Engineered geothermal systems have wide potential as a renewable energy source

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Citation: Physics Today **71**, 9, 22 (2018); doi: 10.1063/PT.3.4017
View online: https://doi.org/10.1063/PT.3.4017
View Table of Contents: https://physicstoday.scitation.org/toc/pto/71/9
Published by the American Institute of Physics

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A test site in Utah will focus on tackling technical barriers.

What will it take to put geothermal energy to use on a large scale? Iceland uses it nearly exclusively for heat and hot water and for about a fifth of its electricity (see related story on page 26). Many countries have geothermal projects. But the vast stores of heat deep beneath Earth's surface remain largely untapped. "If we can unlock the technologies to make extracting heat in the subsurface technically and commercially viable on a large scale, the promise is huge," says Bridget Ayling, director of the Great Basin Center for Geothermal Energy at the University of Nevada, Reno. That's why, she adds, "despite only incremental gains over the last 40 years, the geothermal community continues to pursue engineered geothermal systems," or EGS, also known as enhanced geothermal systems.

In conventional geothermal systems, heat is harvested from hot water in deep rocks that have natural permeability. In EGS, by contrast, permeability has to be engineered, usually by injecting cold water into rocks to open existing fractures and create new ones. The water flows through the fractures and absorbs heat from hot rocks before being retrieved. The hot water produced can be used to generate electricity or heat before it is reinjected. With sufficiently deep drilling, the EGS method could be implemented almost anywhere and could be a widespread source of renewable energy. But that requires technical advances, social acceptance, and cost reduction.

Aiming to tackle the technical hurdles to realizing EGS, the US Department of Energy in 2014 created the Frontier Observatory for Research in Geothermal Energy (FORGE) initiative. This past June DOE selected the University of Utah from among five candidates as the steward of a dedicated site for that purpose. The Utah team, with its EGS site located 300 kilometers south of Salt Lake City, will receive $140 million over five years.

In a press release announcing the FORGE award, Secretary of Energy Rick Perry said, "Enhanced geothermal systems are the future of geothermal energy, and critical investments in EGS will help advance American leadership in clean energy innovation. Funding efforts toward the next frontier in geothermal energy technologies will help diversify the United States' domestic energy portfolio, enhance our energy access, and increase our energy security."

CLAY JONES, ENERGY AND GEOSCIENCE INSTITUTE, UNIVERSITY OF UTAH

CORE SAMPLES are studied to learn where and how to create fractures for heat reservoirs. This mostly granitic core is about 10 centimeters in diameter.

A test laboratory

A single vertical well, 2297 meters deep, was drilled at the FORGE site last year. With the new award, additional wells will be drilled and fractures will be stimulated to create a reservoir to test and study the full EGS process. That includes looking at fracture predictability, monitoring seismicity, and studying rock characteristics relating to permeability, geochemistry, and more.

About half the FORGE funding will go toward drilling, infrastructure, and seismic and other maintenance. The rest

THIS UTAH SITE was selected by the Department of Energy for dedicated research on enhanced geothermal systems. The rig in the distance was used to drill a vertical well for preliminary scientific measurements. The site, about 300 kilometers south of Salt Lake City, is collocated with solar and wind-energy production.

will be awarded for R&D through peer-reviewed competitions to be overseen by the Utah team.

In the US, EGS projects have often piggybacked on conventional geothermal sites that were already producing electricity. "The plant operators don't want their production to be negatively impacted. That can be scientifically limiting," Ayling says. "FORGE is fairly unique in that it is independent. The best domestic and international researchers can test and develop innovative, cutting-edge, subsurface technologies. I am hopeful that this will give us the opportunity to be bold and brave and to try things that, so far, we have not been able to try."

Creating a reservoir where injected water can be heated is among the toughest challenges in EGS. "We want to create permeability by opening the existing fractures," explains FORGE principal investigator Joseph Moore. "That's why one emphasis is on understanding the stress field in the rocks."

For adequate heat exchange, an EGS reservoir requires a large network of small fractures, a millimeter wide or less. "You need an effective radiator for water to percolate and circulate through," says Moore. "You have to avoid short circuiting," in which the water flows out, via a dominant fracture, too fast to be adequately warmed.

To maximize well productivity, the researchers want to create multiple fracture networks in a single reservoir, which can be several kilometers across. One area of intensive research is isolation—stopping fractures from forming at a given part of a borehole and then stimulating them at successively deeper locations. The stopping can be done, for example, with a fibrous material that is solid when injected and breaks down and becomes soluble at high temperatures, says Susan Petty, whose Seattle-based company AltaRock Energy holds the patent for that method of isolation. (See also the interview with her at http://physicstoday.org/petty.)

The EGS community is increasingly embracing horizontal drilling, an approach adopted from the oil and gas industry. (See the articles in PHYSICS TODAY by Michael Marder, Tadeusz Patzek, and Scott Tinker, July 2016, page 46, and by Brian Clark and Robert Kleinberg, April 2002, page 48.) Fractures often form vertically, so a reservoir with wellbores approaching horizontal—perpendicular to the fractures—could be effective, says John McLennan, a FORGE coprincipal investigator. Drilling a deviated well at great depth is tricky, and the change in inclination needs to be gradual to accommodate the well casing, steel insertions that maintain the well's integrity. So far, geothermal wells up to about 40° from vertical are common, but McLennan and others hope to get closer to horizontal. "It opens up new opportunities for success," he says.

Another focus is understanding how the rocks interact with the injected water. Will clays or other minerals form that eventually block flow pathways? Will cold injected water shrink the rocks so the fractures widen? Ayling's specialty is reservoir characterization, including fluid chemistry, hydrothermal alterations, and physical properties such as rock strength and permeability. For EGS, she says, it's important to evaluate the probable rock types and conditions before deep drilling. "We still don't know what the best sites are for developing large-scale EGS. It's a knowledge gap."

To get to useful temperatures—the DOE's goal is 175 °C to 225 °C—requires going several kilometers deep, into hard

BRIDGET AYLING

THE NOW-DECOMMISSIONED HABANERO PILOT PLANT in South Australia's Cooper Basin produced geothermal power under conditions of extreme heat and pressure. The U-shaped loops allow the pipes to withstand thermal expansion and contraction when hot geothermal fluids flow through, a design that prevents damage to the wellhead. Heat exchangers and cooling towers are visible in the background.

rocks. Drill bits wear faster in those environments than in shallower shales and other sedimentary rocks encountered by the oil and gas industry. Electronics and other materials for characterization and ongoing monitoring have to withstand higher temperatures. So while tools and know-how are transferable from the oil and gas industry, the EGS approach also requires different—and sometimes innovative—instruments. "There are materials from the nuclear industry that survive high temperatures," notes Petty. "But we haven't yet applied them in drilling."

Australia's Habanero site gave (see photo above) the EGS community experience working at great depth, high temperatures, and at very high pressures. During a five-month test run in 2013 that produced 1 MW of electrical energy, Ayling injected chemical tracers there. "Tracer testing is one of the few direct methods where you can definitively prove your wells are connected," she says. "You can also calculate your average fluid-flow velocity along with other reservoir parameters." The Habanero project "was expensive, but it proved EGS could be done under extremely challenging conditions." The economics of scaling up to a larger 50 MW power plant did not stack up, she adds, and the site was decommissioned in 2016.

"The ability to create multiple-fracture sites is still a challenge," says McLennan. So are steering the drill bits, cutting costs by drilling faster, working underground at high temperatures, and making sure subsequent wells intersect the engineered fractures optimally to retrieve the heated water. "That is the purpose of FORGE—to provide a test laboratory."

Seismicity risk and social acceptance

Studies on EGS go back to the late 1970s, when Los Alamos National Laboratory first looked into harvesting energy from hot, dry rocks. Budget cuts ended that project around 1990, but a smattering of efforts carried on around the globe. Two EGS plants in the Alsace region of France produce energy commercially: Soultz-sous-Forêts, which began as a scientific project, has since 1986 produced about 1.7 MW of electricity for the French grid. And 10 kilometers away, a plant in Rittershoffen produces 24 MW of thermal energy from high-temperature geothermal water.

Besides technical and financial challenges, seismicity can also derail EGS. In Basel, Switzerland, for example, a project was shuttered about a decade ago after a magnitude 3.4 earthquake, attributed by some to EGS, damaged buildings. And last fall a magnitude 5.5 earthquake, which was followed by a smaller tremor, put a halt to an EGS project in South Korea. In that case, says Ernest Majer of Lawrence Berkeley National Laboratory, it's not clear that the EGS project caused the earthquakes, but the earthquakes definitely cast a shadow over international EGS efforts.

Some seismicity is unavoidable during the creation of an EGS reservoir. But Lauren Boyd, EGS program manager at DOE, notes that unlike fracking in the oil and gas industry, which involves injecting more liquid than is removed, the water injected in EGS is taken out and reinjected in a closed loop, which reduces the seismicity risk.

Brian Carey, an engineer at GNS Science's Wairakei Research Centre in Taupo, New Zealand, and the International Energy Agency's executive secretary for geothermal technical collaboration, stresses that the sustainability of EGS depends on community acceptance. "That is probably one of the most significant aspects."

Turn on the heat

Interest in EGS in the US and elsewhere was rekindled by a 2006 study, *The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century*. Commissioned by DOE and written by an MIT-led interdisciplinary panel, the report estimated total US EGS resources of 13 million exajoules in crystalline rock formations at depths of 3 km to 10 km. That's roughly equivalent to the energy in 2 quadrillion barrels of oil, according to study chair Jefferson Tester, now at Cornell University. Extracting a small fraction could satisfy "a major portion of the US's primary energy needs," he says.

Tester says the 18-member panel was restricted to electricity in its consideration of EGS. But EGS has more to offer. "We lose about 90% of its energy value by converting the geothermal heat to electricity instead of using the heat directly," he says.

Other factors are also converging to raise hopes for EGS. Science has advanced in recent years: The geophysics and geochemistry of the subsurface are better understood, numerical modeling is more accurate, and new tools and know-how from the oil and gas industry can be applied. At a time when climate change is recognized as among the greatest threats to the planet, the prospect of low carbon emissions enhances the approach's appeal. And EGS could be a steady source to complement the fluctuating power supplied by the wind and Sun.

Peter Meier, CEO of Geo-Energie Suisse, notes that in Switzerland, "We have no sea, and therefore not a lot of wind. Solar is not enough, and hydropower is almost to capacity." Last year the country decided to phase out its nuclear reactors. "That is why we are motivated to do EGS," he says. If it works, his company predicts that injection–production well pairs could provide up to 5 MW of electricity from the local rock conditions. The company is reassessing the project's seismicity risk and hopes to get the green light to start construction late next year or in early 2020.

One key attraction of EGS is its wide applicability. Conventional geothermal energy relies on natural convective flow. For the US, that's in the western states. "Successful EGS will extend the geographical applicability to other parts of the country," says McLennan. "In many parts of the country, you can find heat, but you don't have water or fractures. EGS adds both."

Take the Northeast, says Tester. "Imagine using EGS to take heat out of ground and use it for heating homes." That, of course, would require distribution systems. "You have to be reasonably close to the source—transporting hot water or steam long distances is technically possible but not economically attractive."

The country needs to transform its infrastructure in any case, says Tester, so why not be creative. "A lot of geothermal failures have been because of a lack of continuity in support and patience." The capital investment in EGS is high, but systems should be designed to work for at least two decades. And, he adds, if the US doesn't pursue EGS seriously, "we are going to fall behind the rest of the world."

Toni Feder