Project objective

• Global intent is to lower the cost of geothermal wells
  – No magic bullet to get to “3x faster rate of drilling than conventional rotary drilling”

• Development and adoption of new geothermal drilling technology is hampered by the sheer lack of development activity in comparison to other drilling sectors
  – Size of industry impacts adoption and qualification for numerous reasons

• Where possible - leverage what others have done
Project objective (cont.)

- Improve technology transfer to the geothermal drilling industry by surveying technologies and processes in comparable drilling industries
  - Oil & Gas obvious, but include mining, construction, …

- Includes investigation of processes as well as technology
  - Not just better “mouse traps”, look at the system

- Technologies and processes investigated must be successful in other industries
  - What can be adopted, with or without modification for geothermal conditions
Initial Efforts

- Survey interesting technologies
  - Water/mud hammers
  - Underreamers

- Status reviewed
  - Water/mud hammers could work, but likely too much development work needed to be applied to geothermal
  - Underreamers available and used in geothermal – more advanced fixed cutter devices subject to the same issues as PDC bits

- Low-level effort but path of looking for new “mouse-traps” unsatisfying.
Scientific/Technical Approach

Current Approach

• Industry partnership developed
  – Absolutely necessary

• Working in partnership with Ormat Technologies
  – Ormat is an active partner and funding their participation internally

• Engagement of academia and O&G industry
  – Bill Eustes, CSM (costs covered by Ormat)
  – Fred Dupriest, TAMU / ExxonMobil retired

• Group decides on project focus
Current Approach

• Active monitoring of drilling has been shown to have real impact in the O&G sector
  – e.g., ExxonMobil “Fast-Drill” / “Limiter Redesign”

• Directly applicable to the geothermal sector
  – Monitoring technologies available today without adaptation to geothermal conditions

• By monitoring drilling performance and understanding the data one can identify what is limiting improved production

• Monitoring of mechanical specific energy (MSE) was the foundation of the ExxonMobil “Fast-Drill” approach
Scientific/Technical Approach

MSE

\[ MSE = \left( \frac{F}{A} \right) + \left( \frac{2\pi}{A} \right) \left( \frac{NT}{u} \right) \text{in} \cdot \text{lb/in}^3 \]

Where

- \( F \) = weight-on-bit (WOB)
- \( A \) = area
- \( N \) = bit rotation rate (RPM)
- \( T \) = torque-on-bit (TOB)
- \( u \) = rate-of-penetration (ROP)

**MSE is a measure of the efficiency of the drilling process, basically:**

\[ MSE = \frac{\text{Input Energy}}{\text{ROP}} \]
“Fast-Drill” workflow: Identify, Redesign, Extend

- MSE monitoring is used to identify bit related dysfunctions
  - Balling
  - Vibrations
  - Bit Dulling
- Borehole Quality Initiative tries to address other non-bit related limiters
  - Borehole instability

Current Approach

• Ormat monitoring MSE at selected sites for background information

• Workshop / Training to include project participants scheduled from March 21-22. All available Ormat drilling personnel will attend.

• Sandia & Ormat together will work together to provide support to Ormat drilling personnel.
  – On-Site as necessary / but off-site engineering support as well

• “Limiters” will be identified and addressed.
Accomplishments, Results and Progress

- Two separate technologies were reviewed – results underwhelming
- Substantive portion of the project just now underway
- Biggest challenge is moving from a “mouse-trap” mentality to a more data driven, systems framework that focuses on improved knowledge and requires the participation, understanding, acceptance, and training of all stakeholders
- New approach on schedule

<table>
<thead>
<tr>
<th>Original Planned Milestone/ Technical Accomplishment</th>
<th>Actual Milestone/Technical Accomplishment</th>
<th>Date Completed</th>
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<tbody>
<tr>
<td>From Working Group</td>
<td>10/12</td>
<td>10/12</td>
</tr>
<tr>
<td>Identify Technologies/Processes for Investigation</td>
<td>11/12</td>
<td>10/12</td>
</tr>
<tr>
<td>Identify at least two candidates for field trials</td>
<td>4/13</td>
<td>Focusing on one presently (12/12) Second will depend on results</td>
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Future Directions

- Following the training session, Ormat has committed to implementation of MSE monitoring and use to help drive decisions in selected drilling operations.
- Leveraging activities associated with a separate project, advanced, fit-for-purpose PDC bits and/or other commercially available drilling assemblies will be deployed in concert with MSE efforts.
- Publish Results

<table>
<thead>
<tr>
<th>Milestone or Go/No-Go</th>
<th>Status &amp; Expected Completion Date</th>
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<tbody>
<tr>
<td>Plan and Perform Field Test</td>
<td>8/13, on schedule.</td>
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</table>
• If properly implemented, monitoring of MSE and making decisions on such can provide substantial benefits to geothermal drilling performance
• Improved technology remains needed, but improved knowledge is the low hanging fruit
• The engagement and active participation of Ormat is essential to this project
• Through participation of O&G expertise, the project is in a unique position to contribute to geothermal drilling improvements
Project Management

- Budget does not reflect resources dedicated by Ormat in this effort
- Expectation that resources from advanced bit demonstrations will leveraged to support this effort (MSE monitoring with state-of-the-art bit designs)
- Budget does not reflect out-year costs if project is continued past FY13

### Timeline:

<table>
<thead>
<tr>
<th>Planned Start Date</th>
<th>Planned End Date</th>
<th>Actual Start Date</th>
<th>Actual /Est. End Date</th>
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### Budget:

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<th>Cost Share</th>
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<th>Actual Expenses to Date</th>
<th>Value of Work Completed to Date</th>
<th>Funding needed to Complete Work</th>
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