Technology Development and Field Trials of EGS Drilling Systems
April 22-25, 2013

This presentation does not contain any proprietary confidential, or otherwise restricted information.

David W. Raymond, PI
Steven D. Knudsen, Co-PI
Sandia National Laboratories
ARRA Funded R&D
Relevance/Impact of Research

• Objective
  – Develop fit-for-purpose EGS drilling solutions for geothermal exploration and production drilling
    • Hard/abrasive/fractured rock, high temperature, deep drilling

• Purpose
  – Improved drilling technologies that reduce costs by drilling faster with improved life, capabilities for improved hard stringer penetration, and are appropriate for deep drilling applications
  – Improved support for economic development of geothermal resources
    • Increase in the number of tools / options available for geothermal well construction
    • Service companies engaged in geothermal drilling market
    • Broad experience base to promote continued geothermal well construction
Relevance/Impact of Research (continued)

• Challenges/Barriers addressed on this project
  – Risk Reduction
  – Limitations of Laboratory Testing
  – Service Company Investment
  – Drilling Industry Acceptance

• Impact/Performance
  – Potentially reduce geothermal drilling costs via improved ROP & increased bit life
    • Nominal baseline is sealed roller cone performance in hard abrasive rock
      (low ROP: 10-20 ft/hr, short life: 40 hrs)
    • PDC Bits drill proportionally faster
  – Derive benefit from O&G/Minerals research in comparable domains
  – Catalyze industry via improved / economical deep hole access

• Innovation
  – Provides pathway for introduction of advanced technology with service company support
Scientific/Technical Approach

Overall Approach

Three Phases over Three Years (ARRA-funded for two of three years)

• Phase 1 - Preliminary field trials to demonstrate potential & highlight deficiencies (Yr 1: ARRA-funded)
• Phase 2 - Service company involvement in performance remediation and custom development (Yr 2: ARRA-funded)
• Secondary/Follow-Up field trials for verification & validation (Yr 3: Non-ARRA funded)
  – Demonstrate technology readiness for geothermal drilling
  – Verify design improvements realized in year two

Highlights

– Direct partnership with geothermal operators/developers
– Service companies directly involved in bit development & testing
Scientific/Technical Approach (continued)

Overall approach included the following elements:

- Technical Interchange Meetings with Team
- Develop well-defined drilling plans
- Pre-selection of fit-for-purpose bit solutions
- Data acquisition system development
  - Surface system integration
  - Downhole via service company tools
- Sandia-monitored field drilling deployment with on-going monitoring activities
- Direct involvement of service companies during tool specification and field testing
- Data reduction and analysis
- Post-mortems on bit conditions
- Next generation bit development and testing
Accomplishments, Results and Progress (continued)

Bit 1 Test Results

Bit 1 ROP Per Stand

Bit 1 stand average ROPs

Bit 1A: Pre-Drill

Bit 1A: Post-Drill After 726 ft.
Bit 2 Test Results

Bit 2 Test Results

Bit 2 ROP Per Stand

Depth (ft)

2200
2300
2400
2500
2600
2700

ROP (ft/hr)

10 15 20 25 30

Average ROP

Bit 2 stand average ROPs

Bit 2: Pre-Drill

Bit 2A: Pre-Drill

Bit 2: Post Drill after 566 ft.
Accomplishments, Results and Progress (continued)

Phase 2 bit is similar to bit 1
Phase 2 bit is denoted bit 3
First run in Sierra White showed minor cutter selection problem
Accomplishments, Results and Progress (continued)

E813M ROP - WOB

ROP (ft/hr) vs WOB (klbs) for different RPMs:
- 70-1
- 110-1
- 70-2
- 110-2
- 70-3
- 110-3
E813M TOB - WOB

The graph shows the relationship between Total Operating Burden (TOB) and Workover Burden (WOB) for different RPM values. The data is divided into three groups: 70-1, 110-1, 70-2, 110-2, 70-3, and 110-3. As the WOB increases, the TOB also increases, indicating a direct relationship between the two variables. The graph helps in understanding the performance and efficiency under different RPM conditions.
DEFINING TWO VARIABLES OF INTEREST

\[
\text{SPE} = \frac{2 \times \text{TOB} \times 60 \times \text{RPM}}{r^2 \times \text{ROP}} \quad \text{psi}
\]

\[
S = \frac{\text{WOB}}{r \times \text{DOC}} \quad \text{psi}
\]

WHERE:

- \( \text{TOB} \) = Torque On Bit
- \( \text{RPM} \) = Bit Revolutions Per Minute
- \( \text{ROP} \) = Rate Of Penetration
- \( \text{DOC} \) = Depth Of Cut
- \( r \) = Radius of the bit
Accomplishments, Results and Progress (continued)

Bit Comparison 70 RPM

SPE (Kpsi) vs. S (Kpsi)

Granite Line
Bit 1
Bit 3-1
Bit 3-2
Bit 3-3
Accomplishments, Results and Progress

- Major results from Phase 1 testing
  - 813 didn't have much impact damage
  - 713 had significant impact damage
  - Torque control components are key
  - Abrasion not an issue
  - Rig needs more torque capacity

- Major results from Phase 2 design effort
  - New bit designed building on success of earlier 813 bit
  - TCC type and setback optimized
  - Will result in 2 bits to test

<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>Phase 1 Field Test</td>
<td>Chocolate Mountain</td>
<td>Dec 2011</td>
</tr>
<tr>
<td>Phase 2 Bit Design</td>
<td>Successful Bit 2 Test</td>
<td>Nov 2012</td>
</tr>
</tbody>
</table>
• Rock Reduction Technology
  – Mature for conventional geothermal drilling
  – Present technology (roller cone bits) will inhibit commercially – viable development of EGS resources
  – PDC bits provide improvements that are necessary to access EGS resources
• PDC bits will prove benefit when coupled with capable rig
  – Backed by significant R&D
  – Drilling comparable rocks/depths
• Demonstration project has validated PDC technology for geothermal drilling
• Phase 2 bit follows in the footsteps of the successful phase 1 bit run at Chocolate Mountain drilling site
### Timeline:

<table>
<thead>
<tr>
<th></th>
<th>Planned Start Date</th>
<th>Planned End Date</th>
<th>Actual Start Date</th>
<th>Current End Date</th>
</tr>
</thead>
</table>

### Budget:

<table>
<thead>
<tr>
<th>Federal Share</th>
<th>Cost Share</th>
<th>Planned Expenses to Date</th>
<th>Actual Expenses to Date</th>
<th>Value of Work Completed to Date</th>
<th>Funding needed to Complete Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,336,565</td>
<td>$52,500</td>
<td>$1,297,203</td>
<td>$841,092*</td>
<td>$1,177,887</td>
<td>$80,000</td>
</tr>
</tbody>
</table>

- **Management**
  - No well of opportunity found for downhole hammer.
  - Considering purchase new hybrid bit and alternate diameter bits to test in Geothermal
  - Integrates well with Sandia’s overall effort to lower drilling cost
  - NOV Downhole heavily involved in phase 2
- Scheduling in NOV Downhole facility delayed phase 2 completion into FY-13