Exceptional service in the national interest

Sandia National Laboratories

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

Marianne C. Walck, PhD

Vice President, Energy Programs &

California Laboratory

Sandia National Laboratories

May 14, 2015

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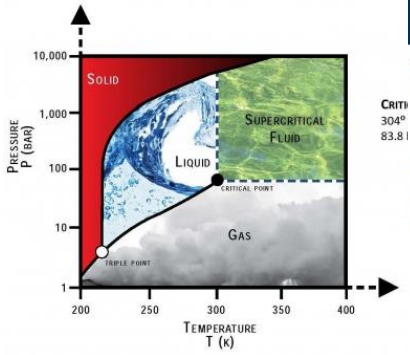
U.S. DEPARTMENT OF ENERGY

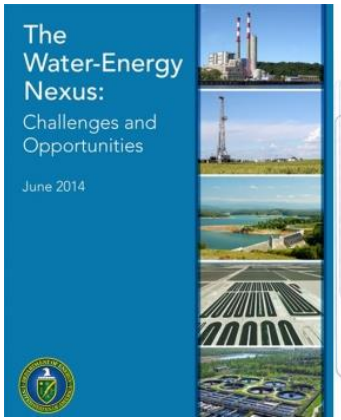
NNSA National Nuclear Security Administration

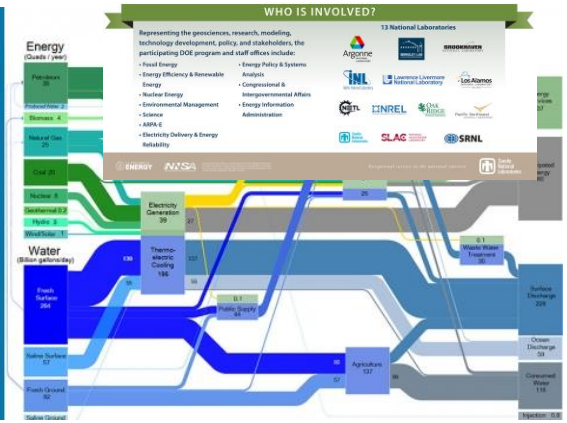
New Structure and Emphasis at DOE

- **Secretary Moniz created:**
  - Undersecretary for Science and Energy position: better integration of Energy Technology Programs with Fundamental Research
  - 6 crosscutting “Tech Teams”
    - **Grid***
    - Water-Energy (WETT)
    - Supercritical CO_2 Brayton Cycle
    - Advanced Computing
    - Manufacturing
    - **Subsurface Technology and Engineering RD&D (SubTER)***

***Large FY16 programs proposed**







SubTER: DOE Office Involvement

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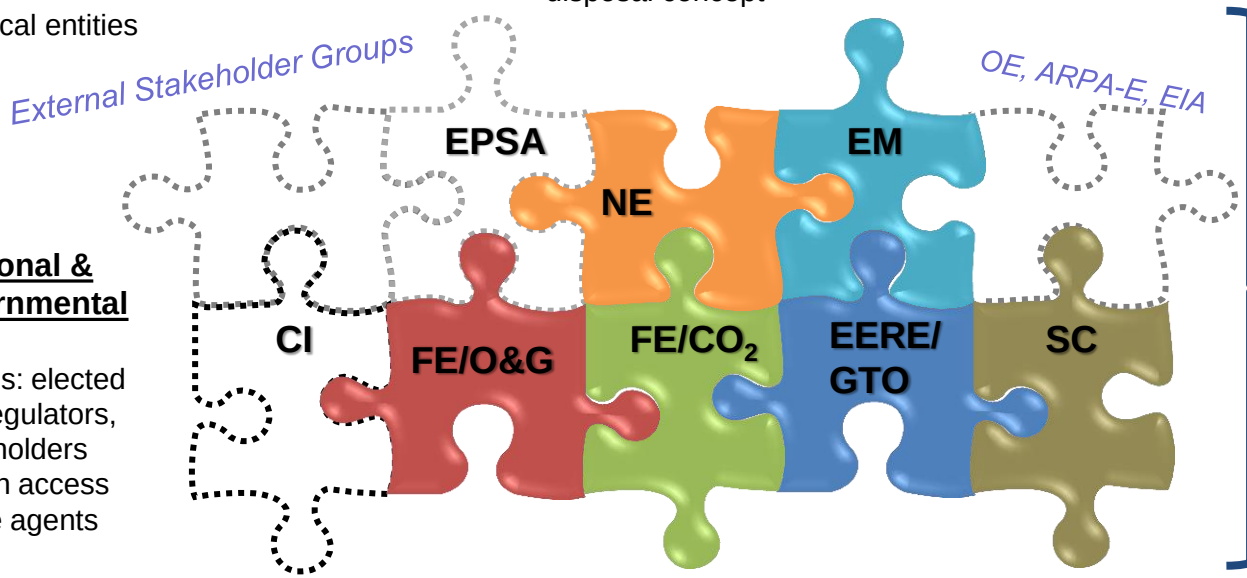
Energy Policy & Systems Analysis
- Advisement: Secretary of Energy
- Policy: low-carbon and secure energy economy
- Technical assistance: States and local entities

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

Subsurface Engineering: Common Subsurface Challenges

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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

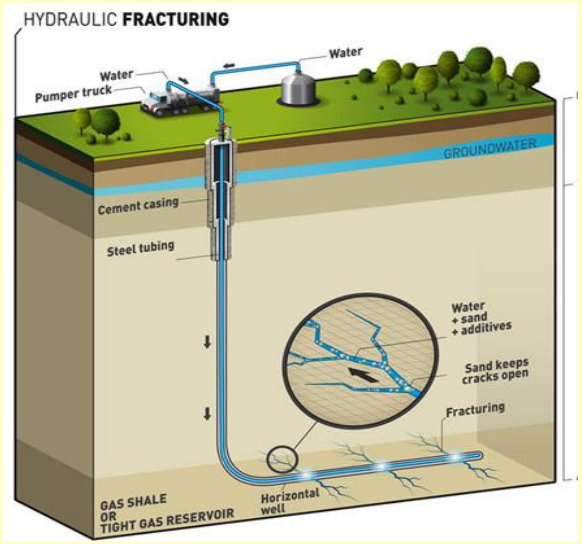
Engineering
Create/construct desired subsurface conditions in challenging high-pressure/high-temperature environments

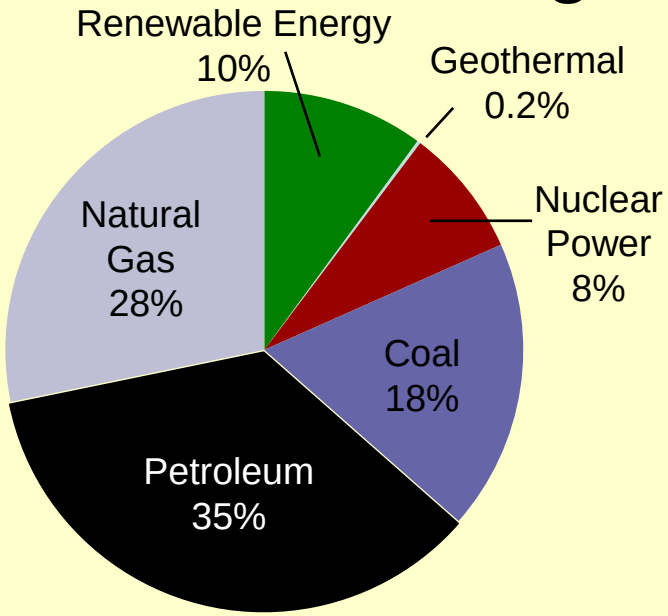
Sustaining
Maintain optimal subsurface conditions over multi-decadal or longer time frames through complex system evolution

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

Mastery of the Subsurface needed for a Safe and Secure U.S. Energy Future: The Technical Challenge

Shale hydrocarbon production

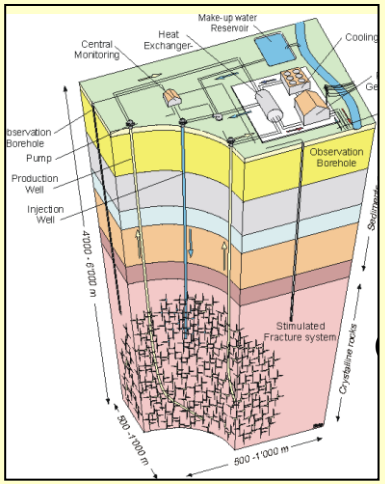




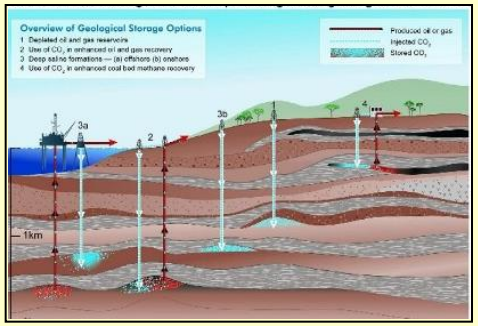
Primary Energy Use by Source, 2014

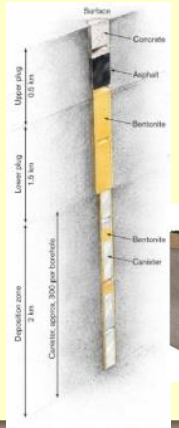
Quadrillion Btu [Total U.S. = 98.3 Quadrillion Btu]

Enhanced geothermal energy

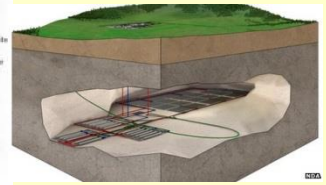


Safe subsurface storage of CO_2

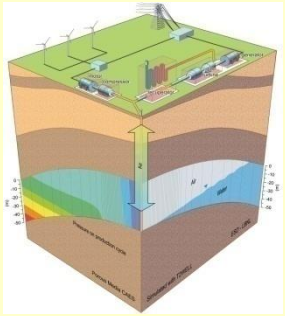




Safe subsurface storage of nuclear waste

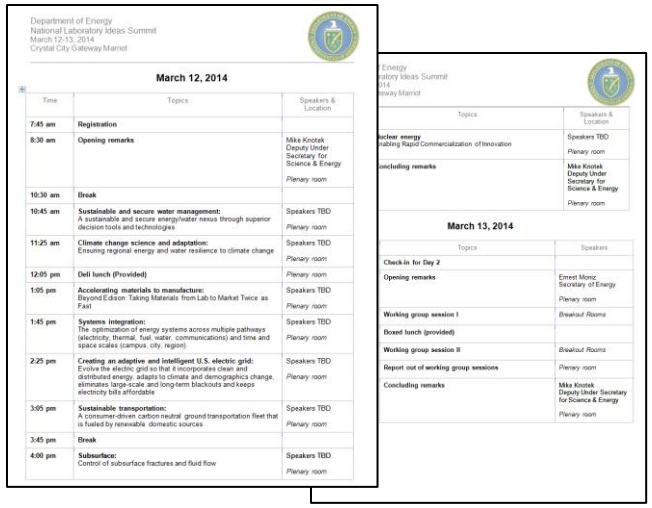


Compressed Air Energy Storage



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 fueled 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

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

- **Summit meeting: March 12-13, 2014**

Subsurface Working Team: 13 Laboratories

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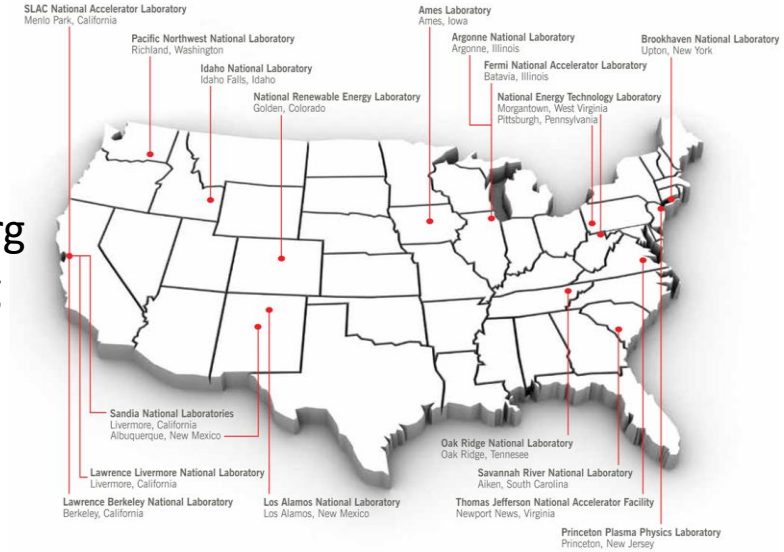
ANL: Randall Gentry
BNL: Martin Schoonen
INL: Earl Mattson, Hai Huang
LANL: Rajesh Pawar, Melissa Fox, Andy Wolfsberg
LBNL: **Susan Hubbard (co-lead)**, Curt Oldenburg (deputy), Jens Birkholzer
LLNL: Roger Aines, Jeff Roberts, Rob Mellors
NREL: Charles Visser
NETL: Grant Bromhal
ORNL: Eric Pierce, Yarom 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

Adaptive Control of Subsurface Fractures and Fluid Flow

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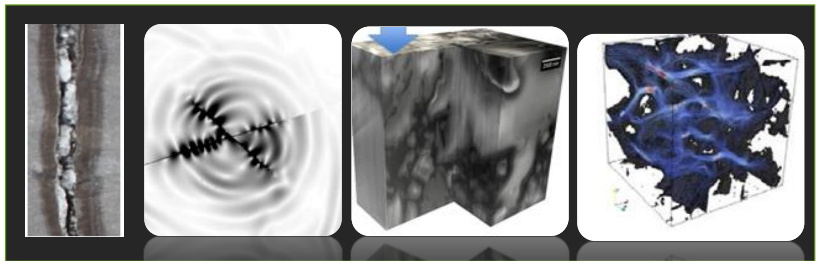
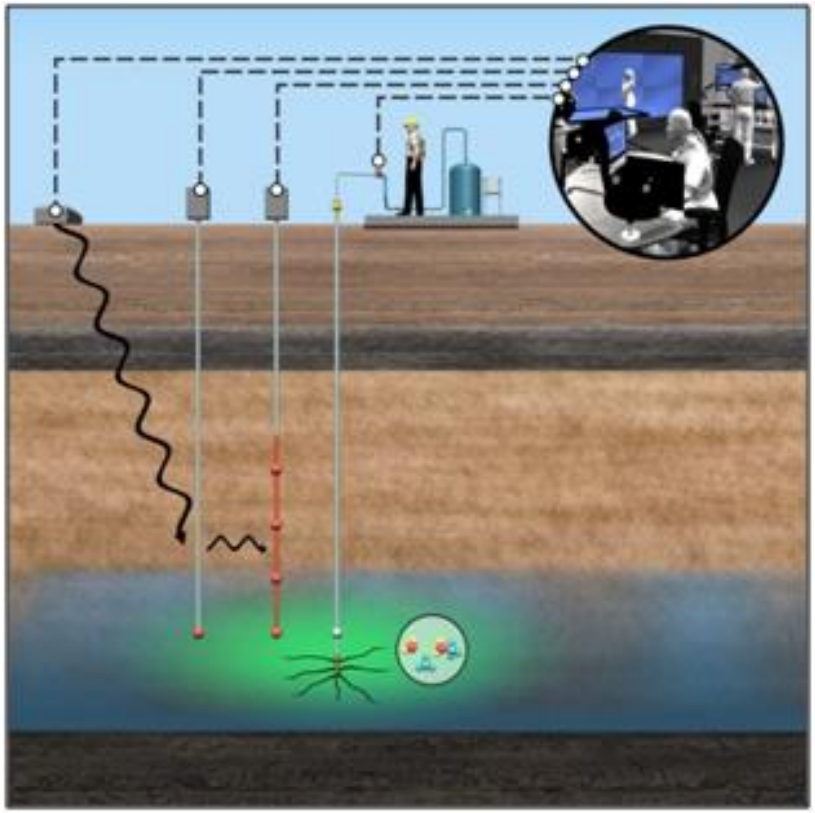
Ability to adaptively manipulate - with confidence and rapidly- subsurface fracture length, aperture, branching, connectivity and associated reactions and fluid flow.

A "Grand Challenge"



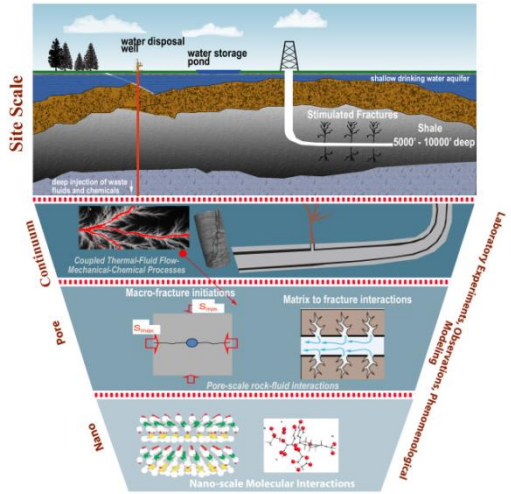


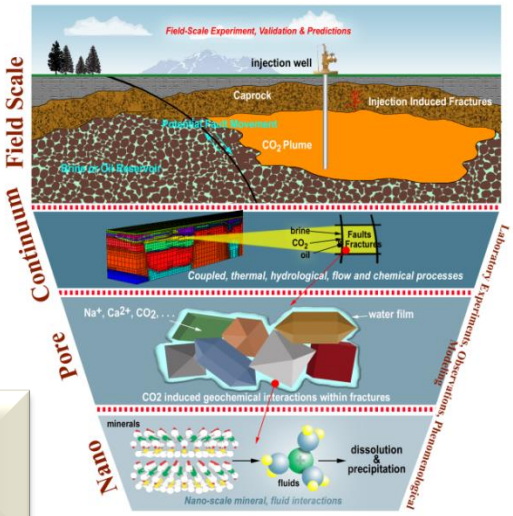
Range of RD^3 Challenges:

Fundamental Science to Engineering Application

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.

The Crosscut Team and the Big Idea Come Together

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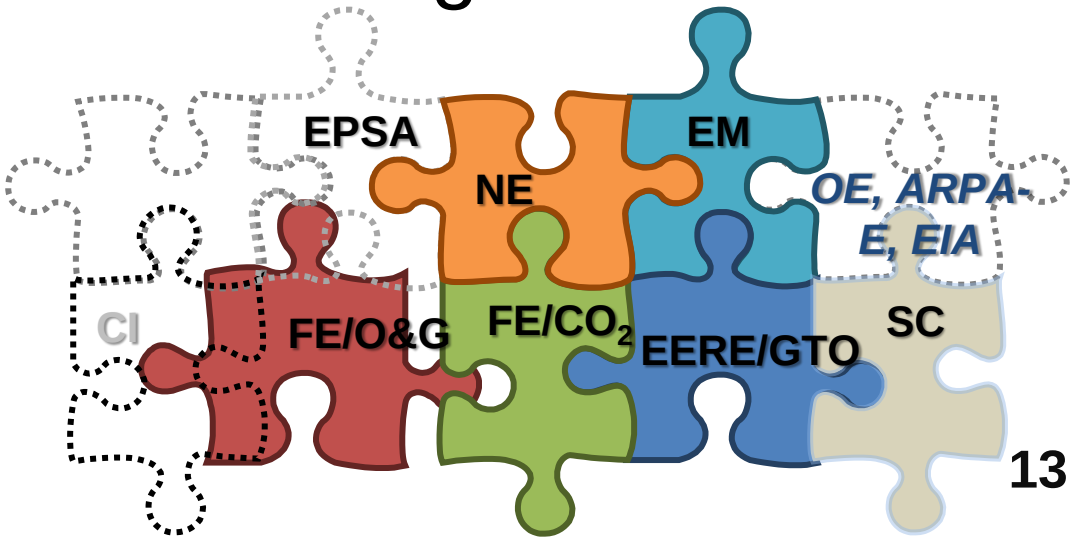

13 National Laboratories

Argonne NATIONAL LABORATORY
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OAK RIDGE National Laboratory
Pacific Northwest NATIONAL LABORATORY
Sandia National Laboratories
SLAC NATIONAL ACCELERATOR LABORATORY
SRNL

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: national laboratories partnered with academia and industry

How can the Community be Involved?

- **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.**

Subsurface Control for a Safe and Effective Energy Future

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Adaptive Control of Subsurface Fractures and Fluid Flow

Wellbore Integrity	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

Criticality of Core Themes

Subsurface Stress and Induced Seismicity

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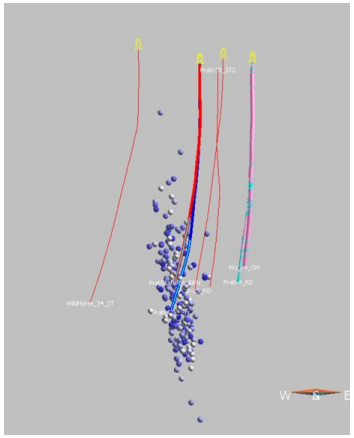
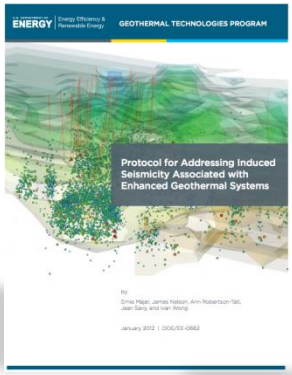
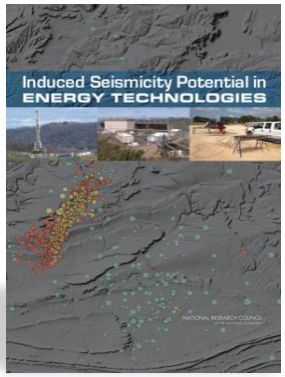


Induced Seismicity at The Geysers Geothermal Field (Calpine)

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: Field observatories are critically important to SubTER efforts

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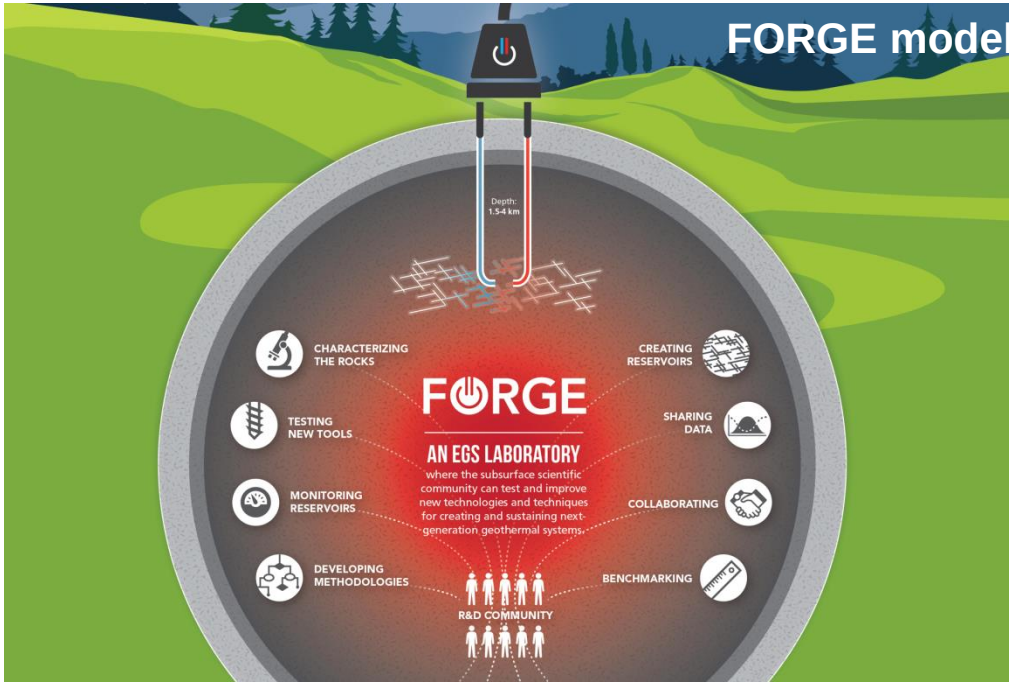
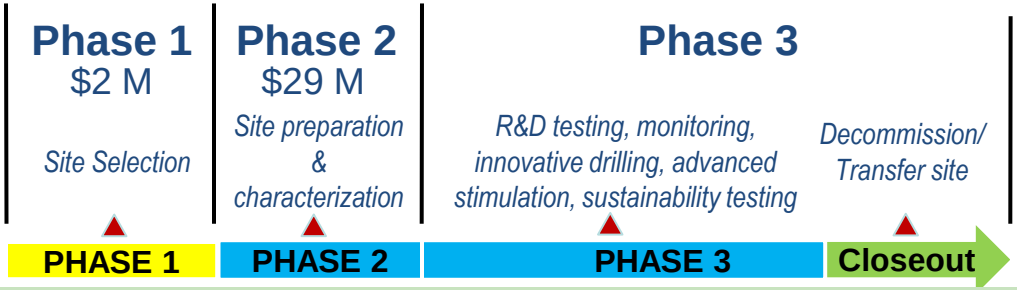
Required for fundamental subsurface progress

- 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

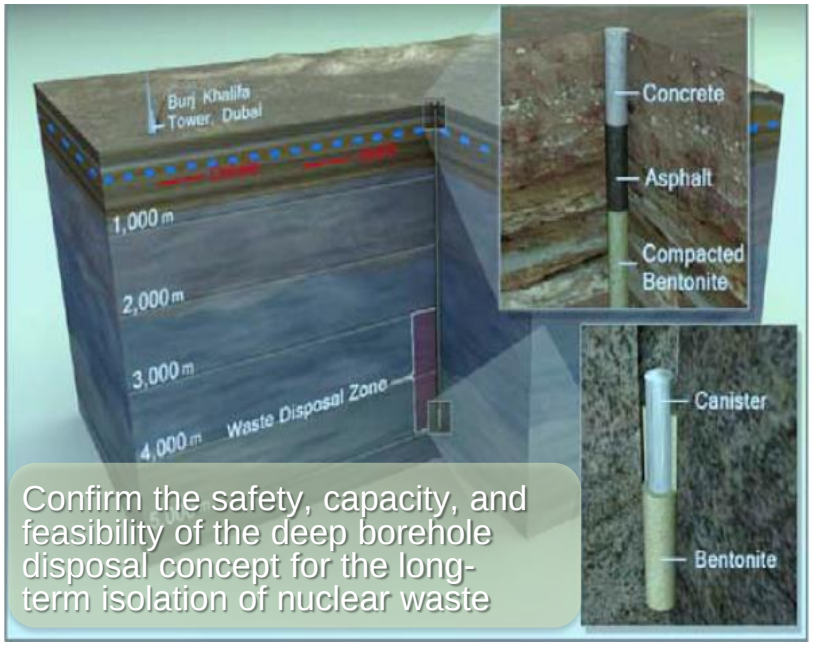


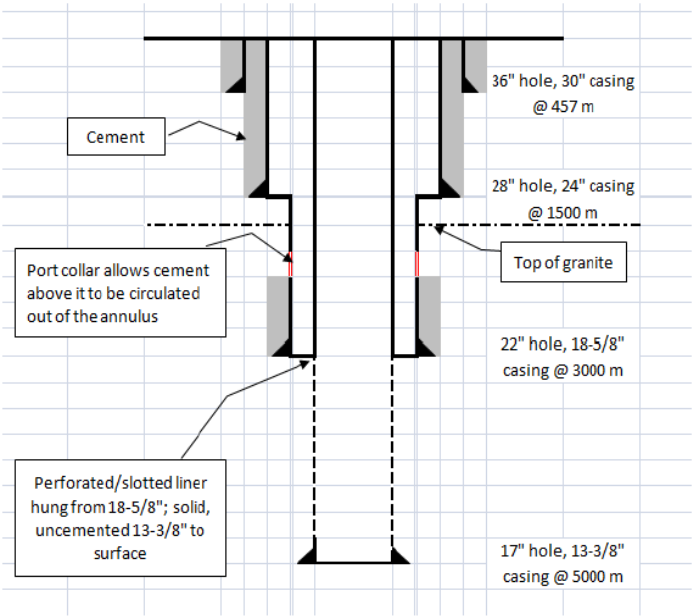


Validation of new results and approaches at commercial scale;
Road-test monitoring, stimulation, and permeability- and flow-control tools

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.*

SubTER Progress

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FY15 project proposals

FY14 Seed projects initiated

Lab Rep Scoping

Town Hall

AGU American Geophysical Union

White Papers

National Labs

Big Ideas Summit March, 2014

- **Initiated unifying "system of labs" approach with common vision, message and sense of purpose**
- **Developed effective partnership between labs and DOE**

2015

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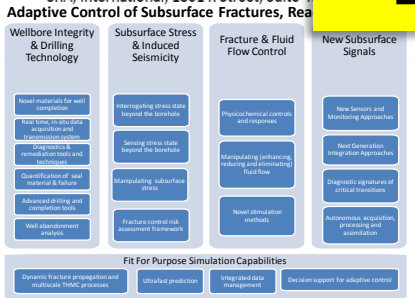

Crosscut framework identified

Subsurface Briefings to Staffers

Forge FOA released

EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES
OFFICE OF MANAGEMENT AND BUDGET

Initial SubTER Crosscut Seedling Projects

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$2M in FY14 funding towards SubTER lab projects from EERE and FE from among:

- ***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** – ORNL: Ultrasonic Phased Arrays and Interactive Reflectivity Tomography
- ***Stress –*** NETL: Big Data and Analytics for Induced Seismicity
- ***New Signals –*** PNNL: Borehole muon detector for 4D density tomography of subsurface reservoirs
- **New Signals:** - LLNL: microBayesloc location method
- **Stress, Permeability:** - SNL: Imaging Fracture Networks

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

FY2015 Example Priority Aligned Activities Within Offices

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Energy Efficiency and Renewable Energy

- FORGE (Frontier Observatory for Research in Geothermal 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

Fossil Energy, Oil & Gas and Carbon Storage

- NRAP
- Unconventional Resources Field Laboratories

Approximately $6M may be available for collaboratively funded SubTER projects in FY15. This builds on the kick-off "seed" funding in FY14. FY15 projects are multi-lab and include university and industry partners. Decisions on these projects are pending.

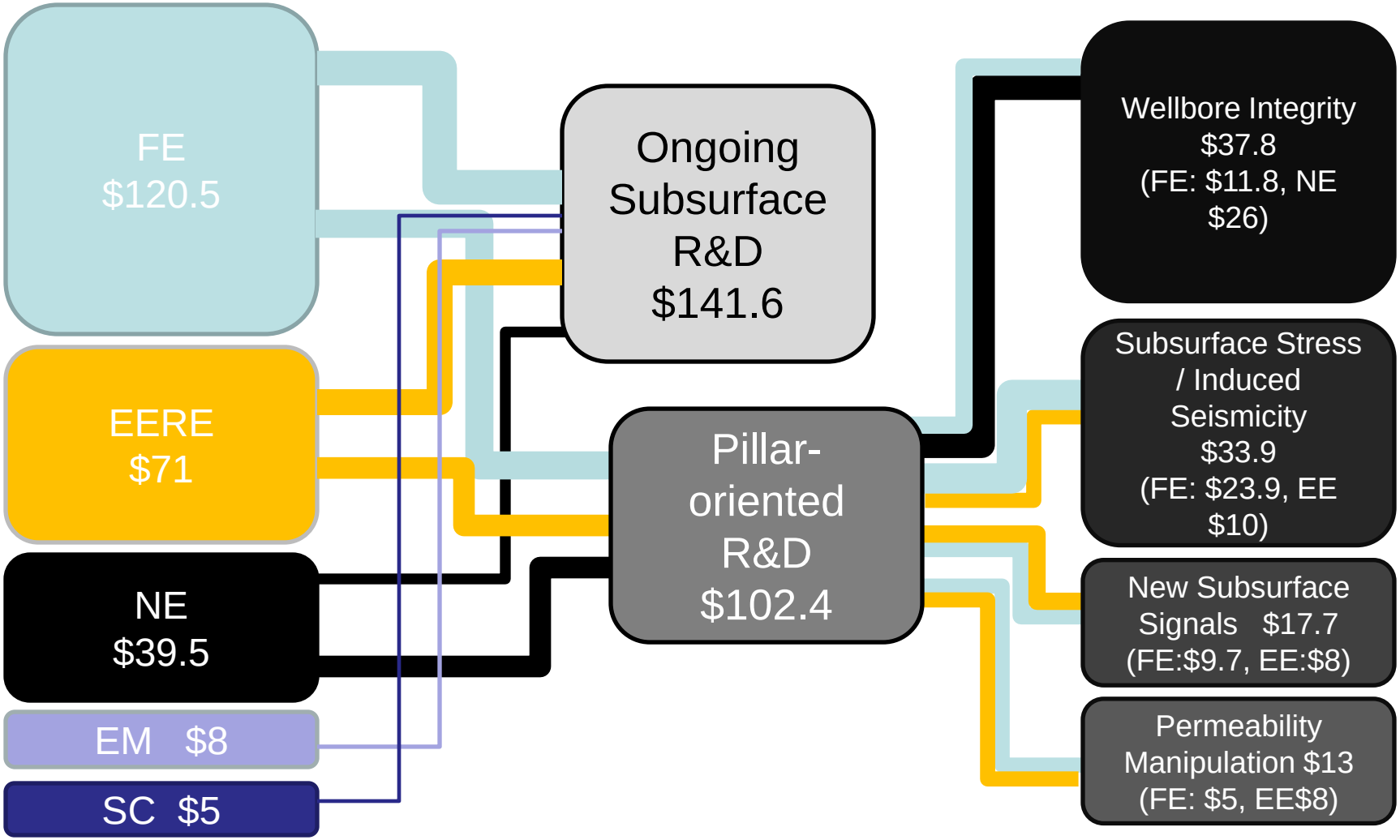
Nuclear Energy, Office of Used Nuclear Fuel Disposition

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

Environmental Management

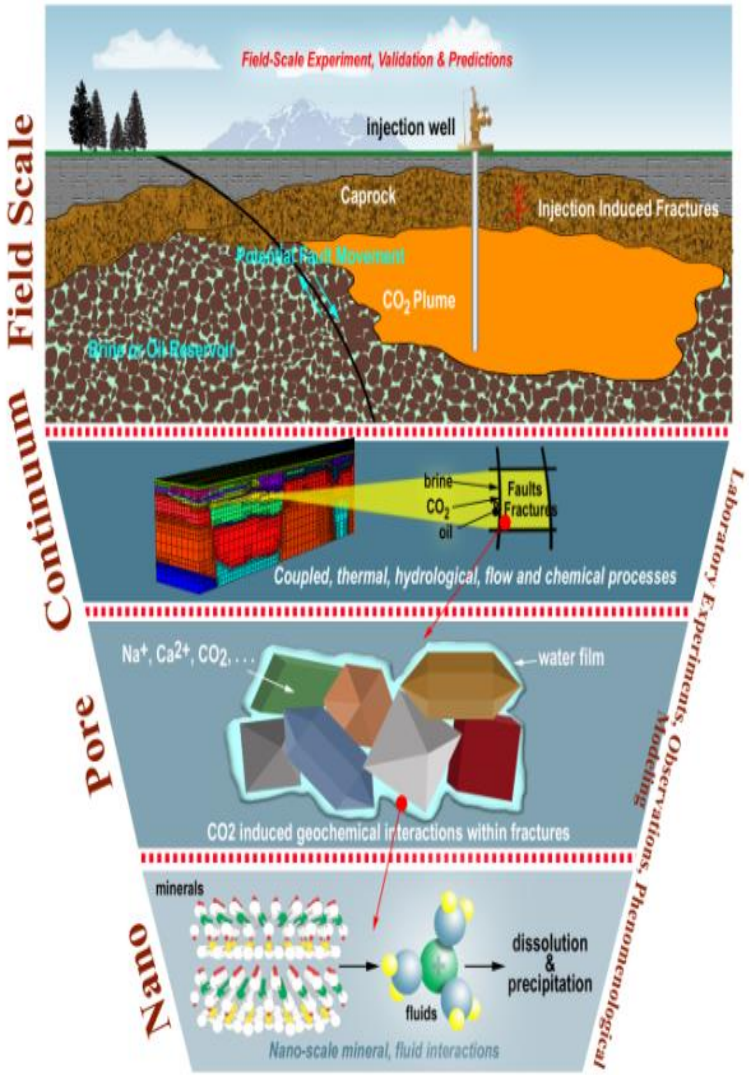
- Investigate the use and development of universal canisters for EM waste disposal in borehole

SubTER in FY2016
President's Budget Request ($M)



Program Risks

- Financial
  - Need multi-office commitment
  - Requires broad funding support
- Operational
  - Multi-office, multi-lab complexity
- Technical
  - Adaptive control is a ‘moonshot’
    - Basic research to application
    - Multi-scale heterogeneity
    - Cannot “see” the subsurface



Elements of Success

- Focused Technical Goal
  - True crosscut – supports needs of many Energy offices
- Strong Management Team
  - DOE and Lab Leads work well together
    - Frequent contact, common goal
  - Building the Lab Team
    - Frequent communication
    - In-person meetings with whole team
  - Seed Funding FY 14 and FY15
    - Creates Momentum
- Outreach
  - Stakeholders
  - Partners: Universities, Industry, Federal Agencies

For More Information: SubTER Adaptive Control of Subsurface Fractures & Fluid Flow

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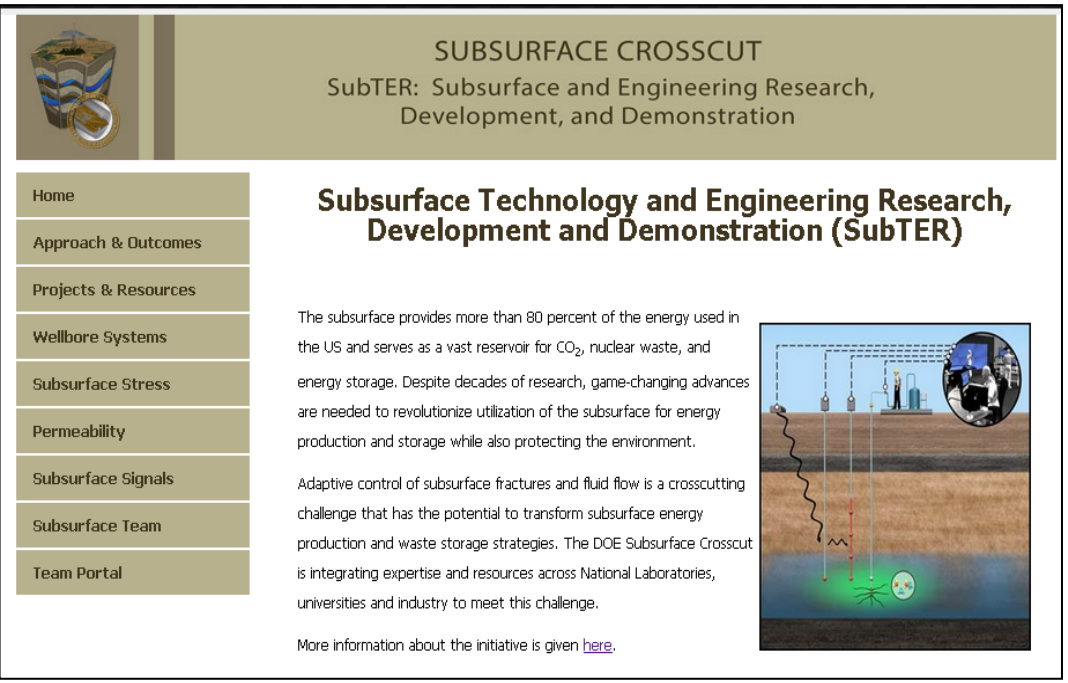

http://esd.lbl.gov/research/projects/subter_mtg_2014

energy.gov/subsurface-tech-team

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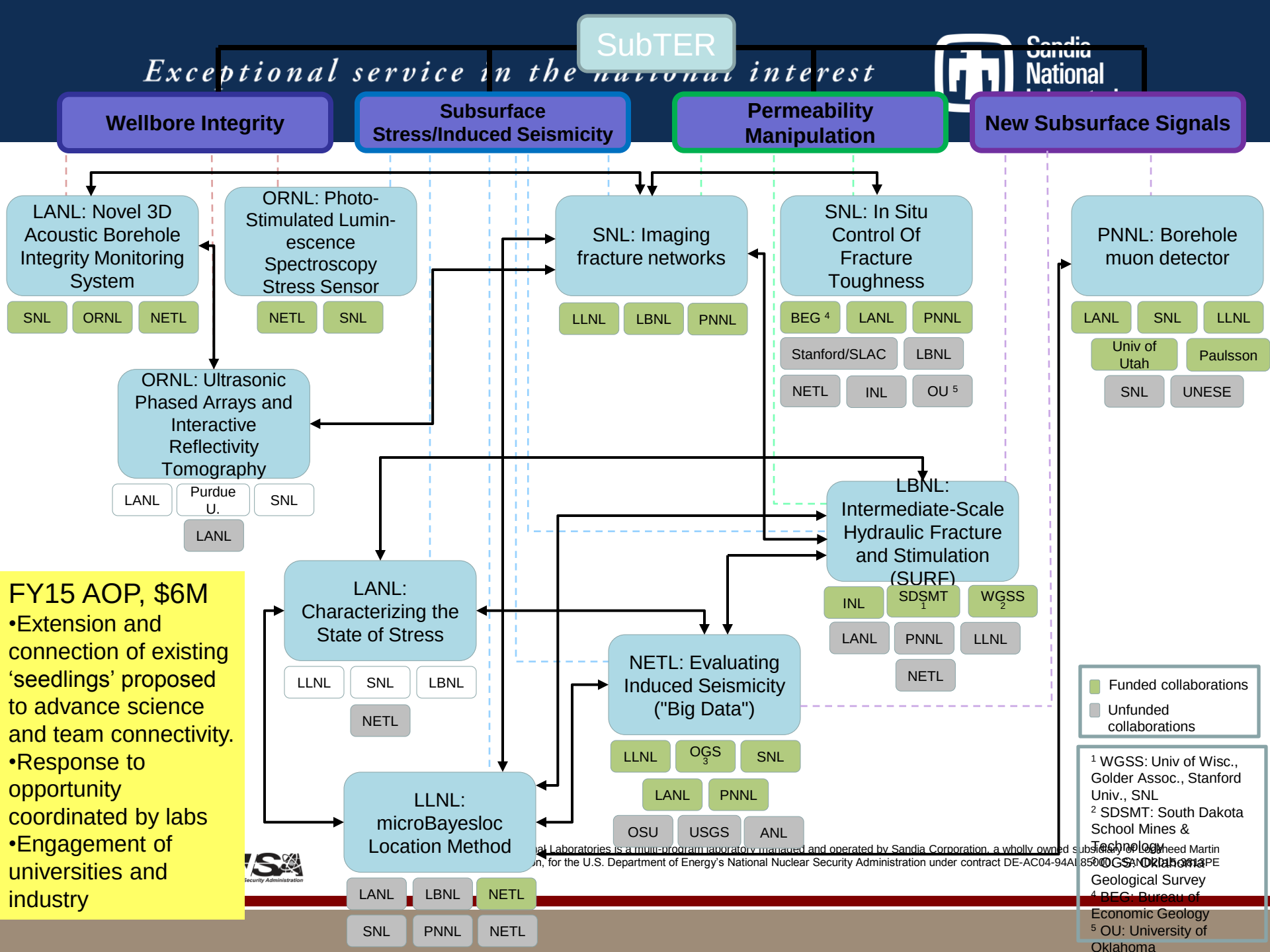
Backup Slides


SubTER
Exceptional service in the national interest
Sandia National
Wellbore Integrity
Subsurface Stress/Induced Seismicity
Permeability Manipulation
New Subsurface Signals
LANL: Novel 3D Acoustic Borehole Integrity Monitoring System
SNL
ORNL
NETL
ORNL: Photo-Stimulated Lumin-escence Spectroscopy Stress Sensor
NETL
SNL
SNL: Imaging fracture networks
LLNL
LBNL
PNNL
SNL: In Situ Control Of Fracture Toughness
BEG 4
LANL
PNNL
Stanford/SLAC
LBNL
NETL
INL
OU 5
PNNL: Borehole muon detector
LANL
SNL
LLNL
Univ of Utah
Paulsson
SNL
UNESE
ORNL: Ultrasonic Phased Arrays and Interactive Reflectivity Tomography
LANL
Purdue U.
SNL
LANL
LBNL: Intermediate-Scale Hydraulic Fracture and Stimulation (SURF)
INL
SDSMT 1
WGSS 2
LANL
PNNL
LLNL
NETL
LANL: Characterizing the State of Stress
LLNL
SNL
LBNL
NETL
NETL: Evaluating Induced Seismicity ("Big Data")
LLNL
OGS 3
SNL
LANL
PNNL
OSU
USGS
ANL
LLNL: microBayesloc Location Method
LANL
LBNL
NETL
SNL
PNNL
NETL
FY15 AOP, $6M
•Extension and connection of existing 'seedlings' proposed to advance science and team connectivity.
•Response to opportunity coordinated by labs
•Engagement of universities and industry
Funded collaborations
Unfunded collaborations
1 WGSS: Univ of Wisc., Golder Assoc., Stanford Univ., SNL
2 SDSMT: South Dakota School Mines & Technology
3 OGS: Oklahoma Geological Survey
4 BEG: Bureau of Economic Geology
5 OU: University of Oklahoma
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Subsurface Stress and Induced Seismicity

Example of Goals and Metrics for a Single Pillar

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Quantify and reduce risk of induced seismicity through quantitative understanding and manipulation of subsurface stress and improve reservoir performance by an order of magnitude

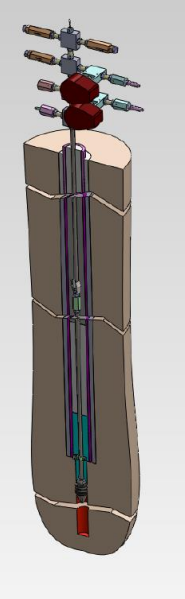
Element	2-year goals	5-year goals	10-year goals
State of stress (measurement and manipulation)	Assess and improve stress measurement resolution and uncertainty methods, begin field deployment	Achieve stress tensor precision, orientation, and spatial resolution goals for borehole, interwell, and field scales	Use automated inversion for stress tensors (at different scales) to optimize adaptive control
Induced seismicity (measurement and manipulation)	Design and execute lab, numerical and field studies to measure and modify induced seismicity	Integrate passive and active seismic imaging to ID and locate faults capable of M4-5 with 95% confidence	Demonstrate forecast and management mechanisms to decrease likelihood of M2-3 event by 10x over a defined time period.
Relating stress manipulation and induced seismicity to permeability	Test fracture/permeability relationships using multi-physics models for available data sets	Characterize in-situ permeability tensor of a fault/fracture zone	Demonstrate 10x improvement in characterizing flow paths in a faulted environment
Applied risk analysis of subsurface manipulation	Apply induced seismicity risk assessment to a benchmark field site.	Demonstrate risk-informed control framework including field validation.	Demonstrate risk-driven adaptive controls on operational envelopes (injection rates, volumes, pressure, well locations).

Approach: New Ways to Control Permeability and Flow

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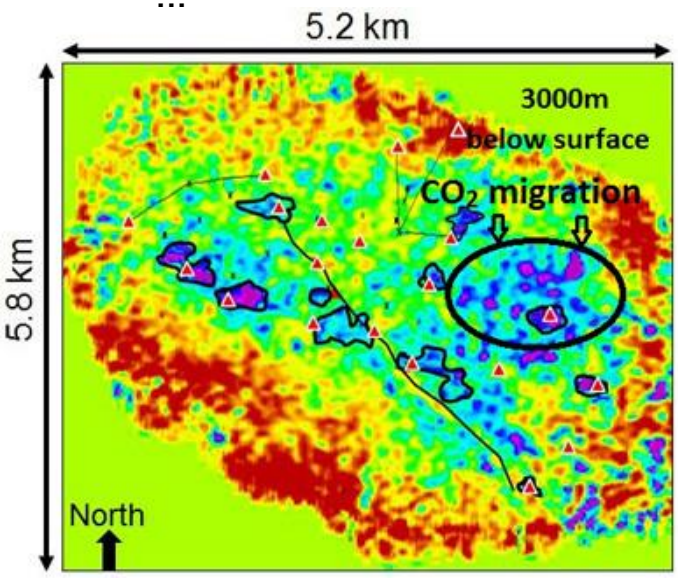
High fidelity characterization of subsurface environments is critical to successful subsurface engineering efforts.

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:

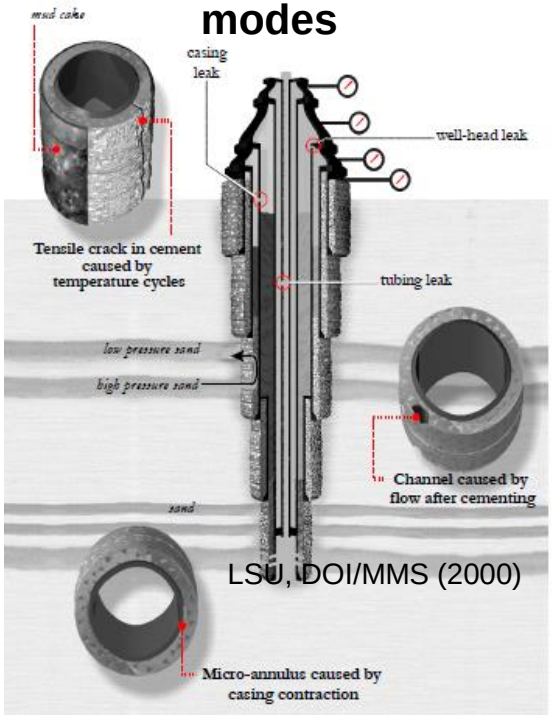
- New ways to “see” subsurface fractures and fluid pathways.
- Acquisition of data necessary for adaptive control of subsurface fractures and fluid flow.

Approach: Intelligent Wellbore Systems R&D

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

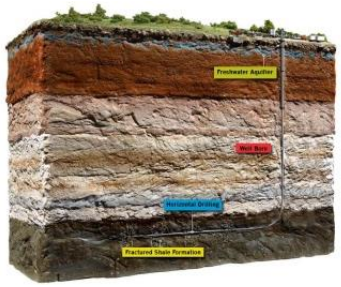
wide band gap semiconductors + advanced manufacturing + HT electronics and sensors + materials science industry + national labs + academia

Casing/cement failure modes



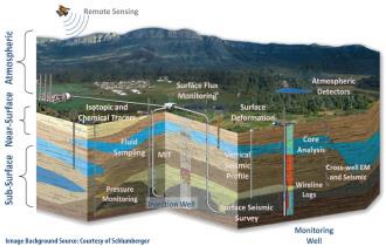
LSU, DOI/MMS (2000)

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

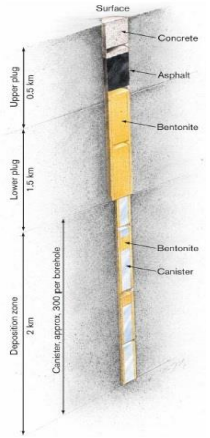


Oil and Gas

Geothermal



CO_2 Storage



Nuclear Waste Deep-Borehole Disposal

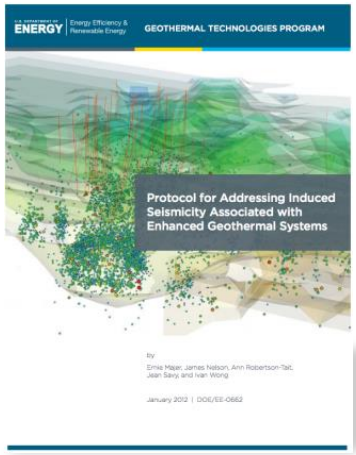
Class VI permit process, used-fuel disposition regulatory framework…

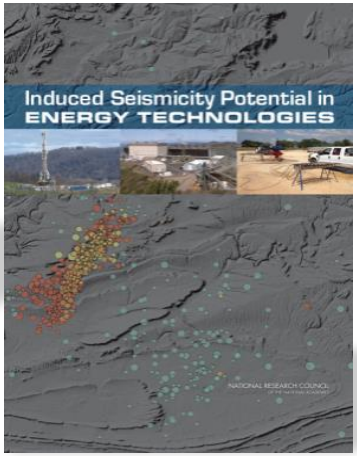
Approach: “Virtual” Field Observatory

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