U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

GTO Overview and Perspectives on EGS

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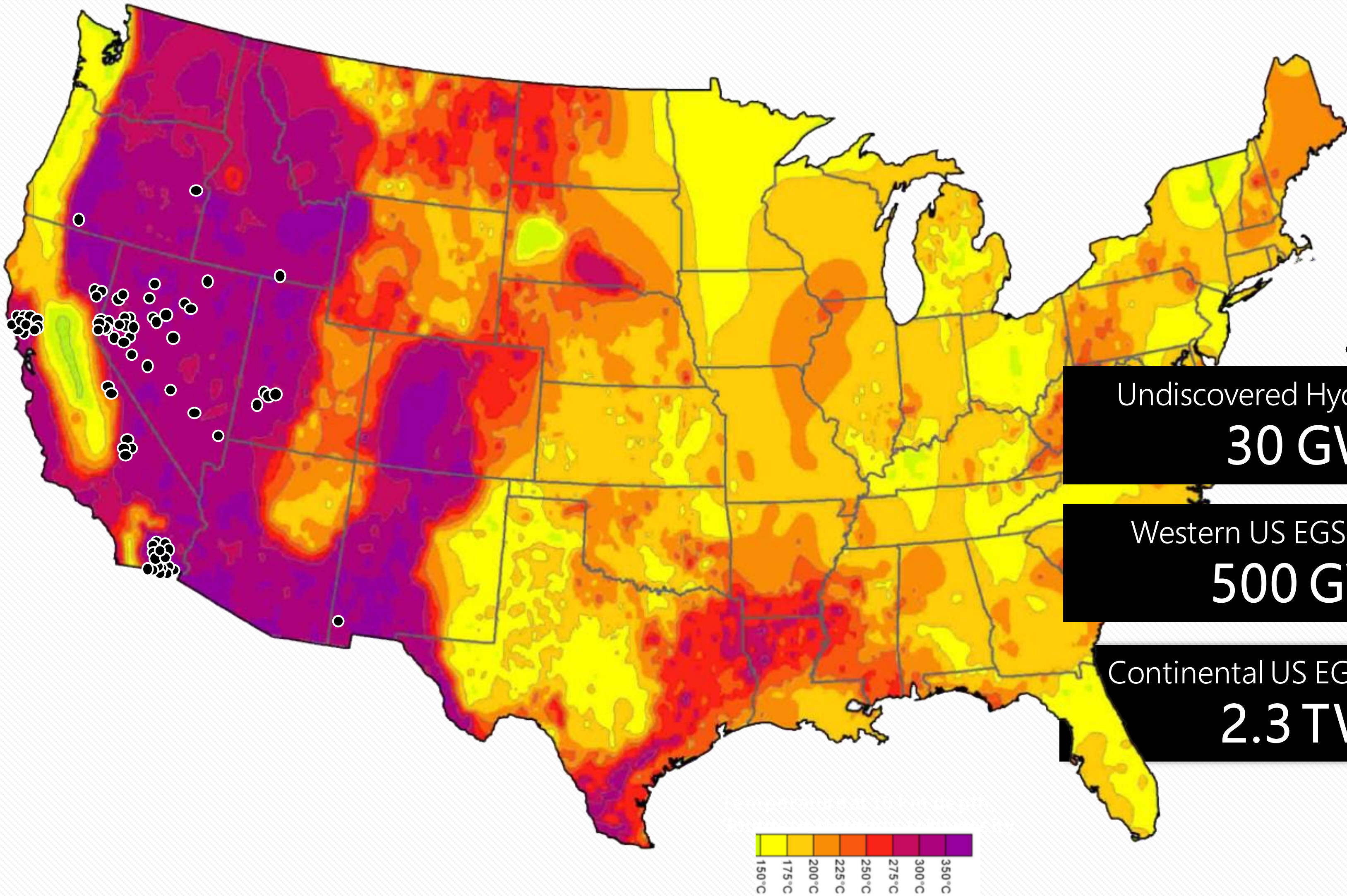
U.S. Geothermal Resources



Undiscovered Hydrothermal
30 GW

Western US EGS potential
500 GW

Continental US EGS Potential
2.3 TW

Adapted from Cladouhos, 2018 (SGW)

International State of EGS

Shyi-Min Lu, 2018 (Renewable and Sustainable Energy Reviews)

Site name (Development period)	Country	Reservoir lithology	Development attribution	Important feature
Fenton Hill (1974–1995)	United States	Granite	Greenfield	The world's first EGS site, and there were 60 kW binary power system demonstrations.
Rosemanowes (1977–1991)	United Kingdom	Granite	Greenfield	Laid the foundation of EGS development for the followed Eden and Redruth in the United Kingdom.
Hijiori (1981–1986)	Japan	Granodiorite	Greenfield	Japan's first EGS site, and there were 130 kWe binary power system demonstrations.
Fjällbacka (1984–1989)	Sweden	Granite	Greenfield	500 m deep shallow EGS site, applicable as a heat pump greenhouse.
Ogachi (1989–2001)	Japan	Granodiorite	Greenfield	Combined with CO_2 sequestration and CO_2-EGS test.
Basel (2005–2006)	Switzerland	Granite	Greenfield	Tests were suspended due to earthquake, and the EGS relevant specifications were introduced.
Insheim (2008-present)	Germany	Granite	Greenfield	Power plant of 4 MWe is constructed in commercial grade.
Landau (2004-present)	Germany	Granite	Greenfield	2.9 MWe/3 MWt power plant, in commercial grade, and in conjunction with greenhouse.
Groß Schönebeck (2007-present)	Germany	Sandstone/conglomerate	Greenfield	Hydraulic fracturing process is in progress, and three units of a total installed capacity of 1 MWe operated in binary power generation cycles have been built in the site.
Soultz (1987-present)	France	Granite	Greenfield	The first commercial-scale EGS power plant in France with installed capacity of 1.5 MWe.
KiGam at Pohang (2010-present)	South Korea	Granodiorite	Greenfield	1.5 MWe-targeted demonstration plant, site test in progress.
Habanero (2003-present)	Australia	Granite	Greenfield	1MWe demonstration plant is in operation, targeting for 40 MWe in the first phase, and the overall objective is 450 MWe.
Paralana (2005-present)	Australia	Sedimentary/metamorphic	Greenfield	Targeting for 3.75 MWe power plant, and fluid cycle test in progress.
Newberry (2009-present)	United States	Marl, quartz porphyry, granite	Greenfield	1. Hydraulic fracture and fluid circulation had been completed in 2013. 2. Use of the thermo-degradable zonal isolation materials (TZIM) to shorten the hydraulic fracturing process.
The Geysers (2009-present)	United States	Metasandstone	Near field	1. 5 MW demonstration plant in progress. 2. Urban wastewater reinjection to the reservoir to increase capacity. 3. Use the method of cold crack to create fractures in the surrounding of wells.
Raft River (2009-present)	United States	Granite	Near field	1. 5 MWe EGS demonstrated plants are targeted by 2020, and the flow rate is at least 20 kg/s per well. 2. The method of cold crack is used to create fractures in the surrounding of wells.
Bradys Hot Spring (2008-present)	United States	Rhyolite, metamorphic substrate	In field	Use of the existing geothermal wells to increase capacity, and the establishment of 2–3 MWe EGS power plant in commercial-scale is targeted.
Desert Peak (2002-present)	United States	Metamorphic tuff	In field	1. The establishment of a 1.7 MWe power plant in commercial-scale was scheduled at end of 2013. 2. Mix the cold cracking, shear, chemical and other hydraulic fracturing technologies.

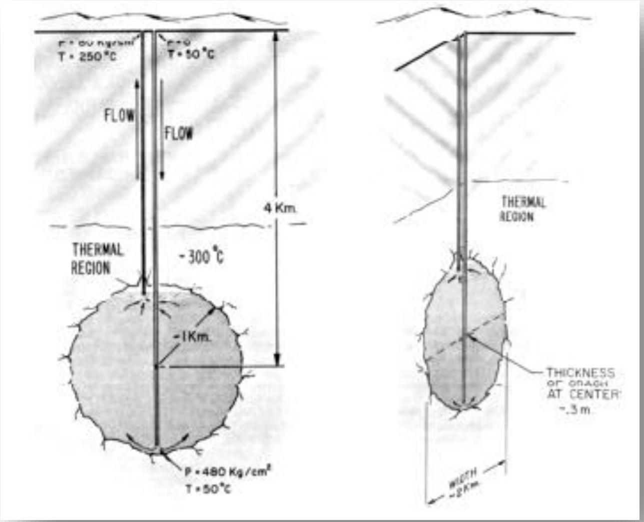
FORGE
DESTRESS
DEEPEGS GEOTHERMAL
GEMex
GeoWell

EGS State of Technology:

LESSONS LEARNED

- **Improved understanding of fracture in crystalline rocks**
  - Natural reactivation and induced fracturing
  - Geochemical implications
- **Drill – fracture – drill again**
  - Target enhanced permeability zones
- **Lowered water loss and enhanced flow impedance**
- **Harnessed induced seismicity**
  - Improved monitoring/management
- **Multi-zone stimulations**
  - **Path to increased productivity/well**

Fenton Hill, Adhoc committee on rock melting drills
The Atom, 1971

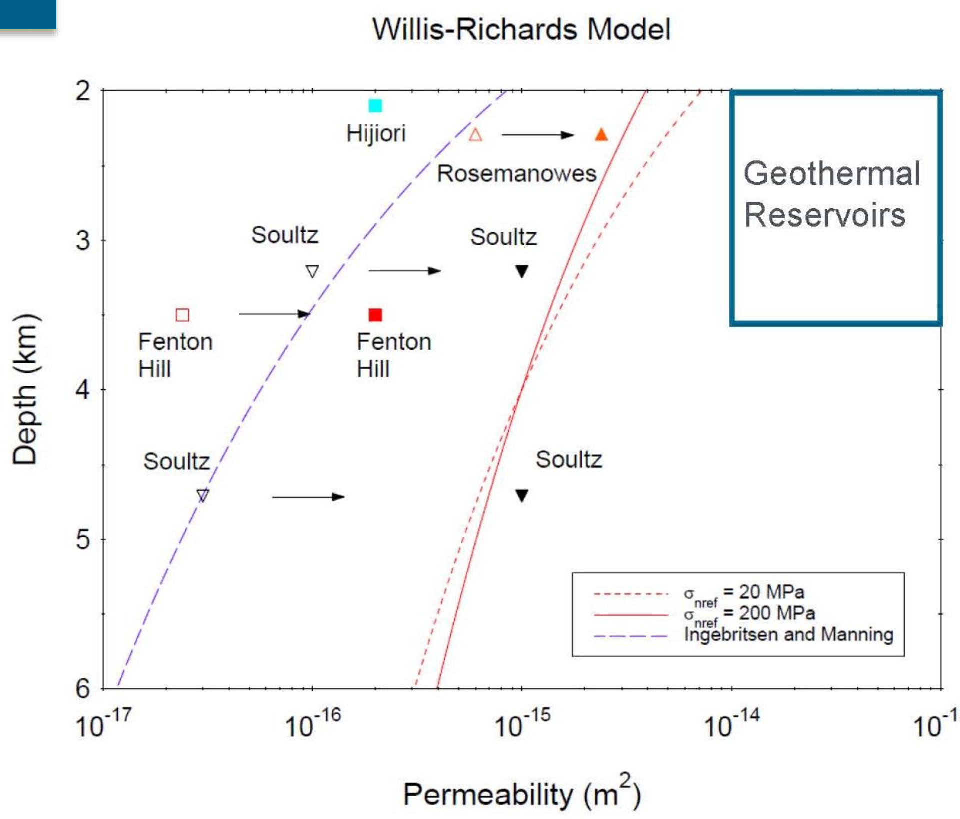


Originally proposed model for HDR
Robinson et al, 1971

EGS Technical Headroom

CRITICAL NEEDS

- ***Reservoir Access:*** New well geometries, optimized drilling
- ***Reservoir Creation:*** Characterization of local stress, chemical potential, and thermal pathways, zonal isolation, novel fracturing methods
- ***Productivity***: Increasing flow rates without excessive pressure needs or flow localization
- ***Sustainability:*** Maintain productivity w minimal thermal drawdown, fracture closure, water losses, seismicity



Permeability increase (open to closed symbols) at EGS sites compared with natural geothermal reservoirs and model results (Willis-Richards et al., 1996)

EGS Technical Headroom

Past | 2005 | 2010 | 2015 | 2020 | 2025 | 2030

CHARACTERIZE

- Infer in situ conditions with geophysical techniques
- Couple observations with simple geologic & geophysical models
- Optimized geologic model workflow for individual sites
- Generalize geologic model workflow for distinct plays

Metric: *Reduce viable play risk*

-Reflection Seismology
-Electrical Methods
-Ambient Noise Tomography
-Electro-Seismics

CREATE

- Traditional O&G, I/E high-pressure fracking techniques
- Controlled, staged hydro-shearing and hydrofracking
- Innovative wellbore and fracture geometries constrained by comprehensive monitoring
- Optimize Productivity in Real Time

Metric: *Enthalpy out per volume of reservoir rock over operational lifetime*

-Advanced Hydraulic Stimulation Methods
-Alternative Methods
-Viscosifiers
-Diverters
-Packers

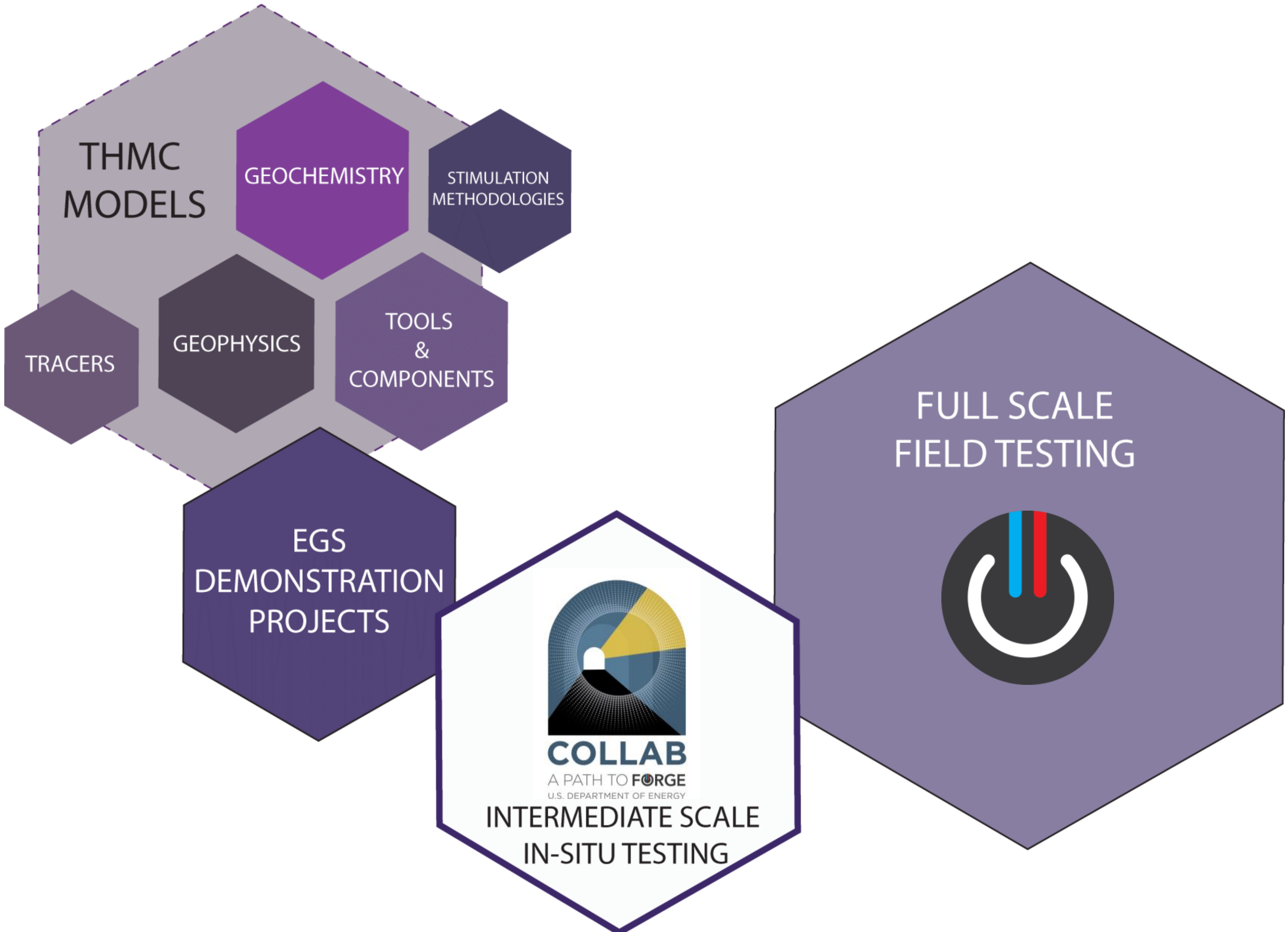
OPERATE

- Simple Extraction and Injection (E&I) Strategies
- E&I with In-Situ Monitoring Feedback
- E&I with Monitoring and Modeling Feedback
- Real-time Monitor & Model Operations

Metric: *Maximize reservoir sustainability*

- Fracture Permeability Evolution
- Chemical Injection
- Zonal Isolation
- Field Expansion
- Maintain Enthalpy

EGS Program Strategy



Mine Scale: EGS Collab

COLLAB
A PATH TO FORGE
U.S. DEPARTMENT OF ENERGY

- EGS Collab brings together a National Laboratory-led team comprised of eight national labs, academia, and industry.
- Experiment 1 at the 4850 level is underway– objectives include:
  - Research hydraulic fracturing with predictive modeling
  - Stimulation using LBNL's SIMFIP tool
  - Long term flow testing
- Team is currently analyzing stimulation results in anticipation of executing long-term flow testing in late fall 2018.

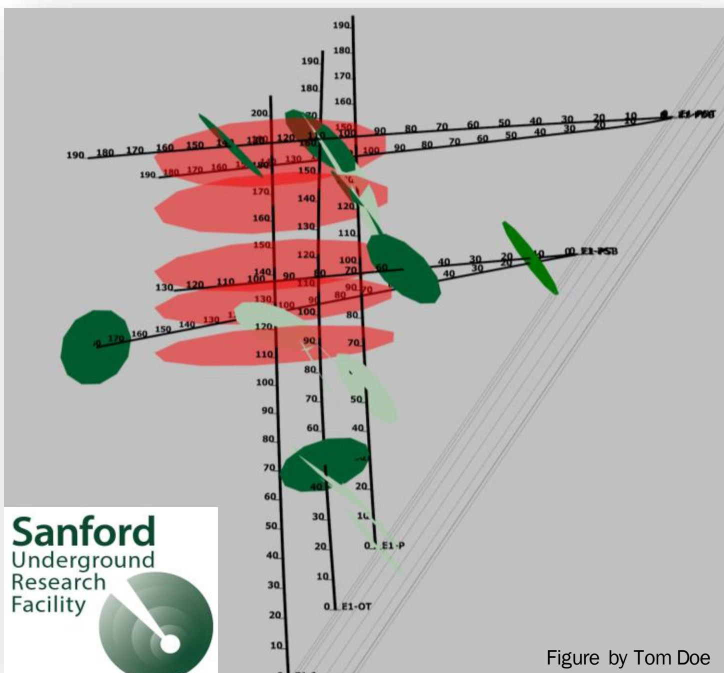


Figure by Tom Doe


Photo: Mark White

Field Scale: FORGE

DIVERSE & TRANSFORMATIONAL

research in subsurface engineering and geoscience

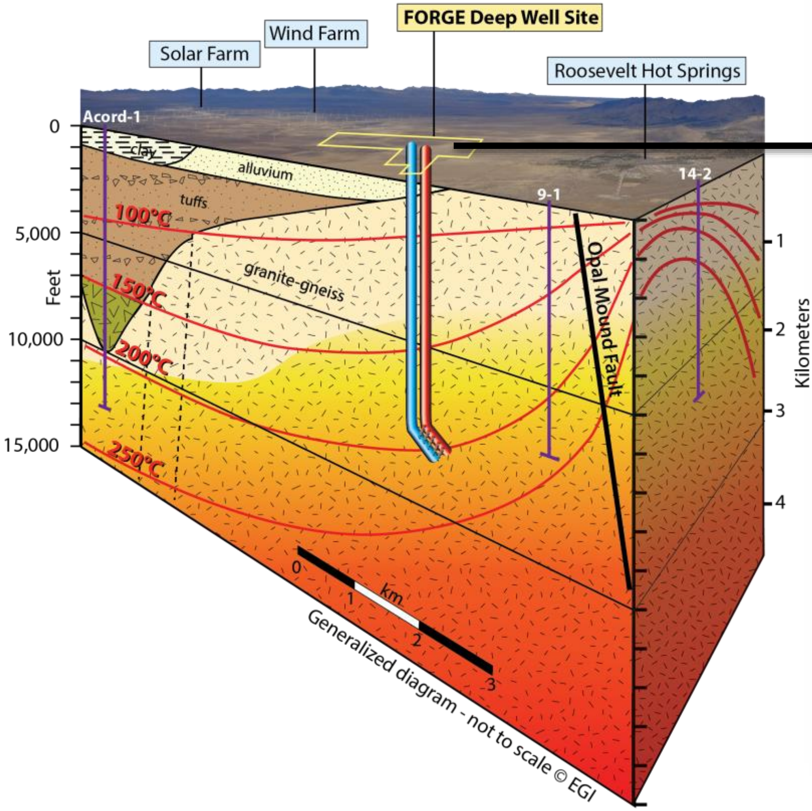
WORLD-CLASS LABORATORY

Opportunity for the community to take advantage of a world-class, fully characterized & controlled environment

SHARE, COMMUNICATE, EDUCATE

Data and findings to the broader technical and non-technical community

Field Scale: FORGE



FORGE is a flagship 7-year initiative to design and test a breakthrough approach to developing large-scale, economically sustainable EGS reservoirs.

Photo: Joseph Moore

Field Scale: FORGE

University of Utah FORGE site in
Milford, Utah