Super Hot EGS
Reducing the Cost of Geothermal Through Technology Breakthrough

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USA Geothermal Resources

Current conventional geothermal:
3.5 GW

Western US EGS potential:
500 GW

Continental US EGS Potential:
2.3 TW

Temperature at 10 km depth, Southern Methodist University
Energy per Well

- **Shale Gas**
  - Typical Haynesville
  - Depth: 3 km
  - Temperature: 230°C
  - Power: 10 MWe

- **Conventional Geothermal**
  - Depth: 2 km
  - Temperature: <200°C
  - Power: 7 MWe

- **EGS**
  - Depth: 3-5 km
  - Temperature: <200°C
  - Power: <5 MWe

- **Super Hot EGS**
  - Depth: >5 km
  - Temperature: 400°C
  - Power: 40-50 MWe
Performance Moonshot

50 MWe/well compared to 5 MWe/well at 200°C

10x output/well

- 5x producing potential compared to liquid water at 200°C
- 2x higher conversion efficiency of thermal heat to electricity
Temperature Matters
100 MW utility-scale plant

200°C
- 120 MW\textsubscript{gross}
- 55% < 10 km deep
- 30 km\textsuperscript{2} geothermal leases
- 18 injection wells
- 24 production wells
- 85 kg/s fluid

400°C
- 106 MW\textsubscript{gross}
- 33% < 20 km deep
- 1 km\textsuperscript{2} geothermal leases
- 2 production wells
- 60 kg/s fluid
- 1 injection well
Economic Advantage – plants online in 2022

Levelized Cost of Electricity ($/MW-hr)

- Super Hot EGS: 46
- Onshore wind: 56
- EGS today: 80
- Solar PV (avail weight): 85
- Advanced Nuclear: 96
- NG - Comb. Cycle: 99

Cost ($/MWhr) - EIA’s 2017 projections and AltaRock for EGS
LCOE for 100 MW Super-hot project

Capital and Interest Cost (million dollars)
- Drilling (3 x 5 km deep wells)
- Ti alloy casing
- Stimulation
- Other Drilling
- Power generation units ($1750/kW)
- Transmission Lines
- Interest (20 yrs @ 5%)

Revenue
- 100-83 MW for 20 years
- 2% annual resource decline
- With redrills at 10 years

Ongoing Expenses
- $6M / year O&M
- $42M in year 10 for redrills
- 6% discount rate

LCOE = $46/MWh
The International Race to Super Hot Rock is On!

NEWGEN ICDP Workshop Fall 2017

Iceland Deep Drilling Project-2
2016 reached 425°C at 4.5 km

GEMex Project

DESCRAMBLE Project

Japan Beyond Brittle

HADES Hotter and Deeper Project

The International Race to Super Hot Rock is On!
Super Hot EGS is the ideal energy source

- Dependable: 95% available
- Flexible: Peaking available
- Widely Deployable: 16% world pop. at <10 km, 81% world pop. at <20 km
- High Energy Density: 100 MW/km²
- Free Fuel: 400°C fluid
- Low Cost: $46/MW-hr
Innovations needed: Temperature

Start in Magmatic Areas

- Improvement in drilling equipment and techniques at >400°C: bits, coring, & mud
- Advanced well construction materials: casing, couplings, & cement
- Reservoir creation and maintenance techniques in super hot rock: hydraulic, thermal, & chemical
- Characterization: Sonic & image logs, fiber optic, stress measures, seismic calibration and sensors
Improvement: Drilling Equipment and Techniques at >400°C:

**Current Technology**
- Cool well with water/aerated water
- Underbalanced drilling for hole cleaning
- Pressure control through cooling
- Maintain cooling throughout drilling and completion process. Prevent thermal cycling.
- HT mudmotors for directional control cooled with water/aerated water
- Logging while tripping for directional/T/P data
- Roller cone bits with metal/metal seals

**Technology Improvement**
- Cooling through water/aerated water/liquid nitrogen
- Pressure controlled drilling with HT stable polymer sweeps
- Well casing and cement design to withstand thermal cycling
- HT mudmotors with very HT electronics for directional control cooled with liquid nitrogen
- Solid body bits with cavitation
Improvement: Advanced Well Construction Materials

Current Technology

- Foamed reverse circulation cementing with HT stable cement formulations up to 325°C
  - Brittle noncompliant cement can fail with thermal cycling. Foamed cement is compliant
  - At very high temperatures, cement systems will not crystallize
  - Gaps in cement fatal flaw. Foamed cement expands

- Well designs for very HT from thermal heavy oil recovery used with success in geothermal

- Casing connections
  - Connections that seal in compression and tension withstand thermal cycling with foamed complete cement job work
  - Casing connection failures still a large problem
  - Testing at very high temperature has been limited
  - Most connections tested by modeling

- Casing materials
  - Titanium works but is very high cost
  - High strength alloys may not last through thermal cycles
  - Supercritical fluids can be highly corrosive

Technology Improvement

- Ultra high temperature stable compliant cements – very high silica content
  - Superfine sand well sealing systems
  - New very HT cements needed. Must be compliant/elastic to withstand thermal cycling
  - Materials testing facilities for very HT limited

- Well completion designs for very temperature and thermal cycling need modeling and testing
  - Most models can’t handle supercritical temperatures
  - Lab facilities have limited sample size

- Casing connections designed to seal through thermal cycling need testing at scale
  - Current testing is through modeling only
  - Connection failure in IDDP-2

- Casing materials – Innovations used in space probes may be extended to very HT geothermal
Improvement: Reservoir Creation And Maintenance Techniques In Super Hot Rock

**Current Technology**
- Hydroshearing through pressure injection along entire open hole
- Pre-existing permeability needed for good results
- Zonal isolation through diverters in perfed liners or modified oil field packers in open hole
- Multizone stimulations limited to areas with pre-existing permeability
- Can create really large stimulated volumes
- Require large amounts of water and long stimulation times
- Stress changes with depth as brittle/ductile transition is approached a challenge for creating large stimulated volumes

**Technology Improvement**
- Combine tensile fractures near the wellbore with hydroshearing in the far field
- Fracture initiation in impermeable hard, brittle very hot rock
- Zonal isolation in holes with perforated liners to achieve multizone stimulation with very high flow rates
- Create large stimulated volumes with low water methods, shorter times
- CO2 based stimulation methods
- HT stable targeted explosive fracture initiation
- Cryogenic stimulation to solidify and extend fractures in ductile rock
Improvement: Characterization

**Current Technology**

- Fracture imaging:
  - Wellbore cooling above ~250°C
  - Ultrasonic BHTV (Sandia) temperature limit ~275°C. Rotating element fails
  - Microresistivity requires cooling to about 175°C

- Logging cable upper limit 300°C (600°F) but few available
  - Memory tools using lithium batteries for temperatures above 300°C in heat shielded tools
  - Lithium batteries can explode above 165°C. Must be kept cool
  - MWD/LWD requires cooling through circulation
  - Logging while tripping in cooled wellbore

- Production logging: PTS on wireline up to 300°C. Over 300°C using memory tools

- Sonic/neutron density/gamma/resistivity in heat shielded tool on HT cable limited to 300°C

- Fiber optic DTS/DAS
  - Critical for monitor stimulation
  - Fails above ~250°C

**Technology Improvement**

- Phased array ultrasonic borehole imager using HT electronics in heat shield avoids moving parts. In development.

- Extended HT cable limit using polyaramid for strength and water proofing/weight reduction

- HT stable batteries – recent breakthrough needs development/testing

- Ultrasonic flow measurement for no-moving-part velocity logging

- MWD/LWD needs HT batteries plus better connections on wired drill string

- Fiber optic sensors and cable for >350°C needed
Innovations needed: Depth

Well completion techniques and materials to economically reach 10-20 km

Next generation drilling equipment, energetic drilling, casing while drilling

Super Hot EGS Anywhere
Super Hot Site at Newberry

Two Geothermal wells drilled in 2008
- 55-29 and 46-16
- Depth: 3.1 and 3.5 km
- BHT: 325 °C and 340 °C
- Gradient: 110 °C/km
- Target: 500 °C at 4.6 km
Newberry Deep Drilling Project

Project to deepen 46-16 to supercritical temps
ICDP Workshop, Bend, OR, Sept. 2017
55 participants from 11 countries

Goals

• test technology for drilling, well completion, and geophysical monitoring in a very high temperature environment.

• test EGS above the critical point of water

• collect samples of rocks within the tectonic brittle-ductile transition

• investigate volcanic hazards

• study magmatic geomechanics

• calibrate geophysical imaging techniques
Newberry Volcano will power Oregon

Super Hot EGS in 8 western states powers significant portion of West

Balance intermittent renewable generation

Expand Super Hot EGS when advanced drilling technology ready to drill to >10 km

Achievements – 10 year plan