SAND2011-3248C

Technology Development and Field Trials of EGS Drilling Systems

June 6-10, 2011

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ARRA Funded R&D

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Overview

- Summary
  - Conventional geothermal drilling is hampered by challenges of hard/ abrasive/fractured rock, high temperatures and loss of circulated drilling fluids to the formation
  - Apply mature/proven rock penetration systems used in Oil &Gas/Minerals industry to improve geothermal drilling technology

- Timeline
  - Project start date: Oct 2010 (startup activities in preceding 6 months)
  - Project end date: Sept 2012 (for ARRA-funded activities)
  - Percent complete: 25%

- Budget
  - Total project funding: $1,414,065
  - DOE share: $1,336,565
  - awardee share (cost share amount): $77,500
  - total spent: 20%

Relevance/Impact of Research

- Objective
  - Development of 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)

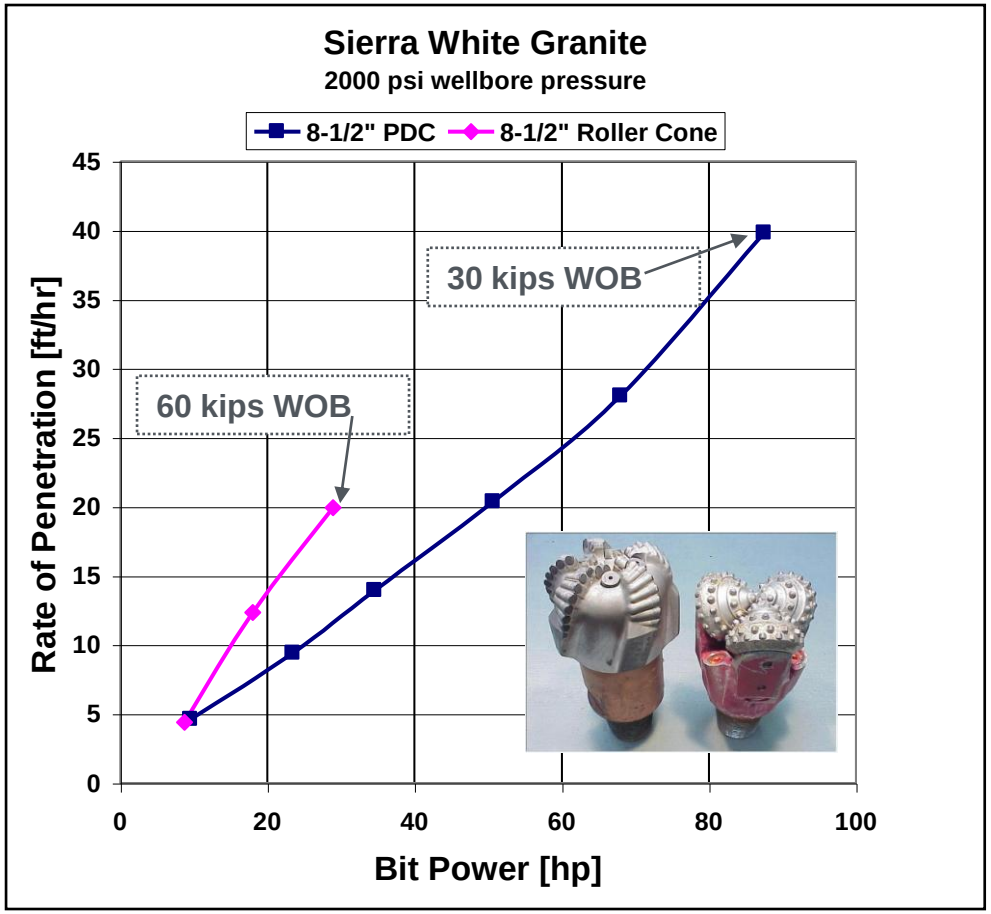
- Challenges/Barriers addressed on this project
  - Risk Reduction
  - Limitations of Laboratory Testing
  - Service Company Investment
  - Drilling Industry Acceptance
- Impact/Performance
  - Potentially reduce geothermal drilling costs via improved ROP & increased bit life
    - Nominal baseline is sealed roller cone performance in hard abrasive rock (low ROP: 10-20 ft/hr, short life: 40 hrs)
    - PDC Bits / Pneumatic Hammers drill proportionally faster
  - Derive benefit from O&G/Minerals research in comparable domains
  - Catalyze industry via improved / economical deep hole access

Scientific/Technical Approach

Fundamentally this will be accomplished by:

- Advanced Materials (synthetic diamond)
  - Increase rock/bit interfacial stress concentrations
  - Reduce abrasive wear mechanisms
- Energy Augmentation (percussive hammers)

Sandia percussive hammer test rig



Sandia data from laboratory testing in a 2000 psi wellbore

Scientific/Technical Approach (continued)

Overall Approach

Three Phases over Three Years (ARRA Funding for two years only)

- 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)
- Phase 3 - Secondary 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 development & testing

Scientific/Technical Approach (continued)

- Key Issues Currently Being Addressed
  - Formation Assessment
  - Well Profile & Drilling Plan
  - Test Plan Development
  - Review current product line offering for applicability and technology improvements
    - PDC Bit abrasion resistance / impact resistance
    - Percussive hammer high temperature operation
  - Field Drilling Testing Coordination
    - Data acquisition system development & integration
    - Daily drilling activities
    - Well logging

Scientific/Technical Approach (continued)

- Percussive Hammers / Key Issues
  - Potential temperature-sensitive components to be addressed
    - Valve
    - O-rings
    - Foot Valve
    - Check Valve

- PDC Bit / Key Issues
  - Thermally-Stable PDC Cutters
  - Cutting structure consistent with anticipated formation
  - Operating Conditions per Service Company recommendations
  - Down hole data collect for performance analysis & diagnostics

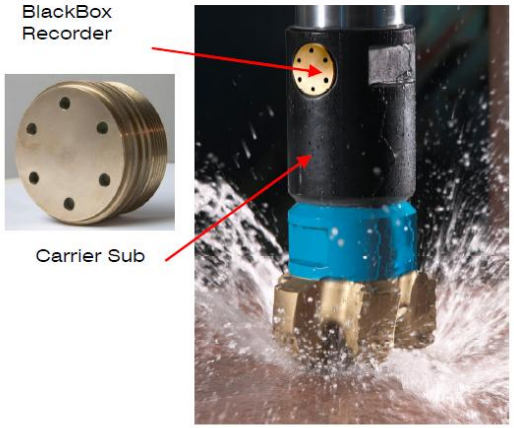
Accomplishments, Results and Progress

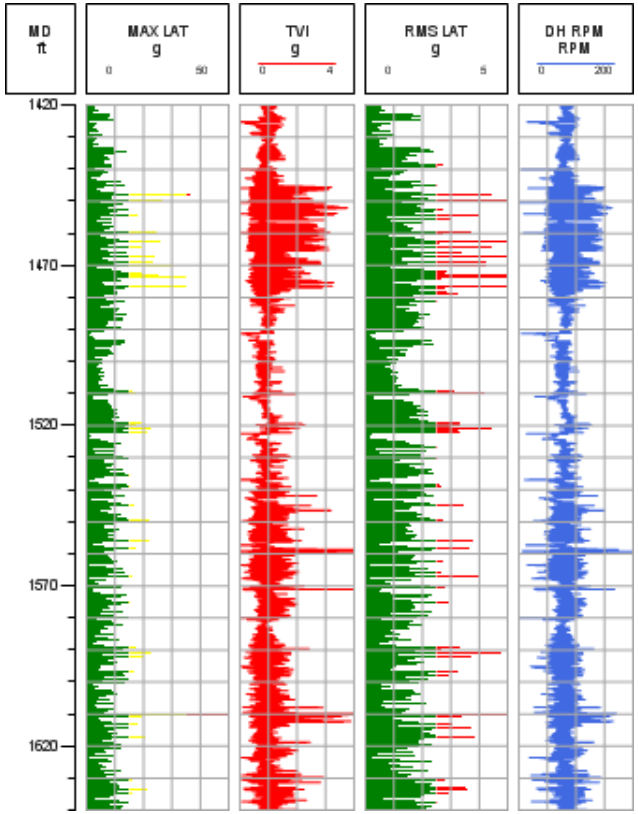
- Geothermal Developer/Drilling Company Identification
  - US Navy GPO has agreed to collaborate by providing wells of opportunity
  - MOU with Sandia/Navy (DOE/DOD) in place
  - Barbour Well, Inc.,
    - USN GPO drilling contractor
    - Will provide drill rig time, integration, and coordination with test plan

- Test Site/Well of Opportunity Identified
  - Chocolate Mountains Aerial Gunnery Range, CA
  - Two geophysical test holes planned
  - Investigate temperature field/hydrothermal alteration
  - Metamorphosed volcanic rocks anticipated

Accomplishments, Results and Progress (continued)

- Major service companies now under contract
  - NOV Reed Hycalog, PDC Bit manufacturer
  - Atlas Copco, Percussive hammer manufacturer
  - Cost share contracts
    - Will provide internal R&D to foster development of appropriate product line





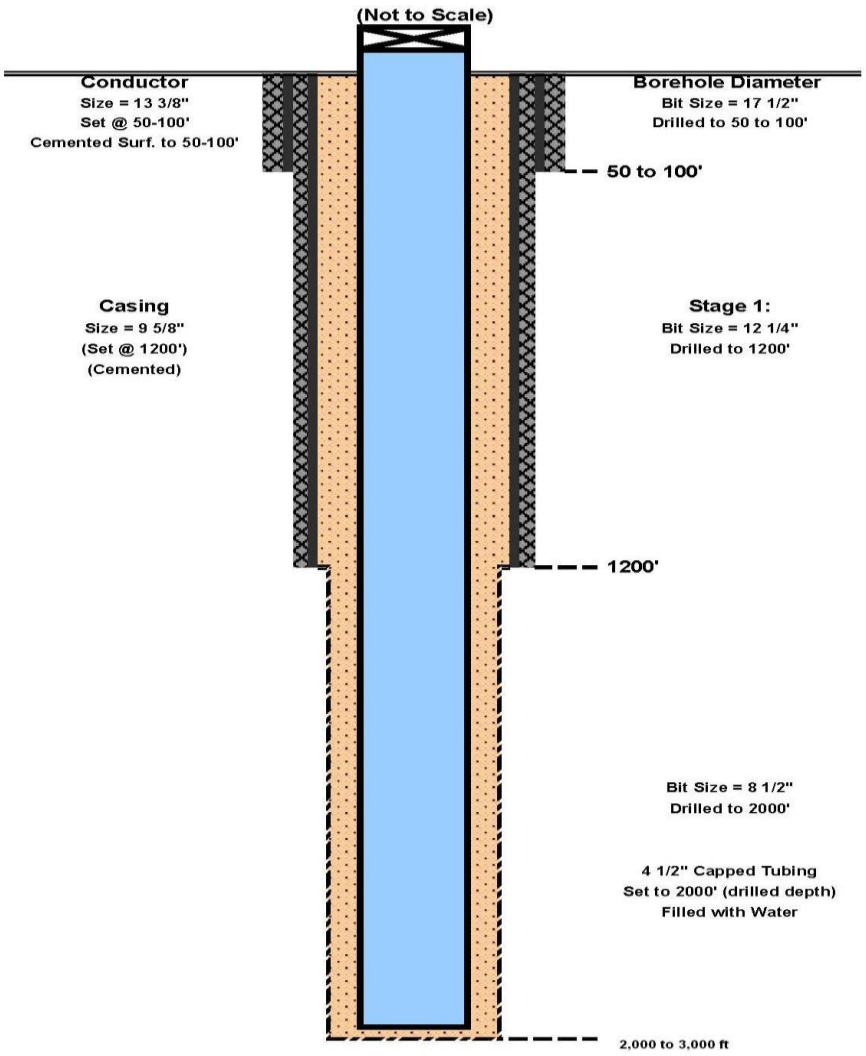
Down hole data collect for performance analysis & diagnostics

Representative Fixed Cutter Bit per NOV Reed Hycalog:
7 bladed, heavy set bit with aggressivity limiters

Accomplishments, Results and Progress (continued)

- Drilling Plan Coordination
  - Formation Assessment
  - Well Profile & Drilling Plan Developed
  - Test Plan Development underway
  - Service Company Product line under evaluation for down select

- Drilling Tests Pending
  - Scheduled for Summer 2011



Project Management/Coordination

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- Project on schedule (following re-scoping due to late start)
  - Work officially commenced in Sept 2010
  - Budget allocations proceeding per original plan
  - Schedule subject to integration with USN GPO drilling schedule

WBS	Task	Subtask	Description	FY11												FY12												FY13									
				2010			2011									2012												2013									
				10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
				O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Project Management	*1*	*1.1*	Report on First year results																																			
		1.2	Review Feasibility of Developing EGS Drilling Systems																																			
		1.3	Go/No-Go decision on year 2 funding																																			
		1.4	Report on Second year results																																			
		1.5	Review impact of enabling technologies																																			
		1.6	Go/No-Go decision on year 3 funding																																			
		1.7	Final Report																																			
Field Trials	*2*	*2.1*	Identify field test partner (USN GPO/Barbour)																																			
		2.2	Identify well of opportunity																																			
		2.3	Develop well plan (diameters, depths, formations, temperatures)																																			
		2.4	Develop surface measurement system																																			
		2.5	Conduct First Generation Field Trials of EGS Drilling Systems																																			
		2.6	Conduct Second Generation Field Trials of EGS Drilling Systems																																			
High-Temperature Pneumatic Hammer	*3*	*3.1*	Identify industry partner(s) (Atlas Copco)																																			
		3.2	Review designs																																			
		3.3	Modify designs as conceivable for first generation HT DTHH																																			
		3.4	Fabricate HT DTTH																																			
		3.5	Test in Sandia test rig																																			
		3.6	Correct design deficiencies																																			
		3.7	Review field trial test results																																			
		3.8	Develop enabling technologies (ht seals, material coatings)																																			
		3.9	Develop second generation HT DTHH																																			
System-Engineered PDC Bits	*4*	*4.1*	Identify industry partner(s) (Reed Hycalog)																																			
		4.2	Model Rig/Drillstring compliance																																			
		4.3	Specify BHA (bit cutting structure, damper, etc)																																			
		4.4	Fabricate EGS PDC Bits																																			
		4.5	Review field trial test results																																			
		4.6	Develop Enabling technologies (dampers, modeling, etc)																																			
		4.7	Develop system-engineered EGS PDC Bits																																			

Data Sharing

Generated data will include

- *Drilling performance data (ROP, Life) for various systems (PDC Bits, Hammers) in typical geothermal rock types (alluvial fill, metamorphosed volcanics, granitic basement rocks)*
- *Compatibility format for DOE Geothermal Data Repository being addressed*
- *A technical paper will be submitted to the Geothermal Resources Council (GRC) Transactions*

Collaborations

- Project Collaborators
  - Sandia National Laboratories
  - US Navy Geothermal Program Office (USN GPO)
  - Barbour Well, Inc.
  - Atlas Copco Secoroc
  - NOV Reed Hycalog

- ARRA Impact
  - Employment opportunities created at Sandia, Atlas Copco & Reed Hycalog thru project funding (equivalent of 3.5 - 4 FTEs) in FY11/FY12
  - Future jobs will result thru expanding geothermal market within drilling service companies

Future Directions

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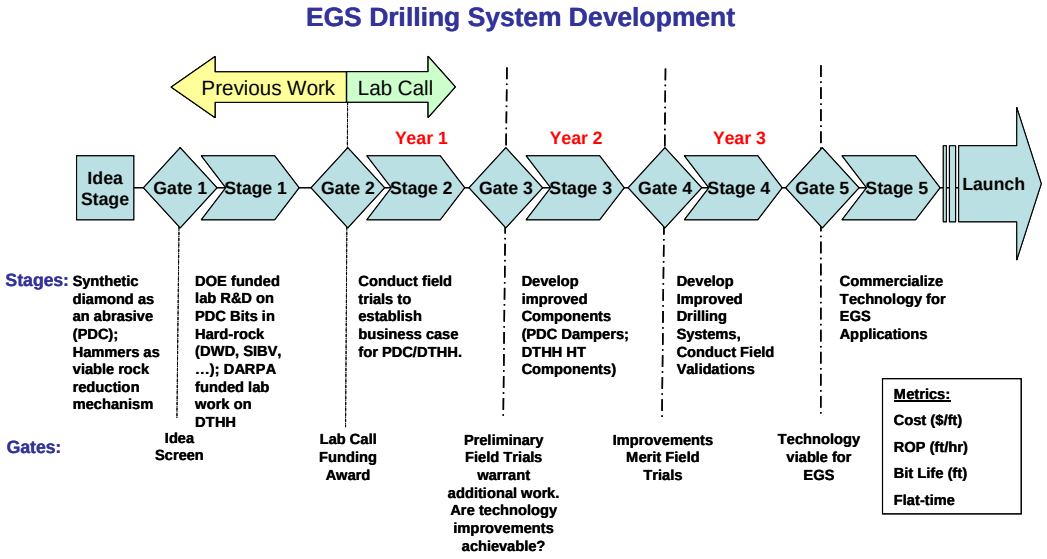
Deployment Strategy

- Facilitates involvement of service companies in future BHA specification, development, deployment & operation
- Ensures valid outcome in drilling technology development thru early involvement
- Project will follow Stage/Gate strategy illustrated

Future Research

- Key activities for FY11
  - Project team collaborations
  - Drilling tests
  - Data analysis
- To completion (FY12)
  - Collaborate with service companies
  - Verify improvements in test fixtures
- Field testing (Yr 3/FY13)



Mandatory Summary Slide

- Rock reduction technology
  - mature for conventional geothermal drilling
  - present technology will inhibit commercially – viable development of EGS resources
- Improvements are necessary to access EGS resources
- O & G/Mineral drilling systems will prove beneficial (PDC Bits, Percussive Hammers) for improved drilling
  - Backed by significant R&D
  - Drilling comparable rocks/depths
- Demonstration project with follow-on technology developments will validate technologies for geothermal drilling

	FY2011	FY2012
Target/Milestone	Complete Initial Field Trials	Implement Design Changes from Initial Field Trials
Results	Well of opportunity identified; service companies engaged; working towards deliverable	Work initiation pending completion of field trials