

EGS – Challenges and Technology Adaptation

Coal and Geothermal: A Path Forward Workshop

Dallas, TX

January 10, 2017

- Approximately 30 EGS pilot projects since 1974
- Locations include: Australia, France, Germany, Japan, Korea, Sweden, Switzerland, UK, and USA
- Examples of pilot projects that have produced power:
 - Landau (Germany) – 3 MW
 - Soultz-sous-Forêts (France) – 1.5 MW
 - Cooper Basin (Australia) – 1 MW
- Despite availability of heat, EGS underutilized to-date:
 - High capital cost and perceived technical risk



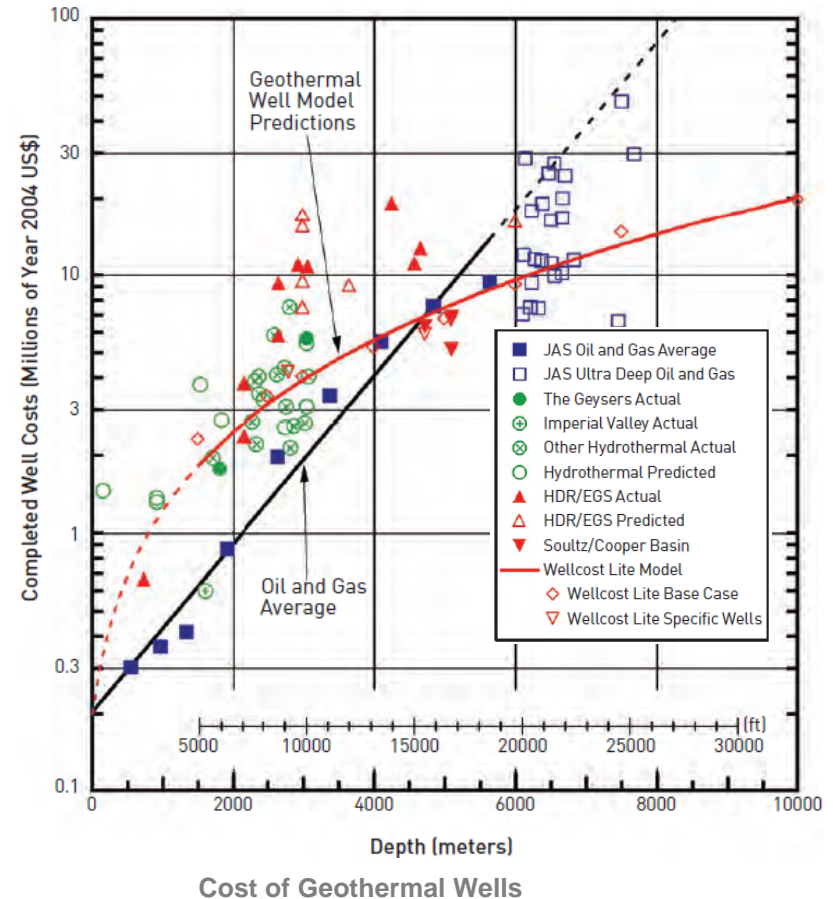
Habanero Pilot Plant, Cooper Basin (Australia)

Source: ThinkGeoEnergy | www.thinkgeoenergy.com

EGS has only seen limited implementation in pilot-scale operations.

- Reservoir Development
 - Stimulation techniques and technologies to effectively create multiple flow paths between wells
 - Preventing “short circuiting” and temperature decay over time

- Well Construction and Completion
 - High capital costs
 - Thermal well design
 - Well Integrity Management



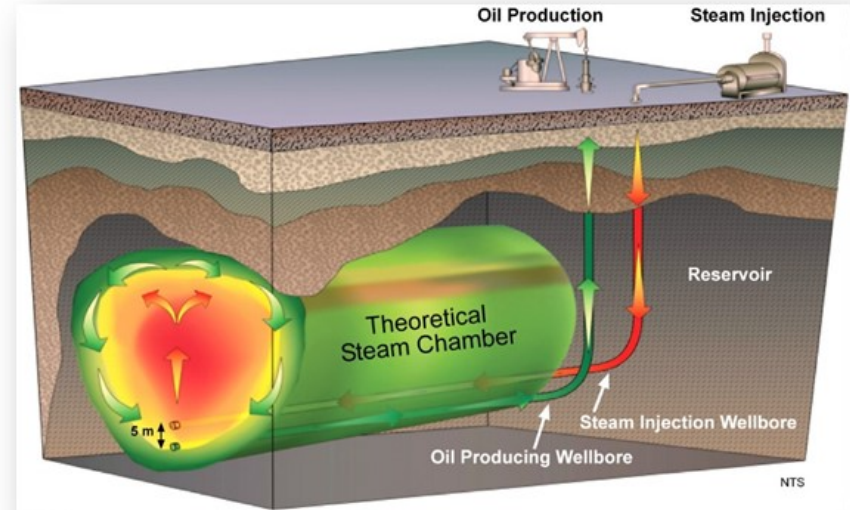
Source: The Future of Geothermal Energy | <http://geothermal.inel.gov>

- Production Management
 - In-well designs to control injection and production flow paths
 - Reliable artificial lift systems
 - Flow assurance: corrosion and scale mitigation



SAGD aka Reverse EGS

- Thermal heavy oil operations heat the ground with steam to mobilize bitumen instead of recovering heat from the ground
- Well pairs used with flow between injector and producer
- SAGD 180 – 250 °C
- CSS ~ 350 °C
- Equipment and practices may be adapted to EGS

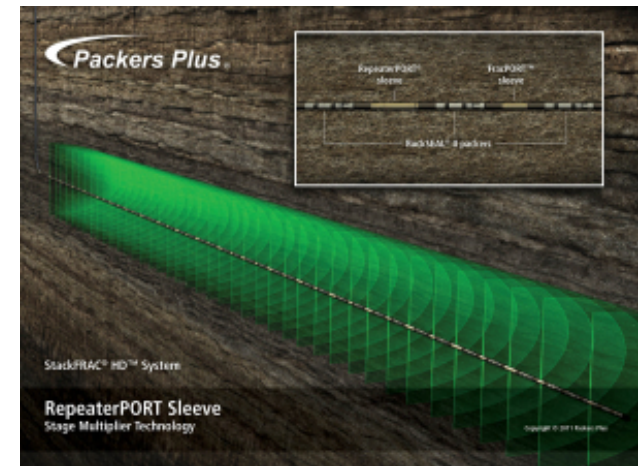
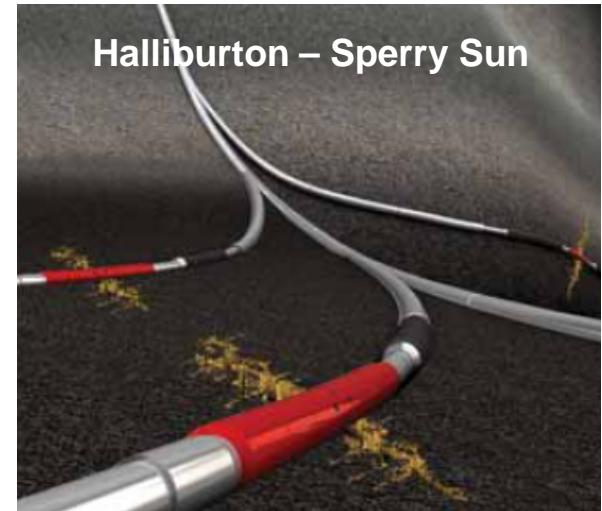


Steam-assisted Gravity Drainage

Source: The Geological Society | www.pgc.lyellcollection.org

Thermal well design approaches and equipment could improve the safety, reliability and efficiency of EGS operations.

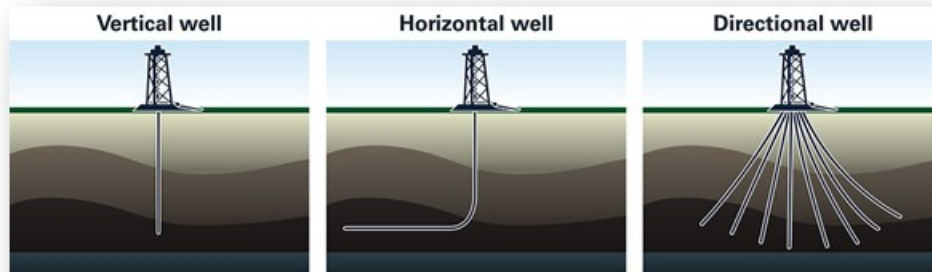
- Expertise and new technologies developed for SAGD and unconventional production
 - Multi-lateral wellbores
 - Multi-zone hydraulic fracturing
 - Thermal well casing design
 - Thermal completion equipment
 - Downhole flow control devices
 - High temperature pumping systems
- Potential to adapt these for EGS



Reservoir Development

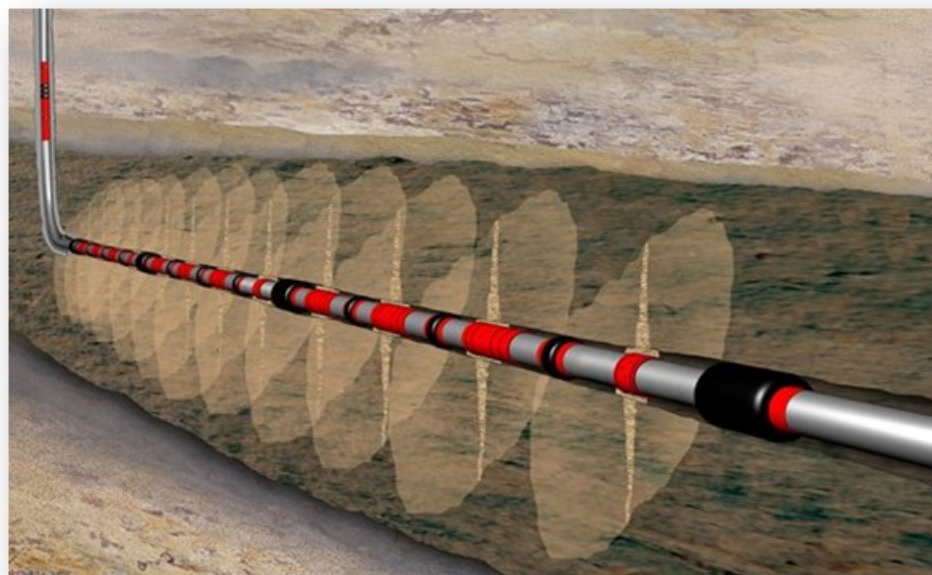
- Drilling costs
 - Directional drilling may enable horizontal wells, multi-lateral completions may reduce costs
- Increased reservoir contact
 - Multi-stage hydraulic fracturing may increase the connected reservoir contact for injected fluid

More efficient well designs could reduce costs and increase efficiency



Types of Drilling Trajectories

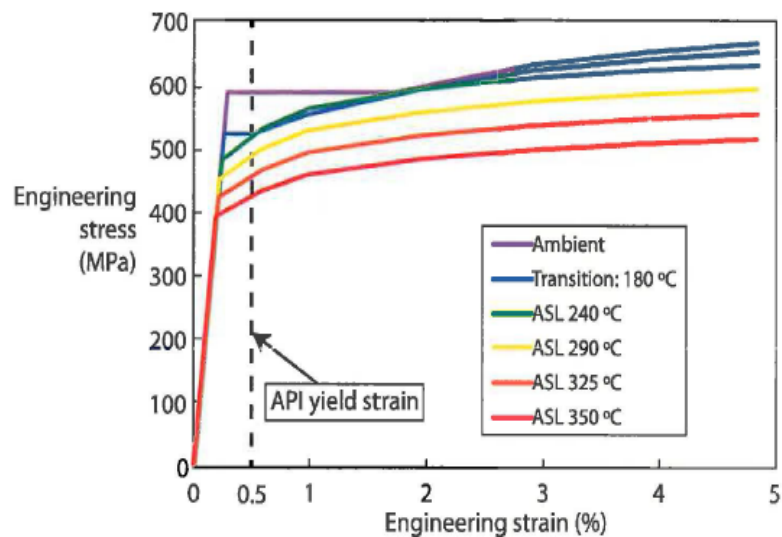
Source: Tortoise Capital Advisors | www.uncoverenergy.com



Frac Valve Completion

Source: Halliburton | www.Halliburton.com

- Well Reliability
 - Improved well design leads to reduced risk and improved economics
- Thermal Well Design
 - Temperature differentials may result in plastic deformation and strain localization in cemented casing
 - Use of post-yield, strain-based design approaches recommended
 - Casing selected to provide favorable post-yield characteristics (not elastic capacity)
- Thermal Casing Connections
 - Procedures such as ISO/PAS 12835:2013 suitable for qualifying geothermal casing connections
 - Use of qualified thermal connection designs may enhance well integrity



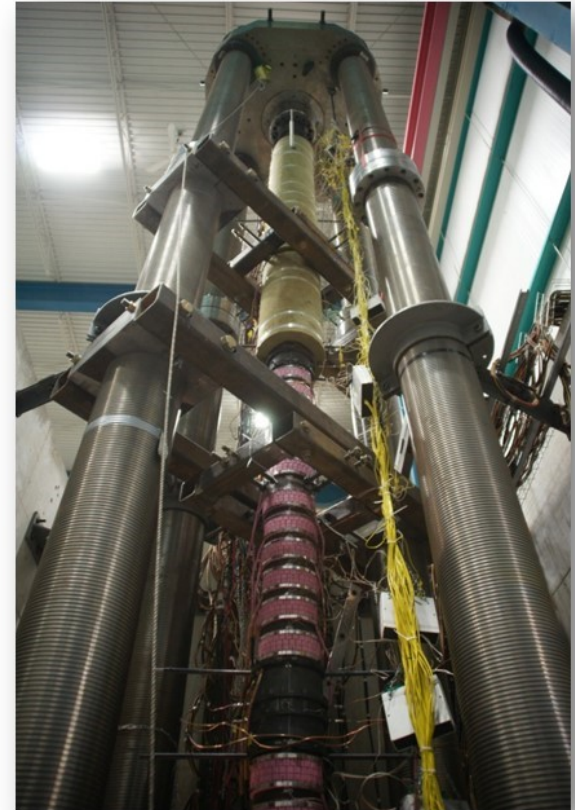
Example Stress-Strain Curves

Source: ISO/PAS 12835 | <http://www.iso.org>

Well Construction and Completion (1)

- Casing Design
 - ΔT may result in plastic deformation and strain localization
 - Use of post-yield, strain-based design recommended
 - Material selected to provide favorable post-yield characteristics (not elastic capacity)
- Casing Connections
 - Use of qualified thermal connection designs may improve well integrity
 - Evaluation protocol used to qualify casing connections up to 350 °C

Casing connection qualification procedures help to ensure well integrity



Connection Testing System (CTS)

Source: C-FER Technologies | www.cfertech.com

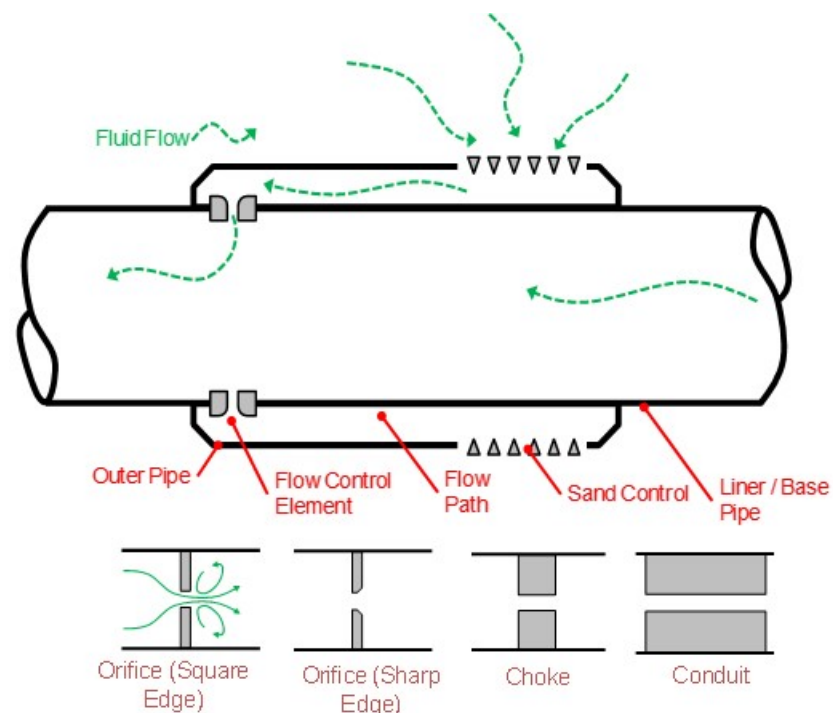
Well Construction and Completion (2)

- Thermal Wellheads
 - Novel completion designs used for thermal oil wells have been applied to geothermal wells
 - Streamlined workover operations
- Thermal Cement
 - Alternative thermal well cements
 - Improved cement placement procedures
- Vacuum Insulated Tubing (VIT)



Source: C-FER Technologies | www.cfertech.com

- Downhole Flow Control Devices (FCDs)
 - Could be placed on EGS injector and/or producer well(s)
 - Reduce short-circuiting by managing flow rates and pressures
 - Provide the ability to shut-off regions



Source: Vachon et al. | SPE Paper 174416

Well completions with FCDs can be custom designed to minimize EGS short-circuiting

- Artificial lift
 - Lineshaft Pumps (LSPs) are commonly used but may limit well design options
 - High temperature Electric Submersible Pumps (ESPs) may enable new Hz developments
 - ESPs currently operating at up to 250°C for thermal O&G operations



Geothermal Lineshaft Pump

Source: Frost Consulting Group | www.frostconsultinggroup.net

Reliable pumps capable of operating in directional wells would allow optimized well designs



REDA Electric Submersible Pump System

Source: Schlumberger | www.schlumberger.com