Concept Testing and Development at the Raft River Geothermal Field, Idaho

Project Officer:  W. Vandermeer
Total Project Funding:  $10,214,987
April  22, 2013

Principal Investigators:  
J. Moore and J. McLennan
Organization:  University of Utah
Track Name:  EGS Demonstration Projects

This presentation does not contain any proprietary confidential, or otherwise restricted information.
1. Develop and demonstrate techniques required to form and sustain EGS reservoirs by combining thermal and hydraulic stimulations.

2. Improve performance and output of Raft River geothermal field by increasing production or injectivity.

3. Objectives directly address the following barriers and DOE goals:

   - Demonstrate 5 MW reservoir creation by 2020
   - Lower LCOE to 6 cents by 2030
   - Improve methods reservoir characterization
   - Demonstrate flow rates of at least 20 kg/s
   - Demonstrate interwell connectivity
   - Develop long-term reservoir sustainability
   - Predict seismic activity

   - Operational in January 2008
   - Maximum resource T ~150 C
   - Produces ~10.5-11.5
   - 4 Production Wells; 3 Injection Wells
   - Production: ~ 5,000 gpm (individual wells produce 850-2,200 gpm)
   - 433 gpm per MWe
Accomplishments, Results and Progress

- Completed all Phase 1 activities
  - Successfully completed well RRG-9 ST1 for stimulation
  - Developed a geologic model
  - Prepared a stimulation plan based on the results of step-rate testing and the geologic model
- Stimulation program (Phase 2) approved
- Drilling of 4 seismic monitoring wells to commence shortly

Planned milestones were accomplished. There were no variances from proposed program since last review.

<table>
<thead>
<tr>
<th>Original Planned Milestone/Technical Accomplishment</th>
<th>Actual Milestone/Technical Accomplishment</th>
<th>Date Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete pre-stimulation activities</td>
<td>Phase 1 activities completed</td>
<td>10/2013</td>
</tr>
<tr>
<td>Prepare Phase 1 report for Go/No-Go approval</td>
<td>Phase 2 and stimulation plan Approved</td>
<td>1/24/2013</td>
</tr>
</tbody>
</table>
Scientific/Technical Approach

Developing an EGS Reservoir

Success requires adequate flow rates and thermal stability

1) Understanding resource’s geologic setting:
   ✓ Petrologic analyses of well cuttings and cores
   ✓ Water geochemistry
   ✓ Geophysical log analysis
   ✓ Field data (MT, gravity, seismic, geochemistry)
   ✓ Rock mechanics testing

2) Understanding reservoir properties
   ✓ Borehole televiewer imaging and logging
   ✓ Injection testing
   ✓ Seismic monitoring
   ✓ Hydraulic fracture modeling
   ✓ Infer production potential

3) Phase 2: Go/No Go Review
   ✓ Develop stimulation program
     **Stimulate well**

4) Monitor stimulation metrics – pressure, temperature, microseismicity, and well interference.

All checked activities have been completed

Televiwer survey provided by SNL
The Geologic Setting
Geologic Setting: Petrologic Studies

**Plan view**

**Elba Quartzite**

**Quartz Monzonite**
Geologic Setting: Water Geochemistry

![Graphs and diagrams showing geologic settings and water geochemistry.](image-url)
Geophysical Studies
Reservoir Properties: Borehole Televiewer Imaging

- 86 fractures between 5,525 to 5,920 ft
- 75% of fractures trend from N30W to N30E
- Major fracture zone at 5645-5660 ft. Fractures dip NW (22-57 degrees) and strike N11 - 42E)
Reservoir Properties: Injection Testing

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>True Vertical Depth</td>
<td>5168 ft TVD</td>
</tr>
<tr>
<td>Fracture Gradient</td>
<td>0.59-0.62 psi/ft</td>
</tr>
<tr>
<td>Minimum in-situ principal stress</td>
<td>3050-3200 psi</td>
</tr>
<tr>
<td>Reservoir Pressure</td>
<td>2938 psi</td>
</tr>
<tr>
<td>Permeability</td>
<td>0.03 md</td>
</tr>
</tbody>
</table>

Injection parameters:
- rates of 11 to 756 gpm,
- maximum wellhead pressure ~1,150 psi,
- total injected volume 81,648 gal
Reservoir Properties: Distributed Temperature Sensor Survey

Courtesy B. Freifeld, LBL

March 15
Reservoir Properties: Seismic Monitoring

- All local events 8/10 to 3/13
- 57 events
- Moment Mag 0.0 to 1.5

- Events during Injection 2/24 – 25/12
- Moment Mag 0.2 to 0.5

Courtesy E. Majer, LBL
Future Directions

Phase 2 Milestones
- Drill seismic monitoring wells (4/2013)
- Conduct thermal and hydraulic stimulation (4-9/2013)

Phase 2 Activities
- Numerical modeling – reservoir volume, area, temperatures, fracture characteristics, stresses (M. Plummer, H. Huang, R. Podgorney, INL)
- Monitor seismicity (E. Majer, LBL)
- Monitor temperatures – Stages 1, 2 (B. Freifeld, LBL)
- Noble gas concentrations (B.M. Kennedy, LBL)
- Televiewer surveys – pre/post Stage 3 (D. King, SNL)
- Tracer studies – Stage 3 (P. Rose, EGI)
- Monitor electrical resistivities – Stage 3 (G. Newman, LBL)
- Prepare Phase 2 report

Phase 3: Long-term monitoring (9/2013)
- Tracer concentrations, temperatures (RRG-9 ST1); pressures (RRG-9 ST1 and production wells); seismicity, production rates
Thermal Stimulation Modeling of a Single Fault Zone

- Evaluation of thermal stimulation stage 1 in RRG-09
- Preliminary model results, 90 day injection
- Suggest thermal stimulation may significantly increase permeability
THM Stimulation of Multiple Fault/Fracture Zones

- Use FracMan fracture distributions
- Map into FALCON via automatic mesh refinement
- Simulate pressure and thermal stimulation at the reservoir scale

Automatic mesh refinement-FracMan fractures in FALCON code
Temperature profiles over time in fracture network
### Previous Stimulations

<table>
<thead>
<tr>
<th>RRGP-4</th>
<th>RRGP-5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4-Stage Kiel Frac 8/20/1979</strong></td>
<td><strong>Conventional (Planar) Frac 11/12/1979</strong></td>
</tr>
<tr>
<td>Frac Fluid</td>
<td></td>
</tr>
<tr>
<td>7,900 bbl (331,800 gal)</td>
<td>7,600 bbl (319,200 gal)</td>
</tr>
<tr>
<td>10 lb H.P. Guar/1,000 gal</td>
<td>30 lb H.P. Guar/1,000 gal</td>
</tr>
<tr>
<td>2 lb XC Polymer/1,000 gal</td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td></td>
</tr>
<tr>
<td>50,400 lb 100 mesh</td>
<td>84,000 lb 100 mesh</td>
</tr>
<tr>
<td>58,000 lb 20/40 mesh</td>
<td>347,000 lb 20/40 mesh</td>
</tr>
<tr>
<td>Rate</td>
<td></td>
</tr>
<tr>
<td>50 bpm (1862 gpm)</td>
<td>50 bpm (1862 gpm)</td>
</tr>
<tr>
<td>Interval</td>
<td></td>
</tr>
<tr>
<td>4,705-4,900 ft (195 ft)</td>
<td>4,587-4,803 ft (216 ft)</td>
</tr>
<tr>
<td>Frac Height</td>
<td></td>
</tr>
<tr>
<td>195 ft</td>
<td>135 ft</td>
</tr>
<tr>
<td>Orientation</td>
<td></td>
</tr>
<tr>
<td>N72°E</td>
<td>N29°E</td>
</tr>
</tbody>
</table>
The Stimulation Plan

Microseismic Network
- Drill monitoring wells to 300 ft
- Install geophones
- Install ground motion sensors

Connect Pipeline to Plant Injection Pump
- 5000 gpm of injectate at 140 F available

Initiate Phase 1 Stimulation
- Inject 140 F injectate at 210 gpm and 300 psi
- Inject for min. 30 and max. 60 days
  *(300 psi = max pipeline pressure, 210 gpm based on step rate test done in Phase 1)

Continue until:
- Well is on vacuum - increase rate if capacity is available
- Pressure increases to more than ~300 psig - decrease injection rate to pressure <300 psig
- The Injectivity Index stable for 7 days and no change in Hall plot

Seismic Activity
- Seismic activity or ground motion > 1/2 allowable limit
- Evaluate seismic risk

Seismic risk exceeds allowable limits
- STOP

Run Acoustic Televiewer

Run Acoustic Televiewer

Initiate Phase 2 Stimulation
- Inject 50F blow down at 210 gpm and 300 psi
- Inject for min. 30 and max. 60 days
  *(300 psi = max pipeline pressure, 210 gpm based on step rate test done in Phase 1)

Connect Pipeline to Cooling Tower

Conduct Falloff Test
- Pump for 1 day
- Monitor pressure decay
The Stimulation Plan

Initiate Phase 3
Conduct High Rate Large Volume Hydraulic Fracturing

Inject 1,000,000 gal injectate at 2100 gpm

Wellhead pressure = 2/3 allowable limit - reduce rate to <80%
Ground and microseismic activity = allowable limit
→ stop pumping, reinitiate injection at 75%

Ground and microseismic activity exceeds allowable limit

Long term Monitoring

Garcia and Nagel, Itasca

STOP
• RRG-9 ST-1 was successfully completed to a total depth of 5,932 ft
• Step Rate testing yielded a fracture gradient of 0.59 to 0.62 psi/ft
• 86 natural fractures trending N20W to N20E were identified in the open hole section; fractures at ~5660 ft are permeable

• A three stage stimulation plan will be implemented at RRG-9 ST-1
  • Phase I: 140° F Water
  • Phase II: 55° F Water
  • Phase III: Hydraulic
Principal Investigator: Dr. Joseph Moore (EGI)
- Oversees work and coordinates communication and reporting activities among team members, DOE Project Managers and Technical Monitoring Team; assumes overall responsibility for budget; Managers and their

Leveraging of funds
- U. of Utah (cost share for students); U.S. Geothermal (access to field and cost share); Geothermal Resources Group; APEX-HiPoint
- DOE provides support for field activities by LBL and Sandia National Laboratories

Coordination and integration with other projects
- Several of the team members are also part of other demonstration teams and DOE projects
- The DOE Technical Monitoring Team provides contact information and links to reports