OCTOBER 2012 TECHNOLOGY

ENHANCED GEOTHERMAL SYSTEMS

CENTER FOR CLIMATE AND ENERGY SOLUTIONS

Quick Facts

- **Enhanced geothermal systems utilize advanced, often experimental, drilling and fluid injection techniques to augment and expand the availability of geothermal resources, which can be used to generate electricity from the heat in the earth's crust.**
- **Enhanced geothermal systems, when recharged, can provide near continuous output, making the technology a renewable, zero-carbon option for supplying baseload electricity generation.**
- **While no commercial-scale enhanced geothermal plants exist today, a panel of geothermal experts convened by MIT in 2006 estimated that, with the proper incentives, enhanced geothermal systems could provide 100,000 megawatts (MW) of generating capacity by 2050, equivalent to 10 percent of today's generating capacity.[1]**

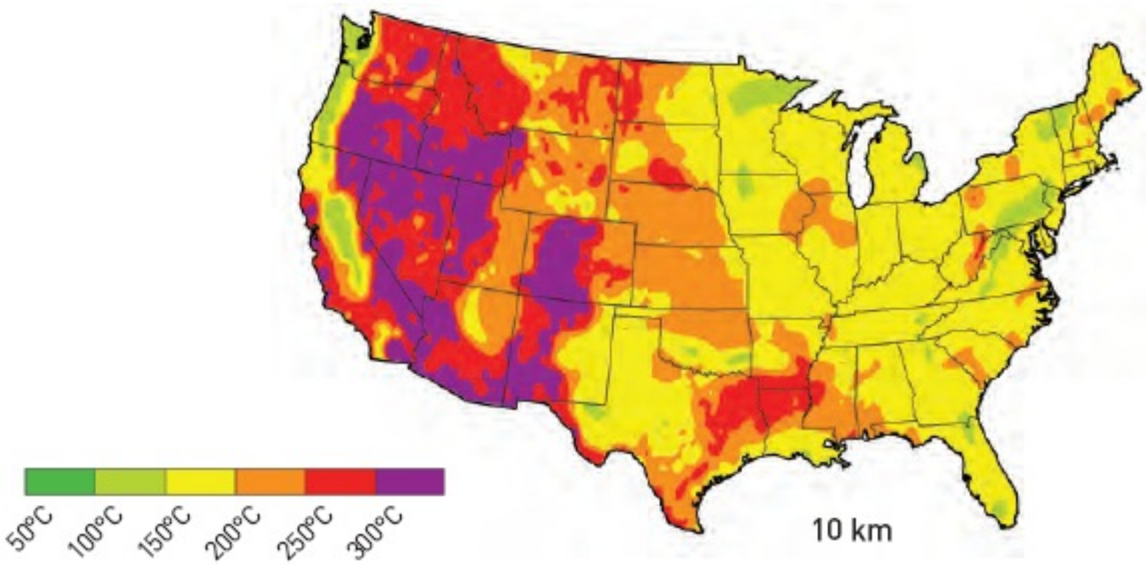
BACKGROUND

The term enhanced geothermal systems (EGS), also known as engineered geothermal systems (formerly hot dry rock geothermal), refers to a variety of engineering techniques used to artificially create hydrothermal resources (underground steam and hot water) that can be used to generate electricity. Traditional geothermal plants (see Climate TechBook: Geothermal Energy) exploit naturally occurring hydrothermal reservoirs and are limited by the size and location of such natural reservoirs. EGS reduces these constraints by allowing for the creation of hydrothermal reservoirs in deep, hot geological formations, where energy production had not been economical due to a lack of fluid or permeability.[2] EGS techniques can also extend the lifespan of naturally occurring hydrothermal resources.[3]

Given the costs and limited full-scale system research to date, EGS remains in its infancy, with only research and pilot projects existing around the world and no commercial-scale EGS plants to date. The technology is promising, however, as a number of studies have found that EGS could quickly become widespread. One MIT study projected that EGS could reach an installed capacity of 100,000 MW in the United States by 2050—for comparison the United States currently has roughly 319,000 MW of coal-fueled generating net summer capacity.[4] Were the United States to realize a significant fraction of this potential, it would make EGS one of the most important renewable energy technologies.

According to the U.S. Geologic Survey, the western United States has sufficient geological resources for over 517,800 MW of EGS capacity—roughly the equivalent of half the current total U.S. installed electric generating capacity from all energy sources.[5] Nonetheless, the technologies needed to utilize this energy reserve are not yet commercially viable. According to the MIT report, realizing the theoretical potential of EGS will require consistent investment in research and development for up to 15 years before commercial viability and deployment are achieved.[6]

Figure 1: EGS resources at depth of 10km



Source: Tester, J., 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].

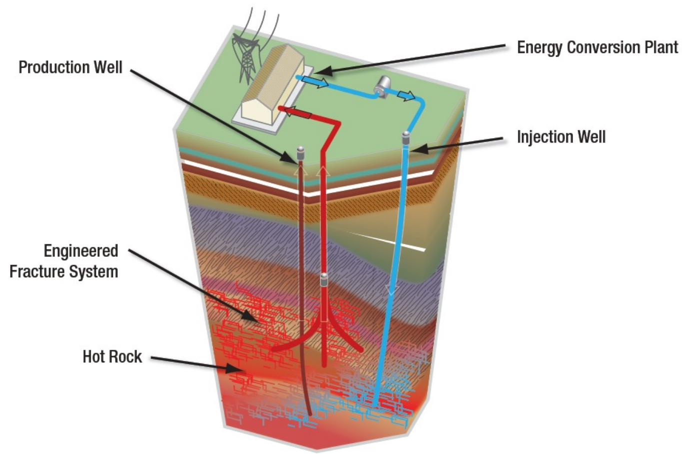
DESCRIPTION

Similar to traditional geothermal generation, EGS technologies use the heat of the earth's crust to generate electricity. Traditional geothermal plants draw on naturally occurring hydrothermal resources at relatively shallow depths. EGS, however, attempts to artificially reproduce the conditions of naturally occurring hydrothermal reservoirs by fracturing impervious hot rocks at 3 to 10 kilometers depth,[7] pumping fluid into the newly porous system, and then extracting the heated fluid to drive an electricity-generating turbine (see **Error! Reference source not found.**).[8] Artificially creating hydrothermal reservoirs gives EGS greater siting flexibility than traditional geothermal power plants, which can only be developed at sites with naturally occurring hydrothermal resources that may be limited in their size and their proximity to end-users of electricity.

The backbone and most difficult elements of EGS are the creation of the hydrothermal reservoir and a flow of fluid—typically water–through the fractured rock. In order to operate continuously, a geothermal plant must have access to a steady stream of heated fluid. This requires the creation of a reservoir that not only holds enough fluid but also allows it to readily move through the system.[9] However, the hot rocks best suited for EGS are rarely porous enough, as they are buried so deep that they become compressed by the weight of the earth.[10] As a result, EGS begins with increasing the natural porosity of a geological structure—often referred to as "stimulation." Upon drilling an initial bore hole, highly pressurized water is pumped underground. As pressure mounts, the water stimulates fractures that branch out through the geological formation, creating a hydrothermal reservoir.[11] Stimulation can be assisted by treatments involving the injection of various acids into the reservoir to corrode accumulated debris. [12]

After stimulation, EGS operators must estimate the volume and shape of the newly created reservoir. A variety of technologies, from seismic imaging to radioactive tracers, can then be used to design the best array of injection and production wells.[13] In proposed designs, the injection well will be placed near the center of the reservoir, with multiple production wells flanking either edge of the reservoir. This allows water to flow outward from the injection well in all directions, optimizing flow rate and minimizing fluid loss. Once the reservoir has

FIGURE 2: EGS Cutaway Diagram



Source: U.S. Department of Energy Geothermal Technologies Program. 2008. An Evaluation of Enhanced Geothermal Systems Technology.

been established, it is functionally similar (with exceptions for well cost, restimulation and fluid replenishment) to traditional hydrothermal systems. An EGS power plant operates almost exactly like a traditional geothermal plant. Water is injected into the man-made hydrothermal reservoir, heated as it percolates through the stimulated fractures, and finally extracted at a production well, where it travels to the surface to drive an electricity-generating turbine. It is projected that the majority of EGS plants will use binary cycle geothermal technology to convert hydrothermal resources to electricity.[14]

The widespread application of EGS, however, will ultimately depend on advances in drilling technology. While oil and gas drilling techniques apply to geothermal drilling (both traditional and EGS), temperatures above 250°F that are necessary for geothermal reservoirs complicate the process. The high heat increases the probability of well failure due to collapse, mechanical malfunction, loss of telemetry, and casing failure.[15,16,17] These limitations apply doubly to EGS wells, as EGS drilling requires drilling deeper, into harder and hotter rock than traditional geothermal plants.[18]

ENVIRONMENTAL BENEFIT / EMISSION REDUCTION POTENTIAL

EGS, like traditional geothermal energy, constitutes a source of electricity that is almost entirely free of greenhouse gas (GHG) emissions. Only small traces of carbon dioxide and other GHGs might be released from geological formations during the drilling phase of an EGS plant's life. [19]

The greatest environmental benefit of EGS comes from its ability to satisfy baseload electricity demand. Unlike intermittent renewable energy technologies, such as wind and solar power, EGS could provide a consistent electricity supply similar to carbon-intensive coal-fired power plants. 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 (roughly 0.1 percent of total U.S. CO_2 emissions from electricity generation[20]).[21]

The installation of EGS would likely be expanded under a national climate or energy policy. Unfortunately, projections of renewable energy innovation under climate policies typically do not include predictions about EGS growth, given the experimental nature of the technology.[22]

These same projections, however, expect traditional geothermal to grow under a climate policy.[23] The overlap of the two geothermal technologies means that innovations in traditional geothermal should bolster the prospects of EGS as well. According to a panel of experts convened by MIT in 2006, EGS could reach an installed capacity of 100,000 MW by 2050—roughly a third of today's installed coal capacity.[24]

Abandoned or unproductive domestic oil fields could be adapted to EGS.[25] The unproductive oil fields of Texas, for example, not only have already drilled bore holes, but also have verified thermal and geological information. Retooling these fields to produce hot water, instead of oil, could greatly expand the installed capacity of EGS once it reaches commercial deployment.[26]

COST

The experimental nature of EGS technology makes it difficult to evaluate the costs of a commercial scale EGS power plant. Initial estimates suggest that with current technology, the capital costs of an EGS plant would be roughly twice that of a traditional geothermal plant.[27] While the capital costs of an EGS plant currently exceed those of a traditional fossil fuel power plant, one must look at the actual cost of generating electricity. Unlike a coal or natural gas plant, EGS facilities do not need to purchase fuel to generate electricity. This difference can be accounted for through a levelized cost analysis.[28] Estimates of the cost of EGS vary and are uncertain because the cost of reservoir creation varies greatly depending on the geological formations at each EGS site. Using current drilling technology at an ideal site (marked by high temperatures at shallow depths and easily drillable geology), would allow for electricity generation at an estimated levelized cost of 17.5 to 29.5 cents per kilowatt-hour (kWh).[29] At less suitable, yet still technically feasible locations (that require deeper drilling, often through hard granite formations), EGS could generate electricity at a cost of as much as 74.7 cents per kWh.[30]

EGS costs are especially difficult to calculate given that current EGS plants are small pilot facilities designed for research, not power production. Subsequent commercial-scale plants are expected to achieve economies of scale.[31] As such, the costs of currently operating plants provide limited insight into the costs of a commercial-scale EGS facility. Cost reductions seen for similar technologies used in the oil and gas industry in the past indicate the potential for significant cost reductions for EGS. With time, as EGS nears commercialization, EGS is projected to competitively produce electricity at 3.6 to 9.2 cents per kWh.[32,33]

The variability in cost estimates is largely attributable to the risks and inherent variability involved in the drilling and reservoir development stages of EGS. Drilling alone is estimated to be more than one-third of the capital costs of an EGS plant.[34] EGS drilling is especially expensive given the greater depths often required to reach geological formations of sufficient heat. Deeper bore holes require more materials and have higher risks of failure, causing drilling costs to increase nonlinearly with depth.[35] At a depth of 6,000 meters, drilling the initial bore hole for EGS is projected to cost $12 million to $20 million—roughly two to five times greater than oil and gas wells of comparable depth.[36] Furthermore, these estimates do not include the cost of exploratory well drilling, a necessary but expensive step in developing a geothermal site that entails both risk and uncertainty.[37]

CURRENT STATUS OF ENHANCED GEOTHERMAL ENERGY

EGS remains in the research and development stage. Experimentation with EGS first began in the 1970s with a series of pilot projects at Fenton Hill, New Mexico. While the projects did not operate on a commercial scale, they did demonstrate the feasibility of the geologic engineering and drilling techniques needed to artificially create hydrothermal reservoirs. Since then, experimental EGS plants and pilot projects have been undertaken around the world.[38] Realizing the full potential of EGS will take some time, and the International Energy Agency (IEA) believes that substantially higher research, development, and demonstration (RD&D) efforts are needed to ensure EGS becomes commercially viable by 2030.[39]

In the United States, there has been growing interest in EGS. In 2009, the American Recovery and Reinvestment Act included $80 million for research and development of EGS technologies.[40] The U.S. Department of Energy's (DOE) Geothermal Technologies Program oversees on-going research and development related to EGS with the goal of improving the performance and lowering the cost of EGS technologies. The Geothermal Technologies Program partners with national laboratories, universities, and the private sector on EGS component technology research and development projects[41] and EGS system demonstration projects.[42] Two prominent EGS-related research projects are wastewater injection at The Geysers in California (the oldest geothermal field in the United States and largest geothermal venture in the world) and Desert Peak in Nevada, where EGS capacity will be added to an existing geothermal field.[43] Finally, the Bureau of Land Management leases land in eleven Western states for continued geothermal resource development.[44]

The European Union has long been involved in the efforts to research and develop enhanced geothermal systems technologies.[45] France and Germany have operational EGS demonstration projects (1.5 to 2.5 MW),[46] while Iceland and Switzerland are members of the International Partnership for Geothermal Technology (IPGT).[47] The United States and Australia are also members of the IPGT, which is working to identify effective methodologies and practices for EGS development.[48]

OBSTACLES TO FURTHER DEVELOPMENT OR DEPLOYMENT OF EGS

Need for Technology Research, Development, and Demonstration (RD&D)

A lack of RD&D constrains the deployment of EGS power plants. Most technologies used in EGS, such as drilling and geologic imagery techniques, are not yet adapted for specific use in EGS development.

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, when high fluid temperatures and flow rates are not located .[49] The combination of high risk and high capital costs can make financing geothermal projects difficult and expensive.[50]

Knowledge of Geothermal Geology

The ability to artificially create geothermal reservoirs consistently is greatly limited due to a lack of understanding of how geothermal reservoirs occur in nature. Researching the geological characteristics of natural geothermal resources is essential to adapting stimulation and drilling techniques in such a way that drives down the costs of EGS development.[51]

Geographic Distribution and Transmission

Despite the siting flexibility of EGS technologies, the most promising EGS sites often occur great distances from regions of large electricity consumption, or load centers. The need to install adequate transmission capacity can deter investment in geothermal projects.[52]

POLICY OPTIONS TO HELP PROMOTE EGS

Price on Carbon

A price on carbon would raise the cost of electricity produced from fossil fuels relative to the cost of electricity from renewable sources, such as EGS, and other lower-carbon technologies. A price on carbon would increase both deployment of mature low-carbon technologies and R&D investments in less mature technologies.

Clean Energy Standard

A clean energy standard is a policy that requires electric utilities to provide a certain percentage of electricity from designated low carbon dioxide-emitting sources. At present, 31 U.S. states and the District of Columbia have adopted clean energy standards,[53] and clean energy standard has been proposed at the federal level.[54] Clean energy standards encourage investment in new renewable generation and can guarantee a market for this generation.

Research, Development and Demonstration

Rapidly moving along the EGS technological “learning curve” requires sustained funding of further research efforts in the form of pilot plants and basic research in geology, drilling techniques and other associated EGS technologies.

Streamline Government Leasing and Permitting Procedures

Quickly deploying EGS will require federal agencies to more efficiently process applications for the development of EGS plants on public lands. Accelerating the speed of siting, leasing and permitting decisions will help make already risky EGS projects more attractive to investors.

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

Alcoa

DTE Energy

GE

Johnson Controls

PG&E

RELATED C2ES RESOURCES

Climate Change 101: Technological Solutions, 2011

Race to the Top: The Expanding Role of U.S. State Renewable Portfolio Standards, 2006

C2ES Climate Techbook: Geothermal Energy, 2011

FURTHER READING / ADDITIONAL RESOURCES

- U.S. Department of Energy (DOE). 2008. *The Basics of Enhanced Geothermal Systems*.
- DOE's Geothermal Technologies Program website
- Geothermal Energy Association. 2012. "Geothermal Basics."
- 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.*
- International Energy Agency (IEA). 2011. *Technology Roadmap - Geothermal Heat and Power*
- International Partnership for Geothermal Technology's website

ENDNOTES

[1] "Tester, J., 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

[2] U.S. Department of Energy. 2008. "The Basics of Enhanced Geothermal Systems." Accessed 22 August 2012. http://www1.eere.energy.gov/geothermal/pdfs/egs_basics.pdf

[3] Williams, E., et al. 2007. *A Convenient Guide to Climate Change Policy and Technology*. http://www.nicholas.duke.edu/ccpp/convenientguide/cg_pdfs/ClimateBook.pdf

[4] U.S. Energy Information Administration (EIA). 2011. "Table 8.11a Electric Net Summer Capacity: Total (All Sectors), 1949-2010." Accessed 2 May 2012.

[5] Williams, C., et al. 2008. *Assessment of Moderate-and High-Temperature Geothermal Resources of the United States*. United States Geological Survey. http://pubs.usgs.gov/fs/2008/3082/pdf/fs2008-3082.pdf

[6] Tester et al., 2006.

[7] Ibid.

[8] For an illustrated explanation, see the U.S. Department of Energy's Geothermal Technologies Program's webpage: "How an Enhanced Geothermal System Works" http://www1.eere.energy.gov/geothermal/egs_animation.html

[9] U.S. Department of Energy (DOE). 2008a. *An Evaluation of Enhanced Geothermal Systems Technology*. http://www1.eere.energy.gov/geothermal/pdfs/evaluation_egs_tech_2008.pdf

[10] DOE. 2008b. *Geothermal Tomorrow 2008*. http://www.nrel.gov/docs/fy08osti/43504.pdf

[11] DOE, 2008a.

[12] Ibid.

[13] Tester et al., 2006.

[14] Rather than using hydrothermal steam to drive a turbine, a binary cycle geothermal plant uses heated water from the hydrothermal reservoir 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. To learn more about the conversion of hydrothermal resources to electricity see C2ES Climate Techbook: Geothermal Energy, 2009.

[15] DOE. 2008c. *Multi-year Research, Development and Demonstration Plan: 2009-2015 with program activities to 2025*. http://www1.eere.energy.gov/geothermal/pdfs/gtp_myrdd_2009-complete.pdf

[16] DOE, 2008a.

[17] A well's casing is the pipe placed in a wellbore as an interface between the wellbore and the surrounding formation. It typically extends from the top of the well and is cemented in place to maintain the diameter of the wellbore and provide stability. Telemetry refers to the transmission of data from the drill bit to the operators on the surface.

[18] Fridleifsson, I.B., et al. 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.

[19] Kagel, A., Bates, D. and Gawell, K. 2007. *A Guide to Geothermal Energy and the Environment*. 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, E., et al. 2007).

http://geo-energy.org/reports/environmental%20guide.pdf

[20] U.S. Environmental Protection Agency (EPA). 2011. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009*.

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

[22] For example, the U.S. Energy Information Administration (EIA) models proposed climate and energy policies but does not include EGS as a technology choice in its model, stating that EGS are not included as potential resources since this technology is still in development and is not expected to be in significant commercial use within the projection horizon [by 2030]." See EIA, *Assumptions to the Annual Energy Outlook 2009: Renewable Fuels Module.* http://www.eia.gov/oiaf/aeo/assumption/pdf/0554(2009).pdf

[23] Ibid.

[24] EIA, 2011.

[25] This practice involves creating hydrothermal reservoirs within the geological structures of abandoned oil fields. This allows the EGS plant operators to take advantage of verified thermal and geological data in order to more cheaply create a hydrothermal reservoir. For more information, see McKenna, J., et al. "Geothermal electric power supply possible from Gulf Coast, Midcontinent oil field waters." The Oil and Gas Journal. 103:33 (2005).

[26] McKenna et al., 2005.

[27] Delaquil, P., Goldstein, G., and Wright, E. 2008. "US Technology Choices, Costs and opportunities under the Lieberman-Warner Climate Security Act: Assessing Compliance Pathways." International Resources Group. http://docs.nrdc.org/globalwarming/files/glo_08051401A.pdf

[28] The levelized cost of electricity is an economic assessment of the cost of electricity generation from a representative generating unit of a particular technology type (e.g. wind, coal, EGS) that includes costs over the lifetime of the plant: initial investment, operations and maintenance, cost of fuel, and cost of capital. The levelized cost generally does not include costs associated with transmission and distribution of electricity. Levelized cost estimates can vary based on uncertainty regarding and differences in underlying assumptions, such as the size and application of the system, what taxes and subsidies are included, location of the system, and other factors.

[29] Tester et al., 2006.

[30] Ibid.

[31] Ibid.

[32] Ibid.

[33] DOE, 2008b.

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

http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CCIQFjAA&url=http%3A%2F%2Fwww.westgov.org%2Fcomponent%2Fjoomdoc%2Fdoc_download%2F95-geothermal&ei=ahg1UO6DGdCJ6gGRmYDYCA&usg=AFQjCNH687XB7H1YqOf0Hqmc1zMMiHCVpg

[35] Tester et al., 2006.

[36] Ibid.

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

[38] International Partnership for Geothermal Technology (IGPT). 2012. "About IGPT." Accessed 22 August 2012. http://internationalgeothermal.org/IPGT.html

[39] International Energy Agency (IEA). 2011. *Geothermal Heat and Power Roadmap.* http://www.iea.org/papers/2011/Geothermal_Foldout.pdf

[40] DOE. 2009. "Recovery Act Announcement: President Obama Announces Over $467 Million in Recovery Act

Funding for Geothermal and Solar Energy Projects." http://apps1.eere.energy.gov/news/progress_alerts.cfm/pa_id=173

[41] DOE. 2012. "Geothermal Technologies Program - EGS Component R&D." http://www4.eere.energy.gov/geothermal/projects?filter[field_project_area][0]=%2248%22

[42] DOE 2012. "Geothermal Technologies Program - EGS Systems Demonstration." http://www4.eere.energy.gov/geothermal/projects?filter[field_project_area][0]=%2249%22

[43] Geothermal Energy Association (GEA). 2012. "Geothermal Basics Potential Use." Accessed 22 August 2012. http://www.geo-energy.org/PotentialUse.aspx

[44] Bureau of Land Management (BLM). 2011. "Renewable Energy and the BLM: GEOTHERMAL." http://www.blm.gov/pgdata/etc/medialib/blm/wo/MINERALS__REALTY__AND_RESOURCE_PROTECTION_/energy.Par.74240.File.dat/Fact_Sheet_Geothermal_Oct_2011.pdf

[45] Ledru, P. et al. 2007. "ENhanced Geothermal Innovative Network for Europe: the state-of-the-art." Geothermal Resources Council Bulletin. http://engine.brgm.fr/Documents/GRC_ENGINE_Presentation_06092006.pdf

[46] GEA, 2012.

[47] IGPT, 2012.

[48] Ibid.

[49] DOE, 2008b.

[50] Deloitte, 2008.

[51] For an example of this work, see Blankenship, D., et al. 2009. *Development of a High-Temperature Diagnostics-While-Drilling Tool.* Sandia Report 2009-0248. http://www1.eere.energy.gov/geothermal/pdfs/ht_dwd_tools.pdf

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

[53] Center for Climate and Energy Solutions (C2ES). 2012a. "C2ES State Policy Map - Renewable & Alternative Energy Portfolio Standards." Accessed 22 August 2012. http://www.c2es.org/what_s_being_done/in_the_states/rps.cfm

[54] C2ES. 2012b. *Summary of the Clean Energy Standard Act.* http://www.c2es.org/docUploads/bingaman-clean-energy-standard-act-summary.pdf