Geothermal Energy

Active regions

Geothermal energy is literally the heat of the earth. Geothermal resources at shallow enough depths for economic development are most likely to be found near portions of the earth with active tectonics and young volcanism. Figures 1 and 2 show the major plate boundaries and the regions of the earth with potential for producing electricity from conventional, hydrothermal-geothermal resources.

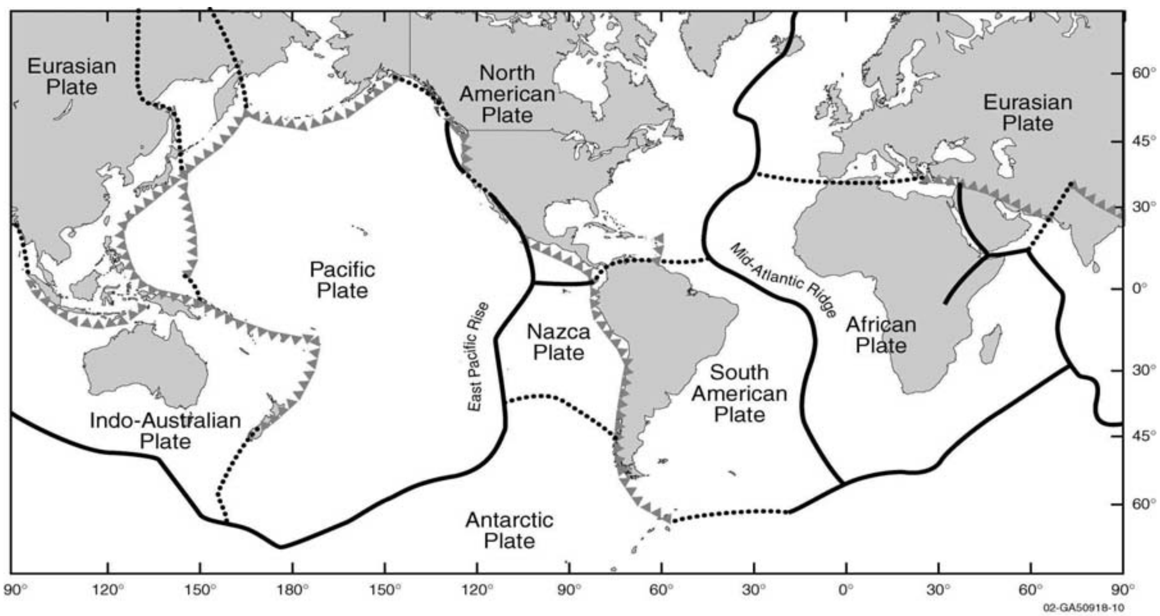

Fig. 1. Major tectonic plates of the world. Solid, bold lines are extensional boundaries, hachured lines are zones of convergence with the hachures on the overriding plate, and dotted lines indicate translational or diffuse plate boundaries.

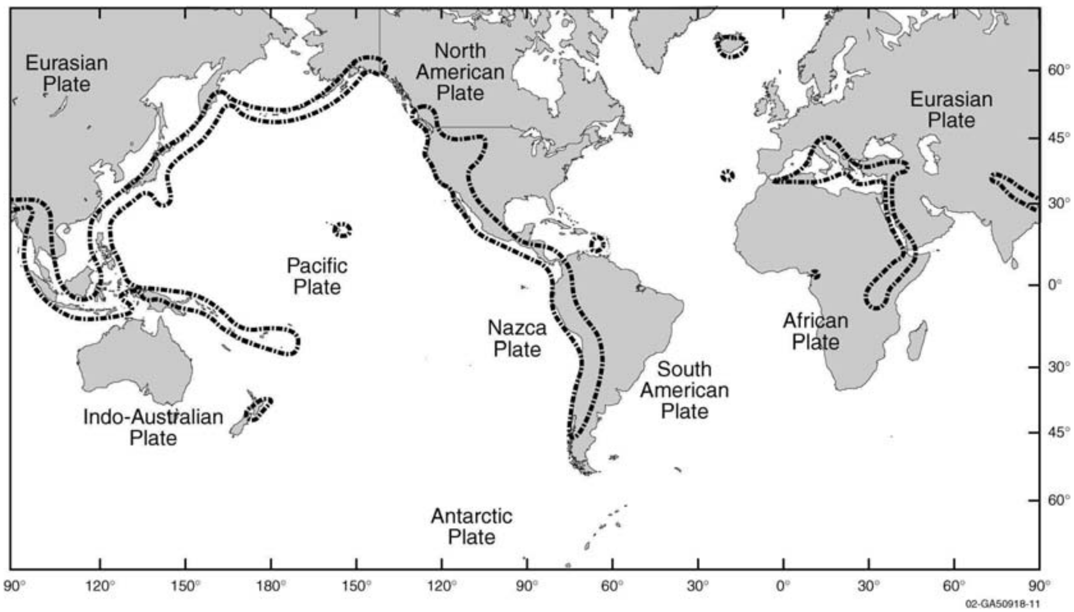

Fig. 2. Areas of the world with greatest potential. The areas within the dash-dotted lines contain the greatest near-term potential for producing electricity using geothermal energy.

Use of geothermal energy for direct uses such as space heating, aquaculture and agriculture require lower temperature resources and have a wider geographic distribution. See Lund et al. (2005) for details on worldwide use of geothermal energy for direct uses.

Electrical production from geothermal resources is currently limited to geothermal systems at depths less than about 3 km and which contain a sufficient volume of fluid and sufficient natural productivity to provide economic production. These systems are termed hydrothermal systems. Iceland, Indonesia, New Zealand, Philippines and United States are most active in development of new geothermal resources. There is also ongoing exploration and development in Central and South America, the East African Rift, eastern Caribbean, and several of the island nations in the South Pacific.

Currently developed hydrothermal systems are only one end member of a wide spectrum of geothermal resources that may be developed in the future. Researchers and geothermal developers are attempting to develop geothermal energy from hot rock where there is little or no natural permeability and/or water. Such technology is termed Enhanced Geothermal Systems (EGS) and includes the entire range of current hydrothermal systems to hot, dry rock. EGS is discussed further under current research.

Several other categories of geothermal energy are also under consideration for development. Significant resources of hot water are available in over-pressured or geopressured reservoirs along the U.S. Gulf Coast. Once considered to be uneconomic, recent work suggests that this should be reconsidered. Many oil and gas fields produce large amounts of warm to hot water in association with the oil and gas. Recently a small turbine generator set was installed at the Teapot Dome oil field near Casper, Wyoming. (See Current Research.)

Current production

Estimates of geothermal power generation and thermal energy used for direct applications are available for most areas of the world. The most recent review, of worldwide electrical generation reports that 8,900 MW_e (megawatts electric) of generating capacity was installed in early 2005, with about 8,000 MW_e operating in 24 countries (Bertani, 2005). This capacity supplies about 57,000 GW·h (gigawatt hours) of electricity per year. Producers of electricity from geothermal energy generally report availability factors greater than 90%.

Geothermal power plants are currently operating in eight states in the U. S.: Alaska, California, Hawaii, Idaho, Nevada, New Mexico, Utah and Wyoming. The Geothermal Energy Association released its 2008 of geothermal production and development in the United States in August 2008 (Slack, 2008). They report total installed capacity of 2,957.94 MWe in seven states. (Wyoming joined the list of producing states shortly after release of the report.) The update also identifies up to 3559.7 MWe of new geothermal power plant capacity under development. This total includes projects ranging from grass roots exploration to projects undergoing power plant construction. The report is available at http://www.geo-energy.org .

In 2005, seventy-one countries made use of geothermal resources for heating applications. Lund et al. (2005) estimated the installed thermal power for direct-use at the end of 2004 was 27 825 MW_t and the thermal energy used was 261,418 $TJ \cdot y^{-1}$ (72,622 $GW \cdot h \cdot y^{-1}$. They reported that the thermal energy was used by geothermal heat pumps, for bathing, swimming and balneology, and for space heating.

Sources of funding

The majority of funding and geothermal development is carried out by private developers in most countries. Indonesia and Philippines are privatizing much of the government owned geothermal power production. Of the largest geothermal producing countries only Mexico continues to have government ownership of all geothermal production.

Current research

Ongoing research worldwide is attempting to develop geothermal systems that do not have sufficient natural fluid or productivity for economic production. Such systems are termed enhanced geothermal systems (EGS) and are geothermal systems where hydraulic stimulation is being used to create sufficient permeability for production. If this technology can produce reservoirs with sufficient productivity, about 80 kg/sec of 200°C fluid, geothermal resource development has been postulated have the potential to become a universal resource limited only by the cost of drilling wells to great enough depths to obtain sufficiently high temperatures for electrical production. See Tester et al. (2006) for a detailed discussion of the potential for EGS.

Australia is currently the most active country developing EGS. The Cooper Basin, a major oil and gas production basin in Australia, is the focus of the most active development. Geodynamics is currently drilling at two areas in the Cooper Basin to expand their geothermal operations and is also operating a test loop to ascertain operating conditions of their previously drilled Habanero field in the Cooper Basin. The Geodynamic wells reach temperatures of about 240°C at about 5 km.

An experimental EGS system is also operating near Soultz, France at temperatures of about 200°C and 5km deep wells. A small power plant was recently installed near Landau, Germany. The geothermal field required only moderate hydraulic stimulation before production.

Leading companies

Chevron Corporation is the world's largest producer of geothermal energy. Their operations are in Indonesia and Philippines. Geodynamics is the most active company in Australia however many other companies are also active. ENEL owns and operates geothermal fields in Italy and several subsidiaries are actively involved in exploration for geothermal resources in the Americas. Icelandic companies are active in Iceland, the United States and elsewhere in the world both as operators and as investors.

Recent activity

In addition to the research and development activities associated with EGS, a small geothermal power plant began operating this summer at the Teapot Dome oil field near Casper, Wyoming. The 250 KWe plant operates on water at about 92°C, co-produced with oil. Interest in similar production from other oil and gas fields in the United States with high water-cuts is increasing. Additional information on the concept can be found on the web site of the Geothermal Laboratory at Southern Methodist University, http://www.smu.edu/geothermal/Oil&Gas/Oil&GasPresentations.htm.

Estimated U.S. and international resources/reserves

Gawell et al. (1999) estimate that identified geothermal resources using today's technology have the potential for between 35,000 and 73,000 MW_e of electrical generation capacity. The Gawell study relied on expert opinions and generally focused on identified resources. Stefansson (1998) prepared an estimate of identified and unidentified worldwide potential based on the active volcanoes of the world. He estimates a resource of about 11,200 ± 1,300 TWh per year using conventional technology and 22,400 using conventional and binary technology. Stefansson (2000) in a later report points out that his estimate is in general agreement with that of Gawell et al. although the estimates for individual regions may not be in agreement.

Scientists with the U.S. Geological Survey (USGS) recently completed an assessment of U. S. hydrothermal resources (Williams, et al., 2008). The assessment indicates that the electric power generation potential from identified geothermal systems is 9,057 MWe, distributed over 13 states. The mean estimated power production potential from undiscovered geothermal resources is 30,033 MWe. Additionally, another estimated 517,800 MWe could be generated through implementation of technology for creating geothermal reservoirs in regions characterized by high temperature, but low permeability, rock formations.

EGS are a much larger resource. Tester et al. (2006) estimate that the U.S. resource base is more than 13 million exajoules (10^{18} joules = 1 exajoule) and that 100,000 MWe of electrical generation from EGS could be online in the U. S. by about 2050.

McKenna et al. (2005) estimate that between 94 and 451 x 10^{15} joules are available from fluids produced from oil and gas operations in the U. S. Gulf coast and Midcontinent.

Critical technology needs and how are these being addressed

The continued development of traditional, hydrothermal systems requires a substantial improvement in exploration technology coupled with decreased costs for drilling and power plant construction. EGS requires improved technology for creating and managing reservoirs and will need dramatically lower drilling costs before widespread development will be economically feasible in all but high temperature-gradient areas of the United States. Development is more feasible in countries with high electrical costs. High-temperature logging tools and downhole equipment will be required for operations in geothermal fields with temperatures greater than about 200°C. Exploration technology developed by the mining industry is applied to geothermal exploration and drilling and reservoir engineering technology from the petroleum industry is modified for use in geothermal development.

The U. S. Department of Energy funded about 20 research projects to develop technology for EGS development, much of which is also applicable to development of traditional, hydrothermal resources. U. S.DOE has also funded six field demonstration projects.

Critical environmental or geohazard issues

Geothermal resources are considered to be renewable resources and have only minimal emissions of CO_2. The most common environmental concern is the visual impact of development. Development of geothermal resources can also influence natural thermal activity near production so care must be taken if valuable surface manifestations such as hot springs and geysers are nearby. Without proper control of production and injection of the produced fluids, subsidence is also possible. EGS development may create felt seismic activity as a result of the hydraulic stimulation of the field and also through thermal stress of the field during operation. The seismic activity is generally less than magnitude 3 and usually is not felt. However, such seismic activity stopped EGS development in Bern, Switzerland and delayed operations near Soultz, France. Felt seismic activity associated with geothermal production at The Geysers, California geothermal field has caused some complaints from nearby homeowners.

Technical sessions, publications, workshops
The largest annual geothermal workshops are held in the United States and are hosted by the Geothermal Resources Council and Stanford University. Every five years the International Geothermal Association hosts a World Geothermal Congress (http://. The next Congress will be held in Bali, Indonesia in 2010. See http://www.wgc2010.org/.

Useful geothermal web sites

Geothermal Energy Association (GEA): http://www.geo-energy.org

Geothermal Resources Council: http://www.geothermal.org

International Geothermal Association: http://iga.igg.cnr.it/index.php
I
International Geothermal Association publication database:
http://pangea.stanford.edu/ERE/db/IGAstandard/default.htm

U.S. Department of Energy geothermal program:
http://www1.eere.energy.gov/geothermal/

U.S. DOE report database: http://www.osti.gov/geothermal/

Direct use; Geo-Heat Center: http://www.oit.edu/~geoheat

U. S. geothermal resource maps: http://geothermal.inl.gov

Massachusetts Institute of Technology EGS study: http://geothermal.inl.gov one 14 MB file or http://www1.eere.energy.gov/geothermal/ for chapter by chapter files

Southern Methodist University geothermal program: http://www.smu.edu/geothermal/

Stanford University geothermal program:
http://pangea.stanford.edu/ERE/research/geoth/index.html

Educational materials: http://geothermal.marin.org

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Williams, C. F., Reed, M. J., Mariner, R. H., DeAngelo, J., Galanis, S. P., Jr., 2008, Assessment of moderate- and high-temperature geothermal resources of the United States: U.S. Geological Survey Fact Sheet 2008-3082, 4 p.