Enhanced Geothermal Systems

by Lorraine Manz

"In all parts of the world in which the earth's crust has been examined, at sufficiently great depths to escape influence of the irregular and of the annual variations of the superficial temperature, a gradually increasing temperature has been found in going deeper." (William Thompson [Lord] Kelvin, 1864)

Introduction
Conventional methods of electricity generation using geothermal energy rely on hot (> 212°F/100°C) relatively shallow (< 10,000 ft/3,000 m), easily developed hydrothermal resources (fig. 1). Generally associated with active plate boundaries and/or volcanism, these high-grade hydrothermal systems are characterized by high geothermal gradients, and highly fractured, porous reservoir rocks through which natural waters or steam can freely circulate.

Figure 1. There are eighteen geothermal power plants currently operating in the Geysers geothermal field, located in the Mayacamas Mountains 72 miles (115 km) north of San Francisco, CA. These power plants obtain their heat (at about 330°F/170°C) from a magma chamber about 4.5 miles (7 km) below Earth's surface. The Geysers is the world's largest geothermal development, producing enough electricity to power approximately 1 million northern California homes. (Photo courtesy of Pacific Gas & Electric.)

Unfortunately, with only a few notable exceptions in countries like Iceland, Japan, and New Zealand, natural sources of high-grade hydrothermal energy are rare. In the U.S. they are restricted to the western states and currently represent less than 1% of the nation's baseload electrical power generating capacity. Yet the amount of heat at depths less than 30,000 feet (10,000 m) below the surface of the continental U.S. is enormous. Moreover, although this heat is not uniformly distributed (fig. 2) it is, hypothetically at least, available throughout the entire country. A recent Massachusetts Institute of Technology (MIT) study (Tester et al., 2006) estimated that the nation's in-place thermal energy reserves at depths between 10,000 and 30,000 feet (3,000 and 10,000 m) are on the order 14 x 10^6 EJ*. By comparison, the total U.S. energy consumption in 2005 was a mere 100 EJ; which means that even at the most conservative recovery rates, these geothermal reserves far exceed demand, and to all intents and purposes are limitless.

The concept of EGS
Most of the heat in the upper 30,000 feet (10,000 m) of the lithosphere is contained in low-permeability, more often than not dry, sedimentary and basement rocks. Access to these reservoirs is straightforward enough, and is routinely achieved (albeit for different reasons) during drilling operations in the oil and gas industry. But if the hydrothermal conditions are inadequate their viability as a productive and cost-effective energy resource is not high.

The good news is that modern drilling technology has provided a solution to this problem. Hydraulic fracturing (hydrofracing) is a well-established process that is used to enhance the productivity of oil and gas wells by increasing the permeability of the producing formation. This is achieved by the injection of water (or other fluid) and sand under high pressure sufficient to fracture the rock, creating a network of pathways along which the oil or gas is able to flow more freely toward the wellbore. Applied to a dry and/or low-permeability geothermal well, hydrofracing technology is capable of creating the fluid circulatory system required to bring the heat energy to the surface. These human-made hydrothermal reservoirs are known as enhanced (or engineered) geothermal systems (EGS).

The U.S. Department of Energy (DOE) defines EGS as engineered reservoirs designed to produce energy as heat or electricity from geothermal resources that are otherwise not economical due to lack of water and/or permeability (U.S. Department of Energy, 2008). This definition includes reservoirs derived from dry/low-permeability rocks, geopressured zones, magma, low-grade hydrothermal systems, as well as "unconventional" resources such as hot waters co-produced with oil and gas.

* 1 exa (E) joule = 10^{18} joules (equivalent to 9.48 x 10^{14} Btu, 1.72 x 10^8 bbls oil, or 3.41 x 10^7 tonnes coal).

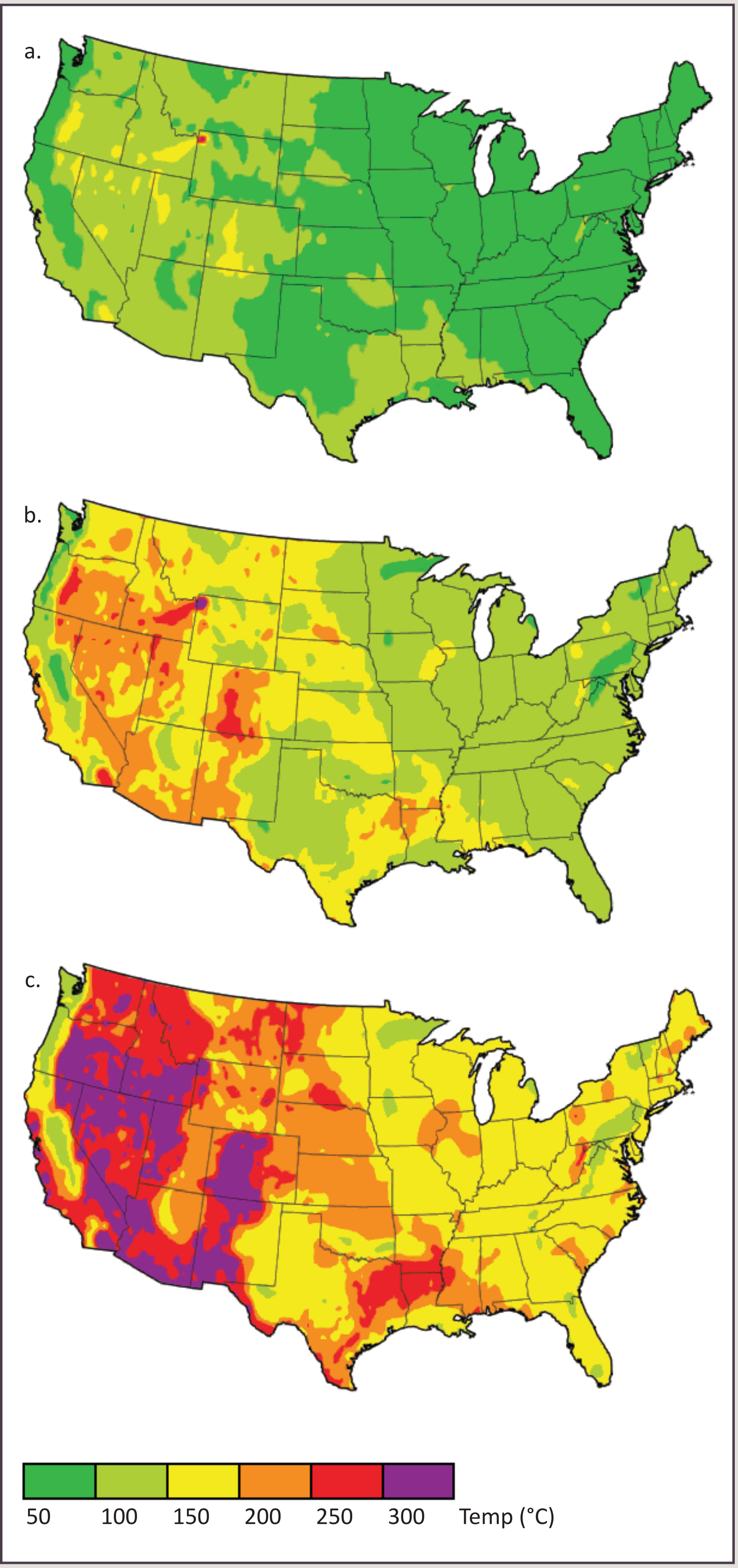

Figure 2. Average subsurface temperatures in the continental United States at (a) 11,000 feet (3,500 m), (b) 21,000 feet (6,500 m), and (c) 30,000 feet (10,000 m). Note the red "hot spot" in (a) and (b) that is Yellowstone National Park. (Modified from Tester et al., 2006).

Development of conventional EGS begins with site selection and characterization. Once these are complete, wells are drilled into the hot rock, which is then hydraulically fractured to create a permeable geothermal reservoir. Heat is collected by circulating fluid (water or steam) through the reservoir via a system of injection and production wells (fig. 3).

The way in which the extracted heat energy is converted into electricity depends on the temperature and state of the hydrothermal transfer fluid (water or steam). There are three basic options: dry steam, flash steam, and binary cycle. Most commercial geothermal power plants are either dry or flash steam that route water at temperatures above 350°F (180°C) directly through a turbine or generator to produce electricity. In binary cycle power plants the turbine is driven by vapor created by the transfer of heat from the hydrothermal fluid to a secondary (binary), low-boiling (< 32°F/0°C) liquid, or refrigerant. Binary cycle power plants operate as closed, virtually emission-free systems and at lower temperatures (120-300°F/50-150°C) than steam plants. As such, they are an important part of EGS technology.

The ability to replicate natural hydrothermal systems has the potential to increase the United States' geothermal electrical power output by orders of magnitude. The MIT study concluded that, even based on current technology, EGS could be producing more than 100 gigawatts of affordable electricity by 2050 - equivalent to roughly 10% of the U.S. present-day capacity.

Oil and gas - an unconventional EGS resource

With infrastructures already in place and the abundance of horizontally drilled and/or artificially stimulated wells, hydrocarbon fields are prime candidates for the application of EGS technology. Of particular interest are those wells regarded as marginal or unproductive because they produce too much water. Geothermal waters that are coproduced with oil and gas are an expensive waste product that must be disposed of either in evaporation ponds (illegal in North Dakota), at a commercial disposal facility, or by re-injection into the subsurface. If sufficiently hot and available in sufficient quantity, however, these waters may be capable of generating cost-effective electricity (McKenna et al., 2005).

The breakthrough came in September 2009 when the first successful generation of electricity using geothermal hot water from a producing oil well was accomplished at the DOE's Rocky Mountain Oil Test Center (RMOTC) near Casper, WY. Using 185-195°F (85-90°C) water from the Pennsylvanian-age Tensleep Formation, the plant produced between 150 and 250 gross kilowatts of electricity – sufficient to supply 12-13% of the onsite operational requirements** throughout most of a 12-month trial. At present this unit is still the only one of its kind but RMOTC expects at least two more to be up and running within the next few months.

With the potential to increase both productivity and longevity, this achievement could mark the beginning of an exciting new chapter for U.S. oil fields. In Texas alone, the DOE has identified around 8,000 wells similar to the one in Wyoming, and countrywide,

** Roughly the equivalent of 6 to 10 average-sized (2,000-2,500 sq ft) homes at 100%.

including North Dakota, it is estimated that there are enough existing wells to generate more than 5,000 megawatts of electricity.

Status and future of EGS

Although it is the world's largest producer of geothermal energy the U.S., until very recently, has failed to recognize its enormous potential. Ignored by government policies and with a lack of research and development funding, geothermal energy has remained conspicuously absent from the U.S. energy debate for more than a decade. The reason for this is not clear but it may be rooted in the misconception that geothermal energy is a limited resource, constrained by the paucity of high-grade hydrothermal systems, and that insurmountable technical barriers prevent the development of EGS. Consequently, most of the major advances in EGS technology have occurred outside the U.S., at project sites such as the Cooper Basin in Australia and Soultz in France (Tester et al., 2006). Results from these and other EGS projects have been impressive, to the point that the MIT panel optimistically concluded that: "Most of the key technical requirements to make EGS work economically over a wide area of the country (United States) are in effect, with remaining goals easily within reach." And with that assertion, the stance of government and private investors has suddenly and spectacularly changed.

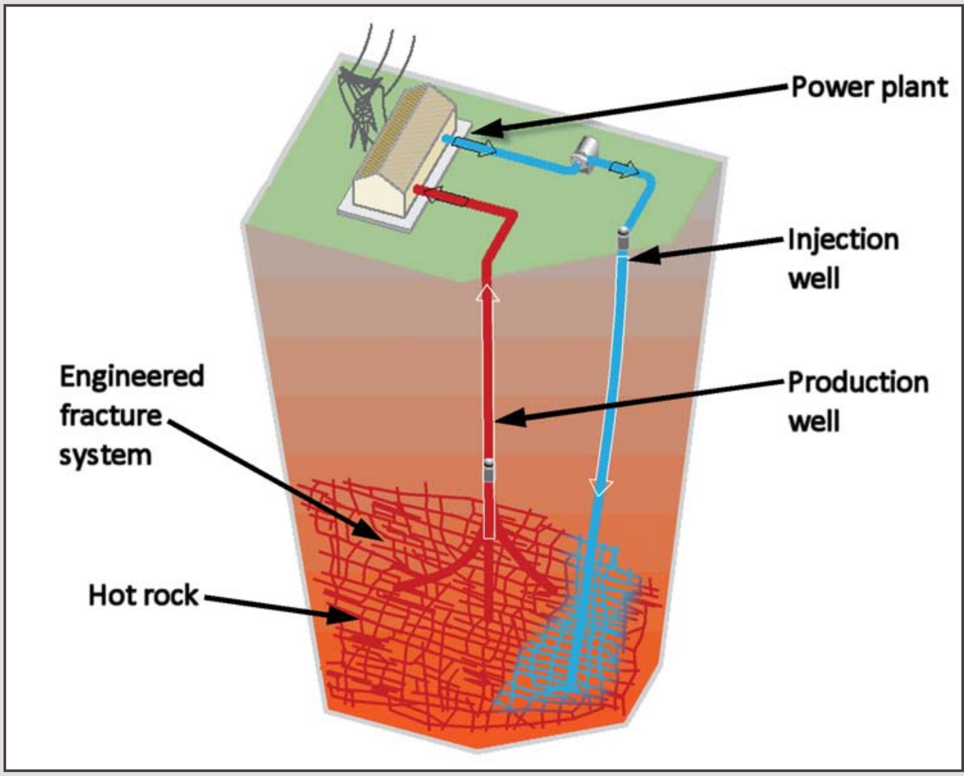

Figure 3. A simple two-well enhanced geothermal system in low-permeability rock. (Modified from U.S. Department of Energy, 2008.)

Committed to demonstrating its technical feasibility by 2015, EGS research and development is now a major component of the DOE's Geothermal Technologies Program. On October 29th, 2009 Energy Secretary Stephen Chu announced awards totalling $338 million for geothermal energy across the country (U.S. Department of Energy, 2009). Of the 123 projects earmarked for funding under this grant package, 59 are related in some way to EGS. Eleven of these fall into the co-produced, geopressured and low temperature category including two which, once fully approved, will mean that in 2010, somewhere in Bowman County, one of those new RMOTC binary units will be running on geothermal energy from a North Dakota oil field. Exciting times are ahead.

References

McKenna, J., Blackwell, D., Moyes, C., and Patterson, P.D., 2005, Geothermal electric power supply possible from Gulf Coast, Midcontinent oil field waters: Oil & Gas Journal, Sept. 5, 2005 p. 34-40.

Tester, J. W., Anderson, B., Batchelor, A., Blackwell, D., DiPippo, R., Drake, E., Garnish, J., Livesay, B., Moore, M.C., Nichols, K., Petty, S., Toksoz, N., Veatch, R., Augustine, C., Baria, R., Murphy, E., Negraru, P., Richards, M., 2006., The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century: Massachusetts Institute of Technology, DOE Contract DE-AC07-05ID14517, Final Report. Full text is also available at http://www1.eere.energy.gov/geothermal/future_geothermal.html (Version 1/24/2007).

U.S. Department of Energy, 2008, An evaluation of enhanced geothermal systems technology: http://www1.eere.energy.gov/geothermal/enhanced_geothermal_systems.html (Version 9/24/2008).

U.S. Department of Energy, 2009, Department of Energy Awards $338 Million to Accelerate Domestic Geothermal Energy: http://www1.eere.energy.gov/geothermal/news_detail.html?news_id=15589 (Version 1/24/2010).

Other useful web sites

The following is a sampling of the host of web sites where more information on EGS and geothermal energy in general can be found.

Geo-Heat Center, Klamath Falls, OR: http://geoheat.oit.edu

Geopowering the West: the Idaho National Laboratory's geothermal program: http://geothermal.id.doe.gov/

Geothermal Education Office: http://geothermal.marin.org/index.html

Google.org: http://www.google.org/egs/. This website has links to several EGS-related animations, 3D models and video/YouTube clips. Google SketchUp 7 is available as a free download at http://sketchup.google.com/download/

RenewableEnergyWorld.com: http://www.renewableenergyworld.com/rea/home. News and information on all types of renewable energy.

Southern Methodist University Geothermal Laboratory: http://smu.edu/geothermal/

The National Renewable Energy Laboratory Geothermal Technologies home page: http://www.nrel.gov/geothermal/

The Rocky Mountain Oilfield Testing Center: http://www.rmotc.doe.gov/

U.S. Department of Energy Geothermal Technologies Program: http://www1.eere.energy.gov/geothermal