RELIABILITY OF RENEWABLE ENERGY: GEOTHERMAL

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The Institute of Political Economy (IPE) at Utah State University seeks to promote a better understanding of the foundations of a free society by conducting research and disseminating findings through publications, classes, seminars, conferences, and lectures. By mentoring students and engaging them in research and writing projects, IPE creates diverse opportunities for students in graduate programs, internships, policy groups, and business.
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EXECUTIVE SUMMARY

As public interest in renewable energy sources has grown, policymakers have responded by enacting legislation that favors renewable energy like geothermal power. These policies, including mandates and subsidies, have helped the geothermal industry grow artificially fast. One way to determine whether these mandates and subsidies are wise is to examine the reliability of geothermal energy as a source of electricity. The Institute of Political Economy (IPE) examined the physical, economic, and environmental aspects of geothermal power to assess its overall reliability as an energy source. IPE found that geothermal power’s high startup costs discourage many investors from entering the geothermal market. Due to this high cost, geothermal energy is economically dependent on government subsidies for its growth. It is, however, physically reliable and more environmentally friendly than traditional fossil fuels.

Geothermal energy production has large capital investment costs for exploration, drilling, and plant installation. Furthermore, exploring and drilling for geothermal resources is risky and does not always yield profitable results. Much of the geothermal industry relies on government support to overcome these costs and risks. For this reason, geothermal power is economically unreliable. One of the most influential geothermal policies is the 2004 American New Jobs Creation Act, which gives geothermal energy producers a production tax credit (PTC) of 2.3 cents per kilowatt-hour. The Energy Policy Act of 2005 created additional tax incentives and loan guarantees. In 2013 alone, the geothermal industry received $345 million in government funds. If the start up subsidies are left out of the cost-benefit analysis, geothermal plants are a cost-efficient way to produce electricity because of its low fuel and operations and maintenance costs.

Geothermal energy is physically reliable because it is consistent, efficient, and can easily accommodate changes in electricity demand. Unlike intermittent renewable energy sources such as wind and solar, geothermal power plants can consistently run at nearly full capacity and they can flexibly change their electricity output as needed. One of the main drawbacks of geothermal power is its geographic dependency. An area must have specific geological characteristics for the production of geothermal power to be possible there.

Geothermal power does have some environmental impacts, but these impacts are small and manageable. Geothermal power plants produce few emissions and do not require backup sources of power, therefore they have minimal impacts on air quality. Geothermal power plants can emit toxic amounts of hydrogen sulfide, but these emissions are controlled with advanced abatement equipment. Geothermal power is produced using high temperature water from underground reservoirs. This water contains materials that can contaminate the environment surrounding a geothermal plant if it is not contained. To prevent contamination, these fluids are generally injected back into the ground, where casings prevent them from leaking into other areas. If geothermal energy producers do not inject the water they extracted from the reservoir back into the ground, land subsidence can result. Geothermal power plants can also increase seismic activity in the surrounding area, but not enough to cause substantial damage. Most of these environmental costs are minimal, and proper management techniques can mitigate them.

Iceland produces more than a quarter of its electricity from geothermal resources, and doing so has demonstrated the physical reliability of geothermal power. This level of geothermal penetration, however, would not have been possible without the Icelandic government’s subsidization of geothermal power in the early stages of its development. For the United States, a country with much larger energy demands than Iceland, an attempt to reach similar penetrations of geothermal power would be extraordinarily expensive and would require massive government subsidies, as it did in Iceland.

New technology and increased market demand could eventually make geothermal economically viable, meaning that it could be developed without subsidies. Enhanced Geothermal Systems may increase the potential for geothermal power in areas where geothermal power was previously impossible.
INTRODUCTION

Many Americans view renewable energy as an environmentally-friendly substitute for energy from fossil fuels. Policymakers have responded to their constituencies by mandating and subsidizing renewable energy sources. Although geothermal power is not as well known as wind and solar, geothermal power is growing as an energy source. As of 2014, there were 64 operating geothermal power plants in the United States, with an additional 83 projects in the development stage by early 2015.\(^1\)\(^2\) Despite governmental assistance and industry growth, geothermal power accounted for just 0.4 percent of net U.S. electricity generation in 2014, as seen in Figure 1 below.

FIGURE 1. TOTAL U.S. ELECTRICITY GENERATION\(^3\)

One way to determine whether the mandates and subsidies that increase geothermal power production are beneficial is to examine the reliability of geothermal power.

DEFINING RELIABILITY

The term “reliability” is ambiguous and goes beyond an energy source’s ability to generate power consistently. To gain a more comprehensive understanding of geothermal power, IPE subdivided “reliability” into three categories: economic, physical, and environmental.

First, although “economic reliability” is not a common academic term, in the context of this report economic reliability refers to the ability of an energy source to be self-sustaining and affordable without government mandates or subsidies.

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Second, “physical reliability” refers to the ability of an energy source to consistently meet electricity demands by supplying and transmitting its power without interruption.

Finally, to be considered “environmentally reliable” by this report, an alternative energy source must have fewer negative environmental impacts than fossil fuels.

**HOW GEOTHERMAL ENERGY WORKS**

Over millions of years, water collects in underground reservoirs by seeping through cracks in the earth’s surface. In areas with high underground temperatures, due to close proximity to magma or molten rock, the water from these underground reservoirs can reach temperatures up to 700 degrees Fahrenheit. Geothermal wells tap into these superheated reservoirs, bring the water to the surface and use it to generate electricity.

Like fossil fuel plants, geothermal power plants convert heated water into steam, which powers steam turbines to produce electricity. Traditional power plants burn fossil fuels to turn water into steam; geothermal plants use steam directly from the superheated underground reservoirs or use the heat from that water to turn a secondary liquid into steam. In most cases, once the water has cooled, geothermal power plants inject the water back into the reservoir.

**THREE TYPES OF GEOTHERMAL POWER PLANTS**

There are three different types of geothermal power plants: dry-steam, flash-steam, and binary-cycle. Each type requires a different water temperature to operate.

**DRY-STEAM**

If the underground water is hot enough (320 °C to 230 °C), a power plant can generate electricity by piping steam from underground geothermal reservoirs directly to the turbine unit of the power plant. The direct use of steam eliminates the need for additional fuels. Used first in 1904, dry-steam systems are the oldest type of geothermal plant. The world’s largest complex of dry-steam geothermal power plants, called “The Geysers,” is located in Northern California.

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FLASH-STEAM

Flash-steam is the most common type of geothermal power plant, which uses water from 200 °C to 320 °C. Naturally-pressurized geothermal water is pumped to a holding tank on the surface. Because the pressure in the tank is lower than the underground pressure, some of the fluid vaporizes into steam, which is then used to drive the turbine, producing electricity.

BINARY-CYCLE

Binary-cycle power plants use a secondary fluid, instead of heated underground water, to produce electricity. Binary-cycle systems use water with temperatures from 120 °C to 190 °C, which is pumped through a heat exchanger. The

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water’s heat causes a secondary fluid, which has a low boiling point, to vaporize and produce the steam that drives the electricity-producing turbine.13

FIGURE 4. BINARY-CYCLE POWER PLANT14

![Binary Cycle Power Plant Diagram](image)

ECONOMIC RELIABILITY

This section examines the “economic reliability” of geothermal energy, which refers to the ability of an energy source to be self-sustaining and affordable without government mandates or subsidies. This definition of economic reliability is similar to what may be academically referred to as economic viability or sustainability.

Since the late 1970s, the federal government has encouraged geothermal power production through subsidies, mandates, and other policies that favor geothermal over other types of energy. The growth of the geothermal industry relies on government aid because the high startup costs and risks associated with geothermal development discourage private investment in geothermal power. Geothermal energy in many cases is economically unreliable because of its dependence on government assistance.

GOVERNMENT INVOLVEMENT IN THE GEOTHERMAL INDUSTRY

HISTORY OF GOVERNMENT INVOLVEMENT

In 1960, the annual output of geothermal net electricity generation was 33 million kilowatt-hours.15 Since then, the geothermal industry experienced two major growth spurts, each prompted by government policies designed to encourage the use of renewable energy, or geothermal energy in particular. With the help of these policies, the annual geothermal electricity production had grown to 16,628 million kilowatt-hours by the end of 2014.16

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The Geothermal Steam Act of 1970 was the federal government’s first significant effort at encouraging the use of geothermal energy. The act gave the Bureau of Land Management the authority to lease public lands for geothermal development. In 1974, the federal government passed the Geothermal Research, Development, and Demonstration Act, which created the Geothermal Loan Guarantee Program. This program provided over $136 million in loan guarantees to geothermal projects from 1974 to 1982, when the program ended.

The first growth spurt began in 1978 when the international energy crisis prompted Congress to pass the Public Utility Regulatory Policy Act (PURPA). The purpose of this act was to decrease the United States’ dependence on fossil fuels and increase its reliance on alternative energy sources. PURPA ended the monopoly utilities had on owning and running electricity-generating facilities and required utilities to purchase power from independent power providers (IPPs) as long as their power could be produced cheaper than power generated by utility-owned power plants. The act also gave the Federal Energy Regulatory Commission the authority to require utilities to transmit, or “wheel” power generated by IPPs. Requiring utilities to wheel independently-generated power gives IPPs an advantage over utilities because they are able to transmit their power without having to build their own expensive transmission lines. Instead, they piggyback on the transmission lines already built and paid for by the utility. The combination of PURPA and rising oil prices allowed renewable energy sources to gain a foothold in the United States’ energy sector. After PURPA was passed, the renewable-energy sector, including the geothermal industry, grew dramatically through the 1980s.

California’s Geothermal Grant and Loan Program was created in 1980 to encourage the use of geothermal energy. The Program provides geothermal developers with grants and loans to build and expand geothermal operations. The funds for the program are taken from revenues of geothermal facilities located on federal lands in California, allowing the geothermal industry in California to perpetuate itself.

PURPA’s effectiveness at bolstering the use of renewable energy diminished in the 1990’s, likely for two reasons. First, the price of natural gas fell, making the use of natural gas more attractive. Second, regulatory changes made pricing

in electricity markets more competitive and less favorable to renewable energy.\textsuperscript{29} Geothermal power’s growth tapered off until it was jump-started again by government programs.\textsuperscript{30}

**FIGURE 5: U.S. INDUSTRY GEOThermal NAMEPLATE & NET CAPACITY\textsuperscript{31}**

![Geothermal Power Production Chart](image)

*Note: PCA (Planned Capacity Additions), pilot plants and utility scale geothermal plants built in the first half of the 20th century and then decommissioned are not included in the above time series.*

In 2001, a summit was held by representatives from the Department of the Interior and other federal agencies to decide how to encourage renewable energy development on public land. This summit resulted in mandates for the Bureau of Land Management to lift environmental regulations for geothermal, hasten the process of issuing leases for geothermal development on federal lands, and gather information on geothermal resources and the constraints to their development.\textsuperscript{32} Following the summit, the 2004 American New Jobs Creation Act added geothermal energy (among


other renewable energy sources) as a qualifier for the Federal Production Tax Credit (PTC) for a partial 5-year period, original renewable energy sources were qualified for a 10-year PTC period.33

Four years later, in 2005, the Energy Policy Act, the rules by which the federal government leases land for and extracts money from geothermal operations, was changed to be more favorable to the growth of the geothermal industry.34 The American Recovery and Reinvestment Act distributed $368.2 million to the Geothermal Technologies Office in 2009, and the Geothermal Technologies Office went on to divide the funds among 148 geothermal projects across the nation.35 With the help of these policies, annual electricity generation from geothermal has increased by 13 percent from 2005 to 2014.36

The periods of growth within the geothermal industry followed the passage of major federal and state laws designed to increase renewable energy production, a pattern which suggests that the growth of geothermal industry needs government assistance to grow.

GEOTHERMAL POWER ON NATIVE AMERICAN LANDS37

The greatest potential for geothermal energy lies in the Western United States where the majority of lands are owned by the federal government.38 39 In addition to the federal government, Native American tribes own substantial amounts of western lands as well. There is tremendous potential for renewable power generation on Western Native American lands, including geothermal power generation potential. Over 300 million megawatt hours per year of geothermal potential exist on Native American lands, enough to power over 30 million homes annually.40 Although many Native

40 This calculation was made by taking the total tribal potential generation from renewable resources (16,610,867,594 megawatt hours) and multiplying it by the proportion of those resources that were geothermal (.02) to find that there are 332,217351.88 megawatt hours of geothermal potential on tribal lands. In 2014, the average annual electricity consumption for a U.S. residential utility customer was 10,932 kilowatt hours or 10.932 megawatt hours. The geothermal potential of tribal lands was divided by the average annual electricity consumption of a U.S. residential utility customer to conclude that geothermal power on tribal lands could power 30,389,439.43 homes. Citations for the numbers used in this calculation are listed below.

Tribal potential generation from renewable resources:
Average annual electricity consumption for a U.S. residential utility customer in 2014:

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American tribes have been enthusiastically involved with developing geothermal resources on their land, traditionalists within Native American tribes oppose developing geothermal resources that have spiritual or cultural significance to their tribe.\textsuperscript{41, 42} Government and tribal ownership of such vast amounts of geothermal rich western lands can result in conflicts of interest between renewable energy developers and parties such as environmentalists and traditional Native Americans. For example, tribal opposition to the development of geothermal power on a Native American cultural site resulted in a 14-year court battle and the blockade of an area with massive potential for geothermal energy, as well as a large loss of capital and bankruptcy for a major geothermal developer.

In northern California, the Medicine Lake Highlands were designated by the Secretary of the Interior as the Glass Mountain Known Geothermal Resource Area because of the area’s geothermal potential. After the declaration, two environmental assessments were conducted by the U.S. Forest Service in 1981 and 1984. The first environmental assessment failed to take into account the area’s cultural, religious, and historical value to the surrounding Native American tribes. The second assessment acknowledged the cultural importance of the area to the Native Americans, yet exploration was still approved.

In 1998, leases began being issued in the Medicine Lake Highlands and Lake Caldera areas to different organizations and companies for geothermal exploration. If any of these companies wanted to construct a geothermal project on these sites, additional environmental assessments, beyond the assessments in 1981 and 1984, were required. Additionally, before any construction or drilling could begin, the developer had to receive approval of their development plan. This same year Calpine Corporation, a prominent geothermal energy producer, purchased a ten year lease to explore the resources of Fourmile Hill, an area in the Lake Caldera region. Calpine did not submit an exploratory plan until 1996 and, despite opposition from the local Pit River Tribe, the US Forest Service accepted Calpine’s development plan.

The National Register of Historic Places released a report in 1999 which allowed the Medicine Lake area to become a national historic site. After the report was released, a halt was put in place on the development of sites surrounding the Medicine Lake area, including Fourmile Hill, while additional environmental evaluations were conducted.

Calpine purchased Telephone Flats, another lease located in the Medicine Lake area, in 2001. Due to the environmental evaluations which followed the 1999 report, land development on Telephone Flats had been suspended until the assessments were complete. Frustrated with the government’s seemingly constant interference, Calpine sued the government for $100 million. The lawsuit was dropped by Calpine when the government conceded to reconsider its plan. As a result of the lawsuit, both suspensions were lifted, and Calpine’s leases were extended for 40 years.

The Pit River Tribe then brought a lawsuit against Calpine and the relevant federal agencies for extending both of Calpine’s leases. The Tribe was able to cite over six violations of federal law, including the violation of (NEPA) the National Environmental Protection Act as well as (NHPA) the National Historic Protection Act. According to the Pit River Tribe, the federal government had violated these laws by selling and extending the leases to Calpine without the proper amount of environmental and historical evaluations. Calpine initially had the case ruled in their favor by the Eastern District of California, but the case was appealed to the 9th Circuit Court of Appeals. The 9th Circuit, after hearing the case, began reversing many key components of the decision in favor of the Pit River Tribe.

After a lengthy battle in court, Calpine, the ninth largest company in the United States, declared Chapter 11 Bankruptcy in 2005. Although Calpine recovered from the bankruptcy in 2008, the company still faced difficulties developing potential geothermal development sites in the Medicine Lake Caldera region.

Calpine’s two leases have become a financial waste caused by the lack of coordination between the Bureau of Land Management and the U.S. Forest Service, and the National Register of Historic Places. All three of the federal agencies failed to follow current regulations while leasing the Medicine Lake Caldera region to private investors and Calpine suffered the consequences. To summarize, uncoordinated federal agencies and environmental regulation blocked the construction of two major clean energy plants, capable of powering over 10,000 homes. The development of these two sites would have provided a profitable venture for Calpine while further reducing dependence on dirty fossil fuels.

CURRENT STATUS OF GEOTHERMAL SUBSIDIES AND MANDATES

The federal government currently offers a number of subsidies and other forms of assistance to geothermal energy producers and developers. According to the Energy Information Administration (EIA), the geothermal industry received a total of $345 million in government funds in 2013. The geothermal industry receives government funds in three main forms: direct expenditures, tax expenditures, and research-and-development funds.

DIRECT EXPENDITURES

Direct expenditures are funds paid by the federal government directly to the geothermal industry. Direct expenditures for geothermal power represent the largest percentage of the government’s financial support of the industry. In 2013, $312 million was spent in direct expenditures, which accounts for roughly 90 percent of all government support to the geothermal industry that year.

TAX EXPENDITURES

Tax expenditures reduce the amount of taxes owed by companies or individuals involved in the geothermal energy industry. Tax expenditures account for only a small amount of federal support for geothermal. The government gave geothermal developers $31 million in 2013 in the form of tax expenditures, which accounts for less than ten percent of all government support to the geothermal industry that year.

The PTC and ITC

One of the most prominent subsidies for the renewable energy industry is the Production Tax Credit (PTC), which was introduced in 1992. Geothermal energy, however, did not become eligible to receive the tax credit until 2004. The tax

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credit, which offers a 2.3-cents-per-kilowatt-hour subsidy to renewable energy projects, has expired and been renewed many times, expiring most recently at the end of 2014. Projects that were under construction by the end of 2014 still receive the tax credit. Whether the PTC will be renewed again is unknown.

Whenever the PTC has been set to expire, investments in renewable energies have plummeted. In 2014, the American Council on Renewable Energy predicted that the number of geothermal projects would decrease in part because of the PTC expiration. Very little growth occurred in the geothermal industry in 2014, and the Geothermal Energy Association (GEA) attributes the expiration of, and the uncertainty surrounding the renewing of the PTC, as a main cause.

The Business Energy Investment Tax Credit (ITC), which has recently been expanded in both 2008 and 2009, gives electricity-generating geothermal projects that are running by the end of 2016 a ten percent tax credit on all equipment purchased (excluding transmission equipment).

LOAN GUARANTEES

The federal government can also aid geothermal developers by offering them loans or by offering loan guarantees to geothermal developer’s creditors. Although no new loan guarantees were issued in fiscal year (FY) 2013, the geothermal industry received $13 million in loan guarantees in FY 2010, an amount second only to direct expenditures that year. This type of geothermal industry support is important because exploring and drilling for geothermal reservoirs is financially risky. Private investors have no guarantee that enough geothermal resources to make a return on their investment will be found. Loan guarantees mitigate the risks involved with investing in geothermal projects. Loan guarantees only mask the risks associated with developing geothermal power, therefore they are not true solutions to the problems associated with geothermal. By using government funds to guarantee loans to geothermal developers, risks are not going away. The costs of those risks are just being born by taxpayers. These loan guarantees are a short term governmental fix rather than meaningful progress towards geothermal power’s economic reliability.

RPS MANDATES

Twenty-nine states within the U.S. increase their renewable energy production using Renewable Portfolio Standards (RPS). These state-implemented laws mandate that a specific amount of a state’s electricity consumption, production, or sales must come from renewable sources. Some states require that certain amounts of a state’s RPS be fulfilled...
by a certain energy source such as wind. There are no geothermal-specific RPS requirements, but geothermal power qualifies to fulfill the majority of state RPS mandates.55

In some states, RPS has had little effect on the geothermal industry. For example, a study by ZGlobal Incorporated on the effect of California’s RPS reported that several thousand megawatts of both wind and solar power capacity had either been added, or had been put under development since the state’s RPS was passed, but only 100 megawatts of geothermal power capacity had been added, despite California’s abundant geothermal resources.56 In other states, geothermal power companies have benefitted more obviously from RPS. In Nevada, a utility company called Nevada Power specifically purchased power from three geothermal power plants in the state in an effort to fulfill RPS requirements.57

ECONOMICS OF GEOTHERMAL DEVELOPMENT

Among the largest barriers to the use of geothermal resources are the risks and high upfront costs associated with the exploration and drilling phases of geothermal development. These upfront capital costs and the high risks deter investment in geothermal energy because there is no guarantee that the expensive capital costs will bring a return on investments. Geothermal power plants, however, have low operations and maintenance costs, as well as zero fuel costs, which allows them to produce electricity cheaply once installed.

CAPITAL COSTS FOR GEOTHERMAL POWER PLANTS

Geothermal power plants have high capital costs compared to other energy sources. The most recent data from the Energy Information Administration indicate that the capital costs of a flash geothermal power plant with a 50 megawatt capacity amount to $6,243 per kilowatt. In contrast, a conventional combustion turbine natural gas plant with a greater 85 megawatt capacity has capital costs that amount to just $973 per kilowatt.58 The International Energy Agency lists the high capital costs of geothermal power plants as one of the main deterrents to the expansion of geothermal power production.59

EXPLORATION AND DRILLING RISKS

Due to the fact that the exploration and drilling phases of a geothermal project may fail to find an adequate geothermal resource, geothermal projects must be financed by investors who are willing to take considerable financial risks. This makes it difficult for geothermal projects to find funding.60 A geothermal developer may expend millions of dollars in the exploration phase before realizing that they are unlikely to find a useful geothermal reservoir in the area, and have to abandon the project.61 Well drilling for geothermal resources is frequently unsuccessful. A recent study of over 2,500

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geothermal wells by the International Finance Corporation found that, on average, 78 percent of well drillings were successful, with variation in success rates occurring across different geothermal fields. Roughly one third of geothermal fields studied had drilling success rates of 60 percent or lower. Thirteen percent of fields, however, had drilling success rates of 90 percent or higher. Success rates also varied depending on the stage of geothermal development being assessed. The study found that success rates are the lowest in the earlier stages of a geothermal project (59 percent for the first five wells), but that success rates increased as the project progressed. This potential for risk, combined with high capital costs, discourages investors from financing geothermal projects.

Drilling for oil may seem similar to drilling for geothermal, and as a result, should suffer from the same lack of investment as seen in the geothermal industry. But drilling for oil is less expensive, less risky, and has higher returns on investments than drilling for geothermal. As mentioned before, success rates for geothermal drilling stand at about 78 percent, but the drilling success rates for oil wells is approximately 90 percent. Furthermore, drilling for geothermal reserves is more difficult and costly than drilling for oil reserves. The Handbook of Best Practises for Geothermal Drilling notes that oil reserves are accessed through sedimentary rock, whereas geothermal reserves are usually accessed by drilling through metamorphic and igneous rocks, which are hotter, harder, more abrasive, and more corrosive. A Massachusetts Institute of Technology study that quantified the cost difference between drilling for geothermal resources and drilling for oil and gas found that the cost of drilling a geothermal well is at least double the cost of drilling an oil or gas well of the same depth. Not only is drilling for geothermal more risky and expensive, evaluating geothermal resources requires more exploratory drilling than drilling for oil and natural gas. This is because there is less survey data on geothermal resources than there are for oil and gas resources. Furthermore, the analytical software that is used to evaluate and model subsurface resources is tailored for analyzing potential oil and gas resources, and is poor at analyzing geothermal resources. These factors make drilling for geothermal more time-consuming and costly than oil-drilling operations, and make the rate of return on investments lower for geothermal drilling than they are for oil and gas drilling. The profit to investment ratios for geothermal development are also lower than they are for oil and gas. In other words, the payoff for investing an amount of money in a geothermal project is lower than the payoff for investing that same amount of money in oil or natural gas.

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Another risk is that geothermal reservoirs, once developed, may not produce as much power as expected, sometimes leaving investors with an inability to pay off their loans. One beneficiary of the 2009 American Reinvestment and Recovery Act was the Blue Mountain geothermal power plant in northern Nevada, owned by Nevada Geothermal. The power plant received $79 million in loan guarantees and a grant of $66 million through the American Recovery and Reinvestment Act. Even with such generous government support, the power plant still struggled to pay back its private loans because, upon startup, it was only able to produce 27 megawatts rather than the 45 megawatts Nevada Geothermal had predicted. As a result, the government partly guaranteed a second $98.5 million loan for Nevada Geothermal in 2010.\textsuperscript{71}

Government subsidies make it easier for developers to overcome the high risks and startup costs associated with geothermal power development, but these risks and costs are then borne by taxpayers. Furthermore, when public funds are used to back developers’ investments, developers do not face as much personal loss for making a poor investment, and have less of an incentive to be risk-averse. When developers use private investments, however, they have a greater incentive to minimize potential losses by avoiding unnecessary financial risk.

Improvements in geothermal exploration and drilling technologies could decrease the costs and risks associated with geothermal development by increasing drilling efficiency and making resource evaluations more accurate, for example. Success rates for geothermal well drilling during the exploration phase are already improving, most likely due to advancements in geothermal surveys.\textsuperscript{72} In an effort to expand the use of geothermal energy, the Department of Energy (DOE) opened up $70 million in funding for the improvement of geothermal resource evaluation, exploration, drilling, and engineering in 2011.\textsuperscript{73} The profit motive faced by geothermal developers also acts as an incentive to find more cost-effective ways to develop geothermal resources.

**OPERATING COSTS OF GEOTHERMAL PLANTS**

Despite its high initial capital costs, geothermal power plants have low operations and maintenance costs. Figure 6 breaks down the costs of a geothermal power plant from its exploration phase to its operations phase. Exploration and drilling costs make up approximately 51 percent of the total project costs for geothermal power plants, and plant construction essentially makes up the other 49 percent. In comparison to the capital costs, the costs to operate a


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Geothermal power’s low operation and maintenance costs are in part due to the fact that geothermal plants, unlike coal or natural gas plants, have no fuel costs.\textsuperscript{75}

**OVERALL COST OF GEOTHERMAL**

In summary, geothermal power plants have high capital investment costs for exploration, drilling wells, and plant installation, but have exceptionally low operation and maintenance costs.\textsuperscript{76} The levelized cost of energy (LCOE) is a measure used to compare the costs different energy sources over their entire lifetime. A power source’s LCOE, expressed in dollars per kilowatt hour, is calculated by taking the average total cost to build and operate a power plant and dividing it by a power plant’s total output over its lifetime.\textsuperscript{77} According to recent estimates by the Energy Information Administration (EIA), geothermal power has one of the lowest LCOE values compared to other energy sources (see Figure 8). This is because the low operating costs, long plant lifetime, and the high efficiency of geothermal power plants balance out their high initial investments.

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FIGURE 7. LEVELIZED COST OF ENERGY COMPARISON FOR GENERATION SOURCES IN 2020.

<table>
<thead>
<tr>
<th>Power Plant Type</th>
<th>Levelized Cost of Energy ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal</td>
<td>47.8</td>
</tr>
<tr>
<td>Wind (Onshore)</td>
<td>73.6</td>
</tr>
<tr>
<td>Natural gas (conventional combined cycle)</td>
<td>75.2</td>
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<tr>
<td>Hydroelectric</td>
<td>83.5</td>
</tr>
<tr>
<td>Conventional Coal</td>
<td>95.1</td>
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<tr>
<td>Advanced Nuclear</td>
<td>95.2</td>
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<tr>
<td>Biomass</td>
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<td>Solar (PV)</td>
<td>125.3</td>
</tr>
<tr>
<td>Solar (Thermal)</td>
<td>239.7</td>
</tr>
</tbody>
</table>

The levelized cost estimate does not encompass the full costs of investing in a geothermal project. Levelized costs estimate the cost to develop, operate, and decommission a power plant over its lifetime, but this does not take into account that fact that a geothermal project may fail in the early stages and not result in a power plant at all. Levelized costs, by their definition, do not take into account the financial losses that come with projects that do not result in a power plant.

power plant. Investors have to take into account the costs of these risks, as well as the levelized cost of geothermal energy.

VERDICT ON ECONOMIC RELIABILITY

Government subsidies are using taxpayer dollars to distort the energy market and artificially favor risky geothermal projects. Without subsidies, the market for geothermal will dictat its overall success, with entrepreneurs developing the most cost-effective geothermal sites at their own risk. As new technology develops, drilling and exploration costs may go down, making geothermal power more attractive for investors. Until then, geothermal power cannot be considered economically reliable. Geothermal energy is currently not an economically reliable source of energy due to its reliance on government programs and funding to compete and expand in the energy market.

PHYSICAL RELIABILITY

Geothermal power plants are physically reliable because they can consistently provide enough power to meet electricity demand and can adjust their output in response to changes in electricity demand. The potential to harness geothermal power, however, is limited because certain geological conditions must be present to make geothermal power production in an area possible. A second physical barrier to the use of geothermal power is the need for new transmission infrastructure to move remotely-located geothermal power to population centers.

EFFICIENCY

Geothermal plants, like nuclear and fossil fuel plants, are highly efficient. This gives geothermal energy an important advantage over wind and solar energy, which are inefficient due to their intermittency. The efficiency of a power plant is measured by its capacity factor, which is the ratio of the power plant’s actual output to its potential output (if operating at full capacity) over a period of time. Geothermal power plants have a capacity factor range of 70 to 95 percent, a range comparable to other efficient power plant types such as nuclear (85-90%) and natural gas plants (40-90%). In contrast, wind power plants have a capacity factor range of 30-50 percent, and solar power plants a range of 16-30 percent.79

BASELOAD POWER AND FLEXIBILITY

Base load power is the amount of power that an electricity company must be generating at all times to meet minimum demands for electricity.80 Geothermal power plants can serve as a baseload supply of electricity due to their ability to operate around the clock.81 A geothermal power plant’s ability to provide consistent baseload power makes it superior, from a reliability perspective, to wind and solar power plants, which have an inconsistent, weather-dependent power output. Currently, there are 24 countries that make use of geothermal power plants as a baseload for electricity, with more exploring the possibility of using geothermal for baseload power in the future.82

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Not only can geothermal power plants produce the consistent output needed to fulfill base load demands, they can also operate in modes which allow them to serve as load following or reserve power plants, plants that change their output as electricity demand fluctuates. According to the Geothermal Energy Association, a load-following plant operates as a slow response to changes in electricity demands throughout the day and night. During the morning and afternoon, when energy demands are high, a load-following plant increases its energy output. At night, the plant reduces output as demand decreases. Reserve power plants are used by grid operators to meet smaller changes in demand that occur within minutes. The flexibility of geothermal power plant’s output makes them useful for a wide variety of purposes, and gives them an advantage over wind and solar power, whose output is at the mercy of the weather.

DEPENDENCE ON GEOGRAPHY

Certain geological conditions must be present in an area to make the generation of geothermal power possible: high underground temperatures, geothermal fluid, and access to that fluid. Figure 8 illustrates geothermal potential throughout the U.S. The black dots indicate the locations of naturally-occurring geothermal reservoirs, and the colors of the map indicate underground temperatures across the U.S. at 3-10 kilometers below the surface. Areas with high underground temperatures but no naturally-occurring reservoirs are potential locations for Enhanced Geothermal Systems, which are discussed in another section of this report. In the United States, potential geothermal locations are most commonly found in the West because of its high underground temperatures.

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The greatest subterranean temperatures occur in areas near active volcanos. Seismic activity together with the movement of magma in these areas crack and fracture rock casing, permitting hot water to escape to the surface, which causes geysers and hot springs to form. These geysers and hot springs can reach temperatures greater than 430 degrees Fahrenheit, making these areas very suitable for geothermal power plants. The Pacific Rim, also known as the Ring of Fire is both an area of high volcanic activity and geothermal potential. At the end of 2013, the United States had 124 geothermal power projects under development or in the planning stages, most of which were located near the Pacific Rim in Nevada, California, and New Mexico.

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POTENTIAL FOR EXPANSION OF THE GEOTHERMAL INDUSTRY

Significant opportunities for the expansion of the geothermal industry exist across the United States, primarily in western states. A report by the U.S. Geological Survey indicates that 39 gigawatts of geothermal production potential exist in 13 of the most geothermal-friendly states in the U.S. Nine gigawatts of this geothermal production potential exists in already-identified geothermal reserves, and the other 30 gigawatts is estimated to exist in undiscovered geothermal reserves. If all this geothermal potential was harnessed, geothermal could produce 4.8 percent of total U.S. electricity production. Enhanced Geothermal Systems could increase the potential for geothermal power production even further. This possibility will be discussed in the “New Technology” section of this report.

TRANSMISSION OF GEOTHERMAL ENERGY

Most of the United States’ geothermal resources are located far away from population centers where electricity is most needed. The majority of geothermal resources in the United States are found in the Western half of the country, but the vast majority of energy demands come from large population centers in the Eastern United States. This disparity limits the potential for geothermal power to supply a significant amount of the United States’ energy consumption. Although electricity can be transmitted long distances, electrical losses from long-distance transmission and lack of...
available transmission infrastructure make long-distance transmission an unideal solution to the geographic constraints of geothermal power.\(^{91}\) In its report on geothermal interconnection, National Renewable Energy Laboratory (NREL) concluded that the most effective use for geothermal power is at the local level.\(^{92}\) The NREL notes that for geothermal power to be transmitted over long-distances, multiple geothermal power plants would need to be aggregated, which would allow geothermal energy to have greater access to existing transmission lines and provide greater justification for the construction of new transmission lines to transmit geothermal power.\(^{93}\)

**VERDICT ON PHYSICAL RELIABILITY**

Geothermal energy is a physically reliable and efficient source of renewable energy when placed in areas with abundant water and geothermal heat. The Western United States is more conducive to geothermal energy because of its high underground temperatures. The physical reliability of geothermal energy gives geothermal plants the ability to provide both a baseload supply of electricity and flexible output of power that can match changes in electricity demand. When accessible in appropriate locations, geothermal is an efficient and versatile source of power.

**ENVIRONMENTAL RELIABILITY**

In comparison to fossil fuels, geothermal energy is an environmentally friendly source of energy. Using geothermal energy, however, is not without environmental costs. Geothermal fluid contains toxic chemicals that must be managed carefully to avoid environmental contamination. Geothermal energy also produces minor emissions, can cause land subsidence, and may induce seismic activity. Most of these problems can be minimized or prevented entirely by using certain technologies and management practices. Because geothermal energy’s environmental costs are small and manageable, geothermal energy is environmentally reliable.

**WATER**

Geothermal fluid can contain heavy concentrations of salt, as well as harmful chemicals and heavy metals like hydrogen sulfide, arsenic, boron, mercury, lead, and aluminum.\(^{94}\) The hotter the geothermal fluid, the more dissolved minerals it carries. High levels of minerals in geothermal reservoirs are problematic because they can contaminate local environments and water sources.\(^{95}\)

To prevent environmental contamination, geothermal fluids are injected back into different reservoirs from where they were extracted. The thick casings of geothermal wells prevent the geothermal fluid from coming in contact with groundwater during this process.\(^{96}\) To prevent runoff from escaping into local ecosystems, geothermal developers

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collect the surface runoff from geothermal power plants into impervious holding ponds.97 The success of these measures is illustrated by the lack of a single reported instance of water contamination from a geothermal site in the United States.98

Geothermal power plants use water to cool the steam they use back into a reusable liquid form. The amount of water a geothermal plant needs depends heavily on the type of cooling system used. To illustrate, a report by the NREL found that binary-cycle geothermal plants with cooling towers used 1,700-3,963 gallons of water per megawatt hour. In contrast, binary-cycle geothermal plants with dry cooling systems used 0-270 gallons of water per megawatt hour.99

Geothermal power plants can use local freshwater sources for their water needs or they can use the geothermal fluid and recycle it by re-injecting the fluid back into its geothermal reservoir.100 Even if water is recycled, however, geothermal plants still lose water to steam during the cooling process. Because of this water loss, geothermal power plants still have to add water to geothermal reservoirs to maintain water levels.101 Using local fresh water supplies, however, is not the only option. Geothermal developers at the Geysers in California, for example, resupply their reservoirs by injecting them with sewage water.102

**AIR EMISSIONS**

There is variation in the emissions produced by geothermal plants. This is because geothermal sites naturally produce emissions regardless of whether a power plant is present or not and each naturally-occurring geothermal site has a unique chemical makeup, which affects the amount as well as the type of emissions it produces. Furthermore, different types of geothermal power plants and management practices have different effects on the naturally-occurring geothermal emissions already present in the area. For example, geothermal power plants typically accelerate the release of carbon dioxide from a geothermal reservoir into the atmosphere. The practice of regularly injecting fluid back into the reservoir, however, can mitigate this effect because the injected fluid absorbs carbon dioxide that would otherwise seep into the atmosphere. Overall, geothermal power plants produce minor emissions, although there is also variation from plant to plant.103

Geothermal power plants have significantly fewer emissions than fossil-fuel power plants.104 Geothermal plants do not burn fuel as a means of energy, which results in minimal amounts of emissions. The amount of emissions a geothermal power plant produces significantly depends on the power plant type. Flash and dry-steam plants, which directly use geothermal fluid, produce emissions because geothermal fluid contains dissolved gases that are released into the

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atmosphere when brought to the surface. These plants can emit nitrogen oxide, sulfur dioxide, particulate matter, and carbon dioxide in small amounts. Binary geothermal plants produce almost no emissions because they vaporize a secondary fluid to produce power instead of using the steam from geothermal fluids directly. When compared to coal power plants, flash and dry-steam geothermal power plants emit less than one percent of the nitrous oxide, one percent of the sulfur dioxide, and about five percent of the carbon dioxide emitted by a coal-fired plant of the same production capacity.

LIFE CYCLE ASSESSMENTS

Life Cycle Assessments (LCA) are a measure of the greenhouse gas emissions a power plant will cause over its entire lifetime, from its construction phase to its decommissioning. LCAs of geothermal plants affirm that geothermal plants produce less greenhouse gas emissions than fossil fueled plants, and reveal that a significant portion of geothermal plant emissions are produced during their construction, exploration, and drilling phases.

Drilling operations have the largest impact on geothermal power’s lifetime emissions. This is due to the combustion of diesel fuel in order to power drilling machines through large amounts of earth and rock. Once a geothermal power plant is constructed, the greenhouse gas emissions that occur over the rest of its life are negligible for most types of geothermal power plants. In theory, binary plants emit zero greenhouse gas emissions during their operations phase.
but flash plants, the most common types of geothermal power plant, have noticeably larger emissions during the operations phase due to the exposure of geothermal fluid to the atmosphere.\textsuperscript{114,115,116,117,118}

According to a study by the US Department of Energy, the average carbon dioxide emissions for a geothermal plant over its lifetime amount to 91 grams per kilowatt hour (g/kWh), with flash plants averaging 106 g/kWh.\textsuperscript{119} Coal plants emit 939 g/kWh and natural gas plants emit 549 g/kWh.\textsuperscript{120} Furthermore, compare these numbers to the average carbon dioxide emission for renewable power plants including: 10 g/kWh for wind,\textsuperscript{121} 40 g/kWh for solar,\textsuperscript{121} 4-14 g/kWh for hydropower,\textsuperscript{122} and 16-74 g/kWh for biomass.\textsuperscript{124} To summarize these numbers, geothermal emits far less carbon dioxide than fossil fueled plants, but does have higher average numbers than we typically see in other renewables. These numbers can be misleading, however.

Electricity generation from wind and solar does not produce emissions directly, but the intermittency of wind and solar power forces grid operators to back them up with more dependable sources like coal or natural gas when the wind stops blowing or clouds block out the sun. Because wind and solar power often require fossil fuel power plants for backup, and because the emissions produced by these backup sources is not accounted for in the LCAs of wind and solar power, the LCAs of wind and solar power suggest that these power sources are more environmentally friendly than they actually are. Unlike wind and solar plants, geothermal plants can produce power consistently, and do not need to be backed up by potentially dirty sources of power. If one of the main purposes of using clean, renewable energy is to displace environmentally harmful fossil fuels, geothermal energy, where available, is a much better alternative than wind and solar energy.

LCAs are also limited by the variation that occurs between geothermal plants. The environmental friendliness of a single geothermal plant depends on the power plant’s reservoir conditions as well as the power plant’s type.\textsuperscript{125} LCAs


\textsuperscript{125} Lacirignola, M. and Blanc, I. (2012, August). Environmental analysis of practical design options for enhanced geothermal systems (EGS)
are useful for making broad conclusions about the environmental friendliness of geothermal power, but they cannot be used to effectively determine environmental impacts of a particular geothermal plant, due to variation in individual plant emissions.

HYDROGEN SULFIDE

In addition to carbon dioxide emissions, geothermal plants can emit up to 1900 lbs./hr. of hydrogen sulfide, a toxic and flammable gas that is naturally present in many geothermal reservoirs. These federal hydrogen sulfide regulations have helped reduce hydrogen sulfide emissions from their highest average of 1900 lbs./hr. in 1979 to an average of less than 200 lbs./hr. Some geothermal developers manage hydrogen sulfide emissions with advanced abatement equipment, which converts more than 99 percent of hydrogen sulfide into sulfur, an element with practical agricultural uses.

LAND USE

The amount of land used by a geothermal power plant depends on its power capacity, the spacing of its wells, the size of its reservoirs and auxiliary buildings, and the type of conversion and cooling systems it uses. As a general rule, geothermal power plants are built at or near geothermal reservoirs because geofluid energy, in the form of temperature and pressure, is lost in transmission. The U.S. Department of Energy estimates an average geothermal field uses 1-8 acres per megawatt, as opposed to the 5-10 acres for nuclear plants and 19 acres for coal power plants. Geothermal power’s land use requirements make it favorable to other renewable power sources such as solar power, which uses between 4.7 and 10 acres per MW depending on the technology, and wind power, which requires anywhere from 22 to 247 acres per megawatt. Land use is an important environmental consideration. The less land needed to produce energy, the less likely it is that energy production will affect natural ecosystems.

Another land-based environmental risk associated with geothermal energy is the potential for land subsidence, which occurs when the removal of water from underground reservoirs causes the land above to sink in. This phenomenon was through life-cycle assessment. Renewable Energy, 50, p. 913. Retrieved from http://www.researchgate.net/profile/Isabelle_Blanc/publication/235653833_Environmental_analysis_of_practical_design_options_for_enhanced_geothermal_systems_EGS_through_life_cycle_assessment/links/54f46ec40cf299c8d9e76082.pdf


Reliability of Renewable Energy: Geothermal
first observed in the Wairakei Power Station in New Zealand, where the plants did not use any type of reinjection. The rate of subsidence in this area was recorded at levels as high as 0.45 meters per year. To prevent land subsidence, plants have continued the practice of injecting used geothermal fluids and other sources of water back into the reservoirs once the heat has been captured.\(^{135}\)

**SEISMIC ACTIVITY**

Geothermal plants are usually located on or near geological "hot spots," which generally have higher amounts of seismic activity.\(^{136}\) Figure 9 below shows the areas in the United States that have the highest risk for seismic activity. These areas also tend to be areas with high geothermal potential.

**FIGURE 9. SIMPLIFIED 2014 HAZARD MAP (PGA, 2% IN 50 YEARS).**\(^{137}\)

Drilling for geothermal resources, as well as removing fluid from and injecting it back into underground reservoirs can increase seismic activity in these areas. A 2013 study on a geothermal field in Southern California found a strong correlation between seismic activity and the amount of fluid being extracted from and injected into the earth by geothermal power plants in the area.\(^{138}\) Furthermore, all the earthquakes that have occurred at The Geysers, another California Geothermal Plant, since 1975 have been caused by geothermal energy production. The largest earthquake


had a magnitude of just under 4.5. Geothermal developers can minimize the amount of seismic activity they induce by reducing the size of the fractures they drill into the earth’s crust. The larger the fracture created, the more seismic activity induced. At The Geysers, developers aim to keep earthquakes small, with a magnitude of less than 2. Generally speaking, the seismic activity caused by geothermal energy production is notable, but not a serious threat.

**NOISE POLLUTION**

Another environmental impact from geothermal energy is its noise pollution, which negatively impacts wildlife, as well as humans. According to the Office of Energy Efficiency and Renewable Energy, the highest noise levels caused by a geothermal project generally occur during the drilling-and-exploration phase, and range from about 80 to 115 decibels, a range typical of many industrial activities. The normal operations of geothermal plants result in noise levels between 71 and 83 decibels, or approximately the same amount of decibels emitted by a vacuum cleaner. The level of noise pollution emitted by geothermal plants is not high enough to cause notable impacts on the surrounding environment.

**VERDICT ON ENVIRONMENTAL RELIABILITY**

Geothermal energy is environmentally reliable compared to fossil-fueled energy sources. The production of geothermal power does have negative environmental impacts, such as increased seismic activity and greenhouse gas emissions, but these impacts are negligible. As long as developers take appropriate measures to prevent or mitigate these environmental impacts, geothermal energy is environmentally reliable.

**NEW TECHNOLOGY: ENHANCED GEOTHERMAL SYSTEMS**

The ability to produce geothermal power is constrained to areas that have several key geological characteristics. Even areas with high underground temperatures may lack water to be vaporized into steam or sufficient accessibility through rock openings. The development of Enhanced Geothermal Systems (EGS) could dramatically increase geothermal potential in the United States. The U.S. Geological Survey evaluated 13 different states and its mean estimates indicate that there are 518 gigawatts of potential power production in EGS, compared to the 30 gigawatts of potential power available for conventional geothermal power systems.

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Though full scale EGS power plants have not been developed, pilot EGS projects have been successfully implemented in Europe, as well as in Australia and Japan. In the United States, the DOE has started its multiphase effort, Frontier Observatory for Research in Geothermal Energy (FORGE), by selecting 5 projects to fund for EGS development. FORGE beginning phases will grant a total of $31 million to selected projects and fund one project to full development. The DOE estimates that its FORGE projects could supply power to 100 million US homes.

The deployment and use of EGS, however, increases the risk of earthquakes. The increased risk of earthquakes is attributed to the pumping of high-pressure water to frac underground hot-rock reservoirs. This practice has been compared to the method of hydraulic fracturing used to extract natural gas from rock. In December 2006, a geothermal project in Basel, Switzerland drilled three miles into the earth’s crust. The drilling set off larger-than-expected earthquakes. The drilling team responded by attempting to halt their activities, and, in doing so, set off an even larger earthquake with a magnitude of 3.4.

Furthermore, the costs of EGS are prohibitively high. The largest barrier to the deployment of geothermal systems generally is the high upfront capital costs. This problem is even more prominent for EGS. Data on the costs of EGS is limited because EGS is still a new technology, but early estimates indicate that EGS has, and will continue to have, higher capital costs than conventional geothermal in the future.

The International Resources Group reports that the capital costs of EGS are 37 percent higher than the capital costs of conventional geothermal systems. A separate study on the costs of EGS by GeothermEx Inc. estimated that the capital costs of EGS systems in 2050 will be 14 percent higher than the capital costs of conventional geothermal power plants. Figure 10 below shows estimates of the capital costs for EGS versus those of building a geothermal plant on naturally occurring geothermal reservoirs from 2008 to 2050. In each year, the capital costs of EGS decrease, but they are still estimated to be significantly higher than those of conventional geothermal in 2050.

FIGURE 10. CAPITAL COSTS OF CONVENTIONAL GEOTHERMAL AND ENHANCED GEOTHERMAL SYSTEMS\textsuperscript{155}

<table>
<thead>
<tr>
<th>Year</th>
<th>Conventional Geothermal Capital Cost ($/kW)</th>
<th>EGS Capital Cost ($/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>6,240</td>
<td>10,400</td>
</tr>
<tr>
<td>2010</td>
<td>5,940</td>
<td>9,900</td>
</tr>
<tr>
<td>2015</td>
<td>5,940</td>
<td>9,720</td>
</tr>
<tr>
<td>2020</td>
<td>5,940</td>
<td>9,625</td>
</tr>
<tr>
<td>2025</td>
<td>5,940</td>
<td>9,438</td>
</tr>
<tr>
<td>2030</td>
<td>5,940</td>
<td>9,250</td>
</tr>
<tr>
<td>2035</td>
<td>5,940</td>
<td>8,970</td>
</tr>
<tr>
<td>2040</td>
<td>5,940</td>
<td>8,786</td>
</tr>
<tr>
<td>2045</td>
<td>5,940</td>
<td>8,600</td>
</tr>
<tr>
<td>2050</td>
<td>5,940</td>
<td>8,420</td>
</tr>
</tbody>
</table>

Furthermore, because the capital costs of EGS are higher than that of conventional geothermal, the rate of return on EGS investments and their profit-to-investment ratios are expected to be lower than the already-low rates of return and profit-to-investment ratios for conventional geothermal.\textsuperscript{156} Despite the large amount of EGS potential in the United States, EGS is even less likely to be developed than conventional geothermal because it has higher upfront costs and lower returns on investments, thus requiring more government assistance than conventional geothermal to become economically viable.

**CASE STUDY: ICELAND**

Iceland is located on the Mid-Atlantic Ridge, where divergent tectonic plates bring magma close to the earth’s surface, providing the island country with an abundance of geothermal resources.\textsuperscript{157}


The three biggest obstacles to geothermal development are the risks of early-stage geothermal exploration, high capital costs, and lack of technical and scientific data and knowledge. Less than half a century ago, the government of Iceland invested in geothermal research and development because of a lack of private investment in the geothermal industry. Today, Iceland uses geothermal energy to meet a large proportion of its energy needs. Iceland’s experience does demonstrate the physical reliability of geothermal power, however, implementing geothermal power production on a scale comparable to Iceland would be prohibitively costly for the United States.

**HISTORY OF GEOTHERMAL POWER IN ICELAND**

As stated by the National Energy Authority and Ministries of Industry and Commerce, the production and distribution of electricity from geothermal resources in Iceland has almost always been in the public domain or carried out by publicly-owned corporations. In 1965, the government founded Landsvirkjun, the national power company of Iceland, to optimize the country’s natural energy resources. As mentioned by Askja Energy, Landsvirkjun is currently the greatest electricity producer in Iceland, generating 75 percent of electricity used in the country. Even today, the company

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oversees most of the power plants and provides long-term renewable energy contracts for energy-intensive industries.\textsuperscript{161}

As explained by President of Iceland Olafur Ragnar Grimsson, in his testimony to the U.S. Senate in 2007, the Icelandic government set up the Energy Fund in 1967 to provide loans and grants to companies interested in geothermal drilling. But, because the results of drilling did not always yield the expected results, the loans sometimes had to be converted into grants.\textsuperscript{162} In 1969, the National Energy Authority conducted its first exploration program, and since then it has carried out and supervised most of the country’s geothermal projects together with government or municipal companies.\textsuperscript{163}

In 2003, the Icelandic government passed Electricity Act No. 65/2003, which allows private enterprises to generate and sell their own electricity. The passing of this act disrupted the government’s monopoly on Iceland’s energy market.\textsuperscript{164} Three companies now dominate Iceland’s current energy market: Landsvirkjun, the biggest state-owned company; Orkuveita Reykjavikur, which is owned by municipalities; and HS Orka, the only company in private hands, owned by the Canadian firm Alterra Power and a group of Icelandic pension funds. Other smaller energy firms and utilities are owned by the Icelandic state government and municipalities.\textsuperscript{165}

As of 2015, Iceland has seven geothermal power plants. These power plants are operated by public and private companies and produced a total of 5,245 gigawatt hours in 2013, which accounted for 29 percent of Iceland’s total electricity production.\textsuperscript{166} As the statistics from the National Energy Authority of Iceland report show, the rest of Iceland’s power production came almost exclusively from hydropower plants.\textsuperscript{167}

According to Eurostat, Iceland has among the lowest electricity prices in the European Union.\textsuperscript{168} These low prices are likely attributable to the low operations and maintenance costs and zero fuel costs of geothermal plants.\textsuperscript{169} These low electricity prices are attractive to electricity-intensive industries. For example, three major international aluminum investors: Alcoa, Rio Tinto Alcan, and Century Aluminum, have located their electricity-intensive aluminum smelters in Iceland.\textsuperscript{170}

ANALYSIS

Iceland is held up as a shining example of the benefits and cost-effectiveness of geothermal power, but such praise neglects important considerations. Iceland may be able to produce electricity cheaply now, however, the majority of the costs and risks associated with developing geothermal were subsidized by the Icelandic government and thus necessarily born by Icelandic citizens through taxation or debt. Current electricity prices hide the true cost that implementing geothermal energy has had on Icelandic citizens.

Also, Iceland has specific characteristics that make achieving such high penetrations of geothermal power possible. Meeting a large proportion of energy demands through one energy source was possible in Iceland, but would be unrealistic for countries like the United States. Iceland has a small population, and by association, small energy demands, which makes it easier for Iceland to draw all of its power needs from a single energy source. The United States already produces three times more geothermal power than Iceland, yet geothermal energy accounts for just 0.4 percent of the United States’ total electricity generation. At most, geothermal could account for 4.8 percent of total U.S. electricity production, but this would require massive subsidization to overcome upfront costs and risks, as well as the construction of transmission infrastructure to transmit power from remote geothermal resources to population centers. In the future, EGS may allow more electricity needs in the U.S. to be supplied by geothermal, but EGS systems are even more costly and would require more government subsidization than conventional geothermal.

Furthermore, the entire country of Iceland is conducive to generating geothermal energy. Other countries, like the United States, only have easily accessible geothermal reserves in localized areas. These geographic restrictions limit the ability of the United States to supply energy demands with geothermal power to a similar proportion as Iceland without the construction of new transmission lines.

The United States’ large energy demands and localized geothermal reserves indicate that it would be unrealistic for the United States to attempt to supply significant proportions of its energy demands using geothermal power. Even Iceland, which did not have these limitations, needed extensive government involvement and subsidization to draw significant proportions of its energy from geothermal resources. The need for subsidization would be exacerbated if a similar attempt at high penetrations of geothermal power was made in the United States. Iceland’s experience does illustrate that geothermal power is a physically reliable power source, however, it would be prohibitively costly for the United States to implement geothermal power production on a scale comparable to Iceland.

CONCLUSION

Public interest in renewable energy is growing, and policymakers have enacted legislation intended to distort energy markets in favor of renewables like geothermal power. Although geothermal electricity production is physically reliable


173 See footnote 90 for references and explanations regarding this calculation.
and more environmentally friendly than traditional fossil fuels, its high startup costs discourage private investment in geothermal energy. Although policymakers favor geothermal power through mandates and subsidies, markets, not government policies, are best equipped to determine the true economic viability of geothermal power. New technology and increased market demand will likely decrease the need for subsidies and make geothermal more economically viable.

Much of the geothermal industry relies on government support, and has grown most rapidly after the enactment of major renewable-energy government policies. Because of the high capital investment costs for exploration, drilling, and plant installation, geothermal power is not attractive to investors, who fear a low return on investment. Government subsidies offset these high costs for the energy producer, but these costs are supported by taxpayer money. The true cost of geothermal power is higher than most people think due to the hidden costs of government policies. Once a geothermal facility is established and becomes operational, however, it can be profitable for decades due to low operation and maintenance costs. Ignoring the costs of subsidies and other financial incentives for the geothermal industry, a geothermal plant has one of the lowest levelized costs of any renewable energy.

Geothermal energy is physically reliable because it can provide a consistent baseload supply of electricity. Its flexibility also allows it to be used to accommodate changes in electricity demand. Geothermal has one of the highest capacity factors for a renewable energy source, ranging from 70-95 percent. Geothermal power, however, is geographically constrained. In the United States, viable geothermal sites are located in Western states.

Geothermal is more environmentally friendly than traditional fossil fuels because it has fewer emissions and impacts on land. Environmental considerations for geothermal include: geothermal fluids that contain toxic chemicals, minor air emissions of greenhouse gases and pollutants, risks of land subsidence, and a higher risk of increased seismic activity. Despite these negative environmental impacts, technology and management practices can reduce these environmental costs to a negligible level.

Iceland produces more than a quarter of its electricity from geothermal energy. Iceland’s experience illustrates geothermal power is reliable and potentially profitable in ideal locations. But for the United States, reaching Iceland’s levels of geothermal energy would require far more geothermal plants to be built in less viable locations, necessitating increasing amounts of money to be spent in exploration-and-drilling costs, transmission lines, and subsidies to keep the geothermal industry afloat. American taxpayers would have to bear the burden of those costs through higher taxes and electricity prices.

Geothermal power’s largest barrier in the United States is the economic cost of exploring and drilling new sites, but as technology develops, more private investors may find more enticing returns on investment in the geothermal industry. The role of geothermal power in America’s energy portfolio is a question best addressed by market forces, not government policies.