Subsurface Energy Application: Cross-Cutting Research Needs and the Role of Deep Geoscience Observatories

Jens Birkholzer
Lawrence Berkeley National Laboratory

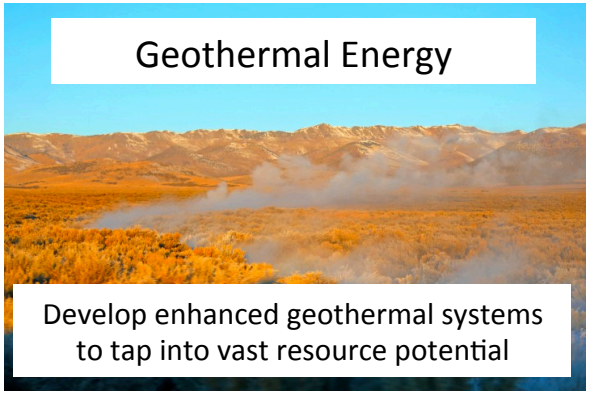
GSA 2016, Denver, Colorado

Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

BERKELEY LAB

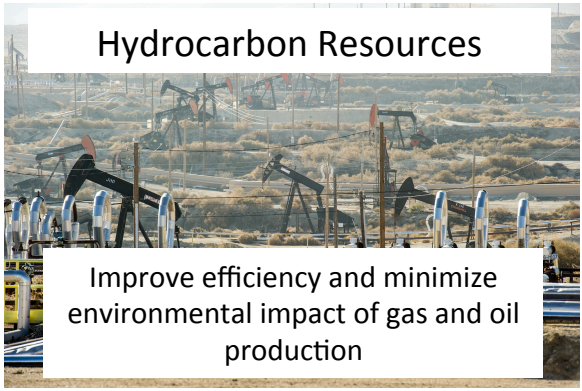
Subsurface Resources for a Safe and Efficient Energy Future

Geothermal Energy

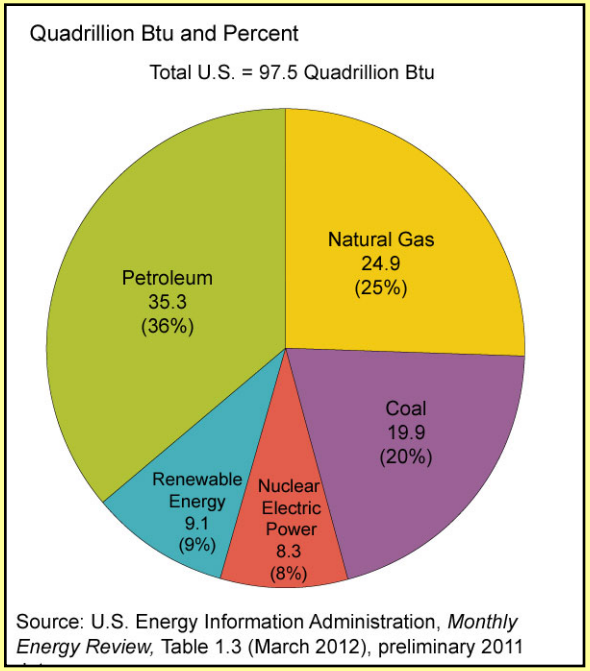


Develop enhanced geothermal systems to tap into vast resource potential

Hydrocarbon Resources



Improve efficiency and minimize environmental impact of gas and oil production



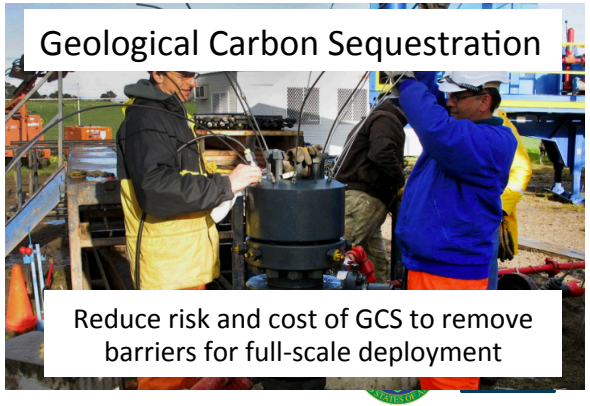
THE SUBSURFACE:

- Supplies/enables **>80%** of the energy consumed in the U.S.
- Serves as a **vast reservoir** for storage of CO_2, nuclear and other energy waste streams

Nuclear Energy & Waste

Develop alternative solutions for geologic disposal of radioactive waste

Geological Carbon Sequestration



Reduce risk and cost of GCS to remove barriers for full-scale deployment

Common Subsurfaces Challenges

Discovering, Characterizing, and Predicting
Efficiently and accurately locate targets and predicting their response to engineered perturbations

Accessing
Safe and cost-effective drilling, while assuring reservoir integrity

Manipulating
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

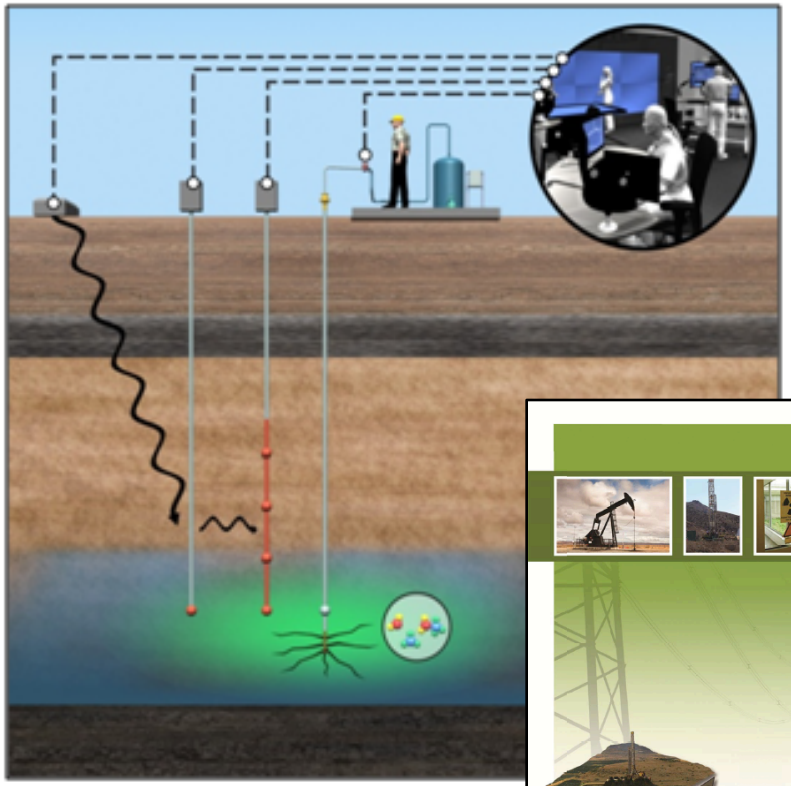
Monitoring
Improve observational methods and advance understanding of multi-scale complexities through system lifetimes

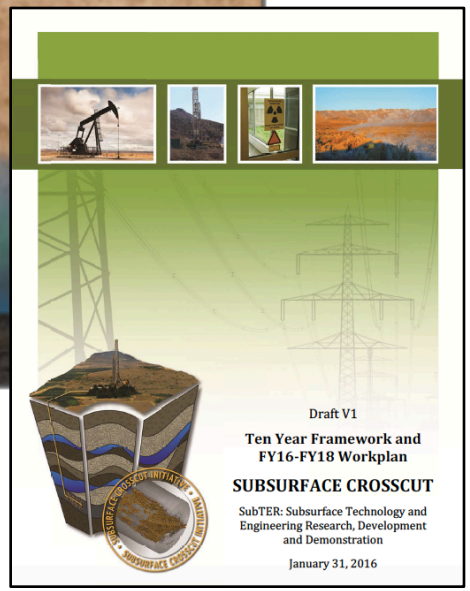
SubTER Crosscut Initiative

Big Idea: Adaptive Control of the Subsurface for a Safe and Effective Energy Future

10-Year Vision:

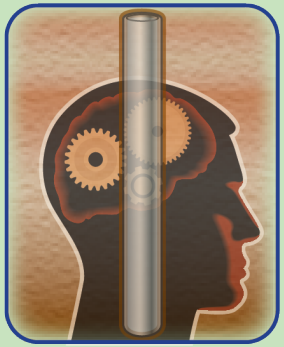
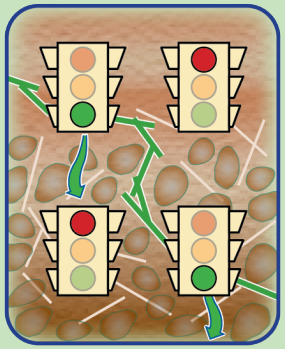
- Enable large-scale safe CO_2 sequestration
- More than double U. S. electricity production from geothermal reservoirs
- Double reservoir effectiveness (recovery factor, EOR efficacy, CO_2 sequestration capacity) with reduced footprint
- Establish practical feasibility of deep borehole disposal of nuclear waste
- Concurrently protect the environment (GHG reductions, water and air resources, induced seismicity)





Visit GSA Exhibitor Booth #306 to learn more about SubTER

SubTER Technical Framework

Wellbore Integrity and Drilling Technologies	Subsurface Stress & Induced Seismicity	Permeability Manipulation & Fluid Control	New Subsurface Signals
			
Materials and technologies to ensure wellbore integrity over decadal timeframes	Characterization and control of subsurface stress and induced seismicity	Approaches to manipulate subsurface fractures, reactions and flow	Sensors and algorithms to monitor subsurface dynamics and facilitate adaptive control

Geoscience Field Observatories

Advanced Simulation Capabilities

Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

BERKELEY LAB

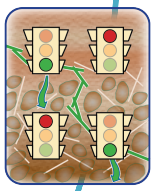
Coordinated Breakthrough on Many Fronts: Example Goals

Demonstrate next generation wellbore integrity approaches in the field: on path to significantly reducing well failures in 10 years

- New materials that provide significant increase in bond strength and pressure integrity
- Autonomous sensing systems for lifetime State of Health information
- New high temperature and high pressure drilling and completion technologies: 300^0 C and 2500 bar

Demonstrate measurement, characterization, and manipulation of in-situ subsurface stress in the field: on path to drastic reduction of damaging induced seismicity in 10 years

- Dramatic improvement of stress estimates away from the borehole and locations of critically stressed faults and associated microseismicity
- Control and characterize flow along activated fractures and faults
- Develop risk-driven approaches to manage induced seismicity



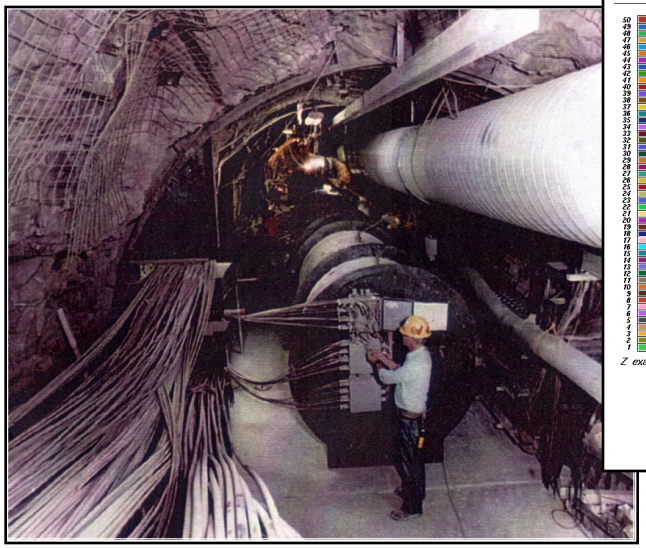
Demonstrate adaptive control of permeability in the field: on path to predictable fractures in 10 years, leading to doubling of energy extraction efficiency for EGS and fossil fuels

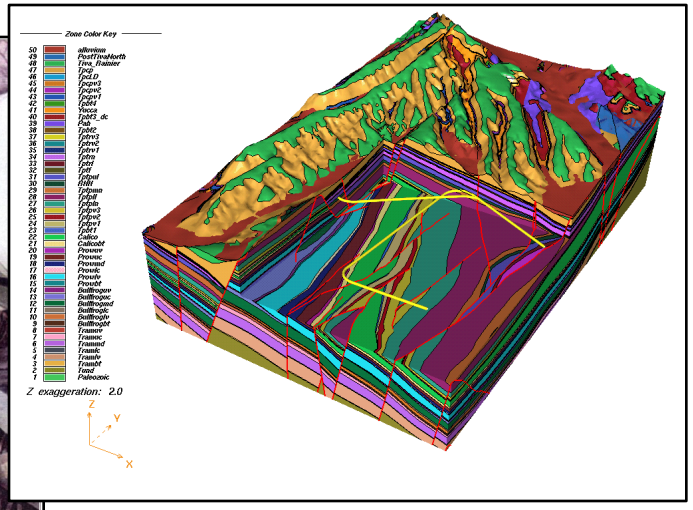
- New capabilities to accurately simulate fracture initiation and growth in heterogeneous materials
- New chemical and hydrodynamic strategies to manipulate subsurface permeability

Transform monitoring of subsurface system behavior on path to assured subsurface storage in 10 years

- Critical system threshold identification with fiber-based technologies
- Large sensor array and rapid processing techniques to inform adaptive control strategies
- Big/heterogeneous multi-sensor data integration, joint inversion and analytics

Geoscience Field Observatories: Nuclear Waste





Yucca Mountain

Stripa Mine

Project	Where	←1960	←1970	←1980	←1990	←2000	←2010	
Lyons Mine (Project Salt Vault)	USA							URL and SNF demo
Asse Mine	Germany							LLW/ILW currently in remediation
Stripa Mine	Sweden							
Climax Mine	USA							Former nuclear testing; SNF demo
G-Tunnel	USA							Former nuclear testing
Fanay-Augeres	France							Former uranium mine
HADES-URF*	Belgium							
Konrad**	Germany							Being developed as a repository
Grimsel Test Site	Switzerland							
AECL URL (Lac du Bonnet)*	Canada							
Gorleben**	Germany							Operations curtailed 2012
WIPP**	USA							URL testing for heat-generating waste
Amelie	France							Former potash mine
Tono Mine	Japan							
Kamaishi Mine	Japan							
Tournemire Tunnel	France							Former rail tunnel
Aspo HRL*	Sweden							
Olkiluoto Research Tunnel	Finland							Developed for LLW/ILW investigations
Mont Terri	Switzerland							Former highway tunnel
Pecs**	Hungary							Former uranium mine
ESF (Yucca Mountain)**	USA							
Busted Butte*	USA							
Bure URL (Meuse/Haute Marne)**	France							
Morsleben**	Germany							LLW/ILW repository 1981-1998
Mizunami URL*	Japan							
ONKALO**	Finland							
Horonobe URL*	Japan							
Korea UG Research Tunnel*	Rep. of Korea							

NOTE: Timelines accurate to approx. ±3 years.

Salt
Crystalline
Tuff
Plastic clay
Argillaceous
Other sedimentary

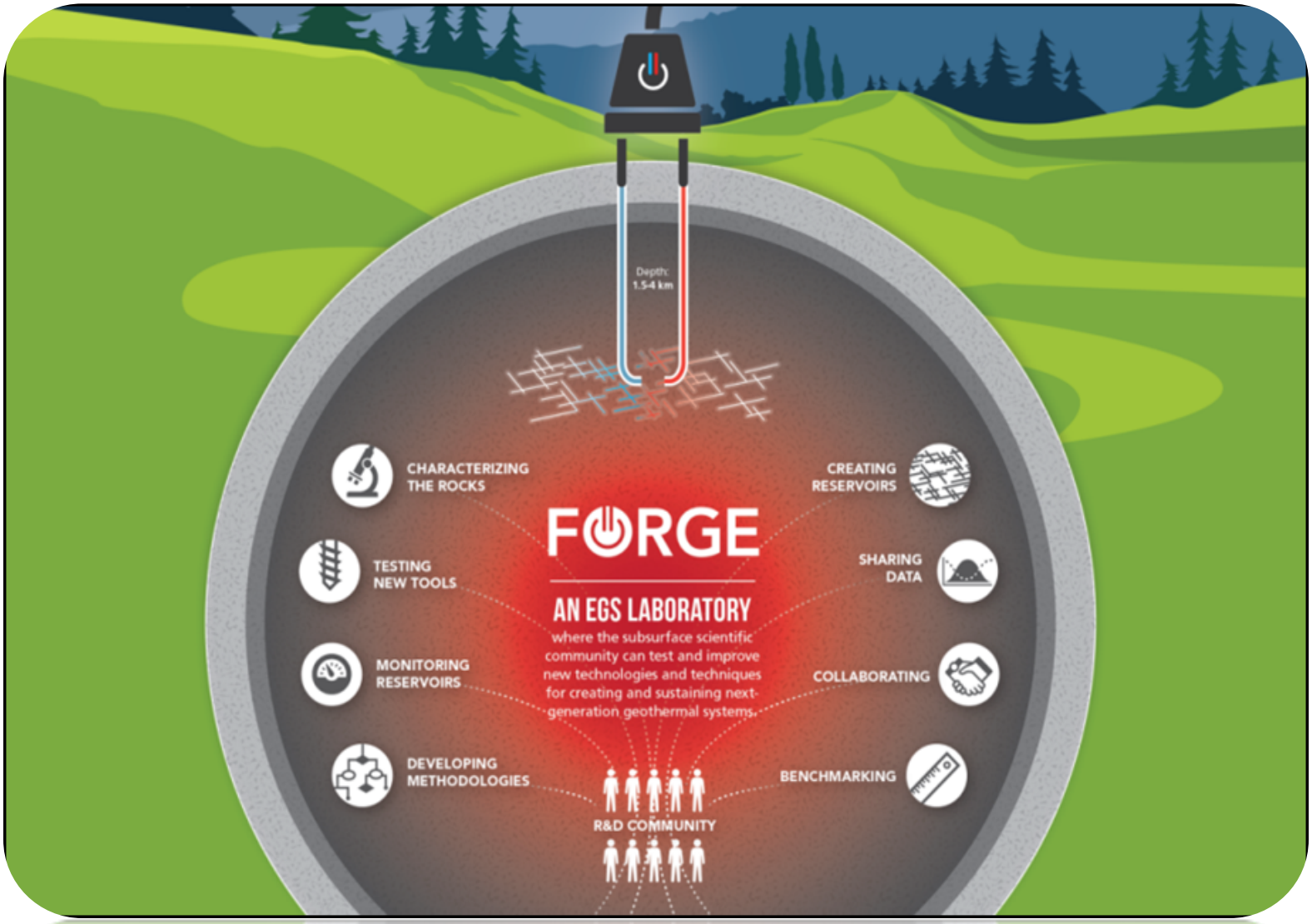
* Purpose-built, generic
** Purpose-built, site-specific
(Generic pre-existing URLs have no marks)

NOT SHOWN: Early U.S. URLs (Avery Island, CSM Mine, etc.) and more recent U/G investigations in the Czech Republic, Canada, and elsewhere.

Long History of Underground Observatories for Nuclear Waste Disposal R&D

Geoscience Field Observatories: Geothermal

FORGE – Frontier Observatory for Research in Geothermal Energy



Energy Geosciences Field Observatories

Characteristics:

Dedicated facilities for observation and controlled experiments, located in representative lithologies

Ability to manipulate the subsurface & perform destructive testing

Comprehensive characterization and monitoring

Testing at scale, under in situ conditions, in complex and heterogeneous subsurface systems

Community facilities with partnership between science, industry, and other stakeholders; open access to data

Objectives:

Improve process understanding

Test simulation capabilities

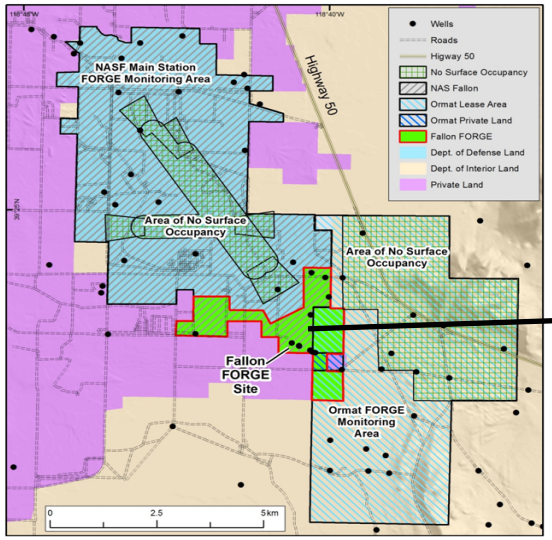
Apply new manipulation technologies

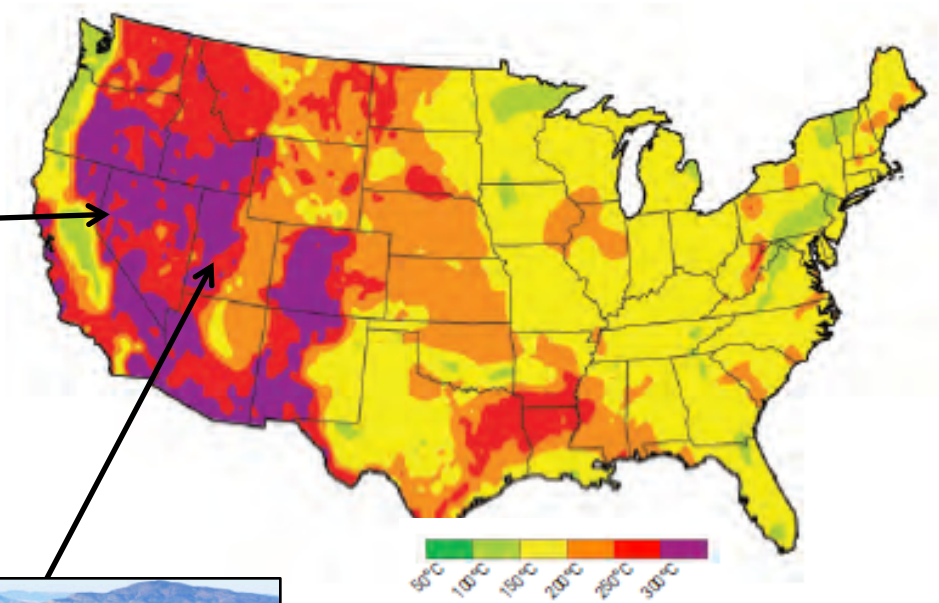
Prototype advanced imaging/monitoring methods

Advance new approaches through testing and demonstration to adoption

Potential FORGE Sites: Phase II Projects

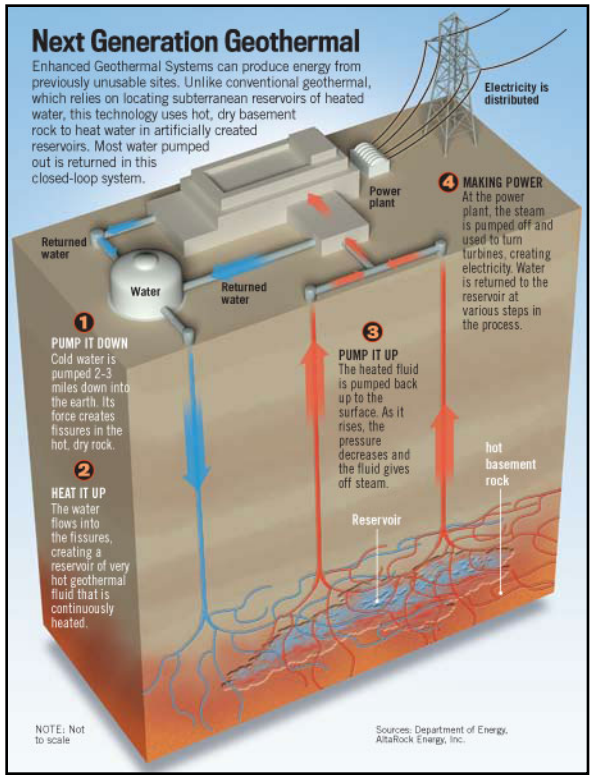
Fallon, NV

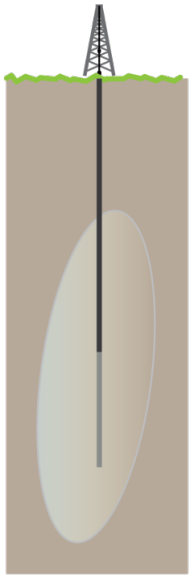




Milford, Utah

Potential FORGE Focus Areas

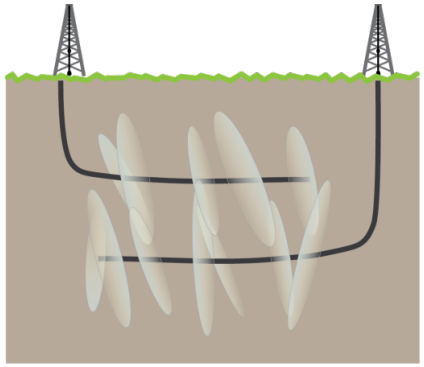




Original Hot Dry Rock Concept

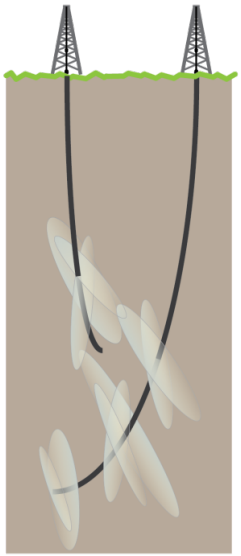
1970s

Potential EGS Test Site Concepts

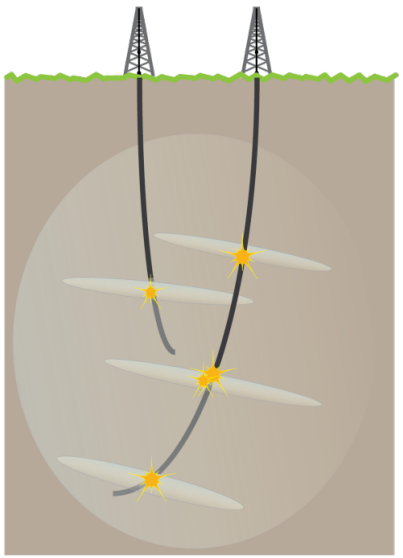


New Well Configurations

Precision Data Collection & HT/HP Tool Testing



Zonal Isolation

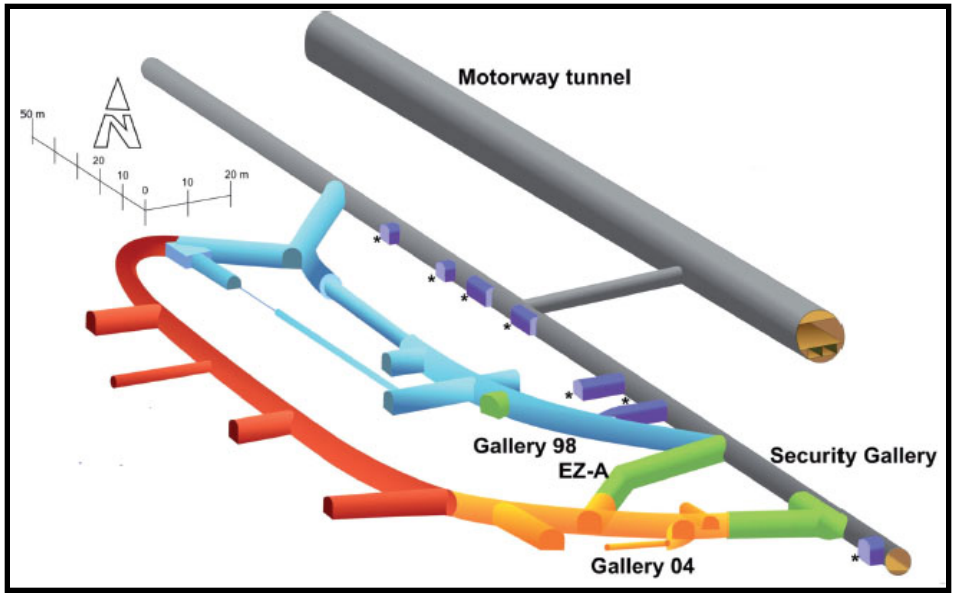


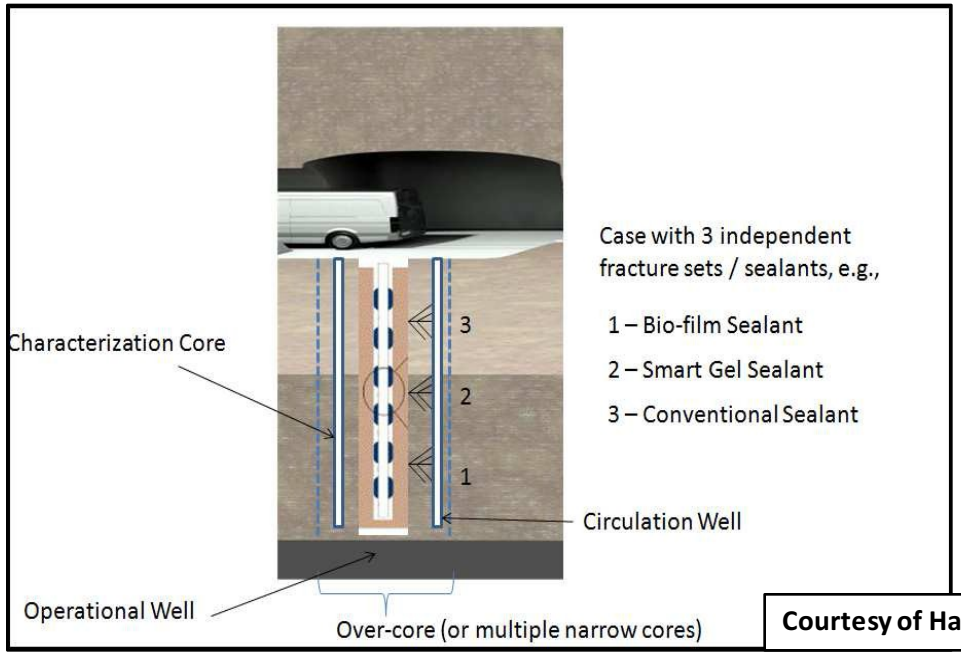
New Stimulation Technologies

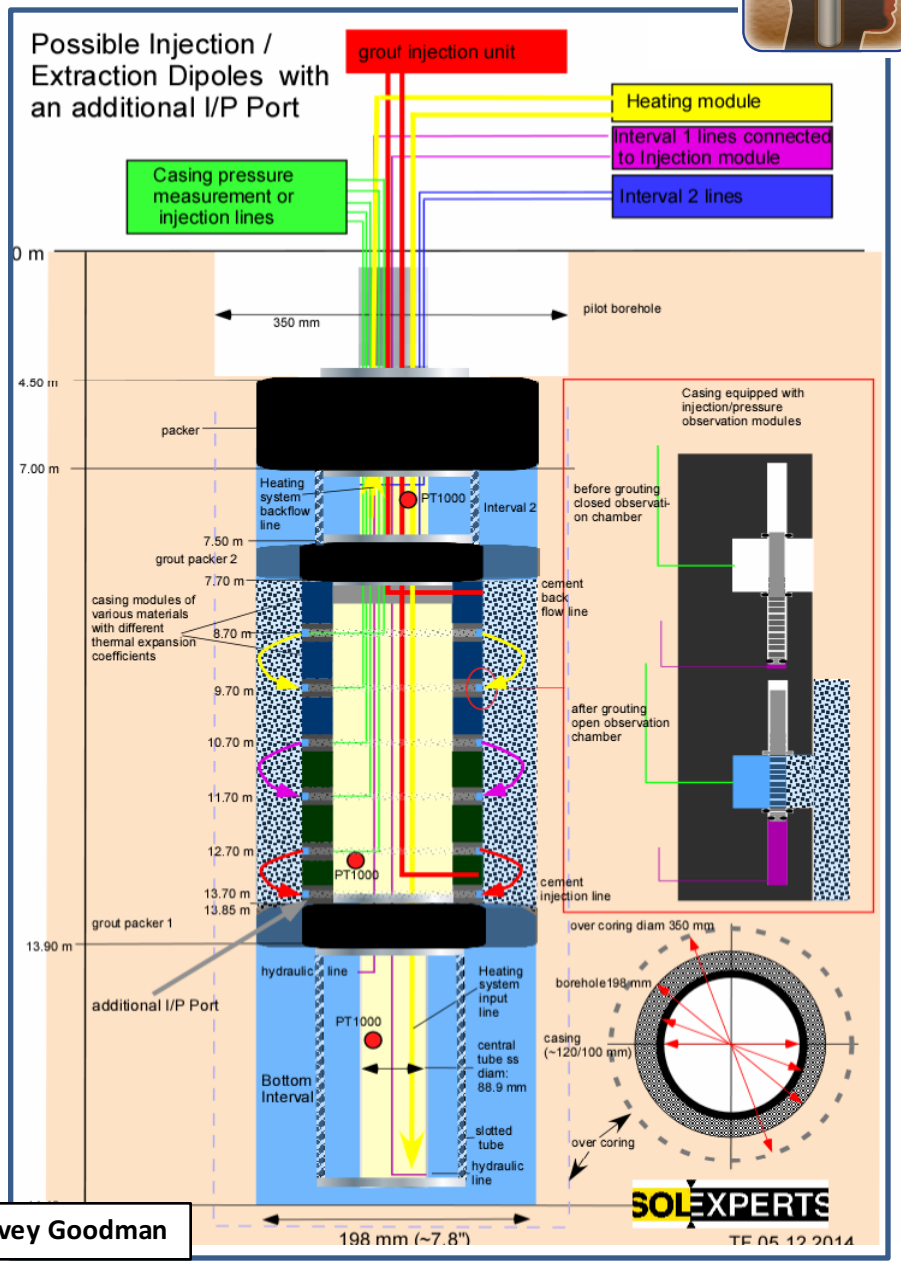
Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

BERKELEY LAB

Wellbore Leakage & Sealing Experiment (Mont Terri)

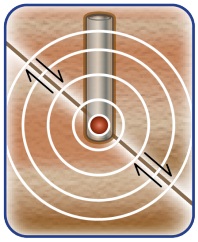


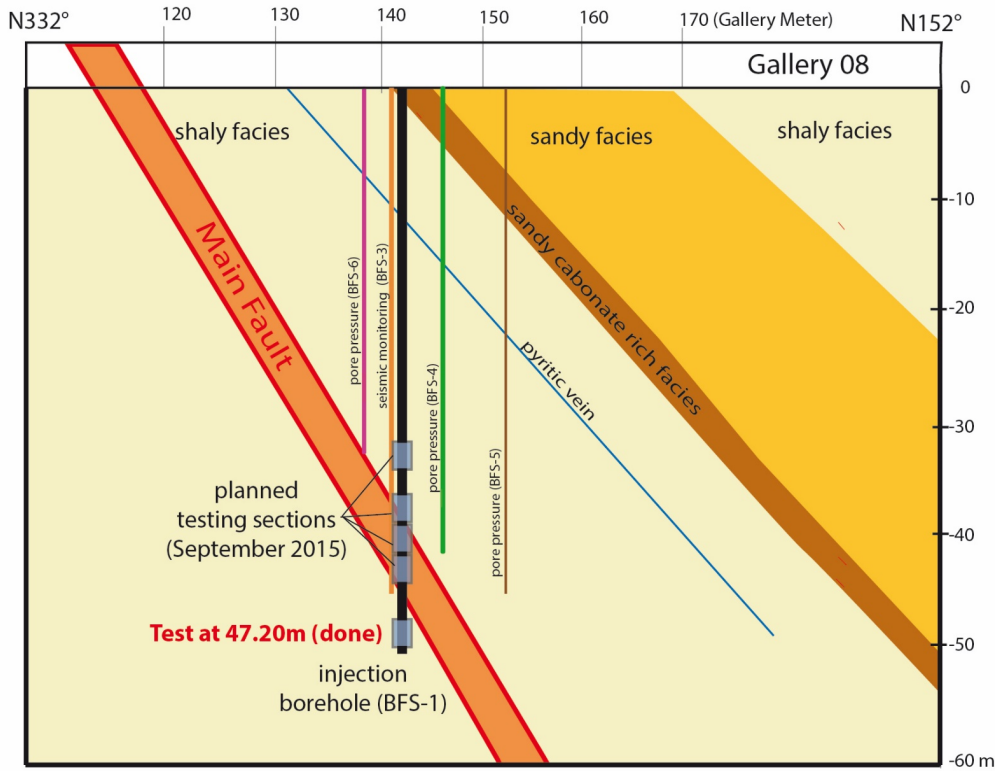


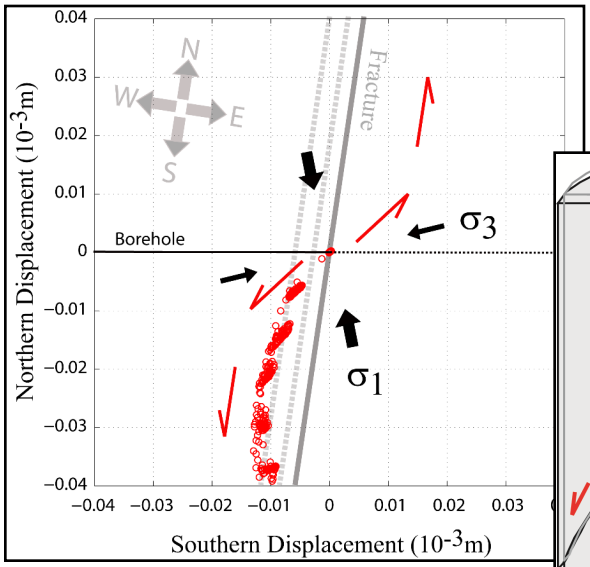


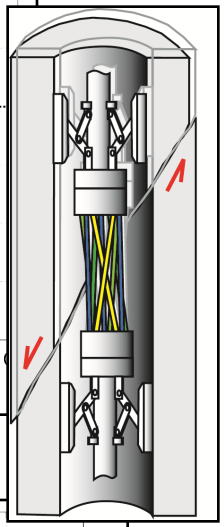
Courtesy of Harvey Goodman

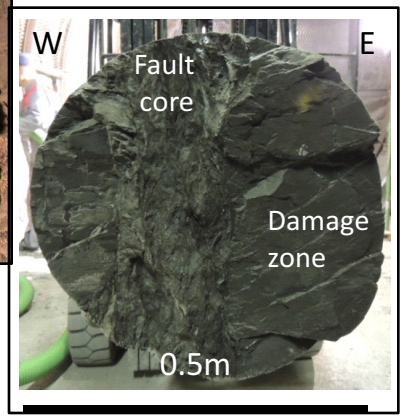
A Controlled Fault Slip Experiment in a Shale Layer

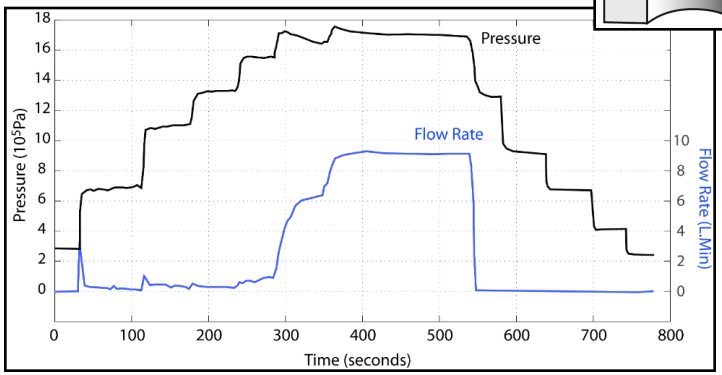








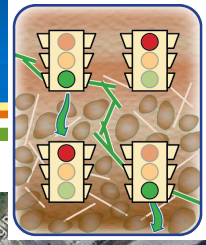




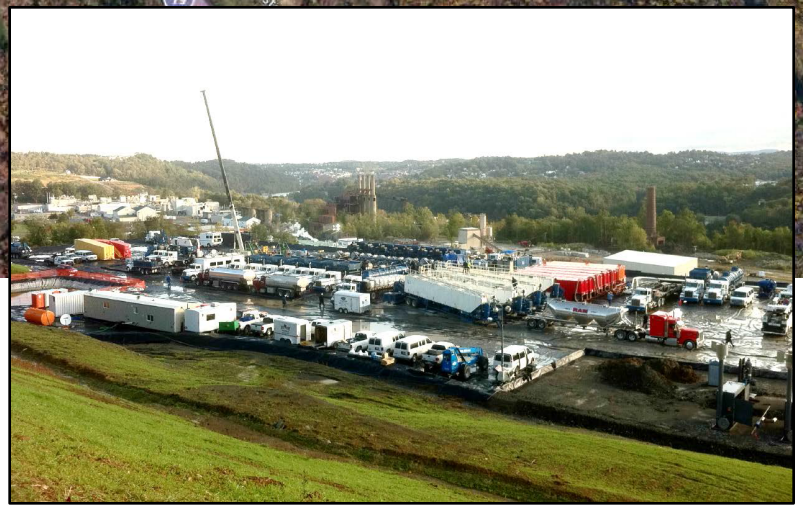
Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

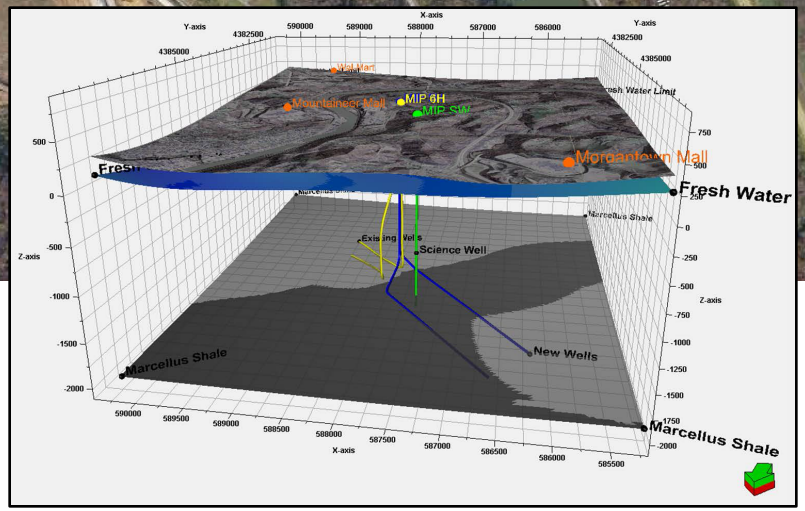
BERKELEY LAB

Marcellus Shale Laboratory (MSEEL)



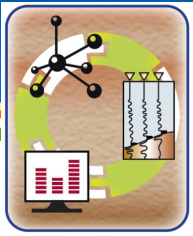
Monitor hydraulic fracturing characteristics and evaluate potential environmental issues

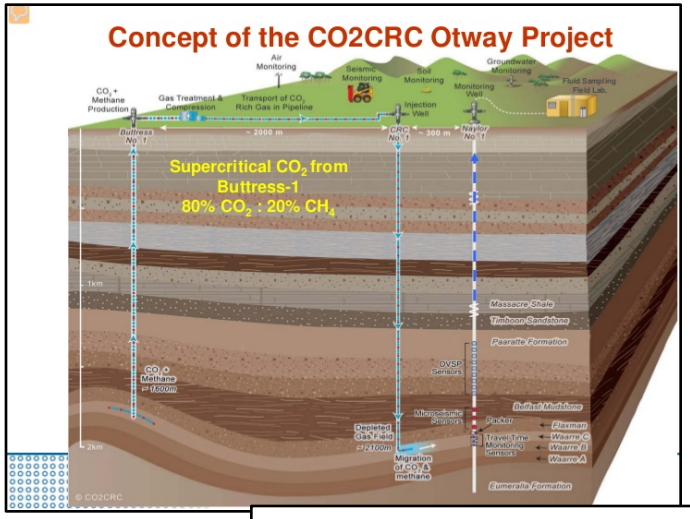




Courtesy of Richard Hammack, NETL

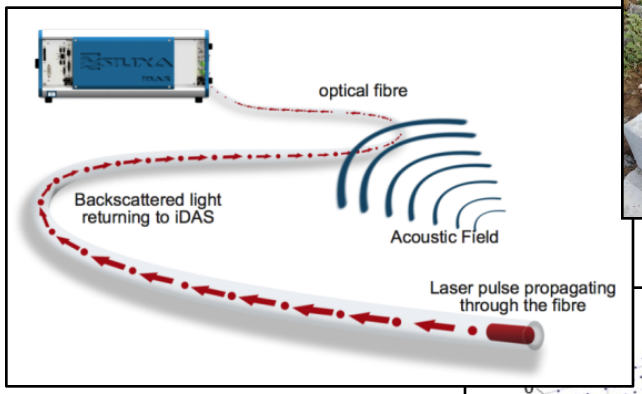
Advanced Monitoring in CO_2 Demonstration Projects





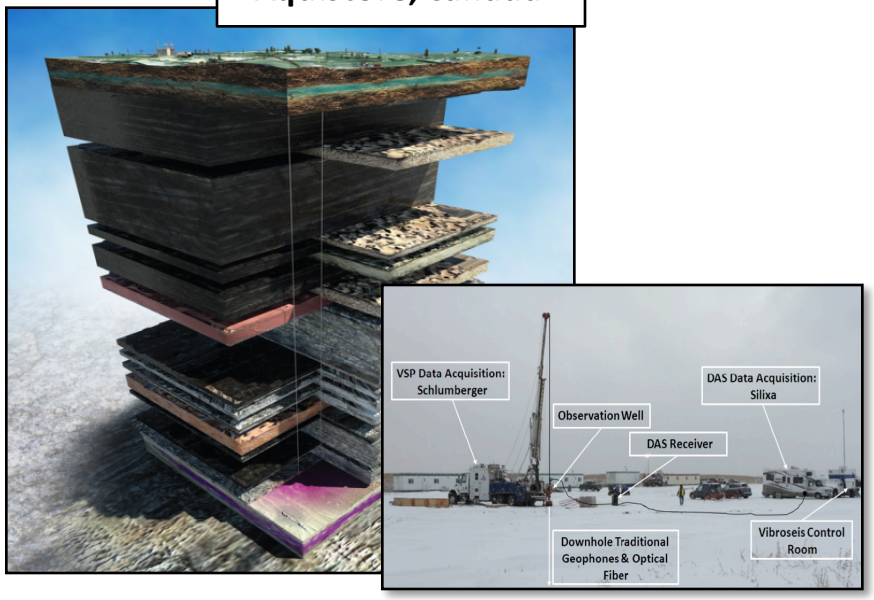
Otway Project, Australia

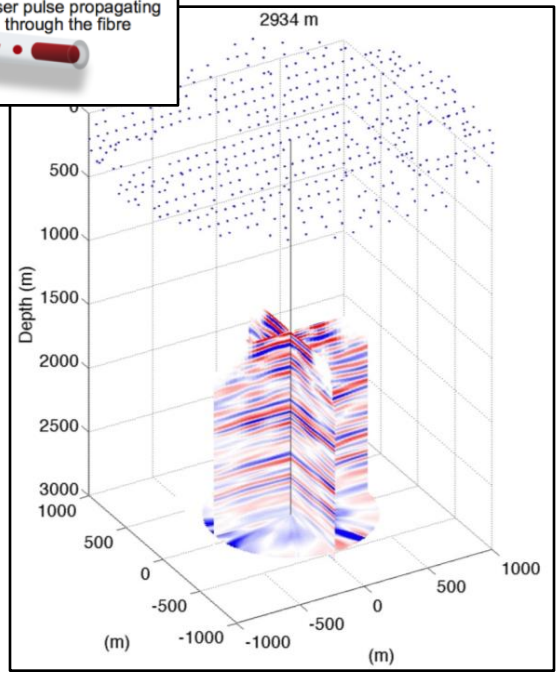
Distributed acoustic sensing for high spatial and temporal resolution, with permanent excitation through permanent fixed rotary sources



Surface Orbital Vibrator

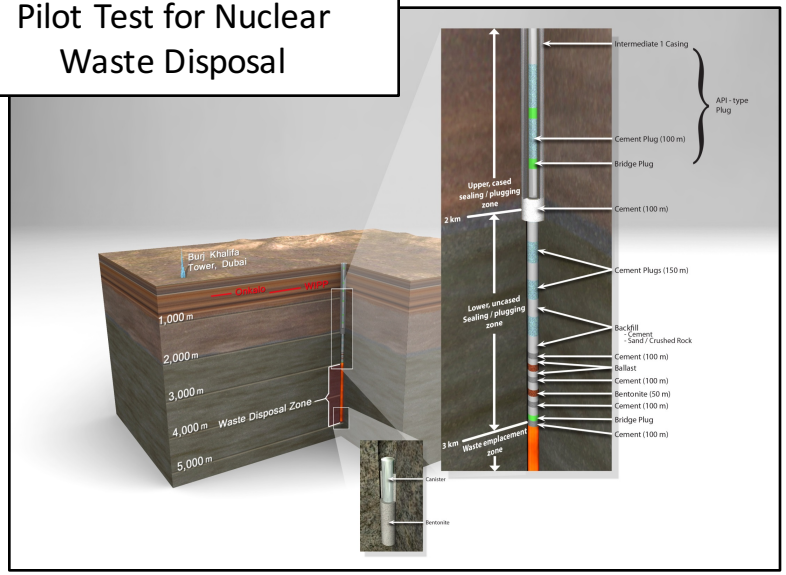
Aquistore, Canada



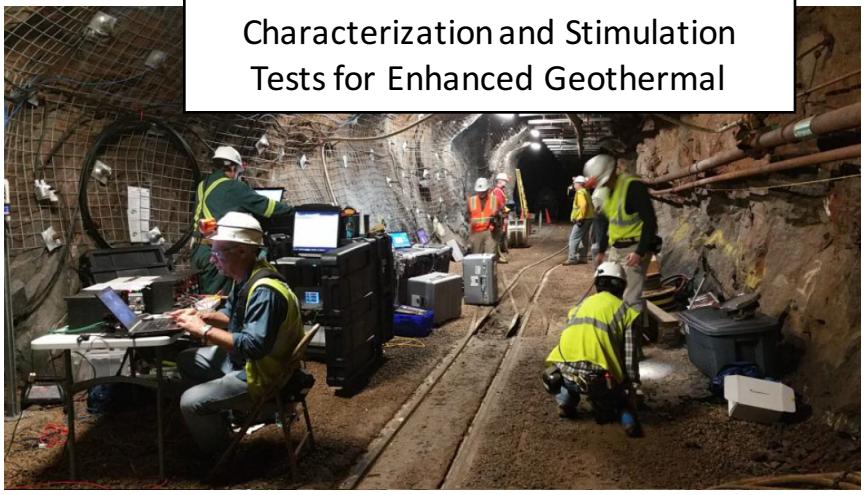


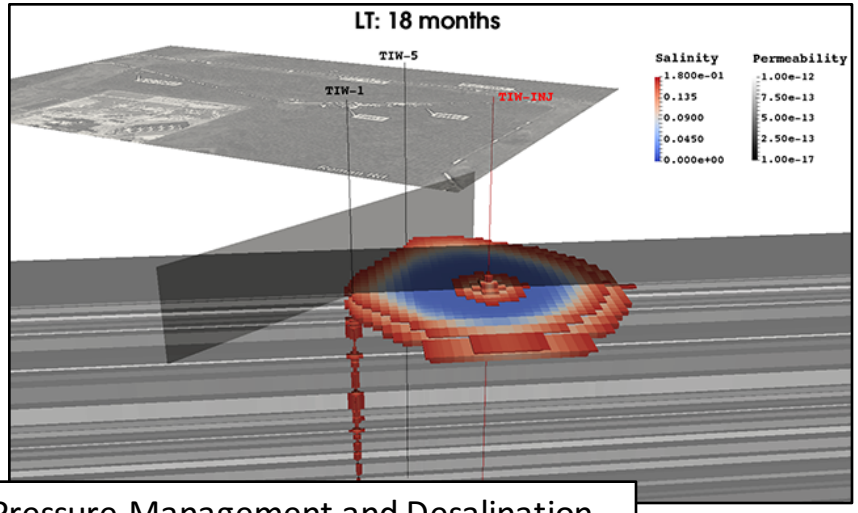
Other Subsurface Energy Geoscience Observatories

Deep Borehole Disposal Pilot Test for Nuclear Waste Disposal



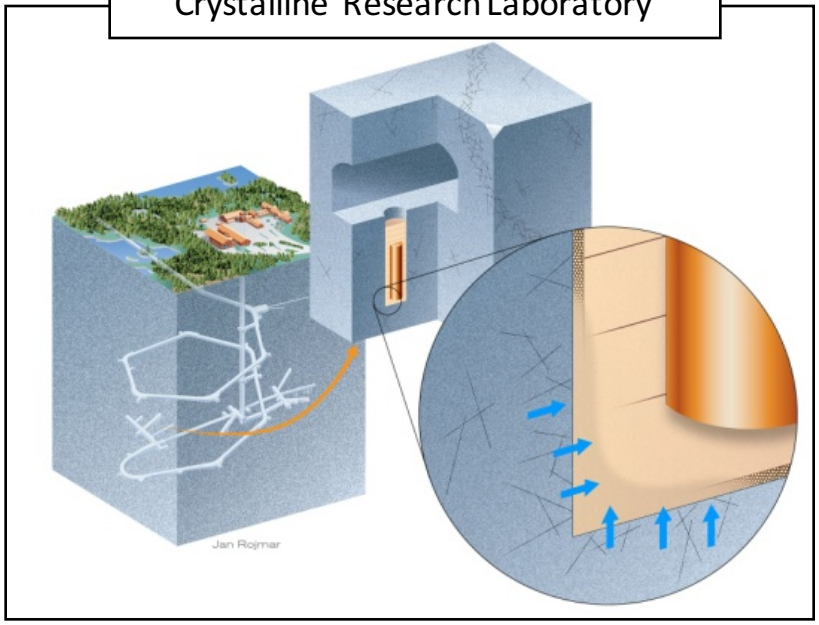
kisMET at SURF – Stress Field Characterization and Stimulation Tests for Enhanced Geothermal





Pressure Management and Desalination Pilot Test for CO_2 Sequestration

Äspö Hard Rock Laboratory – Deep Crystalline Research Laboratory



Geoscience Observatories…. Build Communities

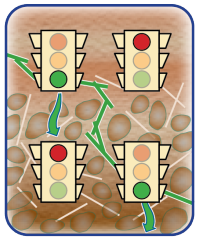
Mont Terri Rock Underground Lab Meeting

Yucca Mountain Field Trip

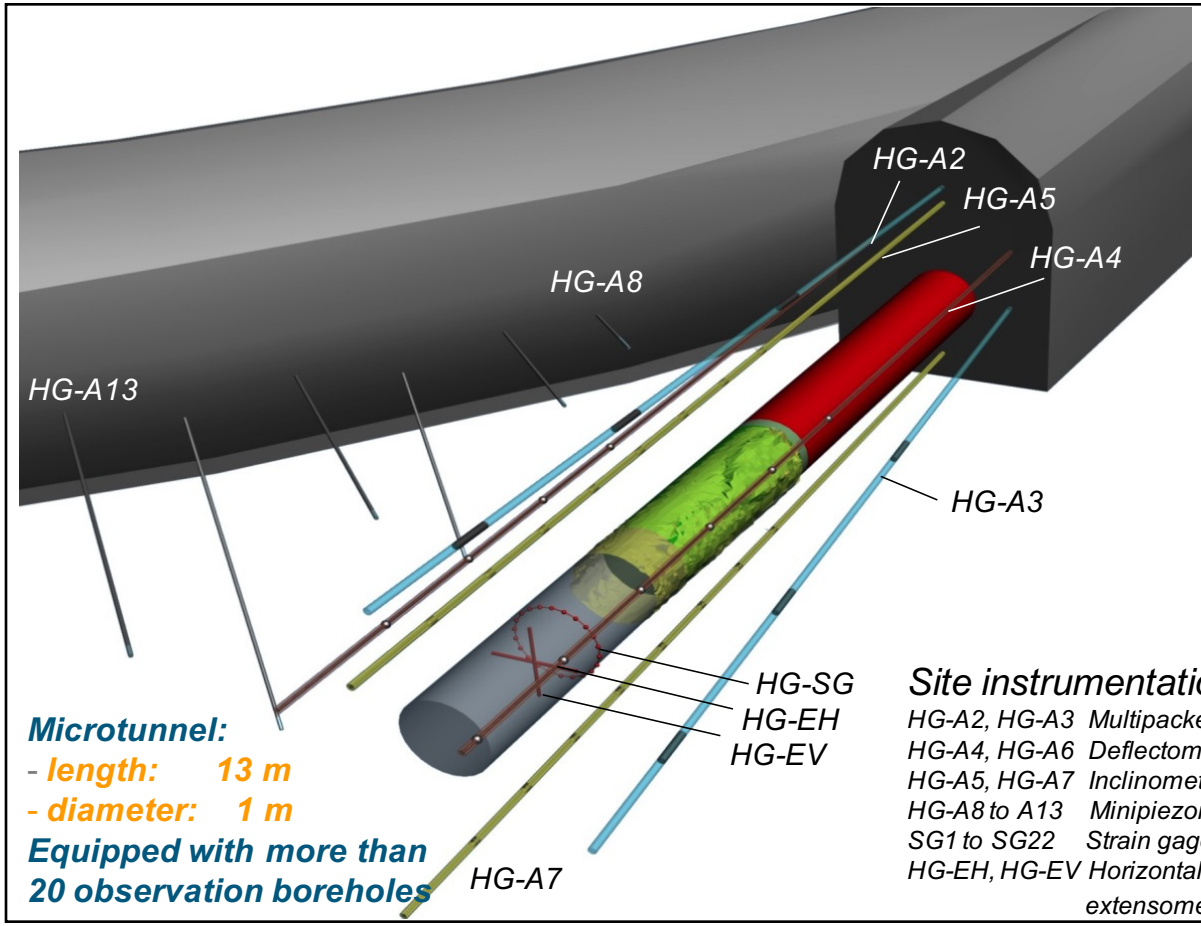
SubTER Planning Meeting

Backup

HG-A Experiment – Damage Zone Assessment



Measurements and predictions of fluid / gas flow in the tunnel nearfield after backfilling to understand damage zone sealing and healing

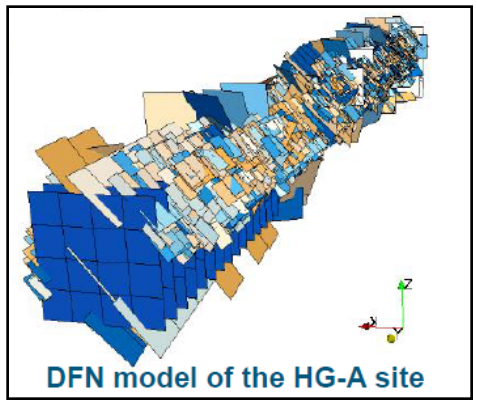


Microtunnel:
- **length: 13 m**
- **diameter: 1 m**

Equipped with more than 20 observation boreholes

Site instrumentation:

HG-A2, HG-A3	Multipacker systems
HG-A4, HG-A6	Deflectometer chains
HG-A5, HG-A7	Inclinometer chains
HG-A8 to A13	Minipiezometers
SG1 to SG22	Strain gages
HG-EH, HG-EV	Horizontal/vertical extensometer



DFN model of the HG-A site

Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

BERKELEY LAB