

The Status and Future of Geothermal Electric Power

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THE STATUS AND FUTURE OF GEOTHERMAL ELECTRIC POWER

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ABSTRACT

Geothermal electricity production in the United States began in 1960. Today there are over 20 plants in the western United States providing a total of about 2,200 MW of clean and reliable electricity. Currently identified resources could provide over 20,000 MW of power in the U.S., and undiscovered resources might provide 5 times that amount.

In the 1990s industry growth slowed due to the loss of market incentives and competition from natural gas. However, increased interest in clean energy sources, ongoing technological improvements, and renewed opportunities abroad hold promise for a resurgence in the industry.

This review paper covers the status of the technology, the issues faced, and the latest research. While the focus is on geothermal in the U.S., a brief description of the large international market is included.

1. INTRODUCTION AND OVERVIEW

Geothermal energy can be defined as heat that originates within the earth. This heat occurs from a combination of two sources: the original heat produced from the formation of the earth by gravitational collapse and the heat produced by the radioactive decay of various isotopes. Because the thermal conductivity of rock is so low, it is taking many billions of years for the earth to cool.

Geothermal resources can be divided into four types: hydrothermal, geopressured, hot dry rock, and magma. Except for geothermal (or ground-source) heat pumps,

which utilize the heat contained in shallow soil, all existing uses of geothermal energy make use of hydrothermal resources, which consist of some combination of hot water and steam located in permeable rock. The hot geothermal fluid is used for direct heating applications such as spas, greenhouses, district heating and the like. If the resource temperature is greater than about 90°C, it can be utilized to generate electricity, the subject of this paper. A map of U.S. geothermal resources is shown in Figure 1.

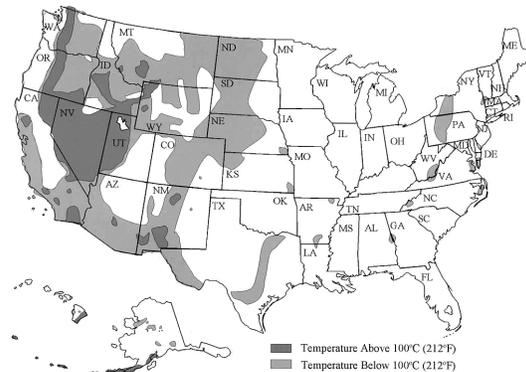


Fig. 1: Geothermal resources map of the U.S. The darkest regions represent hydrothermal resources with temperatures above 100°C, which are suitable for electricity generation (Geo-Heat Center).

Although geothermal energy has been used for direct heating purposes since ancient times, its use for the generation of electricity began only in the 20th century. The first experiments to make use of geothermal energy to generate electricity occurred in Larderello, Tuscany, Italy in 1904. A 250-kWe geothermal power plant began operation there in 1913.

Currently, geothermal energy is used to generate a total of about 8,000 MW of electricity in 21 countries. The United States is the largest user with about 2,200 MW of current capacity. A list of geothermal electric generating plants in the U.S. is shown in Table 1 (1). Most of the geothermal

power in the United States is generated in California and Nevada with California accounting for over 90% of installed capacity. A considerable amount of this power (1,137 MW) is generated at The Geysers in Northern California, which has hosted a number of commercial

TABLE 1: U.S. GEOTHERMAL POWER PLANTS

	Locality	Electrical Output ¹ (MWe)	Year	Units	Comments
California	The Geysers	1,137	1960-89	23	Dry steam plants
	Coso	260	1987-89	9	Flash plants
	Salton Sea	267	1982-96	10	Flash plants
	East Mesa	105	1979-89	71	Binary plants
	Heber	80	1985-93	14	Flash and Binary
	Mammoth Lakes	43	1984-90	4	Binary plants
	Honey Lake	30	1989	1	Hybrid (geothermal/wood waste)
	Amadee Hot Springs	2	1988	2	Binary plants
	Susanville (Wineagle)	1	1985	2	Binary plants
Hawaii	Puna	25	1992	10	Flash/binary plants
Nevada	Dixie Valley	66	1988	1	Flash plant
	Steamboat Springs	35	1986-92	13	Flash and binary plants
	Soda Lake	17	1987-91	9	Binary plants
	Beowawe	16	1985	1	Flash plant
	Stillwater	13	1989	14	Binary plants
	Desert Peak	9	1985	2	Flash plants
	Empire	4	1987	4	Binary plants, crop drying
	Brady Hot Springs	21	1992	3	Flash plants
	Wabuska	1	1984-87	2	Binary plant
	SBH3	14	1988	1	Flash plant
Utah	Cove Fort	11	1985-90	5	Dry steam and binary
	Roosevelt Hot Spring	20	1984	1	Flash plant

¹Actual output for The Geysers, rated output for others.

geothermal power plants since the first one was built there in 1960. The Geysers, like Larderello, is a fairly unusual (and ideal) resource because its wells produce virtually pure steam with no water.

It has been estimated that identified hydrothermal resources in the United States could provide 23,000 MWe for 30 years, and undiscovered resources might provide 5 times that amount (2). If it were to become economic to tap into more widespread “hot dry rock” resources (which involves deeper drilling and injection of water to recover the heat), the U.S. geothermal energy resource would be sufficient to provide our current electric demand for tens of thousands of years.

Although steam plants tend to release some gases from the geothermal fluid, amounts are usually small, and there are suitable means for mitigating most of these releases. Thus, geothermal energy tends to be quite clean. In fact, Lake County, which is the location of The Geysers geothermal power plants, is reported to be the only county in California that is in compliance with all of California’s air quality regulations.

While geothermal energy is very clean, it is not as renewable as solar and wind energy. Like the energy of the sun, the energy within the earth is immense and has a lifetime measured in billions of years. However, unlike the use of sunlight, tapping into local sources of the earth’s heat

can result in a temporary decrease in the local amount of energy available. Reinjecting geothermal fluid that remains after steam is extracted helps preserve the fluid volume of the reservoir. However, even with reinjection, the heat content of the reservoir gradually declines.

The recovery period for a geothermal resource depends on how it is used. A recent study (3) indicates that the recovery period is approximately 30 years for heat pumps, about 100-200 years for district heating, and several hundred years for electricity generation. Resources tapped for electricity generation could provide energy for 50 years or more, if properly managed, but plant equipment typically reaches the end of its useful life before the resource is depleted. Continuous long-term use of geothermal energy for electricity generation would require the periodic construction of new plants at new sites, while previously used reservoirs recover.

While geothermal is not immediately renewable like technologies such as solar and wind, it has a number of important advantages. Geothermal electric plants operate 24 hours per day and thus produce base-load electricity. There is no need for storage, and dispatchability is not an issue. Geothermal plants are not vulnerable to weather effects, except that cycle efficiencies (and hence plant output) tend to be higher in the winter (when heat is rejected to a lower sink temperature) than in the summer. (This is especially true for binary plants that are air-cooled.)

Geothermal plants are also extremely reliable and typically operate more than 95% of the time, with some plants at over 99%. This compares to availabilities of 60%—70% for coal and nuclear plants.

Geothermal plants are often located in areas of high scenic value, where the appearance of the plant is important. Fortunately, geothermal power plants take up little land space, and, with careful design, they can easily blend into the surrounding environment. Wet cooling towers at plants can produce plumes of water vapor, which some people find unsightly. In such cases, air-cooled condensers can be used. A good example of an aesthetic geothermal power plant is the 35-MW binary-cycle plant located near the Mammoth Lakes ski area in northern California. The plant uses air cooling, has a low profile, is painted in colors that match the natural landscape, and is surrounded by trees. As a result, passing motorists on the nearby highway don't even notice it.

2. TECHNOLOGY DESCRIPTION

The current power plants for generating electricity from hydrothermal resources can be divided into two general

types: steam and binary. Steam plants are the most cost-effective technology when the resource temperature is above about 175°C. In these plants, steam is expanded through a turbine to generate electricity. For geothermal resources rich in steam (such as at The Geysers), the steam can be used directly. Because such sites are rare, it is much more common for hot water from a geothermal resource to be flashed to steam by spraying it into a tank where its pressure is decreased. This can occur in either a single- or dual-stage process. A schematic of a typical flash plant is shown in Figure 1.

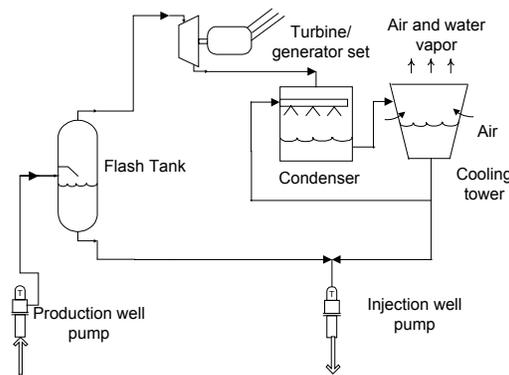


Fig. 1: Example flash-steam geothermal power plant.

For lower quality resource temperatures below about 175°C, flash plants lose their efficiency. It is more efficient to transfer heat from the geothermal fluid to a volatile working fluid (typically a hydrocarbon such as isobutane or isopentane) that vaporizes and is passed through a turbine. Such plants are called “binary” because a secondary fluid is used in the actual power cycle. These plants tend to have higher equipment costs than flash plants. Because they transfer heat from the geothermal fluid and return all the geothermal fluid to the ground, they do not have condensed steam available as cooling water. Thus, they must use a separate water source or air-cooled condensers.

Because all of the geothermal fluid is returned to the reservoir, binary-cycle plants do not require mitigation of gaseous releases and reservoir fluid volume is maintained. Because larger binary plants are typically comprised of small modules, maintenance can be done on one module at a time, thus minimizing the impact on plant output. A schematic of a typical binary plant is shown in Figure 2.

Current installed costs for steam plants are about \$700/kW of capacity for exploration and drilling plus another \$700-800/kW for the plant equipment, yielding a total cost of about \$1,400-1,500/kW. Installed costs of binary plants are about \$500/kW for exploration and drilling plus about \$1,600/kW for the plant equipment for a total of about

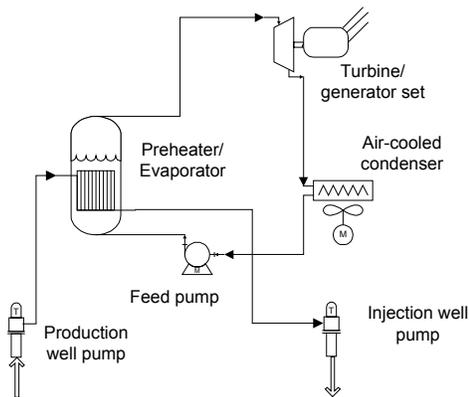


Fig. 2: Example binary-cycle geothermal power plant.

\$2,100/kW. Operation and maintenance costs are typically about \$100/kW per year for each type of plant (4).

These costs are for plants of 5 MW size or larger, which represent the vast majority of existing plants. For small plants under 5 MW in size, the cost per kW goes up significantly because of a loss in equipment economies of scale, and because the fixed costs associated with exploring a site and drilling wells are divided by a smaller number of kilowatts. (Although a small plant requires a smaller-diameter well, as well diameter decreases, the well power output drops much more rapidly than the drilling cost.) In addition there are some minimum fixed O&M costs associated with operating a plant which also become significant when divided by a smaller plant capacity.

Despite their higher energy costs, small-scale plants offer a number of potential advantages. Skid-mounted units can be built in the factory and shipped anywhere in the world. Because they are modular, a plant owner can start with a small investment and add additional modules later. Small plants can be designed to operate automatically. Their economics can become attractive in regions where low-cost shallow wells are available and where the exit brine from the plant can be used for direct heating applications. Small plants may be especially well suited for mini-grid applications in developing nations where the competition is imported diesel fuel (5).

3. TECHNOLOGY STATUS

Between 1980 and 1990, about 900 MWe of geothermal electric capacity were installed in the United States. Most of these plants were built in California and Nevada under power purchase agreements that guaranteed prices of more

than 10 cents per kWh. Today, most of these price guarantees have expired, and plants must sell their power at competitive rates. With the loss of government market incentives, the advent of low-cost electricity from natural gas turbines, and the decline in electricity load growth, geothermal power plant construction in the United States declined greatly in the 1990s. Geothermal electricity costs, in the range of 5 to 8 cents per kWh, while very attractive compared to many other clean energy technologies, cannot compete against 3 cents per kWh electricity from natural gas power plants.

The actual power output of plants has also declined, with U.S. generation now at 2,200 MW compared with a rated output of about 2,800 MW. This decline is mostly the result of changes at The Geysers, where power output has dropped from 1,875 MW in 1990 to 1,137 MW today. This drop is due both to the retirement of older plants and a loss in reservoir volume over the years.

To address the reservoir depletion problem, two projects have been initiated to inject reclaimed wastewater into the reservoir. The first phase of the Southeast Geysers Effluent System has recently been completed. This transports 20,500 L/min (5,400 gpm) of wastewater from several Lake County communities to The Geysers via a 30 mile pipeline. This has enhanced steam production and increased power output by 39 MW between January 1998 and January 1999. A second phase of that project is planned, and there is a plan to transport wastewater from the City of Santa Rosa a distance of 41 miles to The Geysers. These projects not only prolong the lifetime of the geothermal resource but also provide a solution to wastewater disposal problems.

As a result of the unfavorable economic conditions for geothermal energy in the United States, the industry has looked for opportunities abroad. Good opportunities for geothermal power plants exist in many developing countries, where the Geothermal Energy Association has estimated there is the potential for approximately 75,000 MW of capacity for 30 years. Especially attractive are Central America (22,000 MW), Indonesia (16,000 MW), East Africa (10,000 MW), and the Philippines (8,000 MW). Considerable new activity was underway in the Philippines and Indonesia until the Asian economic crisis put many planned geothermal power plant construction projects on hold.

4. CURRENT RESEARCH ACTIVITIES

The Department of Energy research program is aimed at reducing the cost of geothermal electricity. This involves research in the following areas:

4.1 Exploration and Reservoirs

Exploration research focuses on developing more accurate and lower cost means for finding and mapping geothermal resources. In this way the financial risk of developing a project can be minimized. Reservoir research is aimed at maximizing the production rate and lifetime of the geothermal resource. Both areas involve the development of improved computer models and better instrumentation. Recent accomplishments include development of instrumentation that can work in higher-temperature environments and more accurate field survey procedures.

4.2 Drilling

The cost of drilling a well can be a significant portion of the overall plant cost. Drilling research has focused on means to reduce the costs of drilling through hard rock in high-temperature, corrosive environments. Recent accomplishments include the development of slimhole drilling that reduces costs by up to 50% and improved drilling control and tools.

4.3 Energy Conversion

Energy conversion research is aimed at reducing the delivered electricity cost by improving performance, lowering equipment cost, and reducing O&M costs of geothermal power plants. Because geothermal power plants operate at relatively low temperatures compared to other power plants, thermodynamics dictates that they reject to the environment as much as 90% of the heat extracted out of the ground. Research has thus focused on improving the heat rejection equipment, and new designs of both water-cooled and air-cooled condensers have been developed. Other research accomplishments include improved thermodynamic cycles that extract more energy out of each kilogram of brine, better maintenance techniques, and the development of heat exchanger linings that protect low-cost heat exchanger materials from corrosion and scaling when subjected to geothermal fluids.

5. THE FUTURE OF THE INDUSTRY

Operators of existing plants are working hard to lower O&M costs in order to improve their profit margins now that price guarantees for many plants have expired. The need to reduce labor costs has produced a trend toward more automation. Plant owners are also actively looking at ways to improve plant efficiency and, in some cases, are adjusting plant operation to accommodate a resource that is declining with time.

In some cases, totally new power plant concepts are being considered. For example, one company is exploring use of the Kalina cycle, a binary cycle that utilizes a mixture of ammonia and water as the working fluid. This cycle has the potential to extract a third more energy from the geothermal fluid than a conventional cycle.

There are a number of reasons to believe that the economic climate may improve. The movement toward consumer disclosure, associated with utility restructuring, will likely favor all clean energy sources, including geothermal. Portfolio standards aimed at requiring that a certain percentage of electric power generation must come from clean sources, and “green marketing” will also help make geothermal more attractive.

Combining geothermal power production with other processes may provide sufficient financial incentives to make plants economic. For example, a new plant at the Salton Sea in California extracts zinc from highly saline brine that is also used to generate electric power.

In addition to new plant development at the Salton Sea, there are two new proposed 50-MW plants at Glass Mountain, California, being done under a California Energy Commission program. According to Reference (6), there are plans for a total additional U.S. geothermal electric capacity of 578 MW over the next five years, although it is not clear how much of this will actually be built. As Asia emerges from its economic crisis, the geothermal industry there is expected to pick up again. A number of opportunities in Latin America and Africa are also being pursued.

In order to improve the cost-effectiveness of small geothermal power plants, the U.S. Department of Energy, as part of a new Geopowering the West initiative, has released a Request for Proposals entitled “Field Verification of Small-Scale Geothermal Power Plants.” Through this solicitation, DOE hopes to build several power plants in the size range of 300 kW to 1 MW. Data on performance and O&M costs will be collected for a 3-year period, after which it is intended that the plants will continue to generate electricity for sale to the grid or to provide power for a local process. Additional solicitations will be aimed at improved drilling and enhancing the recovery of energy from existing geothermal reservoirs.

Geothermal electricity has already proven itself to be a clean, reliable, and comparatively inexpensive alternative to fossil fuels. Continued government-funded research in exploration and reservoirs, drilling, and energy conversion, performed in close collaboration with industry, offers considerable promise for significantly lowering the cost of geothermal power production. Combined with deployment

programs and environmentally sensitive energy policies, geothermal can become a major energy contributor throughout the western United States and in many countries around the world.

6. REFERENCES

- (1) Sifford, A. and Bloomquist, R. G., Geothermal Electric Power Production in the United States: A Survey and Update for 1995-1999, submitted to the Geothermal World Congress, May 2000.
- (2) Muffler, L.J.P., ed., Assessment of Geothermal Resources of the United States—1978, U.S. Geological Survey Circular 790, 1979.
- (3) Rybach, L., Megel, T., Eugster, W.J., How Renewable are Geothermal Resources?, Geothermal Resources Council Transactions, Vol. 23, October 17-20, 1999.
- (4) EPRI, Renewable Energy Technology Characterizations, DOE Report TR-109496, December 1997.
- (5) Vimmerstedt, L., Opportunities for Small Geothermal Projects: Rural Power for Latin America, the Caribbean, and the Philippines, NREL/TP-210-25107, National Renewable Energy Laboratory, November 1998.
- (6) Sifford, *ibid.*

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