Exceptional service in the national interest

Sandia National Laboratories

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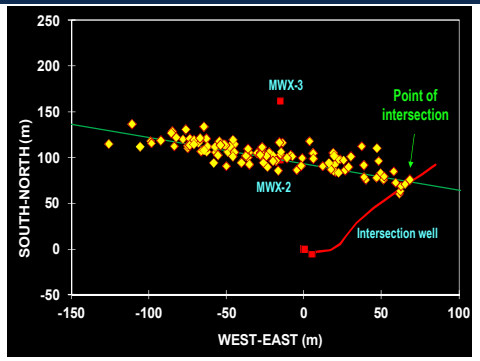
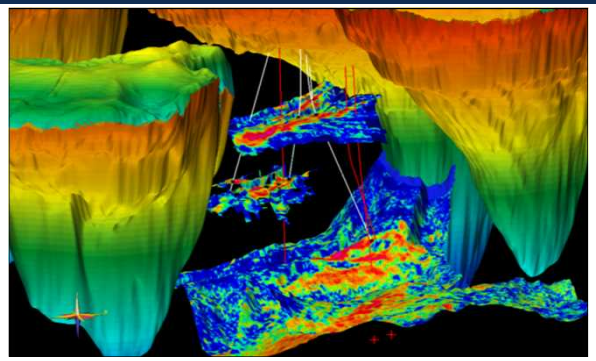
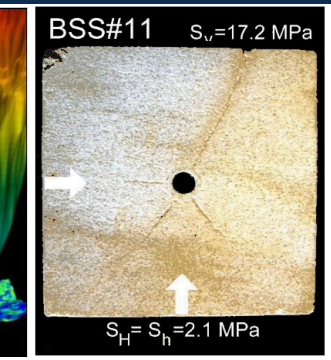






DOE Subsurface Technology and Engineering RD&D (SubTER) Overview

Offices of . . .

Energy Efficiency and Renewable Energy
Fossil Energy
Nuclear Energy
Environmental Management
Science
Energy Policy and Systems Analysis
Electricity Delivery and Energy Reliability
Congressional and International Affairs
Energy Information Administration
ARPA-E

Marianne Walck

January 16, 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

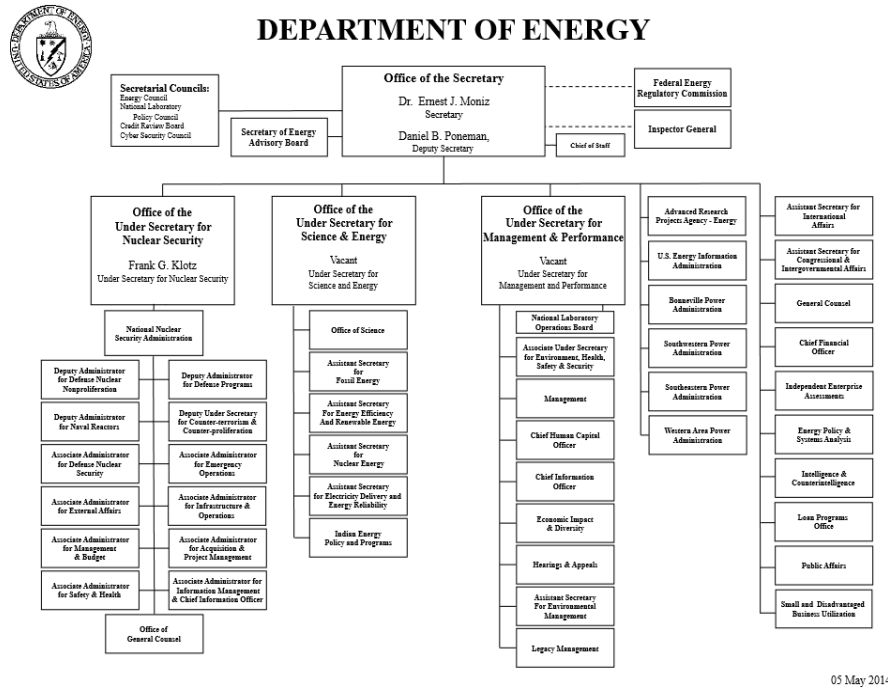
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

New structure and emphasis at DOE

Sandia National Laboratories

- **Secretary Moniz created:**
  - Undersecretary for Science and Energy to better integrate Energy Technology Programs with basic research
    - Lynn Orr confirmed by Senate for Undersecretary Post
  - 6 crosscutting "Tech Teams" : Goal – Large FY16 programs
    - **Grid***
    - Water-Energy (WETT)
    - Supercritical CO_2 Brayton Cycle
    - Advanced Computing
    - Manufacturing
    - **Subsurface Technology and Engineering RD&D (SubTER)***

***Moving forward for FY16**



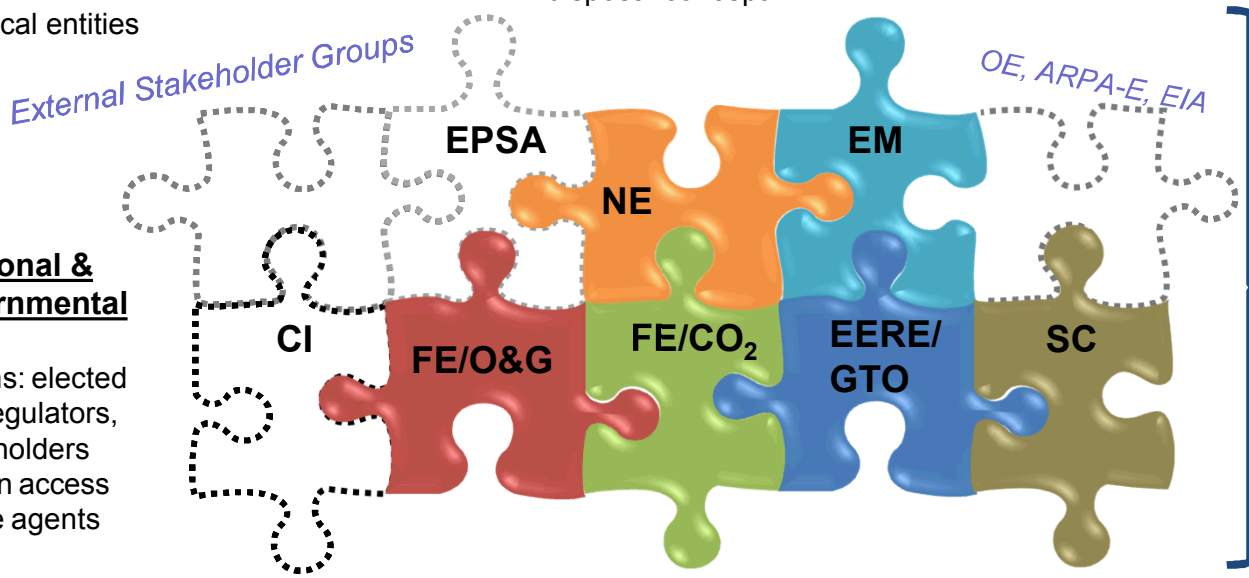
Overview of Program Roles

Sandia National Laboratories

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 spend plan and 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

Common Subsurface Energy Challenges

Sandia National Laboratories

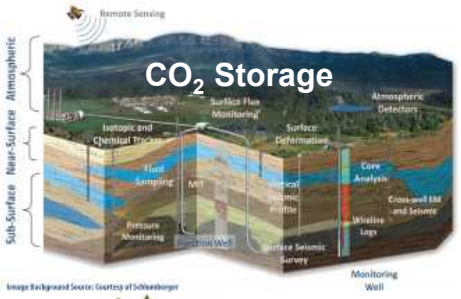
Discovering, Characterizing, and Predicting
Efficiently and accurately locate target geophysical and geochemical responses, finding more viable and low-risk resource, and quantitatively infer their evolution under future engineered conditions

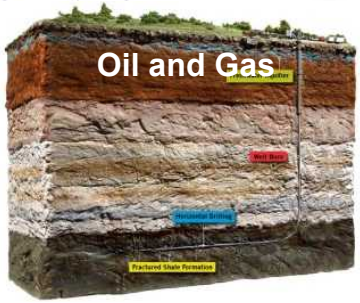
Accessing
Safe and cost-effective drilling, with reservoir integrity

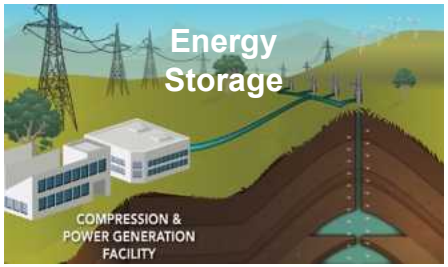
Engineering
Create/construct desired subsurface conditions in challenging high-pressure/high-temperature environments

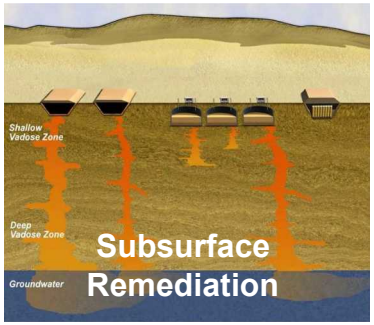
Sustaining
Maintain optimal subsurface conditions over multi-decadal or longer time frames through complex system evolution

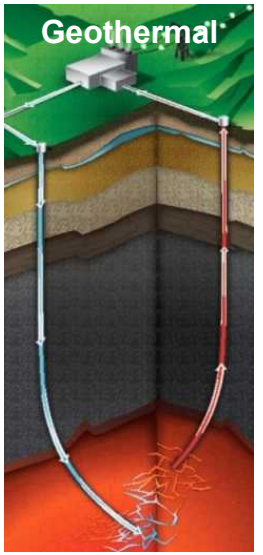
Monitoring
Improve observational methods and advance understanding of multi-scale complexities through system lifetimes

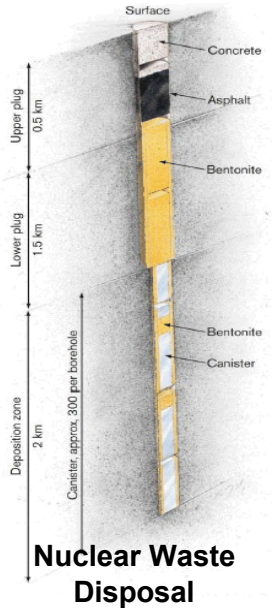










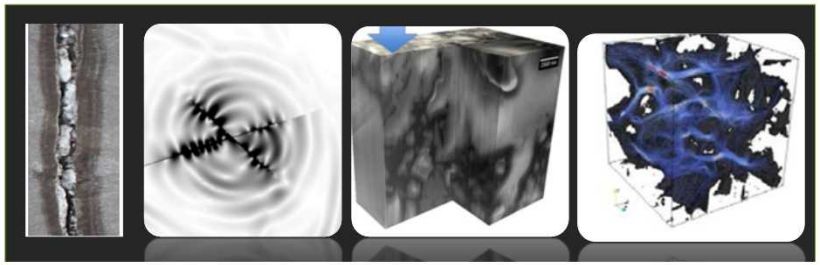


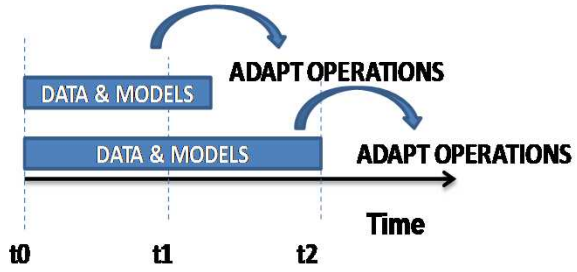
“Adaptive Control” of subsurface fractures and flow

Sandia National Laboratories

Ability to adaptively manipulate - with confidence and rapidly- subsurface fracture length, aperture, branching, connectivity and associated reactions and fluid flow.

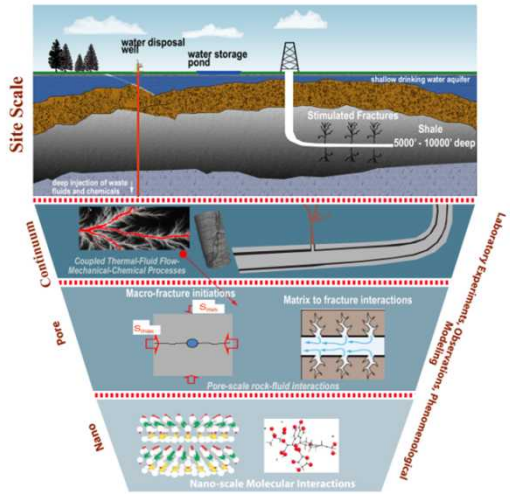
A “Grand Challenge”

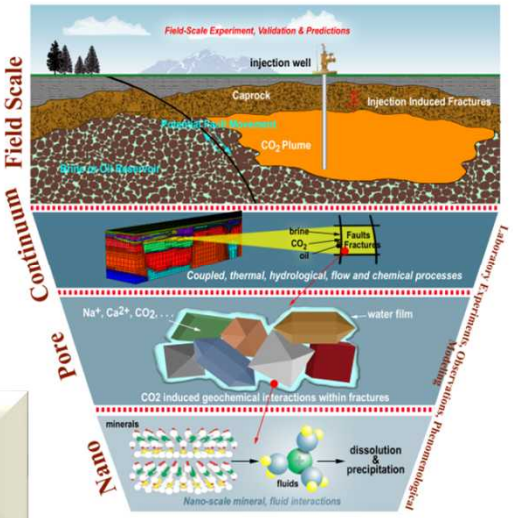




General Technical Baseline: State of Knowledge & Practice

- Reservoir stress distribution and material properties are highly heterogeneous and largely unknown
- Mechanistic understanding of multi-scale processes that influence stress distribution and thus fracture formation and flow is lacking - limits both production and subsurface storage
- Industry is developing approaches to improve fracture creation, commonly guided by empirical field evidence. Industry not attempting 'real time' control
- Significant public concern and uncertainty associated with environmental risks





Today we cannot accurately image, predict, or control fractures with confidence or in real-time.

Subsurface Control for a Safe and Effective Energy Future

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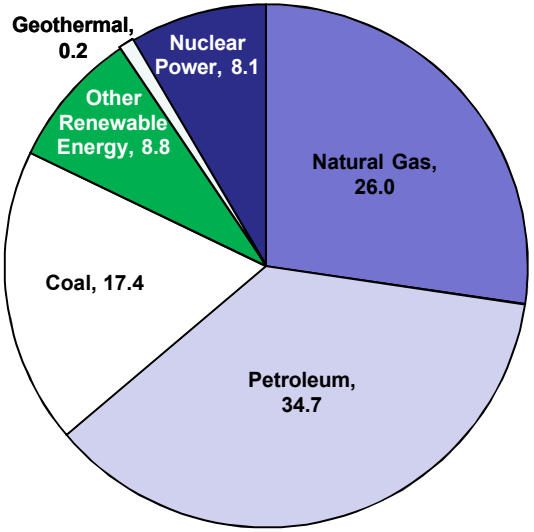
Adaptive Control of Subsurface Fractures and Fluid Flow

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 multiple uses

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 CO2 to meet GHG emissions reduction targets
- Safe storage/disposal of nuclear waste
- Reduced risk of induced seismicity
- Protect drinking water resources

ENERGY SECURITY

- Increased recovery factors from tight formations can vastly increase the longevity of US energy security

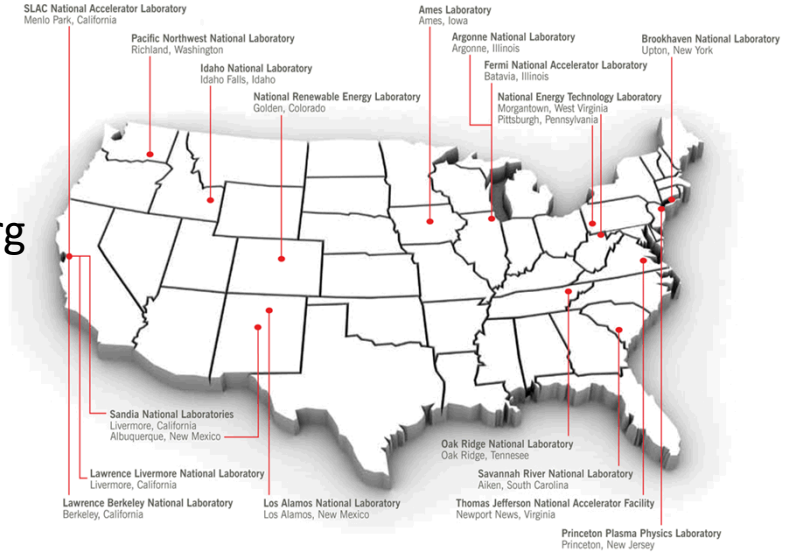
What Is Unique About the SubTER Initiative?

- Facilitates innovation to address **climate change** and reduce greenhouse gas emissions
  - Safe storage of CO_2
  - Increased deployment of renewable energy (geothermal)
  - Reduction of fugitive methane emissions through improved wellbore technologies, etc.
- Addresses challenges and opportunities with **water** management
- Drives innovation to improve **safety** associated with subsurface energy operations
- Advances new concepts for safe and responsible disposal of **nuclear waste**
- Increased recovery factors from tight formations can vastly increase the longevity of US **energy security**
- Implementation of a **new collaborative model** to tackle an energy "grand challenge" faced by multiple sectors

Subsurface Working Team:
13 Laboratories

Sandia National Laboratories

ANL: Randall Gentry
BNL: Martin Schoonen
INL: Earl Mattson, Hai Huang
LANL: Rajesh Pawar, Melissa Fox, Andy Wolfsberg
LBNL: **Susan Hubbard (co-lead)**, Curt Oldenburg (deputy), Jens Birkholzer
LLNL: Roger Aines, Jeff Roberts, Rob Mellors
NREL: Charles Visser
NETL: Grant Bromhal
ORNL: Eric Pierce, Yarom Polsky
PNNL: Alain Bonneville, Dawn Wellman, Tom Brouns
SLAC: Gordon Brown
SNL: **Marianne Walck (co-lead),** Doug Blankenship (deputy), Susan Altman
SRNL: Lisa Oliver, Ralph Nichols



Argonne NATIONAL LABORATORY
BROOKHAVEN NATIONAL LABORATORY
INL Idaho National Laboratory Operated by Battelle Energy Alliance
Los Alamos NATIONAL LABORATORY EST.1943
BERKELEY LAB LAWRENCE BERKELEY NATIONAL LABORATORY
Lawrence Livermore National Laboratory
NETL
NREL NATIONAL RENEWABLE ENERGY LABORATORY
OAK RIDGE National Laboratory
Pacific Northwest NATIONAL LABORATORY
SLAC NATIONAL ACCELERATOR LABORATORY
Sandia National Laboratories
SRNL SAVANNAH RIVER NATIONAL LABORATORY

Subsurface Control for a Safe and Effective Energy Future

Sandia National Laboratories

Adaptive Control of Subsurface Fractures and Fluid Flow

Intelligent Wellbore Systems	Subsurface Stress & Induced Seismicity	Permeability Manipulation	New Subsurface Signals
Improved well construction materials and techniques	Measurement of stress and induced seismicity	Physicochemical fluid-rock interactions	New sensing approaches
Autonomous completions for well integrity modeling	Manipulation of stress and induced seismicity	Manipulating flowpaths	Integration of multi-scale, multi-type data
New diagnostics for wellbore integrity	Relating stress manipulation and induced seismicity to permeability	Characterizing fractures, dynamics, and flows	Adaptive control processes
Remediation tools and technologies	Applied risk analysis of subsurface manipulation	Novel stimulation methods	Diagnostic signatures and critical thresholds
Fit-for-purpose drilling and completion tools (e.g. anticipative drilling, centralizers, monitoring)			
HT/HP well construction/ completion technologies			

Energy Field Observatories

Fit For Purpose Simulation Capabilities

FY2014-2015 SubTER Crosscut

What is currently underway?

Sandia National Laboratories

<u>JASON advisory group report:</u> "State of Stress in Engineered Subsurface Systems," 9/14
Co-funded by 7 DOE offices (FE, EE, NE, EPSA, SC, EM, ARPA-E)

Recommends ***"that DOE take a leadership role in the science and engineering needed for developing engineered subsurface systems, addressing major energy and security challenges of the nation."***

<u>$1.6M FY14 funding towards SubTER lab projects from EERE and FE:</u>

- Wellbore – LANL: 3D acoustic borehole integrity monitoring system
- Stress, Permeability – LBNL: Field Laboratory in a Deep Mine for the Investigation of Induced Seismicity and Fracture Flow
- Stress – LANL: Evaluating the State of Stress Away from the Borehole
- Stress – ORNL: Luminescence spectroscopy stress sensor for in-situ stress measurement
- Stress – NETL: Big Data and Analytics for Induced Seismicity
- New Signals – PNNL: Borehole muon detector for 4D density tomography of subsurface reservoirs

Seed funding to these projects will kick-start efforts in FY15, FY16 and beyond . . .

FY2015 Example Priority Aligned Activities Within Offices

Sandia National Laboratories

Energy Efficiency and Renewable Energy

- FORGE (Frontier Observatory for Research in Geothermal Energy)

Fossil Energy, Oil & Gas and Carbon Storage

- NRAP
- Unconventional Resources Field Laboratories

Nuclear Energy, Office of Used Nuclear Fuel Disposition

- Activities related to initiating the Deep Borehole Field Test in FY16, which is a high priority item for the Office of Nuclear Energy

Science, Basic Energy Science (BES)

- Foundational Research
- EFRCs: Centers for Geologic Storage of CO2, Frontiers of Subsurface Energy Security, and Nanoscale Controls on Geologic CO2

At least $6M could be available for collaboratively funded SubTER projects in FY15. This builds on the kick-off "seed" funding for $1.6M in FY14. Details will be communicated in coming months at energy.gov/subsurface-tech-team

Environmental Management

- Investigate the use and development of universal canisters for EM waste disposal in borehole

How can the Academic Community be Involved?

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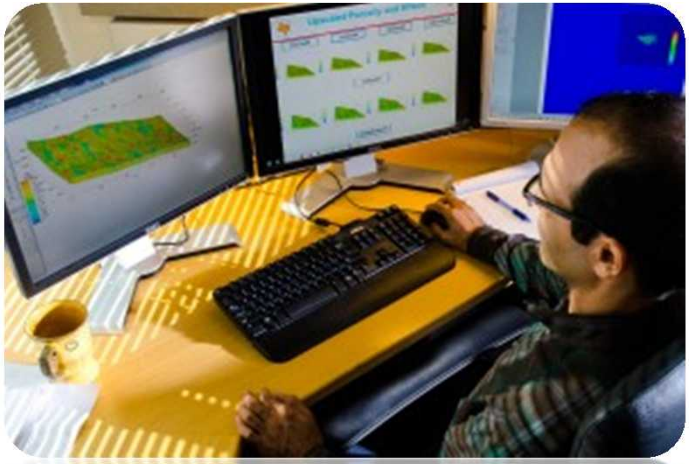


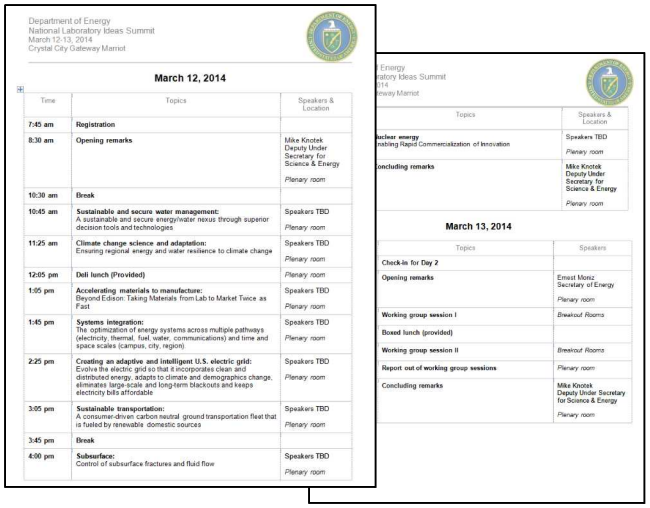
- **Your input now can contribute to shaping the scope of SubTER.**
- **Funding opportunities will be announced leading up to and/or after the full launch of this initiative in FY16 (pending appropriations).**
- **Partnerships with National Labs can facilitate involvement in other aspects of the Subsurface Crosscut starting in FY15.**

Sandia National Laboratories

Backup Slides

National Laboratory "Big Idea" Summit: March, 2014

- **DOE asked the NL Chief Research Officers to develop a set of "Big Ideas" for DOE to consider for large FY16 investments**
- **Laboratories developed multi-lab teams for 8 ideas:**
  - Advanced Manufacturing
  - Nuclear Energy
  - Climate
  - Energy/Water
  - Subsurface
  - Grid
  - Energy Systems Integration
  - Transportation


Department of Energy
National Laboratory Ideas Summit
March 12-13, 2014
Crystal City Gateway Marriot

March 12, 2014

Time	Topics	Speakers & Location
7:45 am	Registration	
8:30 am	Opening remarks	Mike Knotek Deputy Under Secretary for Science & Energy *Plenary room*
10:30 am	Break	
10:45 am	Sustainable and secure water management: A sustainable and secure energy/water nexus through superior decision tools and technologies	Speakers TBD *Plenary room*
11:25 am	Climate change science and adaptation: Ensuring regional energy and water resilience to climate change	Speakers TBD *Plenary room*
12:05 pm	Deli lunch (Provided)	*Plenary room*
1:05 pm	Accelerating materials to manufacture: Beyond Edison: Taking Materials from Lab to Market Twice as Fast	Speakers TBD *Plenary room*
1:45 pm	Systems integration: The optimization of energy systems across multiple pathways (electricity, thermal, fuel, water, communications) and time and space scales (campus, city, region)	Speakers TBD *Plenary room*
2:25 pm	Creating an adaptive and intelligent U.S. electric grid: Evolve the electric grid so that it incorporates clean and distributed energy, adapts to climate and demographics change, eliminates large-scale and long-term blackouts and keeps electricity bills affordable	Speakers TBD *Plenary room*
3:05 pm	Sustainable transportation: A consumer-driven carbon neutral ground transportation fleet that is fuelled by renewable domestic sources	Speakers TBD *Plenary room*
3:45 pm	Break	
4:00 pm	Subsurface: Control of subsurface fractures and fluid flow	Speakers TBD *Plenary room*

Topics	Speakers & Location
Nuclear energy: Pathway Rapid Commercialization of Innovation	Speakers TBD *Plenary room*
Concluding remarks	Mike Knotek Deputy Under Secretary for Science & Energy *Plenary room*

March 13, 2014

Topics	Speakers
Check-in for Day 2	
Opening remarks	Ernest Moniz Secretary of Energy *Plenary room*
Working group session I	*Breakout Rooms*
Boxed lunch (provided)	
Working group session II	*Breakout Rooms*
Report out of working group sessions	*Plenary room*
Concluding remarks	Mike Knotek Deputy Under Secretary for Science & Energy *Plenary room*

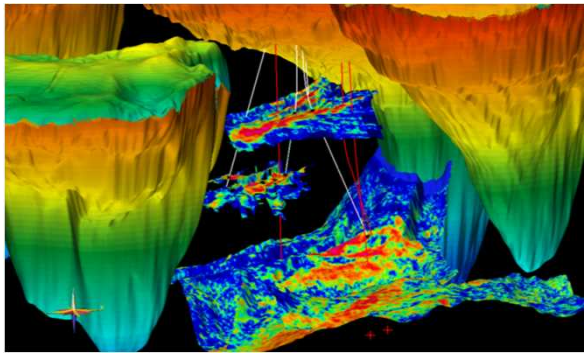
- **SNL Leadership in Subsurface, Energy/Water, Transportation**
- **Summit meeting: March 12-13, 2014**

Sandia Capabilities – SubTER themes

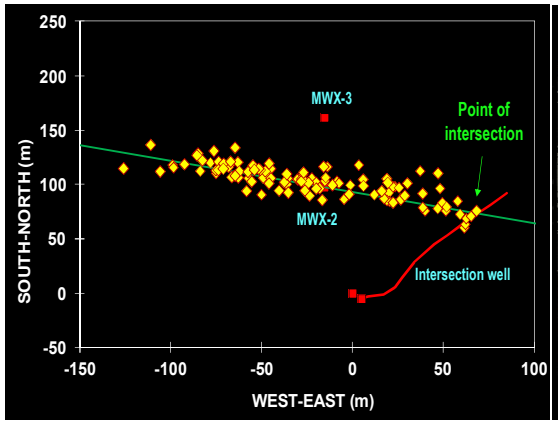
- **Wellbore Integrity and Drilling Technology**
  - Rock reduction and HT/HP Drilling Technologies
  - Drilling vibration mitigation using active cancellation of drill-string dysfunctions
  - Lost circulation control in harsh environments
  - Casing centralization
  - Field studies
- **Subsurface Stress and Induced Seismicity**
  - Hydraulic fracturing research for *in situ* stress Determination
  - Microseismic Monitoring of Reservoir Stimulation
  - Computational Modeling of Hydraulic Fracturing
  - Development of Core Based Stress Measurements (Anelastic Strain Recovery)
  - Computational Geomechanics

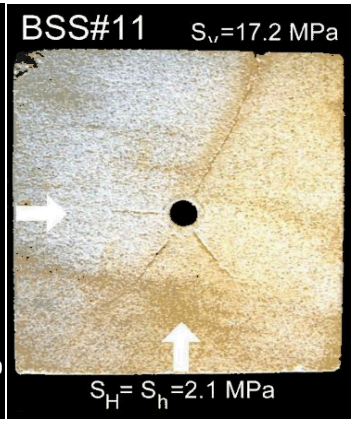

Modern PDC Bit (Courtesy of NOV)

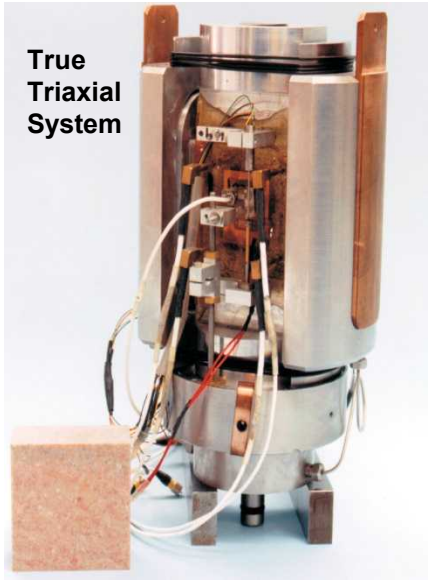

Drilling Dynamics Simulation




Multiwell Experiment (MWX)

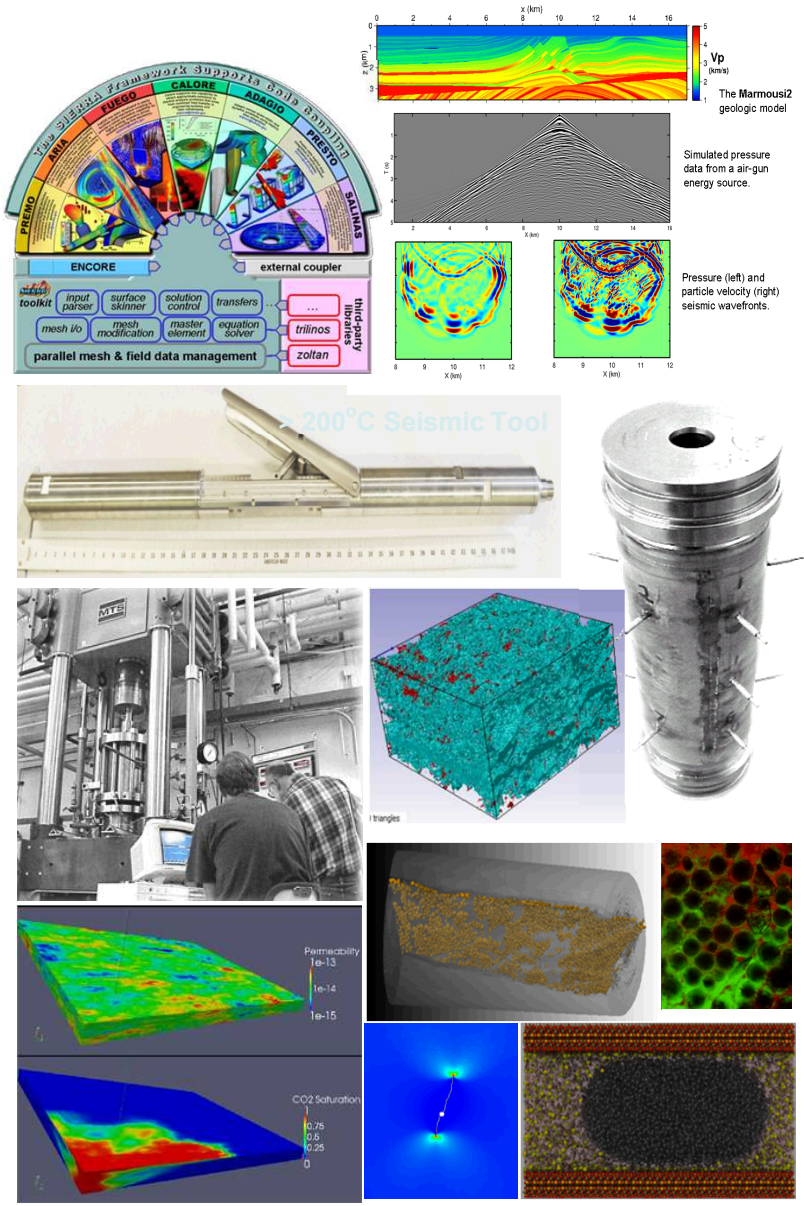





True Triaxial System

Sandia Capabilities – SubTER Themes

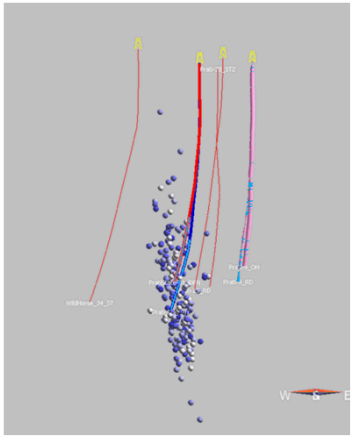
- **New Subsurface Signals**
  - High temperature, high pressure monitoring tools
  - Design, implementation, and interpretation of geophysical experiments: seismic, acoustic, EM
  - Finite difference geophysical modeling: data processing, analysis and interpretation
  - Natural tracer experiments
  - Proppant studies
  - Wide band gap devices for instrumentation (CINT/MESA
- **Permeability Manipulation**
  - High pressure and multiphase fluid delivery system for pore-scale flow experiments
  - Advanced “Waterless” Stimulation Technologies with Controlled Energetic Materials
  - Geomechanical testing: uniaxial, triaxial, creep, hydrostatic
  - Porescale and nanoscale experiment and modeling; reactive transport
  - Flow, Imaging and Coupled Constitutive Behavior of Porous Media
  - Risk Analysis methodologies: WIPP, YMP
- **Fit for Purpose Simulation Capabilities**
  - Large-scale Atomic/Molecular Massively Parallel Simulator (LAMMPS)
  - Sierra Mechanics engineering analysis codes
  - Constitutive models, e.g., Kayenta
  - Simulating fluid-induced discrete-fracture propagation using random finite-element meshes
  - Peridynamics fracture modeling



Criticality of Core Themes

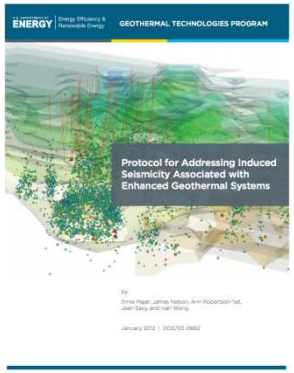
Subsurface Stress and Induced Seismicity

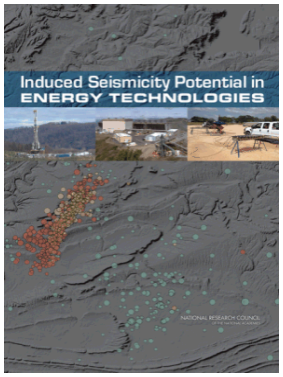
Sandia National Laboratories



Induced Seismicity at The Geysers Geothermal Field (Calpine)

Approach to Date: Geothermal sector has proactively developed its own induced seismicity management protocol. CO_2 storage developing new risk assessment tools through NRAP.





Increasing societal relevance of induced seismicity as EGS deployment and CO_2 storage grow, akin to oil and gas today

Experts Eye Oil and Gas Industry as Quakes Shake Oklahoma
-New York Times, Dec. 12, 2013

***Subsurface Stress and Induced Seismicity Program*:**

- Improved stress measurements
- Broader data acquisition and sharing
- Advanced risk assessment tools

Permeability *Manipulation* and ***New Subsurface Signals*** are also critical components of overall effective reservoir management that are essential for scaling up EGS and CO_2 storage safely and effectively

Outcomes:

- Improved understanding of the subsurface
- Mitigation and reduced risk
- Safe scale up
- Improved resource identification and development

Criticality of Core Themes

Wellbore Integrity

New Study Published in the Proceedings of the National Academy of Science Highlights Wellbore Integrity as a critical issue

-Darrah et al. PNAS- ***September 15, 2014***

"We document fugitive gases in eight clusters of domestic water wells overlying the Marcellus and Barnett Shales, including declining water quality through time over the Barnett. Gas geochemistry ***data implicate leaks through annulus cement*** (four cases), ***production casings*** (three cases), and ***underground well failure*** (one case) rather than gas migration induced by hydraulic fracturing deep underground."

Deep borehole disposal provides an alternative approach.

Quarrels Continue Over Repository for Nuclear Waste –New York Times, June 27, 2013

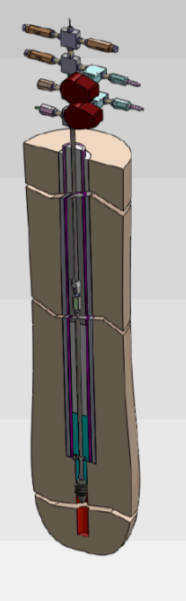
Approach: New Ways to Control Permeability and Flow

Sandia National Laboratories

Precise control over fracturing and fluid flow is critical for efficient extraction of energy resources, as well as for containment of CO_2 and waste streams.

Approach to Date:

- Geometry-based approaches
- Chemical manipulation
- Incomplete physical treatment in models



Gas phase bi-propellant energetic stimulation design (Sandia National Laboratories)

***SubTER Permeability Manipulation objectives*:**

- Novel stimulation techniques (e.g., water-free energetics, shape-memory alloys)
- Advances in reservoir and seal performance mechanisms for contaminant flow and trapping
- In-situ, real time imaging, modeling, and analysis of flow

Outcomes:

- Improved control over fluid migration and reservoir integrity
- Mitigation and reduced risk
- Safe scale up of EGS, carbon storage, and high-level waste disposal

Approach: New Ways to Acquire and Integrate Subsurface Signals

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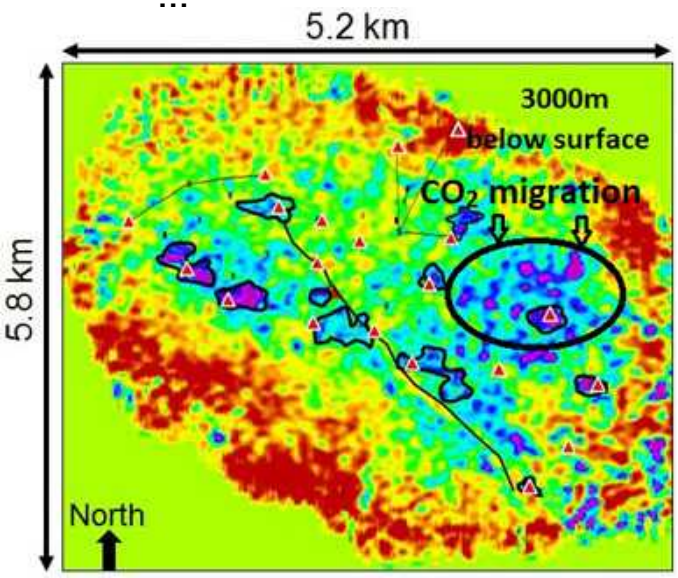
High fidelity characterization of subsurface environments is critical to successful subsurface engineering efforts.

Approach to Date:

- Seismic, electromagnetic, and gravity methods from the surface and the ...



High resolution inverted seismic images of CO_2 migration at the Cranfield injection site

***SubTER Subsurface Signals Objectives*:**

- R&D on small-scale deployable sensors
- Autonomous acquisition, processing and assimilation
- Identification of critical system transitions

Outcomes:

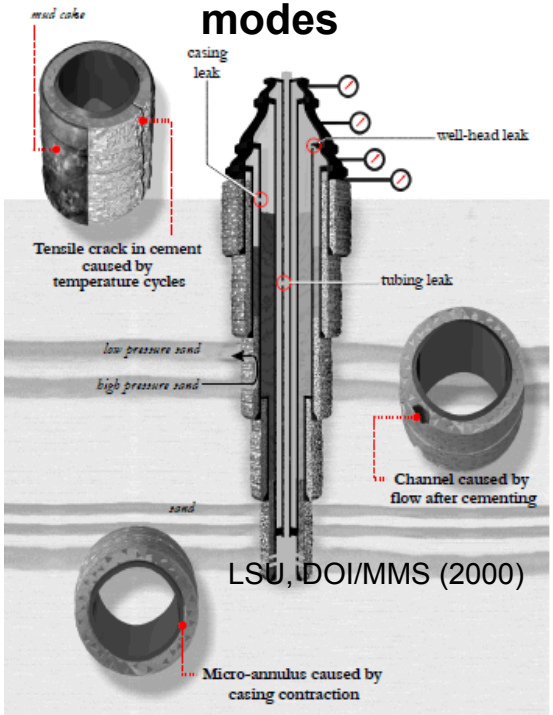
- New ways to "see" subsurface fractures and fluid pathways.
- Acquisition of data necessary for adaptive control of subsurface fractures and fluid flow.

Approach: Intelligent Wellbore Systems R&D

Intelligent Wellbores: Self-healing cements and integrated-casing monitoring systems for enhanced wellbore performance assurance

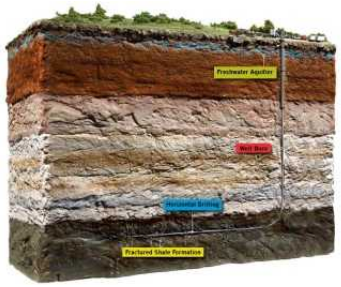
wide band gap semiconductors + advanced manufacturing + HT electronics and sensors + materials science industry + national labs + academia

Casing/cement failure modes

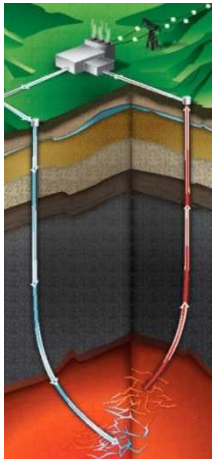


LSU, DOI/MMS (2000)

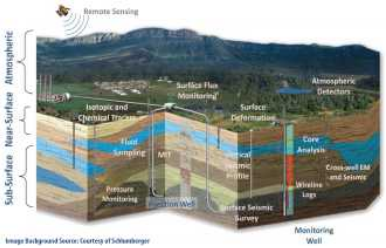
multi-decadal **REQUIRED LIFETIME** **millennial**



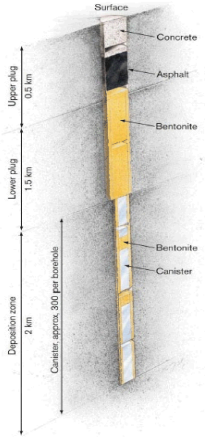
Oil and Gas



Geothermal



CO_2 Storage



Nuclear Waste Deep-Borehole Disposal

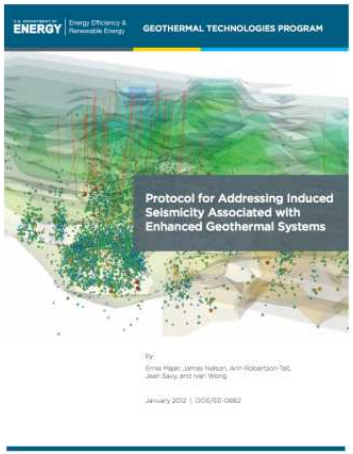
Class VI permit process, used-fuel disposition regulatory framework…

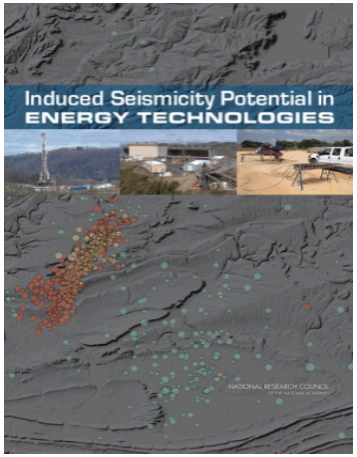
Approach: "Virtual" Field Observatory

Increasing societal relevance of induced seismicity as wastewater injection associated with natural gas extraction continues to expand and as EGS deployment grows.

Approach to Date:

- Induced seismicity management protocol





***SubTER Subsurface Stress and Induced Seismicity Program*:**

- Improved stress measurements
- Broader data acquisition and sharing
- Advanced risk assessment tools

Permeability *Manipulation* and ***New Subsurface Signals*** are also critical components of overall effective reservoir management that are essential for ensuring safe and effective subsurface operations.

Outcomes:

- Improved understanding of the subsurface
- Mitigation and reduced risk
- Safe scale up of EGS and carbon storage
- Improved resource identification and development

Approach: Field observatories are critically important to SubTER efforts

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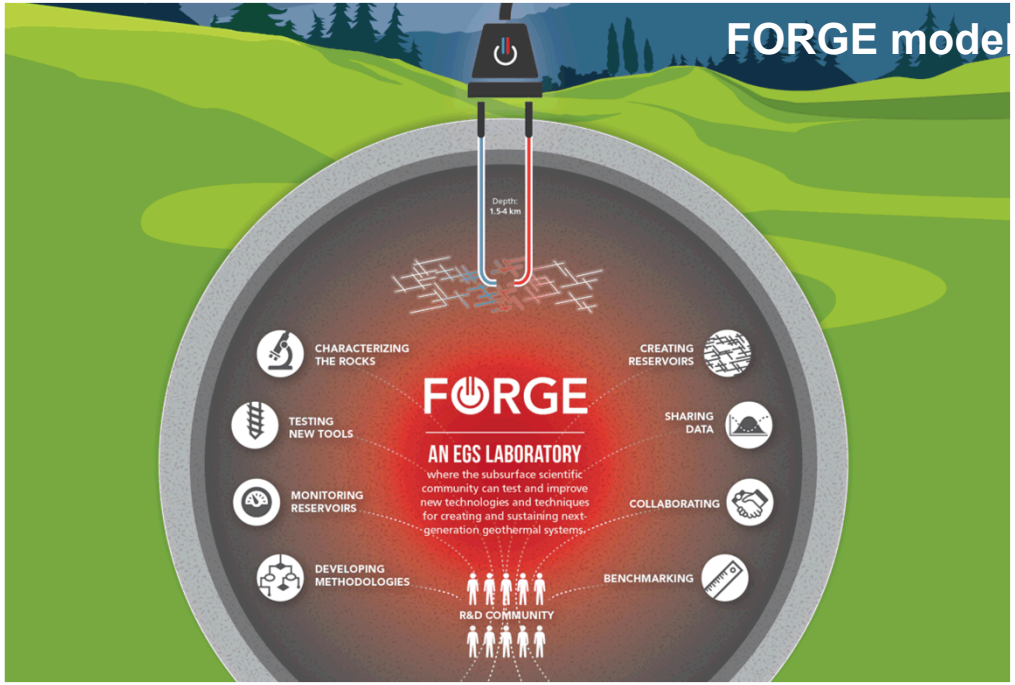
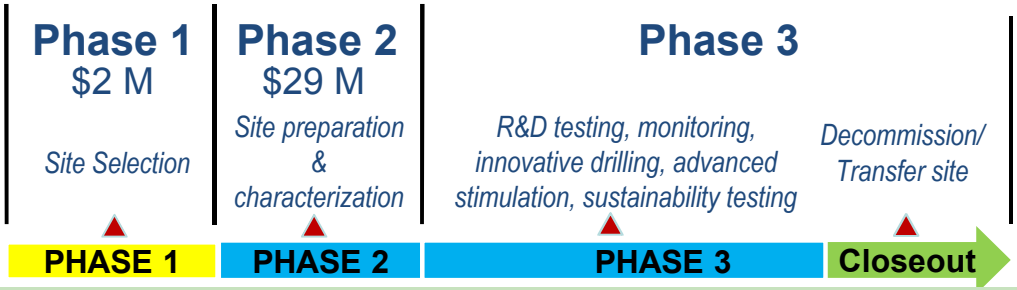
Required for fundamental subsurface progress

- Validation through monitoring/production
- Site-specific conditions
- Strong industry engagement
- Multiple business models:
  - Fit-for-purpose, dedicated site (FORGE, RMOTC)
  - Isolated, targeted effort (Frio CCS pilot)
  - Opportunistic (Weyburn)
- Expensive: individual sites = $10-35M/year commitment

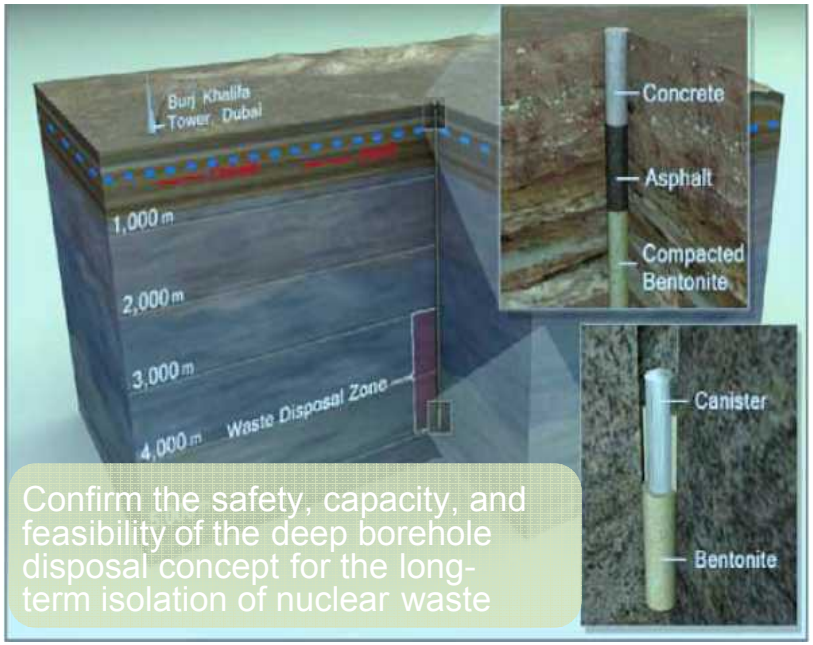


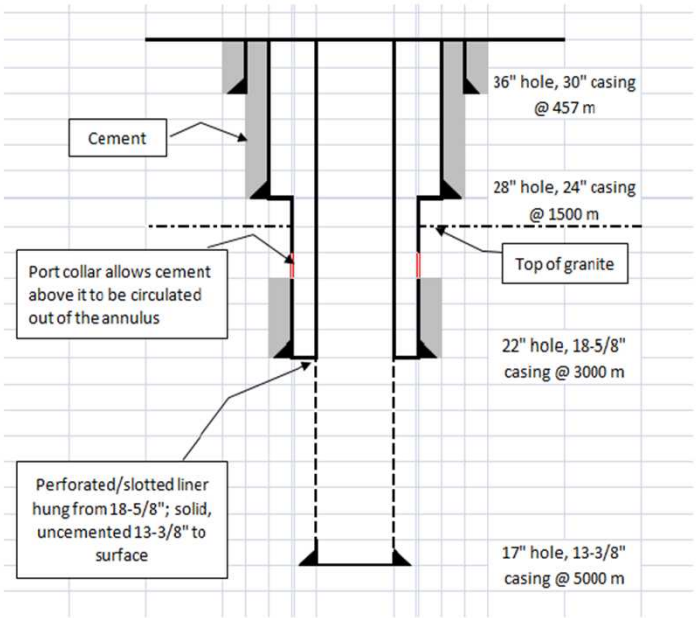


Validation of new results and approaches at commercial scale;
Road-test monitoring, stimulation, and permeability- and flow-control tools

Approach: Deep Borehole Field Test

- Demonstrate the feasibility of characterizing and engineering deep boreholes (no actual waste disposal)
- Demonstrate safe processes and operations for safe waste emplacement downhole





Crosscut Benefit: *Drilling technology, well construction and integrity, and subsurface characterization.*

Clear Alignment with Industry and Stakeholder Priorities

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HALLIBURTON

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

SPE 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***

Outreach and Consultation

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Past:

- Subsurface Technology & Engineering Challenges and R&D Opportunities: Stress State & Induced Seismicity"
  U.S. DOE Public workshop hosted by the United States Energy Association (USEA), October 2014, Washington, DC
- Geothermal Research Council Annual meeting, October 2014, Portland, OR
- National Research Council CER-COGGE joint meeting on Critical Issues in the Subsurface, October 2014, Washington, DC
- Chevron and ConocoPhillips Technology Boards, October 2014
- Industry letters of support, September 2014:

  Ben Bloys, Manager, Chevron/Los Alamos Technology Alliance: "… extremely supportive of the overall objectives of this program … Adaptive control of fracturing and fluid flow … is becoming increasingly critical for environmentally sustainable, safe, and profitable utilization of subsurface resources for various energy extraction and storage applications."

  Bob Kleinberg, Senior Fellow, Schlumberger: "… a nationally-important initiative that deserves a high level of support … I would advocate for cooperation on such subjects as wellbore integrity, fracture mechanics, rock-fluid interactions and flowback water sensing and diagnostics."
- Shell Amsterdam Centennial Conference Breakout Session: "Toward Control of Reservoir Fracture Dynamics, Reactions and Flow ", September 2014, Amsterdam
- NSF September 2014, Arlington
- USGS August 2014, Reston
- Subsurface Technology & Engineering Challenges and R&D Opportunities: Control of Fracture Propagation & Fluid Flow"
  U.S. DOE Public workshop hosted by the United States Energy Association (USEA), July 2014, Washington, DC
- ExxonMobil, Apache July 2014
- National Research Council Committee on Geological and Geotechnical Engineering Meeting, May 2014, Washington, DC
- Carbon Mitigation Initiative, a 15-year partnership between Princeton University and BP, April 2014, Princeton
- National Lab Partners, SubTER Workshop, March 2014, Washington, DC

Outreach and Consultation

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Upcoming:

- DOE Crosscutting Subsurface Initiative: "Adaptive Control of Subsurface Fractures and Flow"

  American Geophysical Union (AGU) Annual Meeting, Town Hall Forum, December 2014, San Francisco

- Subsurface Technology & Engineering Challenges and R&D Opportunities: Subsurface Signals"

  U.S. DOE Public workshop hosted by the **United States Energy Association (USEA)**, October 2014, Washington, DC