# Geothermal 101

## Basics of Geothermal Energy


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GEOTHERMAL
ENERGY
ASSOCIATION

# Geothermal 101: Basics of Geothermal Energy

Prepared by Leslie Blodgett 

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Cover: Four types of conventional geothermal power plants, clockwise from top left. Flash Plant, Coso, California (Terra-Gen Power); Dry Steam Plant, The Geysers, California (Calpine Corp.); Binary Plant, Stillwater, Nevada (Enel Green Power North America); Flash/Binary Plant, Puna, Hawai'I (Ormat Technologies)

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# 1. Technology Basics

Geothermal energy—the heat of the Earth—is a clean, renewable resource that provides energy in the U.S. and around the world. The U.S. has been using commercial, large-scale geothermal power plants at deep resource temperatures (between 200˚F and 700˚F) since the 1960s. Geothermal energy development and production is a thriving international market.

> More from GEA: The Values of Geothermal Energy: A Discussion of the Benefits Geothermal Power Provides to the Future U.S. Power System (Oct. 2013); Promoting Geothermal Energy: Air Emissions Comparison and Externality Analysis (May 2013); The State of Geothermal Technology - Part II: Surface Technology (Jan. 2008); The State of Geothermal Technology - Part I: Subsurface Technology (Nov. 2007)

## 1.1. What is geothermal energy?

Heat has been radiating from the center of the Earth for some 4.5 billion years. At 6437.4 km (4,000 miles) deep, the center of the Earth hovers around the same temperatures as the sun's surface, 9932°F (5,500°C) (Figure 1). Scientists estimate that 42 million megawatts (MW) of power flow from the Earth's interior, primarily by conduction

Geothermal energy is a renewable resource.[1] One of its biggest advantages is that it is constantly available. The constant flow of heat from the Earth ensures an inexhaustible and essentially limitless supply of energy for billions of years to come.

[1] The National Energy Policy Act of 1992 (Sec. 1202) and the Pacific Northwest Electric Power Planning and Conservation Act of 1980 (Sec. 12H, 839a(16), page 84) both define geothermal energy as a renewable resource.

**Figure 1: Temperatures in the Earth**

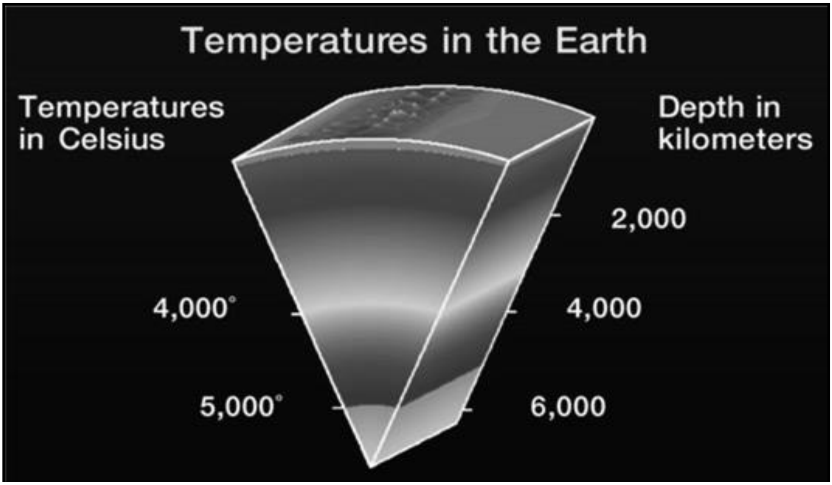


Figure 1 Source: Geo. Edu. Office Slide Show, Slide 5

The uses of geothermal for heat and other purposes were indigenous practices across a variety of world cultures: “The Maoris in New Zealand and Native Americans used water from hot springs for cooking and medicinal purposes for thousands of years. Ancient Greeks and Romans had geothermal heated spas. The people of Pompeii, living too close to Mount Vesuvius, tapped hot water from the earth to heat their buildings. Romans used geothermal waters for treating eye and skin disease. The Japanese have enjoyed geothermal spas for centuries.”[2]

[2] Nersesian, page 334

A viable geothermal system requires heat, permeability, and water. Developers explore a geothermal reservoir to test its potential for development by drilling and testing temperatures and flow rates.

Rainwater and snowmelt feed underground thermal aquifers (Figure 2). When hot water or steam is trapped in cracks and pores under a layer of impermeable rock, it forms a geothermal reservoir.

**Figure 2: Geothermal Reservoir**

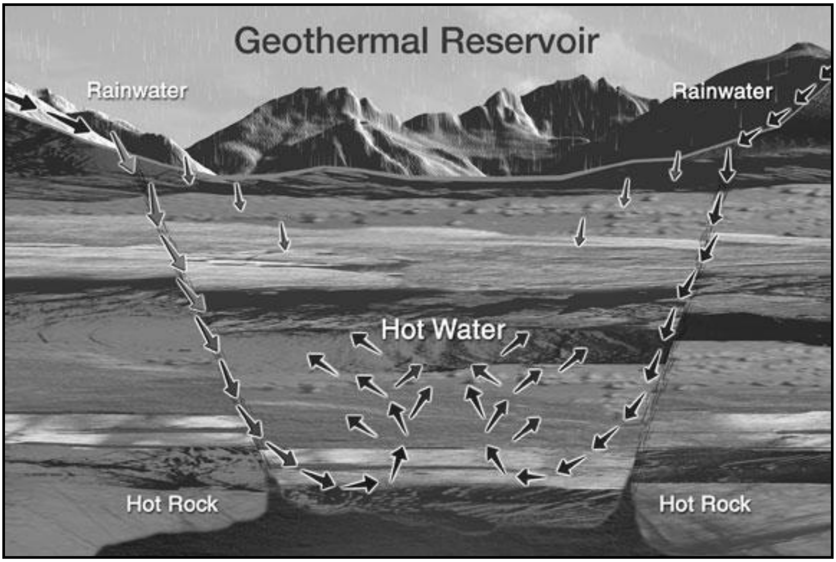


Figure 2 Source: Geo. Edu. Office Slide Show, Slide 12

At the Larderello, Italy dry steam field, Prince Piero Ginori Conti first proved the viability of geothermal power plant technology in 1904 (Figure 3). Larderello is still producing today.

**Figure 3: First Geothermal Plant, 1904, Larderello, Italy**

First Geothermal Power Plant, 1904, Larderello, Italy

Figure 3 Source: Geo. Edu. Office Slide Show, Slide 50

## 1.2. What is a baseload power source? What is a dispatchable power source?

A baseload power plant produces energy at a constant rate. In addition to geothermal, nuclear and coal-fired plants are also baseload. Because the energy is constant, its power output can remain consistent nearly 24 hours a day, giving geothermal energy a higher capacity factor than solar or wind power, which must wait for the sun to shine or the wind to blow, respectively.[3] This means a geothermal plant with a smaller capacity than a solar or wind plant can provide more actual, delivered electricity.

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[3] “Capacity” and “capacity factor” essentially refer to the distinction between megawatts (MW) and megawatt-hours (MWh). MW is a unit of power or the rate of doing work, whereas MWh is a unit of energy or the amount of work done. One MWh is equal to 1 MW (1 million watts) applied over the period of an hour. In geothermal development, one megawatt is roughly equivalent to the electricity used by 1,000 homes.

A geothermal plant can also be engineered to be firm, flexible, or load following, and otherwise support the needs of the grid.[4] Most geothermal plants being built now have adjustable dispatching capabilities. In addition to geothermal, natural gas is dispatchable. This means a geothermal plant can meet fluctuating needs, such as those caused by the intermittency of solar and wind power.

**1.3. How does a conventional geothermal power plant work?**
After careful exploration and analysis, wells are drilled to bring geothermal energy to the surface, where it is converted into electricity. Figure 4 shows the geothermal installed capacity in the U.S. from 1975 to 2012, separated by technology type.

**Figure 4: Total U.S. Geothermal Installed Capacity by Technology (MW) 1975–2012**

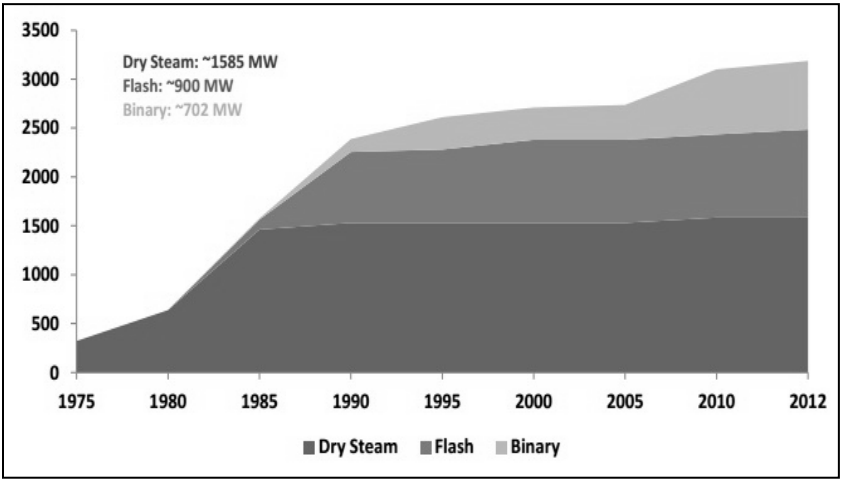


Figure 4 Source: Geothermal Energy Association

[4] GEA "The Values"

The USGS has defined moderate-temperature resources as those between 90°C and 150°C (194 to 302°F), and high-temperature geothermal systems as those greater than 150°C.[5]

Figures 5-7 depict the three commercial types of conventional geothermal power plants: flash, dry steam, and binary.

In a geothermal flash power plant, high pressure separates steam from water in a "steam separator" (Figure 5) as the water rises and as pressure drops.  The steam is delivered to the turbine, and the turbine then powers a generator.  The liquid is reinjected into the reservoir.

Under one-third of the installed geothermal capacity in the U.S. is comprised of flash power plants, with the majority in California.[6]

**Figure 5: Flash Power Plant**

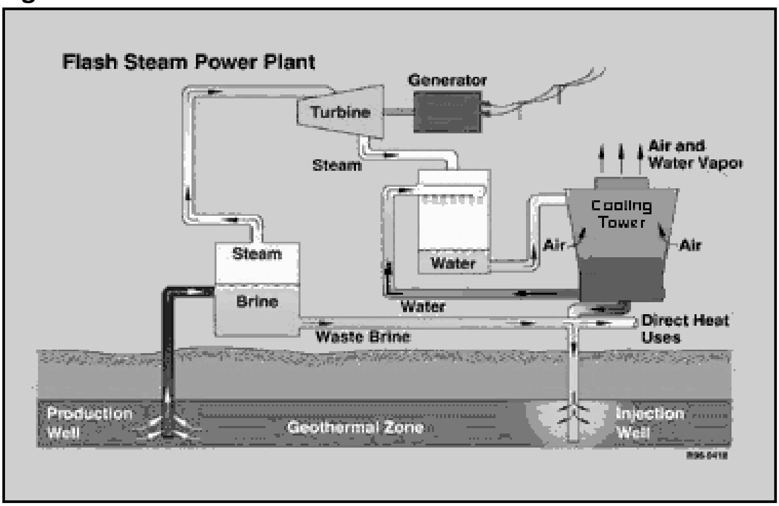


Figure 5 Source: Geo-Heat Center

[5] U.S. Geological Survey

[6] GEA "Annual" 2012, page 7

In a geothermal dry steam power plant, steam alone is produced directly from the geothermal reservoir and is used to run the turbines that power the generator (Figure 6). Because there is no water, the steam separator used in a flash plant is not necessary. Dry-steam power plants account for approximately 50% of installed geothermal capacity in the U.S. and are located in California.

**Figure 6: Dry Steam Power Plant**

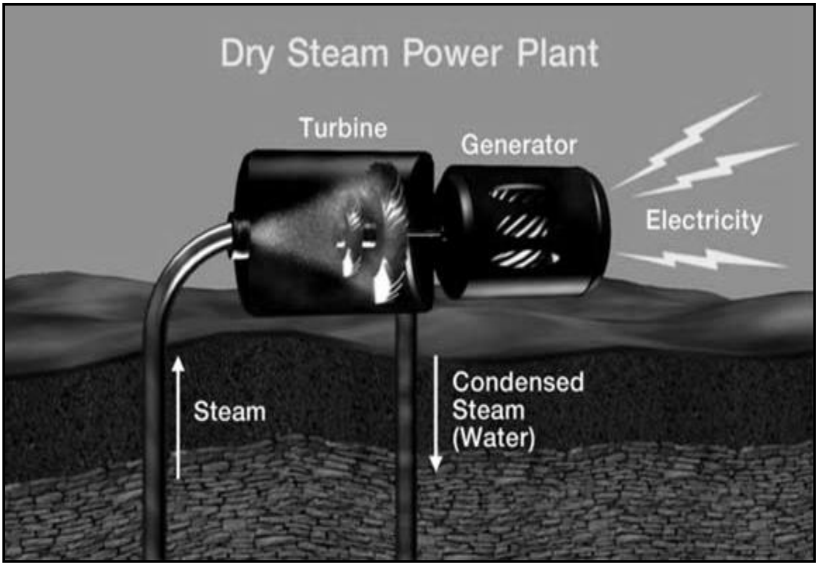


Figure 6 Source: Geo. Edu. Office Slide Show, Slide 49

In 1981 at a project in Imperial Valley, California, Ormat Technologies established the technical feasibility of the third conventional type of large-scale commercial geothermal power plant: binary. The project was so successful that Ormat repaid its loan to the Department of Energy (DOE) within a year.[7] Binary geothermal plants have made it possible to produce electricity from geothermal resources lower than

[7] GEA "Annual" 2012, page 7

302°F (150°C). This has expanded the U.S. industry's geographical footprint, especially in the last decade.

Binary plants use an Organic Rankine Cycle system, which uses geothermal water to heat a second liquid that boils at a lower temperature than water, such as isobutane or pentafluoropropane. This is called a working fluid (or "motive fluid" in Figure 7). A heat exchanger separates the water from the working fluid while transferring the heat energy. When the working fluid vaporizes, the force of the expanding vapor, like steam, turns the turbines that power the generators. The geothermal water is then reinjected in a closed loop, separating it from groundwater sources and lowering emission rates further (see section 5). Most new geothermal plants under development in the U.S. are binary.

**Figure 7: Binary Power Plant**

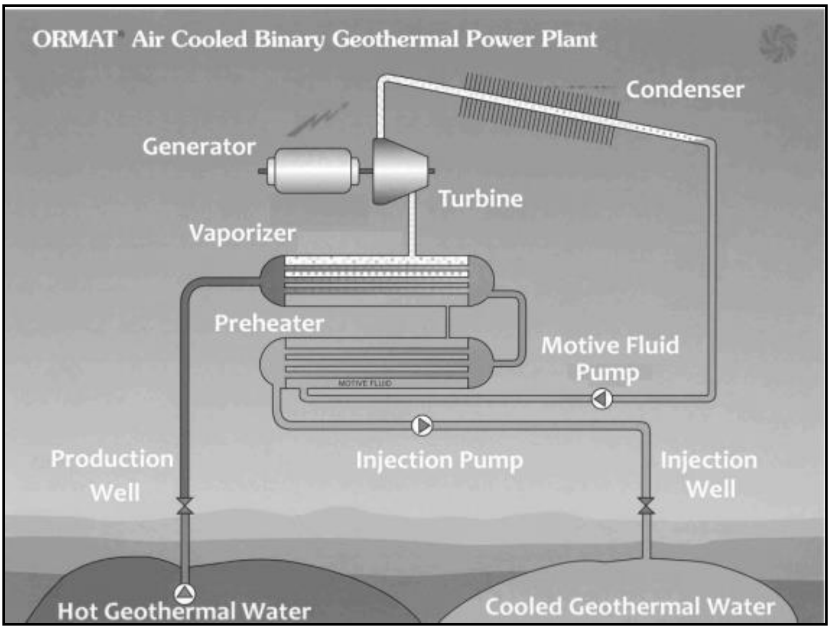


Figure 7 Source: Ormat

Hybrid power plants allow for the integration of numerous generating technologies. In Hawai'i, the Puna flash/binary combined cycle system optimizes both flash and binary geothermal technologies. Geothermal fluid is flashed to a mixture of steam and liquid in a separator. The steam is fed to a turbine as in a flash-steam generator and the separated liquid is fed to a binary cycle generator (Figure 8).

**Figure 8: Flash/Binary Power Plant**

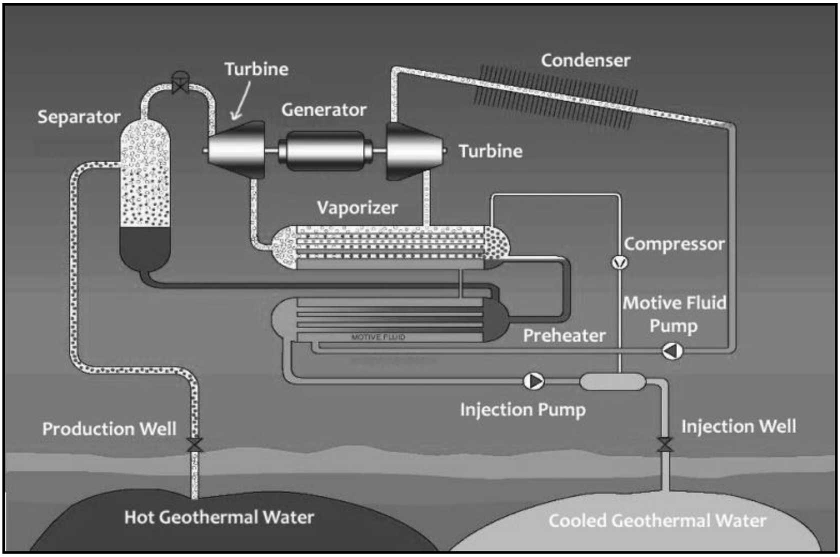


Figure 8 Source: Geo-Heat Center

Another type of hybrid plant is Enel Green Power's solar-geothermal plant in Stillwater, Nevada. This type of hybrid could be an option in areas that are rich in resources but require extra economic or technological support to make them viable for energy development.

## 1.4. How do geothermal heat pumps work?

Animals burrow underground for warmth in the winter and to escape the heat of the summer. The same basic principle of constant, moderate temperature in the subsurface is applied to geothermal heat pumps (GHPs).[8] GHPs utilize average ground temperatures between 40˚and 70˚F.[9] In 1948, a professor at Ohio State University developed the first GHP for use at his residence. A groundwater heat pump came into commercial use in Oregon around the same time.[10]

**Figure 9: Geothermal Heat Pumps**

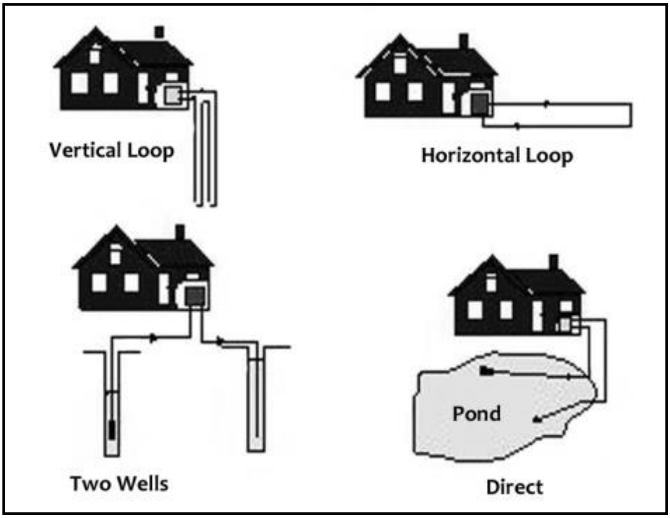


Figure 9 Source: Geo-Heat Center

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[8] Also called a geoexchange system or Ground Source Heat Pump.

[9] Geothermal Exchange Organization

[10] U.S. Department of Energy "A History"

GHP heating and cooling systems circulate water or other liquids to pull heat from the Earth through pipes in a continuous loop through a heat pump and conventional duct system. For cooling, the process is reversed; the system extracts heat from the building and moves it back into the Earth loop. The loop system can be used almost everywhere in the world at depths below 10 ft to 300 ft. GHPs are used in all 50 states and are over 45% more energy efficient than standard heating and cooling system options.[11]

Homeowners who install qualified GHPs are eligible for a 30% federal tax credit through December 31, 2016. They can be buried conveniently on a property such as under a landscaped area, parking lot, or pond, either horizontally or vertically (Figure 9). A GHP system can also direct the heat to a water heater unit for hot water use.

**1.5. How do direct use applications work?**

Geothermal heat is used directly, without a power plant or a heat pump, for applications such as space heating and cooling, food preparation, hot spring bathing and spas (balneology), agriculture, aquaculture, greenhouses, snowmelting, and industrial processes. Geothermal direct uses are applied at aquifer temperatures between 90˚F and 200˚F.[12]

Examples of direct use applications exist all across the U.S. Boise, Idaho's Capitol Building uses geothermal for direct heating and cooling. President Franklin D. Roosevelt frequented Georgia's healing hot springs and founded the Roosevelt Warm Springs Institute for polio treatment in 1927. And the City of Klamath Falls, Oregon began piping hot spring water to homes as early as 1900.[13]

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[11] U.S. Environmental Protection Agency "Heat Pumps"

[12] Geothermal Exchange Organization

[13] Klamath Falls, City of

In a typical geothermal direct use configuration, geothermal water or steam is accessed and brought to a plate heat exchanger (Figure 10). New direct use projects in numerous states, including some on Indian reservations, are encouraged by the provisions of the Geothermal Steam Act Amendments passed by Congress in 2005 (see section 4).

**Figure 10: Direct Use Geothermal Heating System**

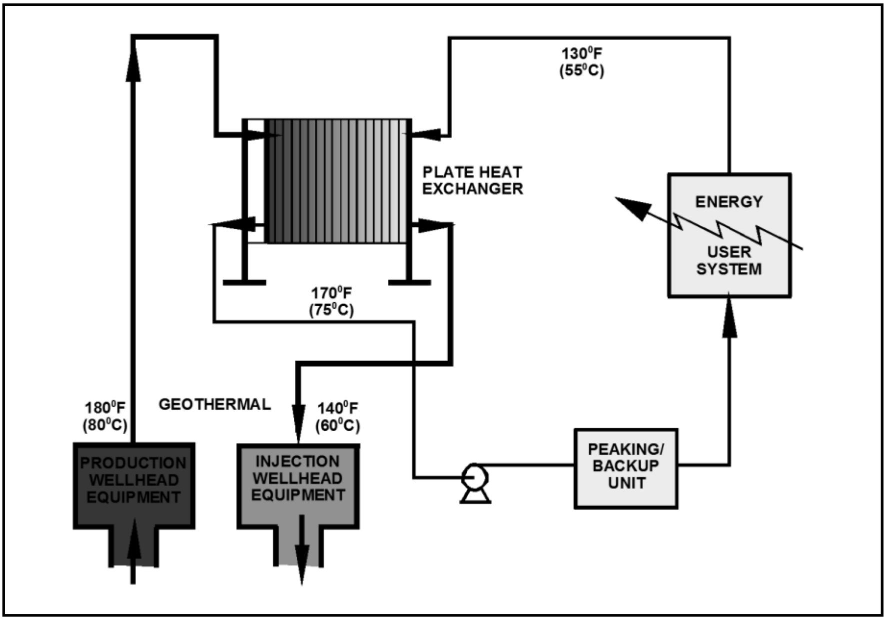


Figure 10 Source: Geo-Heat Center

# 2. Current Use

In the 1920s, geothermal electrical generation in the U. S. began at what would become known the world over as The Geysers geothermal field.[14] The U.S. geothermal industry produces more energy from geothermal plants than any other country. Technology experts are expanding the definition of useable geothermal resources and are improving the economics of generation. Geothermal energy produced about 3% of renewable energy-based electricity consumption in the U.S. as of a 2011 DOE count.[15]

More from GEA: Annual U.S. and Global Geothermal Power Production Report (Apr. 2014); previous U.S. and international production reports

## 2.1. How much geothermal energy is used in the U.S.?

GEA provides estimates on industry statistics that are based on direct feedback from companies. According to GEA research, "The geothermal power industry reached about 3,442 MW at the end of 2013 . . . In 2013 there were about 1,000 MW of planned capacity additions under development and about 3,100 MW of geothermal resources under development."[16] The industry's U.S.-based additions in 2013 added about 85 MW of new capacity at new and refurbished power plants in Utah, Nevada, California, and New Mexico.

In the Western states, natural geothermal reservoirs form relatively close to the surface. Surface manifestations such as geysers, hot springs, and even volcanoes give geologists plenty to study to learn

[14] Located in the Mayacamas Mountains of northern California, The Geysers is the oldest geothermal field in the U.S. and is the largest commercially productive geothermal field in the world.

[15] U.S. Department of Energy "Renewable Energy Consumption"

[16] GEA "Annual" 2014, page 4

what is happening under the surface in states such as California and Nevada. The industry sometimes refers to these Western resources as the low-hanging fruit of the industry, yet when comparing the U.S. Geological Survey (USGS) estimate to current MW under production, only about 10% of the estimated Western states resource base has been developed.

Renewable energy generation in California has been dominated by geothermal energy for since the 1980s (Figure 11). In 2011 the California Energy Commission (CEC) reported 42% of California's commercial in-state renewable electricity generation, or about 6.2% of all power generated in-state, was geothermal.

**Figure 11: California Renewable Energy Generation by Fuel Type, 1983-2010**

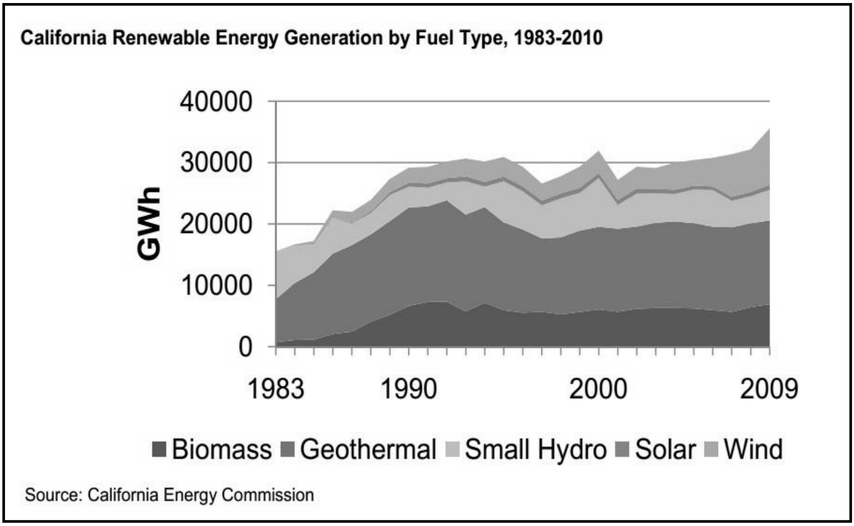


Figure 11 Source: California Energy Commission. Note that resource types, listed left to right, are represented in order on the y-axis from bottom to top.

## 2.2. What non-conventional technologies are used for geothermal production?

Additional non-conventional technologies being developed and used today are discussed in section 3.2., "What technologies will expand geothermal energy uses in the short term?"

### 2.2.1. Working Fluids

Advances in working fluids for binary power systems make it possible to achieve greater heat transfer efficiency while producing power at lower temperatures. The Kalina Cycle's ammonia-water mix increases production by up to 50% and has been used in applications since the 1990s.[17] ElectraTherm developed the Green Machine, and Turbine Air Systems provided the unit at Beowawe Flash Plant, Nevada.

### 2.2.2. Distributed Generation

Distributed generation facilities produce geothermal on a smaller scale to provide local or on-site electricity needs of a facility. Energy not being used by the facility can sometimes be sold to the grid. Distributed generation benefits remotely located systems such as Wendel-Amedee in northeastern California; Chena Hot Springs in Alaska; the Oregon Institute of Technology in Klamath Falls; and the Rocky Mountain Oil and Gas Testing Center in Wyoming.

### 2.2.3. Combined Heat and Power

Combined heat and power plants, also used in fossil fuel technologies, efficiently use low-temperature resources in combination with binary or Organic Rankine Cycle power units. The use of energy is cascaded, which in turn improves the economics of the entire system.[18]

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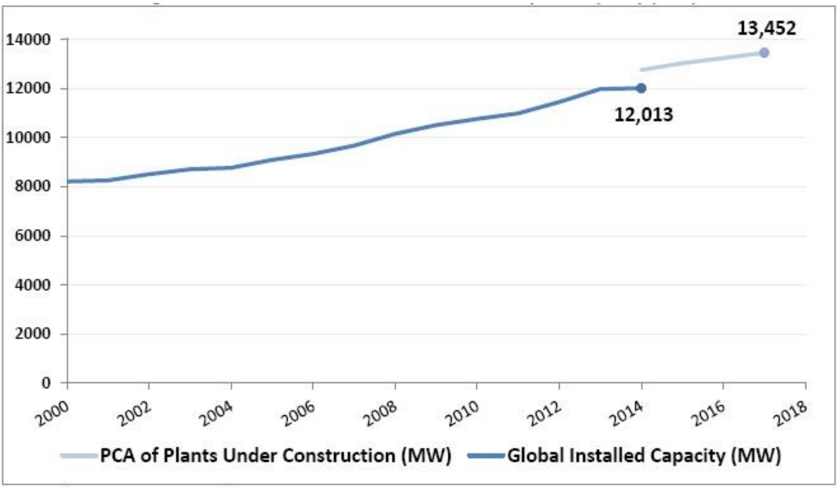
[17] http://kalinacycle.net/

[18] Oregon Institute of Technology "Combined"

**2.3. How much geothermal energy is used internationally?**
GEA estimates that the international geothermal power market is growing at a sustained rate of 4% to 5% (Figure 12). Almost 700 geothermal projects are under development in 76 countries. “Many countries anticipating the threats caused from by climate change realize the values of geothermal power as a baseload and sometimes flexible source of renewable energy. These countries are on every continent and range from small island nations to large developed economies like China or the United States.”[19]

**Figure 12: International Geo Power Nameplate Capacity (MW)**




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.

Figure 12 Source: Geothermal Energy Association

[19] GEA “Annual” 2014, page 4

Countries around the world also utilize geothermal direct use applications. Including GHPs, direct use capacity reached 51 GWt in 2010.[20, 21]

Opportunities for U.S. geothermal companies abound in the global market. In the near term, "exports from the United States are likely to increase in the subsectors that currently enjoy a competitive advantage, including the drilling, financing, and engineering sectors, as well as the growing geothermal heat pump industry," with estimated U.S. exports totaling $70.1 million worth of geothermal equipment in 2009.[22]

Known potential estimates of geothermal resources in the East African Rift System range between 10,000 and 20,000 MW and remain largely undeveloped. The African Rift Geothermal Energy Development Facility underwrites drilling risks in six African nations and is backed by the United Nations Environment Programme (UNEP).

Kenya and Ethiopia both have installed geothermal capacity already, and both have plans for projects that will be greater than 100 MW. The average geothermal power plant in the U.S. is about 25 MW.[23]

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[20] 1 GWt is the thermal power produced or consumed at the rate of 1 gigawatt. In the electric power industry, thermal power (as in MWt or GWt) refers to amount of heat generated, which creates steam to drive a turbine. Electric power (as in MWe or GWe) is the amount of electricity generated.

[21] Pike Research

[22] National Export Initiative, pp. 18-19

[23] GEA "Annual" 2014, page 8

Many countries in Central and South America have developed a portion of their geothermal resources for utility scale power production. El Salvador and Costa Rica are seasoned users of geothermal energy. Chile, Argentina, Columbia, and Honduras have significant amounts of geothermal potential; however, these countries are still in the early stages of exploring and identifying their resources.

Countries within Asia's geothermal sector including Indonesia, the Philippines, and Japan are incentivizing the development of geothermal resources. Indonesia alone contains over 27,500 MW of potential geothermal resources, the largest known in the world.

In early 2014, GEA estimated Europe and Turkey had a total installed capacity of 1,996 MW for geothermal energy, and there were 111 new power plants under construction or under investigation in EU member states. Within Europe, Italy was the market leader with over 50% of the European capacity. Iceland derived between one-quarter and one-third of its electricity, and 90% of its heating, from geothermal resources; Iceland's geothermal history is considered a model for transitioning indigenous practices to modern technology use. World Bank and the geothermal initiatives of the European Bank for Reconstruction and Development are supported by European Union climate policies.[24]

[24] GEA "International" 2010, page 5

# 3. Potential Use

The heat of the Earth is considered infinite; its use is only limited by technology and the associated costs, but the potential is there to provide enough energy to meet the power needs of humankind many times over. Production is becoming viable in more states and areas of the world as research and development uncovers the possibilities.

| More from GEA: Annual U.S. and Global Geothermal Power Production Report (Apr. 2014); previous U.S. and international production reports |
|---|

**3.1. What is the potential of using geothermal resources in the U.S.?**
The temperature at a depth of 6.5 km is above boiling nearly everywhere in the U.S., so the potential for generating electrical power from geothermal resources could be realized in every state in the country.

The USGS has identified potential for geothermal energy production in 13 Western states of up to 16,457 MW from known geothermal systems; up to 73,286 MW from resources yet to be discovered; and up to 727,900 MW from the use of EGS (Table 1).[25]

The Western Governors Association has stated that by 2025, around 13,000 MW of identified geothermal resources could be developed in Western states.[26]

In 2013 the Imperial Irrigation District in California pledged to build 1,700 MW of additional geothermal power by the early 2030s.

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[25] U.S. Geological Survey. The report assessed Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. Not included in the assessment: geothermal systems located on public lands closed to development, such as national parks; geothermal direct use, small power, oil and gas coproduction and geopressured resources

[26] Western Governors Association

Production is already happening beyond the Western states and will continue to expand. In recent years there are geothermal projects in development as far east as Texas and Louisiana.

**Table 1. Geothermal Resource Potential in Western States**

| Category | Potential MWe (% probability) | Description |
|---|---|---|
| Identified Geothermal Systems | 3,675 (95%) to 16,457 (5%) | The resource is either liquid or vapor dominated and has moderate to high temperature. The resource is either producing, confirmed, or potential. |
| Undiscovered Geothermal Resources | 7,917 (95%) to 73,286 (5%) | Based on mapping potential via regression analysis. |
| Enhanced Geothermal Systems | 345,100 (95%) to 727,900 (5%) | Resource probability in regions characterized by high temperatures but low permeability and lack of water in rock formations. |

Separate studies by the National Renewable Energy Laboratory (NREL) and the Massachusetts Institute of Technology (MIT) concluded over 100,000 MWe could feasibly be reached in the next 15 to 50 years, respectively, with a reasonable, sustained investment in R&D.[27,28]

[27] Massachusetts Institute of Technology

[28] U.S. Department of Energy “Geothermal—The Energy.” This report does not include hidden or undiscovered geothermal systems, which the USGS report estimates have substantial energy potential; nor does it examine small power systems or distributed generation.

In 2010, in a study funded by Google.org,[29] Southern Methodist University (SMU) collected data that broadened the known geothermal potential for EGS technology across the U.S. to 2,980,295 MW—a near 40-fold increase compared to traditional geothermal technology potential. A major discovery within this study was that West Virginia, with temperatures of 392°F (200°C) at 5-km depths, places the state's geothermal power potential at 18,890 MW: a significant increase over prior estimates and the largest known geothermal reserve in the Eastern U.S.

### 3.2. What technologies will expand geothermal energy uses in the short term?

This section covers mineral recovery, enhanced or engineered geothermal systems (EGS), coproduction of geothermal and oil/gas, geopressured resources, and supercritical cycles.

#### 3.2.1. Mineral Recovery

Mineral recovery is the practice of extracting minerals from water at conventional geothermal sites, reducing the environmental impacts of mining. Known minerals found in geothermal fluids include: silica in many forms, strontium, zinc, rubidium, lithium, potassium, magnesium, lead, manganese, copper, boron, silver, tungsten, gold, cesium, and barium.[30] Different geothermal sites contain different suites of minerals.

[29] Google's investment made it the top investor in geothermal energy in the U.S. at the time, outspending the federal government.

[30] Canty and Mink

Simbol Materials is working to produce lithium from geothermal plants at a demonstration facility in Imperial Valley, California. Lithium has been called an energy-critical element, needed for high-performance battery materials and electrolyte solutions in electric vehicles and other clean-energy storage applications.[31] Imperial Valley could be well-positioned strategically to competitively, sustainably, and reliably meet the world's needs for high-performance battery materials for years to come.

### 3.2.2. Enhanced Geothermal Systems

Enhanced or engineered geothermal systems (EGS) refer to the creation of artificial conditions at a site where a reservoir has the potential to produce geothermal energy. A geothermal system requires heat, permeability, and water, so EGS techniques make up for reservoir deficiencies in any of these areas by enhancing existing fracture networks in rock, introducing water or another working fluid, or otherwise building on a geothermal reservoir.

At The Geysers, California, two pipelines bring treated sewage water from Lake County and Santa Rosa to improve the generation capacity of the wells.

In the Deschutes National Forest in Oregon, AltaRock Energy, Inc. is leading an EGS demonstration project.

The 260-MW Coso facility in southern California used EGS technology to extend capacity by 20 MW.

Desert Peak, Nevada, hosts an EGS expansion of an existing natural geothermal field.

[31] American Physical Society Panel on Public Affairs and the Materials Research Society

### 3.2.3 Coproduction of Geothermal and Oil/Gas

Heated water is a natural byproduct of oilfield production processes that has long been considered unusable. But much of the “wastewater” produced at oil wells each year in the U.S. is hot enough to produce electricity through geothermal coproduction.

Many of these wells are estimated to have clean energy capacities of up to 1 MW. A 1-MW power generator is small in conventional power generation terms, but the potential for hundreds of these to be brought on line within a short period of time is promising.

“According to reports by Massachusetts Institute of Technology and the National Renewable Energy Laboratory, there are 823,000 oil and gas wells in the U.S. that co-produce hot water concurrent to the oil and gas production,” states the white paper for the six-month demonstration at the Denbury, Mississippi oil field in 2011. “This equates to approximately 25 billion barrels annually of water which could be used as fuel to produce up to 3 GW of clean power.”[32]

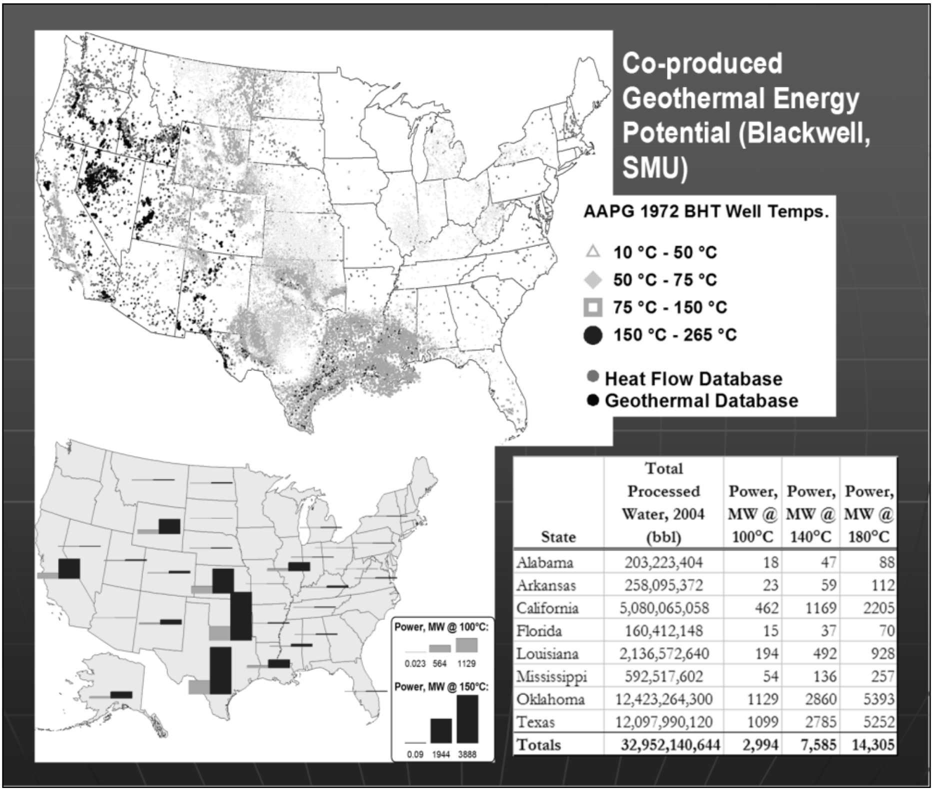
At the DOE’s Rocky Mountain Oil Test Center (RMOTC), Wyoming, geothermal company Ormat Technologies built a successful 0.25 MW coproduction demo unit which first ran in 2008.

A DOE-funded coproduction demonstration projects is underway by the University of North Dakota.

Figure 13 provides a perspective of the known estimated coproduced geothermal potential as of the 2006 report from MIT.

[32] ElectraTherm

## Figure 13: SMU Estimated Co-Produced Geothermal Potential




| State | Total Processed Water, 2004 (bbl) | Power, MW @ 100°C | Power, MW @ 140°C | Power, MW @ 180°C |
|---|---|---|---|---|
| Alabama | 203,223,404 | 18 | 47 | 88 |
| Arkansas | 258,095,372 | 23 | 59 | 112 |
| California | 5,080,065,058 | 462 | 1169 | 2205 |
| Florida | 160,412,148 | 15 | 37 | 70 |
| Louisiana | 2,136,572,640 | 194 | 492 | 928 |
| Mississippi | 592,517,602 | 54 | 136 | 257 |
| Oklahoma | 12,423,264,300 | 1129 | 2860 | 5393 |
| Texas | 12,097,990,120 | 1099 | 2785 | 5252 |
| **Totals** | **32,952,140,644** | **2,994** | **7,585** | **14,305** |

Figure 13 Source: Southern Methodist University and Massachusetts Institute of Technology. Chad Augustine and Dave Falkenstern's 2012 paper "An Estimate of the Near-Term Electricity Generation Potential of Co-Produced Water from Active Oil and Gas Wells" provides some updates; for example, new geothermal potential was recently discovered in West Virginia.

### 3.2.4. Geopressured Resources

Geopressured resources are reservoirs of naturally high-pressured hot water. Figure 14 shows major oil-producing basins in the U.S. The most significant of these located in Texas, Louisiana, and the Gulf of Mexico.

**Figure 14: Geopressured Basins in the United States**


Figure 14 Source: Department of Energy. Known geopressured strata indicated by gray dotted shading and solid outline

A demonstration plant in Texas produced electricity from geopressured resources as part of a DOE research program from 1979 to 1983.[33] In 2012, DOE funded a Geopressured Demonstration Project by Louisiana Tank in Louisiana.

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[33] Campbell

### 3.2.5. Supercritical Cycles

Supercritical fluids are in a physical state in which the temperature and pressure are above the critical point for that compound, meaning there is no distinction between liquid and vapor. Carbon dioxide is an example of a fluid that, when used in a supercritical state, can be pumped into an underground geological formation where it will heat up and expand, enhancing the fracture system in the rock as needed for geothermal production. It is then pumped out of the reservoir to transfer the heat to a surface power plant or other application and then returned to the reservoir.

A demonstration plant is underway by GreenFire Energy at the Arizona-New Mexico border region. The project would compress and reinject naturally occurring $CO_2$ to carry heat to the plant.[34] It has the potential not only to utilize natural carbon dioxide, but also to sequester human-made $CO_2$ from nearby power, resulting in net negative emissions.

The Iceland Deep Drilling Project (IDDP), a supercritical geothermal project, unexpectedly drilled into magma in 2009. IDDP has been able to fund continuing studies. The superheated high-pressure steam exceeded 842°F (450°C), a record for geothermal heat.[35]

### 3.3. What is the international potential of geothermal energy?

Based on industry announcements and feedback, in early 2014, GEA estimated about 12,000 MW of geothermal planned capacity additions, and about 30,000 MW of geothermal resources, under development worldwide.[36] Since geothermal sources are considered essentially limitless, estimates of its potential focus on commercial

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[34] U.S. Department of Energy "Innovative Geothermal"

[35] http://iddp.is/

[36] GEA "Annual" 2014

possibilities using quantifiers such as available lands and technology limits. Geothermal resources were estimated to potentially support between 35,448 MW and 72,392 MW of worldwide electrical generation capacity using technology available at the time of a 1999 GEA study. Table 2 shows University of Utah estimates of world geothermal resources for four different geologic regimes.[37]

**Table 2. World Continental Geothermal Resources**

| Geologic Regime | Joules (J) | bbl oil equivalent |
|---|---|---|
| Magmatic Systems | $15 \times 10^{24}$ J | $2,400,000 \times 10^{9}$ |
| Crustal Heat | $490 \times 10^{24}$ J | $79,000,000 \times 10^{9}$ |
| Thermal Aquifers | $810 \times 10^{18}$ J | $130 \times 10^{9}$ |
| Geopressured Basins | $2.5 \times 10^{24}$ J | $410,000 \times 10^{9}$ |
| Total Oil Reserves (for comparison)* | $5,300 \times 10^{9}$ J | Not given |

*Includes crude oil, heavy oil, tar sands, and oil shale[38]

Indonesia is the country holding the highest percentage of known geothermal resources, estimated at 28 GW, or 40% of the world total. Of this, about 5% has been developed.

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[37] University of Utah

[38] National Academy of Sciences

# 4. Supporting Policies

Public policies play a significant role in energy development and production and have shaped utility and energy systems for decades. Geothermal energy production and use are governed by numerous federal, state, and local laws ranging from environmental protection statutes to zoning regulations.  Policies and incentives that are essential to new geothermal development include: state renewable portfolio standards; federal and state tax incentives; geothermal leasing and permitting; research and technology support; and pollution and climate change laws.

More from GEA: Geothermal Revenue Under the Energy Policy Act of 2005 (Jan. 2009)

## 4.1. Are U.S. laws driving new growth in geothermal development today?

At the federal level, tax incentives are considered one of the most important incentives for driving growth in renewable energy.  There are loan and grant programs, research support, and other federal measures that encourage geothermal and other renewable technologies.[39]

The Energy Policy Act of 2005 qualified geothermal power projects for a choice between the federal Investment Tax Credit or the Production Tax Credit, though the status of the credit is pending at the time of this printing.

The Geothermal Research Development and Demonstration Act, passed by Congress in 1974, establishes a wide range of policies from loan guarantees to educational support, but while the statute remains on the books it is largely not in effect.

[39] http://www.dsireusa.org/

In 2007, Congress passed the Advanced Geothermal Energy Research and Development Act,[40] which provides the authorization for much of the current DOE effort.

**4.2. What laws govern geothermal energy on U.S. public lands?**

Federal geothermal leasing is governed by the John Rishel Geothermal Leasing Amendments passed as part of the 2005 energy bill. These provisions are also codified in Title 30, Chapter 23, Sections 1001-10028 of the U.S. Code. You can access the U.S. Code online through the House of Representatives Web site or through other law sources such as Cornell Law School's online directory.[41]

Geothermal leasing and permitting on federal land is managed by the U.S. Bureau of Land Management (BLM). Most state BLM offices have Web sites with information about geothermal lease sales and permit status. BLM published its Programmatic Environmental Impact Statement (EIS) for Geothermal Leasing in the Western U.S. in 2008.[42]

**4.3. What state laws govern geothermal energy in the U.S.?**

In additional to geothermal leasing and permitting on federal lands, states also issue leases for geothermal on state lands and have both regulatory and permitting requirements for geothermal development. There is no unified source of information about state programs, so you would need to check with each state for more information.

[40] Passed as part of H.R. 6.

[41] http://www.law.cornell.edu/uscode/text

[42] U.S. Department of the Interior "Final PEIS for Geothermal"

The primary sources for geothermal research and technology support are the U.S. DOE's Geothermal Technologies Program and the California Energy Commission, and in particular its Geothermal Resource Exploration and Development Program. For climate change, the U.S. EPA provides a range of information on its Web site.[43] For California, the Air Resources Board leads their climate efforts.[44]

At the state level, the most important laws are the renewable portfolio standards (RPS) that require utility companies to have a growing percentage of renewable power generation in their mix. In addition to this, states offer a wide range of additional rules, policies and incentives for renewable generation. A database of state incentives is available online.[45]

California has a unique grant fund “to promote the development of new or existing geothermal resources and technologies” known as the Geothermal Resources Development Account, which is funded from geothermal royalty revenues.[46]

The California Geothermal Energy Collaborative’s Geothermal Permitting Guide looks at environmental regulatory requirements after land and mineral rights have been acquired, through the steps of resource exploration to project closure.

[43] http://epa.gov/climatechange/

[44] http://www.arb.ca.gov/homepage.htm

[45] http://www.dsireusa.org/

[46] http://www.energy.ca.gov/geothermal/grda.html

# 5. Environmental Benefits

In an international community increasingly worried about worsening effects of climate change, geothermal can play an important role in reducing air emissions. Experts generally agree that effects of climate change pose significant environmental dangers, including flood risks, drought, glacial melting, forest fires, rising sea levels, loss of biodiversity, and potential health dangers.[47] Geothermal involves no combustion, and most geothermal plants being developed will produce nearly zero air emissions. So, using geothermal helps to offset energy-related carbon dioxide, which accounted for 82% of greenhouse gas (GHG) emissions in the U.S. in 2011.[48]

Using geothermal also eliminates the mining, processing, and transporting required for electricity generation from fossil fuel resources; and, it has among the smallest surface land footprint per kilowatt (kW) of any power generation technology.[49]

Geothermal power plants are designed and constructed to minimize the potential effects on wildlife and vegetation in compliance with a host of state and federal regulations. A thorough environmental review is required before construction of a generating facility can begin. Subsequent monitoring and mitigation of any environmental impacts continues throughout the life of the plant.

More from GEA: Promoting Geothermal Energy: Air Emissions Comparison and Externality Analysis (May 2013); GEA Issue Brief: Geothermal Energy and Induced Seismicity (Aug. 2009); GEA Issue Brief: Geothermal Energy and Water Consumption (Aug. 2009)

[47] IPCC Third Assessment Report

[48] U.S. Department of Energy "Emissions"

[49] 1 MW = 1,000 kW

**5.1. How effectively does geothermal help in improving air quality and decreasing greenhouse gas emissions?**

At geothermal power plants, billows seen rising from cooling towers are composed of water vapor or steam, not burned fuel or smoke emissions, and are caused by the evaporative cooling system. A binary or flash/binary geothermal plant produces nearly zero air emissions; air emission levels at dry steam plants are considered to be slightly higher, because even without human intervention, geothermal systems already contain naturally-occurring dissolved gases. The exact relationship between human-caused and naturally occurring geothermal emissions at geothermal power plant sites is difficult to characterize, and varies based on the site's unique resource chemistry, the resource temperature, type of power plant, and a number of other factors. In summary, though, geothermal technology is considered environmentally benign and any emissions are negligible when compared with using technologies that involve combustion of fossil fuels (Figure 15).

**Figure 15. Comparison of Coal, Natural Gas, and Geothermal $CO_2$ Emissions**

***Estimated Emission Levels by Pollutant and Energy Source of Power Plants***

| [lbs/MWh] | Dry Steam | Flash | Binary | Natural Gas | Coal |
|---|---|---|---|---|---|
| $CO_2$ | 59.82 | 396.3 | - | 861.1 | 2200 |
| $CH_4$ | 0.0000 | 0.0000 | - | 0.0168 | 0.2523 |
| $PM_{2.5}$ | - | - | - | 0.1100 | 0.5900 |
| $PM_{10}$ | - | - | - | 0.1200 | 0.7200 |
| $SO_2$ | 0.0002 | 0.3500 | - | 0.0043 | 18.75 |
| $N_2O$ | 0.0000 | 0.0000 | - | 0.0017 | 0.0367 |

***Source: Climate Registry 2012, EIA 2013e, EPA 2009, EPA 2011, NRC 2010***

GEA estimated, "When comparing the $CO_2$ emissions data obtained from the Environmental Protection Agency (EPA) and Energy Information Administration (EIA) for coal and natural gas power plants, the average rate of carbon dioxide emissions for coal-fired power plants and natural gas power plants are 2200 lbs $CO_2$/MWh and 861 lbs $CO_2$/MWh, respectively. Geothermal systems, on the other hand, produce significantly less emissions, approximately

197 lbs $CO_2$/MWh."[50] Most new geothermal plants being built in the U.S. use binary technology, which produce zero or near-zero emissions (see section 1, Technology Basics).

GEA estimated the externality benefits of producing electricity using geothermal resources as opposed to fossil fuels are $0.01 for natural gas and $0.035 for coal per kWh.  Geothermal provides approximately $278 million in externality benefits per year to the entire U.S. by avoiding fossil fuel emissions.

Nevada's 300 MW of geothermal power can save 4.5 million barrels of oil (the equivalent fuel used by 100,000 cars) and avoid emissions of 2.25 million tons of $CO_2$ annually.

Lake County, California, located downwind of The Geysers geothermal complex, has met all federal and state ambient air quality standards since the 1980s.  An abatement system at the complex actually improves air quality by processing natural hydrogen sulfide, which would ordinarily be released into the atmosphere by hot springs and fumaroles, and reducing the amount released by 99.9%.[51]

Reducing power plant emissions has substantial benefits to public health and associated costs. Clean Air Task Force estimated, in 2010, that the healthcare cost for illness and premature death associated with coal plant impacts in the U.S. alone exceeds $100 billion/year[52].

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[50] GEA "Promoting Geothermal Energy"

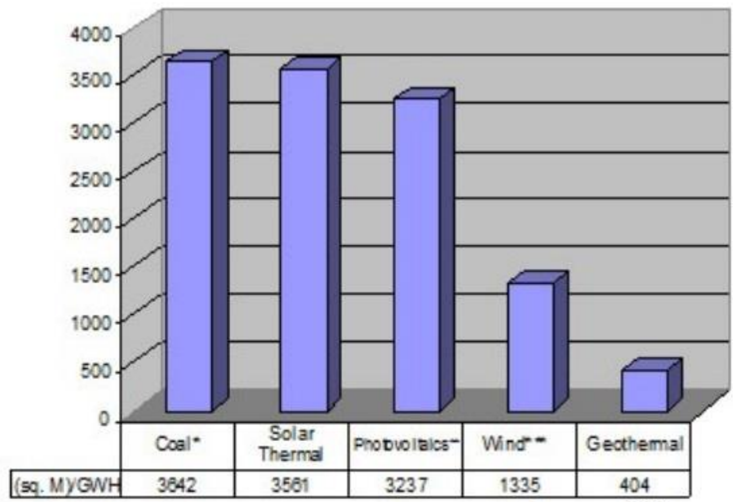
[51] GEA "A Guide"

[52] This included 13,200 deaths, 9,700 hospital admissions, 20,400 heart attacks, and over 1.6 million lost work days directly resulting from national power plant impacts.

## 5.2. How much land does geothermal energy use?

Geothermal development activities result in lower long-term land disturbance than other technologies (Figure 16). In its 2008 Programmatic Environmental Impact Statement, the BLM estimated that the total surface disturbance for a geothermal power plant ranges from 53 to 367 acres. This covers all activities such as exploration, drilling, and construction, and reflects variability in actual area of land disturbance based on site conditions and the size and type of geothermal plant. Much of this land is reclaimed after the exploration, drilling, and construction phases of development, so the long-term land use is much lower.

**Figure 16: Thirty-Year Land Use Comparison**




**Source: GEA**

Figure 17 breaks out land use throughout development, assuming plant sizes of a range between 30 MW and 50 MW.[53]

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[53] U.S. Department of the Interior "Final PEIS for Geothermal," page ES-8 and Table 2-8

## Figure 17. Typical Disturbances by Phase of Geothermal Resource Development

**Table 2-8**
**Typical Disturbances by Phase of Geothermal Resource Development**

| Development Phase | Disturbance Estimate per Plant |
|---|---|
| Exploration | **2 – 7 acres** |
| Geologic mapping | negligible |
| Geophysical surveys | 30 square feet[1] |
| Gravity and magnetic surveys | negligible |
| Seismic surveys | negligible |
| Resistivity surveys | negligible |
| Shallow temperature measurements | negligible |
| Road/access construction | 1- 6 acres |
| Temperature gradient wells | 1 acre[2] |
| Drilling Operations and Utilization | **51 – 350 acres** |
| Drilling and well field development | 5 – 50 acres[3] |
| Road improvement/construction | 4 – 32 acres[4] |
| Powerplant construction | 15 – 25 acres[5] |
| Installing wellfield equipment including pipelines | 5 – 20[6] |
| Installing transmission lines | 24 – 240[7] |
| Well workovers, repairs and maintenance | Negligible[8] |
| TOTAL | **53 – 367 acres** |

1 Calculated assuming 10 soil gas samples, at a disturbance of less than three square feet each.
2 Calculated assuming area of disturbance of 0.05 to 0.25 acre per well and six wells. Estimate is a representative average disturbance of all well sites. Some wells may require a small footprint (e.g., 30x30 feet), while others ma require larger rigs and pads (e.g., 150x150 feet).
3 Size of the well pad varies greatly based on the site-specific conditions. Based on a literature review, well pads range from 0.7 acres up to 5 acres (GeothermEx 2007; FS 2005). Generally a 30MW to 50 MW power plant requires about five to 10 well pads to support 10 to 25 production wells and five to 10 injection wells. Multiple wells may be located on a single well pad.
4 One-half mile to nine miles; assumes about ¼ mile of road per well. Estimates 30-foot wide surface disturbance for a 18-20 foot road surface, including cut and fill slopes and ditches.
5 30 MW plant disturbs approximately 15 acres; 50 MW plant disturbs approximately 25 acres.
6 Pipelines between well pad to plant assumed to be ¼ or less; for a total of 1½ to seven miles of pipeline in length, with a 25-foot-wide corridor
7 Five to 50 miles long, 40-foot-wide corridor.
8 Disturbance would be limited to previously disturbed areas around the well(s).

Figure 17 Source: Bureau of Land Management

Geothermal plants are constructed to blend in with their environmental surroundings, minimizing the land use footprint and often allowing for activities such as farming, skiing, and hunting on the same lands in compliance with the BLM's multiple use strategy. Pipelines, for example, which connect the geothermal resource base to the power plant, can be elevated so that small animals can roam freely and native vegetation can flourish. Natural color paint is a BLM requirement for power plants and piping on public land: for example, Ormat's Mammoth Geothermal Power Plant on the eastern slope of the Sierra Mountains in California blends in with the high-desert terrain.[54] Surface features such as geysers or fumaroles are not used during geothermal development, though some deterioration may occur if located near a facility, so sometimes special efforts are made to prevent this, especially if the features are of cultural significance.

**5.3. How do geothermal developers control noise levels?**
During drilling, temporary noise shields can be constructed around portions of drilling rigs. Geothermal developers use standard construction equipment noise controls and mufflers, shield impact tools, and exhaust muffling equipment. Once the plant is built, noise from normal operation of power plants comes from cooling tower fans and is very low. Turbine-generator buildings, designed to accommodate cold temperatures, are typically well-insulated acoustically and thermally and are equipped with noise absorptive interior walls.[55]

When noise issues arise, they can be dealt with effectively in ways that do not impact plant performance. Enel Green Power North America addressed high noise levels at its Stillwater, Nevada geothermal plant: "In response to unexpected high noise levels experienced during the start-up of the Stillwater Geothermal facility,

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[54] U.S. Department of Energy "Program Areas"

[55] GEA "A Guide"

Enel Green Power North America's Nevada-based geothermal team worked diligently to design Acoustical Energy Dissipaters, or Silencers. The purpose of the Silencer is to significantly reduce the sound levels caused by the acoustical energy flowing in the discharge piping of the turbine, without affecting turbine performance and plant output . . . The final product not only addressed a technical issue, but also helped the Company effectively respond to community concern about noise levels from the plant."[56]

**5.4. How much water do geothermal plants use?**
Water is commonly used in electricity production across the spectrum of generating technologies. The amount of water used in geothermal processes varies based on the type of resource, type of plant, type of cooling system (wet/dry or hybrid cooling), and type of waste heat reinjection system.[57]

Water is a critical component of geothermal systems. In a conventional system, it comes from the geothermal system source and is reinjected back into the reservoir to maintain reservoir pressure and prevent reservoir depletion.[58] Rainwater and snowmelt feed underground thermal aquifers, naturally replenishing them. Geothermal resources are considered renewable on timescales of technological and societal systems, meaning that unlike fossil fuel reserves, they do not need geological times for regeneration when reinjection is done properly.

Reinjection keeps the mineral-rich saline water found in geothermal systems separate from groundwater and fresh water sources to avoid

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[56] Enel Green Power application for GEA's 2011 Honors awards

[57] Farison, page 1,025

[58] Reinjection to protect groundwater resources is a requirement for most geothermal applications under the EPA Underground Injection Control Program requirements, BLM, and state well construction requirements.

cross-contamination. Injection wells are encased by thick borehole pipe and are surrounded by cement. Once the water is returned to the geothermal reservoir, it is reheated by the Earth's hot rocks and can be used over and over again to produce electricity.

For lifetime energy output, flash geothermal plants consume 0.01 gal/kWh; binary plants consume between 0.08 and 0.271 gal/kWh; and EGS projects consume between 0.3 and 0.73 gal/kWh (Figure 18; Table 4-3 of DOE "Water use")[59,60].

In 2011, Argonne National Lab found: "Average values of [life cycle water] consumption for coal, nuclear, and conventional natural gas power plant systems are higher than for geothermal scenarios. . . . With the exception of geothermal flash, which primarily relies on the geofluid in the reservoir for cooling, PV appears to be more water efficient, with consumption estimates of 0.07–0.19 gal/kWh. Overall, the geothermal technologies considered in this study appear to consume less water on average over the lifetime energy output than other power generation technologies."[61]

Geothermal energy can make use of wastewater that might otherwise damage surface waters (see section 3.2.3.) Additionally, studies have shown condensate at geothermal power plants could potentially be used to produce potable water, but no completed projects have thus

[59]These numbers provided by Argonne are aggregated values from several sources including the Electric Power Research Institute, DOE, and The National Energy Technology Laboratory. Argonne notes in its report that some of the sources used modeling outputs rather than data from power plants.

[60]Includes water consumed for drilling wells; assumes freshwater withdrawal. Flash systems use very little fresh water, while air-cooled binary plants use essentially no potable water.

[61] U.S. Department of Energy "Water Use," page 26

far incorporated this.[62] Section 3 includes a discussion of mineral recovery from geothermal water at power plant sites.

**Figure 18. Aggregated Water Consumption for Electric Power Generation, Lifetime Energy Output**

**TABLE 4-3 Aggregated Water Consumption for Electric Power Generation at Indicated Life Cycle Stages in Gallons Per kWh of Lifetime Energy Output[a]**

| Power Plant | Fuel Production | Plant Construction | Plant Operations | Total Life Cycle[b] |
|---|---|---|---|---|
| Coal | 0.26 | - | 0.004–1.2 | 0.26–1.46 |
| Coal with carbon capture | 0.01–0.17 | 0.13–0.25 | 0.5–1.2 | 0.57–1.53 |
| Nuclear | 0.14 | - | 0.14–0.85 | 0.28–0.99 |
| Natural gas conventional | 0.29 | - | 0.09–0.69 | 0.38–0.98 |
| Natural gas combined cycle | 0.22 | - | 0.02–0.5 | 0.24–0.72 |
| Hydroelectric (dam) | - | - | 4.5 | 4.5 |
| Concentrated solar power | - | 0.02–0.08 | 0.77–0.92 | 0.87–1.12 |
| Solar photovoltaic | - | 0.06–0.15 | 0.006–0.02 | 0.07–0.19 |
| Wind (onshore)[c] | - | 0.02 | 3.62E-08 | 0.01 |
| Geothermal EGS | - | 0.01 | 0.29–0.72 | 0.3–0.73 |
| Geothermal binary[d] | - | 0.001 | 0.08–0.27 | 0.08–0.271 |
| Geothermal flash[d] | - | 0.001 | 0.005–0.01 | 0.01 |
| Biomass | - | - | 0.3–0.61 | 0.3–0.61 |

[a] Sources: Adee and Moore (2010), Maulbetsch and DiFilippo (2006), Frick et al. (2010), Gleick (1994), Goldstein and Smith (2002), Harto et al. (2010), NETL (2005), NETL (2008), Vestas Wind Systems A/S (2006).

[b] Reported when provided, otherwise summed from values in table.

[c] Assumes recovery of water in the end-of-life management stage.

[d] Assumes water consumed as makeup for operational loss is a small percentage of total operational geofluid loss.

Figure 18 Source: Argonne National Laboratory

[62] Geothermal Development Associates of Reno, Nevada worked on a design for a power plant in Djibouti, East Africa that would have produced potable water.

## 5.5. Does seismic activity affect geothermal applications (and vice versa)?

Seismicity is a natural geological phenomenon in geothermal areas. Geothermal operations can create low-magnitude events known as microearthquakes. These events typically cannot be detected without sensitive equipment.[63]

The careful study and understanding of a geothermal reservoir's seismic levels is included in a company's preparation prior to development, and many geothermal companies monitor for induced seismicity throughout the life of a plant. According to BLM, "seismic risk is more likely to impact geothermal facilities than operation of geothermal facilities is to increase seismic risk."[64]

To address public concern, the U.S. DOE commissioned a risk assessment and a revised induced seismicity protocol in 2012.[65] The authors met with the domestic and international scientific community, policymakers, and other stakeholders to gain their perspectives. They incorporated lessons learned from EGS projects around the world to better understand the issues. The protocol concluded that with proper study and technology development, induced seismicity will not only be mitigated, but will become a useful tool for reservoir management.

The reinjection of geothermal water practiced by most geothermal plants on line today (see section 5.4.) results in a near-zero net change in the resource. This is distinguishable from the practice of directly injecting high-pressure fluids into fault zones, which has been linked to micro-seismicity in some cases.

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[63] National Academy of Sciences "Induced Seismicity"

[64] U.S. Department of the Interior "Final PEIS for Geothermal" pp. 4-18

[65] U.S. Department of Energy "Protocol"

## 6. Economic Benefits

Geothermal energy provides long-term answers to some of the most pressing issues in today's economy. Warning signs of climate distress and volatile fuel costs are leading people to question where their power comes from and how rising energy costs will affect their communities and businesses. Unlike coal and natural gas, geothermal incurs no hidden costs such as land degradation, high air emissions, forced extinction and destruction of animals and plants, and health impacts to humans. Since geothermal energy production is domestic, it helps offset involvement in foreign energy affairs.

A geothermal project will only provide the highest benefits to developers and customers if the economics have been thought through in advance. Like any investment, geothermal projects require an understanding of the risks, costs, and benefits. See section 7 for factors affecting the cost of a geothermal project.

> More from GEA: The Manageable Risks of Conventional Hydrothermal Geothermal Power Systems (Feb. 2014); The Values of Geothermal Energy: A Discussion of the Benefits Geothermal Power Provides to the Future U.S. Power System (Oct. 2013); Energizing Southern California's Economy: The Economic Benefits and Potential for Geothermal Energy in Southern California (Oct. 2011)

### 6.1. How does geothermal energy benefit the U.S. economy?

Geothermal power is a low cost energy source that diversifies the fuel supply and benefits the transitioning power grid. It does not require purchase of fuel, and because it is a baseload resource, geothermal power is reliable, helping to stabilize prices. It is also dispatchable, or able to be ramped up or down quickly to make up for intermittency caused by wind or solar power. The average cost of geothermal plant over its lifetime is dramatically lower than that of traditional sources of power.

Geothermal energy is locally produced, reducing foreign oil imports and boosting rural economies through royalties and tax payments. A geothermal power project development will involve hundreds of individuals, employing local people full time as well as stimulating induced jobs.

**6.2. Is geothermal market investment growing?**

A 2006 GEA estimate showed that for every dollar invested in geothermal energy, the resulting growth of output to the U.S. economy is $2.50, or, a geothermal investment of $400 million would result in a growth of output of $1 billion for the entire U.S. economy.[66] Renewable energy technology projects worldwide saw $70.9 billion of new investments in 2006, and $117.2 billion in 2007, according to a DOE assessment.[67] "This is no longer just an interesting alternative, but a large scale transformation in global energy markets," DOE wrote.

Since that time, the capital represented by geothermal projects coming on line has increased substantially. With roughly 100 MW added annually in the U.S., and projects taking several years to construct, the capital investment in new U.S. geothermal projects would be in excess of $10 billion.

The geothermal industry is supported by both public and private investments. In 2008, Google.org outspent the government at the time and was the largest private investor in geothermal, injecting $11 million in advanced geothermal technology research and development. [68]

[66] Assuming an average capital cost of a geothermal project corresponding to $4000/kW.

[67] U.S. Department of Energy "Geothermal Risk Mitigation"

[68] The funding facilitated geothermal heat maps that can be accessed at Google Earth, http://www.google.org/egs/.

Table 3 summarizes a 2006 WGA estimate that near-term geothermal development of approximately 5,600 MW would result in nearly $85 billion dollars to the U.S. economy over 30 years.  Potential also exists in Wyoming, Montana, Texas, Kansas, Nebraska, South Dakota, and North Dakota, but the resource in those states was not studied in the WGA report.

**Table 3. Near-Term Geothermal Potential & Resulting Economic Contribution**

| State | New Power Capacity (MW) | 30-Year Economic Output (nominal) |
|---|---|---|
| California | 2,400 | $36 billion |
| Nevada | 1,500 | $22.5 billion |
| Oregon | 380 | $5.7 billion |
| Washington | 50 | $749 million |
| Alaska | 25 | $375 million |
| Arizona | 20 | $300 million |
| Colorado | 20 | $300 million |
| Hawaii | 70 | $1 billion |
| Idaho | 860 | $12.9 billion |
| New Mexico | 80 | $1.2 billion |
| Utah | 230 | $3.4 billion |
| **Total** | **5,635 MW** | **$84,410,046,000.00** |

### 6.3. How does geothermal energy benefit local economies?

Rural areas, where many of the geothermal resources that can be produced for energy consumption are located, can suffer from economic depression and high unemployment.  Geothermal developers bring significant economic advantages such as jobs and tax payments.  Many geothermal companies provide additional voluntary contributions to their neighbor communities.

In Imperial County, California, MidAmerican Renewables is the single largest taxpayer.[69] Overall geothermal activities supply a full 25% of the county tax base, and over $12 million in tax revenue. [70] In Nevada, geothermal power plants pay sales and use tax, property tax, net proceeds of mine tax, modified business tax, bonus lease payments, royalties to the state and county, salaries and benefits to employees, and a range of local vendors for products and services.[71]

Since enactment of the 2005 Geothermal Steam Act Amendments, 25% of revenues from geothermal leasing and production are allotted to state and local governments. In 2008, Nevada received $7.5 million and put all of the money in a state fund that supports K-12 schools throughout the state. The same year, California received $9.9 million and put 40% to the counties of origin; another 30% to the Renewable Resources Investment Fund; and 30% to the CEC for grants or loans to local jurisdictions or private entities.[72]

Geothermal power plants can be a tourist draw when students, scientists, or interested individuals visit the site, thereby bringing business to the local community. Iceland's most popular tourist destination is the Blue Lagoon, a geothermal spa connected to the Svartsengi power plant in the island's southwest. As of August 2012, the Calpine Geysers Visitor Center in California had hosted more than 75,000 visitors from all 50 U.S. states and 79 countries since it opened in 2001.

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[69] GEA "A Handbook," page 16

[70] MidAmerican Energy Holdings Company operates geothermal energy through MidAmerican Renewables (formerly CalEnergy U.S.).

[71] GEA "Why Support"

[72] GEA "Geothermal Revenue," page 5

**6.4. How does geothermal energy benefit developing countries?**
Kenya, Indonesia, and many Caribbean islands are some of the developing countries that stand to directly benefit from developing their abundant geothermal resources. Geothermal energy can provide answers to infrastructure needs while preserving the cleanliness of these regions.

Many developing countries are seeking energy and economic independence while learning from the lessons, both positive and negative, of the trade and subsidy practices employed by developed nations. Australia, China, Germany, Iceland, Italy, Japan, and the U.S. are some of the more developed countries that are facilitating geothermal development projects around the world. This support includes financing as well as technology sharing, training, and geological surveys.[73]

Indonesia holds about 40% of the world's known geothermal resources, but has developed very little of this. Since geothermal energy is developed locally rather than extracted and transported around the world, Indonesia could develop its geothermal resources for local use thereby freeing up its portable energy fuels—such as coal and natural gas—for higher mark-up export.

The East African Rift System is another of the world's largest known geothermal reserves, and energy needs in Africa are a topic of international interest. Biomass production has led to unwanted deforestation, and droughts have made hydropower plants unreliable. Dependence on expensive, imported petro-products and diesel supplies has increased in recent years. The Rift System's geothermal resources could provide an indigenous generation system with a predictable supply and price for remote locations.

[73] GEA "International" 2010

# 7. Power Plant Costs

All types of electricity generation have capital costs as the project is being planned and constructed, as well as operating and maintenance (O&M) costs once the plant is producing.

The DOE's Transparent Cost Database contains thousands of estimates from more than 100 published studies and DOE program-planning or budget documents, part of ongoing road-mapping efforts for various technologies.[74]

| |
|---|
| More from GEA: A Handbook on the Externalities, Employment, and Economics of Geothermal Energy (Oct. 2006); Factors Affecting Cost of Geothermal Power Development (Aug. 2005) |

## 7.1. What factors influence the cost of a geothermal power plant?

The costs for individual geothermal projects and for all power projects change over time with economic conditions. Some factors are universal to the power industry, including the cost of steel, other metals, and labor. Environmental policies, tax incentives, and financing options all factor in and are often influenced by competing markets.

The size of the plant, the specific geothermal technologies that a company chooses, cost of drilling, and cost to connect to the electric grid will vary from plant to plant. A company must factor in costs of obtaining knowledge of a resource, including rock formation, temperature, and chemistry. "The resource risk in connection with the financing of geothermal projects can be subdivided into questions of: resource existence, resource size, deliverability, cost of

[74] http://en.openei.org/wiki/Transparent_Cost_Database

development and operation, environmental constraints, management and operational problems, and resource degradation."[75]

To fully explore a geothermal resource a developer leases exclusive rights, which can be expensive and time consuming—especially on federal lands, home to 90% of geothermal projects. Financers of geothermal projects take an upfront risk, sometimes investing millions of dollars just to find out whether a geothermal reservoir has the right conditions for production. Risks change over time, and there is a learning curve effect on drilling success rates.[76] The risks can be offset by certain tax incentives and federal sureties (see section 4: Policy).

**7.2. How do costs compare between geothermal and other technologies?**

A geothermal project competes against other renewable and non-renewable power developments as well as all other projects that use similar commodities and services.[77] Geothermal is capital intensive; the upside to this is that essentially the entire resource base is paid for upfront; on the other hand, fossil fuel plants such as natural gas and coal have high fuel costs, especially if they are imported. Once a geothermal plant is built, the fuel is free. For a completed geothermal power project, most O&M costs are known and few market parameters can modify them, making the levelized cost of a geothermal plant over its lifetime extremely cost-competitive (Figure 19).[78] It can act as a price stabilizer, offsetting effects of volatile fossil fuel power markets.

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[75] Sanyal and Koenig, page 1

[76] Sanyal and Morrow

[77] U.S. Department of Energy "Geothermal Tomorrow"

[78] U.S. Department of Energy "Levelized Cost," Table 1

## Figure 19: Estimated Levelized Cost of New Generation Resources

**Table 1. Estimated levelized cost of new generation resources, 2018**

| Plant type | Capacity factor (%) | U.S. average levelized costs (2011 $/megawatthour) for plants entering service in 2018 | | | | |
|---|---|---|---|---|---|---|
| | | Levelized capital cost | Fixed O&M | Variable O&M (including fuel) | Transmission investment | Total system levelized cost |
| **Dispatchable Technologies** | | | | | | |
| Conventional Coal | 85 | 65.7 | 4.1 | 29.2 | 1.2 | 100.1 |
| Advanced Coal | 85 | 84.4 | 6.8 | 30.7 | 1.2 | 123.0 |
| Advanced Coal with CCS | 85 | 88.4 | 8.8 | 37.2 | 1.2 | 135.5 |
| Natural Gas-fired | | | | | | |
| Conventional Combined Cycle | 87 | 15.8 | 1.7 | 48.4 | 1.2 | 67.1 |
| Advanced Combined Cycle | 87 | 17.4 | 2.0 | 45.0 | 1.2 | 65.6 |
| Advanced CC with CCS | 87 | 34.0 | 4.1 | 54.1 | 1.2 | 93.4 |
| Conventional Combustion Turbine | 30 | 44.2 | 2.7 | 80.0 | 3.4 | 130.3 |
| Advanced Combustion Turbine | 30 | 30.4 | 2.6 | 68.2 | 3.4 | 104.6 |
| Advanced Nuclear | 90 | 83.4 | 11.6 | 12.3 | 1.1 | 108.4 |
| Geothermal | 92 | 76.2 | 12.0 | 0.0 | 1.4 | 89.6 |
| Biomass | 83 | 53.2 | 14.3 | 42.3 | 1.2 | 111.0 |
| **Non-Dispatchable Technologies** | | | | | | |
| Wind | 34 | 70.3 | 13.1 | 0.0 | 3.2 | 86.6 |
| Wind - Offshore | 37 | 193.4 | 22.4 | 0.0 | 5.7 | 221.5 |
| Solar PV[1] | 25 | 130.4 | 9.9 | 0.0 | 4.0 | 144.3 |
| Solar Thermal | 20 | 214.2 | 41.4 | 0.0 | 5.9 | 261.5 |
| Hydro[2] | 52 | 78.1 | 4.1 | 6.1 | 2.0 | 90.3 |

*[1] Costs are expressed in terms of net AC power available to the grid for the installed capacity.*
*[2] As modeled, hydro is assumed to have seasonal storage so that it can be dispatched within a season, but overall operation is limited by resources available by site and season.*
*Note: These results do not include targeted tax credits such as the production or investment tax credit available for some technologies, which could significantly affect the levelized cost estimate. For example,new solar thermal and PV plants are eligible to receive a 30-percent investment tax credit on capital expenditures if placed in service before the end of 2016, and 10 percent thereafter. New wind, geothermal, biomass, hydroelectric, and landfill gas plants are eligible to receive either: (1) a $22 per MWh ($11 per MWh for technologies other than wind, geothermal and closed-loop biomass) inflation-adjusted production tax credit over the plant's first ten years of service or (2) a 30-percent investment tax credit, if placed in service before the end of 2013 (or 2012, for wind only).*
*Source: U.S. Energy Information Administration, Annual Energy Outlook 2013,December 2012, DOE/EIA-0383(2012)*

Figure 19 Source: DOE/EIA. Levelized cost is the total capital, fuel, and O&M costs associated with the plant over its lifetime divided by the estimated output in kWh over its lifetime. The Total System Levelized Cost (rightmost column) gives the cost ($/MWh) that must be charged over time in order to pay for the total cost.

**7.3. What is the cost of geothermal power?**
In the U.S., geothermal plants can produce electricity for rates between 5 cents and 11 cents per kilowatt-hour (kWh), including tax incentives, a rate competitive with traditional fossil fuel generation.[79] Some plants can charge more during peak demand periods, depending on the economy of the region. Power at The Geysers is sold at $0.03 to $0.035 per kWh.[80]

Whether the cost of power affects the customer, and by how much, could depend on the existing energy portfolio of the utility, which is often driven by state policies.

A study conducted by Lawrence Berkley National Laboratory in 2008 analyzed data on a dozen state renewable energy policies and found the impact on electricity rates to be a fraction of a percent in most cases.

The U.S. Energy Information Administration in 2009 projected electricity rates through 2030, using models both with and without a national renewable energy standard, and found little difference in effects on consumers.

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[79] California, State of

[80] U.S. Department of Energy "Geothermal FAQs"

## 8. Jobs in Geothermal Energy

Jobs created by geothermal production, development, and use vary widely, from exploration geologists who locate new resources to welders and mechanics involved in power plant construction. In fact, geothermal is labor intensive and provides a stable source of employment for a wide variety of skills, often in regions with high unemployment rates.

More from GEA: Updated U.S. Geothermal Education and Training Guide (Aug. 2011); Green Jobs Through Geothermal Energy (Oct. 2010); GEA Issue Brief: Geothermal Energy and Jobs (Aug. 2009); A Handbook on the Externalities, Employment, and Economics of Geothermal Energy (Oct. 2006)

**Figure 20: Job Types throughout the Project Timeline**

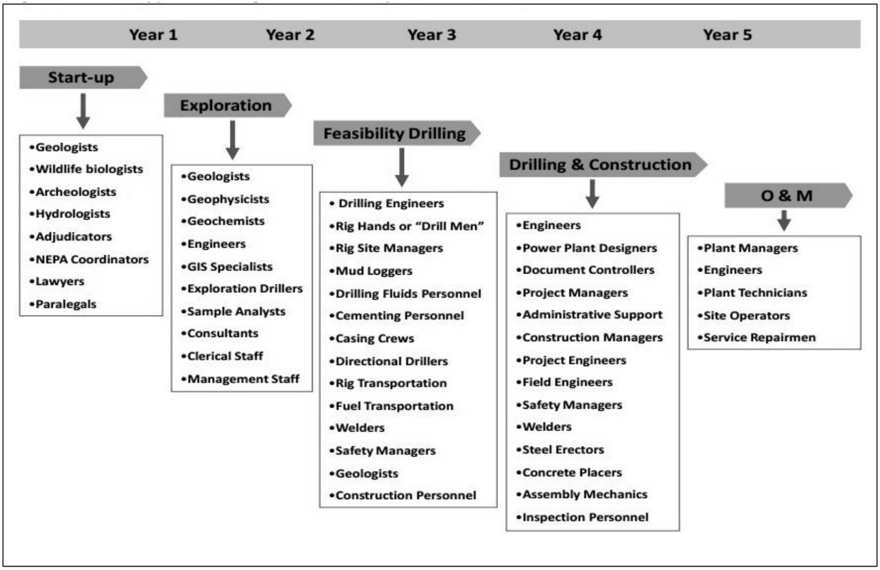


Figure 20 Source: Geothermal Energy Association

**8.1. What types of jobs are involved in a geothermal power project?**
In a 2010 study, GEA examined how many different people were involved in one power project. For one 50-MW power plant, roughly 700-800 different people were employed in one way or another in the project. The type of jobs varies over the project timeline (Figure 20). Employment surges when projects are in active drilling stages because of the labor involved in drilling teams.

In the EIS of the Salton Sea Unit 6 Geothermal Power Plant, in the Imperial Valley, total workforce for the construction period for the 185-MW plant is estimated to be 6,898 person*month (Figure 21).

**Figure 21: Number of Employees (y) per Month of Construction (x) at Salton Sea Unit 6**

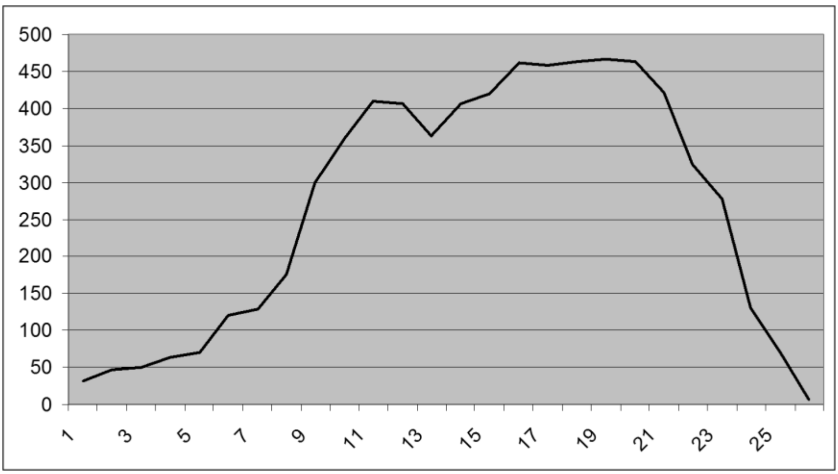


Figure 21 Source: CalEnergy, "Salton Sea Geothermal Unit #6 Power Project - EIS & EIR," July 2002

**8.2. How many people does the geothermal industry employ in the U.S.?**

Previous GEA analysis, widely reviewed by industry, academic, and government experts, helps provide a view of the number of people involved in a geothermal power project (Table 4). GEA found that (1) Direct employment results in 1.7 full-time positions and 6.4 person*years per MW; and (2) Induced and indirect impacts can be calculated assuming a multiplier of 2.5 for a total direct, indirect, and induced employment impact of 4.25 full-time positions and 16 person*years per MW.

Using these employment factors, the GEA estimated direct employment in 2005 to be 4,583 full-time positions, or 1.7 permanent jobs per megawatt of capacity installed, while the total number of jobs supported by the geothermal industry that year was 11,460. In comparison, GEA estimated that in 2010 the industry supported approximately 5,200 direct jobs related to power production and management, while the total direct, indirect, and induced impact of geothermal energy was 13,100 full-time jobs. [81, 82]

**Table 4. People Involved in Geo Development for a 50-MW Plant**

| Stage of Development | | No. of people involved |
|---|---|---|
| Start-up | | 10–13 |
| Exploration | | 11–22 |
| Drilling | | 91–116 |
| Plant Design and Construction (EPC) | | 383–489 |
| Operation and Maintenance | | 10–25 |
| Power Plant System Manufacturing | | 192–197 |
| | **Total** | **697–862** |

[81] GEA "Geothermal Industry Employment"

[82] GEA "Green Jobs"

**8.3. How does job creation in geothermal projects compare to other power technologies?**

MidAmerican Geothermal has plans for a new 235-MW geothermal plant in Imperial Valley, one of California's highest unemployment areas. The project will take 4 years to build and will employ 323 construction workers. The completed project will require 57 full-time positions for operations, engineering, maintenance, and administration. This compares favorably with either a gas or wind project, which MidAmerican Renewables notes would each require 18 full-time employees for a similar-size project.

**8.4. Is geothermal energy supported by educational and workforce training in the U.S.?**

As geothermal energy becomes more prominently recognized in today's renewable energy landscape and the industry grows, academic institutions are taking note of the need for geothermal education and training.

There is a shortage of trained industry professionals – especially higher-level geothermal power plant managers, geologists, resource analysts, permitting staff, drillers, engineers, and geothermal heat pump installers. Supporting education programs are needed across the educational spectrum, from graduate level university programs to community college and company training programs.

Generally a background in physical sciences or engineering will benefit students entering the geothermal industry or pursuing more advanced degrees suited for geothermal. Southern Methodist University (SMU) offers a geothermal focus within a major. The Oregon Institute of Technology, Massachusetts Institute of Technology, Cornell University, University of California at Davis, and University of Nevada, Reno (UNR) offer undergraduate programs which highlight geothermal.

Due to the specialized nature of graduate studies, more opportunities in geothermal education exist at the graduate level than at the undergraduate level. Graduate degrees including civil and environmental engineering, chemical engineering, geology, geological engineering, geophysics, hydrology, mechanical engineering, and petroleum engineering are useful for pursuing a geothermal career.

Research facilities and/or geothermal research opportunities exist at a growing number of institutions. Stanford University and SMU both offer geothermal Master's and Doctorate degrees.[83]

In 2012, 2013, and 2014, a collaboration of instructors from universities across the U.S. offered the National Geothermal Academy, an intensive course funded by the DOE and hosted at UNR.

Geothermal training is needed abroad. The U.S.-East Africa Geothermal Partnership, launched by the U.S. Agency for International Development and the GEA in 2012, has led training modules in East Africa. Aside from the U.S., Iceland and New Zealand are some of the other countries that have become involved in specialized training for geothermal energy.

[83] GEA "U.S. Geothermal Education"

# GEA Publications

Geothermal Energy Association publications are listed by date from newest to oldest. GEA offers free access to many original industry publications at www.geo-energy.org/reports.

Annual U.S. and Global Geothermal Power Production Report. April 2014.

The State of Geothermal Energy in California. February 2014.

The Manageable Risks of Conventional Hydrothermal Geothermal Power Systems. February 2014.

The Values of Geothermal Energy: A Discussion of the Benefits Geothermal Power Provides to the Future U.S. Power System. October 2013.

Geothermal Power: International Market Overview. September 2013.

Promoting Geothermal Energy: Air Emissions Comparison and Externality Analysis. May 2013.

Annual U.S. Geothermal Power Production and Development Report. April 2013.

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Why Support Geothermal Energy? Feb. 2012.

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