Agenda

- Welcome – Dr. Susan Hamm (Geothermal Technologies Office, DOE)
- SubTER update – Dr. Susan Hubbard (Berkeley Lab)
- Basic Research Agenda Report – Dr. Laura Pyrak-Nolte (Purdue Univ.)
- Discussion
Other SubTER AGU Activities

SubTER - Subsurface Technology & Engineering Research
Adaptive control of the Earth’s subsurface for our energy future

Join the following SubTER events at the AGU
American Geophysical Union
FALL MEETING
14 - 18 December 2015

Presented by the U.S. Department of Energy and the National Laboratory System

Booth #1104
SubTER Booth #1104 – All Week, Exhibit Hall, Moscone North
Interested in participating? Stop by our “DOE Subsurface Crosscut (SubTER)“ booth to learn more about future developments, collaboration and funding opportunities, and internships!

SubTER Townhall (TH25I) – Tuesday Dec 15, 6:15-7:15 pm, Moscone West 2004
Revolutionizing Utilization of the Earth’s Subsurface for America’s Energy Future: the DOE Subsurface Crosscut Initiative
  SubTER Initiative (S. Hubbard, Berkeley Lab)
  SubTER Science Roundtable Report (L. Pyrak-Nolte, Purdue University)

Poster Session H51M
SubTER Poster Session (H51M) – Friday Dec 18, 8 am-12:20 pm, Moscone South
Subsurface Control of Fractures and Flow for Responsible Energy Production and Storage
  Co-chairs: T. Daley, D. Blankenship, R. Pawar & A. Bonneville
DOE Crosscutting ‘Big Idea’ Summit: the Birth of SubTER

March 2014
- DOE Big Idea Summit I

Dec 2014
- SubTER retreat & AGU Townhall

2014, 2015
- Outreach, many venues

March 2015
- DOE Big Ideas Summit II

Summer 2015
- SubTER Retreat
- Science roundtable

Nov 2015
- SubTER NL Plan briefing to DOE

FE/O&G: Fossil Energy/Carbon Storage
EPSA: Energy Policy & Systems Analysis
EM Environmental Management
NE Nuclear Energy
SC: Science
Mastery of the Subsurface needed to Greatly Enhance its Utilization

Shale hydrocarbon production

Safe subsurface storage of CO₂

Renewable Energy

Geothermal

Nuclear Power

Coal

Petroleum

Natural Gas

Primary Energy Use by Source, 2014

Quadrillion Btu [Total U.S. = 98.3 Quadrillion Btu]

Enhanced geothermal energy

Compressed Air Energy Storage

Safe subsurface storage of nuclear waste
Adaptive Control of Subsurface Fractures and Flow

Ability to adaptively manipulate subsurface – with confidence and rapidly.

Within 10 Years:

- A ten-fold increase of U. S. electricity production from geothermal reservoirs
- Double hydrocarbon production from tight reservoirs
- Establish practical feasibility of deep borehole disposal
- Large-scale safe CO₂ sequestration to meet targets described in the President’s Climate Action Plan

Concurrent protection of the environment (water and air resources, induced seismicity)
‘Adaptive Control of fractures’ is a Grand Subsurface Challenge

Requires an understanding and ability to manipulate subsurface stress, geochemical reactions, and multi-phase fluid flow

- within heterogeneous geological environments
- across nanometer to kilometer length scales
- remotely within the deep subsurface reservoirs

Requires fundamental through engineering RD&D
Activities & Input to SubTER Plan: Select Examples

- National Resource Council, 2014
- National Energy Association, July 2014
- National Academy of Sciences, October 2014
- DOE Subsurface grand challenge RFI May 2014
- AGU town hall 2014
- SubTER –led workshops, 2015:
  - Shale at all Scales
  - Grand Challenges in Geological Fluid Mechanics
  - 3D Printing techniques relevant to rock physics
  - Novel Cements
- SEG 2015
- National Laboratory Day, June 2015
- GSA SubTER booth 2015
- Centennial Grand Challenges in Rock Physics 2015
- Several discussions w/universities, industries, agencies and NGOs
JASON, 2014: ‘State of Stress in Engineered Subsurface Systems’

- “DOE should take a leadership role in the science and technology for improved measurement, characterization, and understanding of the state of stress of engineered subsurface systems in order to address major energy and security challenges of the nation.”
- “Coordinated research and technology development at dedicated field sites to connect insights from laboratory scales and models to operational environments”

DOE Roundtable, 2015: ‘Imaging of stress and geological processes’

Identified Basic Research Priority Research and Crosscutting Directions (Laura Pyrak Nolte)
Overall Goal:
- Successful demonstration of adaptive control for several energy strategies

Additional Year 10 goals:
- Manipulate stress away from the borehole
- Inject fluid (e.g., carbon sequestration, waste disposal, CAES) with acceptable/predictable seismicity
- Create and plug fractures at will in a variety of subsurface environments
- Create boreholes that do not leak for every subsurface energy application
- Develop and successfully implement technologies that enable access, modeling, and monitoring at scales and resolution for guiding adaptive control
- Provide science to enable a new class of responsible energy production and waste storage options

Year 5 goals...
Year 2 goals...
SubTER Framework
Adaptive Control of Subsurface Fractures and Fluid Flow

Wellbore Integrity and Drilling Technologies
Materials and technologies to ensure wellbore integrity over decadal timeframes

Subsurface Stress & Induced Seismicity
Characterization and control subsurface stress and induced seismicity

Permeability Manipulation & Fluid Control
Approaches to manipulate subsurface fractures, reactions and flow

New Subsurface Signals
Sensors and algorithms to monitor subsurface dynamics and facilitate adaptive control
### SubTER Framework
Adaptive Control of Subsurface Fractures and Fluid Flow

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<tr>
<th>Wellbore Integrity and Drilling Technologies</th>
<th>Subsurface Stress &amp; Induced Seismicity</th>
<th>Permeability Manipulation &amp; Fluid Control</th>
<th>New Subsurface Signals</th>
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<tr>
<td>Improved well construction materials and techniques</td>
<td>State of Stress (measurement and manipulation)</td>
<td>Manipulating Physicochemical Fluid-Rock Interactions</td>
<td>New Sensing Approaches</td>
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<td>Autonomous completions for well integrity modeling</td>
<td>Induced seismicity (measurement and manipulation)</td>
<td>Manipulating Flow Paths to Enhance/Restrict Fluid Flow</td>
<td>Integration of Multi-Scale, Multi-Type Data</td>
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<td>New diagnostics for wellbore integrity</td>
<td>Relate Stress and IS to Permeability</td>
<td>Characterizing Fracture Dynamics and Fluid Flow</td>
<td>Adaptive Control Processes</td>
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<td>Remediation tools and technologies</td>
<td>Applied Risk Analysis to Assess Impact of Subsurface Manipulation</td>
<td>Novel Stimulation Technologies</td>
<td>Diagnostic Signatures and Critical Thresholds</td>
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<td>Fit-for-purpose drilling and completion tools (e.g. anticipative drilling, centralizers, monitoring)</td>
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<td>HT/HP well constr. &amp; completion technologies</td>
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**Energy Field Observatories**

**Fit For Purpose Simulation Capabilities**
# Subsurface Stress and Induced Seismicity Element:
Relate Stress to Induced Seismicity and Permeability

<table>
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<tr>
<th>Element</th>
<th>2-year goals</th>
<th>5-year goals</th>
<th>10-year goal</th>
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<tr>
<td>Relate Stress and IS to Permeability</td>
<td>Compile database(s) of publicly available data to test models of permeability/slip relationship(s)</td>
<td>Conduct field demonstration(s) of optimal integrated monitoring, analysis, and characterization techniques</td>
<td>Develop the ability to utilize stress and induced seismicity to control flow paths along reactivated faults and fractures, predicting permeability behavior with an order of magnitude improvement over current capabilities</td>
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<td>Design and carry out laboratory and numerical experiments to identify and acquire missing data needed to achieve goals</td>
<td>Demonstrated improved permeability prediction by a factor of 3 over baseline</td>
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<td>Establish dedicated field observatory site(s). Perform integrated analysis and interpretation of results from initial field experiments, using state-of-the-art techniques</td>
<td>Demonstrate characterization techniques to predict seismic vs. aseismic slip behavior</td>
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<td>Establish benchmarks for permeability prediction capabilities including both fault leakage and fractured reservoir productivity</td>
<td>Identify and prioritize techniques capable of achieving 10 year goals</td>
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Subsurface Stress and Induced Seismicity 

Element: Relate Stress to Induced Seismicity and Permeability

10-year goal

Develop the ability to utilize stress and induced seismicity to control flow paths along reactivated faults and fractures, predicting permeability behavior with an order of magnitude improvement over current capabilities.

Element

Relate Stress and IS to Permeability

- Demonstrate characterization techniques to predict seismic vs. aseismic slip behavior.
- Identify and prioritize techniques capable of achieving 10 year goals.
- Develop the ability to utilize stress and induced seismicity to control flow paths along reactivated faults and fractures, predicting permeability behavior with an order of magnitude improvement over current capabilities.
- Establish benchmarks for permeability prediction capabilities including both fault leakage and fractured reservoir productivity.
- Perform integrated analysis and interpretation of results from initial field experiments, using state-of-the-art techniques.
- Establish dedicated field observatory site(s).
- Relate Stress and IS to Permeability.
Activity: Underground facility for testing IS as controlled by stress, rock properties & existing fractures

**kISMET: Permeability and Induced Seismicity Management for Energy Technologies**

- Stress measurements and modeling of natural stress state
  - Univ. Wisconsin, Stanford, Golder Associates
- Joint inversion of displacement (GPS/tilt meter) and velocity (seismic) for the 3D stress field.
- Stimulated fault slip experiments to characterize relationship between rock fabric, stress and the evolution of fractures.
Wellbore Integrity & Drilling Technologies
Motivation and Objectives

Motivation

- Current well systems may not meet long term integrity needs and these well systems require further advancement to meet goals of SubTER

Objectives and Goals

- Improve understanding of interaction between well system and natural environment in order to engineer wells that:
  - maintain integrity over decadal time scales
  - facilitate SubTER other pillar goals

Many possible leakage pathways along a well, including:
- between cement and outside of casing
- breached casing
- through fracture in annulus cement
- between cement and rock
- through and around internal wellbore seals

(from Gasda et al., 2004)
Example Element: Improved Well Construction Materials

**Activity**

**Quantify stress / chemical evolution needed for material/process improvements**

**Develop materials and processes that improve well integrity**

**Year 2 Goals**

- Establish industry partnerships
- Define basis for evaluating performance of candidate materials/technologies
- Perform synthesis and laboratory testing of 5 materials and methods compatible with representative subsurface environments
- Plan for performing field-like deployment

**Year 5 Goals**

- Perform field demonstration of candidate systems using **advanced materials** and/or processes that provide, for example, at least a **25% increase in bond strength** for anticipated range of well conditions (100-foot demo wells).
- Establish standards and **protocols for evaluating long-term performance** of well construction materials in representative environments and loading conditions.
- Develop methodologies for understanding the **effect of in situ stress evolution** and other forcing functions on the wellbore sealing system

**Year 10 Goals**

Develop or implement economical fit-for-purpose wellbore construction methods across a wide range of applications (e.g., producing wells, disposal wells, monitoring wells, etc.).
Motivation

- Methodologies to control permeability, fracture development and fluid flow pathways *with finesse* is missing.

Objective

- Develop the scientific basis and technologies to **quantify, characterize and manipulate** subsurface flow
- through an integration of physical alterations, physicochemical fluid/rock interaction processes, and novel stimulation methods implemented at the field scale

*Fox et al., 2015*
Example activity: Simulation of fracture networks & flow

- New numerical methods to simulate fracture initiation, propagation, flow and reactions
- Successful testing at laboratory through field scales
Transform ability to characterize subsurface systems by developing new approaches to:

- sense the subsurface
- analyze multiple datasets
- identify critical system transitions
- develop process control approaches
Novel tracers for fracture system characterization and monitoring

Example activities

Advanced Fiber-Optic Monitoring Tools for Seismic & Electrical Detection

Identify candidate intrinsic tracers, co-injected tracers, and natural fracture geophysical signatures suitable for pursuit.

Design and construct a fiber-optic point EM vector sensor and distributed EM sensor.

Demonstrate in field the use of improved tracers and natural signals to characterize a field fracture network.

Demonstrate the utility of the enhanced fiber-optic sensing systems for field scale real-time monitoring of fracture behavior.

Identification of diagnostic signatures and critical thresholds through transformative collection and analysis of new subsurface signals.
Field Energy Observatories Enable:

- In situ testing under controlled conditions - a critical aspect of RDD&D
- Coordination of SubTER activities (common site, materials)
- Community engagement
- Partnership with industry and stakeholders
- Partnerships across projects

Blue Canyon, NM
Several advances are required. Examples:

- **Modeling stress evolution** in wellbore environment and in reservoirs
- **Accurate simulation of coupled permeability, fracture propagation, fluid flow** and proppant behavior
- **Anticipate induced seismicity** constrained by diverse datasets
- **Risk assessment** frameworks
- **Integrated and rapid data processing, management, and knowledge** generation from multiple big & diverse datasets
- **Ultra-fast predictions and decision support** – toward decision support using exascale
SubTER @ AGU: Poster Session

➢ Friday AM, H51M

- 6 dB power beam pattern on the face of the concrete barrel

- Wide band, low frequency collimated beam (20-120 kHz)

- No side-lobes
More Information and Next Steps

Next Steps
- SubTER Industry Roundtable, Feb 2016
- Webinar and Engagements with Universities, 2016
- Pending FY16/17 Budget ~ SubTER Funding Opportunities

For More Information:
DOE Webpage: http://energy.gov/subsurface-tech-team
Natl. Lab Team Webpage: http://esd.lbl.gov/subter/home/subsurface-team/
Twitter: https://twitter.com/SubTERCrosscut
LinkedIn Groups: https://www.linkedin.com/groups/7017263