ADDRESSING ENHANCED GEOTHERMAL SYSTEM CHALLENGES

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Enhanced (or engineered) Geothermal Systems

Three components are needed to extract geothermal energy from the subsurface: 1. hot rock, 2. a heat transfer fluid – typically water or brine, and 3. flow pathways contacting the fluid and the rock. These combined components occur naturally in many locations resulting in hydrothermal systems, however there are vast regions containing hot rock at depth that do not have adequate fluid, and/or appropriate fluid permeability. In these locations, engineering or enhancing the system would be required to extract the energy. These regions provide the possibility of long-term extraction of significant quantities of energy.

Enhanced (or engineered) Geothermal Systems (EGS) are engineered reservoirs created to extract economical amounts of heat from low permeability and/or porosity geothermal resources. EGS offers tremendous potential as an energy resource. Estimates of the EGS resources in the western US could exceed 500 GWe, surpassing conventional hydrothermal systems resource [Williams et al., 2008]. When considering the entire United States, Augustine [2016] estimated that the EGS resource could be ten times larger. The magnitude of these resource estimates makes EGS attractive to utilize. There are technological challenges, however, that need to be addressed. These include: (1) lack of a thorough understanding of techniques to effectively stimulate suitable subsurface "heat exchangers" that communicate between multiple wells by fractures in different rock types and under different stress conditions, (2) inability of techniques to image/monitor permeability enhancement and evolution at the reservoir scale at the resolution of individual fractures, (3) limited technologies for effective zonal isolation for multistage stimulations under elevated temperatures, (4) lack of technologies to isolate zones for controlling fast flow paths and control early thermal breakthrough, and (5) lack of scientifically-based long-term EGS reservoir sustainability and management techniques [Kneafsey et al., 2019].

Creating a viable EGS resource requires accessibility to the rock. Drilling multiple holes is required to access the hot rock to enable injection and extraction of water. Deep boreholes are expensive, costing many millions of dollars, thus drilling must be optimized. Heat energy is extracted from the reservoir by contacting the hot rock with the fluid, thus the fracture system (heat exchanger) needs be designed and stimulated (fractured) considering in situ hydrologic, lithologic, and geologic conditions. If sufficient quantities of water are heated to a high enough temperature, it may be economical to produce electricity. An often-discussed quantification of "how much is needed" is 50 kg/s from a 200°C body of rock, with no more than 10°C temperature drop in the produced fluid over a project life of 30 years [Tester et al., 2006]. Heat from lower temperature or lower flow rate systems might be used to directly heat buildings or have other direct use depending on economics. Because much of the hot subsurface rock is present beneath arid regions, water resource management and recycling will be required.

Much research has been done and is being done to investigate EGS related processes including zonal isolation, improved drilling, and waterless stimulation. Field tests have been performed at a number of locations around the world, and each project contributes knowledge towards understanding EGS. To address the technological challenges and reduce the risks in implementing EGS, the US DOE Geothermal Technologies Office and geothermal agencies from other countries have supported field tests over a range of scales and conditions. Two current field test projects in the US include the Frontier Observatory for Research in Geothermal Energy (FORGE) and the EGS Collab Project.

FORGE

The FORGE project will create a subsurface research laboratory allowing investigations of EGS processes at the full field scale in rock between 175°C and 225°C. This project does not have the goal of producing electrical power, but rather the intent is to provide a heavily instrumented research site for developing, testing, and accelerating breakthroughs in EGS technologies to enable a commercial pathway for EGS technologies. After a rigorous selection process considering several locations, a low permeability site on the flank of the Roosevelt Hot Springs Geothermal Field near Milford, Utah was selected. At this site, a large volume of hot crystalline granite is will be accessed between two deep directionally drilled wells at around 8000 feet depth. The project is managed by a multi-disciplinary team of engineers and scientists from universities, national laboratories, federal and state funded institutions, and private industry led by the University of Utah [Moore et al., 2019].

FORGE investigations will begin in 2020 during facility construction and continue through 2024 and include competitive funding rounds open for public application to attract outstanding programs of innovative research and development. During site development, investigations to improve drilling, stimulation, injection-production, and subsurface geophysical imaging technologies will be performed. These will help establish and sustain continuous fluid flow and energy transfer from an EGS reservoir.

EGS Collab

To improve understanding of subsurface stimulation and heat exchange in crystalline rock, the GTO established the EGS Collab project. Working at nearly a mile deep in the Sanford Underground Research Facility (SURF) to simulate EGS stress conditions, the project is creating intermediate-scale (10’s of meters) test beds via hydraulic stimulation and is circulating chilled water to model the injection of cooler water into a hot rock. Chilled water injection tests into this well-characterized rock mass, coupled with conservative, nonconservative, reactive, and DNA tracers and numerous types of geophysical instrumentation, are used to constrain thermal-hydrological-mechanical-chemical (THMC) modeling approaches for validation of utility in FORGE and commercial EGS. The project is a collaborative multi-lab and university research endeavor bringing together a team of skilled and experienced researchers and engineers in the areas of subsurface process modeling, monitoring, and experimentation to focus on intermediate-scale EGS reservoir creation processes and related model validation in crystalline rock. Numerous geophysical techniques have been used in the project including microseismic monitoring, continuous active-source seismic monitoring (CASSM), electrical resistance tomography, distributed temperature sensing, Step-rate Injection Method for Fracture In-situ Properties (SIMFIP), and distributed acoustic sensing.

Addressing EGS Challenges

Addressing EGS technological challenges is occurring in these and other field projects, however the issues are complex and additional investigations will be needed. Research needs will include continued improvements to understanding subsurface stress, rock stimulation methods to allow better subsurface heat exchanger creation, and better geophysical imaging and monitoring of the resulting permeability enhancement that occurs. Many techniques useful in shallow applications cannot be directly implemented at depth due to either drilling costs or high temperature/ pressure conditions. Like in an industrial heat exchanger, uniformly distributed flow is key to optimal operation. Thus, proper stimulation, combined with yet-to-be-engineered, well-based zonal isolation tools will be needed. These, combined with fast path control techniques such as silica gel can be used to distribute flow optimally. Understanding the effects of dissolution and precipitation reactions that will occur during reservoir operation from chemical disequilibrium between the injected water and the rock is required to predict and engineer reservoir sustainability. Additional understanding of these complex processes and engineering techniques to control reservoir sustainability will be needed.

The challenges to implement EGS are significant but the rewards will be great. Thus, efforts such as FORGE, EGS Collab, and other efforts around the world are appropriate and necessary steps towards minimizing these challenges. Multi-disciplinary approaches are needed to bring the optimal thermal, mechanical, chemical, hydrological, geophysical, engineering and other expertise together to address these challenges.

References

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