National Laboratory Perspective & Capabilities:

Adaptive Control of Fractures and Fluids

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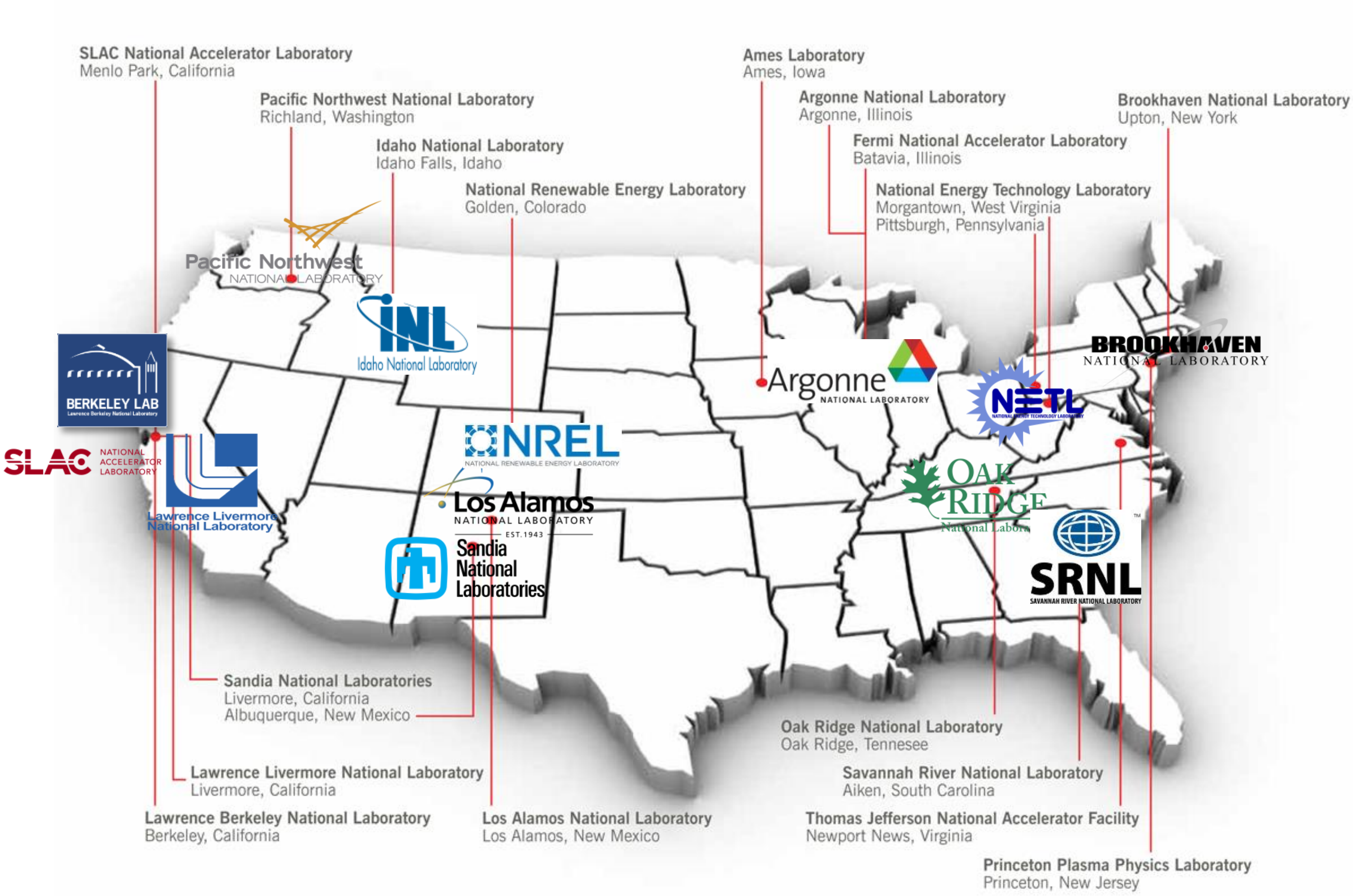
Subsurface Crosscut National Lab Team

Presented to USEA
July 2014

13 Department of Energy Laboratories contributing to the ‘Adaptive Control of the Subsurface’ Crosscut



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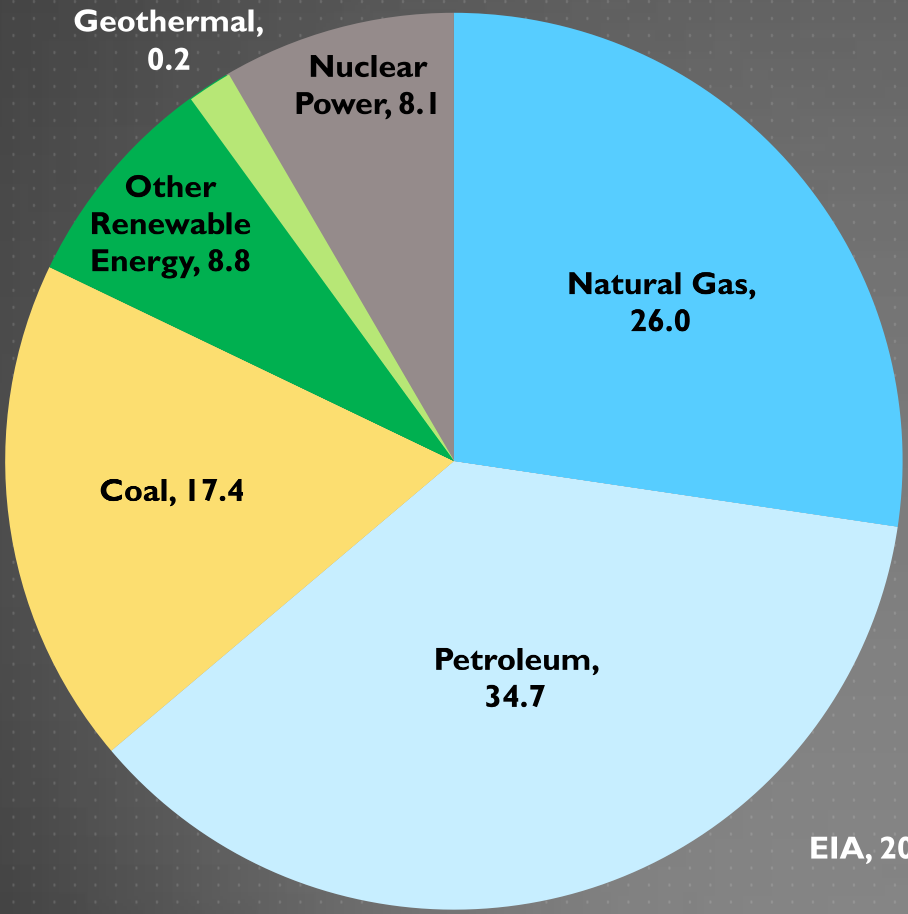
IMPORTANCE OF SUBSURFACE FOR US ENERGY

2012 US Energy Use

By Percent. Total U.S. = 95.1 Quadrillion Btu



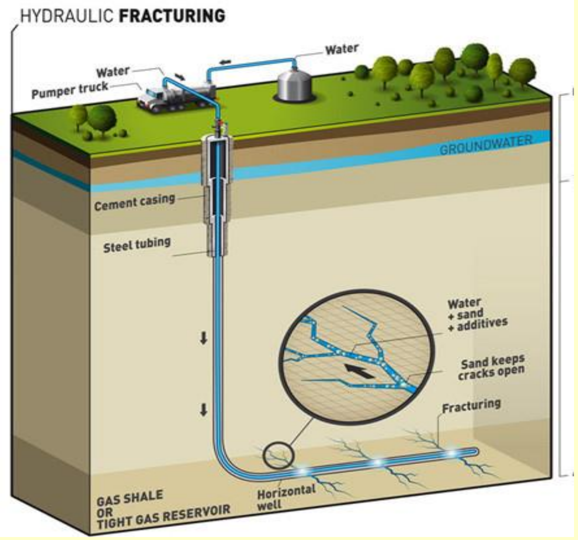
EIA, 2012

- The subsurface supplies/enables **>80%** of the energy consumed in the U.S.
- The subsurface serves as a vast reservoir for storage of CO_2, nuclear and other energy waste streams
- The subsurface can also serve as a reservoir for energy storage

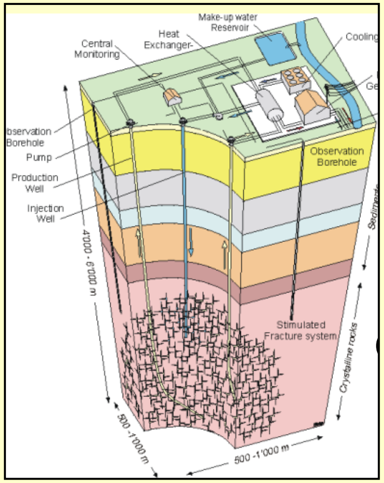
~Improved Subsurface Utilization is key to US Energy Security~

Optimizing Subsurface Energy Strategies Requires Control of Subsurface Fractures

Shale hydrocarbon production

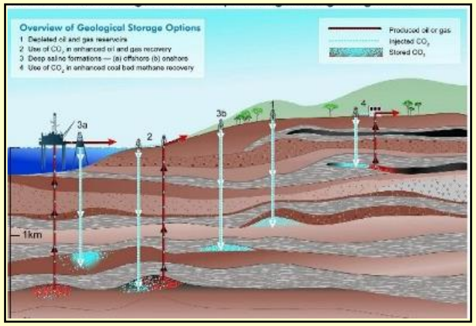


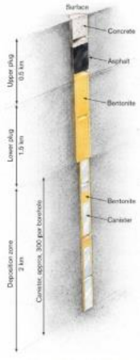
Enhanced geothermal energy



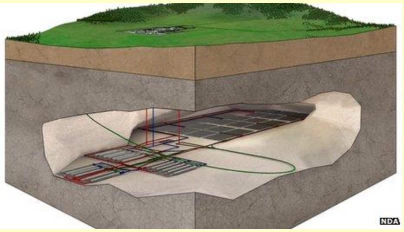
- **Control fracture length & branching patterns**
- **Enhance injectivity & optimize storage**
- **Plug/seal leakage pathways**

Safe subsurface storage of CO_2

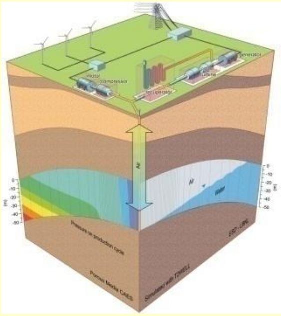




Safe subsurface storage of nuclear waste



Compressed Air Energy Storage

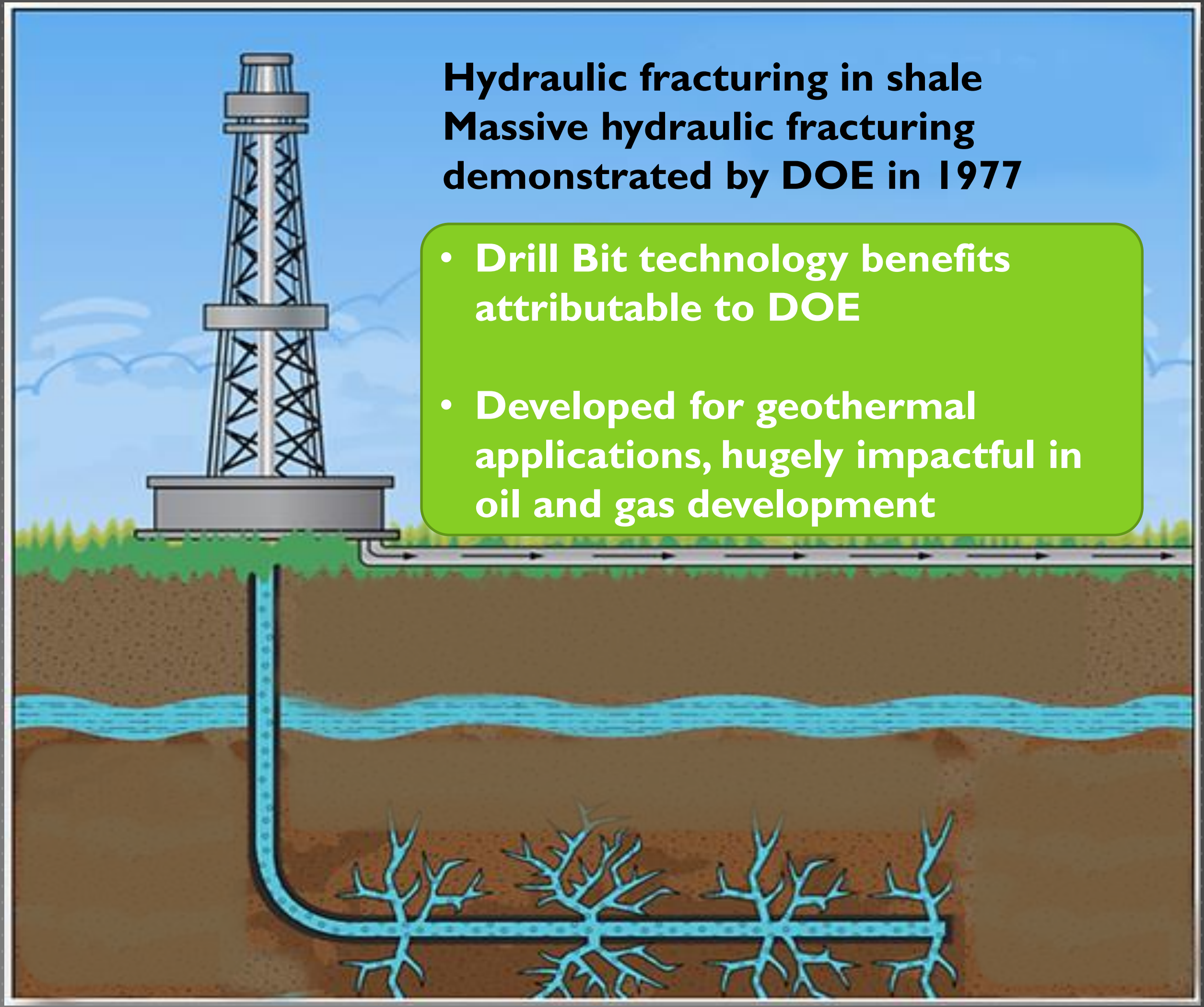


ADVANCES IN SUBSURFACE R&D LED THE WAY

Government funded R&D

- Drill bit improvement
- Horizontal drilling
- Multiple massive fractures
- Hydraulic fracture mapping

Technology advances deployed by independent producers



Hydraulic fracturing in shale
Massive hydraulic fracturing demonstrated by DOE in 1977

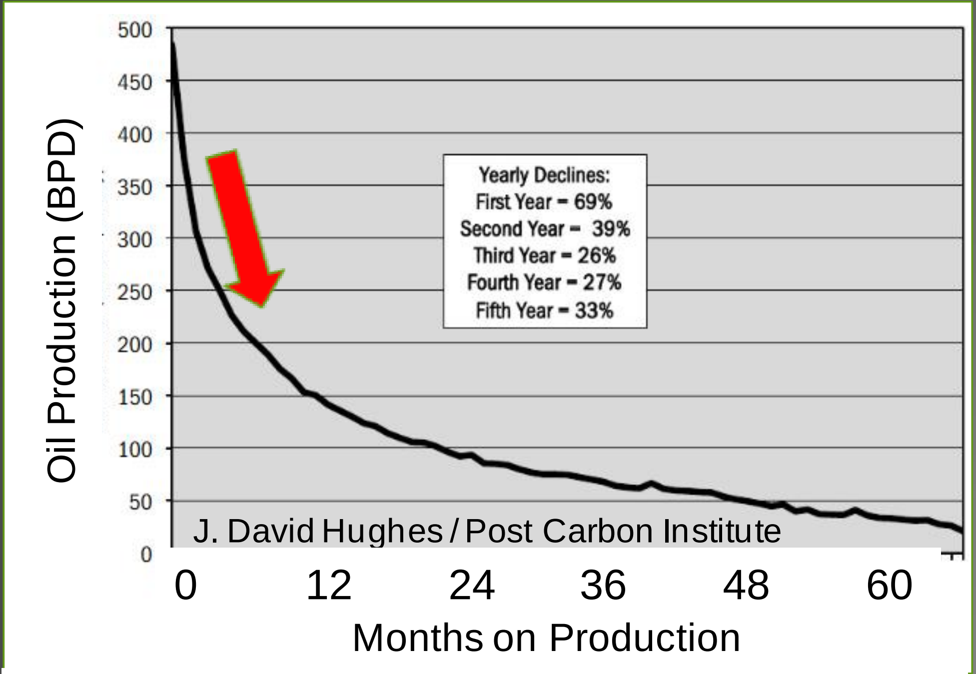
- **Drill Bit technology benefits attributable to DOE**
- **Developed for geothermal applications, hugely impactful in oil and gas development**

thebreakthrough.org

DOE Energy 100 Award for
Synthetic Diamond Drill Bits (2000)

CHALLENGE:
LONG TERM SUSTAINABILITY

Typical production decline curve
Barnett Shale Gas Wells



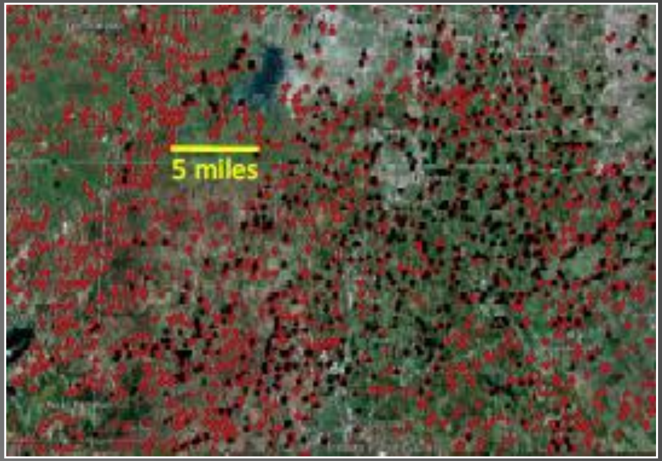
J. David Hughes / Post Carbon Institute

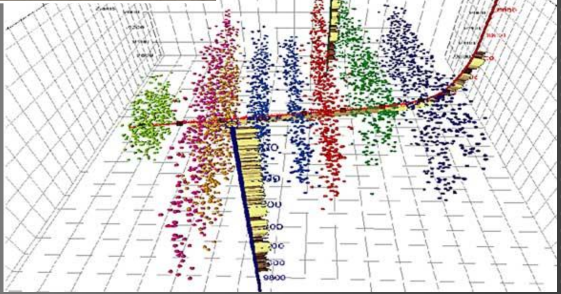
TO SUSTAIN PRODUCTION:

30-50% wells need to be replaced per year:

- ➢$42B/year capital costs for drilling
- ➢Environmental costs

Well Density
Barnett Shale

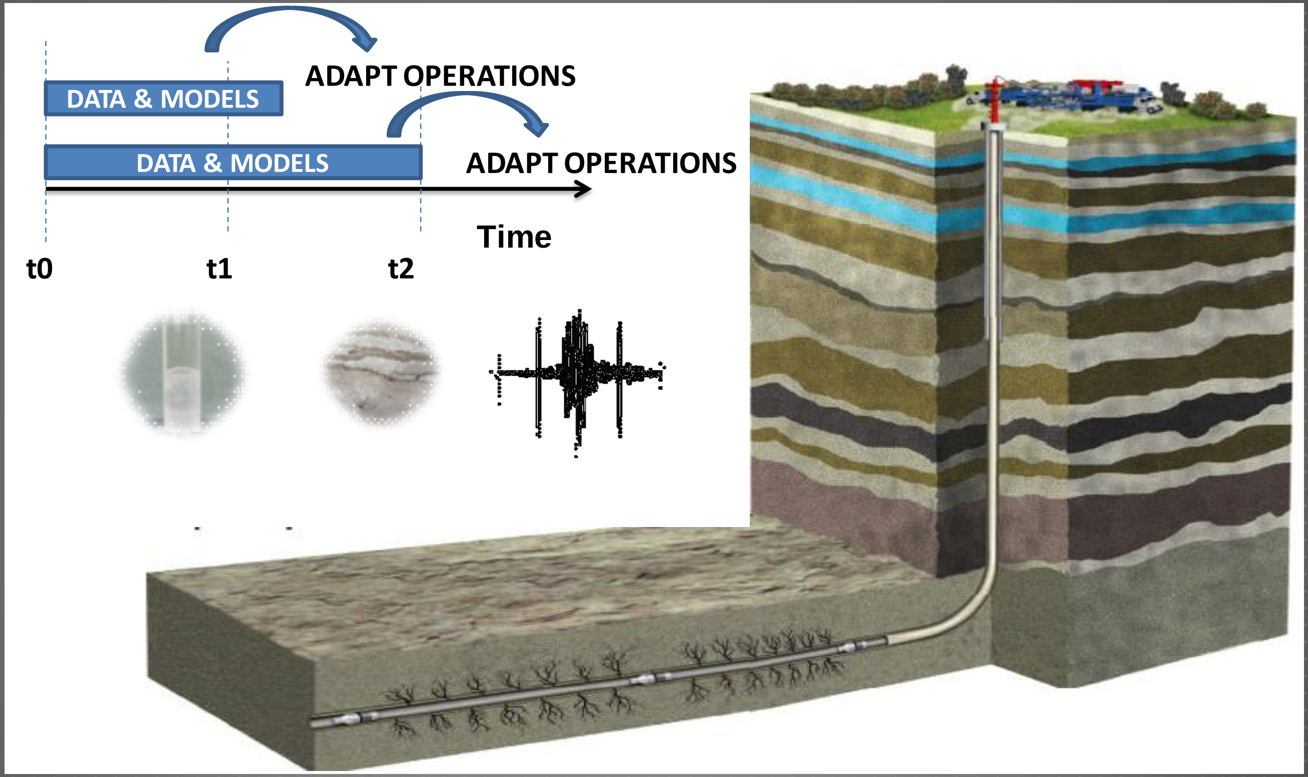




"ADAPTIVE CONTROL" OF SUBSURFACE FRACTURES AND FLOW

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

A "Big Idea"



Confounding Fracture Control

Reservoir stress distribution and material properties are highly heterogeneous, scale dependent, and largely unknown

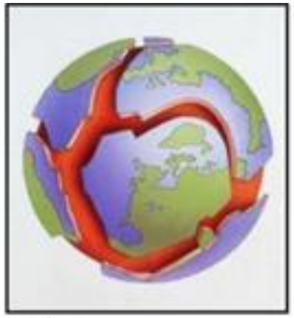
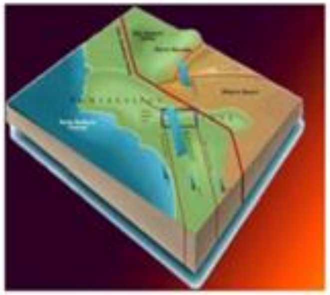
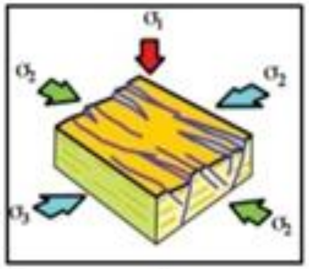


Plate (> 1000 km)

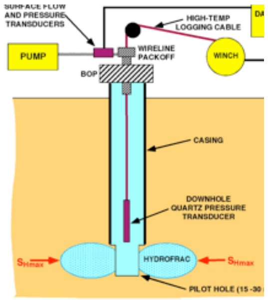
Regional (500 - 1000 km)



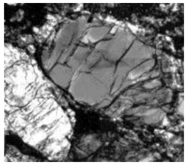
Local (100 - 500 km)



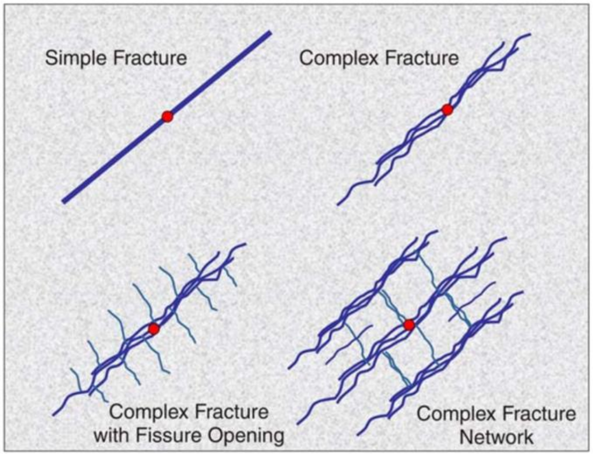
Reservoir (< 100 km)



Wellbore



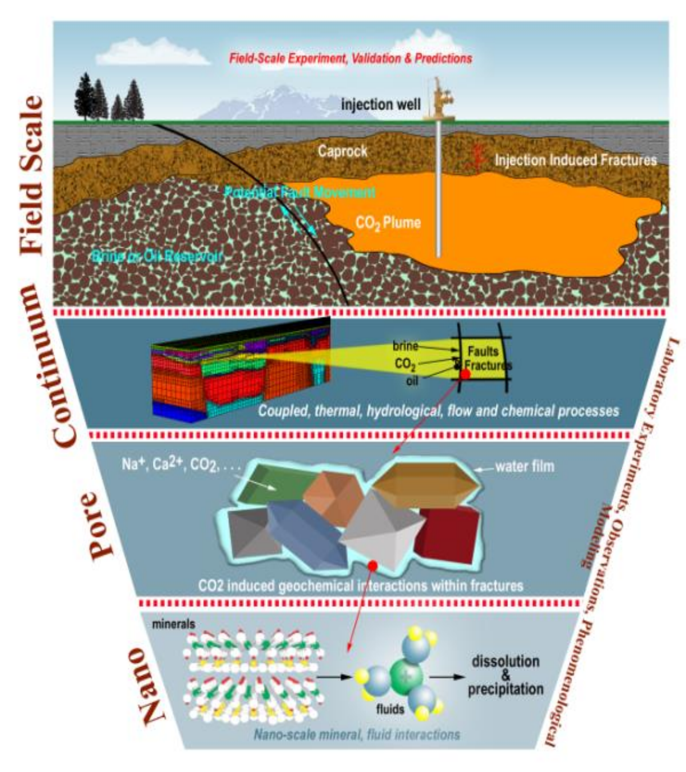
Grain



Subsurface rock property **HETEROGENEITY** (Hierarchy of hydraulic fracture complexity, from Fisher et al. 2002; Fisher and Warpinski, 2011)

TECHNICAL BASELINE: STATE OF KNOWLEDGE & PRACTICE

- Mechanistic understanding of multi-scale processes that influence fracture formation and flow is lacking - limits both production and subsurface storage
- Industry is developing approaches to improve fracture creation
- Petroleum industry has been approaching National Laboratories for assistance: DOE is a leading sponsor of subsurface R&D
- Significant public concern and uncertainty associated with environmental risks



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

Identified 'Adaptive Control' Key Research Categories

Wellbore Integrity & Drilling Technology

- Novel materials for well completion
- Real time, in-situ data acquisition and transmission system
- Diagnostics & remediation tools and techniques
- Quantification of seal material & failure
- Advanced drilling and completion tools
- Well abandonment analysis

Subsurface Stress & Induced Seismicity

- Sensing stress state beyond the borehole
- Manipulating subsurface stress
- Fracture control risk assessment framework

Fracture & Fluid Flow Control

- Physicochemical controls and responses
- Novel stimulation methods
- Manipulating (enhancing, reducing and eliminating) fluid flow

New Subsurface Signals

- New Sensors and Monitoring Approaches
- Next Generation Integration Approaches
- Diagnostic signatures of critical transitions
- Autonomous acquisition, processing and assimilation

Fit For Purpose Simulation Capabilities

- Dynamic fracture propagation and multiscale THMC processes
- Ultrafast prediction
- Integrated data management
- Decision support for adaptive control

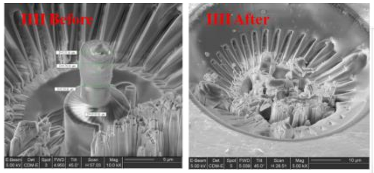
Energy Field Observatories

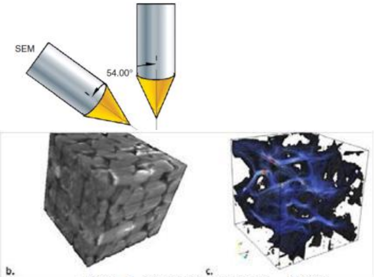
~A few examples of National Laboratory Strengths~

FRACTURE & FLOW CONTROL ~ Rock Physics

- Geomechanical, hydrological, geochemical process coupling in fractures and tight geological materials
- Quantification of fracture initiation, propagation and branching - across scales, in heterogeneous materials & influence on flow
- Dissolution, precipitation, reactivity in fractures and influence on flow
- Interpretation of effective signatures
- Use of significant DOE synchrotron and other unique measurement facilities

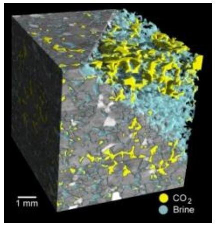
FIB/SEM imaging



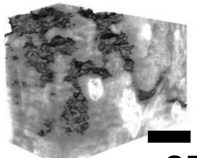


Silin & Kneafsey et al., 2012

Synchrotron approaches, including microtomography

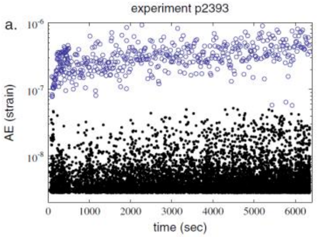


Ajo-Franklin et al., 2011



25 µm

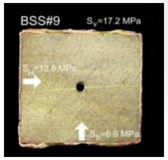
Neutron diffraction-based strain (Polsky, 2013)

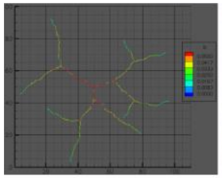


Acoustic emissions
Johnson et al., 2013

CT Scaning under relevant conditions

True triaxial lab experiments and associated msmts

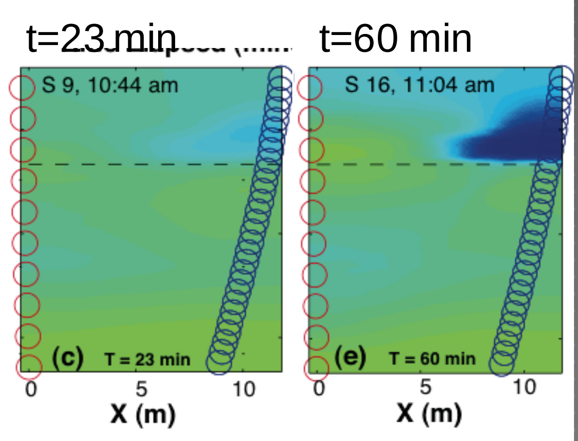




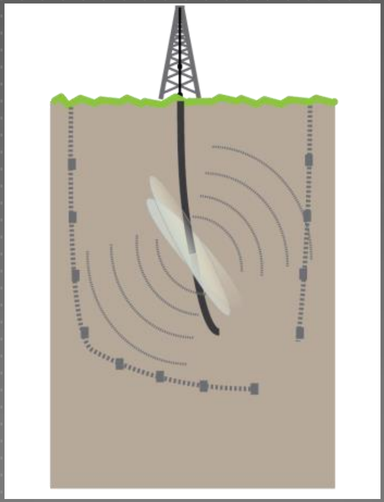
Block manipulations

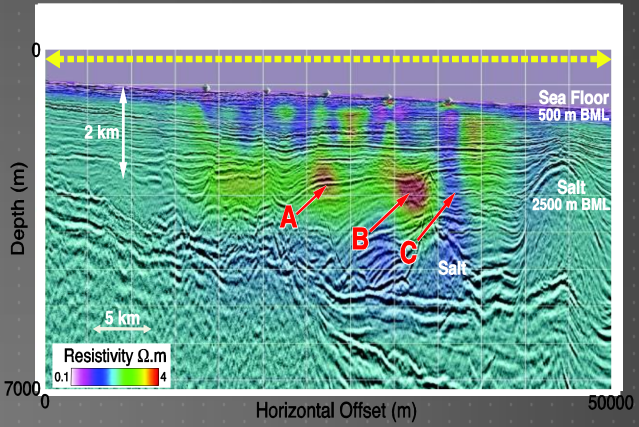
NEW SUBSURFACE SIGNALS

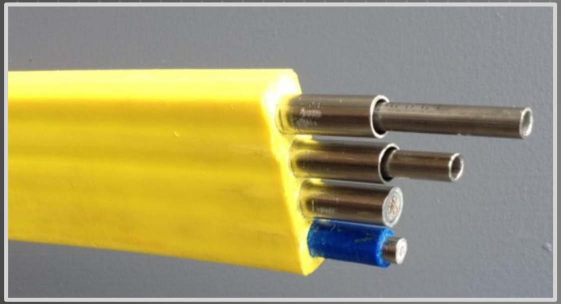
- Many geophysical methods (including seismic, electromagnetic, InSAR)
- New acquisition geometries, joint inversions including MEQ, sensor development (fiber optics, high temperature sensors), geophysical 'tracers'

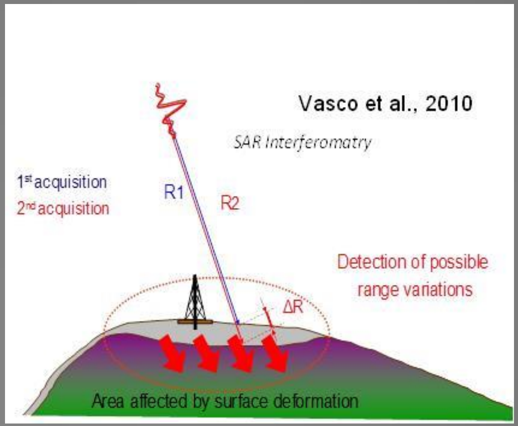


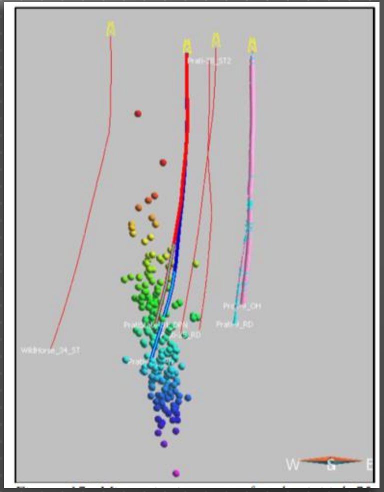
Ajo-Franklin et al., 2011



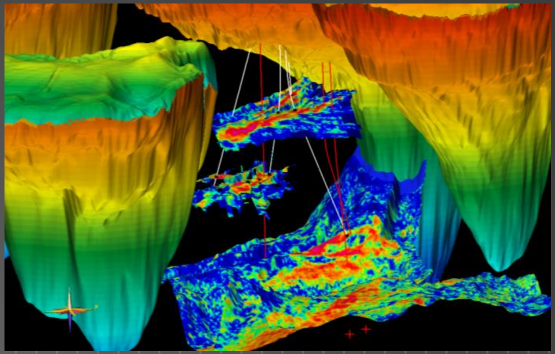


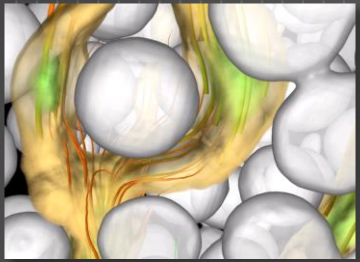


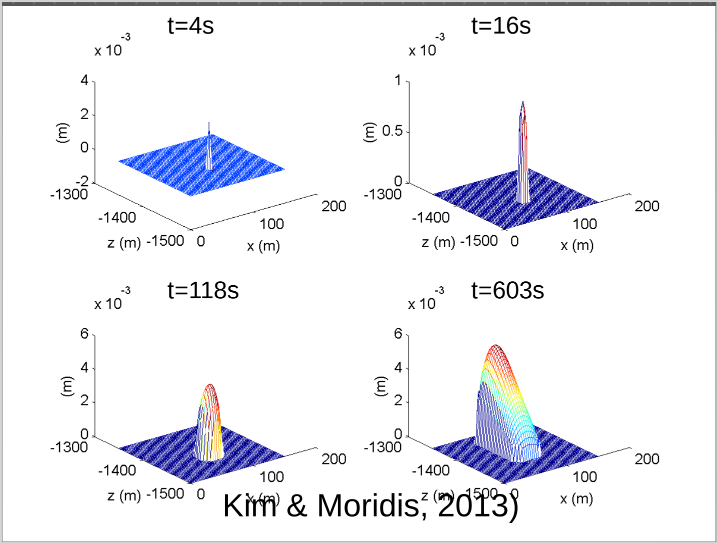




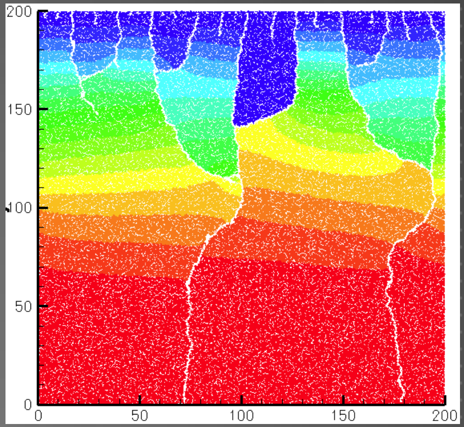
SIMULATION CAPABILITIES

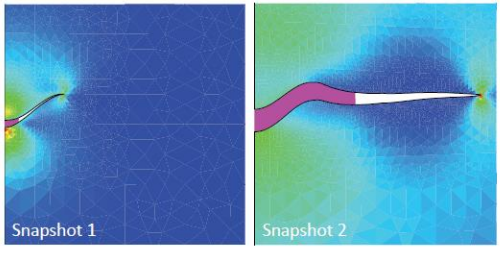




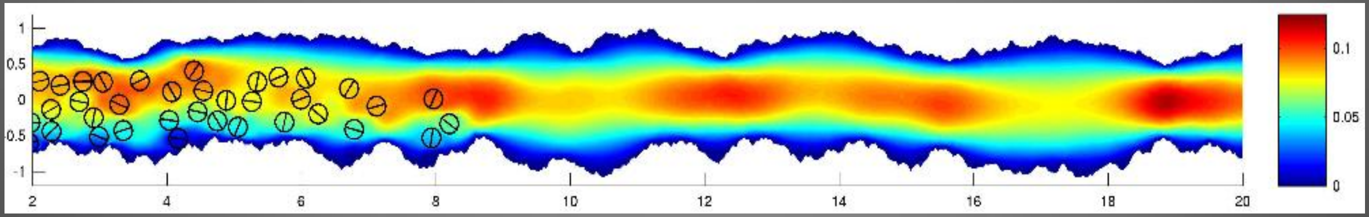


Kim & Moridis, 2013)



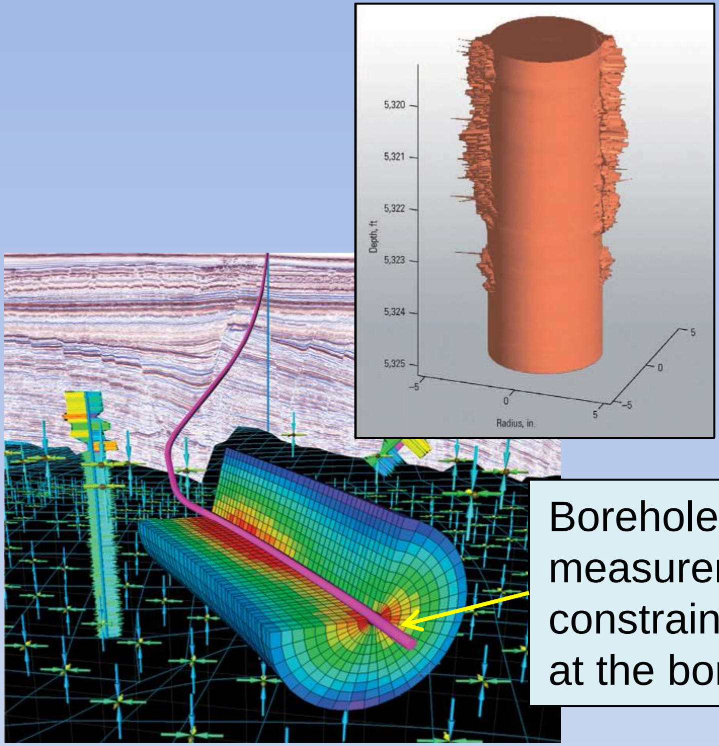


Simulation of coupled thermal, hydrological, mechanical & chemical processes….across relevant scales

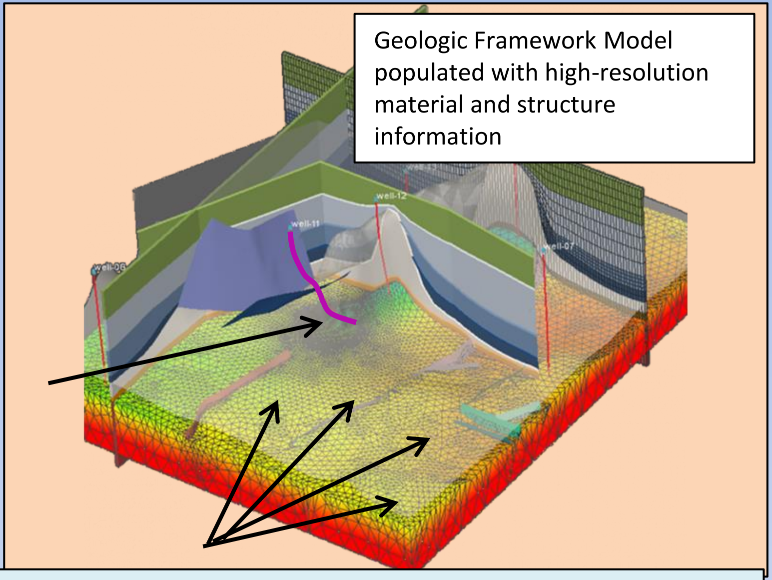


Lew et al., 2014

INTEGRATION & JOINT INVERSION



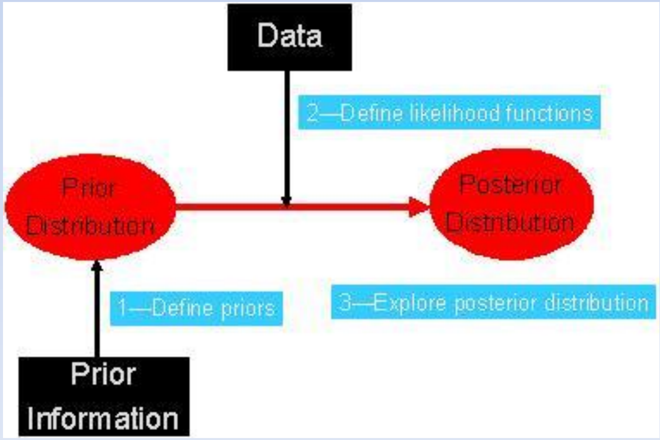
Borehole stress measurements constrain predictions at the borehole….



Geologic Framework Model populated with high-resolution material and structure information

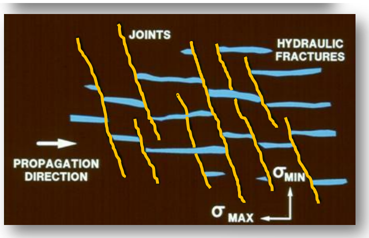
But stress estimates are needed here…

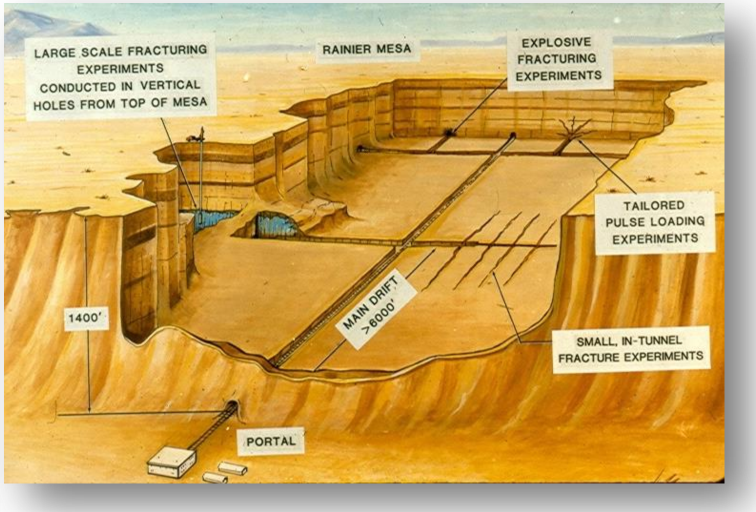
- Joint consideration of direct measurements, indirect measurements, knowledge of geologic framework, and theory
- Opportunity to quantify away from borehole and to assess uncertainty
- Needed to guide subsurface manipulations with confidence

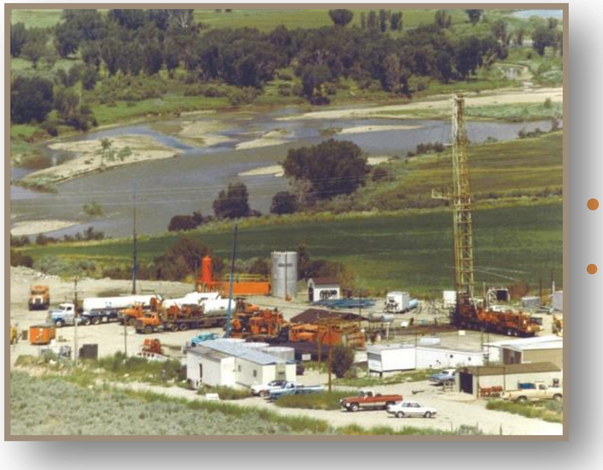


Field Observatories & Experiments

- **Nevada Test Site**, 1976-1985
- Extensive characterization of fractures, cores, seismic, tiltmeters, geology



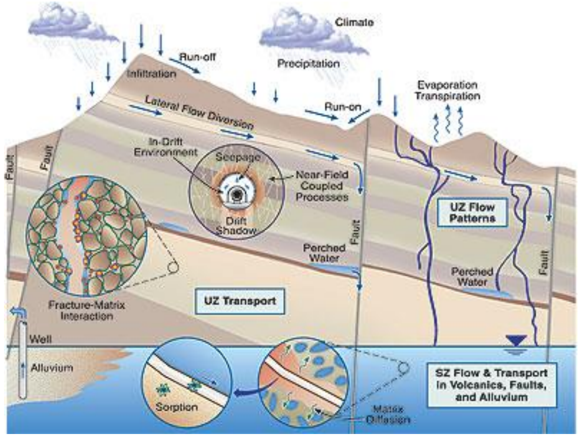




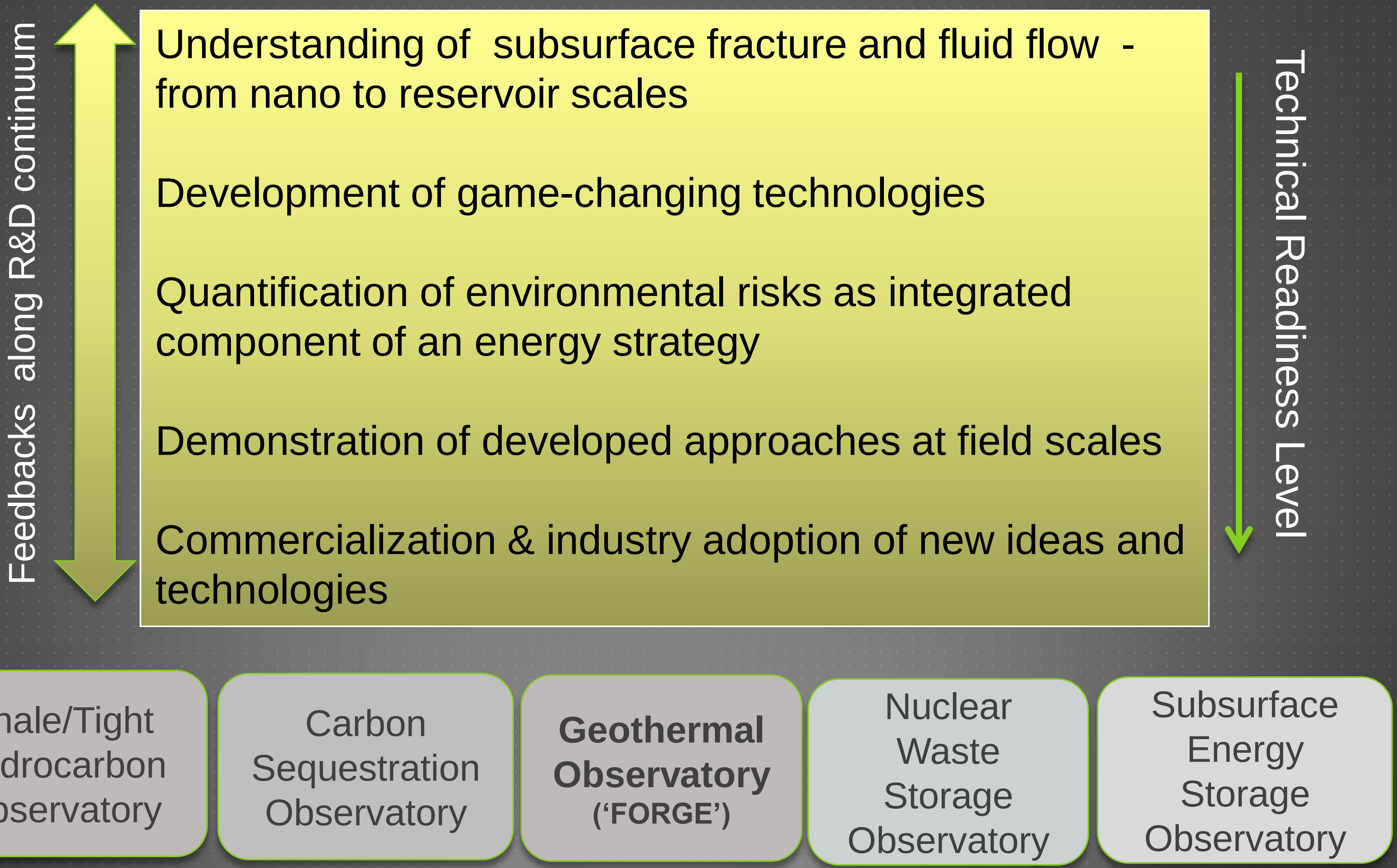
- **Multiwell Experiments, Rifle CO**. 1981-1988
- Stimulation experiments using 3 closely-spaced vertical wells to improve production from "tight" sands

Yucca Mountain, NV 1997-2010

Characterization and experiments to gain a predictive understanding of thermal-hydrological-chemical coupled-process testing and modeling in the deep vadose zone



APPROACH:
A NEW SUBSURFACE R&D PARADIGM IS REQUIRED FOR SUCCESS



Feedbacks along R&D continuum

Understanding of subsurface fracture and fluid flow - from nano to reservoir scales

Development of game-changing technologies

Quantification of environmental risks as integrated component of an energy strategy

Demonstration of developed approaches at field scales

Commercialization & industry adoption of new ideas and technologies

Technical Readiness Level

Shale/Tight Hydrocarbon Observatory

Carbon Sequestration Observatory

Geothermal Observatory (‘FORGE’)

Nuclear Waste Storage Observatory

Subsurface Energy Storage Observatory

A BIG IDEA!

- Transformational improvements are needed to gain mastery of the subsurface
- Current level of effort is not commensurate with importance and scale of challenge
- Efficient investment: Very high rate of return expected*
- New paradigm for subsurface R&D that integrates and expands National Laboratory capabilities toward common big goal.
- Vastly enhanced partnerships between National Laboratories, universities, industry, regulators and stakeholders

FRACTURES-BY-DESIGN

ENERGY PRODUCTION

- Increase U. S. electrical production from geothermal reservoirs
- Increase U.S. unconventional oil and natural gas for multiple uses

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

ECONOMIC & SOCIAL BENEFITS

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

*Annual US energy Expenditures $1.8Trillion