Geothermal Energy for Electric Power

A REPP Issue Brief

December 2003

By Masashi Shibaki
Fredric Beck, Executive Editor

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FORWARD

This paper provides a general background on utility-scale geothermal power and seeks to teach the readers a basic understanding of geothermal power, as well as build a solid foundation for further understanding of the technical, economic, and policy dimensions of geothermal power worldwide. Economic data and current U.S. geothermal policy help illustrate the concepts of this paper. Readers may refer to the extensive references to reports and Web links to well-established geothermal energy sources, at the end of this brief to learn the latest developments in geothermal power's role in clean energy generation.

INTRODUCTION

Geothermal[1] energy is energy derived from the heat of the earth's core. It is clean, abundant, and reliable. If properly developed, it can offer a renewable and sustainable energy source. There are three primary applications of geothermal energy: electricity generation, direct use of heat, and ground-source heat pumps. Direct use includes applications such as heating buildings or greenhouses and drying foods, whereas ground source heat pumps are used to heat and cool buildings using surface soils as a heat reservoir. This paper covers the use of geothermal resources for production of utility-scale electricity and provides an overview of the history, technologies, economics, environmental impacts, and policies related to geothermal power.

GEOTHERMAL RESOURCES

Understanding geothermal energy begins with an understanding of the source of this energy—the earth's internal heat. The Earth's temperature increases with depth, with the temperature at the center reaching more than 4200 °C (7600 °F). A portion of this heat is a relic of the planet's formation about 4.5 billion years ago, and a portion is generated by the continuing decay of radioactive isotopes. Heat naturally moves from hotter to cooler regions, so Earth's heat flows from its interior toward the surface.[2]

Because the geologic processes known as *plate tectonics*, the Earth's crust has been broken into 12 huge plates that move apart or push together at a rate of millimeters per

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year. Where two plates collide, one plate can thrust below the other, producing extraordinary phenomena such as ocean trenches or strong earthquakes. At great depth, just above the down going plate, temperatures become high enough to melt rock, forming magma.[3] Because magma is less dense than surrounding rocks, it moves up toward the earth's crust and carries heat from below. Sometimes magma rises to the surface through thin or fractured crust as lava.

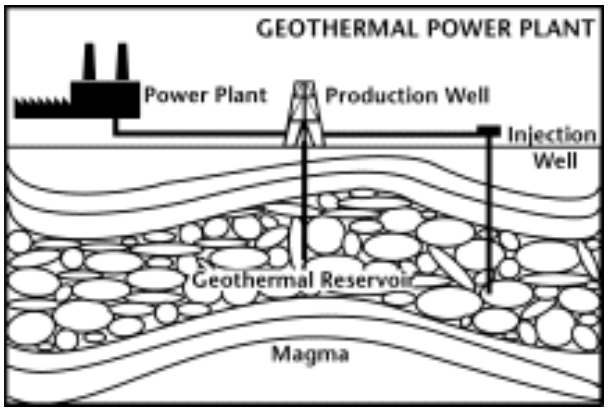


Figure 1. Schematic of geothermal power plant production and injection wells.

Source: U.S. Department of Energy
http://www.eia.doe.gov/kids/renewable/geothermal.html

However, most magma remains below earth's crust and heats the surrounding rocks and subterranean water. Some of this water comes all the way up to the surface through faults and cracks in the earth as *hot springs* or *geysers*. When this rising hot water and steam is trapped in permeable rocks under a layer of impermeable rocks, it is called a *geothermal reservoir*. These reservoirs are sources of geothermal energy that can potentially be tapped for electricity generation or direct use. Figure 1 is a schematic of a typical geothermal power plant showing the location of magma and a geothermal reservoir.[4] Here, the production well withdraws heated geothermal fluid, and the injection well returns cooled fluids to the reservoir.

Resource Identification

Geological, hydrogeological, geophysical, and geochemical techniques are used to identify and quantify geothermal resources. *Geological and hydrogeological studies* involve mapping any hot springs or other surface thermal features and the identification of favorable geological structures. These studies are used to recommend where production wells can be drilled with the highest probability of tapping into the geothermal resource. *Geophysical surveys* are implemented to figure the shape, size, depth and other important characteristics of the deep geological structures by using the following parameters: temperature (thermal survey), electrical conductivity (electrical and electromagnetic methods), propagation velocity of elastic waves (seismic survey), density (gravity survey), and magnetic susceptibility (magnetic survey).[5] *Geochemical surveys* (including isotope geochemistry) are a useful means of determining whether the geothermal system is water or vapor-dominated, of estimating the minimum temperature expected at depth, of estimating the homogeneity of the water supply and, of determining the source of recharge water.

Geothermal exploration addresses at least nine objectives:[6]

1. Identification of geothermal phenomena
2. Ascertaining that a useful geothermal production field exists
3. Estimation of the size of the resource
4. Classification of the geothermal field
5. Location of productive zones

6. Determination of the heat content of the fluids that will be discharged by the wells in the geothermal field
7. Compilation of a body of data against which the results of future monitoring can be viewed
8. Assessment of the pre-exploitation values of environmentally sensitive parameters
9. Determination of any characteristics that might cause problems during field development

Drilling

Once potential geothermal resources have been identified, exploratory drilling is carried out to further quantify the resource. Because of the high temperature and corrosive nature of geothermal fluids, as well as the hard and abrasive nature of reservoir rocks found in geothermal environments, geothermal drilling is much more difficult and expensive than conventional petroleum drilling. Each geothermal well costs $1–4 million to drill, and a geothermal field may consist of 10–100 wells. Drilling can account for 30–50% of a geothermal project's total cost.[7] Typically, geothermal wells are drilled to depths ranging from 200 to 1,500 meters depth for low- and medium-temperature systems, and from 700 to 3,000 meters depth for high-temperature systems. Wells can be drilled vertically or at an angle. Wells are drilled in a series of stages, with each stage being of smaller diameter than the previous stage, and each being secured by steel casings, which are cemented in place before drilling the subsequent stage. The final production sections of the well use an uncemented perforated liner, allowing the geothermal fluid to pass into the pipe. The objectives of this phase are to prove the existence of an exploitable resource and to delineate the extent and the characteristics of the resource. An exploratory drilling program may include shallow temperature-gradient wells, "slim-hole" exploration wells, and production-sized exploration/production wells. Temperature-gradient wells are often drilled from 2–200 meters in depth with diameters of 50–150 mm. Slim-hole exploration wells are usually drilled from 200 to 3000 meters in depth with bottom-hole diameters of 100 to 220 mm. The size and objective of the development will determine the number and type of wells to be included in exploratory drilling programs.[8]

HISTORY

People have used geothermal resources in many ways, including healing and physical therapy, cooking, space heating, and other applications. One of the first known human uses of geothermal resources was more than 10,000 years ago with the settlement of Paleo-Indians at hot springs.[9] Geothermal resources have since been developed for many applications such as production of electricity and geothermal heat pumps. Prince Piero Ginori Conti invented the first geothermal power plant in 1904, at the Larderello dry steam field in Italy.[10] The first geothermal power plants in the United States were operated in 1960 at The Geysers in Sonoma County, California. Table 1 (below) shows the timeline of the recent history of geothermal energy in the United States.

Table 1. Important Events in the History of Geothermal Energy in the United States[11]

Year	Event
1960	The first large scale geothermal plant was opened and operated at The Geysers in California, with a capacity of 11MW.
1970	The Geothermal Resources Council is formed to encourage the development of geothermal resources worldwide. The Geothermal Steam Act is enacted, providing the Secretary of the Interior with the authority to lease public lands and other federal lands for geothermal exploration and development in an environmentally sound manner. Re-injection of geothermal fluids of spent geothermal fluids back into the production zone began as a means to dispose of wastewater and maintain reservoir life.
1972	The Geothermal Energy Association is formed. The association comprises U.S. companies that develop geothermal resources worldwide for electrical power generation and direct-heat uses. Deep-well drilling technology improvements led to deeper reservoir drilling and access to more resources.
1974	The U.S. government enacts the Geothermal Energy Research, Development and Demonstration (RD&D) Act, instituting the Geothermal Loan Guaranty Program, which provides investment security to public and private sectors using and developing technologies to exploit geothermal resources.
1975	The Energy Research and Development Administration (ERDA) is formed, with the goal of focusing the federal government's energy research. The Division of Geothermal Energy takes over the RD&D program begun in 1974.
1977	The U.S. Department of Energy (DOE) is formed. Hot dry rock geothermal power demonstrated with financial assistance from DOE. Scientists develop the first hot dry rock reservoir at Fenton Hill, New Mexico.
1978	The Public Utility Regulatory Policies Act (PURPA) is enacted. PURPA mandated the purchase of electricity from qualifying facilities (QFs: small power producers using renewable energy sources and cogenerators) meeting certain technical standards regarding energy source and efficiency. PURPA also exempted QFs from both State and Federal regulation under the Federal Power Act and the Public Utility Holding Company Act.
1981	With support from DOE, Ormat successfully demonstrates binary technology in the Imperial Valley of California. The project established the technical feasibility of larger-scale commercial binary power plants. The project is so successful that Ormat repays the loan within a year.
1982	Economic electrical generation begins at California's Salton Sea geothermal field using crystallizer–clarifier technology. The technology resulted from a government/industry effort to manage the high-salinity brines at the site. Geothermal (hydrothermal) electric generating capacity, primarily utility-owned, reached a new high level of 1,000 MW
1989	The world's first hybrid (organic Rankine/gas engine) geopressure-geothermal power plant begins operation at Pleasant Bayou, Louisiana, using both the heat and the methane of a geopressured resource.
1994	DOE creates two industry/government collaborative efforts to promote the use of geothermal energy to reduce greenhouse gas emissions. One effort is directed toward the accelerated development of geothermal resources for electric power generation; the other is aimed toward the accelerated use of geothermal heat pumps.
1995	A DOE low-temperature resource assessment of 10 western states identified nearly 9,000 thermal wells and springs and 271 communities co-located with a geothermal resource greater than 50°C. Worldwide geothermal capacity reaches 6,000 MW
2000	DOE initiates its GeoPowering the West program to encourage development of geothermal resources in the western United States. An initial group of 21 partnerships with industry is funded to develop new technologies.

GEOTHERMAL POWER TECHNOLOGY

Utility-scale geothermal power production employs three main technologies. These are known as dry steam, flash steam and binary cycle systems. The technology employed depends on the temperature and pressure of the geothermal reservoir. Unlike solar, wind, and hydro-based renewable power, geothermal power plant operation is independent of fluctuations in daily and seasonal weather.

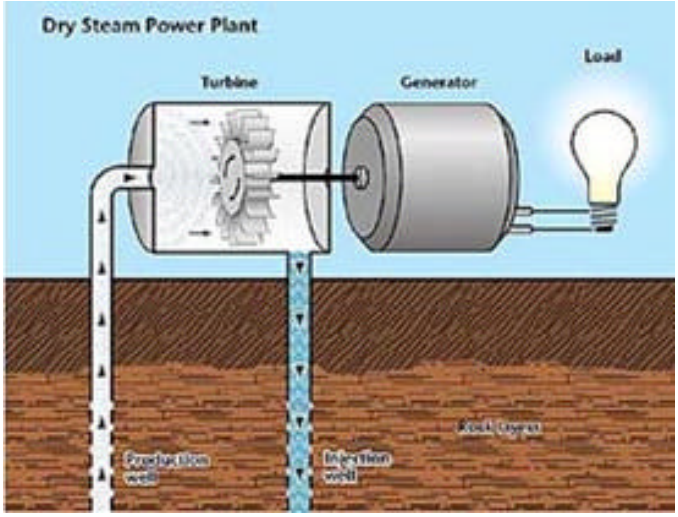


Figure 2. Dry Steam Power Plant Schematic
Source: National Renewable Energy Laboratory (NREL)

Dry steam

Dry steam power plants use very hot (>455 °F, or >235 °C) steam and little water from the geothermal reservoir.[12] The steam goes directly through a pipe to a turbine to spin a generator that produces electricity. This type of geothermal power plant is the oldest, first being used at Lardarello, Italy, in 1904.[13] Figure 2 is a schematic of a typical dry steam power plant.[14]

Flash steam

Flash steam power plants use hot water (>360 ºF, or >182 ºC) from the geothermal reservoir.[15] When the water is pumped to the generator, it is released from the pressure of the deep reservoir. The sudden drop in pressure causes some of the water to vaporize to steam, which spins a turbine to generate electricity. Both dry steam and flash steam power plants emit small amounts of carbon dioxide, nitric oxide, and sulfur, but generally 50 times less than traditional fossil-fuel power plants.[16] Hot water not flashed into steam is returned to the geothermal reservoir through injection wells. Figure 3 is a schematic of a typical

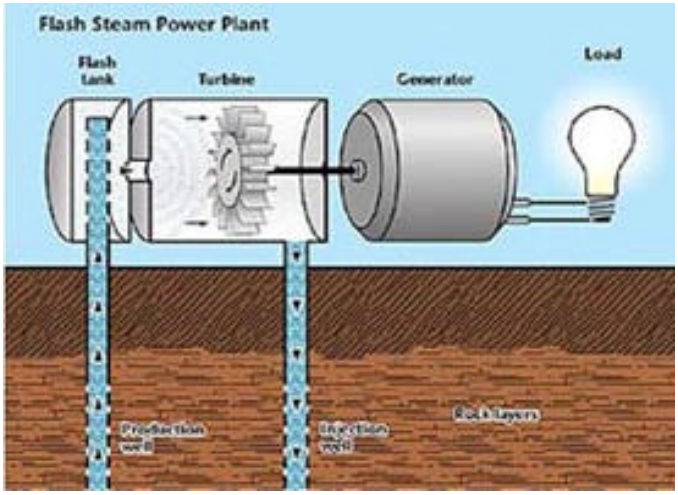


Figure 3. Flash Steam Power Plant Schematic
Source: National Renewable Energy Laboratory (NREL)

flash steam power plant.[17]

Binary-cycle

Binary-cycle power plants use moderate-temperature water (225 ºF–360 ºF, or 107 ºC–182 ºC) from the geothermal reservoir. In binary systems, hot geothermal fluids are passed through one side of a heat exchanger to heat a working fluid in a separate adjacent pipe. The working fluid, usually an organic compound with a low boiling point such as Iso-butane or Iso-pentane, is vaporized and passed through a turbine to generate electricity. An ammonia-water working fluid is also used in what is known as the Kalina Cycle. Makers claim that the Kalina Cycle system boosts geothermal plant efficiency by 20–40 percent and reduces plant construction costs by 20–30 percent, thereby lowering the cost of geothermal power generation.

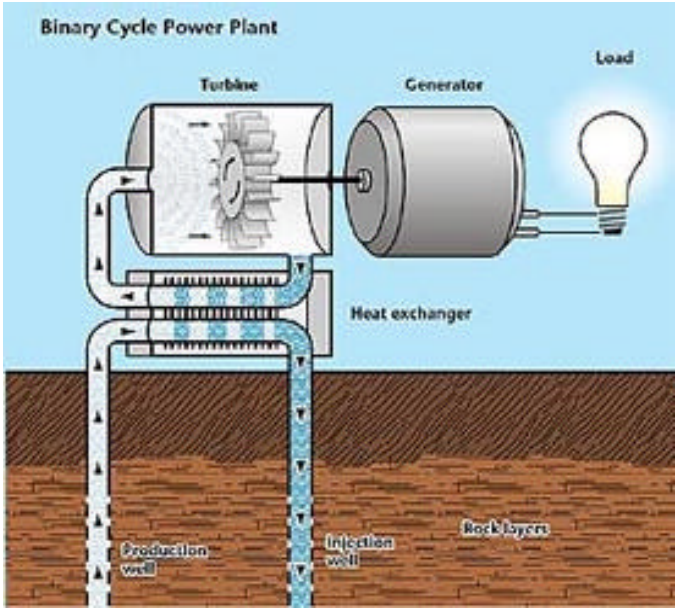


Figure 4. Binary Cycle Power Plant Schematic
Source: National Renewable Energy Laboratory (NREL)

The advantages of binary cycle systems are that the working fluid boils at a lower temperature than water does, so electricity can be generated from reservoirs with lower temperature, and the binary cycle system is self-contained and therefore, produces virtually no emissions. For these reasons, some geothermal experts believe binary cycle systems could be the dominant geothermal power plants of the future. Figure 4 is a schematic of a typical binary cycle power plant.[18]

GEOTHERMAL POWER GENERATION

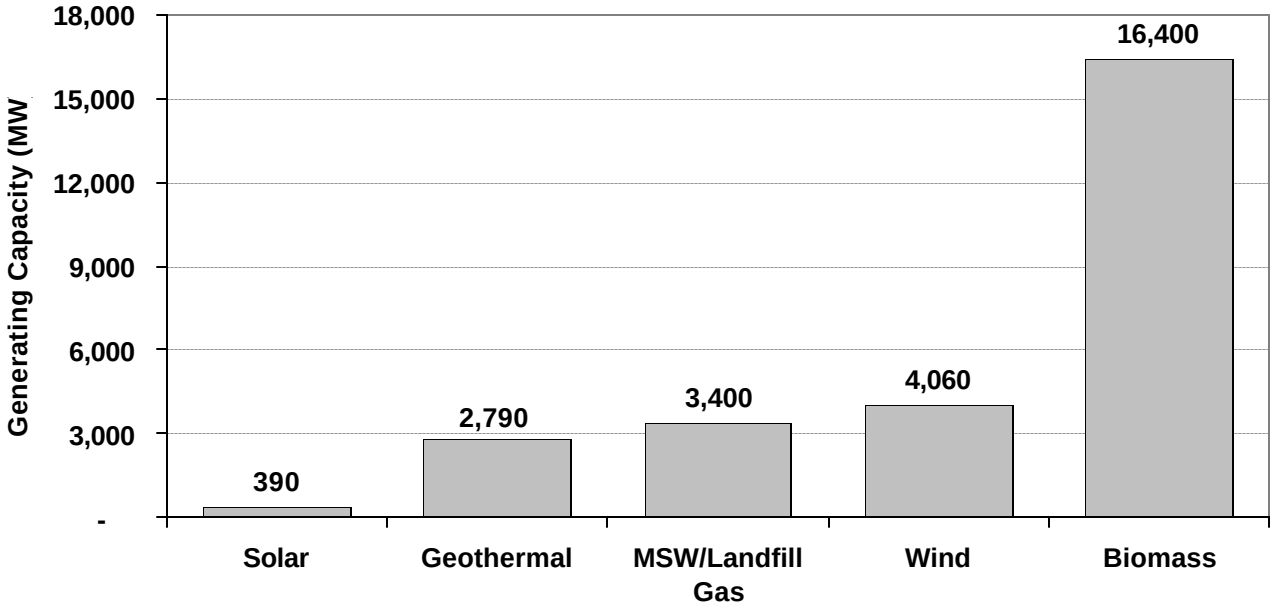
As of 2000, approximately 8,000 megawatts (MW) of geothermal electrical generating capacity was present in more than 20 countries, led by the United States, Philippines, Italy, Mexico, and Indonesia (see Table 2 below). This represents 0.25% of worldwide installed electrical generation capacity. In the United States, geothermal power capacity was 2,228 MW, or approximately 10% of non-hydro renewable generating capacity in 2001 (see Figure 5 below).[19] This capacity would meet the electricity needs of approximately 1.7 million U.S. households.[20]

Current geothermal use is only a fraction of the total potential of geothermal energy. U.S. geothermal resources alone are estimated at 70,000,000 quads[21], equivalent to 750,000-years of total primary energy supply (TPES) for the entire nation at current rates of consumption. The geothermal energy potential in the uppermost 6 miles of the Earth's crust amounts to 50,000 times the energy of all known oil and gas resources in the world.[22] Not all of these resources are technologically or economically accessible, but

tapping into even a fraction of this potential could provide significant renewable resources for years to come. The Geothermal Energy Association reports the potential for developing an additional 23,000 MW of generating capacity in the United States using conventional geothermal energy technology. [23]

Table 2. Installed Geothermal Generating Capacities Worldwide [24]

Country	1995 (MWe)	2000 (MWe)	Country	1995 (MWe)	2000 (MWe)
United States	2,817	2,228	Kenya	45	45
Philippines	1,227	1,909	Guatemala	33	33
Italy	632	785	China	29	29
Mexico	753	755	Russia	11	23
Indonesia	310	590	Turkey	20	20
Japan	414	547	Portugal	5	16
New Zealand	286	437	Ethiopia	0	8
Iceland	50	170	France	4	4
El Salvador	105	161	Thailand	0.3	0.3
Costa Rica	55	142	Australia	0.2	0.2
Nicaragua	70	70	Argentina	0.7	0
Total (MW)				6,833	7,974



Source: EIA Renewable Energy Annual 2001. Biomass excludes agriculture byproducts/crops, sludge waste, tires, and other biomass solids, liquids and gases.

Figure 5. U.S. Non-Hydro Renewable Power Generating Capacity, 2001

Capacity Factor

The percentage of time a power plant runs is the plants c*apacity factor*. Geothermal power plants typically produce electricity about 90% of the time, though can be run up to 98% of the time if the contract price of power is high enough to justify increased operational and maintenance costs. In comparison, coal-fired power plants are typically run 65–75% of the time, while nuclear plants in the United States have run at very high capacity factors (95–98%) in recent years due to lucrative market and regulatory conditions.

ECONOMICS

The commercial viability of geothermal power production is influenced by capital costs for land, drilling, and physical plant; operating and maintenance costs; the amount of power generated and sold from the plant; and the market value of that power. However, because geothermal power plants incur high capital costs at the beginning of the project, they are typically at an economic disadvantage to conventional fossil fueled power plants. Fossil fuel plants have lower up-front capital costs, but incur fuel costs for the life of the plant. This section discusses capital cost, operating and maintenance cost, average cost of power production over the life of the plant (known as the levelized cost of power production), as well as the economic impacts of geothermal power such as labor creation, tax base contributions, and balance-of-trade impacts.

Capital Cost

Capital costs are the fixed costs for power plant construction. Geothermal capital costs include the cost of land, drilling of exploratory and steam field wells, and physical plant, including buildings and power-generating turbines. Geothermal plants are relatively capital-intensive, with low variable costs and no fuel costs. The capital cost for geothermal power plants ranges from $1150 to $3000 per installed KW, depending on the resource temperature, chemistry, and technology employed. These costs may decrease over time with additional technology development. Plant lifetimes are typically 30–45 years. Financing is often structured such that the project pays back its capital costs in the first 15 years. Costs then fall by 50–70%, to cover just operations and maintenance for the remaining 15–30 years that the facility operates.[25] Table 3 shows the capital costs for geothermal plants, and Table 4 shows conventional baseload power direct capital costs for comparison.

Operating and Maintenance Cost

Geothermal power plant operating and maintenance costs range from $0.015 to $0.045 per KWh, depending on how often the plant runs. Geothermal plants typically run 90% of the time. They can be run up to 97–98% of the time, but this increases maintenance costs. High run times are found when contractual agreements pay high prices for power. Higher-priced electricity justifies running the plant at high-capacity factors because the resulting higher maintenance costs are recovered. Table 5 provides geothermal operating and maintenance cost by plant size. Large plants tend to have lower O&M costs due to economies of scale. As shown by Table 6, geothermal operating costs of 0.4–1.4 ¢/kWh are within the range of O&M costs of conventional power plants.

Table 3 Geothermal Power Direct Capital Costs (US$1999 /KW installed capacity)[26]

Plant Size	Cost	High-Quality Resource	Medium-Quality Resource
Small plants (<5MW)	Exploration	$400–800	$400–1000
	Steam field	$100–200	$300–600
	Power plant	$1100–1300	$1100–1400
	Total	$1600–2300	$1800–3000
Medium plants (5–30MW)	Exploration	$250–400	$250–600
	Steam field	$200–500	$400–700
	Power plant	$850–1200	$950–1200
	Total	$1300–2100	$1600–2500
Large plants (>30MW)	Exploration	$100–200	$100–400
	Steam field	$300–450	$400–700
	Power plant	$750–1100	$850–1100
	Total	$1150–1750	$1350–2200

Table 4. Conventional Baseload Power Direct Capital Costs

Resource	Capital Cost ($US1999/kW)
Geothermal	$1150–$3000
Hydropower[27]	$735–$4778
Coal[28]	$1070–$1410
Nuclear[29]	$1500–$4000

Table 5. Geothermal Operating and Maintenance Costs by Plant Size (U.S. cents/kWh)[30]

Cost Component	Small plants (<5MW)	Medium plants (5–30MW)	Large plants (>30MW)
Steam field	0.35–0.7	0.25–0.35	0.15–0.25
Power plants	0.45–0.7	0.35–0.45	0.25–0.45
Total	0.8–1.4	0.6–0.8	0.4–0.7

Table 6. Operating and Maintenance Cost Comparison by Baseload Power Source (U.S. cents/kWh)

Resource	O&M Cost (cents/kWh)
Geothermal	0.4 – 1.4
Hydropower[31]	0.7
Coal[32]	0.46
Nuclear[33]	1.9

Levelized Cost

The levelized cost of power production is the average cost of power production over the life of a power plant, taking into account all capital expenses and operating and maintenance costs, as well as fuel costs for power plants that rely on external fuel sources. Major factors affecting geothermal power cost are the depth and temperature of the resource, well productivity, environmental compliance, project infrastructure and economic factors such as the scale of development, and project financing costs.

Real levelized costs for geothermal electricity generation are $0.045-$0.07 per KWh, which is competitive with some fossil fuel facilities, without the pollution.[34] The lowest cost of geothermal electricity is approximately $0.015 per KWh. At the Geysers, power is sold at $0.03 to $0.035 per KWh. Some geothermal power plants can charge more per KWh during some time periods, because of incentives related to reliability of generation and power provided during peak demand. The cost of generating power from geothermal resources has decreased about 25% over the past two decades.[35]

The goal of the geothermal industry and the U.S. Department of Energy is to achieve a geothermal energy life-cycle cost of electricity of $0.03 per KWh. It is anticipated that costs in this range will result in about 10,000 MW of new capacity installed by U.S. firms within the next decade. Table 7 presents the levelized cost comparison of power by source. It shows that in some cases, geothermal energy can compete directly with conventional baseload power sources.

Table 7. Levelized Cost Comparison of Baseload Power by Source

Resource	**Levelized Cost**[36] (US cents/kWh)
Geothermal	1.5–7.0
Hydropower	0.5–2.4
Coal	2.0–5.0
Nuclear	1.5–3.0

Job Creation

In 1996, the U.S. geothermal energy industry as a whole provided approximately 12,300 direct jobs in the United States, and an additional 27,700 indirect jobs in the United States. The electric generation part of the industry employed about 10,000 people to install and operate geothermal power plants in the United States and abroad, including power plant construction and related activities such as exploration and drilling; indirect employment was about 20,000.[37] Table 8 provides estimates of job creation from renewable energy development based on existing and planned projects in California and the market outlook of project developers and equipment manufacturers. Natural gas is included in the table because the bulk of new nonrenewable generation is expected to rely upon natural gas. The table indicates that geothermal and landfill methane energy generation yields significantly more jobs per MW of installed capacity than do natural gas plants.

Table 8. Employment Rates by Energy Technology[38, 39]

Power Source	Construction Employment (jobs/MW)	O&M Employment (jobs/MW)	Total Employment for 500 MW Capacity (person-years)	Factor Increase over Natural Gas
Wind	2.6	0.3	5,635	2.3
Geothermal	4.0	1.7	27,050	11.0
Solar PV	7.1	0.1	5,370	2.2
Solar thermal	5.7	0.2	6,155	2.5
Landfill Methane/ Digester Gas	3.7	2.3	36,055	14.7
Natural Gas	1.0	0.1	2,460	1.0

Economic Impacts

One of the most important economic aspects of geothermal energy is that it is generated with indigenous resources, reducing a nation's dependence on imported energy, thereby reducing trade deficits. Reducing trade deficits keeps wealth at home and promotes healthier economies. Nearly half of the U.S. annual trade deficit would be erased if imported oil were displaced with domestic energy resources.

Geothermal energy production in the United States is a $1.5-billion-dollar-per-year industry.[40] Nevada's geothermal plants produce about 210 MW of electricity, saving energy imports equivalent to 800,000 tons of coal or 3 million barrels of oil each year. In addition, state governments receive tax revenue. In 1993, Nevada's geothermal power plants paid $800,000 in county taxes and $1.7 million in property taxes. The U.S. Bureau of Land Management collects nearly $20 million each year in rent and royalties from geothermal plants producing power on federal lands in Nevada—half of these revenues are returned to the state.[41]

Economic Impacts in Developing Countries

Nearly half of the developing countries have rich geothermal resources, which could prove to be an important source of power and revenue.[42] Geothermal projects can reduce the economic pressure of developing country fuel imports and can offer local infrastructure development and employment. For example, the Philippines have exploited local geothermal resources to reduce dependence on imported oil, with installed geothermal capacity and power generation second in the world after the United States. In the late 1970s, the Philippine government instituted a comprehensive energy plan, under which hydropower, geothermal energy, coal, and other indigenous resources were developed and substituted for fuel oil, reducing their petroleum dependence from 95% in the early 1970s to 50% by the mid-1980s. [43]

Developing countries will likely require increasing amounts of power in the coming years. Through technology transfer programs, some industrialized countries are helping developing countries make use of their local sustainable and reliable geothermal energy resources.

ENVIRONMENTAL IMPACTS

Geothermal power plants do have some environmental impacts. However, these impacts should be balanced against geothermal energy's advantages over conventional power sources when conducting assessments of power plant project environmental impacts. The primary impacts of geothermal plant construction and energy production are gaseous emissions, land use, noise, and potential ground subsidence.

Gaseous Emissions

Geothermal fluids contain dissolved gases, mainly carbon dioxide (CO_2) and hydrogen sulfide (H_2S), small amounts of ammonia, hydrogen, nitrogen, methane and radon, and minor quantities of volatile species of boron, arsenic, and mercury. Geothermal power provides significant environmental advantage over fossil fuel power sources in terms of air emissions because geothermal energy production releases no nitrogen oxides (NO_x), no sulfur dioxide (SO_2), and much less carbon CO_2 than fossil-fueled power. The reduction in nitrogen and sulfur emissions reduces local and regional impacts of acid rain, and reduction in carbon-dioxide emissions reduce contributions to potential global climate change. Geothermal power plant CO_2 emissions can vary from plant to plant depending on both the characteristics of the reservoir fluid and the type of power generation plant. Binary plants have no CO_2 emissions, while dry steam and flash steam plants have CO2 emissions on the order of 0.2 lb/kWh, less than one tenth of the CO_2 emissions of coal-fired generation (see Table 9). According to the Geothermal Energy Association, improved and increased injection to sustain geothermal reservoirs has helped reduce CO2 emissions from geothermal power plants.

Table 9. Comparison of CO_2 Emissions by Power Source[44]

Power Source	CO_2 Emissions (lb/kWh)
Geothermal	0.20
Natural Gas	1.321
Petroleum	1.969
Coal	2.095

Hydrogen sulfide emissions do not contribute to acid rain or global climate change but does create a sulfur smell that some people find objectionable. The range of H_2S emissions from geothermal plants is 0.03–6.4 g/kWh.[45] Hydrogen sulfide emissions can vary significantly from field to field, depending on the amount of hydrogen sulfide contained in the geothermal fluid and the type of plant used to exploit the reservoir. The removal of H_2S from geothermal steam is mandatory in the United States. The most common process is the Stretford process, which produces pure sulfur and is capable of reducing H_2S emissions by more than 90%.[46] More recently developed techniques include burning the hydrogen sulfide to produce sulfur dioxide, which can be dissolved, converted to sulfuric acid and sold to provide income.

Landscape Impacts and Land Use

Geothermal power plants require relatively little land. Geothermal installations don't require damming of rivers or harvesting of forests, and there are no mineshafts, tunnels, open pits, waste heaps or oil spills. An entire geothermal field uses only1–8 acres per MW versus 5–10 acres per MW for nuclear plants and 19 acres per MW for coal plants.[47]

Table 10 compares acreage requirements by technology. Geothermal power plants are clean because they neither burn fossil fuels nor produce nuclear waste. Geothermal plants can be sited in farmland and forests and can share land with cattle and local wildlife. For example, the Hell's Gate National Park in Kenya was established around an existing 45-MWe geothermal power station, Olkaria I. Land uses in the park include livestock grazing, growing of foodstuffs and flowers, and conservation of wildlife and birds within the Park. After extensive environmental impact analysis, a second geothermal plant, Olkaria II, was approved for installation in the park in 1994, and an additional power station is under consideration.[48]

Table 10. Comparison of Land Requirement for Baseload Power Generation

Power Source	**Land Requirement** (Acre/MW)
Geothermal	1–8
Nuclear	5–10
Coal	19

Geothermal plants are also benign with respect to water pollution. Production and injection wells are lined with steel casing and cement to isolate fluids from the environment. Spent thermal waters are injected back into the reservoirs from which the fluids were derived. This practice neatly solves the water-disposal problem while helping to bolster reservoir pressure and prolong the resource's productive existence.[49]

Noise

Noise occurs during exploration drilling and construction phases. Table 11 (next page) shows noise levels from these operations can range from 45 to 120 decibels (dBa). For comparison, noise levels in quiet suburban residences are on the order of 50 dBa, noise levels in noisy urban environments are typically 80–90 dBa, and the threshold of pain is 120 dBa at 2,000–4,000 Hz.[50] Site workers can be protected by wearing ear mufflers. With best practices, noise levels can be kept to below 65 dBa, and construction noise should be practically indistinguishable from other background noises at distances of one kilometer.

Ground Subsidence

In the early stages of a geothermal development, geothermal fluids are withdrawn from a reservoir at a rate greater than the natural inflow into the reservoir. This net outflow causes rock formations at the site to compact, particularly in the case of clays and

sediments, leading to ground subsidence at the surface. Key factors causing subsidence include:

- A pressure drop in the reservoir as a result of fluid withdrawal
- The presence of a highly compressible geological rock formation above or in the upper part of a shallow reservoir
- The presence of high-permeability paths between the reservoir and the formation, and between the reservoir and the ground surface

If all of these conditions are present, ground subsidence is likely to occur. In general, subsidence is greater in liquid-dominated fields because of the geological characteristics typically associated with each type of field. Ground subsidence can affect the stability of pipelines, drains, and well casings. It can also cause the formation of ponds and cracks in the ground and, if the site is close to a populated area, it can lead to instability of buildings.

The largest recorded subsidence in a geothermal field was at Wairakei in New Zealand. Here the ground subsided as much as 13 meters. Monitoring has shown that a maximum subsidence rate of 45 cm/year occurred in a small region, outside the production area, with subsidence of at least 2 cm/year occurring all over the production field.[51] Effects of the subsidence in the Wairakei region included:

- The creation of a pond about 1 km in length and 6 m in depth in what was originally a fast-flowing stream;
- Cracking of both a nearby highway and the main waste water drain on the site;
- Compressive buckling and tensile fracturing of steam pipelines;
- Fissures in surroundings fields.

Although Wairakei presents an extreme example, little is currently known about how to prevent or mitigate subsidence effects. The only action is to try to maintain pressure in the reservoir.[52] Fluid re-injection can help to reduce pressure drop and hence subsidence, but its effectiveness depends on where the fluid is re-injected and the permeability conditions in the field. Typically, re-injection is done at some distance from the production well to avoid the cooler rejected waste fluid from lowering the temperature of the production fluid and may not help prevent subsidence.[53]

Table 11. Geothermal Exploration and Construction Noise Levels by Operation[54]

Operation	Noise Level (dBa)
Air drilling	85–120
Mud drilling	80
Discharging wells after drilling (to remove drilling debris)	Up to 120
Well testing	70–110
Diesel engines (to operate compressors and provide electricity)	45– 55
Heavy machinery, e.g. for earth moving during construction	Up to 90

POLICY

Renewable energy can reduce dependence on fossil fuels, reduce harmful pollution from energy production and consumption, and reduce emissions of greenhouse gases. However, most renewables have very different cost structures from conventional energy generating technologies, with high up-front costs and low operating costs. This is true for geothermal energy, which has high exploration and drilling costs in aditional to capital plant expenses. With additional technology development, these costs can be lowered, and geothermal energy can become more cost-competitive with other energy sources.

To spur geothermal technology and market development, the United States has developed policies at the federal and state government level offering a variety of tax incentives for the manufacture, installation, and use of renewables. This section discusses U.S. federal and state policies to promote geothermal energy, as well as policies in other nations with significant geothermal resources.

U.S. Federal Policies

With the oil embargoes and energy crisis of the 1970s, as well as growing environmental awareness, concerns about the United States continued dependence on conventional fossil fuels, as well as energy-related health and environmental hazards were raised. Policies to promote renewable energy and energy efficiency were developed to help decrease the Nation's dependence on fossil fuels and increase domestic energy conservation and efficiency. This section focuses on the some approaches by the U.S. government to encourage the development of geothermal energy, including R&D funding, tax credits, and regulatory policy.

Federal Research and Development (R&D)

Federal energy R&D funding is important for maintaining technological progress in energy development since private industry cannot afford to fully fund, on its own, the continued research required. Energy R&D progress reduces cost, as well as increases energy yields from existing resources. Federal energy R&D includes nuclear, fossil fuel, renewable, energy conservation, and other energy technologies. Many geothermal energy R&D projects are undertaken in conjunction with industry partners and universities to ensure rapid deployment of the new technology into the marketplace.

During the mid-1990s, ongoing deregulation of the electric and natural gas utility industry in the United States, along with lower energy prices, resulted in a significant downturn in the private sector's support for energy R&D. President Clinton, reacting to the trends, asked his Committee of Advisors on Science and Technology (PCAST) to perform an assessment of the U.S. energy R&D effort.[55] As a result of PCAST's energy R&D assessment, a recommendation was made to set aside $51 million for geothermal energy R&D. This proposal included recommendations to expand advanced drilling R&D through the National Advanced Drilling and Excavation Technologies Institute, increase R&D on reservoir testing and modeling, and increase geothermal productivity. However, appropriations for FY'01 only amounted to $26.6 million, less than half of PCAST's recommended funding. As demonstrated in Figure 6, appropriations for

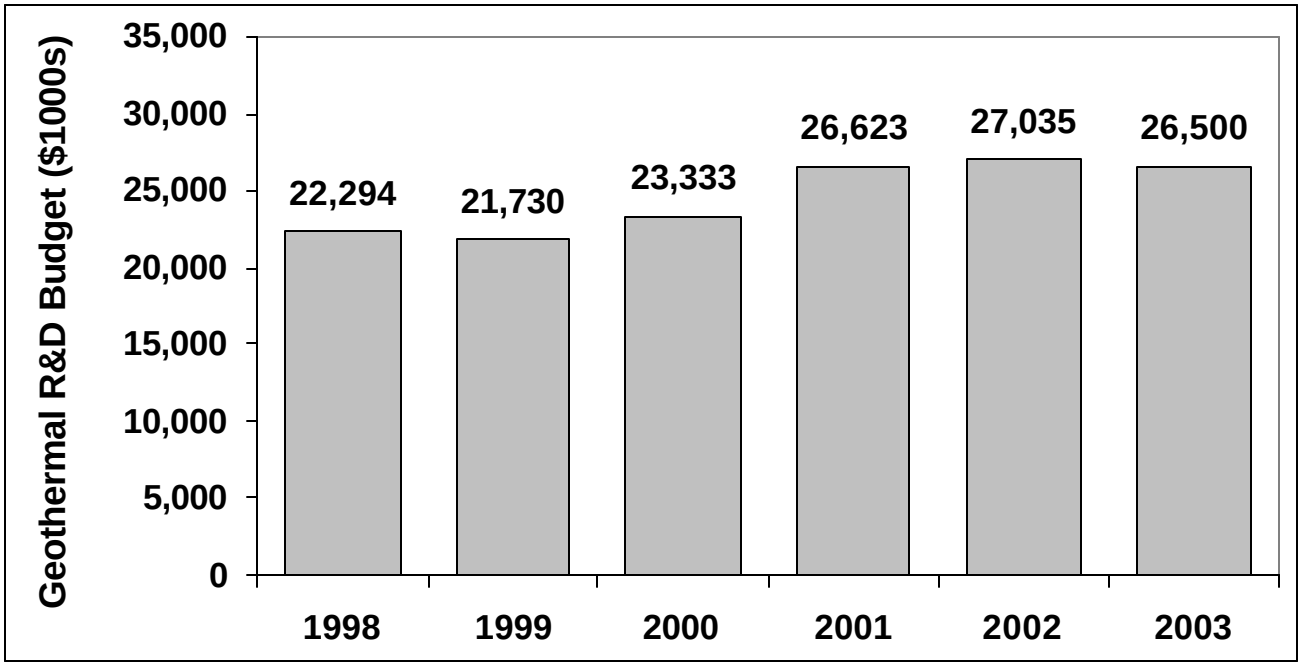


Figure 6. U.S. Geothermal Energy R&D Budget, 1998 – 2003
Source: Department of Energy Office of Budget

geothermal R&D have remained relatively flat from 1998 to 2003, at approximately half of the PCAST recommended level. [56] Increased federal geothermal R&D appropriations would help geothermal energy is to expand to its fullest potential.

Public Utility Regulatory Policies Act (PURPA)

The Public Utility Regulatory Policies Act (PURPA) is one of five statutes of the National Energy Conservation Policy Act of 1978, which sought to decrease the Nation's dependence on foreign oil. The intent of PURPA is to encourage the development of independent, non-utility, fuel-efficient cogeneration plants and small renewable energy power projects by requiring utilities to buy power from such plants at the utility's avoided cost. An avoided cost is that amount that a utility would otherwise have to spend to generate or procure power. As state above, PURPA requires utilities to buy power from two types of independent power producers: (1) small power producers using renewable energy sources; and (2) co-generators. Under PURPA, independent power producers are designated as qualifying facilities (QFs). A QF seeking a small power producer status must produce energy with at least 75 percent of the total energy input provided by renewable energy. A QF seeking co-generator status under PURPA must produce electricity and another form of energy sequentially while using the same fuel source. One of the benefits of PURPA is that it allows a period of fixed payments for both energy and capacity via long-term contracts which then makes a favorable environment for renewables, including geothermal, to obtain financing.

Tax credits

Tax credits are used as a tool to encourage certain behaviors or influence decisions. The U.S. government has been using tax credits to influence energy production decisions for decades. The first energy tax incentives arrived on the scene in 1978 with the passage of

the Energy Tax Act of 1978. Tax incentives have been created, terminated, and reactivated in the United States over the past 20 years. In 1978, the Energy Tax Act extended a 10% business energy tax credit for investments in solar, wind, geothermal, and ocean thermal technologies. In 1986, the Tax Reform Act repealed the 10% business energy tax credit. In 1992, the 10% business energy tax credit returned as a permanent tax credit under the Energy Policy Act, but the credit could only be applied to investments in solar and geothermal equipment.

Other factors influence the ebb and flow of tax credits, such as politics, economics, and energy supply. Variability in the political support of tax incentives creates uncertainly in long-term renewable markets, therefore, making it difficult for developers to maximize the opportunities for development of renewables. However, without tax credits, the penetration of renewable energy, such as geothermal, into the energy production sector would be more difficult. Including geothermal energy under the federal Production Tax Credit (PTC) could provide a significant boost to the geothermal sector.

U.S. State Policies

State governments, in addition to the federal government, have initiated programs and policies to drive the diversification of the nation's energy portfolio by incorporating renewable energy into the energy supply. Identified below are some policy measures that are influencing energy policy decisions at the state level.

Public Benefit Funds

Public Benefit Funds (PBF) are generated from a few sources such as a customer charge on utility bills and new user access fees to fund various public programs. These programs include low-income energy assistance, energy efficiency, consumer energy education, and renewable energy technology development and demonstration. California was the first state to create a PBF. In 1996, California placed a charge on all electricity bills from 1998 through 2001 that would provide $540 million for "new and emerging" renewable energy technologies. As of 2002, at least 24 states have a Public Benefit Fund program in place. See REPP's map of state PBF policies for specific details of these policies at http://www.repp.org/sbf_map.html.

Renewable Portfolio Standards

Renewable Portfolio Standards (RPS) mandate a state to generate a percentage of its electricity from renewable sources or meet a specific renewable capacity requirement. Each state has a choice of how to fulfill this mandate using a combination of renewable energy sources, including wind, solar, biomass, geothermal, or other renewable sources. As of 2002, 12 states have adopted an RPS as part of their restructuring processes. California, for example, has an aggressive renewable portfolio standard requiring utilities to purchase 20% of their electricity from renewable sources by 2017. In 1999, Texas initiated a capacity-based standard to ensure that 2,000 megawatts (MW) of new generating capacity from renewable energy technologies be installed by 2009. Geothermal energy will most likely help fulfill RPS requirements in western states where geothermal energy is more prevalent. See REPP's map of state RPS policies for specific details of these policies at http://www.repp.org/rps_map.html.

Policies in Other Nations

The Philippines, the world's second largest user of geothermal energy for power generation, provides an example of several incentives to attract geothermal development. They are as follows:

- Recovery of operating expenses not exceeding 90% of the gross value in any year with carry forward of unrecovered cost
- Service fee of up to 40% of net proceeds
- Exemption from all taxes except income tax
- Income tax obligation paid out of government's share
- Exemption from payment of tariff duties and compensating tax on the importation of machinery, equipment, share parts and all materials for geothermal operation
- Depreciation of capital equipment over a 10-year period
- Easy repatriation of capital equipment investment and remittance of earnings
- Entry of alien technical and specialized personnel (including members of immediate families

According to the Philippine Department of Energy, an additional eight geothermal power plants will come on line from 2003 to 2010. Expected capacity additions during this time total 621 MWe.[57]

FUTURE DEVELOPMENTS

Renewable energy technology is continuously evolving with the goal of reducing risk and lowering cost. The goal of the geothermal industry and the U.S. Department of Energy is to achieve a geothermal energy life-cycle cost of electricity of $0.03 per KWh.[58] To achieve the goal of lowering cost and risk, other types of nontraditional resources and experimental systems are being explored. Among these are hot dry rock resources, improved heat exchangers, and improved condenser efficiency.

Hot Dry Rock

Hot dry rock geothermal technology offers enormous potential for electricity production. These resources are much deeper than hydrothermal resources. Hot dry rock energy comes from relatively water-free hot rock found at a depth of about 4,000 meters or more beneath the Earth's surface. One way to extract the energy is by circulating water through man-made fractures in the hot rock. Heat can then be extracted from the water at the surface for power generation, and the cooled water can then be recycled through the fractures to pick up more heat, creating a closed-looped system. Hot Dry Rock resources have yet to be commercially developed. One reason for this is that well costs increase exponentially with depth, and since Hot Dry Rock resources are much deeper than hydrothermal resources, they are much more expensive to develop. Figure 7 shows the projected capital cost for hot dry rock compared to traditional geothermal power technology from 1996 to 2030. The figure shows that the capital cost of hot dry rock will decrease by almost half in 30 years, but it will still be twice as expensive as other

traditional geothermal technologies. If the technology can evolve to make hot dry rock resources commercially viable, hot dry rock resources are sufficiently large enough to supply a significant fraction of U.S. electric power needs for centuries.

Heat Exchanger Liners

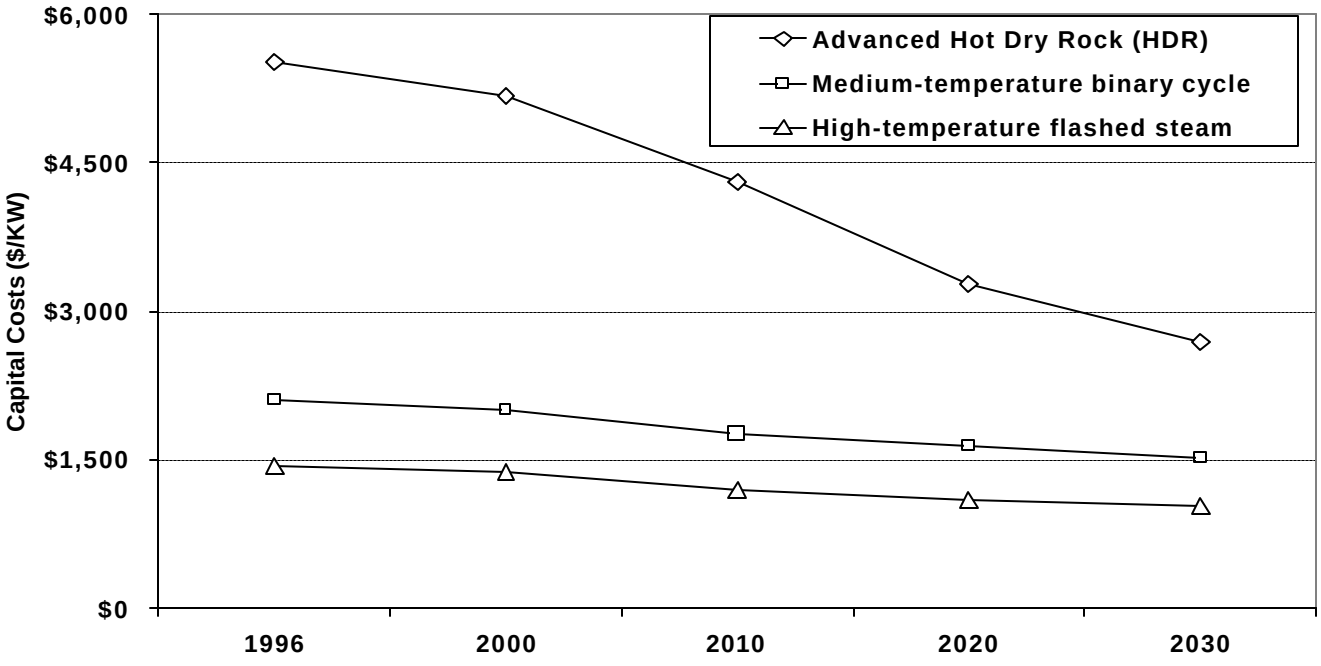
The highly corrosive nature of geothermal plants poses a challenge to heat exchangers by reducing their thermal conductivity. Research is currently being conducted to replace the use of expensive heat exchanger materials, such as stainless steel and titanium, with new, less expensive polymer-base coated carbon steel. The polymer-base-coated carbon steel is proving to be as resistive to corrosion as the conventional, expensive materials. [59]

Air-Cooled Condensers

Currently, the National Renewable Energy Laboratory (NREL) is investigating ways to improve the efficiency of air-cooled condensers that are commonly used in binary-cycle geothermal plants. Air-cooled condensers use large airflow rates to lower the temperature of the gas once it has passed through the system to produce condensation. The fluid is then collected and returned to the cycle to be vaporized. This cycle is

Figure 7

Projected Capital Costs for Hot Dry Rock compared to traditional Geothermal Power Technology, 1996-2030

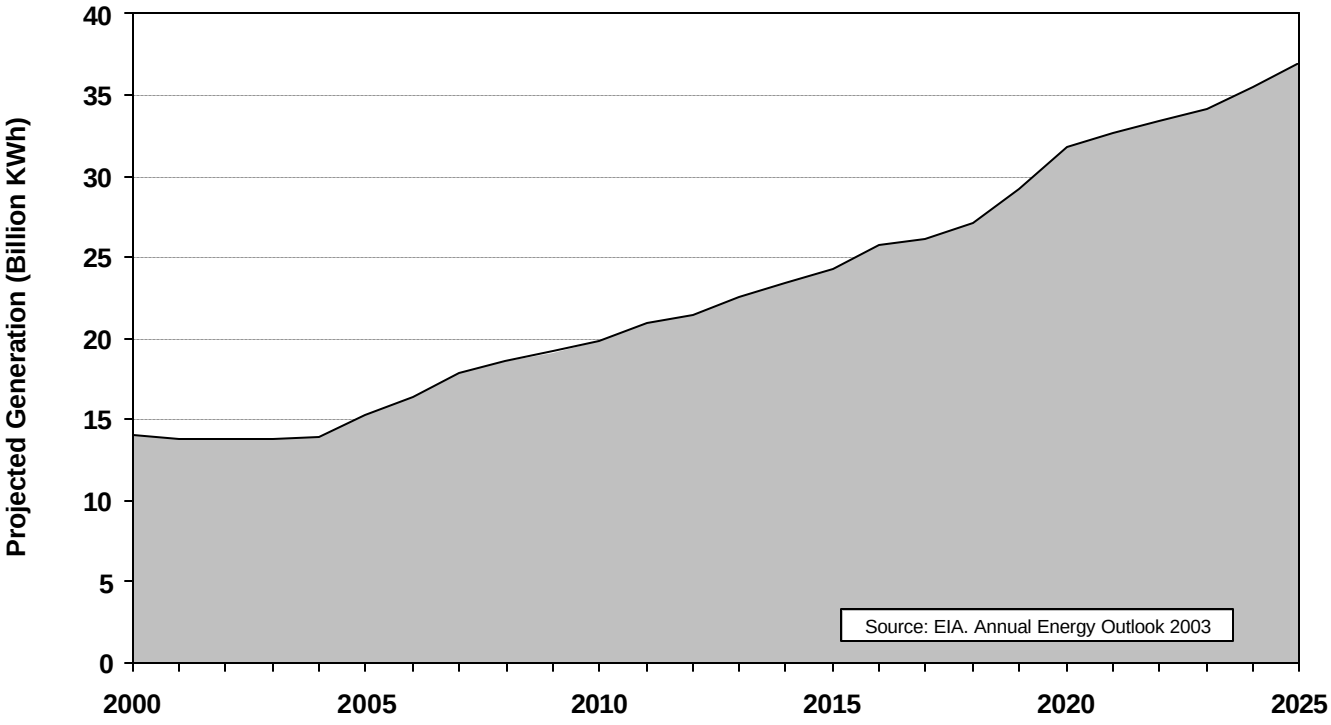


Source: U.S. Department of Energy, 1997.

important in binary-cycle geothermal plants because of the lack of make-up water. To increase the heat exchange efficiency, NREL is currently testing the use of perforated fins in the condensers, with all of the air flowing through the perforations, to increase the heat exchange and therefore, condensation. Initial tests have indicated a 30–40% increase in heat transfer. Such an increase in heat transfer technology could increase the efficiency of future binary-cycle geothermal plants.

As technological improvements continue to be discovered and more geothermal plants are brought online, geothermal generating capacity in the United States will continue to increase. Figure 8 shows projected geothermal power generation under these scenarios and projected generation from Annual Energy Outlook 2002. [60] Installed capacity is likely to increase via new installation, as well as technological improvement leading to increased yield. The U.S. DOE projects that U.S. geothermal generation will increase by over 160% from 2000 to 2025, from 14.1 to 36.9 billion kilowatt-hours per year.

Figure 8. DOE Annual Energy Outlook
Projected Geothermal Generation 2000-2025 (Billion KWh)



CLOSING

Our intention has been to provide the reader with a balanced overview of the utility-scale geothermal power industry. We believe clean, reliable power can be developed from renewable resources, with geothermal power making an important contribution. Examples from the U.S. geothermal sector have been used to illustrate the costs, benefits, policies, and trends in geothermal energy today. What follows is a list or further resources available on the world-wide web to allow the reader to gain a deeper understanding of the potential of geothermal power and the issues surrounding its development. We urge the reader to seek further understanding of these issues, and the means to their resolution, in order to support the progress of geothermal energy in providing clean, reliable, and economic power.

SOURCES OF FURTHER INFORMATION

U.S. Government Programs

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

National Renewable Energy Laboratory: Geothermal Technologies Program
http://www.nrel.gov/geothermal/geoelectricity.html

International Programs

Philippines Department of Energy
http://www.doe.gov.ph/

The World Bank Group
http://www.worldbank.org/html/fpd/energy/geothermal/

Industry Associations

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

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

International Geothermal Association
http://iga.igg.cnr.it

Non-Profit Organizations

Marin County Geothermal Education Office
http://www.geothermal.marin.org/

Renewable Northwest Project
http://www.rnp.org/RenewTech/tech_geo.html

Technical Information

University of Utah Energy & Geoscience Institute
http://egi-geothermal.org/

Idaho National Engineering and Environmental Laboratory
http://geothermal.id.doe.gov/

Oregon Institute of Technology
http://geoheat.oit.edu

Geothermal Resource Assessment

Geothermal Energy Research State Maps
http://geothermal.id.doe.gov/maps-software.shtml

United States Geothermal Potential
http://www.eere.energy.gov/geopoweringthewest/geomap.html

Opportunities for Near-Term Geothermal Development on Public Lands in the Western United States (CD-ROM)
http://www.nrel.gov/docs/fy03osti/33105.pdf

US Geothermal Projects and Resource Areas
http://geoheat.oit.edu/dusys.htm

Additional Resources

http://www.geo-energy.org/Links.htm
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