SAND2015-2976C

# Subsurface Crosscut Initiative

*Adaptive Control of Subsurface Fractures and Fluid Flow*

Argonne NATIONAL LABORATORY

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

BROOKHAVEN NATIONAL LABORATORY

Pacific Northwest NATIONAL LABORATORY

INL Idaho National Laboratory
Operated by Battelle Energy Alliance

NETL

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

SLAC NATIONAL ACCELERATOR LABORATORY

Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY
EST. 1943

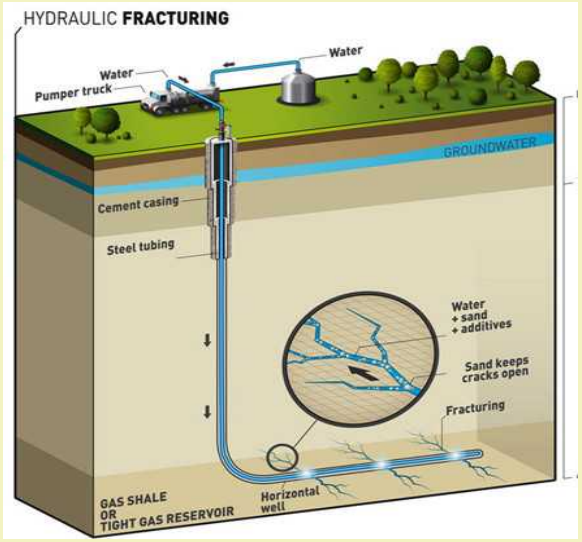
Sandia National Laboratories

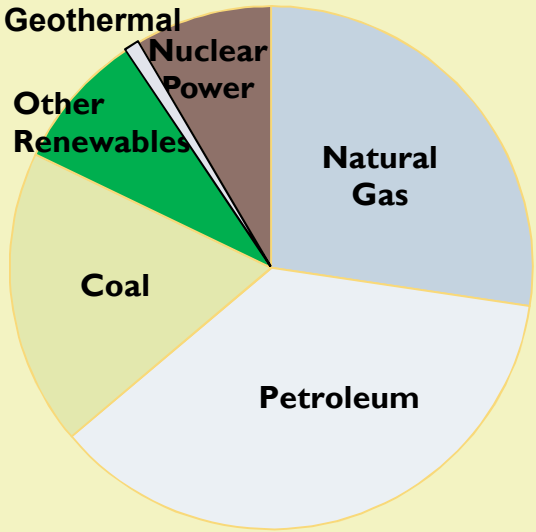
OAK RIDGE National Laboratory

SRNL
SAVANNAH RIVER NATIONAL LABORATORY

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

Shale hydrocarbon production

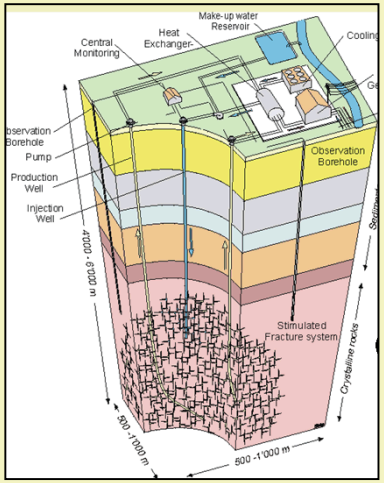


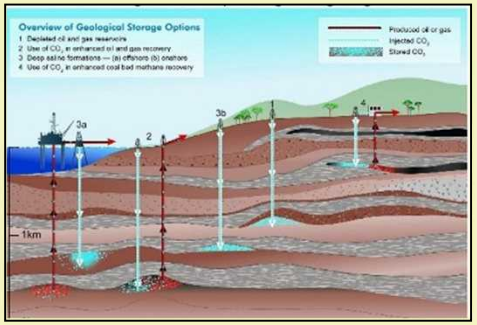

**Primary Energy Use by Source, 2012**

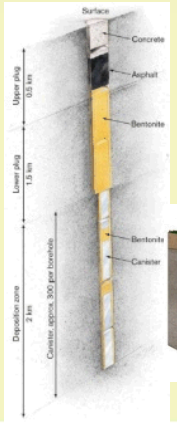
Quadrillion Btu [Total U.S. = 95.1 Quadrillion Btu]

Enhanced geothermal energy

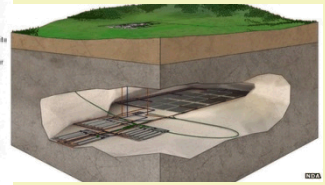



Safe subsurface storage of $CO_2$

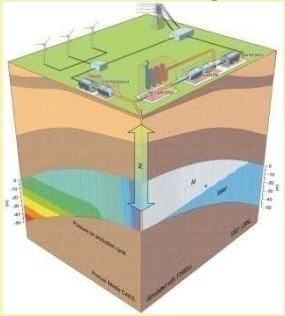



Safe subsurface storage of nuclear waste



Compressed Air Energy Storage



# *Subsurface Engineering: Common Subsurface Challenges*

**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

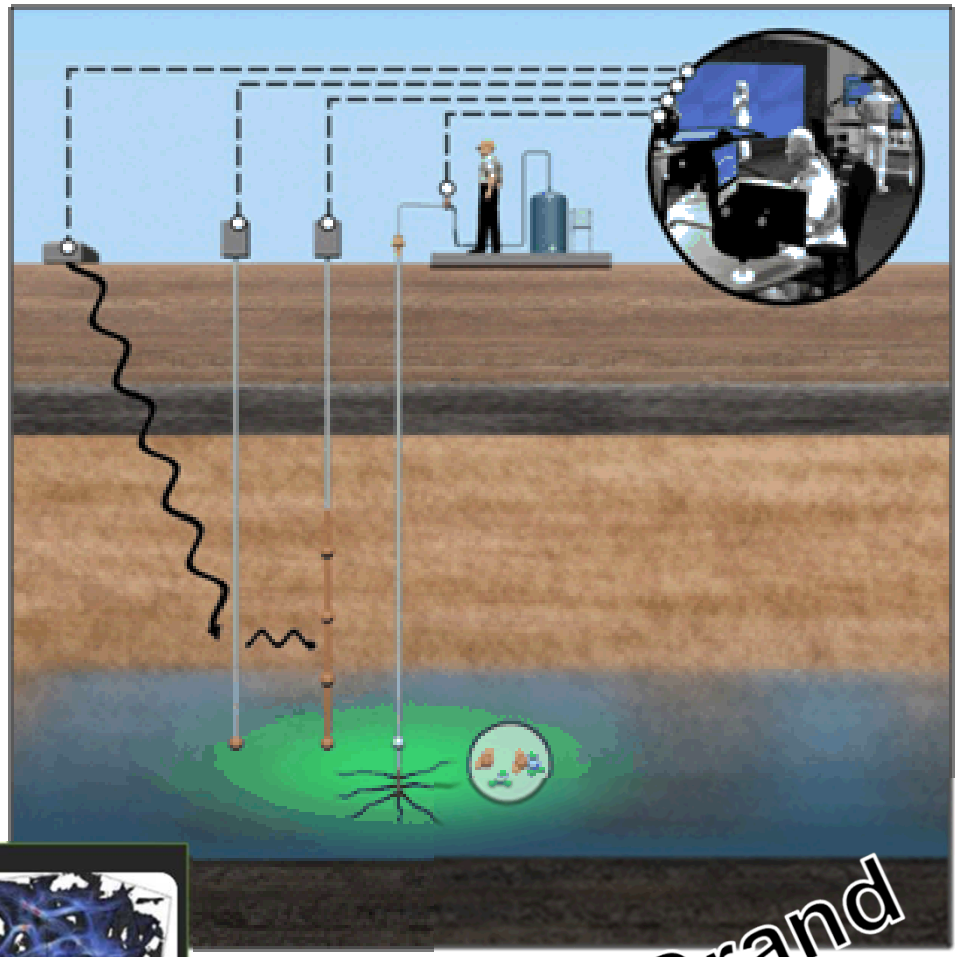
**Sustaining**
Maintain optimal subsurface conditions over multi-decadal or longer time frames through complex system evolution

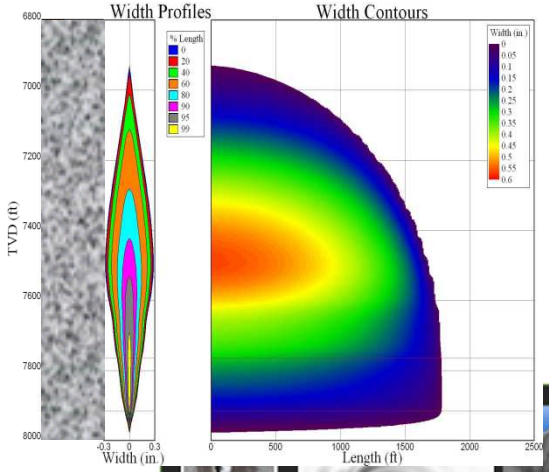
**Monitoring**
Improve observational methods and advance understanding of multi-scale complexities through system lifetimes

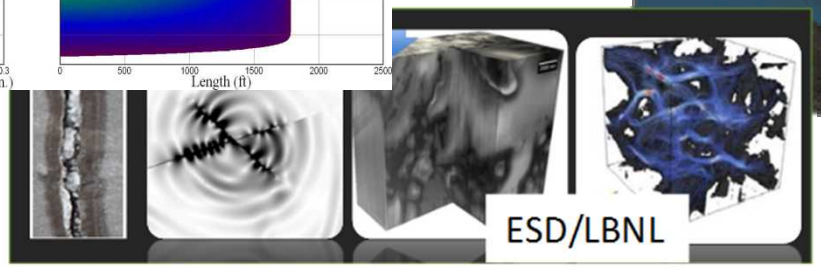
# The Big Idea: Adaptive Control of Subsurface Fractures and Fluid Flow

Range of $RD^3$ Challenges:

Fundamental Science to Engineering Application






Fracture processes mineral-organic interactions flow

A Grand Challenge

# Subsurface Control for a Safe and Effective Energy Future

- President's Climate Action Plan
  - Meet GHG emission reduction targets through safe storage of $CO_2$ and increased low-carbon power generation
- Safety
  - Reduce risks associated with operating in the subsurface
- Energy Security
  - Increased recovery factors from tight formations can vastly increase the length of US energy security

**Inaction Exposes Significant Risks**

Energy Security

Environmental Security

Economic Security

# Clear Alignment with Industry and Stakeholder Priorities

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***

# Subsurface Crosscut Research Framework

## 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**

# Subsurface Stress and Induced Seismicity

**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). |

# SubTER Progress

National Labs

White Papers May

Big Ideas Summit March, 2014

FY14 Seed projects initiated

Lab Rep Scoping

FY15 project proposals

Town Hall

AGU American Geophysical Union

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

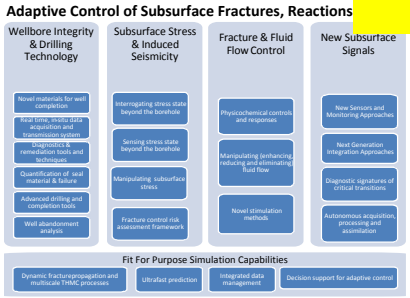
2015

QTR

THE GEOLOGICAL SOCIETY OF AMERICA®

DOE

SubTER Workshop
Subsurface Technology and Engineering R&D
March 14, 2014
SRA, International, 1801 K Street, Suite 46




Crosscut framework identified


Subsurface Briefings to Staffers

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The MITRE Corporation
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McLean, Virginia 22102-7508
(703) 983-6997


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

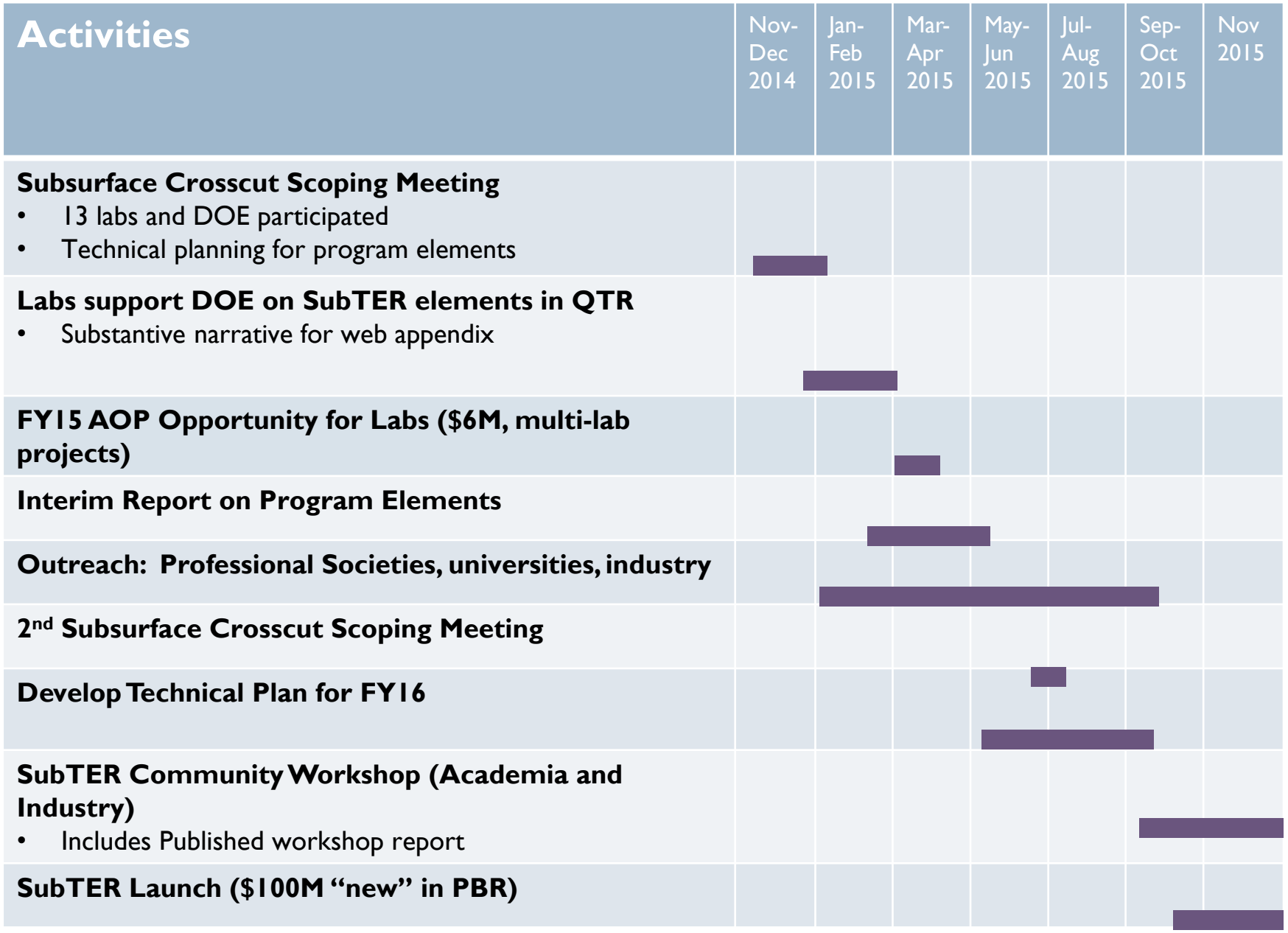
# FY2014 SubTER Crosscut Seedling Projects

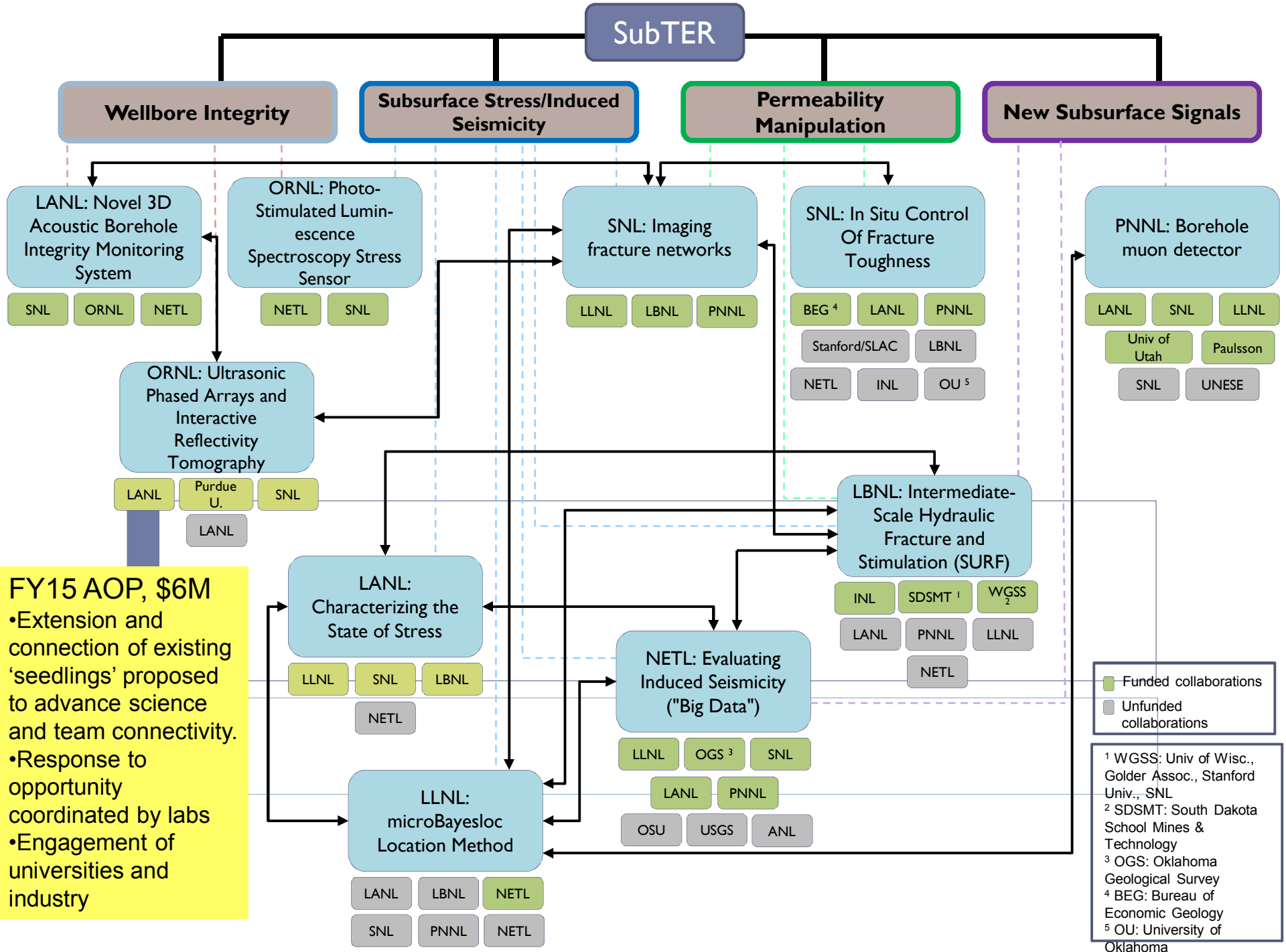
**$2M FY14 funding towards SubTER lab projects from EERE and FE:**

- ***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

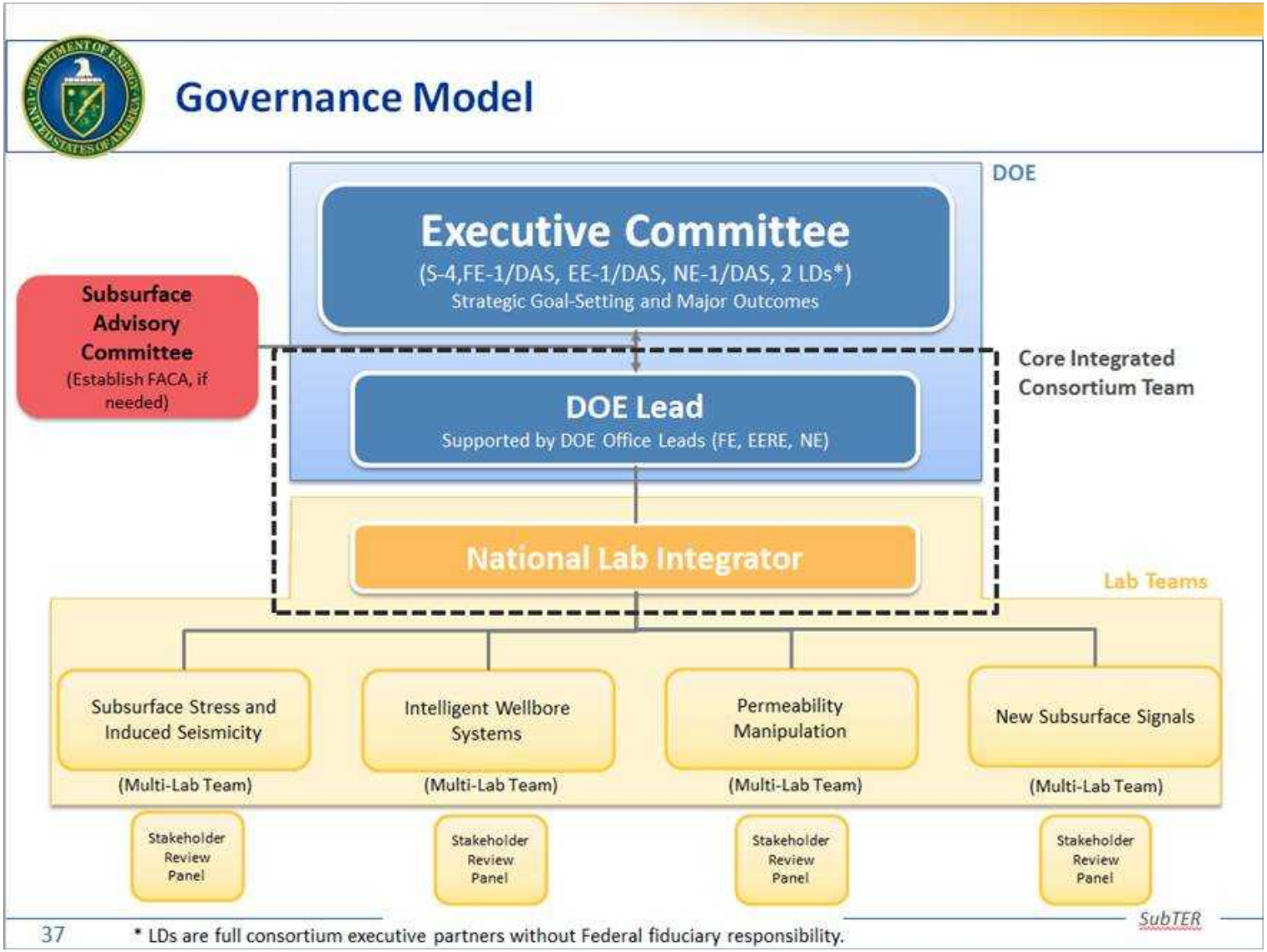
*Seed funding to these projects will kick-start efforts in FY15, FY16 and beyond . . .*

# FY 2015 Schedule

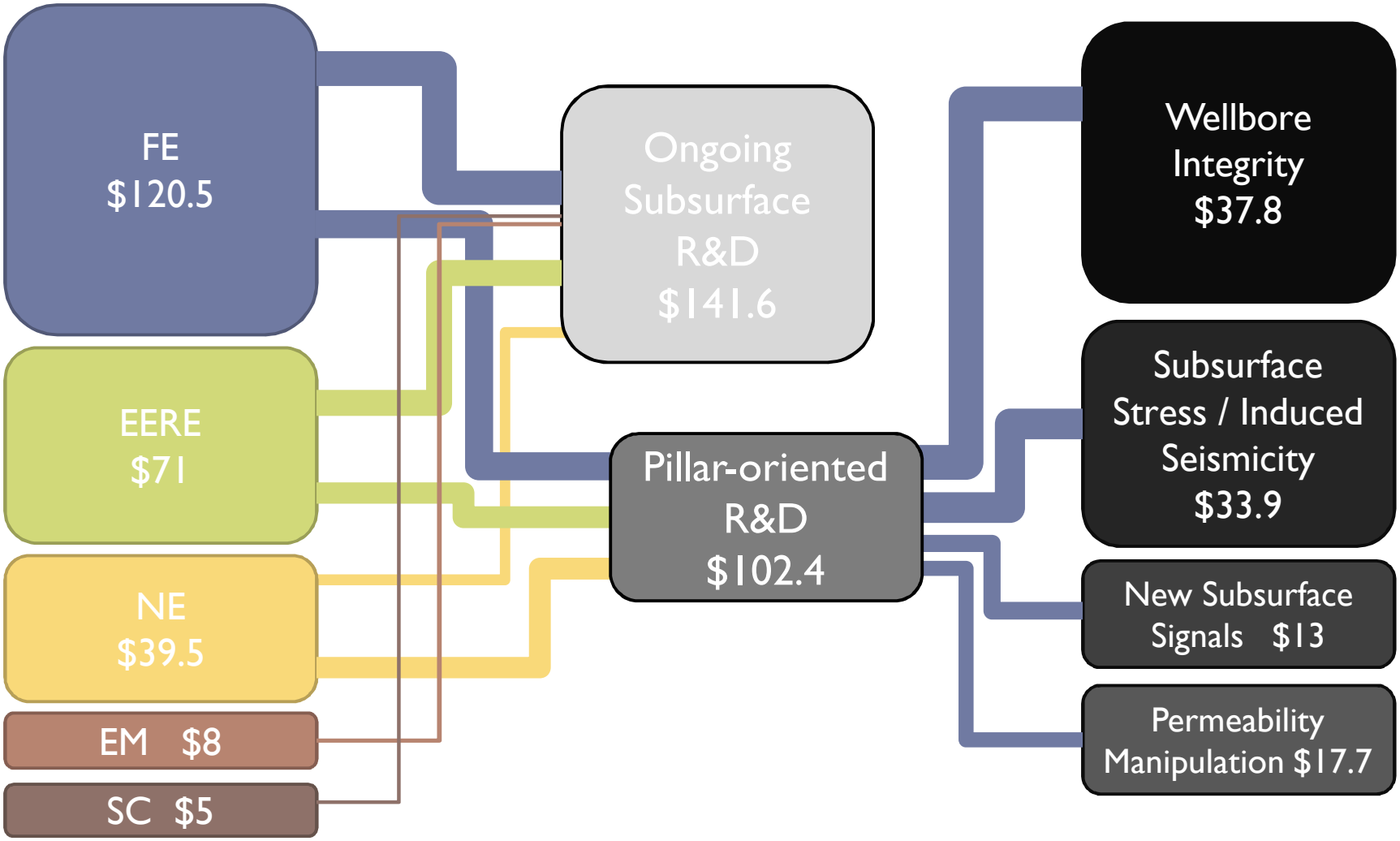



SubTER
Wellbore Integrity
Subsurface Stress/Induced Seismicity
Permeability Manipulation
New Subsurface Signals
LANL: Novel 3D Acoustic Borehole Integrity Monitoring System
SNL
ORNL
NETL
ORNL: Photo-Stimulated Lumin-escence Spectroscopy Stress Sensor
NETL
SNL
SNL: Imaging fracture networks
LLNL
LBNL
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

# Proposed Organizational Structure

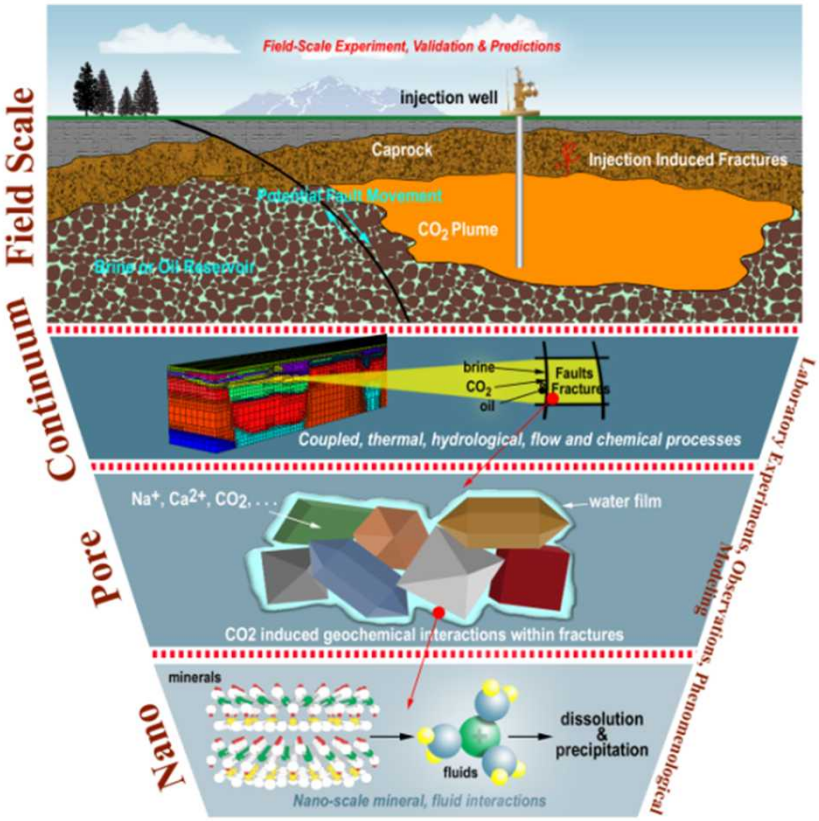


# SubTER in FY2016
# President's Budget Request ($M)



# Program Risks

- Financial
  - Need multi-office commitment
  - Need Congressional support for several programs
- Operational
  - Multi-office, multi-lab complexity
- Technical
  - Adaptive control is a 'moonshot'
    - 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 In FY 14 and FY15
    - Creates Momentum
- Outreach
  - Stakeholders
  - Partners


# Adaptive Control of Subsurface Fractures and Fluid Flow

For More Information:
energy.gov/subsurface-tech-team

U.S. DEPARTMENT OF ENERGY | Office of the Under Secretary for Science and Energy

## Energy Department Subsurface Crosscut

### Addressing Common Subsurface Challenges

The ability to master the subsurface continues to elude researchers and practitioners working on a variety of energy production and storage applications. The DOE is implementing a new collaborative model to tackle this "energy grand challenge" through a coordinated RD&D strategy. Common challenges faced by the participating offices include:

1. **Discover, Characterize, and Predict**
   - accurately characterizing the subsurface using integrated geophysical and geochemical technologies
   - Quantitatively inferring subsurface evolution under current and future engineered conditions
   - Finding viable, low-risk resources
2. **Access**
   - safe, cost-effective reservoir integrity
3. **Engineer**
   - Creating/constructing desired subsurface conditions in challenging high-pressure/high-temperature environments
4. **Sustain**
   - maintaining optimal subsurface conditions over multi-decadal or longer time frames through complex system evolution
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The SubTER technical team identifies and facilitates crosscutting RD&D and policy activities for DOE, to enable programs with common technical challenges to work together toward solutions. The SubTER crosscut reports to the Under Secretary for Science and Energy and leverages program budget priorities to better plan for investment and assistance. While each of the offices brings new activities to the table, the sector benefits as a whole from crosscutting solutions. Partnerships include Departmental programs and offices, labs, academia, and industry, as well as synergies across federal agencies.



### Subsurface Technology and Engineering Research, Development, and Demonstration (SubTER) Crosscut

Subsurface energy sources satisfy over 80% of total U.S. energy needs. Finding and effectively exploiting these resources while mitigating impacts of their use constitute major technical and socio-political challenges. Still, the opportunities are vast. Next generation advances in subsurface technologies will enable increases in domestic natural gas supplies, as well as 100+ GWe of clean, renewable geothermal energy. The subsurface provides hundreds of years of safe storage capacity for carbon dioxide ($CO_2$), and opportunities for environmentally responsible management and disposal of hazardous materials and other energy waste streams. The subsurface can also serve as a reservoir for energy storage for power produced from intermittent generation sources. These opportunities have immediate connection to societal needs and administration priorities. Clean energy deployment and $CO_2$ storage are critical components of the President's Climate Action Plan, necessary to meet the 2050 greenhouse gas (GHG) emissions reduction target. Increasing domestic energy supply from greater hydrocarbon resource recovery, in a sustainable and environmentally sound manner, are also Administration goals that enhance national security and fuel economic growth.

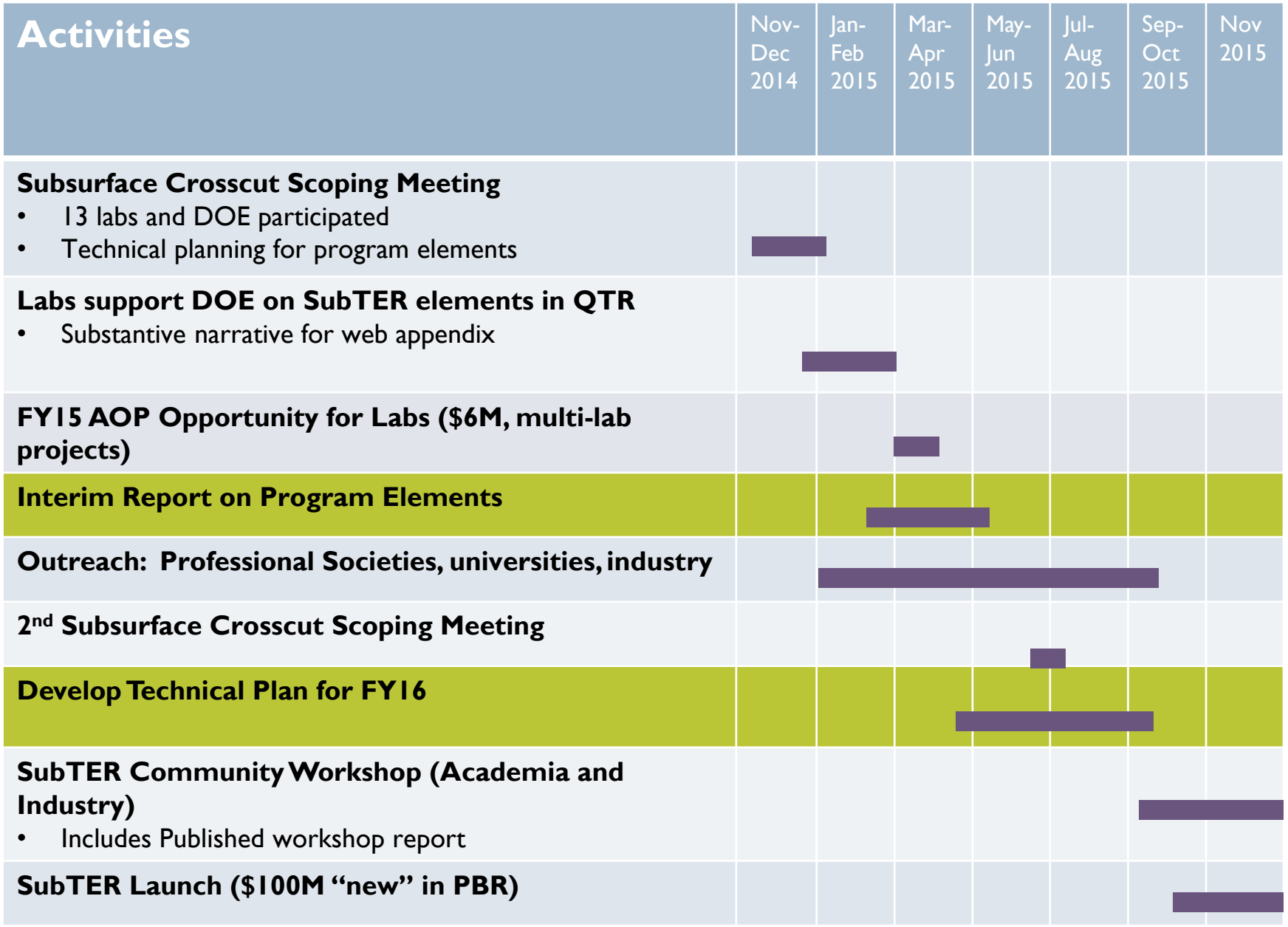
### Who's Involved?

Representing the geosciences, research, modeling, technology development, policy, and stakeholders, the participating program offices include:

- Fossil Energy-Oil and Gas
- Fossil Energy-$CO_2$ Storage
- EERE-Geothermal Technologies Office
- Nuclear Energy
- Environmental Management
- Office of Science
- ARPA-E
- Office of Electricity
- Energy Policy & Systems Analysis
- Congressional & Intergovernmental Affairs
- Energy Information Administration

# Thank You

# FY 2015 Schedule



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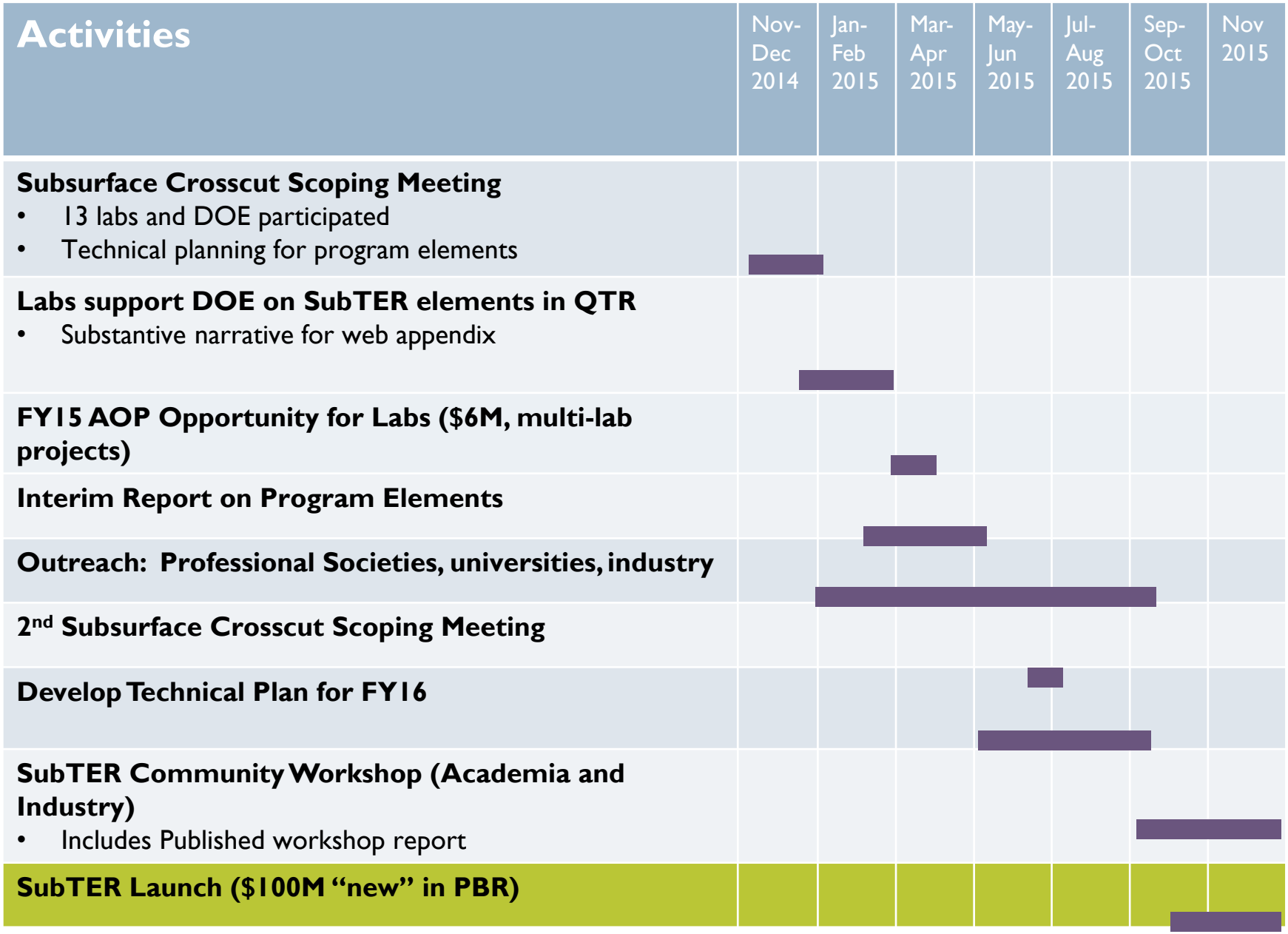

# SubTER in FY2016 President's Budget Request

| | Wellbore Integrity | Subsurface Stress and Induced Seismicity | Permeability Manipulation | New Subsurface Signals | Ongoing Subsurface-Related R&D | TOTAL |
|---|---|---|---|---|---|---|
| *Defense Environmental Cleanup, TOTAL* | --- | --- | --- | --- | 8,000 | 8,000 |
| Headquarters Operations: Technology Development | --- | --- | --- | --- | 2,000 | 2,000 |
| Idaho National Laboratory | --- | --- | --- | --- | 3,000 | 3,000 |
| Richland/Hanford: Hanford Site | --- | --- | --- | --- | 3,000 | 3,000 |
| *Energy Efficiency and Renewable Energy, TOTAL* | --- | 10,000 | 8,000 | 8,000 | 45,000 | 71,000 |
| Geothermal Technologies: Enhanced Geothermal Systems | --- | 5,000 | --- | --- | 34,000 | 39,000 |
| Geothermal Technologies: Hydrothermal | | 5,000 | 8,000 | 8,000 | 11,000 | 32,000 |
| *Fossil Energy Research & Development, TOTAL* | 11,788 | 23,888 | 5,071 | 9,687 | 70,084 | 120,518 |
| Carbon Storage: Advanced Storage R&D | 5,000 | 7,384 | --- | 5,000 | --- | 17,384 |
| Carbon Storage: Storage Infrastructure | --- | --- | --- | --- | 60,084 | 60,084 |
| Carbon Storage: Sub-Disciplinary Storage R&D | 5,600 | 15, 316 | 3,888 | 3,500 | --- | 28,300 |
| Crosscutting Research: Coal Utilization Science | 1,188 | 1,188 | 1,187 | 1,187 | --- | 4,750 |
| Natural Gas Technologies: Environmentally Prudent Development | --- | --- | --- | --- | 10,000 | 10,000 |
| *Nuclear Energy, TOTAL* | 26,000 | --- | --- | --- | | 26,000 |
| Fuel Cycle R&D: Used Nuclear Fuel Disposition | 26,000 | --- | --- | --- | | 26,000 |
| *Science, TOTAL* | --- | --- | --- | --- | 5,000 | **5,000** |
| Basic Energy Sciences: Chemical Sciences, Geosciences, and Biosciences | | | | | 5,000 | 5,000 |
| *Total, Subsurface Technology and Engineering* | 37,788 | 33,888 | 13,071 | 17,687 | 141,584 | **244,018** |

# Adaptive Control of Subsurface Fractures and Flow

For More Information:
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- Nuclear Energy
- Environmental Management
- Office of Science
- ARPA-E
- Office of Electricity
- Energy Policy & Systems Analysis
- Congressional & Intergovernmental Affairs
- Energy Information Administration

# Preliminary 10-year Metrics

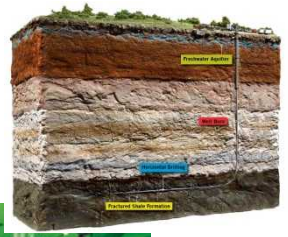
**Double hydrocarbon production** from tight reservoirs while decreasing environmental impact

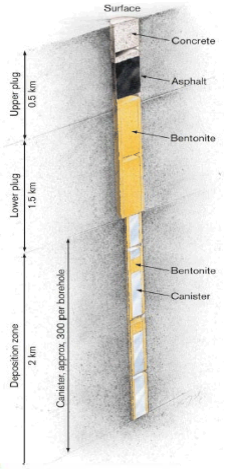
- Increase longevity of US energy security
- Cut in Half:
  - The number of wells drilled
  - the emissions associated with extraction and truck use
  - Water use for tight reservoir production

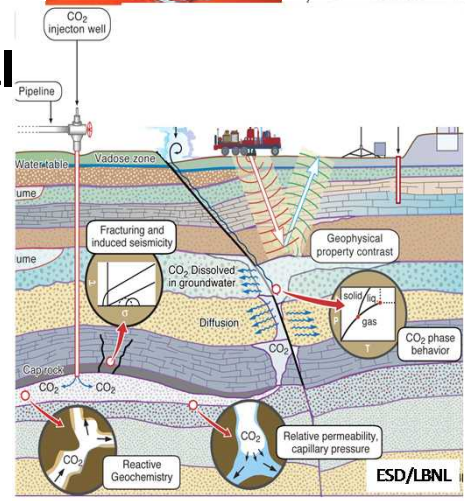
**Achieve order-of-magnitude increase** in U. S. electrical production from geothermal reservoirs

Establish practical feasibility of **deep borehole disposal** for specialty nuclear wastes

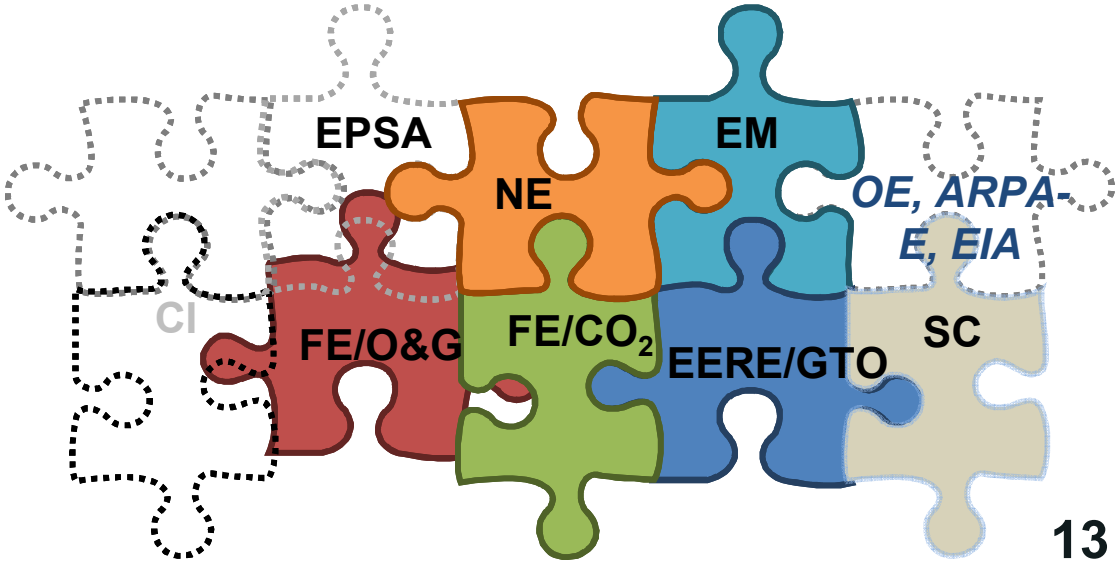
**Double confidence level** in safe subsurface storage of CO2





# The Crosscut Team and the Big Idea come Together




**13 National Laboratories**

Argonne NATIONAL LABORATORY
BERKELEY LAB Lawrence Berkeley National Laboratory
BROOKHAVEN NATIONAL LABORATORY
INL Idaho National Laboratory
Lawrence Livermore National Laboratory
Los Alamos NATIONAL LABORATORY EST. 1943
NETL
NREL NATIONAL RENEWABLE ENERGY LABORATORY
OAK RIDGE National Laboratory
Pacific Northwest NATIONAL LABORATORY
Sandia National Laboratories
SLAC NATIONAL ACCELERATOR LABORATORY
SRNL

# Getting Started

- FY14 SubTER Kickstart:

  $2M investment in 9 seedling projects
- FY15:
  - ~$6M opportunity to propose high priority, integrated and collaborative multi-lab projects that build on seedlings
- FY16:
  - President's Budget Request includes $244M for SubTER
  - ~$100M new funds