SubTER Tech Team
(Subsurface Technology and Engineering RD&D)

Co-Chairs: Doug Hollett (EERE) and Julio Friedmann (FE)

FE, EERE, NE, EM, SC, ARPA-E, OE, EPSA, CI, EIA

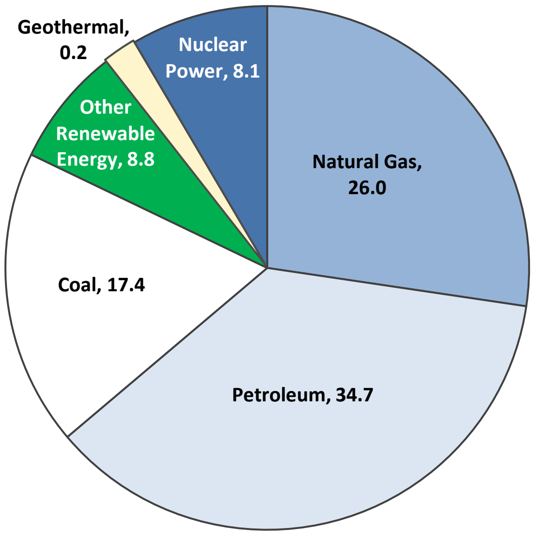
USEA July 22, 2014

Subsurface Control for a Safe and Effective Energy Future

Adaptive Control of Subsurface Fractures and Fluid Flow

Intelligent Wellbore Systems	Subsurface Stress & Induced Seismicity	Permeability Manipulation	New Subsurface Signals

Energy Field Observatories



Primary Energy Use by Source, 2012
Quadrillion Btu [Total U.S. = 95.1 Quadrillion Btu]

ENERGY PRODUCTION

- Increase U. S. electrical production from geothermal reservoirs
- Increase U.S. unconventional oil and natural gas for industrial and power applications and export
- Enhanced secure domestic supply

ECONOMIC & SOCIAL BENEFITS

- Retain U. S. leadership
- Increased public confidence
- Increase revenues (taxes and royalty) to Federal, State, and local governments

PROTECT THE ENVIRONMENT

- President's Climate Action Plan: Safely store CO_2 to meet GHG emissions reduction targets
- Safe storage/disposal of nuclear waste
- Reduced risk of induced seismicity
- Protect drinking water resources
- Alternatives for energy storage

ENERGY SECURITY

- NNSA core missions

Common Challenges: Solvable or "Chasms"?

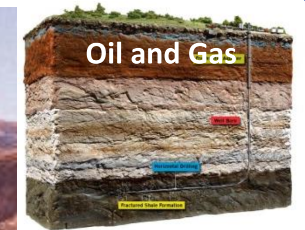
Discovering, Characterizing, and Predicting
Efficiently and accurately locate target geophysical and geochemical responses, finding more viable and low-risk resource, and quantitatively infer their evolution under future engineered conditions

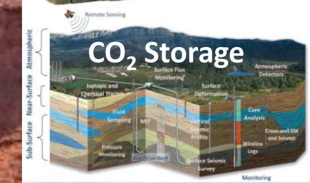
Accessing
Safe and cost-effective drilling, with reservoir integrity

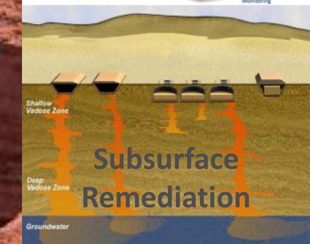
Engineering
Create/construct desired subsurface conditions in challenging high-pressure/high-temperature environments

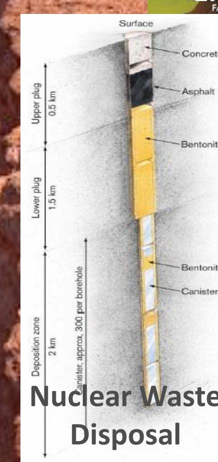
Sustaining
Maintain optimal subsurface conditions over multi-decadal or longer time frames through complex system evolution

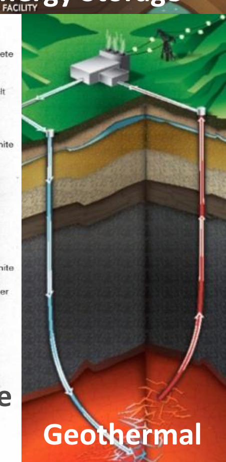
Monitoring
Improve observational methods and advance understanding of multi-scale complexities through system lifetimes











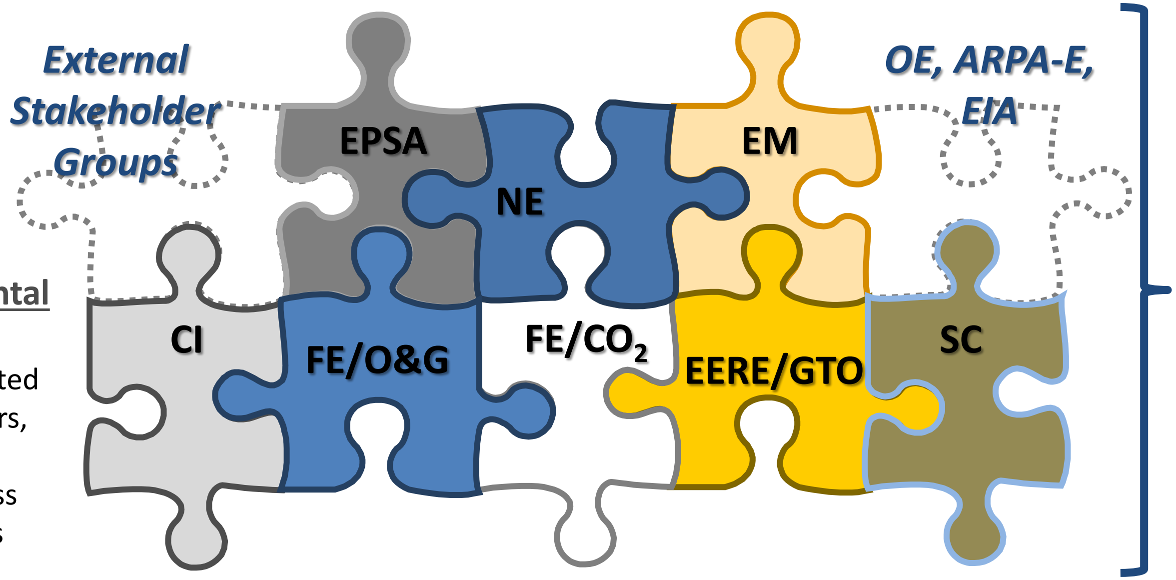
Coordination of Program Roles

Energy Policy & Systems Analysis
- Advisement: Secretary of Energy
- Policy: low-carbon and secure energy economy
- Technical assistance: States and local entities

Nuclear Energy
- Policy and technology: disposition of used nuclear fuel and waste
- R&D: deep borehole disposal concept

Environmental Management
- Modeling and tools: subsurface evaluation and characterization
- Cleanup: nuclear weapons legacy

Congressional & Inter-governmental Affairs
- Interactions: elected officials, regulators, and stakeholders
- Information access for change agents



SubTER Tech Team
- Encompasses relevant offices
- Reports to Under Secretary for Energy and Science
- Identifies and facilitates crosscutting subsurface R&D and policy priorities for DOE
- Develops collaborative FY15 spend plan and FY16 funding scenarios

Fossil Energy/Oil & Gas
- R&D and access: clean, affordable traditional fuel sources
- R&D: drilling, well construction and integrity, and hydraulic fracturing technologies

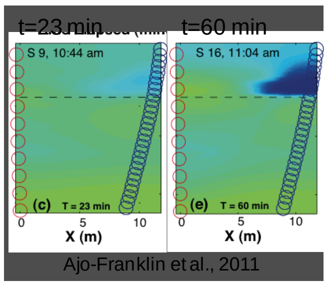
Fossil Energy/Carbon Storage
- Policy and technology: challenges of CO_2 storage to inform regulators, industry, and the public
- R&D: CO_2 offshore and onshore storage

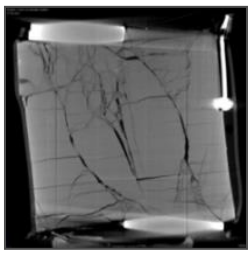
Energy Efficiency & Renewable Energy/ Geothermal Technologies Office
- R&D: locate, access, and develop geothermal resources
- R&D: access, create, and sustain enhanced geothermal systems (EGS)

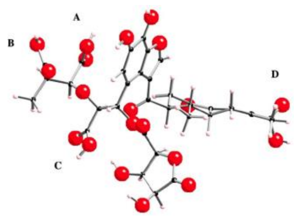
Science
- Basic research: geology, geophysics, and biogeochemistry
- Expertise: subsurface chemistry, complex fluid flow

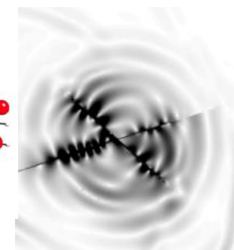
Lab Big Idea: March 12-13, 2014
Adaptive Control of Subsurface Fractures and Fluid Flow

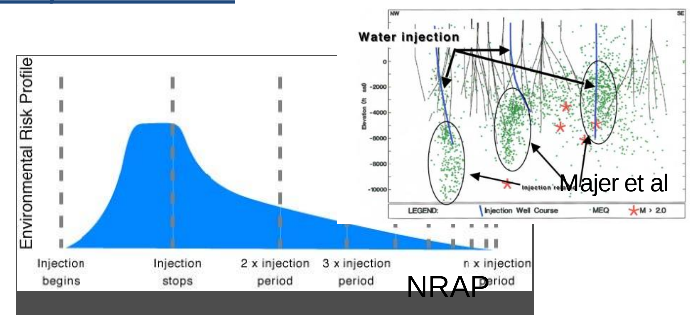
GOAL: Real-time measurement and control of fracture networks & associated flow
APPROACH: Experiments, simulations, theoretical frameworks, & field tests
OUTCOMES: Improved recovery factors, reduced operational and environmental risks, safety and reliability, new energy sectors – *major policy implications*











Fracture geomechanics, geochemistry and fluids basics

Characterization, Monitoring and Prediction

Strategies for Large-Scale Control

Adaptive Control of Subsurface Fractures and Fluid Flow

Environmental Risk

Drilling technologies and materials

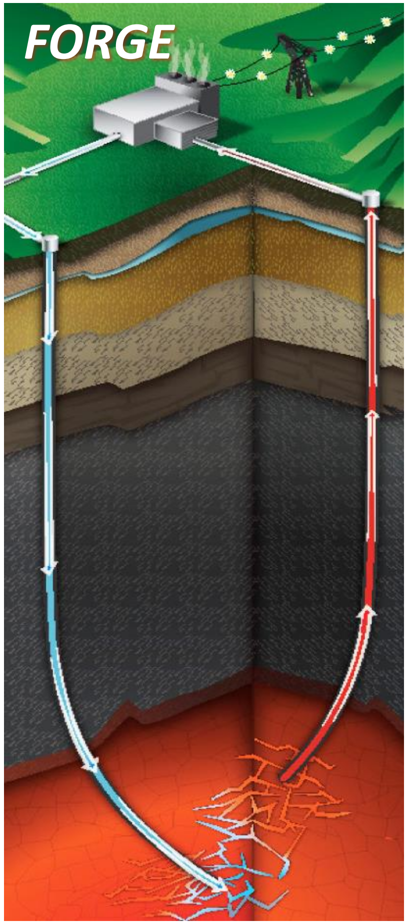
Energy Field Observatories

Field observatories: critically important SubTER efforts

Required (!) for fundamental subsurface progress

- Validation through monitoring/production
- Must manage restrictive subsurface environment well or fail
- Strong industry engagement
- Multiple potential business models:
    - Fit-for-purpose, dedicated site (FORGE, RMOTC)
    - Isolated, targeted effort (Frio CCS pilot)
    - Opportunistic (Weyburn)
- Expensive: individual sites = $10-25M/year commitment
- Each site: geology must accurately represent key phenomena

PHASE 1	PHASE 2	PHASE 3	Closeout
Select candidate sites	*FORGE site preparation & characterization*	*Continuous R&D testing and monitoring, innovative drilling, advanced stimulations, flow, sustainability testing*	*Decommission/ Transfer site*



Validation of new results and approaches at commercial scale;
Road-test monitoring, stimulation, and permeability control tools

Clear Alignment with Industry and Stakeholder Priorities

HALLIBURTON

- Nanotechnology
- Photonics
- ***Interfacial Chemistry***
- ***Complex Fracture Modeling in Real-time***
- Spectroscopy at the Bit
- Green Chemistry

Society of Petroleum Engineers

JPT

- ***Higher Resolution Subsurface Imaging***
- Challenges in Reusing Produced Water
- ***In-Situ Molecular Manipulation***
- Increasing Hydrocarbon Recovery Factors
- ***Carbon Capture and Sequestration***

the Bernard M. Gordon Center *for Subsurface Sensing & Imaging Systems*

- ***Subsurface Sensing and Imaging***
- ***Physics-Based Signal Processing and Image Understanding***

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

Grand Challenges for Earth Resources Engineering

- ***Make the earth transparent***
- ***Understand engineering control of coupled subsurface processes***
- ***Minimize environmental footprint***
- Protect people

USGS

science for a changing world

- Recognizing the signal within the natural variability
- ***Identifying feedback between natural and perturbed systems***
- Quantifying consequences, impacts, and effects
- ***Effectively communicating uncertainty and relative risk***

SubTER Workshop: Identified Challenges

SubTER Workshop With National Lab Partners - March 14, 2014

New subsurface signals

- Are there previously unexploited, measurable rock properties that can be used to further interrogate the subsurface? Are there new ways to integrate multiple signals?

Stress state beyond the borehole

- Are there new ways to measure the stress orientation and magnitude at various scales away from the borehole?

Multi-scale fracture evolution

- How can we improve our understanding of the initiation, growth, distribution and reactivation of natural and induced fractures across key scales?

Coupled physicochemical signatures

- How can we use natural and engineered geochemical signatures to further understand subsurface environments?

Fit for purpose modeling

- What are novel and advanced computational approaches that can be applied to subsurface interrogation?

Permeability Manipulation

- How can new knowledge of fracture mechanics and other fundamental physical properties of earth materials be applied to design more effective engineering procedures and help us understand the sustainability of engineered subsurface environments?

Novel stimulation methods

- Are there new ways to apply alternative energy sources to remotely affect subsurface bodies? Are there novel/advanced fluids and materials and new practices associated with these materials that could be used in subsurface engineering?

Beyond drill bits

- Are there new technologies for faster and cheaper access to the subsurface? How can advances in characterization and monitoring be most effectively coupled in real time with subsurface accessing and engineering (e.g., seeing ahead of the bit)?

Wellbore integrity

- How can risks with wellbore integrity be mitigated? What are new materials, self-healing cements? Can new sensors be developed to identify problems? Can we develop new, more effective and less costly remediation techniques?

SubTER Crosscut: Pillars and Themes

Adaptive Control of Subsurface Fractures and Fluid Flow

Intelligent Wellbores	Subsurface Stress & Induced Seismicity	Permeability Manipulation	New Subsurface Signals
Materials: adaptive cements, muds, casing	Stress state beyond the borehole	Physicochemical rock physics, including fluid-rock interactions	Diagnostic signatures of system behavior and critical thresholds
Real time, in-situ data acquisition and transmission system	Signal acquisition and processing and inversion	New approaches to remotely characterize in-situ fractures and to monitor fracture initiation/branching and fluid flow	Autonomous acquisition, processing and assimilation approaches
Diagnostics tools, remediation tools and techniques	Localized manipulation of subsurface stress	Manipulating (enhancing, reducing and eliminating) flow paths	Integration of different measurements collected over different scales to quantify critical parameters and improve spatial and temporal resolutions
Quantification of material/seal fatigue and failure	Risk assessment	Novel stimulation methods	
Advanced drilling and completion tools (e.g., anticipative drilling & centralizers)			
Well abandonment analysis/ R&D			

Energy Field Observatories: (Wells, Ops and Logistics)

Impact of R&D Crosscut – Select Examples

Energy Field Observatories: (Wells, Ops and Logistics)

FY16 SubTER expanded programs

FY16 Programs

What is Industry Doing?

Intelligent Wellbores

- **Adaptive materials**
- **Additive manufacturing of sensors**
- **Downhole power and wireless telemetry**

- Cements
- NRAP
- Corrosion prevention
- High-T steerable drilling

- Cements
- Fiber Optics
- P/T sensors

Subsurface Stress & Induced Seismicity

- **Far-field stress measurement**
- **High-T wireline logging**

- Mini-fracs
- MEQ focal mechanism inversion

- Borehole-based measurement
- Microseismic processing

Permeability Manipulation

- **Shape-memory alloys**
- **In-situ, real time analysis of flow**
- **High-T proppants**

- Polymer gels
- Interfacial chemistry

- Fracture stimulation
- Geometry-based approach
- Chemicals

New Subsurface Signals

- **Geophysically detectable nano-injectates**
- **Muon tomography**
- **Autonomous acquisition & processing**

- Joint inversion of data sets
- Tracers

- Seismic reflection, attributes, processing

Workshop Goals and Objectives

- Do these challenges and related R&D directions, accurately represent the technology landscape related to fracture propagation and fluid flow in the subsurface?
- Are there additional areas or themes within this topic, which should be considered?
- Is this a high-impact problem or challenge?
- Is the topic sufficiently open ie, does it address the broad problem, and is it appropriately open to new ideas, approaches, directions?
- Does solution of this problem, result in enduring benefit to the United States – economic, environment etc? What could be the impact?
- What are the gaps between what is being pursued in the private sector, vs publicly funded R&D?