EGS Over Easy

Reinvigorating Tired Geothermal Systems and Upgrading Marginal Ones

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Geothermal energy use continues to grow at a modest yet steady pace worldwide. Geothermal electrical developments are mostly concentrated in areas of Quaternary volcanism, reflecting the presence of shallow magma and/or hot plutons heating groundwater at economically drillable depths within the crust. Direct applications of geothermal heat are dispersed across all continents (except Antarctica), reflecting the fact that even the Earth's below-boiling warm springs and areas of "normal" underground temperatures can be put to use in effective, economic projects.

The latest available figures put current installed geothermal capacity worldwide at over 9,000 megawatts-electric (MWe, see Table 1), and direct-use projects at over 11,000 megawatts-thermal (MWt). Corresponding values for the United States are about 2,800 MWe and 600 MWt. A recent review by Lund (2003) puts present U.S. generating capacity at ~2,000 MWe. This "snapshot" is probably accurate, but projects poised to come online in the very near future should boost generating capacity in the United States to near 3,000 MWe.

Contemporary developments in the U.S. geothermal industry have been fueled principally by changes in the structure of power markets, environmental awareness, and Renewable Portfolio Standards (RPS) adopted by many states. RPS laws require that a specified percentage of electricity from renewable sources be purchased by utilities. There is also a move at the federal level to provide geothermal operators with a Production Tax Credit analogous to that granted to wind energy producers.

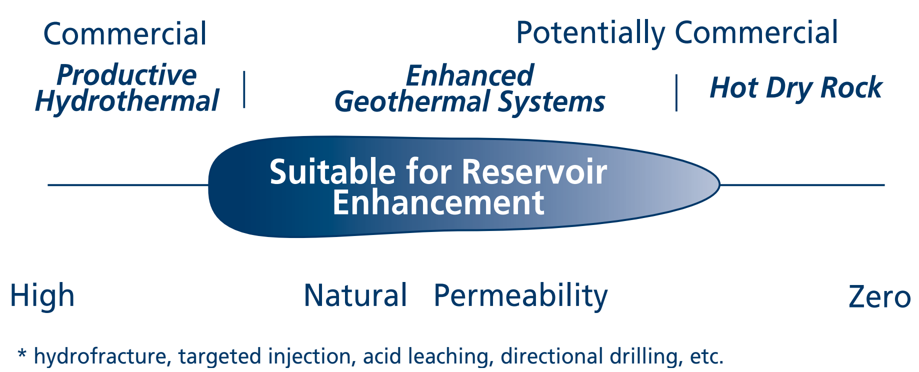
Geothermal facilities with costs amortized during the PURPA (Public Utilities Regulatory Policy Act of 1978, P.L. 95-617) period of the 1980s—when utilities paid a premium for renewable energy—can compete with conventional natural gas- and coal-fired power plants without subsidies. In states that have instituted an RPS, investment in new renewable power generation capacity is beginning. Sites where geothermal energy expansion and development are contemplated include three locations each in both California and Nevada, two in Idaho, and one in New Mexico.

Enhanced Geothermal Systems

The recent focus for geothermal electrical projects in the United States has been to improve the productivity and longevity of known hydrothermal systems, and to reevaluate systems thought to be uneconomic in the past. These improvements involve a broad spectrum of approaches and technologies, encompassed by the phrase "Enhanced Geothermal Systems" (EGS). The EGS concept was adopted by the U.S. Department of Energy (DOE) in the late-1990s, after DOE funding for Hot Dry Rock (HDR) research and development had ended.

Starting in the mid-1970s, scientists and engineers at Los Alamos National Laboratory (Los Alamos, NM) conducted the principal domestic HDR experiment at Fenton Hill, on the western margin of the Valles Caldera in New Mexico. A small hydrothermal reservoir was created in hot—but essentially impermeable—rock by pumping water down a borehole at pressures high enough to create fractures. These new fractures allowed water to flow through hot rock to a second nearby well, thus creating a continuous loop of fluid flow. The project "mined" heat at an average rate of 5 MWt during intermittent flow tests conducted over the 20-year life of the project. Much knowledge was gained, but the project was terminated without demonstrating commercial viability. The primary problem was that expensive, high-pumping pressure was required to maintain even modest water circulation through the engineered reservoir.

Figure 1. Illustration of the permeability range for different classes of geothermal systems.



Many hydrothermal systems have been discovered and evaluated, only to be left undeveloped because of insufficient permeability—and therefore limited productivity from geothermal wells. Some systems of this sort (sometimes called "hot wet rock"), though not economic under present market conditions, could become competitive with increased permeability (Fig. 1). EGS occupies a large part of the spectrum between high-permeability, commercially successful hydrothermal systems, and the very low permeability systems that formed the basis of early HDR research and development. To evaluate the potential of EGS, uneconomic zones within and around the margins of developed hydrothermal reservoirs also are currently being targeted for research and development projects.

As the Fenton Hill project demonstrated, HDR reservoirs are not economic under current (or foreseeable) technological and power-market conditions. Nonetheless, techniques developed specifically for creating HDR reservoirs may be applicable to a large range of potential geothermal resources. These techniques are being applied to increase permeability in marginally productive natural hydrothermal systems. Thus, EGS technology is appropriate for a broad class of targets between the extremes of currently commercial and HDR systems.

Stimulation of permeability in an EGS experiment can be undertaken in a variety of geologic environments. The technology includes fault and fracture (stress) analysis; hydraulic fracturing to increase permeability; directional drilling to intersect fractures that are oriented favorably; and injection of groundwater or wastewater at strategic subsurface locations to replenish depleted naturally-occurring fluids and to reverse reservoir pressure declines. These enhancement and remedial measures can extend the productivity and longevity of an existing hydrothermal reservoir. In addition, they can allow hitherto uneconomic reservoirs to be brought online, or increase the size and output of existing reservoirs by allowing development of previously unproductive portions of a geothermal field.

There remain some differences of opinion as to what constitutes EGS. For programmatic reasons, DOE limits the definition to underground activities designed to enhance the permeability of reservoirs. By contrast, targeted injection of water to replace depleted pore fluids is included by DOE in other program areas. The narrow focus is understandable from a program perspective, but we consider targeted injection as one of the most important EGS activities.

On the issue of nomenclature, DOE Geothermal Program Team Leader Alan Jelacic reports: "The Executive Committee of the Geothermal Implementing Agreement under the International Energy Agency has voted to replace all references to 'HDR' in its work and other activities with 'EGS.' The Committee is comprised of all major geothermal interests from developed countries and marks a significant shift in how geothermal resources are classified."

The "HDR" projects currently being pursued by a French-German consortium in France (Soultz sous Forêts) and those recently terminated in Japan (Hijiori and Ogachi) are probably better described as EGS projects because they seek to increase the productivity of existing hydrothermal reservoirs rather than creating new ones from impermeable rock. Programs to inject water at The Geysers (California) and Dixie Valley (Nevada) are also examples of successful EGS projects.

Currently, DOE is co-sponsoring several EGS projects in the western United States to "prove up" additional geothermal resources. These include a project to increase permeability on the margins of the reservoir and strategically target injection at the Coso geothermal power complex (Caithness Operating Co., LLC); a program to investigate the potential for hy-

Table 1. World Geothermal Generating Capacity.

Country	Installed MWe Capacity
Australia	0.17
Austria	1.25
China	28.18
Costa Rica	142.50
El Salvador	152.00
Ethiopia	8.52
France (Guadeloupe)	4.20
Guatemala	24.00
Japan	548.70
Iceland	200.00
Indonesia	787.50
Italy	862.00
Kenya	53.00
Mexico	865.00
Nicaragua	77.50
New Zealand	438.00
Philippines	1905.00
Portugal(Azores)	14.00
Russia	73.00
Thailand	0.30
Turkey	20.40
USA	2800.00
Total	**9005.22**

Source: Marnell Dixon and Mario Fanelli

Calpine Corp.

A section of the Santa Rosa Geysers Recharge Project pipeline under construction.

draulically stimulating a large volume of rock adjacent to the Desert Peak geothermal power facility in northern Nevada (ORMAT Nevada); and a proposed chemical stimulation project in a well near Four Mile Hill in the Medicine Lake geothermal power prospect in northern California (Calpine Corp.)

California

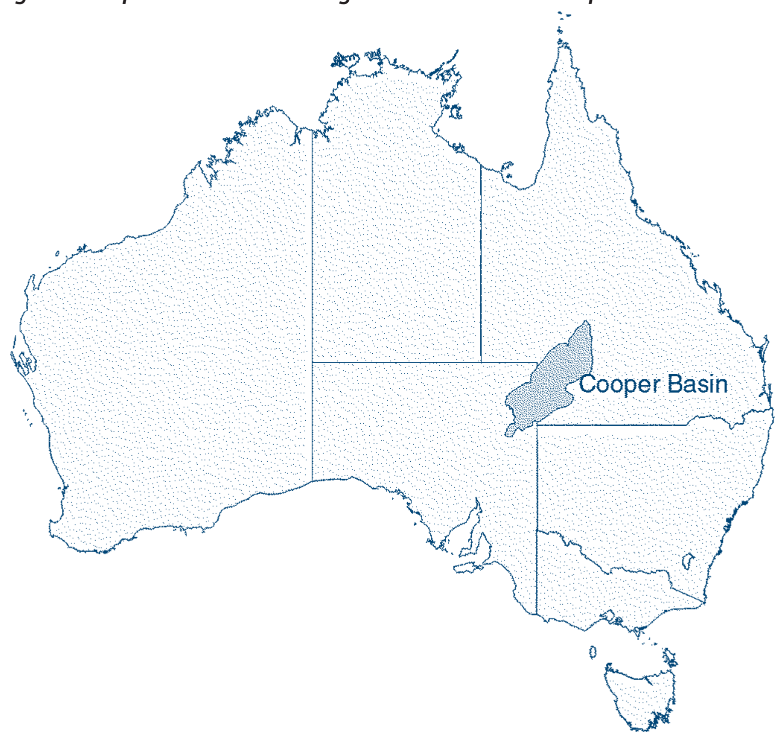
The Geysers dry steam geothermal reservoir in northern California provides fuel for the largest geothermal electrical development in the world. It has been producing electricity for 40 years, and it is a major EGS success story. As noted in many recent reports, there has been a decline in the rate of steam production (and therefore, electrical generation) due to loss of pressure in production wells. Steam production peaked in 1988, and declined for the ensuing decade.

Despite several decades of generating substantial amounts of electricity at The Geysers, most geothermal energy in the system remains intact, stored in hot rock that constitutes the thermal reservoir. A team of private companies and government agencies has devised a clever and effective solution to mitigate the decline of steam pressure in production wells and thereby extend the useful life of The Geysers resource. The solution also addresses how to best dispose of increasing volumes of treated wastewater from nearby communities. Simply put, the effluent is injected underground through appropriately positioned wells. As it flows toward the intake zones of production wells, the wastewater is heated by contact with hot rock. Production wells then tap the natural steam augmented by the vaporized effluent.

By late-1997, a 47-km (29-mile) pipeline began delivering about 35 million liters (8 million gallons) of treated wastewater per day from Lake County for injection into the southern part of The Geysers Geothermal Field. This slowed the pressure decline in that area, and has resulted in the recovery of approximately 85 MW of generating output. This initial injection project was considered so successful that construction of a 65-km (40-mile) pipeline from Santa Rosa and adjacent cities will deliver another 50 million liters (11 million gallons) of tertiary treated wastewater per day by late-2003 to the central part of the geothermal field.

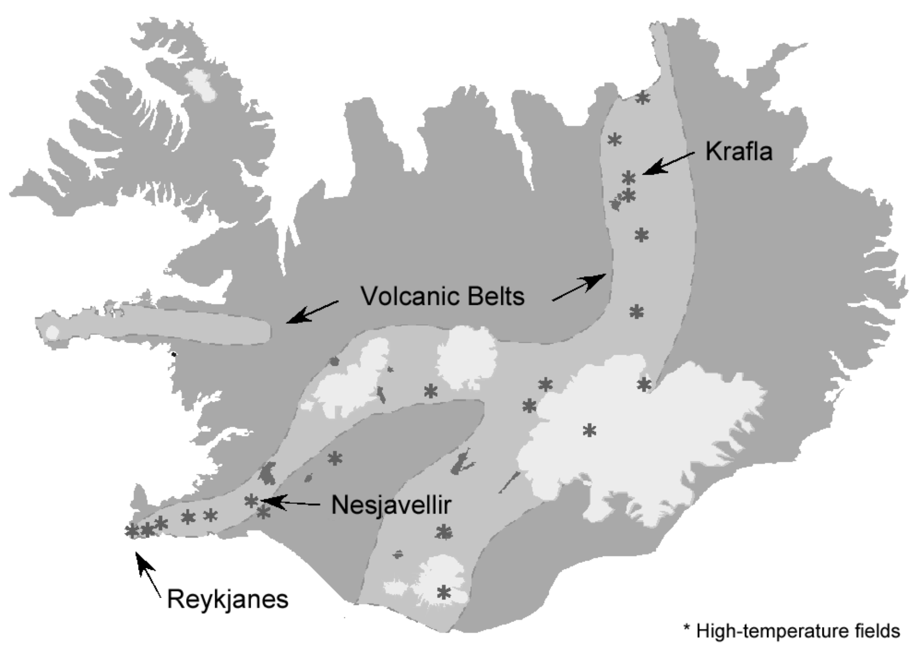
Together, these two sources of artificial "recharge" water will replace nearly all geothermal fluid being lost to electricity production at The Geysers. The injection program is expected to reduce the decline in electrical output from the geothermal field, resulting in approximately 150 to 200 MW of additional power output for at least two more decades, and possibly much longer. Additional EGS projects involving injection into The Geysers high-temperature reservoir in the vicinity of the Aidlin geothermal power plant are now being proposed to further enhance heat recovery.

Figure 2. Map of Australia showing the location of the Cooper Basin.



Prame Chopra

Figure 3. Map of Iceland showing the track of active volcanic belts and the locations of sites being considered by the IDDP for research drilling.



Iceland National Energy Authority

Australia

Two-thirds of the Australian continent is composed of a Precambrian shield, and the eastern third has only a trace of the young igneous activity most often associated with hydrothermal systems. Nevertheless, there is concerted activity in Australia aimed at developing geothermal resources in sedimentary basins with basement rocks having high radioactivity.

An exploratory well (Habanero 1) is currently being drilled in the Cooper Basin near Innamincka, South Australia (Fig. 2). The well is planned to reach a depth of 4.9 km, with bottom-hole temperature expected to be about 290°C. As of mid-May 2003, the well had reached a depth of 4.2 km. It was cased to that depth, and a hydraulic stimulation experiment was scheduled for July-August 2003. A second well, with a circulation and production test, is scheduled for 2004. This work is characterized as an HDR project, at a cost of approximately $10 million (US). If reservoir rocks have significant permeability, however, it will more accurately be described as an EGS project.

Iceland

Now in the planning stage, the Iceland Deep Drilling Project (IDDP) is in part another EGS project. Iceland is currently producing about 200 MW of electric power from geothermal systems along the mid-Atlantic Rift system that traverses the country (Fig. 3). This is likely to be doubled within the next decade or so, mostly from additional development at partly exploited geothermal systems. The reservoirs are dilute water-brine systems at temperatures from 200° to 350°C. Recently, some public opposition has emerged to developing new hydrothermal systems, mainly for aesthetic reasons. However, most Icelanders realize that the environmental impact of geothermal power is insignificant compared to that of alternative energy sources.

The primary goal of IDDP is to find out if hydrothermal resources at supercritical condition (400° to 600°C) can be tapped within the deep upflow zones feeding the country's conventional geothermal reservoirs. Another goal of the IDDP project is to acquire a better understanding of the deeper temperature regime to assess the feasibility of heat mining. In the event that a super-hot dry well results from the deep drilling, the cycle will simply be reversed by injecting cold water to a depth of 4 to 5 km to enhance the overlying conventional reservoir. Either way, this would allow significant increases in energy output without disturbing otherwise pristine areas.

Summary

Geothermal energy is presently making advances worldwide. In the United States, the first significant additions to geothermal electrical generating capacity in over a decade are under way. The expansion is being fueled by significant changes in the electricity market and by the adoption of RPS laws in many states. Much of the expansion is occurring through the enhancement of existing geothermal systems. DOE is supporting a number of EGS projects with cost-shared funding among industry participants. Other EGS projects are being funded solely by industry. For example, after a hiatus of several decades, Shell International has reentered the geothermal energy sector through the creation of a "Hot Fractured Rock" research group, which is a partner in the Soultz EGS project and active in El Salvador.

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Reference

Lund, John W., 2003, "U.S Geothermal Update," Geothermal Resources Council *Bulletin*, vol. 32, no.2, p.71-75.