Geothermal Technologies Office 2017 Peer Review

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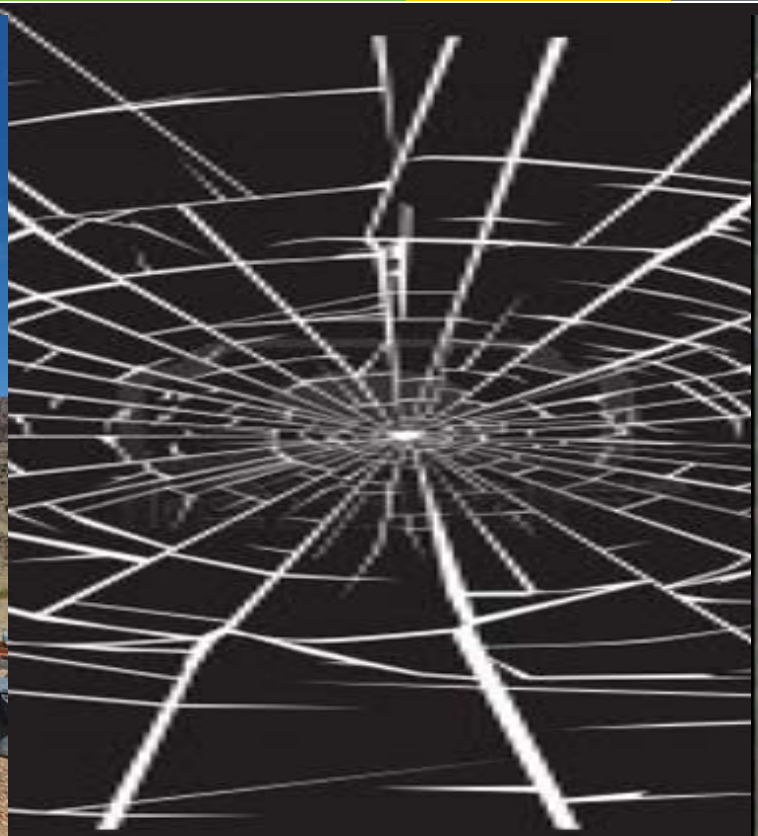

Controlled Pressurization Using Solid, Liquid and Gaseous Propellants for EGS Well Stimulation

Project Officer: Lauren Boyd

Total Project Funding: $5.8M

Nov 14 2017

Principal Investigator:
Mark Grubelich
Sandia National Laboratories

EGS: Innovative Stimulation Techniques

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Relevance to Industry Needs and GTO Objectives

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- Objective: EGS require an effective method of generating a high surface area network of fractures, or the stimulation of existing fractures, in a formation in order to increase permeability/heat-transfer. A high surface area heater exchanger is required for successful EGS development. Our goal is to develop a realizable family of stimulation tools to increase well bore permeability and enhance heat transfer. Energetic controlled rate pressurization can produce near field fractures without inducing well bore damage and provide a method of producing multiple fractures without the environmental impact of hydraulic fracturing
  - Challenges: Tailoring of energetics to produce desired reaction rates and species, harsh environment operation, instrumentation and validation (did it do what we wanted it to do?). Preserving well bore integrity.
- Benefit: Potential to make EGS a reality by providing methods to enhance wellbore permeability with a simple non-hydraulic environmentally friendly fracturing system.
- Innovation: Pressurization rate and peak pressure control, reaction product species control, high temperature resistant energetics, well bore fluid interaction Tailoring of event to formation materials properties. Potential for self propping event.
- Impact: In order for EGS to be successful a simple, cost effective environmentally method will be required to enhance well bore permeability. This technology provides a path forward for developing EGS.

Methods/Approach

- A review (nomenclature):

Type	Rate (m/s)	Energy Output (cal/g)	Power Output (W/cm^3)
Detonation	$7x10^3$	10^3	10^9
Deflagration	1	10^3	10^6
Burn	10^{-3}	10^3	10^3
Fuel-Air Combustion	10^{-6}	10^4	10

Methods/Approach

- **Review**
- dp/dt -
  - Low rate generates single fracture >>Hydraulic fracturing<<
  - High rate generates multiple fractures >>Energetics<<
- Peak pressure
  - Must be high enough to overcome material properties and in situ stress(crack propagation)
  - Low enough to prevent crushing (well bore damage)
- High explosive (detonate): A detonation is defined as a reaction wave propagating at supersonic velocity relative to the unreacted material immediately ahead of the reaction zone
  - Can be too fast and too high (solid HE)
- Pyrotechnics & Propellants (deflagrate/burn): A deflagration is defined as a reaction wave propagating at subsonic velocity relative to the unreacted material immediately ahead of the reaction zone
  - Can be too slow
  - Ideal solution is somewhere between high explosive and propellant

Methods/Approach

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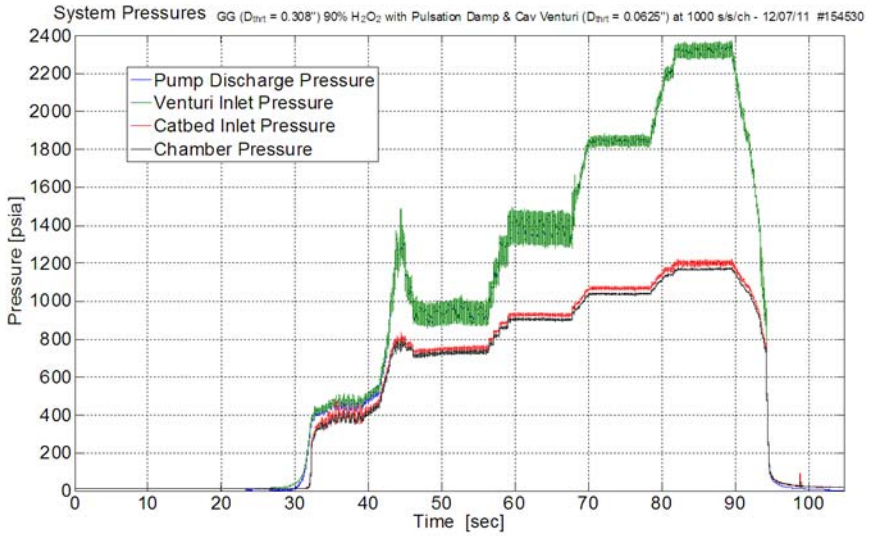
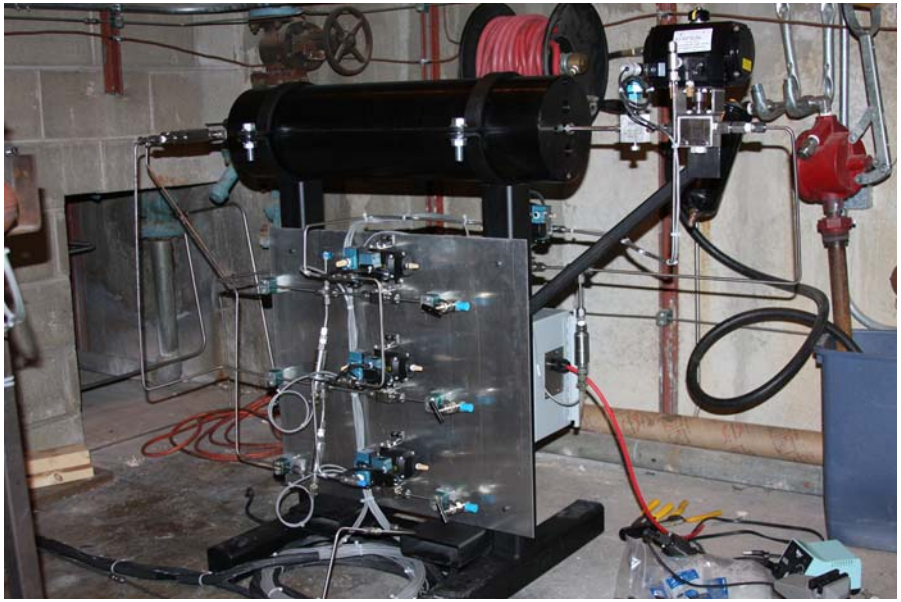
- Where we started:



Methods/Approach

- Where we went:



Short run up to DDT
~7000 ft/s
Pressure 300 - 80,000 psi

Methods/Approach

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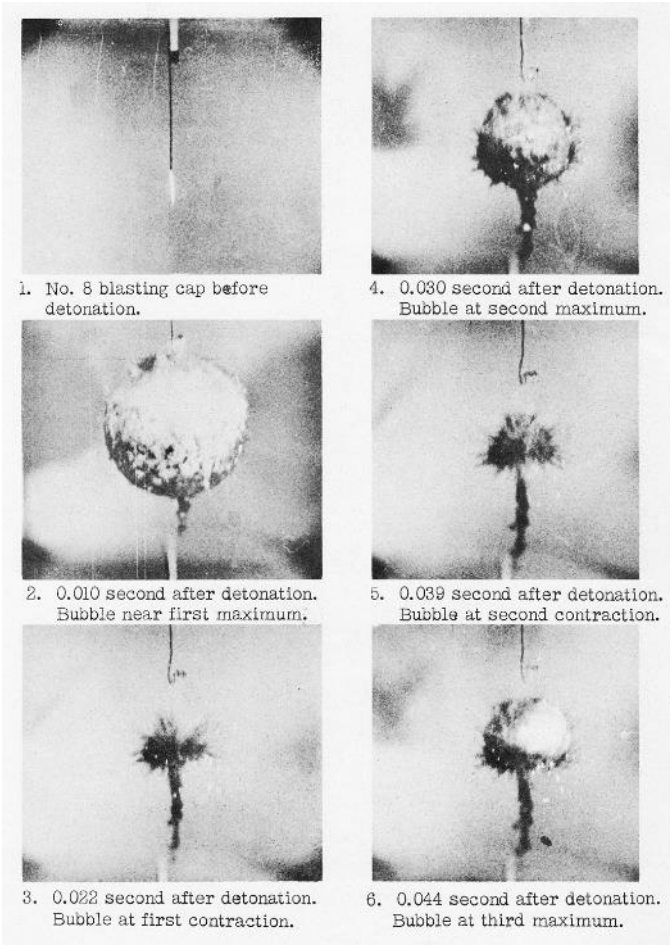
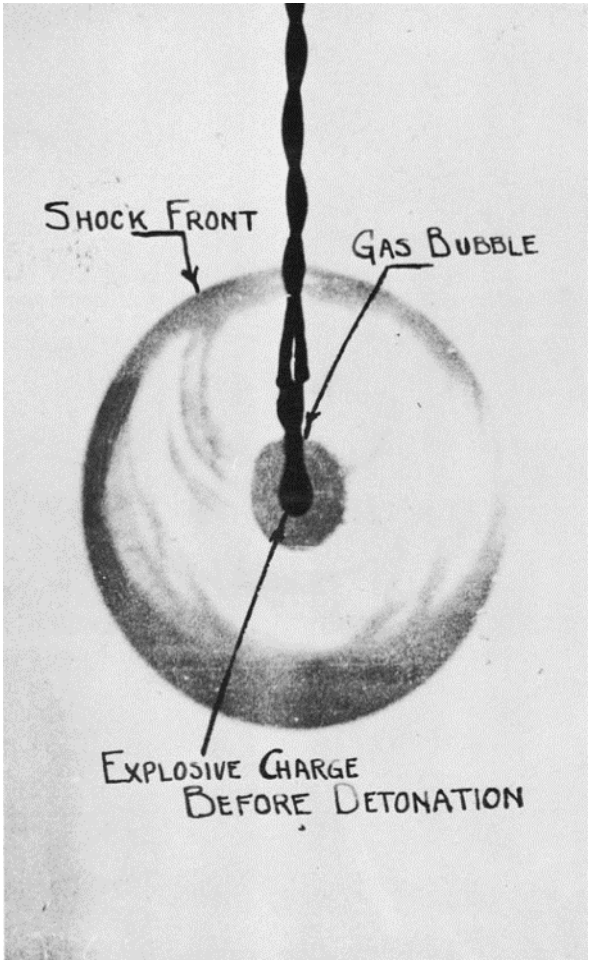
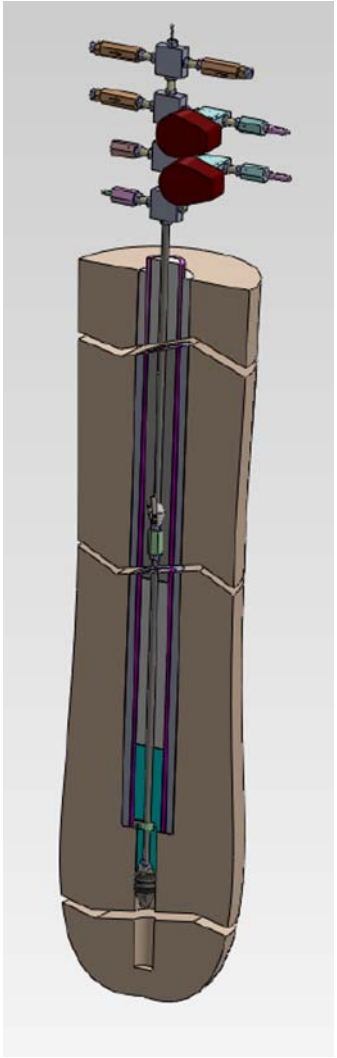
- Where we were:

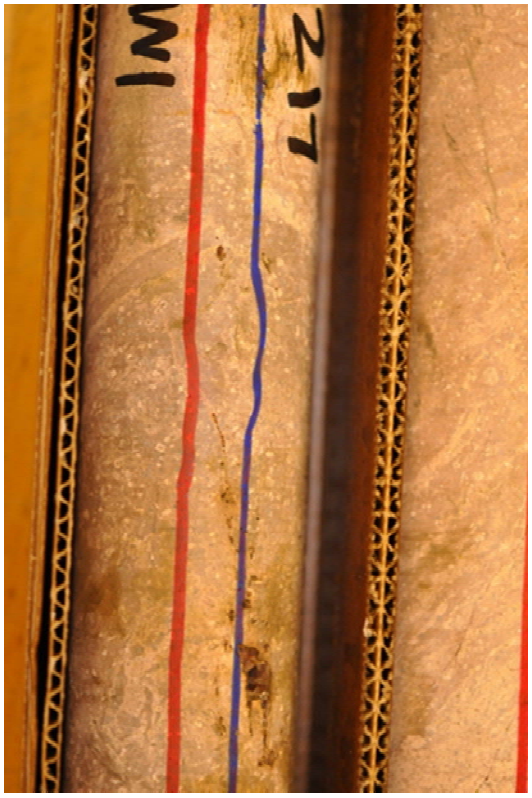




Methods/Approach

- Test site





Methods/Approach

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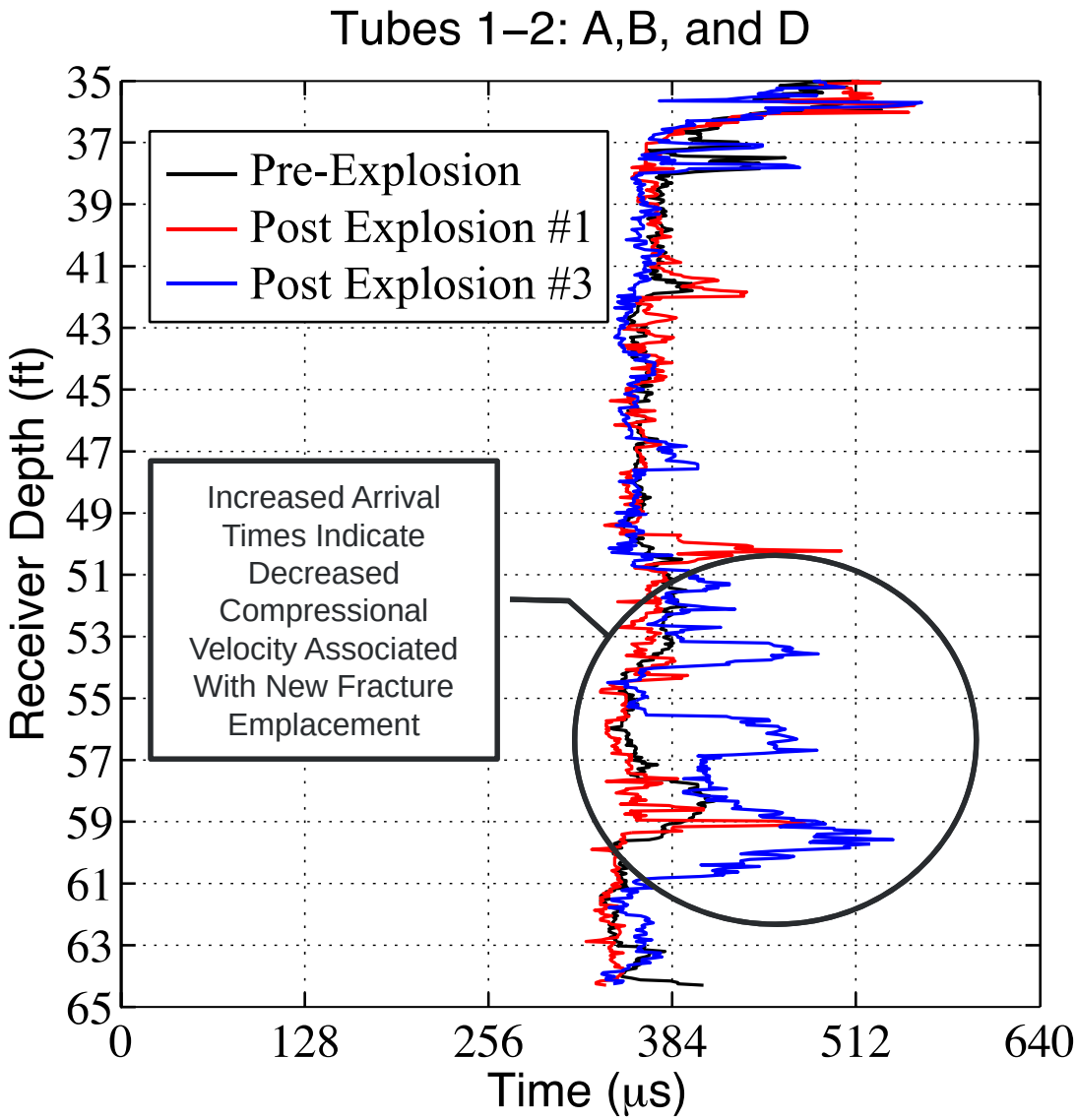
- Finding fractures:

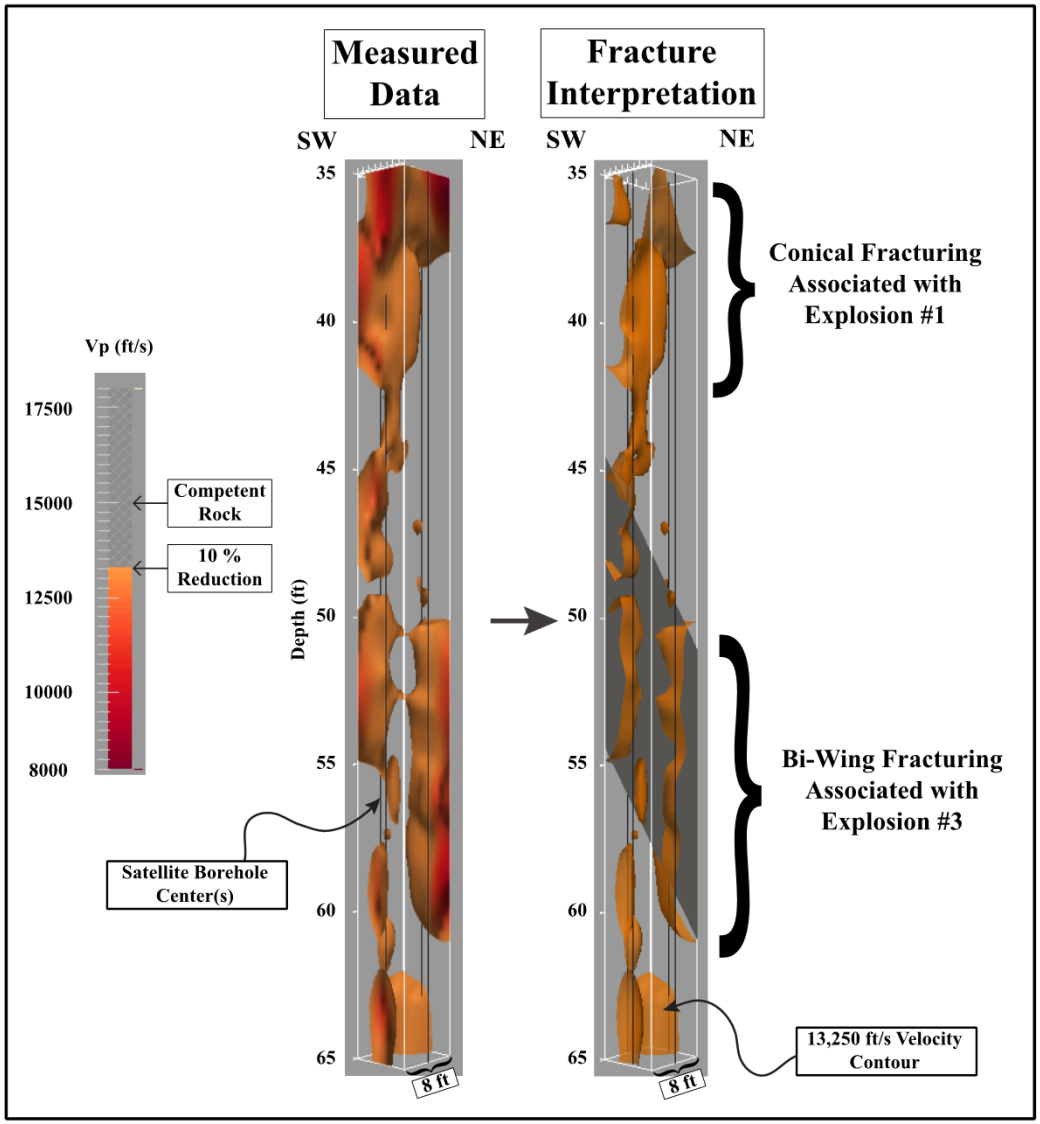
Technical Accomplishments and Progress

Testing & Data Analysis:

- Four 3-D high-resolution tomographic imaging tests conducted with Cross-hole Sonic Logging (CSL) equipment.
  - Pre-explosion #1
  - Post-explosion #1-3
- 100k waveforms handpicked by subject matter expert and error analysis is complete.
- Environmental changes(i.e. rain/snow fall) shown to effect velocity data.
- Comparison of logging data shows fracture zones at depths coincident to uncased borehole section



Technical Accomplishments and Progress



Imaging and Interpretation:

- 3-D high-resolution tomographic image representing dataset post-explosion #3.
- Good Model Fit: 90% variance reduction compared to assumed background model (~16,400 ft/s).
- Geometric interpretation of zones of velocity reductions show:
  - Conical fracture volume above uncased section associated with explosion #1.
  - Bi-wing fracture through uncased section associated with explosion #3.
    - Observation further supported by video footage in shot hole.

Technical Accomplishments and Progress

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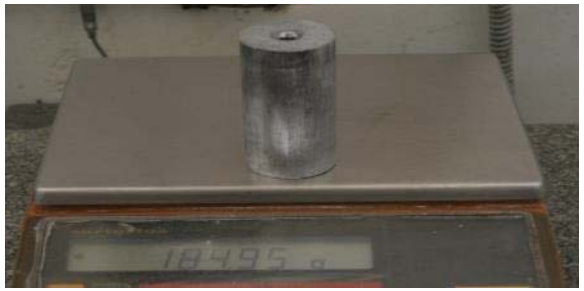
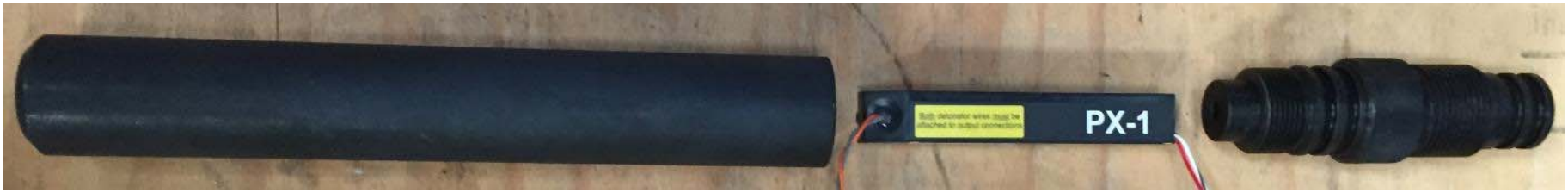




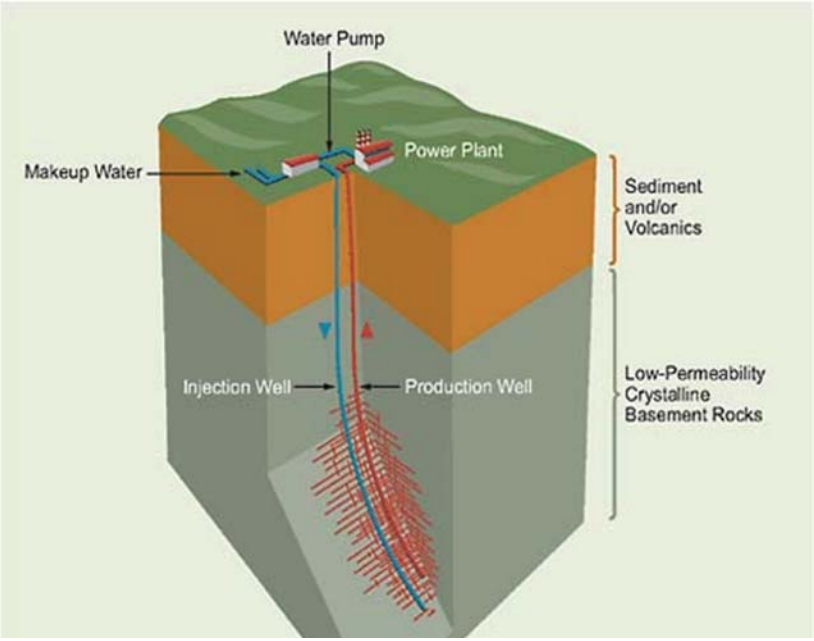
Technical Accomplishments and Progress

Technical Accomplishments and Progress

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
FY(15) Determine maximum additive to sustain a detonation in existing baseline formulation (RDX) and new explosive (HMX).	Replacement successful. Higher temperature capability	12/2015
FY(16) Conduct explosive test with higher density additives	Successful detonation at high density loading	3/2016
FY(16) In situ testing of in shallow well(s) of high density energetic materials and assessment of viability	Factures generated. Increase in permeability. Sustained pressure pulse.	6/2016
FY(16) (SMART) Prototype design of a full scale wireline deployable energetic system	Design completed and in production	9/2016-10/17
FY(16) Demonstrate directional pressure effects	Shaped charges fabricated and tested	12/2016
FY(17) Evaluate polymeric binder for energetic system using fluorocarbon for 435F temperature	PBX with fluoropolymer successfully tested	3/2017
FY(17) Determine viability of energetic system for use in slotted liner of at least 8 inch diameter	Liner test conducted. Demonstrated transmission of pressure to simulated formation	6/2017
FY(17-18) Fabricate/Demonstrate prototype energetic system in 5000 foot injection well using high temperature materials	Working on it for early 2018. Hardware delivered. Hazmat shipping arranged. Surface verification test in progress.	On going…

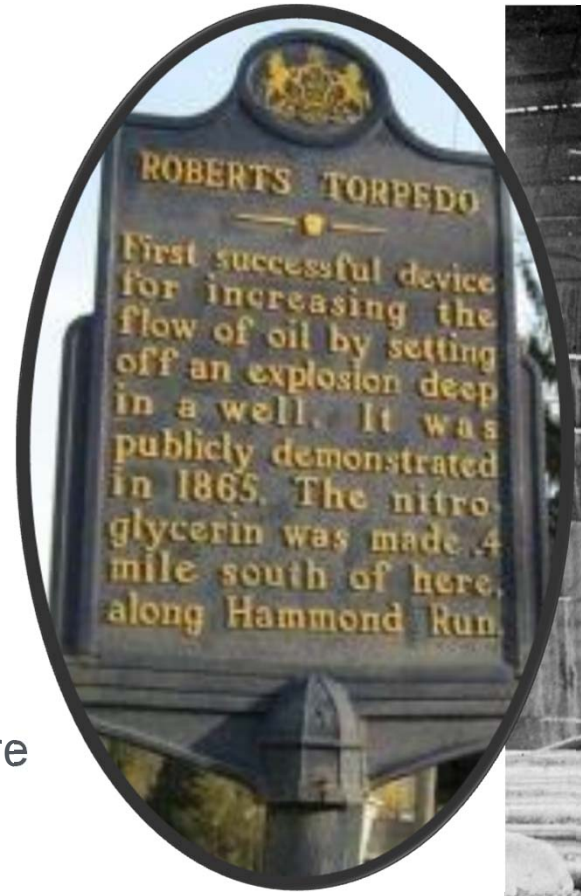
Research Collaboration and Technology Transfer

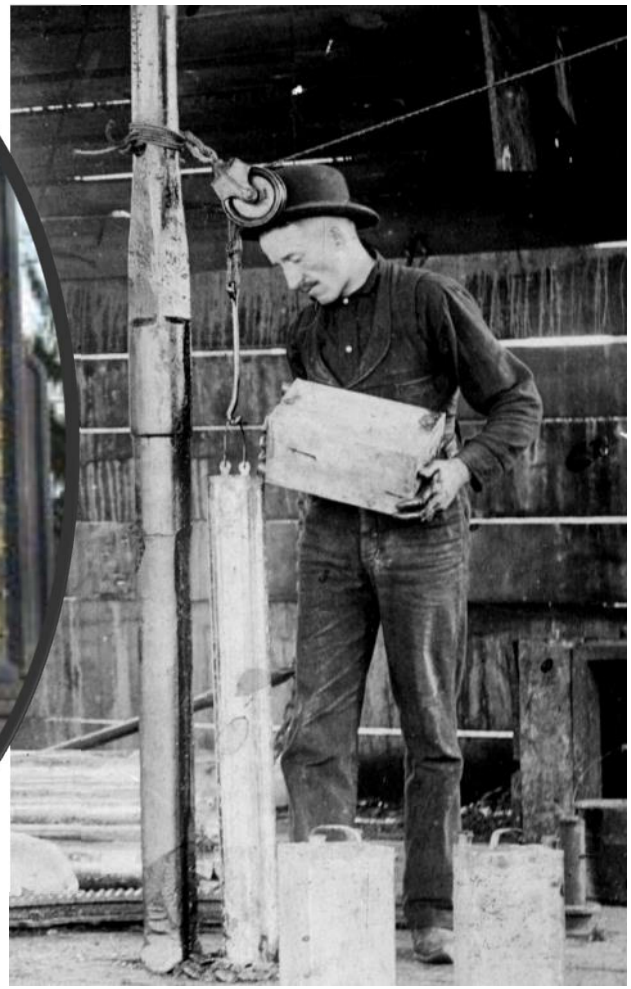
- Continued testing with NMT/EMRTC and Purdue University / Zucrow Labs
- Alta Rock Field Demonstration
- Patent Application for multiple technologies



Future Directions

- Developing improved energetic formulation
  - Shock pressure reduction & impulse increase & optimized rate
  - More reactive products….
  - Non-condensable
- Continued field testing
- Operational hardware
  - High temperature energetic
  - Wire line capability
  - Integration down hole
    - Fire-set, energetics
  - Test at depth and temperature





Mandatory Summary Slide

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- Developed high energy fracturing technique
  - Tailored energetics
    - Binary gas phase & non-ideal energetics
  - Control of peak pressure and pressure rate demonstrated
  - Tailored reaction products
    - Non-condensable & water reactive
- Lab scale research and field experiments conducted
  - Good scaling!
- Detection of fractures
  - Video
  - Core drilling
  - Seismic imaging
- Progressing to “deep” demonstration test in a geothermal injection well with Alta Rock