Hot Rocks Part 3 – Widespread Geothermal Power

By John Benson

August 2022

1. Introduction

The title of this post indicated it's the third part in this series. The first part was posted a little over a year ago, and the second this spring. These are described and linked below:

Hot Rocks – The Perfect Renewable Energy: *This post will start in my deep past, over 40 years ago and travel several decades into the future. The subject of this post is Geothermal Power, a renewable energy source that was first used to generate electricity in Larderello, Italy, in 1904, and thus is one of the oldest renewable energy sources. It has been used in my home state (California) to generate a significant amount of our electric energy since the early 1960s.*

In 1985 I became heavily involved with the Geysers Geothermal Generating Field, what is now (still) is the largest in the world by several metrics.

However I have never posted a paper about Geothermal Power. I have decided to rectify this failure and write this post. As I started researching this, I found that this technology has not only been amazing in the past and present, it will be important to our efforts to overcome climate change in the future.

https://energycentral.com/c/cp/hot-rocks-%E2%80%93-perfect-renewable-energy

Hot Rocks, part 2: *The original "Hot Rocks" post focused on mainstream geothermal power, that is, hydrothermal resources, which are considered conventional geothermal resources because they can be developed using existing technologies.*

I called these the "low hanging fruit" because a large quantity of these have been identified and developed, but there are still many undeveloped hydrothermal resources still out there. Thus, in the first section below, we will focus on existing firms that develop all types of resources. In the following sections we will focus on unconventional geothermal resources.

https://energycentral.com/c/cp/hot-rocks-part-2

Although there are several variations on the themes, there are basically two types of geothermal resources:

Hydrothermal resources: the natural formation of a hydrothermal resource typically requires three principal elements: heat, water, and permeability. When water is heated in the Earth, hot water or steam can become trapped in porous and fractured rocks beneath a layer of relatively impermeable caprock, resulting in the formation of a hydrothermal reservoir.

Enhanced Geothermal Systems (EGS): The principal elements of heat, water, and permeability—when found together and in sufficient amounts—can support cost-competitive rates of energy extraction. Independent of water and permeability, thermal energy (heat) exists everywhere on Earth and increases with depth. Research funded in part by the U.S. Department of Energy (DOE) in the 1970s opened new frontiers of geothermal resources by studying EGS. At the most basic level, EGS are manmade geothermal reservoirs. Where the subsurface is hot but contains little permeability and/or fluid, pumping water into wells can stimulate the formation of a geothermal reservoir capable of supporting commercial rates of energy extraction.

Hydrothermal resources are rare, but have the potential to be economically developed into medium to large electric generation projects. The classic example of these are the Geysers, north of San Francisco, which has a peak output of almost 1,600 MW of dispatchable, greenhouse gas-free generation. See part 1 of this series for details.

EGS is wide-spread, but more difficult and expensive to develop. However with large investments (mainly by the U.S. Department of Energy), this generation source is becoming increasing viable. This post is about EGS.

2. Utah FORGE

Our mission is to enable cutting-edge research and drilling and technology testing, as well as to allow scientists to identify a replicable, commercial pathway to EGS. In addition to the site itself, the FORGE (Frontier Observatory for Research in Geothermal Energy) effort will include a robust instrumentation, data collection, and data dissemination component to capture and share data and activities occurring at FORGE in real time. The innovative research, coupled with an equally-innovative collaboration and management platform, is truly a first of its kind endeavor.[1]

Utah FORGE is a dedicated underground field laboratory sponsored by the Department of Energy (DOE) for developing, testing, and accelerating breakthroughs in Enhanced Geothermal Systems (EGS) technologies to advance the uptake of geothermal resources around the world.

2.1. Utah Forge: Pathway to Success

All deliverables at FORGE will focus on strengthening our understanding of the key mechanisms controlling EGS success, specifically how to initiate and sustain fracture networks in basement rock formations. This critical knowledge will be used to design and test a methodology for developing large-scale, economically sustainable heat exchange systems, paving the way for a rigorous and reproducible approach that will reduce industry development risk and facilitate EGS commercialization. R&D activities may include, but are not limited to, innovative drilling techniques, reservoir stimulation techniques and well connectivity and flow-testing efforts. The site will also require continuous monitoring of geophysical and geochemical signals.

Additionally, dynamic reservoir models will play an integral role in FORGE by allowing the site operator to synthesize, predict, and verify reservoir properties and performance. R&D activities will have open participation via competitive solicitations to the broader scientific and engineering community.

As advancements in EGS are made over the course of FORGE's operation, R&D priorities are likely to shift and change in response. As a result, FORGE will be a dynamic, flexible effort that can adjust to and accommodate the newest and most compelling challenges in the energy frontier!

[1] Utah FORGE, About, https://utahforge.com/about/

2.2. Utah Forge Will

- *Provide an underground laboratory for developing and testing innovative tools and stimulation techniques for developing EGS reservoirs*
- *Extend existing technologies developed for oil and gas beyond current capabilities to successfully produce electricity from hot crystalline rocks*
- *Demonstrate technologies that can be applied across the USA*
- *Provide domestic and international scientists and students with funds for research to expand future energy security and availability*
- *Demonstrate suitability and safety of large-scale geothermal energy development to the public*

2.3. In the Lab

The day started inauspiciously for John McLennan, as he tried to break the curse haunting a 45-year quest to coax abundant energy from deep within Earth.[2]

First came news of an overnight accident that left one researcher recuperating in a hotel with a sore back. Then reports trickled in that seismic sensors dangling inside holes bored deep into the Escalante Desert here were malfunctioning. Repairs were delayed by gale-force winds that whipped the sagebrush-covered hills and buffeted a drilling rig that rose 50 meters from the desert like a misplaced lighthouse. Workers were already a day behind schedule, and each day burned an additional $350,000.

Finally, shortly before sunset, McLennan, a geo-mechanics engineer at the University of Utah, was ready to take a critical step in advancing a $218 million project, 4 years in the

[2] Warren Cornwall, in Milford, Utah; Photography by Eric Larson/Flash Point SLC, Science, July 15, 2022, "Catching Fire," https://www.science.org/content/article/utah-researchers-trying-unlock-earths-heat-make-geothermal-energy-reality

making, known as FORGE (Frontier Observatory for Research in Geothermal Energy). If successful, FORGE will help show how to transform dry, intensely hot rock found below ground all over the world into a major renewable source of electricity—and achieve a technical triumph where many others, over many years, have failed.

Gusts no longer rocked the trailer where McLennan, eyes baggy with fatigue and wearing the same brown sweater as the day before, faced five computer screens. The trailer's door opened and a co-worker—a giant of a man wearing a white hard hat—looked in. "You ready for me to go?"

"Yeah," McLennan replied. "We're ready." With that, powerful pumps nearby sprang to life and began pushing thousands of liters of water down a hole drilled 3 kilometers into the hard granite below.

The concept of using Earth's internal heat to generate electricity is attractively simple. Temperatures in the planet's core approach those found at the surface of the Sun, and the heat leaks outward. In places this geo-thermal energy emerges at Earth's surface as molten lava, steaming vents, and hot springs. More often, however, it remains trapped in deep sediments and rock.

There's plenty of it. By one recent estimate, more than 5000 gigawatts of electricity could be extracted from heat in rock beneath the United States alone. That's nearly five times the total currently generated by all U.S. power plants. Geothermal energy is also attractive because it doesn't burn fossil fuels, isn't imported, and can run around the clock, unlike solar panels and wind turbines.

Tapping that heat, however, has proved difficult. Some nations—notably volcanically active Iceland—siphon hot groundwater to heat buildings and generate electricity In most places, however, the rock lacks the water or the cracks needed to easily move heat to the surface. For decades engineers have sought to coax heat from this hard, dry basement rock, which can reach temperatures of more than 250°C. But those efforts have largely failed, often at huge expense—and sometimes after causing damaging earthquakes. As a result, geothermal energy provides just 0.33% of the world's electricity, little changed from 1990, according to the International Energy Agency.

In recent years, new hope for this renewable energy source has come from an unlikely source: new technologies developed by the oil and gas industry. The same methods that have boosted fossil fuel production in the United States, such as targeted drilling and fracking—artificially fracturing deep rock with high pressure fluids—can, it's hoped, be put to work to efficiently and safely extract energy from hot, dry rock. Government agencies and private companies are pouring hundreds of millions of dollars into the approach, called enhanced geothermal systems (EGS), though it, too, has had setbacks. Now, FORGE, situated on a remote patch of land in southeastern Utah, has become a closely watched effort to demonstrate and fine-tune EGS technologies—and finally break the losing streak.

For Mclennan, FORGE brings a sense of déjà vu. In 1983, when he was an engineer at an oilfield company, he worked with scientists from the Department of Energy's (DOE's) Los Alamos National Laboratory on a pioneering attempt to exploit hot, dry rock in New Mexico's Jemez Mountains. The scientists had hoped to create what amounted to artificial hot springs, by injecting water into deep fractures and then channeling the heated water back to the surface via a nearby exit well. But much of the injected water *never resurfaced; researchers later concluded that they had misread the underlying geology, and the water disappeared into undetected cracks.*

“It was a disappointment,” McLennan recalls. And it was one of many.

Much the same thing happened decades later to a $144 million geothermal plant in Australia’s arid Cooper Basin. Water pumped into the wells flowed into a previously unknown fault, and the project shut down in 2016, after just 5 years.

In some places, EGS projects had more dramatic failures, as high-pressure water injected for fracking caused existing faults to slip, setting off earthquakes. In 2006, engineers shuttered a project beneath Basel, Switzerland, after earthquakes caused minor damage. Eleven years later, a magnitude 5.5 quake struck Pohang, South Korea, killing one person, injuring dozens, and causing more than $75 million in damage. It was traced to a new, nearby EGS project where, despite a series of tremors, operators had injected fluid at high pressures near a previously unknown natural fault.

The high cost of drilling into hot, dry rock is also a challenge. Equipment designed for the softer, cooler sedimentary rock often found in oil fields falters in the extremes of hot, hard metamorphic rocks such as granite.

Today, just three EGS power plants—all near the border of France and Germany—produce electricity. In total, they generate less than 11 megawatts, enough to power about 9000 homes.

EGS “always has been fraught with technological challenges,” says Jamie Beard, an attorney and executive director of the new nonprofit Project InnerSpace, which is seeking donations to help geothermal startups. And “EGS in its pure form like FORGE is hard,” she adds.

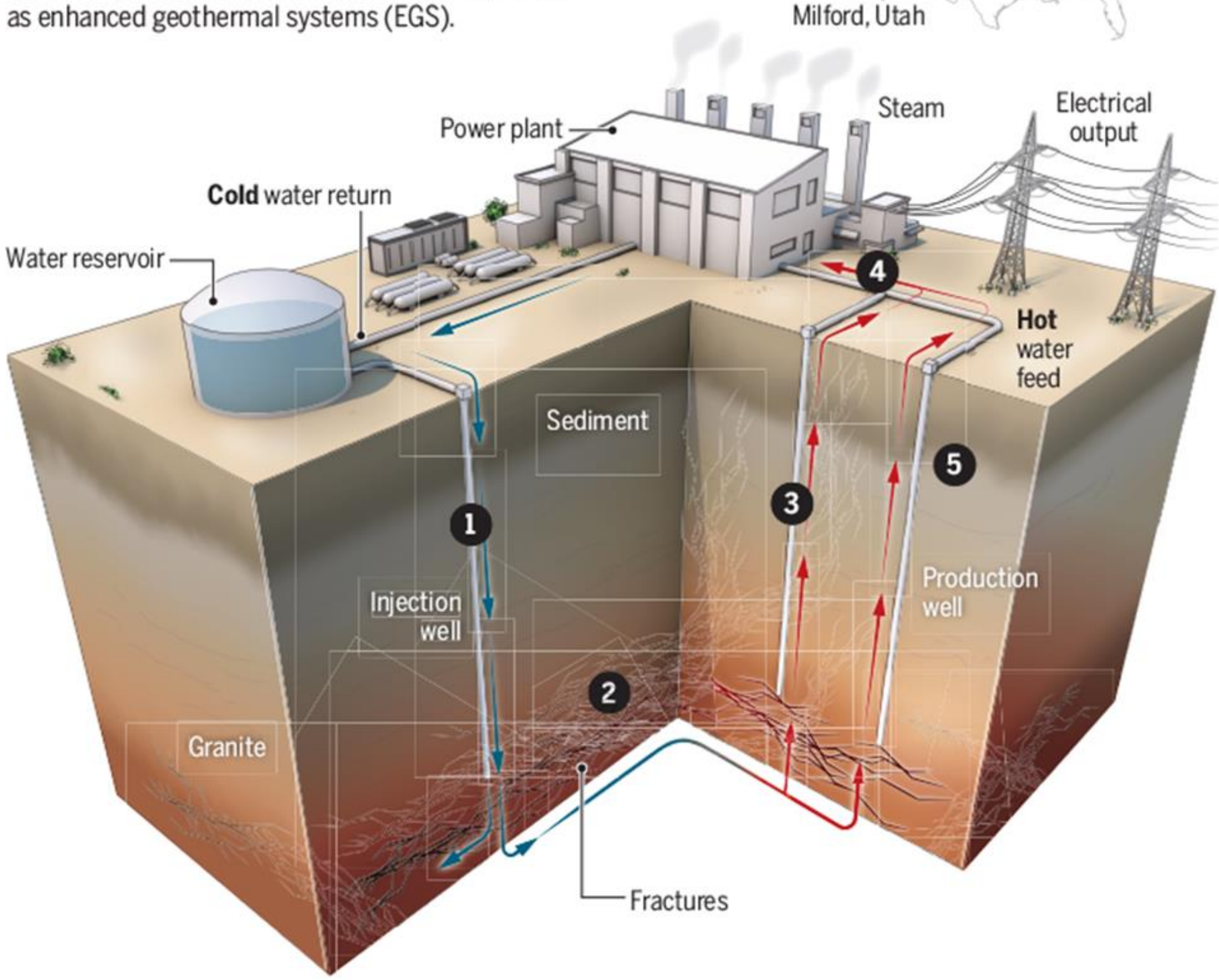
Even as EGS projects have struggled, however, new techniques have emerged from the oil and gas industry. Engineers learned to drill horizontally instead of just vertically. Today they can create wells that can resemble rollercoaster routes, curving and doubling back on themselves. Sophisticated steering systems allow drillers to target their fracking to release oil and gas from veins of rock as narrow as 5 meters. The advances have prompted investors and governments to take a fresh look at EGS.

In the United States, more than two dozen geothermal companies have emerged since 2020, Beard says; that’s more startups than she counts in the previous decade. In Germany, the Helmholtz Association of German Research Centers announced in June it is putting €35 million into a new underground laboratory dedicated to geothermal research in deep crystalline rock, including EGS. And DOE in April announced plans to spend $84 million on four EGS pilot projects. They’ll be placed in different geological settings in the United States to study the best ways to extract heat from different types of rock.

Those plants will build on the results of FORGE, which DOE launched in 2014 with a competition to create a laboratory for honing EGS tools. In 2018, DOE announced the University of Utah and partners had won the funding to build the facility near the small railroad town of Milford, Utah, where Earth’s feverish interior creeps close to the surface.

Plumbing the Earth

Scientists are trying to extract the abundant heat trapped belowground in places where hot water doesn't flow through the bedrock. Their goal: to create artificial systems that act like hot springs, commonly known as enhanced geothermal systems (EGS).



1 In EGS, a cold fluid such as water is injected into wells deep enough to reach hot, dry rock, often kilometers down.

2 Water is heated as it flows into cracks in the rock. In EGS, high-pressure fluids are used to create new fractures or enlarge existing ones, a technique much like the fracking used in the oil and gas industry.

3 Hot water is pumped to the surface via exit wells drilled not far from the injection well. The water turns to steam as the pressure drops closer to the surface.

4 The steam is directed to turbines that generate electricity. Most of the water is reused and continues the cycle.

5 EGS-like techniques can also be used to create water that's not hot enough to efficiently generate electricity. But the artificial hot springs can be used to warm homes and commercial buildings, and drive a variety of industrial processes.

Graphic: C. Bickel, Science

THE MILFORD VALLEY'S VENEER of vegetation is so thin that much of its geologic history is exposed like an open book. Moore has spent more than 40 years reading that tome. Earlier this year, he stood next to a low cliff of silica that runs north to south along the top of a small hill. "This is a fundamental boundary," he declared.

The wall divides what are, for the purposes of geothermal energy, two different worlds. To the east, the ground quickly rises to the flanks of the Mineral Mountains, rounded peaks speckled with granite outcroppings and juniper trees. A flat-topped mountain devoid of granite marks the top of a long-dead volcano, one of nine that testify to the heat still trapped beneath the ground in this region…

Starting in 2020, crews used a similar rig to drill an injection well. The completed shaft, 22 centimeters in diameter, extends for 3.3 kilometers. The well includes features that are standard in fracking operations but still cutting edge in EGS. For example, FORGE's shaft dives into the target granite at an angle that is close to horizontal—chosen to intersect with natural stresses in the rock in a way that would enable engineers to amplify tiny existing fractures.

At its deepest point, the shaft pierces rock that is 1.7 billion years old. Conventional metal drill bits struggled to cut through this stone, and the younger granite above, advancing just 3 meters per hour and frequently disintegrating. That prompted a switch to tougher drills tipped with synthetic diamonds—a first for geothermal drilling in granite. The bits sliced through the rock 10 times faster, and are "definitely a breakthrough," says Peter Meier, an engineer and CEO of the Swiss geothermal company Geo Energie Suisse, who visited FORGE earlier this year to help with seismic monitoring. "This is already a very big result of the project."

The FORGE well is lined with a steel casing that's standard in oil fracking. Such linings make it easier to use specially designed gaskets to seal off sections of pipe in which operators detonate small explosives, shattering the pipe and exposing the surrounding rock. That helps FORGE fracture rock bit by bit—another novelty in EGS.

That piecemeal approach could help EGS projects avoid fracking in seismically sensitive areas that could trigger nearby faults, says William Ellsworth, a Stanford University geophysicist who has studied drilling-induced tremors, including the Pohang quakes. But he cautions that spotting problem faults in hard basement rock is "an exceedingly difficult imaging problem."

At FORGE, moreover, the granite's high heat has crumbled the gaskets typically used in cooler oil and gas wells. It's also fried seismic sensors essential to tracking the fracking operation. So, the team has been testing special high-temperature gaskets and new monitoring tools, including fiber optic cables able to withstand the heat while detecting tiny vibrations in the earth.

Universities, government labs, and companies are currently developing other technologies they hope to test at FORGE. One is a small device, resembling a motorized skateboard that would drive deep into the well to open and shut "windows" in the steel casing that expose nearby rock for fracking, another technique for targeting specific regions of rock. Such "tool development … is absolutely critical" to moving EGS into the mainstream, Moore says.

On 16 April, McLennan and the FORGE team were ready for one of their first big tests: seeing whether they could pump enough water into the deepest part of the well, under enough pressure, to enlarge tiny cracks or create new ones in pockets of granite.

The equipment malfunctions and high winds had initially thrown the schedule into disarray. But by late in the day, McLennan was perched in front of his computer screens, like an air traffic controller ready to guide a plane in for a landing.

Voices crackled over radios. Beside him, Kevin England, a veteran petroleum engineer, issued short bursts of commands…

On McLennan's screen, numbers began to climb, tracking the water flooding into the hole, where the pressure would hit the last 60 meters of rock, left exposed without a steel shell. The engineers hoped that would allow them to create a focused, dense cloud of fractures, like an acupuncturist inserting needles into a specific nerve.

A red line crawled across the screen, marking the gradual rise in water pressure. Eventually, the line wavered, bouncing around a pressure of about 28 megapascals, more than 250 times the atmospheric pressure. The flutter was good news: It probably meant the rock was giving way. "We're getting some action," McLennan announced. "This is nice."

Over the next half hour, the signals continued to be encouraging. For the first time in days, McLennan appeared at ease. "This is beautiful," he said. "It fractures, it stops, then it propagates again."

It was hard to know exactly what was happening nearly 3 kilometers below. But Jim Rutledge, a seismologist at a nearby screen, was gathering clues. Clusters of black dots appeared on a grid, marking tiny earthquakes detected by sensors in a monitoring well half a kilometer away. The tiny tremors were no cause for alarm—just a sign that the fracking was going as planned. "We have a big cloud," Rutledge said.

At 77 minutes in, the volume of water pouring down the well had grown to 50 barrels per minute—an aspirational target some had predicted the team wouldn't reach because of the unyielding rock…

Moore and Mclennan were buoyant the day after the April test: They had pulled off their first successful frack. Now, the FORGE team is sifting through the mountains of data collected during that test as well as two subsequent fracks at locations higher up in the same well. What they learn will shape their next steps.

Others are watching FORGE closely for lessons. Meier is leading plans for an EGS project in Switzerland. He hopes FORGE's technique of executing smaller, segmented fracks will point the way to reducing the risk that EGS will cause damaging earthquakes, like those that shut down his company's previous work in Basel.

Others are eager to see whether FORGE can identify ways to make EGS more commercially attractive by solving problems that today scare off would-be investors, including time-consuming drilling, broken equipment, and prolonged uncertainty over whether a well can produce hot water.

"That's where we're focusing all of our time and energy—taking away the risk from the [geothermal energy] community," says Lauren Boyd, acting director of DOE's Geothermal Technologies Office.

2.4. ESG 2.0

Others, however, see more immediate commercial promise in other strategies. Call them EGS 2.0. Beard, for example, argues for targeting softer, slightly cooler rocks at shallower depths, familiar territory for oil drilling. The approach would still rely on engineered hot springs and possibly fracking. But the formations are easier to work in, *Beard says, and drillers have gained expertise from boring tens of thousands of wells into such geology.*

Sage Geosystems is one company pursuing that strategy. Founded in 2020 by scientists and executives from the oil giant Shell, the Houston-based company aims to drill and frack a single well in sedimentary rock and use a set of concentric pipes to pump cool fluids into the rock and draw out hot ones. Instead of water, the firm might use liquid carbon dioxide, because it has a lower boiling point. The resulting steam would drive turbines specially designed to operate with carbon dioxide.

One longtime EGS proponent is trying a different, less technically challenging approach. Chemical engineer Jeff Tester of Cornell University helped run the Los Alamos work in the 1970s and was the lead author of a 2006 DOE report touting EGS. Now, he's overseeing a program that this summer started to drill a test well in sedimentary rock on the Cornell University campus in New York state. Although rock temperatures could top out at just 100°C, that would be enough to produce hot water to heat all the university's buildings, Tester says. And these lower temperatures are found in rock in many more places. "It doesn't have to be high temperature," he says. "That's the beautiful feature of using [cooler rock] directly for heating..."