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

“This presentation does not contain any proprietary, confidential, or otherwise restricted information”
Title: Chemical Energy Carriers (CEC) for the Utilization of Geothermal Energy

May 18, 2010
Overview

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

\[(\text{CH}_4+\text{N}_2)+\text{H}_2\text{O}+\text{Geothermal heat} \rightarrow \text{NH}_3 + \text{CO}_2\]

• 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
• 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.
<table>
<thead>
<tr>
<th>Task No.</th>
<th>Task Description</th>
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<tbody>
<tr>
<td>1</td>
<td>Identify reversible reactions that could be used for recovering EGS thermal energy.</td>
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<tr>
<td>2</td>
<td>Conduct thermodynamic and process engineering simulation/analysis of the leading candidates to identify bottlenecks and evaluate design modifications and R&amp;D needs for the application of CEC systems to EGS reservoirs available in the United States.</td>
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<td>3</td>
<td>Determine thermodynamic targets for improvements in catalyst performance or development of new catalysts and associated process design.</td>
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<td>4</td>
<td>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</td>
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<td>5</td>
<td>Develop, design, and analyze (chemistry, engineering, economics) CEC systems to match EGS temperatures, pressures, chemistry, and mineralogy with reversible reactions</td>
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<tr>
<td>6</td>
<td>Develop a plan for field testing the leading candidate(s).</td>
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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
• 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”
Example: A CEC system involving methanol (CH$_3$OH) and an EGS at 500 °C

- Forward endothermic reaction
  \[ \text{CH}_3\text{OH} + \text{EGS Heat (450-500 °C)} \rightarrow \text{CO} + 2\text{H}_2 \]

- Reverse exothermic reaction (above ground)
  \[ \text{CO} + 2\text{H}_2 (300 °C \text{ with catalysts}) \rightarrow \text{CH}_3\text{OH} + \text{Heat @ 300 °C} \]

- These processes are practiced commercially and can be adopted to EGS applications
• Methanol can thermally decompose:

\[ CH_3OH \rightarrow CO + 2H_2 \quad \Delta H_r = 128,130 \text{ KJ/Kmol} \]

Or: \[ CH_3OH \rightarrow CH_2O + H_2 \quad \Delta H_r = 92,095 \text{ KJ/Kmol} \]

• Methanol can also react with water:

\[ CH_3OH + H_2O \rightarrow CO + 3H_2 \quad \Delta H_r = 86,960 \text{ KJ/Kmol} \]

*First reaction captures more EGS heat*

• Heat Captured from EGS by the first reaction

Sensible Heat Gain \( = 28,117 \text{ KJ/Kmol CH}_3\text{OH} \)

Chemical Heat Gain \( = 128,130 \text{ KJ/Kmol CH}_3\text{OH} \)

Total Heat Gain \( = 156,247 \text{ KJ/Kmol CH}_3\text{OH} \)

**OR** \( 4883 \text{ KJ/Kg of methanol} \)
Reforming of Methane Captures More Thermal Energy

- Reforming of methane:
  \[ \text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3 \text{H}_2 \]
  \[ \Delta H_r = 128,130 \text{ KJ/Kmol} \]

- Requires high temperatures and catalysts

- H\(_2\) separation and/or increasing H\(_2\)O/CH\(_4\) ration can speed up the reaction rate

- Different CEC systems can be used for different EGS reservoirs
• 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

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

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<tr>
<th>Task</th>
<th>Plan</th>
<th>Actual</th>
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<td>Oct-09</td>
<td>$18,408</td>
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<tr>
<td>Nov-09</td>
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<td>Dec-09</td>
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<td>Jan-10</td>
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<td>Feb-10</td>
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<td>Mar-10</td>
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<tr>
<td>Totals</td>
<td>$217,458</td>
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<tr>
<td>Variance</td>
<td>4.3%</td>
<td>-</td>
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- 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
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
➢ **Go/no-go** decision September 2011
➢ **Milestone M2**- Complete laboratory tests of CEC/catalyst systems March/2012

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
The following paper is being prepared for publication