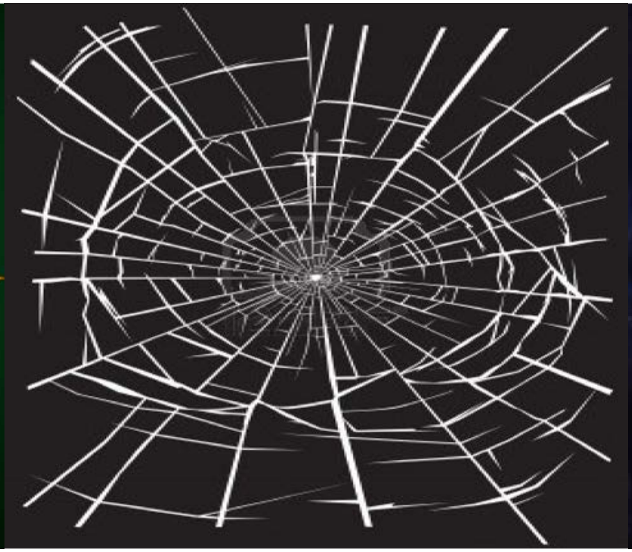
Geothermal Technologies Office 2013 Peer Review

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

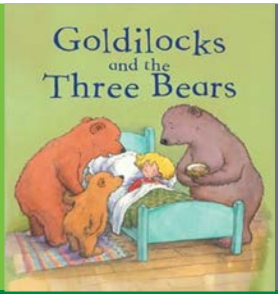


# Energetic Materials for EGS Well Stimulation (solids, liquids, gases)

Project Officer: Lauren Boyd

Total Project Funding: $ 1.6M

April 24, 2013




**Mark Grubelich,**

**Sandia National Lab**

Track Name: HT Tools

Sandia National Laboratories is a multi-program laboratory operated and managed by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SANDXXXX-XXX

# Relevance/Impact of Research – 1

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

- Objective: Develop environmentally safe and field deployable, energetic systems (liquid, gas, and solid phase) that enables branching, far field fracturing and/or stimulate existing fractures.
- Problem: Enhanced Geothermal Systems (EGS) require reservoir stimulation. Typically used energetic methods/materials are:
    - – High Explosives; causes local damage and thus little far field fracture propagation
    - – Propellants; predominantly extends existing fractures, less effective at generating multiple fractures
- Solution: Energetic methods/materials for controllable pressurization rates and peak pressures – **key innovation**
    - – Rapid pressure rise to below the reservoir “rubblization” strength (lower than high explosives) yet above that achieved by propellants
    - – Design and demonstrate a engineered energetic materials to produce a tailored pressure pulse to initiate multiple near well bore fractures and propagate these fractures to the far field.
    - - All systems are designed to have benign environmental interactions and be safe enough for field deployment at large scales.



Patent in process

# Relevance/Impact of Research – 2

- Impact on geothermal energy development:
  - Reduced risk and costs associated with development
  - Increased fracturing efficiency
  - Safe, economical systems
  - Reduced borehole impedance

- Impacts Geothermal Technologies Program goals:
  - Lower development cost: EGS well productivity is essential to 5 MW demonstration and LCOE Program goal. This stimulation technology is directly aligned with achieving higher productivity from EGS reservoirs and wells.

Cost impact example:

*Table I: GETEM Cost Analysis for Flash and Binary Production with and without Single and 3 Fractures*

| Flash/ Binary | Temperature (˚C) | Improvement | Cost of Power 2010 (cent/kw) |
|---|---|---|---|
| Flash | 250 | N/A | 11.53 |
| Flash | 250 | 3x flow rate | 6.88 (40% Less) |
| Binary | 175 | N/A | 31.94 |
| Binary | 175 | 3x flow rate | 16.02 (50% Less) |

Note: Assumed 30 kg/sec base flow rate, 4 km well depth.

From S. Petty et al. Stanford 2011


Patent in process

# Scientific/Technical Approach



• Scientific/technical approach for current year's activities:

Gas system:

- Complete lab scale system validation and shakedown at scheduled pressures (150 to 500 psi gas mixture pressure)
    - Compare computational pressure profiles to measured data
- Demonstrate system in shallow test well
    - Measure pressurization rates and peak pressure
    - Videography of well bore features
    - Permeability measurements via gas pressurization and leak-off

Solid system:

- Down select candidate(s) binary systems based on measured properties for safety (most important), maximum reaction rate (secondary), peak pressure (tertiary).
    - Compare computational pressure profiles to measured data
- Design of high pressure hydro-bomb
- Lab scale testing of selected solid energetic system in fluid environment
    - Pressure time history measurements



Patent in process

# Scientific/Technical Approach

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

- Key issues & significance:
- SAFETY!
  - Gas system field demonstration – safety built into test plan, Purdue & New Mexico Tech. written test plan, 100% remote operation
  - Solid system – friction, electrostatic discharge, impact, and thermal stability characteristics being measured.

- ‘Tunable’ = Demonstrate variable pressure generation so the technology can be adopted in a variety of formations
  - Achieved through chemistry modifications (solids) and density control (gas)

- Scalability
  - Achieved successful scale up from system validation in the lab to field demonstration (gas)
  - Ready path to commercial deployment = low material costs, materials safe for handling and transport, benign environmental interactions

- Additional diagnostics: seismic imaging could not be afforded for the given budget & GPR would suffer from unacceptable attenuation through shallow weathered zone


Patent in process

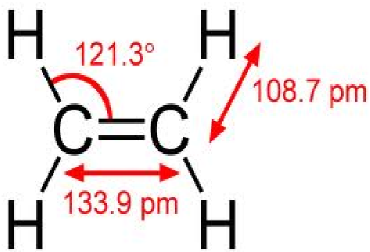
# The systems:

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

- $H_2O_2$ >> Steam (water) + Oxygen


- $N_2O$ + $C_2H_4$ >> Steam (water) + Nitrogen + Carbon






- $KClO_4$ + Si + $H_2O$ >> Potassium Chloride (salt substitute) + Hydrogen






Patent in process

# Accomplishments, Results and Progress

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

Major accomplishments during reporting period:

- –Proof-of-concept liquid mono-propellant, liquid decomposition/gas generation rate
- –Proof-of-concept gas bi-propellant, pressure vs. time data
- –Safety characterization of solid system
- –Shallow test well demonstration of gas phase bi-propellant

| Original Planned Milestone/ Technical Accomplishment | Actual Milestone/Technical Accomplishment | Date Completed |
|---|---|---|
| Proof-of-concept gas bi-propellant (lab testing) 9/2012 | Proof-of-concept gas bi-propellant (lab testing) | 02/2012-2/2013 |
| Solid system safety, reaction rate, and peak pressure measured by 6/2013 | Candidate solid system safety properties measured | 2/2013 |
| Shallow well field test of gas phase system by 4/2013 | 3x shots at New Mexico Tech. testing range (150/150/250 psi) | 3/7/2013 |



Patent in process

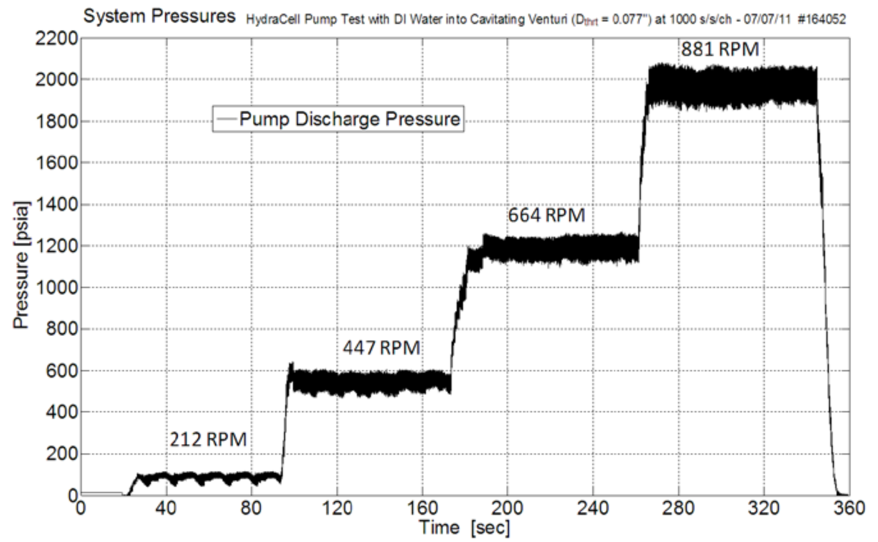
# HP H2O2 Pump System

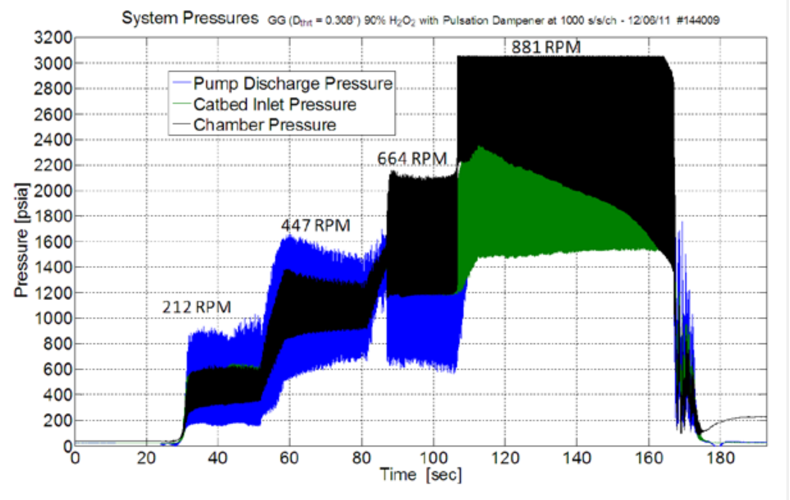


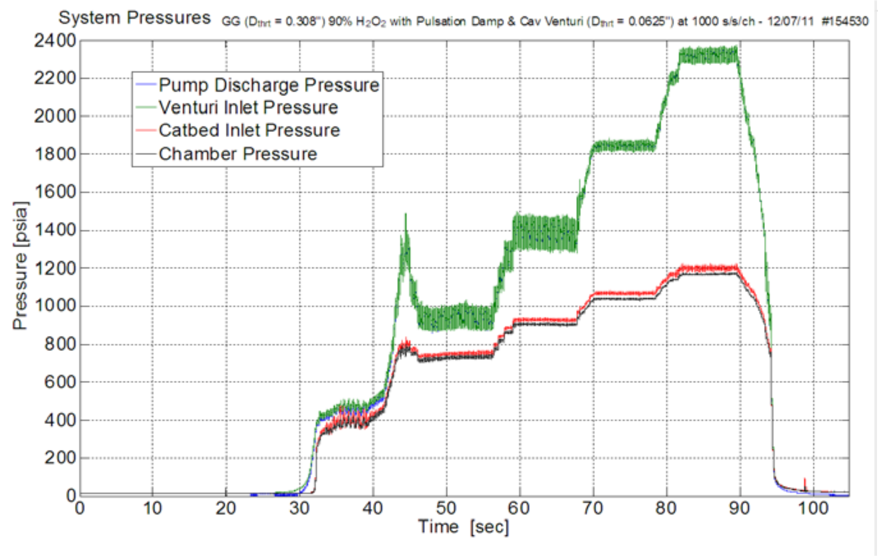
Patent in process

# $H_2O_2$ Gas Generator Pump Test 4000 HP

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






Patent in process

# Solid system safety testing:

| ***Sample*** | ***Batch*** | ***Impact (cm)*** | ***Average*** | ***BAM (friction, N)*** | ***Average*** | ***Ignition Sensitivity (kV)*** | ***Average*** |
|---|---|---|---|---|---|---|---|
| **1** | 1 | >200 | 199.5 | 110 | 136 | 1.34 | 1.39 |
| | 2 | 198.7±2.3 | | 141 | | 1.41 | |
| | 3 | >200 | | 157 | | 1.41 | |
| **2** | 1 | >200 | 199.8 | 110 | 152 | 1.41 | 1.41 |
| | 2 | 199.5±0.0 | | 110 | | 1.41 | |
| | 3 | >200 | | 235 | | 1.41 | |
| **3** | 1 | >200 | >200 | >353 | 290 | >3 | >3 |
| | 2 | >200 | | 282 | | >3 | |
| | 3 | >200 | | 235 | | >3 | |
| **4** | 1 | >200 | 199.8 | 282 | 306 | 1.73 | 1.63 |
| | 2 | 199.5±0.0 | | >353 | | 1.41 | |
| | 3 | >200 | | 282 | | 1.73 | |
| **5** | 1 | 198.9±1.1 | 199.1 | 282 | 294 | <1 | <1 |
| | 2 | 199.3±0.3 | | 247 | | <1 | |
| | 3 | 199.2±0.4 | | >353 | | <1 | |
| **6** | 1 | >200 | >200 | 247 | 278 | >3 | 2.63 |
| | 2 | >200 | | >353 | | 2.24 | |
| | 3 | >200 | | 235 | | 2.65 | |
| **7** | | >200 | | >353 | | 2.65 | |
| **8** | | >200 | | >353 | | >3 | |
| **9** | | >200 | | 235 | | >3 | |
| **10** | | >200 | | 177 | | 2.24 | |

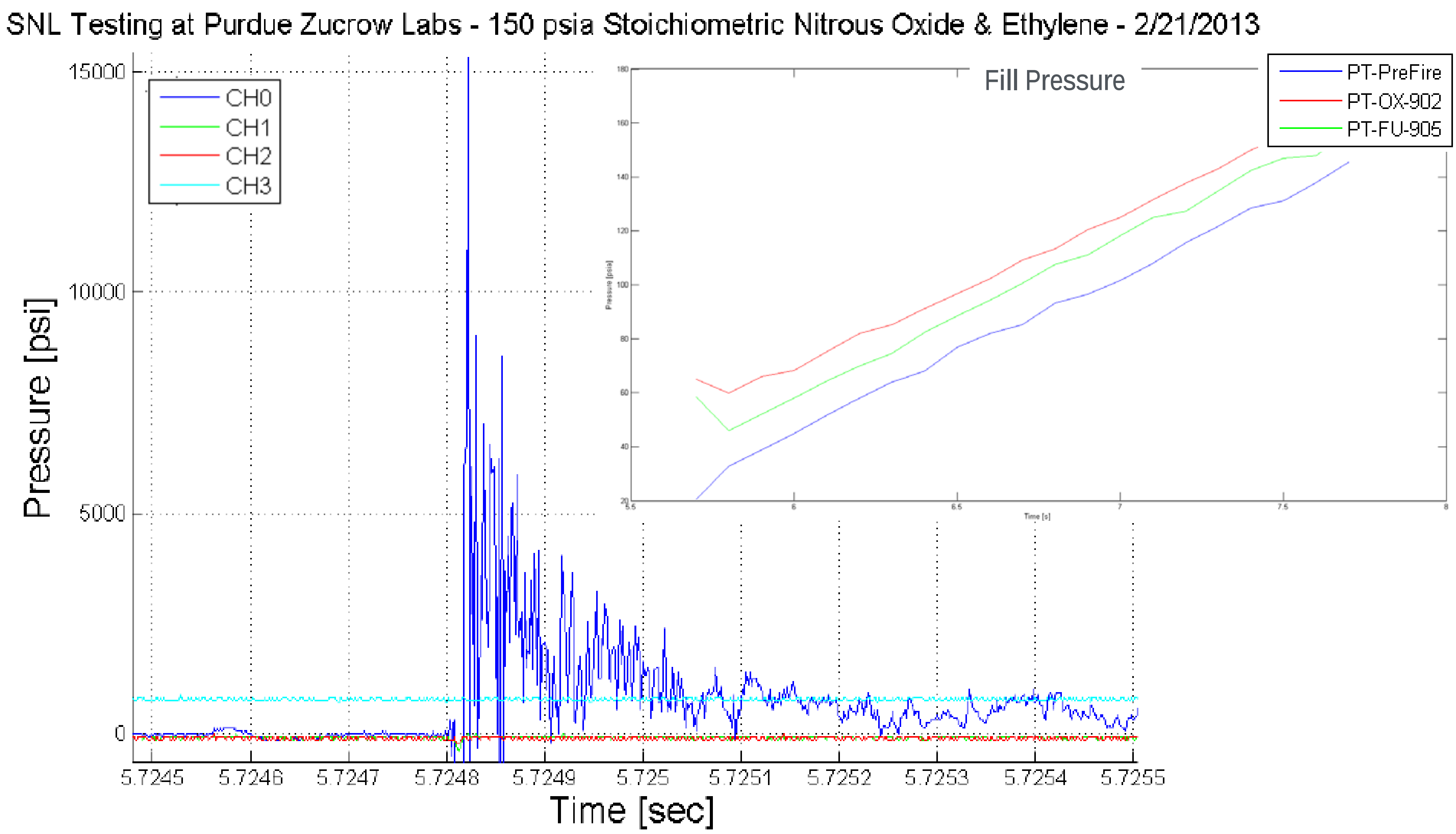
Ignition Sensitivity

BAM Friction Apparatus

Patent in process

# Accomplishments, Results and Progress: Proof of concept (gas phase) lab test








Patent in process

# Accomplishments, Results and Progress

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

[redacted]

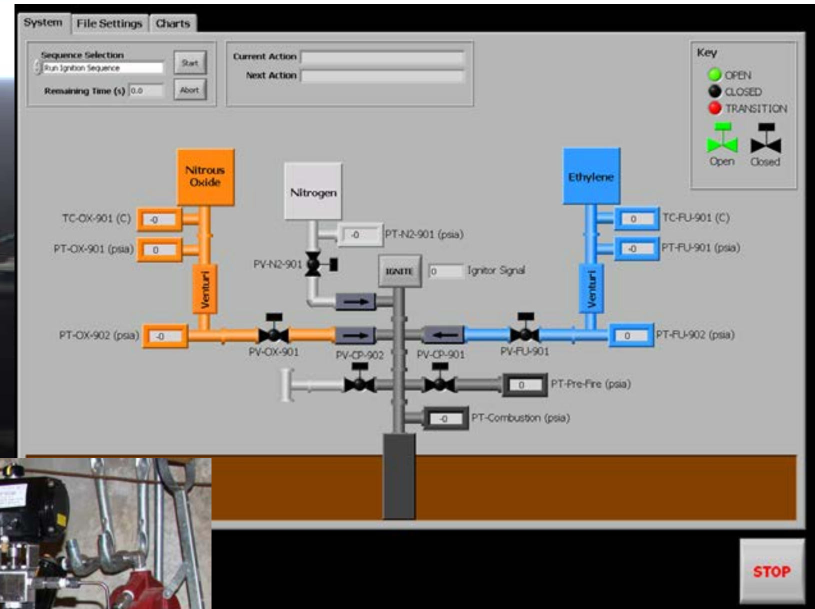


Patent in process

**Tree**

**Gas regulator**

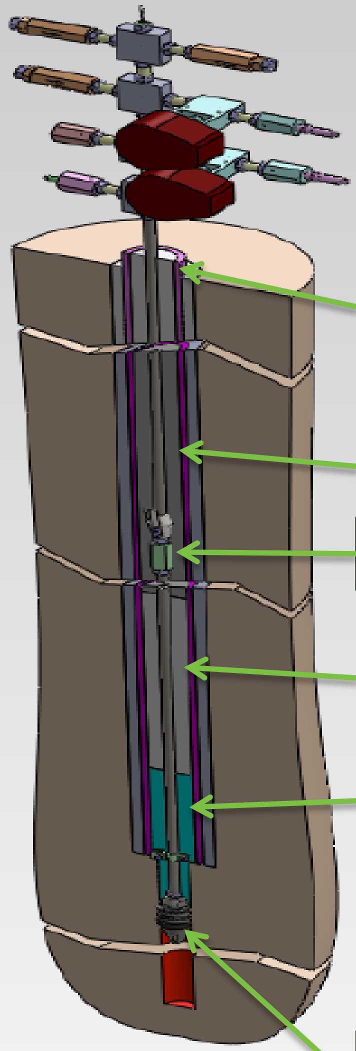
**Control diagram**



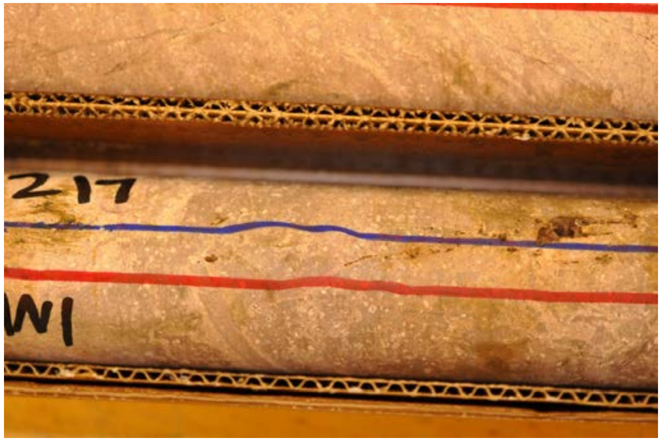

Patent in process

# Field demo gas phase bi-propellant Test well W-1

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




Test location: Blue Canyon Dome, EMRTC


Core shows the test well rock is competent rhyolite with a few fractures.



Patent in process

# From field demo:

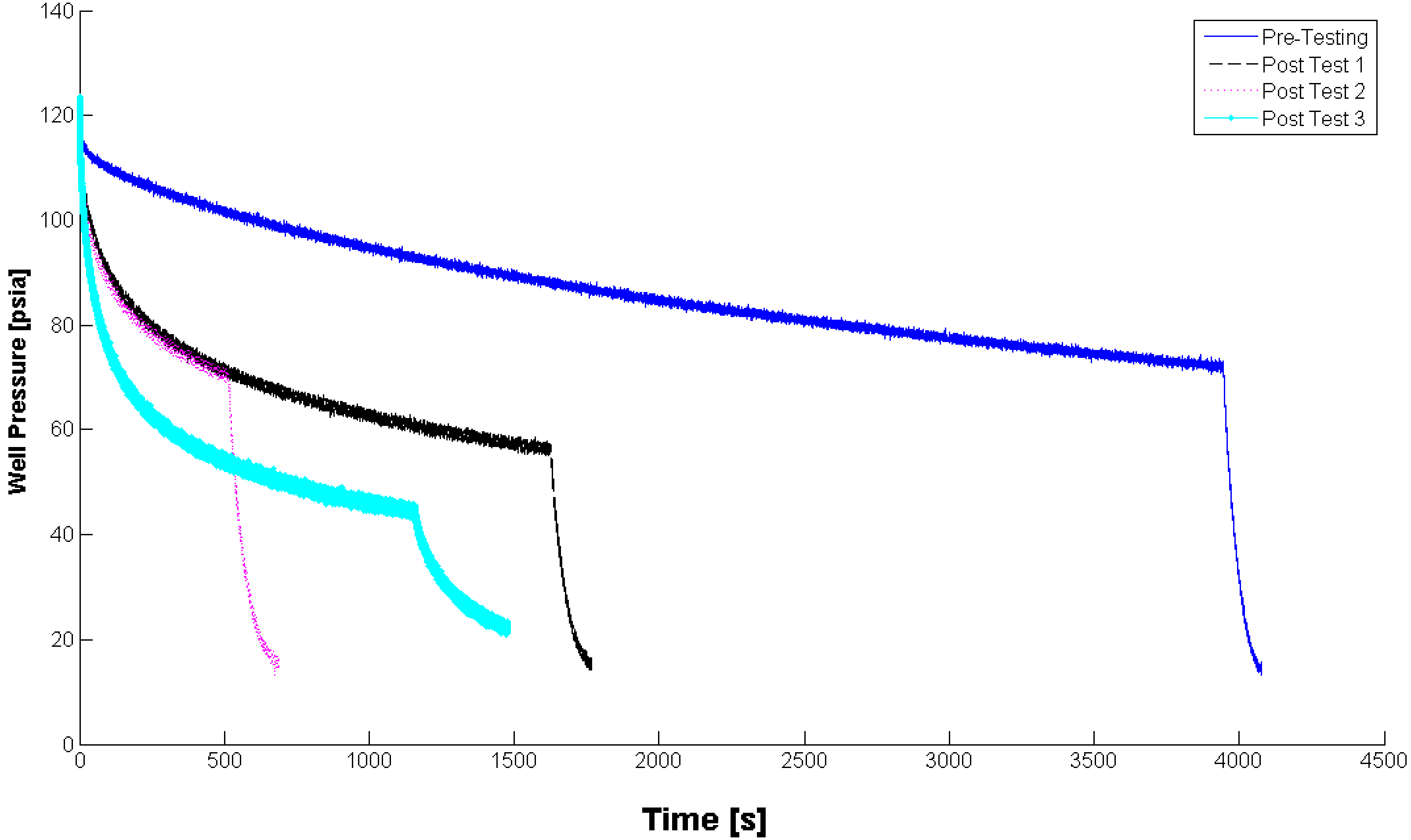
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy




Patent in process

# N2 leak-off data from the field (1 of 2)

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

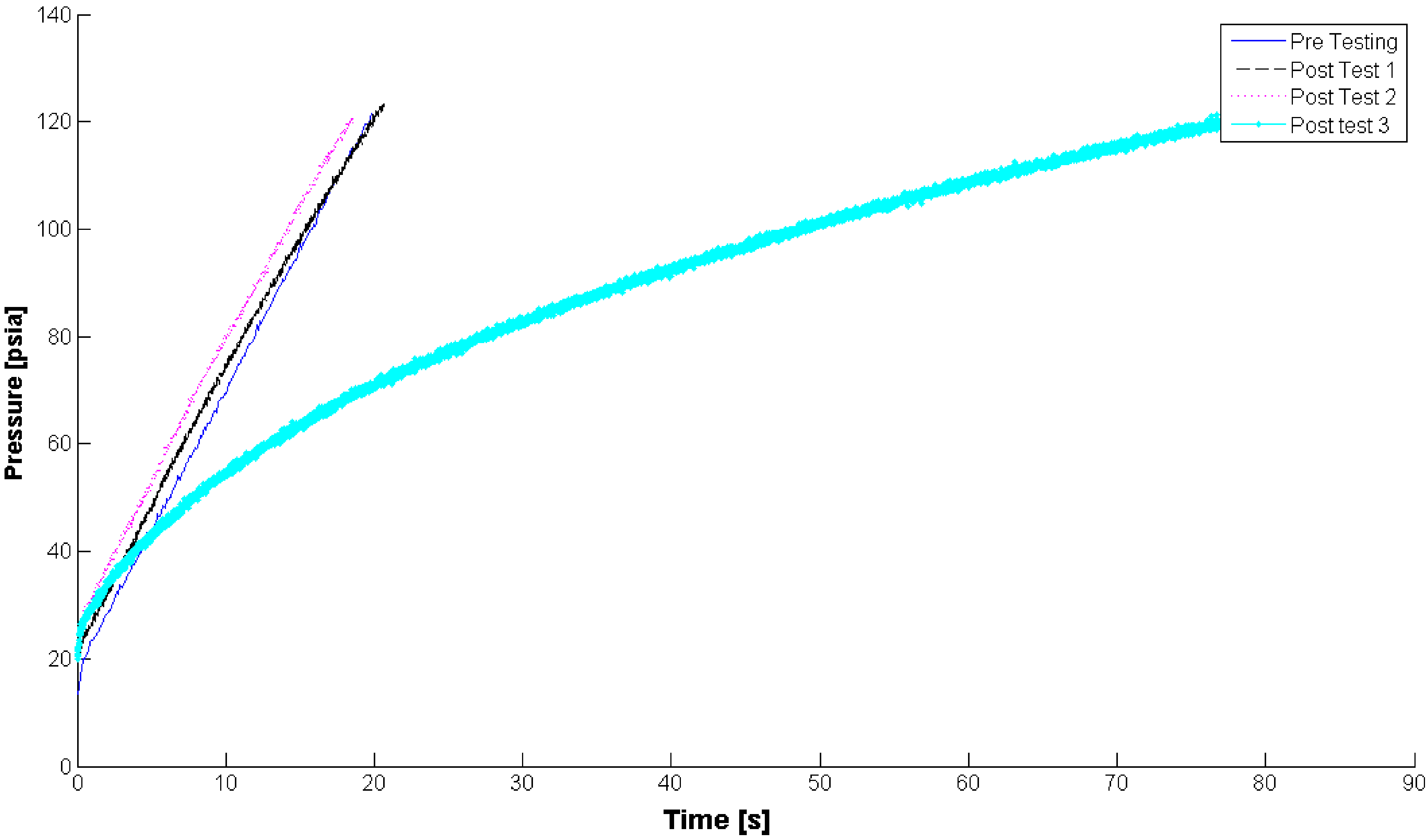





Patent in process

# N2 fill rate data from the field (2 of 2)








Patent in process

# Future Directions

- Additional gas phase bi-propellant field testing in W-1 at EMRTC
- Based on shallow well demonstration testing, design, fabricate hardware for, and execute full/commercial scale test – to be completed by end of FY2015
- Possible high pressure injection of liquid (H2O2) in shallow test well FY2014
- Proof-of-concept test of solid system by end of FY2014

| Milestone or Go/No-Go | Status & Expected Completion Date |
|---|---|
| Solid system reaction rate and peak pressure measurements by 6/2013 | 5 weeks behind schedule; completion as expected |
| Design and fabricate hydro bomb by 9/2013 | May adapt existing hardware (detonation calorimeter), on schedule |
| Testing solid system in fluid environment by 10/2013-12/2013 | Completion as expected, on schedule |



Patent in process

# Mandatory Summary Slide

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

- Proof-of-concept achieved for H202 pump-fed system
- Proof-of-concept achieved for bi-propellant gas phase system
- Successful field demonstration of bi-propellant gas phase system; 3 shots at variable pressures
  - Measured change in permeability
  - Data measurement for peak pressure



Patent in process

# Project Management

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

Timeline:

| Planned Start Date | Planned End Date | Actual Start Date | Actual /Est. End Date |
|---|---|---|---|
| 1/1/2010 | 8/30/2015 | 2/25/2010 | 8/30/2015 |

Budget:

| Federal Share | Cost Share | Planned Expenses to Date | Actual Expenses to Date | Value of Work Completed to Date | Funding needed to Complete Work |
|---|---|---|---|---|---|
| $1,600,000 | $0 | $2,200,000 | $1,343,000 | $1,003,750 | $4,000,000 |

What you don’t see: $1.5 M in direct leveraged funds (hardware & labor)

Coordination between proof-of-concept testing at Zucrow Labs, Purdue University and Energetic Materials Research and Testing Center, New Mexico Tech