Geothermal Energy

Quick Facts

- Geothermal electricity generation is a commercially proven technology that exploits the inexhaustible heat of the earth's core to continuously generate nearly zero-emission renewable electricity at a cost that is competitive 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 13 percent of U.S. non-hydroelectric 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.[1]
- Currently, nine states produce electricity from geothermal plants, with more than 80 percent of total geothermal generation capacity in California.[2]
- While the United States currently has about 3,000 megawatts (MW) of geothermal electric generating capacity, the U.S. Geological Survey estimates the United States possesses 39,000 megawatts MW of geothermal potential, including identified resources and unidentified resources.[3,4,5]

Background

Geothermal energy can be used for electricity generation, heat pumps, or direct uses. This document focuses only on the traditional, commercially available technologies that produce electricity by exploiting the naturally occurring heat of the earth. Enhanced geothermal systems, which utilize advanced (often experimental) drilling and fluid injection techniques to augment and expand the availability of geothermal resources, are the subject of a separate factsheet (see CLIMATE TECHBOOK: Enhanced Geothermal Systems).

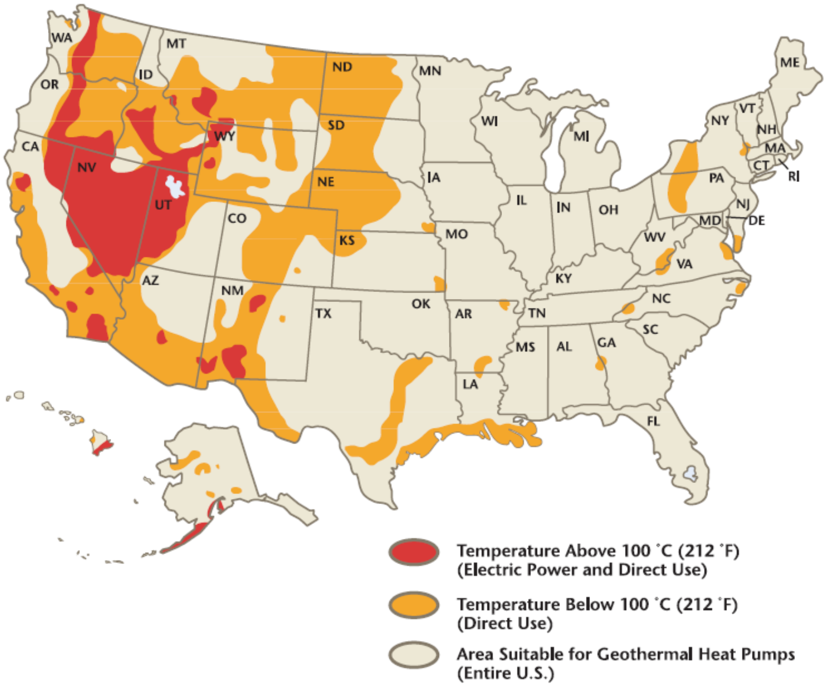
Unlike other renewable energies, such as wind and solar, geothermal power generation can operate steadily nearly twenty-four hours a day, seven days a week. Continual production makes geothermal an ideal candidate for providing nearly zero-emission renewable baseload power.

In 2009, the 15.2 billion kilowatt-hours (kWh) of geothermal electricity generated in the United States constituted 13 percent of the non-hydroelectric, renewable electricity generation, but only 0.4 percent of total electricity generation.[6,7] The same year, nine states generated electricity from geothermal energy (AK, CA, HI, ID, MT, NV, OR, UT, and WY), but California alone accounted for 83 percent of U.S. geothermal electric generating capacity.[8] Geothermal plays an important role in some of the states where it is installed. Geothermal facilities satisfy 4.5 percent of California's electricity consumption and 2.1 percent of Hawaii's.[9,10]

Despite its current limited application, geothermal energy has a very large potential for expansion; although, as Figure 1 illustrates, most of the U.S. geothermal potential is in the western states. 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.[11]

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 taps into 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 called "heat mining."[12]

The various techniques currently used to produce geothermal energy include the following (see Figure 2 for illustrations of these techniques):

- Dry Steam

  Dry steam plants draw steam directly from under the earth's surface to a turbine that drives a generator. The steam then condenses into water and is reinjected into the geothermal reservoir.

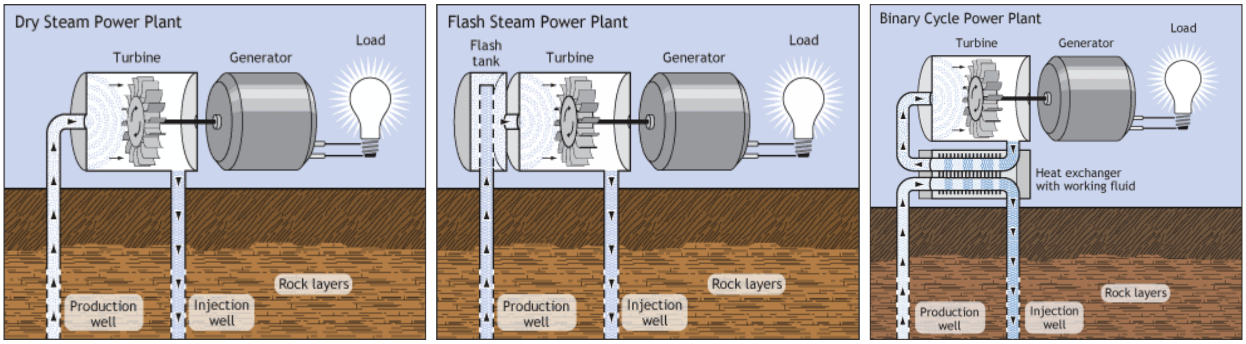
- Flash Steam

  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 vaporize, or "flash," into steam. That steam turns a turbine, which drives a generator, after which the water is 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 turbine that powers a generator, while the extracted geothermal water is promptly reinjected into the reservoir without ever leaving its closed loop system.

Figure 2: The Three Most Common Techniques Used for Geothermal Electricity Generation



Source: U.S. Department of Energy. Geothermal Technology Program. *Hydrothermal Power Systems.* November, 2010. http://www1.eere.energy.gov/geothermal/powerplants.html

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.[13,14] Extensive research has gone into understanding the geological characteristics of geothermal reservoirs and how to adapt drilling technologies to these conditions.[15]

Environmental Benefit / Emission Reduction Potential

Environmental benefits from geothermal energy include near-zero greenhouse gas (GHG) emissions from plant operations and low freshwater use and contamination. Geothermal energy constitutes a source of electricity nearly free of GHG emissions. Traces of carbon dioxide (CO_2) and other GHGs are found dissolved in some hydrothermal reservoirs. Using those hydrothermal resources with dry steam and flash steam geothermal plants does allow these dissolved GHGs to escape into the atmosphere.[16] Recorded GHG emissions from geothermal plants are minimal, though.[17] A geothermal plant will emit only 0 to 4 percent as much CO_2 as a traditional coal-fueled power plant per unit of electricity generated.[18] Geothermal plants also emit significantly less conventional air pollutants (nitrogen oxides, sulfur dioxide and particulate matter) than coal power plants, as these emissions are virtually non-existent.[19]

A market-based policy to reduce GHG emissions and spur the deployment of clean energy technology could lead to much more rapid growth in geothermal electricity generation. For example, in its analysis of a 2010 GHG cap-and-trade proposal, EIA projected that, while geothermal would still constitute a small fraction of total U.S. electricity generation, geothermal electricity generation could grow more than twice as fast as without such a policy.[20]

Globally, the International Energy Agency (IEA) estimates that geothermal electricity generation provided about 0.3 percent of total electricity in 2008. With current policies, IEA projects that geothermal will provide only about 0.5 percent of global electricity by 2035, but with coordinated international action to address climate change and keep GHG emissions in the atmosphere to 450 parts per million, IEA projects that geothermal electricity generation could be twice as important an energy sources, providing more than 1 percent of global electricity generation by 2035.[21]

Cost

There are at least two categories of costs associated all types of electricity generation: capital costs and operating and maintenance costs. 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 (kW) of capacity.[22]

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 also look at the actual cost of generating electricity, which includes operation and maintenance costs. 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.[23] 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.[24]

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.[25] The exploration and well drilling phase constitutes, on average, 36 percent of a geothermal plant's total capital cost.[26] Thus, improvements in drilling techniques could significantly reduce the cost of constructing a geothermal plant.

Current geothermal plants have small capacities, typically ranging from 2MW to 45MW depending on the type of plant[27], although plants with capacities up to 110MW do exist.[28] As experience improves and capacities expand, the price of producing geothermal energy could fall further if plants achieve economies of scale.[29] As plant capacity increases, the average cost of drilling and plant construction decreases and the electricity produced becomes less expensive, as seen in Table 1 and Table 2.

Table 1: Levelized cost of capital electricity

Initial Capital Investment	Cost of Power (cents/kWh)*
$2400 per KW	3.99 - 5.76
$2900 per KW	4.40 – 6.54

$3400 per KW	4.81 – 7.33

*Range depends on the type of financing the project developers receive. These include financing from a municipal utility, a regulated investor-owned utility, a generating company, or an independent power producer.

Table 2: Impact of economies of scale on the capital cost per KW

Plant Capacity (MW)	Capital Cost ($/KW)
5	2500
34	2325
78	2086
107	1940
150	1740

Source: 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

Current Status of Geothermal Energy

From the early 1970s to the early 1990s, geothermal electricity generation saw rapid growth, with an average annual growth rate of more than 16 percent.[30] From the early 1990s until the present, however, geothermal generation has been relatively flat. As of April 2011, the United States possessed about 3,102 MW of installed geothermal capacity.[31] An additional 146 geothermal projects across fifteen states are currently under development.[32] According to the EIA, under current policies geothermal generation is projected to increase much more quickly than total electricity deamnd, with an annual growth rate of 4.2 percent between 2009 and 2035.[33]

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.[34] Geothermal energy also receives a production tax credit (PTC) through 2013.[35]

Geothermal energy plays an important role in global energy generation. Iceland, for example, generates over 80 percent of its electricity from geothermal sources.[36] The United States leads the world in terms of total installed geothermal capacity.[37] Global geothermal energy is expected to grow slowly in the future, with IEA projecting an annual growth rate of only 0.5 to 1.2 percent, depending on climate and energy policies.[38]

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 75-80 percent chance of failure for exploratory well drilling, due to uncertainties regarding reservoir geology.[39] The combination of high risk and high capital costs can make financing geothermal projects difficult.[40]

- Investment Uncertainty

  Changes in government funding for geothermal generation and uncertainty over future climate-related 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.[41] 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. More recent federal budgets have, however, provided funding to promote geothermal research and development, including $338 million from the American Recovery and Reinvestment Act of 2009.

- 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.[42]

- Permitting Delays

  Permitting delays can increase the amount of time it takes to bring new geothermal facilities on-line, and increase project costs and developer risk.

Policy Options to Help Promote Geothermal Energy

- Price on Carbon
  A price on carbon, such as that which would exist under a GHG cap-and-trade program, 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.

- Electricity Portfolio Standard

  Electricity portfolio standards generally require that electric utilities obtain specified minimum percentages of their electricity from certain energy sources. 31 states and the District of Columbia have renewable portfolio standards or alternative energy portfolio standards.[43] Congress has also considered federal renewable electricity standards and clean energy standards. Electricity portfolio standards encourage investment in new geothermal power and can guarantee a market for its generation.

- Tax Credits and Other Subsidies

  The federal PTC for geothermal electricity generation expires at the end of 2013. The PTC can lower the after-tax, levelized cost of electricity from geothermal by as much as 30 percent.[44]

- 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 in the Southwest United States. 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 Solutions, 2011 http://www.pewclimate.org/docUploads/climate101-technology.pdf

The Case for Action: Creating a Clean Energy Future. 2010 http://www.pewclimate.org/docUploads/case-for-action-creating-clean-energy-future.pdf

Deploying Our Clean Energy Future. 2009 http://www.pewclimate.org/docUploads/claussen-deploying-our-clean-energy-future-innovations-fall-2009.pdf

Further Reading / Additional Resources

Blodgett, Leslie, and Kara Slack. 2009. *Geothermal 101: Basics of Geothermal Energy Production and Use*. Geothermal Energy Association.

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

Energy Information Administration. *Geothermal Explained*. 2011.

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.

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

Idaho National Laboratory. 2007. *The Future of Geothermal Energy*. The U.S. Department of Energy National Laboratory operated by the Battelle Energy Alliance.

International Geothermal Energy Association.

Kagel, Alysa, Diana Bates, and Karl Gawell. 2007. *A Guide to Geothermal Energy and the Environment*. Geothermal Energy Association.

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*.

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.

Williams, Eric, Rich Lotstein, Chrisopher Galik and Hallie Knuffman. July 2007. *A Convenient Guide to Climate Change Policy and Technology*. Duke University.

---

[1] Energy Information Administration (EIA). 2010*. Table 8.2 b, Electricity Net Generation: Electric Power Sector, 1949-2009.* http://www.eia.doe.gov/totalenergy/data/annual/txt/ptb0802b.html

[2] Jennejohn, Dan. U.S. Geothermal Power Production and Development Update. April 2010. Geothermal Energy Association. http://www.geo-energy.org/pdf/reports/April_2010_US_Geothermal_Industry_Update_Final.pdf

[3] Ibid.

[4] 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/

[5] Represents a 50 percent chance of at least this amount.

[6] EIA, 2010.

[7] EIA. 2010. *Annual Energy Review 2008*. http://www.eia.doe.gov/totalenergy/data/annual/

[8] Jennejohn, 2010.

[9] Ibid.

[10] Energy Information Administration. 2010. *Hawaii Renewable Electricity Profile.* http://www.eia.gov/cneaf/solar.renewables/page/state_profiles/hawaii.html

[11] Williams et al., 2008.

[12] 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/pdfs/future_geo_energy.pdf

[13] Casing is the pipe that connects the geothermal well to the generation facility, and prevents the mixing of hot geothermal fluids with groundwater at other depths. High temperatures can cause the steel piping to expand or buckle if not properly enforced with cement, a process referred to as "casing failure".

[14] Geothermal Technologies Program. 2011. *Multi-year Research, Development and Demonstration Plan: 2009-2015 with program activities to 2025*. U.S. Department of Energy, Energy Efficiency and Renewable Energy. http://www1.eere.energy.gov/geothermal/pdfs/gtp_myrdd_2009-cover.pdf

[15]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

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

[17] The gases released through geothermal energy production would have eventually entered the atmosphere, regardless of production in the area; however, the timing of their release is material to near-term climate forcing.

[18] Binary plants emit 0 lbs. of CO_2 per MWh, flash plants emit 60 lbs. of CO_2 per MWh, and dry steam plants emit 88.8 lbs. of CO_2 per MWh.

[19] Williams, Eric, Rich Lotstein, Chrisopher Galik and Hallie Knuffman. July 2007. A Convenient Guide to Climate Change Policy and Technology. Duke University. http://www.nicholas.duke.edu/ccpp/convenientguide/

[20] Energy Information Administration. July 2010. *Energy Market and Economic Impacts of the American Power Act of 2010. http://www.eia.gov/oiaf/servicerpt/kgl/index.html*. The text compares EIA's "Reference" and "APA Basic" cases.

[21] International Energy Agency (IEA). 2010. *World Energy Outlook 2010.*

[22] 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

[23] Renewable Energy Transmission Initiative (RETI). 2008. *Phase IA Final Report*. http://www.energy.ca.gov/2008publications/RETI-1000-2008-002/RETI-1000-2008-002-F.PDF

[24] EIA. 2008. *Annual Energy Outlook 2009 Early Release*. http://www.eia.doe.gov

[25] Deloitte. 2008. *Geothermal Risk Mitigation Strategies Report*. Department of Energy, Office of Energy Efficiency and Renewable Energy Geothermal Program. http://www1.eere.energy.gov/geothermal/pdfs/geothermal_risk_mitigation.pdf

[26] Western Governors' Association. 2006. *Geothermal Task Force Report*. Clear and Diversified Energy Initiative. http://www.westgov.org/component/joomdoc/doc_download/95-geothermal

[27] The typical range is 2-45MW for flash plants, and <5MW for binary plants. For dry steam plants the range is higher, at 50-60MW, but they are not very common.

[28] Energy Technology Network. *EIA ETSAP Technology Brief E07: Geothermal Heat and Power*. May 2010. http://www.etsap.org/E-techDS/PDF/E06-geoth_energy-GS-gct.pdf

[29] Willams et. al, 2007.

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

[31] Jennejohn, Dan. U.S. Geothermal Power Production and Development Update. April 2010. Geothermal Energy Association. http://www.geo-energy.org/pdf/reports/April_2010_US_Geothermal_Industry_Update_Final.pdf

[32] Ibid.

[33] Energy Information Administration. 2011. *Annual Energy Outlook 2011: Early Release Overview.* http://www.eia.gov/forecasts/aeo/tables_ref.cfm

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

[35] *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

[36] Williams et al 2008

[37] Jennejohn, 2010.

[38] International Energy Agency (IEA). 2010. *World Energy Outlook 2010.*

[39]Geothermal Technologies Program. 2008. *Geothermal Tomorrow 2008*. U.S. Department of Energy, Energy Efficiency and Renewable Energy. http://www.nrel.gov/docs/fy08osti/43504.pdf

[40] Deloitte, 2008.

[41] Williams et.al, 2007.

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

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

[44] Owens, Brandon. 2002. *An Economic Valuation of a Geothermal Production tax Credit*. National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy02osti/31969.pdf