is already clear that some form of downhole pump must be used to reduce the bottom hole pressure to allow drilling to occur, but how this will be done is not evident - is this to be in the main borehole or within the jet-drilled drain hole, for example ? Issues of controlling the diameter and direction of the borehole are recognized but no solutions are in view. The reviewer is mindful of extensive work that was done on high pressure water-only (no abrasives) jet drilling some years ago. This system was similar in many ways to the present. It was probably less capable in terms of drilling ability, since no abrasives were used, but for the same reason, there were no problems of abrasion or erosion of the system components and no issues of dealing with the waste abrasive. Nonetheless, it suffered from the same problems of lack of steerability and logging. It was ultimately unsuccessful, although several field trials showed limited success.

PI Response:
Reviewer's analysis is mostly correct. Translating the lab/bench drill tests to vertical drill tests has been and will be challenging.

Reviewer 23480

Score: 3.0

Comment: PI has made an honest effort to produce results for this project. Beyond initial engineering studies, tangible results are limited to improved nozzle designs and analyses of fluids. Improvements in directional drilling, a key element in multi-borehole placement for EGS applications, apparently is not required for a microbore system involving 100s of holes. Without directional capability and allowing the drilling to run free, there is a good chance the majority of microbores will tend along a similar track, dictated by geology or in situ fracture geometry. Bench testing and related work fell short of the 300C target temperature. Progress was reasonable for the funding level, but not enough to meet DOE's needs. The ASJ drilling system will require funding in the tens of millions in order to reach the field demonstration stage (without consideration of economic viability). The microbore cloud approach to EGS reservoir development looks promising and worth further investigation, but wellbore size and control of flow through many ports remain major unknowns. Unfortunately, the project will end before key questions about ASJ system viability have been answered. Given the $3M budget and 3+ year schedule, technical accomplishments were meager.

PI Response:
Bench tests cuts on 500F/260C granites were presented.with little difference in performance noted between ambient granites. The microbores will be separated by depth in the main bore and by their initial kickoff direction, which will all force some separation- forming a 'cloud' of bores. This project was not meant to answer all questions on the FLASH ASJ drilling technology, especially for deep drilliing. It was understood that additional testing would be rquired for that application. We were/are hoping for a shallow 'baby step' test.

Reviewer 23478

Score: 5.0

Comment: Among the accomplishments achieved are the evaluation of multiple fluids, conduct of simulations of fluid behavior that showed pressure limitations, and the continued testing of 5th generation nozzles and slurry pumps. Also, they have modified a coiled tubing drill for shallow slurry-drilled holes and they have conducted performance simulations. The results of all this work have been moderately encouraging, but the deep drilling and directional drilling is still in the future. Costs over-runs suggest that the value of the work accomplished does not match the expenditures to date.

PI Response:
Agree, Challenges encountered increased cost, delayed progress.

Reviewer 23447

Score: 5.0

Comment: Satisfactory progress has been made with simulation of microhole array configurations and bench studies optimizing nozzle, fluid and solids design. Unfortunately, proposed work with the 500°F granite slab was not done and the PI ran out of time and money.

PI Response:
Bench tests cutting on 500oF/ 260oC granites were accomplished and presented. Additional high temperature tests have also been perforned todate. Agree with all else stated.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23433

Score: 6.0

Comment: Project management appears to be adequate. There are several stakeholders, carrying out different aspects of the work. Reservoir modeling being carried out at Lawrence Berkeley National Laboratory appears to be largely independent of the other activities, but this is not a disadvantage as their contribution does not require constant input from other members of the team. The work on nozzle development at the university of Tulsa seems to be well directed, and addressing the important issues, Collaboration with other subcontractors (National Oil Well / Varco and others) appears to be well in hand. Contacts with other contributors and suppliers, for example, suppliers of coiled tubing, appear to be proceeding as expected.

PI Response:
Agree

Reviewer 23480

Score: 4.0

Comment: Project management is complex given the number of independent organizations and investigators involved with various elements of the project. Coordination among the various organizations appears acceptable where responsibilities are shared. The project does not appear to have decision points or other means of redirecting work based on results, progress, or consensus judgments. The work has reached a wrap-up point where little additional progress can be attained without infusion of large amounts of new funding.

PI Response:
Agree

Reviewer 23478

Score: 5.0

Comment: Project management has been only adequate. Project results are behind schedule and over budget partially due to management failures to foresee obstacles in equipment purchase/rent plans and partially due to funding concerns not described in detail. This is an extremely complicated project that requires full time attention by all participants, in a University environment, this does not seem possible due to other pressing staff commitments. In light of the delays and cost over-runs and the absence of detailed go-no go decision points, the score is only fair.

PI Response:
Agree

Reviewer 23447

Score: 5.0

Comment: This project is behind schedule and over budget without accomplishing a number of the objectives concerning testing of the process in the yard. Perhaps this project is more complex than anticipated. The project team made adequate progress in overcoming delays and addressing technical challenges with process components.

PI Response:
Agree

STRENGTHS

Reviewer 23433

Comment: The project addresses an important central issue in geothermal drilling, namely, the question of how to increase the contact between the hot rock and the heat collecting fluid. The approach adopted, of developing a novel drilling technique that is particularly suited to the drilling of multiple small-diameter boreholes from an initial injection or production hole, combined with a modeling component that aims to develop an understanding of the benefits of particular

injection and/or drainhole arrays is logical and attractive. The use of an abrasive slurry jet drilling method is attractive, and worth evaluation since it appears to have merit but has not been adequately explored before.

PI Response:
Agree

Reviewer 23480

Comment: Results to date suggest mirobores deserve additional analysis as a means of accessing large portions of EGS reservoirs. Actual deployment of the technology is several years away.

PI Response:
Agree

Reviewer 23478

Comment: The strength of this project lies in the concept. It is certainly worthwhile to try to maximize surface-to-surface contact within an EGS scheme so as to maximize heat flow and permeability. The idea is also that the drilling of up to 100 small holes from a primary bore should greatly increase the chances of intersecting many fractures. Unfortunately, I see this as the only strength. If the many obstacles still lying ahead can be overcome this would constitute another project strength.

PI Response:
Agree

Reviewer 23447

Comment: The project is ambitious and innovative and when successfully field tested can add additional cost saving drilling/completion options to EGS field development.

PI Response:
Agree

WEAKNESSES

Reviewer 23433

Comment: The project has a number of weaknesses, actual and potential. Some of these are becoming apparent as the work progresses, while some of them appear to be inherent. Among the problems that are becoming clearer as the project advances, are the finding at present that rates of penetration in field tests are not as high as would have been predicted from laboratory results. The reasons may relate to the poor performance of the jet drilling process at the level of the nozzle (back pressure too high, with problems of multiphase flow in the nozzle as a result ?). On the other hand, it may be the result of incorrect standoff between hole bottom and nozzle. Too close a standoff may result in the drilling of a hole that is too small for the drill to enter, while too large a standoff probably results in the hole being drilled with too

large a diameter, or at least, an inefficient transfer of jet energy to the work front. Determining the optimum standoff and being able to control it under field conditions is critical to the efficient operation of the process. Other problems relate to the unwanted erosion of system components that carry the stream of abrasive particles. Solution of some of these problems may be possible, but to what extent is not clear. For example, if the question of erosion of surface equipment components cannot be solved adequately, there are potentially serious safety issues involved as a result of the exposure of rig personnel to escaping jets of high pressure abrasive-containing fluids. Problems that appear to be inherent in the drilling process include the question of removal of waste abrasive and rock particles (issues of plugging reservoir flow paths) and the overall problem of being able to steer the drill and being able to know where the hole is once drilled. This last question will not be resolved within the scope of the present project.

PI Response:
Agree

Reviewer 23480

Comment: The project attempts to accomplish too much (two major studies), and both studies are necessarily limited.

PI Response:
Yes, but one must start somewhere.

Reviewer 23478

Comment: The weaknesses in this project begin with its complexity. By adding a great number of new, minimally tested components to a drilling system, multiple failures and time delays can be expected. One of the most difficult tasks will be the precise aiming of the micro-bores while drilling out of the main bore. This has not been adequately addressed in the documents reviewed. I also see the problems in drilling at pressures above 5,000 psi as being important. EGS projects are likely to be at depths of 11,520 feet or more where hydrostatic pressures alone will exceed 5,000 psi. This must be overcome. Finally, rather than minimizing short circuits in an EGS system, I would think that multiple bores intersecting multiple fractures in multiple places would result in more short circuiting. (I could be wrong).

PI Response:
Interesting comment on microhole arrays increasing reservoiir flow short circuiting-we disagree but would like to hear more about that argument.. 2" to 3.5" drilling tubulars that can handle 8000psi are currently available. Higher pressure (15,000psi) capabilities are also available in jointed pipe. These pressures are still below the conventional water jetting technology.

Reviewer 23447

Comment: This technology is in its infancy. Actual field use is in the long term. Directional capabilities are not addressed as yet. Understanding where the microholes actually go in the geothermal reservoir is of particular importance.

PI Response:
Agree

IMPROVEMENTS

Reviewer 23433

Comment: Improvements to the project could include an immediate emphasis on trying to decide why field results are less than expected. If it is established that, for example, high bottom-hole pressures are reducing the effectiveness of the jet nozzles, then this is a problem that is potentially soluble by the use of a downhole pump to reduce back pressure. On the other hand, it could be the result of incorrect standoff between the nozzle and the hole bottom. Having the nozzle too close may result in the abrasive jet missing some of the rock lying towards the periphery of the hole, resulting in a hang-up, and a hole of too small a diameter for the drill to enter. On the other hand, advancing the drill too slowly will result in too much rock being removed and too low a rate of advance. This issue is inherent in all types of stand-off, no contact drilling. The solution relies on being able to control the rate of advance of the drill very precisely, combined with some means of detecting how far the bottom of the hole is away from the nozzle. This may not be easy if there is substantial friction between the drill pipe and the hole wall (as, for example, when the hole has substantial curvature, is rough, or is traversing very "sharp" rock types, all of which are likely features of the proposed jet-drilled drain holes). Some thought should be given to this problem immediately.

PI Response:
We are concentrating on the drilling problems- mostly on the downhole slurry content. Agree that advance rate is the key to hole size control- Too fast and a flow restriction occure but too slow and waste/ too large hole size occurs. Doubt that a hole size indicator can be developed within the remaining time of the project

Reviewer 23480

Comment: At this late stage, few productive improvements are likely. The work performed by the project should be well-documented in a forthright, objective final report. If follow-on funding becomes available, the microbore system should be re-evaluated for less demanding conditions than those attempted here. Depths to 6 km and temperatures somewhat less than 300C would still include huge geothermal resources. Economic feasibility, as well as technical feasibility, should be factored into the analysis, even if that feasibility must be necessarily of a cursory nature. Sensitivity studies would be helpful in deciding where to concentrate engineering development tasks.

PI Response:
Agree

Reviewer 23478

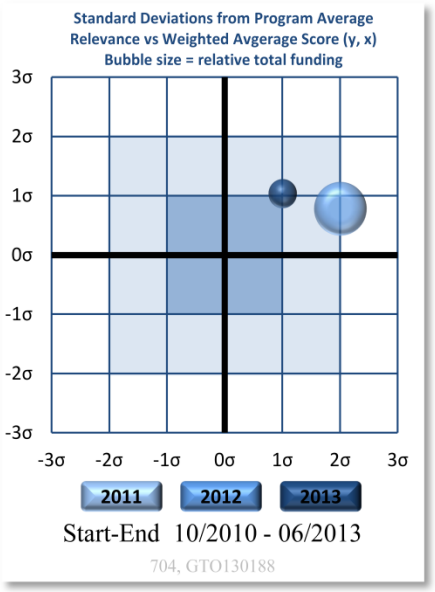
Comment: In a word, I would recommend that the project proponents make it a major objective to simplify all aspects of the plan. This includes the equipment (should be off-the-shelf), the interface with the primary drilling operations, the make-up of the slurry, and the methods employed for directionally drilling the micro-bores.

PI Response:
Agree, where possible

Reviewer 23447

Comment: Project is essentially completed, no time/budget for improvements.

PI Response:
Almost, but we are still trying.



Review: 2013 Geothermal Technologies Office Peer Review
ID: 704
Project: Technology Development and Field Trials of EGS Drilling Systems
Principal Investigator: Raymond, David
Organization: Sandia National Laboratories
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23433

Score: 9.0

Comment: This is a very relevant project. It addresses the well known problem that much promising work done in the laboratory never makes the transition to full commercial practice. There is a variety of reasons why this should be so, many of which are the result of natural skepticism on the part of commercial operators. However, as well as the psychological factors involved, there are genuine reasons why it is more difficult to introduce new technology in some sectors than others. The geothermal drilling industry provides a good example for several reasons. First, the field trial of a new drilling technique is a costly undertaking, both in time and money. Second, failure of the test can be very expensive and visible, possibly attracting adverse criticism. However, success frequently is only measured in small percentage gains. Third, and most importantly, it is usually very difficult to actually prove that some success has been achieved. Every hole that is drilled is different in an infinite variety of ways, starting of course with the lithology, but continuing with major or minor changes in the state of the equipment, the operating conditions and moment-by-moment decisions made by the driller. "Luck" may be seen as a major reason for either success or failure rather than technical merit. Overall, therefore the chances of achieving a provable success are small, while the risk of a visible, expensive and embarrassing failure is large. The solution to the problem is obvious : some organization must assume the risk of the trial, which, while being carried out in as near "normal" commercial conditions as possible, is insulated from as many sources of variability (e.g. commercial pressures on time or cost) as can be achieved. This is the rationale for the present project, to allow for the testing of new equipment - in this case, PDC bits - under near commercial conditions, while being isolated from arbitrary sources of variability.

PI Response:
No Comment

Reviewer 23480

Score: 9.0

Comment: This work potentially has immediate impact for geothermal drilling by enabling PDC bits to perform at or better than the performance levels of conventional rotary cutters. A fair amount of effort has been expended on this problem in the past, and presumably that work has been incorporated into this project. The cost of drilling remains the greatest deterrent to EGS applications, and anything that can reduce those costs would benefit the industry.

PI Response:
This project incorporates lessons learned from DOE – sponsored research (e.g. Diagnostics While Drilling) and seeks to leverage it for the benefit of EGS.

Reviewer 23478

Score: 8.0

Comment: This project is certainly relevant to the GTO objectives because it seeks to improve drilling technologies that will lower costs of exploration and development by increasing both ROP and bit life. If successful, this project can reduce drilling risks, convince drilling companies and service industry companies that the use of these new bits will be worthwhile (overcome apathy towards anything new). I achieving these outcomes, the project can serve as a catalyst to the entire geothermal industry.

Drilling rates and bit life have always been important factors in the economics of drilling, so this project is going right to the heart of drilling wishes.

PI Response:
No Comment

Reviewer 23447

Score: 9.0

Comment: Project objective is to redesign polycrystalline diamond carbon (PDC) bits currently used in about two thirds of oil and gas wells for use in EGS reservoirs. Project is relevant because it advances current technology to overcome harsh geothermal conditions in a relatively short time frame. Other benefits include increased drilling efficiency with longer bit life and providing an additional drilling tool option for geothermal environments.

PI Response:
No Comment

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23433

Score: 8.0

Comment: The scientific approach is valuable even if it is not revolutionary. As noted above, the project is consciously aimed at demonstrating, evaluating and improving an existing technology (that of PDC bits) that has been available for several years, but which is proving hard to introduce into the geothermal drilling industry. This reluctance to accept the use of PDC bits is despite their having been widely used for many years in the petroleum sector. The approach has therefore been to experiment with commercial and near-commercial bits in drilling projects that are as close as possible to commercial geothermal drilling practice, but which are isolated from commercial pressures. The project has been divided into three phases. In the first, preliminary tests were carried out to demonstrate the potential of PDC bits. In the second phase, commercial companies were involved and design improvements were made to the bit design. The third phase

involves further testing and validation of results obtained previously. In the second and third phases, much emphasis is placed upon involving both the bit manufacturers and the drilling and other service companies. The overall approach is therefore best described as being pointed towards convincing the commercial partners of the value of existing (or somewhat improved existing) technology, rather than attempting to bring in a completely novel approach. Along the way, care is being taken to evaluate the results being obtained, and to learn lessons from, for example, the state of wear of the bits and the specific energy required for rock destruction.

PI Response:
No Comment

Reviewer 23480

Score: 7.0

Comment: The approach establishes a baseline for field performance of two extant bit designs by using them in a geophysical well being drilled by the Navy with industry service companies. Working with service companies is essential to gaining acceptance of improved bit designs. Of two candidates, one design was improved in Phase II and laboratory tested at a service company's facility. The approach falls a bit short in execution since the Phase III field testing of the improved bit depends on funding from another source.

PI Response:
The funding for Phase III testing of the Phase II bit has been made available by DOE. Sandia and an industry partner have identified a site for Phase III testing.

Reviewer 23478

Score: 8.0

Comment: Sandia has broken the scientific and technical approaches of this project into three phases. Phase I comprised preliminary field trials of new bits to demonstrate their potential and to note any deficiencies. Phase II Involved interfaces with Service Industry companies so as to get them to improve bit performance and to seek custom developments. Phase III involves reconfirmation of latest design improvements and demonstration that the new bits are fully ready for Geothermal Drilling on a commercial basis. The plans have been carefully designed, staffed, instrumented, etc. The project objectives are being achieved within the budget but about 9 months late in finalization.

PI Response:
No Comment

Reviewer 23447

Score: 8.0

Comment: Scientific approach was simplified to include only PDC bits and not pneumatic down the hole hammers. The approach consisted of two steps: 1) field trials of two off the shelf PDC bits in a Chocolate Mountains' well and 2) design improved PDC bit based on shortfalls of field trials. The project team included service company involvement during tool specification and field testing and developed data acquisition system, surface system integration, data reduction and

analysis which resulted in next generation bit development and then tested in Sierra white granite at the NOV Downhole test facility.

PI Response:
No Comment

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23433

Score: 7.0

Comment: Under the heading "Results, Accomplishments and Progress" should be two sub-headings. The first should address the raw scientific and technical results achieved. These have been broadly successful; results from the studies of rate of penetration, state of wear and specific energy of rock destruction are valuable, and the team was able to improve the performance of the second bit by applying lessons learned from the behavior of the first bit tested. An interesting finding was that the second bit, having been adjusted to be more aggressive than the one initially tested, turned out to be more difficult to control. This emphasizes a performance feature that may not be obvious in laboratory testing. In the former case, close control of all parameters is generally possible, so dealing with a bit that is very "skittish" (e.g. having a very strong dependence of torque and rate of penetration on weight-on-bit) is usually not difficult. In the field, however, it may be better to have a bit that has a more consistent performance, that is not much influenced by the inevitable variations in drilling parameters that occur under field conditions. The use of buttons on the bit face to limit the depth of cut is very important for this function.

The second sub-heading should be entitled "Level of acceptance by the industry", since this is a major driver and justification of the project. This is a less tangible subject, and much more difficult to evaluate. As far as the reviewer could judge, however, the collaboration with the industrial partners was successful. The real test, however, will be to see whether the industry partners are sufficiently impressed by the results of the project to start using the technology on their own. This is not yet clear, so some more time must be allowed for the final conclusion to develop.

PI Response:
No Comment

Reviewer 23480

Score: 7.0

Comment: The project has achieved its expected results for the first two phases. The 7-armed bit performed less well than the 8-armed bit, a result contrary to expectations. Insufficient rig torque is cited as the reason for the poorer performance. However, SNL abandoned the 7-arm design without attempting to modify its design. The ROP data for the 7-armed bit shows a steady decline with depth. Could some other factor be coming into play to account for this decline, such as change in lithology or other rock properties? Based on these performance results, the 8-arm bit was selected for Phase II design work. The new design performed measurably better than the earlier version. PDC bits will work well in geothermal environments provided they are "matched" to the rig. The matching process would appear to involve modifications that may prove expensive---this point was not fully developed. Supporting studies were not cited that show

the extra cost of PDC bits will be more than offset by improvements in drilling performance (e.g., ROP, etc). The extent to which PDC bits can be used top-to-bottom was not addressed.

PI Response:
The 7 blade bit without torque control components (TCC) was indeed abandoned from further study in Phase II. Testing showed that the lack of TCCs was responsible for the unfortunate performance of the 7 bladed bit in the Chocolate Mountains test. The Phase II bit retains some of the aggressive nature of the 7 blade bit, and adds TCCs to the new 8 blade design. The need to closely match the rig to the bit is alleviated by the use of properly designed TCC elements. The cost per foot of PDC bits was addressed in our 2012 GRC paper. The cost of a PDC bit was shown to be comparable to that of a roller cone bit given that the PDC bit is not damaged beyond repair.

Each drilling program must be evaluated to determine the most cost effective way to drill the given lithology; as such our effort in Phase I was to examine the most difficult section of the Chocolate Mountains borehole. Drilling with the same bit for the entire hole poses different challenges.

Reviewer 23478

Score: 8.0

Comment: Phases I and II have been successfully completed. Phase I resulted in the 813 bit showing very little impact damage, and abrasion not being an issue. However, indications were found that the dill rig being used needs more torque capacity in order to optimize ROP and bit life. Also, they noted that improved torque control components will be key to success. Phase II lab tests indicate that the good bit #813 is now even better and that there will be at least 2 other new bits available for Phase III field tests. The quality, results and projects of the phased work are quite good and they are totally relevant to the goals of the project.

PI Response:
No Comment

Reviewer 23447

Score: 8.0

Comment: Good information was gathered from field trials from two off the shelves PDC bits and compared with the standard roller cone bit. From the field trials it was discovered that abrasion was not an issue, torque control components are key and rigs with adequate torque capacity had to match the bit. An improved PDC bit was designed and manufactured based on results from the field trial. While testing this next generation PDC bit in Sierra white granite a minor cutter selection problem was identified and resolved. Two improved PDC bits will be available for field testing not funded in this project.

PI Response:
No Comment

PROJECT MANAGEMENT/COORDINATION

Reviewer 23433

Score: 9.0

Comment: The project management appears to be good. Good management of activities is important in a project of this type, for which there is a need for coordination between a government lab. and industry partners. However, and more importantly in this case, there is an explicit requirement to make the whole process of adopting the new technology simple, straightforward and user-friendly. As far as the reviewer can tell, this is being achieved.

PI Response:

No Comment

Reviewer 23480

Score: 5.0

Comment: The first two phases have been completed on time and well within budget. A question remains why Phase III testing must be done with separate funding when there are still substantial funds (~$500K) available from this project? Proprietary rights of industry participants are not addressed, and perhaps this explains why details of the redesigned bit are not given. Will the new designs be generally available to all bit manufacturers?

PI Response:
The remaining funds from Phase II will be expended to support bit testing in Phase III in a broader suite of tests that previously envisioned. As part of a planned operator drilling campaign, more holes will be available for testing of the advanced PDC bits and recently available hybrid bits will be included in the matrix. The bits and the designs are the property of the respective service companies involved in this project.

Reviewer 23478

Score: 7.0

Comment: Sandia appears to be managing this project very efficiently. They are on budget and slightly behind the original schedule only because of delays at the NOV Downhole drill site. There seems to be excellent co-operation and collaboration between Sandia, the U.S. Navy GPO, Barber Drilling, Service Industry companies, and NOV Downhole partners. There are not reported any discrete decision points (go-no go milestones), however, given the capabilities of the proponents, perhaps no such reviews were deemed necessary.

PI Response:
No Comment

Reviewer 23447

Score: 8.0

Comment: Project was delayed but under budget. Good coordination/involvement with service company and geothermal operator.

PI Response:
No Comment

STRENGTHS

Reviewer 23433

Comment: The over-riding strength of this project is the pragmatic and realistic approach. There has been a conscious effort to place priority on getting an existing new technology introduced into commercial practice, rather than developing yet another novel device or technique. The topic chosen, the introduction of PDC bits into the geothermal industry, is well chosen. On the one hand, Sandia National Labs. has a very long and distinguished experience of innovation and evaluation in this area, while on the other, PDC bits have been widely adopted in the petroleum industry but not in the geothermal sector. Only their adoption in the geothermal field has been slow. This may be due to a number of factors. First, geothermal drilling is mostly concerned with hard and often fractured rocks, This makes for high levels of abrasive and shock wear, both of which are particularly damaging to drag bits, and to PDC bits in particular. Second, and possibly of greater importance, is the small size of the industry. This has meant, on the one hand, that there is not much of a pool of operators willing to try new technologies, while on the other, the service companies, and in particular the bit manufacturers, do not see a large potential market that merits the research and marketing effort that would be needed to develop the geothermal market. The reviewer therefore considers the choice of project as very well founded. Concerning the technical approach, it is seen as systematic and measured, proceeding in logical steps. A significant, even essential strength of the project is the emphasis placed on ensuring industry interest and participation.

PI Response:
No Comment

Reviewer 23480

Comment: The project is limited in scope (doesn't attempt to deliver more than what is practical), has strong industry involvement, and uses real field test conditions.

PI Response:
No Comment

Reviewer 23478

Comment: This is a well thought out, systematic plan to identify at least two new bits that will increase ROP and bit life, two parameters that have been the objectives of inventors for as long as drilling has been undertaken. The partners in this venture are all experienced and dedicated to the successful evolution of fast drilling, long-lived bits suitable for drilling deep, high pressure, high temperature holes on geothermal projects. The combination of excellent planning, capable execution, and unbiased critiques of the test results can surely be considered major strengths.

PI Response:

No Comment

Reviewer 23447

Comment: Redesigned current PDC bits for use in harsh geothermal environments. Actual field use availability in relatively short time frame. Increased the number of tools/options for geothermal well construction. Engaged service companies in developing new tools. Took advantage of collective knowledge. Produced two redesigned PDC bits available for field testing.

PI Response:
No Comment

WEAKNESSES

Reviewer 23433

Comment: If there is a weakness to this project it could be summarized as having a lack of ambition. No really significant innovation is proposed or expected, unless it be a gradual adaptation and improvement of PDC bit designs, The improvements demonstrated so far, however, while useful, have not been of a strikingly new nature. If the DOE has, as an objective, to support significant research in the present program, this project falls somewhat short. However, if the objective is to introduce new technology to the industry, which is, presumably, the ultimate objective, then this project is right on target. This is one of few projects that have the ultimate beneficiary in clear view. Too often, the research community tends to be seduced by novel projects that are interesting and exciting from the technical point of view. Research is carried out until the interesting technical points have been investigated. After that, the attitude is too often that "the technical features and advantages have been demonstrated. It should be self-evident to the industry folks that they should take it up" - while not recognizing the multitude of non-technical issues that may inhibit actual field application (safety, environmental issues ...).

PI Response:
No Comment

Reviewer 23480

Comment: Actual field testing of the improved bit design is not being done within the scope of the project. This leaves a degree of uncertainty in the extent to which objectives have been achieved.

PI Response:
Testing of the improved design will be performed under a separate project.

Reviewer 23478

Comment: The only weakness to this project is the fact that it will not be able to test bits in a really deep actual EGS hole as one does not appear to be available in a timely manner. Because of this, the most trying, difficult geothermal drilling

conditions will not have been encountered yet. Possibly, if permission were to be obtained to drill in one of the Australian EGS projects, this deficiency could be cured.

PI Response:
No Comment

Reviewer 23447

Comment: Demonstrations based only on vertical wellbores. How will results differ in deviated wellbores? Temperatures not described at depth in field trial. Need to train rig to run new PDC bits. Need to match rig (torque capacity) to PDC bit.

PI Response:
There is no expectation that results in deviated holes would be different than vertical, however verticality removes a complicating variable for this testing effort. The temperature of the Chocolate Mountain hole was low (that is why there is not more drilling at this site) - about 100 C. The reviewer is correct that drillers need to understand how to run these bits just as they need to understand how to use any equipment they employ. NOV provided a drilling consultant to provide guidance to the crew during the time that the test bits were in the hole. Issues of rig torque/bit design are discussed above.

IMPROVEMENTS

Reviewer 23433

Comment: No significant improvements are suggested. As noted above, there are two major results hoped for from this project. The first is to demonstrate the technical success of PDC bits in drilling geothermal wells. The second is to demonstrate that this result has been understood by the industry, resulting in widespread adoption of the technology. How the second result is evaluated is not clear. Presumably, the widespread adoption of the new technology will only become clear after some years as news of repeated successes becomes widely known. However, if it occurs, there is always the possibly that this was going to be inevitable, in view of the current success of PDC bits in the petroleum sector. The only improvement suggested, therefore, is that efforts to publicize the activities and results of the project should be intensified.

PI Response:
No Comment

Reviewer 23480

Comment: Reviewer did not provide comments for this criterion.

PI Response:
No Comment

Reviewer 23478

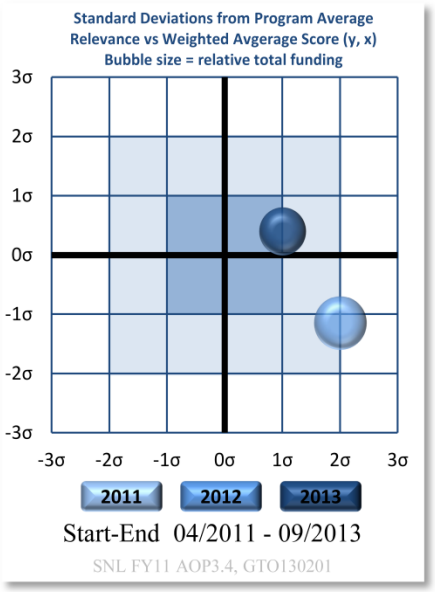
Comment: See previous suggestion under the "weakness" category: Seek one or more deep, very hot holes in which to try the new bits before declaring them fit for use under EGS conditions.

PI Response:
No Comment

Reviewer 23447

Comment: If possible, field testing of newly redesigned PDC bits.

PI Response:
No Comment



Review: 2013 Geothermal Technologies Office Peer Review
ID: SNL FY11 AOP3.4
Project: Auto-Indexer for Percussive Hammers
Principal Investigator: Su, Jiann
Organization: Sandia National Laboratories
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23433

Score: 7.0

Comment: While there is considerable enthusiasm for the use of wear and impact resistant PDC drill bits in geothermal well drilling, variants of percussive drilling, either from roller-cone bits or by conventional hammer bits still attract a lot of attention. Indeed, the majority of geothermal well footage drilled today is by roller cone bits. Improving alternative percussion bit drilling techniques is therefore an attractive option. For deep holes, reciprocating the drill stem to achieve a percussive action is not possible (as it is for blast hole drilling in mines, for example), so use must be made of down-hole hammers. Hammer drilling has several advantages over rotary roller cone drilling. Generally, the required weight on bit and applied torque are lower. This results in greater directional stability (important in directional drilling), and the lower required weight on bit and torque demand a less powerful drilling rig. For any hammer drill, it is necessary to rotate the bit so that successive impacts do not always fall in the same place. Often it is not practical to rotate the bit from surface, so a down hole rotation system must be provided. Down hole rotation motors could include positive displacement types, but these currently use elastomeric components in the stator section, and such materials cannot stand the high temperatures of typical geothermal wells. Hence the attraction of using, for example, an air-driven vane motor as the source of rotation. Development of such a motor is the objective of this project. Its successful introduction will widen the scope for percussive drilling in geothermal wells.

PI Response:
I agree with the reviewer's comments.

Reviewer 23478

Score: 7.0

Comment: This project is relevant to GTO objectives because, if successful, it will improve well construction capabilities so as to lower drilling costs. The project addresses challenges of the deep, hot geothermal environment that makes optimum drilling difficult with existing hardware and techniques. The goal of the project is to invent new technology to supplement the existing tools and thereby expand the drillers "toolbox choices". The primary innovations are the design of a new, high temperature down-hole motor with high peak torque capabilities and with improved ROP using down-hole rotation in the hot and very hard, brittle rock types anticipated in EGS environments.

PI Response:
I agree with the reviewer's comments.

Reviewer 23527

Score: 9.0

Comment: This is an innovative and challenging project. If successful, it would define a new pathway for developing directional percussive drilling technology that could significantly improve drilling capabilities. This capability will likely be critical to future efforts associated with EGS and would likely also be of value to hydrothermal applications where deviated wellbores are becoming more commonplace. The combination of this directional capabilities with the high penetration rate potential of down the hole hammers amplifies the potential impact of the project on programmatic objectives. The above being said, getting the technology to a commercial readiness level will be a challenge.

PI Response:
I agree with the reviewer's comments. Improving the technology to a commercial level will be challenging. We are actively seeking commercial partners to further develop the tool.

Reviewer 23447

Score: 8.0

Comment: Project is innovative as it advances the use of percussive hammers in geothermal drilling. The project proposes to develop a high temperature downhole auto indexing tool permitting the rotation required to allow the bit to strike new material for each impact of the percussive hammer. Current technology of generating rotation (positive rotating motor) is limited to 160°C but by eliminating elastomers as proposed in this project percussive hammers could be used in geothermal conditions with temperatures of 250°C. If successful, this project makes available high peak torque in a compact package. The impact of this project is faster penetration (lowering well costs) and more drilling options. The downsides of this project are: 1) a target temperature of only 250°C which is less than the 300°C GTO target and 2) most likely won't have application for all geothermal fields.

PI Response:
The indexer, along with percussive hammers is not suited for every drilling requirement. However, they expand the tools available to drillers which gives them more flexibility to make hole for any conditions they encounter.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23433

Score: 7.0

Comment: The scientific and technical approach is sound. The project builds on prior work in the area, in which a suitable design for the primary rotation motor was developed. In recent work, the emphasis has moved to the design of the auto-indexer, a device for imparting an impulsive rotation to the drill bit and motor. The approach is one of conventional mechanical engineering design - theoretical design and stress analysis, materials selection, fabrication and testing of prototypes, followed by progressive optimization. This appears to be a sound approach, and development is proceeding steadily, with the inevitable snags being solved in an effective manner.

PI Response:
Your observations are correct.

Reviewer 23478

Score: 8.0

Comment: This project appears to very wisely take existing tools and then modify them to work better and more efficiently instead of starting from scratch. To date they have improved the torque output so that it can be up to 40 times greater than that delivered by conventional DH hammers. The technical approach includes engineering design of the new tool, materials selection, fabrication of the prototype, lab testing, modifications as required after lab testing, and then field drill-testing. Photos and graphs resulting from the work completed through 2012 evidence adequate progress, though the project is slightly over budget at this time.

PI Response:
Your observations are correct.

Reviewer 23527

Score: 9.0

Comment: The technical approach is well planned and sound. Design and prototype testing tasks are appropriate and well defined. The approach considers likely technical challenges and provides opportunities for redress that will likely be necessary. More representative field-like testing in the laboratory should be considered to address reliability and potential long term performance degradation issues.

PI Response:
Tool development is continuing and we are seeking opportunities for testing beyond the laboratory.

Reviewer 23447

Score: 8.0

Comment: The scientific/technical approach is sound and logical. The work plan is well thought out with a clear understanding of the pros and cons of this technology and the tasks needed to adapt this to geothermal environments.

PI Response:
Thank you for the feedback.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23433

Score: 7.0

Comment: Results obtained so far are good, with steady progress being reported. Problems encountered in the design (inability to rotate in certain starting positions, brittle failure in steel components) have been understood and solutions are being implemented. At this stage, no full system tests have been tried, so it is not clear how well the device will work in the field, or indeed, even in lab. conditions. Further on, if tests are satisfactory, some collaboration must be sought with a commercial company to take over the manufacture and marketing of the device. It is probably too early to begin this phase of the project at present. However, Sandia has a collaboration with a commercial hammer manufacturer to develop a high-temperature hammer, so this may provide an avenue for future field testing.

PI Response:
Testing is continuing. The working relationship with the commercial hammer manufacturer puts us in a good position to develop the tool commercially when the time comes.

Reviewer 23478

Score: 8.0

Comment: The significant accomplishments to date include completion of engineering design and analyses, construction of prototypes, testing of the power and drive sections via dynamometer, and the quantification of the torque output. Challenges overcome are the materials selection, the optimum geometry of the drive section and the accurate and repeatable quantification of torque output. Drill testing has been planned, but has not yet been conducted. The photos attest to the significant progress made and the results appear to be justifying the merits of the project.

PI Response:
We agree with the reviewer's comments.

Reviewer 23527

Score: 8.0

Comment: The results to date are excellent. This project is extremely challenging from the engineering perspective and remarkable progress has been achieved to date. The prototypes fabricated and tested are impressive and provide reasonable confidence at this stage of the project that there will be useful, applicable hardware developed. Design considerations have been comprehensively addressed and while there are likely to be issues that were not initially considered, the key elements of the technology have been logically and systematically developed.

It is not clear that the goal of employing the technology in an actual test well is feasible for the current state of the technology (is this why field testing is listed as pending?). There should be some effort to ensure that the technology is developed and tested outside of a laboratory environment. Long term operation of the system components in particular should be performed in some manner to better evaluate the readiness of the technology.

PI Response:
We are continuing to develop the tool in terms of reliability and performance. Current activities are in a controlled lab environment. We want to be confident in the operation of the tool before fielding it in order to have the most positive impact when demonstrating its capabilities.

Reviewer 23447

Score: 8.0

Comment: Good progress has been made over the last two years of this project. During the bench testing problems were identified and resolved such as material selection, drive section geometry and quantifying performance. While testing of the tool is continuing, the prototype was fabricated, the power section was tested on dynamometer, the drive section testing was completed and torque output of tool was quantified.

PI Response:
We concur with the reviewer's comments.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23433

Score: 7.0

Comment: Project management appears to be adequate. At this stage, the work is mainly in-house, so no great skill is required to keep the project on track. A higher level of attention will no doubt be needed in the future when field testing becomes necessary.

PI Response:
Agreed

Reviewer 23478

Score: 7.0

Comment: Very little has been reported regarding the management of this project. There have been no well-delineated go-no go decision points, but the progress made to date suggests that management has been effective. There are no partners or subcontractors on this project. All work is being done by Sandia. Future plans are now to field test the performance of the new tool, but nothing was reported as to where or under what conditions this testing will be conducted. Management rating has been downgraded slightly to reflect these omissions, but overall, the management has been quite good.

PI Response:
Thanks for the feedback.

Reviewer 23527

Score: 8.0

Comment: Project administration has been executed efficiently and effectively. The project appears to be a bit behind schedule but that is the nature of novel technology development. you build, things break and you have to adapt.

PI Response:
Agreed.

Reviewer 23447

Score: 7.0

Comment: Project management/coordination overall is good. The project is a little behind schedule but under budget. A target well of 200°C has been slated for field testing prototype in 2013.

PI Response:
Thanks for the comments. We are a little behind but are making steady progress in the overall project.

STRENGTHS

Reviewer 23433

Comment: The strength of the project is that it responds to a well-defined need - to investigate alternative methods for drilling in hot, hard rock. While roller-cone drilling is the current most widespread method, percussive drilling by down-hole hammer is a strong contender as an alternative approach. This project addresses an important feature required of any such hammer drilling method, namely the need to rotate the bit while hammering. This project addresses the requirement by aiming to develop a rotation system that can be added to any down-hole hammer. The approach is via conventional mechanical engineering development, so no exotic technology is required (the prime mover is a conventional compressed-air vane motor). Assuming details of the design and materials selection can be solved, progress should be steady, with a more-or-less guaranteed result.

PI Response:
Agreed. Thanks for the comments.

Reviewer 23478

Comment: Drilling deep, high pressure, wet, hot, very hard rocks has always been a very slow process and the costs of running big drill rigs for many days gets very expensive. If the ROP can be greatly increased with the proposed new hammer drill down-hole motor, a significant impact will be made of the overall costs of geothermal exploration and the ultimate LCOE. Sandia has years of experience in drilling-related projects. They have staff that is unmatched in the field and they frequently hire consultants to augment their engineers. Finally, they maintain close ties with the drilling and the service industry that will no doubt, help in eventually confirming the capabilities of this new tool and readying it for commercial deployment.

PI Response:
Thanks for the comments.

Reviewer 23527

Comment: This project leverages prior development efforts associated with the technology being pursued. This somewhat mitigates the technical risk but also increases the likelihood of commercial viability based on some familiarity with likely issues going into the project. There is still a long way to go to reach this point, but the excellent experience of the PI with the technology and nature of the technical risk make commercial viability a possibility. This project also complements other ongoing hammer efforts that involve commercial hammer manufacturers. Those efforts and the strong industry tie significantly improves the prospect for success of the overall project objective.

PI Response:
Thanks for the positive comments.

Reviewer 23447

Comment: This project advances current percussive hammer technology for use in geothermal environments by eliminating elastomers (higher temperature) and auto indexing tool which allows rotation of the bit so new material is struck with each successive impact. The benefits provided by this project are better penetration lowering well costs and another geothermal drilling tool option.

PI Response:
Agreed

WEAKNESSES

Reviewer 23433

Comment: No obvious weaknesses were identified. With such a project, there is always the risk that the required power or forces cannot be attained in the space available, either because of design problems or simply that here are no materials available to carry the expected loads. This risk is unusually great where high impact loads are involved, since failure in fatigue becomes a big problem. There is already a premonition of such problems in the failure of one of the major components of the impacting system. At present, work is in hand to change the material selected for this component, so one can hope for a satisfactory outcome. If this is not immediately successful, further choices in materials are possible. The reviewer has in mind the use of maraging steels that combine high levels of strength and ductility, at least in prototype testing (they may be too expensive for eventual commercial manufacturing). Maraging steels have levels of resistance to fatigue that may be lower than their high values of yield stress and ductility suggest, however. Alternatively, case hardening of a steel of high intrinsic toughness could be a solution. On the design side, attention should be given to eliminating all sharp internal corners, and abrupt changes of cross-section. In the final analysis, if no suitable design and material combination can be found, it will remain to de-scope the performance parameters. This will still yield a working device, although perhaps of insufficient performance to impress the potential users.

PI Response:
Thanks for the recommendations and feedback. Several of the material options are being explored and the design details are being addresed.

Reviewer 23478

Comment: There are few weaknesses in this project. One that should be mentioned is the inability of this tool to be effective in drilling soft, compliant (not brittle) formations. In situations where hard and soft units are interbedded, this might require frequent drill string trips to change bits at the cost of time and money.

PI Response:
Percussive hammers are well suited to drilling holes in hard rock. However, the rock reduction mechanisms that work well in hard rock are not as effective in compliant formations. This is true whether rotation is driven downhole or from above. The auto indexer will be effective in the same situations where hammers are effective.

Reviewer 23527

Comment: Nothing significant. The technology is inherently risky but this is high risk, potentially high reward R&D.

PI Response:
Thanks for the comments.

Reviewer 23447

Comment: Percussive hammers, even with the auto indexer, may have depth limitations and not be applicable to all geothermal fields. Since hammer tools are not used extensively in geothermal drilling it may take time to build the confidence of geothermal operators as to the reliability and cost benefits of hammer drills with auto indexer.

PI Response:
This is a very good point. That is also a primary reason to test the tool extensively before deployment. An early failure with the tool would be a huge setback in it's acceptance and eventual use.

IMPROVEMENTS

Reviewer 23433

Comment: No major suggestions are offered for improving the project. The potential problems in design and/or materials selection were discussed above. These may prove to be a non-issue. However, it may be worthwhile to start periodic project reviews with the manufacturer of down hole hammers who is foreseen as an eventual candidate for taking the indexing system to commercialization. This company will no doubt have had significant experience in design and material selection for the hot, corrosive and shock-prone conditions that are encountered in geothermal wells, and insights gained from the company could be very valuable.

PI Response:
We are actively working on that aspect of the project. Thanks for your comments.

Reviewer 23478

Comment: If possible, design a bit that could be rotated (like a tri-cone) as well as hammered so as to avoid having to trip-out frequently in hard/soft interbeds.

PI Response:
That is a good idea and approach, but it is beyond the scope of work for the current project.

Reviewer 23527

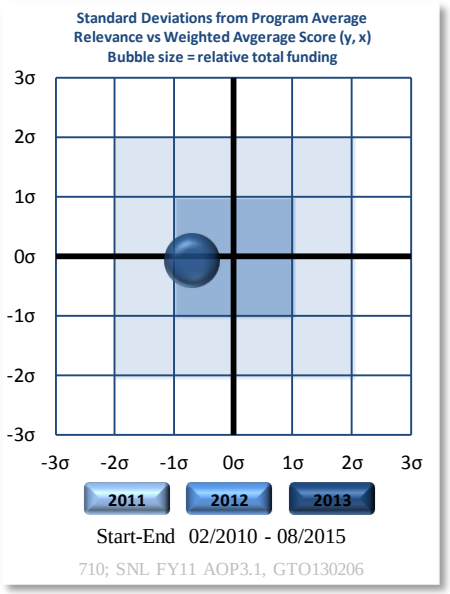
Comment: Incorporate reliability and performance degradation testing in the project scope prior to field trials.

PI Response:
These are considerations for future testing and work.

Reviewer 23447

Comment: Continue to seek out geothermal operators to partner with and together work towards more field testing.

PI Response:
We are actively working on that aspect of the project. Thanks for the comments.



Review: 2013 Geothermal Technologies Office Peer Review
ID: 710; SNL FY11 AOP3.1
Project: Gas Generator Development and Testing for Controlled Rapid Pressurization Using Liquid Propellants for EGS Well Stimulation; Energetic Materials for EGS Well Stimulation
Principal Investigator: Grubelich, Mark
Organization: Sandia National Laboratories
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23409

Score: 10.0

Comment: Very little rigorous scientific research has been done on pressurization of formations for EGS, gas wells, and oil wells. This project is investigating alternatives for ways to do hydraulic fracturing. They are applying a rigorous scientific approach for developing new materials for pressurizing formations, and also to measure their effectiveness.

The approach uses a rapid pressurization to provide shock resulting in controlled fracturing.

PI Response:
Correct. Thank you for the positive comment.

Reviewer 23521

Score: 10.0

Comment: Fracturing and stimulation of existing fractures is of great importance to the EGS systems, and not only. Oil and gas industry are also possible beneficiaries.

PI Response:
We believe there are great opportunities to adapt this technique to hydrocarbon reservoirs.

Reviewer 24895

Score: 8.0

Comment: Creation of a reservoir (fracture volume) is a basic requirement for EGS. This project provides the possibility of creating a large network with energetic materials. It is not clear that it could create adequate fracture volume for a reservoir, but could at least initiate a substantial volume (multiple fractures near the wellbore) which could then be extended. Reliable creation of reservoir volume in the target zone is one of the hurdles that geothermal needs to have

reliable reproducible methods of achieving, irrespective of the differences in formation characteristics. This project holds out the promise of being able to achieve that.

PI Response:
Ideally we will be able to propagate a reaction within each for fracture with multiple stimulation shots. This could produce a large fracture volume.

Reviewer 23567

Score: 7.0

Comment: The method of efficient well stimulation for increasing local permeability and formation of fracturing and extension of existing fractures is highly needed for future large scale EGS projects. The proposed research seems to be positioned for competing with conventionally accepted method of stimulation by hydraulic fracturing and have a potential if significant advantages could be demonstrated. At a first glance the method of using energetic materials may provide simpler and likely less costly methods to achieve goals of well fracturing, however aspects of safety, contamination and smaller process window for achieving optimal parameters may add extra complexity and reduce value of the approach.

PI Response:
Hydraulic stimulation does not necessarily produce multiple fractures. Regarding safety: as it stands the gas phase materials are mixed within the well bore which provides inherent safety, for solid explosive systems the risks are well known and can be managed. Regarding contamination: Reaction products are merely nitrogen, water and carbon dioxide and aluminum oxide for the solid system.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23409

Score: 10.0

Comment: Technical approach appears sound. Includes computational modeling, safety, and performance characterization of the solid and gas materials. Laboratory testing and field testing both were undertaken.

PI Response:
Thank you for the positive comment.

Reviewer 23521

Score: 10.0

Comment: The Scientific/Technical approach for this project seems to be well-thought, proposing to investigate different systems to achieve successful well bore fracturing.

PI Response:
Thank you for the positive comment.

Reviewer 24895

Score: 8.0

Comment: The approach includes 3 simultaneous paths, which increases the chances of success. It leverages the technical knowhow from existing government projects and extends that knowhow for the benefit of geothermal. It has an appropriate focus on safety as the first priority. Past energetic attempts have demonstrated the importance of being able to tailor the pulse to the formation and wellbore dimensions. Variable control on the energy pulse is the second priority after safety. There are significant challenges to moving this to a commercial reality, but the PI's technical approach to getting there is sound.

PI Response:
Correct. We agree that the science and engineering must be completely understood before moving forward with commercialization which will be a challenging task.

Reviewer 23567

Score: 6.0

Comment: The approach is focusing on the development of energetic materials tailored to provide characteristics falling somewhere in between those of propellants and high explosives. The end results are claimed to produce a good control for creating near field / far field fractures by controlling the shock velocity which is the function of energetic material density rather than any other ambient parameter of the well. While the theory of approach is sound and the lack of far field stimulation could be overcome by multiple or staged stimulation processes, the center for the energy release is still localized at a single point and the gradient of pressure along the well is expected to be significant, posing significant challenges for avoiding wellbore collapse. A set of convincing experiments performed in deep wells are needed for proving the method and demonstrating control over stimulation process maintaining the integrity of the wellbore.

PI Response:
Correct. We agree that the science and engineering must be completely understood before moving forward. We have demonstrated loading below the formation compressive strength and have shown that there is no wellbore damage. Far field crack propagation will most likely will most likely occur with injection of reactive material into the fracture. Budget constraints prevent the implementation in deep wells at the moment.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23409

Score: 10.0

Comment: Successful proof-of-concept test at Purdue's laboratories, led to a safe and successful field demonstration. Pressurization data was collected and was being analyzed at the time of writing the report to DOE, along with gas fill and leak-off data. Initial assessment of the field data indicated changes in formation permeability with each test run.

PI Response:
Correct. Thank you.

Reviewer 23521

Score: 10.0

Comment: Several accomplishments and tests reported, with supporting data. Everything seems to advance according to theplan. Patent submitted.

PI Response:
Thank you for the comment.

Reviewer 24895

Score: 7.0

Comment: The project is on target to reach its objective, with no set-backs to date. Progress is in the early stages as yet. Funding, timing and/or technical resources may constrain how far three simultaneous paths can be maintained, but each has some advantages at this point. The gas approach is most able to be tailored to well conditions, but may be limited to low permeability reservoirs, so most applicable to EGS creation and the first system tested in the simulated field conditions. The liquid and solid systems could handle the existing permeability of hydrothermal systems that were not permeable enough, but may be less easy to tailor and/or have safety problems to overcome at high temperatures. I think the 3 simultaneous paths should be continued, if possible.

PI Response:
An excellent synopsis off our approach. Thank you for the commentary

Reviewer 23567

Score: 7.0

Comment: Several energetic material systems have been studied for feasibility and as reviewer understood the gas phase system considered being the most promising as it has required thermal stability with operating temperatures in excess of 400 deg C and provides greater degree of control. Solid phase energetic materials unfortunately proved themselves not useful in prior experiments and produced the conventional wisdom that explosive stimulation tends to create near-wellbore damage. High energy gas fracturing does have hopes if premature ignitions could be avoided as it has potential to avoid wellbore damage and blockage of the well. The reported experimental setup for shallow well trial involved pumping liquids in the well, initiating reaction and controlling the flows. The initial results achieved in the project are quite promising with two shallow well fractures mentioned and increase in the permeability demonstrated. The scale up version of such system for stimulating deeper geothermal well would probably look more like a system for hydraulic stimulation rather than just a “hydro-bomb” based on the description of preformed experiment and in this case a clear advantage evidence over just using water and sand has to be proven. Permeability improvement and its usefulness for establishing commercial production rates in a scaled system are hard to derive from the experimental data.

PI Response:
We are still reviewing data and believe that scale up is possible.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23409

Score: 10.0

Comment: Coordination, management and oversight among the three partnering institutions (Purdue, SNL, and NMIMT) appears to have gone well with each instituion carrying out their tasks as proposed. Project has had some delay but seems to be now ontrack.

PI Response:
Our partners at Purdue and New Mexico Tech have done a great job in supporting the project.

Reviewer 23521

Score: 10.0

Comment: Coordination and project management seems to be in line with expectations.

PI Response:
Thank you for the comment.

Reviewer 24895

Score: 9.0

Comment: The project is properly staffed with a good team and a good plan. Safety, and more importantly, the perception of safety, will be important to the success of the project and is receiving the proper attention.

PI Response:
Thank you for the positive comment. A great deal of attention has ben given to engineered safety.

Reviewer 23567

Score: 7.0

Comment: The coordination and management of the project is reasonable with the project being on track.

PI Response:
Thank you for the positive comment.

STRENGTHS

Reviewer 23409

Comment: Good to science science and a technical approach being taken to gas pressurization of formations. Too little science has been done in the past with the unintended consequences of such technology as hydraulic fracturing unknown because of the lack of science that was done before this technology received widespread usage.

PI Response:
Thank you for the positive comment.

Reviewer 23521

Comment: Investigated several systems (gas, liquid, solid) for fracing. Supposed to be environmentally safe.

PI Response:
Thank you for the positive comment. A system constraint has been low toxicity reaction products

Reviewer 24895

Comment: Good team of experts that do not exist within the geothermal industry. The project is bringing new expertise to bear on long standing problems. Initiating a near wellbore fracture network in the target zone may overcome some of the out-of-zone fracturing seen in the hydraulic stimulations (Newberry).

PI Response:
Thank you for the positive comment. Purdeu and New Mexico tech have add greatly to the success of the project.

Reviewer 23567

Comment: A large degree of attention is paid to determining thermally stable energetic material systems.

PI Response:
Thank you for the positive comment.

WEAKNESSES

Reviewer 23409

Comment: Would like to see additional laboratory and field testing done so that more exact control over pressurization can be obtained, and the results of the proposed technologies on the permeation can be more fully assessed. Three shots does not seem adequate.

PI Response:
We have conducted several more tests all with increasing permeability. The number of tests conducted is based on finacial considerations. With significantly more funding we can conduct significantly more experiments.

Reviewer 23521

Comment: -

PI Response:
NA

Reviewer 24895

Comment: The project is based on energetic chemical reactions. The public, and perhaps the geothermal industry, will read this as explosive stimulation. Permitting hydraulic fracturing has become a public issue as well as the seismic events generated by hydraulic fracturing, so you can imagine that there will be difficulty progressing a successful project to wide-spread acceptance. The project is trying to deal with this reality, but it is a significant hurdle.

PI Response:
We believe we can tailor the induced seismicity to a more than acceptable level. Conventional oil/gas well stimulation routinely uses explosive. We agree that the public opinion must be addressed with care.

Reviewer 23567

Comment: The potential for creating far field effects without wellbore damage are not obvious.

PI Response:
Unlike conventional explosives we are able to limit the near field pressure below that which will cause well bore damage and we can stimulate energetically at the crack tip.

IMPROVEMENTS

Reviewer 23409

Comment: Design of experiments to better assess the effects of the newly developed technologies may provide more complete answers as to factors that better control permeation. However, it may be impractical to do such experiments in the field.

It is good to see new science being developed for fracturing.

PI Response:
Correct. Thank you for the positive comment.

Reviewer 23521

Comment: -

PI Response:
NA

Reviewer 24895

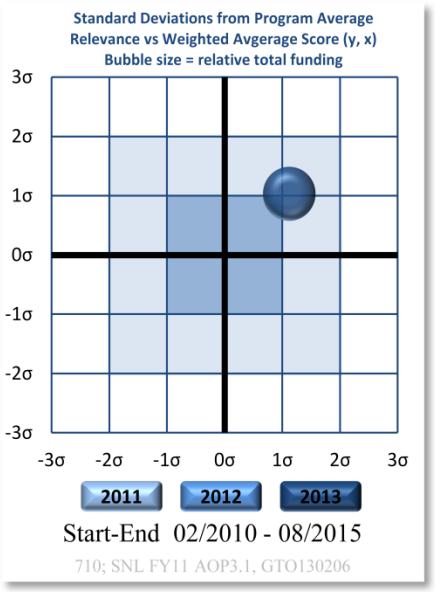
Comment: No suggestions.

PI Response:
NA

Reviewer 23567

Comment: Drop investigations of energetic materials which have potential for wellbore damage (especially solid phase?), rather focus on select material system and try to include investigation of seismicity benefits for comparison with hydraulic stimulation.

PI Response:
We believe we can address the issue associated with solid explosives by controlling initial density ad wellbore coupling. It is too early in the program to eliminate possibilities. Futher experiments are warranted.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002788
Project: Perforating System for Geothermal Applications
Principal Investigator: Smart, Moises
Organization: Schlumberger Technology Corporation
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23409

Score: 1.0

Comment: No information presented. No presentation. No show at peer review.

PI Response:

Reviewer 23521

Score: 1.0

Comment: No presentation materials provided to reviewers.

PI Response:

Reviewer 23519

Score: 1.0

Comment: No submission

PI Response:

Reviewer 23567

Score: 1.0

Comment: PI has not provided materials for review and did not show at the meeting to present.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23409

Score: 1.0

Comment: No show at peer review

PI Response:

Reviewer 23521

Score: 1.0

Comment: -

PI Response:

Reviewer 23519

Score: 1.0

Comment: No submission

PI Response:

Reviewer 23567

Score: 1.0

Comment: PI has not provided materials for review and did not show at the meeting to present.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23409

Score: 1.0

Comment: no materials provided

PI Response:

Reviewer 23521

Score: 1.0

Comment: -

PI Response:

Reviewer 23519

Score: 1.0

Comment: No submission

PI Response:

Reviewer 23567

Score: 1.0

Comment: PI has not provided materials for review and did not show at the meeting to present.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23409

Score: 1.0

Comment: no show

PI Response:

Reviewer 23521

Score: 1.0

Comment: -

PI Response:

Reviewer 23519

Score: 1.0

Comment: No submission

PI Response:

Reviewer 23567

Score: 1.0

Comment: PI has not provided materials for review and did not show at the meeting to present.

PI Response:

STRENGTHS

Reviewer 23409

Comment: no information submitted for this proposal

PI Response:

Reviewer 23521

Comment: None - no material provided to reviewers.

PI Response:

Reviewer 23519

Comment: No submission

PI Response:

Reviewer 23567

Comment: PI has not provided materials for review and did not show at the meeting to present.

PI Response:

WEAKNESSES

Reviewer 23409

Comment: no proposal

PI Response:

Reviewer 23521

Comment: Same as above.

PI Response:

Reviewer 23519

Comment: No submission

PI Response:

Reviewer 23567

Comment: PI has not provided materials for review and did not show at the meeting to present.

PI Response:

IMPROVEMENTS

Reviewer 23409

Comment: no proposal submitted

PI Response:

Reviewer 23521

Comment: Provide presentation and supporting material to reviewers.

PI Response:

Reviewer 23519

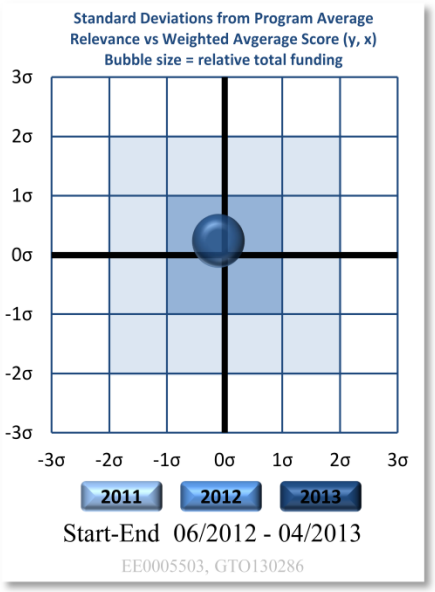
Comment: No Submission

PI Response:

Reviewer 23567

Comment: PI has not provided materials for review and did not show at the meeting to present.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005503
Project: Extreme Temperature (300 C) P/MWD with Energy Storage and Generation, Enabling Substantial Cost and Risk Reduction in Geothermal Exploration
Principal Investigator: Signorelli, Riccardo
Organization: FastCAP Systems Corp.
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23409

Score: 9.0

Comment: Generator and capacitors represent notable progress and impact on the DOE's Geothermal Technologies Office missions and goals as they have been demonstrated to operate at 150 degree C, which is progress toward the goal of 250 degree C.

This is a high temperature generator development project. Goal is to have it functional at up to 250 degrees so as to be applied to geothermal applications.

PI Response:

Reviewer 23521

Score: 10.0

Comment: High temperature solutions for electrical energy generation and storing are desirable for EGS systems. The authors are proposing a solution for providing electrical power for logging and measurements while drilling in geothermal exploration.

PI Response:

Reviewer 23500

Score: 5.0

Comment: High temperature capable energy generation and storage systems are an enabling technology not only for MWD systems, but also high temperature logging and monitoring tools. High temperature batteries have been promised for years, but have yet to reach the commercial marketplace. A 250C ultracapacitor could fill a niche in high temperature downhole energy storage. Successful completion of this project may help enable better resource exploration, but failure does not prohibit the development of new hydrothermal and/or EGS resources.

PI Response:

Reviewer 23567

Score: 6.0

Comment: This project has the potential to have some impact on the goals of the Geothermal Technologies Office. High temperature battery technology if existed would be an enabling technology for high temperature EGS tools to support continuous operation and data logging minimizing valuable data loss in deep and hot geothermal wells. Current battery technologies frequently fail even at Oil and Gas temperatures and will not work at the elevated temperatures found in geothermal environments and this project is proposing to overcome the limitations. Therefore, the reviewer rates the relevance of this project as important. However, the feasibility of capacitor technology has to be still proven at temperatures above 200 deg C and the maximum operating temperature goal of 250 deg C could be not adequately high for most of EGS systems. The operating temperature goal is more suited towards Oil and Gas rather high efficiency high temperature EGS applications.

PI Response:
FastCAP originally proposed a 300C max operating goal, but due to funding constraints (FastCAP was awarded significantly less than was needed to reach the goal), that goal was scaled back to 250C, itself an ambitious goal given the current level of funding. FastCAP is confident that with additional funding and/or resources, it could reach 300C max operating temperatures.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23409

Score: 8.0

Comment: The project team has developed a systematic iterative process for selection of materials, laboratory testing under simulated conditions, and making updates as needed to improve the performance of the power systems under development. However, I would have liked to have seen some computer modeling of designs to help shorten/improve the empirical laboratory work. Would also have liked to have seen FASTCAP develop a requirements spec to predetermine system requirements.

PI Response:

FastCAP utilized MatLab and FEM software to simulate different generator designs prior to the prototyping phase. These were not included in the presentation due in part to their proprietary nature, but also because they introduced a level of detail into the presentation that time limitations did not permit. With regard to the specifications requested above, those are defined in detail in FastCAP's grant proposal and program milestones task table, but were not presented during the presentation due to time constraints.

Reviewer 23521

Score: 8.0

Comment: Incremental scientific advancement is proposed, starting with commercially-available products, and extending the temperature rating from 150C to about 250C. While this is a good approach, the description of the 'Scientific/Technical Approach' is very vague. This may be due to the proprietary information aspects of the project, but it makes it hard to judge.

PI Response:
Much of FastCAP's progress on the program over the last few quarters is in the process of being patented, and therefore is not ready for public presentation in great detail. FastCAP expects to be able to include a greater level of detail with regard to its technical approaches during the next peer review.

Reviewer 23500

Score: 3.0

Comment: There is a different technical approach presented for each phase of this project.

For the energy storage development, the approach is to start with existing FastCAP technology, assess its durability, identify changes to the electrochemical process and iterate on cell construction. This is a very general approach and does not identify areas where FastCAP thinks their technology can be improved. Their existing technology can survive at 175C, but the stated goal for this program is to reach 250C. There are many capacitor technologies that work perfectly fine at 175C or 200C that cannot survive at 250C. FastCAP needs to layout why they think their technology can work at 250C.

The electronics development approach is also presented in a general manner. The statement in the presentation "circuit topology is largely decoupled from temperature & vibration milestones" is quite concerning. A circuit topology that may work 175C or 200C may not work at 250C due to degradation in high temperature electronic component performance. When placed in a circuit, even SOI or SiC parts that are rated to survive at high temperatures can cause circuits to operate differently at high temperatures because of shifting performance parameters. It should not be assumed that a standard power electronics circuit will operate properly at high temperatures just because it is built with high temperature parts.

The generator technical approach is a bit more detailed showing modeling, prototyping and design iteration. A concern in this part of the project is that FastCAP appears to have been founded on their ultracapacitor technology. Generator design, especially high temperature generator design, requires a much different area of expertise. Knowledge of the high temperature performance of materials, metallurgy and the design of rotating machinery in harsh fluid environments are necessary.

PI Response:
The reviewer references capacitors in discussing current technologies that are available at very high temperatures, and it is correct that some capacitors can operate at extreme temperatures. However, capacitor use in the downhole applications FastCAP proposes is impractical and not feasible given size, weight and cost constraints. FastCAP's technology is unique because it offers high temperature performance in an ultracapacitor, which is much smaller, lighter and cheaper than capacitors of equivalent energy densities.

Regarding the electronics, the use of the term "circuit topology" here specifically refers to the aspects of the circuit that are not bounded by the choice of part numbers or values, i.e. a Boost converter may generally be designed to operate at 85 C or at 250 C. Certain topological considerations may come into play as we are limited by component selection or by other secondary aspects, but generally we expect the topology to remain constant and circuit details to change as we traverse temperature milestones. Examples of circuit details that we expect to change include part selection, material

selection, gate drive technique, switching frequency, dynamic response, efficiency, etc. We have surpassed our milestones to date. Further FastCAP is a leader in high temperature power converter design, and is currently deploying these systems for use at temperatures up to 175 C.

Regarding the generator design, the qualification of FastCAP to address this technical area was a in-depth aspect of the proposal process. FastCAP has surpassed its milestones to date with regard to generator development.

Reviewer 23567

Score: 7.0

Comment: The approach of the project scoped well for designing and proving major components of the power system: power generator, capacitor and electronics components. The development of the high temperature capacitor is a critical task and likely to be the core of the project with milestones set for three phases as 175 deg C, 200 deg C and 250 deg C. Due to the proprietary nature of the development it was not clearly explained if last milestone could be easily achieved in the course of the project and if the final target temperatures in excess of 250 deg C is feasible at all. However, the approach is logical and solid and addresses most of the required system components.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23409

Score: 10.0

Comment: The accomplishments, results, and outcomes have been outstanding in relation to the resources expended and progress towards project objectives and technical targets/goals. Project quality and productivity is on target with their stated targeted goals.

PI Response:

Reviewer 23521

Score: 7.0

Comment: The accomplishments/results/progress seem to be in very good shape. The authors claim that the milestones were all exceeded to date. This is hard to judge, as there are no previous information presented regarding the milestones.

PI Response:

Reviewer 23500

Score: 2.0

Comment: There are no concrete results shown in the presentation or write-up for this project. Three high-level accomplishments are shown in the presentation. Development of a 1 W/kg energy generation element, development and commercialization of a 150C energy storage component and prototypes of 200C energy storage components. While the need for IP protection is understood, certainly some graphical results could have been shared. For example, a graph of cell voltage vs time at room temperature and 150C. In addition, some more description of the test apparatus for combined environment temperature and vibration testing would be helpful for judging the validity of the tests.

PI Response:
Much of FastCAP's progress on the program over the last few quarters is in the process of being patented, and therefore is not ready for public presentation in great detail. FastCAP expects to be able to include a greater level of detail with regard to its technical approaches during the next peer review.

Reviewer 23567

Score: 7.0

Comment: Overall progress and accomplishment are quite good given the project is in its first phase. High temperature generator has been demonstrated and high temperature capacitor has been proven for temperatures up to 175 deg C. A missing element seems to be demonstration of accomplishments on the electronic components side, where the reviewer would appreciate progress happening with incremental improvements and temperature milestones similar to ones defined for the high temperature capacitor technology development. The learning derived from refining integration of the power system at lower temperatures should serve as a “breadboard” type concept to design and deliver system rated for a higher temperature.

PI Response:
To date, we have had no milestones due to demonstrate this, however, our downhole products demonstrate working power converter designs upt o 175C. Expect the next reports and reviews to show progress here.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23409

Score: 10.0

Comment: Management of this project has been effective. Milestones are being met on-time, and are on-budget. There are no other entities other than FASTCAP Systems involved in the project.

PI Response:

Reviewer 23521

Score: 8.0

Comment: This section doesn't really come across from the information provided by the team.

PI Response:

Reviewer 23500

Score: 5.0

Comment: It is very hard to judge if this project is on track or not due to the lack of details in both technical approach and results. However, the remaining funding amount of $2.2 million seems low considering the project goals of developing a 250C generator, energy storage system and power converter.

PI Response:
Much of FastCAP's progress on the program over the last few quarters is in the process of being patented, and therefore is not ready for public presentation in great detail. FastCAP expects to be able to include a greater level of detail with regard to its technical approaches during the next peer review.

Reviewer 23567

Score: 7.0

Comment: Project management and coordination appears to be good, with a logical design, testing and development approach defined. However, it could be more helpful if a complete timeline was presented with measurable milestones associated and assigned to specific phases of the project. The development of the system enclosure or casing has not been mentioned during the review, but it is understood that the solution has to be offered by FastCap since final product will be manufactured in house and offered for rental as per commercialization plan described during the review presentation.

PI Response:
There is a relatively rigid presentation template provided to reviewers that they are asked to follow as they put together project information for presentation. The presentation materials are focused on the accomplishments made during a specific performance period, not necessarily the entire project timeline, and all specifications for the entire program length. Perhaps in the future if this comment comes up often amongst peer reviewers, participants could be given a few additional minutes for their presentation to present the entire project timeline and goals to the audience, and a slide dedicated to this information could be added to the template.

STRENGTHS

Reviewer 23409

Comment: Steady progress is being made for the downwell power system. Already operating at 150 degree C.

PI Response:

Reviewer 23521

Comment: The topic of providing electrical power solutions for logging and measurements while drilling is of great interest to the Geothermal community.

PI Response:

Reviewer 23500

Comment: If this project is successful it could provide revolutionary new products for use in high temperature downhole drilling, logging and monitoring tools. Also, the energy storage elements and power electronics could have a broader application in renewable energy grid integration.

PI Response:

Reviewer 23567

Comment: A useful power system platform concept for high temperature energy generation and storage has been developed. The proposed technology holds fair promise for elevated temperature operation and addresses an existing gap in battery technology capable to operate at temperatures above 200 deg C.

PI Response:

WEAKNESSES

Reviewer 23409

Comment: Would have liked to have seen a requirements spec. This would have provided specific targets for functionality for each component of the system.

PI Response:
There is a relatively rigid presentation template provided to reviewers that they are asked to follow as they put together project information for presentation. The presentation materials are focused on the accomplishments made during a specific performance period, not necessarily the entire project timeline, and all specifications for the entire program length. Perhaps in the future if this comment comes up often amongst peer reviewers, participants could be given a few additional minutes for their presentation to present the entire project timeline and goals to the audience, and a slide dedicated to this information could be added to the template.

Reviewer 23521

Comment: The project timeline is poorly presented, which makes the judging difficult.

PI Response:
There is a relatively rigid presentation template provided to reviewers that they are asked to follow as they put together project information for presentation. The presentation materials are focused on the accomplishments made during a specific performance period, not necessarily the entire project timeline, and all specifications for the entire program length. Perhaps in the future if this comment comes up often amongst peer reviewers, A-9

Participants could be given a few additional minutes for their presentation to present the entire project timeline and goals to the audience, and a slide dedicated to this information could be added to the template.

Reviewer 23500

Comment: The main weakness of this project is the lack of transparency in technical approach and accomplishments. A more concrete display of results is necessary to truly rate the status of this project.

PI Response:
Much of FastCAP's progress on the program over the last few quarters is in the process of being patented, and therefore is not ready for public presentation in great detail. FastCAP expects to be able to include a greater level of detail with regard to its technical approaches during the next peer review.

Reviewer 23567

Comment: The reviewer understood that the plan for realization of high temperature power electronics for interfacing energy generator and battery elements is not properly addressed, but definitely requires attention and needs to be determined at this stage to ensure stable project progress in future. The maximum operating temperature goal is set at 250 deg C, which could be not adequately high for most efficient and attractive EGS systems.

PI Response:
FastCAP originally proposed a 300C max operating goal, but due to funding constraints (FastCAP was awarded significantly less than was needed to reach the goal), that goal was scaled back to 250C, itself an ambitious goal given the current level of funding. FastCAP is confident that with additional funding and/or resources, it could reach 300C max operating temperatures.

IMPROVEMENTS

Reviewer 23409

Comment: None

PI Response:

Reviewer 23521

Comment: Provide more detailed info related to the project timeline/management.

PI Response:

Reviewer 23500

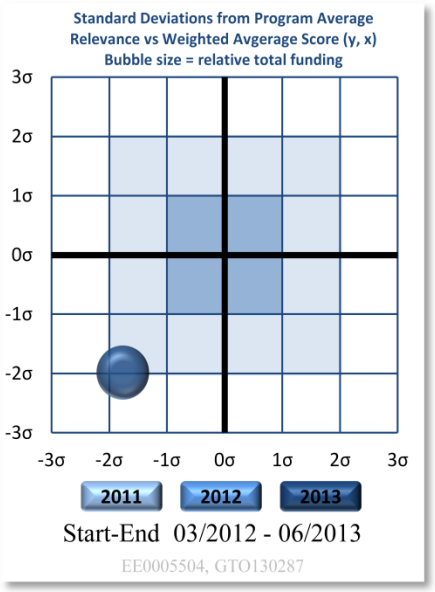
Comment: Partnering with established companies in the high temperature industry during the development and testing of the generator and power electronics could help this project reach its stated goals.

PI Response:
Due to the highly proprietary nature of FastCAP's work at this stage of development, the Company is not currently pursuing outside partnerships. When FastCAP reaches a stage of development where field testing is desireable, existing partnerships with two geothermal drilling companies will be utilitized to further project goals.

Reviewer 23567

Comment: As a suggestion for improvement: establish early if all-SiC based electronics could be feasible and pursue hybrid approaches (include more mature SOI components) in an alternative solution; high temperature packaging of the complete system should not be underestimated and may turn out to be not as straightforward to realize.

PI Response:
We appreciate this comment, and have found that the integrated components present the highest technical risk at these temperatures. However, SOI solutions for the needed integrated components off-the-shelf are available that are rated up to 230 deg C and so we expect that in-house qualificiation and moderate re-packaging can bring these parts to the required spec of 250C. Discrete passives can be sourced off-the-shelf and de-rated for these temperatures. SiC or GaN switching devices or repackaged conventional devices all present active device options for 250C. An all-SiC route is somewhat more risky technically because it requires a full discrete implementation or custom integrated SiC solutions, both of which are not readily available. We believe however that these paths would be required to extend the temperature beyond the scope of this project.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005504
Project: Deep Geothermal Drilling using Millimeter Wave Technology
Principal Investigator: Oglesby, Kenneth
Organization: Impact Technologies, LLC
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23433

Score: 4.0

Comment: There is clearly a need for improved drilling techniques in extracting geothermal energy. The project description notes that some 80% of the total cost of a geothermal project is attributable to the cost of drilling and completing the borehole(s), so anything that can be done to reduce the costs of drilling and completing the required wells will be of major interest. Much work has been done over the years on "conventional" techniques of rock breakage that essentially break the rock by mechanical forces - in either shear by rotary drag bits or under impact, as exemplified by rotary roller cone or hammer drilling, and the technology may reasonably be described as "mature". A case can therefore be made for investigating novel methods for making hole and this is the object of the present project. It is proposed to remove the rock to be excavated by heating, with the heat being supplied by using millimeter wavelength radio frequency energy. The radio frequency energy will be generated on surface and conveyed to the hole bottom using the drill pipe as a waveguide. In its present state of development, the work is mainly concerned with establishing some of the underlying conditions that will eventually determine the feasibility of the method. Current work is thus aimed at establishing how much energy is required to melt or vaporize a given rock, and to establish whether some of the melted rock can be retained on the borehole wall as a glassy lining material. The end product of this phase of the work is to present a feasibility study that will establish the merit of the technology. If successful, there is the potential for developing an entirely new method for drilling geothermal wells.

PI Response:
We are focused on DOE's need for ROP improvements and cost savings on casing/lining. We agree that this project is relevant (our ranking is 10) to the GTP mission and goals, but has had little impact SO FAR (our ranking is 1) since it is early stage research. Thus an average of about 5 appears reasonable.

Reviewer 23480

Score: 3.0

Comment: To my knowledge, millimeter wave (MMW) electromagnetic energy has not been investigated as a potential drilling technique. Considerable work has been done in the microwave and rf portions of the spectrum, and MMW would seem to have the same drawbacks as those systems. This study should help to settle the question of the efficacy of electromagnetic radiation as an energy source for drilling. However, a totally new drilling system is probably not the answer for meeting the GTP's goals, especially a system that is in the most nascent stages of development. Even back-of-envelope calculations showing the potential cost savings of MMW would be helpful in deciding the relevance of this work.

PI Response:
Millimeter wave technology has certain theoretical and real advantages over microwave and rf for drilling and melting rock for creating liners. There are also challenges in using MMW that we are now researching. This is early stage research and the final results nor timing of a successful test are not known.

Reviewer 23478

Score: 6.0

Comment: This purely R&D project is designed to address the GTO objective of achieving a ROP three times that of conventional air drilling rotary rigs. This is to be maintained to depths of more than 10 km and in temperatures of more than 300C. The objective is to lower drilling, casing, and cementing costs by melting/vaporizing rock and using the melted rock as a bore lining material. The goals may be relevant, but not timely. The impacts of this effort will far in the future, with many questions yet to be addressed.

PI Response:
Agree to all this reviewer has stated, but timing is unknown.

Reviewer 23447

Score: 3.0

Comment: Project objective is to further develop micro millimeter wave (MMW) technology to drill geothermal wellbores by melting/vaporizing rock and create a wellbore liner/casing in the process to reduce overall well cost by more efficient drilling and casing/liner cost savings. This technology while innovative has never been used in drilling of oil, natural gas, or geothermal wells. For an extremely complex project with numerous unknowns, it has an extremely short project time frame. Actual field use is anticipated in the far future as a significant amount of technical hurdles must first be overcome for bench testing with field testing an even more complex endeavor. In addition to scientific and technical hurdles, environmental issues should provide major delays to the implementation of this technology. As yet this technology has not been used in any drilling industry, and therefore has no Federal or state environmental regulations. As with the current fracking situation, general public concern about this new technology will most likely be a hindrance in its field application. Therefore, in this reviewer's opinion, the impact of this project is below what could be expected as little progress has been made in addressing GTO's mission and goals.

PI Response:
Actual field tests and commercial implementation may have some regulatory difficulties. As for the current project efforts, it is a complex problem and we have had difficulties in setting up the bench test for efficient operation. We later identified other key bench tests needed and that is ongoing. Progress has been made, but more is needed by the end of the project.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23433

Score: 3.0

Comment: The technical approach to the novel drilling technique is similar in many ways to that of various advanced drilling methods that have been investigated over many years. Several of these may be grouped under the heading of "Thermal rock destruction methods" All depend on generating high temperatures at the hole bottom with the objective of either melting or vaporizing the rock at the work front. Methods for delivering the required energy differ, and have included, inter alia, air/fuel flames, rocket-like burners, electron beams, lasers, electric arcs or plasmas, or simply using an electric current to heat a mandrel made of a suitable refractory metal to a temperature high enough to melt its way through the rock. Many of these techniques were investigated during the 1970s, and the results are well surveyed in the book "Advanced Drilling Techniques" by W C Maurer, published by Petroleum Publishing Co. Tulsa OK (1980). Overall, none of these novel methods has proven successful. There are some problems that are specific to the techniques being investigated, but all of them have several disadvantages that are common to all thermal rock destruction methods. First and foremost, large quantities of energy are required to heat the rock to its melting point, or even worse, to ensure its vaporization. Conveying this energy down hole without loss is difficult in practical situations. The energy and temperatures required vary from rock to rock, whose melting points range from 1,100 to 1,600 C for igneous rocks, to 2,600 C for limestone. Second, there will always be problems in removing the excavated rock and whatever fluid is used to clear it from the hole, in view of their high temperatures. Supposing that the melted or vaporized rock can be somehow absorbed into the hole wall is unlikely to work unless the rock being traversed is extremely porous. Thirdly, most of the techniques require at least a dry environment in which to work, if not a gas-filled hole. Entry of water into the hole, even intermittently, is enough to quench the high temperatures required for drilling. As is common to all stand-off drilling methods, it is difficult to control the diameter of the hole. All of these problems have proven sufficiently intractable that, to the reviewer's knowledge, no thermal drilling technique has been used commercially, with the exception of the use of air/fuel flame drills for drilling taconite. The proposers suggest, as has been advanced before, that some of the melted rock removed from the hole may be left on the borehole walls to form a lining or casing that will seal the hole. This seems unlikely to the reviewer. No doubt it is possible to form a glassy layer on the walls of a hole drilled in dry rock under laboratory conditions, but the reviewer believes that this is unlikely to be the case if the rock is wet, fractured or does not easily form a glass (for example, limestone forms calcium oxide, which will absorb water and turn from quicklime to slaked lime, neither of which has any mechanical strength. Thus, unless the proposed technique is capable of solving these problems, the reviewer believes that while hole drilling by microwaves may be demonstrated in the laboratory, it is unlikely to find commercial application.

PI Response:
We agree with the evaluation of the reviewer as to the prior energy drilling efforts and the problems that they had. However, we do have a few new strategies using MMW, to be tested, that will address the rock removal, fluid influx , low porosity zone lining, even hole diameter and the limestone issues/ problem mentioned. It will take time to prove, demonstrate and field test….and to become commercial. However, we do like banging our heads against the wall…until the wall gives.

Reviewer 23480

Score: 4.0

Comment: The approach appears reasonable, beginning with the basics of bench-scale studies of the key subsystems. Previous studies of electromagnetic drilling systems are not referenced in the project materials available to this reviewer, so the extent to which the project builds on those studies (e.g., waveguide design) is unclear. There are issues of scale that

have not been addressed. The gyrotron used for the laboratory experiments is a 10 kw unit of considerable physical size. A field-capable gyrotron would be sized at 100-500 kw (at least); the physical unit may be too large to deploy without an intense miniaturization effort. The waveguide is a vital component of the system, responsible for delivering the MMW energy to the rock face. This component is analogous to the barrel of a rifle. Studies of waveguide design and materials have apparently not been done---this should be an objective of the laboratory experiments. Melting of the rock face to create a glass casing, while attractive in concept, has proven impractical in the field. The "casing" would have highly variable thickness and composition which could easily lead to breaches especially in saturated zones. The need to maintain "overpressure" could easily lead to fracturing of the rock face that may extend well beyond the affected zone. The potential for interference with the beam from millimeter-sized rock particles in the well annulus is not discussed. Nor is the means to maintain hole gauge with depth.

PI Response:
A 100kW gyrotron has been mounted on a Hummer by the Army. Two MW gyrogrons can be semi-truck mounted-designed by the Army but funding stopped. The basics (materials, size, internal wall patterns, etc…) of waveguides are well known, but understanding the application of that knowledge to drilling is part of this project. Much must still be understood of MMW mode during the drilling or liner formation. Several hole diameter benefits of MMW, not possible with prior technologies, may mitigate (not eliminate) the hole diameter concerns. Variable composition of rock melt formed liners will occur, but strageties have been identified to mitigate that composition concern. The long extension of a fracture during MMW drilling is highly improbable due to the solidification of the rock melt or vapor immediately as it exits the wellbore and encounters massive amounts of cooler rock or fluids. Vapor volumetric expansion at the MMW 'drill' site (ie. at the bottom of the wellbore) will immediately volumetrically collapse in the reservoir into melt then quickly to a solid. Much is stillleft to learn.

Reviewer 23478

Score: 4.0

Comment: Inasmuch as this is a very new concept, never before tried, the proposers have suggested a 4 point initial scientific/technical approach.

1. build and bench test a full MMW system to melt different rock types using the single existing 10 KW, 28 GHz cyclotron (at MIT) .
2. test the melted rocks to learn their suitability for use as the bore lining material.
3. compare the test results with theoretical predictions.
4. attempt to synthesize the MMW drilling and lining with all other aspects of geothermal drilling.

This approach is very "big picture". Many details will have to be addressed as they will inevitably arise. Will there be enough time and money available to do all that will be needed to complete a realistic feasibility study? Finally, while it admitted that water in the bore will be a major problem for MMW drilling, they seem to ignore the fact that geothermal wells are drilled in order to find water, not keep it out !! This seems like a major dichotomy in the premise of this project.

PI Response:
It is challenging. but we will keep working on it. We feel that we will have a basic understanding of how MMW can be applied for drilling and lining wellbores in the earth by the end of the project. Water influx will be a problem that we must prevent/stop and we have strategies for that concern. In HOT ROCKS the rock is dry and water is added afterwards as the heat transfer medium. We expect that we will dry drill a mono-bore to total depth. Possibly also dry drill laterals or minimal water fracture the rock. Once that is done water or CO_2 or other media can be added for heat transfer. No dichotomy here!

Reviewer 23447

Score: 5.0

Comment: While the approach is logical the complexity of the project and number of tasks appear too great for the one year time frame. Major technical hurdles to be resolved are: understanding of transmission fluids above ambient conditions, understanding of MMW generated rock melt as a sealing liner, water impact on MMW power and understanding of drilling systems needed for MMW drilling. Some considerations not recognized include: sealing of the reservoir formation, what happens if liner cracks - how to reseal, and drilling through lost circulation zones (LCZ).

PI Response:
There is a lot of work proposed and even added after we started. It is doubtful that we will have all the answers at the end of this project-most likely we have more questions identified. We have discussed the questions that the reviewer has brought up.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23433

Score: 5.0

Comment: The work done so far has been broadly successful. However, as noted above, the reviewer believes that there are sufficient long-term and inherent problems in developing the technique that the chances of ultimate success are limited.

PI Response:
Our crystal ball is broken, but we remain optimistic.

Reviewer 23480

Score: 4.0

Comment: Results are limited, as indicated by the funding expended to date. Equipment has been designed, fabricated and assembled, however, and more test results should be forthcoming as laboratory work proceeds. Even with a no-cost extension till the end of FY13, meaningful results to guide future work seem unlikely.

PI Response:
We disagree. It took much effort and overcoming several problems to get the bench test equipment working properly. MIT's Paul Woskov should be congratulated for his efforts. The fruits of his effort should be forthcoming.

Reviewer 23478

Score: 5.0

Comment: This group of out-of-the-box thinkers has accomplished a few things of note. They have designed and built the 10 KW gyrotron, a wave guide, a reflected power isolator and protector, and a measuring system. They have designed and built a chamber in which to test gasses at temperatures of 500C and pressures of 5,000 psig. They have also held "brainstorming" meetings during which they identified at least 5 major topics of concern (challenges), not the least of which was the need to keep water out of the bore while letting it in after the bore is completed. It is hard to put a value on the work completed, but it seems to be valued at almost twice the expenditures..... I'm not sure how this was done. It appears as if there is a long way to go before there will be enough data gathered for a full feasibility study, but we will see.

PI Response:
Thank you 23478! Would that then be a 10?

Reviewer 23447

Score: 5.0

Comment: Some progress has been made in developing this technology as a way to create casing/liners while drilling as a scaled down system consisting of the 10 kilowatt, 28 GHz gyrotron, waveguide assembly, reflected power isolator and measurement system was designed, built and bench tested (at 2/3 full power). Progress has also been made in developing lab testing equipment for fluid transmission at elevated pressures and temperatures. Other factors have been identified during this phase such as 1) needing only to melt rock not vaporize it (less power needed), 2) overbalanced pressurized fluid transmission system needed because of heat of system, 3) further investigation of various rock types melts as possible wellbore liners and 4) better understanding of top to bottom waveguide system in real, imperfect geothermal system. Most of these accomplishments remain largely in the theoretical arena with much more work to do to achieve practical applications.

PI Response:
Agree.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23433

Score: 5.0

Comment: Management of the project in the short term has been adequate, However, the reviewer believes that the project managers should have the long term issues in mind, and devote some time to looking ahead of the immediate laboratory-scale work to determine if solutions to the loner term problems inherent in field application can be solved, at least in principle. The reviewer accepts that one must walk before beginning to run, and some preliminary work must be carried out before addressing issues of field implementation, but as was noted above, some of this ground has been worked over before, and the fact remains that in general, thermal rock destruction drilling methods have not yet been successful.

PI Response:
Agree with all stated, but we CAN BE the first thermal rock destruction drilling method success. We just feel that others have taken a few wrong paths!

Reviewer 23480

Score: 3.0

Comment: Not clear why actual expenditures are 1/3 of planned expenses, necessitating a request for a no-cost extension. Impact Tech must depend on MIT for all lab tests; the project participants may not have been well-coordinated. The prospects of completing future work (slide #14) in the projected timeframe (5 months) seem unlikely.

PI Response:
Many problems with the MMW bench test equipment were encountered and overcome. Once problems were encountered during testing, evaluations, redesign of components done, machining new parts, reinstalling and retesting were required. This was done several times. MIT-Paul Woskov must be commended for his effort in getting to this level of MMW testing. Impact's efforts were delayed to obtain MIT results, but evaluation of the MMW drilling system and process identified several known critical variables that the team later decided to test- and this is ongoing.

Reviewer 23478

Score: 5.0

Comment: The management of this project is only fair. It is behind schedule and some very challenging tasks have yet to be started. To date it appears as if only supporting type activities have been undertaken, without the building of the components needed to drill or be integrated into a drilling lab test. I could be wrong. I saw no indication of any go-no go decision points within the report documents. There does seem to be adequate coordination between the partners and with their consultant. There are many critical questions left to be answered before feasibility can be confirmed or denied.

PI Response:
There are no decision points proposed nor required within the 1 year project. There are many critical feasibility questions still needing answers. The PI takes the counsel and will work to get successful outcomes in the project.

Reviewer 23447

Score: 6.0

Comment: The project is behind schedule and under budget. Team collaboration of academia and industry experts is a good idea to share collective knowledge.

PI Response:
Thanks.

STRENGTHS

Reviewer 23433

Comment: The main strength of the project is that it investigates a novel drilling technique that, in spite of the reviewer's skepticism, may yet be successful. It is thus worth something to establish whether a solution can be found where previous attempts have failed.

PI Response:
Agree fully.

Reviewer 23480

Comment: The project examines the feasibility of using a new portion of the EM spectrum for rock drilling. If technically and economically viable, the new drilling system could revolutionize the drilling industry. The approach being taken to evaluate feasibility is reasonable.

PI Response:
Agree fully.

Reviewer 23478

Comment: The only strength of this project lies in the scientific and engineering imaginations and expertise of the proponents and their consultant. The idea is very novel and is a long way from fruition, but if successful, it could change the way drilling is undertaken decades in the future.

PI Response:
Agree fully.

Reviewer 23447

Comment: Innovative technology could save significant drilling expense especially in casing/lining certain portions of the wellbore.

PI Response:
Agree fully.

WEAKNESSES

Reviewer 23433

Comment: In the section reviewing the Scientific and Technical Approach to the project, the reviewer has noted many problems that make him believe that the new technology may not ultimately be successful in the field, in spite of providing promising results at laboratory scale. These issues will not be revisited here.

However, the reviewer considers that in formulating the project proposal, the proposers should have carefully reviewed the existing literature on thermal rock destruction methods, and should have asked themselves very carefully and critically if they have good reasons to believe that microwave drilling technology will really be capable of field implementation. As noted above, although microwave drilling technology itself may be novel, many features of the method are shared by other thermal drilling techniques, and these have eventually turned out to have critical disadvantages. In short, as well as proposing some interesting lab. experiments, the proposers should have included in the proposal a well-argued discussion of the failings of previous thermal rock destruction methods, and a list of good reasons as to why the new approach will succeed.

PI Response:
It should be noted that this is not microwave technology. Millimeter wave technolgy has key differences with microwaves in its transmission and penetration. There are a few Sandia rock melt references that we are only now procurring for review. There are also some non-published techniques we would love to obtain information on, but otherwise we feel that we covered the prior art well. If the reviewer has additional information or references, we would enjoy obtaining them.

Reviewer 23480

Comment: The technology is in its infant stage and not proven at any scale. To reach a field demonstration of a commercial scale drilling system will require an investment of many $millions. DOE or any other investor may not be willing to risk the time and money needed without convincing analysis justifying the effort. This work will not impact any of DOE's near term goals.

PI Response:
Agree that it will not come cheap or easy. Otherwise my crystal ball is broken.

Reviewer 23478

Comment: The major weakness of this project is that it appears to try to preclude water entry into bores being drilled, while the objective of most drilling is to identify water entry points to exploit. Other weaknesses of the project include the great complexity of the equipment being designed and the likelihood of antipathy to the scheme by drilling companies and/or service companies.

PI Response:
All stated concerns are valid.

Reviewer 23447

Comment: MMW drilling technology has safety and environmental hurdles as well as public perception to overcome. New regulations may need to be drafted to monitor/regulate this new technology. LCZ could be problematic. Drilling through reservoir formation is problematic. Reliability and durability of melted rock liner is not verified at this time.

PI Response:
All stated concerns are valid.

IMPROVEMENTS

Reviewer 23433

Comment: The reviewer suggests some experiments that may throw some light on the prospects for field implementation of the microwave drilling method. The project team should obtain samples of rocks other than typical igneous rocks, that are porous and permeable. These might include sandstone, limestone and volcanic tuff. These should be saturated with water and drilled. This experiment should then throw light on what is to be expected under real, wet, downhole conditions. If successful , the experiment should be repeated with the rock blocks standing to full depth in a water tank. This would further simulate a drilling situation in which free water can enter the borehole. Attention should be paid to the energy requirements for drilling and to the condition of the glassy hole lining. Finally, the experiment should be repeated using two rock blocks set one on top of the other in a tank of water, with a half-inch horizontal gap between them, to allow free flow of water into the gap. Note that drilling through a water-filled gap is not an unusual situation in a geothermal well, so that this is not an unrealistic test. Further, note that a regular roller cone or PDC bit would have not the slightest problem in dealing with this situation.

PI Response:
Agree. Some version of such set of tests using millimeter wave technology must be made in the next phase of the development.

Reviewer 23480

Comment: In order for MMW drilling systems to compare with the drilling rates of conventional rotary drilling systems, a generator approaching 4 MW will be required. Evaluation of MMW as a feasible system should be made at or near that power level. Scale-up from the current 10 kW generator may not be practicable. A more powerful gyrotron is needed, and a light, inexpensive, modular waveguide is required. Drill pipe or coiled tubing might be good surrogate waveguides.

PI Response:
Agree that a 2MW gyrotron needing a 4MW electric generator should be targeted as the desirable size, at this time. We believe that we can theoretically scale up to this size using the 10kW system, to be tested further with higher powered mobile 100kW units that are now available. Both steel drillpipe and coiled tubing are considered for use as waveguides, but certain modifications (lining or machining) may be required.

Reviewer 23478

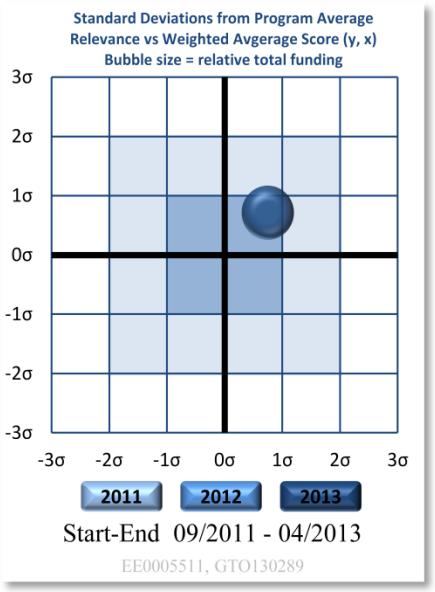
Comment: I believe that all the required theoretical and preliminary design and testing work should be funded by private (venture capital-type) entities. I recommend that the DoE only get financially involved if and when this project reaches the field testing stage. In my opinion this project is too far from practicality for the Federal Government to be investing $1,000,000.

PI Response:
The PI disagrees completely!!!!! From what I have seen in industry and in VC entities, the federal government must be the primary source of funds for advanced technology development through the proving or field test stage. Only at that point of development will industry and VCS become interested, because most of the risk is now out of the development. There are numerous examples of such early stage federal funding that lead to BIG advancements by industry…..coal bed methane large scale slick water fracinf for shale development,…. The service industry has built in resistance due to their existing product lines. VCs hate risk and DO NOT FUND EARLY STAGE RESEARCH. Only end users (DOE, resource develpers, etc…) have vested interests in new technology that lowers cost or allows new opprotunities that provide them an advantage.

Reviewer 23447

Comment: Use project team collaboration to brainstorm about issues listed in weakness section.

PI Response:
We diagree. We have seen it most beneficial where we have technology leaders/ researchers that do not know about the application (drilling) and application experts (eg., drillers) that do not know the technology. I see no way to bridge the understanding gap unless there is collaboration of such groups to come up with solutions to the challenges presented.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005511
Project: Rotation-Enabled 7-DOF Seismometer for Geothermal Resource Development
Principal Investigator: Laughlin, Darren
Organization: A-Tech Corporation
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23409

Score: 7.0

Comment: The 7-DOF Seismometer directly addresses a possible need for high precision seismic monitoring of EGS stimulation activity. It represents new technology, that if is functional, will substantially reduce costs of geothermal well drilling. The device adds a rotational sensor to a linear sensor for a 7 degree angular measurement of seismic activity. The big concern here is whether there is a customer market (demand) for such a device. Market study has not yet been completed to determine the market, so it is undetermined whether there is a market need for the device.

PI Response:

Reviewer 23521

Score: 10.0

Comment: The Geothermal industry is in great need of a seismometer that can withstand the harsh conditions usually present in Enhanced Geothermal Systems. The proposed work is focusing on the development of a seismometer with 7 degrees of freedom, and includes a triaxial accelerometer, a pressure sensor or hydrophone, and an in-house triaxial rotation rate sensor.

PI Response:

Reviewer 23519

Score: 9.0

Comment: The need for mapping fractures during EGS activities is critical. The method of using a surface array of seismic sensors is the only means for mapping fractures being used by the geothermal. This method has the disadvantage of seismic signal loss caused by loose surface material and random surface vibration. The mapping of the fracture is dependent on acoustic modeling of the various rock formations between the seismic source and the array sensors. This modeling can lead to a 10% uncertainty of fracture location. This uncertainty increases the risk when drilling secondary wells intended to intersect the fracture network.

By placing the seismic sensors deep inside geothermal well, most of the surface array disadvantages can be compensated for. The wellbore sensors are removed from most surface noise and in direct contact with the formation being fractured which reduces the dependence of formation models. Finally, the direct coupling to the hard geothermal rock provides for increased signal strength and frequency content. In short, such a system improves fracture mapping and reduces the risk of drilling secondary wells.

On the downside, the cost of deployment and risk of losing equipment inside the well add cost to any EGS project.

PI Response:

Reviewer 23567

Score: 7.0

Comment: Motivational aspects of this R&D effort, benefits of knowing rotational seismic signatures and their value of monitoring in EGS systems were not very well explained in the review presentation. It would have benefited from a clear statement of the state-of-the art seismic sensors available as a large variety of systems and approaches have been already pursued to date. How does sensitivity and accuracy compare to the other type of sensors? Does specified frequency range window is sufficiently broad and the data quality improvement is of additional value for utilizing sensor in the EGS systems?

The main benefit of the system seems to be in the nature of the design where single sensor can replace a whole network of distributed sensors and an increase of the sensitivity and accuracy could be obtained provided the sensor is placed deep enough in the well. Demonstration of high temperature version of the sensor capable to survive and perform at temperatures up to 300 deg C and beyond will have high impact.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23409

Score: 10.0

Comment: Well design development methodology that includes a requirements specification, modeling, materials selection, build, test, analyze, and update.

PI Response:

Reviewer 23521

Score: 10.0

Comment: The scientific/technical approach is sound. The team proposes to develop a seismometer with 7 degrees of freedom, having three main components:
1. a triaxial accelerometer
2. a pressure sensor
3. a triaxial rotation rate sensor.

Incremental advancement is proposed for the first two components. The team plans to investigate commercially-available sensors, and improve their temperature range to conditions more suitable for EGS systems.
The triaxial rotation rate sensor is novel, and based on Applied Technology Associates' (ATA) rotational sensing technologies.

PI Response:

Reviewer 23519

Score: 6.0

Comment: This approach is unique and offers the potential for reducing the cost of wellbore seismic systems. ATA claims the addition of triaxial rotation rate sensors allows for the calculation of seismic wave direction with a single point measurement. Standard practice is to use multiple seismic pods to determine direction. I assume this claim is reasonable given the DOE proposal process requires technical review. A single point seismic pod is significantly easier to deploy than standard wellbore array. Being easier to deploy means reduced operating cost and reduced risk of losing equipment in the well. Reducing cost and risk allows faster commercial acceptance.

ATA is proposing to use the seismic system in shallow wells or wells with temperatures below 200C. The suggested target of 200C is too low for many geothermal reservoirs. Using the seismic system in shallow wells removes many of the advantages of having a seismic system deployed downhole. ATA does not have experience building seismic systems. They are depending on Sandia National Labs (potentially the USGS) to aid in identifying industry requirements. This is good but wider net needs to be thrown. The national labs never deal with the real cost tradeoffs facing geothermal reservoir engineers. All geothermal projects are budget constrained. In the oil industry, such systems are justified because they produce improved reservoir mapping which is converted to reservoir inventory which is given commercial value in billions of barrels of oil. As such, the deployment cost of $150K+for a wellbore seismic system in the oil industry is easily justified. The geothermal reservoir engineer does not have such a clear cut cost/benefit argument. ATA need a geothermal reservoir engineer with experience budgeting geothermal projects on their Technical Working Group.

It's my technical opinion, downhole deployment of seismic systems needs to be in the reservoir formation to provide a favorable cost/benefit ratio over existing surface arrays; to meet this need for most geothermal reservoirs requires an operating temperature >200C and significant well testing.

PI Response:

Reviewer 23567

Score: 6.0

Comment: Rotational measurements are not widely available and this project provides quite unique and maybe more efficient solution for data collection not found in other seismic measurement systems. The approach of identifying the best sensor out of two available solutions is logical and straightforward for the first phase of the project. The transitioning of the prototype from low temperature design to high temperature design is not clear in terms of expected technical challenges and solutions for successful outcome. The target operating temperature point should be rather set as 300 deg C rather than just above 200 deg C as every 25 deg C increment provides significant value added for EGS systems development and also means improved reliability if temperature requirement is de-rated.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23409

Score: 10.0

Comment: Draft specification for the 7-DOF sensor has been completed; a triaxial rotational measurement unit and a Low-Frequency Improved Torsional Seismometer have both been developed and compared with respect to performance. The triaxial unit appears to have better results. Both quality and productivity results have been outstanding. Validated devices with real volcanic seismic activity.

PI Response:

Reviewer 23521

Score: 8.0

Comment: The accomplishments, results, and progress section of this project seems to be more or less on track. I do not see too many results presented at this time. There was no mention of the pressure sensor/pressure measurements. The team plans to investigate higher temperature ranges in the future.

PI Response:

Reviewer 23519

Score: 7.0

Comment: The quality of their work as defined within their project plan is appreciated by this reviewer. They have been gaining a working knowledge of seismic systems and how to apply their technology to the measurement of seismic events. The work in Hawaii is good and complemented by Sandia's technical publication. However, questioning at the Program Peer Review leaves questions as to the amount of effort taken in Phase I to determine the level of effort needed in Phase II to move ATA existing technology to 200C. Questions still exist as to the use of mercury in the sensor and basic electronic instrumentation. Discovery and possible solutions were an objective of Phase I.

Nanometrics has been identified as a future supplier of seismic sensor pods produced by ATA. However, it seems reasonable given the cost and operational advantages given to the 7-DOF seismic measurement tool there should be no issues with finding a US company to add to ATA team.

PI Response:

Reviewer 23567

Score: 7.0

Comment: Feasibility studies for the sensor approach has been completed and a clear decision drawn in favor of MHD system for the sensor design. Sensor technology down-selection, component level development and testing performed to date are reasonable. To some extent this is expected as already established design developed by the company being re-fitted to suite EGS tool requirements. The development of the high temperature sensor design and package in addition to proving the effectiveness of the measurement method scheduled for the next two phases of the project should greatly enhance project accomplishments.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23409

Score: 9.0

Comment: Coordination between ATA and Sandia Labs has been outstanding with ATA doing development work and Sandia to performance testing of the devices. Project start was delayed due to lack of availability of personnel. However, the project has caught up and is now on schedule.

PI Response:

Reviewer 23521

Score: 8.0

Comment: The Project Management/Coordination aspect of this project seems to be in line with expectations. The timeline of the project is not presented very well.

PI Response:

Reviewer 23519

Score: 8.0

Comment: The Go-NoGo is based on having sells of the 7-DOF to justify their cost share. This is a honest realist view. ATA should be aware that their are other developments under this effort which may offer value. One is the Earth rotation sensor which can detect azimuth without magnetics. In geothermal, being able to determine well high-side and azimuth inside casing has value. Also, ATA should consider partnering with a service company on a cost share agreement for supplying a complete EGS fracture mapping program.

It's going to take a lot of work to demonstrating value of in well seismic monitoring This process could take years. So, having a long range plan should be considered. This is a place where Sandia and the USGS could be of help.

PI Response:

Reviewer 23567

Score: 7.0

Comment: The management of the project seems to have been conducted reasonably well. The coordination may need more focused and measurable milestones for achieving temperature performance and reliability. Geothermal applications operate with low margins in challenging hot and harsh environments and the tool capability to operate at 300 deg C and provide meaningful reliability and lifetime are one of the key requirements.

PI Response:

STRENGTHS

Reviewer 23409

Comment: Sound technical development approach. Excellent testing capabilities with testing done at an actual volcanic site as well as through explosive shots.

PI Response:

Reviewer 23521

Comment: A seismometer that can withstand adverse conditions in EGS systems is a really needed tool in the Geothermal Industry, and the 7-degrees of freedom seismometer proposed can be of great use in the industry.

PI Response:

Reviewer 23519

Comment: Reducing the cost of building a downhole seismic system is great. Reducing the instrumentation pods makes the system easier to deploy.

PI Response:

Reviewer 23567

Comment: TRL5 level prototype is included in the plan as a deliverable. Data collection is scheduled in the real well environment.

PI Response:

WEAKNESSES

Reviewer 23409

Comment: Because the described technology has never before been developed, it is unknown how the technology will actually perform in downwell environments. Not sure whether there will be an actual market for the device -- not sure there is going to be actual demand. Original some early schedule delays, but has since made these up.

PI Response:

Reviewer 23521

Comment: -

PI Response:

Reviewer 23519

Comment: Meeting geothermal requirements for higher temperatures will be difficult and currently imcomplete. The market is small and will require testing to develop the market beyond this time period of this project. A longer term effort should be developed to aid in downhole seismic which benefit the long-term DOE effort in EGS.

PI Response:

Reviewer 23567

Comment: There is no early investigation of barriers and enablers for demonstration of high temperature prototype, at least how the review it understood.

PI Response:

IMPROVEMENTS

Reviewer 23409

Comment: Need to complete a market study. Will anybody buy the product??

PI Response:

Reviewer 23521

Comment: I would have liked to see more data from measurements using the developed seismometer.

PI Response:

Reviewer 23519

Comment: ATA should evaluate the effort difference between a 200C sensor package and a 235C. The results may lead to opening the market for more future geothermal projects.

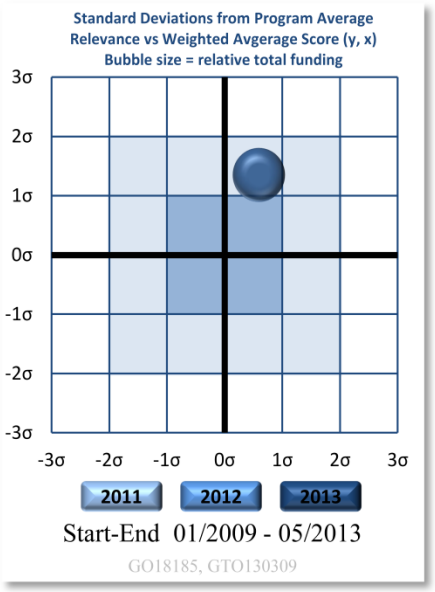
Should add more industry people to the working group to help develop requirements which will aid in industry acceptance. A longer term effort should be developed to aid in downhole seismic which benefit the long-term DOE effort in EGS.

PI Response:

Reviewer 23567

Comment: May look into increasing the frequency range span.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: GO18185
Project: Well Monitoring Systems for EGS
Principal Investigator: Normann, Randy
Organization: Perma Works LLC
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23409

Score: 8.0

Comment: Project is relevant and has impact on the Geothermal industry as it will (if successful) provide a longer-term monitoring of well stimulation activity.

PI Response:

Reviewer 23521

Score: 10.0

Comment: This project deals with a very broad range of tools for well monitoring in EGS systems. Good performance of downhole tools for extended period of times is a quality required in the Geothermal Industry and can save money.

PI Response:

Reviewer 23447

Score: 9.0

Comment: The relevance of this project of producing high temperature logging tools for well stimulation and production well monitoring is crucial for EGS development. The proposed tool is designed to be run into the well prior to stimulation and remain in the well monitoring its production. Accurate real time downhole data is necessary to successfully manage the resource and could reduce stimulation costs. Current high temperature logging tools require logging trucks and have relatively short downhole times. The proposed logging tools if successful will allow downhole production well monitoring for years. The development of a high temperature fluid monitoring sensor is superior to the current mechanical spinner.

PI Response:

Reviewer 23567

Score: 10.0

Comment: This project addresses the development of novel high temperature electronic components needed for building a high temperature down-hole tool to support critical measurements in geothermal wells in addition to exploring existing state of the art components and pushing them to the limit. There is definitely a need for such tools to enable continuous monitoring of well parameters and the impact of project outcome is high. Besides developing a final product with a serious intent for offering it for use, the PI is carrying out a valuable activity of stimulating the supply chain and increasing supplier's awareness of geothermal needs in high temperature electronic components.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23409

Score: 4.0

Comment: Scientific approach is not well outlined or described in the proposal.

PI Response:

Reviewer 23521

Score: 10.0

Comment: This is one of the most complex projects, addressing a suite of tools for EGS systems, that can withstand high pressures and high temperatures in corrosive media. The team is exploring a large number of components, starting with the circuit boards, all the way to high temperature electronic memory storage.

PI Response:

Reviewer 23447

Score: 9.0

Comment: The scientific/technical approach is sound and logical. Careful attention was paid to the many steps of this complex project. Partnering with other geothermal collaborators was integral to the success of this project. Suppliers of specialized high temperature components are needed to build a commercial high temperature geothermal logging system. The PI worked successfully with these suppliers to gain their support.

PI Response:

Reviewer 23567

Score: 8.0

Comment: The approach is relying on existing circuit designs of electronic components based on proved and fairly mature SOI technology developed previously for high temperature applications. Although these circuits didn't find high volume applications and may not provide full functionality and meet lifetime requirements at target temperature of 300C, the procurement is not as challenging, but achievable task, reducing the overall risk of the projects. Besides signal processing electronics, other gaps in sensors, cables, clock, high temperature boards, solders, cables and battery have been actively addressed. This is a well scoped approach researching all aspects needed to build a complete high temperature measurement system.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23409

Score: 4.0

Comment: Sandia Labs dropped out of the project so development of HT solder is now in question; manufacturing issues in producing a HT battery.

PI Response:

Reviewer 23521

Score: 8.0

Comment: The team succeeded in most of their proposed work: 300C circuit boards, >250C digital clock, high temperature electronic memory, high temperature magnetic flow sensors (under test). Some components need additional work, like the high temperature battery and the high temperature solder, and I'm not sure this will be completed by the end date of the project.

PI Response:

Reviewer 23447

Score: 8.0

Comment: Tremendous progress has been made during the course of this project. A number of high temperature components are now available commercially as the result of this project. These included high temperature ceramic circuit board, 300°C digital clock, high temperature memory chip, high temperature cable, and analog EGS well monitoring tool. An actual field test was run successfully using the analog well logging tool developed from this project. A digital EGS well monitoring tool is nearing completion. It was disappointing that the high temperature solder was not completed and

progress on this component is not moving forward. Without the high temperature solder, the cost of the logging tool rated above 285°C nearly doubled.

PI Response:

Reviewer 23567

Score: 9.0

Comment: The results of the project are good. Several outstanding accomplishments include development of flow sensor suitable for continuous operation at 300 deg C in addition to P/T sensor system. As a result a 535A analog tool is now available from Permaworks to aid measurements in geothermal wells, which is easy to use and the tool does not require temperature compensation. To further extend temperature operation a viable circuit board technology was developed and a 300 deg C digital clock demonstrated. Despite several setbacks encountered in the form of delays with sourcing digital circuits, shortfalls with battery and high temperature solders, the project generated a solid platform to be used for integrating improved and updated components in the future when they available, providing intermediate working solution and delivering learning by doing. Slight improvements of the system are expected when novel high temperature components will be available to address identified gaps. Digital version of the well monitoring system prototype seems to be close to completion.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23409

Score: 6.0

Comment: Many subcontractors involved. Not explicit how subs are being managed or how coordination is occurring. Some problems with subs (Sandia dropping out; Electrochemical Systems having manufacturing issues with battery). Sandia's departure is an issue because they received 20% of the funding for a HT solder, and this technology was not developed.

PI Response:

Reviewer 23521

Score: 8.0

Comment: Project management seems well performed. An extension was added (18 months) to address some of the issues not executed in the initial time frame.

PI Response:

Reviewer 23447

Score: 8.0

Comment: Project management/coordination of this project was very good. This was a complex project much was accomplished in a relatively short time frame. Problems were quickly identified and remedied. Good coordination between PI and sub awardees was evident by the success of this project. An 18 months no-cost extension was necessary due to staffing and supplier delays and was approved.

PI Response:

Reviewer 23567

Score: 8.0

Comment: The project coordination has encountered significant delays; however most of critical steps have been addressed appropriately and seem to be scheduled and accomplished by the end of phase 3. It is not surprising that delays were encountered as a large number of single source components being utilized due to the nature of this field.

PI Response:

STRENGTHS

Reviewer 23409

Comment: Innovative device for full purpose well monitoring throughout all production areas of the well including well monitoring before, during and after stimulation without the need for an expensive logging truch. Success building a HT clock, HT circuit boards, and a memory chip for storage of data once powered is turned off.

PI Response:

Reviewer 23521

Comment: Very broad and complex project with great benefit for the Geothermal Industry.

PI Response:

Reviewer 23447

Comment: Project successfully produced commercial, real time, high temperature logging tools (analog and nearly completed digital). The analog tool was successfully tested in a geothermal well. The calibration results were good when the tool was tested. An accurate high temperature magnetic flow sensor is superior to the current mechanical spinner.

PI Response:

Reviewer 23567

Comment: Overall, this is a very good project with a wide range of goals set. The project addresses a large number of components to be developed and variety problems to be solved with majority of the key ones achieved to date. It sets the pace and standards for both high temperature electronic components and sensors manufacturers. Working prototype of the measurement system is now available from Permaworks. The developed technology is a first iteration which will benefit in the future from redesigns utilizing updated components rated to higher temperatures.

PI Response:

WEAKNESSES

Reviewer 23409

Comment: Several components of the system are not functional and it is not clear are being resolved such as the HT solder and the HT battery.

PI Response:

Reviewer 23521

Comment: Some of the components need additional work for the system to be complete.

PI Response:

Reviewer 23447

Comment: Lack of research of the high temperature solder component hinders the cost effectiveness of the logging tools rated over 285°C. The high temperature battery is only rated to 200°C; however, this research is being continued and will be funded by the supplier. Currently if the high temperature electronic memory loses power it needs to be reset with use of a high temperature cable.

PI Response:

Reviewer 23567

Comment: The selected approach may encounter significant difficulties for extending operating tool temperature beyond currently demonstrated 535F without sacrificing performance and increasing costs involved.

PI Response:

IMPROVEMENTS

Reviewer 23409

Comment: This project needs to be much better managed than as currently described. A more explicit and systematic scientific approach needs to be developed and followed.

PI Response:

Reviewer 23521

Comment: -

PI Response:

Reviewer 23447

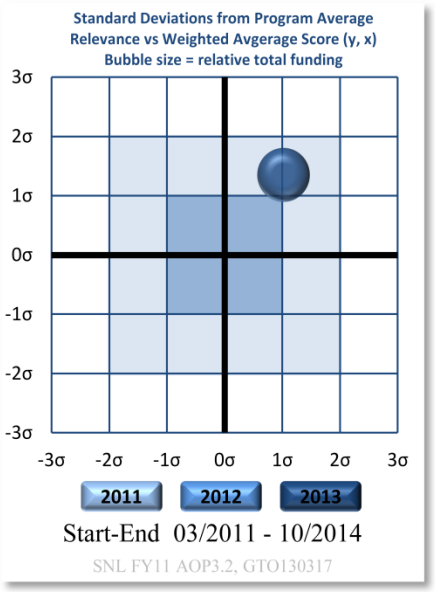
Comment: In the future, please refrain from using inappropriate descriptions in the project summary. On page 4 -"In the photo, the girl is holding the tool." The reviewer found this description offensive. We can all agree if a male was holding that tool, he would not be described as a boy holding the tool.

PI Response:

Reviewer 23567

Comment: Keep working on improving solder technology and look for ways to incorporate wide-bandgap devices and circuits when those are available for improving temperature scalability.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: SNL FY11 AOP3.2
Project: Evaluation of Emerging Technology for Geothermal Drilling Applications
Principal Investigator: Blankenship, Doug
Organization: Sandia National Laboratories
Panel: High Temperature Tools; Drilling Systems

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23433

Score: 10.0

Comment: This is an interesting project in view of its evolution. It was initially directed towards the evaluation and improvement of specific technologies (mud hammers and under-reamers) that were believed to have immediate potential for increasing the rate of penetration while drilling geothermal wells. Over time, the emphasis has changed. It is now believed that greater gains can be achieved by the adaptation to the geothermal industry of techniques and technologies that have already been proven to work in related fields. This activity is clearly of great and direct importance to the geothermal industry, since, as noted elsewhere, well construction costs can amount to 80% of the total project costs when installing a geothermal plant. The present project is interesting and original, insofar as its current emphasis is directed not so much at the development of entirely new technologies, but at discovering and importing into the geothermal industry, technologies and techniques that have been proven to work in related industries. Particularly notable is the realization that not only hardware is amenable to this process of importation, but also methodologies. If such technologies and techniques can be successfully transposed into the geothermal drilling industry, the potential gains are very large by comparison with the effort deployed, This is because little money or effort will have to be devoted to research and development of the new tools, with all the risks that these activities entail. Instead, it should be possible to bring them into the industry with the only effort being the requirement to identify and adapt existing successful devices and techniques that are already in use elsewhere.

PI Response:
Agreed and thank you for the comment.

Reviewer 23478

Score: 9.0

Comment: This project is addressing the need to decrease overall geothermal development costs by more efficiently drilling deeper, faster, and at lower cost. This is being approached by identifying beneficial process changes that can be adopted by the geothermal industry instead of just new technologies. The models for these processes are coming from the O & G, mining, construction, and other industries. They will be studied to see if they can be used to advantage by the geothermal industry with or without modifications. If successful, this project can speed drilling improvements quite quickly and thus really help achieve the cost reductions and project development rate being sought by the GTO significantly.

PI Response:
Agreed and thank you for the comment.

Reviewer 23527

Score: 9.0

Comment: This project is hard to beat in terms of "bang for the buck" for the DOE program. It represents low hanging fruit in some respects, but exemplifies the influence that DOE can have in improving the condition of the geothermal industry at large. The type of operational practice improvements promoted by the project are likely to have a significant near-term impact on reducing drilling costs. The likelihood that the industry would recognize or adopt these practices on its own is low so the beneficial role of DOE would be demonstrated if the project is successful.

PI Response:
Agreed and thank you for the comment.

Reviewer 23447

Score: 9.0

Comment: This research project focuses on examining and improving geothermal drilling process instead of producing advanced geothermal drilling tools. The main focus of this project is adapting Exxon Mobil's Fast-Drill or mechanical specific energy (MSE) monitoring. The working group consisting of academia, geothermal operator, and an oil and gas (O&G) consultant is considering how to adapt the MSE technology and then implement it in a geothermal field. This project is innovative in that the drilling process is examined. To a much lesser extent this has been done in geothermal with success but over a much longer time frame. For example, The Geysers geothermal field has been on line for 53 years and has had about 700 producer/injector wells drilled over that time period (which pales when compared to the number of wells drilled in an O&G field). Drilling efficiency has improved over time with experience, knowledge of different parts of the field and improvements in drilling technology. However, certain drilling challenges remain at The Geysers such as lost circulation zones, under balanced drilling while trying to directionally drill to hit targets, and downhole temperatures exceeding 300°C which will be overcome by improved drilling technology/tools (better mousetraps). This project could improve geothermal drilling efficiency by monitoring MSE in a shorter time frame and then the drilling process can be made even more efficient when coupled with better mousetraps. This project benefits from having direct involvement with an experienced geothermal operator (Ormat) to start field testing immediately. Technology transfer and training is critical for adaptation of this technology to the geothermal industry as a whole.

PI Response:
Agreed and thank you for the comment.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23433

Score: 9.0

Comment: The approach is novel and interesting. Instead of attempting to develop an entirely new technical process or method, the aim is to put effort into finding technologies and methods that have already been developed, have been proven to work elsewhere, and which appear to be directly applicable to the geothermal drilling industry. The potential advantages in terms of cost-effectiveness are huge, since it will, in principle, be possible to avoid all the expense of identifying, developing and implementing an untried new technology. This includes avoiding risks ranging from the possibility that the hoped-for gains offered by the new idea cannot be realized to the very real risk that, even if the technical aspects are successful, acceptance by the end user may not be achieved for reasons of conservatism or prejudice. Of particular note is the fact that the search has been broadened to include techniques of process management using the measurement and interpretation of drilling mechanics parameters. This approach has reportedly resulted in Exxon-Mobil having been able to increase their net rate of penetration by 40% worldwide in the space of one year. In parallel, close collaboration is being pursued with Ormat, a company active in the sector, to make sure that at least one potential end user is fully engaged in adopting the new ideas. This is an essential part of the process for adopting the new technology.

PI Response:
Agreed and thank you for the comment.

Reviewer 23478

Score: 8.0

Comment: The initial survey of new technologies that could decrease drilling costs was not productive. Accordingly, Sandia switched tracks and decided to study processes that if appropriate and implemented in the geothermal industry, could cot drilling costs. Sandia first convened an industry partnership including Ormat and consultants from the oil & gas fields and from academia. The purpose of this group was to determine on which processes the investigation should focus. The outcome of the meetings was to begin by conducting active monitoring of the Mechanical Specific Energy (MSE) on active Ormat wells. MSE = Input Energy/ROP and is calculated using a reported formula. Ormat is now monitoring the MSE of wells that it is drilling in order to obtain background information. They have scheduled an MSE in-house workshop for March 21-23 2013. Sandia and Ormat plan to collaborate, with Sandia providing MSE support to Ormat drilling staff both in and out of the field. The first objective of the Ormat monitoring will be to identify "limiting factors" and then to eliminate them. This is a wonderful example of open collaboration between the National Lab and Industry to achieve a common goal. Hopefully, "limiters" will be found during the monitored Ormat drilling and quantified so that progress can be seen in 2013.

PI Response:
Agreed and thank you for the comment.

Reviewer 23527

Score: 7.0

Comment: The survey conducted for the project is arguably of little value. It is nonetheless appreciated by the reviewer that there has been significant thought put into obtaining results of real, tangible value with real, potential impact. This could have easily been an exercise in identifying and trying to implement what might superficially seem like an "advanced" technology solution that in practice what have had little impact on the geothermal state of the art. The engagement of assorted drilling experts on how to improve technology and practice in geothermal drilling applications, on the other hand, is an excellent approach to addressing the challenge of the project. Convergence on the use of MSE minimization in drilling practice as a field enhanced is a great conclusion and the onboarding of an industry collaborative partner (ORMAT) further strengthens the project.

PI Response:
The first sentence is confusing – if the reviewer is stating that the early work was of little value we generally agree, thus the reason we stepped back and took a broader view.

Reviewer 23447

Score: 9.0

Comment: The project team first looked at technologies used in O&G, mining and construction to see how it could be applied to geothermal environments either directly or with some modification. Two technologies that were considered and then dismissed were water/mud hammers and underreamers as too many modifications would be necessary for geothermal application. The group decided by focusing on the drilling process efficiencies could be realized as seen in O&G and no modifications would be needed for geothermal application. Partnering with an experienced geothermal operator was essential to this project. Training for all drilling personnel was scheduled. Two wells were selected for field trials. Collaboration of working group members is integral to the success of the project to analyze the data, then select and address limiters. The geothermal operator is providing funding for all field tests. MSE monitoring will be coupled with advanced drilling tools as available.

PI Response:
Thank you for the comment - We must clarify that the operator is covering their costs, including the MSE monitoring activities but associate cost at Sandia are being covered through DOE funding

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23433

Score: 8.0

Comment: Progress so far has been good. Early work was concentrated on examining new and developing technologies. This led to the conclusion that the highest potential gains could be obtained not by developing new technologies but by adopting existing, successful ones. To the extent that some time was spent on considering whether to develop new technologies rather than going directly to the search for good existing technologies, it could be argued that some time was lost. However, the reviewer believes that this was all part of the learning process, since an important factor in the decision to go for the adoption of existing technologies was the realization that there were, in the judgment of the project leaders, no novel technologies available that could offer sufficiently high potential returns. The reviewer thus considers progress so far to have been very good, with the significant result that enough important information was obtained to merit the redirection of the main effort.

PI Response:
Agreed and thank you for the comment.

Reviewer 23478

Score: 7.0

Comment: The accomplishments for this project are modest, given that the Ormat field monitoring has only recently been implemented. It is too early to tell what "limiters" may be identified and eliminated. Expenses so far have been less than $50,000, so a great deal has been accomplished considering the low cost. This project has great potential. Only time will see what can really be accomplished.

PI Response:
Agreed and thank you for the comment.

Reviewer 23527

Score: 9.0

Comment: Results to date seem reasonable, particularly given that there has been almost no money spent on the project to date!

PI Response:
Agreed and thank you for the comment.

Reviewer 23447

Score: 9.0

Comment: A wide scope of possible emerging technologies was quickly narrowed to MSE monitoring. MSE monitoring is currently being used in a geothermal field and the data is being collected to be analyzed. Limiters will be identified and addressed. This information will be used in while drilling the next well. The process will be repeated and drilling efficiencies monitored.

PI Response:
Agreed and thank you for the comment.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23433

Score: 8.0

Comment: The project management has been good. A critical reason for the change in emphasis was the engagement of Mr Fred Dupriest, formerly of Exxon-Mobil. His joining the project provided the team with an important new perspective, not only as concerns the overall direction of the project (the search for adaptable existing technologies as opposed to the invention and development of new ones), but also in the identification of the "Fast-Drill" drilling management process. The project managers are to be commended for this open-ness of view and their willingness to consider an approach that was not envisaged initially.

PI Response:
Agreed and thank you for the comment.

Reviewer 23478

Score: 8.0

Comment: The management of this project for Sandia has shown great flexibility in switching focus from pure technological improvements to a search for process improvements that could materially decrease drilling costs. They have created an excellent industry panel and a perfect industry drilling partner with whom to work. Costs are far below budget and the work is more or less on schedule.

PI Response:
Agreed and thank you for the comment.

Reviewer 23527

Score: 9.0

Comment: The project seems organized. The right folks are involved. There appears to be a good plan in place.

PI Response:
Agreed and thank you for the comment.

Reviewer 23447

Score: 8.0

Comment: Coordination between group members is very good. The success of the project depends largely on the MSE training process and assuring “buy in” from all participants. The direct involvement/funding from the geothermal operator are also an important factor in the project’s success.

PI Response:

Agreed and thank you for the comment.

STRENGTHS

Reviewer 23433

Comment: The reviewer considers the project so far to have three major strengths. The first has been the willingness of the management team to take a broad perspective of the task allocated (increase the effectiveness of geothermal well drilling). This has resulted in an evolution of the project from looking at candidates for developmental research to the idea that much cost-effective progress can be made by seeking out and adopting existing technologies. The second lies in their having identified a suitable existing technology (the "Fast-Drill" drilling management system). The third strength is that they are maintaining a close contact with at least one potential end user (The Ormat company).

PI Response:
Agreed and thank you for the comment.

Reviewer 23478

Comment: In my opinion, the strength of this project is that it is exemplifying inter-entity cooperation and collaboration that should have begun years ago so as to optimize drilling procedures that slowly evolved from the O&G industry since the 1960s. By tapping into new strategies being successfully employed by Exxon-Mobil and transferring them into the geothermal realm, hopefully, rapid progress can be made. For too many years, resource companies have kept their :proprietary" processes to themselves so as to stave off competition. Maybe this Sandia initiative will begin to change that mentality and the geothermal industry will be able to benefit from "imported processes."

PI Response:
Agreed and thank you for the comment.

Reviewer 23527

Comment: High probability of impact based on effective leveraging of techniques employed widely in O&G. Direct involvement of O&G folks that were instrumental to the utilization of the approach in O&G is a tremendous asset.

PI Response:
Agreed and thank you for the comment.

Reviewer 23447

Comment: Focusing on the drilling process can provide efficiencies and be accomplished in a very short time frame with partnership with a geothermal operator. Through good technology transfer this methodology can quickly be made available throughout the geothermal industry.

PI Response:
Agreed and thank you for the comment.

WEAKNESSES

Reviewer 23433

Comment: One possible criticism of the project lies in the question of whether the work being carried out is truly "research", since the likely outcome of the project will be no new technology but rather the adoption of existing technology that was developed elsewhere. The Department of Energy may consider that funding for such activity should thus be obtained elsewhere. The reviewer does not subscribe to this view, having in mind the fundamental objective of the program, which is to improve the efficiency of geothermal well installation and operation. This is the over-riding objective, and should be pursued by whatever means seem the most effective. This approach seems to have more merit than investigating new technologies simply because they are new, in spite of the fact that some such candidates can probably be eliminated a priori because of fundamental limitations imposed by considerations of safety, problems of integration with existing well-drilling methods or simply the limitations imposed by the underlying physics.

PI Response:
Agreed and thank you for the comment. Similar to the reviewer we believe this is an appropriate use of DOE GTO funds and a proper model for govermental support.

Reviewer 23478

Comment: The only weakness that I see is the risk that MSE monitoring will not successfully identify limiters and that little drilling savings will be realized. Risk of failure is not really a weakness, so maybe it does not belong here. I think that given enough time and field work, this project will have few if any weaknesses.

PI Response:
Thank you for the comment. We believe that MSE monitoring will (has) identify that drilling efficiencies are less than optimum in current drilling practices. The risk in our view is whether a company can maintain the resolve to address these inefficiencies.

Reviewer 23527

Comment: none obvious

PI Response:
NA

Reviewer 23447

Comment: Specific drilling conditions vary from field to field and often within a given field. The general concept can be used throughout the geothermal industry. Training and assurance of drilling personnel “buy-in” as well as expertise in analyzing the data and identifying/addressing limiters is critical in the success of the technology.

PI Response:

Agreed and thank you for the comment.

IMPROVEMENTS

Reviewer 23433

Comment: No improvements are suggested. However, if successful, the current approach, of searching for and adapting existing technologies to the needs of the geothermal industry may perhaps be broadened to examine not just drilling technologies, but also activities in related fields, such as completion and stimulation methods and instrumentation of all sorts. In view of the recent widespread expansion of fracturing technology for oil and gas extraction in tight formations, is there some scope for seeing what could be learned from the petroleum industry in this respect ? Fracturing to increase reservoir accessibility is a perennial issue in geothermal reservoirs. In high temperature instrumentation, how about a systematic search for suitable techniques in other industries that deal with high temperatures and harsh environments (Engine monitoring, the chemical industry, weapons, the nuclear industry ... and extending the search to activities in these fields in other countries) The reviewer understands that managers of current R & D projects are expected to have an awareness of activities in their own and other fields, but he has in mind the establishment of projects whose explicit purpose is the systematic search for adoptable technologies, rather than relying on a series of informal contacts as is usually the case at present)

PI Response:
Agreed and thank you for the comment. If the project progresses as we plan the intent is to broaden the scope beyond the current area of focus.

Reviewer 23478

Comment: It is recommended that the findings from the Ormat field monitoring of MSE be made public as soon as possible after their realization so that other drilling companies in the geothermal business can benefit. I can see where drilling plans designed by several consultants could change significantly to spread the "new" more efficient procedures throughout the industry.

PI Response:
Agreed and thank you for the comment. If the project progresses as we plan the intent is to broaden the scope beyond the current area of focus.

Reviewer 23527

Comment: Nothing obvious to point out at this point.

PI Response:
NA

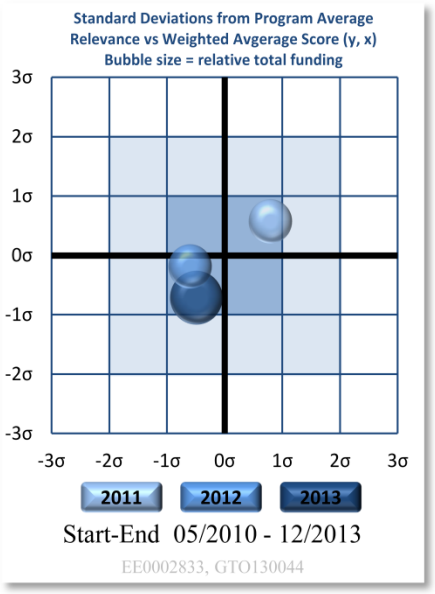
Reviewer 23447

Comment: None at this time.

PI Response:
NA

Innovative Exploration Techniques Reviewer Comments and Principal Investigator Rebuttals

Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002833
Project: Validation of Innovative Exploration Technologies for Newberry Volcano
Principal Investigator: Waibel, Albert
Organization: Davenport Power, LLC
Panel: Innovative Exploration Techniques



RELEVANCE/IMPACT OF RESEARCH

Reviewer 23537

Score: 3.0

Comment: To date this project has combined fairly standard exploration techniques with a few other techniques that have provided results ranging from ambiguous to none. Several fields have mature micro-earthquake (MEQ) arrays and continue to employ cutting edge algorithms to refine structures and fluid flow pathways. The application of LASEA in this project didn't seem to reveal anything beyond an ambiguous linear signal. Also, It is also difficult to consider the flanks of active volcano a "blind" system as a heat source and previously drilled wells with heat are nearby.

Work to date has not really furthered industry's understanding of how to evaluate blind systems. Consequently the overarching GTO mission of advancing developing/validating cost-competitive tools toward accelerating industry growth has not been achieved. Most importantly, the presenter/PI wrote and stated that current "economics" really hinders the future of this project and that this project is "ideal" for EGS (presumably because no fluid flow conduits (faults, other permeable ground) have been identified.

This project unfortunately deserves a rating of 3 and deserves careful consideration for being defunded and cancelled.

PI Response:
This comment covers a lot of ground. First, with regard to the "Blind" system. The ideal use fo the term is to refer to a thermal anomaly with no surface indications of the heat below. That does fit the west flank of Newberry Volcano. As stated in the grant proposal, a thermal anomaly was identified through temperature gradient holes drilled on the upper western flank of Newberry Volcano, an area with no surface indication of the presence of any subsurface heat. The purpose of this effort has been to try to deliniate the anomaly, to attempt to understand why the heat was there, to investigate the anomaly, to identify a possible hydrothermal system, and to work with a combination of tools, including the newly-patented Apex Highpont micro-seiemic monitoring technique, for the purpose of evaluating how this combination of tools worked in deliniating a truely blind thermal anomaly in volcanic terrain.
It seems unlikely that the reviewer is suggesting that any reaearch done for testing and evaluating exploration tools for deliniating blind geothermal resources be done only in areas that there is no reason to think that there is anomalous thermal energy.

A review of published information regarding micro-earthquake arrays employed in the US show them to be just that, micro-earthquake arrays rather than micro-seismic arrays. They are looking at micro-earthquakes as changes in rock stresses within a producing field or with injection programs. They are not designed nor intended to detect microseisms produced by fluid moving through natural fractures at depth, and the design of these arrays would not have the geometry to 3-dimentionally plot fluid flowing through natural fractures. This description had been presented in the Davenport grant application.

With regard to the Apex Highpoint LASEA program, the results presented were for the first of two arrays. The program was changed, with the test being divided into two arrays, one to the south and one to the north. This change in program was done in order to accommodate testing done by the overlapping DOE-supported EGS program taking place on a segment of the west flank of the volcano. The completed array to the south, the reported on, was done in an area with no ancillary data, just a blind test. The results were what they were. The second array is now scheduled to take place in late August of this year. This array is located in the area near deep exploration well 46-16, the well that did intersect hydrothermal fluid. This second part of the program will be done with the pressure in well 46-16 being bleed off and the well open to atmospheric pressure for a number of hours, and then closed back in for a number of hours. This cycle will be repeated three times. The true test of the LASEA technique will be to see if the changes in pressure can be seen by the monitoring array as the pressure change moves back along formation fractures. The cycle will be repeated in order to look for signals peculiar to repeated changes in pressure. Only at the completion of this second array will the process be open for critical review as to its ability or lack of ability to detect in a 3-D form geothermal fluid flowing in subsurface fractures.

The low price for natural gas has affected the short-term economic viability of this project. Likewise it has, for the same reason, affected the current economic viability of most geothermal exploration projects in the U.S. A number of geothermal companies are under the directive "no more drilling until a power purchase contract that provides the producer with a profit margin is signed". This problem, therefore, is not unique to the Davenport program. The financial investment companies funding the program have cut off additional funding until an economically viable power production market returns.

The results of the Davenport program to date has shown that the upper western flank of Newberry Volcano is underlain by high temperature. It has shown that the area in the vicinity of well 55-29 is fractures, though there is no evidence of hydrothermal connectivity to these apparent isolated fractures. This area, therefore, is demonstrably ideal for EGE research. Well 46-16 did intersect hydrothermal fractures and fluid. This area is, therefore, demonstrably suited for conventional geothermal exploration, and is not suitable for EGS. The area around well 55-29 is a remarkably suitable EGS site in that it is known to be underlain by very hot rock, road access is excellent, and socially acceptable use of the area for geothermal purposes is established by law in the Monument legislation. While the Davenport team is addressing the hydrothermal potential of the Newberry Volcano flank, they have no interest in, and see nothing scientifically to be gained, by ignoring the value of that portion of the flank that is ideal for EGS; and their recognition of that portion the area that is ideal for EGS provides no basis for one to propose that there is not also a valuable hydrothermal target identified.

As stated in the review presentation, the financial backers for this program had already decided to terminate the funding for any additional work until such time as the economic viability of geothermal power plant development changes. To this end they have been working with DOE staff to bring the project to a reasonable, though truncated, close.

Reviewer 23478

Score: 8.0

Comment: Because most geothermal prospects having overt surface signatures have been explored, this project addresses the very real need to seek and characterize blind prospects. The project utilizes multiple old and some new (LASEA) techniques, integrates the results of these studies, includes the results and interpretations of older work, and is resulting in a dynamically changing, flexible model of the target area. As a result, the characterization of the Newberry Volcano is being significantly revised.

To date, the impact of the ongoing (30% complete) research has not had a major impact on the geothermal industry, exploration costs, or on market barriers, however, when completed and validated by drilling, such impacts will be considerable. Of note should be the cost impacts of funding delays, drilling complications, and permitting obstacles.

The exploration approach being taken in the project should be replicable in volcanic areas world-wide, thus decreasing the time and expenses involved in their exploration.

PI Response:

Reviewer 23404

Score: 8.0

Comment: The project utilized a fair number of methods in assessing this site, clearly the project was well positioned to make such an assessment. The presenter indicated that all the methods together were needed for the assessment and that there were no clear risers. This is a bit worrisome, as not all projects are allowed such a luxury. I was hoping some ranking would be developed, as practically speaking, everyone will not be allowed to utilize all resources extensively.

PI Response:

Reviewer 23401

Score: 5.0

Comment: Potentially high impact. Lack of results due to external factors and lack of clarity in explaining any integration between methodologies rather severely attenuates the actual impact.

PI Response:

The presentation did lack reference to this very important issue. It is hoped that the final report will provide clarification to readers.

In a pecking order of value, the tools that worked best were temperature and gravity. LIDAR, not part of the original proposal, became available and was integrated into the program, and turned out to also be of critical importance. MT, as interpreted by the geothermal community for decades (the "mushroom" model), would have lead to wells drilled in areas with no potential of hydrothermal discovery. However the team increased the density of MT stations and completed a number of re-processing iterations. The results of this "unconventional" processing of the data produced extremely valuable shallow (<1..5 km) structural data. This data set, integrated with LIDAR and lithologic and mineralogical data from existing wells, really changed the understanding of the volcano, and provided valuable insight as to why the area

around well 55-29 had no interconnectivity of fracturing, and why the area around well 46-16 did have fracture-hosted geothermal fluid.

Please refer to the paper presented at the 2013 Stanford Geothermal Workshop for details. Also all reviewers and DOE staff are heartily invited to the Newberry Volcano Scientific Symposium, to be held at the USFS facilities in Bend, Oregon on 22 and 23 August 2013. This scientific symposium is a direct outgrowth of the DOE/Davenport-coupled research on the volcano.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23537

Score: 3.0

Comment: The integrated application of mapping, LiDAR, MT and gravity in volcanic terrain is tried and tested. The LASEA passive seismic "technology" has added nothing to date. This reviewer does not agree that the revelation of a dynamic magma chamber at Newberry ("sauntering") has added significantly to the body of knowledge. The closing slogans (DON'T rely on preliminary interpretations of data; "Exploration is teamwork") are definitely true and should be reinforced by leadership when a questionable mid-level management team is in place; however, these are hardly summary comments in a funded project designed to validate innovative technologies and forward/accelerate the industry.

If funding were designed to assist in the identification of drilling targets for hydrothermal at Newberry and didn't necessarily need to meet some "innovation" threshold, then the combination of traditional mapping and potential fields geophysics and LiDAR would be a great start. However, the technical approach requires a robustness in results to date which just aren't there.

PI Response:

There was an obvious failure to communicate at the presentation, and the use of the term "sauntering" seems to have hit a negative nerve.

At no time was it the intent to present a magma chamber that was moving geographically. The current presence or absence of a magma chamber is not addressed and is really of little consequence to the exploration for geothermal resources on the volcano. The data show a migrating pattern of pluton emplacement over time, each of which could be considered having been a separate "magma chamber" at the time of emplacement. The migration of these pluton emplacements does not follow a straight line. Rather, the pattern seems to be oscillating as it moves eastward. The oldest plutons, to the west, are cool and are likely of reduced interest for geothermal exploration. The younger plutons to the east, under the upper western flank of the volcano, contain substantial heat. We now can have a certain amount of confidence that the underlying thermal anomaly under the upper western flank of the volcano can be attributed to younger plutons. The presence or absence of a magma under the current caldera is of academic interest only, as the Monument is off-limits to geothermal exploration and development.

As Heiken published in the early 1980s, the greater percentage of heat loss from a typical pluton is from conductive cooling, and a smaller percentage of heat loss is from convective cooling. The issue is to try to figure out what parts of the pluton are conductively cooling, and where the convective cooling might be taking place. Of no little importance, the "team effort" showed that the longstanding MT panacea produces an erroneous model for the Newberry Volcano project

area. The team has been able to identify specifically why this long-used model is invalid at this setting for identifying an active geothermal system. The work has also been able to provide insights as to why the area around well 55-29, and similar settings on the volcano, are best for EGS, with a low likelihood of a hydrothermal system.

Financing was available for only 30% of the proposed program. Maybe the limited results have shown a bit more than 30% robustness, though certainly not 100% robustness.

Reviewer 23478

Score: 8.0

Comment: Though two of the slides contained under this section of the full presentation are missing legends and the slide related to the LASEA survey is almost unreadable, the scientific approach on this project has been excellent. Multiple techniques are being used, their results integrated and there has been a lot of on-going communications between management and the field workers so as to optimize data acquisition.

There have definitely been funding delays and other problems, but considering the challenges thus imposed, the amount of new data acquired is impressive. It has enabled better focus on areas in the volcanic complex previously given lower priority, and has greatly improved the chances of drilling successful wells.

PI Response:

The slides did leave ample room for improvement.

Reviewer 23404

Score: 8.0

Comment: The scientific/technical approach was well designed, as indicated above a number of methods were used. In using geophysical methods, it became unclear to me why the reprocessing of data continued--it seemed that the reprocessing continued until methods showed similar results? It was also not made clear which methods represented the highest confidence levels. The project had, in my judgement significant resources, yet, from the last slide, indicates that not all information for this work has been yet gleaned.

PI Response:

The reprocessing occurred with the MT data. The first pass was done by the geophysical company using the standard 3 layer approach, which really provided little insight. Additional MT stations were added to increase the density on the upper western flank. The company was then asked to process the shallow depths with much greater resolution than the standard "geothermal" approach employed. Note that mineral and oil and gas exploration programs do not process MT for the same model that is done for geothermal companies. Taking advantage of the higher station density, the MT data actually was able to show structural off-sets in remarkable detail. The quest was not to keep reprocessing data until it fit an preconceived idea. It was to process the data more like other industries do, and pay attention to the details at shallower depths where MT can provide highest resolution. The geometry of the MT technique provides progressively less resolution with depth, regardless of station density. With the much better shallow resolution the MT results were then integrated a second time with the other geophysical data. It was at this time that things really began to fall into place and

the team was able to understand how earlier volcanic structures were affecting geothermal exploration, and better explain the results of both wells 55-29 and 46-16.

The results show that the model used for what was going on under the western flank prior to the DOE/Davenport program was wrong, and the long-standing MT interpretation model was also wrong. The resulting conclusions are a posteriori not a priori.

Reviewer 23401

Score: 6.0

Comment: Presentation and summary never quite got to the point of addressing the objective of integrating technologies.

PI Response:

Yes, the presentation was deficient. An attempt will be made to resolve these things in the final report.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23537

Score: 4.0

Comment: The acquisition and interpretation of MT and gravity are solid and additive. In an outcome driven project with multiple steps, these are solid first steps. While the images in the presentation illustrated a great, regional overview of this important volcano, they weren't effectively applied in any innovative way nor were they explained at all.

On the basis of generating a solid MT and gravity data set that other workers may use, accomplishments to date on this project rate a generous 4.

PI Response:

Each annual review report is applicable to the work done in the previous year, not a composit review of all results to date. The reviewer seems to be handicaped by not having been attending earlier reviews. The reviewer seems not to have had access to the Davenport publications to date that this program produced.

Reviewer 23478

Score: 7.0

Comment: To date, the project has accomplished largely all of the objectives set out initially, which is good considering the very significant delays imposed by funding constraints and some drilling completion problems. The fact that ~30% of the planned work has been finished using 29% of the initially requested funding is impressive.

The model of the volcano has been changed considerably as a result of interpretations made possible by data from the MT, seismic and petrographic studies augmented by mining and alteration expertise provided by several of the investigators.

It is very likely that all of the information gleaned via this study will be put to use by the EGS study under way in the same volcanic complex.

There is still 70% of the work to be done. If the quality and timeliness of the project continues, the planned accomplishments should be achieved.

PI Response:

Reviewer 23404

Score: 8.0

Comment: It appears that this project team, as represented, was extremely set on developing high quality work products. They were quite productive in developing each of the work products and discussed and communicated the ongoing work to each other and outside the project for feedback. They completed goals to the extent appropriate.

PI Response:

Reviewer 23401

Score: 6.0

Comment: Stated various conclusions, mostly negative, about magnetotellurics (MT), but did not justify those conclusions in enough detail.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23537

Score: 7.0

Comment: This is a difficult category to assess because the effort required for the permitting phases of this work to date can be nightmarish. Nevertheless these hurdles were overcome. However, the PI also stated and wrote that the primary industry underwriter to this project has lost their interests and funding to further support this work.

This reviewer essentially heard the PI announce that this project probably doesn't deserve any future funding. A good PM will tell management when to quit. I believe this PM is telling DOE to quit. On that basis as well as work, technical and

non-technical, accomplished to date, the PM rating for this is a solid 7 and possibly 8. Hopefully DOE heeds the suggestion of the PI.

PI Response:

There seems to have been some miss-communication here. The Davenport team ardently believes that the project deserves to be funded to completion. The financiers funding Davenport however, do not see the near-term monetary return on investment, not only for this project, but got any geothermal development project in the US at this time. This opinion is based on current contract prices offered by utilities. They can generate very cheap electricity currently by building gas-fired generation. These financial companies owe their investors a return on investment, something they do not see for geothermal exploration projects in the near future in the US. They, therefore, have established a stop-point for continued funding of their geothermal project.

No one has lost interest. What has been lost if financial incentive. DOE was not told to quit. DOE was told that company matching funds were coming to an end, bringing DOE matching funds also to an end.

Reviewer 23478

Score: 7.0

Comment: The project team is excellent and their coordination has been constant. Spending has been very well controlled, but progress has been slowed by funding problems and investor apathy. Future plans appear to be modest as outlined in the presentation, being limited to upgrading of the model and completion of MEQ work in the northern part of the interest area.

The project proposers have now been integrated with Alta Rock Co., so that management may be changed somewhat. It is therefore not certain whether the management efficiency will continue to be high.

The presentation failed to address decision points, so no conclusions can be drawn regarding their appropriateness.

PI Response:

Reviewer 23404

Score: 8.0

Comment: It appears that the project folk are sharing their data and information with a sister project, a university and DOE, all commendable. As well they have and will share the information with the public and the technical community.

PI Response:

Reviewer 23401

Score: 4.0

Comment: External corporate problems are severe.

PI Response:

STRENGTHS

Reviewer 23537

Comment: Solid MT and gravity. Newberry is a worthy exploration target.

PI Response:

Reviewer 23478

Comment: The strengths of this project lie in the identification and application of a combination of old, proven, and new innovative exploration techniques to delineate drilling targets in a totally blind geothermal prospect area. Because previously undertaken drilling did prove the existence of very high temperatures, but no permeability, some characteristics of the volcano had been assumed. The current project is trying to create a new model based on reliable data acquired in carefully designed field programs so as to validate or invalidate all or parts of the pre-conceived regional model. An open mind is being kept during the search for positive (or negative) geothermal indicia.

The project participants are all highly skilled and experienced. They have been operating under difficult financial conditions and have accomplished a lot. If the management team is allowed to continue without adverse input from the new project managers, then the existing project strengths listed above should continue.

PI Response:

Reviewer 23404

Comment: The strength of the project is its integrated approach utilizing many technical methods. As well the project has sought to communicate progress and results to the technical community and the public.

PI Response:

Reviewer 23401

Comment: Project setting has a great deal of prior study on which to build and considerable investment.

PI Response:

WEAKNESSES

Reviewer 23537

Comment: Nothing innovative about most aspects of this work.

Nothing innovative done with what appears to be an excellent gravity and MT data set.

Industry developer has lost its desire to further pursue this.

PI says this is good EGS project which leads the reviewer to imply that the PI can't find or has lost interest in finding a hydrothermal resource.

PI Response:

Most of this has been addressed above. The other message here seem to be not to point out the presence of both hydrothermal and EGS exploration targets on the western flank when your project is hydrothermal. It is difficult to understand how recognizing EGS potential on part of the flank is interpreted to negate everything said about the identified hydrothermal area.

Reviewer 23478

Comment: The only project weaknesses that I can identify are the financial delays and the apathy that the geothermal investment market is showing due to the low price of and abundance of natural shale gas. If money becomes readily available, this project could finish in a timely manner. If not, more delays can be expected and planned studies might have to be curtailed or postponed with resulting negative impacts on the final results/impact on the geothermal industry.

PI Response:

Reviewer 23404

Comment: For whatever reason (perhaps the low price of natural gas) the project has lost some portion of its funding? This is unfortunate.

PI Response:

There is much work going on now to assemble a final report that does not just answer to the recent Grant efforts, but assembles substantial data as a first-stop document for those in the future who will re-invigorate this project when the economics of electrical energy generation form geothermal resources change. It is not a matter of if, but when.

Reviewer 23401

Comment: Corporate partners weak and/or inexperienced in supporting a development program of the magnitude required by the depths and temperatures of this resource.

PI Response:

IMPROVEMENTS

Reviewer 23537

Comment: If not done already, make available all geophyscial data from the project. The reviewer suggests cancelling the remainder of this project and defunding immediately. In the future, perhaps another team may truly wish to write and vigorously pursue an innovative approach to hydrothermal exploration at Newberry.

PI Response:

The reviewer and the Davenport team are of the same mind. It is the intent of the team to assemble the Grant data and the work done processing and integrating earlier surveys into an accessible document for the future to build on.

This is also one of the underlying reasons for convening a scientific symposium to bring scientists working or having an interest in Newberry Volcano to share data from works in progress and to provide a forum for discussion and exchange of ideas. This would not have been possible without the DOE/Davenport grant effort.

Reviewer 23478

Comment: I really have no recommendations to make to improve this project. Ultimately, deep drilling into newly established targets will be needed to convince skeptical investors that new techniques are reliable and worthy of proliferation in a commercial sense.

PI Response:
The project at this stage is sadly lacking, with an absence of the last 70%.

Reviewer 23404

Comment: None apparent other than being able to stand back and rank applied methods to decide which is the cream. This is vital information for the geothermal program, as developers will not be able to utilize every and all methods.

PI Response:

There is much work going on now to assemble a final report that does not just answer to the recent Grant efforts, but assembles substantial data as a first-stop document for those in the future who will re-invigorate this project when the economics of electrical energy generation form geothermal resources change. It is not a matter of if, but when.

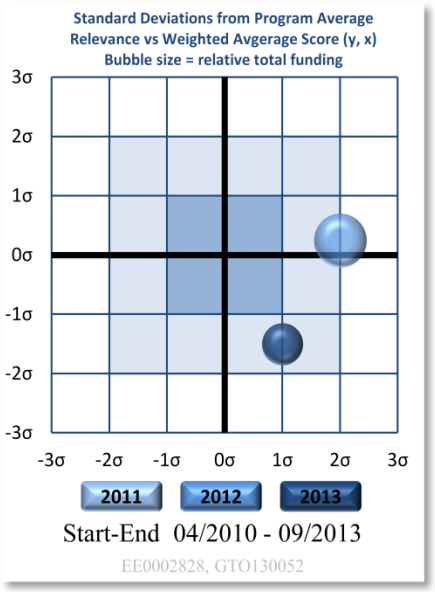
Reviewer 23401

Comment: The project deserves a much more clearly reasoned explanation of whether the PI finds fault with MT because of data acquisition or other objective problems or because he simply doesn't agree with prior investigators' interpretations. The integration promised is not evident in the project summary and the presentation was a rambling discourse on geology that never focused on the key objectives.

PI Response:

The reprocessing occurred with the MT data. The first pass was done by the geophysical company using the standard 3 layer approach, which really provided no insight. Additional MT stations were added to increase the density on the upper western flank. The company was then asked to process the shallow depths with much greater detail than the standard "geothermal" approach employed. Note that mineral and oil and gas exploration programs do not model MT in the same manner that is done for geothermal companies. Taking advantage of the higher station density, the MT data actually was able to show structural off-sets in remarkable detail. The quest was not to keep reprocessing data until it fit an preconceived idea. It was to process the data in a way that would provide high resolution in the shallow (<1.5 km) depths where MT is capable of providing highest resolution. Just the geometry of the MT technique provides progressively less resolution with depth, regardless of station density. 3-D modeling of the data set reduces resolution even further. With the much better shallow resolution the MT results were then integrated a second time with the other geophysical data. It was at this time that things really began to fall into place and the team was able to understand how earlier volcanic structures were affecting geothermal exploration, and better explain the results of both wells 55-29 and 46-16.

The results show that the model for what was going on under the western flank prior to the DOE/Davenport program was wrong, and the long-standing MT interpretation model was also wrong. The resulting conclusions are a posteriori conclusions not a priori conclusions.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002828
Project: Direct Confirmation of Commercial Geothermal Resources in Colorado using Remote Sensing and On-Site Exploration, Testing and Analysis
Principal Investigator: Robinson, F.
Organization: Flint Geothermal LLC
Panel: Innovative Exploration Techniques

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23537

Score: 5.0

Comment: It is agreed that CO likely contains utility-grade geothermal resources. The application of remote sensing toward the identification and geothermal resources in CO or anywhere is highly relevant.

The state-wide application of these methods as a screening tool with additional, more focused work to follow is also reasonable and could expedite the discovery and development of resources.

However, the impacts of these activities so far is minimal. State-wide remote sensing data seems to have "discovered" regions in the state long-since known to contain warm to hot water. The detailed structural and alteration mapping to follow is not apparent from the data provided (unless the lineament map is considered structural mapping). From such work should come an understanding of faults that may be permeable.

It is unclear how this work advances the mission of the GTO much less the ambitious objectives stated in the introductory slides.

The relevance of this research is fair, at best.

PI Response:

Reviewer 23454

Score: 6.0

Comment: Successful completion of this project would have a substantial impact on geothermal exploration in frontier areas. The ability to use airborne survey to quickly identify potential geothermal resources would yield a significant saving in time and cost. The technique could also be widely applied in areas not covered by significant thickness of alluvium. It is impossible to fully evaluate this project's impact without confirmation of the technique by field measurements.

PI Response:

Reviewer 23404

Score: 3.0

Comment: It is unclear, after reviewing this project, as to the importance of achieving the project's objectives relative to the broader Geothermal Office's mission and goals. The project settled on sites that, from my perspective, became technically viable by virtue of their land access. This is not good.

PI Response:

Reviewer 23401

Score: 5.0

Comment: Potentially high impact not realized due to flaws in execution.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23537

Score: 4.0

Comment: Resources - Solid remote sensing team. Is there no more processing of these data in the works?

Remote sensing data quality appears to be fine. The leap from acquiring and interpreting these types of data to achieving objectives like prioritizing "10 MW targets" in CO (this method does successfully identify locations of previously identified warm and hot spring systems in CO) and "revolutionizing" the industry is an overreach. Neither the scientific approach nor results to date support these or the other hyperbolic claims sprinkled throughout material.

Did not understand how or why drill targets were selected although I can see that they were. There was no rigor involved in co-locating drill targets on a lineament map, especially when these lineaments aren't placed in any structural context. Where were results of "detailed" structural mapping that the material claims occurred?

The initial phase, broad brush integration of remote sensing data as a screening tool is sound. Unfortunately, it is unclear exactly what steps are/were to be taken to focus in and more rigorously understand why and where one should drill in these regions.

The technical approach of the phases discussed were fair to poor.

PI Response:

Reviewer 23454

Score: 7.0

Comment: The general technical approach is sound. Choosing promising sites from aerial surveys and confirming those sites with ground measurements is perfectly reasonable, although the lack of resolution in the surveys might have been investigated earlier. Delays in the project have been primarily due to socio-cultural issues rather than the technical approach.

PI Response:

Reviewer 23404

Score: 3.0

Comment: The quality of the technical approach, rated for the rigor and appropriateness of the employed technical approach, is not terribly great; the methods applied did not generally provide decisive measures of the geothermal potential. Overall the work was a bit disappointing. The criteria for determining the location of slimholes was poorly explained. It was unclear if the methods utilized could differentiated between a large lower temperature target and a small high temp target.

PI Response:

Reviewer 23401

Score: 4.0

Comment: Fundamental resolution issues with remote sensing data seem to have been overlooked in the design phase and were not corrected after they were manifested in the results. The lack of attention to hydrothermal alteration mineralogy mapping was not explained.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23537

Score: 4.0

Comment: This project provides a great 50,000 ft glance of warm ground in CO. It doesn't seem to have advanced far beyond this so far. The quality of the initial remote sensing data is solid. The quality of the other 50,000 ft view maps are okay if one wants to provide an generalized overview of the state. To go from a 50,000 ft view (figuratively and literally), there needs to be a detailed plan with key objectives and strong technical arguments supporting how achieving these objectives advances the research to the next level. These are not apparent and the PI/presenter seems unprepared to present the technical information if an argument existed.

The previous comment was not made in haste. If a group proposes to spend a few million dollars of federal funds to conduct technical work, they should put their best foot forward when presenting interim results. If results of work conducted to date exist, it was not apparent from the material presented or the presentation.

Accomplishments to date rate a solid fair.

PI Response:

Reviewer 23454

Score: 5.0

Comment: The accomplishments to date are incomplete and behind the planned schedule, but are appropriate to the costs incurred. Work has been adequately documented, although not yet published. The recipient has established that significant perception barriers exist, which is something of a negative accomplishment, but is important information. Because there is no verification of the underlying premise, it is impossible to evaluate the quality of the accomplishments, but the project definitely deserves continuation, at least through confirmation tests at one candidate site.

PI Response:

Reviewer 23404

Score: 4.0

Comment: There are clearly no gold nuggets in this project's results. The technical methods applied do not really provide substantive information, and as indicated above, the project moved towards sites with access; albeit this is reality's bite, but for this area of judgment the project cannot be scored too highly.

PI Response:

Reviewer 23401

Score: 6.0

Comment: Accomplishment were limited by the NIMBY factor, which seems not to have been taken into account in stating the project objectives.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23537

Score: 6.0

Comment: I assume PM work to date is ok.

PI Response:

Reviewer 23454

Score: 7.0

Comment: Project coordination has been adequate, in terms of working with appropriate other entities and scientific partners. Program changes based on technical results are appropriate.

PI Response:

Reviewer 23404

Score: 3.0

Comment: The project is behind in achieving results; spending is similarly low (this is a good thing). Since the results of this work will not significantly move the geothermal world forward significantly (even if successful- and it is unclear how success will be measured), perhaps this project should be discontinued.

PI Response:

Reviewer 23401

Score: 6.0

Comment: Management seems OK in fiscal terms but the objectives were set up so they could not be achieved, i.e., the project was bound to fall short by lack of realistic consideration of the Colorado social situation.

PI Response:

STRENGTHS

Reviewer 23537

Comment: Good remote sensing data. Good remote sensing team.

PI Response:

Reviewer 23454

Comment: The principal strength of this project is that it investigates an exploration technology which, if successful, could have wide and significant application. If remote sensing can be used to identify viable geothermal resources, that would lead to considerable expansion of this renewable energy.

PI Response:

Reviewer 23404

Comment: It is not clear that this project has strengths worth enumerating

PI Response:

Reviewer 23401

Comment: Reviewer did not provide comments for this criterion.

PI Response:

WEAKNESSES

Reviewer 23537

Comment: No detailed argument for how this project will achieve any of its goals. Saying that detailed mapping will be conducted is a great introductory remark. Then one needs to explain exactly what this entails, what information is being sought and how these data lend to a more focused understanding of where one should drill. This does not exist in this project.

The presentation seemed to provide data related to technical sales rather than providing hard technical data relevant to earth scientists looking to scrutinize limited federal research dollars available for geothermal. Considering the limited federal research dollars available for geothermal, the approach of this project is counter-productive.

PI Response:

Reviewer 23454

Comment: A weakness of the sensing used to date is its relatively low resolution. This might have been identified as a problem earlier in the project. Another weakness is the limited number of ground sites that can be further investigated by Temperature Gradient (TG) Holes and other methods, although the limited access to these sites was unexpected.

PI Response:

Reviewer 23404

Comment: Lack of progress, poorly conceived project.

PI Response:

Reviewer 23401

Comment: Lack of experience in commercial use of remote sensing.

Lack of opportunities to test methodologies without stirring up local resistance.

PI Response:

IMPROVEMENTS

Reviewer 23537

Comment: Rigorous plans explaining what the next steps are, how (in detail) they are going to be achieved, and why data generated from this work will better vector drilling plans. Otherwise, put this project on hold until this work can be accomplished.

PI Response:

Reviewer 23454

Comment: It is late in this project to make any useful suggestions. The proposed continuation is reasonable, and should give adequate information for a decision on further work.

PI Response:

Reviewer 23404

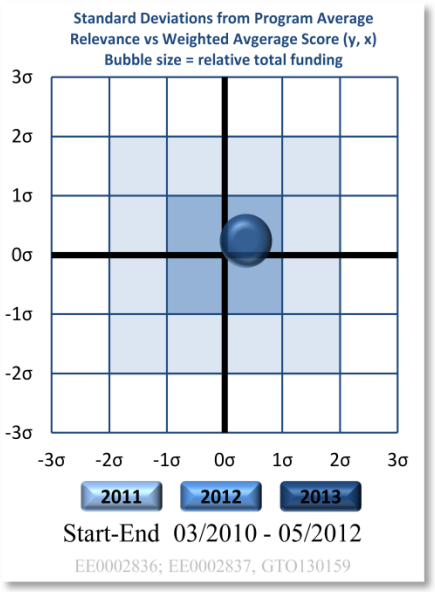
Comment: Stop now, cut losses.

PI Response:

Reviewer 23401

Comment: Redefine project to use available funds to re-sample target area with higher resolution and a more complete remote sensing spectrum. Add some additional technical support to raise quality.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002836; EE0002837
Project: Merging High Resolution Geophysical and Geochemical Surveys to Reduce Exploration Risk at Glass Buttes, Oregon; Blind Geothermal System Exploration in Active Volcanic Environments; Multi-phase Geophys
Principal Investigator: Walsh, Patrick
Organization: Ormat Technologies Inc.
Panel: Innovative Exploration Techniques

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23537

Score: 8.0

Comment: Multiple projects included.

Re: Maui, exploring in a rift zone with the goal of expediting geothermal development and "testing" and modeling integrated geophysical tools is solid and additive.

Re: Glass Buttes, similarly integrating techniques, while not revolutionary, is a solid approach to understanding the potential geothermal system in this young volcano.

Unclear if Wister was supposed to be presented or not as it was included in the title of some of the material made available.

PI Response:

Reviewer 23478

Score: 6.0

Comment: These two projects are definitely relevant with respect to GTO objectives inasmuch as they both are testing relatively new types of geophysical and geochemical techniques to identify blind geothermal targets. On Maui, the proponents are comparing the several signatures of the known geothermal area on Hawaii at Puna with the potential geothermal area anticipated to exist within the Haleakala SW rift zone.

If successful, this use of a "roadmap" could lessen exploration costs in the basaltic, shield volcano environment typified by Hawaii and thus lower the ultimate cost of power generation.

To date, the work has had no real impact on the geothermal industry, development costs, marketing, etc. Hopefully, if drilling identifies a resource, real, positive impacts will result.

At Glass Buttes, a somewhat simpler suite of geophysics and geochemistry is being used to narrow down the potential exploration drilling targets. The work to date has enabled the creation of a 3D geological map and the mapping of potentially permeable fault and fracture zones.

To date, this work has had no impact of importance to the geothermal industry. However, if successful, exploration in dry, siliceous Basin and Range environments could be undertaken with lower costs, in less time.

PI Response:

Reviewer 23404

Score: 8.0

Comment: The project addresses a known technical knowledge gaps, exploration of a blind volcanic system for its geothermal potential well it utilized gravimetry and aeromagnetics as an exploration tool, with perceived success.The CO_2 work was limited in success, and perhaps is more of a challenge (and at some point should not be pursued).

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23537

Score: 8.0

Comment: The tools incorporated thus far in both areas are highly appropriate given the resources, geologic setting and overall objectives of GTO.

PI Response:

Reviewer 23478

Score: 7.0

Comment: The scientific/technical approaches being used both on Maui and at Glass Buttes are sound and have resulted in the definition of several possible drilling targets. On Maui, sites have been found where geothermal signatures are somewhat similar to those found at Puna (a known commercial geothermal area). At Glass Buttes, though, no details have been given regarding the precise nature of the geophysical or geochemical studies being used, reportedly a 3D geological map has been created and potentially permeable fault systems mapped.

It is not possible to rate the rigor or appropriateness of of the work approach, as few details have been described for Maui or for Glass Buttes. Accordingly, a lower score has been preliminarily assigned.

PI Response:

Reviewer 23404

Score: 8.0

Comment: The scientific approach was to combine high resolution geophysical and geochemical techniques to reduce exploration risk. It appears that the geophysical methods employed were more informative to the researchers and that the geochemical methods were somewhat less informative. The methods were used to guide the researchers sufficiently to develop a 3-D geologic model, and then to design their drilling plan from that.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23537

Score: 8.0

Comment: Obviously permitting issues on Hawaii are and will continue to be a major obstacle to all geothermal development. I assume the team could be given high ratings in this regard for patience and persistence. Similarly drilling permits in Oregon take time. Overall, however, the quality of work accomplished so far toward meeting goals is solid.

PI Response:

Reviewer 23478

Score: 8.0

Comment: A complete list of achieved objectives has been supplied for the Maui project. Archives have been reviewed and relevant data gleaned and synthesized with new geophysical and geochemical information, CO_2 fluxes have been compared for K?lauea East Rift Zone (KERZ) and Haleakala Southwest Rift Zone (HSWRZ) and some environmental and permitting hoops have been jumped-through (though not completed).

The same can be said for Glass Buttes, however the only tangible work product listed is a 3D geologic map together with the delineation of major fault zones.

To date, the achievements appear to have used only a small portion of the funds allocated to the projects (10-15%). Despite this, drilling can be contemplated at both sites in the relatively near future. It is assumed that the lion's share of the funding will be spent on the proposed Phase I drilling.

Accordingly, one can say that the accomplishments are of reasonably high quality and, judging by the budget figures, that productivity has also been good.

PI Response:

Reviewer 23404

Score: 6.0

Comment: It appears that the accomplishments versus costs is at a respectable ratio. It appears, as well, that a sticking point for the project is rooted in permitting. This is a recurrent theme that perhaps DOE should consider addressing. As well the value and quality of the accomplishments is well represented

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23537

Score: 8.0

Comment: Progress to date and PM/coordination of activities seems to be solid.

PI Response:

Reviewer 23478

Score: 7.0

Comment: There has been no information provided regarding this topic. The professionals involved in the projects are experienced, and well respected in their fields. Unfortunately, nothing is revealed regarding policy, scheduling, or decision points. The same must be said regarding coordination between collaborators, stakeholders and other entities. There is, however, some detail provided regarding commonly successful dealings with permitting and environmental agencies on Maui.

PI Response:

Reviewer 23404

Score: 7.0

Comment: It appears that the technical work is somewhat on schedule, with delays due to permitting.

PI Response:

STRENGTHS

Reviewer 23537

Comment: Good team for both projects. Solid plans. Good results to date. Potentially additive toward GTO objectives not to mention Ormat's

PI Response:

Reviewer 23478

Comment: The strengths of these two projects are that they seem to be successfully evaluating the potential of two blind geothermal sites while spending relatively small amounts of money. They are also working their way through seas of regulations and regulators that are difficult to navigate both in Maui and in Oregon.

The management teams appear to be working effectively (though no details are available) judging by the outcomes to date. When all pending permits are obtained, the first drilling of targets, newly identified targets under the DOE aegis, should begin at both project sites.

PI Response:

Reviewer 23404

Comment: The project appears to be well organized, has a good project team and has identified and is working in a focused manner towards its goals.

PI Response:

Reviewer 23401

Comment: Management by a commercially-accountable company provides good decision-making support to the PI.

PI Response:

WEAKNESSES

Reviewer 23537

Comment: "Leader" or presenter of project results should be versed in project accomplishments. A significant focus of this funding is the innovative nature of the proposed work. Presenter should probably know what "innovative" work was accomplished , especially when asked by a peer reviewer. Stating that the reviewer should look at previous year's papers is unsatisfactory.

PI Response:

Reviewer 23478

Comment: The weaknesses in these projects are hard to assess because of the minimal amount of specific data provided in these papers. Difficulties have been encountered on both projects, but these seem to have been overcome eventually by the management team. Accordingly, these difficulties do not really comprise weaknesses.

PI Response:

Reviewer 23404

Comment: Drilling portion of the project anticipates problems

PI Response:

Reviewer 23401

Comment: Results unlikely in the near future.

PI Response:

IMPROVEMENTS

Reviewer 23537

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23478

Comment: Until more project-related detail is provided, there is no way that suggestions for improvement can be made.(On the other hand, I guess that a requirement of the operators to release more specific data could be considered as a recommendation).

PI Response:

Reviewer 23404

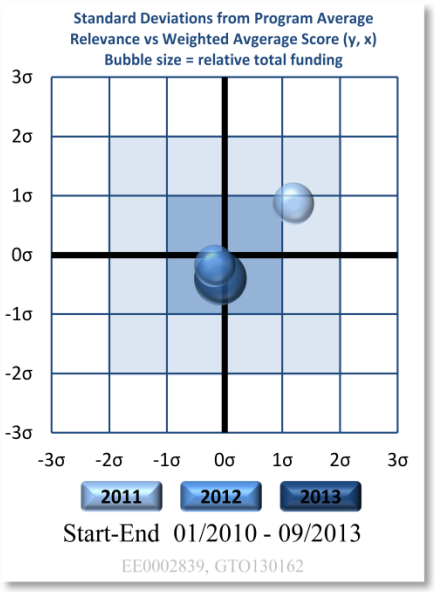
Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23401

Comment: Consider whether consolidating funds to push one project forward and abandon the less likely would produce useful results more quickly.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002839
Project: Advanced Seismic data Analysis Program (The "Hot Pot Project")
Principal Investigator: Misseldine, Frank
Organization: Oski Energy, LLC
Panel: Innovative Exploration Techniques

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23537

Score: 6.0

Comment: The selected area seems worthy of geothermal investigations/R&D. The application of reflection seismic data processed using Optim's algorithms is not terribly innovative (as many other workers use this) but it will certainly enhance our understanding of Hot Pot, or at least the potential drilling targets.

I am not sold on the relevance of incorporating this approach to improve the "quality of quantity" of drill targets. I think the timely transparency of all DOE funded research would probably better accomplish this objective. Hopefully all drilling campaigns make developers smarter, sooner. If they don't, then the developer will become broker faster. It can be argued that it is not so much the selection of drilling targets (although targets can and will always be questioned) that enhances industry's ability to expedite the development of more geothermal resources as much as the opaqueness of this nascent industry when it comes to sharing information. I don't totally agree with the premise or the relevance of this project.

PI Response:
The fact that Optim's algorithms have been used for some time is, and has been, acknowledged. As the reviewer suggests, the real contribution at Hot Pot is the opportunity to validate the seismic technique in a prospect with several strucutural styles/target concepts.

The slide utilized in the presentation mentioned the .."quality and quantity…" of drilling targets.

Quality. Just drilling a deep well does not automatically provide all the answers. To the exent that wells are not drilled appropriately to test intended targets and/or target concepts are poorly defined, if at all, the state of confusion after a well has been drilled can be about the same as before. All drilling campaigns are definitely not created equal, and do not provide the same level of information.

Quantity. The number of wells required for successful project development is substantial. In the presenter's experience the most difficult question after "why did this well fail?' is "ok that is great, where do we go next to achieve exactly the same results?" A one target, or possibly even a one target concept, project will probably not be successful.

The transparency of all DOE funded research is recognized, however in the end wells must be drilled in order to confirm the resource. Any technique that improves the exploratory drilling success rate and enables successes to be repeated during the development process is very beneficial to the industry. Given the time and expense of drilling and the

consequent effects on project economics, the project team feels that focus on drilling target selection is entirely appropriate and that validation of the DOE funded seismic technique at Hot Pot is of great value.

Reviewer 23527

Score: 7.0

Comment: The reviewer is not an expert in reflection seismic, but the structural information obtained from the analysis of the reflection seismic data acquired during the project appears to be useful as a basis for guiding the selection of optimal drilling locations. The development and validation of such tools to facilitate exploration for geothermal resources is of value to the geothermal program in general. The knowledge transmitted to the community should also improve future geothermal prospecting efforts.

PI Response:

Reviewer 23404

Score: 6.0

Comment: The project has the potential, for this site, to contribute to the broader Geothermal Office's mission and goals because the project is applying reflection seismology to help define the geologic structure. If this is new, and if it is a contribution in a positive way, it will be beneficial. Local high or low velocity zones will impact the interpretation of the results.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23537

Score: 7.0

Comment: If previously mapped faults such as N-trending, down-to-east normal fault on slide 8 are well constrained, why do you need to test efficacy of Optim's interpretations on all of the other faults? Why not locate a few of the other wells at sites best suited to prove the existence of warm/hot water? Or do you contend that the drilling targets, all located on seismic lines, are best use of drilling dollars?

With the exception of the above question, the survey lines, data interpretation to date and drill targets are reasonable.

PI Response:
The above referenced down-to-east fault is the best constrained and consequently is probably not the best test of the seismic technique. The two NNE trending faults have less (or no) surface expression and represent a better validation of the seismic. Additionally, Jim Faulds research suggests that the NNE orientation could be potentially more productive. Finally, as mentioned in the Phase 1 and (as the presenter recalls) at the Peer Review presentation, the deep Valmy

structural detail is the most exciting discovery of the entire project thus far. Validation of these deep structures could be a real contribution to Basin and Range geothermal exploration and development.

Regarding well locations. Presenter has stated more than once (but perhaps not in April) that it takes real courage to locate a well away from a seismic line. This is especially true when 1) the seismic data is good, and 2) the purpose of DOE funding is to validate the seismic. The uncertainties of off-line structural projection simply add unnecessary complications at this stage of the project.

Reviewer 23527

Score: 7.0

Comment: The general technical approach is sound and has a reasonable technical basis. There have been previous efforts focusing on the use of reflection seismic to better understand fracture and fluid presence associated with geothermal fields (e.g. Camelli et al, "Contribution of the seismic reflection method to the locating of deep fractured levels in the geothermal fields of southern tuscany"). Prior work by others claims to have reasonably demonstrated in many situations a capability to distinguish even been productive and non-productive fractures based on analysis of seismic reflection signatures. Does the technique utilized in the reviewed work claim to be able to do the same?

PI Response:
Ability to distinguish productive vs. non productive fractures is not part of this project.

Reviewer 23404

Score: 6.0

Comment: The technical approach utilized was to deploy a seismic survey to help map the geologic structure. From this effort the temperature hole locations were determined. The proof of the methods used will not be validated until the temperature holes are completed so it is difficult to pass judgment at this time.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23537

Score: 8.0

Comment: Work generated thus far is good. Data acquisition and interpretation thus far appears to be solid. Goals and objectives are clearly stated and the project is on a path to achieve those (permitting issues notwithstanding).

PI Response:

Reviewer 23527

Score: 7.0

Comment: The results obtained to date look to be quite good and look to have been obtained with reasonable efficiency. Most of the substantive work on the project was done prior to the current review period.

PI Response:

Reviewer 23404

Score: 5.0

Comment: The guts of the work has been completed (the seismic survey and interpretation). However, the validation by drilling is not yet complete, so assessing the productivity and quality of the work is not yet possible.

PI Response:
Agree. As a matter of clarification, it might be argued that the big unknown at this point is accuracy…..did the seismic information enable an accurate determination of subsurface lithlogies and did it place structures in their correct locations.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23537

Score: 8.0

Comment: PI knows what he is doing, understands the obstacles, has presented his results in a coherent manner and appears to have placed decision points at reasonable stages throughout this work.

PI Response:

Reviewer 23527

Score: 7.0

Comment: The projects looks appears to be effectively and efficiently administered.

PI Response:

Reviewer 23404

Score: 8.0

Comment: It appears the team is well organized and working towards their goals.

PI Response:

STRENGTHS

Reviewer 23537

Comment: Good team assembled to do the work. Interesting study area.

PI Response:

Reviewer 23527

Comment: This exploration technique and application seems well suited to better understanding exploration strategies for this class of geological structure.

PI Response:

Reviewer 23404

Comment: The work appears to be well founded and solid thus far.

PI Response:

Reviewer 23401

Comment: Reasonably good chance of drilling low cost wells to get confirmation data eventually.

PI Response:

WEAKNESSES

Reviewer 23537

Comment: Unsure that the relevance of the research is worth the investment.

PI Response:
This point was discussed earlier.

Reviewer 23527

Comment: This is not necessarily a weakness, but it was not clear from the descriptions provided whether or not the PI felt that the seismic reflection technique utilized could be used to distinguish between productive (or at least previously productive) and non-productive fractures with respect to geothermal activity. This may have been a misunderstanding on my part. If the technique can be used for this purpose then it would seem to be of great value.

PI Response:
This seismic technique may not be able to distinguish productive vs. non-productive fractures. In any event, and as as mentioned earlier, such a distinction was not part of this research. Ultimately, no matter what the seismic may predict, drilling must be carried out. The seismic helps to optimize drilling targets with respect to fracture orientation, depth, and potentially even thickness of alteration zone.

Reviewer 23404

Comment: The punch line of success (validation) is left to the end.

PI Response:
Comment is totally correct, but not sure that it represents a weakness. The ultimate fact of resource exploration is that until drilling is carried out, the success, or lack thereof, is unknown. This is unlikely to change.

Reviewer 23401

Comment: Troubling inconsistency in testing methodology in which drill hole data was required to get a plausible interpretation of the seismic data, which was supposed to reduce the need to get drill hole data. The presenter and the summary are silent on how one would know whether the results obtained by Optim's interpretation could be believed if there were no drill holes.

PI Response:
The presentation did address this concern, but probably too briefly. The points made, or intended to have been made, were: 1) conduct a very thorough search for subsurface data, not only geothermal test holes but oil and gas, mining, water wells etc. It is often too easy to simply say…there is no adquate historic data…especially when one is being funded to acquire new data. 2) Depending of project scheduling, lease obligations, and other factors, it might be possible to drill a test hole early in the project, 3) pay particular attention to other subsurface information. Presenter would like to believe that had the drill hole data not been available, the project team would have looked at the gravity data, which also shows a locally high basement, and then adjusted the velocity model thereby achieving the same result. As a sidebar, the Phase 1 report contains gravity - derived basement depths superposed on two of the seismic lines. This was done in response to an excellent reviewer comment. and 4) If items 1 - 3 all fail, consider running some "what if" velocity models before giving up and saying the seismic program results are no good. Some reprocessing is far less expensive than unsuccessful wells, or worse yet, walking away from a potentially viable project.

Presenter does remember saying that this (drill hole data - velocity adjustment) is not about needing subsurface drill data to successfully carry out the seismic work but rather about how sensitive the Optim approach is to velocity model adjustments.

IMPROVEMENTS

Reviewer 23537

Comment: Would like to see historical data (fluid geochemistry) integrated into the next presentation. I defer to this particular PI to know better than most whether this area is a worthy exploration target. I realize that developing this potential resource is not the focus of this funded research but it would be comforting to know that this site stands a demonstrable chance of being developable.

PI Response:
Agree that fluid geochemistry is important, there simply was not time to get into the topic given time constraints and fact that the DOE funding was for a seismic project. The Phase 1 report contains a brief discussion of historical geochemical data, the project team wishes there were more.

Regarding developable project or not, presenter stands by comment made at the meeting. In 1973 no, in 2013 quite possibly, thanks to better exploration methods and lower temperature turbine technologies. In any event, the DOE funded seismic program has provided an excellent shot at locating an intermediate depth temperature gradient hole program in order to conclusively answer this question.

Reviewer 23527

Comment: Determine if there is a way to more comprehensively correlate the seismic data to geothermal activity. This may not be practical or may be more logical during the project production phase. If this is done the information should disseminated to the broader geothermal community.

PI Response:
Agree that such a correlation could be more feasible during production phase. Correlation of seismic results with potentially productive fracture zones would be a useful result. Determination of temperatures and production capability may not be a realistic expectation. This discussion goes back to the basic project goal, that of focusing the drilling program to most efficiently characterize a given geothermal system.

Reviewer 23404

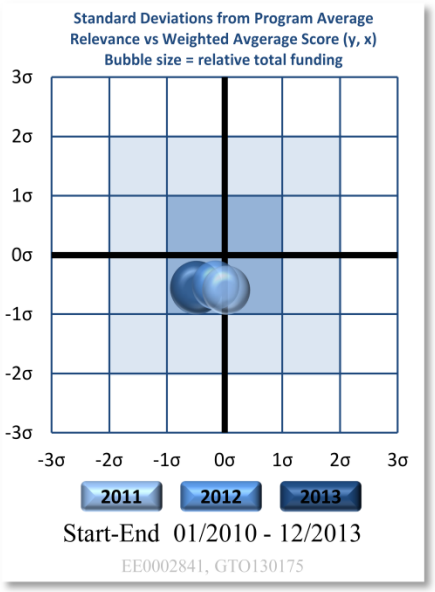
Comment: None noted

PI Response:

Reviewer 23401

Comment: Run a blind comparison using another seismic interpreter to see whether meaningful differences are apparent between the "established" and the "innovative" methods, with and without the use of the drill hole data.

PI Response:
Two of the seismic lines were processed in a conventional manner. As discussed in the project Phase 1 report, the conventional processing did not yield useful results. This comparison was also presented, albeit briefly, at the 2011 Peer Review conference. The use of drill hole data has been discussed earlier.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002841
Project: Innovative Exploration Techniques for Geothermal Assessment at Jemez Pueblo, New Mexico
Principal Investigator: Kaufman, Greg
Organization: Pueblo of Jemez
Panel: Innovative Exploration Techniques

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23537

Score: 5.0

Comment: Unclear how any aspect of this project, other than the proposed tracer testing, is innovative or expedites the industry's development of geothermal resources. However, if drilling on this reservation proves successful, then the investment into this project will prove to have been worthwhile. The technical gaps associated with finding the upflow or ultimate source of an outflow plume are many. It remains to be seen whether any of these gaps will be bridged by this project.

The potential market penetration by geothermal in this region is highly valuable.

PI Response:
The seismic performed in this project is highly innovative; contrary to "normal" seismic surveys using roll along data acquisition, a fixed array, high resolution field layout has been chosen to not only process the data using Kirchhoff and wave equation algorithms, but also using an elastice-wave reverse-time migration with a wavefield-separation imaging condition. That migration, performed by the Los Alamos National Laboratory, is unique. The results have been shown in the presentation along with the standard migration results. The unique methods shows additional faults and fractures, not easily or not at all visible in the standard migrations.

No exploration project acts or results in certainty prior to drilling. All exploration projects explore to obtain a higher degree of certainty. This project is not different in that regard.

On a permitting level the established vendor-regulator model for permitting development on tribal trust land by a sovereign nation has been proven to be extremely efficient and very acceptable by all parties involved. That is a very innovative approach to geothermal development on such ground. Compared to regular State or Federal base permitting processes it is about 90% more efficient.

Reviewer 23454

Score: 7.0

Comment: The project will have substantial impact in the localized market of northern New Mexico. It will address significant knowledge gaps relevant to the Valles Caldera resource, and it is possible that new geophysical techniques, if

validated here, will find widespread application. It is not possible to evaluate the impact accurately before the drilling and testing are complete, and those results are compared with the structural models developed from geophysical data.

PI Response:
Thank you.

Reviewer 23404

Score: 4.0

Comment: I am unsure of the impact of success of this research relative to the broader geothermal office mission and goals. The knowledge gap is focused on understanding a single site's geothermal potential. There were no real innovative methods employed.

PI Response:
See reviewer comment 23537 and the projects comment to that reviewer. Very innovative methods have been already employed. The applied innovative seismic is highly recommended to be used in all geothermal projects to mitigate investment risks responsibly.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23537

Score: 6.0

Comment: The acquisition, interpretation and integration of seismic and 3D MT on a geothermal prospect is always additive although not entirely innovative. The cross section and the (somewhat vague) conceptual model illustrating a broad upflow zone in this region have added to the body of work and have some value.

At this point, this project seems to be the integration of interpreted geophysical data followed by deep drilling. It is an ok but very risky approach to geothermal exploration in a region that does not contain abundant utility-grade resources. I don't think that enough rigorously constrained information has been generated that would make a developer feel that his risk has been limited to the point that the deep drilling costs are worth the effort.

It is unclear (or perhaps I missed) how tracer testing will be conducted, especially as only one well is to be drilled. It seems like this project has devolved from an innovative integration of multiple tools into a straight exploration program on land where previous work has never been done.

PI Response:
Following power generation potential data determined and published by the USGS in 2009, New Mexico has more potential than Utah, more than Arizona, and is fully comparable to many other States that are considered States with identified resources, like Hawaii, Alaska and Oregon. Stating that the region has not abundant utility-grade resources is not correct. It is correct to say that the region, out of historical reasons, did not see abundant exploration. The resources are there, and they are waiting to be explored.

The project followed an exploration plan presented to and approved by the DOE, repeatedly reviewed and constrained by the Technical Monitoring Team of the DOE, and related budget and awarded project obnjective constraints.

The tracer testing is innovative because it will use two conservative tracers with different diffusion coefficients (bromide and a naphthalene sulfonate) in two separate injection-withdrawal tests to evaluate the ambient water flux in the vicinity of the well, which will provide an estimate of the advective heat flux through the system to give you an idea of what sort of heat extraction rate you might be able to sustain. The two tests would be conducted with different rest or drift periods and an analysis of the differences in the tracer responses in the two tests will provide constrained estimates of the ambient water flux or flow rate. In one of the two single-well tests, use lithium ion and a reactive dye tracer from EGI in conjunction with the conservative tracers to interrogate surface area available for heat transfer in the system.

Reviewer 23454

Score: 8.0

Comment: S/T A appears sound and available resources are commensurate with results to date. Project is somewhat behind schedule but delays are mostly attributable to uncertainties in the permitting process. Decision points have been reasonably chosen and observed. Staffing and collaborators appear very good and of appropriate extent.

PI Response:
Thank you.

Reviewer 23404

Score: 3.0

Comment: Having developed a geologic map/cross section from limited geophysical information the plan is to drill a well. It is unclear as to the confidence level one can place upon the constructed cross section. The bottoming of the well is in a zone of anticipated high degree of fracturing, so as an observer one may question data quality in this zone. The subsurface structure as presented is rather complex.

PI Response:
The cross section has been constructed with a high degree of confidence based on the exceptional quality of the seismic data and related interpretation that is linked directly to the geological mapping performed by the project team. It is not clear to what data the reviewer is referring to when expressing concerns about data quality in the fractured zone. The depth model of the cross section is dependent on the velocity model developed during the seismic data processing. The innovative seismic method as described above, show slightly shiften fault positions as a result of its processing versus standard processing. Drilling will help calibrating, comparing and judging those methods further.

Reviewer 23401

Score: 7.0

Comment: Hard to tell whether approach really represents a change from conventional because no comparisons are included.

PI Response:
The presentation did show and explain the comparison between migration based upon conventional methods and migration and fault interpretation based upon the innovative elastice-wave reverse-time migration with a wavefield-separation imaging condition. See our very first reviewer response.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23537

Score: 5.0

Comment: The seismic and MT data were acquired and are solid. The required permitting process has been undertaken and with solid results to date. The value of these data, however, toward the identification and development of a geothermal resource remains to be seen. It is premature to announce the discovery or indications of a "huge geothermal resource" until a huge geothermal resource is actually identified. At this point, a successful well with elevated temperatures and some permeability would be additive and would support, one way or another, interpretations from the data acquired thus far.

I assume the tracer test has been abandoned even though it was unclear what this was designed to accomplish.

I did not see results of geologic mapping. Perhaps this was presented earlier and was not discussed (or written about) in this presentation.

Unsure what the hydrogeochemistry is intended to achieve and/of when and where this will be applied.

PI Response:
The tracer testing has not been abandoned. A detailed description of the tracer testing plan is described in a PI response above. The past peer review presentations went into more detail regarding the geological mapping. In this presentation the geological mapping has been shown to be applied to the interpretation of the cross section, where the surface geology has been nicely linked to the seismic migration results.

Initially the project was planning on drilling two wells about three thousand feet deep west of the Indian Springs fault zone. Based upon the very extensive hydrogeochemical work done, this plan had to be changed in order to target a deeper resource with reasonable expectation of finding commercial temperatures; instead of drilling two wells west of the fault zone, one well had to be drilled east of the fault zone. That decision would not have been made without the very important hydrogeochemical work done.

Reviewer 23454

Score: 6.0

Comment: Accomplishments to date are high quality and are commensurate with costs incurred, but the crucial part of the project is not yet done, so this reflects on the accomplishments' value. In simplified terms, the project is to construct a structural model of the reservoir, using a variety of geophysical techniques, and then confirm that model with an exploratory well. All of the modeling has been done, but its value depends on its accuracy, and that will not be known

until drilling and testing are complete. If the model proves accurate, the score for this attribute could well be a 9 or 10, but without confirmation, that score would be unjustified.

PI Response:
Thank you.

Reviewer 23404

Score: 4.0

Comment: Right now, the project has developed a geologic/structural model of the site in order to develop a location for the drill hole. The confidence in the model must be significant in order to take the next step to drill a well. The success of the project hinges on the success of this hole. It is unclear to the reviewer if the hole will or can be completed for the stated cost structure. I suppose time will tell. There is always unknowns and uncertainty in drilling in such an environment.

PI Response:
To date the project and drilling related expenditures are still in the stated cost structure.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23537

Score: 8.0

Comment: PM seems to be on top of tasks required to move this project along.

PI Response:
Thank you.

Reviewer 23454

Score: 7.0

Comment: Management is reasonably well coordinated, with excellent interaction among a number of agencies and entities. Timely decisions were made in changing drilling location, and results are documented. There doesn't seem to be a contingency plan for drilling costs in excess of the budget.

PI Response:
The project does have a contigency plan in place to maintain drilling costs in the budget. Drilling costs will not exceed the budget.

Reviewer 23404

Score: 6.0

Comment: The work is well coordinated between the Native Americans, the permitting agencies and the technical people to move the project forward. Paramount to continued forward movement is tight and strict project management in order to complete the drill hole on budget.

PI Response:
We fully agree.

Reviewer 23401

Score: 8.0

Comment: Drilling plan looks cost-effective.

PI Response:
Thank you.

STRENGTHS

Reviewer 23537

Comment: Team

Geophysical data acquired and interpreted

Intriguing region

PI Response:
Thank you.

Reviewer 23454

Comment: Potential breakthrough in integration of geophysical techniques for structural modeling. Potential identification of significant geothermal resource for northern New Mexico.

PI Response:
Thank you.

Reviewer 23404

Comment: None apparent

PI Response:
See other reviewers.

Reviewer 23401

Comment: Ggood management, clear teamwork.

PI Response:
hank you.

WEAKNESSES

Reviewer 23537

Comment: No real innovation other than the application of some good geophysical data to an area where no such work has never been performed.

PI Response:
See prior PI responses regarding innovation.

Reviewer 23454

Comment: Not really a weakness of the project, but results to date can't be meaningfully evaluated yet.

PI Response:
Thank you.

Reviewer 23404

Comment: A great deal at stake in the single borehole.

PI Response:
Thank you.

Reviewer 23401

Comment: Presenter declared victory in reducing risk when no drilling results are yet available. This may indicate a tendency to presuppose answers and not fully consider alternative interpretations of data. For example, the one method of

seismic interpretation used is described as producing superior results but no comparison was offered with other methods applied to the same data.

PI Response:
The comparison was offered in the graphic presented. As described above, five different methods have been applied to the same data - standard time migration, standard Kirchhoff migration, standard wave-equation migration, LANL wave-equation migration, and LANL elastice-wave reverse-time migration with a wavefield-separation imaging condition. Compared to the standard methods, the elastice-wave reverse-time migration with a wavefield-separation imaging condition has been found innovative. Due to time constraints a more method specific presentation of that comparison could not be presented.

IMPROVEMENTS

Reviewer 23537

Comment: A few techniques and tools were intended to be applied to this project at the outset including "3 new exploration methods." It was not clear in the text or the presentation what these. were. If they were abandoned for whatever reason, it needs to be made clearer that they were and why.

All well-constrained data in any area offers value. I don't share the team's enthusiasm for the overall value of this project. Hopefully a well is drilled and some of the interpretations are demonstrated to be viable.

PI Response:
See prior PI responses.

Reviewer 23454

Comment: Need a contingency plan for what to do if the money runs out before drilling and testing are complete.

PI Response:
Continguency plan is in place.

Reviewer 23404

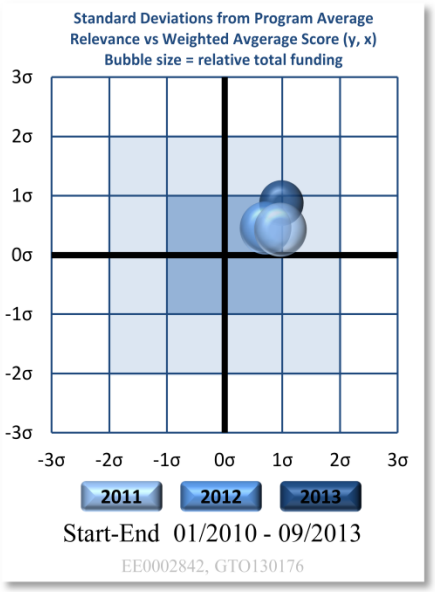
Comment: The project is too far along for such suggestions.

PI Response:
Thank you.

Reviewer 23401

Comment: Take the seismic data to an alternate interpreter like Bill Keach (EGI) or Halliburton or Western Geco for a blind comparison. See whether there is a distinguishable difference in the results when compared to the drilling outcome.

PI Response:
Something like that has been done. Five different methods have ben applied to the same data - standard time migration, standard Kirchhoff migration, standard wave-equation migration, LANL wave-equation migration, and LANL elastice-wave reverse-time migration with a wavefield-separation imaging condition. Compared to the standard methods, the elastice-wave reverse-time migration with a wavefield-separation imaging condition has been found superior. The standard migration methods have been conducted by state of the art oil and gas processing companies with some geothermal experience. Based upon the results, LANL's elastice-wave reverse-time migration with a wavefield-separation imaging condition has been found to be truly innovative. Standard Kirchhoff migration and standard wave-equation migration were supperior compared to LANL's wave-equation migration. Due to time constraints a more method specific presentation of that comparison could not be presented.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002842
Project: Comprehensive Evaluation of the Geothermal Resource Potential within the Pyramid Lake Paiute Reservation
Principal Investigator: Noel, Donna
Organization: Pyramid Lake Paiute Tribe
Panel: Innovative Exploration Techniques

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23537

Score: 9.0

Comment: The relevance of this work is appropriate and timely. The project area selected is also a great venue for testing this research.

PI Response:

Reviewer 23454

Score: 8.0

Comment: This project has significant impact through its combination of seismic modeling, shallow temperature data, and drilling data that provide not only confirmation of the model, but strong indications of a substantial geothermal resource. Based on results to date, exploration of a new area shows some promise of expanding the resource further.

PI Response:

Reviewer 23404

Score: 8.0

Comment: The project objectives and their successful accomplishments may provide added value through their applications toward the broader missions and goals of the GTO. The development of geologic and reservoir models represents a needed component of geothermal reservoir assessment and the methods used by these researches to develop those models have merit.

PI Response:

Reviewer 23401

Score: 9.0

Comment: High potential

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23537

Score: 9.0

Comment: The approach is solid and logical. The integration of these methods (and subsequent reporting of results) will advance GTO's mission as well as projects objectives. I didn't initially understand the value of reservoir modeling but in light of how these data informed ongoing research, I look forward to seeing final results of this work. The project team and project area are solid.

PI Response:

Reviewer 23454

Score: 8.0

Comment: S/T A has been good. Project objectives were comprehensive, well organized, properly prioritized, and implemented efficiently within the scope of available resources. Staffing and collaborators were well-balanced. It's a standard approach -- gather data, develop a model, drill a hole to confirm the model -- but it was effectively executed in this case.

PI Response:

Reviewer 23404

Score: 9.0

Comment: The work attempted and completed is comprehensive. It includes geology, geomechanics, geophysical methods (borehole and seismic), 3-D geologic models and 3-D reservoir models. Successful completion of this work reduced risk in assessing this asset enormously.

PI Response:

Reviewer 23401

Score: 7.0

Comment: The claim of 27m accuracy in locating fractures is not well supported. The foundational assumption was not stated, namely that only one fracture existed that was both imaged and drilled. The likelihood of multiple fractures was not discussed, nor was the likelihood of random fracture location by the subject methodology. A more rigorous error analysis is warranted.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23537

Score: 9.0

Comment: The type and quality of the data acquired, how it is interpreted and how/why each piece of data informs the next step in the research is well planned and executed so far. This project integrates multiple tools and the work produced thus far is solid. This seems to be a high producing team fully performing on an ambitious and relevant project.

PI Response:

Reviewer 23454

Score: 8.0

Comment: The accomplishments are high quality and commensurate with the costs incurred to date. This has been an excellent example of an exploration campaign, efficiently implemented and with a positive result. Identification of a new geothermal resource is valuable to the industry and to the tribe.

PI Response:

Reviewer 23404

Score: 9.0

Comment: The productivity and quality of the work was quite high. It was sufficiently successful that the researchers began to extend their approach/methods/models to a nearby area, with some success. The accomplishments may allow the Native Americans to develop a geothermal resource.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23537

Score: 9.0

Comment: Good team, Reasonable schedules. Spend plans appear in order.

PI Response:

Reviewer 23454

Score: 7.0

Comment: Project is within budget and very nearly on schedule. Decision points were appropriate and apparently were observed properly. Plans for next phase are comprehensive and proper. Coordination with permitting agencies was effective, and results have been well documented.

PI Response:

Reviewer 23404

Score: 9.0

Comment: The impression of project management/coordination for this work is that it is extremely well coordinated and well communicated amongst the co-workers

PI Response:

STRENGTHS

Reviewer 23537

Comment: Team.

Approach.

Methods.

Project area.

Efficiency of work

Outcomes to date.

PI Response:

Reviewer 23454

Comment: The project has demonstrated good practice in exploration and has identified a significant geothermal resource. Spending has been reasonable for the results obtained. Integration and coordination of multiple entities have been carried out in good order. Plans for follow-on work are well-directed.

PI Response:

Reviewer 23404

Comment: Well coordinated project team that works efficiently and communicates frequently

PI Response:

Reviewer 23401

Comment: Good potential here for the first Indian Country generation.

PI Response:

WEAKNESSES

Reviewer 23537

Comment: None apparent

PI Response:

Reviewer 23454

Comment: None significant.

PI Response:

Reviewer 23404

Comment: None noted

PI Response:

Reviewer 23401

Comment: See S/TA

PI Response:

IMPROVEMENTS

Reviewer 23537

Comment: No recommendations

PI Response:

Reviewer 23454

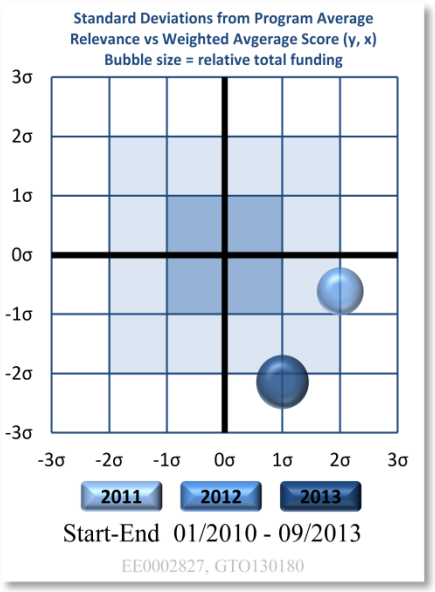
Comment: none

PI Response:

Reviewer 23404

Comment: None noted

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002827
Project: El Paso County Geothermal Electric Generation Project: Innovative Research Technologies Applied to the Geothermal Resource Potential at Ft. Bliss
Principal Investigator: Lear, Jon
Organization: El Paso County
Panel: Innovative Exploration Techniques

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23537

Score: 6.0

Comment: Testing a region of known warm and maybe warmer water for utility-grade or even direct use potential, especially when direct-use fluids would have immediate applicability, is always relevant. The relevance of this project in the context of GTO's mission and goals is hard to justify, however, as the innovation in this project is questionable save for the innovative drilling method #2 (as the coiled tube drilling of Sierra was long ago abandoned) which clearly didn't work.

Many of the team members are solid performers and their contributions have been excellent. But as for the relevance of this work, it rates above poor but not much higher.

PI Response:

Reviewer 23454

Score: 5.0

Comment: Impact on broader program seems low, considering that the project is focused on one potential resource. There is some development of new interpretive methods, but the validity of those methods is not yet demonstrated. There has also been a limited demonstration of a heli-portable drill rig, but it proved inadequate for the local geology, and there was no estimate of how widely applicable this technology might be. There is also value to supporting military involvement in renewable energy development, although a negative result here might be counterproductive to the overall effort.

PI Response:

Reviewer 23404

Score: 2.0

Comment: The methods employed in this project to achieve its objectives have not yet demonstrated the potential to positively impact and effect he broader Geothermal Office's mission and goals. There is simply not enough meaningful meat in this project to honestly suggest that the "research" will have impact.

PI Response:

Reviewer 23527

Score: 2.0

Comment: It is not clear based on the material presented that any of the work performed has advanced any of the basic project objectives. This appears to have been a marginal at best resource prior to the initiation of the project and the work done to date does not appear to have substantially changed any of the initial conclusions concerning the resource. The reviewer can find no evidence in any of the provided project descriptive material that indicates one way or the other that there is reason to believe that this resource can support a 20 MW application. Furthermore, the overall project objective seems somewhat unclear given that there has not yet been a clear definition of how the resource will be used.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23537

Score: 7.0

Comment: Petrography of previously acquired cuttings provided insights into the potential permeability of the limestone. Acquisition of remote sensing and gravity data are additive but its not clear how these contribute to utlimate target identification.

It is also unclear how (or why) it was determined that the very moderate temperatures identified at ~3,000 ft in the 1990s is now a potential 20MW resource. It is unclear how this can be a direct-use resource either although assumptions could be made about pumping X gpm from a larger diameter wellbore; those calculations and those assumptions do not exist in the work presented.

If the goal of this project is to re-drill in and around McGregor Field to see if better temperatures than ~185 degrees F from ~3,000 ft bgs might exist or if more permeable zones exist which might produce high flow volumes, then this project's approach is sound. However, nothing in this approach suggests that anything more than this type of "resource" exists in this basin.

PI Response:

Reviewer 23454

Score: 5.0

Comment: The technical approach was originally well-designed but has been refocused from drilling one or more slim holes to drilling a full-size demonstration/confirmation well,. The rationale for that change is not clear to this reviewer, at least partly because there is no definition of what data will be acquired from the larger well that would not be available from a slim hole. It also appears that even a "best-case" result will be marginal in terms of power production. The principal positive outcome of this project will be a definitive evaluation of power-production potential for this reservoir.

It should be noted that some of the criticism in these comments may be due to the reviewer's unfamiliarity with previous work on this project.

PI Response:

Reviewer 23404

Score: 3.0

Comment: The drilling method attempt(s) was/were a bust. There was slimhole work done in the area and it was found during the process. This information should have been found and evaluated a priori. This information may have driven the project in a completely different direction. The method of drill cutting analysis may be something new in geothermal, but it remains unproven.

PI Response:

Reviewer 23527

Score: 3.0

Comment: Given that this project has apparently been re-scoped after the mid-point it is not clear how the technical approach can even be reasonably evaluated. The project has been re-scoped to "drill a single resource confirmation test well". It was never convincingly communicated that this would provide information in addition to that acquired from the original temperature gradient (TG) wells. How does this dovetail with the geological characterization performed in phase 1?

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23537

Score: 7.0

Comment: The quality of the work performed to date is solid. The team has conducted the work they said they would conduct in a timely manner, The data quality appears high and milestones are being met.

PI Response:

Reviewer 23454

Score: 6.0

Comment: Given previous comments about technical approach, accomplishments relative to the project goals are reasonable. Much of the accomplished work, although necessary to proceed, can be characterized as bureaucracy -- permits, contracting, and agreements with various involved parties. It is difficult to evaluate the technical accomplishments because very little detail is available on exactly what has been done. There are, of course, space limitations imposed by the Peer Review process, but the Project Summary could have been more informative, and no reports have been produced.

PI Response:

Reviewer 23404

Score: 3.0

Comment: The quality of the work completed is OK, but nothing earth shattering. 1/3 of the techniques applied were the result of literature surveys. This is not, in my judgment, worthy to claim much as an accomplishment for this work. It would have been meritorious to use this information to make more intelligent decisions in planning this project.

PI Response:

Reviewer 23527

Score: 2.0

Comment: It is not clear that there has been much progress on this project since the last evaluation period. The heli-portable drill rig does not appear to have been demonstrated to have met its intended purpose and only 2 of the 14 planned milestones have been met to date. Frankly, it is not obvious based on the material at our disposal what there is to evaluate. The work performed during the review period appears to have focused almost exclusively on bureaucratic activities.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23537

Score: 8.0

Comment: All things considered the work appears to miving ahead and schedules, plans and stakeholder communication is being conducted successfully.

PI Response:

Reviewer 23454

Score: 6.0

Comment: It is difficult to assess the project management because it is not clear whether the numerous delays that were experienced should have been predicted or avoided. There seemed to be few decision points, with all aspects of the project proceeding regardless of results. Coordination with other collaborators and agencies was good. Again, it is ineffective for a reviewer to see the third year of a project as his first exposure to it, but that is a defect of the system, not the project.

PI Response:

Reviewer 23404

Score: 3.0

Comment: The work is on budget, however it is admittedly behind schedule.

PI Response:

Reviewer 23527

Score: 2.0

Comment: There does not appear to have been much progress with respect to planned activities. The permit to drill the resource confirmation will was obtained in June of 2012 based on the provided material. Why has the well not been drilled yet?

PI Response:

STRENGTHS

Reviewer 23537

Comment: Good team

Project success would have immediate benefits

PI Response:

Reviewer 23454

Comment: The principal strength of this project is that it will provide a definitive evaluation of the geothermal potential of this reservoir. There is some strength in demonstration of new data interpretation methods, and the helicopter-portable drill rig, but there was little information as to how widely applicable those technologies might be.

PI Response:

Reviewer 23404

Comment: The drilling method attempt(s) was/were a bust. There was slimhole work done in the area and it was found during the process. This information should have been found and evaluated a priori. This information may have driven the project in a completely different direction. The method of drill cutting analysis may be something new in geothermal, but it remains unproven. Additionally, in this exploratory mode, a slim hole, is it a needed expense? Are funds spent better elsewhere?

PI Response:

Reviewer 23527

Comment: Reviewer did not provide comments for this criterion.

PI Response:

WEAKNESSES

Reviewer 23537

Comment: Stated objective of a 20MW resource is entirely unrealistic given all prior data from region. If a utility-grade resource is found (and I hope it is), it will be because something was uncovered that none of the data generated thus far anticipates.

PI Response:

Reviewer 23454

Comment: The principal apparent weakness (to this reviewer) is the lack of strong rationale for a viable geothermal resource in this reservoir. Little information is given to show how results in the demonstration/confirmation well will differ from earlier drilling.

PI Response:

Reviewer 23404

Comment: Generally lack luster

PI Response:

Reviewer 23527

Comment: This project seems to lack focus and a clear objective and it is not obvious that any of the work performed to date supports the statement of work objective 2 goal of justifying the assessment of a notional 20 MW resource target. It is hard to understand why this target number was set in the first place given how marginal the resource appeared to be based on previous work.

PI Response:

IMPROVEMENTS

Reviewer 23537

Comment: Would appreciate more robust reporting, at least for purposes of this review. It probably wouldn't be too hard to provide succinct bullets outlining what was previously performed and the results.

PI Response:

Reviewer 23454

Comment: Because this project is in a late stage, it is probably too late to suggest significant changes. The expected temperatures in the demonstration well, even best case, are almost certainly too low for a self-sustaining flow test, so it might be worth reconsidering a cheaper slim hole.

PI Response:

eviewer 23404

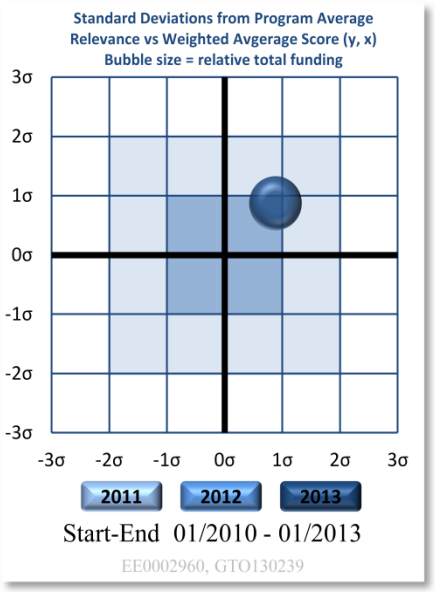
Comment: I am not sure if the project has sufficient knowledge to drill a confirmation well.

PI Response:

Reviewer 23527

Comment: Reviewer did not provide comments for this criterion.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002960
Project: Recovery Act: Detachment faulting and Geothermal Resources – An Innovative Integrated Geological and Geophysical Investigation of Pearl Hot Spring, Nevada
Principal Investigator: Stockli, Daniel
Organization: University of Texas at Austin
Panel: Innovative Exploration Techniques

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23527

Score: 9.0

Comment: This project represents a significant front-end effort in geothermal resource assessment. It is thorough, comprehensive, logical and should further the programs goals for better understanding how to find and develop hydrothermal resources.

PI Response:

Reviewer 23478

Score: 8.0

Comment: This non-industry/academic project is highly relevant to the GTO objectives. It has cost-effectively employed a series of geophysical, geologic, and geochemical techniques to a search for blind geothermal prospects in the vicinity of Clayton Valley, NV. Of special interest is the use of shallow (2 meter) thermal gradient studies and thermochronometry (T/C) to define thermal anomalies. To my knowledge, T/C has not been previously used to assess the ages of thermal anomalies during geothermal exploration. This can be useful in learning where the thermal anomalies are youngest.

To date the work completed can be considered to be a technical success, however, it remains to be seen whether the project turns out to be an economic success. This will be determined after holes are drilled so as to confirm or deny the theories formed as a result of the Phase I work.

PI Response:

Reviewer 23404

Score: 8.0

Comment: The project's objectives included significant systematic integration of geologic and geophysical methods - thermochronometrics, structural geologic analyses, complementary reflection and refraction seismology and existing data. These methods, when successful and intelligently integrated, can be applied in other potential geothermal "plays".

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23527

Score: 9.0

Comment: The approach was very systematic with respect to understanding the structural geology and assessment of the resource in the region of interest. The integrated nature of the activities appear to have delivered an excellent understanding of the resource. Of course the proof will come after drilling is completed, but the case made with the data seems compelling.

PI Response:

Reviewer 23478

Score: 8.0

Comment: This project should receive high marks for the quality, rigor, and appropriateness of the scientific and technical approaches to the exploration. At least six geoscientific techniques have been used and the results integrated with previously gathered data. The project has utilized the expertise of the PI together with a cadre of undergraduate and graduate students to undertake rigorous field and laboratory studies.

The acquisition of permits, the planning of logistics and the orchestration of the project activities were all remarkably well done. This was done despite a change in the venue for the primary study site (from the University of Kansas to the University of Texas) and the fact that a major industry partner (Ram Power) underwent internal turmoil that mandated that it remove itself from project participation

Phase I appears to be more than 90% complete, however no cost figures were presented so the actual cost-effectiveness can not be calculated by this reviewer..

PI Response:

Reviewer 23404

Score: 8.0

Comment: The technical approach is multifaceted in terms of geologic and geophysical methods successfully applied. The success of the project relied on appropriate application of specific methods followed by well organized integration of the results to develop a working geothermal model which can be evaluated by drilling.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23527

Score: 9.0

Comment: The assortment of tests and analysis performed to date is a significant accomplishment. There was not much activity reported during the review period but the prior results and accomplishments are nonetheless impressive. The reviewer finds the reflection seismic data interpretation particularly intriguing. The assessment of this data in bullet 2 on slide 13 (indication of geothermal fluid flow based on seismic data) should be validated in the field development phase. If it proves true then this effort will represent a demonstration of a powerful prospecting tool.

PI Response:

Reviewer 23478

Score: 8.0

Comment: The many project participants have accomplished virtually everything that they set out to do: Geologic mapping thermochronometry, seismic, magnetic, and gravity surveys, isotope analyses, thermal gradient measurements in 2 meter holes and shot holes, and integration of all the data gleaned with previously gathered information obtained from Ram Power and others.

The results of this work include generation of a 3D geologic map, as well as contoured thermal gradients, gravity gradients, the magnetic scene, and new concepts of the roles of detachment and antithetic faults in the creation of Clayton Valley.

Because no costs were given, it is not possible to compare costs and values of the work, but the conclusions reached appear to have very sound bases and should lead to interesting drilling targets in the northern and eastern parts of the Valley.

PI Response:

Reviewer 23404

Score: 8.0

Comment: The results, accomplishments and progress are all high and consistent with the level of effort/status of the overall project. The integration of the results should serve as a model for the DOE to seek for future efforts to replicate. The combination of methods should be considered for evaluation of other blind geothermal resources.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23527

Score: 9.0

Comment: Nothing to say here really. The project has been managed well. The issues experienced with commercialization entities are not unusual for this type of endeavor.

PI Response:

Reviewer 23478

Score: 8.0

Comment: It appears, from the very positive results achieved during Phase I of this project, that management and coordination have been excellent. Staffing has been primarily with university students and the work was accomplished despite a change in headquarters from KU to UT and the loss of support from Ram Power.

Management was successfully able to obtain all permits required to conduct the seismic and gravity surveys and there has been cooperation between project management and Ram Power together with Rockwood Lithium Co.

Future plans hinge upon the availability of funding for drilling. This could come from the DoE and/or from geothermal industry developers. If work continues at the project sites, then it will provide additional educational opportunities for students as well as employment for local and regional workers.

PI Response:

Reviewer 23404

Score: 7.0

Comment: The PI has done an excellent job of coordinating and directing this work during the course of a job location change, working with industrial partners, and mobilizing students. The relocation also caused delays in funding which have yet to be amended.

PI Response:

Reviewer 23401

Score: 5.0

Comment: Future management uncertainty not the fault of the PI.

PI Response:

STRENGTHS

Reviewer 23527

Comment: A fairly comprehensive array of field data was compiled over the course of the project and used to produce a highly detailed description of the resource. The manner in which it was acquired is also valuable in itself. The use of students on the project should benefit the future geothermal work pool, particularly given that much of the work represents meaningful field experience and actual exploration activities.

PI Response:

Reviewer 23478

Comment: This project has resulted in the acquisition of a very large amount of data from multiple geoscientific surveys. This information can comprise a road-map for similar projects in the Basin and Range as well as other geologic environments.

Because fracture permeability is always problematical in geothermal prospects, the fault delineation techniques employed in this project could lessen questions regarding potential fluid flow patterns at other sites.

A final project strength is the fact that the PI and his staff persevered despite funding and logistical challenges in order to obtain an impressive Phase I result.

PI Response:

Reviewer 23404

Comment: A well coordinated effort, lots of workers (students) facilitated success

PI Response:

Reviewer 23401

Comment: Good academic support now in place.

PI Response:

WEAKNESSES

Reviewer 23527

Comment: None obvious

PI Response:

Reviewer 23478

Comment: The only weaknesses that I have found are related to the graphical presentations. No cross- section lines were seen, and the legends could be slightly more comprehensive.

With respect to the actual work, I'm sure that there were many stumbling points, but they were not described and they were obviously overcome in order to provide a logical, comprehensive Phase I result.

An interactive, multi-layer, downloadable 3D earth model would tie the multiple technologies together and make the presentation more descriptive.

PI Response:

Reviewer 23404

Comment: Delay caused by relocation

PI Response:

Reviewer 23401

Comment: Uncertain industry support.

PI Response:

IMPROVEMENTS

Reviewer 23527

Comment: none obvious

PI Response:

Reviewer 23478

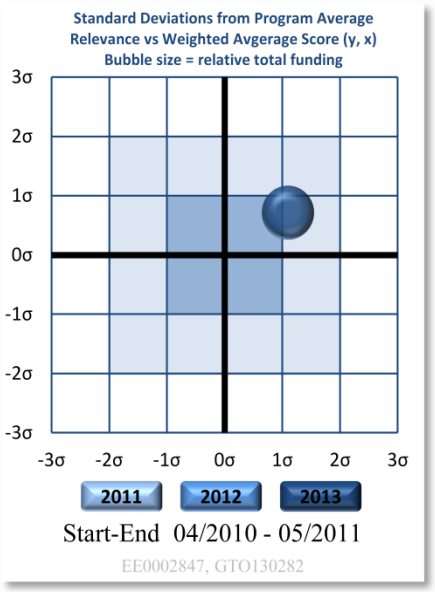
Comment: At this point I have no recommended improvements other than the one contained in the previous section called "weaknesses"..

PI Response:

Reviewer 23404

Comment: None noted

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002847
Project: Finding Large Aperture Fractures in Geothermal Resource Areas Using a Three-Component Long-Offset Surface Seismic Survey
Principal Investigator: Teplow, William
Organization: US Geothermal, Inc.
Panel: Innovative Exploration Techniques

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23537

Score: 9.0

Comment: The integration of geophysical and geological tools is complimentary and relevant. Results of this work will advance GTO's mission and expand on developers understanding of extent of resource of production targets.

PI Response:

Reviewer 23478

Score: 8.0

Comment: Because one of the primary GTO goals is to improve exploration efficiency while decreasing costs, this project can be considered to be highly relevant with a strong potential for positive impacts on the geothermal industry.

The project innovations include: 1) new methods for utilizing geophysical techniques including seismic, magnetics, and kinematic analyses of deformation patterns, 2) successful modifications of previously existing techniques so as to cut costs and increase the rates of data acquisition, 3) the modification of a small drill rig to allow rapid, inexpensive drilling of medium depth holes to 8 inch diameter, and 4) optimization of well designs to save money while still achieving objectives.

In Phase 2, drilling targets identified in Phase 1 were drilled and tested with excellent results: temperatures were increased by 10-15F while the reservoir extent was increased by about 1 sq. mile.

Best of all, this project resulted in the design of an integrated exploration plan that should be replicable throughout the Basin and Range province.

PI Response:

Reviewer 23404

Score: 8.0

Comment: This project used a few geophysical methods to their advantage to better understand the geothermal potential for their site. While it is unclear to the reviewer if these methods are transportable to other terrains/structural styles, these workers demonstrated deployment and integration of the methods in a manner such that they may beneficially impact the broader Geothermal Office's mission and goals.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23537

Score: 9.0

Comment: The technical approach is rigorous and additive in that successful and relevant portions of this work should be applicable elsewhere in the Basin and Range if not other settings. The teams assembled and the accomplishments thus far attest to the rigor of this approach.

PI Response:

Reviewer 23478

Score: 8.0

Comment: The results of this project speak for themselves. The several geologic, geophysical, and remote sensing methods used to identify large aperture fractures worked well. The densely spaced data was interpreted integrated with existing information and used to find targets having geothermal signatures similar to those in the known-resource area.

Models were made and constantly refined using the latest information. Accordingly, plans were changed frequently so as to optimize the chances of good results. As a result, the original model of the San Emidio geothermal reservoir was changed considerably over the 2 year investigation period.

All of the work conducted, and especially the drilling was completed at or below budget. The few significant time delays were due to a shortage of funds immediately available in light of other pressing corporate obligations.

Of significant importance to the prompt conduct of all work phases was the permitting of extra activity sites well before the anticipated need to occupy the sites. This minimized delays and consequent extra costs.

PI Response:

Reviewer 23404

Score: 9.0

Comment: The researchers utilized a combination of geological and geophysical methods to their advantage to evaluate the geothermal potential in this specific tectonic environment/structural setting. They appear to have been quite successful. They had a working hypotheses which they were able to evaluate through measurement and analysis. This is an impressive project overall.

PI Response:

Reviewer 23401

Score: 7.0

Comment: The good drilling outcome seems to be the basis for declaring success of the methods of interpretation, which does not necessarily follow. See further comments in the "improvements" section.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23537

Score: 9.0

Comment: The proof of concept lay in results generated. The quality of accomplishments to date is high and is achieving project objectives. Slimhole drilling results are positive. Illustrations of drill traces superimposed on acquired/processed data testify to the accomplishments. Would like to have seen the interpretations of structures on your seismic reflection profile (slide 8).

PI Response:

Reviewer 23478

Score: 9.0

Comment: This project must be scored very high in this category. Productive fractures were found in 4 out of 5 wells drilled at sites identified by synthesis of multiple geophysical and remote sensing methods. Successful slim holes were drilled at or below budgeted costs. Remote sensing was used optimally so as to avoid environmental issues and permitting delays, finally drill rig modifications allowed easy access to all target sites, rig-on-hole testing of the resource and prompt P-T measurement using tools kept on site at all times.

It should be noted that geothermally experienced, commercially available contractors, with state-of-the-art equipment and tested methods were used on this project.

Project results were excellent, with temperatures recorded that were 10-15F higher than those found at the original San Emidio field and the field extent enlarged by about 1 sq. mile.

PI Response:

Reviewer 23404

Score: 9.0

Comment: The quality of accomplishments and results deserves merit. The geophysical method results correlated well and the tectonic setting was conducive to the type of fracturing at depth desired. It is inferred that this set of methods is transferable to other areas of the Basin and Range province in the western U.S.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23537

Score: 9.0

Comment: Project seems to be on task and target for deadlines is reasonable.

PI Response:

Reviewer 23478

Score: 9.0

Comment: This project utilized geothermal industry leaders in each of the techniques employed so as to optimize the chances of getting reliable, replicable results and interpretations. This plan obviously paid off, as shown by the very high success ratio of the slim hole drilling.

The management decision to calibrate each tool on known geothermal sites and to then step out in search of new productive faults and resources also worked well.

Finally, management drilled and tested multiple target areas to confirm the findings and interpretations of the integrated exploration plan.

The management flexibility and ingenuity paid off in low cost, highly accurate identification of new geothermal resources and the ability to enlarge the existing San Emidio power generation capacity.

PI Response:

Reviewer 23404

Score: 9.0

Comment: It appears the project is extremely well managed. the team had a good plan and execution strategy, and they were successful in getting the work done in a timely and cost effective manner.

PI Response:

Reviewer 23401

Score: 9.0

Comment: Commercial developer brings good management oversight skills.

PI Response:

STRENGTHS

Reviewer 23537

Comment: The team, concept and outcomes.

PI Response:

Reviewer 23478

Comment: The strengths of this project lie in the fact that this area was discovered at all. Heat was indicated via drilling related to gold exploration and then confirmed by shallow drilling west of the mining claims. There were abundant jasperoid outcrops at and below the surface, but no overt geothermal indicia.

This "second stage" project has greatly increased understanding of the local structural framework and precisely identified fractures that are open and permeable so as to conduct thermal fluids.

Permeability has always been a problem in geothermal areas, so the techniques used in this project should greatly assist others in efficiently defining the locations of good fluid flow conduits.

An additional strength of this project is the use of simpler drilling equipment and techniques to drill slim holes. Geothermal drilling has always followed in the footsteps of the oil and gas industry with regard to the equipment needed. Too often, this habit has resulted in the use of oversized, very expensive, cumbersome rigs and tools. This project may have helped break the mold.

PI Response:

Reviewer 23404

Comment: A good plan, a good team, great execution to build their success.

PI Response:

Reviewer 23401

Comment: Company support suggest high likelihood of completion.

PI Response:

WEAKNESSES

Reviewer 23537

Comment: None apparent.

PI Response:

Reviewer 23478

Comment: The only weakness that I can see in this project is the fact that the analytical techniques used to correlate the results of the various surveys are understood only by a few scientists. In order for this work to proliferate, these talents should be passed on to others in the academic and industrial worlds.

Otherwise, I believe that this is an excellent project with good results and strong potential for replicability in similar geologic environments.

PI Response:

Reviewer 23404

Comment: None apparent

PI Response:

Reviewer 23401

Comment: Lacks comparisons of methodologies to tell whether "innovation" deserves credit for the claimed drilling success, or the wells were just drilled in a good spot because that's all that was available.

PI Response:

IMPROVEMENTS

Reviewer 23537

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23478

Comment: See recommendation within the text under the "Weaknesses" category.

PI Response:

Reviewer 23404

Comment: None cited

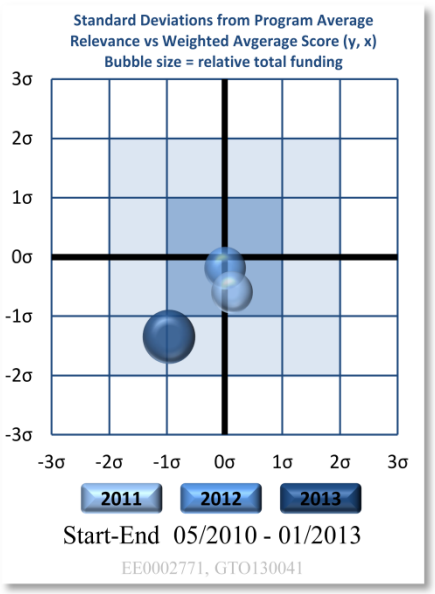
PI Response:

Reviewer 23401

Comment: It is unclear whether the LAF's of the seismic interpretation correlate with the production zones in the wells. In the case of one example, OW-10, it appears they do not. The labels on the seismic profiles are inadequate for the reader to be certain, but it appears that the tabulated inflow zones are all above the inferred fracture. A clearer exposition of this interpretation, and a comparison between alternative interpretations, beginning with shot point migration, would make the results more applicable to other areas.

PI Response:

Materials, Zonal Isolation, and Innovative Methods of Heat Recovery Reviewer Comments and Principal Investigator Rebuttals



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002771
Project: High Temperature, High Pressure Devices for Zonal Isolation in Geothermal Wells
Principal Investigator: Fabian, Paul
Organization: Composite Technology Development, Inc.
Panel: Materials; Zonal Isolation; Innovative Methods of Heat Recovery

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23447

Score: 3.0

Comment: Project focuses on only one component of zonal isolation without any real understanding of the process and logistics of how EGS wells are stimulated or how unwanted flow zones are sealed off currently in geothermal fields. While the theory of using porous expandable seal (PES) capsules for zonal isolation is innovative, not enough thought has been given to technical details for actual field application such as surface equipment requirements for pumping rates, deployment and retrieval of PES system downhole and other crucial logistics necessary for successful field operation. Project has demonstrated little to no advancement in addressing knowledge gaps and barriers; impact is below what could be expected.

PI Response:

Reviewer 23491

Score: 8.0

Comment: Diverters that can be used in the various stimulation methods will be needed to effectively stimulate EGS type projects both now and in the future. The current products may or may not work in every application. Adding tools to the tool box is relevant.

PI Response:

Reviewer 23527

Score: 3.0

Comment: Much of the challenge associated with successfully using the subject technology relates to system level deployment. This is arguably more challenging than the development of the isolation material and since deployment, even on a conceptual level, does not appear to have been a significant part of the project, the value of the work with respect to programmatic objectives is arguably limited. While this is interesting technology, its deployment will likely require a significantly different equipment infrastructure than currently exists in field practice. Furthermore, there are many potential performance issues with the approach that will need to be addressed at some level to develop confidence that it is feasible. The claim was made during the presentation that the current TR level of the technology is 4/5. A more realistic assessment would put it in the 2/3 range since from what I can gather there were at best only simple laboratory studies performed indicating that the pellets could be delivered and expanded in a simplified borehole representation.

PI Response:

Reviewer 23454

Score: 6.0

Comment: The project's research is highly relevant to the needs of zonal isolation, but its impact on the drilling market is much harder to evaluate. That impact depends on the successful commercialization of the expanding-pellet technology, and that appears to be far away. CTD has done bench-scale experiments to demonstrate pressure quasi-sealing, but progress to market would require, at minimum, a field test showing plugging in an actual wellbore, along with successful deployment of the pellets, and withdrawal of the drill string after stimulation. It is also unclear whether industry will accept the "controlled leak" approach, rather than an absolute seal.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23447

Score: 4.0

Comment: The focus of this project is mainly on the design, development and manufacture of PES capsules. Much thought went into the scientific/technical approach as to how to accomplish this end. This reviewer feels many important elements of the actual zonal isolation process in an EGS field were overlooked. While meetings with geothermal collaborators (Altarock and Geodynamics) occurred at the start of the project, follow-up meetings with these collaborators did not occur throughout the project. Perhaps with continued support of the geothermal experts the larger picture of how this PES system could be applied in an EGS field could be realized.

PI Response:

Reviewer 23491

Score: 8.0

Comment: This project demonstrates a valid technical approach, the project appears to progress through a logical sequence of events to end a a field testable product, within budget and time constraints. This product will require several field tests to validate the effectiveness of the deployment method as well as the products ability to effectively be used as a diverter. One of the items that needs further explanation is how the product is to be injected into the fluid system without damage to the diverter.
PI Response:

Reviewer 23527

Score: 3.0

Comment: Again, the there are numerous deployment challenges associated with this technology that are not even touched in the work plan. A more complete concept system describing how the particles will be delivered to the wellbore region of interest should have been developed. There should have been more comprehensive laboratory scale demonstrations planned showing that the pellets can be distributed over a reasonable length and activated (over the entire length) and perform their sealing function with a focus on replicating potential field features that may adversely affect field implementation (e.g. demonstrate the ability to pump the pellets through a longer, more representative drill string, evaluate potential for pellet bridging before pellets reach the region of interest, etc.). It is difficult to see how the tasks performed enable a reasonable assessment of the potential feasibility of the concept.

PI Response:

Reviewer 23454

Score: 7.0

Comment: The S/TA has been good, although directed toward a limited objective. Essentially all effort has been gone toward development of the compressed pellets, which is clearly a necessary step, but other items in the SOPO have been addressed minimally, if at all. Specifically, the deployment and retrieval methods have received only cursory attention, and the cost model, none at all. The presentation focused on use of this technology as a packer for stimulation, but its use to seal off an intermediate zone (i.e., a zone that is not at the bottom of the hole) and allow flow past it is not addressed.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23447

Score: 4.0

Comment: Results completed methodology to successfully manufacture and wrap PES capsules. No testing was done to verify if PES capsules actually work in field use.

PI Response:

Reviewer 23491

Score: 7.0

Comment: This project has met the goals setout for it within the costs and timeline. It is unfortunate that field that at least preliminary field testing was not called for in the project. This project is now complete according to the presentation. It would be wise to fund at least a preliminary field test, even in a low temperature well.

PI Response:

Reviewer 23527

Score: 5.0

Comment: The statement of work mentions that there was a proof-of-concept lab scale demonstration of the technology but there was little detail to evaluate what was done in the provided material. It is assumed by the reviewer that this occurred in preceding years. There does appear to have been significant progress made with respect to pellet fabrication and there was considerable content in the presentation describing the details.

PI Response:

Reviewer 23454

Score: 7.0

Comment: As noted under Approach, the accomplishments toward development of the compressed pellets are of high quality, and are commensurate with the costs incurred. Other project objectives, however, are not fully addressed or those results are not included in the materials available to reviewers. This project has produced interesting and potentially valuable technology but its commercialization and actual application in the field are very far away.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23447

Score: 5.0

Comment: Project completed on time and on budget. No testing of concept was done. Altarock and Geodynamics' expertise used only in initial stage of project. As far as future project plans, this reviewer feels a field demonstration should be completed prior to mass production of PES capsules.

PI Response:

Reviewer 23491

Score: 7.0

Comment: The project management and coordination appears to have been accomplished within the outline of the project documents. The one remaining item that was not covered in the project was field testing, and the field testing will determine whether this product is indeed useful in the field.

PI Response:

Reviewer 23527

Score: 5.0

Comment: This is difficult to evaluate without access to information from preceding years. Objectives appear to have been met for this year based on reported information, but it is difficult to evaluate this criterion without access to the original project plan. This is a general flaw of the current peer review process. Reviewers should be given original plan and scheduling details to better evaluate this criterion.

PI Response:

Reviewer 23454

Score: 7.0

Comment: Project management has gone reasonably well, although it is not clear that the decision points described in the SOPO were reached or observed. AltaRock and Geodynamics are listed as "industry collaborators" but there is no description of what role they have played in the project. Again, a project of limited scope has gone well.

PI Response:

STRENGTHS

Reviewer 23447

Comment: Good idea if tested in actual wellbore.

PI Response:

Reviewer 23491

Comment: This is a cleaver idea that may help with EGS stimulation diverter technology. If this product proves itself in the field it will provide another level of diverter materials that can be used to provide a more far reaching stimulation

effect. The product might also be useful in at least temporarily providing a plug across open perforations and casing splits until permanent repairs can be made.

PI Response:

Reviewer 23527

Comment: The project team appears to be well versed in the materials aspect of the technology.

PI Response:

Reviewer 23454

Comment: Good work on development of the compressed pellets, trigger mechanism, and manufacturing process.

PI Response:

WEAKNESSES

Reviewer 23447

Comment: Only one component of the process, production of PES capsules, was accomplished in this project. If the process doesn't work in field application, little real value was gained from project. Are any vendors interested in field testing product?

PI Response:

Reviewer 23491

Comment: There is in my estimation a weakness that was designed into this project in that the project was not required or funded to field test this product. This is not the fault of the PI but rather an omission in the award. Another striking weakness is that use of this product in non vertical holes does not seem to have even been considered. How could this product be used in horizontal holes.

PI Response:

Reviewer 23527

Comment: It is not apparent that the project team is adequately knowledgeable with respect to the fieldability issues associated with the technology. Such factors are critical to the potential commercial success of the technology.

PI Response:

Reviewer 23454

Comment: Lack of systems approach -- little consideration of deployment and retrieval mechanism, or of all zonal isolation applications.

PI Response:

IMPROVEMENTS

Reviewer 23447

Comment: Project already completed.

PI Response:

Reviewer 23491

Comment: Since this project is complete there is no path to improvement. I would like to see an evaluation of system like this that could be pumped through the bit for LC control.

PI Response:

Reviewer 23527

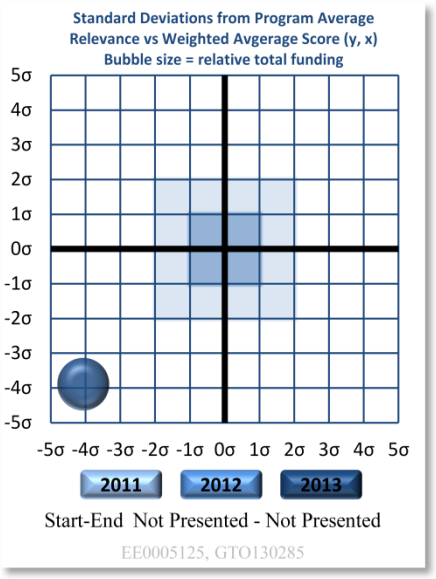
Comment: Projects such as this that focus on developing a fieldable solution to a relevant industry (geothermal) problem should be required to address all aspects of the proposed technology (at least at a detailed conceptual level) to demonstrate that it is feasible. This is especially true when the technology involves potentially complex and non-standard deployment methods and technologies.

PI Response:

Reviewer 23454

Comment: Appears too late for suggestions -- project essentially over.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005125
Project: Geothermal Resource Development with Zero Mass Withdrawal, Engineered Convection, and Wellbore Energy Conversion
Principal Investigator: White, Christopher
Organization: LA State Univ.
Panel: Materials; Zonal Isolation; Innovative Methods of Heat Recovery

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23526

Score: 1.0

Comment: Presenter was a no-show. Can't comment on this.

PI Response:

Reviewer 23491

Score: 1.0

Comment: No Show

PI Response:

Reviewer 23527

Score: Not scored

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23454

Score: 1.0

Comment: 0

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23526

Score: 1.0

Comment: Presenter was a no-show. Can't comment on this.

PI Response:

Reviewer 23491

Score: 1.0

Comment: No Show

PI Response:

Reviewer 23527

Score: Not scored

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23454

Score: 1.0

Comment: 0

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23526

Score: 1.0

Comment: Presenter was a no-show. Can't comment on this.

PI Response:

Reviewer 23491

Score: 1.0

Comment: No Show

PI Response:

Reviewer 23527

Score: Not scored

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23454

Score: 1.0

Comment: 0

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23526

Score: 1.0

Comment: Presenter was a no-show. Can't comment on this.

PI Response:

Reviewer 23491

Score: 1.0

Comment: No Show

PI Response:

Reviewer 23527

Score: Not scored

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23454

Score: 1.0

Comment: 0

PI Response:

STRENGTHS

Reviewer 23526

Comment: Presenter was a no-show. Can't comment on this.

PI Response:

Reviewer 23491

Comment: No Show

PI Response:

Reviewer 23527

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23454

Comment: 0

PI Response:

WEAKNESSES

Reviewer 23526

Comment: Presenter was a no-show. Can't comment on this.

PI Response:

Reviewer 23491

Comment: No Show

PI Response:

Reviewer 23527

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23454

Comment: Didn't show up

PI Response:

IMPROVEMENTS

Reviewer 23526

Comment: Presenter was a no-show. Can't comment on this.

PI Response:

Reviewer 23491

Comment: No Show

PI Response:

Reviewer 23527

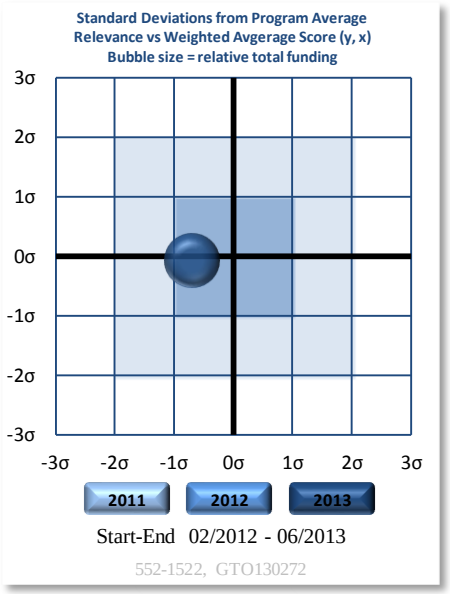
Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23454

Comment: 0

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: 552-1522
Project: Self Consuming Downhole Packer
Principal Investigator: Grubelich, Mark
Organization: Sandia National Laboratories
Panel: Materials; Zonal Isolation; Innovative Methods of Heat Recovery

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23447

Score: 7.0

Comment: Project objective is to advance current drillable packer technology by using an epoxy system to isolate a zone by 1) injecting both components separately downhole, 2) mixing epoxy downhole to form packer, 3) when packer is to be removed it is ignited either chemically or thermally and 4) then it is self-consumed downhole in a high temperature, high pressure, and aqueous geothermal wellbore. This innovative project if successful could be far more effective in well stimulation and zone isolation than current drillable packer technology while minimizing the overall well cost. The epoxy system is still in early stages of development and a number of technical barriers must be overcome before this process can be successfully applied to a geothermal wellbore.

PI Response:
Correct. Thank you for the comment.

Reviewer 23412

Score: 5.0

Comment: This project would be difficult to bring to commercialization with other completion tool competition. It would be favorable to have a completion tool vendor collaborate on the project.

PI Response:
We are in the early R&D phase. A completion tool vendor would be beneficial as we approach field trials.

Reviewer 23527

Score: 4.0

Comment: This is interesting technology but it is not clear that there is a pathway towards commercial viability based on the work performed. In general there would seem to be many challenges associated with implementing a multi-stage epoxy stem and addressing the additional complications associated with deployment in a wellbore environment do not even seem to be within the scope of the project. The advantages of the technology are also not apparent. Why is this

material and degradation method superior to chemically simpler single component options that can be deployed and more simply chemically degraded? Such questions should be answered as part of the work.

PI Response:
The advantage over environmentally degraded materials is the system can be command trigged at any time and does not require drilling.

Reviewer 24895

Score: 7.0

Comment: Removable packers are needed for temporary suspension and isolation of lower zones (EGS, geothermal and oil and gas), normally called bridge plugs, and a self-consuming one could have cost advantages by avoiding the drill out process. The critical packer need is to isolate upper zones from the stimulation interval, with tubing back to the surface through the upper packer, so the isolated zone can be stimulated. This application would be useful for isolating the lower zone (bridge plug), but may prove more difficult to utilize for the upper isolation that has to convey the tubing through it.

The advantages claimed are probably overly optimistic on the number of trips saved and packer use per well. It could be more for EGS, depending on how controls for multiple fracturing is needed/handled, but too high for conventional wells - still an important tool if it works.

PI Response:
Thank you for the positive comment.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23447

Score: 9.0

Comment: Approach is sound, logical and thorough. An experienced team has given much thought to details in all parts of process such as: transportation, deployment, use downhole and cleanup afterwards, including environmental and regulatory concerns. This project leveraged heavily from existing self-consuming materials developed at Sandia National Laboratory thereby reducing the overall project cost. Safety was a high priority as resin formulations were investigated that used high temperature materials, were water resistant with stable properties, and cured without thermal runaway at ambient and high temperature brine environments.

PI Response:
Thank you for the positive comment.

Reviewer 23412

Score: 8.0

Comment: The materials testing approach is adequate. It would be better if industry collaboration was included such as available materials and production of devices.

PI Response:
We are in the early R&D phase. Industry collaboration would be beneficial as we approach field trials.

Reviewer 23527

Score: 3.0

Comment: The method for field implementation of the proposed technology should be addressed early on in order to assess fundamental feasibility of the concept. There are many complexities associated with utilizing this technology in a downhole environment related both to performance of the sealing material and delivery to the region of interest. In other words, obtaining the desired functional characteristics of the isolation material is only one part of the overall approach that needs to be considered in the development of the technology. This may even be less challenging than deploying the technology in a field environment. The technical approach should consider the system as a whole.

PI Response:
We are working towards a systems approach.

Reviewer 24895

Score: 8.0

Comment: This project was pretty far out on the experimental level when it was initiated, so the approach was necessarily experimental. Project extends existing materials from other applications into use as a self-consuming packer. There are still gaps in doing the testing underwater, let alone at pressure in a water environment and gaps on moving to a commercial application of placing a two part epoxy in a deep well, etc. These are probably follow on projects if the feasibility can be demonstrated. They have a good science team, but will need some industrial partners after feasibility is demonstrated.

PI Response:
We agree with the need for an industrial partner.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23447

Score: 8.0

Comment: Good progress has been made in the first phase of the project. During testing in Task 1 several formulations were ruled out as thermal runaway occurred during the curing process. In bulk quantities the resin could auto ignite. In Task 2 chemical changes were made to the fuel/oxidizer in the existing formulation for high temperature curing and stability. Two formulations burned successfully under hot water at ambient pressure. The material has been shown to be stable to 315°C in the laboratory and remain stable for more than two days. Task 3- fabrication and laboratory

demonstration of a 3" by 3" scaled monolith remains to be completed in July 2013. Further work on a triggering system either chemical (acid) or thermal (hot wire) is ongoing and dependent on the formulation used. Two patents have been submitted from this project.

PI Response:
Thank you for the positive comment.

Reviewer 23412

Score: 5.0

Comment: This project is a new project and difficult to evaluate the results and progress.

PI Response:
NA

Reviewer 23527

Score: 3.0

Comment: Achieving the desired material performance in application-like conditions appears to be quite challenging for the proposed technology. The reported data indicates that the project has been unsuccessful in its efforts to obtain a formulation that works at design temperature specifications to date. It was mentioned that there was a path forward to demonstrating feasibility of a component system that will work but no details were provided. Since the objective of the project is to demonstrate an epoxy based isolation system that works at high temperature the pathway for creating the material needs to be more convincingly described given the current state of results.

PI Response:
The project has been an R&D challenge with a significant amount of learning on the way. The degree of difficulty is worth the technological risk for such a complex system.

Reviewer 24895

Score: 7.0

Comment: The project has made acceptable progress considering the highly experimental nature of what is trying to be done. The project was to build on existing technology, but that technology was for lower temperatures and did not include working under water, so more building on a prior concept than building on prior work, although the laboratory equipment could probably be adapted to make a new/different product. The primary PI left the project and had to be replaced. Considering those realities, the progress has been acceptable and the quality good.

PI Response:
Thank you for the positive comment.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23447

Score: 8.0

Comment: Project is about four months behind schedule and on budget. Project management was good as many problems with formulations were quickly identified and resolved. Good coordination with chemists and lab personnel resulted in adaptation of existing formulations to yield two promising candidates. A thorough understanding of the logistics of current drillable packer technology in geothermal wellbores allowed the project team to anticipate most aspects of how the epoxy system technology can be transferred from laboratory tests to field use.

PI Response:
Thank you for the positive comment.

Reviewer 23412

Score: 8.0

Comment: Project management is adequate.

PI Response:

Thank you for the positive comment.

Reviewer 23527

Score: 4.0

Comment: There is little detail provided in the presentation and other materials to evaluate this criterion. As mentioned in other evaluation categories, the inclusion of a convincing plan for deploying the technology in the field should also be a part of this work. If there is excessive risk associated with the field deployment of the process downhole then the value of the material development may be limited.

PI Response:
We are in the early R&D phase. There is the typical risk reward balance that needs to be considered. It is, no doubt, a challenging project.

Reviewer 24895

Score: 5.0

Comment: The project has had some staffing issues, which have hopefully been resolved. In addition, it needs some well-defined milestones that break the project into manageable pieces with go/no-go decision points, including when to bring in potential commercial partners. Defining a sequence of milestones may have been difficult to do in the beginning, because of the experimental nature of the first phase, but it should be doable now.

PI Response:
We agree, we are presently evaluting new materials.

STRENGTHS

Reviewer 23447

Comment: Innovative technology could save in overall EGS well costs.

PI Response:
Thank you for the positive comment.

Reviewer 23412

Comment: The strength of the project is that it is will be short in duration.

PI Response:
NA

Reviewer 23527

Comment: The materials expertise of the project staff is significant and appropriate for the material development goal of the project.

PI Response:
Thank you for the positive comment.

Reviewer 24895

Comment: Although there were some struggles, I believe they have a good team, which is enthusiastic about the project. There is a good likelihood they will be able to overcome the remaining hurdles. Having a bridge plug that does not have to be drilled out has some advantages from both a cost and formation damage standpoint (preventing damage to the fracture or reservoir created in the isolated zone).

PI Response:
Thank you for the positive comment.

WEAKNESSES

Reviewer 23447

Comment: Many technical hurdles to overcome before the epoxy system can be field tested.

PI Response:
We agree. The project has been an R&D challenge with a significant amount of learning on the way.

Reviewer 23412

Comment: This new project has not shown any weaknesses.

PI Response:
Thank you for the positive comment.

Reviewer 23527

Comment: The deployment considerations for the proposed technology must be more convincingly developed, at least at the conceptual level, as part of the project. As with many technologies of this type, the translation from laboratory implementation to field implementation is tremendously challenging and often the biggest obstacle to commercial application.

PI Response:
We agree. After a satisfactory material is developed and deployment methods are demonstrated the field trials will be the most challenging part of the program.

Reviewer 24895

Comment: The project is on the edge of known technology, so has an experimental nature to it. It will be difficult to laboratory test the deep well placement and decomposition of the packer material. Making a packer that can be pumped through for stimulation will be a greater challenge than making a bridge plug to isolate the bottom zones.

PI Response:
We agree.

IMPROVEMENTS

Reviewer 23447

Comment: Continue project through field testing.

PI Response:
Thank you for the positive comment.

Reviewer 23412

Comment: The only improvement would be industry collaboration.

PI Response:
We agree.

Reviewer 23527

Comment: Develop a thorough and detailed conceptual design for how this material system will be deployed downhole.

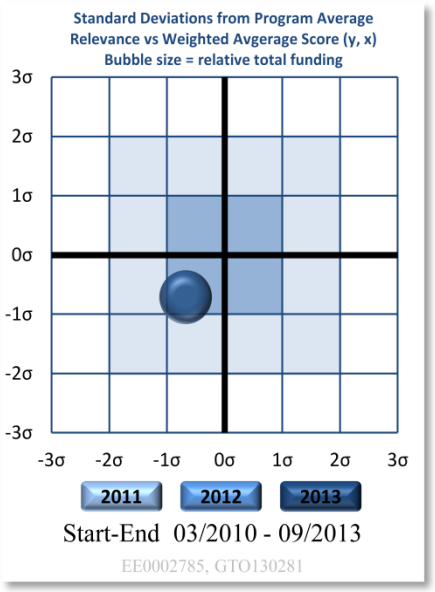
PI Response:
We will plan for that as we progress towards a field trial.

Reviewer 24895

Comment: In a general sense, agreeing on some specific milestones would help focus the work on the important targets.

As an additional consideration, the project is focused on placing the self-consuming packer as a two part liquid in the open hole. There may be an opportunity to make the self-consuming material as a deformable material around an pipe (say aluminum) core, which would allow running the set material into the well and hydraulically deforming it to pack off the hole (as is currently done with rubber element packers – ECP's) and then have the self-consuming thermal burn remove both the aluminum and the packer material. Since the packer could be run into the hole as set material, it would avoid having to deal with the difficulties of placing a two part material in a deep wellbore.

PI Response:
We have considered that concept and it is valid. Great idea! Providing enough energy to melt a metal core is a thermochemical challenge though.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002785
Project: Development of an Improved Cement for Geothermal Wells
Principal Investigator: Trabits, George
Organization: Trabits Group, LLC
Panel: Materials; Zonal Isolation; Innovative Methods of Heat Recovery

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23433

Score: 7.0

Comment: Reducing the costs and difficulty of constructing geothermal wells is a central objective of the Geothermal Technologies program. Costs associated with well completion are a significant fraction of total well costs, and within this category, issues of cementing are of significant importance. Existing cements for geothermal wells, often based on calcium aluminate phosphate, have some disadvantages. These include sensitivity to certain cement retarders or accelerators, and incompatibility with conventional cements. The development of an easy-to-use alternative cement is therefore an important task, which if successful, will make procedures for well cementing considerably simpler.

PI Response:

Reviewer 23638

Score: 8.0

Comment: Goal 2 of the DOE GTO MYRDD Technical Plan is to develop low-cost, high-efficiency well construction which includes completion technology associated with low cost, high temperature cements. The development of a zeolite-containing lightweight, high temperature, high pressure geothermal cement will enable the use of a cementing system that saves time and simplifies logistics, as the need to sterilize pumping equipment before use will not be needed with this cement. This lightweight cement would also eliminate the need for nitrogen foaming. The costs of processed (to the desired particle size) zeolites was estimated to be around 12 cents/lb, only slightly higher than that of regular cement (9 cents/lb). The zeolite additive is lightweight, resistant to carbonation, and initial experiments suggest that the zeolite cement mixtures examined have good compressive strength.

PI Response:

Reviewer 24895

Score: 3.0

Comment: Don't see much value. There is a lot of existing work and don't see how this adds much to the options that are already available. Class G based, light weight (13.5 ppg), 0 free water slurries with adequate compressive strength are

readily available and have been for many years. Foaming to get this density has advantages, but is not necessary. If you need a 10 ppg slurry with adequate strength, you cannot get there with zeolites, but you can with foam and some other techniques such as hollow glass spheres. Carbonation is not normally an issue. The cement in the wells drilled by Unocal at Brawley carbonated, but the cement still had adequate strength There is an SPE paper published on those results (the cement was exhumed when the wells were abandoned –SPE 18618). Thermal cycling and cracking of the cement from thermal cycling is a problem, but independent of carbonation of the cement and usually solved by making the cement more flexible (such as with foam). Carbonation is an issue when there are acid containing zones that can then attack the carbonate. These are usually associated with CO_2 gas zones formed over high temperature systems that leak steam, which then condenses and leaves the CO_2 behind as a separate gas phase. The dissolved CO_2 is not an issue and I would not expect carbonation to be an issue for EGS development.

PI Response:
There is not a lot of existing work on zeolites cements at HPHT in the literature. Most work reported was conducted at temperature less than 200F. A major portion of this work was to explore the viability and use of zeolite in HPHT cements. Lower temperature response of zeolites is signfincantly different than the high temperature response. As a means for characterizing the zeolite influence, a standard density of 13.5 ppg was established. As the responses are better understood, changes in density can be explored further. The reponse of zeolites and retarders is also variable and changes consiserably with changes in tempeature.

Proprietary cements for HPHT applications may exist, however, these have the disadvantages of being custom designed mixtures, which must be used following rigorous protocols and sterilized cement placement equipment. The main goal of this project is to develop a zeolite based HPHT cement that will have a more "generic" formulation and will be easy to use, so that the regular cement handling equipment can be used for this zeolite based cement as well, without the need to sterilize the equipment.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23433

Score: 7.0

Comment: The approach proposed is to develop cements based on a zeolite-containing system. This potentially has numerous advantages over the current calcium aluminate phosphate system, including temperature stability, no free water, good rheological properties during placement, adequate strength when set, and, importantly for ease of mixing and placement, it should not be adversely affected by residual amounts of conventional cement in the mixing and placement equipment. This latter feature will obviate the need for thorough cleaning of the mixing and placement equipment before using the high-temperature cement. The approach is systematic, starting with a literature search and assessment of current practice, running through the location and evaluation of suitable sources of zeolites to the testing and evaluation of trial mixes. The program of work is following this approach, and appears to be on track.

PI Response:

Reviewer 23638

Score: 8.0

Comment: The project is being conducted in conjunction with the University of Alaska, Fairbanks and Baker Hughes. The project is an extension of an earlier developed zeolite cement that Halliburton has been using for gas wells in Canada. The developer of this cement serves as a technical consultant/reviewer for the project. Five different combinations of zeolites have been tested. The zeolites were characterized using XRF, XRD, and SEM to confirm their mineralogy - in many cases, they are mixtures of more than one zeolite phase. A jet mill was used to produce zeolites with a range of different particle sizes (5, 10, and 44 microns). If this method is commercialized, then a collider mill might be more practical. Three different ratios of zeolite to cement were also evaluated (15, 27.5, and 40% zeolite). A number of screening criteria were used (such as the amount of free water, the compressive strength, and cost), and based on these tests, two different zeolite options were selected for further testing: ferrierite (which contains 15% mordenite) and clinoptilolite. Additional testing is being conducted to examine how adding silica flour and/or diatomaceous earth would improve the thermal stability and compressive strength of the cements. The compatibility of different retarders is also being evaluated. The next major step for this project is to demonstrate the viability of this cement in the field. Two field demonstration projects are planned - one at Chena Hot Springs, and the other (with Ormat) at Brawley. These field tests are critical for establishing the utility of the zeolite cements in geothermal wells.

PI Response:

Reviewer 24895

Score: 5.0

Comment: The early phases of this research appears to have duplicated some of the zeolite work done previously with the same conclusions, but perhaps necessary to have a foundation to build on.

The strength retrogression work should at least have more input from the industry, as retrogression at the higher temperatures has required more and larger size silica, not smaller size. The smaller size builds strength early, but has not been adequate to prevent strength retrogression at high temperatures, which has required more silica and larger size silica. Now that they have a new industry partner, maybe this will progress in a different direction (Geodynamic used 65% silica, with part of it having to be larger mesh size).

The carbonation requires some focus on the goal. Carbonation prevention is not necessary unless there are acid zones that will attack the carbonation. The acid zones also attack the binder materials formed by Portland cement, so the zeolites may be resistant, but the binder is not. Do they need to prevent carbonation? Do they need to have an acid resistant cement? Most EGS projects will not have an existing geothermal system, which would be required to form the acid system that would attack the carbonation. Acid resistant cement was a target of prior Brookhaven work, as there are hydrothermal systems that have acid bearing formations above the geothermal system, but I am not convinced that EGS systems would have such an acid system. That said, working with IRL on the process they used in the laboratory to duplicate an acid system should provide adequate testing.

PI Response:
The initial screening phase likely reproduced work that has been done on zeolites as the screening phase was performed at relatively cool temepratures. The screening phase was important in that the behavior of different zeolites needed to be quantitified. A large number of tests were not practical on the HPHT testing devices.

We have tested both coarse silica >100 micron (fine sand) and powdered silica. As mentioned by the reviewer, the powdered silica does tend to provide better short term benefits. Our decision to procede with the powdered silica source is primarly based on research published by Eilers and Root (1974) which showed than 40 micron silica powdered yielded

the best combinatin of strenght and reduced permeability. Within that data set, coarser silica consistenly yielded higher permeabilities when cured in brine than the powdered silica. Powdered silica with a particle size of 40 micron seemed to yield the most positive results. It is acknowledge that the curing times were 1 month and that coarser silica may provide long term benefits as the solution rate of silica is coarse silica is much slower. A combination of both powdered and coarse silica may be beneficial. Work by Neil Milestone indicates that excessive silica leads to rapid carbonation of cements. His work suggests that a 20% addition by weight of cement is a good compromise between carbonation and strength stability.

This work is attempting to explore both the high temperature ability of zeolite cements as well as their potential in carbon dioxide impacted geothermal reservoirs.

I do not think carbonation prevention is a goal of our project. We are trying to develop a cement that will remain competent after carbonation. If EGS systems are not likely to have carbonation problems, as stated by the reviewer, then that is well and good.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23433

Score: 6.0

Comment: Progress so far has been satisfactory. The project has suffered from the withdrawal of the partner company, Thermasource. Progress in the project was contingent upon being able to use the test equipment in the Thermasource lab., so the project team has had to obtain their own equipment, and in addition, find an alternative source for the funding that was to have been provided by Thermasource. This has led to some delay, although replacement equipment and alternative funding have now been found.

In terms of experimental results achieved so far, two candidate zeolites have been selected, and testing of formulated cements has begun. So far, all formations tested have proven to have adequate strength, and the effects of retarders is being studied. Investigation of the effects of different silica flours (to inhibit strength retrogression) is under way. Studies of carbonation (causing initial increase in strength but eventual degradation) have been started, using actual brines from a real geothermal well. Further work appears to be on schedule and no problems were announced.

Overall, progress and results are good, in spite of the delays mentioned above.

Several presentations have been made to interested parties, although none was a formal publication.

PI Response:

The project has suffered not "some delay", but significant delay as a result of ThermaSource's hesitations and eventual withdrawal. UAF was not equipped to conduct the HPHT tests. After ThermaSource's departure, there was additional delay by the equipment vendor in fabricating and delivering the HPHT equipment to UAF. UAF personnel then had to undergo a steep learning curve to get the equipment functional and tests running. Given all these obstacles, I think our progress is nothing less than outstanding.

Formal publications will be made only after project is complete.

Reviewer 23638

Score: 6.0

Comment: The project is progressing a bit behind schedule, as the loss of the initial industry partner (Thermasource) resulted in delays and the need to build a testing facility at UAF, which added more costs to the project. The current listed project end date is 9/30/2013 - this leaves little time to conduct the remaining laboratory tests and the two planned field tests. This being said, the project has completed an extensive sequence of laboratory tests on a suite of zeolite - cement mixtures, and has identified two mixtures that satisfy the initial screening criteria. The review team was provided with "concrete" proof of these tests, as small cubes of the cement were handed out at the review. While a few presentations have been made by the PI, no publications have yet resulted from this work. It is important that the results of this work are captured through publication - perhaps this will be done by the UAF participants.

PI Response:
When the data set becomes comprehensive with phase quantification, the hope is to publish portions of this work.

The data are being treated as confidential at this point, hence there have been no publications. Publications will follow the project completion and submission of final report.

Reviewer 24895

Score: 4.0

Comment: The quality and the productivity suffered when Thermasource pulled out. Although the PI coped well with the change as far as equipment goes, I think they suffered from inadequate industry input on the basic plan, how to progress the testing and how to focus the goals as discussed in the two sections above. Hopefully that will now be remedied with the new industry partner on board and the project will get refocused with improved quality.

PI Response:
Sometimes it is better to think without being told what and how to think.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23433

Score: 8.0

Comment: It was noted above that the project has suffered a setback with the withdrawal of the industry partner Thermasource from the program. The project managers have done what was needed to compensate for this loss. Replacement equipment has been purchased, and alternative funding has been secured. Delays resulting from the loss of the industry partner have resulted in an agreed extension to the Period of Performance. The reviewer therefore considers that the quality of project management has been good, particularly in response to the changes imposed on the project.

PI Response:

Reviewer 23638

Score: 8.0

Comment: The project appears to be well managed and coordinated. The work is being conducted by the PI and his colleagues at UAF. The project has an external expert (who developed the first zeolite cement for Halliburton) who reviews the project on a regular basis. There appears to be good coordination with the industry partner (Baker Hughes). The carbonation experiments are being conducted using brine compositions provided by Ormat. The future work plans focus on the key remaining laboratory and field tests.

PI Response:

Reviewer 24895

Score: 3.0

Comment: There are lots of potential collaborators and stakeholders with extensive experience in geothermal cementing, including the service companies, DOE National Labs and operators. I feel the project suffered from a lack of collaboration and stakeholder input. Maybe that is out of the control of the PI, but there should have been other alternatives to purchasing cementing equipment. The lack of being able to attract collaborators and stakeholders either speaks to a problem with the management of the program or a disconnect between the goals and objectives of the program compared to the needs of the collaborators and stakeholders.

PI Response:

An extensive effort was made to fund the purchase of the cementing equipment from private industry under the Alaska Education Tax Credit. Companies that were given a detailed proposal on the purchase and then donation of the equipment to UAF under the Tax Credit were; Halliburton, Baker Hughes, Shell Alaska, ENI Petroleum Alaska, Dowland Bach Alaska and Solsten XP. Also contacted as a potential source of funding were the Alaska Industrial Development and Export Authority and the Alaska Department of Labor.

STRENGTHS

Reviewer 23433

Comment: The project responds to a clearly defined need. The approach is logical, and work is proceeding systematically. The project team have shown an ability to reconfigure and adapt the program as a result of unexpected changes in the project team. Inevitably, with the numerous demands placed on high temperature cements, there is the possibility of encountering some insurmountable problem, but results obtained so far are good and there can be every expectation of a successful conclusion. The reviewer notes that plans are already being formulated for an initial field test at Chena Hot Springs, and a larger test in a geothermal well is foreseen in conjunction with Ormat Technologies.

PI Response:

Reviewer 23638

Comment: The main strengths of this project is that it has a very clear cut objective - to build upon past efforts by Halliburton to create zeolite well cements and evaluate a range of zeolite compositions, grain sizes, and cement-zeolite mixtures to come up with a lightweight zeolite cement suitable for geothermal well completions. The laboratory activities appear to be progressing well, and two different zeolites (ferrierite and clinoptilolite) were selected for a second phase of testing. The zeolite cements have met the screening criteria that were established, and appear to be cost effective. There is good coordination between the PI, the colleagues at the University of Alaska, Fairbanks, and the industry partner Baker Hughes.

PI Response:

Reviewer 24895

Comment: The project currently has the inventor of zeolite cements and Baker as advisor/industry partners. They are working with IRL to duplicate the laboratory testing for acid resistant cement.

PI Response:

WEAKNESSES

Reviewer 23433

Comment: No weaknesses were identified.

PI Response:

Reviewer 23638

Comment: The main weakness of the project is that the planned field tests (which are critical to establishing whether the zeolite cements are suitable for geothermal wells) have not yet been conducted, and only a few months remain in the

project. The results of this work have not yet been published - hopefully the PI and his colleagues will document the results of their research in a publication.

PI Response:

Reviewer 24895

Comment: Until recently, there has been a lack of industry input. Consequently, the project has lacked focus. For instance, 13.5 ppg cements are as common as hen's teeth, but 13.5 ppg is equivalent to 0.7 psi/ft, which exceeds the fracturing gradient in many geothermal settings (0.5 to 0.6 psi/ft), requiring much lower densities (10 ppg). EGS is targeted at impermeable systems, which may have a higher fracturing gradient, but would not have acidic zones. Is the target use for this project EGS or hydrothermal – it does not fit either, as geothermal would need lower densities and EGS would not need acid resistance. It has not focused on what is most important, density or acid resistance, nor has it asked if carbonation is really a problem.

PI Response:
A major portion of this work was to explore the viability and use of zeolite in HPHT cements. Previous work by Halliburton on zeolites was primarily confined to temperatuers less than 300F. Lower temperature response of zeolites is signfincantly different than the high temperature response. As a means for characterizing the zeolite influence, a standard density of 13.5 ppg was established. As the responses are better understood, changes in density can be explored further.

The DOE FOA under which this project was funded was geared towards developing geothermal drilling solutions at TVD of 20,000 ft and more. Currently, 13.5 ppg cements may be "as common as hen's teeth" simply because current wells rarely go anywhere close to these depths. If and when drilling becomes common at 20,000+ ft TVD, 13.5 ppg cement will likely be as common as shark's teeth!

Industry input was indeed solicited and received in deciding on the 13.5 ppg cement weight at the start of the project. This decision on cement weight was made from our initial consultations with ThermaSource, which is a geothermal specialist company. Since this is a geothermal project, it made sense to heed the advice of geothermal industry.

IMPROVEMENTS

Reviewer 23433

Comment: It is not clear whether the team personnel have any contacts with current commercial suppliers of high temperature cements. It may well be that such companies are seen (or see the present project team) as competitors. If so, it is understandable that such contacts will be difficult to establish. If not, however, it may be that useful insights may be obtained that will be valuable to the project. The reviewer has in mind not so much the basic chemistry of cement formulation and evaluation, but insights that may be gleaned from folks that have extensive experience of field placement of geothermal well cements. It may help to advance the project, particularly in the later stages, to try to develop such contacts. The reviewer notes that plans are in hand to carry out two field tests, at Chena Hot Springs and with Ormat, so these contacts may provide some useful field experience. However, additional contact with a cement formulator or a specialist cementing service company may be of significant value.

PI Response:

Reviewer 23638

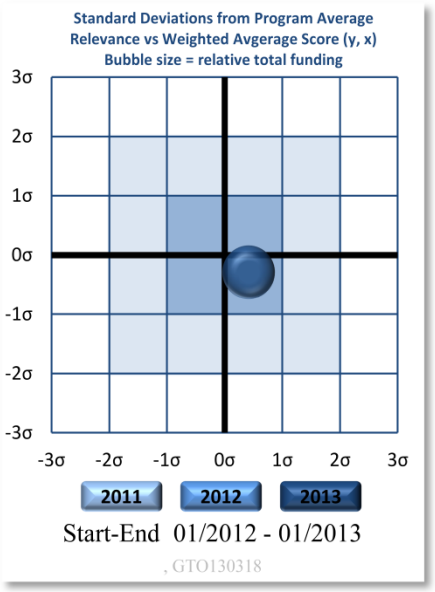
Comment: My main suggestion is that the PI and his collaborators publish the results of their work in an appropriate venue (such as the GRC Transactions or an appropriate trade journal) so that the results of their study are transmitted to the community.

PI Response:
When a more throrough data set is obtained, the hope is to publish the work.

Reviewer 24895

Comment: Decide what it wants to be – I think it wants to be a less expensive 13.5 ppg cement, but there are lots out there, so it is not clear that is the goal, as they only compared themselves to acid resistant cement (Thermalock). With a Portland cement component that is susceptible to acid attack, it is unlikely that the cement will be acid resistant, which is easy to test – Brookhaven had some basic testing protocols that could be followed for acid resistance without going to the high cost, high pressure flow through CO_2 testing that has been done by IRL, but it is unclear if the project goal is acid resistance or not, as they only talk about carbonation. Carbonation is not a problem, as long as it is not followed by an acid attack. I am not sure the project realizes that.

PI Response:
The goal of this project is to address the challenges listed in the DOE FOA, rather than catering to any particular company or group. This was decided right from the time of proposal preparation.



Review: 2013 Geothermal Technologies Office Peer Review
ID:
Project: Self-Degrading Temporary Cementation Sealers
Principal Investigator: Sugama, Toshi
Organization: Brookhaven National Laboratory
Panel: Materials; Zonal Isolation; Innovative Methods of Heat Recovery

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23433

Score: 8.0

Comment: The development of temporary sealers in of importance in the construction of geothermal wells. On the one hand, is it usually desirable to drill the hole without loss of the drilling mud to the adjacent formations (or for inflows to occur if drilling with air or otherwise in underbalanced conditions), while on the other hand, maximum connectivity to surrounding formations is to be desired when the well is placed in production or injection. Hence the attraction of sealers whose action is temporary, allowing them to be used as sealing agents while the well is being drilled, but which can be removed when the well is put into production. Use of such temporary sealers can result in many advantages: temporary sealing of lost-circulation zones, the resultant possibility of being able to reduce the number of casings and/or liners, and the possibility of being able to use a wider range of down hole pressure regimes for the better control of influxes and losses.

PI Response:
Thank you for the reviewer's support to the progress and success of our R&D project.

Reviewer 23638

Score: 9.0

Comment: The primary objective of this project is to develop cost-effective temporary sealing materials for geothermal wells. The project is an extension of previous cement-related studies conducted at BNL. The project objectives are to: 1) upgrade the self-degrading performance of a previously developed sealer, 2) investigate the compatibility of sealers with drilling fluid, 3) develop fibrous bridging additives, so that the sealer slurry adequately plugs different sized fractures, 4) evaluate the self-decomposing performance of fiber-bridged sealers, and 5) transfer technology to geothermal industry. Based on responses to questions following the presentation, it appears that these sealing materials can not be added to the drilling mud (as would LCM), but instead are emplaced in a way similar to cement plugs used to address lost circulation conditions encountered while drilling. The key advances associated with this research appear to be the development of materials that degrade, thus allowing later well access to fractures that impede drilling because of mud losses, but would be critical for fluid circulation and energy extraction from a geothermal reservoir.

PI Response:
We appreciated the reviewer's expression of support for this R&D project.

Reviewer 24895

Score: 3.0

Comment: Lost circulation in the upper part of the hole where casing will be cemented does not require a degradable cement, so the only use for this cement in in the production zone that will be left open for production. It is an added tool between permanent cement used in upper formations that is not suitable for production intervals, because it plugs off desired permeability, and LCM, which is not always successful. However, wouldn't be used unless other alternatives were not working, as it takes more rig time than drilling blind, air drilling or using LCM. Consequently, I think it would get very limited use, if at all. The EGS wells are called EGS, because they do not have adequate permeability to be hydrothermal, so would not be likely to benefit from this technique. The hydrothermal reservoirs that have high permeability and losses are usually drilled blind or with air, limiting the usefulness of this product.

PI Response:
I regret a lack of interpretation about the details of this material system. This system simply consisted of two phases, cement matrix and additives. In additives, sodium carboxy methyl cellulose (CMC) was employed as self-degradation promoter. Without CMC, this cement can be used as conventional non-degradble cement. Thus, this cement system is applicable to both temporary sealer and casing cement, reflecting a possibility of a dual use of the same placement tool for upper cement formation and bottom sealer formation.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23433

Score: 8.0

Comment: The approach is to use a cement based either on blast furnace slag of fly ash, both of which have pozzolanic properties, combined with sodium silicate to cause the required setting reactions. Apart from having the properties required to make effective cements, the raw materials have the additional advantage of being formed as byproducts of other industrial processes. They are therefore cheap and widely available. For the formulations investigated, the self-destructive capacity was arranged by noting that the set cements can be degraded by the action of carbon dioxide. The source of the carbon dioxide is sodium carboxy methyl cellulose (CMC). This can be caused to decompose by the action of sodium hydroxide, which is in turn obtained by the dissociation of sodium silicate. Adjusting the molecular weight of the CMC makes it more or less susceptible to attack by the sodium hydroxide, resulting in formulations of cement that can be caused to decompose at different temperatures. This allows the development of the desired products viz. a range of cements that can be tailored to decompose at different temperatures. These cements are otherwise compatible with conventional cementing equipment. This is therefore a very effective solution to the problem. This having been noted, the task then becomes one of determining the best combination of components to achieve the desired result. This is being done in an effective manner. Once the basic understanding and formulation of the cement has been achieved, attention turns to the incorporation of various types of fiber that will enhance the bridging qualities of the cement, but which are again decomposable by heat. The approach taken is again systematic and effective.

PI Response:
Thank you for explaining your positive evaluation.

Reviewer 23638

Score: 9.0

Comment: The PI described a wide range of tests that were being conducted to evaluate temporary sealing materials, additives that help activate the sealer, others that help promote self degradation, and others that improve bridging characteristics. The effects of molecular weight of carboxymethyl cellulose materials was determined through a series of experiments - higher molecular weights led to the release of more exothermic energy when contacted with water, which enhanced the breakdown of the sealer. The plugging performance of different lengths of polyvinyl alcohol fibers was also evaluated. The compatibility of these materials with drilling mud is also being evaluated. The PI and his colleagues are experts in the subject matter, and have the ideal background for conducting these types of experiments.

PI Response:
Thank you for your support to our R&D approach.

Reviewer 24895

Score: 6.0

Comment: Built on existing work, extending the plugging to larger slots and improving the degradation to a smaller size. Technical approach is appropriate for the project. It may have been better to resolve the retarder issue before some of the other tasks. The placement of the material requires tripping out, removing the bit, tripping back in to place the degradable cement, tripping back out to pick up a bit, then back in to clean out the excess cement. It may have been better to concentrate on being able to pump through the bit than to bridge larger fractures, but others may have different opinions. However, the length of time involved in the placement will be an impediment to widespread use.

PI Response:
We agreed to your suggestion. Work to develop set control additive suitable for this cement system is currently be undertaken using HTHP Consistometer. Thus far, we found that the combination of tararic and boric acides is promissing for use as set-control additive.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23433

Score: 8.0

Comment: Results obtained so far have been thoroughly satisfactory. Significant progress has been made in formulating the basic chemistry of the thermally-degradable cement, and in finding fibers that can be added to improve the bridging action of the sealer. Some additional concerns have been investigated, one of which is the compatibility of the new cement with drilling muds remaining from drilling activities. The presence of drilling mud has been shown not to be detrimental. The results achieved have been documented in five reports, two of which are in the open literature, and three of which are BNL reports.

PI Response:
We appreciated the reviewer's favorable statement for our accomplishment.

Reviewer 23638

Score: 9.0

Comment: The amount of work that has been accomplished on this project relative to the budget is outstanding. The PI and his colleagues has tested carboxymethyl cellulose self degradation additives with different molecular weights to determine their effectiveness in breaking down the sealer under elevated temperature (200 C) conditions in the presence of water. The research has also evaluated the effectiveness of different types of fiber additives (and fiber lengths) to help seal up different slot sizes at different pressures. Good performance was observed for PVA and PE fibers; a combination of fiber lengths was observed to be most effective in minimizing filtration loss. Another series of experiments involved evaluating the compatibility of the sealer with drilling fluids. The main remaining task is to conduct a field test of the sealer to confirm the laboratory tests in a real-world setting.

PI Response:
We agreed with the reviewer's comment describing the requirement of a field test as the next task to validate the field applicability of developed sealer.

Reviewer 24895

Score: 7.0

Comment: The project has made good progress on a small amount of funding. The quality issue is also the technical approach issue, where the retarder issue has not yet been addressed. The project has industry partners. If they have commercial applications for this degrading cement and will push it out to their customers, some of the concerns I have may be mitigated. It may be beneficial for someone to see if they are committed to commercialization or just to providing advice.

PI Response:
As I mentioned earlier, work to develop set-retarders is currently under way. In response to reviewer's comment, we plan this year to invite geothermal well servicing industries for presenting an updated information, conducting an in-house-scale demonstration, and assessing a technical feasibility of developed sealer system.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23433

Score: 7.0

Comment: Project management has been satisfactory; this is a project that has not yet moved to a field implementation phase, and is mainly concerned with the work of Dr. Sugama. Thus the management effort required has not been large. The reviewer notes that several suggestions were made by reviewers during last year's review. Dr. Sugama has taken note of these suggestions and has modified his program of work accordingly.

PI Response:
The reviewer's suggestions in conjunction with other advice at review meetings are very important us to justify our scientific and technical approach.

Reviewer 23638

Score: 7.0

Comment: The project is coordinated with a number of industry partners, including Halliburton, Schlumberger, Baker Hughes, Geodynamics, and Dow Chemical Corp. Many of the past research developments from this lab have gone on to become widely used in the geothermal industry. The original project end date was January 2013, but there are still a number of tasks that remain to be completed. This work will continue using carryover funds to complete the planned testing by the end of this year.

PI Response:
We are continuing this R&D work using carryover funds to complete the rest of our originally planned tasks.

Reviewer 24895

Score: 8.0

Comment: The service companies are involved, which will be important to the successful deployment. The key is whether they going to deploy or not? Brookhaven had done a good job of managing the project, with the exception of the retarder being delayed, but it is not totally clear if the service company partners are along for the ride or are committed partners, as they do not have any money invested at this point.

PI Response:
We plan to set this year the technical meeting with several geothermal drilling industries for discussing a possibility of commercial application along with an in-house technical demonstration.

STRENGTHS

Reviewer 23433

Comment: The project addresses a well-defined need in the geothermal drilling industry, and looks as if it will provide an efficient and cost-effective solution. Some desirable improvements are being studied (e.g. filtration/plugging behavior in wider fissures). The project leader himself notes that some problems may become evident as the work progresses, since sealing systems of this type for high temperature use do not exist at present. However, he has an established track record in this type of work, so the reviewer is confident that solutions will be found if at all possible.

PI Response:
As is addressed by reviewer, this type material doesn’t exist in current commercial sealing market. Thus, it is very difficult to evaluate the economical feasibility of this material system. So, we try to design the sealing system in which the total raw material cost is equal or less to Ordinary Portland Cement (OPC)-based sealing system.

Reviewer 23638

Comment: This project is leveraging the demonstrated expertise of this group to build upon past work and create a modified sealer that has the ability to self-degrade into small particles at elevated temperature, thus opening up fractures. The team has demonstrated that their research is effectively transferred to and employed by the geothermal industry. The work that is conducted by this group is done in an extremely cost effective manner.

PI Response:
Thank you for supporting our cost-effective R&D effort and approach.

Reviewer 24895

Comment: Brookhaven's experience and history of developing cement products to solve specific problems in geothermal, along with the participation of the major service companies to drive commercialization.

PI Response:
Thank you for positively describing in a historical context and our mission of cement development.

WEAKNESSES

Reviewer 23433

Comment: The underlying approach to the current project is to develop sealing materials whose setting and subsequent degradation are determined by changes in temperature. Thus they will be effective only insofar as the sealers can be placed in relatively cool conditions but can then be heated in order for them to break down. It is conceivable that some placement situations will be so hot that the cement/sealer can not be kept cool enough during the placement phase (i.e. while the well is being drilled), so that they will be degraded before being able to carry out their intended sealing function. The converse may also be possible, for example, in an injection well, where the borehole temperature may be expected to be considerably lower than that of the reservoir. In such a situation, the hole will not become hot enough to degrade the seal when it is no longer needed. In this case, however, one may envisage a scenario in which, before starting injection, the borehole is allowed to heat up sufficiently to allow the temporary sealing material to degrade. Whether it will be possible to put an injection well on temporary production to achieve this effect will no doubt depend on the particular geothermal project involved. However, it may be worthwhile for the project leader to consider some of these less-than-optimal situations to determine what might be done. The proposer notes that he intends to check the compatibility of the sealer with typical drilling muds. Is it necessary to check compatibility with reservoir fluids?

PI Response:
Thank you for noting that we need to consider quit different well conditions, in particular for hot wells during drilling operation and cool bottom wells. For the former condition, concern is that sealer may degrade prior to plugging the fractures, while concern for the latter involves no degradation of plugged sealer. Since our material systems were designed to control the rate of degradation by combination of CMC and PVA fiber and varying their molecular weights at well temperatures, ranging from 120° to 200°C, it is possible to establish a new modified formula assuming these specific well conditions. Additionally, we will assess the compatibility of sealer with reservoir fluids.

Reviewer 23638

Comment: One concern is how well this will work when deployed in a real well - i.e., will the temporary sealer last long enough to resolve the lost circulation issues that require it to be deployed during drilling, yet break down effectively enough so that the temporarily sealed fractures will be unsealed so that they can connect the geothermal reservoir with the wellbore. Hopefully this will be evaluated during planned field tests.

PI Response:

Prior to conducting the field validation test, we plan to assemble and install an in-house scale apparatus, which will make it possible to obtain data leading to the plugging duration and the onset of degradation as well as its magnitude as a function of temperature and pressure.

Reviewer 24895

Comment: The product is targeted at a problem that may not really need a solution, or at least not a solution as expensive as the project will produce. It is not clear who is driving and identifying the need and the customers that will use it. Is it a self-generated project within Brookhaven or is there a group of customers for this product that are driving the need and setting the specifications?

PI Response:
As I descried earlier, we will invite several geothermal drilling industries this year to discuss the issues raised from reviewer.

IMPROVEMENTS

Reviewer 23433

Comment: It may be desirable to check the compatibility of the cement with a range of typical reservoir fluids to see if they affect either the setting or degradation properties. As noted above, some thought should be devoted to considering how the cement may be used in less than optimal temperature conditions. Concerning the possibility that, under very hot conditions, the cement will begin to degrade before desired, there is a clue as to what may be done by noting that changing the molecular weight of the CMC component appears to change both the setting and degradation behavior. There thus exists a possibility that changing the molecular weight of the CMC may allow the behavior of the cement to be tuned to suit different wellbore conditions. It is not clear to what extent the project leader has begun to develop contacts with the eventual end users, or whether there are yet any plans for a field test. It is probably a good idea to begin this process as soon as possible.

PI Response:
In response to reviewer's comments, first, we will investigate the compatibility of sealer with typical reservoir fluids. Second, for controlling the rate of degradation at high temperature well condition, we will set several experimental works including the lower content of cement according to reviewer's suggestion, the combination of CMC and PVA fibers with different molecular weights, and the incorporation of silica sand into cement system to replace some portion of cement. Further, we plan to invite several geothermal drilling industries this year for dealing with these issues being addressed by reviewer.

Reviewer 23638

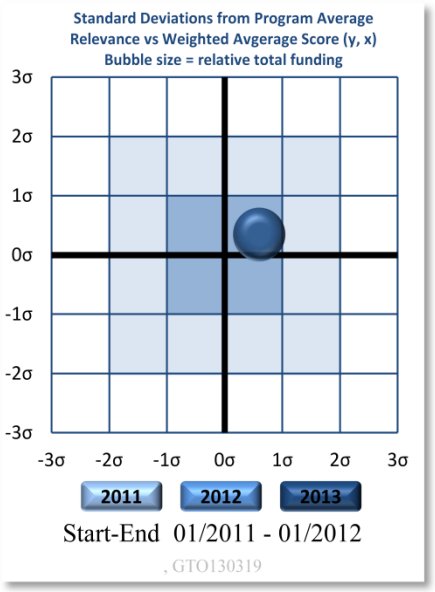
Comment: For the limited budget, the project seems to have accomplished a great deal in a short amount of time. The PI has a good track record of publishing his results, and the planned final publication should help with transferring the results of this work to industry. A future research direction might be how to develop more effective LCM that could be deployed while drilling, rather than needing to trip out of the hole and spot a cement plug or a temporary sealer in zones with lost circulation. This would reduce the amount of rig time needed, thus cutting costs.

PI Response:
In our effort to reduce rig time-related cost, the development of set-controlling additives suitable for this sealer as a function of well temperature is currently being undertaken.

Reviewer 24895

Comment: Make sure that there is an end user who understands the cost (rig hours for tripping) involved in deploying this product.

PI Response:
Assuming the convention placement tool and procedure can be used, work to estimate the total operation cost including raw material, and an approximate time-span and man power consumed for placement and completion based upon the information from our exclusive industrial partner, will be performed.



Review: 2013 Geothermal Technologies Office Peer Review
ID:
Project: Multifunctional Corrosion-resistant Foamed Cement Composites
Principal Investigator: Sugama, Toshi
Organization: Brookhaven National Laboratory
Panel: Materials; Zonal Isolation; Innovative Methods of Heat Recovery

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23433

Score: 8.0

Comment: The objective of this project is to provide a lightweight foamed cement that, as well as having satisfactory thermal and mechanical properties, is also non-corrosive to standard steel casing alloys. Such a material does not exist at present, so its development would clearly be of interest in the construction of geothermal wells, particularly in cases where the geopressure gradient is low. Two key requirements then become clear. The first is for the cement to provide corrosion resistance over a range of temperatures, while the second is for the cement to have a low density. The project is aimed at developing a cement with these and other important properties. Having such a cement is clearly of interest to the geothermal industry, particularly for wells drilled in zones of low geopressure, and where the produced fluids are corrosive. Use of such a corrosion-inhibiting cement may, in some circumstances, enable the replacement of very expensive "exotic" metals (e.g. titanium) by regular steels.

PI Response:
Thank you for your support to our R&D goal and approach.

Reviewer 23638

Score: 9.0

Comment: The main objective of this project is to develop a low cost, corrosion-resistant foamed cement suitable for carbon steel casing. If successful, this project would address one of the DOE GTO's goals of reducing well completion costs. One of the key aspects of this project is to extend the use of carbon steel to environments which might otherwise require the deployment of much higher cost alloys. Thirteen different material criteria were developed for the new composite cement, including a slurry density of less than 1.3 g/cm3, stability at temperatures > 300C, reduction of steel corrosion rates, a compressive strength > 1000 psi, and the ability to resist thermal shock, a key parameter for EGS wells. This work builds upon previous studies on cement conducted at BNL.

PI Response:

Yes, this principal concept and project goal aimed at developing high-temperature corrosion-resistant cement was designed based upon the results from our previous DOE-funding R&D project.

Reviewer 24895

Score: 6.0

Comment: Brookhaven developed acid resistant foamed cement (CaP), publish the results and saw it through commercialization. That cement was not used for a comparison with the current product. Both cements are based on refractory cement plus fly ash so will have similar costs. Are there a deficiency in the earlier development concerning thermal resistance that have not been disclosed, or is this just an alternative? The resistance to thermal shock is important, as this is a problem for both EGS and hydrothermal systems. At the research points out, the Portland cement systems are susceptible to thermal shock, but the project does not distinguish if this is a problem with the CaP systems developed previously or not.

This project does address the higher permeability of foam cements and the potential for that higher permeability to lead to higher corrosion rates, but this relates to the corrosion resistance of the cement, which is only selectively a problem in a few hydrothermal fields and would not be expected to be a problem with EGS systems.

PI Response:
First of all, the major difference in chemistry between CaP cement and thermal-shock resistant cement (TSRC) is the cement-forming activator: For the former cement, the activator is sodium phosphate; and, for the latter, it is sodium metasilicate. Thus, CaP generally is called as chemical-bonded glass cement, while TSRC belongs to hydro-ceramic family and exhibits a higher ductility and better thermal stability than those of brittle CaP glass cement. Further, our preliminary work to evaluate the resistance of the carbonated-CaP and- TSRC cements to acid (pH ~ 2.0) at 90°C suggested that TSRC showed a better resistance to acid. Although CaP cement possessed a minor retrogression of compressive strength after it was carbonated, the exposure to a strong acid caused its degradation because the carbonation of CaP led to the conversion of its crystalline phase into an amorphous one. In contrast, the carbonation of TSRC converted it into nano-scale crystalline compounds. Nevertheless, there is no information on thermal shock- and steel corrosion -resistance for CaP cement thus far. For comparison purposes, we plan to evaluate these properties for foamed CaP cement.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23433

Score: 8.0

Comment: The scientific approach is sound. Associated with the issue of corrosion resistance is the requirement of thermal shock resistance, particularly for injection wells, where temperatures may alternate between reservoir temperature and surface temperature. Development therefore started with work on this problem, and continued with the testing and development of a suitable foaming agent (air). Work has continued with research into the discovery of a suitable corrosion inhibitor. This work was accompanied by a corresponding series of tests that allowed development to proceed in a systematic manner. Results obtained so far look very promising, and work is currently under way to transfer the technology to the three industrial partners.

PI Response:
We appreciated for your support to our R&D approach.

Reviewer 23638

Score: 9.0

Comment: The scientific approach to this work consisted of a series of laboratory tests to evaluate the material properties of a variety of composite cements. The cement that met all of the 13 criteria contains hydrogarnet, a hydro-ceramic phase (similar to zeolite), and a hydro-Al-oxide, all generated from refractory calcium aluminate cement, Class F fly ash, and sodium silicate. This composite cement exhibited sustained compressive strength when subjected to repeated heat-water quenching cycles, and also was shown to maintain a high shear bonding strength with carbon steel casing . An acrylic polymer was added to the cement to improve the corrosion resistance of carbon steel casing, and even adding 2% of the polymer reduced cathodic corrosion of the steel based on laboratory testing. A foaming agent was also evaluated to determine how much was needed to attain the specified cement density, while still retaining sufficient compressive strength.

PI Response:
Thank you for your support to our R&D approach.

Reviewer 24895

Score: 7.0

Comment: The approach to testing the thermal shock resistance and the investigation of methods to reduce the permeability and improve the bonding followed conventional practice with Portland cements. In a way that is good, building on past experience, but Portland cement may have equally benefited from increased thermal stability and bonding, but that was not compared.

I do not think the air created foam is a realistic model, which was also recognized in a prior Brookhaven publication on air created foams with the CaP cement. This repeats that experiment without improving on the results. Of necessity, field created foams will be made at high pressure with nitrogen, as an air foam would not create a low density. Additionally, the stability of the foam at moderate temperatures (90-110C) prior to setting or hardening is of critical importance and was not tested. The foam must be stable with no gas/liquid separation at these temperatures for the 3-6 hours it takes for the cement to harden.

PI Response:
The reviewer’s comment is correct. Using the air bubble foaming agent is not practical in the field. At present, this agent is adapted in our in-house work to select an alternative high temperature-resistant corrosion inhibitor and other additive suitable for TSRC. When our cement technology reaches a field applicable level, we will employ field-created foaming technology, and then the stability of foaming formation under a high temperature and pressure will be evaluated in collaboration with geothermal drilling industry.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23433

Score: 8.0

Comment: The results obtained so far appear to be excellent. during the course of the work, two critical issues were identified. The first was to concentrate on developing the cement's resistance to thermal shock. As well as being important to maintaining stable casing support (of course) maintenance of a crack free cement that is well-bonded to the casing is important in reducing the access of harmful fluids to the casing surface and hence in reducing corrosive attack. This work has been successful. Future work will be devoted to further investigating the resistance of the cement to thermal cycling, and to investigating its behavior at even higher temperatures. Work will also begin on developing field-usable cement compositions, notably in making sure that the cement is pumpable. This activity should lead to the decision to start field tests in collaboration with the industry partners. All of this work has progressed well, and there appear to be excellent prospects of success. Three publications and one internal BNL report have been produced so far.

PI Response:
Thank you for referee's statement expressing that the progress of our R&D is in the right direction.

Reviewer 23638

Score: 8.0

Comment: Three main accomplishments were achieved to date for this project: 1) the development of a cement that is resistant to thermal shocks; 2) incorporation of a foaming agent for this cement; and 3) the development of a corrosion inhibitor for the cement. One of the key attributes of the foamed cement is that it has low permeability, which enhances its corrosion resistant properties. A presentation of this work at the 2012 GRC meeting won a best paper award. The cost of this composite cement is less than 20 cents/pound, so it should be a cost-effective alternative to existing geothermal well cements. The project schedule notes a go/no go decision point later this year. Hopefully, if the cement meets all of the criteria, it will be tested in an actual well environment.

PI Response:
Once the developed cement meets all material criteria, the cement samples will be deployed in the field to conduct a real well-site exposure test in collaboration with industrial partner for evaluating their durability and integrity as a function of exposure time.

Reviewer 24895

Score: 8.0

Comment: There has been a lot of progress on a very modest budget and the quality of the work done is good, even with some of the caveats that have already been expressed. Some of the cited problems may be legal in nature while others may be budgetary, so it is difficult to separate out and measure without including the amount done and the modest budget.

PI Response:
Thank you for your appreciation of current federal budget restriction reflecting some limitations on R&D work.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23433

Score: 7.0

Comment: Project management appears to have been good so far. This should not have been difficult, however, as the project at present has not entailed any extensive collaboration with external partners. The reviewer notes the low overall budget, and considers the value for money obtained so far to be excellent.

PI Response:
Thus far, we try to deriver the information covering all of our R&D works to geothermal industries who expressed their own interest in this technology. However, in a near future, we plan to select exclusively one industry for expediting the progress of R&D and conducting a field validation test.

Reviewer 23638

Score: 7.0

Comment: This project has accomplished a great deal, especially given its modest ($300K) budget. While the nominal end date for this project was Dec. 2012, carry over funds will be used to complete the planned tasks by Dec. 2013. Continuing work includes developing high temperature corrosion inhibitors, developing toughness enhancement and setting control additives, and measuring the thermal conductivity of the cement. Finally, a peer-reviewed journal article and transfer of this technology to industry partners is planned.

PI Response:
Most recently, we received $160 K from DOE to support and continue this project. This funding is very valuable for completing the rest of the tasks.

Reviewer 24895

Score: 7.0

Comment: The project was on schedule and within budget. There is a large set of collaborators, which has changed during the project, so there may have been some problems with the collaboration. In previous projects, the collaborators worked with Brookhaven and were co-authors on the published papers, but that has not happened this time. The cited paper did not have any of the collaborators as co-researchers or co-authors, which raises questions about their level of participation and commitment. Consequently, the changes may have been disruptive to the quality of the advice or collaboration that could be expected during the project.

PI Response:
This project aimed at developing a new-type of cement and it was initiated in FY12. Therefore, we had no ideas as to whether any geothermal industries may have had interest in this type of cement. Fortunately, the presentation at 2012 GRC meeting was successful, and consequently, we received strong support from several geothermal industries. Since then, we provided all of the information on our R&D work to these industries. However, in the near future, we plan to select exclusively one industry to avoid any disruption in quality advice and collaboration as described by the reviewer.

STRENGTHS

Reviewer 23433

Comment: The major strength of this project, apart from obtaining successful results for a project of considerable interest to the geothermal industry, is the fact that the PI has an excellent and long standing track record of successful work in the area of cement chemistry. This gives high confidence that the work will be well executed and has a high probability of success.

PI Response:
Thank you for your encouraging statement.

Reviewer 23638

Comment: The main strength of this project is that it leverages the demonstrated expertise of the BNL cement group to develop new products that should help reduce costs for the completion of geothermal wells. In particular, the development of a thermal shock resistant cement should be helpful for EGS projects, where repeated heating and cooling associated with stimulation, injection, resting, and flowing of the well can result in rapid changes in the thermal conditions of the well.

PI Response:
Thank you for your support to our project scope and concept.

Reviewer 24895

Comment: Brookhaven has a lot of experience in this area and was able to build on that past experience. A lot was accomplished with a small budget. The product has achieved the goals of having a thermally resistant, acid resistant, foam cement with low permeability to combat casing corrosion.

Brookhaven, and Sugama in particular, have developed useful products that have greatly helped the geothermal industry. Sometimes it is difficult to decipher from their presentations what is working and what is not, but they have consistently produced usable products. My comments and grading reflect some of the difficulty in assessing this work, which should be kept in mind along with their record of success.

PI Response:
In an earlier stage of new-initiative R&D work on cement, the reviewer's comments would have been very valuable and important for adjusting the direction of our work, although BNL has had some success records in the past our work.

WEAKNESSES

Reviewer 23433

Comment: No weaknesses are noted.

PI Response:
Thanks.

Reviewer 23638

Comment: There are no major weaknesses that were identified. Several stages of testing still need to be completed to determine whether the new composite cement meets all of the evaluation criteria. Field testing will ultimately verify the long-term performance of this new cement.

PI Response:
We agree with the reviewer's comment expressing that project success is contingent upon the outcome from field demonstration and validation tests.

Reviewer 24895

Comment: Used air foam instead of high pressure nitrogen foams required in any commercialization of the product. Did not test the stability of the unset foam at temperature for the pumping time (~6hrs) to make sure it would remain stable. Did not test and compare the similar refractory cement/fly ash cement developed previously for comparison. The difficulty of the previous development was its incompatibility with Portland cement and its cost, which are unlikely to be addressed by the new formulation, so the new formulation should be addressing some short coming of the older formulation.

PI Response:
As described earlier, the current study for air-foamed cement prepared under non-pressured conditions was focused on selecting and developing the potential additives contributing to the improvement of its physicochemical properties. Once this task is completed, works to explore the stability of foaming structure and to inspect the pumpability of foamed cement slurry under pressure will commence. Additionally, the compatibility of new cement with Portland cement as well as the cost-effectiveness of new formula, compared with that of the older one, will be investigated.

IMPROVEMENTS

Reviewer 23433

Comment: No specific improvements are suggested, unless it be to widen the corrosion tests to cover a broad range of possible corrosive reservoir fluids. It is never too soon to start discussions with the industry partners with a view to the eventual field implementation of the results. The reviewer notes, however, that a report on work done so far has been prepared and sent to the DOE and industry partners for evaluation. This is obviously a good start.

PI Response:
Once the ideal 300°C-stable corrosion inhibitors are developed based upon the results of an in-house minimum 6-mo.-long hydrothermal and heat exposure test, the ability of developed inhibitor to mitigate corrosion of casing will be assessed by exposing the carbon steels coated with inhibitor-modified cement to corrosive reservoir fluids extracted from real wells at different geological locations in collaboration with industrial partner.

Reviewer 23638

Comment: The PI and his collaborators have done a very rigorous set of experiments to develop this new cement by building upon past work. The only improvement that I can think of is to make sure that when the composite cement has been fully formulated and tested in the laboratory, a field test is conducted to verify that the cement works in an actual geothermal field setting.

PI Response:
Yes, the ultimate goal of this project is to conduct a field-placement demonstration of developed cement slurry and to monitor the changes in quality of cement placed in well for validating the creditability and reliability of new cement in ensuring that this new cement satisfactorily extends the integrity and service life-span of wells.

Reviewer 24895

Comment: Brookhaven, and Sugama in particular, have developed useful products that have greatly helped the geothermal industry. Sometimes it is difficult to decipher from their presentations what is working and what is not, but they have consistently produced usable products. They have greatly benefited from industry participation with them in their research, both from the standpoint of getting field usable products and from better clarity on the presentation of the research papers. The collaborators should be more engaged in the research as participants and co-authors.

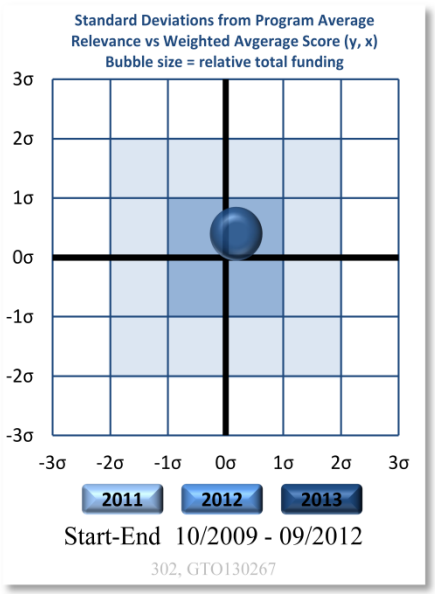
Test the foam stability and compare this formulation to foamed Portland blend with AP and foamed CaP with AP. Need apples to apples comparisons and not apples to oranges. Need to know if this formulation is filling a gap in the technology or supplying an additional product where there is not gap.

Don't claim to replace alloys, which are used for internal corrosion problems, as this cement will not address the internal corrosion, which is the only time expensive alloys such as titanium are used. External corrosion has been addressed by some Portland cement blends and the CaP cement that Brookhaven developed previously. This new cement would be competing for stopping external corrosion.

If the CaP cement has deficiencies in thermal shock resistance, that needs to be identified to the geothermal community. Brookhaven developed the CaP cement system and should be willing to let the geothermal community know if it has discovered shortcomings in that system.

PI Response:
Once an optimized formula for new cement is established, we plan to conduct studies comparing the foam stability and corrosion-inhibiting ability between new cement, Portland cement, and CaP cement. Further, the thermal shock-resistance test for CaP will be conducted for comparison purpose with new cement.

Modeling Reviewer Comments and Principal Investigator Rebuttals



Review: 2013 Geothermal Technologies Office Peer Review
ID: 302
Project: FRACSTIM/I: An Integrated Fracture Stimulation and Reservoir Flow and Transport Simulator
Principal Investigator: Podgorney, Robert
Organization: Idaho National Laboratory
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23425

Score: 8.0

Comment: This project is about developing an EGS simulation capability. This is very important because the issues confronted by decision makers in developing an enhanced geothermal system are difficult and complex. It is often not understood how different types of formation characteristics (fracture density, aperture, orientation, stress field) will affect the ultimate EGS product, which is energy production. Given that the flow of geothermal fluids through the system will change the EGS with time, knowing how to make the best decision becomes even more complex. Simulation capabilities such as the one proposed by Idaho National Laboratory (INL) and others can provide a "window" into how an EGS is affected in the present by varying the different parameters that define it as well as how the changing of those parameters (e.g., fracture aperture, cooling of formation, etc.) will affect the output of the system decades later. It is less apparent that the global solution approach taken by the PI is really critical to EGS objectives.

PI Response:

Reviewer 23509

Score: 7.0

Comment: This project is developing a new thermal-hydro-mechanical-chemical (THMC) simulation code based on an INL framework library-Multiphysics Object Oriented Simulation Environment (MOOSE). The implementation is fully-coupled, which contrasts with most of the other THMC offerings. New simulation codes are always welcome additions and this code may offer some unique advantages for solving certain types of problems. It was not clear during the presentation, however, which EGS projects would particularly benefit from having this capability versus other THMC codes.

PI Response:

Reviewer 24862

Score: 8.0

Comment: The presentation clearly identifies the challenges and barriers addressed

PI Response:

Reviewer 23568

Score: 8.0

Comment: Many geothermal codes are out there, but some are kludges (makeshift or "jury rigged"). The FALCON code is a de novo start written in a modern language to fully couple THMC into a single set of equations for inversion with the goal of improved performance and accuracy.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23425

Score: 5.0

Comment: There is definitely validity to solving the relevant thermal, mechanical and chemical equations simultaneously (globally) rather than using separate coupled codes. However, the global approach can be very demanding and may require many man years of code development before the desired product is achieved if starting from scratch. It is also true that this approach will tend to be more efficient than linking codes together to achieve more or less the same end result. To the code developer, making a highly efficient simulation capability is often a very important goal. To the customer for the simulations, getting results sooner rather than later while avoiding a major code-development effort may be more important than having a code that is computationally more efficient. Furthermore, issues relating to computing efficiency have become less important with time as computers have become more powerful with many more parallel processing nodes. In many cases, we can afford to be inefficient because the computing power is generally so great. In most cases, codes that are coupled (e.g., thermal and mechanical) can capture the same processes as global codes if the coupling is properly carried out and I would tend to disagree with the statement that global codes are better in this respect.

PI Response:

Reviewer 23509

Score: 8.0

Comment: The platform being used and robust numerical methods are sound. One concern was on the chemistry module added recently to the code. That capability was not demonstrated in the review materials and the PI was unclear whether

an in-house code was used, something written from scratch, or a module was adapted from a 3rd-party source. The chemistry capabilities also appear to be quite limited and not well described in the review materials.

PI Response:

Reviewer 24862

Score: 8.0

Comment: Numerical approach is sound

PI Response:

Reviewer 23568

Score: 7.0

Comment: The argument is that sequential, loose coupling, which is what has been done to date, is inefficient and leads to errors. Therefore, FALCON is built from scratch using a fully coupled, fully implicit approach that is readily able to use parallel computing. One wonders if there are situations in which the coupling is weak and building in those variables in a globally implicit manner goes past the peak of efficiency and accuracy gains. A methodological question about the global approach is that different variables in a partial differential equation (pde) should sometimes be approximated by different orders, e.g., pore pressure in a poroelastic problem is approximated one order less than displacement. How is that taken into account?

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23425

Score: 5.0

Comment: Quality - Most of the accomplishments appear to be of the code-development type. Given the PI's comments, the quality of those accomplishments appears to be very good. They have not solved all the issues as indicated in the summary. Fracture interactions is an example. It is a little difficult to judge overall quality of the accomplishments to date as we have no real results to compare with existing simulations. If code development is really the main objective, it would be very helpful to run comparison problems between FALCON and TOUGH, for example, so that the reviewer can really appreciate what is new and better about the INL product. As it is, it is very difficult to estimate quality. If developing insight into EGS is another objective, it would help to show some examples of how FALCON might simulate the flow of geothermal fluids in a realistic fracture distribution as well as estimate the energy output of a system as a function of time.

Productivity - Again, it is difficult to judge productivity. Three years of funding have now been completed but it remains unclear exactly what EGS problems can currently be addressed by FALCON. Writing a new code is a difficult undertaking and may require more than 3 years of effort given that many codes of this variety evolve over decades.

PI Response:

Reviewer 23509

Score: 6.0

Comment: Code development work appears to be complete and consistent with a modified plan proposed to GTO program management. This reviewer, though, is downgrading the score here because the review materials provided scant evidence of problem sets where the code has been applied and its capabilities exercised. Integration with important geological software such as PETREL was also lacking. Finally, project output is a bit disappointing. A considerable number of presentations have been given but only two publications are documented both on numerical algorithms and nearly 3 years old.

PI Response:

Reviewer 24862

Score: 9.0

Comment: On time, within budget. Demonstrated an example problem.

PI Response:

Reviewer 23568

Score: 9.0

Comment: Excellent progress in developing FALCON has been made.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23425

Score: 5.0

Comment: This project was evidently affected by glitches in funding according to the Summary which may have made management and coordination more challenging. Possibly a more effective use of decision points and re-scoping of the project might have avoided some of the issues that are mentioned. Over all, I think management/coordination is probably somewhere in the middle of the pack.

PI Response:

Reviewer 23509

Score: 8.0

Comment: Budget and schedule seem to be well managed.

PI Response:

Reviewer 24862

Score: 7.0

Comment: Seems fine

PI Response:

Reviewer 23568

Score: 7.0

Comment: A big management issue in this project is not within the project itself, but how the results extend to the user community. A lot of thought has been given to the licensing process in an open source way. While enthusiasm is high, the long-term viability of the code requires institutional memory to secure it. DOE could be very helpful here if it were to provide 10-year funding for code maintenance and user support.

PI Response:

STRENGTHS

Reviewer 23425

Comment: The project is primarily a code-development effort that attempts to take advantage of the MOOSE framework that was developed at INL. Developing a dedicated geothermal code from scratch that can globally simulate the thermal, mechanical and chemical regimes is a very lofty and desirable objective from a computational physics perspective.

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 24862

Comment: Developed a highly parallel code to solve coupled equations in porous media. Demonstrated scalability on ~200M Depth of Field (DOF).

PI Response:

Reviewer 23568

Comment: The comprehensive, state-of-the-art approach to computational THMC coupling is the strong suit here.

PI Response:

WEAKNESSES

Reviewer 23425

Comment: It is possible that the strengths mentioned in the previous section are not consistent with levels of available funding for this type of project. Use of decision points earlier in the management history might have been helpful for rescaling the project. The presentation and summary could benefit from more examples of how the code development effort is producing a result that is an improvement over existing capabilities.

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 24862

Comment: Need to see discussion of convergence, accuracy, time stepping, verifications. Comparison with field/lab data would be valuable. Need to demonstrate applicability on a realistic problem.

PI Response:

Reviewer 23568

Comment: If there is a weakness, it is the indiscriminate coupling of different processes without consideration of how strongly coupled the different variables are. Can this potentially lead to a loss of accuracy when using a fully implicit solver?

PI Response:

IMPROVEMENTS

Reviewer 23425

Comment: 1. Additional re-scoping when objectives don't match available time or support

2. Examples of how code represents improvement over existing capabilities

3. Simulations of relevant EGS processes that show how code might be used to improve insight regarding a very complex problem

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 24862

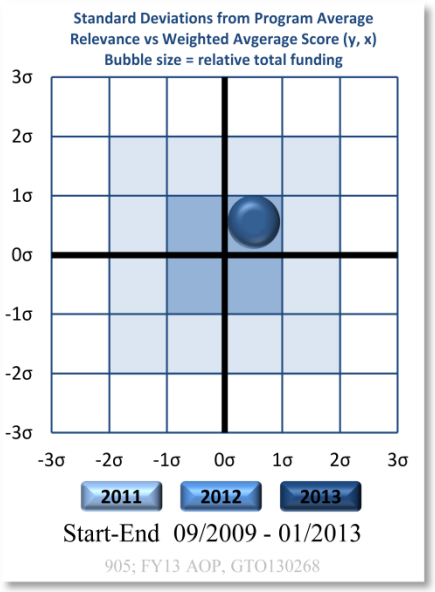
Comment: Doing very well in seeking application areas - continue with this effort. May have application to an existing EGS project - consider Newberry or Coso.

PI Response:

Reviewer 23568

Comment: Reviewer did not provide comments for this criterion.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: 905; FY13 AOP
Project: Coupled Thermal-Hydrological-Mechanical-Chemical Model and Experiments for Optimization of Enhanced Geothermal System Development and Production; Evaluation of Stimulation at the Newberry Volcano EGS
Principal Investigator: Sonnenthal, Eric
Organization: Lawrence Berkeley National Laboratory
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23453

Score: 9.0

Comment: This projects is focused on development of state-of-the-art modeling tools that can be used for analysis of geothermal production. Specifically, the developed codes will be able to treat thermal, hydrological, mechanical, and chemical processes for multiphase systems in fractured rock. Ultimately, this may provide quantitative capabilities and realistic simulation tools that are currently lacking. In addition to code development, the PIs are performing laboratory experiments, and apply their codes to interpret data from the EGS demonstration sites. Both activities are essential for the code validation and calibration.

PI Response:
No response necessary.

Reviewer 23435

Score: 7.0

Comment: Coupling the modeling development with field data (as opposed to bench scale data here) is important but not enough detail is provided to determine if this an effective validation exercise. The PI is certainly courageous in showing an upper leak in the borehole when the operators would prefer that none be shown there. Including isotopes in the modeling is arguably an advance but unlikely to show discrete permeability paths except in the case of fuzzy isopleths in an already developed field. As with most other, Thermal-Hydrological-Mechanical-Chemical (THMC) presentations, I saw no explicit recognition or recommendations for field scale data acquisition that would allow for systematic and defensible extension of modeling results away from the borehole. This limitation is especially troubling given the advances in microseismic interpretation where we are close to absolute location and source/stress field characterization such that flow and diffusive events can be differentiated and precisely located. In the upcoming THMC code validation exercise, DOE should encourage those PIs that can efficiently incorporate such data into their codes (general THMC comment).

PI Response:
Considerable work has been done since the review in analyzing the EGS stimulation test with detailed comparison to DTS measurements and wellhead pressures. A preliminary report was submitted to DOE since the Peer Review, and new work is being finalized in a white paper. Now that the well casing leak analysis is nearly complete, and the pressure/temperature

history in the wellbore has been matched throughout the experiment, we can make a better constrained assessment of what chemical signeature should be looked for in the zones where microearthquakes were observed.

Reviewer 24862

Score: 8.0

Comment: Barriers and relevance clearly stated.

PI Response:
No response necessary.

Reviewer 23568

Score: 8.0

Comment: The Newberry Crater EGS demo is a major GTO effort and so the THMC modeling of the results is a high priority and very relevant. A step was taken to integrate the THC code with the M rather than sequentially iterate between two codes. This is a clear evolution in the geothermal modeling world as integrating the coupling will have significant computational and user advantages.

PI Response:
No response necessary.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23453

Score: 10.0

Comment: The PIs take advantage of the existing codes for the thermo-hydro-chemical (TOUGHREACT) and mechanical (ROCMECH) analyses to develop a fully coupled code that can handle highly non-linear problems involving fluid flow, deformation of the host rock, heat transfer, chemical reactions, and permeability changes within an integrated computational framework. Because simulation of geothermal reservoirs requires 3-D geometries, computational efficiency is an important factor. Therefore there is emphasis on parallel computing. The PIs have demonstrated that their new code is able to run in parallel on multiple cores, and scales reasonably well. The multi-physics capabilities include fluid-driven fracture propagation, chemically induced subcritical crack growth and pressure solution, and porosity-permeability changes. All of these processes are expected to be important during geothermal heat recovery. The PIs are also conducting high-temperature, high-pressure experiments to evaluate the long-term behavior of sheared fractures, test predictions of their numerical models against experimental data, as well as against field-scale data from the actual EGS demonstration projects (Newberry and Dixie Valley). Another innovative aspect of the project is the use of geochemical and isotopic tracers to evaluate the reaction rates and fracture surface areas after stimulation and over longer production time periods.

PI Response:
No response necessary.

Reviewer 23435

Score: 5.0

Comment: The inclusion of reactive transport and isotope components is a potential advance given recent data concerning rates and magnitudes of rock and fluid chemistry with geothermal well stimulation and production. The use of the TOUGH code and multiple-interacting-continua (MINC) assumption will likely ensure commonality, discussion, and interest among other TOUGH users which are numerous. The project showed significant initiative in developing processing schemes to decrease computation times. The code seemed to be verified via the Kim et al., 2012 publication but this is not the same as validation against field scale data. The native state simulations were reasonably detailed and seemed to confirm subjective estimates of pressure and property distributions. The modeled Newberry stimulation was short on field measurements and the cause of the upper borehole pressure transient is problematic. Likewise, the correlation to micro earthquakes (MEQS) is problematic without a systematic discussion regarding relative location error and source mechanisms. It is noteworthy and a sign of success that the epicenter linear NE trend was coincident with the modeled pressure trend.

PI Response:
Yes, now that the THMC code has been developed, and we have analyzed, and for the most part, matched the downhole temperatures at Newberry using TH modeling, we plan on running full THM and THMC simulations given a much better set of hydrological proprerties. Regarding the MEQs, having not looked at these data before, I didn't recognize the errors in determining locations. We have both the unrelocated and relocated events, and will consider both in further analyses. Information on the source mechanisms will be used to evaluate the types of mechanisms, and the sizes of the fractures needed to consider for THM models.

Reviewer 24862

Score: 8.0

Comment: The heat transfer, fluid flow and chemistry well handled. What is the need of the MINC approach for the mechanical equations?

PI Response:
The MINC approach can yield more accurate solutions for rock deformation under strongly transient conditions of cold water injection and be consistent with fluid pressure and temperature calculations at fracture matrix interfaces. It has the potential for yielding more accurate mechanical effects in fractures when average effects in the rock matrix are still small. Given the strong cycling of pressure and temperature during changes in pumping rates during stimulation this is likely to be important.

Reviewer 23568

Score: 9.0

Comment: The approach is to develop a separate RocMech code and integrate it with TOUGH-REACT. There are also laboratory tasks against which the code is validated.

PI Response:
No response necessary.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23453

Score: 8.0

Comment: The PIs have made a good progress on the code development and testing. A new version of the TOUGHREACT code (V2) was released last summer (June 2012). A parallel version of the code (V2.2G) is planned for release this year. Preliminary results for coupled 3-D THCM numerical models have been obtained for the Newberry geothermal site. Pressure and temperature variations in the substrate resulting from the water injection have been compared to local seismicity. A 2-D THC model was also applied to the Dixie Valley geothermal area. Laboratory experiments on sheared fractured were performed at moderate temperatures (60 deg. C). Experiments at higher temperatures relevant to in situ reservoir conditions (up to 200 deg. C) have been delayed due to equipment malfunction (failed controller). The experiments will be executed within a few months. These experiments will provide insights into geochemical and hydrological changes during a pressure induced shear event, and will help with code validation.

PI Response:
No response necessary.

Reviewer 23435

Score: 5.0

Comment: The use of reasonably extensive and spatially variable field parameters for input and subsequent validation is a significant achievement. The code seemed to be verified via the Kim et al., 2012 publication but this is not the same as validation against field scale data. The native state simulations were reasonably detailed and seemed to confirm subjective estimates of pressure and property distributions. The modeled Newberry stimulation was short on field measurements and the cause of the upper borehole pressure transient is problematic. Likewise, the correlation to MEQS is problematic without a systematic discussion regarding relative location error and source mechanisms. It is noteworthy and a sign of success that the epicenter linear NE trend was coincident with the modeled pressure trend. A significant number of abstracts have been produced but only one peer reviewed publication. The core scale tests are a start and the systematic and high quality data acquisition is useful but there are or have been similarly successful efforts (Stanford, EGI, ORNL, LLNL, etc.).

PI Response:
Yes, now that the THMC code has been developed, and we have analyzed, and for the most part, matched the downhole temperatures at Newberry using TH modeling, we plan on running full THM and THMC simulations given a much better set of hydrological proprerties. Regarding the MEQs, having not looked at these data before, I didn't recognize the errors in determining locations. We have both the unrelocated and relocated events, and will consider both in further analyses. Information on the source mechanisms will be used to evaluate the types of mechanisms, and the sizes of the fractures needed to consider for THM models. We recognize the need to publish additional papers using the code, and now have another paper that includes the chemical effects in addition to mechanical deformation that has been submitted (Kim et al.), and have another paper using the code for hydrothermal modeling of the DIxie Valley system (Wanner et al.). While

others have done core-scale tests, we are not aware of any others that have monitored the fluid chemistry, acoustic emissions, and dilation/displacement in real time during a shear event.

Reviewer 24862

Score: 9.0

Comment: Timely modeling, comparison with chemistry data and analysis of casing leaks. Interesting experiments showing correlation between acoustic emissions and chemistry.

PI Response:
No response necessary.

Reviewer 23568

Score: 7.0

Comment: The effort to date has been primarily in the code development and that has been successfully accomplished. The integration at this stage is still more like two codes under one roof, rather than a truly integrated THMC code. That job seems worthwhile but the personnel for doing is currently lacking.

PI Response:
We agree that intially ROCMECH was more like a separate code, and now we have a geophysicst (at 50% effort on this) who has added MPI to the TOUGHREACT in the past year and now is working on integrating and improving the coupling, use, and speed of TOUGHREACT-ROCMECH.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23453

Score: 9.0

Comment: This project involves several investigators with expertise in different disciplines, and frequent interactions with collaborators from industry (AltaRock). The overall management of the project appears to be quite efficient. The project is meeting all major milestones, and is on track time-wise and budget-wise. There are some minor delays due to laboratory equipment and sample collection, however they are being resolved. The project also takes advantage of synergetic activities such as the Newberry Demonstration Project and a DOE FOA project on model development for nontraditional isotopes.

PI Response:
No response necessary.

Reviewer 23435

Score: 7.0

Comment: Project management and coordination have been above average with respect to the acquisition and use of the Newberry data, the increase in computational speeds, and detail of the models run. The isotope sampling seems to be problematic so this portion of the effort needs monitoring.

PI Response:
No funds have been spent on the isotope portion except to analyze the injected groundwater. We are hoping to collect samples from Newberry during later tests, if they are approved.

Reviewer 24862

Score: 7.0

Comment: Seems fine

PI Response:

No response necessary.

Reviewer 23568

Score: 9.0

Comment: Aside from the issue of sufficient personnel, the PI is clearly on top of the technical aspects.

PI Response:
We have hired a geophysicist to work 50% on this now.

STRENGTHS

Reviewer 23453

Comment: Coupled multi-physics simulations are essential for understanding how the geothermal reservoirs operate on various time and length scales. The developed models are state of the art. The use of laboratory and field-scale observations to validate the models is highly warranted. The ability of models to resolve variable spatial and temporal scales is a definite strength, as is the ability of the models to run in parallel.

PI Response:
No response necessary.

Reviewer 23435

Comment: Use of TOUGH based approach likely to increase acceptance?

PI Response:
No response necessary.

Reviewer 24862

Comment: Combination of code development and field applications. Interesting lab experiments

PI Response:
No response necessary.

Reviewer 23568

Comment: The strength is the Newberry demo site is a major experiment that needs to be THMC modeled.

PI Response:
Yes, we have done a preliminary test of TOUGHREACT-ROCMECH on Newberry, but now that data from the stimulation are availble and we have modeled the pressure and temperatures, we will run THMC simulations.

WEAKNESSES

Reviewer 23453

Comment: There is no discussion of how laboratory data will be extrapolated to the reservoir length scales (km), and the associated issues.

The isotopic tracers is an interesting and potentially promising component of the work plan, but it is not well integrated with the modeling activities.

The finite element code used to simulate deformation (ROCMECH) appears to use structured meshes. This may be a limitation in case of complex geometries (e.g., faults and petrologic contacts).

PI Response:
Laboratory data will be incorporated into subgrid-scale models for fractures as in the MINC approach and discrete fractures. Having the correct phenomena at small-scales and incorporating enough information on the large-scale fracture size distributions and orientations will be necessary to capture km-scale effects. MEQ data will be used to constrain the km-scale deformation mechanisms and magnitudes, because little other information outside the wellbore is available.

The isotopic tracer project is a completely separate project. It was included for convenience by DOE with the EGS THMC review since it was a newly funded project.

Reviewer 23435

Comment: The isotope component is not going well and continued bench scale work is not likely to improve code validation beyond what has already been accomplished.

PI Response:
The isotopic tracer project just started in Sept. last year and depends on data from Newberry. No geochemical data were collected and money was only spent on groundwater isotopic analyses.

Reviewer 24862

Comment: No discussion of how well the mechanical model to TOUGH coupling works, convergence, time steps, problem size etc. Slide 7 is interesting but verification is needed. On the experimental side, there doesn't seem to be coordination with other experimental projects at Lawrence Berkeley National Lab (LBL) and/or other institutions.

PI Response:
We have another paper submitted with more emphasis on simulating chemo-poro-mechanics. Coordination with the other projects will be a priority, and we have done this for the current set of AOP funding requests.

Reviewer 23568

Comment: The project is directly coupling a reactive transport model with rock mechanics. This effort is impeded by a lack of personnel at the present time so that the code, although under one roof, is really still like a duplex.

PI Response:
Hired a geophysicist 50% to work on this.

IMPROVEMENTS

Reviewer 23453

Comment: Adding a continuum damage mechanics module to the coupled THCM code may improve the code's predictive capability with regard to micro-seismicity.

PI Response:
Yes, we will need to do this, likely in the fashion of McClure and Horne (2013) with multiple mechanisms operating and discrete fractures implemented

Reviewer 23435

Comment: PI should consider what type of field data can most efficiently allow code utility for permeability creation in the far field.

PI Response:
We are looking at the MEQ data more closely, as well as geochemical data that can guide the properties of fractures (clay coatings, etc.) that affect slip.

Reviewer 24862

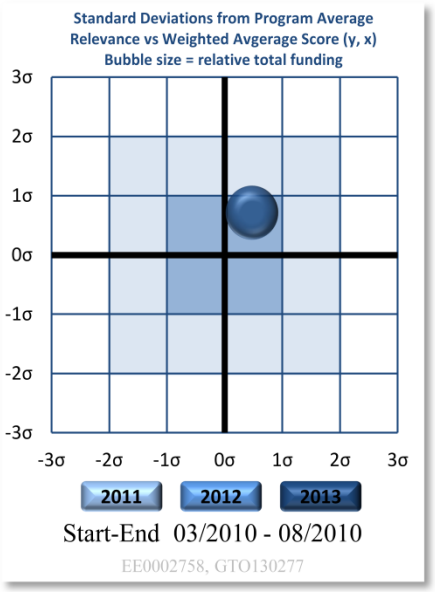
Comment: Present discussion of how well the mechanical model to TOUGH coupling works, convergence, time steps, problem size etc and present verification. On the experimental side, the reviewer recommends coordinating with experimental projects at Lawrence Berkeley National Lab (LBL) and other institutions.

PI Response:
We will include this in future papers.

Reviewer 23568

Comment: Reviewer did not provide comments for this criterion.

PI Response:
No response necessary.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002758
Project: Integration of Noise and Coda Correlation Data into Kinematic and Waveform Inversions With Microearthquake Data for 3D Velocity Structure, Earthquake Locations, and Moment Tensors in Geothermal Reserv
Principal Investigator: O'Connell, Daniel
Organization: William Lettis & Associates, Inc.
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23425

Score: 8.0

Comment: Obtaining high accuracy absolute locations in a geothermal field can be very useful for determining exactly where stimulation is occurring in relationship to a site's geology as determined from borehole cores. Achieving the objective may also help to define fault planes and other geologic structures that provide insight into a site's response to geothermal fluid injection.

PI Response:
This has been one of the primary objectives of the project.

Reviewer 23509

Score: 8.0

Comment: Project is strongly aligned with GTO goals to map fractures and estimate poro-elastic stresses to improve EGS performance, accurately position wells, and minimize seismic risks. PI has been able to significantly improve spatial resolution of hypocenter location driving down to 10 m or less.

PI Response:
Since the 2013 Peer Review meeting, we've extended our non-linear uncertainty analyses to obtain fully-nonlinear estimate of absolute and relative hypocenter locations so we can rigorously quantity all aspects of hypocenter locations uncertainties.

Reviewer 24862

Score: 8.0

Comment: Relevant to reducing risks associated with well locations and induced seismicity

PI Response:

We are currently evaluated seismicity in relation to injection and production wells at the Coso geothermal field and the test injection well at Newberry.

Reviewer 23568

Score: 9.0

Comment: High resolution location of MEQs is important for locating induced earthquakes onto faults. Moment tensors are important for identifying the fracturing mechanism, e.g., tensile or shear, as the mechanism gives inferences about permeability enhancement.

PI Response:
Since the 2013 Peer Review meeting we have developed a way to integrate fully-nonlinear absolutate and relative hypocenter location calculations in the waveform inversion for 3D velocity structure and moment tensors to improve resolution of earthquakes and moment tensors and their uncertainties.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23425

Score: 9.0

Comment: While I am not an expert in this particular area, I am impressed by what I understand of the technical approach that seems highly competent from both seismic and data analysis perspectives.Speeding up analysis with the GPU-optimized approach indicates an important commitment to decision makers in the field. Coda Wave Interferometry seems a relatively recent development in seismology (90's) that appears to have significant potential for understanding changes in geothermal systems due to fracturing and other poro-elastic matrix modifying processes.

PI Response:
We are focusing on extracting the maximum amount information from the earthquake and noise waveform data that are collected by typical seismographic monitoring networks in and near geothermal fields.

Reviewer 23509

Score: 8.0

Comment: PI is using a robust combination of numerical methods. Of particular note is elimination of S-wave arrival time error biases using Bayesian S-wave picking and coda-wave bulk shifts.

PI Response:
We are also looking at using the group delays calculated during waveform inversion to improve the resolution of S-wave arrival times and difference times.

Reviewer 24862

Score: 8.0

Comment: Validation with Paradox data seems sound

PI Response:
A weakness of the Paradox data is that most of the earthquakes have nearly vertical strike slip focal mechanisms. We are also analyzing the Newberry data that has a richer set of more varied and complex dipping focal mechanisms and more three-component data.

Reviewer 23568

Score: 6.0

Comment: The approach is to borrow and develop computer science techniques and waveform coda analysis techniques in oil and gas to improve the location accuracy. A similar approach was taken to perform poroelastic modeling with high efficiency. What was missing was integration between the earthquake locations and velocity models with the modeling.

PI Response:
The 3D velocity structure from the hypocenter-velocity inversion and the earthquake locations from the waveform cross-correlation relative relocations were used as input for the poro-elastic modeling.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23425

Score: 7.0

Comment: Quality - It is a little difficult to evaluate exactly where the coda wave interferometry work puts the effort relative to the objectives that were expressed. This comment also applies to some of the other accomplishments that are shown in the presentation. Lots of results are presented but exactly how they contribute to achieving the final objectives is somewhat unclear. I encourage the PI to possibly present a framework for achieving the objectives and exactly where these accomplishments fit in that framework.

Productivity - Seems high and problems that have been addressed are challenging. Again, exactly how the volume of results obtained contributes towards the target objectives could be more clearly stated.

PI Response:
The coda wave interferometry is focused on resolving velocity changes in space and time, particularly changes associated with geothermal injection and production activities. The Colorado School of Mines will support an additional year of research beyond the end of DOE project funding to finish the work begin to develop, test, and apply 3D coda-wave interferometry tomography at the Coso geothermal field. We are also applying coda wave interferometry to detect velocity changes associated with the initial fracturing injection activities during 2012 at Newberry.

Reviewer 23509

Score: 7.0

Comment: PI has demonstrated significant progress in interpreting seismic events in the Paradox Valley project. However, project output in terms of publications and presentations is low after over 3 years of effort.

PI Response:
We are focusing the last several months of the project on submission of multiple papers for each of the project areas (Paradox, Coso, and Newberry).

Reviewer 24862

Score: 8.0

Comment: Approach seems to be well validated. Application to Coso seems quite promising.

PI Response:
We are working more closely with Terragen to apply our results at Coso.

Reviewer 23568

Score: 7.0

Comment: The individual tasks were completed but the two halves (waveform analysis and poroelastic modeling) were not integrated, as indicated in the previous comments. Another concern is knowing just how the new tools are being distributed to the geothermal community.

PI Response:
The waveform inversion is used to develop the 3D elastic modulii and densities provided the USGS to create the poroelastic model The poroelastic model is being developed by the USGS and will be publicly available. The waveform inversion capabilities are being developed by Fullwave Technologies along with analysis services that will be available to the geothermal community.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23425

Score: 7.0

Comment: Again, lots of results but unclear exactly as to how they contribute to meeting original objectives. Principal objective of 10m or less earthquake locations probably has not been met as I understand vertical positioning of the location is more difficult and needs more work. All the results shown are for horizontal locations of earthquakes which do seem to have been improved relative to earlier location efforts.The PI wants input and has been responsive to previous review comments which is a definite positive. Project is finishing late which possibly is a small negative. Management is probably better than average.

PI Response:
Some aspects of the project have been difficult and taken more time than initial projected. However, we are accomplishing nearly all we set out to do.

Reviewer 23509

Score: 9.0

Comment: PI has encountered unexpected technical problems in performing the work that has impacted schedule and budget. However, additional cost share resources were procured to ensure that project deliverables were met. Project is slightly behind schedule but has sufficient budget to complete remaining objectives.

PI Response:
We've been able to hire additional people with extensive geothermal experience, which has been a big help.

Reviewer 24862

Score: 8.0

Comment: Work seems well coordinated between multiple entities

PI Response:
It has been a challenge coordinating so many activities but the project team members have worked well together.

Reviewer 23568

Score: 7.0

Comment: The PI contributed personally to the waveform results and while he coordinated the poroelastic modeling, he seemed less knowledgeable about that aspect, although he hired a senior geologist to do coordination based on a previous peer review.

PI Response:
As PI my primary expertise is in the seismological aspects (earthquake location, tomography, waveform inversion, and coda-wave interferometry) that is why we have two poro-elastic experts working on the project (Drs. Denlinger and Roeloffs of the USGS).

STRENGTHS

Reviewer 23425

Comment: The field approach, data analysis and simulation capabilities all appear to involve cutting edge technologies. PI and colleagues appear to be extremely strong in their specialties. Seismic positioning seems impressive. Their results have modified the assumptions about the nature of Coso seismicity.

PI Response:
We are developing a better understanding of the associates between injection, production, and deformation using additional well data from Terragen.

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 24862

Comment: Developed a valuable tool for locating structures with MEQ data. Interesting results for Paradox and Coso.

PI Response:
We are applying these approaches to the 2012 Newberry injection sequence seismicity data.

Reviewer 23568

Comment: The more accurate MEQ locations was the strength.

PI Response:
We have found a way to improve the earthquake location uncertainty analyses presented at the 2013 Peer Review meeting and are using the improved fully-nonlinear joint absolute and relative location uncertainty approach with the Newberry and Coso data to demonstrate these capabilities.

WEAKNESSES

Reviewer 23425

Comment: To me, the main weakness is about understanding how all the work and results comes together to achieve the stated objectives. Clearly, lots of work has been done and significant improvements in event positioning appear to have been achieved but it remains unclear to me how close to achieving the objectives we are as a result of this effort.

PI Response:
We are working to develop several publications using the 2012 Newberry injection data to illustrate the integration of the various components of the project in a unified analysis of seismicity and poro-elastic responses to injection and fracturing.

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 24862

Comment: There doesn't seem to be any discussion of source mechanism or energy release. It's not clear if the theoretical model is sensitive to formation temperatures.

PI Response:
We had not completed the moment tensor analyses at the time of the preesntation. We will include discussion of source mechanisms and energy release in the moment tensor discussions. The theorectical model accounts for formation temperature.

Reviewer 23568

Comment: The lack of integration of the velocity model and MEQs with the poroelastic modeling was the weakness.

PI Response:
I apologize that there was so much material to present that I did not provide a good overview of the work flow. The velocity inversions and moment tensor inversions are done prior to the poroelastic modeling to provide 3D modulli and density inputs for the poroelastic model and earthquake locations and mechanism constraints to compare againsts.

IMPROVEMENTS

Reviewer 23425

Comment: See previous comments

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 24862

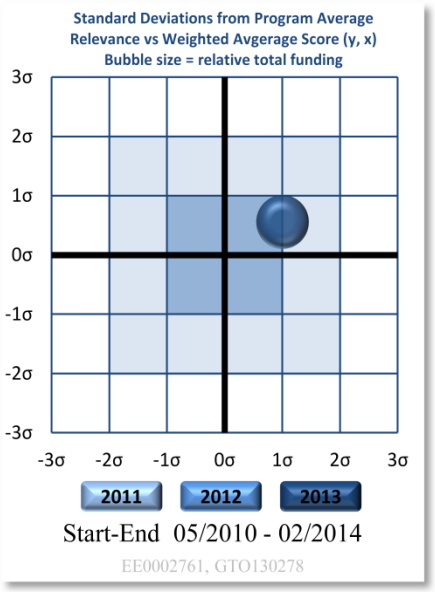
Comment: Add discussion of source mechanisms and energy release.

PI Response:
We will do this in our analyse of the moment tensor results

Reviewer 23568

Comment: Reviewer did not provide comments for this criterion.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002761
Project: THMC Modeling of EGS Reservoirs – Continuum through Discontinuum Representations: Capturing Reservoir Stimulation, Evolution and Induced Seismicity
Principal Investigator: Elsworth, Derek
Organization: Pennsylvania State University
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23453

Score: 9.0

Comment: This project aims at developing the modeling capabilities that will allow quantitative understanding of the behavior and productivity of EGS reservoirs over multiple timescales ranging from individual stimulation events, to the lifetime of the reservoir. This is a challenging task, as the evolution of temperature, fluid flow, fluid pressure, permeability, etc. are highly coupled in space and time, and the medium properties are not well known. The investigators are addressing these problems by developing continuum and discontinuum numerical codes that incorporate the relevant multi-physics. The effectiveness of these numerical models is tested by comparing the model predictions to observations from the on-going EGS demonstration projects. The proposed set of tasks is directly relevant to several of the GTO goals, including development of better predictive capabilities of the geothermal production.

PI Response:
Agreed.

Reviewer 23412

Score: 7.0

Comment: The relevance/impact of this project will help provide theories of mechanism when creating an EGS system.

PI Response:
Yes, and also contribute to define crucial needs for a successful EGS reservoir.

Reviewer 24878

Score: 8.0

Comment: This project addresses the role of different effects on effective and thermal stresses and chemical effects especially in the long term behavior of EGS. This is an important project in order to understand the behavior of these systems during fracking and the healing of the cracks after stimulation. This project is completely relevant to the DOE mission.

PI Response:
Agreed.

Reviewer 23568

Score: 8.0

Comment: Relevance of THMC coupled modeling is highly relevant to GTO. This group is one of several attacking the problem.

PI Response:
Agreed.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23453

Score: 9.0

Comment: Upon identifying and evaluating main feedbacks that affect operation of geothermal reservoirs (e.g., between fluid flow, heat transfer, chemical reactions, pressure changes, evolution of porosity and permeability etc.), the investigators are focusing on extending and merging capabilities of the existing numerical codes (such as TOUGHERACT and FLAC3D), and developing discrete particle models capable of predicting details of rock failure, porosity evolution, induced micro-seismicity, and thermo-mechanical and chemical coupling. This is a powerful approach that takes advantage of both the deterministic nature of physical laws and stochastic nature of heterogeneous media in which material properties cannot be fully characterized. The developed models of induced seismicity look promising.

PI Response:
Agreed.

Reviewer 23412

Score: 8.0

Comment: The key scientific/technical approach is that the project tests itself or reality checks itself regularly to understand the physics of the creation of an EGS system.

PI Response:

Reviewer 24878

Score: 8.0

Comment: The project is based on using both a discontinuous approach (pore scale) and a continuum (representative elementary volume) modeling approach. The focus on induced seismicity using a combination of TOUGH-REACT AND FLAC3D (mechanics + chemistry) is interesting . I like also the wish to apply the modeling to Newberry field. I like the modeling showing that the thermal front and not the fluid pressure front controls the evolution of the seismicity. The discontinuous approach is really required to understand the fracture propagation. There are still a lot of simplifications in the model.

PI Response:
Yes. Certainly the model is simplified, but we believe, not simplistic.

Reviewer 23568

Score: 9.0

Comment: Two attributes of the approach stand out. The first is that the project examines the magnitude of different pairings of the coupling. The second is that the project examines continuum vs. discrete approaches separately.

PI Response:
Agreed.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23453

Score: 9.0

Comment: While the project is still on-going, there's been a considerable progress. The PI has presented a coupled model describing permeability evolution with THMC feedbacks. Also, there are interesting and encouraging results on the evolution of pore pressure, thermal stress and their relationship to induced seismicity (in particular, the spatio-temporal patterns of micro-earthquakes following a borehole stimulation). These results are timely and cutting-edge. The PI is disseminating the project results through publications in leading peer-reviewed journals and major scientific meetings.

PI Response:
Agreed.

Reviewer 23412

Score: 8.0

Comment: This project is near completion/funding. Results and testing on real data sets show promising results.

PI Response:
Yes, we believe these results are also promising.

Reviewer 24878

Score: 9.0

Comment: The project is on track. There are a number of nice results that have been obtained.

PI Response:
Agreed.

Reviewer 23568

Score: 8.0

Comment: The project has achieved its goal of determining the magnitude of different pair-wise couplings. The project has emphasized induced seismicity. A notable result is that they obtain a frequency-magnitude b value for Cooper Basin that is a very good match to field results. This type of model validation, while at the macro level, is very reassuring. Overall though the results tended to be more generic than specific.

PI Response:
Our approach is to define process - we will apply the model to Newberry and potentially to Soultz. Maybe this will add more specific results and also help in ratiionalizing generic observations and in particualr process-based observations.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23453

Score: 9.0

Comment: The project seems to be meeting all major milestones and budget schedules. There are regular interactions between the project participants (including collaborators from academia, industry, and government labs). Importantly, the project provides training and support for graduate students.

PI Response:
Agreed.

Reviewer 23412

Score: 9.0

Comment: Project management and coordination with AltaRock and Desert Peak is key to the project success

PI Response:
Yes, these are important connections for this project - especially with AltaRock.

Reviewer 24878

Score: 8.0

Comment: Good project management and coordination. It seems that there is an effective collaboration with stakeholders and the future of the project is clear.

PI Response:
Agreed.

Reviewer 23568

Score: 9.0

Comment: This did not seem to be a complicated project to manage.

PI Response:
I think that is fair comment.

STRENGTHS

Reviewer 23453

Comment: Using a combination of numerical tools (such as TOUGHERACT/FLAC3D and a discrete particle code) is a powerful approach that can help illuminate poorly understood aspects of EGS operation. Physics-based numerical simulations of highly coupled non-linear behavior are providing new insights into pressing problems such as seismicity associated with the geothermal production.

PI Response:
Agreed.

Reviewer 23412

Comment: Industry collaboration

PI Response:
Yes, this is a crucial component - both to inform the current demonstration project and to learn from their results.

Reviewer 24878

Comment: Excellent project with good science and good management. The presentation was excellent as well the responses to the questions of the referees. I don't have too many comments on this project because I think the PI is going in an excellent direction that will be useful to the community.

PI Response:
Thanks. We appreciate the comment..

Reviewer 23568

Comment: Examining the importance of coupling between different variables is highly laudatory as was the match of 'b' value for a geothermal field's induced seismicity.

PI Response:
Yes, we have attempted to incorporate the essential physics, to follow processes as appropritate and to attempt validation to make the results meaningful.

WEAKNESSES

Reviewer 23453

Comment: There are no major weaknesses of this project.

PI Response:
Thanks.

Reviewer 23412

Comment: This project has no apparent weaknesses

PI Response:
Thanks.

Reviewer 24878

Comment: None as far as I can say.

PI Response:
Thanks.

Reviewer 23568

Comment: Very few results were presented for discrete modeling.

PI Response:
Agreed. This is definitiely the most challenging part of the study. But potentially the most rewarding.

IMPROVEMENTS

Reviewer 23453

Comment: Discontinuum models of fault slip and permeability evolution can take advantage of the existing experimental data on rate-state friction and slip-induced damage and porosity changes. Specifically, the models can be tuned to match the observed "aging" effect on friction (a logarithmic dependence of the static coefficient of friction on hold time).

The presentation/statement of work documents should more clearly specify project accomplishments to date.

PI Response:
Rate state models can be used. The model we showed was a micromechanical attempt to replicate the RS ageing process by the precipitation around asperities. As a practical matter, the use of RS methods is a ready way to represent real behavior through phenomenological models - although few data are available for RS definition of fractures.

Reviewer 23412

Comment: The only improvement might be is to keep the conclusions objective. It is a bold conclusion that later seismic events are thermally related. Seismic events occur when the rock releases energy. Magnitude of the event has no correlation to permeability of porosity created.

PI Response:
Fair comment. However, at later time, the fluid flow field has already stabilized (invariant in time) but thermal drawdown continues. Thus it is only the thermal regime that is changing and therefore linking the late-time events to the thermal stress change is, I think, defensible.

Linkages of perm with siesmicity - we don't link this directly but stress drop does elicit a change in permeabilty through effectuve stress and the constitutive relations.

Reviewer 24878

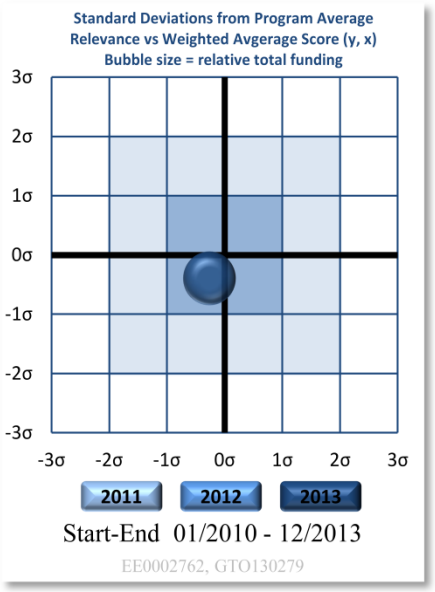
Comment: I cannot suggest improvement here. This project is developing coupled THMC models capable of accommodating static and dynamic rupture and failure in discontinuous fractured reservoirs with THMC interactions. This is a very rigorous project based on micro and macro-physics .

PI Response:
Thanks.

Reviewer 23568

Comment: Reviewer did not provide comments for this criterion.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002762
Project: Development of Advanced Thermal-Hydrological-Mechanical-Chemical (THMC) Modeling Capabilities for Enhanced Geothermal Systems
Principal Investigator: Wu, Yu-Shu
Organization: Colorado School of Mines
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23412

Score: 7.0

Comment: Numerical tools are needed to determine the processes of developing an EGS system.

PI Response:
Yes, modeling studies are needed to complement to laboratory and/or field studies for development of EGS reservoirs.

Reviewer 23435

Score: 5.0

Comment: Yet another THMC code of generic utility but problematic in a pragmatic geothermal specific sense. The mean stress assumption may make applicability of the code to far field data inclusion (state of stress via MEQ and geologic data for example) limited.

PI Response:
We admit that with the mean stress we may not be able to capture MEQ properly but our main focus is to simulate fluid flow to help determine long term evaluation of a geothermal field. Thus, the use of mean stress could provide efficient way to capture the effect of stress change on fluid and heat flow in long term production.

Reviewer 23445

Score: 7.0

Comment: The goal of this project is to develop a fully coupled fluid, thermal, chemical and mechanical simulator for a geothermal reservoir. This model is to investigate the long term (20 year) operation of a geothermal system. The goal of the PI is to put this model into the public domain so that others may add additional models to the code to allow ease of evaluating different models for geothermal processes. I feel that the placement of this model into the public domain will generate a lot of interest, but may turn out to be a much larger project than the PI anticipates. Yet, even without the placement of the model into the public domain, the project seems well thought out and could provide significant insight into the operation of EGS reservoir systems.

PI Response:
Thanks for the positive comments for the project. We are working on having the TOUGH2-EGS into public domains for geothermal community to use, add on and improve. For example, we offered a TOUGH2-EGS simulator training workshop in the early of June of this year and we had 35 professional participants of the workshop from the world-wide geothermal communities.

Reviewer 23509

Score: 7.0

Comment: THMC modeling is critical to many EGS projects and developing new THMC computer simulators codes is desirable to expand on existing capabilities. This project's goal to have a THMC simulator in the public domain is laudable but the PI was unclear whether that goal will ultimately be accomplished due to use of TOUGH2 and licensing agreements that apparently are still in negotiation. Also, other than the public domain aspect, it is not clear from either the presentation materials or Project Summary what technical advances, if any, have been made beyond capabilities that already exist in available THMC codes.

PI Response:
We worked out with LBNL on release of TOUGH2-EGS for the workshop participants in June one time. We are working on dveloping new THM geothermal simulators, separated completely from TOUGH2 codes, to be release to public soon. To the best of our knowledge, there were no fully coupled THMC codes for geothermal reservoir simulation before TOUGH2-EGS in both public or private domains.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23412

Score: 8.0

Comment: Having the involvement of CMG STARS software to compare to Tough2 EGS is beneficial

PI Response:
Thanks!

Reviewer 23435

Score: 5.0

Comment: The use of the TOUGH approach is well known and likely to be understood and used. The verification against simplified analytical and CMG-STAR solutions and other simulation studies is a nominal success but not especially encouraging with respect to complex, anisotropic and heterogeneous boundary conditions.

PI Response:

The purpose of the verification cases is to make a brench mark or cross-check with theories to confirm the correctness of the code implementation. We agree that there is always the need for modeling complex simulation cases and TOUGH2-EGS is designed for handling complex, anisotropic and heterogeneous media and code verification for such appplications is difficult to carry out and needs to be done case by case.

Reviewer 23445

Score: 7.0

Comment: The approach seems well thought out. There is one point that may generate some discussion. A primary parameter in the model is the mean stress. The model allows generation of sub models based on the local mean stress. Thus, permeability and porosity are expressed as functions of mean stress, and not a function of the more general stress tensor. This is done because it simplifies the model. As stated by the presenter, development of a porosity model as a function of the full stress tensor is a daunting task. The model also includes a variety of ways of modeling the existing fractures and the fractures that are created during the simulation. This hybrid model offers great flexibility in the simulation.

PI Response:
We fully agree with the comment.

Reviewer 23509

Score: 6.0

Comment: The PI has selected TOUGH2 as the basic platform and added a chemistry module and geomechanics module. The chemistry module duplicates capability already available in TOUGH-REACT and the poroelastic module is a basic extension available in other codes. Testing to date appears limited to benchmarking against previous test problems and a field test. No particularly new or significant insights were presented.

PI Response:
The main purpose of this project is to create a numerical simulator capable of THMC calculation for long term production evaluation. So, it would not focus on new physics or insight but rather the completeness of describing the coupled-physics in public domain. Secondly, existing geomechnical simulators are generally sequentially coupeld with fluid and heat flow, e.g., linking reservoir and mechanics codes, which is inherently non-mass or -energy conservative and may converge to wrong answers.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23412

Score: 8.0

Comment: The project is near completion. It would be interesting to attend the demonstration workshop.

PI Response:

The workshop for TOUGH2-EGS was carried out during 3-4 June 2013 and it was very sucessful with 35 international attendees.

Reviewer 23435

Score: 7.0

Comment: The verification with the Geysers injection and core data is a plus but again the boundary conditions are quite simple.

PI Response:
This verification case was compared to the TOUGH-FLAC simulation study. Thus, we had to use the same assumptions on bounday conditions made by the previous study.

Reviewer 23445

Score: 7.0

Comment: The results presented demonstrated that the model is running and obtaining reasonable solutions in a reasonable time period. The need for parallel computers was clearly demonstrated. I would have preferred to see more details of the model (especially the hybrid fracture model), and less emphasis on the various simulations that have been completed. However, that is my interest. I am sure that others wanted to see more of the chemical model, etc., so satisfying all in the audience is difficult. The presentation was limited in time. It might be possible in future peer reviews to have greater detail provided in written materials.

The only comparison of the model against field data was done to simulate the injection index for a site. This was not a very difficult task. The presenter indicated that an additional simulation against field data is planned in the near future. However, the time and money available (considering other tasks that are left) suggests that this may not be completed under this project.

The project has generated a number of conference papers. However, some peer reviewed journal articles about this work would seem warranted.

I was surprised that the presenter did not present any convergence studies of the code. This is standard in numerical modeling, but seems to be lacking in all of the geothermal presentations I observed at the peer review.

PI Response:
We have devoted signicant efforts to collecting feild data and communicating with geothermal communities for data sharing, modeling studies and collaboration. We will continue our effort even after the project is completed to work on field scale modeling studies.

One peer-reviewed journal paper has been recently published:
Hu, Litang, Philip H. Winterfeld, Perapon Fakcharoenphol, and Yu-Shu Wu. “A Novel Fully-coupled Flow and Geomechanics Model in Enhanced Geothermal Reservoirs.” Journal of Petroleum Science and Engineering 107 (July 2013): 1–11. doi:10.1016/j.petrol.2013.04.005.

Computatioinal effiency has been studied and we will report the results in future reports.

Reviewer 23509

Score: 5.0

Comment: The PI has largely accomplished the code development goal. However, this reviewer is left questioning whether the relatively large funding expenditure has produced something that offers a significant return on this investment. Completing the public domain aspect of the simulator is in question based upon statements made by the PI at the review and the value of a public domain THMC code is uncertain given the relatively small user community and recognizing that top researchers in this field already have access to simulators with equivalent or superior capabilities.

To date, the PI has only published in conference proceedings, a disappointing level of output given the funding level and after over three years of effort.

PI Response:
Thanks for the insightful comment. I would like to mention that the investiment of code development is worthwile, because the devlopemnt of a general reservoir simulator, such as a simpler black-oil simulator, is not cheap and it takes 10-people-10-year efforts on average. This is why there are few reservoir simulation software companies or reservoir simulators, survived or used currently in the industry around the world. Even in private sections, there are few fully coupled THMC general-purpose reservoir simulators available, there may have been from time to time reports or publications on THM or THMC modeling studies using simepl geometry, 1D or 2D models, or looselylinked simulators.

The following peer-reviewed journal paper was just published:

Hu, Litang, Philip H. Winterfeld, Perapon Fakcharoenphol, and Yu-Shu Wu. "A Novel Fully-coupled Flow and Geomechanics Model in Enhanced Geothermal Reservoirs." Journal of Petroleum Science and Engineering 107 (July 2013): 1–11. doi:10.1016/j.petrol.2013.04.005.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23412

Score: 8.0

Comment: The project management and coordination has been adequate

PI Response:
Thanks!

Reviewer 23435

Score: 4.0

Comment: A collaborator is mentioned but not identified. All of the publications are conference proceedings.

PI Response:
We have a collaboration with Mighty River Power in New Zealand. We have published one journal paper listed as follows:

Hu, Litang, Philip H. Winterfeld, Perapon Fakcharoenphol, and Yu-Shu Wu. "A Novel Fully-coupled Flow and Geomechanics Model in Enhanced Geothermal Reservoirs." Journal of Petroleum Science and Engineering 107 (July 2013): 1–11. doi:10.1016/j.petrol.2013.04.005.

Reviewer 23445

Score: 6.0

Comment: The project seems to be on track, and well run. It is difficult to determine the coordination between the various partners since the work of each was not identified. I was under the impression that the bulk of the work was conducted at the Colorado School of Mines.

PI Response:

Yes, the majority of the work has been completed at Colorado School of Mines, while LBNL contributed on part of parallel computing . Also, LBNL provided several validation simulation cases.

Reviewer 23509

Score: 7.0

Comment: Project seems to be on track in terms of schedule and funding. However, it is unclear why licensing agreements for TOUGH2 are being negotiated at this late stage in the project. One would have expected that to be done early on so the public domain release would not be in question after 3 years of work towards that goal.

PI Response:
Part of the reason is that TOUGH2 is itself considered as a public domain code, because of the funding for the code developemnt from DOE. LBNL is also a team member of the project and it has agreed with the work scope and the term for code 's public releasing in the beginning of the project.

STRENGTHS

Reviewer 23412

Comment: Commercial software participation

PI Response:
No.

Reviewer 23435

Comment: The PI seems to have handled all of the numerical and computational challenges associated with this work.

PI Response:
Thanks!

Reviewer 23445

Comment: It was impressive to see that this group put together the framework, and the detailed coding to couple a wide variety of physical models into a single code. The validation work demonstrated that the various modules worked together to obtain reasonable results.

PI Response:

Thanks!

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:
N/A

WEAKNESSES

Reviewer 23412

Comment: No apparent weaknesses

PI Response:
Thanks!

Reviewer 23435

Comment: The verifications are all simple compared to real world conditions.

PI Response:
We are aware of the problem and agree with the comment. However, the verification cases do make a brench mark or cross-check with theories or existing solutions to confirm the correctness of the code implementation.

Reviewer 23445

Comment: No convergence studies were presented.

PI Response:
Several convegence studies were carried out, has been reported in project reports, but not reported in details. We wll include convergence studes in future reports.

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:
N/A

IMPROVEMENTS

Reviewer 23412

Comment: What is the preferred software? The commercial or tough2

PI Response:
For EGS or geothermal reservoir simulation in general, we prefer TOUGH2-EGS. This is because to the best of knowledge there are no commercial simulators with the modeling capability of handling THM or THMC, where THM is very important processes for energy production from EGS reservoirs.

Reviewer 23435

Comment: Consider running field scale models with geologically reasonable conditions and properties.

PI Response:
We are limited with the avialable public or field data. We would like to carry out field scale modeling studies as long as we could find relavent data.

Reviewer 23445

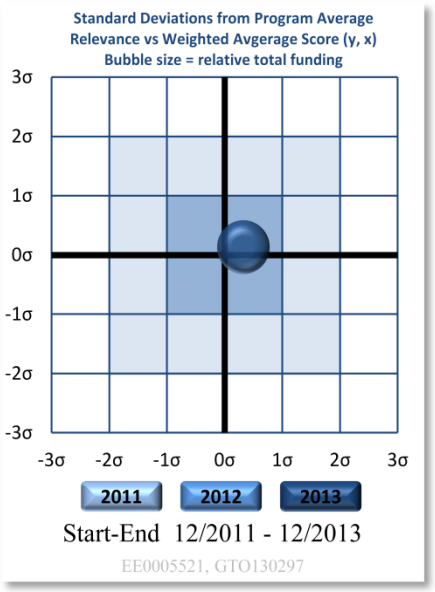
Comment: Very limited field data was used to validate the model. However, I realize that field data is very difficult to obtain. Nobody can measure fracture creation due to injection (etc.). This might be an area for future work. One might consider first examining what field data is used to validate oil/gas reservoir modeling codes. Maybe this data can be used directly for validation of the geothermal codes (oil fracking?), or maybe a review of the validation procedure used in the oil industry would suggest a route for obtaining validation data for the geothermal community.

PI Response:
Thanks for the very thoughtful comments and suggestions. We will look into the possibity to validate geomechnics module using oil/gas field data, because we are working geomechanics modeling with shale gas reservoirs.

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:
N/A



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0005521
Project: Innovative computational tools for reducing exploration risk through integration of water-rock interactions and magnetotelluric surveys
Principal Investigator: Moore, Joseph
Organization: University of Utah
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23425

Score: 7.0

Comment: The basic idea seems to be to improve the interpretability of magnetotelluric methods using geochemical means to estimate permeability fields in geothermal systems. The concept seems novel involving an empirical approach to understanding one characteristic of a geothermal regime (electrical resistivity) in terms of another (rock-water interactions as embodied in isotopic signatures). There is some confusion about what electrical methods tell us about a geothermal regime and a better understanding will enhance the value of the electrical method as an exploratory tool for siting EGS development.

PI Response:

Reviewer 23509

Score: 7.0

Comment: This project aims to advance remote sensing via magnetotellurics (MT) to improve prospecting for promising geothermal reservoir sources. Given that many MT geothermal exploration surveys have been completed worldwide but with marginal success, the project's goal is certainly laudable and if successful would directly impact geothermal exploration activities. The fluid sampling aims to connect fluid-rock geochemistry indicators to reservoir permeability hoping to establish a connection between the indicators and resistivity and hence a connection between MT survey data and reservoir permeability. These connections are tenuous and mismatched in scale thus making the fundamental hypothesis questionable.

PI Response:

Reviewer 24862

Score: 8.0

Comment: Relevant for estimating the conditions away from wellbores

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23425

Score: 7.0

Comment: The project involves two phases. The first establishes the methodology in two well-characterized geothermal systems. This requires performing a number of tasks including determining mineral distributions and isotopic compositions, relating downhole permeabilities to geochemical indicators; relating electrical results to permeabilities with the aid of a conceptual framework. The second phase involves extending procedures to a more complex geological environment than considered in Phase 1. This project has a lofty goal and I think the effort will be a big success if only Phase 1 can be achieved. Geothermal systems are inherently complex and performing the tasks of Phase 1 well to minimize uncertainty is far better than spreading the effort too thinly by including a Phase 2 involving a "geologically complex" environment. Because the PI is still trying to establish a methodology relating resistivities to geochemical indicators, it is far more important at this stage to achieve a proof of concept that his approach is appropriate.

PI Response:

Reviewer 23509

Score: 6.0

Comment: The PI did not adequately explain the distinguishing or innovative features being developed in this project versus the many previous efforts in geothermal MT surveys. Also, the PI is attempting to develop broad correlations from indicators or measurements that are arguably disconnected across the length scales of interest. For example, the oxygen isotope ratios being sampled can as the PI suggests be related to fluid flux. But, the depletions can also be correlated to other factors, such as the degree of disequilibrium between the fluids and rock. Small influxes of highly acidic or alkaline components can generate equivalent degrees of weathering thus breaking the connection between fluid flux and permeability. Fluid sampling is also a highly localized measurement whereas permeability or at least the permeability of interest is averaged over reservoir lengths. This is also a fundamental problem with the MT survey. Resistivity is fundamentally determined by the combined effects of the minerals making up the rock, voids, and fluids in pores/fractures. Hence, resistivity is largely uncorrelated to properties like permeability that are critically dependent on interconnections across a broad set of scales from pores, to fractures, to interconnected fracture systems. So, while the overall objective is laudable, and geologic examples where the correlations seem to work important to identify, it will be equally important to identify other geologic settings where the correlations are expected to break down.

PI Response:

Reviewer 24862

Score: 8.0

Comment: Combination of Magnetotellurics (MT) and mineralogy to get water-rock ratio is a good approach.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23425

Score: 8.0

Comment: Quality seems good and from the presentation, the team seems to be gathering the electrical, physical (permeability) and chemical data need to develop the methodology they need.

PI Response:

Reviewer 23509

Score: 7.0

Comment: Project has only been going for a little over a year but reasonable progress seems to have been made. Only one conference proceeding publication has been produced to date, which is a bit disappointing for a university led project.

PI Response:

Reviewer 24862

Score: 8.0

Comment: Considerable amount of work has been done, method is validated with Coso and Lightening Dock data.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23425

Score: 8.0

Comment: Project management seems highly competent and the management approach with go/no go decision points appears to be followed. Coordination with industry seems good. However, I would like to see the work be more hypothesis oriented. This might possibly be done by working with geothermal models that have reactive transport capability (e.g., TOUGH-REACT).

PI Response:

Reviewer 23509

Score: 8.0

Comment: Project seems to be managed well with the PI obtaining all the planned data needed to complete the project objectives. Project budget and schedule are mostly on track.

PI Response:

Reviewer 24862

Score: 8.0

Comment: Good coordination with industry to obtain data and apply the method.

PI Response:

STRENGTHS

Reviewer 23425

Comment: Breakthroughs using novel ideas such as drive this effort are needed to make EGS a practical possibility. The PI has a good understanding of what needs to be done to make progress and seems to be working with a strong team of researchers. He seems to have access to needed data which is no small matter in the geothermal world.

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 24862

Comment: Integration of magnetotellurics (MT) and mineralogy to apply to real field situations

PI Response:

WEAKNESSES

Reviewer 23425

Comment: This reviewer's main concern is the lack of a dependable model relating permeability to rock-water isotopic ratios. The PI is attempting to establish such a model or interpretive framework relating permeability and rock-water chemistry and one gets the feeling that the project is casting about for a methodology relating permeability to water chemistry by collecting a lot of data until one is found. (Maybe more discussion of Taylor's paper would have helped.) Such empirical results might be geology dependent and difficult to generalize which is necessary if the results are to be useful for EGS. There are also concerns about the water and matrix material not being in isotopic equilibrium. Will flowing water in a permeable zone be characterized by the same chemistry as water that is not moving within an identical zone having identical permeability?

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 24862

Comment: A clear distinction between porosity and permeability should be discussed

PI Response:

IMPROVEMENTS

Reviewer 23425

Comment: It would help the reviewer at least, if a preliminary framework was developed even if it is only hypothetical and being tested by observations. It would be helpful if the relevant assumptions made in developing this framework were expressed. I would seriously consider re-scoping by dropping consideration of the "complex geology" of Phase 2 and focusing the extra support and research time on making sure that a proof of concept can be achieved.

PI Response:

Reviewer 23509

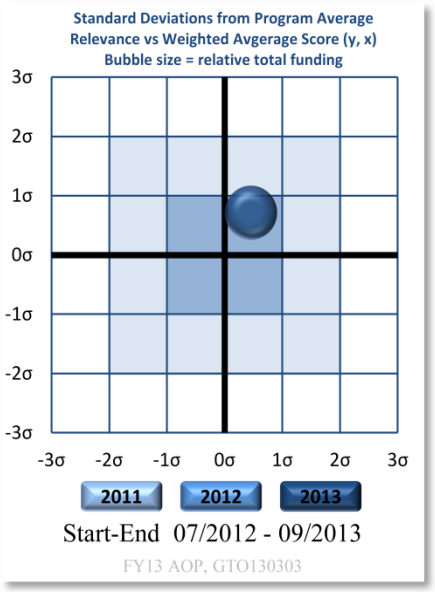
Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 24862

Comment: Distinguish between porosity and permeability. Can other isotopes be used? A discussion of resolution should be added

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: FY13 AOP
Project: Stimulation at Desert Peak and Brady's reservoirs: modeling with the coupled THM code FEHM
Principal Investigator: Kelkar, Sharad
Organization: Los Alamos National Laboratory
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23453

Score: 8.0

Comment: This research project is focused on development of numerical models of deformation associated with stimulation of geothermal reservoirs. The investigators adapted a modified version of a coupled finite element code developed at Los Alamos National Lab (LANL). The project does address several technical challenges and barriers - in particular, insufficient modeling capabilities to predict the behavior of coupled hydro-chemical and thermo-mechanical systems. The developed model is applied to interpret data from the Brady's geothermal filed.

PI Response:
Thank you for the comment.

Reviewer 23435

Score: 8.0

Comment: The continued development of another THM code may not be as important as obtaining the core and field scale data with which to validate such a code. Nonetheless, the project is coupled with field data in a systematic manner that makes it potentially useful and worth continuing. The PI has good grasp of the difference between modeling and validation (do the models reflect reality).

PI Response:
Thank you for the comment. Indeed, obtaining more data is invaluable. Data by itself is valuable only for the circumstances under which is it acquired. To make it more generally applicable requires the use of models. And as the reviwer has noted, this project combines the two aspects.

Reviewer 23479

Score: 9.0

Comment: Preexisting models were not adequate to simulate EGS experiments and operations, mainly because they lacked the ability to simulate shear and tensile failure and consequent permeability changes (which are the essential core of the EGS concept).
PI Response:
Thank you for the comment.

Reviewer 24878

Score: 8.0

Comment: This project is relevant to optimize fracking and especially here the effect of fracture reactivation by shear. It should allow a better evaluation of existing codes for EGS. The goal is to model shear failure and connection to microsismicity and permeability enhancement., from meter to reservoir scales, from hours to tens of years. Chemistry and multiphase flow could be done (that would make the work more unique) but nothing has been done so far in this direction as opposed to similar projects.

PI Response:
Thank you for the comment. Incorporating chemical effects would indeed be an important next step for this project, especially for applications over longer time scales. In the present project, this was outside the scope of work.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23453

Score: 7.0

Comment: The developed method is based on a continuum approach to take into account damage that results from the reservoir stimulation. Specifically, the method uses the observed or inferred distribution of cracks and principal stresses in the control volume, and computes normal and shear stresses on the given crack population. These stresses are compared to the Mohr-Coulomb failure criterion. If the criterion is met, the target crack is assumed to slip by an amount, dictated by the difference between static and kinetic friction. The resulting slip amplitude is then used to evaluate changes in the effective permeability using existing laboratory data. Computed changes in fluid permeability are then used to update the fluid flow and temperature in the reservoir.

PI Response:

Reviewer 23435

Score: 5.0

Comment: The attempt to use field data is a great improvement over other efforts. Unfortunately, these data seem to be the basis of simplified analytical models which will limit broad applicability beyond the specific field calibration. This does not seem to be a significant advance beyond commercially available codes (such as COSMOL) which have modeled stress, pressure distributions and earthquake co-location reasonably well using field injection and micro seismicity data.

There was no discussion of the initial conditions and physical properties used in the model so it is impossible to tell what the model sensitivities might be and how useful field data acquisition might be improved. How is this different from a "type curve" approach? The parameters seem reasonably well derived but it is important to consider the spatial distribution of these parameters which is not done here. The modeling challenges (slide 7) was extremely useful and concise.

PI Response:
he reviewer is correct in noting the usefulness of tye type-curve and analytical approaches. The project work included an analytical model as well as a numerical model based on the code FEHM. Analytical models are valuable for verifying the numerical results, as well as for obtaining conceptual insights. And 'type curve' approaches based on semi-analytical solutions in simplified systems have proved to be of great value before the advent of powerful computers.

However, more complex 3D geometries with heterogeneous, anisotropic properties require the use of numerical models. Such problems are beyond the abilities of the 'type curve' approach. The model presented here is capable of modeling fluid flow in fracture dominated, deformable media with heterogeneous, anisotropic properties under non-isothermal conditions. The fluid flow and heat transfer equations are here iteratively coupled with the deformation equations using a Newton-Raphson scheme. The code is stable, capable of handling permeability changes over orders of magnitude. The reviewer will recall that such general numerical codes are verified against analytical solutions and then used for developing models of increasing complexity for validation against field data. Given the nature of the field data, i.e. wellhead pressures, flow rates, and some temperature logs, and project scope limitations, we made the model only as complicated as necessary. Future models will include the study of effects of geometry and inhomogeneities. This is a significant demonstration of the state of the art capability in modeling coupled THM phenomenon in geomedia. COMSOL is indeed a useful code with powerful capabilites in the area of material deformation, but without performing a detailed code comparison, we can state that we are not aware of similar field-validation work in a system with permeability changing by over an order of magnitude as a function of stress, published using COMSOL.

Given the limitations on the length of the presentation, we could not provide all the details of the initial conditions and properties used, but refer to Kelkar et al (2012), Lewis et al (2013), and Dempsey et al (2013).

Reviewer 23479

Score: 9.0

Comment: The Desert Peak results are a fairly convincing demonstration of model capability.

PI Response:

Reviewer 24878

Score: 6.0

Comment: This project builds heavily on the finite element and heat modeling codes developed at Los Alamos National Laboratory including fluid and heat flow and mechanical simulations. I am not sure I saw some novelty with respect to what was existing before. The model seems a bit weak on the type of rheological behavior at high temperatures. The code should predict the extension of the damage zone and the permeability enhancement (by a max factor 15) based on experimental data on granite. I wonder if the calibration through lab data is a good idea because of some up-scaling issues

with cracks distribution and permeability. All the code is not expected to account for the chemistry which is a big issue in these very reactive environments as sealing and healing of cracks/fractures is an important topic.

PI Response:
Novel aspects of the work include: a) the model includes interatively coupled solution of heat transfer-fluid flow equations with deformation equations including thermal stresses, b) development of a stable, mass conserving scheme to couple heat-mass equations with stresses calculated from solid deformation equations, c) shear failure using Mohr-Coulomb law which depends on calculated stresses rather than displacements, d) a permeability-damage relationship for fractures failed in shear, e) validation against field data.
Rheological considerations: The code includes the thermodynamic behavior of water at temperatures of interest including density and viscosity variations. At the temperatures of interest, the granitic and sedimentary rock formations are generally taken to remain elastic unless the stresses reach failure limit.
Recognizing the upscaling, we used lab data not as a calibration but as a guide for forming the conceptual model of stress-permeability relationship.

Although the code can handle chemically reactive flow, it was not taken into account in the present model because of the relatively short duration (less than 100 days) of the field test.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23453

Score: 8.0

Comment: The project team has made a good progress on the code development, including new features such as permeability enhancement upon shear failure on pre-existing cracks. The investigators tested the models using a geologically reasonable range of parameters. Model results compared favorably with available pumping data from Desert Peak.
The investigator productivity is well above average. Given a relatively modest budget, the value of the accomplishments compared to the costs is high. The project appears to be on track, and all major targets specified in the work plan have been met. Main findings from the project are disseminated via presentations at the major scientific meetings, and publications in the peer-reviewed literature.

PI Response:
Thank you for the comment

Reviewer 23435

Score: 6.0

Comment: In spite of access to significant amounts of field data, there does not seem to an effort maximize these data. There was too much discussion and defense of the code as opposed to validating the results with field data. It is a bit strange to invest a lot of effort in developing and verifying a computer code when the simplified analytical solution seems to produce equally good results with a lot less effort. Slide 12 shows some potentially important results but it is not clear how the code fits in. It is good that an actual stress geometry is considered but it is not clear exactly how this improved

code effectiveness. Slide 14 a good attempt at validation with borehole measurements but the same results could be obtained with type curve analysis nonetheless slide 15 seems to show promise.

PI Response:
The reviewer is correct in noting the usefulness of analytical approaches. The project work included an analytical model as well as a numerical model based on the code FEHM. Analytical models are valuable for verifying the numerical results, as well as for obtaining conceptual insights. However, more complex 3D geometries with heterogeneous, anisotropic properties require the use of numerical models. Such problems are beyond the abilities of the 'type curve' approach. While 'type curve' approaches based on semi-analytical solutions in simplified systems have proved to be of great value before the advent of powerful computers, complex problems are beyond the abilities of the 'type curve' approach. The model presented here is capable of modeling fluid flow in fracture dominated, deformable, with heterogeneous, anisotropic media under on-isothermal conditions. Perhaps the reviewer will recall that the more general numerical codes are justified against theoretical arguments and equations, verified against analytical solutions and then models of increasing complexity are developed for validation against field data. This is the approach we have followed in this project.

Reviewer 23479

Score: 9.0

Comment: The research team has done an admirable job of enhancing a longstanding “THM(C)” code, Finite Element Heat and Mass Transfer Code (FEHM), to include many new capabilities, most importantly the ability to model deformation-induced permeability changes.

The enhanced model was able to match the stimulation history at the Desert Peak EGS site, and the experience gained at Desert Peak is being used to plan EGS efforts at nearby Bradys Hot Spring.

PI Response:
Thank you for the comment.

Reviewer 24878

Score: 8.0

Comment: Good research. Some papers submitted in the peer-reviewed literature.

PI Response:
Thank you for the comment.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23453

Score: 9.0

Comment: The PI supervises two post-doctoral associates, and collaborates with partners from the USGS and the industry. These activities appear to be well organized and coordinated. The work plan is feasible.

PI Response:
Thank you for the comment.

Reviewer 23435

Score: 9.0

Comment: There obviously extensive and productive involvement with the operators (within budget and on time, a DOE lab first!). There could be more effective use of MEQ data? but I am not sure such data exist. Slide 17 shows that the PI has the exactly right idea for future work and increasing code utility and validation efforts.

PI Response:
Thank you for the comment.

Reviewer 23479

Score: 8.0

Comment: Please see comments elsewhere.

PI Response:

Reviewer 24878

Score: 8.0

Comment: I like the potential application to Desert Peak and Brady with ORMAT.

PI Response:
Thank you for the comment.

STRENGTHS

Reviewer 23453

Comment: The developed model uses physically-based criteria for computing permeability enhancement due to shear failure on a network of through-going fractures. Therefore it should be applicable to a variety of geothermal environments, provided the model is validated and calibrated on the selected study areas.

The developed model does a reasonable job reproducing the observed flow rates from the Brady and Desert Peak wells.

PI Response:
Thank you for the comment.

Reviewer 23435

Comment: Operator cooperation and use of field data are real strengths.

PI Response:
Thank you for the comment.

Reviewer 23479

Comment: In addition to comments elsewhere -- An interesting side-product of this study – not mentioned in the material provided – was Kayla Lewis's recent and excellent Eos, Transactions, American Geophysical Union essay on "Forgotten Merits of the Analytic Viewpoint".

PI Response:
Thank you for the comment. Indeed it was a noteworthy contribution.

Reviewer 24878

Comment: Good project that builds heavily on the expertise at Los Alamos National Laboratory regarding thermohydromechanical modeling (CO_2 storage, nuclear wastes, etc).

PI Response:
Thank you for the comment.

WEAKNESSES

Reviewer 23453

Comment: Potential weaknesses of the approach include: 1) uncertainties in the initial distribution of cracks and/or the initial stress field. In addition, the respective measurements may not be readily available in most cases, so that some assumptions will be needed regarding the initial conditions. Such assumptions will affect the results in a significant way. 2) The assumed low value of kinetic friction (0.4) implies that the suitably oriented cracks fail seismically. This assumption has not been tested against the data.

It is not clear how important the contribution of shear-enhanced permeability to opening and closure of tensile cracks.

PI Response:
Comments regarding the limitations of the data are well-taken.
The present work focuses on shear failure with cracks that have significant contact areas where the 'cubic law' cant be used. Future work will include models of hydraulic fracturing with fractures opening in tension.

Reviewer 23435

Comment: The PI needs to do a better job showing exactly what his code is predicting and extending it to 3-d far field data utilization, such as MEQs.

PI Response:
There were no MEQ's recorded during the stimulation treatment under consideration. Fuure work will focus on larger treatments conducted later that did generate significant MEQ atcivity. For that case, models will be developed including the far field.

Reviewer 23479

Comment: Apparent weaknesses of the code in its current state include (I think) a necessity to use two grids, one for the TH(C) (thermo-hydro-chemical) part of the problem and another for the M (magneto)part, because the former uses a CV approach, the latter a FE approach. Unless the gridding is fully automated, this must complicate grid design and (particularly) grid changes. It may also encourage the use of geometrically simpler (rectilinear?) grids, and make it harder to replicate the geometric complexity of some real systems. Along similar lines – the coupling with "M" is serial, rather than simultaneous, and I wonder how much (if at all) this affects solutions.

The "C" capability of the code was stated, but only in very general terms, and I suspect that the reactive-transport capability is much less than that of the competing TOUGHREACT code. If so, this is not a major criticism; I think that, given the complexity of these systems (and models), it is important to have more than one model under development (see e.g. the climate-modeling community).

PI Response:
The work presented here uses only one grid; however, the TH part uses the Control Volumes formed by the bisecting faces surrounding a given node and its neighbours, while the Mechanical part used the hexahedral finite elements formed by the same set of nodes.No grid change is required in this approach. This approach has the limitation of logically rectilinear grids (but not necessarily orthogonal; i.e. more general than finite difference grids), however, offers the

advantage of conserving mass and using the 'superconvergence' properties for calculating stresses using Finite Elements. The coupling between TH amd M, while not fully simultaneaous, is not serial, but iterative, done using a Newton-Raphson scheme that checks for convergence. This shceme offers the advantage of lower memory requirements, lower computational efforts, and faster solver performance (lower degrees of freedom matrices), while offering good stability, and convergence.
The chemical capability of the code was not used in the present work. Although the code can handle chemically reactive flow, it was not taken into account in the present model because the work scope was limited to a field test of relatively short duration (less than 100 days).

Reviewer 24878

Comment: The approach does not account for the chemistry, which is important to model the healing and sealing of cracks and fractures over time.

PI Response:
Although the code can handle chemically reactive flow, it was not taken into account in the present model because the work scope was limited to a field test of relatively short duration (less than 100 days). In future work we hope to cover longer time spans (10's of years) the processes of healing and sealing of cracks are likely to be important and will be taken into account.

IMPROVEMENTS

Reviewer 23453

Comment: It would be of interest to compare the observed cumulative seismic moment of micro-earthquakes in the study areas to the moment due to slip on cracks in the model (crack area times slip times shear modulus). In case of an agreement, this could be used as a predictive tool for induced seismicity (a potential major strength). If there is a disagreement, it would imply that most of slip is occurring aseismically. In the latter case, the assumption of a low kinetic coefficient of friction would be likely invalid, and alternative possibilities would be warranted.

PI Response:
Point well-taken. We agree and plan to include models of induced seismicity in future work. There were no MEQ's recorded during the stimulation treatment under consideration. Future work in FY14 will focus on larger treatments conducted later that did generate significant MEQ atcivity. For that case, models will be developed including the far field.

Reviewer 23435

Comment: Prepare the code for incorporation of far field data and properties from geophysical, geological and MEQ characterization results.

PI Response:
Point well taken. We hope to do some of this work in FY14.

Reviewer 23479

Comment: Although the Desert Peak results are a fairly convincing demonstration of capability, I was left wondering – perhaps naively – about a few points. For instance,

(1) the conceptual model assumes that permeability enhancement is due to shear failure; I would like to see clear evidence that this is the case, because tensional failure also seems likely in the context of (relatively) cold-water injection.

(2) I wonder about the symmetry (circular) of the simulated permeability ellipses. Doesn't Mohr-Coulomb failure imply some preferred failure direction? And if so, shouldn't these ellipses also have some preferred orientation?

An interesting extension of this (and similar) studies would be to use the simulations themselves to generate synthetic earthquake sequences, and compare them to the actual earthquake (EQ) hypocenters mapped during stimulation. That is – although EQs are not simulated, they are invoked to explain the simulated permeability changes. The simulated permeability changes themselves could be used to generate synthetic EQs sequences using e.g. a shear-dilation model. The comparison of actual versus synthetic sequences might be revealing, and serve as a partial test of some key assumptions. It might also be useful to consider actual versus synthetic EQs iteratively as a calibration step.

On a more operational note: I think that it is very important that the extended FEHM model be documented sufficiently well that it can be used by the broader community. FEHM has a pretty good history of use beyond LANL – consider for instance past FEHM-based research by Barbara Dutrow (LSU) and Mark Person (NMT). But I don't know of a formal documentation effort since the late 1990s. This work is mainly tool-development, and documentation is a key to any sustained value. In response to a question about documentation, the PI indicated good intentions but a lack of dedicated funding.

And still on an operational note – the broader utility of the model will also be enhanced by continued attention to the actual needs of field operators. The ongoing collaborations at Desert Peak and Brady position the PIs to incorporate operator input effectively.

PI Response:

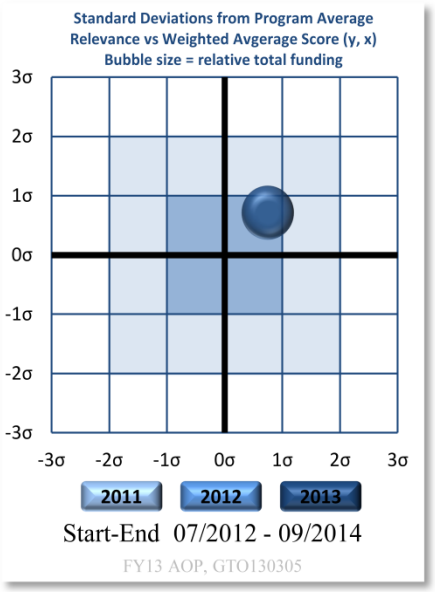
1) We agree with the comment regarding tensional failure. Although not used in the present work, the code has the capability of enhancing permeability using a relationship different from that designed for the shear failure. We plan to take into account the effects of tensile opening of cracks in the future work when addresssing the more aggressive stimulation treatments.
2) the symmetry results form the relatively wide distribution of the pre-existing fractures reported in the core data.
3) We agree with the suggestions regarding the extension to EQ generation. We hope to do this in future.
4)We are carring on the work of documenting, albeit at a slow pace.
5) Thank you for the comment regarding continued attention to the needs of the operators.

Reviewer 24878

Comment: Take into account the chemistry. Another extension of the modeling could be to forward model some of the geophysical responses starting with seismic (acoustic emission) and possibly tracer modeling. This would be a real novelty and very useful to backup the response in field conditions.

PI Response:

Agreeded, thank you for the suggestions. We hope to do some of this work in FY14.



Review: 2013 Geothermal Technologies Office Peer Review
ID: FY13 AOP
Project: Code Comparison Study
Principal Investigator: Scheibe, Tim
Organization: Pacific Northwest National Laboratory
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23453

Score: 7.0

Comment: The proposed testing and comparison of numerical codes will result in higher confidence in predictions of numerical models, and ultimately help improve the quality of EGS reservoir engineering and management, and reduce the costs of geothermal exploration. The project is addressing several known gaps and barriers, in particular: 1) uncertainties in natural environment conditions at depth, 2) inherent complexities and heterogeneities across many orders of magnitude of length scale; 3) limited access to and difficulty of characterizing the subsurface environment; 4) diverse assumptions, process descriptions and numerical solution techniques are embodied in a wide range of highly complex and computationally intensive simulation codes.

PI Response:

Reviewer 23479

Score: 9.0

Comment: This project is to assess the capabilities of diverse numerical simulation codes for THMC modeling of EGS systems. I was involved in International Partnership for Geothermal Technology (IGTP) modeling discussions at early stages and am very pleased to see substantial progress being made.

As other communities have learned, meaningful model-based science requires systematic comparison, calibration, and benchmarking of independently developed models – the climate community being a highly visible example. This is particularly the case when models start to address complex problems where simulation codes may use different methods and/or the "true" solution is not known. EGS models definitely fall into this category, because (1) they describe complex, coupled, and (in some instances) imperfectly understood processes and (2) as in all subsurface problems, there is a high level of parameter uncertainty.

PI Response:

Reviewer 24878

Score: 7.0

Comment: This project concerns codes evaluations and comparisons for geothermal systems (especially EGS) and benchmarking. This is an important task to understand the limit of existing codes and how we should improve them.

PI Response:

Reviewer 23568

Score: 10.0

Comment: The relevance is extremely high given the necessity of good reservoir models and that no code comparison exercise has been carried out since 1981.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23453

Score: 8.0

Comment: The code validation activity begins with building a community of code developers. Toward this goal, the PI has convened a workshop and compiled a set of benchmarks of various degrees of complexity. To facilitate exchange between the participants, and comparisons between model outputs, the PI has developed a wiki-based web interface Velo. A second workshop to review progress of participating teams and compare initial results is planned in the next several months.

PI Response:

Reviewer 23479

Score: 10.0

Comment: The embryonic geothermal code-comparison is well-designed and has already benefited from a good deal of community discussion and consensus-building. It entails three levels of problems designated as (1) benchmark (known solution); (2) test cases (solutions reasonably constrained); and (3) challenge (realistic EGS case with “unknown” solution). The benchmark problems are based on an IGTP list.

PI Response:

Reviewer 24878

Score: 7.0

Comment: In this project, a Wiki-web based platform is used to exchanging information regarding the different codes. The project include some collaboration with IPGT reservoir modeling working group and Workshops have been and will be generated for stimulating discussions on this topic. Stump was also used but not in the comparisons . The comparisons will include benchmark, test cases, and challenges problem regarding THMC (thermodynamics, hydrology, mechanics, and chemistry). A starting Workshop was organized at Stanford in February 2013 to define these benchmark, test cases, and challenges problem. This is an important task but I did see super exciting research subjects during the presentation.

PI Response:

Reviewer 23568

Score: 7.0

Comment: A lot of thought has been put into the design of the effort. These include an interactive wiki site and a survey of code comparisons in other earth science disciplines. Participation in the IPGT can save a lot of reinventing the wheel. The offering of a well-planned workshop at the Stanford Workshop showed a sincere effort for community involvement. Perhaps more thought can be given to combining this effort with related efforts in carbon sequestration. Fundamentally, THMC is involved in several areas of geoscience research and need to be seen that way without getting biased too soon in the particulars of geothermal applications. Also, the role of commercial codes must necessarily be integrated into the project. In oil and gas, the dominant code is commercial and if the geothermal industry achieves growth, that might be the case, too.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23453

Score: 7.0

Comment: The web interface for model comparison has been developed and is on-line. Demonstration was given to the International Partnership for Geothermal Technology (IPGT) working group on Reservoir Modeling in September of 2012. Kickoff workshop was conducted on February 14, 2013 at Stanford University, following Stanford's annual Geothermal Workshop. The code validation workshop was well attended (~40 participants). The Velo web portal is being further developed based on feedback received from GTO program office and workshop participants. There are more than 20 registered users of the Velo system.

PI Response:

Reviewer 23479

Score: 9.0

Comment: Test cases were agreed upon during a community workshop following the 2013 Stanford Geothermal Workshop, and at least one of them will be based on lab experiments also sponsored by this program (the neutron imaging at Oak Ridge National Lab (ORNL)). The challenge case is still being framed, but will be a "fully prescribed" problem based on results of the test cases and generalized EGS experience. I wholeheartedly agree with the decision to make complete specification of the test problem, because the intent here is to assess the codes themselves. Actually arriving at level (3) – the challenge problem(s) – will be an important success metric for the overall effort.

PI Response:

Reviewer 24878

Score: 8.0

Comment: Very good accounting for the fact that the project has started in July 2012. The project is on track.

PI Response:

Reviewer 23568

Score: 7.0

Comment: The project is only 6 months old. The start has been made in holding one workshop and establishing titles of test and challenge problems. Much needs to be done yet in getting a core group of coders embedded into the process.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23453

Score: 9.0

Comment: This project requires integrated efforts among the PIs, Pacific Northwest National Laboratory (PNNL), DOE-GTO, and the international community. The project team seems to be successful in bringing together and fostering the modeling community in this area of research. Chosen activities (community workshops and web-facilitated discussions and code comparisons) are optimal for the declared set of goals.

PI Response:

Reviewer 23479

Score: 9.0

Comment: The use of the Velo system (a web-based wiki platform) to share information should promote ongoing dialog and contribute to the sustained value of this effort.

PI Response:

Reviewer 24878

Score: 9.0

Comment: A lot of things have been done in a short period of time but I did not see yet a lot of results in terms of code inter-comparisons.

PI Response:

Reviewer 23568

Score: 9.0

Comment: The PI is well integrated with the international community, other national laboratories, and the GTO office.

PI Response:

STRENGTHS

Reviewer 23453

Comment: Getting various software developers together and engaging them in code validation activities is a major achievement. The outcome will be clearly beneficial to the entire community. A decision to use well-defined "synthetic" benchmarks (rather than to fit actual observations) is a good one.

PI Response:

Reviewer 23479

Comment: Please see comments elsewhere.

PI Response:

Reviewer 24878

Comment: This is a very good project in order to understand the difference between the numerical codes for the so-called "challenges problems".

PI Response:

Reviewer 23568

Comment: There is a real need not only to do coupled THMC code comparison within the geothermal community but also other earth science application communities.

PI Response:

WEAKNESSES

Reviewer 23453

Comment: It wasn't clear how many codes, with what capabilities are actually involved in the comparison exercise. Participation of users and/or developers of commercial codes should be more strongly encouraged. There is no well-defined strategy of how to deal with model predictions that differ between the codes, especially in complicated cases (that are of most interest from the practical standpoint).

PI Response:
The specific teams and codes were identified in discussions with program managers at the peer review meeting and have subsequently been invited to participate. We acknowledge that addressing different model predictions will be a challenge, particularly when there is no well-defined "right answer." This is one of the reasons why we have chosen an intercomparison effort rather than a "competition"; our intent is that the community of participants will work together to identify reasons for differences and define additional test problems based on those hypotheses.

Reviewer 23479

Comment: Please see comments elsewhere.

PI Response:

Reviewer 24878

Comment: The project could have been more focused on modeling field data. I personally think this would have made the project more exciting.

PI Response:
We hope to include some field data in the final challenge problem.

Reviewer 23568

Comment: The project has just gotten started so it is too early to say there is a weakness.

PI Response:

IMPROVEMENTS

Reviewer 23453

Comment: Current web site (Velo) is unnecessarily restrictive. Most of the content should be accessible to the world, without the need to request an account. This would facilitate dissemination of knowledge and results. This project would benefit from borrowing ideas and concepts from the highly successful SCEC/USGS Spontaneous Rupture Code Verification Project, http://scecdata.usc.edu/cvws/

PI Response:
We will review the suggested website. We intend to provide access to any party with valid interest, but because the wiki system is interactive and editable do not want potentially malicious users to have access. Ultimately the results will be published openly.

Reviewer 23479

Comment: As the PIs indicate, there has not been a geothermal code-comparison since the DOE-sponsored Stanford Workshop effort in 1981, which tested the first generation of multiphase codes. However, there are many other recent and ongoing code-comparison efforts. The PIs should (and I am sure will) take full advantage of lessons learned and best practices from those other efforts. In this light, I applaud the idea of a wide-ranging "code comparison" session at the American Geophysical Union (AGU) that would include representatives from e.g. the climate-model community. The apparently very successful "Dynamic Rupture Code Validation" group should also be represented, if possible. The "dynamic rupture" group held a large workshop in Menlo Park on March 15 2013, hosted by Ruth Harris (USGS). That community-based effort seems to be successful and more-or-less self-sustaining, and there is obvious overlap with EGS concerns re rock mechanics.

I like the test cases; the PIs might also consider adapting the quasi(?)-analytical solution for thermoelastically induced permeability change presented by Germanovich and Lowell (Science, 1992).

Ongoing issues for this project will include:

(1) How to encourage participation of key "unpaid" participants

(2) The role of commercial (and typically closed-source) codes

(3) How to best use and assess potentially disparate results from the challenge problem(s).

I agree with the PIs that commercial-code vendors and users should be encouraged to participate, but that it may be harder to evaluate and define the causes of potential differences among closed-source codes.

A final consideration is to what extent these test problems, and the codes themselves, serve the needs of industry. This is beyond the scope of the code comparison per se, but industry input is potentially very useful and should be encouraged.

PI Response:
We agree with the reviewer's suggestions and are pursuing actions to address them. For example, we have worked with the program managers to identify funding for invited participants.

Reviewer 24878

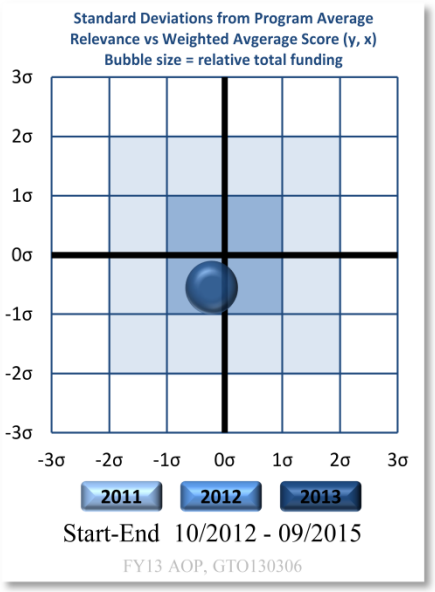
Comment: Code inter-comparison is not model inter-comparison (but why not!). Having the developers of the non-proprietary codes participating would be a good idea. Using tests case based on experiments would be also a good idea. Participation of the industry could be interesting in order to know what the industry would like to do with these codes at the end of the day.

PI Response:
We agree that model comparison and use of field data is of interest. As a first step we are performing code comparisons, but hope in the final challenge problem to include field data and model conceptualization in the intercomparison process.

Reviewer 23568

Comment: Do not limit the project to geothermal applications but connect all across the geoscience energy fields.

PI Response:
The focus of this project is on EGS in keeping with the mission of the funding agency. However, many of the results will be relevant to other geoscience energy applications.



Review: 2013 Geothermal Technologies Office Peer Review
ID: FY13 AOP
Project: Reservoir-Stimulation Optimization with Operational Monitoring for Creation of Enhanced Geothermal Systems
Principal Investigator: Carroll, Kenneth
Organization: Pacific Northwest National Laboratory
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23453

Score: 8.0

Comment: The proposed development of reactive polymers is potentially relevant for EGS, as they may improve current methods of reservoir stimulation and creation of new fracture surfaces. The proposal directly addresses Goal 4 of the GTO program announcement, namely: develop the ability to create EGS with the technical characteristics required for economic viability.

PI Response:

Reviewer 23435

Score: 2.0

Comment: The use of geophysics to monitor effects is potentially useful but is unclear if the assumptions regarding scale, viscosity and diffusion radii will result in field scale geophysical signals. The bench scale controlled conditions represent idealized input and output.

PI Response:

Reviewer 24878

Score: 8.0

Comment: The project is relevant in addressing issues related to the increase of permeability during fracturing (increase productivity by increasing permeability). The idea is also to minimize the amount of water for fracking. The PI said the release of chemicals through polymer dissolution are non-toxic, but this needs to be confirmed. If would be good to double check that the surfactants and polymers are eco-friendly.

PI Response:

Reviewer 23568

Score: 7.0

Comment: Developing a fluid that expands into reservoir fractures from the wellbore could lead to significant near-field permeability enhancement. The idea is quite novel and risky given many potential barriers to success. The project is also only 6 months old so future reviews will be able to provide more feedback.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23453

Score: 7.0

Comment: The investigator team is developing a reactive polymeric fluid that is capable of substantial volumetric expansion at the pressure and temperature conditions corresponding to those at the geothermal production depths. An important aspect of this development is that the volume change is reversible, and can be controlled in the process of injection. The PIs are using carbon dioxide as a trigger for gel formation and volume expansion, and variable pH of the injection fluid to dissolve the gel. The achieved results so far are encouraging, with demonstrated volume expansion as much as 100% at in situ pressure and temperature conditions. The PIs also suggest that the surfactant can be used (injected and recovered) multiple times, and that the cost of the material can be relatively models (tens of $k for a typical borehole stimulation experiment).

PI Response:

Reviewer 23435

Score: 4.0

Comment: A diverse and competent team has assembled a complex but systematic approach for evaluating fluid and fracture properties. The hardware design and implementation seems adequate for the proposed experiments at the bench scale. It is not clear to me that the core characterization work is significantly different from similar work done at Stanford. Nonetheless, the x-ray micro tomography images are impressive. Real time kinetics analysis is valuable but only under pure water and carbon dioxide conditions. Reactive polymer behavior is potentially useful but is only likely to be important only near the well bore. Would viscosity increase plug fractures created with expansion shearing? It is likely that propants are needed. How would such injection be permitted? How would pressure be maintained in borehole (typically open fractured intervals) to keep expansion from flowing back up the well?

PI Response:

Reviewer 24878

Score: 9.0

Comment: Excellent. Build heavily on the full range of expertise available at Pacific Northwest National Lab (PNNL) (including the measurements in the change in acoustic impedance to look at fracture developments and X-ray microtomography). For instance, the ability to do measurements in pressure and temperature and to look directly at the fractures. The overall idea to manipulate fluid for fracturing is very good.

PI Response:

Reviewer 23568

Score: 7.0

Comment: The approach is laboratory based. The polymer dissolved in water is first tested at reservoir conditions to determine the volume expansion. It will then be injected into a core sample again at reservoir conditions to determine its effect on creating fractures. The core will be imaged using ultrasonics and X-Ray Microtomography (XMT).

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23453

Score: 8.0

Comment: The investigators made a good progress on the laboratory testing (including equipment development and sample characterization). X-ray Micro Tomography (XMT) has been shown to work very effectively. Real-time monitoring of fluid chemistry using nuclear magnetic resonance (NMR) is demonstrated as well, but at pressures and temperatures that are factor of two smaller than the target (30 MPa, 300 deg. C). The reactive polymer shows a good potential regarding the volume increase (up to 100% volume increase, compared to the milestone goal of 10%). The observed rheology of the polymer was found to be strongly non-linear, with significant viscosity increases at low strain rates. The project expenses are commensurate with the work plan.

PI Response:

Reviewer 23435

Score: 4.0

Comment: Successful bench scale work with little consideration of real geothermal fracture flow systematics.

PI Response:

Reviewer 24878

Score: 10.0

Comment: A lot of accomplished tasks. This project is fully on track.

PI Response:

Reviewer 23568

Score: 6.0

Comment: As the project is only 6 months old, the accomplishments are modest. The biggest success is having a polymer expand 100%. Also the acoustic and X-Ray Microtomography (XMT) imaging systems have been set up.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23453

Score: 6.0

Comment: This is a big collaborative project that involves a number of investigators in different disciplines. Interactions between individual investigators appears somewhat limited - everybody is doing their own work (not necessarily a bad thing, but the project might benefit from closer/more frequent interactions between the team members). There is reduced involvement of some of the original team members due to job transitions.

PI Response:

Reviewer 23435

Score: 2.0

Comment: The project seems to be way over budget and not yet ready for real geothermal context.

PI Response:

Reviewer 24878

Score: 8.0

Comment: Seems well managed. I remain unsure in terms of the discussions between the project manager and the stakeholders.

PI Response:

Reviewer 23568

Score: 6.0

Comment: While there are several experimental tasks that must be coordinated, the bubble diagram in slide 6 of the presentation gives the impression that it is a more complicated organizational job than it would play out in practice.

PI Response:

STRENGTHS

Reviewer 23453

Comment: A novel injection fluid capable of significant (and reversible) volume changes, having a relatively low cost and minimum environmental impact may be greatly beneficial for the reservoir stimulation and, ultimately, the enhanced recovery of geothermal energy. If the reactive polymer is proven to be efficient at the in situ reservoir conditions, it may be widely used in the geothermal exploration, as well as in other industries relying on borehole drilling and hydrofracture, such as oil, gas, water extraction etc.

PI Response:

Reviewer 23435

Comment: Highly competent chemical engineers.

PI Response:

Reviewer 24878

Comment: The use of active polymer technology for fracking using the expansion of the polymer in presence of CO_2 through fluid shear thinning properties (proppant) is very good and potentially will be very useful to the industry.

PI Response:

Reviewer 23568

Comment: This is a novel project.

PI Response:

WEAKNESSES

Reviewer 23453

Comment: Thermo-chemical reactions that lead to the polymer expansion also result in increases in the effective viscosity (liquid vs gel), which is likely to limit fluid flow into the stimulated hydrofracture, and thereby prevent fracture propagation. This effect is opposite to that described in the presentation. The presenter suggested that the gel could be made porous to allow fluid flow, but this needs to be demonstrated experimentally (along with the effect of gel porosity on volume expansion). The efficiency of removal of gel from the stimulated fracture, as well as the possibility of multiple use of the polymer are among other potential weaknesses. It is not clear what is the main advantage of using reactive polymers for the reservoir stimulation compared to injection of regular borehole fluids at elevated pressures.

PI Response:

Reviewer 23435

Comment: The team is mostly composed of chemical engineers.

PI Response:

Reviewer 24878

Comment: I will be curious to see the next phase of the project especially the field development. I am also curious to see more numerical modeling of the lab experiments. Seems a very promising technology. I was wondering about the connection with the oil and gas industry regarding fracking in unconventional oil and gas reservoirs. The presentation was very good. I would like to see more published papers in the peer-reviewed literature.

PI Response:

Reviewer 23568

Comment: Reviewer did not provide comments for this criterion.

PI Response:

IMPROVEMENTS

Reviewer 23453

Comment: Once the polymer fills the fracture and "solidifies", it will be increasingly difficult to supply the borehole fluid with desired solvent properties (modified pH etc) to the main body of the polymer. Demonstrating the efficiency of the polymer recovery would strengthen the main results of this project.

PI Response:

Reviewer 23435

Comment: Thoroughly research geothermal well bore conditions before proceeding further.

PI Response:

Reviewer 24878

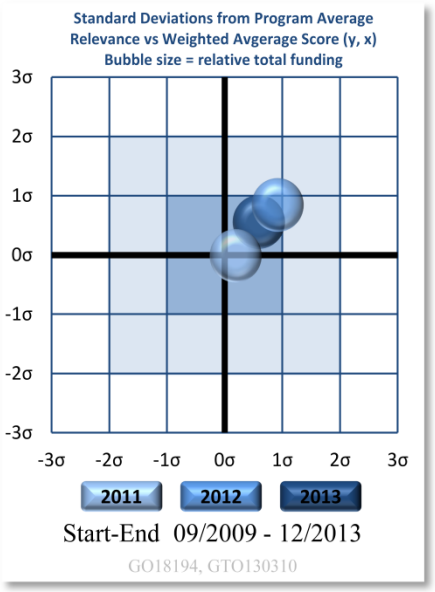
Comment: Complete numerical modeling of the behavior of the polymer in in situ conditions.

PI Response:

Reviewer 23568

Comment: This will require a field test to prove the concept.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: GO18194
Project: Analysis of Geothermal Reservoir Stimulation using Geomechanics-Based Stochastic Analysis of Injection-Induced Seismicity
Principal Investigator: Ghassemi, Ahmad
Organization: University of Oklahoma
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23412

Score: 8.0

Comment: Permeability randomness is often considered and helpful within reservoir flow models to predict a range of outcomes. The execution of an EGS project probably has a higher degree of randomness and prediction of outcome will be more difficult

PI Response:

Reviewer 23435

Score: 9.0

Comment: Uncertainty in the treatment of parameters (especially rock damage and stress dependent permeability is a real advance and represents the introduction of more pragmatic concerns into the model paradigm. This strategy is missing in most modeling approaches. This model starts with rock heterogeneity which is very good. I would think that a power law distribution might be more useful for fracture volumes.

PI Response:

Reviewer 23445

Score: 7.0

Comment: The goal of this project is to develop a stochastic model of injection induced seismicity to allow understanding of the reservoir (permeability, strength, stress state, etc.) and to predict the susceptibility to induced seismicity. A code has been developed that allows one to start with an experimental data set, start with a random domain, simulate the injection process, adjust the properties to the domain until the output of the model best represents the data obtained. This is a standard procedure in underground modeling. This will allow one to evaluate properties of a geothermal reservoir after a well has been drilled, and allow one to evaluate the progress of EGS stimulation.

I think all would have preferred for this tool to allow evaluation of a geothermal resource without the need for first drilling the well, but that at this point is not possible.

PI Response:

Reviewer 23509

Score: 8.0

Comment: This is a high impact project using seismicity-based reservoir characterization (SBRC) to infer information about stimulated volume and reservoir permeability. Laboratory and field data are being used to validate the 3D model. The overall impact of the project is potentially high in meeting GTO program goals.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23412

Score: 8.0

Comment: Work flow of and procedure of a 3D application includes permeability and bulk modulus models

PI Response:

Reviewer 23435

Score: 9.0

Comment: Explicit and quantitative (stochastic) variability in initial conditions is a real plus. Validation via the Soultz project seems to have been successful at a qualitative level. MEQ model assumes absolute location of MEQs. The impact of this approximation is likely small but may need to be addressed.

PI Response:

Reviewer 23445

Score: 7.0

Comment: I think the approach is very reasonable. Start with 2 dimensions, and proceed to 3. Start with simple submodels, and develop more complex ones as the need is demonstrated. The code allows pressure or flow inputs to allow simulation of most injection experiments.

PI Response:

Reviewer 23509

Score: 8.0

Comment: The inversion methods being used are technically sound but not necessarily state-of-the-art. Single parameter at a time Monte Carlo minimization methods are notoriously slow to converge and can converge to false minima (saddle points) unless supplemented with another gradient search method. Still, the PI has produced some impressive results matching a set of test problems.

PI Response:
The method used here for our estimations is not the Monte Carlo method. This is more than a simpel MC minimization procedure. We do actually incoporate the MEQ data through error estimation and filtering. The method is a variant of the Ensemble Kalman Filter, which is known to be quite efficient as a stochastic estimation approach among the subsurface modeling community. In essence, the EnKF uses a descent direction that is identified from the ensemble of models used in the implementation without requiring an adjoint model to find the exact gradient. This topic has been discussed in the literature and EnKF is very well known for its efficiency and robustness. EnKF has also some limitations when applied to large datasets. As part of our study, we have developed and implemented a variant of it that improves this effect.

Regarding single paramter issue, we started with estimating heterogeneous property field (permeability distribution as well as geomechanical rock properties such as Young's Modulus and Poisson Ratio) to study the feasibility of estimating these properties from MEQ data. Two points to consider: We did start out to study the impact of a single paramter but in general this is not a single parameter approach, it involves estimation of complex heterogeneous properties of rock; 2) as far as we know, this is the first study to undertake such developments. We have extended this work to simultaneous (joint) estimation of flow and geomechanical properties. Our preliminary results for joint estimation are reported in recent publication (SPE-ATCE and Eastern Regional Meetings).

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23412

Score: 8.0

Comment: Progress of developing the simulators is complete. Rigorous testing of laboratory experiments and field testing of fracture mapping exercise is still remaining

PI Response:

Reviewer 23435

Score: 9.0

Comment: The quantity, quality and real world applicability of the project are outstanding. They seem to have captured every aspect of related conceptual EGS models in a systematic and cost effective manner. The future of this type of modeling is clearly going to be in its ability to incorporate far field data (especially MEQ derived fracture and permeability geometries and properties) into exploitable reservoir properties, i.e. where do we drill? In particular,

coupling this modeling with MEQ (and other geophysics and geology data) may allow the differentiation between diffusive (non-productive) and flow (productive) induced stresses.

PI Response:

Reviewer 23445

Score: 6.0

Comment: I think that this project has only partially achieved its goals. It has indeed developed a model that couples various physical processes. It runs and provides reasonable results as demonstrated by the simulations presented on slide 9. Many of the submodels are simple, but it is not necessary to use the most complex models to demonstrate the code and its capabilities.

However, the optimization portion was only partially demonstrated. Slide 10 demonstrates that the code can reproduce a manufactured solution. However, the code was not demonstrated against any field data. The presenter admitted that only block experimental data is to be used to test the code. The presenter also admitted that the optimization routine can only find a solution for a single parameter. This will not prove to be enough since there are many unknown parameters in a geothermal reservoir and they cannot be grouped into a single parameter.

PI Response:
We have not tested the model with field data. We are planning to do so. The project objective has been to develop a tool and such a tool is now developed and can be used to syudy the impact of different parameters. Some of the simulations we had presented were for 1 paramter for the sake of illustration, but we also considered 2-3 parameters and can consider more. However, in numerical modeling one usually does not consider all possible parameters at the same time to minimize computational efforts. It is the task of the expert engineer/geologist/EGS designer to find the most relevant parameters and modelig and analyses help in this area.

Reviewer 23509

Score: 8.0

Comment: The project appears to be on track to meet the original objectives. A good number of publications and presentations has been produced documenting the project development and conclusions. This reviewer is skeptical that the remaining goals for future work can/will be completed as the project appears to have expended all the available funds.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23412

Score: 8.0

Comment: Project management has been adequate

PI Response:

Reviewer 23435

Score: 8.0

Comment: Impressive integration of physics and numerical schemes using allocated tie and resources. Delays due to delayed fund allocation is typical.

PI Response:

Reviewer 23445

Score: 5.0

Comment: The project seems to be run mostly by the PI. No credit to the other partners was provided in the verbal presentation. Alta Rock was a partner, and I assume that they were to provide field scale data to test the model. This was not accomplished.

PI Response:
We are not sure what the reviwer is suggesting. Indeed, the PI initially envisioned this project and togther with the the co-pi, formualted how to achive its objectives. The PI has identified other collaborators explicitly in the project summary and in the slides, and this was also mentioned in the presenttion. At the time the presentation was prepared and submitted, AltaRock's data were not available and furthermore, our project is not finished yet so analysis of field data will be carried out in the last phase of the project.

Reviewer 23509

Score: 8.0

Comment: Despite change in the PI's employer, the project goals have been largely accomplished.

PI Response:

STRENGTHS

Reviewer 23412

Comment: Error checking and simulation results that make sense

PI Response:

Reviewer 23435

Comment: The ability to identify the important numerical issues with respect to geothermal utility of the code.

PI Response:

Reviewer 23445

Comment: The coupled code that can run on a PC is a great accomplishment. It will allow simulations of coupled problems by the smallest enterprise.

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

WEAKNESSES

Reviewer 23412

Comment: No apparent weaknesses

PI Response:

Reviewer 23435

Comment: None.

PI Response:

Reviewer 23445

Comment: The PI did not demonstrate the ability of the model to be run in its intended form. It was only tested against a manufactured solution, so it is not surprising that it converged to that solution. These types of validations are good to demonstrate that there are no errors in the coding of the model, but does little to demonstrate the usefulness of the model. this model should be tested preferably with field data, or at least block data. The model should also allow optimization of more than a single parameter.

PI Response:
What we have used in our inversion examaples are based on synthetic data as no field data was available at the time. The model was able to estimate the distribitiopn of for example, reservor permeability that would produce a given set of MEQ. This is how inversion models are initially tested/verfied. The procedure for field data testesting is no different, except that there are more parameters that need to be optimized. The point is that we are developing and have devloped the state-of-the-art model. This is the only model that can consider geomechancis, and data uncertainty. Similarly to any model, by nature, it cannot be perfect. Consideration of more paramters has been carried out and will be presnted in the near future.

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

IMPROVEMENTS

Reviewer 23412

Comment: Try to acquire a field size data set to back into an average permeability and bulk modulus

PI Response:

Reviewer 23435

Comment: It is likely that the code could be validated with borehole injection and televiewer damage data.

PI Response:
Yes, this is a good suggestion and we will explore obtaining data from additional EGS projects for this purpose.

Reviewer 23445

Comment: The model should be expanded to allow optimization of more than a single parameter. This can be accomplished by exercising the model in a serial manner, treating one parameter at a time. This is not a very efficient process, but is simple to implement and will allow for more realistic applications of the model. When this is demonstrated, one may investigate multi-parameter optimization.

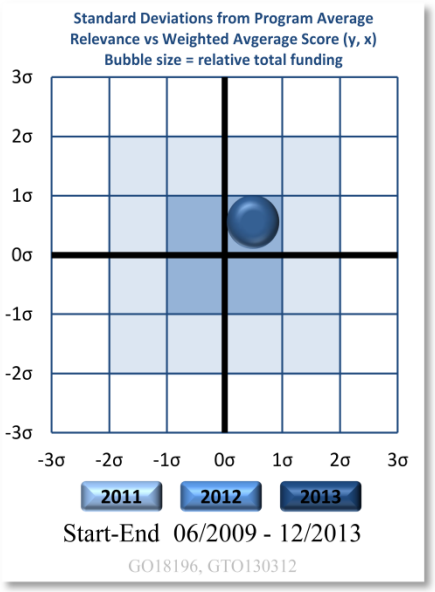
No field data was used to validate the model. However, I realize that field data is very difficult to obtain. Nobody can measure fracture creation due to injection (etc.). This might be an area for future work. One might consider first examining what field data is used to validate oil/gas reservoir modeling codes. Maybe this data can be used directly for validation of the geothermal codes (oil fracking?), or maybe a review of the validation procedure used in the oil industry would suggest a route for obtaining validation data for the geothermal community.

PI Response:
We are working to obtain data and to use them for aditional "validation" purposes. In particular, AltaRock data, and also data from oil-field stimulations will be used. Multi-parameter optimization is very complex, we have carried out certain examples of this and hope to have some more results soon.

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: GO18196
Project: Use of a Reservoir Model to Predict Potential Effects of Fracturing Techniques
Principal Investigator: Ghassemi, Ahmad
Organization: University of Oklahoma
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23412

Score: 8.0

Comment: Project helps determine the type of rock failure Type I through III and fracture propagation

PI Response:

Reviewer 23435

Score: 8.0

Comment: Full and explicit incorporation of anisotropy and heterogeneity in 3-d is a real advance in the public literature. The recognition of other fracture propagation modes is likely to ensure future utility.

PI Response:

Reviewer 23445

Score: 7.0

Comment: The goal of this project is to develop a fracture propagation model for use in simulating the stimulation of an EGS reservoir. This project will consider three modes of fracture growth so to be more general than existing models. Field and lab data is to be used to calibrate the model.

PI Response:

Reviewer 23509

Score: 9.0

Comment: The goal of this project is to develop a new numerical model for generating realistic fracture networks generated from hydrofracking geothermal reservoirs. Such a capability does not presently exist and is sorely needed to more accurately assess EGS projects. The virtual multi-dimensional internal bond (VMIB) approach being pursued can treat tensile, shear, and out-of-plane propagation of multiple fractures and fracture clusters and appears well-suited to the problem being addressed.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23412

Score: 8.0

Comment: Models 3D fracture propagation in multiple modes

PI Response:

Reviewer 23435

Score: 9.0

Comment: Fully three dimensional discretization, including fracture interaction is a challenging (and apparently successful here) approach that will be very useful as the characterization of geothermal reservoir physical properties improves (rheology, stress, fractures, flow). The virtual internal bond approach is very flexible approach that will allow consideration of many physical laws and constitutive relations describing fracture systematics (location, geometry, permeability, etc.).

PI Response:

Reviewer 23445

Score: 7.0

Comment: The approach is well reasoned. Since stress fields are not uniform in underground reservoirs, this approach should be more general in the prediction of propagation of fractures.

PI Response:

Reviewer 23509

Score: 9.0

Comment: The virtual internal bond (VIB) theory being used by the PI appears to handle well hydraulic and thermo-hydraulic fracturing processes in both 2D and 3D. A computer code implementing the theory has been completed and used to analyze several well constrained test problems. The PI has largely accomplished the original objectives of the project.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23412

Score: 8.0

Comment: Project has successfully modeled test problems

PI Response:

Reviewer 23435

Score: 8.0

Comment: The underlying mathematics of the code seem to be comprehensive and versatile with respect to geothermal utility. The numerical implementation of these mathematics in a robust code is a significant achievement. Slide 9 is particularly impressive in that it shows fractures in the far field being considered. This is the only presentation I have seen which comes close to this level of potential utility and visualization.

PI Response:

Reviewer 23445

Score: 6.0

Comment: A model has been completed that allows the simulation of fracture growth in realistic geologic media. The model has been exercised to show that it produces reasonable solutions. However, the validation with lab data is limited, and validation with field data non-existent. Since the formulation and coding of the model was not unique, I expected many more simulations to be presented to demonstrate the model in different applications. None of the simulations presented looked like an EGS stimulation of a geologic medium.

No mesh convergence studies were presented. This is important in all numerical studies, but most critical in fracture modeling. The PI claimed that these were completed, but was not prepared to present the results.

PI Response:

We are limited in the number of slides and the project summary pages we can use. So, we can't present all the work we have done over the years. The issues raised by the reviewer were addressed previously and have appeared in our publications.

We presented simulation of cooling and pressurized cracks. Fracture propagation in rock is an integral part of EGS. If the reviwer means the scale of numerical simulation was small, then that is correct. Larger scale simulations would require more memry and time. These are planned for the future.

Reviewer 23509

Score: 7.0

Comment: Very good progress has been made in completing the project objectives and documenting the results. The test problems that have been run appear to have adequately demonstrated the model's capabilities. The number of publications produced is acceptable but not outstanding.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23412

Score: 8.0

Comment: Project management has been adequate

PI Response:

Reviewer 23435

Score: 8.0

Comment: A lot of complex work has been well done. The future plan to fracture a large block to validate the code is useful.

PI Response:

Reviewer 23445

Score: 5.0

Comment: This project was presented as the work of one person (and likely his graduate students). Thus, coordination with others was not a critical item. Results were noticeably lacking, with the project completion date coming soon. The presenter did not indicate how he was to complete the project with the time and funding remaining. It was unclear that the

recent move of the professor from one school to another resulted in losing graduate students, or even if graduate students were involved in the program. The project end date has already been extended two years.

PI Response:
It is no secret to anyone familir with Universoity research that the actual work details are perfomed by graduate students under the supervision of faculty. The presentation did mention research "team" moving to another institution. By team we mean PI and students. If the transfer of studets was a conceern, then this should have been asked. But for the record, the students are at the new institution also. The move of the research team has indeed slowed down the work, particulalry since project trnasfer does lag behind people transfer by 6-8 months. Previously, the project end date was extended by 9 months via an extension. Such changes are not uncommon when graduate students are involved in research work.

Reviewer 23509

Score: 7.0

Comment: Project appears to be on track to meet the original scope and objectives. The project is behind schedule and the PI stated that no spending has occurred since October due to change of employment.

PI Response:

STRENGTHS

Reviewer 23412

Comment: Project is near completion

PI Response:

Reviewer 23435

Comment: Efficiency in coupling complex mathematics into numerical code which is robust with respect to geothermal parametrization and an understanding of the potential contributions and importance of MEQ data.

PI Response:

Reviewer 23445

Comment: The presenter was obviously well prepared to accomplish the work. His background and knowledge of the subject seemed to be excellent.

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

WEAKNESSES

Reviewer 23412

Comment: No apparent weaknesses

PI Response:

Reviewer 23435

Comment: Could the PI have used borehole breakout and injection data to validate the code?

PI Response:

Reviewer 23445

Comment: The output of the project seemed limited. I expected more applications of the model to various problems of interest.

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

IMPROVEMENTS

Reviewer 23412

Comment: Needs graduate student training to complete work

PI Response:

Reviewer 23435

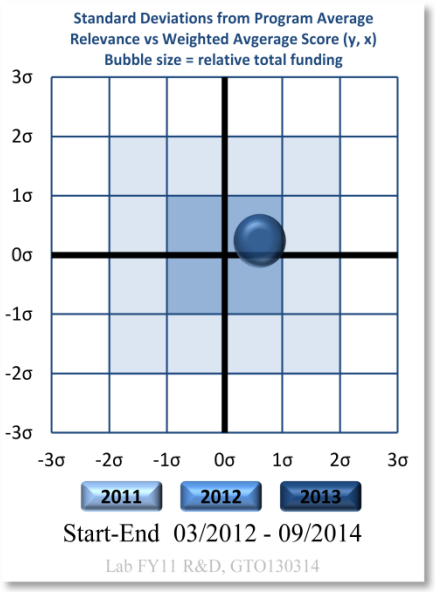
Comment: Consider researching advances in MEQ source location and characterization to determine common parametrization functions such as source moment and fracture area/geometry inputs.

PI Response:

Reviewer 23509

Comment: So far, the virtual multi-dimensional internal bond (VMIB) modeling has been restricted to simulating fracture generation and propagation. While important, the fracture network must also be assigned permeability properties to eventually be useful for reservoir modeling and heat recovery simulations. The PI should consider devoting some of the remaining funding resources to fracture property generation capability in addition to fracture geometry presently simulated. Also, the VMIB computer code is completely standalone. Usefulness and impact to the GTO program would be greatly improved by evaluating methods for coupling into a THMC type of reservoir simulator.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: Lab FY11 R&D
Project: Integration of Nontraditional Isotopic Systems Into Reaction-Transport Models of EGS For Exploration, Evaluation of Water-Rock Interaction, and Impacts of Water Chemistry on Reservoir Sustainability
Principal Investigator: Sonnenthal, Eric
Organization: Lawrence Berkeley National Laboratory
Panel: Modeling

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23453

Score: 7.0

Comment: This project seeks to investigate the role of "non-traditional" isotopic systems as markers of geothermal alteration, fluid flow, and permeability changes from mineral alteration. The project addresses several existing challenges, barriers, and knowledge gaps, such as design and development of improved geothermometers and geochemical tools to assist in discovering blind systems, fluid rock interaction research to improve reservoir creation and reservoir sustainability, and understanding permeability using chemical signatures. If successful, results from this project may help increase success rate in drilling and decrease drilling costs per hole during resource exploration (due to better accuracy in determining the size and location of the geothermal resource), and ultimately lower risks of exploration and improve resource evaluation. This project is a "proof of concept" with a higher risk, but potentially a higher return.

PI Response:
No response necessary.

Reviewer 23412

Score: 8.0

Comment: Application on geochemistry techniques will help EGS creation understanding

PI Response:
No response necessary.

Reviewer 24878

Score: 7.0

Comment: Very good project to understand non-classical isotope fractionation sorption/precipitation on and the use of geothermometers based on reactive transport modeling to assess reservoir temperatures and host rock interactions especially in EGS. I am a bit unsure regarding the strong applications of these methods to the direct impact in geothermal energy development.

PI Response:
No response necessary.

Reviewer 23568

Score: 8.0

Comment: This research can significantly add to geochemical techniques used for reservoir characterization of temperatures and fracture flow evolution.

PI Response:
No response necessary.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23453

Score: 8.0

Comment: The premise of the proposal is that the identified isotope systems (in particular, Ca, Sr, and Li) are sensitive to, and can be used as fingerprints of hydrothermal reactions that occur in natural geothermal systems, as well as exploited reservoirs. The PIs are incorporating the isotope systematics into reactive-transport models of mineral- water-gas reactions in geothermal systems. Specifically, TOUGHREACT was modified to include the respective isotope systematics. Los Alamos National Lab (LANL) has a strong expertise in the development of coupled hydrothermal-chemical flow simulators. The PIs also consider the effects of dissolution, precipitation, gas exsolution and fractionation, as well as kinetic and equilibrium isotopic fractionation. Other tasks include modeling of sorption, ion exchange, and aqueous kinetics, and determination of the relevant isotopic fractionation factors and rates under geothermal temperatures using laboratory experiments. Developed numerical models are being tested against data from field sites (Newberry EGS, Dixie Valley, and Desert Peak).

PI Response:
All researchers are at Lawrence Berkeley National Lab.

Reviewer 23412

Score: 8.0

Comment: Scientific approached uses sound geochemical techniques

PI Response:
No response necessary.

Reviewer 24878

Score: 8.0

Comment: The project has the goal to integrate non-traditional isotopic systems Into reaction-transport models of EGS for exploration, the evaluation of water-rock interaction, and the impacts of water chemistry on reservoir sustainability, e.g., improved geothermometers (e.g. lithium). I like the good validation tests with experimental data both in the lab and in the field (Newberry, Dixie Valley, Desert peak). The followed approach is good to me.

PI Response:
No response necessary.

Reviewer 23568

Score: 8.0

Comment: The approach is a combination of laboratory experiments, field data from Desert Peak, Long Valley, Newberry,etc. and modeling. Therefore, the approach covers all available avenues.

PI Response:
No response necessary.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23453

Score: 8.0

Comment: An updated version of TOUGHREACT code (V2) was released last year; a new high-performance parallel version (V2.2G) is under development and is planned for release in 2013. Thermodynamic and kinetic data on Sr and Rb isotopes is being collected in Desert Peak rhyolite, and on Li isotopes in Newberry EGS. Calcite precipitation experiments and modeling are delayed due to migration of lab equipment to another area; data from Desert Peak rhyolite were modeled in the meanwhile. Data and models for isotope systems investigated in this project may enable a new class of reaction-transport models to evaluate fracture surface areas, reservoir temperatures, water rock interaction, and degree/extent of fracture sealing. The results are disseminated through peer-reviewed literature and presentations at various meetings. The level of productivity is commensurate with the funded efforts.

PI Response:
No response necessary.

Reviewer 23412

Score: 8.0

Comment: Project is near completion and improvements to the Lawrence Berkeley National Lab TOUGHREACT code

PI Response:

No response necessary.

Reviewer 24878

Score: 8.0

Comment: The project started on 1/1/2012. 2 years, it is on schedule but I would like to see more peer-reviewed publications. The understanding of permeability through chemical signature (especially through the Ca isotopes) is also unclear to me.

PI Response:
We have a paper on Li isotopes under internal review which we plan to submit this summer. Regarding Ca isotopic effects, the precipitation/dissolution of calcite is typically dominant in fractures, which control permeability in geothermal systems. Calcite has a strong effect on Ca isotopic ratios and therefore Ca isotopes give another independent constraint on fracture surface areas and fracture permeability.

Reviewer 23568

Score: 7.0

Comment: The project is relatively new and accomplishments to date are appropriate. Right now the modeling is ahead of experimental work. One aspect to pay attention to is how relevant batch flow experimental results apply to field situations in terms of equilibrium.

PI Response:
Batch experiments are planned for this summer and yes, the approach to equilibrium will be tested in fluids collected from the field and in the lab. Lab results will give effects at shorter time scales which may induce greater kinertic effects compared to the field, unless boiling or transient processes are involved.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23453

Score: 9.0

Comment: The project involves several PIs from Los Alamos National Lab (LANL). They are experts in the respective areas and well qualified to perform tasks outlined in the work plan. The project seems to be well coordinated, and there is efficient interaction between the investigators. Despite some minor delays, the project is on track, and all major milestones are being met. Future directions include: Ca isotopic fractionation experiments, and simulation of isotopic effects at Desert Peak and Long Valley (Instead of Newberry). I anticipate that the remaining tasks will be completed and the final products will be delivered in a timely fashion.

PI Response:
All researchers are at Lawrence Berkeley National Lab.

Reviewer 23412

Score: 8.0

Comment: Project management is adequate

PI Response:
No response necessary.

Reviewer 24878

Score: 8.0

Comment: Good management.

PI Response:
No response necessary.

Reviewer 23568

Score: 9.0

Comment: Good PI who attends to all aspects of the project.

PI Response:
No response necessary.

STRENGTHS

Reviewer 23453

Comment: Reviewer did not provide comments for this criterion.

PI Response:
No response necessary.

Reviewer 23412

Comment: Understanding of geochemical processes are well defined

PI Response:
No response necessary.

Reviewer 24878

Comment: The project is built on the excellent expertise of the PI and his team on reactive transport modeling and also the expertise at Lawrence Berkeley National Laboratory on isotopes.

PI Response:
No response necessary.

Reviewer 23568

Comment: The comprehensive lab, field, modeling approach and the development applications to geothermal of new techniques and data are all strengths.

PI Response:
No response necessary.

WEAKNESSES

Reviewer 23453

Comment: Reviewer did not provide comments for this criterion.

PI Response:
No response necessary.

Reviewer 23412

Comment: No apparent weaknesses

PI Response:
No response necessary.

Reviewer 24878

Comment: The project neglects fractionation in the transport itself through diffusion because of the mass difference between the isotopes (e.g., lithium). This component may be investigated by the flow through experiment.

PI Response:
We do plan to evaluate mass-dependent fractionation owing to diffusion. As the reviewer indicates, it could be important under some slow-flow conditions.

Reviewer 23568

Comment: Reviewer did not provide comments for this criterion.

PI Response:
No response necessary.

IMPROVEMENTS

Reviewer 23453

Comment: Reviewer did not provide comments for this criterion.

PI Response:
No response necessary.

Reviewer 23412

Comment: Project is on track

PI Response:
No response necessary.

Reviewer 24878

Comment: I have no specific comments here.

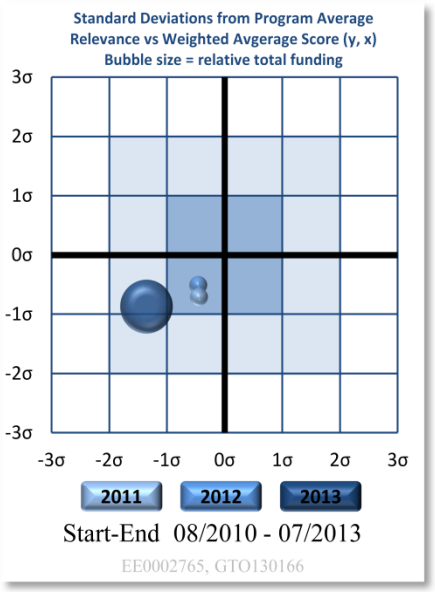
PI Response:
No response necessary.

Reviewer 23568

Comment: The Long Valley system appears to be valuable for model validation, even though it is not an active geothermal field. Pursuing the science where the natural situation can give the best validation is more important at this stage than applications to an EGS Demo site.

PI Response:
Yes, the data are much better for Long Valley, and we intend to analyze this system in more detail.

Supercritical CO_2 and Working Fluids Reviewer Comments and Principal Investigator Rebuttals



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002765
Project: Experiment-Based Model for the Chemical Interactions between Geothermal Rocks, Supercritical Carbon Dioxide and Water
Principal Investigator: Petro, Miroslav
Organization: PARC (Palo Alto Research Center)
Panel: Supercritical CO_2; Working Fluids

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23457

Score: 8.0

Comment: The objectives of this project are to (1) determine the chemical interactions between minerals and water-CO_2 fluids, and (2) understand the effect of chemical interactions on transition to and performance of a CO_2-EGS system.

The project contributes to GTP's goal to better assess risks associated with an EGS reservoir using CO_2 as a working fluid.

PI Response:

Reviewer 23445

Score: 7.0

Comment: The stated goal of this project is to investigate the chemical reactions that occur with CO_2/water mixtures and the impact of these reactions on EGS reservoirs. This is an important goal, and deserves study. An EGS reservoir can only exist if the fractures that allow flow of fluids persist over a reasonable amount of time so that they do not have to be regenerated frequently. The knowledge base at this time is not sufficient, so an experimental program to develop kinetic parameters is warranted.

PI Response:

Reviewer 23509

Score: 2.0

Comment: Understanding fluid/mineral interactions and in this project's case fluid/CO_2/mineral interactions is an important endeavor to enabling use of CO_2 as a subsurface working fluid in EGS. Unfortunately, the PI either through lack of experience, basic knowledge, and isolation from peers has been unable over the 3 yr period this project has been operating to produce any tangible scientific advances that would benefit EGS projects. Project presentation materials for this year were consistent with this unfortunate conclusion. Results are completely anecdotal and semi-quantitative with

no attempts to extract any fundamental parameters such as rate constants, solubility products, or activation energies that are needed for geochemical modeling. Moreover, the PI again failed to provide a rationale for the selected few minerals on which sparse experimental data was presented.

PI Response:

Reviewer 23513

Score: 6.0

Comment: The project is making progress towards its stated objectives relative to what reactions can occur. The level of progress on how these reactions will affect the transition to a CO_2-EGS system was less clear.

The results suggest and the PI indicated during the presentation that these reactions will be complicated by the mineralogy of the formation, and that it would be necessary to 'test' core samples in order to develop the solubilities and reaction rates for that formation. If so, then this work would seem to be identifying that there will be an added cost and additional risk for this fluid in EGS applications, instead of reducing that risk. It will be necessary to both confirm that stimulation will produce a sufficiently large reservoir and that the formation mineralogy will accommodate the use of a CO_2 heat recovery fluid.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23457

Score: 8.0

Comment: The technical approach has the following elements:

1. Experiments using a multi-channel batch system to generate mineral solubility data
2. Simulate the injection/production cycle with a circulation flow-through channel
3. Scanning electron microscope (SEM) analysis on mineral samples to characterize the changes in texture and mineralogy
4. Experiments using rocks from CO_2 injection site at Cranfield, MS
5. Modeling

Application to a real EGS system will require additional testing.

PI Response:

Reviewer 23445

Score: 4.0

Comment: I think that the approach as outlined in the original Statement of Project Objectives (and presented) was very good, with one exception The creation of a model was relegated to a single task (Phase 3 Task 18). I would have desired more emphasis placed on the model development. For without a clear goal for how the experimental data is to be used, there is little to guide an experiment on what data is critical to collect. This lack of emphasis on the eventual model is evident in the presentation. The model was not developed (or at least not presented), and only 10% of the funding is left. It is unclear if a model will be developed in the remaining months that the project has left. The presenter showed little interest in the model stating only that the data collected will be handed off to a modeling group at LBNL (was the use of the future tense an implication that the modeling effort has not started?). It was unclear how the modeling group is to be funded. Does the modeling group have another source of funds, or do they have to rely upon the remaining funding left in this project? It is possible that the modeling effort is well underway, and the presenter just is unaware of the modeling progress?

PI Response:

Reviewer 23509

Score: 2.0

Comment: As this reviewer has commented in past years, the PI has built a commonly available flow-through reactor system for studying fluid/mineral interactions. Never has any attempt been made to address more cutting edge geochemical issues associated with water-wet $scCO_2$, the fluid phase that most of the reservoir rock would contact. Furthermore, there is no evidence of systematic experimental design or planning to extract fundamental fluid/mineral parameters from the experiments that have been performed. Finally, there is no evidence that the PI identified specific problems and uncertainties with existing thermodynamic or kinetic rate law data for the minerals selected for study and then designed an experimental program to address these problems. The approach has been a non-scientific build some expensive equipment first and then use it to see what happens. That approach is simply unacceptable in a field as mature as rock-water interactions.

PI Response:

Reviewer 23513

Score: 6.0

Comment: I've some question as to whether the batch experiments were of sufficient duration to adequately establish equilibrium mineral solubilities and reaction rates.

It was not apparent to what extent available thermodynamic and chemical data bases/models where used to design the tests that were conducted, and how the data being produced is used to test those existing models (beyond TOUGHREACT).

Nothing to suggest that the effect of flow rate on solubilities and reaction rates was tested? Was this considered not important?

Unexpected issues associated with mineral compositions, kinetics, surface areas, … have been encountered; the PI has been proactive in design experiments to resolve/accommodate these issues.

The testing on 'real' rocks has been limited.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23457

Score: 7.0

Comment: Some of the project accomplishments are:

1. Solubility map for several minerals in water-CO_2 environment for a range of PT
2. Effects of particle size and surface area on dissolution kinetics
3. Evaluated changes in mineral texture by scanning electron microscopy (SEM)
4. Reactive transport modeling to evaluate impact of fluid-rock interactions in a CO_2-EGS reservoir

PI Response:

Reviewer 23445

Score: 4.0

Comment: I thought that the presenter was unable to identify what new experimental results were obtained from this program that would allow one to change existing geochemistry models. He also did not identify what experimental results confirmed existing geochemistry models, and why it was necessary to confirm these results. Thus, it was difficult to see how the results of this study were to be used to advance the field.

The author very clearly identified technical challenges that the program faced. I think this showed a great understanding of the field. However, he only provided details on how he addressed the complication of changing surface area with time. And even on this topic he did not provide sufficient detail to allow one to reproduce his approach. He stated that the equilibrium chemical concentrations would be the same for the two powder samples tested, but they only appeared to be different in slide 8 due to the effects of rapidly changing surface areas. Since the lines through the data are apparently only fits to the data, they could not be extrapolated to show that the same equilibrium concentrations will eventually be obtained. It would have been very informative if the presenter could have extrapolated modeling results to demonstrate that the same equilibrium concentration would be obtained from the two different powdered samples. Otherwise, one might assume that the two powdered samples were actually different in some way.

The experiments utilized pure mineral samples and pure water/CO_2 mixtures. It was unclear how the results would be extended to other mineral samples (for the minerals examined were not typical of the minerals in all potential EGS system), mixtures of minerals, and brines.

PI Response:

Reviewer 23509

Score: 1.0

Comment: The author's Project Summary document speaks for itself. Not a single journal publication has been produced in over 3 yrs of effort and nearly $4M spent. Moreover, the presentation materials show not a single tangible scientific advance in the core geochemical or thermodynamic properties of any mineral phase investigated by the project. The PI, upon questioning about this at the review, responded that the data is being sent to LBNL for analysis. That is simply not acceptable at this late stage in the project. The project is now nearly out of funds and the remaining funds appear allocated to do more testing of rock samples from the Cranfield site. It would be far better to use the remaining funds to document some portion of the data that has been collected than continuing tests on whole rock samples that are unlikely to advance fundamental understanding of mineral/CO_2/fluid interactions.

PI Response:

Reviewer 23513

Score: 6.0

Comment: Because of the apparent effect of trace level components, I find it difficult to understand how the behavior of real rocks can be assessed by examining the behavior of individual components.

Slides 6 & 11: My interpretation of slide 6 is that everything inside the thermal chamber is heated to the elevated temperatures (90-180C). Slide 11 indicates the total pressure is held at 1200 psi. My question is how one can maintain a CO_2 partial pressure of 1200 psi (same as total pressure) when the saturation pressure of water is increasing with the rising temperature? There is probably an explanation, if so it should be included in subsequent reporting.

Limited testing has been done on actual rocks from subsurface formation.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23457

Score: 8.0

Comment: The project will be finished within budget. No management issues have been identified.

PI Response:

Reviewer 23445

Score: 4.0

Comment: The project spending is on track to finish on time. However, I was not impressed by the coordination between experiments and modeling. From the presentation materials, the modeling seemed to have progressed little, and the written materials only included the vague statement: "modeling activities at PARC accelerate." From the words used at the presentation LBNL was to perform the modeling. In the presentation materials limited modeling results were presented on slide 13, but no details of the maturity of the model was described.

PI Response:

Reviewer 23509

Score: 2.0

Comment: The failure of this project to achieve any tangible results after over 3 yrs of effort and $4M spent is squarely on the shoulders of the PI. This reviewer can only lament at what a similar level of funding could have accomplished at another institution. GTO project management, however, also has some responsibility here as there was ample evidence of lack of performance early on in the project and appropriate corrective actions could have been taken.

PI Response:

Reviewer 23513

Score: 7.0

Comment: Issues have been encountered, and steps taken to address them. There seems to be quite a bit of work remaining, especially on the modeling tasks; which magnifies the importance of who is doing that modeling. It appears that the modeling work is being done by LBNL, and that the modeling work is progressing along a parallel path was not presented; the working relationship between PARC and LBNL in terms of who is doing what should have been better described in the information provided.

PI Response:

STRENGTHS

Reviewer 23457

Comment: Experimental determination of chemical reactions and parameters needed for the evaluation of a water-CO_2 EGS system.

PI Response:

Reviewer 23445

Comment: I was very impressed by the presenter's ability to identify the challenges of this experimental program. As in all experiments, it is difficult to assure that a controlled experiment represents reality. It was refreshing to see an experimentalist lay out all of the shortcomings of an experiment. This attitude should be encouraged in all experimentalists and modelers.

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23513

Comment: Reviewer did not provide comments for this criterion.

PI Response:

WEAKNESSES

Reviewer 23457

Comment: Work with real rock samples is limited. Additional work will be required to apply this approach to real systems.

PI Response:

Reviewer 23445

Comment: The importance of the experimental observations were not clearly identified (with the exception of accounting for surface area changes with time). Thus, it was difficult to see why this project is critical. The accomplishments outlined on slide 5 are vague, and the importance of these accomplishments is not addressed. How are the solubility maps developed different from those already available? This is not described.

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23513

Comment: The model that is being developed is being based on experimental data. It appears that it would effectively require testing to be conducted on formation rock specific to each EGS resource; I question whether this is feasible.

PI Response:

IMPROVEMENTS

Reviewer 23457

Comment: This work should be continued using rock samples from a variety of possible EGS systems. Also modeling should be accorded a higher priority than was done under the present project.

PI Response:

Reviewer 23445

Comment: The presenter should identify the importance of the results that were obtained. Even if the results are not new, confirmation of previous results is an important result.

PI Response:

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

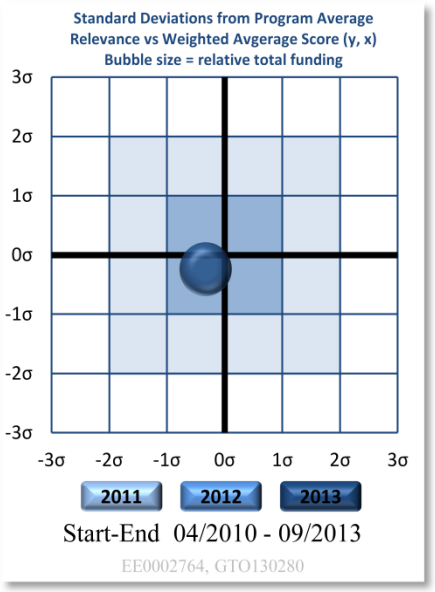
PI Response:

Reviewer 23513

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002764
Project: An Integrated Experimental and Numerical Study: Developing a Reaction Transport Model that Couples Chemical Reactions of Mineral Dissolution/Precipitation with Spatial and Temporal Flow Variations in
Principal Investigator: Saar, Martin
Organization: University of Minnesota
Panel: Supercritical CO_2; Working Fluids



RELEVANCE/IMPACT OF RESEARCH

Reviewer 23457

Score: 7.0

Comment: The main objective of this project is to modify TOUGH2 to include mineral dissolution/precipitation reactions based on observed chemical interactions between CO_2 and EGS reservoir rocks.

The research program contributes to GTP's goal of "Reservoir Sustainability" by improving understanding of rock-fluid geochemistry and mineral dissolution/precipitation.

PI Response:

Reviewer 23445

Score: 6.0

Comment: The goal of this project is to develop empirical models to implement into Tough2 that will account for chemical reactions of brine/CO_2 mixtures reacting with the host rock on the transport properties of an EGS reservoir. It was stated that the empirical approach has advantages over use of ToughReact to accomplish the same simulation. First, it will be faster to run since Tough2 is a simpler code. Second, it will avoids identification of numerous parameters that ToughReact will require. Third, it avoids development of models on how reaction progression alters the transport properties (for these will be empirically accounted for in Tough 2). And finally it is potentially more accurate since the resulting changes in transport properties are based on actual measurements and not unproven models.

The disadvantage is that the empirical models will only be applicable to the materials for which they were developed. Potentially ToughReact models can be applied to any materials if they are indeed first principle models within ToughReact.

These goals are reasonable, but potentially controversial. Not everybody will agree that they can be accomplished. Some will prefer the ToughReact modeling approach due to its first principle nature. It is difficult to evaluate the impact of this Research since the final step has not been accomplished. The Tough2 simulations have not been performed to demonstrate its usefulness.

PI Response:

A first principal approach will give bad data if it (the model) relies on faulty assumtions about (for example) rates and locations of mineral precipitation and associated permeability modifications - justifying a different path forward (as proposed).

Reviewer 23509

Score: 8.0

Comment: The objective of this project is to experimentally determine spatial and temporal variations in pore/fracture geometries in CO_2/rock/water systems and develop semi-empirical correlations that can be used in multiphase flow simulators to adjust associated permeability and flow fields. Such correlations are of core importance to modeling long-term performance of EGS projects using CO_2 as a subsurface working fluid. Significant progress has been made through a series of core flood experiments and lattice boltzmann numerical simulations.

PI Response:
No comment necessary.

Reviewer 23513

Score: 6.0

Comment: It is unclear that the coupling of the experimentally observed interactions to the TOUGH model is going to produce a tool that does not require testing of core samples from each site in order to adequately characterize the reservoir permeability. While the tool appears to be a means to manage the reservoir for long term sustainability, the cost and time required to generate the necessary information are largely unstated – if there is uncertainty as to what will be required for each resource, then there will be increased risk and cost associated with these developments.

The project summary contains reference to application of this work to Enhance Oil Recovery (EOR). The DOE should not be funding any part of this work that pertains scenarios where the original native fluids are non-aqueous fluids or in looking at the sequestration of CO_2 with no heat extraction and energy production.

PI Response:
The explicit goal of the proposed work is to test three quite representative end-member lithologies (arkose (as oppoesed to sandstone so that some reactions are observable), carbonate rock, and basalt) to develop an empirical approach to linking fluid-mineral reactions to permeability changes during CO_2 injection into saline aquifers (we have not looked into hydrocarbon researvoirs) as utilized during CO_2-based geothermal energy extraction (which only coincidentally would also be used as geologic CO_2 sequestration reservoirs).

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23457

Score: 7.0

Comment: The research program includes several somewhat disparate projects, i.e. (1) Laboratory experiments with CO_2, brine, and rock samples, (2) characterization of mineral dissolution/precipitation using X-ray tomography, SEM imaging, etc., (3) Particle image velocimetry (PIV) experiments on multi-phase flow with analogue materials, (4) Lattice Boltzman code development, and (5) TOUGH2 modification.

It is unclear how items (1) through (4) will be used to modify TOUGH2 to make it applicable to potential EGS systems.

PI Response:
The proposal lays out in detail how all 5 tasks are used in conjunction to develop an modified version of TOUGH2 (or TOUGHREACT as we now decided - see our responses below) that has a more robust reactive/transport component that is based on actual lab experiment results and calibrations.

Reviewer 23445

Score: 5.0

Comment: I am unsure of the technical approach of this work. The major problem I have with it is that I see it involving 3 steps. First experimental data must be obtained to model reaction kinetics. Then, the impact of the chemical reaction progression has to be correlated to changes in the transport properties. Third, these changes have to be put into a form that can be used by Tough2. The second step seems awkward since the project outline has identified two independent methods to accomplish this. The first is via evaluation of permeability changes via LB simulations, and the second via classic Darcy tests on samples that have undergone reactions. It is unclear how both approaches can be used. (A man with two watches never knows the correct time.). However, multiple methods to accomplish the same task is much better than zero approaches. It seems that the completion of the final step has not been thought through. The presenter was unable to state how changes in porosity and permeability were to be incorporated into Tough2. They have to be a function of a state variable, and reaction completion is not a state variable within Tough2. The lack of a plan is troubling since the project is about complete.

PI Response:
We use the lab experimenst to determine how permeability changes over the total sample scale due to the observed fluid-mineral reactions. However, the overall sample permeability changes due to potentially small changes in pore-space geometry within the samnple. As pointed out in the proposal, when minerals dissolve or precipitate, it matters significantly where exactly they dissolve or precipitate in terms of how the permeability of the sample (or region in a model) is affected. For example precipitation of a tiny amount of mineral in a bottle neck, to the point of complete clogging of the bottle neck, will reduce the permeability of that bottle neck (and possibly the region surrounding it) by several orders of magnitude or even reduce it to near-zero. Therefore, we conduct X-Ray Computed Tomography (XRCT) experiments before and after lab experiments to learn about such mineral dissolutions and precipitations in a spatial 3D context. We are interested in understanding where such porosity modifications occur. Then we are interested in how such porosity modifications affect the permeability field. For that, we cannot use the overall sample permeability as it integrates over thousands of pores. Instead, we use the 3D XRCT data to run lattice-Boltzmann fluid flow simulations on multiple Representative Elementarty Volumes (REVs), into which we have subdivided the sample core, and from which

we can learn how specific pore space geometries affect the permeability of an REV and how multiple REVs affect the overall permeability field. Thus, we are not talking about two "watches" but rather two complementary approaches. This is outlined in detail in the proposal.

Reviewer 23509

Score: 8.0

Comment: The project has a logical set of integrated experimental and modeling tasks. A number of different core flood experiments have been performed to provide model systems for pore scale simulations. A good set of characterization methods has been applied to interpret the experimental results. One specific weakness seems to be in defining an approach to abstract the experimental data into a constitutive model for reservoir simulations.

PI Response:
No comment.

Reviewer 23513

Score: 7.0

Comment: Unclear that the approach being used in Task 3 – particle image velocimetry- is going to be representative of multi-phase flow in porous media. It seems like a simple characterization of a complicated flow problem. Some added discussion is warranted as to how this information will be used in the Lattice Boltzmann code development.

The use of the Lattice-Boltzmann code to bridge between chemical-rock interactions and the permeability/porosity appears to be a novel way of using the laboratory experiments of changes in permeability to include the simulation of the fluid-mineral reactions and flow fields.

PI Response:
The lattice-Boltzmann code is used as described above and in the proposal.

The PIV experiments and associated flow visualization can be used to understand propagation of contact lines through porous structures and suggest how those effects can be modeled via lattice-Boltzmann fluid flow simulations (or other methods). The extent and speed of contact line propagation translates ultimately into an effective permeability.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23457

Score: 7.0

Comment: Laboratory experiments have been performed on Arkose sandstone and dolostone to characterize effect of dissolution and/or precipitation on permeability. Also Particle image velocimetry (PIV) experiments have been performed on analogue materials.

Lattice Botzmann simulations have been used for flow simulation of droplets through openings.
TOUGH2 modification will be carried out over the next few months.

PI Response:
no comment

Reviewer 23445

Score: 5.0

Comment: The experiments are complete. It is unclear how the data is compiled for use by others (only conference proceedings have been used to publish the data), but it is available to the team for the next step. It is not clear how the limited reactions studied (i.e. pure water instead of various brine concentrations, simple minerals instead of mineral mixtures, etc.) will allow applications to a general geologic setting. The program did identify some unique experimental results that are of interest to the community.

The reacted samples have been analyzed to determine the effect on porosity and permeability. This has been done via two methods: LB simulations and classic Darcy tests.

The next step incorporation into Tough2 is not complete. The presenter could not outline how this was to be completed. The changes in porosity and permeability due to reactions should be a function of reaction completion, and yet reaction completion is not a state variable within Tough2. The time and money left in this project seem to not allow completion.

PI Response:
While we started out with pure water experiments, we have transitioned to brine experiments about one year ago. In addition to publishing in conference proceedings we are also publishing our results in journals. In fact, the next reviewer (Reviewer 23509) points out that "the results have been documented in a substantial number of publications and presentations." We are now including our empirical observations into TOUGHREACT instead of TOUGH2, using the experimental results to determine permeability modifications based on fluid chemistry modifications. This constitutes a compromise that we believe is however justified and promising as it aleviates the issues we have with TOUGHREACT from the beginning by replacing them with our observed experiment behavior while using TOUGHREACT's chemical reaction capabilities to address changes in fluid chemistry over time. We have also started with basalt experiments (about 6 months ago). Much of the work will come to a conclusion by the project end date while some aspects of the work will be continued under separate funding. Third party researchers already have access to some of our data and will have more access once the remainder is published.

Reviewer 23509

Score: 6.0

Comment: The project has made good progress on planned experimental and modeling tasks. These results have been documented in a substantial number of publications and presentations. This reviewer downgraded the score here as specifics around methods to develop an abstracted model for TOUGH2 were lacking in the review materials and the project is clearly behind schedule in meeting those stated objectives.

PI Response:
The project is largely on track (see comments above) and will only require some additional work over another year under separate funding to be finished completely. Additioanl accomplishments, not originally anticipated, as is often the case in research, have also been made as can be seen in the publications.

Reviewer 23513

Score: 6.0

Comment: The testing completed has been done on sedimentary rock. Though testing is being conducted using a basalt, the perception is this effort has been directed largely towards applications in sedimentary applications, including EOR and sequestration.

Several publications have resulted. It appears that most of the recent ones have dealt primarily with CO_2 sequestration; the geothermal related papers are primarily associated with Task 5 – TOUGH2 simulations.

PI Response:
See also comment above concerning that our experiments and tests are geared towards CO_2 based geothermal energy extraction which, as a side benefit, also provides insights that are useful for geologic CO_2 sequestration. No experiments have been conducted with hydrocarbons as the native fluid which would be required for EOR experiments.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23457

Score: 8.0

Comment: The project is on schedule and is expected to end as per plan on September 30, 2014. No management issues have been identified.

PI Response:
I am not sure what the management issues are supposed to be. The date in the above statement is incorrect as it should be September 30, 2013. As stated above, the the project is largely on schedule, however, we plan to continue experiments under separate funding past the above date to finish up some aspects of the work. Also, as stated above, we gained some additional, originally not anticipated, insights.

Reviewer 23445

Score: 6.0

Comment: I think that the project has made good progress on tasks 1 through 4. I do not understand the last statement on Slide 14. How can initial progress, or even any simulations been performed, for this task when the presenter was unable to describe how Tough2 was going to incorporate the output from tasks 1 through 4? It will be interesting to observe what

progress can be made in the remaining months of this project. I understand that this is a small university team, and thus the presenter should have been aware of how this task is to be completed.

PI Response:
See comments above and the original proposal.

Reviewer 23509

Score: 8.0

Comment: Project seems to be mostly on track to wrap up with most of the objectives met. Project seems to be slightly underspent overall with 27% of the budget remaining with 6 months left.

PI Response:
no comment

Reviewer 23513

Score: 6.0

Comment: None of the 5 project tasks appear to have been completed. Though tasks 1-4 are nearing completion, it seems that task 5 is not that far along. This is the task that is crucial to the support of the DOE GTO.

A proposal has been submitted to NSF to continue the work and improve the understanding of effect of the mineral-fluid reaction on permeability. In the information presented for this review I did not see any reference to what information the on-going work has not be able to produce that is needed for this improved understanding (other than the reference to the NSF application).

PI Response:
nterestingly, an earlier reviewer suggested that most of our accomplishments are related to TOUGH2 simulations. Please see above comments and our responses for clarifications.

STRENGTHS

Reviewer 23457

Comment: A basic research project to characterize chemical interactions between CO_2, brine, and rock minerals, and effect of mineral dissolution/precipitation on permeability.

PI Response:
yes

Reviewer 23445

Comment: I think the experimental program is the strength of this program.

The two competing approaches (LB and Darcy tests) allow options on how to incorporate the impact of reactions on the transport parameters should be considered a strength, although this was not presented as one in the presentation.

PI Response:
Please see above comments on how the two approaches complement each other.

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23513

Comment: Reviewer did not provide comments for this criterion.

PI Response:

WEAKNESSES

Reviewer 23457

Comment: No rocks that are typical of EGS reservoirs are being tested. There are no geothermal reservoirs hosted by arkose sandstone or dolostone.

PI Response:
Our research focuses on geothermal resources in sedimentary basins which indeed are often formed by arkose or dolostone. We also investigate basalts. We have not focused on EGS as we are interested in CO_2-based geothermal energy development in sedimentary basins as they likely constitute a much larger total geothermal energy resource than artificially generated, small-scale EGS reservoirs.

Reviewer 23445

Comment: I do not think that the PI has spent much time considering how Task 5 is to be completed. At least he was unable to identify any clear path to completion during the presentation. It will be difficult to incorporate the impact of reactions on transport parameters when Tough2 does not tract reaction completion.

PI Response:
See our responses above concerning TOUGH2 versus TOUGHREACT and how we will iunclude our experimental insights into TOUGHREACT.

Reviewer 23509

Comment: A worry on this project is the lack of significant progress in developing an abstracted model for TOUGH2. There is also a fundamental concern regarding the premise being pursued by the PI that an abstracted model is adequate for reservoir simulations with a non-reactive flow simulator. While the computational demands for reactive transport simulations are high and the PI's desire to avoid that understandable, injecting an acidic fluid like CO_2 will inherently place the reservoir system into disequilibrium and the range of conditions, pressures, temperature, injection rate, etc. makes it virtually impossible to realistically apply non-reactive flow simulations to a fundamentally reactive flow and transport problem. The PI should consider potentially redirecting efforts towards improvement of more fundamental constitutive relationships relating porosity-permeability that can be implemented in reactive transport simulators that are much more likely to be used for CO_2 EGS projects.

PI Response:
We are conducting reactive transport experiments with end-member rock types (arkose, carbonates, basalt) to determine porosity-permeability relationships as these are likley more realistic than for example Kozeny-Carman relationships or other theoretical models. However, we agree that it is necessary to include a reactive transport simulator to keep track of the fluid chemistry. Thus, we will now include our experimental reaction and permeability modification results into TOUGHREACT rather than into TOUGH2. Thus we take advantage of the reactive fluid flow simulation capabilities of TOUGHREACT while using our empirical permeability modification (due to reactions) results instead of TOUGHREACT's theoretical permeability modifications.

Reviewer 23513

Comment: Reviewer did not provide comments for this criterion.

PI Response:

IMPROVEMENTS

Reviewer 23457

Comment: There is a need to define a path for the application of this work to real EGS systems.

PI Response:
We are not interested in EGS. We are interested in CO_2-based geothermal energy extraction from sedimentary basins as these likely constitute a much larger geothermal energy resource than artificially created and thus small-scale EGS reservoirs.

Reviewer 23445

Comment: It seems that at a minimum another state variable will have to be tracked by Tough2 to allow a state variable to represent reaction progression. Potentially this can be done by creating an artificial tracer.

PI Response:
We have thought about this but decided to instead go the above described route of including our results of permeability modifications due to reactions into TOUGHREACT (instead of into TOUGH2).

Reviewer 23509

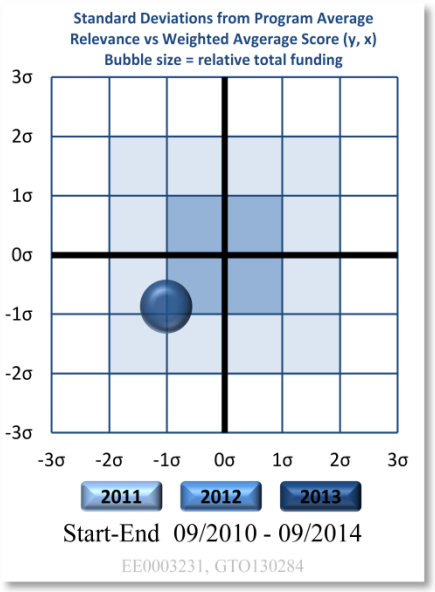
Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 23513

Comment: Reviewer did not provide comments for this criterion.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0003231
Project: Advanced Heat/Mass Exchanger Technology for Geothermal and Solar Renewable Energy Systems(NV)
Principal Investigator: Greiner, Miles
Organization: University of Nevada, Reno (UNR)
Panel: Supercritical CO_2; Working Fluids

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23638

Score: 7.0

Comment: This project consists of five separate components that all have the stated goal of developing and characterizing unique coating materials, surface configurations and membranes capable of accommodating a 10-fold increase in heat/mass exchanger performance via phase change processes and single phase convective heat/mass transfer. If achieved (and commercialized), this would improve power plant system efficiencies, thus leading to improved performance and reduced costs.

PI Response:
No Response

Reviewer 23445

Score: 4.0

Comment: t is important to make sure that the power system that is built takes advantage of the best technology to obtain the most optimum system. Optimum systems should be evaluated on both cost and performance. This project concentrated on optimizing performance with little or no regard to cost. Therefore the impact of this study is likely to be much less than if cost was also considered. However, in the early stages of development of many technologies, it is permissible to examine performance without regard to cost, for if one can demonstrate significantly superior performance, it is possible that with effort, the costs of the improvement can be reduced. Unfortunately I do not feel that the technologies that were studied here are new enough to justify one ignoring costs (such as monetary costs, and other costs such as additional operational and maintenance costs that the improvement may require).

When I read the materials prior to the presentation I noted that University of Nevada, Reno (UNR) identified a potential for system improvement by comparing a geothermal system thermal efficiency of 30% to a fossil fuel plant of 60%. First, both of these numbers are goals, and few geothermal or fossil plants reach these efficiencies. Second, a university should understand that it is not thermodynamically possible for a geothermal plant to have a similar efficiency as a fossil fuel plant as implied by the written materials. And finally, the thermal efficiency of a renewable energy plant is typically not a number that needs to be optimized. Thermal efficiency is only important for power cycles where the fuel costs are a significant portion of the total cost. When the fuel is free, the thermal efficiency is not a driving factor in determining the LCOE. The plant with the lowest capital cost is the winner regardless of the thermal efficiency. Thus, the goal of using expensive heat and mass transfer materials to improve geothermal efficiency is not a goal that the DOE should support.

PI Response:
The objective of this work is to develop five fundamentally-new heat/mass transport technologies that have the potential to significantly enhance the performance and reduce the costs of geothermal power plant components. Enhanced heat transfer in boilers and condensers leads to significantly decreased exchanger sizes and reduced system capital cost and parasitic losses. Enhanced membrane distillation processes can make efficient use of power plant waste heat and reduce water use. To date this project has focused on developing enhancement technologies, and determining the non-dimensional parameter ranges under which these mechanisms operate, without consideration of costs. In the remainder of this project the Investigators will work with equipment manufacturers and plant operators to determine if these parameters ranges are applicable to geothermal power plants, assess the performance gains from integrating one or more of these technologies into plants, and determining the associated reduction in plant costs. Reduced plant costs will decrease the Levelized Cost of Energy (LCOE) from these facilities.

The overall project includes five sub-projects:

i) Efficient Boiling Surfaces for Geothermal Power Cycles

ii) Heat and Mass Transfer in Membrane Contactor Processes

iii) Enhanced Single Phase Heat Transfer in Intermittently-Grooved Channels

iv) Re-inforced Super-hydrophobic Surfaces for High-Performance Condensers, and

v) Nano-Coating, Structured Porous Surfaces for Evaporation/Boiling Heat Transfer Enhancement

These tasks are innovative and have high payoff potentials for use in geothermal power plants if successful.

Reviewer 23509

Score: 7.0

Comment: Improving heat and mass transfer performance of heat exchangers is clearly critical to reducing overall LCOE of geothermal systems. This "project" is structured as a collection of five mostly independent efforts taking different approaches to enhancing heat transfer performance. In this reviewer's opinion, the disjointed nature of the separate "projects" is likely to lessen the overall impact of the project as a whole. It would be far better looking ahead if the PI would downselect to one or two of the most promising "projects" and focus the remaining time and budget resources to making more in depth advances in the selected areas.

PI Response:
We believe that each project holds the potential for high payoff for geothermal power plants. We therefore do not feel it would be appropriate to stop any of the projects at this stage. After we complete all five projects, we will focus on the most promissing projects via other sources of funding.

Reviewer 23513

Score: 5.0

Comment: The information provided and presented failed to provide any indication as to how this work applied to the GTO's mission and goals. The implication is that the improvement in exchanger heat and mass performance is going to improve performance of geothermal power plants, however no quantification of that improvement is provided. What is the impact of a 10-fold increase in heat/mass exchanger performance on power plant output? Power plant cost?

PI Response:
This work has focused on the performance of enhancement technologies that we feel have potential for dramatically improving geothermal power plant output. In the remainder of this project the Investigators will work with equipment manufacturers and plant operators to determine if the parameters ranges were these mechanisms operate are actually applicable to geothermal power plants, assess the performance gains from integrating one or more of these technologies into plants, and determining the associated reduction in plant costs.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23638

Score: 5.0

Comment: The project consists of five different research themes, all linked to heat and mass exchange technology. The first project evaluates the use of using a metallic screen to create a larger surface area and improve the heat flux. Two metal types (copper and stainless steel) and two working fluids were evaluated to create a system with a more efficient boiling surface with less superheat. Because of its greater thermal conductivity, the copper screen had the lower superheat. The second project consisted of a membrane system used for membrane distillation that would take advantage of waste heat. Several different membrane designs were evaluated, and experimental results were compared with different mass transfer models to predict water flux. The vacuum enhanced direct contact membrane distillation system had the highest mass transfer because of decreased air pressure within membrane pores. The third project examined the incorporation of grooved channels instead of a flat plate to improve single phase heat transfer associated with air-cooled condensers. The results of laboratory experiments were compared with numerical models, suggesting that the grooved system would lead to improved heat transfer. The fourth project related to using super hydrophobic surfaces to improve steam condensation. The use of a hydrophobic material would lead to dropwise condensation - drops that have high contact angles would be less likely to coalesce and form a continuous water layer on the surface. Different materials and surface morphologies were examined. The final subproject consists of developing a microporous layer to promote high surface wetting and enhance heat transfer. The presenter ran out of time to fully cover this last topic. The projects are all being conducted by professors and their research groups at University of Nevada, Reno (UNR), but it is not clear how much interaction there is between the different groups.

PI Response:
As mentioned earlier, in the remainder of this project the Investigators will work with equipment manufacturers and plant operators to determine if the parameters ranges in which these technologies operate are applicable to geothermal power plants, assess the performance gains from integrating one or more of these technologies into plants, and determining the associated reduction in plant costs.

Reviewer 23445

Score: 7.0

Comment: I think that the approach to the stated goals is reasonable. The experimental and modeling programs proposed will determine the best performance for the individual devices proposed. However, it is difficult to assign a high score to this category since I do not agree with the goals of the study.

PI Response:
No Comment

Reviewer 23509

Score: 7.0

Comment: Due to the very disparate nature of the separate projects, the technical approaches being pursued are independent and disconnected. In general, the approaches appear sound with some of the "projects" employing both computational and experimental validation. This reviewer would again like to see the number of separate projects reduced to 1 or 2 and perhaps focused along a more unifying technical theme in terms of molecular surface modifications as are being pursued in "projects" 4 and 5.

PI Response:
Please see our earlier responses.

Reviewer 23513

Score: 4.0

Comment: The presentation and information provided was not sufficient to adequately evaluate the approach being used - primarily because the information is effectively for 5 different tasks that are being conducted in parallel with little in common, other than the goal to improved heat and mass transfer processes. It would have been preferable if one or at a max 2 of these tasks were reviewed.

Because of the lack of specifics my perception of the approach used is subjective. Given University of Nevada, Reno (UNR) proximity to operating power plants, I would like to have seen the PI's discuss with the operator/owners of those facilities the conditions under which the facilities' heat exchangers operate. Specifically what are the ranges of values for fluid velocities, physical layouts, fouling experienced, etc. I believe that some level of fouling occurs in these plants on the working fluid side of the heat exchangers. Though the magnitude of this fouling may be low, it will impact the improvements that are projected for the different concepts that will utilize coatings or some surface enhancement on the tube surfaces..

While the concepts proposed are shown to have higher heat transfer performance, are the values of Reynolds' number at which those increases possible typical of those in a commercial heat exchangers. If these Re are atypical (too low) presumably the shell side of the heat exchanger will have to be larger to produce these lower Re - this would seem to be counter productive in terms of reducing cost.

The picture shown of a air-cooled condenser tube is for a air-cooled steam plant. It is unlikely that the tube would be able to operate at the higher pressures associated with the working fluids in a binary plant. Even if possible, this is an atypical condenser tube for these plants. Others have sought to increase the air-side heat transfer performance in these condensers, and though possible to accomplish there is invariably a performance penalty (increased pressure drop) associated with

doing so that negates, in part, the benefits of the increased heat transfer performance. The test results should provide some indication of whether this will occur, but none of those results are provided

Unclear as to where membrane distillation would be used in geothermal plants, and how that use is going to improve performance
.

PI Response:
All five physical phenomena that are being investigated in this program were presented for review in order to give the reviewers and indication of the breath of work being conducted. In future presentations we will concentrate on one or two projects if we are instructed to do so.

The reviewer's comment about high pressure binary cycle condenser tube designs is well taken. However, the grooved-passages that are investigated for enhancing the air side heat transfer in condensers were chosen based on promising results of earlier research, and was described in the project proposal. Experiments and numerical simulations show that transversely-grooved passages produce "organized" mixing patters whose heat transfer is higher than that of laminar flows for the same pumping power. This enhancement mechanism operates in the transitional Reynolds number range (between laminar and fully turbulent flow), which is relevant to air-cooled condensers. Enhanced heat transfer for a given pumping power can lead to lower blower powers and parasitic losses, and/or reduced condenser size and capital costs. While earlier work has focused on the fully-developed flow far from the passage inlet, the current work is considering the developing flow near the passage inlet, which is relevant to air-cooled condensers. Once the performance of the developing regime is characterized, its potential to reduce power plant costs will be assessed. It should be noted that utilizing surface coatings could also help protect heat exchanger surfaces from fouling. While the fouling study was not included in this task, it can be performed in future studies that the PIs will pursue.

Membrane distillation (MD) will utilize low-grade waste heat available at the geothermal plant to produce high quality water. The overall goal of this project is to identify the most efficient way to utilize the 'free' energy source to treat the water, thereby reducing the power plant costs. A fundamental understanding of the heat and mass transfer through the MD membranes, as well as the predictive flux models being developed, are key to understanding and optimizing the waste heat-driven MD process.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23638

Score: 4.0

Comment: There did not seem to be much integration of the individual projects. It is not clear how these projects (either individually or together) have contributed to achieving the stated project goal of a 10-fold increase in heat/mass exchanger performance. While all of the projects have demonstrated significant advances based on laboratory and modeling studies, no clear-cut plans were described as to how this technology might be commercialized. Also, while heat exchange benefits were noted for some of the innovations, there might be other effects that would result in less of an overall energy benefit. For example, for sub-project 3, there may be frictional losses or pumping power penalties associated with a change from a flat plate geometry to one that has grooved channels - do these effects significantly detract from the heat exchange benefits? Four of the five projects made presentations at professional meetings or have had resulted in publications reporting the results to date. Another question that was raised by the review panel is what would be the impact on heat transfer properties if fouling or scaling occurred, as this is a common problem in power plant and cooling systems.

Another issue that wasn't addressed in any detail is the chemical compatibility of geothermal and heat exchange working fluids with the chemical surfaces. Another item that bears further examination is whether the systems could be upscaled to commercially viable sizes, and if the systems would function properly at actual pressure and temperature conditions encountered by typical binary geothermal power plants.

PI Response:
The pumping power penalty of the grooved-passages (project 3) was not presented in the program review presentation due to limited time. As mentioned previously, earlier experiments and numerical simulations in fully-developed grooved passages show that transversely-grooved passages produce "organized" mixing patters whose heat transfer is higher than that of laminar flows for the same pumping power. The objective of this work is to see if the same favorable performance is observed in the developing region of these passages. As also mentioned in the previous answer, a future study can be related to impact of the coating materials for fouling. Assuming that superhydrophobic surfaces can function as a barrier material, there may be another advantage of using coating materials for anti-fouling. In terms of chemical stability of coating materials, further studies may be needed to answer the questions posed.

Reviewer 23445

Score: 4.0

Comment: I am not familiar with mass transfer membranes. Thus, I probably should not comment too much on that portion of the study. However, in all of the studies very few results were presented (this may be a result of the time limits placed on the presentation), and the results were not unexpected. These technologies are not new or novel. It is well known that a porous layer that his hydrophilic will improve boiling, and a hydrophobic material will improve condensation. It is well known that a rough surface will improve single phase heat transfer. Thus, when these concepts are tested, it is not surprising that improvements are seen. It would have been better if the amount of improvements was compared to the expected improvements (based on correlations from the literature on these modifications). In general I was not impressed by the low level of improvement that was demonstrated. For example for Project 5, one had to use a low Reynolds number application to see a significant improvement, and yet this is not an area where typical boilers operate. In an attempt to keep capital costs low, boilers operate with high Reynolds numbers.

I was not impressed that the impact on operational and maintenance costs was not addressed. For example, a complex condenser geometry will be more expensive to build, and will increase the fan blower power. These will likely impact LCOE much more than the performance improvement that was found. The results presented for this portion of the study (on page 10 upper left graph) was especially troubling. This showed that the local Nusselt number increasing as a function of the distance from the entrance. It is well known that the local Nusselt number is large (typically infinite) at the entrance of a channel, and decreases with distance from the entrance, and reaches a steady value once the thermal and fluid flow becomes fully developed. The plot shows a constant result after fully developed flow is established, but this is approached from zero (not infinite) at the entrance. Thus, the entire result is put into question. The presenter was unable to explain this graph. It seems that no experimental results are obtained for this project at this time, and the analytical results are limited to a 2D simulation. It was stated that others had found a significant impact of changing to a 3D simulation. It is unclear why this is important since the geometry is truly only 2D. It is possible that if the turbulence model resolves eddies in the third dimension a possible improvement may be obtained. However, if the modeling is a simple k-epsilon model, adding the third dimension should not impact the result.

PI Response:
The thin-film falling-film evaporator (Project 5) is a two-phase heat exchanger, which mainly relys on evaporation heat transfer. High liquid flow rates tend to degrade the heat transfer because of a large thermal resistance of a thick liquid layer formed on the evaporator tube. Therefore, low flow rates is preferred, if good surface wetting is warranted. The porous-coating evaporator developed by the project outperformed the plain evaporator because of a perfect wetting at low flow rates.

The grooved channel geometry was chosen because it is easily manufactured. Moreover, earlier work shows that for fully developed flow it produces higher heat transfer for a given pumping power than flat passage flows. As a result, compared to flat passages they will reduce parasitic loses and increase net power plant output and LCOE.

A non-typical Nusselt Number was used on page 10. Unfortunately, it was not well defined in the report due to space constraints. This Nusselt number is plotted against location in the channel. It is based on the average heat transfer coefficient between the passage inlet and that location. This heat transfer coefficient is based on the total heat transfer removed from the walls between the inlet and that location (which is zero for the inlet location), the temperature difference between the inlet air and the uniform temperature wall, and the passage average cross sectional area (not the wall surface area between the inlet and that location). The cross sectional area was used because it was the same for the flat and grooved passage. This area allows a meaningful comparison to be made of the total heat transfer performance of grooved and flat passages, and it allows the incremental heat transfer from an additional length of the passage to be evaluated. This Nusselt number definition is similar to a dimensionless temperature used by some other investigators.

The three-dimensional spectral-element simulations used in this work directly simulate fluid motion and heat transfer in all three dimensions. It does not employ a trubulence model such as k-epsilon because they are only appropriate at much higher Renyolds numbers. While the grooved passage configuration is two-dimensional, the flow patterns can be highly three-dimensional at transitional Reynolds numbers. The spectral-element method was used to calculate the time- and location-dependent velocities and temperatures. These results were then averaged over time. Earlier work has shown that three-dimensional simulations give results that are much closer to measurements than two-dimensional calculations, especially at the transitional Reynolds number considered in this work.

Reviewer 23509

Score: 8.0

Comment: Project seems to be mostly on track with budget and schedule. A reasonable number of publications and presentations have been completed. The reported heat transfer enhancements, while preliminary, appear promising on a couple of the projects.

PI Response:
No response

Reviewer 23513

Score: 5.0

Comment: Again the number of concurrent tasks in the limited information presented makes it difficult to assess progress.

Task #1 seems to have made the most progress. Performance is shown for different types of filament coatings, however it is difficult to evaluate benefit because no results are provided for testing a plain tube with no coating. Some added discussion on the surface enhancement ratio would be beneficial in the final report.

Task #3 - some computational fluid dynamics modeling has been done and some heat transfer performance enhancement shown in the presentation. Presumably there are also results for the effect of these enhancements on pressure drop.

Task #4 - The presentation slide #14 indicates a 50% performance improvement (presumably heat transfer) . I don't see this level of performance improvement in the figure on slide #13. It appears that the COSA tube has ~25% (or less) improvement relative to a plain copper tube. Further discussion on impact of oxidation conditions should be included in final report.

PI Response:
For Task 3, we are currently acquiring pressure drop results. For Task 4, discussion on the impact of oxidation conditions will be included in the final report.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23638

Score: 4.0

Comment: The project was initially scheduled to be completed in 2012, but three of the five sub-projects have requested a no-cost extension until 2014. The cause for the delay in completing the work was not discussed, other than a brief mention in one of the slides stating that the researchers will "investigate interesting phenomena that were observed during the course of the work". There appears to be very little integration between the different research groups at University of Nevada, Reno (UNR); such integration might result in an improved overall product. Also, it is not clear how each of these sub-projects contributes to the overall goal of a ten-fold increase in heat/mass exchanger performance. There was no mention of whether these innovations were going to be tested in the field in collaboration with an industry partner, or if these technologies will be commercialized.

PI Response:
This program is a compilation of 5 fundamental studies of promising technologies that, if successful, have the potential to improve the performance of geothermal power plants. As mentioned earlier, in the remainder of this project the Investigators will work with equipment manufacturers and plant operators to determine if these mechanisms operate in parameters ranges that are applicable to geothermal power plants, assess the performance gains from integrating one or more of these technologies into plants, and determining the associated reduction in plant costs.

Reviewer 23445

Score: 5.0

Comment: This project seemed to be a collection of five completely independent projects run by five different faculty. There seems to be little coordination between the projects. However, that is not a problem, for coordination between the separate projects is not required. However, the completion of the projects at the scheduled completion date does not seem

to be possible since a no cost extension was requested. Since this is at no additional costs, it is not a major concern. This project does not seem to be coordinated with other DOE efforts.

PI Response:
No response

Reviewer 23509

Score: 8.0

Comment: Project appears to be on track with both budget and schedule. However, the PI should consider focusing the remaining work on the most promising of the separate "projects" to obtain a larger impact by the end of the project.

PI Response:
We believe that all 5 tasks should be completed as originally proposed.

Reviewer 23513

Score: 3.0

Comment: There does not appear to be a consistent overlying management of these projects. One (the 1st) appears to be complete; the rest are not. There are inconsistencies in the budget and schedule – a no-cost, 1 year extension was requested, however the actual expenses exceed the planned expenses to date. This would suggest either the project is ahead of schedule or it is very much behind schedule and over spent.

PI Response:
While Task 1 will be completed this fiscal year, the other four are now scheduled to be completed during FY 2014.

STRENGTHS

Reviewer 23638

Comment: The research groups at University of Nevada, Reno (UNR) appear to have good laboratory facilities for conducting the work and competent teams to carry out the different phases of the project.

PI Response:
No response

Reviewer 23445

Comment: I found it hard to identify a strength of this project since it was fragmented in many different parts. Very little time was available to present the results from any individual project.

PI Response:
In future review reports, we will concentrate on the results from selected tasks if instructed to do so.

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

PI Response:
No response

Reviewer 23513

Comment: A very diverse and qualified team has been assembled.

PI Response:
No response

WEAKNESSES

Reviewer 23638

Comment: There appears to be little integration between the different research groups at University of Nevada, Reno (UNR) - improving the collaboration between these groups might result in additional innovations. Also, it didn't seem like there was a plan for trying to take the results of this work and test them in the field under operating power plant conditions. This would help demonstrate the commercial viability of these heat exchange concepts, would help identify any issues associated with upscaling and operating under actual field conditions, and might help speed up implementation of these technologies in future heat exchange systems. There were quite a few typos in the presentation materials, which detracted from the presentation.

PI Response:
In the remainder of this project the Investigators will work with equipment manufacturers and plant operators to determine if technologies being developed in this work operate within parameters ranges that are applicable to geothermal power plants, assess the performance gains from integrating one or more of these technologies into plants, and determining the associated reduction in plant costs.

Reviewer 23445

Comment: I was not impressed with the presentation. I assumed that 5 university professors were involved in writing the presentation materials. Yet the materials stated "superheat," when the word should have been "subcooling," and the presenter continued the error with his verbal presentation. The materials implied that one can improve geothermal thermal efficiencies up to the 60% that is possible with fossil plants, and the presenter stated this even more clearly. The stated goals of the program are not in alignment with the goals of the DOE geothermal program. All goals of the DOE program clearly state that the LCOE is the performance criteria that needs to be optimized, and yet this program is still using thermal efficiency as the ultimate metric.

PI Response:
The word "superheat" in the presentation was meant for "wall superheat", which is the tempeature difference between the wall of heat source and satuarated vapor used for a heat transfer calculation. In the future, to the extent possible, LCOE will be used to assess the impact of these technologies.

Reviewer 23509

Comment: "Projects" 2 and 3 seem particularly disjointed from the other activities and also offer the least chance for larger impact on GTO program goals. The PI should consider early closeout of those tasks to refocus work on 1-2 of the more promising tasks.

PI Response:
We believe that all 5 task should be completed as origianlly proposed.

Reviewer 23513

Comment: There has been no attempt to quantify the benefits of this work beyond providing a 10 fold increase in exchanger heat/mass performance. The implication of achieving this on plant cost/performance should be quantified.

I see no indication that the PI's for the individual tasks have had any discussion with geothermal plant owner/operators or equipment manufacturers. It does not appear that there has been any consideration of whether these technologies can be integrated into designs of the equipment for which they are intended or to how they are going to impact those equipment costs. Nor does it appear that there has been consideration as to how applicable some of these technologies are to geothermal plants (membrane distillation and intermittent grooved channels for air-cooled condensers).

There does not appear to be any overlying management of these diverse project activities - more like 5 separate projects operating in parallel.

PI Response:
In the remainder of this project the Investigators will work with equipment manufacturers and plant operators to determine if technologies being developed in this work operate within parameters ranges that are applicable to geothermal power plants, assess the performance gains from integrating one or more of these technologies into plants, and determining the associated reduction in plant costs.

IMPROVEMENTS

Reviewer 23638

Comment: As mentioned earlier, my suggestions for improving the project are:

1) Develop a way of evaluating how each of the sub-components would contribute to the stated goal of achieving a 10-fold increase in heat/mass exchanger performance.

2) Improve collaboration between the different research teams.

3) Test the systems under actual field conditions to identify any issues that could affect overall system performance.

4) Develop a plan for future commercialization.

PI Response:
Please see our earlier responses

Reviewer 23445

Comment: The program should shift to examining LCOE (Levelized cost of electricity) as a performance metric. I understand that this metric is very complicated, and difficult to use. So alternatively one could use the ratio of the capital cost of equipment to the net power output as a metric. All of the proposed technologies considered here will change both the numerator and denominator of this ratio. If this is deemed too difficult to use, one could even use the change in the dollar cost over the change in the net power produced.

PI Response:
In the future, to the extent possible, LCOE will be used to assess the impact of these technologies.

Reviewer 23509

Comment: Reviewer did not provide comments for this criterion.

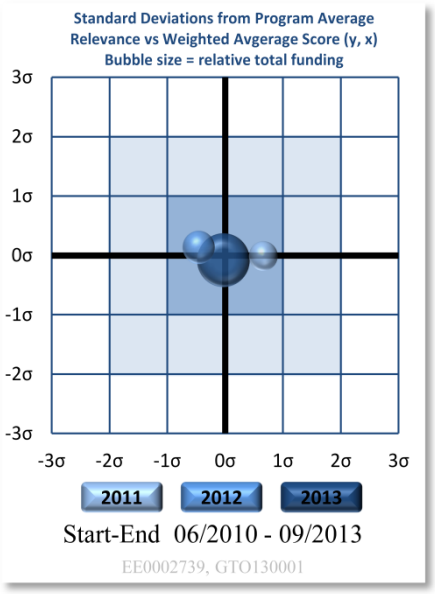
PI Response:
No response

Reviewer 23513

Comment: Reviewer did not provide comments for this criterion.

PI Response:
No response

Systems Analysis Reviewer Comments and Principal Investigator Rebuttals



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002739
Project: Estimation and Analysis of Life Cycle Costs of Baseline Enhanced Geothermal Systems
Principal Investigator: Turaga, Uday
Organization: Adi Analytics, LLC
Panel: Systems Analysis

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23399

Score: 5.0

Comment: This project has made modest progress and impact on GTO missions and goals. The project has estimated the cost of EGS projects and identified the major cost contributors, and has also identified new technologies that can reduce the individual cost components and analyzed the potential combined impact of these cost reductions on overall EGS project costs. The project findings are consistent with the finding of major cost contributors and the impact of technology advances from previous and concurrent studies. Although the results confirm these other studies, which is useful to GTO, they do not provide any significant additional insights or suggestions to GTO on how to advance their mission and goals.

Task 4, exploring the feasibility of combining IGCC and CO_2-EGS, is the focus of the this peer review for this project. Again, the project has done a good job of defining and characterizing this hybrid system, and has correctly identified most of the critical technical metrics, such as flow rate, thermal drawdown, resource temperature, and the pressure profile of CO_2 in the injection/production wells. However, the methodology and results are similar to those advanced by previous projects, most notably the initial analyses presented by Brown and then Pruess at the Stanford Geothermal Workshop in the 2000's. Although their results support these earlier analyses, they do not contribute much further insight. As presented, the project does not provide any insight on the economics of capturing and transporting CO_2 from IGCC plants, which could be useful if such a configuration were ever considered. A final judgment on the contribution can not be made until the economic analysis of this system is completed and presented - novel results and insights in this area could have a greater impact on guiding GTO decisions.

PI Response:
Our project's Task 1 – obtaining an independent and current assessment of the cost structure of EGS – may be similar to current and previous DOE-funded projects. However, such overlap is only beneficial because geothermal energy technology is changing rapidly due to new investment and continual evaluation of costs is helpful. Further, multiple cost estimates that are truly independent and developed in consultation with different experts -- even if they confirm previous studies -- only enables a more representative assessment of costs and should provide various stakeholders more confidence in making decisions around geothermal and EGS.

Even so, we are unaware of any previous work that overlaps with our project's Task 2 (estimating economic impacts of new technologies), Task 3 (understand the state of innovation through patent analytics), and Task 4 (evaluate novel process configurations, e.g., IGCC / CO_2-EGS).

Task 4 is work in progress and the preliminary economic estimates -- shared at various conferences and the 2012 Peer Review -- are being refined and revised and, therefore, not presented at this year's Peer Review. In regard to the comments on our technical assessment, the reservoir models were not the focus of our study as these observations (e.g., Brown, Pruess) are moderately robust. However, our analyses in this domain are robust, defensible and at the state-of-the-art. The focus of our study relates to costs / economics and barriers, including effects/magnitudes/dangers/costs of fugitive emissions and geochemical impacts on reservoir performance. These will be addressed in our final report.

Reviewer 24894

Score: 7.0

Comment: The objectives stated in the beginning of the presentation highlighted both goals and barriers to GTO objectives. I feel this was a good, and broad, approach to project review for purposes of relevancy. Much of the assessment of GTO objectives has been accomplished in prior years, but there were some items in Task 3 not discussed that also were complete in FY12. This should have been included. There is an assessment of LCOE reduction, and impact analysis of EGS R&D through patent analytics, which both serve overall GTO objectives.

Further data on the IGCC combination with EGS will expand the analysis from prior years, but is forthcoming. Task 4 does support the project objective for innovative approaches and further calculations on cost and risk reductions are expected to be useful. Without these figures the relevance/impact of Task 4 is limited based on the original project goals.

PI Response:
Thank you for the encouraging comments. Task 4 is work in progress and, on completion, our final reports will address all relevant and impact goals.

Reviewer 25420

Score: 8.0

Comment: This project brings an important element of analysis that ports experience in the oil & gas industry analysis style to identify barriers, benefits and potential enabling technologies. The approach based on data and information analysis is appropriate. Porting experiences from other energy sectors could benefit the mission of the Geothermal Office by expressing a potentially valid paradigm, once adapted to the geothermal energy sector.

Access to a network of expert in the oil & gas sector, but with a focus on questions relevant to geothermal energy is a valuable achievement of this project. Uniform collation of cost models as well as patent database could become an invaluable resource to potential developers of geothermal projects.

Modeling efforts for combined IGCC/CO_2-EGS, in terms of subsurface modeling, are limited and somewhat crude, so this might lead to state the obvious, so in this sense this part of the approach appears to have little impact. Facilities analysis, through prototyping is more interesting and relevant to the mission. This could bring added value for further analysis.

PI Response:
Thank you for the encouraging comments.

In regard to the IGCC-sCO_2-EGS work, the goal was to evaluate barriers and costs rather than to embark on a complex modeling activity of subsurface / reservoir performance. We agree that faciliteis analysis through prototyping would be beneficial but that is not part of our Statement of Project Objectives (SOPO).

Reviewer 23421

Score: 8.0

Comment: The goal of the project is to develop a model that encompasses a "highly granular assessment of capital costs." If achieved, the project is certainly relevant. This project differs from similar models in two important areas: 1) the qualitative analysis and incorporation of the expected impacts on capital costs of technology advancements gleaned from performing patent analytics, and 2) a relatively high proportion (33%) of the data come from interactions and contributions from private industry. As a matter of fact, this project incorporated more oil and gas industry data than any other projects this Reviewer has studied for this review. Given the wealth of drilling data available from the private sector (which comprises the largest cost and biggest risk to any hydrothermal or geothermal project), it is encouraging to see a study that attempts to access and incorporate that information in a meaningful manner. This will ultimately benefit not only this project, but all other hydrothermal and EGS projects. Access to private sector research and results was cited as one of the top "challenges" facing the PIs during this review process.

PI Response:
Thank you for the encouraging comments.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23399

Score: 6.0

Comment: The project approach in individual goals for the most part is good and for the most part effective, but the overall approach for the project attempts to cover too many areas and is not well focused. Within the individual tasks, the approach is not as in-depth as it could be. Key model inputs could be explored more thoroughly, and deeper conclusions drawn with a more rigorous approach. Coordination and application of results between project tasks could also be better executed. For example, the patent analytics study does not appear to inform the impact of new technologies task at all. And none of tasks 1-3 seems to have been applied to Task 4 yet.

Task 4 itself is too focused on the CO_2 cycle through the reservoir and the power plant and does not dwell at all on the costs, parasitic power requirements, or technical issues with the IGCC CO_2 source. In what has been presented, the IGCC could just as well be a black box CO_2 source. During the economic portion of Task 4, the approach should focus on the costs and power penalties incurred by the IGCC systems for utilizing pure O2 for combustion and then cooling, separating, pressurizing, and shipping CO_2 to the EGS system, and how the power and revenue produced by the EGS system offsets these penalties - is this hybrid system a net benefit? Otherwise, the current approach will not provide any new insights into using CO_2 as a working fluid except for proposing another potential power plant cycle operating at slightly different conditions and slightly different efficiencies than previous studies. Also, the assumption that the EGS reservoir is dry so that there won't be any water-CO_2 interactions subsurface or any water or mixed water-CO_2 flow to the surface plant is not reasonable. No reservoir below the water table is truly "dry" and the technical difficulties and economic impacts on materials from water/CO_2 mixtures in the system must be addressed.

PI Response:
Our project proposal to DOE chose breadth over depth because we saw a lack of high-level, overarching analyses covering various cost, economic, innovation, and technical issues in EGS and geothermal. Even so, we believe that our work is at the appropriate level of depth necessary for meaningful analyses and consistent with our Statement of Project Objectives.

We disagree with the comment that our tasks are not coordinated. In fact, we have spent considerable time in ensuring linkages between the tasks. For example, the patent analytics work in Task 3 has certainly informed both Tasks 1 and 2. Similarly, all tasks have informed Task 4. Some of these linkages will be evident from our previous peer review presentations as well as the forthcoming final reports.

Task 4, as mentioned during the peer review presentation, is work in progress and we are indeed evaluating some of the issues you have mentioned, e.g., parasitic power requirements.

Reviewer 24894

Score: Not scored

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 25420

Score: 8.0

Comment: The project team possesses the expertise to conduct a rigorous information analysis. The interview process with technical experts from the team's network is appropriate and sound. Economic evaluations appear solid, but most of all consistent.

It was not clear if the team has just compiled the database of geothermal and EGS technologies or in fact has processed this resource to go from data -> information -> knowledge. While raw data is important and necessary, the greatest impact could be produced by digesting data and producing knowledge for end users (data mining and creating a knowledge management systems).

PI Response:
Thank you for the encouraging comments. The creation of a knowledge management system is an excellent idea but, unfortunately, we did not think of that at the time of proposing this project. Therefore, it is not within our Statement of Project Objectives. Creating such a knowledge management system could be pursued in a future project.

Reviewer 23421

Score: 8.0

Comment: Given the information available to the Reviewer, it is difficult to confidently assess many of the aspects of the project's scientific/technical approach. That said, from a high-level overview, this Reviewer was impressed with some of the more unique aspects of the project's approach to modeling EGS and combined EGS programs. Mainly, the relatively high level of contribution of data from private industry and the application of patent analytics to the cost determination learning curve. The patent analytic process seems to be a combination of qualitative and quantitative metrics, designed to project the capital costs of an EGS project into the future. In doing so, the model should also serve to highlight where current weakness exist and where the most technology concerns are centered. The overall impression by this Reviewer is that there is a strong combination of scientific approach married with technical application that could ultimately result in a fairly unique, useful tool.

PI Response:
Thank you for the encouraging comments.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23399

Score: 5.0

Comment: The accomplishments to date, in terms of the quality of the results, their insight and impacts, and the number of publications, has been adequate to date. The project has done a good job of staying on schedule, consistently producing results that appear accurate and credible, and of conveying those results through publications and presentations to the public. However, the results to date have not provided much additional insight into EGS costs and technology advancements that had not been published in previous results. Given that over $1 Million dollars has been spent to date, there is plenty of room for improvement in terms of providing novel results and new insights of EGS technical systems.

PI Response:
Our project goals include obtaining an independent and current assessment of the cost structure of EGS, which may be similar to current and previous DOE-funded projects. However, such overlap is only beneficial because geothermal energy technology is changing rapidly due to new investment and continual evaluation of costs is helpful. Further, multiple cost estimates that are truly independent and developed in consultation with different experts -- even if they confirm previous studies -- only enables a more representative assessment of costs and should provide various stakeholders more confidence in making decisions around geothermal and EGS.

We are unaware of any previous work that overlaps with our project's Task 2 (estimating economic impacts of new technologies), Task 3 (understand the state of innovation through patent analytics), and Task 4 (evaluate novel process configurations, e.g., IGCC / CO_2-EGS). Therefore, we would hope that outcomes from that work would be viewed as novel and insightful.

Finally, we hope that a more representative assessment of the quality, novelty, and insightfulness of our project outcomes will become possible after completion of the project and the final reports.

Reviewer 24894

Score: Not scored

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 25420

Score: 8.0

Comment: The team has accomplished a significant compilation of data and have progressed according to schedule, except for one task. The quality of the results is somewhat mixed, but high in general. To peel the onion, as indicated to introductory sessions with DOE, since this project has a strong focus on data, deeper insights regarding barriers must be emphasized. Perhaps this is more clearly reflected in reports and publications. I am aware of charts presented or available, but an interpretation of the score analysis or translation is necessary.

Overall, this project has a high benefit/cost ratio. Standardization of cost analysis reflects quality and moves the project toward high-impact outcomes.

PI Response:
Thank you for the encouraging comments.

Reviewer 23421

Score: 5.0

Comment: The quality of the accomplishments to date seem high. Important variables have been identified, forecasts developed, costs compiled; in short, input data have been gathered, analyzed, sorted, and scrubbed. But now comes the hard part... putting it all together, making it work, identifying the errors or weak spots, and completing a working model. Given the multiple sources of input data collected, merely getting to this point is an accomplishment. However, the project is about 10-13 months behind schedule. And it is unclear from the presentation if cost targets were met and additional funding required is in line with original estimates. But the scope and complexity and background work that has been accomplished so far is fairly impressive in that it covers a broad swath of input and data from diverse constituencies.

PI Response:
Thank you for the comments. We have requested time extensions but no additional funding. We are confident of completing all our work in the revised timeline.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23399

Score: 7.0

Comment: Management of the project appears to be effective, with few variations from the original schedule. Some delays in the project were corrected and do not seem to have a significant impact on the overall project.

PI Response:
Thank you for the encouraging comments.

Reviewer 24894

Score: 6.0

Comment: The project has encountered delays and extensions of stage deadlines. The presenter's response of conflicting academic schedules/responsibilities is understandable, but in Task 4 this has led to a 9 month delay. With respect to the relevance of Task 4 to GTO objectives this delay is likely reason behind incomplete data risk and cost reductions. Additionally, the remaining segments of Task 3 fall under the same situation. This should be improved upon to better adhere to the original project timelines.

PI Response:
We are confident of completing all our work in the revised timeline.

Reviewer 25420

Score: 9.0

Comment: This project is well coordinated and future plans indicate placement of appropriate decision points. The leading team has made outstanding use of their resource network in a well-concerted (coordinated) effort. This has allowed them to make effective use of resources to benefit numerous stake holders. This project serves as a role model regarding similar data-analysis based projects. Moreover, focus of objectives allows quick turnaround of results, which more ambitious project sometimes lack.

PI Response:
Thank you for the encouraging comments.

Reviewer 23421

Score: 7.0

Comment: This reviewer can only guesstimate at the efficiency and effectiveness of the project management and coordination. PI relied on 69 different sources of input data (from research institutions, project developers, private industry, and academia) and has produced a usable data set. So it may be inferred that the project management and

coordination was fairly high. Those are a lot of "expert elicitations" that were incorporated into the data set. It would have taken a coordinated effort to gather that much data from a diverse group of sources. Reviewer can also assume that many more than 69 contributors were approached in order to get that level of participation. Speaks to a well-executed plan to gather the input data required to reach this point in the project.

PI Response:
Thank you for the encouraging comments.

STRENGTHS

Reviewer 23399

Comment: The project has several strengths. The tasks are well-defined and have been executed in an efficient and timely manner. There is the possibility of a project of this scope with so many tasks to get bogged down in details and sidetracks, but the PI's appear to have done a good job in staying focused and remaining on schedule. In their analyses, the PI's have managed to identify the key cost and technology variables that impact EGS projects and evaluate their impact.

The project has also done a good job of documenting and publicizing their results. The PI's have produced a large number of publications and have spread these across a wide audience, including geothermal conferences and peer-reviewed publications.

PI Response:
Thank you for the encouraging comments.

Reviewer 24894

Comment: The project does a good job of adhering to its objectives. Prior work has done well to focus on reducing LCOE and risk in EGS modeling. The inclusion of IGCC-EGS is an innovative approach to modeling EGS options. This project has also done a superb job of communicating the results of the study thus far in the form of papers and conference presentations.

PI Response:
Thank you for the encouraging comments.

Reviewer 25420

Comment: 1. Without a doubt, a viewpoint based on experience with other energy sectors brings a fresh approach and dispassionate style to the team's assessments. This does not mean that my interpretation is that the team lacks intensity, but that the research is conducted objectively.

2. The project team has a significant experience with the type of analysis conducted in this project. They bring data analysis technologies not necessarily available to more geothermal energy focused groups.

3. The team has incorporated parties that might not express an interest at first. The benefit is the communication channels now available.

PI Response:
Thank you for the encouraging comments.

Reviewer 23421

Comment: 1. Data set incorporated 33% input from the private sector; this is the highest level of data collected from industry that Reviewer has seen in this review.

2. Importantly, model incorporated data from the oil and gas industry; where -- by far -- the most drilling and formation information exists; very pleased to see this; should make for a more realistic model.

3. Model construction was comprehensive in its approach in that it used numerous data sources from diverse backgrounds.

4. Model attempts to "localize" its results, drilling down into the economics at the regional and vendor level.

5. There should be many end users for a model as comprehensive and seemingly unique as this one could end up being.

6. The utilization of "patent analytics" represents a different method of identifying current constraints and areas of weakness to be addressed; expect finished project to offer a number of policy insights.

PI Response:
Thank you for the encouraging comments.

WEAKNESSES

Reviewer 23399

Comment: The project also has several weaknesses. The most notable is that the project seems spread thin by the number of tasks. As a result, the tasks tend to not go in-depth to any of their particular subjects. The results of the tasks support those of previous studies, but do not make any significant new insights or add much to the analysis data or knowledge base.

PI Response:
Our project proposal to DOE chose breadth over depth because we saw a lack of high-level, overarching analyses covering various cost, economic, innovation, and technical issues in EGS and geothermal. Even so, we believe that our work is at the appropriate level of depth necessary for meaningful analyses and consistent with our Statement of Project Objectives.

Our project goals include obtaining an independent and current assessment of the cost structure of EGS, which may be similar to current and previous DOE-funded projects. However, such overlap is only beneficial because geothermal energy technology is changing rapidly due to new investment and continual evaluation of costs is helpful. Further, multiple cost estimates that are truly independent and developed in consultation with different experts -- even if they

confirm previous studies -- only enables a more representative assessment of costs and should provide various stakeholders more confidence in making decisions around geothermal and EGS.

We are unaware of any previous work that overlaps with our project's Task 2 (estimating economic impacts of new technologies), Task 3 (understand the state of innovation through patent analytics), and Task 4 (evaluate novel process configurations, e.g., IGCC / CO_2-EGS). Therefore, we would hope that outcomes from that work would be viewed as novel and insightful.

Finally, we hope that a more representative assessment of the quality, novelty, and insightfulness of our project outcomes will become possible after completion of the project and the final reports.

Reviewer 24894

Comment: Given the project outlays, the only real weakness I feel needs to be managed better is regarding missed project deadlines. Although this was explained the resulting delays do seem long for scheduling conflicts. This ultimately resulted in limits on the analysis of Task 4, not from technical, but more economic position. Since LCOE reductions specifically have been a strong point of previous peer reviews, I would expect that a complete analysis of Task 4 to also include a similar approach. This was certainly a missing component in this year's review.

PI Response:
We are confident of completing all the economic analysis and other items in our Statement of Project Objectives in the revised timeline.

Reviewer 25420

Comment: 1. I sense that the project needs participation from more traditional geothermal energy practitioners to contrast evaluation methods, particularly in the subsurface. This does not mean a qualification of the methods employed, but rather a way to gauge results.

2. Metrics used for evaluation of potentially disruptive technologies need some translation.

PI Response:
Some of the subsurface issues will be discussed in our final reports.

Reviewer 23421

Comment: 1. Appears to be an extremely complex model, loaded with variables and assumptions; complexity can magnify erroneous conclusions. Model will be of most use to an educated population who can apply technical and common sense to output data.

2. The incorporation of both qualitative and quantitative data (and the interaction between the two data sets) also greatly increases the variability of any outcome.

3. It is difficult for this Reviewer to evaluate the accuracy and impact of the inclusion of "soft" variables; this includes policy, coordination and integration, and the impact of emerging technology.

PI Response:
Thank you for your comments.

IMPROVEMENTS

Reviewer 23399

Comment: In task 4, the project should focus closely on the economics portion of the analysis, especially the costs and power parasitics associated with the IGCC plant designs, and how revenue and power generated from the EGS CO_2 system can offset these costs. The ability to co-locate EGS and IGCC systems should also be explored, since CO_2 pipelines could be a significant expense for these systems. The presence of water in the reservoir should also be expected and considered, as opposed to the current assumption of a dry reservoir.

Future plans for Task 5 – outreach – were not discussed in the presentation, and in my opinion are not a good use of project time. Other than publishing results as report and presenting at conferences, outreach should be left to GTO so that results can be combined with results from other projects to give consistent message and highlight GTO priorities. A single message from GTO is a better use of resources than multiple messages. The project should limit outreach to planned publications and presentations.

PI Response:
Task 4 is work in progress and will address all of the above issues by the time it is complete.

We will integrate your comments on Task 5 in our plans going forward.

Reviewer 24894

Comment: Schedule management improvements would likely address concerns over the amount of analysis content being submitted for Task 4. Since the explanation of the schedule delays was vague I can only leave the recommended improvements to general comment.

PI Response:
We will complete all our work in the revised timeline.

Reviewer 25420

Comment: 1. I would incorporate the opinion of geothermal energy evaluators to assist with interpretation of results and technology transfer

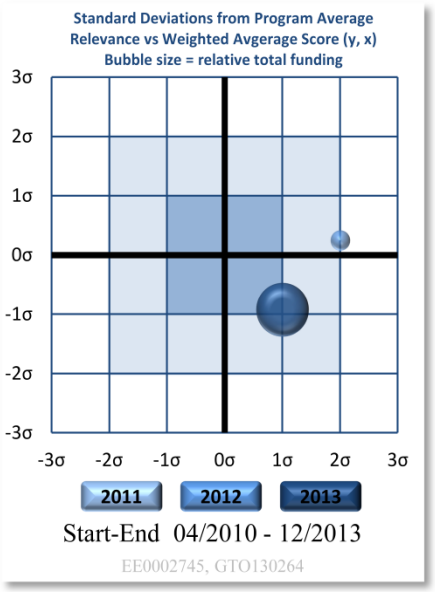
2. The project could use more detailed analysis/modeling of subsurface scenarios. The nature of geothermal resources is dominated by the transport of energy and mass in fractured systems of low porosity, whether those fracture systems are natural or induced.

PI Response:
Our final reports will seek to address some subsurface issues.

Reviewer 23421

Comment: Reviewer's strongest recommendation is to continue to draw on the PI's access to private sector and oil and gas industry data and business connections. The utilization and incorporation of just such data is largely absent from other models/projects this Reviewer has seen as part of this review process. By collecting making available these data, all EGS investigators and users will benefit from the shared data base.

PI Response:
Thank you for the encouraging comments.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002745
Project: Analysis of Low-Temperature Utilization of Geothermal Resources
Principal Investigator: Anderson, Brian
Organization: West Virginia University
Panel: Systems Analysis

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23480

Score: 7.0

Comment: The study expands the scope of geothermal project opportunities to low temperature regions, especially in the eastern half of the U.S. This is in keeping with the Program's goals. A broad range of project options are studied including hybrid applications involving biomass. There are numerous other applications which are not explicitly mentioned, and presumably the case studies chosen here are meant to be representative. The study hopes to show that low-temperature geothermal applications can be economic. If this conclusion can be verified, a whole new set of applications would open for geothermal. A supply curve for low-T resources will be the most useful product of the project.

PI Response:

Reviewer 25420

Score: 7.0

Comment: The project SOPO (Statement of Project Objectives) clearly states the three major objectives that are relevant to the broader mission of the Geothermal Office by addressing opportunities for low-temperature geothermal resources. The three objectives in my view can be summarized as 1) a techno-economic evaluation of supplementing fossil fuel energy use to offset CO_2 emissions (or Use 1), 2) Economic optimization of low-temperature resources and 3) Scale-up to regional cases to map the opportunities of this low-temperature resources. These objectives are further refined into numerous tasks, which in itself creates challenges to meet the goals by potentially spreading efforts.

PI Response:

Reviewer 23421

Score: 3.0

Comment: Reviewer rates this project as relevant on a very high level, in that it attempts to quantifying the gross potential of EGS in lower-temperature locations on the East Coast. The project seems to be searching for the answer to "what if we put geothermal energy generation (both direct and as a source of co-generation) in all the populated places with good

infrastructure... what could we theoretically produce?... and what would the theoretical LCOE be?" This is a practical, if grandiose question. Reviewer has no insight as to whether the model being developed here is on the path to answer these questions. The questions are relevant. But in this Reviewer's opinion, the negative here is that the model may be overreaching in its scope, attempting to answer too many questions at once.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23480

Score: 5.0

Comment: Approach revolves around 4 case studies; note that original SOW specified 3 case studies. Case studies are geared to the strengths of the project's team members; they are not totally representative of the gamut of low-T options. The project uses the latest tools in geothermal analysis (e.g., TOUGH2). While national data about the resource, etc are available, data scaled for a local area are scarce,especially in the East. The flow chart depicting various components of the analysis is thorough, but overly complicated. A step-by-step example using one of the cases would be more instructive. Low temperature is defined as 90-150C resources; obviously, there are other use for geothermal fluids at <90C, including electric power generation.

PI Response:

Reviewer 25420

Score: 7.0

Comment: The project reflects rigor in isolated pieces of research, while not accomplishing this in the bigger picture. I left the presentation with a sense that the database of subsurface models does not necessarily map the universe of systems that the project is attempting to map regionally. Unfortunately, this introduces an element of ambiguity and not uncertainty. In this sense, the presentation of the project did not clearly indicate if there are issues of sensitivity or uncertainty, and this being unclear can steer the evaluation in the wrong direction.

I was under the impression that the project would lead to a ranking of opportunities, so that a transfer of technology of this project would encourage further research to evaluate these opportunities as portfolios. However, I was unable to tell, except for electricity generation as not being competitive, how these low-temperature resources represent a prime opportunity.

PI Response:

Reviewer 23421

Score: 4.0

Comment: From an university/academic standpoint, the scientific approach looks valid. But -- as with so many of the studies conducted in academia -- this model incorporates far too little actual hard data from the real world, when attempting to quantify the cost of an EGS operation.

Reviewer is not qualified to comment on the data programming or integration aspect of the project.

However, the overall impression is that the project is trying to incorporate too much. With all the input variables on top of the variability of the type or degree of EGS energy produced, Reviewer worries that the potential for useful estimates of outcomes is low.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23480

Score: 6.0

Comment: Project has achieved most of its scheduled tasks, and should end on time. Inclusion of go/nogo decision points seem superfluous for a paper study such as this. The compilation of drilling cost data is a valuable contribution---the data apparently do not include geothermal drilling. Despite the bias toward oil & gas wells, the data are useful for estimating current costs for geothermal wells. At depth, exploratory wells are more expensive than development wells. While intuitive, this may not always be the case if vertical slim holes are used for exploration wells. GEOPHIRES may be a useful tool to estimate levelized cost of heat (LCOH) once the model is vetted and bench-marked. Description of the model is lacking--not clear if or how GEOPHIRES relates to GETEM. The results presented for a biorefinery uses 180C resources which falls outside the defined range of low-T. At these temperatures, the cost of geothermal heat approaches that of the base fuel. Aspen model results for the WVU case study look promising, but the specifics of the resource are not given. Results suggest EGS system component costs can approach cost of natural gas. Costs of the EGS component are not presented in these analyses. Why aren't conventional geothermal components included in hybrid design analysis? A direct comparison of the four case studies is missing.

PI Response:

Reviewer 25420

Score: 7.0

Comment: The projects has produced a large number of relevant results toward meeting technical targets and possibly objectives. The quality of the different pieces within each task appear to be of high quality. The emerging analysis from the combination of different pieces does not seem to reflect the level of effort. This might be a perception from what appears to be a dilution of efforts. The project progress appear to present a program, rather than a unified project, which in itself does not speak of the quality of the research teams.

PI Response:

Reviewer 23421

Score: 5.0

Comment: Again, just from what has been presented during the review process, it appears that much has been accomplished. And most of it was on schedule. But it is difficult to tell if what has been accomplished is ultimately useful.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23480

Score: 5.0

Comment: The project is one year behind schedule, and a no-cost extension till the end of 2013 was necessary. As a result, many of the project's objectives, notably the supply curves, are not available. In addition, just over half of planned costs have been spent; there is no indication the balance can be spent in the allotted time. Nevertheless, the PI has kept the project on track, and prospects are good that most products will be completed on time. There is an extensive publications list stemming from the project.

PI Response:

Reviewer 25420

Score: 6.0

Comment: Project management, despite best intentions, faces the difficulty of coordination of a major/large interdisciplinary effort. Slide 4 in the presentation is apparent in this sense, because different tasks destined to meet the Phase 1 objective feed each other without evaluation cycles. It is significant the achievements so far, if one considers the numerous participating parties. As I indicated before, this spreads energies and demands enormous coordination efforts.

PI Response:

Reviewer 23421

Score: 5.0

Comment: As an outside observer, it is tough to comment intelligently on how well this is internally coordinated. But there is a regrettable lack of coordination with the wealth of data that exists in the private sector.

PI Response:

STRENGTHS

Reviewer 23480

Comment: The project examines a new area of potential geothermal markets: low-T, hybrid geothermal systems. The approach is thorough and systematic. Compilation of drilling data is impressive.

PI Response:

Reviewer 25420

Comment: 1. This project possesses a talented team of researchers that can develop in-depth analyses of different aspects of this relevant problem. Low-temperature geothermal resources have a role to play, given their wider geographical spread and perceived regional opportunities.

2. The project team is clearly productive and is qualified to use traditional and cutting-edge tools to produce this massive integration effort.

3. The project, at least partially, has focused some effort to conduct a serious economic evaluation of the opportunities of geothermal energy in biorefining, contrasting it with current practices.

PI Response:

Reviewer 23421

Comment: 1. Ranking potential EGS locations should be a high priority goal. This project is an attempt to do just that.

2. The project is an admirable attempt to integrate subsurface geology with demographics against a backdrop of climate and infrastructure. The resulting model is reaching for a practical answer to the question: "Where should we put what kind of EGS / geothermal system?"

PI Response:

WEAKNESSES

Reviewer 23480

Comment: Judging from the SOW and subsequent delays in execution, the project appears to have been too ambitious in its scope.

PI Response:

Reviewer 25420

Comment: 1. The major weakness of the project is its monolithic approach to evaluation of opportunities. Early selection of the best candidates for use of low-temperature geothermal resources would have allowed the project to focus its energy to more comprehensively elucidate the size (and 'shape') of the opportunities.

2. The aforementioned weakness is perhaps a reflection of commitment to numerous tasks/teams. This reflects a lack of clear decision points, but it is still possible to improve coordination efforts and build major decision-making milestones for completion of the project.

3. Data appears to have been generated, but not always used. For instance, the Principal Investigator did not clearly address the question on the representativeness of the reservoir database. This seems to me to be relevant for efforts to evaluate at the regional level, because it speaks of the quality and energy content/deliverability of the resource.

PI Response:

Reviewer 23421

Comment: 1. In science, "simplicity" usually enhances the chances of coming up with the most correct answers. This is a very complex/complicated model. Especially when you layer in the variables associated with hybrid geothermal systems. Common sense tells this Reviewer that the likelihood of generating scientifically attractive (but practically incorrect) conclusions seems very high. This would render the model unusable.

2. Not enough "real world" drilling data were included.

3. A data base that was built on "1,000 simulations" sounds good, but if the quality of the assumptions used is not of the highest caliber, the complexity merely multiplies the number of incorrect scenarios.

4. Given the complex nature of the model, Reviewer would be uncomfortable relying on any conclusions and/or recommendations generated. This renders the model a low value-add to the decision making process.

PI Response:

IMPROVEMENTS

Reviewer 23480

Comment: Supply curves were possibly too ambitious for this project. The effort might have benefited from a reduced scope, focusing on more case studies and in-depth analysis/comparison of the results therefrom.

PI Response:

Reviewer 25420

Comment: 1. I am not certain that the project is meeting the objective of an in-depth analysis by attempting to meet very ambitious and diverse goals. Perhaps a layered approach that identifies major impacts with a simpler analysis would allow the researchers to go deeper into aspects that would bring a greater impact of the analyses by using the more complex battery of tools already used in the original approach. Surrogate or proxy models could probably screen out opportunities that will have very little impact, even after a refined analysis is conducted. Marginal opportunities do not generally become attractive after using more complex analysis. This might be true only when there is a fundamental aspect of science that is a barrier to this type of analysis, but this is not an objective in this project.

2. I would recommend making a decision on whether the opportunities should be evaluated by location or just in isolation, independent of location. My opinion is that this is up to the Principal Investigator's consideration, but given the emphasis on geographical mapping (GIS), it appears that at least a raking of locations=F(opportunities) would be appropriate.

3. In connection with (2), I sensed excessive spread of activities. At this point, the project management team could make a decision to focus resources to elucidate the most important/relevant opportunities. A score-card method or something along those lines should allow the coordinators to make this decision without jeopardizing meeting objectives. At present, the numerous tasks have not met sufficient decision points.

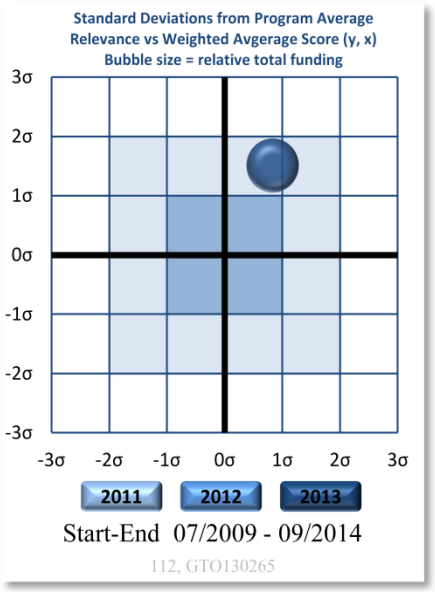
4. To coordinate efforts better, I would recommend a group meeting to ponder all the activities in the entire group. This can be accomplished through a yearly workshop that could as well serve to set decision points. This refocusing effort would allow the overall team energy to be dedicated to the more rewarding and higher impact tasks.

PI Response:

Reviewer 23421

Comment: Perhaps it makes sense to break the model down into completely stand-alone modules. The project appears to scream for more "simplicity." But in the end, it is unclear to the Reviewer how this project is an improvement over sitting down with a Road Atlas and a standard temperature map as a starting place.

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: 112
Project: GETEM Development
Principal Investigator: Mines, Greg
Organization: Idaho National Laboratory
Panel: Systems Analysis

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23480

Score: 9.0

Comment: For a decade, GETEM has been the primary tool used by DOE to estimate the LCOE from geothermal energy and assess the potential impact of its R&D program. As such, the model is highly relevant to virtually everything the GTO funds and should play a role in making informed funding decisions. As a matter of course, GETEM must be current and representative of all aspects of geothermal development. This project is well-directed toward those objectives.

PI Response:
No response

Reviewer 24894

Score: 10.0

Comment: The GETEM model is very much relevant to the GTO goal of reducing LCOE by providing a quantifiable metric for measuring project performance. A long-term result of this project should allow all R&D projects in the GTO portfolio to use the same measure for comparison and funding prioritization. Unlike other LCOE modeling efforts, the GETEM effort is innovative in that it integrates key components of geothermal design to factor costs over time and also define variable relationships. Engaging industry to assess the accuracy of inputs and outputs is a strong step in model confirmation. I believe the functionality of the modeling efforts are improved significantly by the diversity in input options, but agree with the the PI that the model is only as good as those inputs from the user. Expanded efforts in modeling both Hydrothermal and EGS options and the inclusion of the Sandia National Lab well cost models add to this diversity.

PI Response:
No response

Reviewer 25420

Score: 9.0

Comment: The project objectives are clearly defined and the match needs of the Geothermal Office's mission and goals. Uniform (comparable) power generation costs evaluation from geothermal resources is viewed as necessary to create portfolio analysis, rank opportunities within a portfolio, entice attractive geothermal projects and identify investments to increase the potential of geothermal resources through development of more competitive technology alternatives. This is even more important, if costs evaluation methods are deemed reliable and standardized, which in essence means they have been thoroughly tested/bench-marked.

GETEM was presented as a tool that would fill a well-defined gap by allowing GTO and the public to easily access a standardized LCOE from geothermal resources. This was well laid out early in the presentation at the review session and project design was matched with GTO' goals. The project addresses important issues regarding costs estimates in the whole value chain of a geothermal project. It is encouraging to see attempts to benchmark and sensitize the evaluation as well as to examine undiscovered resources, i.e. potential, but with no project design.

PI Response:
no response

Reviewer 23421

Score: 10.0

Comment: The GETEM model attempts to cover a broad swath of technical and economic ground. But the goal of the model gets at the core of the future development of geothermal and hydrothermal energy generation: understanding and quantifying the cost of energy under a user-provided range of scenarios. Therefore, it is extremely relevant. The project is also highly impactful in that the model is available for anyone to use. And that is one of its greatest strengths: the broader and more diverse the universe of users, the more feedback is provided and incorporated, improving the model for everyone over time.

PI Response:
no response

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23480

Score: 7.0

Comment: The project correctly puts emphasis on well costs, as they are often a determining factor in LCOE estimations. Industry input is used to improve model calculations. Five hydrothermal scenarios and five EGS scenarios are used to represent the breadth of resource diversity in temperature, depth, productivity, and power generation. There are some gaps in the scenarios. For instance, hydrothermal resources may exceed 2.5 km in depth, and this can be expected for "undiscovered" resources. Flow rates may routinely be <80kg/s. And EGS can extend much deeper than 4 km (e.g., Soultz). An interesting inconsistency: Hydrothermal case A and EGS case B yield the same power but differ in flow rate by 2.5X? A down select process is used to find the commercial project, but the criteria for selection are not presented. The model had to be adapted to meet DOE requirements, though the extent of this adaptation is not clear.

PI Response:
GETEM provides estimates for any resource depth and temperature scenario that a User defines, with the constraints that the well costs are based on data for depths of 6 km or less, binary plant temperatures of ~225C or less, and flash plant temperatures >100C.

The scenarios that were evaluated, were defined by the GTO to be consistent with its different programmatic activities and take into account EGS resource potential. The expectation is that the initial EGS development in the US would occur at depths of 4 km or less.

The scenarios defined for hydrothermal resources relied on information obtained in interviews with subject-matter experts from the geothermal industry. The values ultimately used to define the scenarios were those most consistently provided in these discussions, i.e., the most likely values. As part of this effort, the impact some of these inputs on the LCOE was assessed – depth was not one of those parameters.

While Hydrothermal A and EGS B have the same power output with different flow rates, the indicated flow rates are from a single production well. EGS case B requires more production wells to produce the 15 MW of sales than Hydrothermal A.

No attempt was made to define the down-selection criteria for the exploration and confirmation sites to the final successful site. The industry interviews indicate that this down-selection occurs, and provided insight as to approximately how many locations/sites had to be considered, but not as to how this down-selection is accomplished.

Reviewer 24894

Score: 8.0

Comment: I applaud the inclusion of project down-select in the model performance. This technique is a necessary part of determining project cost dynamics over the full project lifetime. Differentiating the case parameters for hydrothermal and EGS scenarios is also a very valuable option in the model design, and directly supports ongoing efforts in supporting EGS development and demonstration as part of the R&D portfolio. The inclusion of industry feedback is also provides accuracy in modeling outputs, and I'm encouraged to see that it is being used throughout project development.

For best model performance the discounted cash flow method is a good inclusion since it provides an annualized breakdown of the project performance. For modeling purposes it is a more accurate means of assessing cost over time. I'm happy to see it added, however, I would also like to see some comments on method comparison.

A point of caution is the relationship between the down-select and variable discount rates. The goal is to model project risk by including the reduced probability of success at varying stages of development. In effect both of these options do this and by including both there is likely a multiplied effect within the model. I would encourage the PI to state explicit expectations for setting the discount rate, but use a consistent rate over the life of the project. The adjustable time component of the discounted cash flow method is valuable in the modeling for determining alterations of the time value of money.

PI Response:
The use of both the down selection process and the higher discount rate in the early project phases was discussed internally within the analysis team as to whether using both was assigning undue risk and cost to those phases. The discussions with the industry implied that both occur - project financing costs are high for the early phase of the project, and multiple locations have to be considered. This topic will be revisited with industry to confirm that our interpretation

was correct; if it was not, the model will be modified to allow for the option of using either a higher discount rate at a single location, or using the down-selection process with a lower discount rate, which will be defined after consultation with industry.
The discount rates assigned in the model for the early project phases comes from those industry discussions, as do the number of sites considered in the down selection process. The 7% discount rate used once operation begins is consistent with that used by EERE in its determination of LCOE for all its renewable programs.

Reviewer 25420

Score: 8.0

Comment: The project team has clearly mapped the execution of the project to meet the objectives and milestones. The team has also attempted to access available sources of data, particularly on drilling costs, as this variability affects the evaluation of LCOE estimates. Methods and procedures have been succinctly explained and the project appears to present no staffing issues.

The evaluation of the impact of uncertainties has been limited to the more traditional tornado-type diagram with well-defined ranges of variability. This is valuable and a good starting point for this type of evaluations. I would have considered a higher score, had the team presented analysis of drivers for cost variability and stochastic modeling of sensitivity analysis or uncertainty propagation. During the presentation and upon more careful review of the provided data, I started wondering if an internal correlation among different inputs could not lead to sensitivity of LCOE which would then get compounded to get lowered or enhanced. For instance, can Site Exploration Drilling Cost be considered uncorrelated with respect to Production Well Cost?

Other considerations that came to mind such as, for instance, are there guidelines built-in in the model to expedite the evaluation process among end users? The challenge is to meet the demands for ranking of R&D activities at GTO and other types of users.

PI Response:
The possibility of integrating the ability to perform more rigorous uncertainty and sensitivity analysis into GETEM is being considered.

There is a dependency between a number of the inputs to the model, including those used in developing the tornado charts. If possible to model these interdependencies simply (ie., within the Excel platform), they are included in the model estimates. If not possible to model simply, they are not. Effort has been made to model only those interdependencies that would actually occur if one of the input parameters or resulting calculated values changed. One might expect that exploration drilling costs would have some relationship to the production well drilling costs – that was how the model initially calculated those costs. The discussions with industry indicated there was considerable variation in the type of drilling that occurred in this phase, and in many instances different types of wells or holes were drilled. Most developers appeared to have a ‘drilling’ budget for each location, and that concept was adopted for the model.

Reviewer 23421

Score: 9.0

Comment: Reviewer is impressed with the scientific approach to the development and evolution of the model. Input is derived from multiple sources over time. The source and flow of the data used to develop the model is documented, as are the data themselves. And there is continuous improvement of the model using the feedback loop provided by users of the model. This process follows precisely the Scientific Method: hypothesis, look for data, incorporate, refine, adjust for real-life user experience.

PI Response:
No response

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23480

Score: 8.0

Comment: GETEM uses the latest in drilling cost data, as provided by Sandia National Lab, making the model current. The model is consistent with other renewable programs and therefore on an equal footing for DOE in-house analytic tasks. The ability to vary discount rate is important for commercial project evaluation. An array of calculated results based on selected scenarios are presented, effectively displaying the versatility of the model in analyzing a range of operational possibilities. Using input from industry experts supports the validity of the results, though the exclusion of learning curve effects is questionable since the experts would be offering their input based on their learning experience. The results, especially those related to EGS scenarios, are subject to question or debate, but that is not the project's purpose. In all calculated cases, permitting has the smallest portion of LCOE, even though permitting can be time consuming and expensive, especially if NEPA requirements must be met.

PI Response:
Though permitting had a smaller contribution to the LCOE, that contribution can be significantly larger if delays due to permitting occur after drilling has occurred. If the permitting delays occur prior to drilling activities (before exploration drilling), the impact on LCOE is relatively small because the project has incurred minimal capital cost at this point. The values used in the defined scenarios for time, cost and sequencing of the permitting activities are based on the discussions with industry. These are user inputs that can be varied in the model.

Reviewer 24894

Score: 8.0

Comment: Based on the project results there is a 3-4 month lag in completion dates. It would have been good to see the Sandia National Lab well cost data interact in the model to realize actual sensitivities of the model design to changes in the input data. The parameters for hydrothermal and EGS scenarios is complete and the model performance based on those inputs speaks to the complexity of the models components. I believe the sensitivities for the given scenarios provide an important insight into the modeling dynamics and highlight the stark differentiation between the scenario designs. For example, EGS C is most sensitive to production well flow rate in reducing LCOE, while the production well costs are most sensitive for Hydrothermal C.

PI Response:
No response

Reviewer 25420

Score: 8.0

Comment: This project seems to be progressing as planned to meet goals/targets. In contrast with some other projects, perhaps responding to the product-based nature of the project, this one has timelines more clearly established. As per the content of the presentation, except for small delays, the project is following its planned execution. One small concern is not incorporating cost curves into GETEM at time of review, which was highlighted as an important consideration for the tool. Having said this, the accomplishments are significant and very telling of the effort the team has made to stick to schedule.

An observation is that certain costs were considered too low in previous versions of this type of evaluations, but not enough has been said in the documentation on the impact of this optimistic cost structure. Perhaps the sensitivity analysis could be used to better illustrate the impact of this former deficiency of the cost evaluation structure.

With some revision of future plans, the project could deliver higher value to GTO and serve as a model for "continuous improvement". The presentation speaks of overcoming limitations to make this tool amenable for public use. However, the most important limitations have not been explained. I will provide some potential improvements in the process in the corresponding criteria.

PI Response:
If the presenter and the materials provided gave the impression that the updated cost curves had not been incorporated at the time of the review, they were in error. Those updated cost curves were incorporated earlier in FY13. What was not incorporated into the model was the simple well cost model that replicates the Sandia cost model; this simple model would allow the user to assess the impact of technology improvements on well cost.
The most significant issue relative to the model's use by the general public is the level of input needed. The resource scenarios defined by the GTO will provide the basis for establishing default values in the model that will significantly reduce the level of input required, with a user having the option of modifying any of the default values.

Reviewer 23421

Score: 8.0

Comment: Reviewer is impressed with the quality of the results to date. Especially the establishment of a series of "reference cases" for various scenarios. In deriving the data set, the team utilized industry input and technology projections. It appears that "progress" continues on a daily basis, as there is a methodology for incorporating user feedback and using that feedback to change and improve the model. Project appears to be meeting its timeline (from what Reviewer could tell from the presentation).

PI Response:
No response

PROJECT MANAGEMENT/COORDINATION

Reviewer 23480

Score: 9.0

Comment: The project is on schedule and within budget. The planned future work is reasonable and consistent with bringing GETEM into wider acceptance within the geothermal community. The PI has made good use of current costing information and successfully incorporated it into the model. The plan to move the model to a user-friendly platform is reasonable.

PI Response:

No response

Reviewer 24894

Score: 8.0

Comment: Total project timeline is on schedule, but it would be good to understand the reasons for milestone delays.

PI Response:
No response

Reviewer 25420

Score: 8.0

Comment: Staffing does not seem to be an issue for this project. Schedule shows acceptable delays, but future plans are not sufficiently explained. There are two main issues that I would like to bring to the attention of the team and GTO:

1. The choice of platform has to attend additional considerations. For instance, is it not too late to decide the platform after significant development has been conducted? Is choice of platform responding to the needs for portability, accessibility and updatability? These are important considerations and time is of the essence. Perhaps drawing from other experiences with similar tools, even in other sectors, could indicated the pitfalls of some choices.

2. In my view, to understand the limitations for use by the public and stakeholders, access to public and testing by the final user is a must. This is something that cannot be assumed or guessed.

With the aforementioned points in mind, access to industry through conversations is important, but testing with individuals and other stakeholders should be considered ahead of project completion, perhaps in the way that alpha and beta versions of software are tested.

PI Response:
Agree with the concerns raised relative to the choise of the platform; they are being addressed in the selection of the next platform.

The GTO has made the model available to the public for the 3 to 4 years and has requested feedback both on issues related to its use and the reasonableness of the estimates provided. A workshop on the model was provided where feedback was solicited as well. The feedback received has been predominately on issues related to the mechanics of how the model works; virtually no feedback has been received relative to the costs estimated. Cost and performance estimates different parts of the model have been discussed with industry, and compared to actual cost and performance. Where predicted values deviated from actual, the model has been revised or differences explained. Industry has been provided with copies of the model, however they have been reluctant to provide that feedback. Obtaining industry feedback on the model's estimates continues to be pursued.

Reviewer 23421

Score: 5.0

Comment: Reviewer has nothing to add, comment, or critique here.

PI Response:
No response

STRENGTHS

Reviewer 23480

Comment: GETEM is the only general-purpose, up to date, geothermal power costing model publicly available to the geothermal community. The model is based on actual real world experience.

PI Response:
No response

Reviewer 24894

Comment: In terms of economic analysis, the inclusion of risk into the model is a significant step for such modelling. In the same respect the diversity of inputs allows direct interaction with a wide array of projects in the GTO portfolio, making GETEM a valuable tool for the program office.

I particularly like the down-select method for risk assessment, and support the inclusion of a discounted cash flow method in the model. This adds a positive layer of feedback for understanding the model dynamics. Allowing the duration of each stage to be adjusted is also valued in the analysis of the time value of money.

PI Response:

No response

Reviewer 25420

Comment: 1. This team has clear goals for the project and has identified and mapped the project goals with the needs of GTO. At the same time, the project team has not limited itself to stating clear goals, but also has planned activities within a reasonable time frames to completed the project.

2. Testing, though not extensive enough, has been considered an integral part of the product (GETEM) development. This will certainly serve as the basis for future tutorials. Tools are useful is they are used. Perception of being reliable and standardized, makes this effort worthwhile.

3. The vision of the project is forward-looking, i.e. the impact of future development has been considered.

4. Ambitious, but focused activities should guarantee success of the project.

PI Response:
No response

Reviewer 23421

Comment: 1. Model uses solid economic assumptions and generates estimated costs using both a "full cost" approach as well as a discounted cash flow analysis using varying discount rates. This is impressive. And is an attempt to make the results more "real world."

2. More than other models this Reviewer has seen, this one attempts to access valuable information from the private sector "real world" experience. Compiling industry input -- any way one can -- is woefully lacking in so many projects undertaken by the academic universe.

3. Program study includes reviewing HOW data are being PROVIDED to GETEM in addition to how data are used. This is an excellent and extremely helpful step to assist with future modifications to the program. Reviewer would like to see more programs capture this information.

4. Model incorporates a range of values (optimistic to conservative). This highlights where technology improvements can be most helpful. And anything that can focus where more work needs to be done in an otherwise complex model or system is a practical benefit.

PI Response:
No response

WEAKNESSES

Reviewer 23480

Comment: The model is cumbersome to use and may not represent all actual site conditions. Apparently the model has not been tested against actual project/site performance; validation depends on assertions by industry representatives.

PI Response:
Agree with comments.

The difficulty in using the model is one driver for moving to a new platform. The model is intended to provide the GTO with forecasts of representative generation costs from geothermal, and not necessarily to provide costs for individual site conditions. It will provide estimate for most plausible scenarios intended for power production only.

Though GETEM is a forecasting tool, its predictions are as good as the performance and cost estimates made for the individual phases of a geothermal project. GETEM has not been tested against an actual site/project cost performance. However, its estimates for the two major cost items in geothermal projects (the wells and power plant) are based on work that has actual cost and performance as its basis. While it would be highly desirable to validate the model for an actual site/location, industry has not been willing to provide either cost or performance data in detail sufficient to make this validation.

Reviewer 24894

Comment: Including both the down-select and adjustable discount rates is duplicating risk in the model and adding additional cost to the model. This should be avoided, or mitigated with a constant discount rate over the life of the project (e.g. 7-10%). This will inherently include the fiscal risk but not venture into resource risks.

PI Response:
The approach of using both the higher discount rate and the down-selection process was based on the team's interpretation of the information received from the industry interviews. This topic will be re-visited with industry, and if the interpretation is incorrect the model revised.

Reviewer 25420

Comment: 1. The late decision on a model for access of the tool risks late testing, leaving little room for modifications of GETEM.

2. There are questions of usefulness of the model, because despite important considerations on the impact of uncertainties, this analysis is limited and based on snapshots of costs. This needs to be revised, because it is insufficient to point out large uncertainties. As in other sectors, risked cost analysis with more sophisticated uncertainty propagation methods, create confidence on the outcomes of the model. Most project developers understand that there are no guarantees, but the estimation of risk creates a clearer sense of project opportunity.

3. It is not clear that the model will tend to "get it right". In this sense, the model does not produce a sense that one can be confident of the outputs of the model, because these types of models are often perceived at blackboxes.

4. In connection with (1), the project team has not identified test groups or stakeholders to determine an appropriate effort to "debug" the tool.

PI Response:
No response

Reviewer 23421

Comment: 1. Review got the sense that drilling costs are a weak area of the model and need to have more work done here. Again, the addition of private sector, real-world experience will continue to benefit.

PI Response:
No response

IMPROVEMENTS

Reviewer 23480

Comment: Carry out planned future work. Conduct annual workshops to train users and update model sub-components to remain current. This will require an ongoing, long-term commitment.

PI Response:
Agree

Reviewer 24894

Comment: An appropriate approach to financial risk would be to use a constant discount rate throughout the project (ideally 7-10%). There is no need for allowing adjustable discount rates, as it only inflates the cost. Using the discounted cash flow method is a benefit to allow for alteration of time by development stage, which is a vital component in assessing the time value of money.

PI Response:
This will be revisited with industry and the approach revised if inconsistent with current industry practice

Reviewer 25420

Comment: 1. I would recommend planning earlier testing of the tool. This will leave enough time in the project to identify weaknesses of the tool. It is important to realize that this projects has two different stakeholders to satisfy, GTO and the public. The former tends to be well-informed with policies and technology trends, so considerations on some of the inputs are probably different from those of the public.

2. The decision on mode for access of the tool and the platform should be accelerated, because this decision will impact testing and hence debugging the model. The risk is that the team comes up with improved algorithms and fails to meet the goal of overcoming limitations for access to the public. This would turn the tool into a useful piece for GTO and not something of more general interest and impact. This in turn would eliminate the potential standardization claim as objective of the tool.

3. Improvements in the sensitivity analysis, considering potential correlations among inputs and therefore their impacts on cost evaluations.

4. Once the tool has been created in an alpha version, tutorials should be created and testing conducted to determine the level of understanding and ease of use by final users. Perhaps the plan of having Australians test through real evaluations will take care of part of this, but this is a tool thought out to standardize evaluations, so it must attend a wider users base.

PI Response:
agree

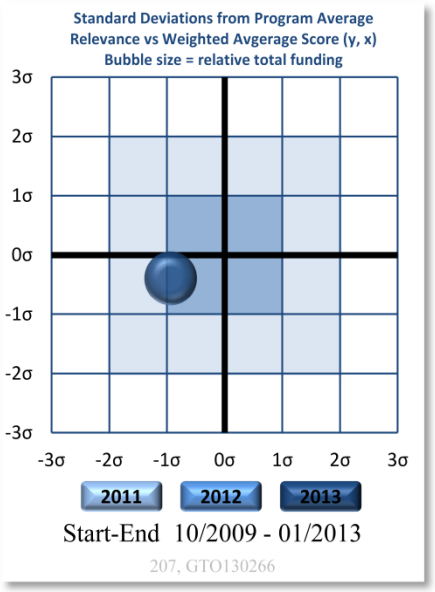
Reviewer 23421

Comment: 1. Thinking in terms of the 80/20 rule, over time it may be of benefit to simplify the model in order to capture and highlight the most important and/or sensitive aspects of the project. No model can precisely match reality. But simpler models may be of more use to the end user.

2. Continue to engage with private industry. There are several "ultra-deep" wells being drilled in the shallow Gulf of Mexico by Freeport McMoran (offshore; Davy Jones #1 and 2) and Chevron (onshore; Lineham Creek) that may provide some more data points to the model.

3. In truth, however, Reviewer has no major comments for improvements as it appears this project is on a course of continuous self-improvement utilizing the best form of feedback: input from the actual users of the model.

PI Response:
agree



Review: 2013 Geothermal Technologies Office Peer Review
ID: 207
Project: Hybrid and advanced air-cooling
Principal Investigator: Bharathan, Desikan
Organization: National Renewable Energy Laboratory
Panel: Systems Analysis

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23480

Score: 6.0

Comment: Summer cooling is a major issue at geothermal plants in the West where cooling water is expensive or not available. Losses in efficiency affect power output and plant economics. The issue is quite relevant to the Office's goals, especially as they relate to EGS. The study tackles this problem by looking at options to improve cooling efficiencies. The problem has been studied extensively in the past, both theoretically and with field experiments. The extent to which this study extends the state of art, at least from a computational perspective, is not clear.

PI Response:
Many previous studies were reviewed in this work. The fact remains that none of the proir work has been implemented on a permanent basis on any geothermal plant for various reasons, especially when it comes to practice. This study primarily focused on why they are not implemented and how the technology can be made easy and practical for routine application. The study resultled in a "patented" arrangement for hybrid cooling that industry has shown interest in applying.

Reviewer 24894

Score: 4.0

Comment: This project attempts to address the issue of power loss due to parasitic factors from air-cooling in water scarce regions. To align with GTO goals, a stated target of this project is to reduce the LCOE of geothermal power with hybrid cooling. Although stated, there is no evidence presented to support this objective. This presents a challenge in accurately evaluating the research relevance.

Given that the project scope was revamped at Phase II, it is recognized that the Phase III focus is shifted towards innovative design goals. Even with the change in scope there should still be an assessment of LCOE impacts and an original objective. The economic analysis provided does compare cooling options, but is in no way complete enough to also be used to determine LCOE.

The results of Phase III provide the potential for an innovative design component to condenser performance. A stated result is a potential cost reduction of 20%. This result, paired with the output improvements, could be supportive of the LCOE objective, but no analysis is provided. For this objective, there is ample opportunity to provide data.

PI Response:
The project scope was altered during the course of the work and was then directed to focus on practical methoods by which the hybrid scheme can be implemented. Certain cost reductions were identified. However, LCOE was not calculated because the schemes come in as a retrofit. Future plant designs must take into account that a hybrid scheme might be incorporated at a later date and that provisions for such must be made in the initial stages.

Reviewer 25420

Score: 6.0

Comment: This project addresses issues associated with air-cooling in geothermal power plants under high ambient temperature conditions. In this sense, the identification of the knowledge gaps is relevant to the mission of the Geothermal Office. Unfortunately, I was unable to find the objective of the project in the scope of work (SOW) and the PI did not present it, either. After the two major conclusions on page two of the SOW, the interpreted objective is to arrive at "best practice" for implementation of hybrid coiling as a potential solution to the cooling predicament. The effort of the project was stated to address specific engineering issues in hybrid cooling, specific barriers, retrofit and new construction. If this objective is assumed, then the project has moderate potential impact once the project objective is achieved. One additional difficulty of the project is the lack of the framing of this need. For the non-expert it becomes a difficult task to determine how important this project is and the PI did not adequately communicate this aspect of the project. Therefore, the impact is subjectively assessed, provided the lack of reference information.

In order to more adequately unveil the value of the project in relation to the Geothermal Office's mission, it is necessary to isolate better the size and impact of the opportunity. This was lacking in the project SOW and presentation. This can be accomplished by presenting a rough economic/financial impact of the solutions to potentially arise from the execution of the project. Also, questions such as, how would this impact the market for geothermal energy?

PI Response:
The project focused on the technical aspects of implementing a practical hybrid scheme that can improve power production from a given plant. Overall market analyses of how this impacts the entire geothermal industry was not the focus of the project and thus was not addressed, as correctly stated by the reviewer.

Reviewer 23421

Score: 10.0

Comment: Immensely practical study designed to generate immediately usable results. Project is not "revolutionary" but "evolutionary" in that it addresses two current issues: water usage in a water-scarce environment and the drop in geothermal generating plant output when ambient temperatures rise above a certain threshold. The first issue is relevant as most of the U.S.'s current geothermal generation is located in areas of the country where water is a valuable and scarce commodity. The second issue is relevant in that in locations where water is scarce, it is usually also a location that gets quite hot in the summer months. And it is in these locations that most of the currently installed hydrothermal plants exist. Therefore, the project is both relevant and any results generated are immediately useful. As a matter of fact, it is just these issues that are -- in good part -- what keeps geothermally-generated power from being considered a truly baseload source of energy. And the U.S. will never be able to grow its renewable energy base without a good portion of it being reliable as baseload. This project is aimed at ameliorating both of these key issues.

PI Response:
We are waiting for an opportunity to implement the suggested scheme in a pilot system to categorically establish the practicality and usefulness in a power plant.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23480

Score: 4.0

Comment: The scope of work appears to have changed dramatically from the original SOW which called for a joint cooperative research and development agreement (CRADA) with Ormat. The approach changed again during the course of the study due to problems with the field site at RMOTC. The PI accommodated these changes by switching from field testing of cooling options to a computational study. Presumably, the new scope was approved by DOE. Project costs were notably reduced by one third. However, the ability to corroborate results with field data was compromised. No field data are presented, although the Approach (slide #3) states that summer testing would be conducted.

PI Response:
Yes, no data could be obtained due to lalck of funding and equipment breakdown.

Reviewer 24894

Score: 5.0

Comment: The economic assessment of alternative cooling systems concluded that the deluge option is the most economically viable. As a reviewer I find these results are limited, as they do not appropriately account for the effects of corrosion. The presenter's response to a question on associated costs to corrosion was to prevent corrosion with further design modifications. This fails to integrate potential cost of prevention into the results of the economic analysis. As a result I am skeptical of the actual viability of the deluge system without further data and analysis.

Furthermore, to meet Program directives there should be an analysis of the LCOE for the different project options. This would have allowed for the inclusion of design costs, water accessibility/cost, and performance benefits. In terms of a more robust assessment of the economic viability of the project results there is more that could be done. Since further publication is part of the future direction of the project I would like to see a more through discussion of the economic results of the project included.

PI Response:
At this stage, there is no hybrid system that operates in a plant on a routine basis. We are looking opportunity to implement such a system in a pilot study. Evaporative condensers are routinely used in the HVAC industry on a regular basis. This study uses them as one of the stages in series for condensing power-cycle working fluid vapor.

Reviewer 25420

Score: 5.0

Comment: The project focused on modeling aspects of the optimization of energy recovery. I could not find the collation of "best practices". The PI restated some of the problems associated with hybrid cooling, but did not investigate solutions. There are apparent difficulties with the proposed cooling method, namely use of water and corrosion, which the technical approach of the project does not address. Best practices might deal with critical limitations/issues of the cooling methods, but there was no apparent effort to investigate potential solutions. In this sense, the outcomes of the project do not seem to match the objectives by design or choice of the technical approach.

The project faced implementation problems at the test site, but the presentation of the project conveyed a sense that the project team did not build a "what-if" scenario and did not adapt/change the project scope sufficiently. The approach seems to have distorted the perceived objective or needs of the project. While it is understandable that the approach was impaired by lack of the test site, the rescoping did not address the loss of value. It appears that the new scope discontinued the field test and maintain other tasks without proper articulation of activities. I would qualify this as weakness of the technical approach, because it was not conducive to produce results of sufficient impact and definitely did not allow the team to meet the objectives.

On the more technical side, the calculations presenting an optimization of the cooling strategy appears interesting and even appropriate, but not necessarily abiding by the presumed objective of the project.

PI Response:
There have been no "best practices" identified as yet in the industry. All efforts studied previously have had major drawbacks in that there is no operating power plant with hybrid systems today! We arrived at a solution that make the most sense in terms of being practical and that solution has been patented at this stage. We are awaiting implementation in a pilot plant (provided we get some funding to do so from DOE and a potential partner who is willing to conduct the pilot study).

Reviewer 23421

Score: 9.0

Comment: Perfect scientific study: generate the theoretical outcomes using proprietary modeling then test expected results against actual field data. Measure impact, observe problems, try solutions and remeasure, draw conclusions and make recommendation for practical implementation. The shortfall in the project was not the fault of the project team. The RMOTC geothermal power unit slated as the test site broke down and has not been restarted. This is a tremendous loss in this Reviewer's opinion.

Technical approach appears particularly sage in that the project team dealt with incremental power yield as a function of incremental water use. This economic approach -- if completed -- should provide useful metrics and process recommendations that will be additive to the existing geothermal decision analysis tools being developed.

PI Response:
Thank you for great comments. It is difficult to understand that how the various reviewers felt varied opinions for the work. We pursued what would be the most practical approach to implementation in a power plant.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23480

Score: 3.0

Comment: Results for five air-cooled condenser (ACC) systems are presented. These point clearly to spray or deluge cooling as the most cost effective. Over the years, experiments with various ACC systems have been performed, but those results are not provided to set the context of this work. The calculated results appear to point toward a more efficient, less costly alternative to ACC on hot summer days: folded condenser tubing. Folded tube arrangement is not explained very well, nor are the cost calculations discussed in detail. The patent application will serve to verify the new design. IP issues seem to have limited the amount of information given in the summary and presentation, thus limiting the ability to judge the accomplishments.

PI Response:
Folded condenser tube arrangement offers a more approximate countercurrent flow between the heat transfer fluids and can be more effective compared to other arrangements. But these are major changes in the current design practices and so will require a pilot system to be designed and demonstrated in order that the industry can acquire confidence.

Reviewer 24894

Score: 5.0

Comment: Based on the economic results alone, there are questions in the accuracy of method and conclusions. I have concern that the cost of preventing corrosion in deluge (and spray) systems is not properly reflected in the assessment of economic viability. Additional results on LCOE analysis are not included and should be considered. Because this would direct the project back to the original Program objectives it is a vital, yet missing, part of the results.

The record of invention for the condenser re-design is a welcome addition to the original scope of the project.

PI Response:
We used galvanized tubes for preventing corrosion for the deluged tubes. Fins have been eliminated in them as well. The cost associated with galvanizing as a means to prevent corrosion is not an expensive method that requires reevaluation of the costs.

Reviewer 25420

Score: 4.0

Comment: The productivity of the project is low, in my view, and the presentation of coordination efforts with industry obscure. IP issues can create an impossibility to promote potentially valuable outcomes of the project to a greater universe of stake holders. The quality of the results are difficult to judge, but it is clear that objectives were met in a very limited fashion. In fact, there is an almost absolute lack of best practices. Since the cooling problem was, in fact, presented as an optimization problem there are critical issues that are more relevant than the presented results. The achievements become secondary in view of the obvious known problems of the hybrid cooling technology. This assessment was probably

available at the initial literature-search based tasks at the outset of the project. This means that the project team did not emphasize critical aspects of the technology that could have a significant impact.

The accomplishments presented during the evaluation process at the meeting only pointed to very specific technical questions and were hardly justifiable in terms of project resources. The PI presented some potential publications as well as some IP product but it was not disclosed at the appropriate level to understand its significance. I am unable to judge the overall quality of the results, due to lack of important details. But as a matter of fact, the overall quality was perceived as low.

PI Response:
Formulation in the form of IP is what makes the industry use a product or and idea with some "advantage" against competitions. Making the results totally public helps no one. On account of this , not all results could be presented in details.

Reviewer 23421

Score: 8.0

Comment: Project was able to complete only Phase I, the modeling phase. Due to no (apparent) fault of the project team, the actual physical test planned for Phase II was unable to be completed as the selected test site at the RMOTC broke down. Therefore, it is difficult to assess "accomplishments."

It appears to this Reviewer that the project team did all they could in a timely manner on Phase I, but due to circumstances outside of their control they had to cancel the Phase II experimental test plans. In light of the partial results being accomplished on time, Reviewer can only score those.

PI Response:
Thank you.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23480

Score: 3.0

Comment: The SOW bears little relation to the work described in the summary and presentation. Adherence to scope, budget, schedule, and staffing plans cannot easily be determined. The project did not appear to have go/nogo decision points---what was the mechanism for revision of scope/budget/schedule? Originally Ormat was to have participated through a CRADA; PI did not address the CRADA in his presentation. Not clear if Ormat has any role? The lack of continuity between the SOW and subsequent work is a matter of concern. The project has morphed substantially from the initial SOW, which, surprisingly did not appear to have caused problems in management of overall budget and schedule. Both of which appear to have been met as planned.

PI Response:
Management is not the strength of the PI. But technical goals to show that hybrid systems do provide a means to reduce the power production decline was shown and practical methods to implement hybrid systems have been idetified in this highly useful and relevant study.

Reviewer 24894

Score: 7.0

Comment: Even with the revised scope, the project appears to have conformed to the new schedule. Timeline delays are questionable (4 months), but are likely understood as a combination of Phase II issues and the down scope of the project. It would be important to know what is the impact of the Phase II failure? Were there results that were salvaged given the costs and lack of field testing? Also, how was the re-scoping of Phase III determined? In terms of project management I think it would be important to identify why the project remained in the portfolio after the Phase II failure.

Due to the project also being a CRADA with Ormat Technologies, what level of input was provided by Ormat in the results prepared in Peer Review?

PI Response:
This project was not a CRADA. Our interactions with ORMAT have been proprietary.

Reviewer 25420

Score: 3.0

Comment: The PI did not make a concerted effort to elaborate on how the meetings and discussions with the geothermal industry improved (or not) the execution of the project and how frequently and how many stakeholders were consulted. The PI also failed to provide any details on staffing plans, how business was conducted or even details of future plans.

Decisions points were absent or not explained, so I have no way of assessing this aspect of the project. The PI stated that frequent communication with DOE was essential in developing the new scope and consequently reducing the project budget. However, the PI did not indicate how the new work scope would allow the team to meet project objectives.

Contact with industry appears to continue, as described by the PI, but it is unclear the extent of this coordination effort, beyond IP documents to which we had no access. I found this troubling because there is a claim of cost-optimized, practical and convenient means for the implementation of hybrid cooling but no solution to critical issues was ever presented or discussed. The claim seems baseless. Perhaps NREL is aware of the technological solution.

This project was presented as being essentially completed. The only future plans I managed to draw from the discussion is something to do with proprietary designs with the private sector. As stated before, this is an area of concern and I would like to suggest to the PI to summarize clearly and concisely the project goals and how the project met those as well as offering adequate closure of this project.

PI Response:
The overall purpose of the project is to provide industry with cost effecctive practical soutions that can be implemented on a routine basis in plant operation. We accomplished that, but are awaiting an opportunity to conduct pilot studies when resources and means are available.

Reviewer 23421

Score: 8.0

Comment: It appears to this Reviewer that the project was well enough managed and coordinated to complete the project... right up to the point where the demonstration plant broke down.

PI Response:
We are awaiting an opportunity to conduct field trials.

STRENGTHS

Reviewer 23480

Comment: The technical ability of the PI is excellent; he has many years of experience in the geothermal energy conversion program at NREL. Staff at NREL were particularly knowledgeable about condenser designs, especially tube bundling and cross-sectional geometry. There is an extensive, well-documented experience base in ACC systems for geothermal applications as well as some performance data for other cooling options, such as spray and wetted media.

PI Response:
Thank you.

Reviewer 24894

Comment: I feel the the strengths of this project are in the record of invention and the technical publications. These results are an excellent communications tool for R&D resulting from GTO funded projects.

PI Response:
Thank you.

Reviewer 25420

Comment: 1. The apparent need for cooling solutions that overcome the limitations of air cooling under high ambient temperature conditions.

2. The original scope included execution of experimental tests at pilot scale. Although the PI did not present it, perhaps this would have been the source of best practices.

I have difficulties in preparing a more detailed assessment of strengths using the incomplete information presented by the PI. However, I would frame the niche area, goals of the project (clearly and concisely) and why this represents an opportunity. I would also discuss the impact of the niche area.

PI Response:
Part of the information presented had to be restricted while the IP is being pursed. IP provides the most effective way to transfer the technology to the industry which is one of the primany goals of the program.

Reviewer 23421

Comment: 1. Well designed project that could yield results that are relatively quick (and easy?) to implement into existing geothermal power generating systems.

2. Very practical approach, looking at the incremental change producing the incremental output. This is a valuable and easily incorporated edition to future economic modeling of geothermal power plants.

PI Response:
Thank you.

WEAKNESSES

Reviewer 23480

Comment: The study lacks for actual field data on the performance of the ACC alternatives. Design parameters of the folded tube arrangement are missing. Folded tubes appear to be the crux of the project---the study of alternative cooling methods is not emphasized.

PI Response:
Some of the data are proprietary and could not be revealed.

Reviewer 24894

Comment: The economic analysis of this project is lacking substantial methods and application with respect to the original objectives. The results of technical modeling should have been translated into LCOE impact analysis. Furthermore, the economic assessment of cooling system options identifies corrosion as a challenges but still concludes that a deluge system is the most economically viable option. I'm concerned that this can not be concluded with out taking into account the costs of corrosion prevention, which was not part of the overall analysis.

PI Response:
Corrosion will be handles through the use of tubes with out fins and that are galvanized on the outside to prevent corrosion. This approach is expected to cost no more than simple tubes.

Reviewer 25420

Comment: 1. As an overall observation, the project lacks clearly defined goals and objectives. This is a significant weakness because it leaves room for ambiguity in the way the project execution was conducted. I would have wanted to see how the experimental design at the test facility would have led to best practices. The problem appears to be a poor

focus. Therefore the project team was more likely to dilute efforts that, while relevant to the overall objectives of the Geothermal Office, tended to not contribute to the intended goal.

2. The new scope of the project does not address the main problem with the project, which is to clearly define the niche area. Nor does it lay out a strategy to attend what-if questions that would have made the project more flexible and able to become more productive.

3. The overall coordination of the project does not appear to show an effective use of the resources. This may also stem from the weak definition of goals and objectives. This aspect gets compounded with the unclear communication with the PI. For instance, despite the claims that constant communication with DOE (Geothermal Program office) led to a good reformulation of scope, it is unclear how effective the communication was, in view of the lack of clarity with respect to the focus of the project.

4. From the point of view of economic/financial evaluations, the analysis presented seems to contain aspects of the technology in isolation and not as a holistic analysis that would highlight the value of the outcomes. In this sense, statements regarding meeting goals do not seem justified in a convincing manner for this reviewer.

PI Response:
The project focused on developing hybrid systems that can be practical in the field. There are no such systems in routine operation in a power plant today.

Reviewer 23421

Comment: 1. Terribly disappointing to this Reviewer that the test plant broke down and the remainder of the study will be conducted, concluded, and patented in the private sector. Because of this, it is unclear to this Reviewer if the results from the completed project will be widely available to the public.

2. Computational fluid dynamics analysis can not predict how scale and corrosion will affect real world implementation of the hybrid system. This will be key to the economic success of the project.

PI Response:
The PI agrees with the comments. Patenting is an effective means to transfer the technology to the industry which is encouraged by the program.

IMPROVEMENTS

Reviewer 23480

Comment: The project is finished. Plans should be proposed for follow-on verification of the folded tube design with laboratory and/or field testing after a techno-economic feasibility study is performed.

PI Response:
Yes.

Reviewer 24894

Comment: Costs for corrosion prevention methods must be included in the analysis of economic viability for each option. Additionally, to align with project/program objectives there needs to be a thorough analysis of LCOE impacts as a result of the study. It is clearly stated as a mutual goal to reduce LCOE for both the project and program, but none of the technical analysis includes this metric in its results. As a result, it is very difficult to assess the projects viability without having a very in-depth understanding of the technical process and results.

Similarly, there should be more attention given to the impacts of innovative design in the project's Phase III results. It is not enough to simply not the record of invention. In the presentation, it was asked and answered as to the future path of the project and that it will likely continue with private support. This is a beneficial result but more could be said as to the anticipated impact of such an innovation.

PI Response:

We are looking for opportunity to conduct field tests when resources and means are available.

Reviewer 25420

Comment: 1. The review process hints on a style in the design and execution of projects that would produce more robust and less risky strategies. I am referring to the definition of a framework along the lines of roadmaps. Most researchers would not easily cast the traditional narrow-focused, task-based project proposal in the roadmap paradigm. However, the benefit of this is that:

1.1 One can map the barriers, potential solutions, decision points and build flexibility.

1.2 This allows the establishment of clear alternatives to attain the goals

1.3 Time and resources can be properly evaluated and communicated to team members and the sponsoring program

2. The aforementioned points are not new or unique, but disparity of styles. While desirable to maintain potential sources of innovation, it makes it harder to transfer technology because of the missing links in the execution of projects.

3. Generation and tracking of meaningful milestones. I sense that meeting objectives has include the process. This in my view means leaving room to exploit potential valuable outcomes of projects that were not intended to meet the original goals and objectives of the project. In some cases these outcomes could lead to greater and higher impact results. This must be handled carefully to avoid wasting resources and should never be done, in my view, at the expense of the execution of planned tasks, except in very special cases. This means, in my view, that teams must be willing to go through a process where a task or activity is discontinued, because early evaluation of results indicates that there is little return on investment. The project GTO130266 could have benefited from such an approach, because it would have forced the team to carefully ponder where the remaining value of the project could have been enhanced and low-value propositions abandoned.

4. Economic/financial evaluations could be defined at the appropriate level to reflect the state of knowledge. This, in other industries, reflects the difference between probable and proved resources (the oil and gas industry uses this approach to

reserves). By defining the type of financial evaluation, barriers could be better defined and uncertainties may be better framed for their impact on decision making for geothermal projects.

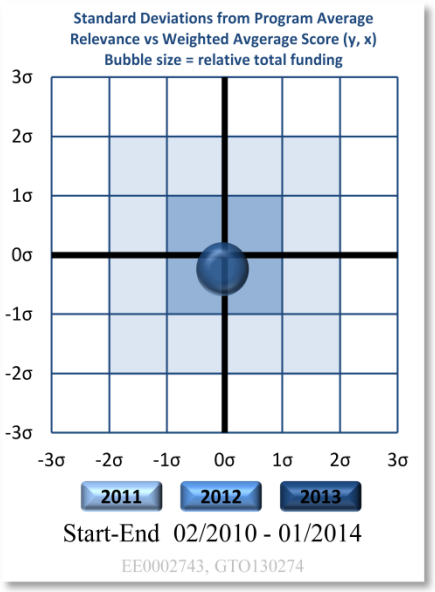
PI Response:

I belive that we made "best" decisions under the circumstances and now have a means to transfer technology to the industry.

Reviewer 23421

Comment: No "improvements" to recommend. Future plans are to complete the patenting process and license the technology to industry users. The PI also plans to continue the field testing in the private sector. It is this Reviewer's hope that any results from the field testing can and will be shared with the geothermal community.

PI Response:
We would love to conduct field studies on our concepts.



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002743
Project: Decision Analysis for Enhanced Geothermal Systems
Principal Investigator: Einstein, Herbert
Organization: Massachusetts Institute of Technology
Panel: Systems Analysis

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23399

Score: 7.0

Comment: This project has demonstrated advancements in addressing several knowledge gaps that are key to understanding in order for the DOE GTO to achieve its missions and goals. Specifically, the project presented results on modeling fracture patterns and circulation through fractures for EGS, and on modeling time and cost uncertainties associated with drilling wells for EGS. Understanding fracture patterns, their interconnectedness and circulation and heat transfer through these fractures is critical to developing sustainable EGS reservoirs. The project demonstrated that the model can be applied to actual EGS systems and generate gross variables such as flow rate that match real world data. However, the ability to simulate heat transfer still needs to be validated. The project also demonstrated the ability to model EGS drilling costs and how uncertainties in drilling cost and time variables can impact overall cost. If these models continue to develop, they could have a significant impact in identifying fracture characteristics that are key to sustainable EGS reservoirs and variables and technologies that could be key in reducing the drilling costs associated with EGS wells.

PI Response:
Thanks, no comment.

Reviewer 24894

Score: 5.0

Comment: With respect to the goals and objective of the Geothermal Technologies Office, this project seemingly only attempts to address the mitigation of sub-surface risk. It would be much better if it could also be related to other GTO objectives, like reducing LCOE, etc. Looking at sub-surface risk, the probabilistic approach to assessing risk does have some merit. Based on the material provided/presented, the details connecting the the different aspects of the project (e.g. probability, cost models, etc.) does seem vague at times. This is likely the case of prior year reviews addressing individual components of the project. This aside, I would have like to have more details on how this project remains relevant to the GTO objectives over time. I give it a five because there wasn't an adequate representation of the material related to those objectives, and even with prior reviews a quantitative value should have been given.

The accuracy of the model and results also seems to be heavily reliant on potential industry feedback. This can also be an appropriate metric for measure if the project is selected for review next year. If this is the case an additional methodology for collecting and assessing industry data should be included. I would also be more confident in the project if there was greater confidence in the well cost data.

PI Response:
Thanks. It was always made clear that the project is limited to subsurface risk. Only after doing this can one do additional steps like LCOE. Agree with need for industry input.

Reviewer 25420

Score: 7.0

Comment: The objectives of the project are important to the program and the mission of the Geothermal office. Tools to assist decision analysis should entice and facilitate the development of geothermal projects. This project aims at incorporating dominant uncertainties in the analysis. These range from geological aspects to economic considerations to enable a decision-making tool(s). The project approach is ambitious in that it attempts to combine elements of fundamental and applied research. While the objective clearly states this, the project execution reflects a strong leaning on basic research with a softer emphasis on applied aspects of tool development. There is a clear need to assist decision-making that properly accounts for sources of uncertainty but this process needs to be bench-marked and tested for practicality. This project outcomes could in principle meet some of these needs and hence the project could serve to overcome knowledge gaps. This reviewer does not sense a practical approach to address market barriers. There is value-added through new knowledge added.

PI Response:
Thanks. No comment.

Reviewer 23421

Score: 8.0

Comment: Reviewer believes that project is extremely relevant to advancing the analysis of the economic and practical feasibility of siting a geothermal plant. Reviewer agrees that the greatest challenge facing an EGS project is the uncertainties encountered during the subsurface drilling, fracturing, and producing the geothermal resource. This model seeks to reduce that risk by placing heavy emphasis on subsurface analysis. Although the subsurface analysis and model methodology was covered in the prior review (steps 1-3 of a 6-task process), recognizing the importance of these (already completed) steps should be reiterated. Especially in light of comments and critiques elsewhere in this review, where Reviewer believes the overall model needs to reach further into existing data bases and information sources in the private sector in order to incorporate real-life, hard data from industry ventures. In Reviewer's opinion, "real life" data is underrepresented in this decision analysis model at this point in time.

PI Response:
Thanks. Agree with need for "real data". This is done at present.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23399

Score: 7.0

Comment: The approach to date appears to be effective in achieving the project's objectives. The project is mainly computer based and is carried out using Matlab, which is a widely available and used software that will ensure that the resulting models will be accessible to researchers in the future. Adequate time and coverage appears to have been applied to each of the project objectives so that the focus is not solely on one aspect, and the project has a plan in place to integrate the five models from the project objectives together using a systems approach so that the EGS problem can be studied as a whole. Each of the models presented appears to be complete and adequate for handling its share of the problem.

PI Response:
Thanks. No comment.

Reviewer 24894

Score: 8.0

Comment: I can only comment on the probability theory approach, as the other technical analysis is outside my purview or too vague to comment on. I do like the decision tree approach to this study and I think that given the context that it is highly appropriate for the flow rate analysis especially this is the case. I am less understanding on the heat transfer dynamics and thus is not part of my comments.

From a general view the estimation of individual probabilities (each branch) would be a welcome addition to the discussion of results. This was not made clear in the presentation. The scholastic approach Is also appropriate for the given context. Again though the tie in of these results to the DAT modeling is vague and could use more explanation for those unfamiliar with DAT.

PI Response:
Thanks. I do not quite understand the second paragraph but a detailed better explanation of the DAT is given in the report that has been submitted to DoE earlier this year.

Reviewer 25420

Score: 8.0

Comment: The PI clearly explained the probabilistic and statistical basis of the approach followed. This project is theoretical in its approach and methods. The project is rigorous in the treatment of the specific statistical model of fracture systems selected to address geological uncertainties. The project appears to reflect strong assumptions on the validity/applicability of distribution functions. These seem to be extrapolated from the analysis of tunneling already developed by PIs at MIT, as the presentation clearly states. On the drilling costs side of the evaluations, the projects relies on examples from Sandia National Labs and others. What remains unclear to this reviewer are the aspects of integration and, most of all, the meaning of validation that the PI conveyed during the presentation. There was a statement as to the availability of software tools on different platforms. But no effort was shown on how to integrate the tools in a manner

that would build a complete decision-making framework. Validation seems to focus on the fracture model, circulation model (heat exchange and flow), etc., but not on the decision outcomes from the models. The project would benefit from evaluation of developed projects to determine if inputs to models are available or can be obtained through relatively simple means. Mention of tracer tests and other field characterization methods is insufficient, because to the best of my knowledge, no standardized characterization is available. This is an aspect that the project team has the time to better incorporate in the project.

PI Response:
Thanks. Integration is under way at present.

Reviewer 23421

Score: 5.0

Comment: PI's objective is to "formalize the expression of risk." To this end, his team seeks to assess risk and then compare modeled results to real life EGS projects. The findings are then incorporated into current software which will be made available to a large universe of potential users. As the program is written on established software, the decision analysis tool is targeted to be easily-integrated into the user's own working models. The attempt here is to construct a readily-available and useable model that is based on both solid theoretical computations and combined with practically-based data from real-life EGS projects.

Reviewer believes this approach is practical. However, the one (and recurring) issue that Reviewer has with this project is the lack of incorporation of real-life hard data into the construction of the decisions analysis model. PI said that hard data were obtained from two EGS sites (in Iceland and the Philippines), but Reviewer would recommend the software development team incorporate drilling and production data from US-based ventures from the oil and gas industry. While private sector drilling projects related to the Exploration and Production industry are (obviously) not focused on hard igneous or metamorphic rock (the preferred sources for EGS working fluids), nonetheless, important data could be obtained. Especially from one or more of the several "ultra deep" wells currently being drilled in and around the shallow Gulf of Mexico. [See "Improvements" section for more information here.]

PI Response:
Thanks. Agree that we need a real data. Difficult to get info from oil/gas industry.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23399

Score: 8.0

Comment: The accomplishments, results, and publications for this project have been good in relation to the resources available. The project has developed several quality models and has published or plans to publish the results in several conference papers, journal articles, and reports. The progress and results made on the fracture pattern and circulation models in particular has been impressive. It appears that these models could be used in the near term or immediately to identify the fracture characteristics of an EGS reservoir capable of sustaining electricity production over a significant period of time. Overall, the project has completed 3 of its 6 objectives, and stated that they have made progress on the remaining objectives.

PI Response:
Thanks. No comment.

Reviewer 24894

Score: Not scored

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 25420

Score: 8.0

Comment: The accomplishments of the project reflect significant, high-quality research production towards meeting goals and objectives. The PI touched on each project objective except one. According to the project SOPO, "the decision analysis tool will make it possible to compare alternatives on the basis of risk and eventually on the basis of life cycle performance". However, this objective was not addressed and it is unclear how this will be accomplished. While the PI succinctly explained that it was possible to obtain input data for the models, this was not apparent during the presentation/review session. The project execution clearly relies on several parties. Task 6, i.e. technology transfer, was not discussed, but it is integral part of the six-task process and progress in this task is crucial to meet the goals of the project. If this aspect is further emphasized I do not foresee a difficulty in meeting goals and objectives.

PI Response:
Thanks. As replied earlier, the objectives are to develop a tool for assessing subsurface related risk. We agree that technology transfer is necessary.

Reviewer 23421

Score: 6.0

Comment: Review is unable to assess the accuracy, impact, and overall quality of project's accomplishments to date. But it appears that capital used to date has been allocated fairly efficiently and that a significant portion of the analysis tool has been completed. PI states that the project is on track and has completed each task within budget.

PI Response:
Thanks. No comment.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23399

Score: 7.0

Comment: The project appears to be well managed and coordinated. The project employs several graduate, undergraduate, and post-doc students to complete the bulk of the work on the project. I am a little concerned that only about 20% of the project funding remains, even though only 3 of the project objectives are completed, but as the main expense is primary staff/students, the remaining budget matches well with the remaining timeline. The PI stated that work on the remaining project objectives had begun, but the progress to date on those tasks was not included in the presentation or supporting material, so it's not possible to make a judgment call on how close they are to completion.

PI Response:
Thanks. Agree that information on remaining tasks was limited.

Reviewer 24894

Score: 7.0

Comment: The values given for cost and time management are approximated, which leaves some question to the comparability to other projects reviewed. In light of that the project appears to be on track regarding time and the cost estimations have kept the project under budget with 9 months remaining. There is a question in my mind as to the possible impacts from industry feedback on the modeling. I don't question the legitimacy of the model but, if there are discrepancies the existing timeline and budget may be inconsistent if major reworking is required. More importantly, although the project has begun this process of acquiring industry feedback the pace for receiving it may slow the project pace. This is not an extreme concern but should be considered with respect to actual project management.

PI Response:
Thanks. Agree.

Reviewer 25420

Score: 7.0

Comment: The project is technically solid and staffing within the PI's group appears in good shape. Close and frequent interaction seems to be productive. Coordination with other researchers is not clear, but one must presume that since the project is meeting its goals that this is being conducted adequately. Decision points were not discussed in the presentation and the material available (summary and SOPO, PDF presentation) did not discuss decision points either. I find that coordination of activities requires strengthening to be able to meet the goals of task 6 Without full and functional integration the project risks developing disconnected tools. Without this the overall objective of developing comparisons among different projects could be jeopardized.

PI Response:
Thanks. Integration is under way.

Reviewer 23421

Score: 5.0

Comment: Project appears to have been well-managed internally, as it is presented as being on track and on budget. However, Reviewer believes there should be more coordination with outside sources of data. Both within the EGS field and the private sector oil and gas exploration industry.

PI Response:
Thanks. See other replies regarding obtaining real data.

STRENGTHS

Reviewer 23399

Comment: The project builds on the PI's and his groups knowledge of risk analysis and probability theory and applies it to all objectives of the project. This is especially well-suited to the fracture and flow modeling work being done by the group. Since the nature of the subsurface is something that is hard if not impossible to characterize with certainty, a stochastic approach is a good method for analyzing this problem.

PI Response:
Thanks. No comments.

Reviewer 24894

Comment: As stated in prior posts, I do like a number things about the approach. The probabilistic decision tree method is a very intriguing approach to modeling the probability of flow rates in a fractured system. Due to limited capacity for the remaining sub-surface analysis I cannot comment further on strengths.

PI Response:
Thanks. No comments.

Reviewer 25420

Comment: 1. The PI presented solid statistical and probabilistic approaches to some aspects of a potential tool for decision making.

2. Consistency of heat exchange and flow solutions highlights the quality of the science in this aspect.

3. There has been a concerted effort to meet goals and objectives. The execution reflects this clearly.

4. The team is well-equipped to deal with the research and development challenge.

PI Response:
Thanks. No comments.

Reviewer 23421

Comment: 1. Utilization of currently-available software

2. Easy for potential users to download and integrate within their own models

3. Rigorous incorporation of theoretical analysis

4. Honest attempt to incorporate "real life" data outcomes

5. Could be used as a simulation model at this point, generating a number of "what if" scenarios that could be back-tested against real-world observations

PI Response:
Thanks. No comments.

WEAKNESSES

Reviewer 23399

Comment: As the PI noted during his presentation, access to industry data, especially for drilling costs, to validate their models has been hard to come by. This is a common problem. The project is likely to encounter similar problems when they look for data for the subsurface time/cost model and exploration decision model and should anticipate this.

PI Response:
Thanks. Agree but contacts have been established.

Reviewer 24894

Comment: The greatest weakness of the material for review is based in the presentation. There are a number of places where the study components do not flow together in a coherent way. Specifically, I think that more details need to be included in the transition from flow rates/heat transfer to the DAT model. Additionally, the material needs to do a better job of highlighting GTO objectives and applauding its successes. Due to the initial age of the project, this may be an issue of ongoing comparability with the current objectives. I don't think it would be difficult to assess the project in a quantitative manner to comment on risk and LCOE reductions. Something I would include in further publications.

PI Response:
Thanks, particularly for the comment on how to go toward LCOE etc.

Reviewer 25420

Comment: 1. The overall weakness of the project is the lack of integration of the different pieces of the potential tool. The PI mentioned this in passing during the presentation. I indicated this in the assessment of all evaluation criteria. There is an opportunity to enhance this aspect of the project, which essentially hinges on coordination and management.

2. Economic aspects are somewhat incomplete. While drilling costs were mentioned and a procedure was somewhat described the project execution seems to lean on technical strengths of the representation of subsurface uncertainties.

3. The necessary benchmark, the clear identification of procedures to obtain inputs to the model and the calibration are lacking or remain unclear.

PI Response:
Thanks. Agree with need to integrate. Detailed reports on the models (already submitted or submitted in near future) provide instruction on model use.

Reviewer 23421

Comment: 1. Lack of interaction with private industry data bases

2. Need to validate model theoretical predictions against practical experience

3. In other words, it appears to be a robust and fairly usable predictive modeling tool, but needs to be back-tested and validated against more field data; results of comparisons to be incorporated into the model

4. Need more well cost data from industry

5. Overall, project seems to be lacking from solid connections/contacts within the private sector... needs a "real-world connection," both from a relationship basis for independent validation and to access additional input data

PI Response:
Thanks. Agree with need for real data. We have been in contact but this is still a problem.

IMPROVEMENTS

Reviewer 23399

Comment: There are several areas where this project can be improved.

First, the fracture and flow model has been used so far to model actual EGS systems, specifically the Hijori system in Japan. The PI stated that information on fracture patterns from boreholes and fracture volume information from tracer data can be used to apply the model to actual systems. But the cost required to acquire this data is prohibitive to make the model widely used, and by the time the data is available, the model does not have much utility - the wells are already drilled and the reservoir is already created. It ends up being more of a diagnostic tool. The PI also noted that the model is not deterministic, so that any correlation between model and actual results could be fortuitous rather than a result of the model actually correctly characterizing the system. Instead, I would like to see this model used to simulate flow through a large number of reservoirs with a wide range of characteristics (fracture interconnectedness, fracture density, aperture spacing, etc.) in order to characterize the properties that result in a sustainable EGS reservoir. Such an effort could do a lot

to inform about reservoir lifetime, when short circuiting can be expected, and what sort of fracture network gives the best EGS reservoir.

For the drilling cost model, the results showed basically that time and cost are linearly correlated for a given well. I would like to see the model probed further to identify which variables contribute most to increases in time/cost, and to identify which uncertainties most contribute to time and cost. These insights from the model could inform key technology R&D areas.

PI Response:
Thanks. We strongly agree and are conducting practical analyses with the fracture flow heat model.

Reviewer 24894

Comment: See comments under Weaknesses.

PI Response:

Reviewer 25420

Comment: 1. At first glance a deep analysis is reflected in statistical and probabilistic aspects of uncertainty, as indicated in the SOPO. But a deeper analysis of the overall impact shows some limitations arise from the lack of integration of the different pieces which would be best combined so that an integrated framework be made available and thereby the potential impact be better reflected.

2. Projects of this magnitude require multidisciplinary integration and pose challenging integration/coordination of activities. Due to the nature of this particular project, namely the development of a decision-making tool, the project needs to account for final-user viewpoint. Therefore, even in a crude way, practical testing of the entire workflow at the use level is a must. Future directions of the project could ponder this need carefully through a more concerted effort in the interdisciplinary team.

3. More emphasis on testing the entire execution of the "tool(s)" should be carried out prior to closing the project.

4. Attention to the aforementioned weaknesses can overcome the perceived problems. Perhaps communication improvements can help mitigate this perception. More integration within the multidisciplinary team should guarantee the creation of a practical tool.

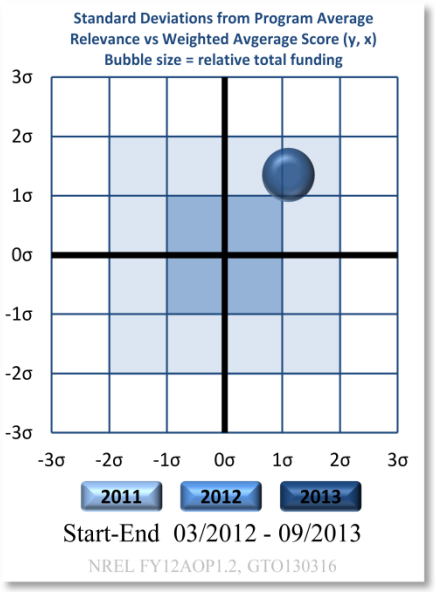
PI Response:
Thanks and agree. We are working on the integration.

Reviewer 23421

Comment: Reviewer suggests that development team spend more time reaching out to private industry and state-level-managed private industry data bases. There are several ultra-deep wells both recently completed and currently drilling in the Gulf of Mexico shallow waters. The most active operator is Freeport McMoran. Reviewer suggests that MIT contact the investor relations person at that company (stock ticker: FCX) to ask to work with the scientific team. Also, Chevron

is drilling an ultra-deep well onshore (called the "Lineham Creek" well) that may provide some reality check points to the model.

PI Response:
Thanks. Past attempts have shown that it is practically impossible to get drill costs from oil/gas companies. We would appreciate very much to get some help in this regard.



Review: 2013 Geothermal Technologies Office Peer Review
ID: NREL FY12AOP1.2
Project: Geothermal Regulatory Roadmap
Principal Investigator: Young, Kate
Organization: National Renewable Energy Laboratory
Panel: Systems Analysis

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23480

Score: 9.0

Comment: This project addresses a key need of geothermal developers: a streamlined geothermal permitting process. The petroleum industry has benefited from such streamlining at both the federal and state levels. The process should effectively reduce costs and risks by removing regulatory obstacles in a consistent and timely manner. The project aims to facilitate matters by providing the process tools needed by regulators.

PI Response:

Reviewer 24894

Score: 8.0

Comment: This project targets lower risk and costs associated to geothermal development. By creating a best practice approach to permitting there is certainly potential in reducing the costs and some risks by streamlining, but this is only reflected indirectly. The strength of the project is by bridging communication among developers and across regulatory agencies, which is were I believe it has its greatest impact potential. The role of the work is important and will be very valuable aiding the geothermal industry, but there should be more to align the project with GTO goals. An impact analysis by state is suggested.

PI Response:

Reviewer 25420

Score: 10.0

Comment: This project is exemplary and the achievements of the project have exceeded the original goals of the project. The impacts are immediate and reflect not only well-design research, but an attitude that champions these type of activities. This projects is relevant not only to the mission of the Geothermal Office, but serves as a role model for other sectors, despite the fact that the team relied on experiences from other offices to initiate activities. The project team must be commended for such an extraordinary and systematic execution. Knowledge gaps have been identified in policies in other sectors as well!

PI Response:

Reviewer 23421

Score: 10.0

Comment: As a geo-scientist and a private sector investor, it is the Reviewer's opinion that this study was the single most important project reviewed during this session. For geothermal/EGS projects to become a baseload reality, it will take private sector investment to produce any needle-moving impact on the US power grid. Currently (and for the the last 5 years), the number one or number two risk cited on any list of Wall Street or buy-side (investment community) investment strategist's concerns is "government/regulation/policy/political risk." It is a large unknown, difficult to quantify, and a solid deterrent to private sector investment. It is not that regulation per se is the "risk." It is the unpredictability of the process; time involved, investment in required paperwork, and often conflicting answers or even "who do I go to in order to get through this step?," that can kill private investor appetite for funding large infrastructure projects such as EGS. And because this uncertainty occurs early in the project engineering cycle, it is a relatively more costly "risk." Because of the "time value of money," delays to a project early on have a disproportionate and negative impact on the present value calculations of the expected financial returns. It doesn't take much these days to drive capital away from investing in (or even considering) important projects. And the uncertainties associated with the maze of navigating through city, local, county, state, and federal regulations with an unknown timeline and an uncertain outcome are enough to keep most private sector investment on the sidelines here in the U.S.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23480

Score: 8.0

Comment: The crux of the project is the permitting roadmap, made up of numerous flowcharts for each element of the regulatory process. Stakeholders are identified and their role, especially decision responsibilities are identified within the context of the flowchart(s). Interviews with permitting agency officials was a very important step in assuring accuracy of the charts. Use of OpenEI and Wiki platforms is an innovative approach for getting results to stakeholders, including the public. Bringing regulators together from federal, state, and local levels produced excellent opportunities for information exchange and improved understanding.

PI Response:

Reviewer 24894

Score: 8.0

Comment: The open source platform is a strong tool for collecting and accessing regulatory data. Interviews with regulatory agencies is a valuable data collection method and opens a dialogue with stakeholders. Addressing perception challenges within the agencies was addressed well through persistent communication, while targeting procedural bottlenecks is valid for determining decision points.

Actions taken during the Part 3 of the project are difficult to identify. Are they quantitative? If so what metric is used?

PI Response:

Reviewer 25420

Score: 9.0

Comment: This project reflects the proper choice of critical goals, among which permitting might be more relevant than some other technical aspects. By defining a clear focus efforts were directed to identity the gaps and then inform the roadmap. This is not unique to the type of tasks conducted in this project and therefore, a roadmap is a paradigm for other types of research projects.

Resources were used effectively and US States were clearly identified and targeted to effectively use energies. I would summarize, in my humble opinion, the secret to the success of this project: identification of critical gaps, definition of clear procedures and workflows in CONTEXT and consultation with stakeholders, and open communication. Undoubtedly, the team has the necessary experience and exposure to the agency to conduct the execution adequately, but this reflects commitment and the importance of the champion.

PI Response:

Reviewer 23421

Score: 8.0

Comment: Not enough data for Reviewer to intelligently comment on the quality of the approach. From the level of detail provided to Reviewer, it appears the technical approach of actively involving both private and public sector constituencies is sound. However, the Total In-House Labor costs to date of $1,025,000 (project started March 2012) appears high. Whether justified or not, it is not possible for this Review to tell.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23480

Score: 8.0

Comment: Completion of flowcharts for 8 states, along with 15 followup feedback meetings over a six month period is remarkable. The results were well-received as noted by comments. The extent to which the positive outcome will

translate into reduced permitting times and lower costs remain to be determined. An irony of the permitting process is that in model analyses, such as GETEM, permitting is the least costly element of LCOE. But there are numerous examples of permitting delays resulting in unacceptable cost burdens. Further discussion of the flowcharts and their use would have been helpful.

PI Response:

Reviewer 24894

Score: 8.0

Comment: Multiple federal agencies and states have been mapped and the project has actively engaged a very broad range of stakeholders. Transference of this data to an online, open source platform is useful and appears to be done in a timely manner.

Active engagement with policy makers allows for an immediate results. This brings some of the longer term goals for the project insight.

PI Response:

Reviewer 25420

Score: 10.0

Comment: As constructive as I would like to build critiques, it is difficult to provide feedback for improvements in this project. The team has accomplished what they set out to do and more. The quality of the results is outstanding and they have followed schedules.

PI Response:

Reviewer 23421

Score: 8.0

Comment: It appears that the project has accomplished much (if not all) of the data collection and regulatory mapping steps. Compared to what comes next, this is the "easy" part. However, it appears that the work flow, documentation, and expenditures to date are within the expected timetable and budget.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23480

Score: 7.0

Comment: The project does not appear to have budget/schedule issues. Plans for future work are ambitious and may not complete by the end of calendar year. Improving the user interface is important for future general use of the flowcharts. Of perhaps greater importance to DOE and other agencies would be the analyses of cost recovery and centralized permitting. Adding states will extend the project well into FY2014, but this added expense would essentially include all the geothermal states in the West.

PI Response:

Reviewer 24894

Score: 9.0

Comment: Project management and coordination appear to be on track for data given. More details should have been provided on the original project timeline for comparison. The number of stakeholders is extensive, and the fact that progress has been maintained supports active management of the project.

PI Response:

Reviewer 25420

Score: 9.0

Comment: Coordination and management are also outstanding. One point to highlight is that the project team maintains flexibility to adjust milestones as they unveil new knowledge gaps without neglecting project objectives. This is important, because in such a short-term project, delays should probably be expected. The choices were perhaps, in my interpretation, more driven by needs than lack of dedication or procrastination. The utmost importance is the feedback from stakeholders, because the project remains open to evaluation and is not shielded from valuable feedback. The team listens and implements improvements as they unroll the project. This indicates an effective and constructive coordination of effort.

PI Response:

Reviewer 23421

Score: 9.0

Comment: More so than any of the other projects Reviewer has examined here, this project requires a massive amount of project coordination between a wildly-differing and deep pool of individuals, organizations, departments, and constituencies. The fact that much has been accomplished to date (federal agencies and 8 states), speaks to the quality of the project management and coordination.

PI Response:

STRENGTHS

Reviewer 23480

Comment: Obtaining buy-in from regulators and other stakeholders on the roadmapping process is a key accomplishment.

PI Response:

Reviewer 24894

Comment: This project is strong in what it brings to industry in understanding and streamlining the permitting process. The methods and flow chart approach are easily understood across stakeholder groups and provide a clear method of communication. Open source publishing via OpenEI allows wide spectrum access and sharing of data. I particularly like the long-term intent of having stakeholders maintain the data over time.

I really liked the fact that there is an exit strategy in practice for the project close, which reflects a longer term strategy.

PI Response:

Reviewer 25420

Comment: 1. A coordinated, open-minded and focused project team.

2. A clear set of goals and a proactive team.

3. A terrific champion and support from the parent agency.

The idea of the roadmap is often interpreted as a bureaucratic exercise not applicable to research projects. This is also thought of as product development. In this case, while a 'product' can be identified, the important consideration for this project is that this focus offered a research methodology in which stakeholders participated from a win-win approach from the beginning and the project team did not appear to be threatening. By analogy, the so-called fundamental research projects could model after projects of this nature by anticipating adaptation through definition of decision points. A tendency to set hard goals of research projects tends to create situations in which workflows or decision points are

neglected. The GTO130316 is exemplary in that the goals/objectives of the project did not define the tasks in an inflexible manner. This allows adaptation and therefore potential attainment of superior outcomes.

I wonder if the strengths of this project could not be replicated, modeled, enticed, etc., so that other research endeavors in the geothermal office benefit from the roadmap approach. The same openness can be applied to the style of different projects. This in no way means that this project, GTO130316, cannot be further improved, but the project appears to have this mechanism (external feedback via open comunication) by construction. It is important to indicate that this project is MULTIDISCIPLINARY and therefore is not benefiting from an 'easy' coordination effort.

PI Response:

Reviewer 23421

Comment: 1. PI recognized the importance of involving the private sector in streamlining the regulatory process.

2. Good use of online data bases (OpenEI and Wiki Platform) and "social networking" (Facebook, Twitter).

PI Response:

WEAKNESSES

Reviewer 23480

Comment: Reviewer did not provide comments for this criterion.

PI Response:

Reviewer 24894

Comment: The lack of quantitative impact metrics is a limiting factor in project assessment. From the onset the goals of the project and program were to reduce costs and risk. At this point it is only insinuated, and should be specified. The presenter commented that external research at NREL will address the LCOE impact analysis resulting of this project. This should be included.

PI Response:

Reviewer 25420

Comment: As I stated before, it is difficult to find weaknesses in such a well executed project. However, I do find that this project requires more promotion. More than the results, the process followed could be popularized outside the boundaries of the geothermal office. I believe this is already happening but I am referring to intended effort in this sense.

PI Response:

Reviewer 23421

Comment: 1. Not so much a "weakness" as a concern: the next step is the crucial one. Basically, getting everyone together on what needs to be done. Then implementing it.

2. Reviewer worries that this project will result in a series of solid recommendations for best practices, but will be unable to see them implemented due to the massive cross-agency issues involved.

3. Money spent to date on in-house staffing appears high. Reviewer is concerned that all the "right people" and correct level of staffing exists here.

PI Response:

IMPROVEMENTS

Reviewer 23480

Comment: The future challenge for this project is to remain current with regulatory developments/changes. This implies that the project remain viable/active in the long term; annual meetings of stakeholders, especially regulators, would help to keep the flowcharts current. NREL should look at the possibility of obtaining support from user agencies for this long-term commitment. Consideration should be given to cascading the flowcharts to the county level in the major geothermal states (e.g., CA, NV, UT).

Comparisons of regulatory processes should be made between states (and counties within states) to identify procedures that work well in terms of budget/permitting time or those that could be improved.

PI Response:

Reviewer 24894

Comment: This project should attempt to quantify its ability to meet stated goals. I would recommend that a LCOE analysis of the impacts of this project in the near and long term be included. Realizing that NREL is conducting a portion of this analysis externally, it would be worthwhile to include it in future reviews of project results.

PI Response:

Reviewer 25420

Comment: I would recommend to redouble efforts to expose the outcomes and processes in this project. Multiple agencies and numerous stakeholders create a sea of information in which this relatively small but successful project could get ignored.

The specific suggestion is to share a distilled version of the project as a simplified roadmap of design and execution of future projects, not only in the Geothermal Office, but in other DOE offices. This might initiate a discussion on how to direct project design and execution more effectively. I am certain that projects of this level of success can be found out there but the massive information overload overshadows the model to even the most aware observer/researcher.

PI Response:

Reviewer 23421

Comment: Presentation noted that the oil and gas sector appears "to have a far more efficient regulatory and permitting process than geothermal." That is due to at least three key (and interconnected) reasons: 1) Regulators in O&G tend to understand the business they are regulating, 2) there seems to be (at least in Reviewer's experience) lower turnover of government personnel in the O&G regulatory offices, and 3) many of the government regulators came from the O&G industry. Number 3 is a good thing. These regulators know what is important and what is not. They speak the language and grasp the concepts. It may be well worth the PI's time and effort to high-grade the time spent benchmarking the geothermal permitting process against the O&G permitting process.

In order to make a real impact with this (much-needed) project, it needs the political backing of someone(s) high up in each of the state governments it targets. Each individual state needs to implement the recommendation its own way. And for that to be accomplished, a high-level, local advocate needs to be passionate about seeing it through.

In-house staffing costs appear high. Try to do more with less. Take the lead and show how both time and money can be more effectively spent. This is a vitally important project. Let me say that again: This is a Vitally Important Project. Do not let it be derailed by running high G&A costs. Set an example and BE that "effective government agency" you are helping to create.

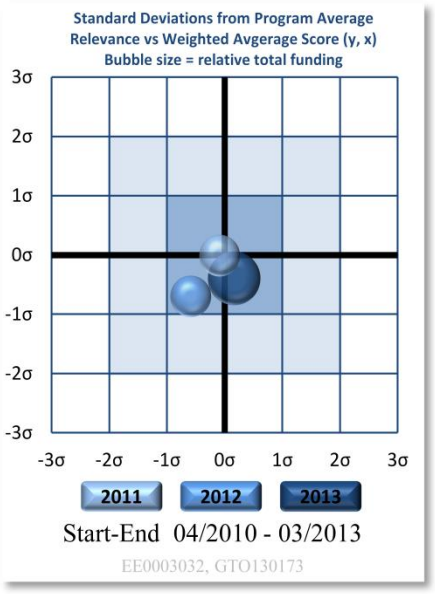
Involve private industry more. If not already doing so, include a local representative (or two or three) from the private sector and the most appropriate local elected official in face-to-face talks about improving the system and understanding the other side's concerns. Nothing beats getting people together in the same room (with a box of donuts and a carafe of coffee), at the appropriate time.

When the study is completed, contact several business-oriented national news organizations (the Wall Street Journal, Forbes, Barron's) to write up the good work you have done (and are doing). It is vital that the investment community at large knows that government agencies and licensing bureaus are working on reducing the regulatory uncertainties around approving and permitting geothermal/EGS projects. For geothermal projects to become a meaningful part of the solution for baseload energy generation, it will take private sector investment. Get the word out to the private sector at large, not just the geothermal-centric private sector (who already use your databases). But to the general investing public. Private equity, hedge funds, pension boards, and the like all read popular investment publications. Make sure your results are broadcast and highlighted via these channels so as to let the investment community know that the U.S. is "open for business and welcomes the investment" in next-generation geothermal projects.

Reviewer's aside: "reducing uncertainties" is not meant to suggest "deregulation," just to be clear.

PI Response:

Tracers Reviewer Comments and Principal Investigator Rebuttals



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0003032
Project: Novel Multidimensional Tracers for Geothermal Inter-Well Diagnostics
Principal Investigator: Tang, Yongchun
Organization: Power, Environmental and Energy Research Institute
Panel: Tracers

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23412

Score: 8.0

Comment: This project uses chemical techniques to better understand flow paths within a porous and fractured reservoir.

PI Response:

Reviewer 23450

Score: 5.0

Comment: This project's relevance is uncertain in the mind of the reviewer as it seems to replicate. The project is structured to develop smart geothermal tracers to query interwell properties of inter-well connectivity, surface porosity and mineralogy, fracture surface area and spacing. These are desirable reservoir engineering variables but these are standard wish lists items and this R&D presents little that is novel.

PI Response:

Reviewer 24878

Score: 5.0

Comment: This project concerns the development of multiple smart geothermal tracer to study well interconnectivity through breakthrough curves.

PI Response:

Reviewer 23552

Score: 8.0

Comment: The project by Tang is a very intriguing application of novel organic geochemical and geothermal tracers. Their development of "smart" tracers takes advantage of the both the reactivity (adsorption) and thermal degradation properties of relatively low environmental impact organic compounds (variations of Carboxylic Acid). The approach is based on a multi-facetted laboratory calibration, laboratory flow testing, and natural test (well characterized quarry). This multi-scale approach us well suited for more rigorous understanding of the interaction of these compounds. The study also convincingly demonstrated their goal of signal enhancement, requiring lower tracer concentrations and dramatically improving the detection limits. The analytical approach is novel and not used in hydro-carbon exploration for obvious reasons (Carboxylic Acid as a naturally occurring compound). However, I would recommend that Tang's team also test the "zero-tracer" case as these compounds are naturally occurring. While geothermal systems are not hydrocarbon systems, rocks with significant TOC content might very well generate non-tracer related carboxylic acid. This is a easy, but important test. In my opinion the most exciting aspect of the applied research lies in the application of the natural chromatography of mono- vs di-carboxylic acids by different minerals (esp quartz and calcite). This might have the potential to evaluate the nature of mineral lining on veins and open flow apertures in natural systems and help with the understanding of the longevity and self-sealing of fractures and flow networks. The observed dispersion of the natural chromatography is also very exciting, but it might be interesting to further investigate and develop this in light of path tortuocity. The literature of different fields (e.g. noble gases or heterogenous flow) is full of models dealing with multi-path retardation or tortuocity.

PI Response:

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23412

Score: 8.0

Comment: The technical approach of laboratory and field test results are very good.

PI Response:

Reviewer 23450

Score: 7.0

Comment: The approach is sound to investigate the tracer/surface interactions and develop laboratory protocol. Theoretical modeling and laboratory testing of tracer reactions on different mineral species is sound and may provide insights into fine-tuning tracer design in different geothermal environments.

PI Response:

Reviewer 24878

Score: 6.0

Comment: The development of smart tracer test is coupled with high level of detectability. What is missing is really some numerical modeling of the behavior of these tracers in dual porosity systems with fracture and matrix permeabilities. The tracer modeling is done with a single dispersion coefficient. This is a bit of a crude approach. There is no distinction between effective and total porosity. The field validation site (dipole test) is a near surface validation site that has little to do with a geothermal system (especially the effect of temperature and pressure).

PI Response:

Reviewer 23552

Score: 8.0

Comment: The project by Tang is well designed with a multi-scale laboratory approach of developing "smart" organic geothermal tracers coupled with a natural test case. The laboratory work has focused on several critical aspects. (1) The development, characterization, and benchmarking of carboxylic acid tracers. This work is basic, but exciting and has been carried out by the team with rigor and the appropriate technical expertise. (2) Enhancement and amplification of tracers by factor X. This is clearly a major contribution and has undoubtedly achieve the stated goals and objectives. The laboratory-based work shows that the amplification goals are realistic and will enable much higher detection limits, lower tracer concentration applications, and also a more detailed time-resolution of the measured tracers. However, as stated before, this is also creates issues. What are the natural abundances of Carboxylic acid compounds in natural systems and especially geothermal systems. This is a minor, but important weakness of the project. Something that could and should be remedied. (3) The natural chromatography of mono- vs di-carboxylic acids. This naturally occurring retardation induced by the interaction with mineral surfaces is extremely interesting and tremendous potential. More systematic testing and understand would be desirable for the future (something that is likely beyond the scope of this study). The natural test (quarry) is very interesting, but the least developed part of this project and could use improvement. For example, a comparison test with traditional tracers, a better understanding of the flow path and flow tortuocity is desirable. This natural test case was chosen for specific reason and is well studied, but the project currently does not take sufficiently advantage of the existing data or understanding.

PI Response:

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23412

Score: 9.0

Comment: Project is completed with excellent results.

PI Response:

Reviewer 23450

Score: 5.0

Comment: The use of a hollow porous needle to pre-concentrate the tracer is an interesting accomplishment applied to geothermal tracer research. The field test results are at a well characterized site.

PI Response:

Reviewer 24878

Score: 8.0

Comment: Good progresses have been made.

PI Response:

Reviewer 23552

Score: 8.0

Comment: I will clearly repeat myself here given the nature of the questions. (1) Quality. The work by Tang and his team is of the highest quality, strategically planned, and leveraging other resources very effectively. The laboratory work is novel, high impact, and adhering to the state-of-the-art technical protocols. The signal amplification and enhancement work is a major technical break through and makes the novel "smart" organic tracer work important and feasible. The laboratory based chromatography/retardation work is also very exiting and brings major potential for future study. I think this could really be one of THE break throughs in tracer work. I mean it and it has potential beyond geothermal work. As stated above, the natural quarry case study seems to lag behind in quality and productivity and might not be the natural strength of the team. However, the initial results are very promising, but require a more whole-hearted approach. (2) Productivity. I have no concerns. The project seems to have achieve major goals and benchmarks, successfully and effectively leveraged resources, met or exceeded the major technical targets. My only criticisms overall are related to the maybe slightly "naive" and too laboratory oriented application of these tracers, e.g., natural occurrence and interference of these organic compounds and the less-well-developed natural case study. Otherwise a very successful study that is on target with major achievements and accomplishments. Technical targets are being met without a doubt.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23412

Score: 8.0

Comment: Project management and collaboration with BJ is beneficial.

PI Response:

Reviewer 23450

Score: 5.0

Comment: Costs and level of effort seem appropriate to the task.

PI Response:

Reviewer 24878

Score: 8.0

Comment: The management of the project seems in good shape with three milestones well completed.

PI Response:

Reviewer 23552

Score: 8.0

Comment: In light of all the accomplishments, the project and the team are well managed and coordinated. The flow of the study is well directed and managed and the goals and milestones are met. The project is well poised to make dramatic break throughs with high-impact science. My only minor suggestion would be to add more expertise on the applied side. The team does state-of-the-are laboratory work and has development some very exciting tools and techniques, but appears less well-versed in the application, natural complexities, etc. For the teams developments to have to long-term impact they deserve, it might be necessary to team up or expand more effectively into the natural realm.

PI Response:

STRENGTHS

Reviewer 23412

Comment: Collaboration with industry.

PI Response:

Reviewer 23450

Comment: Strong lab research and protocol. Theoretical and numerical modeling of tracer behavior.

PI Response:

Reviewer 24878

Comment: The study of well interconnectivity with smart tracer is an important topic.

PI Response:

Reviewer 23552

Comment: Again I would like to apologize for repeating myself here. Below is a list of the strengths of the project:

- Development of "smart" multi-dimensional organic tracers

- Design, testing, calibration of these tracers

- Amplification and boost of detection and resolution of these tracers

- Development, testing, calibration of chromatography of tracers due to interaction with minerals

- Natural observation of retardation of tracers

The strength of the project not only lies in the cutting-egde development, test, and calibration of a new tracer, but really in the visions presented about thermal stability and interaction-induced chromatography of the tracer signal.

PI Response:

WEAKNESSES

Reviewer 23412

Comment: No apparent weaknesses.

PI Response:

Reviewer 23450

Comment: Project relevance in light of other geothermal tracer project is uncertain.

PI Response:

Reviewer 24878

Comment: What is missing is a field validation in a complex geothermal system. The modeling is too simplistic and better and more realistic numerical model should be performed in dual or n-porosity systems.

PI Response:

Reviewer 23552

Comment: This project has few weakness, but some gaps that could should be addressed. Below is a list:

- Natural occurrence of carboxylic acid compounds in nature, the interference, and the ramifications. As state before, natural geothermal systems that interact with rocks with significant TOC content produce a wide range of organic maturation productions. These might be in low concentration, but likely detectable. Given the much boosted detection limit of the project (a major strength), this might be a non-trival issue.

PI Response:

IMPROVEMENTS

Reviewer 23412

Comment: Needs to find better avenues for commercialization.

PI Response:

Reviewer 23450

Comment: N/A

PI Response:

Reviewer 24878

Comment: Better address the relevance to geothermal system, better demonstrate the usefulness of the approach to geothermal field for understanding the connectivity of the reservoir, better numerical modeling in more realistic conditions.

PI Response:

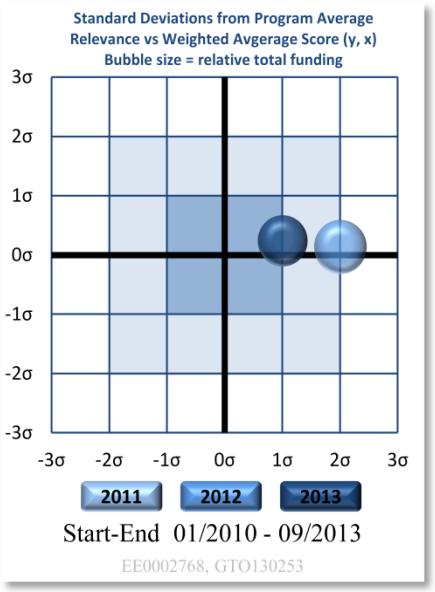
Reviewer 23552

Comment: As discussed previously. Here is a list of possible improvements or further developments:

- Measure Carboxylic acid content in a small, but representative spectrum of geothermal wells to evaluate the impact of naturally occurring Carboxylic compounds. Hopefully show that his reviewer was worried about something that is a non-issue.

- Improve and further develop the natural case study (NY quarry) taking advantage of existing data and also possible inter-calibrate with more traditional tracers. Whenever developing something new and touting it as better, it would be nice to show this explicitly in an intercalibration

PI Response:



Review: 2013 Geothermal Technologies Office Peer Review
ID: EE0002768
Project: Quantum Dot Tracers for Use in Engineered Geothermal Systems
Principal Investigator: Rose, Peter
Organization: University of Utah
Panel: Tracers

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23412

Score: 7.0

Comment: Project needs to collaborate with other national programs that may have temperature solutions such as homeland security projects at LLNL.

PI Response:
Agreed.

Reviewer 23450

Score: 9.0

Comment: This IS one of the more relevant tracer projects highlighting and addressing the need for new geothermal tracers. As geothermal fields conduct tracer tests over time, many conservative tracers are recycled and will persist for years. The quantum dot tracers are an innovative way to expand the tool kit of tracers available for both reactive (surface charge controlled) and non-reactive applications. Especially useful is measurement by optical fluorescence instead of traditional analytical chemical analysis.

PI Response:
Agreed.

Reviewer 24878

Score: 6.0

Comment: The goal of this project is to provide a better characterization of fracture networks in EGS. I am not sure however that the proposed approach will be really helpful for that purpose. There is a lack of validation on both the numerical side and in the field (especially geothermal fields). I wonder about the stability of the molecules. With the presence of cadmium and selenium, I am not sure that these tracers are eco-friendly.

PI Response:
Valid criticisms. Regarding the stability, we have made significant progress by stabilizing quantum dot tracers at 300 C for several hours. In the follow-up proposal we describe plans of further stabilizing quantum dots for long-term

applications. A main focus point of this current proposal is also to move from cadmium based quantum dots to heavy metal free samples.

Reviewer 23552

Score: 8.0

Comment: The project by Rose and his research team and collaborators aims to proliferate the development and calibration of quantum dot tracers for the use in geothermal exploration and especially EGS systems. The teams fundamental approach is the synthesis and laboratory testing of colloidal quantum dote tracers - a new and exciting family of reactive and non-reactive tracers that exhibit fluorescence and specific wavelength is fluorescence as a function of size. Simple flow-through tracers lack the sophistication to provide specific qualitative or even quantitative information about the nature (size or mineralogy) of fractures that would be help to better understand flow in fractured medium or EGS flow fields. Therefore the development of "smart" tracers, such as colloidal quantum dot tracers, is of major relevance to understanding and quantifying flow and changes in flow in fractured reservoirs - something that clearly does not apply to geothermal systems only, but does impact ground-water hydrology and hydrocarbon recovery. The potential to custom design such quantum dot tracers for specific problems as a function of size or reactivity holds significant promise for a better understand of rock-fluid interaction and the temporal changes in naturally occurring or artificially created fractures in rocks. The relatively low thermal or chemical stability of these quantum dot tracers, however, does present a challenge and limits the applicability to certain application and to relatively short-term tracer flow experiments. Never the less a better and high fidelity understanding and thus ultimately predictability of fracture aperture and surface area is highly desirable. In addition, these fluorescence-based techniques are conducive to automated tracing techniques providing faster and more real-time results without time- and labor-intensive laboratory-base methods.

PI Response:
We agree that thermal stability is a concern. However, one set of experiments that we conducted and presented showed that quantum dot luminescence improved by a factor of 3.5 and we demonstrated stabilization of quantum dot tracers at 300 C for several hours. This suggests that high-temperature stability is achievable and, in a follow-on study, we will demonstrate such thermal stability.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23412

Score: 8.0

Comment: Scientific approach with laboratory measurement systems is important.

PI Response:
No comment.

Reviewer 23450

Score: 9.0

Comment: The scientific approach of engineering nano-particles at 5 nm with specific fluorescence and charge is very innovative and illustrates a high degree of understanding of colloidal particle behavior and how to manipulate properties to act as tracers with a range of engineered properties.

PI Response:
We agree.

Reviewer 24878

Score: 6.0

Comment: A new class of (conservative) tracers, colloidal quantum dots, can be potentially interesting for use in characterizing fracture networks in EGS reservoirs. They can be altered to determine the surface area of the fractures and therefore they can be used to characterize fracture networks. These tracers can be detected by fuorescence at visible and longer wavelengths. A realistic numerical modeling of the behavior of these tracers in dual or n-porosity systems ith a statistical distribution of fractures is missing.

PI Response:
Whereas realistic modeling is important, we believe it is more important under the scope of this project to use relatively simple models to infer the transport properties of the quantum dots in laboratory flow systems and then demonstrate how these properties can be used to interrogate reservoir properties (including uncertaintites). It is our belief that this should be the extent of the modeling scope for this project, with the results being transportable to more complex models that account for flow system heterogeneity as appropriate and when appropriate. We have more complex modeling capabilities at our disposal, but we have not seen the need to employ these models to accomplish project objectives.

Reviewer 23552

Score: 8.0

Comment: The basic technical and scientific approach in the laboratory is systematic, but relatively straightforward and attractive. The team lead by Rose is developing new new quantum dot tracers through a complex laboratory-based protocol that involves the synthesis and fluorescence testing of non-reactive (non-sorptive) quantum dot tracers in the laboratory and to calibrate their size-dependent fluorescence. Furthermore, the team has and is investigating the thermal and chemical stability of these quantum dot tracers and their detectability limits. Thermal stability and chemical degradation of geothermal fluids is clearly of particular importance as this impact results and lessen the usefulness and fidelity of quantum dot tracer results. Non-sorptive tracers were tested and intercalibrated using benchtop reactor to study the tracer response. These non-reactive quantum dot tracer experiments are important as benchmarks.

The next step of sophistication taken by Rose's research team was (1) the creation of reactive or sorptive quantum dot tracers through surface chemistry modulations to investigate rock-water interactions, (2) the thermal stability, and (3) the diffusivity into vein pores. These more sophisticated applications of sorptive quantum dot tracers also requires the development of more appropriate and complex numerical modeling and interpretation approaches.

Lastly the teams hopes to both upscale the amount of the quantum dot tracers to make them useable in natural settings with volumetrically much larger fluid reservoirs and more dilute tracer requirements. This upscaling will then allow for field testing of the different types of quantum dot tracers.

PI Response:
This comment summarizes our achievements quite well.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23412

Score: 7.0

Comment: Project is almost near completion. Needs better avenues for commercialization.

PI Response:
Quantum dots are still a very young type of materials and despite a wide range of potential applications, commercialization efforts have just begun. One obvious challenge in using quantum dots as geothermal tracers is the large quantity of samples needed for field testing/applications. In fact, commercial availability of high-quality quantum dots is currently very restricted and available samples are expensive. We recognized this discrepancy between quantum dot potential and availability and part of the team of the current project formed a start-up company in 2012, Navillum Nanotechnologies. Meanwhile, the company has four employees and has secured several commercialization awards and stage-1 SBIR funding. The main goal of this company is to inexpensively mass-produce high-quality quantum dots. While the initial goal of the company is geared towards general applications of quantum dots, the step toward producing quantum dots with properties optimized for geothermal tracing applications is planned. For this step, however, it will be important for us to demonstrate that we can have as much success after replacing cadmium with an environmentally benign metal. These studies are currently ongoing and are also a main focus point of a current proposal.

Reviewer 23450

Score: 9.0

Comment: Dr. Rose and his team have developed a new class of tracers designed to query the fracture and fracture surface properties in a geothermal system. These tracers avoid the cost and time required to conduct traditional tracer measurements. The optical sensor system at different wavelengths presents many other uses beside geothermal tracers.

PI Response:
We agree.

Reviewer 24878

Score: 7.0

Comment: The progresses have been done according to the plan as far as I can say. I did not find many papers published in the peer-reviewed literature as output of this project.

PI Response:
We published one peer-reviewed paper (Nanosci. Nanotechnol. Lett. 2011, 3, 655-658), but yes, we need to further publish our results in peer-reviewed journals.

Reviewer 23552

Score: 9.0

Comment: The team lead by Rose appears to be largely on track with respect to planned activities and and accomplishments.

(1) Development of new quantum dot tracers and their fluorescence size measurement and their low-temperarture stability/decomposition. Through systematic laboratory-based experiments the researchers show and calibrate the fluorescence wavelength shift of non-reactive (non-sorptive) quantum dot tracers as a function of size dependence. This important relationship is also important for pragmatic reasons potentially allowing for nearly real-time analysis (at well site) compared to traditional tracer experiments given the easy spectroscopic measurement.

(2) The team also investigated the thermal and chemical stability of these quantum dot tracers and their detectability limits. Thermal stability and chemical degradation of geothermal fluids is clearly of particular importance as this impact results and lessen the usefulness and fidelity of quantum dot tracer results. Thermal stability was enhanced with silica coating/encapsulation. There are clearly some significant advances, but also outstanding questions, given the thermally-induced degradation and the oxidation effects on the silica encapsulation.

(3) Flow-reactor testing to calibrate and benchmark quantum dot tracers against more traditional tracers. This is clearly important before any upscaling to actual borehole tracer experiments. The experiments also show differences.

(4) After development and laboratory prove-of-concept work, the next step of sophistication taken by Rose's research team was (1) the creation of reactive or sorptive quantum dot tracers through surface chemistry modulations to investigate rock-water interactions, (2) the thermal stability, and (3) the diffusivity into vein pores. This work seems to be ongoing on only in early stages, although the provided documentation shows very promising results. The developed numerical modeling code also appears to predict the behavior of the quantum dot tracer very well for simple reactor experiments. These more sophisticated applications of sorptive quantum dot tracers also requires the development of more appropriate and complex numerical modeling and interpretation approaches.

The main outstanding and critical hurdles for success lie in (1) long-term stability, (2) design of the "ideal" ligands for quantum dot tracer, and (3) the proper upscaling of the amount of the quantum dot tracers to make them useable in natural settings. Last aspect is partly to be done in the lab and partly the focus of possible follow-up studies.

PI Response:
This is a very good summary of both our achievements and potential avenues of further research.

PROJECT MANAGEMENT/COORDINATION

Reviewer 23412

Score: 9.0

Comment: Project coordination was adequate.

PI Response:
No comment.

Reviewer 23450

Score: 8.0

Comment: This a multi-year project nearing completion with the stated objectives achieved.

PI Response:
No comment.

Reviewer 24878

Score: 6.0

Comment: A lot of components are missing in this project and I will review them later on (see below). I am afraid that the experiments conducted at 25 degree C in sand column are very interesting but their relevance to geothermal field is doubtful.

PI Response:
The thermal stability studies showed promising stability at 150 C. One experiment at 300 C also showed stable quantum dot tracer emission for several hours and that thermal stability increased as a result of exposure to high temperatures. More work is obviously needed, but there is nothing to indicate that the quantum dot tracers will not be stable at high temperature.

Reviewer 23552

Score: 8.0

Comment: The project Management/Coordination was successfully handled by Rose. He also coordinated the important collaborations the Bartl group (responsible for chemical synthesis), his own group at EGI (responsible for testing under simulated geothermal conditions), and the Reimus group at LANL (responsible for flow modeling).

PI Response:
We agree.

STRENGTHS

Reviewer 23412

Comment: Novel ideas for tracers and tracer interpretation.

PI Response:
No comment.

Reviewer 23450

Comment: Dr. Rose's understanding of geothermal systems and tracer requirements. Innovative chemistry and lab methods to manufacture lab bench scale quantities. Ability to detect using optical methods instead of analytical chemical methods. Development of numerical models to understand and quantify QD behavior.

PI Response:
We agree.

Reviewer 24878

Comment: A better way to characterize fracture network using an innovative technology.

PI Response:
No comment.

Reviewer 23552

Comment: The Rose "Quantum Dot Tracer" project is an advanced and very novel collaborative project developing, benchmarking, testing, and potentially upscaling designer tracers that can be detected and measured due to their size-dependent fluorescence. The strengths of the project are obvious:

(1) Development of non-reactive and reactive quantum dot tracers that are easily measure in near real-time

(2) Development of thermally "resistant" and sorption-specific designer quantum dote tracers

(3) Benchmarking of new quantum dote tracers against more traditional tracers

(4) Benchtop reactor testing and predicative modeling

The need for "smarter" and more easily and readily detectible tracers is important in an energy and resources environment where flow through fractured media is becoming more and more important. Therefore this project and its findings is important, although some aspects of the projects are not yet fully developed and some problematic issues are not yet fully addressed and/or remedied (see weaknesses).

PI Response:
No comment.

WEAKNESSES

Reviewer 23412

Comment: No plans for commercializion.

PI Response:
Please see our comments above wherein we respond to commercialization activity and plans.

Reviewer 23450

Comment: Perhaps a field test though that was not a stated objective.

PI Response:
We will definitely need to demonstrate the next-generation quantum dot tracers in a field experiment.

Reviewer 24878

Comment: There are several things missing in this project: (1) the realization of numerical simulations of the behavior of these tracers in complex porous media, (2) Some validation in geothermal fields, (3) an investigation of the toxicity of the tracers.

PI Response:
Please see our comments above wherein we responded to these very suggestions/weaknesses.

Reviewer 23552

Comment: Despite all of the fundamental and basic strengths of the project and its findings, there are some weaknesses that keep the study from realizing all of its potential and have the necessary impact.

(1) As the Rose report stated, the development of quantum dotes (non-reactive and reactive) that are thermally and chemically stable longer term is a crucial aspect for the success and the temporal upscalling of the tracer use. Minutes of stability or significant short-term thermal and chemical degradation will undermine the usability of such tracers and make them undesirable or at least undermine their trustworthiness. A key goal is to better understand and improve long-term stability both and room and geothermal temperatures.

(2) Benchtop flow reactors are nice, but more work is needed to demonstrate the use of quantum dot tracers in more realistic settings and eventually geothermal fields. This again is crucial in order to make these potentially exciting tracers useful and marketable.

In addition, more sophisticated multi-path way models would be desirable. Probably so far one significant weakness of the project. This part is not yet developed to be useful, but needs to be more completely developed and more sophisticated in order to be applied to the results and the experimental approach. This includes heterogenous flow incorporating multi-path ways likely resulting in quantum dot tracer signal retardation or dispersion in light of different fractures or temporal variations in quantum dot size. I think this kind of natural chromatography is exciting, but it will need a more sophisticated approach to get the most out of these exciting new quantum dot tracers.

The authors, likely in light of past criticism, also stress the need for design, synthesize, and characterize quantum dot tracers using environmentally acceptable metals (e.g. Zn, Cu, Mg, Fe, Mn). I don't think that's that big of an issues. However, if it is really an issue due to upscaling then the time is now to remedy this during miniaturized testing and not in the end after all the work is done. Either it is an issues or it is not, but the time to determine this is up front in my opinion.

PI Response:
Please see our comments above wherein we responded to these very suggestions/weaknesses.

IMPROVEMENTS

Reviewer 23412

Comment: Test a field scale.

PI Response:
We agree.

Reviewer 23450

Comment: This project is clearly ready for some degree of commercialization, a commercialization/royalty/license arrangement with the geothermal and petroleum industries should be pursued.

PI Response:

Please see our comments above wherein we respond to commercialization activity and plans.

Reviewer 24878

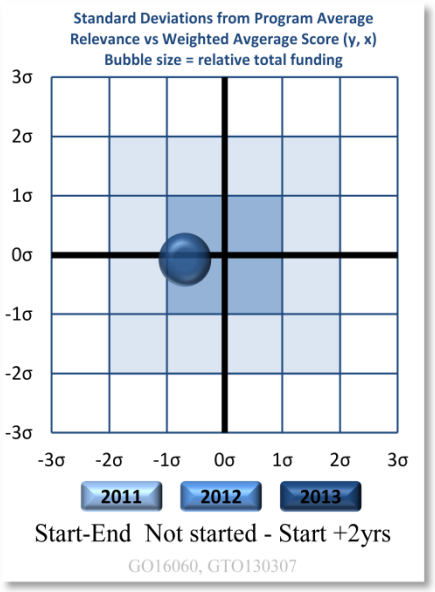
Comment: Perform lab experiments that are relevant of field conditions, perform numerical simulation in realistic porous and fracture media (at least two porosity systems), an the use of eco-friendly tracers.

PI Response:
lease see our comment about about our reluctance to conduct complex numerical simulation experiments under this program, with its focus on chemistry and chemical engineering.

Reviewer 23552

Comment: See statements of project weakness.

PI Response:
No comment.



Review: 2013 Geothermal Technologies Office Peer Review
ID: GO16060
Project: Fracture Evolution following Hydraulic Stimulation within an EGS Reservoir
Principal Investigator: Rose, Peter
Organization: University of Utah
Panel: Tracers

RELEVANCE/IMPACT OF RESEARCH

Reviewer 23412

Score: 7.0

Comment: Identified projects to execute tracer tests after stimulation activities.

PI Response:

Reviewer 23450

Score: 7.0

Comment: This project is handicapped by limited access to active EGS stimulation efforts. The stated objectives, while correctly stated, presuppose access to active efforts by geothermal operators to stimulate wells and create fractures to monitor. If these logistical issues can be overcome, the objective to monitor the evolution of a newly created fracture is sound using tracers in a 4-D context.

PI Response:
We agree.

Reviewer 24878

Score: 8.0

Comment: The idea is to use tracers to characterize the fracture evolution following a hydraulic stimulation within an EGS reservoir. This project addresses topics 4 and 5 of the GTP "areas of interest" identified in the Funding (1) Fracture evolution - Analyze the transient behavior (life cycle) of fractures and fracture systems in saturated and in under-saturated environments. (2) Fracture permeability - Develop an understanding of how fluids flow through rock. Provide the means to measure and monitor the flow of fluids in fracture systems and determine variations in flow capacity over time. This is an important topic and I like the potential application at Desert Peak, Raft Rivers, and the Geysers.

PI Response:
We agree.

Reviewer 23552

Score: 6.0

Comment: As stated by the authors, one of the fundamental objectives of EGS programs is the establishment of a persistent and well-characterized reservoir-fracture network that forms a geothermal heat exchanger. The observed or predicted evolution of fluid circulation due to chemical, thermal, or hydraulic changes in these fracture networks and permeability in EGS and natural systems is often difficult to quantify due to the lack . Despite the fact that major changes in reservoir permeability are well documented, most models are either untestable or lack the capabilities to constrain or predict the temporal or geometric evolution of fracture permeability and as a consequence the reservoir performance. This Rose (EGI) project tries to develop an technological approach for characterizing and quantifying the fracture permeability evolution in EGS networks in the wake of the hydraulic stimulation process. The main approach of this project is to develop and deploy novel tracers to better characterize and map out subsurface fractures and geothermal fluid flow. More specifically, the projects aims to deploy and test new smart tracer technology to better understand and to quantitatively describe both fracture evolution and fracture permeability over time.

PI Response:
We agree.

SCIENTIFIC/TECHNICAL APPROACH

Reviewer 23412

Score: 5.0

Comment: Applied techniques of tracer return results have already been implemented. I always strongly urge that a numerical simulation of a tracer injection be performed prior to the tracer test. The simulation might not be accurate but it will bound the problem with tracer volume to inject and possible sampling frequency.

PI Response:
We agree in principle, but the funding for this project is very modest and modeling is beyond its scope.

Reviewer 23450

Score: 8.0

Comment: The approach to the project objectives are well thought out and should provide good evidence and quantification of fracture evolution with time. Such a data set should be useful for numerical modeling and analysis. Coupling the dynamic flow/tracer data with microseismic data may provide correlative data between microseismic and active reservoir flow volumes. Numerical inversion of tracer results use standard geothermal tracer methods.

PI Response:
We agree.

Reviewer 24878

Score: 7.0

Comment: Use of high-resolution tracer conservative and thermally reactive) tracers to characterize fracture networks following a hydraulic stimulation within an EGS reservoir. I am surprise how naive is the modeling and curves shown in the presentation. Numerical modeling of return curve data in dual porosity system are crucially missing. They should account for realistic fracture networks and potential rock tracer interactions for non-conservative tracers. I also like that the hydraulic data will be correlated with microseismic activity.

PI Response:
Numerical modeling would add value to this research, but it is beyond the scope of the project, whose purpose is to gather data on the evolution of fracture networks following a hydraulic stimulation. These data will be available for numerical modeling studies in follow-on studies with an appropriate budget.

Reviewer 23552

Score: 6.0

Comment: The project's proposed technical and scientific approach can be summarized as follows. (1) Conducted repeat tracer tests at multiple EGS circulation test sites in the W USA (e.g., Desert Peak, Raft River, etc) using conservative and reactive tracers. (2) Using moment-analysis and decay-kinetics-analysis methods to measure progressive changes in pore volume, flow distribution, dispersivity and effective reservoir temperature. (3) Compare microseismic data for the three reservoirs and observed changes in hydraulic/thermal properties of the test case EGS sites. More details on the technical approach are provided, but since this project has not yet been initiated, there appears little point in further discussing the technical approaches.

PI Response:
No comment.

ACCOMPLISHMENTS, RESULTS, AND PROGRESS

Reviewer 23412

Score: 5.0

Comment: The project has not started yet so no results could be identified.

PI Response:
We agree.

Reviewer 23450

Score: 5.0

Comment: The use of thermally reactive tracers with conservative tracers to query the temperature regime in an active geothermal field is good proof of concept. Many elements of this project have yet to get started due to the problems mentioned above.

PI Response:
We agree.

Reviewer 24878

Score: 5.0

Comment: This project has not yet started so I cannot put a mark here, but I am disappointed by the lack of numerical modeling at this point in realistic synthetic case studies and the lack of inversion algorithms to perform the inverse problem. The modeling seems quite naive. That said, the project seems very interesting if the results are obtained according to the plans. The PI argued that the project has not yet started since it was intended to begin only after the successful completion of an EGS project (it will observe and model the evolution of reservoir flow processes immediately following a successful hydraulic stimulation during the subsequent circulation test). That said, numerical simulations could have been performed in the first phase of the project. This is really needed and missing a lot.

PI Response:
Numerical modeling is beyond the scope, budget, and expertise of the PIs. The data will be available, however, for anyone who wants to model the process.

Reviewer 23552

Score: 5.0

Comment: This project has not yet been initiated.

PI Response:

PROJECT MANAGEMENT/COORDINATION

Reviewer 23412

Score: 7.0

Comment: The project has not been started yet but geothermal resources have been identified to execute tracer test.

PI Response:
No comment.

Reviewer 23450

Score: 5.0

Comment: Project goals, accomplishments, and cost to date seem appropriate.

PI Response:
We agree.

Reviewer 24878

Score: 7.0

Comment: Hard to say at this point of the project.

PI Response:
No comment.

Reviewer 23552

Score: 5.0

Comment: This project has not yet been initiated.

PI Response:
No comment.

STRENGTHS

Reviewer 23412

Comment: The tracer interpretation methods have been proven to be effective.

PI Response:
We agree.

Reviewer 23450

Comment: Dr. Rose's experience with geothermal tracers is a strong plus.

PI Response:

Reviewer 24878

Comment: The project is aligned with DOE goals.

PI Response:
No comment.

Reviewer 23552

Comment: This project has not yet been initiated.

PI Response:
No comment.

WEAKNESSES

Reviewer 23412

Comment: No apparent signs of weaknesses.

PI Response:
No comment.

Reviewer 23450

Comment: Dependence on finding a geothermal operator with a well available for stimulation and detailed testing.

PI Response:
No comment.

Reviewer 24878

Comment: The PIs seems to ignore some important works done in Europe (for example at Soultz) on the closure of the fractures after hydraulic stimulation of EGS reservoirs (slide 3 is very incomplete). Numerical modeling of return curve data in dual porosity system are crucially missing.

PI Response:
The Soultz results were taken into account and estimates of pore volume and mean-residence time were calculated. The methods that we are using cannot resolve between fracture closure and fracture opening, but measures only the combined effects of both mechanisms. And, again, numerical modeling, although admittedly invaluable, is beyone the scope of this project. However, the data will be available for any follow-on numerical modeling projects.

Reviewer 23552

Comment: This project has not yet been initiated.

PI Response:
No comment.

IMPROVEMENTS

Reviewer 23412

Comment: Strongly consider some numerical forecast of tracer test before executing the tracer test.

PI Response:
Not feasible for reasons explained above.

Reviewer 23450

Comment: A formal program to evaluate test results.

PI Response:
No comment.

Reviewer 24878

Comment: The PI should focus on performing numerical modeling of return curve data in dual porosity system taking account the existing literature on the healing and sealing of fractures after hydraulic stimulations.

PI Response:
No dual porosity (or any THMC) models are currently available that can modify permeability and porosity in real time as a function of fracture healing/sealing or fracture opening. But, again, numerical modeling is beyond the scope of this project.

Reviewer 23552

Comment: This project has not yet been initiated.

PI Response:
No comment.

Appendix B: Identification Information for Reviewed Projects

P2RMIS ID	Client ID	Project Title	Last Name	First Name	Organization	Panel
GTO130001	EE0002739	Estimation and Analysis of Life Cycle Costs of Baseline Enhanced Geothermal Systems	Turaga	Uday	Adi Analytics, LLC	Systems Analysis
GTO130002	EE0002777	Newberry Volcano EGS Demonstration	Petty	Susan	AltaRock Energy, Inc.	Enhanced Geothermal Systems Demonstrations
GTO130010	EE0002850	State Geological Survey Contributions to NGDS Data Development, Collection and Maintenance	Allison	Lee	Arizona Geological Survey	Data System Development & Population
GTO130015	EE0005505 EE0002782	Directional Measurement-While-Drilling System for Geothermal Applications	Schnitger	Jochen	Baker Hughes Oilfield Operation, Inc.	High Temperature Tools; Drilling Systems
GTO130022	EE0001120	National Geothermal Data System Architecture Design, Testing and Maintenance	Blackman	Harold	Boise State University	Data System Development & Population
GTO130041	EE0002771	High Temperature, High Pressure Devices for Zonal Isolation in Geothermal Wells	Fabian	Paul	Composite Technology Development, Inc.	Materials; Zonal Isolation; Innovative Methods of Heat Recovery
GTO130044	EE0002833	Validation of Innovative Exploration Technologies for Newberry Volcano	Waibel	Albert	Davenport Power, LLC	Innovative Exploration Techniques
GTO130045	EE0002786	Complete Fiber/Copper Cable Solution for Long-Term Temperature and Pressure Measurement in Supercritical Reservoirs and EGS Wells	Kendall	Waterman	Draka Cableteq USA	High Temperature Tools; Drilling Systems
GTO130052	EE0002828	Direct Confirmation of Commercial Geothermal Resources in Colorado using Remote Sensing and On-Site Exploration, Testing and Analysis	Robinson	F.	Flint Geothermal LLC	Innovative Exploration Techniques
GTO130056	EE0002752	High-Temperature-High-Volume Lifting For Enhanced Geothermal Systems	Turnquist	Norman	GE Global Research	High Temperature Tools; Drilling Systems

P2RMIS ID	Client ID	Project Title	Last Name	First Name	Organization	Panel
GTO130065	GO18201	Demonstration of an Enhanced Geothermal System at the Northwest Geysers Geothermal Field	Walters	Mark	Geysers Power Company, LLC	Enhanced Geothermal Systems Demonstrations
GTO130066	EE0004432	Single-Well Low Temperature CO2-Based Engineered Geothermal System	Eastman	Alan	GreenFire Energy	Co-Produced; Low Temperature
GTO130079	EE0002783	Microhole Arrays Drilled With Advanced Abrasive Slurry Jet Technology To Efficiently Exploit Enhanced Geothermal Systems	Oglesby	Kenneth	Impact Technologies, LLC	High Temperature Tools; Drilling Systems
GTO130081	EE0002858	Novel Energy Conversion Equipment for Low Temperature Geothermal Resources	Minor	Eric	Johnson Controls, Inc.	Co-Produced; Low Temperature
GTO130110	AID 19712	Full-waveform inversion of 3D-9C VSP data from Brady's EGS site and update of the Brady reservoir scale modelreservoir scale model	Huang	Lianjie	Los Alamos National Laboratory	Fluid Imaging; Characterizing Fractures; Induced Seismicity
GTO130117	GO18197	Monitoring and Modeling Fluid Flow in a Developing EGS Reservoir	Fehler	Michael	Massachusetts Institute of Technology	Fluid Imaging; Characterizing Fractures; Induced Seismicity
GTO130118	EE0004431	The Canby Cascaded Geothermal Development Project	Merrick	Dale	Modoc Contracting Company	Co-Produced; Low Temperature
GTO130152	ORNL FY13 AOP	Application of Neutron Imaging and Scattering to Fluid Flow and Fracture in EGS Environments	Polsky	Yarom	Oak Ridge National Laboratory	Fluid Imaging; Characterizing Fractures; Induced Seismicity
GTO130155	EE0002859	Osmotic Heat Engine for Energy Production from Low Temperature Geothermal Resources	Hancock	Nathan	Oasys Water	Co-Produced; Low Temperature
GTO130157	GO18200	Feasibility of EGS Development at Brady's Hot Springs	Drakos	Peter	Ormat Nevada, Inc.	Enhanced Geothermal Systems Demonstrations
GTO130158	ID14406	Desert Peak East EGS Project	Drakos	Peter	Ormat Nevada, Inc.	Enhanced Geothermal Systems Demonstrations

P2RMIS ID	Client ID	Project Title	Last Name	First Name	Organization	Panel
GTO130159	EE0002836: EE0002837	Merging High Resolution Geophysical and Geochemical Surveys to Reduce Exploration Risk at Glass Buttes, Oregon; Blind Geothermal System Exploration in Active Volcanic Environments; Multi-phase Geophysical and Geochemical Surveys in Overt and Subtle Volcanic Systems, Hawai'i and Maui	Walsh	Patrick	Ormat Technologies Inc.	Innovative Exploration Techniques
GTO130162	EE0002839	Advanced Seismic data Analysis Program (The "Hot Pot Project")	Misseldine	Frank	Oski Energy, LLC	Innovative Exploration Techniques
GTO130163	EE0004430	Kalex Advanced Low Temperature Geothermal Power Cycle	Sandifer	Cheryl	Technip USA	Co-Produced; Low Temperature
GTO130166	EE0002765	Experiment-Based Model for the Chemical Interactions between Geothermal Rocks, Supercritical Carbon Dioxide and Water	Petro	Miroslav	PARC (Palo Alto Research Center)	Supercritical CO2; Working Fluids
GTO130173	EE0003032	Novel Multidimensional Tracers for Geothermal Inter-Well Diagnostics	Tang	Yongchun	Power, Environmental and Energy Research Institute	Tracers
GTO130175	EE0002841	Innovative Exploration Techniques for Geothermal Assessment at Jemez Pueblo, New Mexico	Kaufman	Greg	Pueblo of Jemez	Innovative Exploration Techniques
GTO130176	EE0002842	Comprehensive Evaluation of the Geothermal Resource Potential within the Pyramid Lake Paiute Reservation	Noel	Donna	Pyramid Lake Paiute Tribe	Innovative Exploration Techniques
GTO130180	EE0002827	El Paso County Geothermal Electric Generation Project: Innovative Research Technologies Applied to the Geothermal Resource Potential at Ft. Bliss	Lear	Jon	El Paso County	Innovative Exploration Techniques
GTO130188	704	Technology Development and Field Trials of EGS Drilling Systems	Raymond	David	Sandia National Laboratories	High Temperature Tools; Drilling Systems

P2RMIS ID	Client ID	Project Title	Last Name	First Name	Organization	Panel
GTO130201	SNL FY11 AOP3.4	Auto-Indexer for Percussive Hammers	Su	Jiann	Sandia National Laboratories	High Temperature Tools; Drilling Systems
GTO130206	710	Gas Generator Development and Testing for Controlled Rapid Pressurization Using Liquid Propellants for EGS Well Stimulation; Energetic Materials for EGS Well Stimulation	Grubelich	Mark	Sandia National Laboratories	High Temperature Tools; Drilling Systems
GTO130207	EE0002788	Perforating System for Geothermal Applications	Smart	Moises	Schlumberger Technology Corporation	High Temperature Tools; Drilling Systems
GTO130213	EE0002852	Heat Flow Database Expansion for NGDS Data Development, Collection and Maintenance	Blackwell	David	Southern Methodist University	Data System Development & Population
GTO130232	EE0001501	National Geothermal Resource Assessment and Classification	Williams	Colin	U.S. Geological Survey	Data System Development & Population
GTO130239	EE0002960	Recovery Act: Detachment faulting and Geothermal Resources – An Innovative Integrated Geological and Geophysical Investigation of Pearl Hot Spring, Nevada	Stockli	Daniel	University of Texas at Austin	Innovative Exploration Techniques
GTO130243	EE0003997	Great Basin Center for Geothermal Energy (I\IV)	Calvin	Wendy	University of Nevada, Reno (UNR)	Geophysics; Geochemistry
GTO130248	EE0002747	Characterizing Fractures in Geysers Geothermal Field by Micro-seismic Data, Using Soft Computing, Fractals, and Shear Wave Anisotropy	Aminzadeh	Fred	University of Southern California	Fluid Imaging; Characterizing Fractures; Induced Seismicity
GTO130250	EE0002750	Fracture Network and Fluid Flow Imaging for Enhanced Geothermal Systems: Applications from Multi-Dimensional Electrical Resistivity Structure	Wannamaker	Phillip	University of Utah	Fluid Imaging; Characterizing Fractures; Induced Seismicity
GTO130253	EE0002768	Quantum Dot Tracers for Use in Engineered Geothermal Systems	Rose	Peter	University of Utah	Tracers

P2RMIS ID	Client ID	Project Title	Last Name	First Name	Organization	Panel
GTO130260	EE0000215	Concept Testing and Development at the Raft River Geothermal Field, Idaho	Moore	Joseph	University of Utah	Enhanced Geothermal Systems Demonstrations
GTO130264	EE0002745	Analysis of Low-Temperature Utilization of Geothermal Resources	Anderson	Brian	West Virginia University	Systems Analysis
GTO130265	112	GETEM Development	Mines	Greg	Idaho National Laboratory	Systems Analysis
GTO130266	207	Hybrid and advanced air-cooling	Bharathan	Desikan	National Renewable Energy Laboratory	Systems Analysis
GTO130267	302	FRACSTIM/I: An Integrated Fracture Stimulation and Reservoir Flow and Transport Simulator	Podgorney	Robert	Idaho National Laboratory	Modeling
GTO130268	905	Coupled Thermal-Hydrological-Mechanical-Chemical Model and Experiments for Optimization of Enhanced Geothermal System Development and Production; Evaluation of Stimulation at the Newberry Volcano EGS Demonstration Site through Natural Isotopic Reactive Tracers and Geochemical Investigation	Sonnenthal	Eric	Lawrence Berkeley National Laboratory	Modeling
GTO130269	0522-1611	Novel use of 4D Monitoring Techniques to Improve Reservoir Longevity and Productivity in Enhanced Geothermal Systems	Rose	Kelly	National Energy Technology Laboratory	Geophysics; Geochemistry
GTO130270	0522-1615	Optimizing parameters for predicting the geochemical behavior and performance of discrete fracture networks in geothermal systems	Hakala	Alexandra	National Energy Technology Laboratory	Geophysics; Geochemistry
GTO130271	510 FY11 AOP 13	Advanced 3D Geophysical Imaging Technologies for Geothermal Resource Characterization	Newman	Greg	Lawrence Berkeley National Laboratory	Fluid Imaging; Characterizing Fractures; Induced Seismicity

P2RMIS ID	Client ID	Project Title	Last Name	First Name	Organization	Panel
GTO130272	552-1522	Self Consuming Downhole Packer	Grubelich	Mark	Sandia National Laboratories	Materials; Zonal Isolation; Innovative Methods of Heat Recovery
GTO130273	EE0002731	Electric Power Generation from Co-Produced Fluids from Oil and Gas Wells	Gosnold	William	University of North Dakota	Co-Produced; Low Temperature
GTO130274	EE0002743	Decision Analysis for Enhanced Geothermal Systems	Einstein	Herbert	Massachusetts Institute of Technology	Systems Analysis
GTO130275	EE0002756	Toward the Understanding of Induced Seismicity in Enhanced Geothermal Systems	Gritto	Ronald	Array Information Technology Inc	Fluid Imaging; Characterizing Fractures; Induced Seismicity
GTO130276	EE0002757	Development of a Geological and Geomechanical Framework for the Analysis of MEQ in EGS Experiments (Geysers)	Ghassemi	Ahmad	University of Oklahoma	Fluid Imaging; Characterizing Fractures; Induced Seismicity
GTO130277	EE0002758	Integration of Noise and Coda Correlation Data into Kinematic and Waveform Inversions With Microearthquake Data for 3D Velocity Structure, Earthquake Locations, and Moment Tensors in Geothermal Reservoirs	O'Connell	Daniel	William Lettis & Associates, Inc.	Modeling
GTO130278	EE0002761	THMC Modeling of EGS Reservoirs – Continuum through Discontinuum Representations: Capturing Reservoir Stimulation, Evolution and Induced Seismicity	Elsworth	Derek	Pennsylvania State University	Modeling
GTO130279	EE0002762	Development of Advanced Thermal-Hydrological-Mechanical-Chemical (THMC) Modeling Capabilities for Enhanced Geothermal Systems	Wu	Yu-Shu	Colorado School of Mines	Modeling

P2RMIS ID	Client ID	Project Title	Last Name	First Name	Organization	Panel
GTO130280	EE0002764	An Integrated Experimental and Numerical Study: Developing a Reaction Transport Model that Couples Chemical Reactions of Mineral Dissolution/Precipitation with Spatial and Temporal Flow Variations in CO2/Brine/Rock Systems	Saar	Martin	University of Minnesota	Supercritical CO2; Working Fluids
GTO130281	EE0002785	Development of an Improved Cement for Geothermal Wells	Trabits	George	Trabits Group, LLC	Materials; Zonal Isolation; Innovative Methods of Heat Recovery
GTO130282	EE0002847	Finding Large Aperture Fractures in Geothermal Resource Areas Using a Three-Component Long-Offset Surface Seismic Survey	Teplow	William	US Geothermal, Inc.	Innovative Exploration Techniques
GTO130283	EE0003219	Fairbanks Geothermal Energy Project (Chena as a sub)	Brand	Denise	Fairbanks North Star Borough	Co-Produced; Low Temperature
GTO130284	EE0003231	Advanced Heat/Mass Exchanger Technology for Geothermal and Solar Renewable Energy Systems(NV)	Greiner	Miles	University of Nevada, Reno (UNR)	Supercritical CO2; Working Fluids
GTO130285	EE0005125	Geothermal Resource Development with Zero Mass Withdrawl, Engineered Convection, and Wellbore Energy Conversion	White	Christopher	LA State University	Materials; Zonal Isolation; Innovative Methods of Heat Recovery
GTO130286	EE0005503	Extreme Temperature (300 C) P/MWD with Energy Storage and Generation, Enabling Substantial Cost and Risk Reduction in Geothermal Exploration	Signorelli	Riccardo	FastCAP Systems Corp.	High Temperature Tools; Drilling Systems
GTO130287	EE0005504	Deep Geothermal Drilling using Millimeter Wave Technology	Oglesby	Kenneth	Impact Technologies, LLC	High Temperature Tools; Drilling Systems
GTO130288	EE0005510	Monitoring EGS Stimulation and Reservoir Dynamics with InSAR and MEQ	Davatzes	Nicholas	Temple University	Geophysics; Geochemistry

P2RMIS ID	Client ID	Project Title	Last Name	First Name	Organization	Panel
GTO130289	EE0005511	Rotation-Enabled 7-DOF Seismometer for Geothermal Resource Development	Laughlin	Darren	A-Tech Corporation	High Temperature Tools; Drilling Systems
GTO130290	EE0005513	Time-lapse joint inversion of GEOphysical Data and its application to gEothermal prospecting - GEODE	Revil	Andre	Colorado School of Mines	Geophysics; Geochemistry
GTO130291	EE0005514	Indentification of Hidden, High-Enthalpy Geothermal Systems in Extensional Regimes Through an Exploration Technology Paradigm Incorporating Magnetotellurics, Soil Gas Geochemisty and Structural Analysis	Wannamaker	Phillip	University of Utah	Geophysics; Geochemistry
GTO130292	EE0005515	Integration of Full Tensor Gravity and ZTEM Passive Low Frequency EM Instruments for Simultaneous Data Acquisition	Wieberg	Scott	Bell Geospace, Inc.	Geophysics; Geochemistry
GTO130293	EE0005517	Spectral SP: A New Approach to Mapping Reservoir Flow and Permeability	Thomas	Donald	University of Hawaii	Geophysics; Geochemistry
GTO130294	EE0005518	Development of a low cost method to estimate the seismic signature of a geothermal field from ambient seismic noise analysis	Tibuleac	Ileana	University of Nevada, Reno (UNR)	Geophysics; Geochemistry
GTO130295	EE0005519	Methodologies for Reservoir Characterization Using Fluid Inclusion Gas Chemistry	Dilley	Lorie	Hattenburg, Dilley, and Linnell, LLC	Geophysics; Geochemistry
GTO130296	EE0005520	Novel Coupled Thermochronometric and Geochemical Investigation of Blind Geothermal Resources in Fault- Controlled Dilational Corners, Dixie Valley, Nevada	Stockli	Daniel	University of Texas at Austin	Geophysics; Geochemistry
GTO130297	EE0005521	Innovative computational tools for reducing exploration risk through integration of water-rock interactions and magnetotelluric surveys	Moore	Joseph	University of Utah	Modeling

P2RMIS ID	Client ID	Project Title	Last Name	First Name	Organization	Panel
GTO130298	EE0005522	Advances in Hydrogeochemical Indicators for the Discovery of New Geothermal Resources in the Great Basin, USA	Simmons	Stuart	Colorado School of Mines	Geophysics; Geochemistry
GTO130299	FY13 AOP	Hybrid Geothermal-Solar	Mines	Greg	Idaho National Laboratory	Co-Produced; Low Temperature
GTO130300	FY13 AOP	Effects of volcanism, crustal thickness, and large scale faulting on the development and evolution of geothermal systems: Collaborative project in Chile	Dobson	Patrick	Lawrence Berkeley National Laboratory	Geophysics; Geochemistry
GTO130301	FY13 AOP	Sustainability of Shear-Induced Permeability for EGS Reservoirs – A Laboratory Study	Kneafsey	Timothy	Lawrence Berkeley National Laboratory	Fluid Imaging; Characterizing Fractures; Induced Seismicity
GTO130302	FY13 AOP	The Viability of Sustainable, Self-Propping Shear Zones in Enhanced Geothermal Systems: Measurement of Reaction Rates at Elevated Temperatures	Carroll	Susan	Lawrence Livermore National Laboratory	Geophysics; Geochemistry
GTO130303	FY13 AOP	Stimulation at Desert Peak and Brady's reservoirs: modeling with the coupled THM code FEHM	Kelkar	Sharad	Los Alamos National Laboratory	Modeling
GTO130304	FY13 AOP	A Revolutionary Hybrid Thermodynamic Cycle for Binary Geothermal Power Plants	Sabau	Adrian	Oak Ridge National Laboratory	Co-Produced; Low Temperature
GTO130305	FY13 AOP	Code Comparison Study	Scheibe	Tim	Pacific Northwest National Laboratory	Modeling
GTO130306	FY13 AOP	Reservoir-Stimulation Optimization with Operational Monitoring for Creation of Enhanced Geothermal Systems	Carroll	Kenneth	Pacific Northwest National Laboratory	Modeling
GTO130307	GO16060	Fracture Evolution following Hydraulic Stimulation within an EGS Reservoir	Rose	Peter	University of Utah	Tracers
GTO130308	GO18000	Electric Power Generation Using Geothermal Fluid Co-produced from Oil and/or Gas Wells	Karl	Bernie	Chena Hot Springs Resort	Co-Produced; Low Temperature

P2RMIS ID	Client ID	Project Title	Last Name	First Name	Organization	Panel
GTO130309	GO18185	Well Monitoring Systems for EGS	Normann	Randy	Perma Works LLC	High Temperature Tools; Drilling Systems
GTO130310	GO18194	Analysis of Geothermal Reservoir Stimulation using Geomechanics-Based Stochastic Analysis of Injection-Induced Seismicity	Ghassemi	Ahmad	University of Oklahoma	Modeling
GTO130311	GO18195	Joint Inversion of Electrical and Seismic Data for Fracture Characterization and Imaging of Fluid Flow in Geothermal Systems	Batzle	Michael	Colorado School of Mines	Fluid Imaging; Characterizing Fractures; Induced Seismicity
GTO130312	GO18196	Use of a Reservoir Model to Predict Potential Effects of Fracturing Techniques	Ghassemi	Ahmad	University of Oklahoma	Modeling
GTO130313	Lab FY11 R&D	Improved Geothermometry Through Multivariate Reaction Path Modeling and Evaluation of Geomicrobiological Influences on Geochemical Temperature Indicators	Cooper	Craig	Idaho National Laboratory	Geophysics; Geochemistry
GTO130314	Lab FY11 R&D	Integration of Nontraditional Isotopic Systems Into Reaction-Transport Models of EGS For Exploration, Evaluation of Water-Rock Interaction, and Impacts of Water Chemistry on Reservoir Sustainability	Sonnenthal	Eric	Lawrence Berkeley National Laboratory	Modeling
GTO130315	Lab FY11 R&D	Stochastic Joint Inversion for Integrated Data Interpretation in Geothermal Exploration	Mellors	Robert	Lawrence Livermore National Laboratory	Geophysics; Geochemistry
GTO130316	NREL FY12AOP1.2	Geothermal Regulatory Roadmap	Young	Kate	National Renewable Energy Laboratory	Systems Analysis
GTO130317	SNL FY11 AOP3.2	Evaluation of Emerging Technology for Geothermal Drilling Applications	Blankenship	Doug	Sandia National Laboratories	High Temperature Tools; Drilling Systems

P2RMIS ID	Client ID	Project Title	Last Name	First Name	Organization	Panel
GTO130318		Self-Degrading Temporary Cementation Sealers	Sugama	Toshi	Brookhaven National Laboratory	Materials; Zonal Isolation; Innovative Methods of Heat Recovery
GTO130319		Multifunctional Corrosion-resistant Foamed Cement Composites	Sugama	Toshi	Brookhaven National Laboratory	Materials; Zonal Isolation; Innovative Methods of Heat Recovery

Appendix C: Sample Project Evaluation Form via P2RMIS

2013 Geothermal Technologies Office 2013 Peer Review

XXXX Projects Proposal Review

Critique Details

Reviewer:
LogNo and PI Last Name:
Title:

Relevance/Impact of Research

ENTER COMMENTS HERE

Score:

Scientific/Technical Approach

ENTER COMMENTS HERE

Score:

Accomplishments, Results, and Progress

ENTER COMMENTS HERE

Score:

Project Management/Coordination

ENTER COMMENTS HERE

Score:

Strengths

ENTER COMMENTS HERE

Weaknesses

ENTER COMMENTS HERE

Improvements

ENTER COMMENTS HERE

Appendix D: 2013 Peer Review Meeting Detailed Agenda

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

GEOTHERMAL TECHNOLOGIES OFFICE

4/22-4/25 2013 Peer Review Agenda

Location
Renaissance Denver Hotel
3801 Quebec Street
Denver, CO 80207
(303) 399-7500

print date 04/10/13

Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday -- Monday

TRACK 1 - Ballroom A

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST & REGISTRATION**	
9:00 AM	10:00 AM	Ballroom C&D	**Plenary Session**	Kate Baker, Bobi Garrett, Doug Hollett, Lauren Boyd and Eric Hass, DOE/NREL
10:00 AM	10:30 AM	Ballroom C&D	**Reviewer Meeting (Closed)**	
10:30 AM	10:45 AM	Foyer	BREAK	
10:45 AM	11:15 AM	Co-Produced	Electric Power Generation Using Geothermal Fluid Co-produced from Oil and/or Gas Wells	Bernie Karl, Chena Hot Springs Resort
11:15 AM	11:45 AM	Low Temp	Electric Power Generation from Co-Produced Fluids from Oil and Gas Wells; Electric Power Generation from Low to Intermediate Temperature Resources	William D. Gosnold, University of North Dakota
11:45 AM	12:15 PM	Low Temp	Hybrid Geothermal-Solar	Greg Mines, Idaho National Laboratory
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH DOE Geothermal Data Repository GDR Data Provider Recognition**	John Weers, NREL Arlene Anderson, DOE
1:30 PM	2:00 PM	Low Temp	Novel Energy Conversion Equipment for Low Temperature Geothermal Resources	Eric Minor, Johnson Controls, Inc.
2:00 PM	2:30 PM	Low Temp	The Canby Cascaded Geothermal Development Project	Dale Merrick, Modoc Contracting Company
2:30 PM	3:00 PM	Low Temp	A Revolutionary Hybrid Thermodynamic Cycle for Binary Geothermal Power Plants	Adrian Sabau, Oak Ridge National Laboratory
3:00 PM	3:15 PM	Foyer	BREAK	
3:15 PM	3:45 PM	Low Temp	Osmotic Heat Engine for Energy Production from Low Temperature Geothermal Resources	Eric Maxwell, Oasys Water
3:45 PM	4:15 PM	Low Temp	Kalex Advanced Low Temperature Geothermal Power Cycle	Cheryl Sandifer, Technip USA
4:15 PM	4:45 PM	Low Temp	Fairbanks Geothermal Energy Project (Chena as a sub)	Bernie Karl, Chena Hot Springs Resort
4:45 PM	5:15 PM	Low Temp	Single-Well Low Temperature CO2-Based Engineered Geothermal System	Alan D. Eastman, GreenFire Energy
5:30 PM	7:30 PM	Foyer	**POSTER SESSION & NETWORKING EVENT**	

TRACK 2 - Ballroom B

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST & REGISTRATION**	
9:00 AM	10:00 AM	Ballroom C&D	**Plenary Session**	Kate Baker, Bobi Garrett, Doug Hollett, Lauren Boyd and Eric Hass, DOE/NREL
10:00 AM	10:30 AM	Ballroom C&D	**Reviewer Meeting (Closed)**	
10:30 AM	10:45 AM	Foyer	BREAK	
10:45 AM	11:30 AM	EGS Demo	Newberry Volcano EGS Demonstration	Susan Petty, AltaRock Energy, Inc.
11:30 AM	12:15 PM	EGS Demo	Demonstration of an Enhanced Geothermal System at the Northwest Geysers Geothermal Field	Mark Walters, Geysers Power Company, LLC
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH DOE Geothermal Data Repository GDR Data Provider Recognition**	John Weers, NREL Arlene Anderson, DOE
1:30 PM	2:15 PM	EGS Demo	Feasibility of EGS Development at Brady's Hot Springs	Ezra Zemach, Ormat Nevada, Inc.
2:15 PM	3:00 PM	EGS Demo	Concept Testing and Development at the Raft River Geothermal Field, Idaho	Joseph Moore, University of Utah
3:00 PM	3:15 PM	Foyer	BREAK	
3:15 PM	4:00 PM	EGS Demo	Desert Peak East EGS Project	Ezra Zemach, Ormat Nevada, Inc.
4:00 PM	4:30 PM	Fluid Imaging	Use of Geophysical Techniques to Characterize Fluid Flow in a Geothermal Reservoir	Michael Batzle, Colorado School of Mines
4:30 PM	5:00 PM	Fluid Imaging	Advanced 3D Geophysical Imaging Technologies for Geothermal Resource Characterization	Greg Newman, Lawrence Berkeley National Laboratory
5:30 PM	7:30 PM	Foyer	**POSTER SESSION & NETWORKING EVENT**	

TRACK 3 - Big Thompson

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST & REGISTRATION**	
9:00 AM	10:00 AM	Ballroom C&D	**Plenary Session**	Kate Baker, Bobi Garrett, Doug Hollett, Lauren Boyd and Eric Hass, DOE/NREL
10:00 AM	10:30 AM	Ballroom C&D	**Reviewer Meeting (Closed)**	
10:30 AM	10:45 AM	Foyer	BREAK	
10:45 AM	11:15 AM	Techno-Econ	Decision Analysis for Enhanced Geothermal Systems	Herbert H. Einstein, Massachusetts Institute of Technology
11:15 AM	11:45 AM	Techno-Econ	Analysis of Low-Temperature Utilization of Geothermal Resources	Brian Anderson, West Virginia University
11:45 AM	12:15 PM	Techno-Econ	Estimation and Analysis of Life Cycle Costs of Baseline Enhanced Geothermal Systems	Uday Turaga, ADI Analytics, LLC
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH DOE Geothermal Data Repository GDR Data Provider Recognition**	John Weers, NREL Arlene Anderson, DOE
1:30 PM	2:00 PM	Techno-Econ	GETEM Development	Greg Mines, Idaho National Laboratory
2:00 PM	2:30 PM	Techno-Econ	Hybrid and advanced air-cooling	Desikan (Desi) Bharathan, National Renewable Energy Laboratory
2:30 PM	3:00 PM	Policy & Reg. Analysis	Geothermal Regulatory Roadmap	Kate Young, National Renewable Energy Laboratory
3:00 PM	3:15 PM	Foyer	BREAK	
3:15 PM	4:00 PM	Data	National Geothermal Data System Architecture Design, Testing and Maintenance	Harold Blackman, Boise State University
4:00 PM	4:45 PM	Data	State Geological Survey Contributions to NGDS Data Development, Collection and Maintenance	Lee Allison, Arizona Geological Survey
5:30 PM	7:30 PM	Foyer	**POSTER SESSION & NETWORKING EVENT**	

GEOTHERMAL TECHNOLOGIES OFFICE

4/22-4/25 2013 Peer Review Agenda

Location
Renaissance Denver Hotel
3801 Quebec Street
Denver, CO 80207
(303) 399-7500

print date 04/10/13

Tuesday -- Tuesday

TRACK 1 - Ballroom A

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST**	
9:00 AM	9:30 AM	CO2	Experiment-Based Model for the Chemical Interactions between Geothermal Rocks, Supercritical Carbon Dioxide and Water	Miroslav Petro, PARC (Palo Alto Research Center)
9:30 AM	10:00 AM	CO2	An Integrated Experimental and Numerical Study: Developing a Reaction Transport Model that Couples Chemical Reactions of Mineral Dissolution/Precipitation with Spatial and Temporal Flow Variations in CO2/Brine/Rock Systems	Martin Saar, University of Minnesota
10:00 AM	10:30 AM	Working Fluids	Advanced Heat/Mass Exchanger Technology for Geothermal and Solar Renewable Energy Systems (NV)	Miles Greiner, University of Nevada, Reno (UNR)
10:30 AM	10:45 AM	Foyer	BREAK	
10:45 AM	11:15 AM	IET	El Paso County Geothermal Electric Generation Project: Innovative Research Technologies Applied to the Geothermal Resource Potential at Ft. Bliss	Ben Barker, El Paso County
11:15 AM	11:45 AM	IET	Validation of Innovative Exploration Technologies for Newberry Volcano	Albert F. Waibel, Davenport Power, LLC
11:45 AM	12:15 PM	IET	Direct Confirmation of Commercial Geothermal Resources in Colorado using Remote Sensing and On-Site Exploration, Testing and Analysis	F. Robinson, Flint Geothermal LLC
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH** **Characterizing Structural Controls of EGS-Candidate and Conventional Geothermal Reservoirs in the Great Basin: Developing Successful Exploration Strategies in Extended Terranes**	James Faulds, University of Nevada, Reno (UNR)
1:30 PM	2:00 PM	IET	Merging High Resolution Geophysical and Geochemical Surveys to Reduce Exploration Risk at Glass Buttes, Oregon; Blind Geothermal System Exploration in Active Volcanic Environments; Multi-phase Geophysical and Geochemical Surveys in Overt and Subtle Volcanic Systems, Hawai'i and Maui	Ezra Zemach, Ormat Technologies Inc.
2:00 PM	2:30 PM	IET	Advanced Seismic data Analysis Program (The "Hot Pot Project")	Mike Lane, Oski Energy, LLC
2:30 PM	3:00 PM	IET	Recovery Act: Detachment faulting and Geothermal Resources – An Innovative Integrated Geological and Geophysical Investigation of Pearl Hot Spring, Nevada	Daniel Stockli, University of Texas at Austin
3:00 PM	3:15 PM	Foyer	BREAK	
3:15 PM	3:45 PM	IET	Innovative Exploration Techniques for Geothermal Assessment at Jemez Pueblo, New Mexico	Greg Kaufman, Pueblo of Jemez
3:45 PM	4:15 PM	IET	Comprehensive Evaluation of the Geothermal Resource Potential within the Pyramid Lake Paiute Reservation	Donna Noel, Pyramid Lake Paiute Tribe
4:15 PM	4:45 PM	IET	Finding Large Aperture Fractures in Geothermal Resource Areas Using a Three-Component Long-Offset Surface Seismic Survey	Ian Warren, US Geothermal, Inc.

TRACK 2 - Ballroom B

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST**	
9:00 AM	9:30 AM	Fluid Imaging	Full-waveform inversion of 3D-9C VSP data from Brady's EGS site and update of the Brady reservoir scale model	Lianjie Huang, Los Alamos National Laboratory
9:30 AM	10:00 AM	Fluid Imaging	Monitoring and Modeling Fluid Flow in a Developing EGS Reservoir	Michael Fehler, Massachusetts Institute of Technology
10:00 AM	10:30 AM	Fluid Imaging	Application of Neutron Imaging and Scattering to Fluid Flow and Fracture in EGS Environments	Yarom Polsky, Oak Ridge National Laboratory
10:30 AM	10:45 AM	Foyer	BREAK	
10:45 AM	11:15 AM	Fluid Imaging	Fracture Network and Fluid Flow Imaging for Enhanced Geothermal Systems: Applications from Multi-Dimensional Electrical Resistivity Structure	Phillip Wannamaker, University of Utah
11:15 AM	11:45 AM	Characterizing Fractures	Sustainability of Shear-Induced Permeability for EGS Reservoirs – A Laboratory Study	Tim Kneafsey, Lawrence Berkeley National Laboratory
11:45 AM	12:15 PM	Characterizing Fractures	Characterizing Fractures in Geysers Geothermal Field by Micro-seismic Data, Using Soft Computing, Fractals, and Shear Wave Anisotropy	Fred Aminzadeh, University of Southern California
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH** **Characterizing Structural Controls of EGS-Candidate and Conventional Geothermal Reservoirs in the Great Basin: Developing Successful Exploration Strategies in Extended Terranes**	James Faulds, University of Nevada, Reno (UNR)
1:30 PM	2:00 PM	Induced Seismicity	Toward the Understanding of Induced Seismicity in Enhanced Geothermal Systems	Doug Dreger, Array Information Technology Inc.
2:00 PM	2:30 PM	Induced Seismicity	Development of a Geological and Geomechanical Framework for the Analysis of MEQ in EGS Experiments (Geysers)	Ahmad Ghassemi, University of Oklahoma
2:30 PM	3:00 PM	HT Tools	Rotation-Enabled 7-DOF Seismometer for Geothermal Resource Development	Darren Laughlin, A-Tech Corporation
3:00 PM	3:15 PM	Foyer	BREAK	
3:15 PM	3:45 PM	HT Tools	Complete Fiber/Copper Cable Solution for Long-Term Temperature and Pressure Measurement in Supercritical Reservoirs and EGS Wells	Kendall Waterman, Draka Cableteq USA
3:45 PM	4:15 PM	HT Tools	Extreme Temperature (300 C) P/MWD with Energy Storage and Generation, Enabling Substantial Cost and Risk Reduction in Geothermal Exploration	Riccardo Signorelli, FastCAP Systems Corp.
4:15 PM	4:45 PM	HT Tools	Perforating System for Geothermal Applications	Moises Smart, Schlumberger Technology Corporation

TRACK 3 - Big Thompson

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST**	
9:00 AM	9:45 AM	Data	Heat Flow Database Expansion for NGDS Data Development, Collection and Maintenance	David D. Blackwell, Southern Methodist University
9:45 AM	10:30 AM	Data	National Geothermal Resource Assessment and Classification	Colin Williams, U.S. Geological Survey
10:30 AM	10:45 AM	Foyer	BREAK	
10:45 AM	11:15 AM	Tracers	Quantum Dot Tracers for Use in Engineered Geothermal Systems	Peter Rose, University of Utah
11:15 AM	11:45 AM	Tracers	Novel Multidimensional Tracers for Geothermal Inter-Well Diagnostics	Yongchun Tang, Power, Environmental and Energy Research
11:45 AM	12:15 PM	Tracers	Fracture Evolution following Hydraulic Stimulation within an EGS Reservoir	Peter Rose, University of Utah
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH** **Characterizing Structural Controls of EGS-Candidate and Conventional Geothermal Reservoirs in the Great Basin: Developing Successful Exploration Strategies in Extended Terranes**	James Faulds, University of Nevada, Reno (UNR)
1:30 PM	2:00 PM	Modeling	Reservoir-Stimulation Optimization with Operational Monitoring for Creation of Enhanced Geothermal Systems	Carlos Fernandez, Pacific Northwest National Laboratory
2:00 PM	2:30 PM	Modeling	Stimulation at Desert Peak and Brady's reservoirs: modeling with the coupled THM code FEHM	Sharad Kelkar, Los Alamos National Laboratory
2:30 PM	3:00 PM	Modeling	Coupled Thermal-Hydrological-Mechanical-Chemical Model and Experiments for Optimization of Enhanced Geothermal System Development and Production; Evaluation of Stimulation at the Newberry Volcano EGS Demonstration Site through Natural Isotopic Reactive Tracers and Geochemical Investigation	Eric Sonnenthal, Lawrence Berkeley National Laboratory
3:00 PM	3:15 PM	Foyer	BREAK	
3:15 PM	3:45 PM	Modeling	Code Comparison Study	Tim Scheibe, Pacific Northwest National Laboratory
3:45 PM	4:15 PM	Modeling	Integration of Nontraditional Isotopic Systems into Reaction-Transport Models of EGS For Exploration, Evaluation of Water-Rock Interaction, and Impacts of Water Chemistry on Reservoir Sustainability	Eric Sonnenthal, Lawrence Berkeley National Laboratory
4:15 PM	4:45 PM	Modeling	THMC Modeling of EGS Reservoirs – Continuum through Discontinuum Representations: Capturing Reservoir Stimulation, Evolution and Induced Seismicity	Derek Elsworth, Pennsylvania State University
4:45 PM	6:45 PM	Big Thompson	Knowledge Exchange on Geothermal Industry Outlook and Needs with GTO Program Director and Staff (meeting open to interested parties)	Doug Hollett, DOE

GEOTHERMAL TECHNOLOGIES OFFICE

4/22-4/25 2013 Peer Review Agenda

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print date 04/10/13

Wednesday -- Wednesday -- Wednesday -- Wednesday -- Wednesday -- Wednesday -- Wednesday -- Wednesday -- Wednesday -- Wednesday -- Wednesday -- Wednesday -- Wednesday -- Wednesday -- Wednesday

TRACK 1 - Ballroom A

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST**	
9:00 AM	9:30 AM	Geophysics	Integration of Full Tensor Gravity and ZTEM Passive Low Frequency EM Instruments for Simultaneous Data Acquisition	Scott Wieberg, Bell Geospace, Inc.
9:30 AM	10:00 AM	Geophysics	Time-lapse joint inversion of GEOphysical Data and its application to gEothermal prospecting - GEODE	Andre Revil, Colorado School of Mines
10:00 AM	10:30 AM	Geophysics	Stochastic Joint Inversion for Integrated Data Interpretation in Geothermal Exploration	Robert Mellors, Lawrence Livermore National Laboratory
10:30 AM	10:45 AM	Foyer	BREAK	
10:45 AM	11:15 AM	Geophysics	Novel use of 4D Monitoring Techniques to Improve Reservoir Longevity and Productivity in Enhanced Geothermal Systems	Kelly Rose, National Energy Technology Laboratory
11:15 AM	11:45 AM	Geophysics	Monitoring EGS Stimulation and Reservoir Dynamics with InSAR and MEQ	Nicholas Davatzes, Temple University
11:45 AM	12:15 PM	Geophysics	Spectral SP: A New Approach to Mapping Reservoir Flow and Permeability	Donald Thomas, University of Hawaii
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH** **Air-Cooled Condensers in Next-Generation Conversion Systems**	Greg Mines, Idaho National Laboratory
1:30 PM	2:00 PM	Geophysics	Great Basin Center for Geothermal Energy (I/V)	Wendy Calvin, University of Nevada, Reno
2:00 PM	2:30 PM	Geophysics	Development of a low cost method to estimate the seismic signature of a geothermal field from ambient seismic noise analysis	Ileana Tibuleac, University of Nevada, Reno
2:30 PM	3:00 PM	Geophysics	Indentification of Hidden, High-Enthalpy Geothermal Systems in Extensional Regimes Through an Exploration Technology Paradigm Incorporating Magnetotellurics, Soil Gas Geochemisty and Structural Analysis	Phillip Wannamaker, University of Utah
3:00 PM	3:15 PM	Foyer	BREAK	
3:15 PM	3:45 PM	Geochemistry	Advances in Hydrogeochemical Indicators for the Discovery of New Geothermal Resources in the Great Basin, USA	Stuart Simmons, Colorado School of Mines
3:45 PM	4:15 PM	Geochemistry	Novel Coupled Thermochronometric and Geochemical Investigation of Blind Geothermal Resources in Fault-Controlled Dilational Corners, Dixie Valley, Nevada	Daniel Stockli, University of Texas at Austin
4:15 PM	4:45 PM	Geochemistry	Improved Geothermometry Through Multivariate Reaction Path Modeling and Evaluation of Geomicrobiological Influences on Geochemical Temperature Indicators	Craig Cooper, Idaho National Laboratory
4:45 PM	5:15 PM	Geochemistry	The Viability of Sustainable, Self-Propping Shear Zones in Enhanced Geothermal Systems: Measurement of Reaction Rates at Elevated Temperatures	Susan Carroll, Lawrence Livermore National Laboratory

TRACK 2 - Ballroom B

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST**	
9:00 AM	9:30 AM	HT Tools	High-Temperature-High-Volume Lifting For Enhanced Geothermal Systems	Norman Turnquist, GE Global Research
9:30 AM	10:00 AM	HT Tools	Well Monitoring Systems for EGS	Randy Normann, Perma Works LLC
10:00 AM	10:30 AM	HT Tools	Gas Generator Development and Testing for Controlled Rapid Pressurization Using Liquid Propellants for EGS Well Stimulation; Energetic Materials for EGS Well Stimulation	Mark Grubelich, Sandia National Laboratories
10:30 AM	10:45 AM	Foyer	BREAK	
10:45 AM	11:15 AM	Drilling Systems	Microhole Arrays Drilled With Advanced Abrasive Slurry Jet Technology To Efficiently Exploit Enhanced Geothermal Systems	Kenneth Oglesby, Impact Technologies, LLC
11:15 AM	11:45 AM	Drilling Systems	Technology Development and Field Trials of EGS Drilling Systems	Steve Knudsen, Sandia National Laboratories
11:45 AM	12:15 PM	Drilling Systems	Deep Geothermal Drilling using Millimeter Wave Technology	Kenneth Oglesby, Impact Technologies, LLC
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH** **Air-Cooled Condensers in Next-Generation Conversion Systems**	Greg Mines, Idaho National Laboratory
1:30 PM	2:00 PM	Drilling Systems	Evaluation of Emerging Technology for Geothermal Drilling Applications	Doug Blankenship, Sandia National Laboratories
2:00 PM	2:30 PM	Drilling Systems	Directional Measurement-While-Drilling System for Geothermal Applications; High Temperature 300°C Directional Drilling System	Jochen Schmitger, Baker Hughes Oilfield Operations Incorporated
2:30 PM	3:00 PM	Drilling Systems	Auto-Indexer for Percussive Hammers	Jiann Su, Sandia National Laboratories
3:00 PM	3:15 PM	Foyer	BREAK	
3:15 PM	3:45 PM	Materials	Self-Degrading Temporary Cementation Sealers	Toshi Sugama, Brookhaven National Laboratory
3:45 PM	4:15 PM	Materials	Development of an Improved Cement for Geothermal Wells	George Trabits, Trabits Group, LLC
4:15 PM	4:45 PM	Materials	Corrosive Resistant Foam Well-Costing Cement Composites	Toshi Sugama, Brookhaven National Laboratory

TRACK 3 - Big Thompson

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST**	
9:00 AM	9:30 AM	Modeling	Analysis of Geothermal Reservoir Stimulation using Geomechanics-Based Stochastic Analysis of Injection-Induced Seismicity	Ahmad Ghassemi, University of Oklahoma
9:30 AM	10:00 AM	Modeling	Development of Advanced Thermal-Hydrological-Mechanical-Chemical (THMC) Modeling Capabilities for Enhanced Geothermal Systems	Yu-Shu Wu, Colorado School of Mines
10:00 AM	10:30 AM	Modeling	Use of a Reservoir Model to Predict Potential Effects of Fracturing Techniques	Ahmad Ghassemi, University of Oklahoma
10:30 AM	10:45 AM	Foyer	BREAK	
10:45 AM	11:15 AM	Modeling	Integration of Noise and Coda Correlation Data into Kinematic and Waveform Inversions With Microearthquake Data for 3D Velocity Structure, Earthquake Locations, and Moment Tensors in Geothermal Reservoirs	Daniel O'Connell, William Lettis & Associates, Inc.
11:15 AM	11:45 AM	Modeling	FRACSTIM/I: An Integrated Fracture Stimulation and Reservoir Flow and Transport Simulator	Rob Podgorney, Idaho National Laboratory
11:45 AM	12:15 PM	Modeling	Innovative computational tools for reducing exploration risk through integration of water-rock interactions and magnetotelluric surveys	Joseph Moore, University of Utah
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH** **Air-Cooled Condensers in Next-Generation Conversion Systems**	Greg Mines, Idaho National Laboratory
1:30 PM	3:00 PM	Big Thompson	Induced Seismicity Potential in Energy Technologies	Jay Nathwani, DOE
3:00 PM	3:15 PM	Foyer	BREAK	

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

GEOTHERMAL TECHNOLOGIES OFFICE

4/22-4/25 2013 Peer Review Agenda

Location
Renaissance Denver Hotel
3801 Quebec Street
Denver, CO 80207
(303) 399-7500

print date 04/10/13

Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday -- Thursday

TRACK 1 - Ballroom A

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST**	
9:00 AM	9:30 AM	Geochemistry	Effects of volcanism, crustal thickness, and large scale faulting on the development and evolution of geothermal systems: Collaborative project in Chile	Patrick Dobson, Lawrence Berkeley National Laboratory
9:30 AM	10:00 AM	Geochemistry	Methodologies for Reservoir Characterization Using Fluid Inclusion Gas Chemistry	Lorie Dilley, Hattenburg, Dilley, and Linnell, LLC
10:00 AM	10:30 AM	Geochemistry	Optimizing parameters for predicting the geochemical behavior and performance of discrete fracture networks in geothermal systems	Alexandra Hakala, National Energy Technology Laboratory
10:30 AM	10:45 AM	Foyer	BREAK	
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH** **Geothermal Data on OpenEI**	Kate Young, National Renewable Energy Laboratory
3:00 PM	3:15 PM	Foyer	BREAK	

TRACK 2 - Ballroom B

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST**	
9:00 AM	9:30 AM	Zonal Isolation	High Temperature, High Pressure Devices for Zonal Isolation in Geothermal Wells	Paul Fabian, Composite Technology Development, Inc.
9:30 AM	10:00 AM	Zonal Isolation	Self Consuming Downhole Packer	Mark Grubelich, Sandia National Laboratories
10:00 AM	10:30 AM	IM&R	Geothermal Resource Development with Zero Mass Withdrawal, Engineered Convection, and Wellbore Energy Conversion	Christopher White, LA State Univ.
10:30 AM	10:45 AM	Foyer	BREAK	
10:45 AM	12:15 PM	Ballroom B	Geothermal Regulatory Roadmap closed door meeting	Tom Williams, National Renewable Energy Laboratory
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH** **Geothermal Data on OpenEI**	Kate Young, National Renewable Energy Laboratory
3:00 PM	3:15 PM	Foyer	BREAK	

TRACK 3 - Big Thompson

Start	End	Panel	Presentation	Presenter
8:00 AM	9:00 AM	Ballroom C&D	**CONTINENTAL BREAKFAST**	
9:00 AM	10:30 AM	Big Thompson	DOE EGS Closed Door Meeting	Greg Stillman, DOE
10:30 AM	10:45 AM	Foyer	BREAK	
10:45 AM	12:15 PM	Big Thompson	DOE EGS Closed Door Meeting	Greg Stillman, DOE
12:15 PM	1:30 PM	Ballroom C&D	**LUNCH** **Geothermal Data on OpenEI**	Kate Young, National Renewable Energy Laboratory
1:30 PM	3:00 PM	Big Thompson	DOE EGS Closed Door Meeting	Greg Stillman, DOE
3:00 PM	3:15 PM	Foyer	BREAK	
3:15 PM	5:00 PM	Big Thompson	DOE EGS Closed Door Meeting	Greg Stillman, DOE

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

GEOTHERMAL TECHNOLOGIES OFFICE

Other Working Groups and Meetings

Location
Renaissance Denver Hotel
3801 Quebec Street
Denver, CO 80207
(303) 399-7500

print date 04/10/13

Date	Start - End	Event	Host, Organization	Location
TUESDAY 4/23/2013				
	1:30 PM - 3:00 PM	Tracers Working Group	Bill Vandermeer, DOE	Platte River Room
WEDNESDAY 4/24/2013				
	9:00 AM - 12:15 PM	Exploration Best Practices on OpenEI Registration @ http://geoexpbestpractices.eventbrite.com/#	Kate Young, National Renewable Energy Laboratory	Vail Room
	2:00 PM - 4:00 PM	Tour of NREL Facilities Contact: Stacee Foster, stacee.foster@nrel.gov	Tom Williams, National Renewable Energy Laboratory	Offsite at NREL facility
THURSDAY 4/25/2013				
	2:30 PM - 4:00 PM	DOE Geothermal Technologies Office - Tour of NREL Facilities **GTO Employees Only**	Tom Williams, National Renewable Energy Laboratory	Offsite at NREL facility

Appendix E: Peer Review Attendees

Last Name	First Name	Organization
Albrecht	Michael	TBA Power, Inc.
Allis	Rick	Utah Geological Survey
Allison	Merle Lee	Arizona Geological Survey
Alvarado	Vladimir	University of Wyoming
Aminzadeh	Fred	University of Southern California
Anderson	Arlene	U.S. DOE
Anderson	Brian	West Virginia University
Augustine	Chad	National Renewable Energy Laboratory
Baker	Kate Hadley	Consultant
Barker	Benjamin	Barker Engineering
Barker	Jacob	CTD
Baumgardt	Frank	Johnson Controls, Inc.
Billo	Richard	Lone Star Advanced Technology
Blackman	Harold	Boise State University
Blackwell	David	Southern Methodist University, Geothermal Laboratory
Boyd	Lauren	U.S, Department of Energy
Brophy	Paul	EGS Inc.
Brown	Brian	Brian Brown Engineering
Burns	Lyle	Clean Tech Innovations, LLC
Calvin	Wendy	GBCGE, University of Nevada
Canaan	Lee	Braeburn Capital Partners
Carrigan	Charles	Lawrence Livermore National Laboratory
Carroll	Susan	Lawrence Livermore National Laboratory
Chabora	Ethan	GeothermEx, a Schlumberger Company
Chickering	Cathy	Southern Methodist University
Christensen	Caleb	MagiQ Technologies
Cladouhos	Trenton	AltaRock Energy
Clark	Corrie	Argonne National Laboratory
Coleman	Andrew	Electric Power Research Institute
Cooper	George	University of California Berkeley
Cosgrove	Sharon	US Department of Energy Geothermal Technologies Office
Crandall	Dustin	URS @ NETL
Creed	Robert	consultant
Cummings	Malcolm	MagiQ Technologies Inc.
Cuyler	David	Sandia National Laboratories
Damjanac	Branko	Itasca Consulting Group, Inc.
Danko	George	University of Nevada, Reno
Davatzes	Nicholas	Temple University
DeCamargo	Marcelo	Schlumberger
Deprizio	Jodi	U.S. Department of Energy
Dilley	Lorie	Hattenburg Dilley & Linnell

Last Name	First Name	Organization
Dillon	David	David K. Dillon PE, LLC
Dobson	Patrick	Lawrence Berkeley National Laboratory
Dreger	Douglas	University of California, Berkeley
Dutrow	Barbara	Louisiana State Univ.
Dykhuizen	Ronald	sandia national laboratories
Eide	Elizabeth	The National Academies
Einstein	Herbert	MIT
Elsworth	Derek	Penn State Univesity
Enedy	Kathleen	Graphic Vision
Faulder	David	DD Faulder, PhD, PE
Faulds	James	Nevada Bureau of Mines and Geology
Fehler	Michael	MIT
Fernandez	Carlos	Pacific Northwest National Laboratory
Fialko	Yuri	University of California San Diego
Finger	John	John Finger
Foley	Duncan	Pacific Lutheran University
Foster	Stacee	NREL
Freifeld	Barry	
Garg	Sabodh	SAIC
Garrett	Bobi	National Renewable Energy Laboratory
Ghassemi	Ahmad	The University of Oklahoma
Gonnion	Sara	CNJV
Gosnold	William	University of North Dakota
Habiger	Rob	Spectraseis
Haering	Markus	Geo Explorers Ltd
Hass	Eric	US DOE GTO
Henderson III	Fred	Mt. Princeton Geothermal LLC
Hess	Ryan	Sandia National Laboratories
Hillesheim	Michael	National Renewable Energy Laboratory (NREL)
Holladay	Jamie	Pacific Northwest National Laboratory
Hollett	Douglas	U.S. Department of Energy
Horne	Roland	Stanford University
Huang	Lianjie	Los Alamos National Laboratory
Huddlestone-Holmes	Cameron	CSIRO
Huttrer	Gerry	Geothermal Management Company, Inc.
Ingebritsen	Steve	U.S. Geological Survey
Iovenitti	Joe	AltaRock Energy Inc.
Jacobson	Jeffrey	Fairbanks North Star Borough
Jagusztyn	Ted	Cotherm of America Corporation
Jelacic	Allan	DOE (retired)
Jenne	Scott	NREL
Karl	Bernie	Chena Hot Springs Resort
Kaszuba	John	University of Wyoming
Kaufman	Greg	Pueblo of Jemez

Last Name	First Name	Organization
Kelkar	Sharad	Los Alamos National Laboratory
Kennedy	Mack	Lawrence Berkeley National Laboratory
Kneafsey	Tim	Lawrence Berkeley National Laboratory
Knudsen	Steven	Sandia National Labs
Kuhmuench	Christoph	Siemens
Kumar	Dharmendra	Colorado School of Mines
Lane	Michael	Oski Energy, LLC
Lao	Kang	GeoMechanics Technologies
Lear	Jon	Ruby Mountain Inc
Lee	Bo-Heng	Industrial Technology Research Institute
Leggett	James	Baker Hughes
Levine	Aaron	NREL
Liu	Chih-Hsi	Industrial Technology Research Institute
Livermore	Jennifer	National Renewable Energy Laboratory
Lowry	Thomas	
Ma	Qisheng	PEER Institute
Marshall	Dave	GeoTek Energy LLC
Martin	Jeff	University of Wyoming
Maxwell	Eric	Oasys Water, Inc
McGrail	Peter	Pacific Northwest National Laboratory
Mellors	Robert	LLNL
Mengers	Joshua	DOE
Merrick	Dale	Modoc Contracting, CanbyGeo, LLC
Metcalfe	Elisabet	SRA International (DOE)
Misseldine	Frank	Oski Energy LLC
Moore	Michael	AltaRock Energy
Moore	Joseph	Energy & Geoscience Institute
Morgan	Paul	Colorado Geological Survey
Mugerwa	Michael	Technip
Muir	Mark	GreenFire Energy
Nathwani	Jay	U.S. Department of Energy
Newman	Gregory	Lawrence Berkeley Lab
Newmark	Robin	NREL
Niple	John	Applied Physics Systems
Nordquist	Josh	Ormat Technologies, Inc.
O'Connell	Daniel	Fugro Consultants
Oglesby	Ken	Impact Technologies LLC
Okabe	Takashi	Geothermal Energy Research and Develpment Co., Ltd
Palmer	William	Harris Corporation
Pantea	Cristian	Los Alamos National Laboratory
Parfenov	Alexander	Physical Optics Corporation
Park	Chanwoo	University of Nevada, Reno
Patten	Kim	Arizona Geological Survey
Patterson	Doug	Baker Hughes

Last Name	First Name	Organization
Paulsson	Bjorn	Paulsson, Inc.
Petro	Miroslav	PARC
Petty	Susan	AltaRock Energy
Phillips	Benjamin	U.S. Department of Energy
Pierce	Michael	GeoTek Energy, LLC
Podgorney	Robert	Idaho National Laboratory
Pohll	Greg	DRI
Polsky	Yarom	Oak Ridge National Laboratory
Prakash	Anupma	Geophysical Institute, Univesity of Alaska Fairbanks
Pritchett	John	SAIC
Pyatina	Tatiana	Brookhaven National Laboratory
Pye	David (Stephen)	David Stephen Pye
Redcorn	Talee	Rendezvous Resources, LLC
Rehfeldt	Kenneth	Los Alamos National Laboratory
Reinhardt	Timothy	DOE
Renner	Joel	N/A
Revil	Andre	Colorado School of Mines
Richard	Christopher	BCS, Inc./ US DOE Geothermal Technologies Office
Richard	Stephen	Arizona Geological Survey
Rittgers	Andrew	DOE
Robinson	Lee	Flint Geothermal LLC
Roegiers	Jean-Claude	U.of Oklahoma / NSI
Rose	Peter	EGI
Rose	Kelly	U.S. Department of Energy National Energy Technology Laboratory
Ross	Frederick	SRA International Inc.
Saar	Martin	University of Minnesota
Sabau	Adrian	Oak Ridge National Laboratory
Sabin	Andrew	US Navy Geothermal Program Office
Sandifer	Cheryl	Technip
Sato	Yosuke	Japan Oil,Gas and Metals National Corporation
Scheibe	Tim	Pacific Northwest National Laboratory
Schnitger	Jochen	Baker Hughes
Schultz	Adam	Oregon State University
Shah	Manoj	GE - Global Research
Sharp	John	Sharp Informatics LLC
Shervais	John	Utah State University
Shubert	Ann	Applied Technology Associates
Simmons	Stuart	Colorado School of Mines
Skeehan	Kirsten	Pagosa Verde LLC
Skeehan	Carman	Temporal Geo Analytics
Smith	Dennis	Applied Technology Associates
Snyder	Neil	NREL
Sonnenthal	Eric	Lawrence Berkeley National Lab

Last Name	First Name	Organization
Spray	Jeff	Geothermal Expandables, LLC
Stern	Paul	PLS Environmental, LLC
Stockli	Daniel	University of Texas
Strickland	Casey	DOE - Golden
Sugama	Toshifumi	Brookhaven National Lab
Sullivan	John	Argonne National Laboratory
Swanton	Erik	CNJV
Takanashi	Koushirou	Geothermal Energy Research & Development Co., Ltd.
Tanikella	Rajanikanth	Siemens Corporation
Templeton	Dennise	Lawrence Livermore National Laboratory
Thomas	Donald	University of Hawaii
Tiangco	Dr. Valentino	ER&D Department, SMUD
Tibuleac	Ileana	Nevada Seismological Laboratory, University of Nevada Reno
Trabits	George	Trabits Group, LLC
Turaga	Uday	ADI Analytics LLC
Turnquist	Norman	GE Global Research
Vert	Alexey	SEMATECH
Visser	Charles	NREL
Waibel	Al	Columbia Geoscience
Wallin	Erin	University of Hawaii
Walters	Mark	Calpine Corporation
Wang	Herb	U. of Wisconsin-Madison
Wannamaker	Phil	University of Utah/EGI
Warren	Ian	U.S. Geothermal Inc.
Waterman	Kendall	Draka Cableteq USA
Weimer	Walter	Pacific Northwest National Laboratory
Wendt	Daniel	Idaho National Laboratory
Wieberg	Scott	Bell Geospace, Inc.
Williams	Tom	National Renewable Energy Laboratory
Williams	Colin	US Geological Survey
Witherbee	Kermit	NREL
Wolfer	Dale	Atlas Copco Secoroc, LLC
Wright	Phillip Michael	Consultant
Wu	Yu-Shu	Colorado School of Mines
Young	Kate	National Renewable Energy Laboratory
Yuksek	Errol	Access Energy, LLC
Zemach	Ezra	Ormat Technologies
Ziagos	John P	Lawrence Livermore National Laboratory

Appendix F: List of Peer Reviewers

Last Name	First Name	Organization
Alvarado	Vladimir	University of Wyoming
Augustine	Chad	National Renewable Energy Laboratory
Barker	Ben	Consultant
Bauer	Steve	Sandia National Laboratories
Billo	Richard	University of Texas, at Arlington
Blankenship	Doug	Sandia National Laboratories
Bloomfield	Kit	Apex Petroleum Engineering
Brophy	Paul	EGS, Inc.
Bruton	Carol	Simbol Inc.
Canaan	Lee	Braeburn Capital Partners
Carrigan	Charles	Lawrence Livermore National Laboratory
Cooper	George	University of California, Berkeley
Crandall	Dustin	National Energy Technology Laboratory
Creed	Robert	Consultant
Cuyler	Dave	Sandia National Laboratories
Dobson	Pat	Lawrence Berkeley National Laboratory
Dutrow	Barb	Louisiana State University
Dykhuizen	Ronald	Sandia National Laboratories
Elsworth	Derek	Pennsylvania State University
Enedy	Kathy	Graphic Vision
Faulder	David	Terra-Gen
Fialko	Yuri	University of California, San Diego
Finger	John	Consultant
Foley	Duncan	Pacific Lutheran University
Garg	Sadodh	SAIC
Haring	Markus	Geothermal Explorers International
Hillesheim	Michael	National Renewable Energy Laboratory
Huttrer	Gerry	Geothermal Management Company, Inc.
Ingebritsen	Steven	United States Geological Survey
Jelacic	Allan	SRA International, consultant to the DOE
Kaszuba	John	University of Wyoming
Kelkar	Sharad	Los Alamos Nationl Laboratory
Knudsen	Steve	Sandia National Laboratories
Lindblom	Scott	Sandia National Laboratories
McGrail	Peter	Pacific Northwest National Laboratory
Mellors	Robert	Lawrence Livermore National Laboratory
Mines	Gregory	Idaho National Laboratory
Normann	Randy	Perma Works
Pantea	Christian	Los Alamos National Laboratory
Phillips	Benjamin	SRA International, consultant to the DOE
Podgorney	Rob	Idaho National Laboratory
Polsky	Yarom	Oak Ridge National Laboratory
Pye	Stephen	Consultant, Unocal Philippines, Inc., Philippine Geothermal Inc.

Last Name	First Name	Organization
Renner	Joel	Consultant, former Idaho National Laboratory
Revil	Andre	Colorado School of Mines
Richard	Christopher	U.S. DOE and BCS, Inc.
Roegiers	Jean-Claude	Oklahoma University
Sabin	Andrew	Department of Defense
Sharp	John	Sharp Informatics
Stockli	Daniel	University of Texas
Vert	Alexey	GE
Visser	Charles	National Renewable Energy Laboratory
Wang	Herb	Univesity of Wisconsin
Wright	Phillip	Consultant
Ziagos	John	Lawrence Livermore National Laboratory

Appendix G: Logistical Lessons Learned from the 2013 Peer Review Meeting

The 2013 Geothermal Technologies Office Peer Review Meeting took place on April 22-25, 2013 at the Renaissance Denver Hotel in Denver, CO. The purpose of the review was to evaluate DOE-funded projects for their contribution to the mission and goals of the office, and to assess progress made against stated project objectives. A total of 112 projects were presented with 97 of them being evaluated by the expert reviewers. Approximately 55 subject-matter experts participated as review panel members. To assist in identifying the reasons for success or shortfalls in outcomes, reviewers also evaluated the merits of the technical and managerial approaches of the Principal Investigators.

The 2013 Geothermal Technologies Office Peer Review Meeting was organized into the following tracks with associated sessions:

- Track 1 – Co-Produced; Low Temperature; Supercritical Carbon Dioxide; Working Fluids; Innovative Exploration Techniques; Geophysics; and Geochemistry
- Track 2 – Enhanced Geothermal Systems Demonstrations; Fluid Imaging; Characterizing Fractures; Induced Seismicity; High Temperature Tools; Drilling Systems; Materials; Zonal Isolation; and Innovative Methods of Heat Recovery
- Track 3 – Systems Analysis; Data System Development and Population; Tracers; and Modeling.

The following is a list of comments and actionable recommendations made by reviewers and review attendees, aimed at improving the process for future Geothermal Technologies Office peer review meetings.

Positives

- The signup sheet for using the reviewer P2RMIS computer lab after hours worked well.
    - Next year we should have predetermined hours and a signup sheet posted for those who need later access to P2RMIS computer lab.
- The reviewer P2RMIS computer lab was consistently busy with reviewers using both personal and loaner computers.
- The meeting/hotel venue worked well for this meeting.
    - Easier to navigate.
    - Food was good/appropriate.
    - A/V was fantastic.
    - Laser pointers/slide advancers were heavily used.
    - Peer Review Staff utilizing a workroom rather than registration desk was positive for all.
    - Size was appropriate for this meeting.
    - Drink coolers seemed effective/efficient over the typical beverage layout.
- Side-meeting signup sheet worked well.
- The visual and printed agenda was greatly improved.
    - Printing size made it easy to read.
    - Posters were helpful.
- Poster session was well attended and flowed surprisingly well.
- Wi-Fi availability was greatly appreciated by meeting attendees.
- Statement of Project Objectives (SOPOs) and Statements of Work (SOWs) were welcome and utilized by the expert reviewers.
- Three tracks was more manageable and seemed to allow better cross-pollination.
- Side meetings seemed effective and were not detractors from the greater overall meeting.

Improvement Opportunities

- Reviewers would like to have more complete project folders provided in advance of review. For many projects, it was not very apparent what had been done previously. If Year 2 work was building on Year 2 results, it is important to know what those results are. Results from previous year(s) work may have been bulleted but sometimes that was not enough information for the reviewers.
- Reviewers request that techncial people lead these techncial presentations. The "promoter" types do their project a disservice and can rarely answer techncial questions.
- The fixed format of the slide presentations required for the peer review still puts more weight on management issues than is necessary.
- Project management information still receives mixed feedback regarding the usefulness in technical presentations.
    - EVM should be considered for greater penetration or removal – first pass yielded decent participation – we should examine the utility and choose to press forward or let it fade.
    - During the reviewer wrap-up of one technology session, reviewers stated they would like to see less project management requirements in the presentation/peer review process. They said these are R&D projects, and the focus of the work is (and should be) on the technical results and progress and not so much on project management aspects.
- Information on submissions to the NGDS should be carefully considered. They were removed this year, but the TDM would have preferred their inclusion.
- Presentation submission improved, but there is more room for improvement. Plenary and lunch presentations would benefit from more urgency or maybe a deadline of the Wednesday before the meeting.
- A "fun" networking event could be of benefit. Tuesday night at the hotel may have been more effective with a shuttle to destination type of "after-event."
- Consider allowing PIs to create full size posters.
- Inquire to see if there is a demand for a Fed/GTO working room.
- Mark the first two rows in the presentation rooms for reviewers and DOE staff. This would create a one row buffer for the reviewers typing notes in the first row.
- It should be made clear to reviewers that they can base their reviews on all available project information – links, SOPOs, presentation, publications, summaries, etc.
- The GTO team felt that there were a lot of 'touch and go attendees.' The GTO would have liked for people/PIs to stay longer and participate further in the networking aspect. Consider ways increase break time away from presentations and/or additional networking events.
- Reviewers felt there was not enough time for questions. Look at potentially increasing the Q&A time slot for 2014 as there will be fewer projects participating.

Appendix H: Acronym List:

ANL: Argonne National Laboratory
AOP: Annual Operating Plan
ARRA: 2009 American Recovery and Reinvestment Act
CEC: Chemical Energy Carriers
CO_2: carbon dioxide
DOE: United States Department of Energy
EERE: Office of Energy Efficiency and Renewable Energy
EGS: Enhanced Geothermal Systems
FOA: Funding Opportunity Announcement
FY: Fiscal Year
GAO: U.S. General Accounting Office
GDR: Geothermal Data Repository
GETEM: Geothermal Electricity Technology Evaluation Model
GTO: Geothermal Technologies Office
GWe: Gigawatt(s) electric
H_2O: water
JEDI: Jobs and Economic Development Model
kWh: kilowatt hour(s)
IEA-GIA: International Energy Agency's Geothermal Implementing Agreement
IET: Innovative Exploration Technologies
IPGT: International Partnership for Geothermal Technologies
LANL: Los Alamos National Laboratory
LBNL: Lawrence Berkeley National Laboratory
LCOE: levelized cost of energy
LLNL: Lawrence Livermore National Laboratory
MEQ: microearthquakes
MOHCs: Metal Organic Heat Carriers
MWD: Measurement-While-Drilling
MWe: Megawatt(s) electric
NAS: National Academy of Sciences
NCG: non-condensable gas
NEPA: National Environmental Policy Act
NGDS: National Geothermal Data System
NREL: National Renewable Energy Laboratory
OMB: White House Office of Management and Budget
ORNL: Oak Ridge National Laboratory
PI: Principle Investigator
PNNL: Pacific Northwest National Laboratory
P2RMIS: Program and Peer Review Management Information System
R&D: Research and Development
RD&D: Research, Development and Demonstration
SAM: System Advisor Model
$scCO_2$: supercritical carbon dioxide
SiC: Silicon Carbide
SNL: Sandia National Laboratories
SWIW: single-well injection withdrawal
THMC: Thermal Hydrological Mechanical Chemical (model)

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For more information, please visit:
http://www.eere.energy.gov/geothermal

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