Geothermal Energy

Quick Facts

- Geothermal energy exploits the inexhaustible heat of the earth's core to continuously generate nearly zero-emission renewable energy at a cost-competitive level with, and in many cases lower than, traditional fossil fuel power generation.
- Geothermal energy is available twenty-four hours a day, seven days a week, avoiding problems of variability associated with other renewable technologies like wind and solar.
- While it constitutes 8 percent of U.S. renewable electricity generation, geothermal energy currently provides less than 1 percent of total U.S. electricity and has grown at 3 percent annually over the last 10 years.
- Currently, only four states produce electricity from geothermal plants, with more than 80 percent of that generation in California.
- The U.S. Geological Survey estimates the United States possesses 350,800 megawatt-hours (MWh) of geothermal resources—enough to satisfy 10 percent of current U.S. electricity demand—that can be tapped with existing, off-the-shelf technologies.

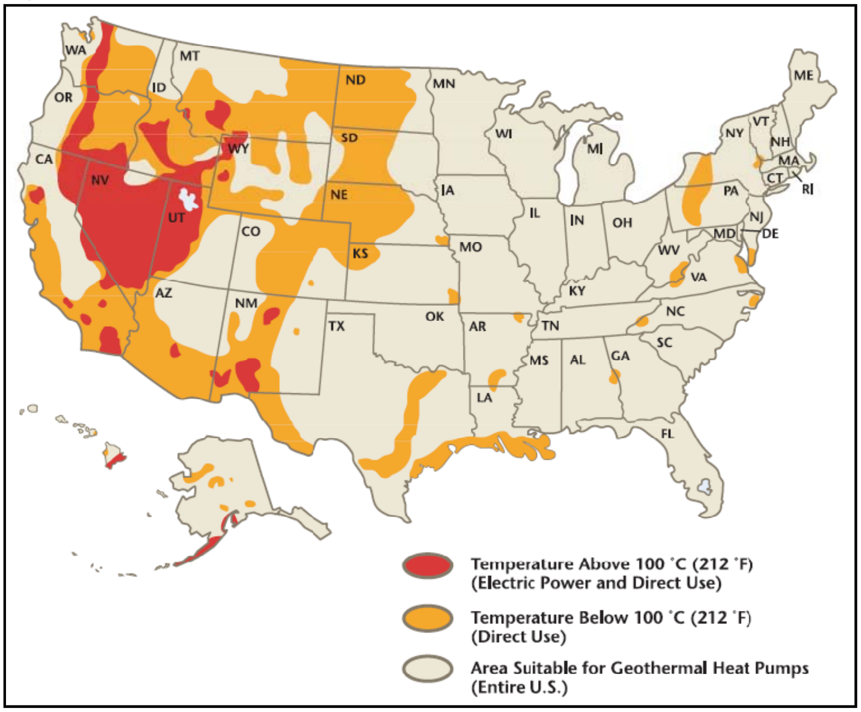
Background

Geothermal energy can be used for electricity generation, heat pumps, or direct uses. This document focuses only on technologies that produce electricity by exploiting the naturally occurring heat of the earth. Unlike other renewable energies, such as wind and solar, geothermal energy can operate nearly twenty-four hours a day, seven days a week. Continual production makes geothermal an ideal candidate for providing nearly zero-emission renewable baseload power.

In 2007, the 2,300 megawatts (MW) of geothermal electric generating capacity installed in the United States constituted 8 percent of the non-hydroelectric, renewable electric generating capacity, but only 0.2 percent of total electric generating capacity. Overall, geothermal provided 0.4 percent of total U.S. electricity.[1,2] In 2006, only four states generated electricity from geothermal energy (CA, HI, NV, and UT), with California responsible for 88 percent of geothermal generation in the United States.[3] Nonetheless, geothermal plays an important role in the states where it is installed. Geothermal facilities satisfy 4.5 percent of California's electricity consumption and 20 percent of Hawaii's.[4]

Despite its current limited application, geothermal energy has a very large potential for expansion. The U.S. Geological Survey estimates that current technologies could exploit nearly 40,000 MW of geothermal resources in America's West, compared to a current U.S. electric generating capacity of roughly 1 million MW.[5] While "enhanced geothermal" technologies would expand this capacity even more, this fact sheet concerns only currently existing technologies.[6]

Figure 1: Distribution of U.S. Geothermal Resources



Source: Green, B.D. and G. R. Nix, *Geothermal: the Energy under Our Feet*, National Renewable Energy Laboratory, November 2006. http://www.nrel.gov/docs/fy07osti/40665.pdf

Description

Geothermal energy exploits the natural heat of the earth to produce electricity. More specifically, conventional geothermal energy draws on the earth's hydrothermal resources (underground heated water and steam). After drilling into these reservoirs, geothermal plants extract heated water and steam from the earth's crust to drive electricity-generating turbines, a process that can be thought of as "heat mining."[7]

The various techniques currently used to produce geothermal energy include the following:

- **Dry Steam**
  Dry steam plants draw steam directly from under the earth's surface to drive a generator. The steam then naturally condenses into water and is reinjected into the geothermal reservoir.

- **Flash Steam**
  Flash steam plants extract geothermal water exceeding 350°F under extremely high pressure. Upon surfacing, a sudden reduction in pressure causes a portion of the heated water to "flash" off as steam. That steam drives a generator, after which the extracted water and steam are reinjected into the geothermal reservoir.

- **Binary Cycle**
  Binary cycle plants operate in areas with substantially lower-temperature geothermal water (225°F). Rather than using hydrothermal resources to drive a turbine, binary cycle uses the earth's heated water to vaporize a "working fluid," any fluid with a lower boiling point than water (e.g., iso-butane).

The vaporized working fluid drives a generator while the geothermal water is promptly reinjected into the reservoir, without ever leaving its closed loop system.

Geothermal energy also depends on advanced hard-rock drilling technology. While oil and gas drilling techniques apply to geothermal drilling, temperatures above 250°F found in geothermal reservoirs complicate the process. The high heat increases the probability of well failure due to collapse, mechanical malfunction, and casing failure.[8,9] Extensive research has gone into understanding the geological characteristics of geothermal reservoirs and how to adapt drilling technologies to these conditions.[10]

Environmental Benefit / Emission Reduction Potential

Geothermal energy, for all intents and purposes, constitutes a source of electricity free of greenhouse gas (GHG) emissions. Both dry steam and flash steam plants, however, do release a small amount of carbon dioxide (CO_2). Traces of this (and other GHGs) are found dissolved in some hydrothermal reservoirs. Using those hydrothermal resources to drive generators allows small amounts of CO_2 to escape into the atmosphere.[11]

Recorded GHG emissions from geothermal plants are negligible. The typical geothermal plant produces less than one percent of the CO_2 emissions per MWh than a typical coal-fueled power plant.[12,13] Replacing the generation from a typical 500 MW coal-fired power plant with electricity from geothermal plants would avoid about 3 million metric tons of CO_2 emissions per year.[14]

Geothermal holds great potential for expansion under climate policy. The U.S. Energy Information Association (EIA) projects that geothermal electricity generation capacity could nearly triple by 2030, to almost 7 GW, if a cap-and-trade program were enacted to put a price on carbon.[15] EIA estimates that, under a cap-and-trade program, the projected average annual growth rate between 2010 and 2030 for geothermal generation capacity could be nearly 6 percent—double the "business-as-usual" projection.[16] The International Energy Agency (IEA) estimates that globally, with coordinated international action to address climate change, geothermal energy could grow from providing roughly 0.3 percent of current global electricity supply to 2.5 percent in 2050 and thus provide 3 percent of the GHG emission reductions required in 2050 from the power sector in order to avoid dangerous climate change.[17]

Cost

The capital cost for a geothermal plant can vary significantly depending upon the conversion technology, the depth of the wells, and the temperature of the hydrothermal resource. The capital cost of a geothermal plant can range from $1,600 to more than $5,000 per kilowatt of capacity.[18] While the capital cost of a geothermal plant can be either comparable to or much higher than that of a traditional fossil fuel power plant, one must look at the actual cost of generating electricity. Unlike a coal or natural gas plant, geothermal facilities do not need to purchase fuel to generate electricity. Accounting for this fact through a levelized cost analysis reveals that geothermal plants can produce electricity for 5 to 11 cents per kilowatt-hour (kWh), including tax incentives, a rate competitive with traditional fossil fuel generation.[19] Depending on tax incentives, the U.S. Energy Information Administration also predicts the levelized cost of geothermal energy to remain below or competitive with these alternatives through 2020.[20]

With time, experts expect the cost of geothermal energy to drop as firms gain more experience with installing geothermal plants and as technology, especially drilling technology, improves. With the *status quo*, drilling an exploratory well costs $12 to $15 million.[21] The exploration and well drilling phase constitutes, on average, 36 percent of a geothermal plant's total capital cost.[22] Thus, improvements in drilling techniques could significantly reduce the cost of constructing a geothermal plant.

Current geothermal plants have small capacities. As experience improves and capacities expand, the price of producing geothermal energy could fall further if plants achieve economies of scale.[23]

Current Status of Geothermal Energy

From the early 1970s to the early 1990s, geothermal electricity generation saw rapid growth, with an average annual rate of more than 16 percent.[24] From the early 1990s until the present, however, geothermal generation has been relatively flat. As of March 2009, the United States possessed about 3,040 MW of installed geothermal capacity.[25] An additional 103 geothermal projects across thirteen states are currently under construction or nearing completion.[26] While this expansion represents a slight increase in geothermal development, multiple projections show geothermal energy growing globally at a rate of roughly 3 percent per year for the foreseeable future.[27,28]

Recent legislation and government incentives may help jumpstart the expansion of the geothermal industry. In 2009, the U.S. Department of Energy announced a $35 million grant program for research into existing geothermal technologies.[29] Geothermal energy also receives a production tax credit (PTC) through 2013.[30]

Geothermal energy plays an important role in global energy generation. Iceland, for example, generates over 80 percent of its electricity from geothermal sources.[31] The United States leads the world in terms of total installed geothermal capacity.[32]

Obstacles to Further Development or Deployment of Geothermal Energy

- **High-Risk Exploration Phase**
  The exploratory phases of a geothermal project are marked by not only high capital costs but also a 75 percent chance of failure, due to the high temperatures found in geothermal reservoirs and uncertainties regarding reservoir geology.[33] The combination of high risk and high capital costs can make financing geothermal projects difficult.[34]

- **Investment Uncertainty**
  Changes in government funding for geothermal generation and uncertainty over future climate regulations create uncertainty for potential project developers. Certainty is especially important in geothermal projects, which take an average of ten years to move from exploration to generation.[35] In the past, Congress has allowed the federal Production Tax Credit (PTC) to expire before renewing it. In addition, after years of moderate funding, the 2007 budget contained no provision to continue funding geothermal research.

- **Geographic Distribution and Transmission**
  Some of the most promising geothermal resources lie great distances from regions of large electricity consumption, or load centers. The need to install adequate transmission capacity can deter investment in geothermal projects. For example, in 2002, MidAmerica Energy abandoned its geothermal project near California's Salton Sea primarily due to lack of available transmission resources.[36]

Policy Options to Help Promote Geothermal Energy

- **Price on Carbon**
  A price on carbon, such as that which would exist under a greenhouse gas cap-and-trade program (see Climate Change 101: Cap and Trade), would raise the cost of electricity produced from fossil fuels relative to the cost of electricity from renewable sources, such as geothermal energy, and other lower-carbon technologies.

- **Renewable Portfolio Standard**
  A renewable portfolio standard (RPS, sometimes also called a renewable or alternative energy standard) requires that a certain amount or percentage of a utility's power plant capacity or electricity sales come from renewable sources by a given date. At present, 29 U.S. states and the District of Columbia have adopted RPSs.[37] RPSs encourage investment in new renewable generation and can guarantee a market for this generation.

- **Tax Credits and Other Subsidies**
  Congress recently extended the federal PTC for geothermal electricity generation through 2013. The PTC can lower the after-tax, levelized cost of electricity from geothermal by as much as 30 percent.[38]

- **Development of New Transmission Infrastructure**
  Improving transmission corridors to areas with geothermal reservoirs would facilitate investment in geothermal energy. Policies to build new transmission to areas with significant renewable energy resources are already proposed for accessing the wind-rich regions of the central plains and the extensive solar resources of the desert Southwest. Such policies could also promote expanded transmission to reach the geothermal fields of the West.

Related Business Environmental Leadership Council (BELC) Company Activities

- ABB
- Alcoa
- CH2M Hill
- DTE Energy
- GE
- Johnson Controls
- PG&E
- UTC

Related Pew Center Resources

Climate Change 101: Technology, 2009 http://www.pewclimate.org/global-warming-basics/climate_change_101

Race to the Top: The Expanding Role of U.S. State Renewable Portfolio Standards, 2006 http://www.pewclimate.org/global-warming-in-depth/all_reports/race_to_the_top

The U.S. Electric Power Sector and Climate Change Mitigation, 2005 http://pewclimate.com/global-warming-in-depth/all_reports/electricity

Further Reading / Additional Resources

Blodgett, Leslie, and Kara Slack. 2009. *Geothermal 101: Basics of Geothermal Energy Production and Use*. Geothermal Energy Association. [www.geo-energy.org]

Deloitte. 2008. *Geothermal Risk Mitigation Strategies Report*. Department of Energy, Office of Energy Efficiency and Renewable Energy Geothermal Program.

Fridleifsson, I.B., R. Bertani, E. Huenges, J. W. Lund, A. Ragnarsson, and L. Rybach. 2008. "The Possible Role and Contribution of Geothermal Energy to the Mitigation of Climate Change." In: O. Hohmeyer and T. Trittin (Eds.) *IPCC Scoping Meeting on Renewable Energy Sources, Proceedings*, Luebeck, Germany, 20-25 January 2008, 59-80.

Geothermal Technologies Program. 2008. *Geothermal Tomorrow 2008*. U.S. Department of Energy, Energy Efficiency and Renewable Energy. [http://www1.eere.energy.gov/geothermal/pd fs/geothermal_tomorrow_2008.pdf]

Geothermal Technologies Program. 2008. *Multi-year Research, Development and Demonstration Plan: 2009-2015 with program activities to 2025 (DRAFT)*. U.S. Department of Energy, Energy Efficiency and Renewable Energy.

Idaho National Laboratory. 2007. *What is Geothermal Energy?*. [https://inlportal.inl.gov/por tal/server.pt?open=512&objID=422&&PageID=3453&mode=2&in_hi_userid=200&cached=true]

International Geothermal Energy Association. [http://iga.igg.cnr.it/index.php]

Kagel, Alysa, Diana Bates, and Karl Gawell. 2007. *A Guide to Geothermal Energy and the Environment*. Geothermal Energy Association. [www.geo-energy.org]

Klein, Joel and Anitha Rednam. 2007. *Comparative Costs of California Central Station Electricity Generation Technologies*. CEC-200-2007-011-SD. California Energy Commission.

National Renewable Energy Laboratory. *Geothermal: the Energy under Our Feet*. [http://www.nrel.gov/docs/fy07osti/40948.pdf]

Owens, Brandon. 2002. *An Economic Valuation of a Geothermal Production Tax Credit*. National Renewable Energy Laboratory. NREL/TP-620-31969

Tester, Jefferson, *et. al*. 2006. *The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century*. Massachusetts Institute of Technology.

Western Governors' Association. 2006. *Geothermal Task Force Report*. Clear and Diversified Energy Initiative.

Williams, Colin, Marshall Reed, Robert Mariner, Jacob DeAngelo and S. Peter Galanis. 2008. *Assessment of Moderate-and High-Temperature Geothermal Resources of the United States*. United States Geological Survey. [http://pubs.usgs.gov/fs/2008/3082/]

Williams, Eric, Rich Lotstein, Chrisopher Galik and Hallie Knuffman. July 2007. *A Convenient Guide to Climate Change Policy and Technology*. [http://www.nicholas.duke.edu/ccpp/convenient guide/cg_pdfs/ClimateBook.pdf]

[1] Energy Information Administration (EIA). 2008. *U.S. Electric Net Summer Capacity*. http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/table4.html

[2] EIA. 2008. *Annual Energy Review 2007*.

[3] EIA. 2008. *Renewable Energy Annual, 2006 Edition*. Table 1.18.

[4] Slack, Kara. March 2009. *U.S. Geothermal Power Production and Development Update*. Geothermal Energy Association.

[5] Williams et al., 2008.

[6] For information on enhanced geothermal, see: Tester, Jefferson, *et. al*. 2006. *The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century*. Massachusetts Institute of Technology. [http://www1.eere.energy.gov/geothermal/egs_technology.html]

[7] Tester *et. al*. 2006.

[8] Geothermal Technologies Program. 2008. *Multi-year Research, Development and Demonstration Plan: 2009-2015 with program activities to 2025 (DRAFT)*. U.S. Department of Energy, Energy Efficiency and Renewable Energy.

[9] Geothermal Technologies Program. 2008. *An Evaluation of Enhanced Geothermal Systems Technology*. U.S. Department of Energy, Energy Efficiency and Renewable Energy.

[10] For an example of this work, see Blankenship, Douglas, David Chavira, Joseph Henfling, Chris Hetmaniak, David Huey, Ron Jacobson, Dennis King, Steve Knudsen, A.J. Mansure, and Yarom Polsky. 2009. *Development of a High-Temperature Diagnostics-While-Drilling Tool*. Sandia Report 2009-0248. [http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online]

[11] Kagel, Alysa, Diana Bates, and Karl Gawell. 2007. *A Guide to Geothermal Energy and the Environment*. Geothermal Energy Association. [www.geo-energy.org]. Yet these emissions should not be considered a disadvantage to geothermal energy. In fact, the gases released through geothermal energy production would have eventually entered the atmosphere, regardless of production in the area. In other words, the production of geothermal energy essentially generates zero net GHG emissions. See Williams, Eric, Rich Lotstein, Chrisopher Galik and Hallie Knuffman. July 2007. *A Convenient Guide to Climate Change Policy and Technology*. [http://www.nicholas.duke.edu/ccpp/convenientguide/cg_pdfs/ClimateBook.pdf]

[12] Kagel et al., 2007.

[13] EIA. 2008. *Geothermal Energy—Energy from the Earth's Core*. [http://www.eia.doe.gov/kids/energyfacts/sources/renewable/geothermal.html]

[14] Assuming a coal-plant capacity factor of 70 percent and an emissions rate of 1 metric ton CO_2 per MWh.

[15] EIA. "Energy Market and Economic Impacts of S. 2191, the Lieberman-Warner Climate Security Act of 2007." Office of Integrated Analysis and Forecasting U.S. Department of Energy. April 2008.

[16] Ibid.

[17] International Energy Agency (IEA). 2008. *Energy Technology Perspectives 2008: Scenarios & Strategies to 2050*. See BLUE Map Scenario (450ppm stabilization goal).

[18] Energy and Environmental Economics (E3). 2007. California Public Utility Commission GHG Modeling: New Generation and Resource Costs. http://www.ethree.com/cpuc_ghg_model.html.

[19] Renewable Energy Transmission Initiative (RETI). 2008. *Phase IA Final Report*.

[20] EIA. 2008. *Annual Energy Outlook 2009 Early Release*. [www.eia.doe.gov]

[21] Deloitte. 2008. *Geothermal Risk Mitigation Strategies Report*. Department of Energy, Office of Energy Efficiency and Renewable Energy Geothermal Program.

[22] Western Governors' Association. 2006. *Geothermal Task Force Report*. Clear and Diversified Energy Initiative.

[23] Willams et. al, 2007.

[24] EIA. 2008. *Annual Energy Review*. See Table 8.2b.

[25] Slack, 2009.

[26] Blodgett, Leslie, and Kara Slack. 2009. *Geothermal 101: Basics of Geothermal Energy Production and Use*. Geothermal Energy Association. [www.geo-energy.org].

[27] REN21. 2008. *Renewables 2007: Global Status Report*. [www.ren21.net/pdf/RE2007_Global_Status_Report.pdf]

[28] US Energy Information Administration, 2008.

[29] US Department of Energy. 2009. *DOE Announces Investment of up to $84million in Geothermal Energy.* [http://www.energy.gov/news2009/6961.htm]

[30] *HR1: The American Recovery and Reinvestment Act*. THOMAS. http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_cong_public_laws&docid=f:publ005.111.pdf

[31] Williams et al 2008

[32] Slack, Kara. August 2008. *U.S. Geothermal Power Production and Development Update*. Geothermal Energy Association.

[33]Geothermal Technologies Program. 2008. *Geothermal Tomorrow 2008*. U.S. Department of Energy, Energy Efficiency and Renewable Energy.

[34] Deloitte, 2008.

[35] Williams et.al, 2007.

[36] See footnote 9 in Tester et. al, 2006.

[37] For more information on state RPSs, see http://www.pewclimate.org/what_s_being_done/in_the_states/rps.cfm.

[38] Owens, Brandon. 2002. *An Economic Valuation of a Geothermal Production tax Credit*. National Renewable Energy Laboratory. NREL/TP-620-31969