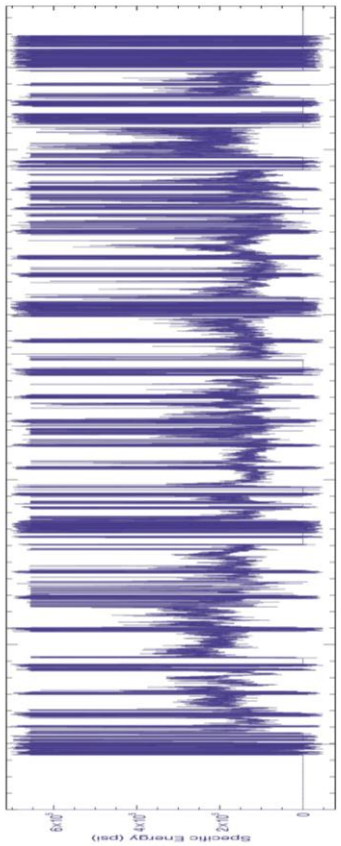

Evaluation of Emerging Technology for Geothermal Drilling and Logging Applications

Project Officer: Lauren Boyd

Total Project Funding: $225K

April 24, 2013

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

Georgia Bettin / Doug Blankenship

Presenter: Doug Blankenship

Sandia National Laboratories

Drilling Systems

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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

Relevance/Impact of Research

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

Scientific/Technical Approach

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

Scientific/Technical Approach

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

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

Where

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

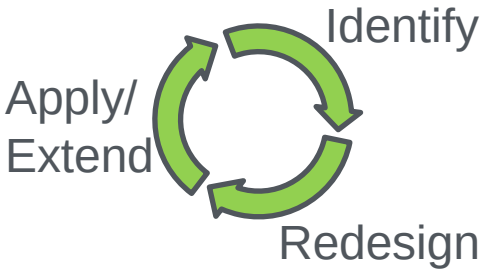
MSE is a measure of the efficiency of the drilling process, basically:

MSE = Input Energy / ROP

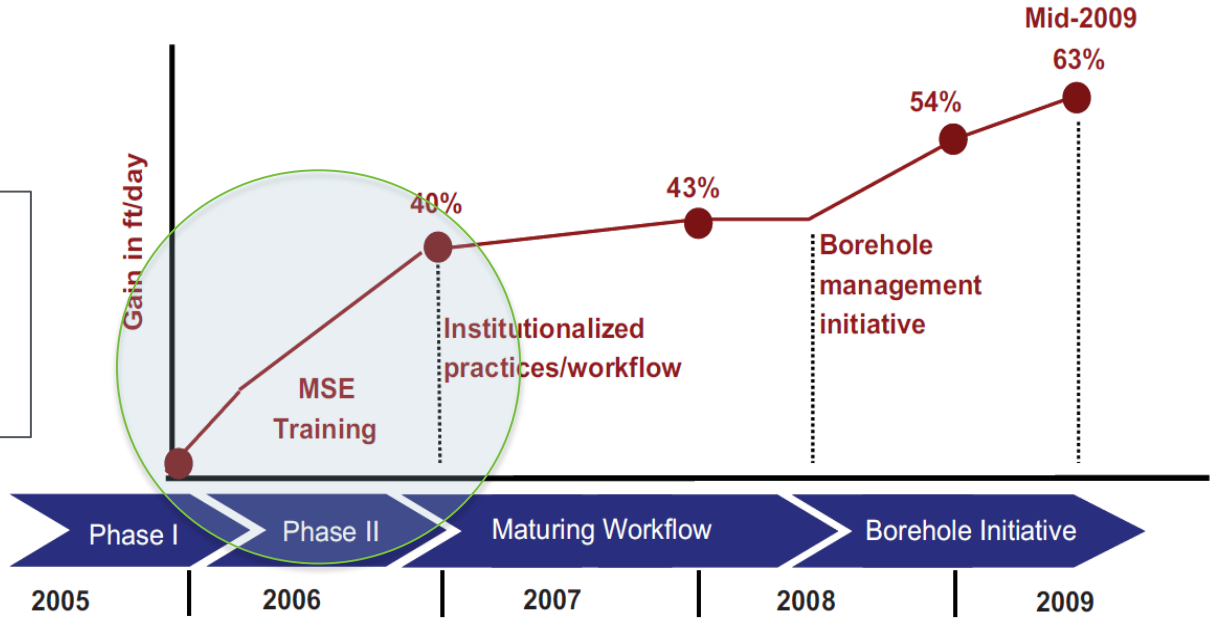
Scientific/Technical Approach

"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



Dupriest F., et al., *Borehole-quality design and drilling practices to maximize drill-rate performance*, in *SPE Annual Technical Conference and Exhibition* 2011: Florence, Italy.



Scientific/Technical Approach

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

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
From Working Group	10/12	10/12
Identify Technologies/Processes for Investigation	11/12	10/12
Identify at least two candidates for field trials	4/13	Focusing on one presently (12/12) Second will depend on results

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

Milestone or Go/No-Go	Status & Expected Completion Date
Plan and Perform Field Test	8/13, on schedule.

Mandatory Summary Slide

- 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

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 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:

Planned Start Date	Planned End Date	Actual Start Date	Actual /Est. End Date
10/1/2010	10/1/2014	3/1/2011	10/1/2014

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$225	$0	$125	$49	$56	$0