Technology Development and Field Trials of EGS Drilling Systems

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ARRA Funded R&D

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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

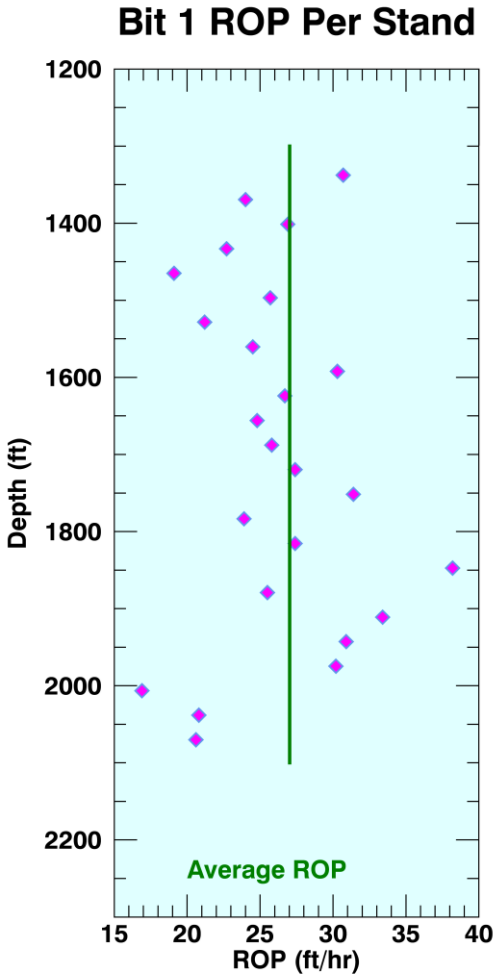
Scientific/Technical Approach (continued)

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 stand average ROPs

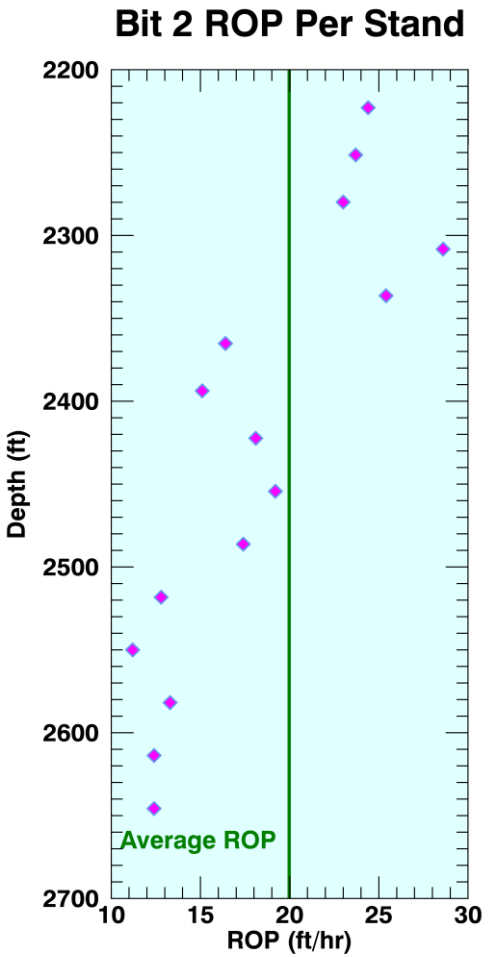
Bit 1A: Pre-Drill

Bit 1A: Post-Drill After 726 ft.

Accomplishments, Results and Progress (continued)

Bit 2 Test Results

Bit 2 stand average ROPs



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

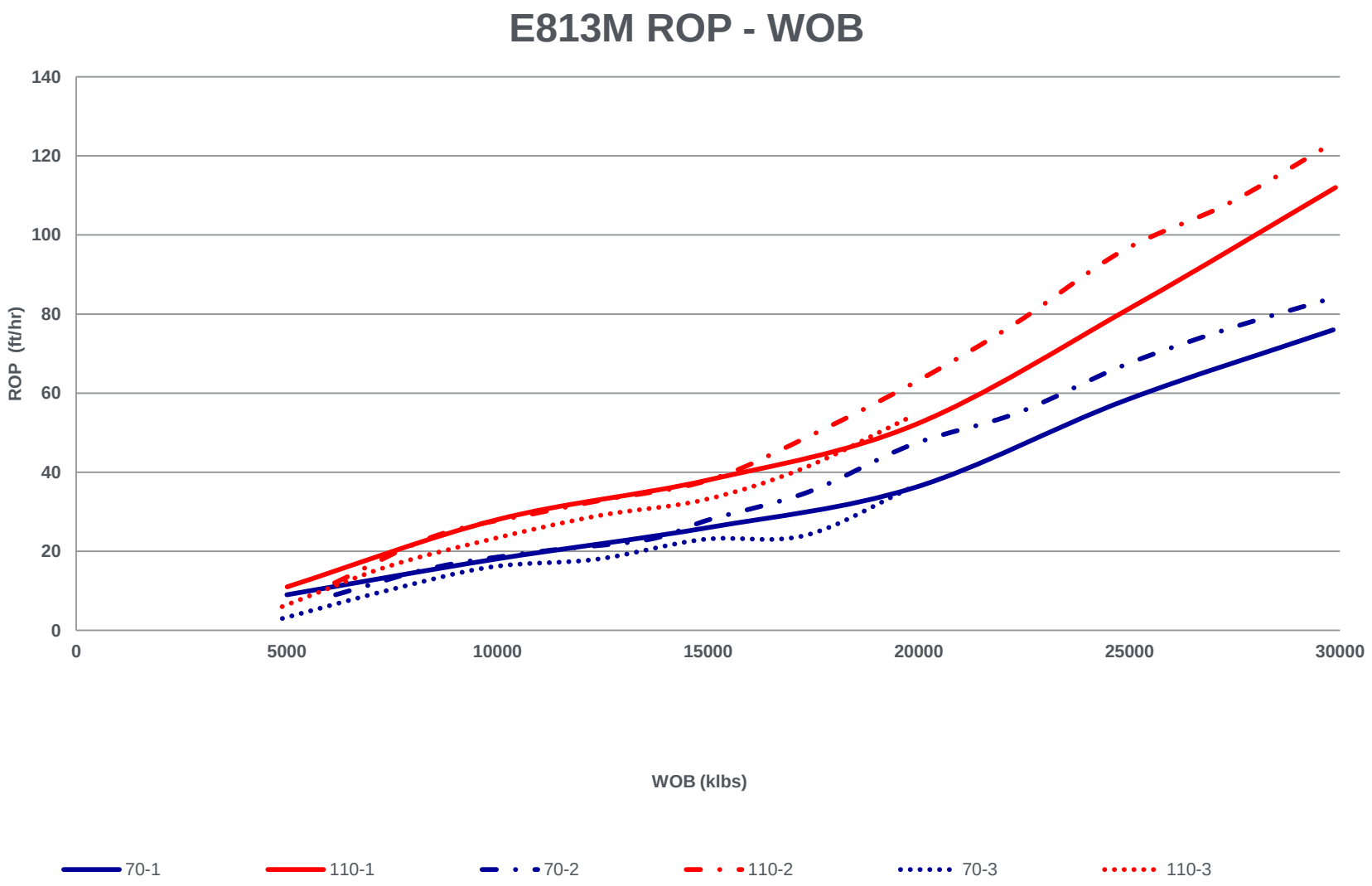
First run in Sierra White showed minor cutter selection problem

3 Bit Pre-drill

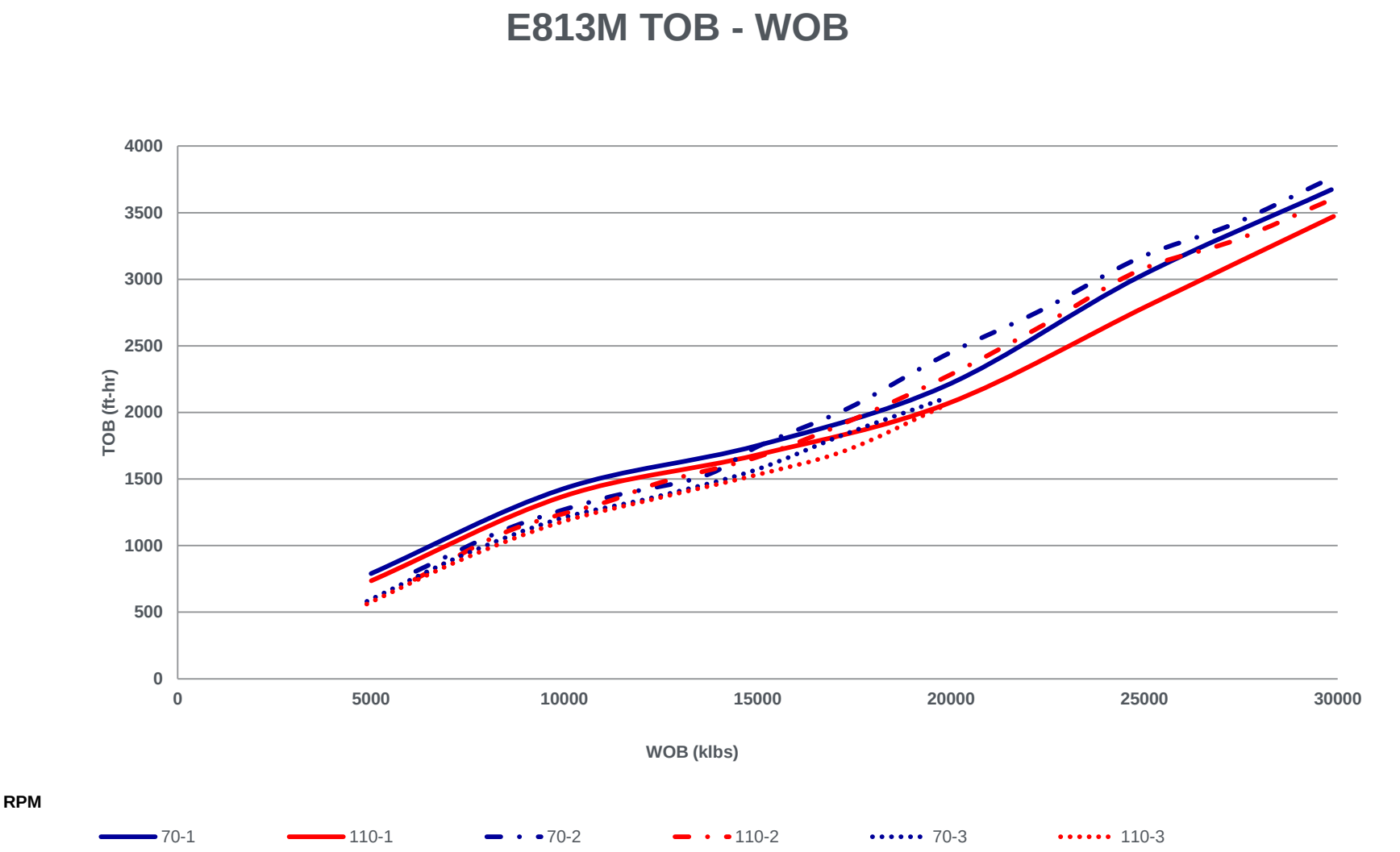
Bit 1: Pre-Drill Sharp Condition

Bit 3 Post drill

Accomplishments, Results and Progress (continued)



Accomplishments, Results and Progress (continued)



DEFINING TWO VARIABLES OF INTEREST

$$SPE = \frac{2 * TOB * 60 * RPM}{r^2 * ROP} \quad psi$$

$$S = \frac{WOB}{r * DOC} \quad psi$$

WHERE:

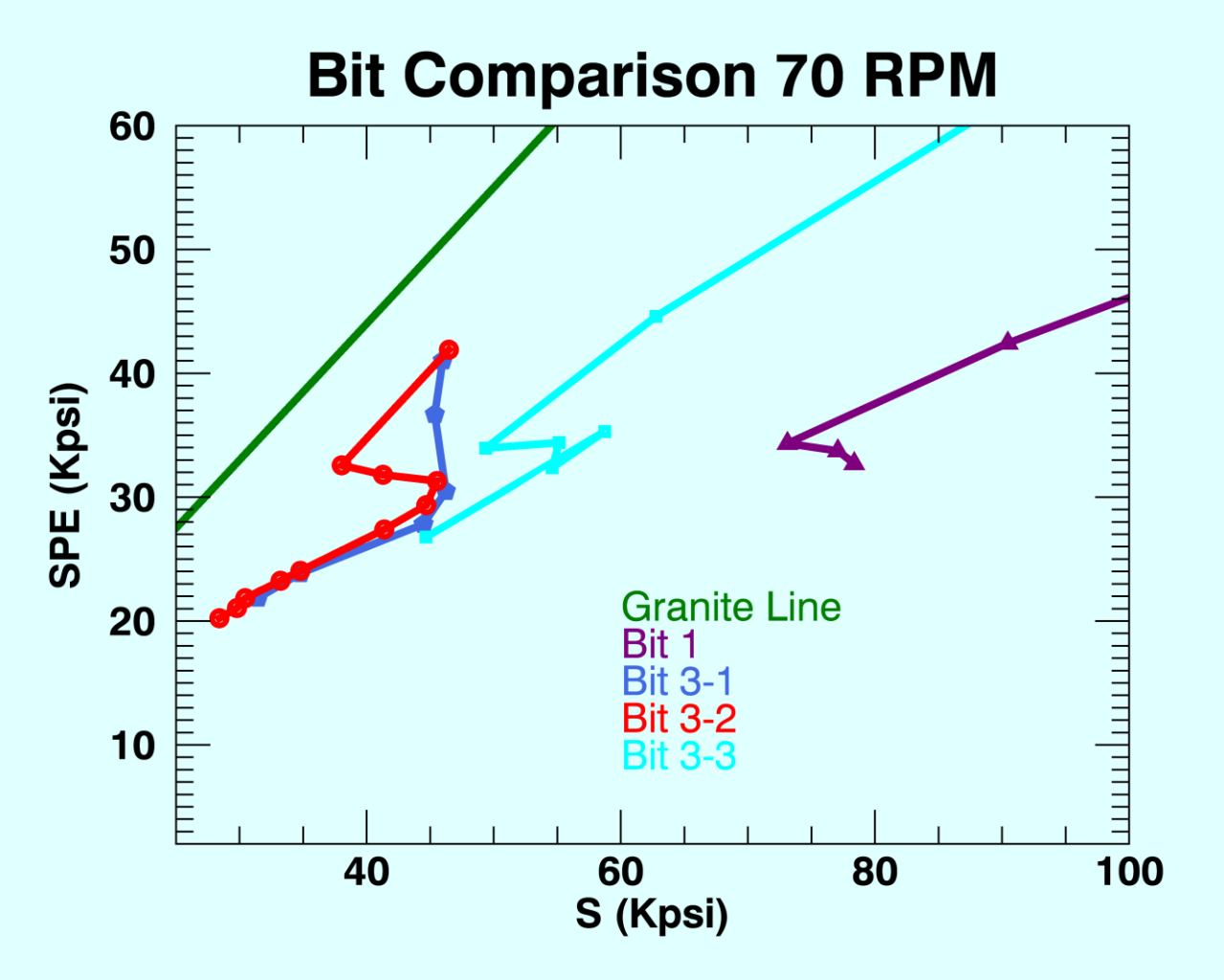
TOB = Torque On Bit

RPM = Bit Revolutions Per Minute

ROP = Rate Of Penetration

DOC = Depth Of Cut

r = Radius of the bit


Bit Comparison 70 RPM
SPE (Kpsi)
60
50
40
30
20
10
40
60
80
100
S (Kpsi)
Granite Line
Bit 1
Bit 3-1
Bit 3-2
Bit 3-3

Accomplishments, Results and Progress

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

- 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

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Phase 1 Field Test	Chocolate Mountain	Dec 2011
Phase 2 Bit Design	Successful Bit 2 Test	Nov 2012

Summary Slide

- 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

Project Management

Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
Apr 2010	Sept 2012	Oct 2010	June 2013

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$1,336,565	$52,500	$1,297,203	$841,092*	$1,177,887	$80,000

- 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