Characteristics of the Utah FORGE Site

August 7, 2019
Dr. Joseph Moore

www.UtahFORGE.com
Characteristics of Conventional Systems

- Large in situ fluid volumes
- Convective heat transfer
- Individual wells produce from a few high permeability fractures
- Flow rates $\geq 40$ L/sec
- Energy densities of 10-20 MWe/km$^2$
- Production from a few to $\sim 800$ MWe
- Low levels of microseismicity

Average = 6 MWe;
Biggest = 50 MWe
At 200°C flow rate of 23 L/s = 1 MWe
750-1000 US homes
40 Years of EGS Stimulations

US (5 sites)
England
France
Japan
Australia
South Korea

Compiled from Tester and others, 2006 and Breed and others, 2013

www.UtahFORGE.com
Current Status of Enhanced Geothermal System Development

- No EGS systems greater than a few MWe developed
- Low flow rates (<40 L/s) and low heat recoveries
- Reactivated fracture zones dominate EGS reservoirs
- Mechanism uncertain

Raft River Geothermal Well RRG-9

Major Fractures Enhanced?
FORGE (Frontier Observatory for Research in Geothermal Energy) is an underground laboratory for developing, testing, and accelerating breakthroughs in EGS development.

Phase 1: Desktop study (5 sites)
Phase 2: Reservoir confirmation (2 sites with selection of Utah as final site)
Phase 3: Drill and stimulate two deep wells. Develop:
- High-temperature drilling tools and zonal isolation technologies
- Novel stimulation and well completion methodologies
- Modify/manage existing stress fields
- Manage and forecast induced seismicity
- Best management practices
- Predictive numerical models
- Education and research opportunities
FORGE Criteria

- Temperature >175°C and <225°C
- Depths >1.5 km
- Low permeability rocks (granite)
- Low risk from induced seismicity
- Low environmental risks
- No connection to hydrothermal system
Milford Utah FORGE Site

www.UtahFORGE.com
Utah Renewable Energy Corridor

No Endangered Species
No Nearby Human Activity
No potable water

- Geothermal fields (3)
- Windfarm
- Solar field
- Biogas facility
Well 58-32

- Completed and tested well to 2297 m (7536 ft)
- Reached a temperature of 199ºC (390ºF)
- Ran full suite of geophysical and image logs
- Conducted geomechanical tests on core from two intervals (~6 m)
- Performed Micro-hydraulic and Diagnostic Fracture Injection Test (DFIT) in barefoot section of well
Fractured Reservoir 58-32

Approximately 2000 fractures in FMI log; Rose diagram & poles projected to upper hemisphere
Stress Directions

Tadpole = natural fracture
Circle = induced fracture

Azimuths of induced fractures from FMI log
2017 Injection Program

- 8 injection cycles over two days
- Injection rates from 0.3 to ~9 bpm
- Minifrac/DFIT injection times from 8-35 min
- Max surface pressure ~4000 psi
- Permeability of ~30 microdarcies
- Stress gradients
  \[ S_{H \text{ min}} = 0.62 \text{ psi/ft} \]
  \[ S_{H \text{ max}} = 0.77 \text{ psi/ft} \]
  \[ S_V = 1.13 \text{ psi/ft} \]
Pre and Post 2017 Stimulation FMI Logs

Before

After
Stimulated three zones in 58-32:
• Open hole section
• Two zones behind casing
• Perform nine injection cycles per zone: step rate and single rate tests at 1, 2, 3, 4, 5, 8, 15 bpm, maximum surface pressure = 7000 psig
• Pump times 1-60 minutes
• Volume pumped range from 1 to 200 bbl
• Overnight shut-in times for large volume injections
• Ran FMI log (no changes observed)

Monitored Microseismicity at the surface and downhole
Seismic Monitoring: Surface Monitoring

- Detect and locate with high precision, injection related seismic events
- Establish microseismic monitoring for times of shut-in or flow tests
- Provide for mechanisms to collect non-traditional seismic data, like DAS, Nodals

Seismometer locations and pre-stimulation microseismic locations (2016-2019)

Nodal Array (150 nodes)
Borehole Instrumentation

- Shallow hole (~ 925’):
  - 3C 15 Hz geophone (4 sensors per component)
  - 3C Silicon Audio accelerometer

- Deep hole (Top of granite 780 m (2560 ft); TD 1000 m (3280 ft)):
  - Schlumberger 12-level 3C geophones, 31 m (100 ft) spacing straddling granite contact
  - Distributed Acoustic Sensor (fiber optic cable) cemented into annulus of 5 ½” production casing
423 events recorded on geophone string; 43 on DAS cable; 19 on shallow borehole.
Stimulation 1: Open Hole

- **2240-2294m (7348-7525 ft) KB**
- Repeated 2017 stress, DFIT and permeability measurements (max. injection rate of ~9 bpm)
- Increased rate to 15 bpm with longer shut-ins
- Breakdown occurred at surface pressure 3500 psig
- Ran FMI log after stimulation
Stimulation 2: Critically Stressed Fractures

Stimulation 2: Cased hole

- Perforated casing from 2123-2126 m (6964-6974 ft) KB
- Stimulated critically stressed fractures (NNE-trending)
- Fracture breakdown initiated during (cycle 4); injection rate of 5 bpm for 6 min; surface pressure 3700 psig
Stimulation 3: Non-Critically Stressed Fractures

Stimulation 3: Cased hole

- Perforated casing from 2001-2004 m (6565-6575 ft) KB
- Stimulate non-critically stressed fractures
- Fracture breakdown uncertain before bridge plug failed at surface pressure of ~6500 psig
- Light blue dots
Equipment Failures

Drilling and stimulating hard, abrasive hot rock:

- Bits (short life)
- Mud motors
- Packers
- Bridge Plugs
- Drill strings

- Damaged Jar
- Failed
- New

- Worn stabilizer
- Failed
- New

- Worn drill bit

UTAH FORGE
U.S. Department of Energy
2019-2024 Activities

- Drill and stimulate injection/production pair
- Stimulate 2-3 stages at toe
- Circulate between wells
- Monitor reservoir development and heat sweep

Deep Wells

68-32
58-32
78-32

www.UtahFORGE.com
Conclusions

• Granitic rocks at Milford Utah have appropriate temperatures (>175°C), low permeabilities and stress orientations and magnitudes for EGS reservoir development
• Injection tests demonstrate stimulation of critically stressed fractures can be accomplished at relatively low pressures and injection rates
• No endangered flora or fauna
• Groundwater is not potable; is underutilized and not fully allocated; sufficient water rights secured
• Low risk of induced seismicity and seismic hazards
THANK YOU

Funding provided by the US Department of Energy with additional support from Utah School and Institutional Trust Lands Administration, Beaver County, the Governor’s Office of Energy Development, and Smithfield Foods.

www.UtahFORGE.com