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.

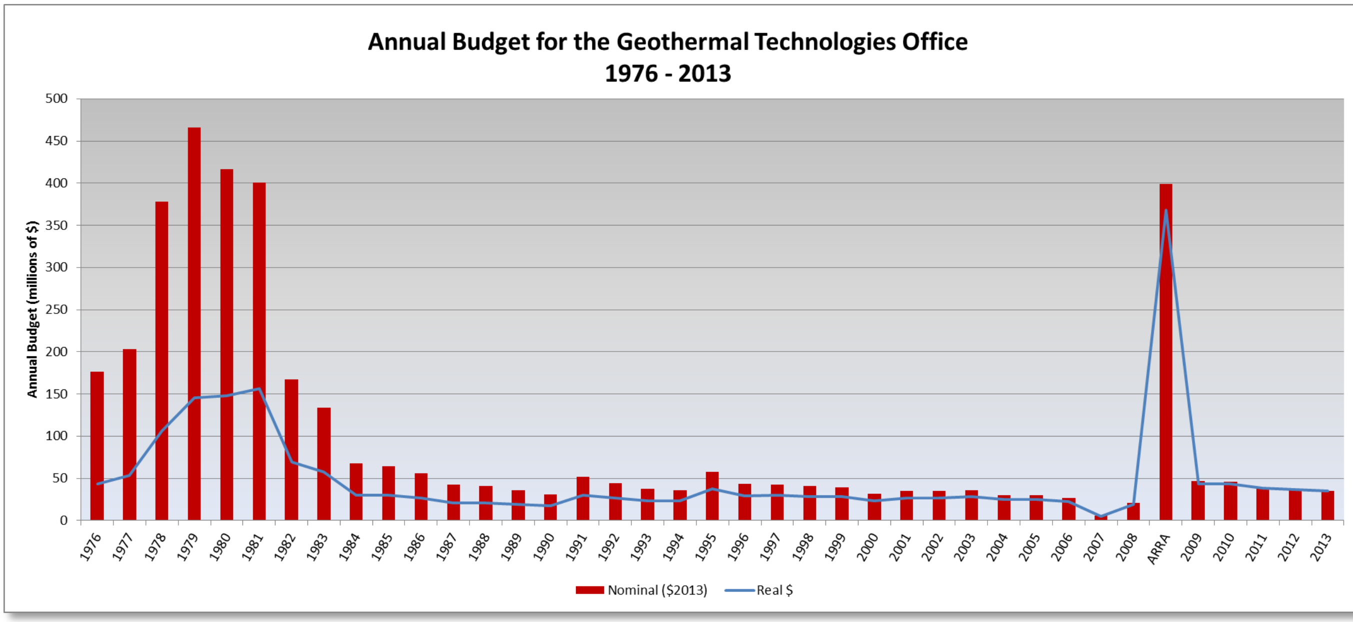


Figure 1-1. Geothermal Technologies Office funding history

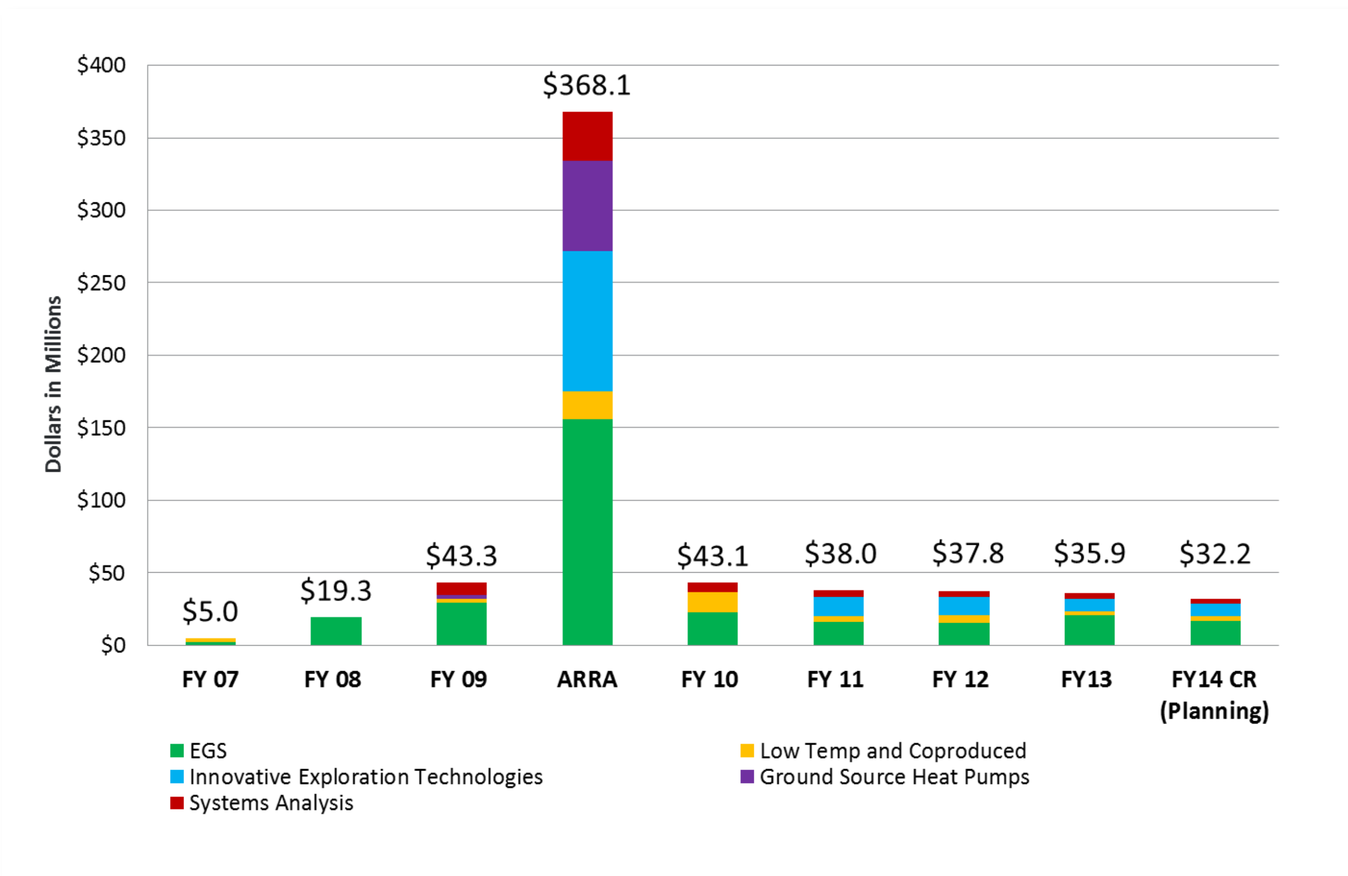


Figure 1-2. Geothermal Technologies Office budget history

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[1] 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.

[1] *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**[2] 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.

[2] 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* (millions)		Technology Area Projects *Total and % of Review*
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

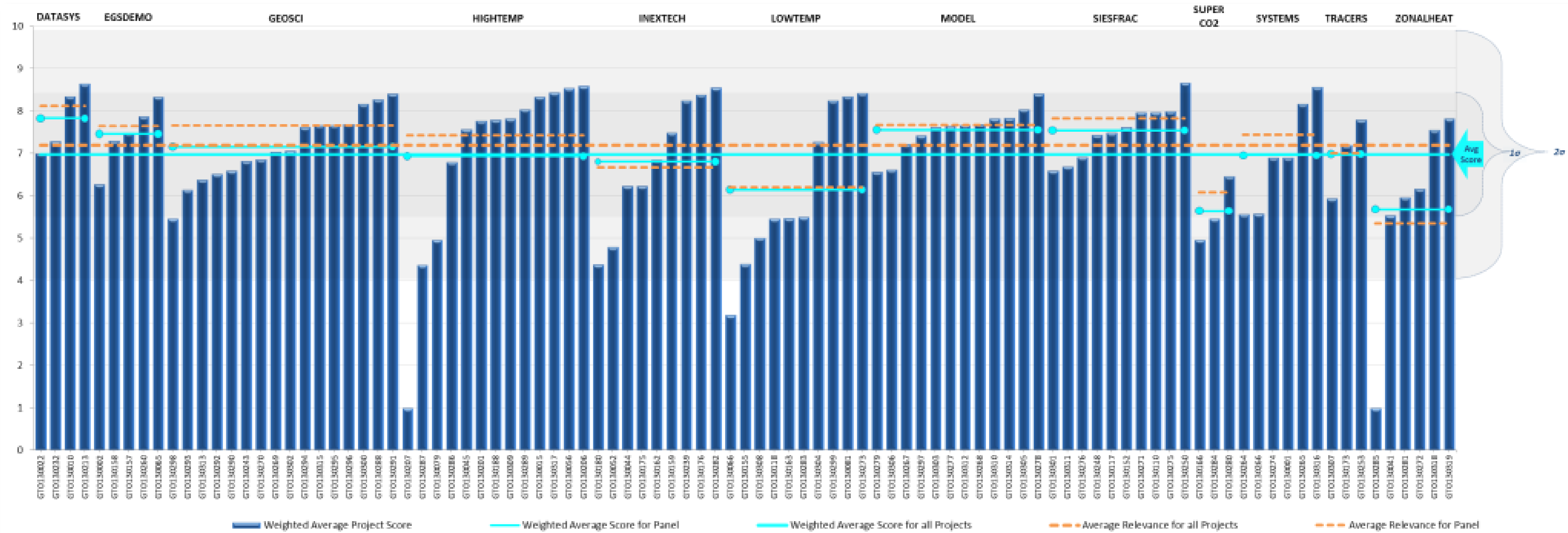


Figure 4-2. Weighted average scores – panel comparison*

**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.

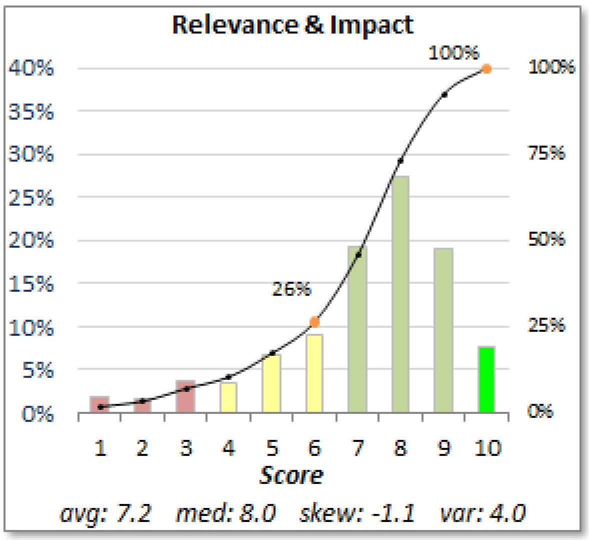


Figure 4-3. Relevance & impact of research

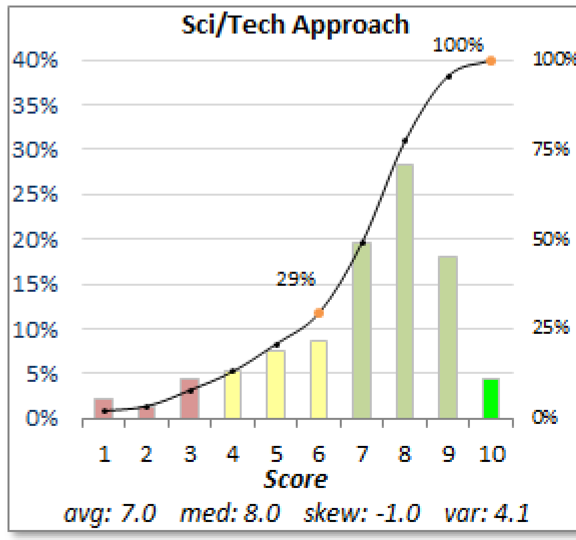


Figure 4-4. Scientific & technical approach

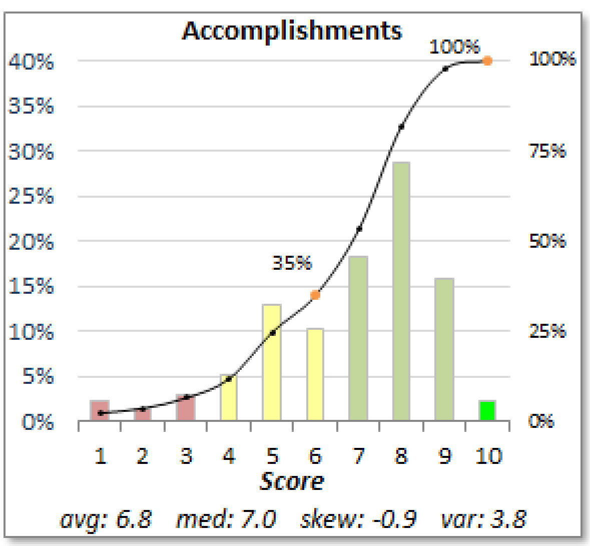


Figure 4-5. Accomplishments, results, & progress

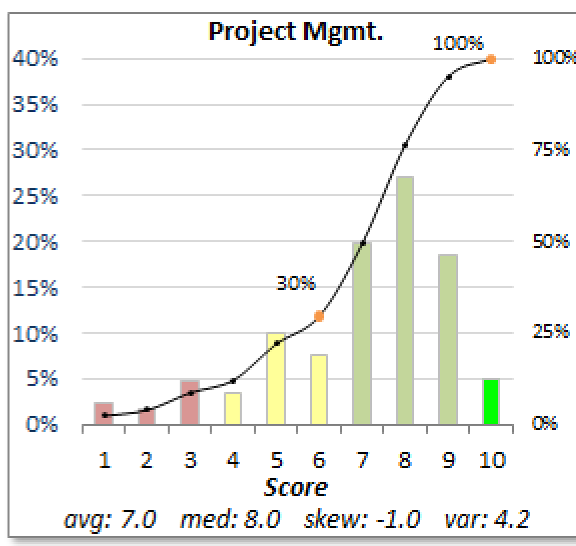


Figure 4-6. Project management & coordination

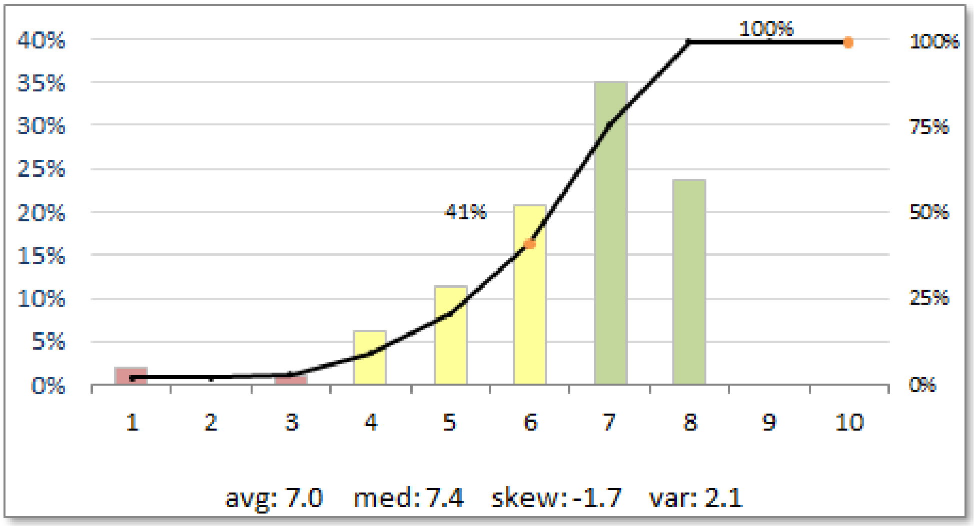


Figure 4-7. Weighted average project score

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 $\leq$ 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.

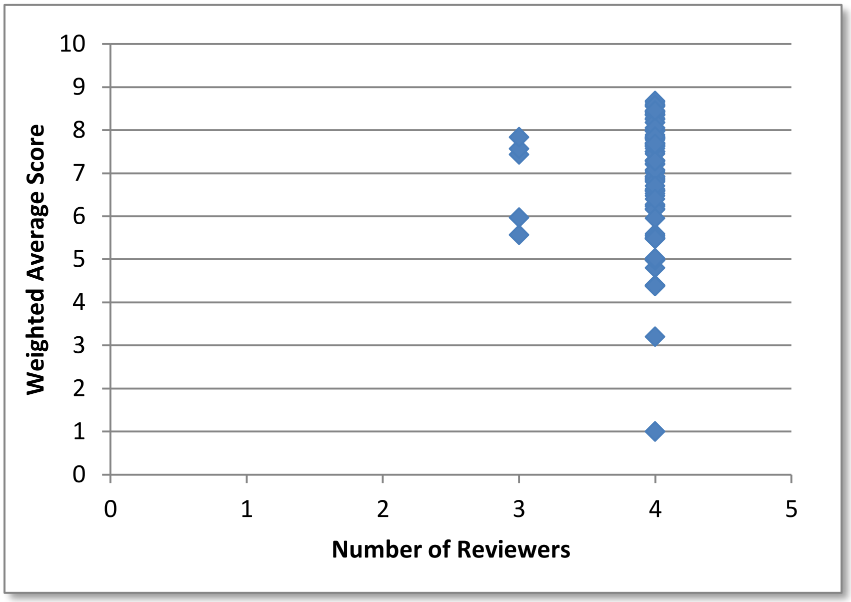


Figure 4-8. Weighted average score vs. number of reviewers

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.

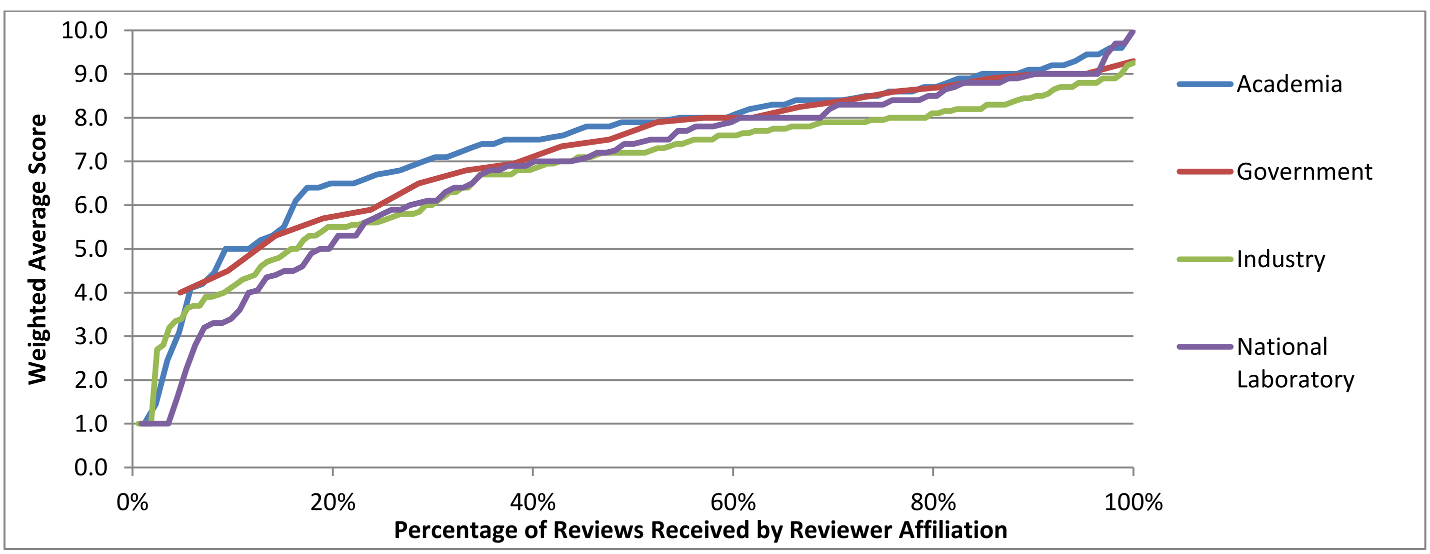


Figure 4-9. Weighted average score vs. reviewer affiliation

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.

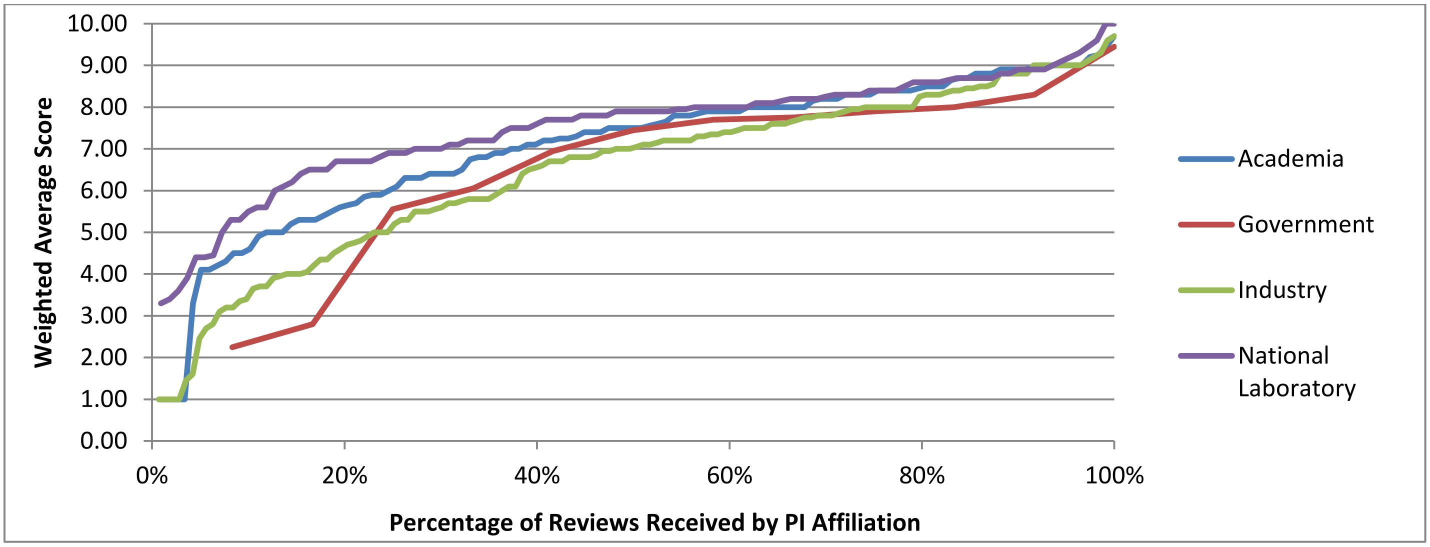
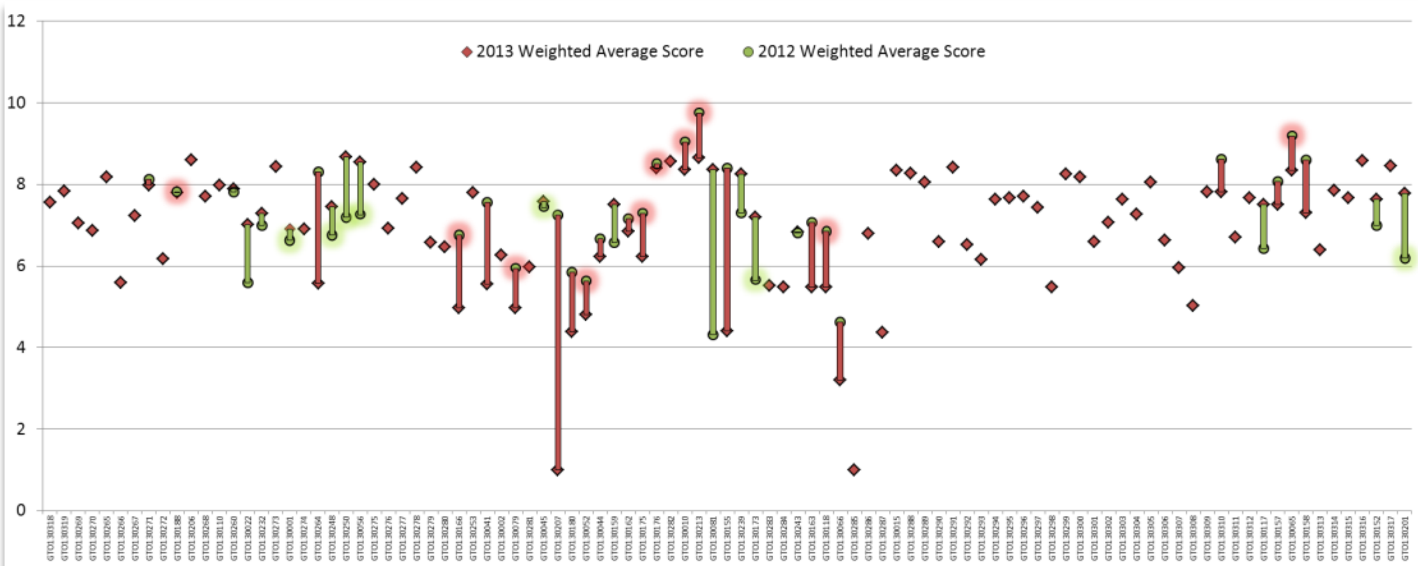


Figure 4-10. Weighted average score vs. PI affiliation

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.

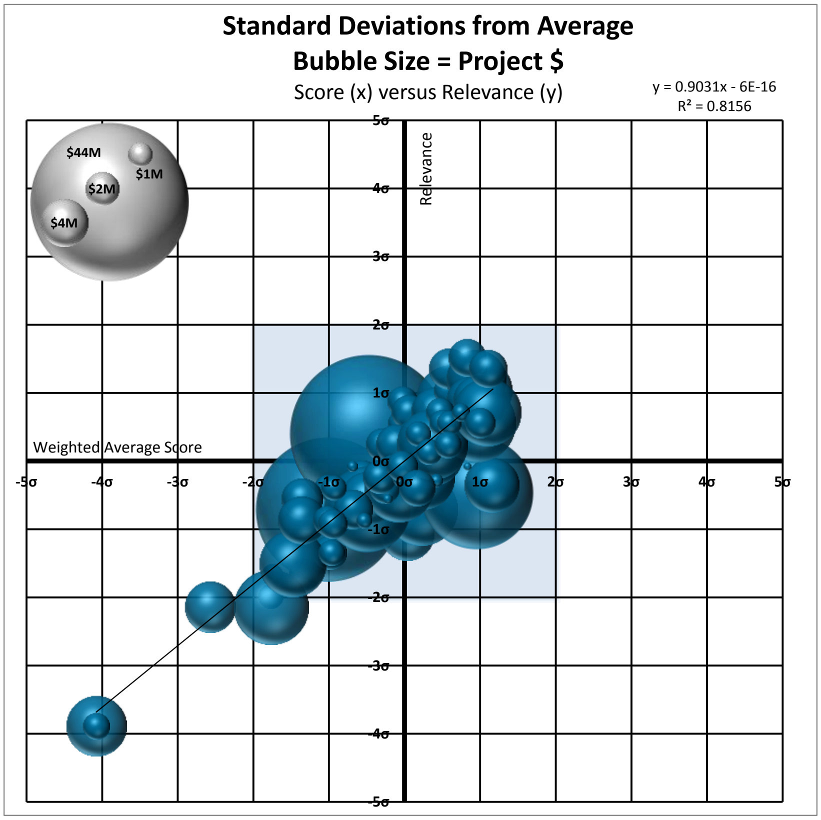


Figure 4-12. Weighted average score versus relevance – project funding

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.

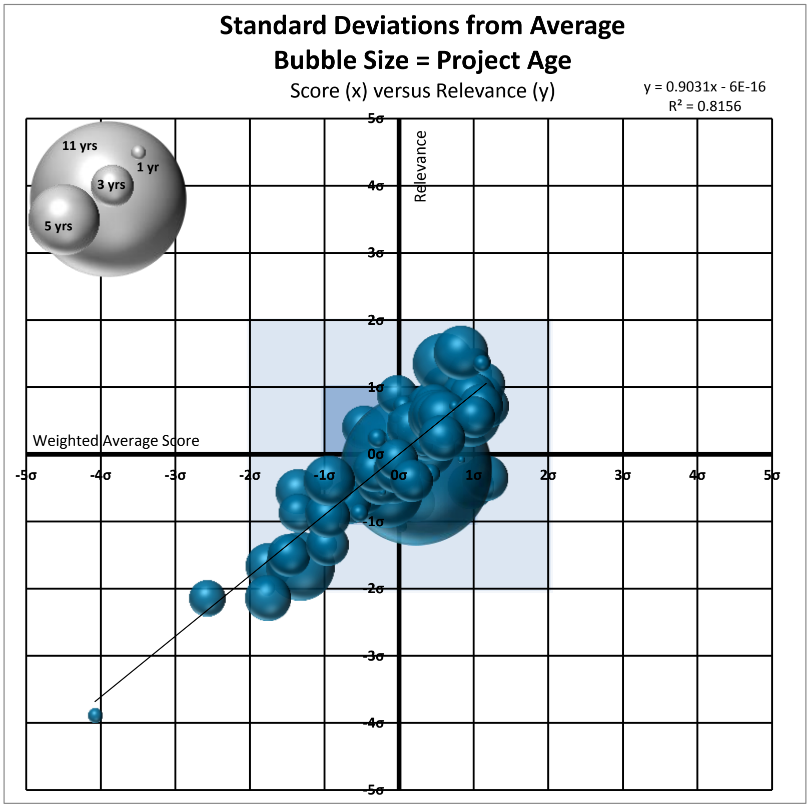


Figure 4-13. Weighted average score versus relevance – project age

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[3] 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."[4] 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.*

[3] 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.
[4] 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.[5] 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.

[5] 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.