

A DECADE OF PROGRESS: A Forum on Advanced Drilling Technologies Summary Report

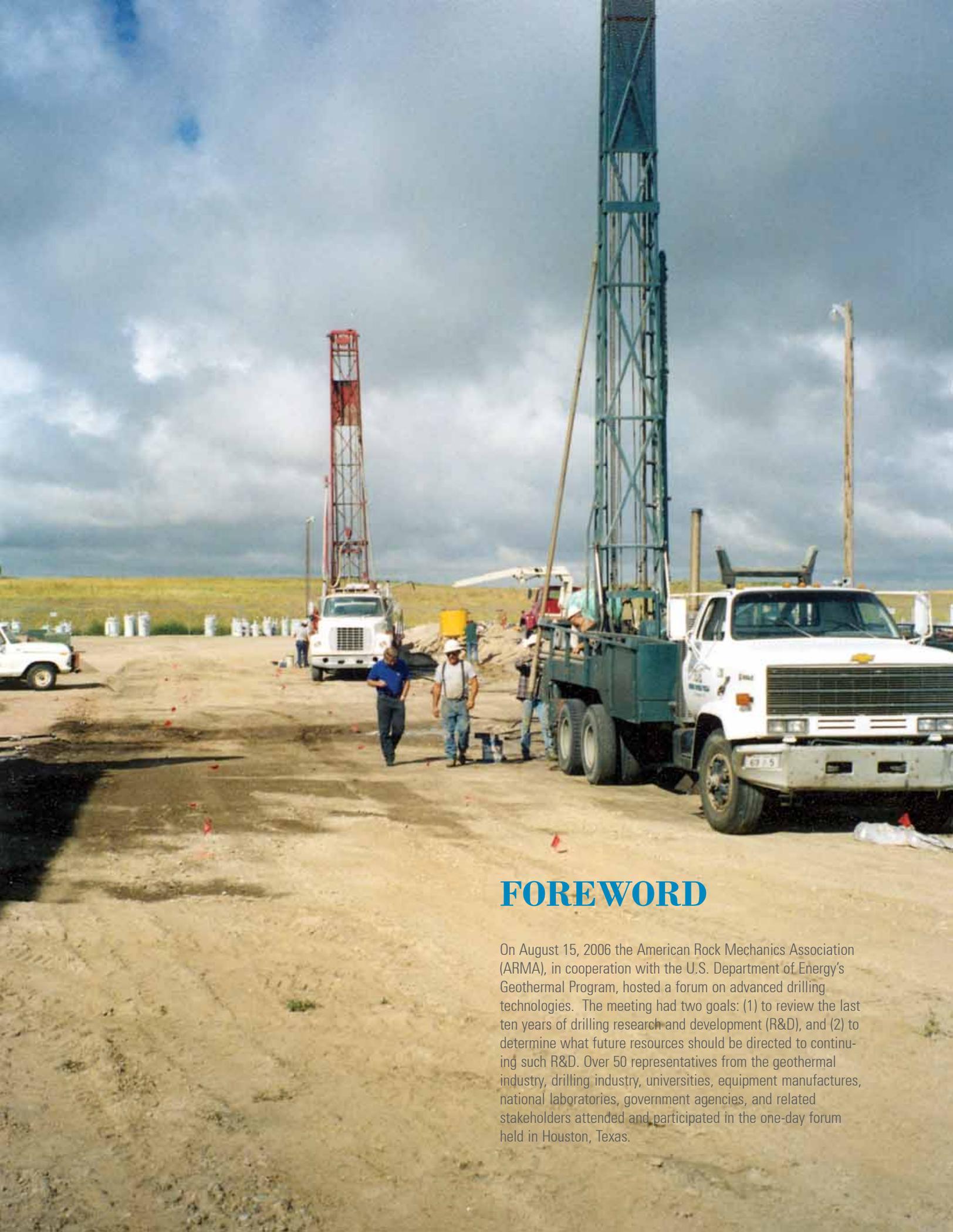
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FOREWORD

On August 15, 2006 the American Rock Mechanics Association (ARMA), in cooperation with the U.S. Department of Energy's Geothermal Program, hosted a forum on advanced drilling technologies. The meeting had two goals: (1) to review the last ten years of drilling research and development (R&D), and (2) to determine what future resources should be directed to continuing such R&D. Over 50 representatives from the geothermal industry, drilling industry, universities, equipment manufactures, national laboratories, government agencies, and related stakeholders attended and participated in the one-day forum held in Houston, Texas.



BACKGROUND

Drilling involves a set of processes for breaking and removing rock to produce boreholes, tunnels, and excavations. Drilling is used extensively for resource extraction, building civil infrastructure systems such as sewers and subways, environmental remediation, and scientific purposes. Efficient and effective drilling technologies are critical elements in a robust and healthy economy. Improvements in the fundamental technologies applicable to drilling rock will benefit the U.S. economy and strengthen the competitive position of the United States in the worldwide drilling, excavation, and comminution industries. The National Academy of Sciences, National Research Council, Committee on Advanced Drilling Technologies referred to the drilling industry as, "...a key technology in several applications of strategic or societal importance, including energy and mineral production, environmental protection, and infrastructure development."

In 1992 the National Academies of Sciences, National Research Council Committee on Advanced Drilling Technologies began its work on the study, *Drilling and Excavation Technologies for the Future*, at the request of the U.S. Department of Energy's Geothermal Program. The National Research Council is the operating arm of the National Academies of Sciences and Engineering. The purpose of the study was to examine opportunities for advances in drilling technologies that would have broad industrial, environmental, and scientific applications, such as energy exploration and production, mining, tunneling, water well drilling, underground storage, and environmental remediation.

The report was completed in 1994 and provides an examination of the technical and scientific feasibility of substantial advances in drilling and related technologies. It (1) examines concepts for

new mechanical and non-mechanical drilling applications, including advances in the knowledge of tool-rock interaction; (2) identifies potential opportunities for research; and (3) makes recommendations on the scope and direction of an R&D program needed to realize these opportunities for improved methods of drilling.

The study concluded that a national R&D program is needed to integrate industry, government, and academia in developing smart drilling systems. The committee defined a smart drilling system as,

"... one that is capable of sensing and adapting to conditions around and ahead of the drill bit to reach desired targets. This system may be guided from the surface, or it may be self-guided, utilizing a remote guidance system that modifies the trajectory of the drill when the parameters measured by the sensing system deviate from expectations."

To realize smart drilling systems, R&D is needed to develop:

- Precise connections between measurable physical and microstructural properties and local drilling resistance
- Sensors for the smart drilling system, capable of detecting and measuring the following:
 - conditions at the drill bit (e.g., pressure - including pore pressure, temperature, permeability, mineralogical and chemical composition of the rock, borehole fluid composition, stress state, and rock strength)
 - conditions ahead of the drill bit (e.g., porosity, elastic properties, and wave attenuation) in order to adjust drilling parameters such as weight on bit and rotary speed to avoid blow-outs or loss of circulation
 - spatial position of the bit in order to steer the bit to desired locations



- Control systems for accurate positioning and steering of the drill bit, and for automatically adjusting drilling parameters according to local conditions so as to optimize rock breakage and removal
- Improved methods for steering the drill bit and reducing the turning radius, such as down-hole motors, flexible drill strings, and guidance techniques
- Continuous monitoring systems for the entire drilling unit (e.g., wear of tools, flow of coolants)
- Improved telemetry for transmitting real-time borehole data to the surface; rates of kilobytes/second or higher are desirable
- Means of continuous and instantaneous support of the rock around the boreholes
- In addition to developing smart drilling systems, the committee also recommended incremental improvements in all aspects of drilling technologies. Key incremental improvements were:
 - Novel drilling technology that reduces the energy requirements for drilling (e.g., hybrid systems combining water jets and conventional rotary drilling)
 - Improved cutter materials and bearings (e.g., diamond-coated cutters)
 - Improved bits for drilling in heterogeneous materials involving (alternating soft and hard layers (e.g., bits with polycrystalline diamonds)
 - Environmentally benign drilling fluids (e.g., foams as alternate for oil-based fluids) that are capable of preventing fluid invasion, providing lubrication, and offering adequate hole-cleaning capability
 - Durable, high-power down-hole motors for directional extended-reach drilling

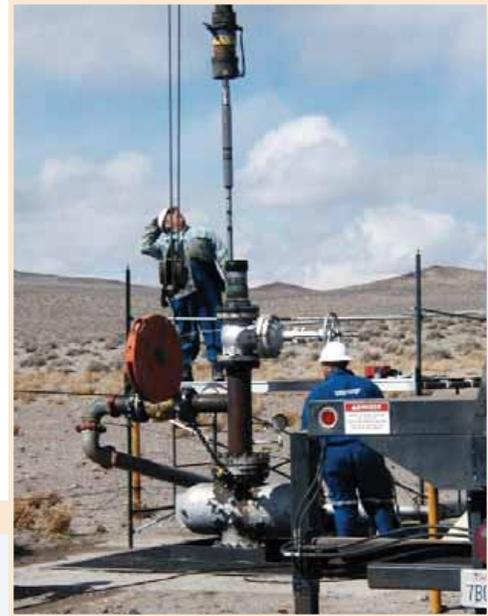
With this study in-hand, the U.S. Department of Energy formed its R&D strategy, which includes the following four focus areas:

- Diagnostics for drilling
- Drill-bit technology
- Cements and linings for drill holes
- High-temperature electronics for drilling

The workshop in Texas provided technical presentations for each R&D focus area from two DOE Laboratories: the National Energy Technology Laboratory and Sandia National Laboratories. After the technical presentations, participants engaged in a facilitated discussion to address the following question,

“What technical issues still remain to be addressed?”

This document reports on the results of the facilitated discussions for each technology focus area. The meeting was intended to determine what near-term actions are needed to facilitate early drilling R&D success. Although the assembled group discussed near-, mid-, and long-term issues, they were only asked to prioritize near-term issues. The group did, however, stress the need for continued research on mid- and long-term issues that addressed the need for a systems-integrated approach.



DIAGNOSTICS FOR DRILLING

A decade ago drill rigs were not designed for advanced drilling applications and did not come with diagnostic equipment. Retrofitting diagnostic systems was not possible because those systems were not designed to “plug and play”. Furthermore, most data processing and archiving systems at the time were proprietary and their details were not open information. The National Academy study discussed in the prior section highlighted the need for these advancements. However, at the time, new drill rigs were not being designed and built.

During the past decade work has been done by industry and national laboratories to address many of the needs highlighted by the Academy study. Next generation rigs are now being developed with automated, computerized, and integrated data management systems, and both high speed telemetry sensors and software are being developed to meet evolving drilling needs. Both the National Energy Technology Laboratory and the Sandia National Laboratories provided summary presentations on the research they have been conducting over the past decade. Exhibit 1 identifies the R&D projects which the National Laboratories presented at the workshop.

Exhibit 1. Decade-long Drilling Diagnostics R&D Conducted by the National Laboratories

National Energy Technology Laboratory:

- Very High-Speed Drill String Communications Network Intellipipe(TM) – *Novatek*
- Electromagnetic (EM) Telemetry Tool for Deep Well Drilling Applications – *E-Spectrum Technologies Inc.*
- Drilling Vibration Monitoring and Control System – *APS Technology*
- Drilling Optimization Utilizing Surface Instrumentation for Downhole Event Recognition – *Maurer Engineering, Inc.*
- An Innovative High-Temperature, High Pressure Measurement-While-Drilling (MWD) Tool – *Schlumberger*
- Real-Time Pore Pressure Prediction Ahead of the Bit Using a Suction Pulse Seismic Source – *Tempress Technologies*
- Development of a Low-Cost Rotary Steerable Drilling System – *Noble Wellbore Technologies*

Sandia National Laboratories:

- Diagnostics While Drilling



After each research presentation was made, the national laboratory offered recommendations for the next phase of drilling research needed. Laboratory recommendations resulting from this research are identified in Exhibit 2.

These recommendations for diagnostics drilling R&D by the national labs were considered by the workshop participants to assist in determining drilling diagnostic R&D needs for the future.

Exhibit 2. National Lab Recommendations for Next-Steps for Drilling Diagnostics R&D

- Develop Wired Drillpipe Add-ons
 - Fuller downhole tool set
 - Electromagnetic short hop over bottom-hole assembly (data while fishing, etc.),
 - Acoustic top end (data while tripping and making connection).
- Improve other Telemetry Schemes (mud pulse, EM, acoustic, wireline wet-connect)
- Improve well site data management protocol
 - Improved time based data protocols,
 - Improved binary data protocols
- Develop Plug and Replace Subsystems
 - Look ahead and resource location / evaluation
 - Drilling data mining
 - Full utilization of surface drilling data
 - Cheap/robust/no new personnel & extra cost smart drilling



Near-, Mid-, and Long-term Drilling Issues

Several near-, mid- and long-term drilling issues were identified during the group discussion, and are presented in Exhibits 3, 4, 5 and 6.

Exhibit 3. Near Term Drilling Issues

- Develop better bottom-hole assembly (BHA) and bit designs to account for vibration problems.
- Systems over time have been developed with incompatible components. Development should be continued with a systems-integrated approach to allow different components from different manufactures to interact (i.e., plug-and-play systems).
- Move away from normal decision making on collected data toward automated decisions.
- Develop inexpensive high-temperature electronics for mainstream applications greater than 190°C.
- Overcome commercialization barriers and increase industry utilization of new technology.
- Improve electromagnetic telemetry for deep well applications.
- Reduce cost for Diagnostics-while-Drilling (DWD) to promote technology transfer.
- Develop the ability to sense the effect that the drill hole has on the formation, such as lost circulation evolution well bore integrity evaluation.
- Develop limited draft gyroscopic controls for directional drilling.
- Reduce bit noise for seismic applications.

Exhibit 4. Near Mid-Term Drilling Issues

- Develop “look ahead” seismic tools with PDC bits.
- Compile a database of rock mechanics.
- Improve radar for imaging applications.
- Commercialize bandwidth technology.
- Reduce cost of emerging equipment.
- Develop performance metrics to monitor improvements based on industry data.

Exhibit 5. Mid-Term Drilling Issues

- Develop electromagnetic telemetry for offshore applications.
- Create gas/hydrocarbon identification and analysis tools.
- Develop diagnostics for identifying pore pressure and rock properties.
- Conduct further development of drilling system diagnostics need to focus on geology and targeting, drilling efficiency, HSE diagnostics, geometric/Pp, and optimized production.

Exhibit 6. Long-Term Drilling Issues

- Improve the ability to get data from downhole to surface - Intellipipe systems are good, but having more systems available may be of benefit in certain applications.
- Improve pore pressure measurement at or near the bit, in shales - need accurate readings, not estimates.
- Develop better robotics to improve systems.
- Continue to push envelope on deep, high pressure/high-temperature drilling.
- Improve downhole and surface automation of sensors and response by equipment to make automated decisions.



DRILL BIT TECHNOLOGY

A decade ago, drill bit technology could not meet the needs for smart drilling systems. Roller cone bit technology was mature but there remained seal and bearing issues. Synthetic diamond bit technology was young, bit producers were limited, and the influence of cutter parameters was not clearly understood. The industry was still looking for easy targets to drill. Bottom-hole telemetry was via measurement while drilling alone, and there were limited active control technologies available to modify downhole conditions.

The Academy identified four major R&D needs in the drill bit technology area:

- Better understanding of the physics between rock and tool interactions,
- Develop wear material for cutters and bearings,
- Develop novel-hybrid drilling technologies to incorporate new novel drilling technologies with conventional mechanical drill technologies for optimum drilling, and
- Continue improvement in mechanical drilling technologies.

Both the National Energy Technology Laboratory and the Sandia National Laboratories provided summary presentations on the research they have been conducting over the past decade. Exhibit 7 lists the titles of projects they discussed.

Exhibit 7. Decade-long Drill-Bit R&D Conducted by the National Laboratories

National Energy Technology Laboratory:

- New High Strength and Faster Drilling Thermally Stable Polycrystalline Diamond Cutters – *Technology International*
- Advanced Drilling Components – *The Pennsylvania State University*
- Laser Drilling – *GTI*
- Integrated Drilling System Using Mud Actuated Downhole Hammer as Primary Engine – *Novatek*
- Optimization of Mud Hammer Drilling Performance – *TerraTek*
- Improving Deep Drilling Performance Development and Benchmark Testing of Advanced Diamond Product Bits and High Pressure/High Temperature Fluids to Significantly Improve Rate of Penetration – *TerraTek*
- Feasibility of Ultra-High Speed Diamond Drilling – *TerraTek*
- Counter-Rotating Tandem Motor Drilling System – *GTI*
- Fundamental Research on Percussion Drilling – *Terralog Technologies, Inc.*
- NETL HPHT Ultra Deep Drilling Lab

Sandia National Laboratories:

- Drag Cutters in Hard-Rock
- Simulation of Drillstring Compliance
- Addressing Rock-Tool-System Interactions While Drilling in the Field
- Advanced Drilling Dynamics Simulator
- Physics of Rock-Tool Interactions - Technology Status
- Advanced Cutter Development
- Improved Bits
- Magnetorheological Fluid-Based Dampers for Drilling Heterogeneous Formations
- Passively-Pulsating, Cavitating Bit

After each research presentation was made, the national laboratory offered recommendations for the next phase of drilling research needed. Laboratory recommendations resulting from this research are identified in Exhibit 8.

Exhibit 8. National Lab Recommendations for Next-Steps for Drill-Bit R&D

- Develop advanced drilling dynamics simulator:
 - Platform for researching bit vibrations
 - Support development of advanced drill bit designs and materials
 - Test and evaluate downhole hardware
 - Evaluate best practices, and
 - Foster development of smart drilling systems.
- Address Integrated Bit- bottom-hole assembly –drill string selection.
- Continue work aimed at the development and validation of a new class of ultra-hard drag cutters.
- Field test & commercialize Magnetorheological Fluid-Damper for bottom-hole assembly stabilization.
- Continue development of unconventional methods of rock reduction.

Near-, Mid-, and Long-term Drilling Issues

Several near-, mid- and long-term drilling issues were identified during the group discussion, and are presented in Exhibits 9, 10, 11 and 12.

Exhibit 9. Near Term Drill-Bit Issues

- Collect and make available data on rock mechanics.
- View the drilling problem as a systems issue, not as an instrument component issue.
- Improve simultaneous drilling and under-reaming techniques – need work on cutters, vibration and other systems.
- Conduct field testing to provide data and information.
- Extend drilling modeling and testing to include cleaning and completion of factors.

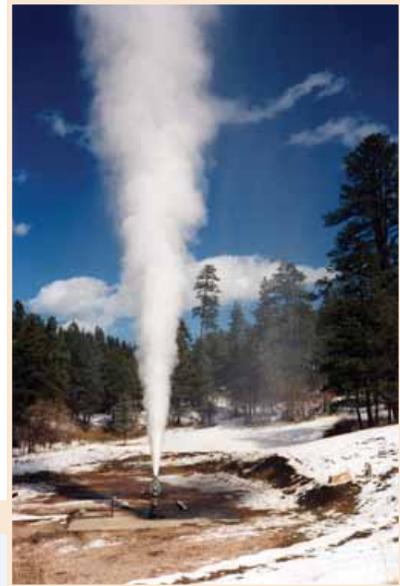


Exhibit 10. Near Mid-Term Drill-Bit Issues

- Capitalize on opportunity offered by smart drilling fluids to improve deep ROP even more than bit design changes can provide.
- Increase rate of penetration in hard rock.

Exhibit 11. Mid-Term Drill-Bit Issues

- Move from shallow to deeper drilling applications.
- Develop better understanding of the interaction between drilling fluid and rock breakage mechanism.
- Develop systems to cut the rock once at the bit then carry out material for further size reduction up hole.

Exhibit 12. Long-Term Drill-Bit Issues

- Do not abandon exploration of revolutionary drilling technologies. Keep looking for the new ideas.
- Address specific energy issues.
- Extend bit life.
- Address scarcity of available resources.
- Provide electrical energy at the bit via a full hard wired drill pipe.
- Instrument bit cutters individually to identify cutting structure loss – provide a strategic link with wire pipe.

CEMENTS/LINING FOR DRILLHOLES

Drill hole cements and linings continue to constitute a significant cost. Casings and linings must work in high temperature environments and operate without significant loss of circulation, and must be capable of dealing with crossflow issues and surviving corrosive environments.

Both the National Energy Technology Laboratory and the Sandia National Laboratories provided summary presentations on the research they have been conducting over the past decade. Exhibit 13 lists the titles of projects they discussed.

Exhibit 13. Decade-long Cements/Lining for Drillholes R&D Conducted by the National Laboratories

National Energy Technology Laboratory:

- Ultra-Lightweight Cement - *CSI Technologies*
- Supercement for Annular Seal and Long-term Integrity in Deep, Hot Wells – *CSI Technologies, Inc.*
- Novel Chemically Bonded Phosphate Ceramic Borehole Sealants for Arctic Environment – *University of Alaska*
- Development and Application of Insulated Drill Pipe for High-temperature, High-pressure Drilling – *Drill Cool Systems, Inc.*

Sandia National Laboratories:

- High Temperature Reactive Grout Systems
- Polyurethane Grout, Silicate Hydrate Grout
- Promotion of Flooded Dual-tube Reverse-circulation Drilling (DTRC)
- Promotion of Reverse-circulation and Tremmie Pipe Cementing
- Development and Commercialization of High-temperature Acid-Resistant Cements



After each research presentation was made, the national laboratory offered recommendations for the next phase of drilling research needed. Laboratory recommendations resulting from this research are identified in Exhibit 14.

Near-, Mid-, and Long-term Drilling Issues

Exhibit 14. National Lab Recommendations for Next-Steps for Cements/Lining for Drillholes R&D

- Provide real time monitoring:
 - Sensing well bore integrity conditions
 - Dealing with problems as encountered.
- Provide through-drill-string lost circulation mitigation.
- Develop spray-on borehole liners.
- Develop High Temperature acid-resistant cements
 - Continue reducing costs while improving material properties.

Several near-, mid- and long-term drilling issues were identified during the group discussion, and are presented in Exhibits 15, 16, and 17.

Exhibit 15. Near Term Drilling Issues

- Develop immediate cements.
- Account for impacts of existing technology, such as casing drilling.
- Adapt well-bore strengthening cements for sands/shales
 - Low viscosity fluids to prevent losses while circulating.
- Improve diagnostics to resolve issues such as cement loss.
- Improve cementing quality control
 - Water Quality
 - Additives
 - Temperature
 - Improved techniques.



Exhibit 16. Mid-Term Drilling Issues

- Address issues relating to the qualification of materials:
 - What are performance standards
 - Long-term performance
 - Diversity of downhole environment

Exhibit 17. Long-Term Drilling Issues

- Drillability of special cements needs to be specifically considered.
- Mitigate well bore integrity without tripping bit.



HIGH-TEMPERATURE ELECTRONICS FOR DRILLING

Much of today's geothermal resources that have been developed to date were relatively easy to access and exploit. New geothermal resources, however, are more difficult to access. One of the major obstacles to overcome is that geothermal resources now being targeted are at much higher temperatures than were those that were exploited a decade ago. This poses technical problems because much of the drilling equipment

available today is only rated for 83°C, and operating life requirements are poorly defined.

The National Energy Technology Laboratory provided a summary presentation on the research it has been conducting over the past decade. Exhibit 18 lists the titles of projects discussed.

Exhibit 18. Decade-long High-Temperature Electronics for Drilling R&D Conducted by the National Laboratories

National Energy Technology Laboratory:

- Development of SOI High Temperature Electronics - *Honeywell*
- MWD Using Silicon-On-Insulator (SOI) Electronics - *Sandia*
- Harsh Environment Solid-State Gamma Detector for Down-hole Gas and Oil Exploration – *GE Global Research*
- Development of a High-pressure/High-temperature Downhole Turbine Generator - *Dexter Magnetic Technologies, Inc.*
- Design of a 275°C Downhole Microcomputer System Integrated Circuit – *Oklahoma State University*
- FY06 Deep Trek Awards

No recommendations for next steps in research for High-Temperature Electronics for Drilling were presented by the national laboratories. Not to undermine its importance, participants for this workshop identified issues which need to be addressed in this technology focus area for the future.

Near-, Mid-, and Long-term Drilling Issues

Several near-, mid- and long-term drilling issues were identified during the group discussion, and are presented in Exhibits 19, 20, and 21.

Exhibit 19. Near Term Drilling Issues

- Develop electronic components (high temp) that have higher resolution (sensors).
- Improve wire systems
 - Technology transfer to other markets.
- Develop a standard platform
 - Compatibility with other (aerospace).
- Involve small businesses.
- Develop high-temperature electronics for pumps.
- Develop high-temperature electronics for dynamic-moving systems to go beyond volume tools.
- Improve high-temperature pumps.

Exhibit 20. Mid-Term Drilling Issues

- Lower the cost of high temperature electronics.

Exhibit 21. Long-Term Drilling Issues

- Make electronics/sensors smaller (MEMS).

RESULTS SUMMARY

The primary objective of the workshop was to determine what the near-term actions should be to facilitate early successes in improving geothermal drilling technology and techniques. Across all four areas of research, the following near-term activities were identified as top priorities.

The group acknowledged that the purpose of the meeting was to identify near-term activities. However, they did stress the need to continue long-term, forward looking research and development to advance drilling technologies in the future.



Exhibit 22. Priority Near-Term Activities for Drilling Technologies

Votes	Issue	Category
9	Data on rock mechanics must be collected and made available	Drill Bit Technology
8	Better bottomhole assembly (BHA) and bit designs are needed to account for vibration problems	Diagnostics for Drilling
8	The drilling problem needs to be viewed as a systems issue, not as an instrument component issue	Drill Bit Technology
8	Development of smart drilling fluids has an opportunity to improve deep rate of penetration even more than do bit design improvements	Drill Bit Technology
8	Electronic components (high temp) need to be developed that have higher resolution (sensors)	High-Temperature Electronics for Drilling
6	Drilling system component compatibility needs to be increased - development should be continued with a systems-integrated approach to allow different components from different manufactures to interact (i.e., plug-and-play systems)	Diagnostics for Drilling
6	Simultaneous drilling and under-reaming should be made possible - work is needed on cutters, vibration control, and other systems	Drill Bit Technology

The group was also asked to suggest any other research categories that should be considered advance drilling technologies. The suggested categories are:

- Microhole drilling to include electric drilling motors, cables, and wires;
- Small diameters bores to include electronics, power transfer, actuators, samplers, and operation in high-temperature and high-pressure environments;
- High-temperature/high-pressure evaluation and understanding of drilling needs/completion fluids;
- Integration of individual technologies into overall system packages, and;
- Fluids research to include completion, drilling fluids, fracture fluids, low- to high-temperature moves, next generation drill pipe, and geomechanics model development for drilling.

Appendix A: Workshop Agenda

A Decade of Progress: A Forum on Advanced Drilling Technologies		
7:30 - 8:00 AM	Continental Breakfast	
8:00 - 8:20 AM	Welcoming Remarks/Introductions	
		Mike Canty, U.S. Dept. of Energy
8:20 - 8:30 AM	Review of NAS Report "Drilling and Excavation Technologies for the Future"	
		Peter Smeallie, American Rock Mechanics Association
8:30 - 9:40 AM	Overview of Diagnostics for Drilling	
8:30 - 8:50 AM	National Energy Technology Laboratory	Roy Long
8:50 - 9:10 AM	Sandia National Laboratory	Chip Mansure
9:10 - 9:40 AM	Discussion: <i>What was achieved?</i> <i>What goals remain?</i> <i>What new goals need to be set?</i>	Facilitated
9:40 - 10:00 AM	Break	
10:00 - 11:10 AM	Overview of Drill Bit Technology	
10:00 - 10:20 AM	National Energy Technology Laboratory	Tim Grant
11:25 - 11:40 AM	Sandia National Laboratory	Steve Bauer
11:40 - 12:00 PM	Discussion: <i>What was achieved?</i> <i>What goals remain?</i> <i>What new goals need to be set?</i>	Facilitated
12:00 - 1:00 PM	Working Lunch	Facilitated

Appendix A: Workshop Agenda, *Cont.*

1:00 - 2:30 PM	Overview of High-Temperature Electronics for Drilling	
1:00 - 1:25 PM	National Energy Technology Laboratory	Tim Grant
1:25 - 1:50 PM	Sandia National Laboratory	Randy Normann
1:50 - 2:30 PM	Discussion: What was achieved? What goals remain? What new goals need to be set?	Facilitated
2:30 - 2:45 PM	Break	
2:45 - 3:45 PM	Technology Transfer and Next Steps	
	What other goals need to be set?	Facilitated
3:45 - 4:15 PM	Review of Day's Results	
		Facilitated
4:15 - 4:30	Closing Remarks	
		Mike Canty, U.S. Dept. of Energy Peter Smeallie, American Rock Mechanics Association
4:30	Adjourn	

Appendix B: Workshop Participants

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Appendix B: Workshop Participants, *Cont.*

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Enerpro, LLC

Ali Mese

Geomechanics Engineering Research

Francis C. Monastero, PhD

Naval Air Weapons Station

Mike Mooney

ConocoPhillips

Daniel Moos

GeoMechanics International, Inc.

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Randy Normann

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Kenneth D. Oglesby

Impact Technologies, LLC.

Lee Hong Ong

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Yarom Polsky

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Robert Radtke

Technology International, Inc.

David Raymond

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Peter Smeallie

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BCS, Incorporated

Veronika Vajdova, PhD

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