Geothermal Technologies Program Peer Review - May 18-20, 2010

Principal Investigator : Bassam Jody

Organization: Argonne National Laboratory

Track Name: Specialized Materials and Fluids and Power Plants

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Geothermal Technologies Program 2010 Peer Review

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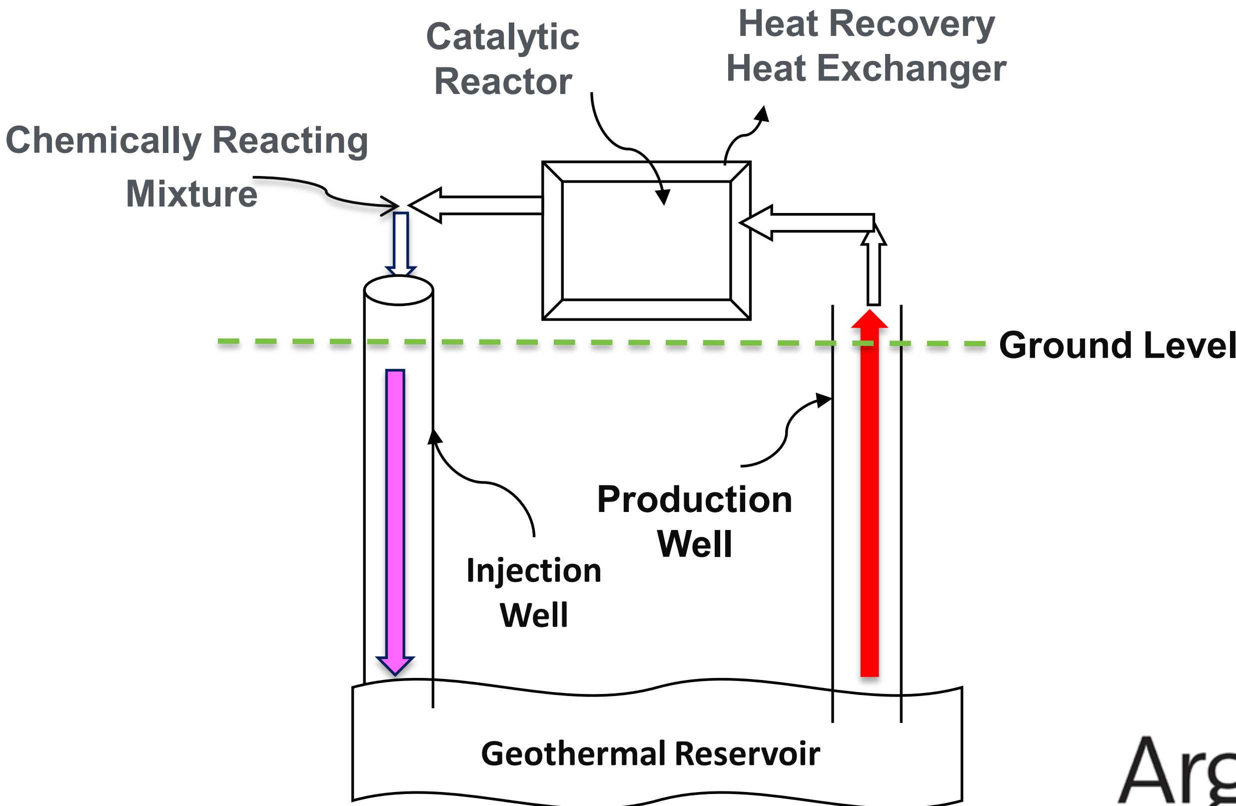

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Title: Chemical Energy Carriers (CEC) for the Utilization of Geothermal Energy

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Overview

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- **Timeline**
  - Project start date: 10/1/2009
  - Project end date: 9/30/2012 (new proposal is required for the 3rd year)
  - Percent complete: 15 %
- **Budget**
  - Total project funding $1,800,000 (for 3 years)
  - DOE share: 100 %, Awardee share: 0 %
  - Funding received in FY09: $510,000 (received September 28, 2009)
  - Funding for FY10: $340,000 (pending full ARRA approval)
- **Barriers addressed**
  - Relatively low temperatures;
  - Dry holes – working fluid is needed
  - Low permeability
- **Partners**
  - TBD

Relevance/Impact of Research

Objective: Develop chemical energy carrier (CEC) systems to recover thermal energy from enhanced geothermal systems (EGS) in the form of chemical energy, in addition to sensible and latent energy

- CEC are reversible chemical reaction systems
- In comparison to water/steam, CEC working fluids offer:
  - Capture more EGS energy per unit mass of working fluid
  - Deliver the captured energy to the power plant at higher average temperatures (higher exergy)

Therefore, capturing the EGS heat with CEC systems can result in more efficient power generation.

- Many CEC working fluids do not use water.

Therefore, water conservation is an added benefit

Relevance/Impact of Research, cont'd

- Sub-quality natural gas can be used as a CEC working fluid. In the process its heating value can be increased.

$$(CH_4+N_2)+H_2O+\text{Geothermal heat} \rightarrow NH_3 + CO_2$$

- CEC systems can utilize EGS reservoirs as chemical reactors or precursors to chemical reactors to produce valuable chemical products

Therefore, CEC systems can open the door to new and more efficient uses of geothermal energy

- Pressure exerted by gases and vapors is considerably less than the pressure exerted by liquids.

Therefore, CEC systems can result in less seismic activity

Scientific/Technical Approach --- (3-year program)

- Identify CEC systems that can capture the geothermal energy as chemical energy, sensible energy and latent energy
- Establish EGS conditions and develop criteria for evaluating
- Conduct technical, economic and environmental analyses, identify knowledge gaps and R&D needs
- Select leading CEC candidates for detailed evaluation and for making a go/no-go decision
- Conduct laboratory testing to validate the analysis and make a go/no go decision
- Identify an industrial partner(s) for the field demonstration

Scientific/Technical Approach, cont'd

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- Milestones and go/no-go decisions
  - *Milestone M1-* Complete thermodynamic and process engineering simulation/ analysis of the leading candidates March/2011
  - *Go/no-go* decision September 2011
  - *Milestone M2-* Complete laboratory tests of CEC/catalyst systems March/2012
- Status: on track.

Accomplishments, Expected Outcomes and Progress–Organization Chart

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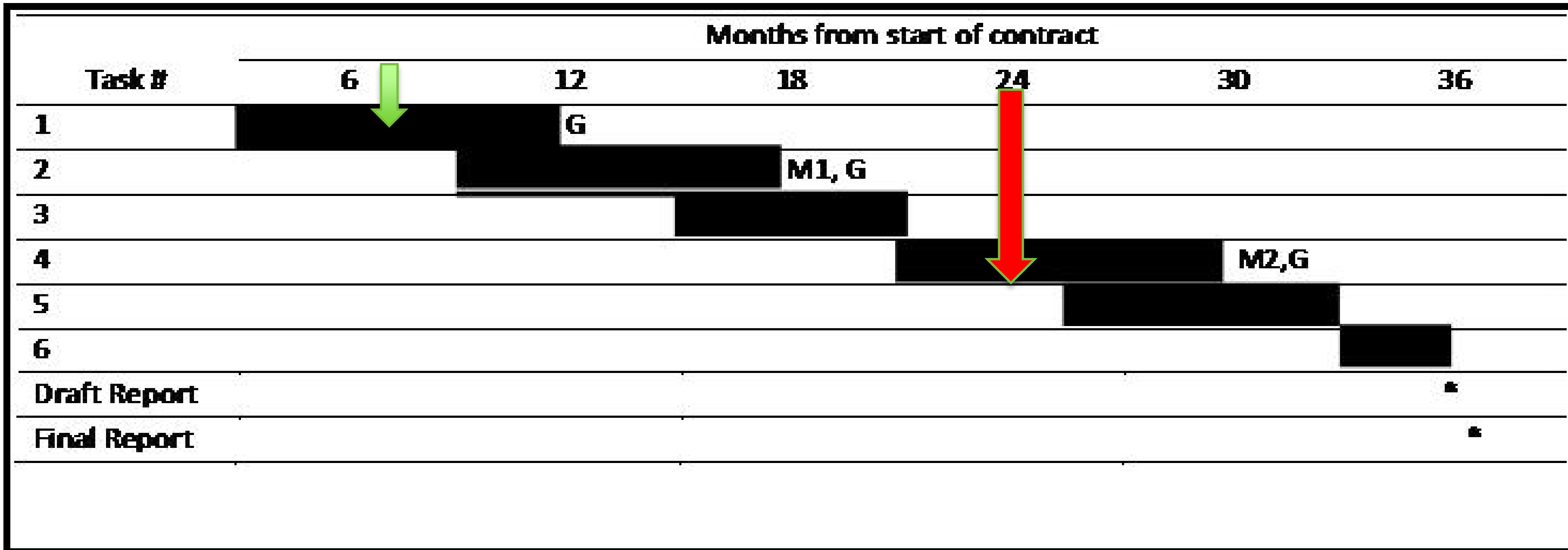
Project Task Organization Chart

Task No.	Task Description
1	Identify reversible reactions that could be used for recovering EGS thermal energy.
2	Conduct thermodynamic and process engineering simulation/analysis of the leading candidates to identify bottlenecks and evaluate design modifications and R&D needs for the application of CEC systems to EGS reservoirs available in the United States.
3	Determine thermodynamic targets for improvements in catalyst performance or development of new catalysts and associated process design.
4	Conduct laboratory tests of CEC/available catalyst systems to confirm thermodynamic analysis and to test new catalysts and assess potential for success under simulated EGS conditions, as necessary
5	Develop, design, and analyze (chemistry, engineering, economics) CEC systems to match EGS temperatures, pressures, chemistry, and mineralogy with reversible reactions
6	Develop a plan for field testing the leading candidate(s).

Work is underway on Task 1

Schedule, Milestones and Decision Points



- M stands for Milestone;
  - M1- Complete thermodynamic and process engineering simulation/ analysis of the leading candidates,
  - M2- Complete laboratory tests of CEC/catalyst systems;
- G stands for Go/No-Go decision point,
- * Report submission date

Accomplishments, Expected Outcomes and Progress , cont'd

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- Developed criteria for evaluating the reactions and identified leading candidates for further evaluation
- Developed a program for calculating pressure variations in the injection pipe, fractured rocks and production pipe for single phase flow
- **Identified 18 potential CEC systems as potential working fluids for EGS applications**
- Conducted thermodynamic analysis of several CEC systems using the ASPEN PLUS® simulator
- Filed an invention disclosure
- Preparing a manuscript "*Enhanced Geothermal Reservoirs --- The Chemical Reactors of the Future*"

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Example: A CEC system involving methanol (CH_3OH) and an EGS at 500 °C

- Forward endothermic reaction

  CH_3OH+EGS Heat (450-500 °*C*)

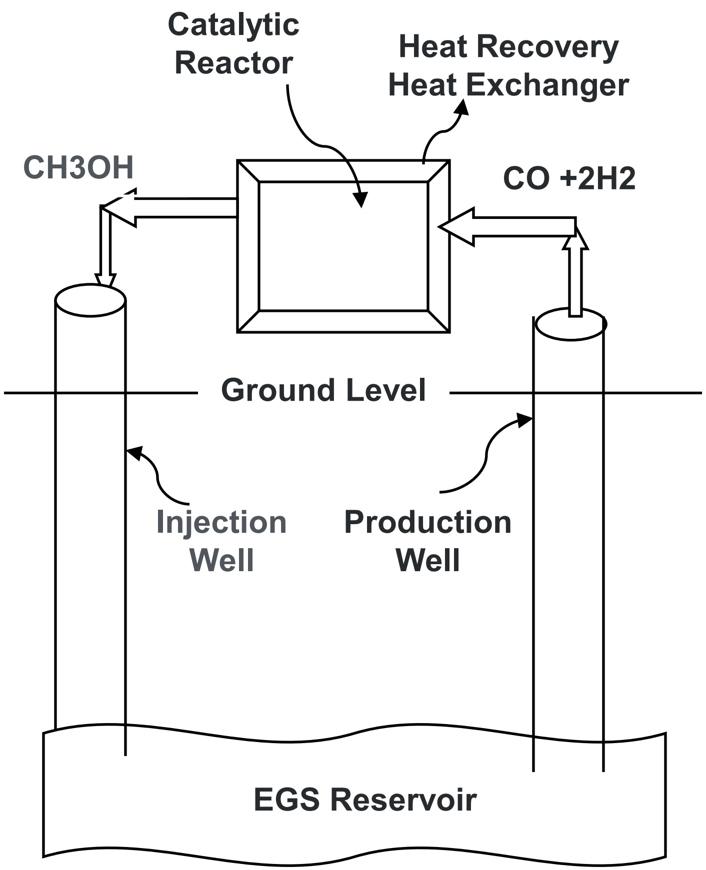
  → CO +$2H_2$

- Reverse exothermic reaction (above ground)

  CO+$2H_2$ (*300 °C with catalysts*)

  → CH_3OH + Heat @ 300 °*C*

- *These processes are practiced commercially and can be adopted to EGS applications*



Accomplishments, Expected Outcomes and Progress, example cont'd

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- Methanol can thermally decompose:

$CH_3OH \rightarrow CO + 2\,H_2$ ΔH_r = 128,130 KJ/Kmol

Or : $CH_3OH \rightarrow CH_2O + H_2$ ΔH_r = 92,095 KJ/Kmol

- Methanol can also react with water:

$CH_3OH + H_2O \rightarrow CO + 3\,H_2$ ΔH_r = 86,960 KJ/Kmol

First reaction captures more EGS heat

- Heat Captured from EGS by the first reaction

Sensible Heat Gain = 28,117 KJ/Kmol CH_3OH

Chemical Heat Gain = 128,130 KJ/Kmol CH_3OH

Total Heat Gain = 156,247 KJ/Kmol CH_3OH

OR 4883 KJ/Kg of methanol

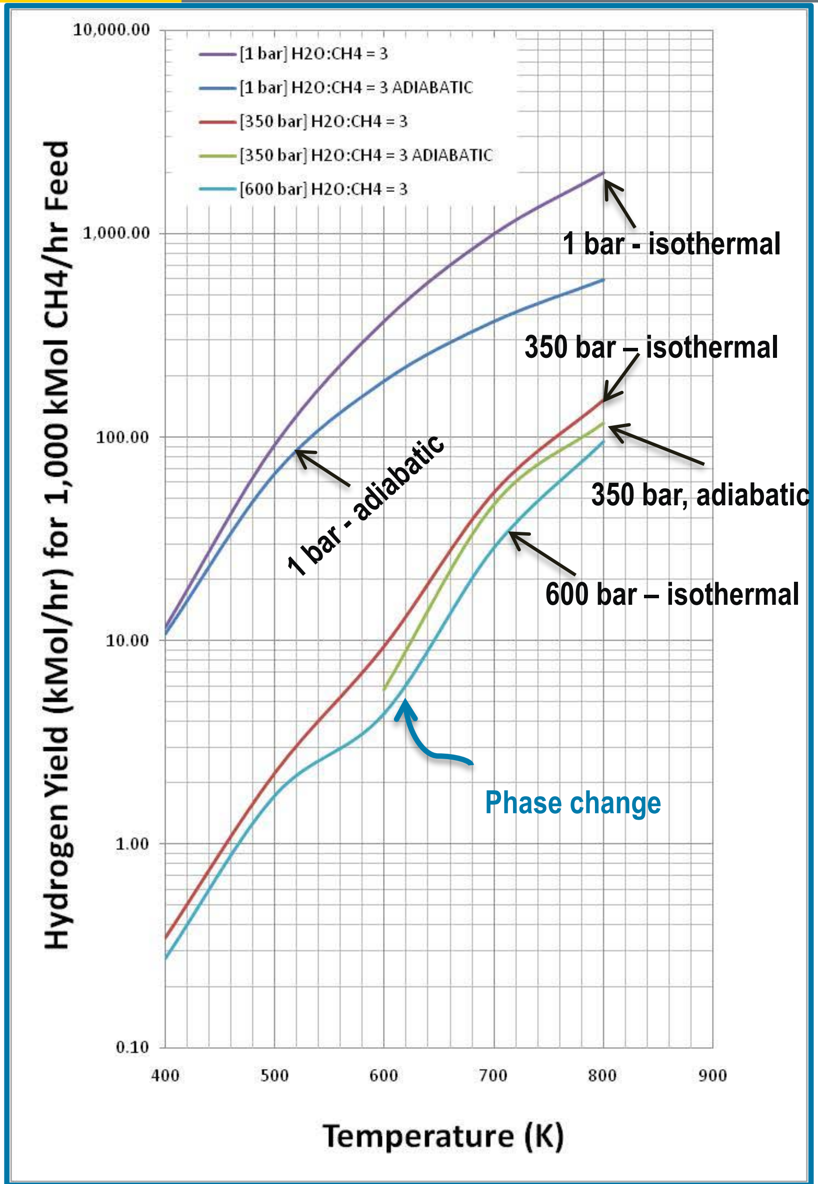
Reforming of Methane Captures More Thermal Energy

- Reforming of methane :

  $CH_4 + H_2O \rightarrow CO + 3\ H_2$

  $\Delta H_r = 128{,}130\ KJ/Kmol$

- Requires high temperatures and catalysts
- H_2 separation and/or increasing H_2O/CH_4 ration can speed up the reaction rate
- Different CEC systems can be used for different EGS reservoirs



Accomplishments, Expected Outcomes and Progress, cont'd

- For water ➔ steam working fluid
  - Water (60 °C → 500 °C, 100 bar) captures 3264 KJ/Kg
  - Methanol CEC captures 33% more thermal energy per unit mass than water
- ~93% of the total energy captured by methanol CEC can be available for power generation at >/=300 °C
- ~66% of heat captured by water/steam is available at >/=300 °C
- Therefore, power generation efficiency is higher with methanol CEC

Doubling of the electric power output may be possible with CEC

- The methanol system does not use water :

Water conservation benefit

Project Team Qualifications

- Qualifications
  - Bassam Jody, Ph.D.-Energy Engineering (Thermodynamics and Heat Transfer), U. of Illinois, Chicago; 32 years of R&D experience, 8 patents and over 50 publications and many awards including 1 R&D 100 award.
  - Seth Snyder, Ph.D.- Biophysics (University of Virginia), leads the Process Technology Research section (>40 people), 2010 chair of Council for Chemical Research,10 patents, over 40 publications and many awards including 2 R&D 100 awards;.
  - Richard Doctor. ChE, P.E., Northwestern Univ.; 36 years of experience in R&D including using ASPEN® process design and cost engineering model, 3 patents and over 100 publications and many awards.
  - Don Petch, Ph.D.-Petroleum and Natural Gas Engineering -- reservoir simulation (Penn. State), 7 years experience in industrial gas engineering.

Quality of special facilities or equipment

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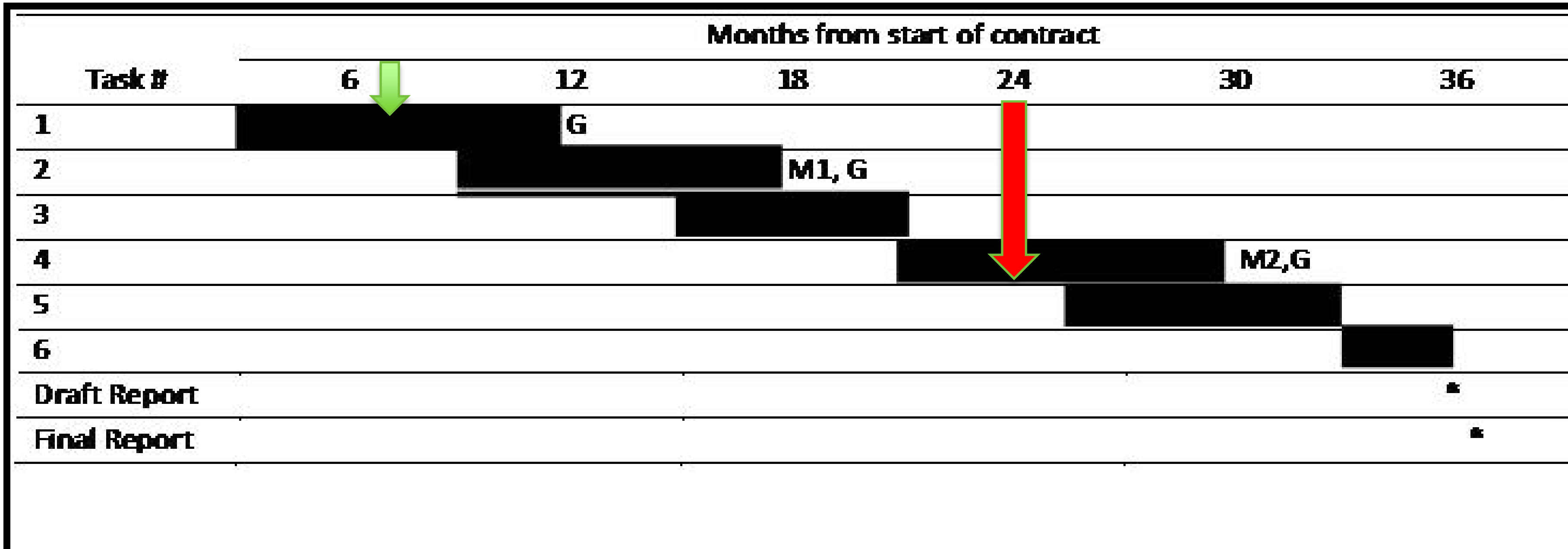
- Argonne is one of the largest national laboratories in the country. Argonne's special facilities include:
  - Substantial experience in piloting and scale-up of chemical processes
  - Advanced photon source & Electron microscopy center
  - Catalysis center
  - High performance computational facilities

Schedule, Milestones and Decision Points



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Project Management/Coordination Application of Resources/Funds/Spend Plans & Reporting

- Actual spending vs. projected spending plan (*Spending plan prepared and submitted on 3/19/2010*)

	Task	Plan	Actual
Oct-09	1	$18,408	$18,408
Nov-09	1	$32,910	$32,910
Dec-09	1	$27,522	$27,522
Jan-10	1	$38,760	$38,760
Feb-10	1	$53,858	$53,858
Mar-10	1	$46,000	$55,392
	Totals	$217,458	$226,850
	Variance	4.3	%

- Quarterly reports submitted on time
- Monthly reports submitted on time
- Peer review meeting 5/18/2009

Summary

- **CEC systems have the potential to –**
  - **Significantly increase the electric power output of EGS when compared to conventional water/steam systems**
  - Conserve water
  - Reduce emissions
  - Prolong the useful life of the EGS reservoir
  - Utilize abandoned sub-quality natural gas as a working fluid. *In the process the heating value of the* gas *can be increased*.
  - Utilize EGS reservoirs as chemical reactors or precursors to chemical reactors to produce valuable products
  - **Open the door to new and more efficient chemical uses of geothermal energy**

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Future Directions

FY 2010

- Select the leading candidate(s) for detailed evaluation
  - Identify knowledge gaps and R&D needs
  - Technical, economic and environmental evaluations

FY 2011

- Commission laboratory for operating conditions, catalysts, reaction yields, etc.
- *Milestone M1-* Complete thermodynamic and process engineering simulation/ analysis of the leading candidates March/2011
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Beyond 2011

- Laboratory evaluation and development of design and scale up data
- Process design and a plan for field testing of the process
- Identify industrial partners for field testing of the technology
- Field testing of the technology

Publications

- The following paper is being prepared for publication

  "*Enhanced Geothermal Reservoirs --- The Chemical Reactors of the Future,*" *by* Bassam Jody, Seth Snyder, Richard Doctor and Tawatchai Petchsingto.