

Geothermal Basics: Q&A

September 2012



Puna Expansion, Hawaii, U.S., 8 MW, 2011



***Clockwise from top left: Flash Plant, Coso, Calif.;
Dry Steam Plant, The Geysers, Calif.; Binary Plant, Stillwater, Nev.;
Flash/Binary Plant, Puna, Hawai'i***

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Geothermal Basics: Q&A

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Collectively, GEA's past reports, available at www.geo-energy.org, have benefitted from input by scores of individuals in the geothermal community; despite being unable to provide an exhaustive list, we wish to thank all those individuals.

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1. Technology Basics

Geothermal energy -- the heat from the Earth -- is a clean, renewable resource that provides energy in the U.S. and around the world through a variety of applications and types of resources. Large-scale geothermal plants utilizing deep resource temperatures between $\sim 200^{\circ}\text{F}$ and 700°F have been producing commercial power in the U.S. since the 1960s. Geothermal energy development and production is a thriving international market.

GEA resources for section 1: *Why Support Geothermal Energy?* (February 2012); *Geothermal Reporting Terms and Definitions* (November 2010); *The State of Geothermal Technology - Part I: Subsurface Technology* (November 2007); *The State of Geothermal Technology - Part II: Surface Technology* (January 2008)

1.1. What is geothermal energy?

Figure 1: Temperatures in the Earth

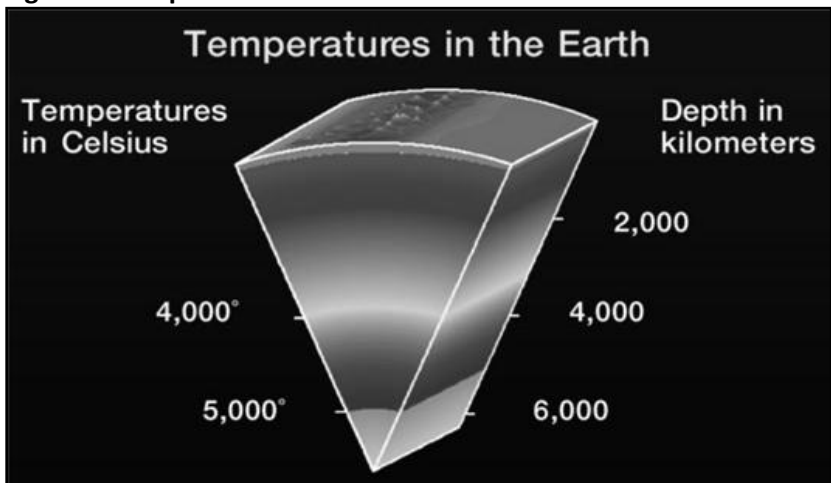


Figure 1 Source: Geo. Edu. Office Slide Show, Slide 5

Heat has been radiating from the center of the Earth for some 4.5 billion years. Temperatures close to the center of the Earth, ~6437.4 km (~4,000 miles) deep, hover around 9932°F (~5,500°C), about as hot as the sun's surface (Figure 1). Scientists estimate that 42 million megawatts (MW) of power flow from the Earth's interior, primarily by conduction. It is expected to remain thus for billions of years to come, ensuring an inexhaustible supply of energy. Since the heat emanating from the interior of the Earth is essentially limitless, geothermal energy is a renewable resource.¹ One of the biggest advantages of geothermal is that it is constantly available.

Figure 2: Geothermal Reservoir

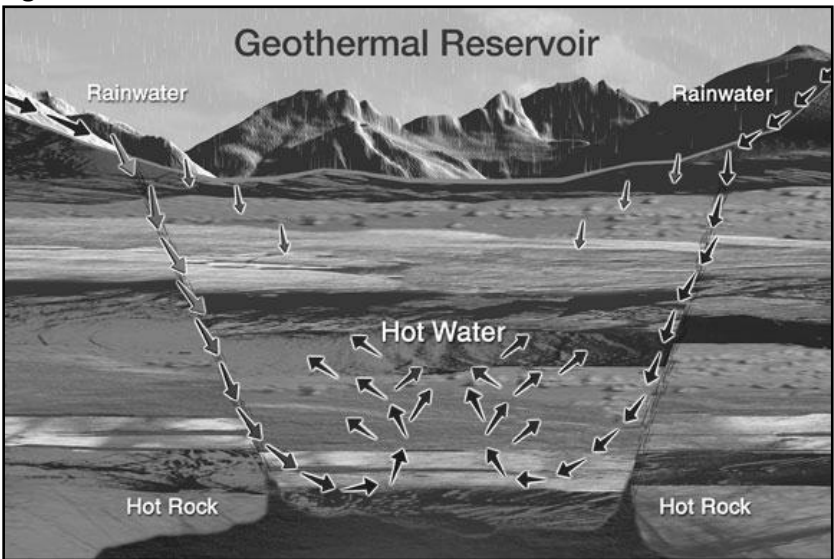


Figure 2 Source: Geo. Edu. Office Slide Show, Slide 12

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.

A geothermal system that can be developed for beneficial uses requires heat, permeability, and water. When hot water or steam is trapped in cracks and pores under a layer of impermeable rock, it forms a geothermal reservoir. Rainwater and snowmelt continue to feed underground thermal aquifers (Figure 2). Exploration of a geothermal reservoir for potential development includes exploratory drilling and testing for satisfactory conditions to produce useable energy, particularly temperature and flow of the resource.

Prince Piero Ginori Conti proved the viability of geothermal power plant technology in 1904, at the dry steam field in Larderello, Italy (Figure 3). The geothermal field has produced continuously since then, except for a brief period during World War II, and is still producing today.

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

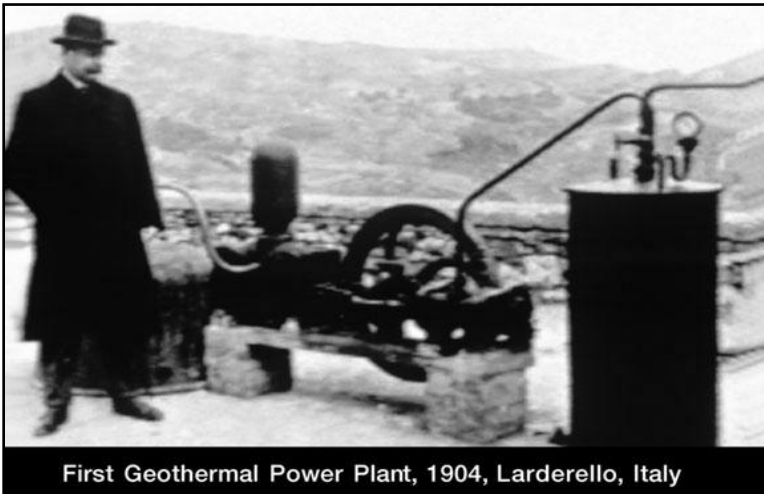


Figure 3 Source: Geo. Edu. Office Slide Show, Slide 50

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.” (*Nersesian 2010*, p. 334).

1.2. What is a baseload resource?

A baseload power plant produces energy at a constant rate, thus production facilities are used to meet some or all of a region's continuous energy demand. In addition to geothermal, nuclear and coal-fired plants are other examples of baseload plants. Among the renewables, geothermal energy is capable of producing year-round constant power, a significant differentiation from both solar and wind power, which must wait for the sun to shine or the wind to blow, respectively.

Capacity and capacity factors, or essentially the distinction between megawatts (MW) and megawatt-hours (MWh), are important in differentiating the unique characteristics of geothermal as a renewable baseload resource. A geothermal plant with a smaller capacity than a solar or wind plant can provide more actual, delivered electricity than most other resources. 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.

On the other hand, geothermal can also be load following if the system is designed for that, meaning its power output can be adjusted

to meet fluctuating needs. In geothermal development, one megawatt is roughly equivalent to the electricity used by 1,000 homes.

1.3. How does a conventional geothermal power plant work?

After careful exploration and analysis, wells are drilled to access a geothermal reservoir and 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. Figures 5-7 depict the three commercial types of conventional geothermal power plants: flash, dry steam, and binary. Figure 8 shows an example of a hybrid plant, a flash/binary combined cycle.

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

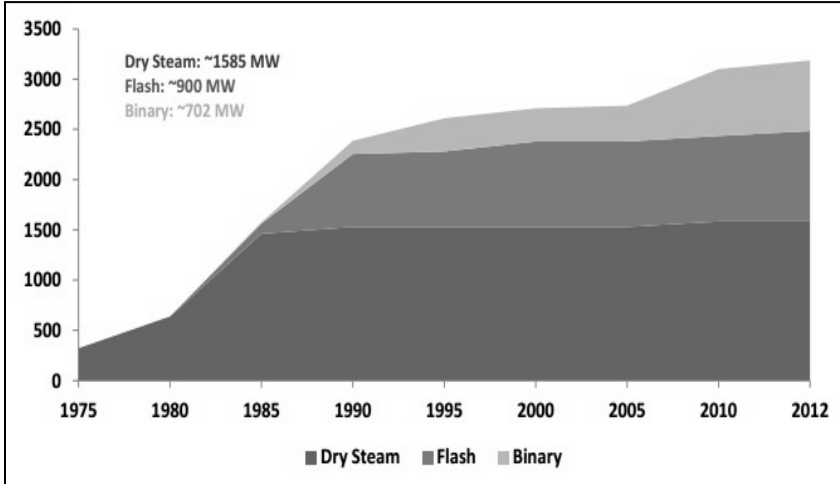


Figure 4 Source: Geothermal Energy Association

In a geothermal flash power plant, high-pressure geothermal water separates into steam and water² as it rises from depth and pressure drops. The steam and liquid are separated in a surface vessel, called a steam separator (Figure 5). The steam is delivered to the turbine, and the turbine powers a generator. The liquid is injected back into the reservoir. As of 2012, about 900 MW of the 3,187 MW of installed geothermal capacity in the U.S. is comprised of steam-flash power plants, with the majority in California (*GEA 2012 Annual*, page 7).

Figure 5: Flash Power Plant

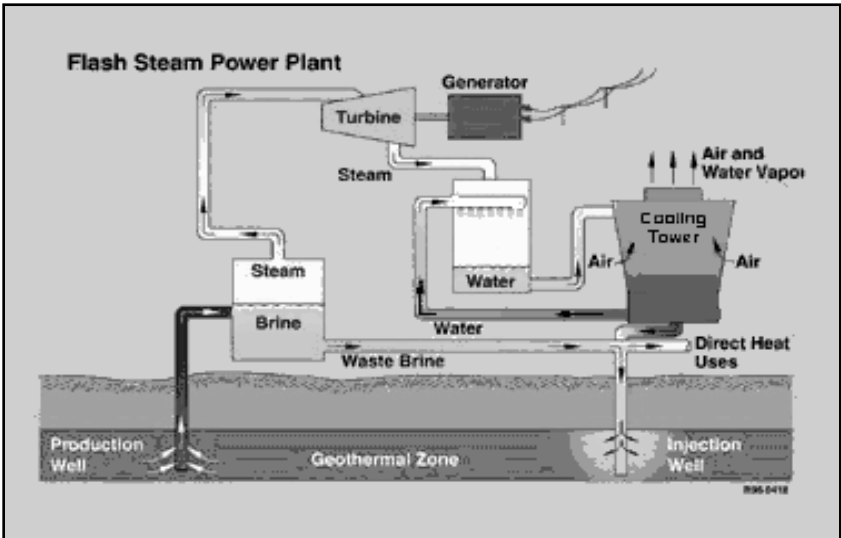


Figure 5 Source: Geo-Heat Center

In a geothermal dry steam power plant, steam alone is produced directly from the geothermal reservoir and is used to run the

² Also referred to as geothermal brine.

turbines that power the generator (Figure 6). Because there is no water, the steam separator used in a flash plant is not necessary. As of 2012, dry-steam power plants account for approximately 1,585 MW (almost 50%) of installed geothermal capacity in the U.S., and are all located in California.

Figure 6: Dry Steam Power Plant

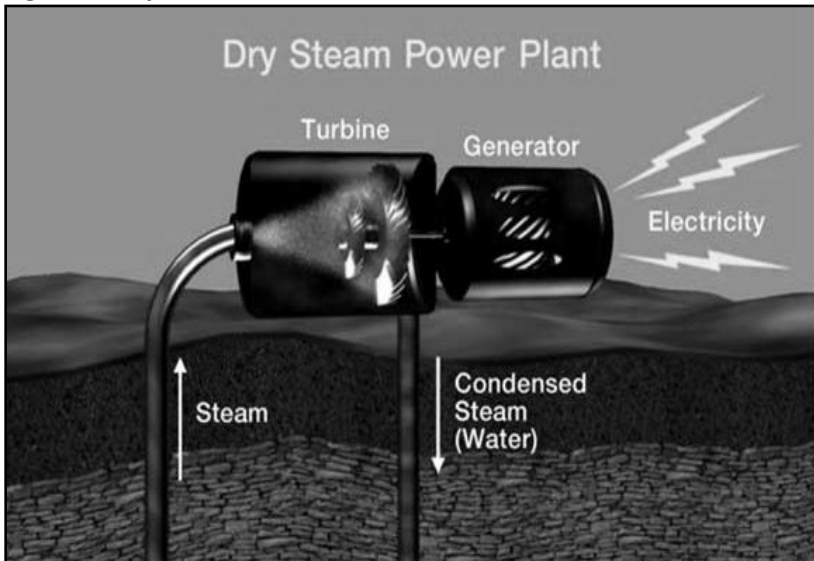


Figure 6 Source: Geo. Edu. Office Slide Show, Slide 49

Binary geothermal plants have made it possible to produce electricity from geothermal resources lower than 302°F (150°C). This has expanded the U.S. industry’s geographical footprint, especially in the last decade. Binary plants typically use an Organic Rankine Cycle (ORC) system. Geothermal water is used to heat another liquid called a working fluid (“motive fluid” in Figure 7) such as isobutane or pentafluoropropane, which boils at a lower temperature than water. A heat exchanger separates the geothermal 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 injected back into the reservoir in a closed loop, separating it from groundwater sources and lowering emission rates further (possibly to zero; see section 5). In 1981, Ormat Technologies established the technical feasibility of larger-scale commercial binary power plants at a project in Imperial Valley, California. The project was so successful that Ormat repaid its loan to the Department of Energy (DOE) within a year (*DOE "A History"*). As of 2012, binary power plants make up ~702 MW of the U.S. installed geothermal capacity.

Figure 7: Binary Power Plant

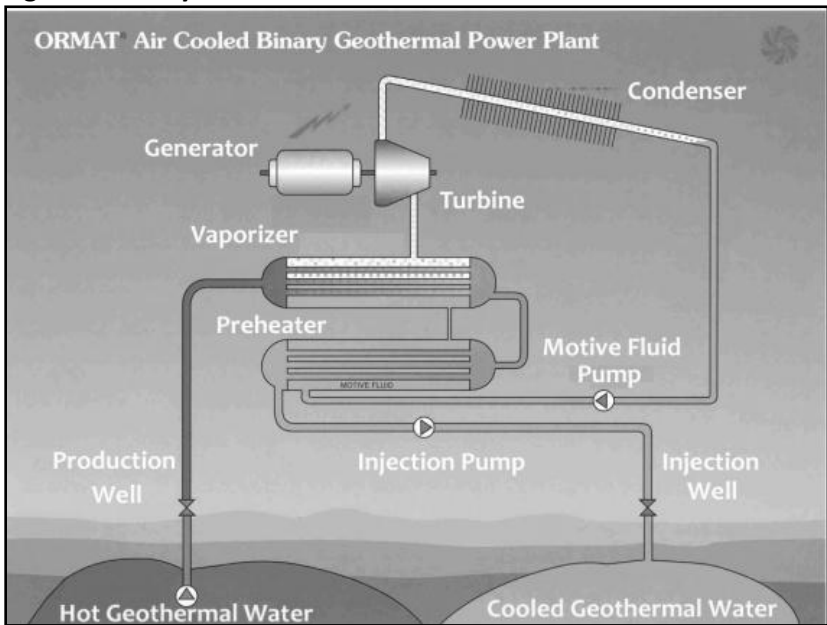


Figure 7 Source: Ormat

Hybrid power plants allow for the integration of numerous generating technologies. In Hawai'i, the Puna flash/binary

combined cycle system takes advantage of the benefits of 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). Another example of a hybrid plant is the Stillwater solar-geothermal plant in Nevada. This technology may help to allow projects that would otherwise have been unfeasible as stand-alone geothermal or solar projects to be more economically and technologically viable.

Figure 8: Flash/Binary Power Plant

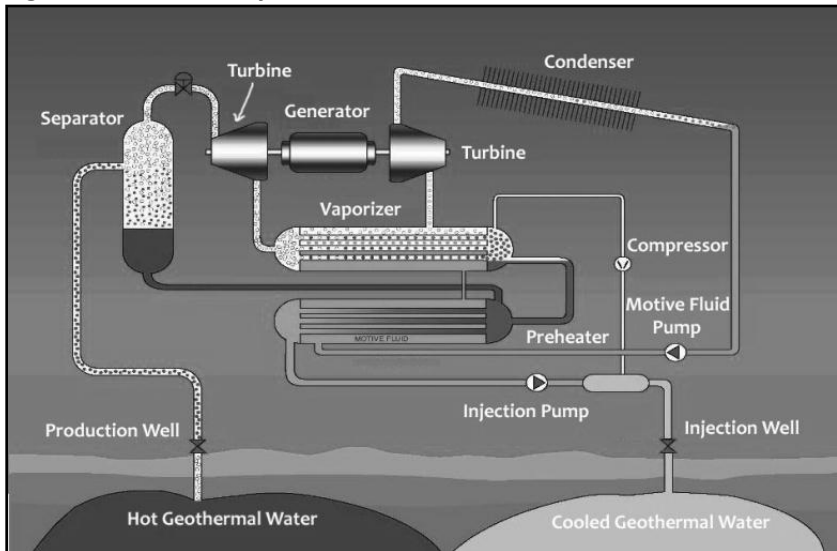


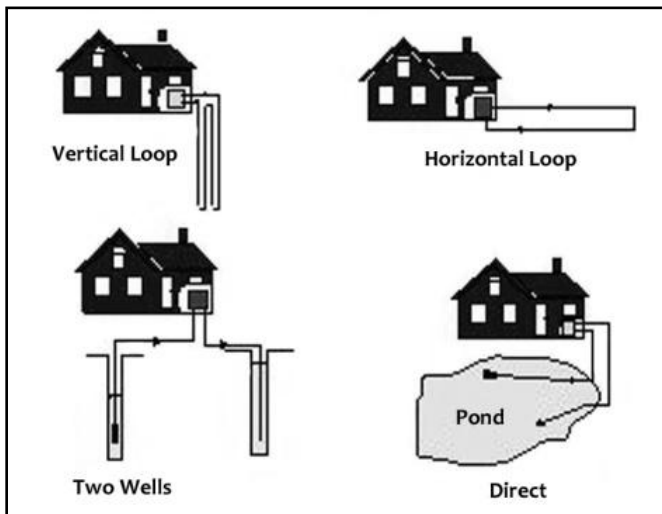
Figure 8 Source: Geo-Heat Center

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),³ which provide both heating and cooling solutions. The Geothermal Exchange Organization notes that geothermal heat pumps can utilize average ground temperatures between ~40° and 70°F (“Spectrum”).⁴

Figure 9: Geothermal Heat Pumps



GHP heating systems circulate water or other liquids to pull heat from the Earth through pipes in a continuous loop.

Figure 9 Source: Geo-Heat Center

Electricity is used to boost or cool the temperature and distribute it 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, taking advantage of the Earth’s relatively constant temperature at depths below about 10 ft to 300 ft,

³ Also called a geoexchange system or Ground Source Heat Pump (GSHP)

⁴ The USGS further defines moderate-temperature (90 to 150°C; 194 to 302°F) and high-temperature (greater than 150°C) geothermal systems (USGS 2008).

and 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.

The U.S. Environmental Protection Agency (EPA) has said geothermal heating and cooling systems are the most energy-efficient, environmentally clean, and cost-effective space conditioning systems available (*EPA 1993*). GHPs are used in all 50 states and are over 45% more energy efficient than standard heating and cooling system options (*EPA "Heat Pumps"*). Homeowners who install qualified GHPs are eligible for a 30% federal tax credit through December 31, 2016.

Modern geothermal heat pump technology took off in the U.S. in the 1930s and 40s. In 1940, the first residential space heating in Nevada began in Reno; and in 1948, a professor at Ohio State University developed the first ground-source heat pump for use at his residence. A groundwater heat pump came into commercial building use in Portland, Oregon around the same time (*DOE "A History"*).

1.5. How do direct use applications work?

Geothermal heat is used directly, without involving a power plant or a heat pump, for a variety of 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 (*Geo. Exchange Org. "Spectrum"*).

Examples of direct use applications exist all across the U.S., including at the Idaho Capitol Building in Boise and at the Roosevelt Warm Springs Institute for Rehab⁵ in Warm Springs,

⁵ Franklin Delano Roosevelt frequented Georgia's healing hot springs and founded the polio treatment center in 1927.

Georgia (*Idaho Public Television; Roosevelt Warm Springs*). In the City of Klamath Falls, Oregon, where hot springs water was piped to homes as early as 1900, a geothermal utility system today provides heating services to commercial and government buildings throughout the downtown core area as well as geothermal sidewalk and bridge snow melt systems (*Klamath Falls*).

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

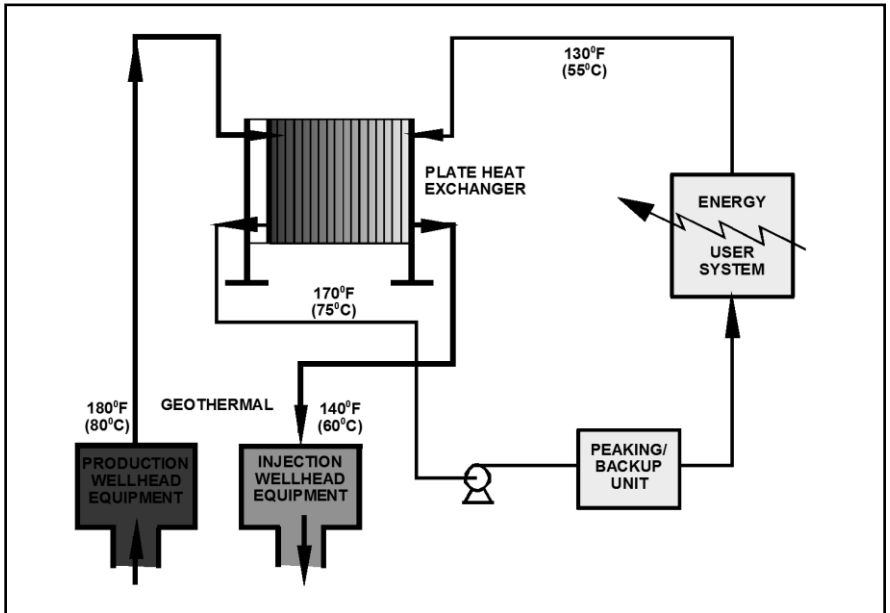


Figure 10 Source: Geo-Heat Center

2. Current Use

In the 1920s, engineers first demonstrated geothermal electrical generation in the U. S. using several small geothermal wells at what would become known the world over as The Geysers geothermal field.⁶ The U.S. geothermal industry grew into the world leader, producing more energy from geothermal plants than any other country. Geothermal energy production in the U.S. comprises approximately 28% of the world total (Table 1).

GEA resources for section 2: *Why Support Geothermal Energy?* (February 2012); *Annual US Geothermal Power Production and Development Report* (April 2012); *Geothermal: International Market Overview Report* (May 2012); *GEA International Market Report* (May 2010); *Geothermal Energy Weekly* (GEA's newsletter)

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

Geothermal energy accounts for about 3% of renewable energy-based electricity consumption in the U.S. (*DOE 2011 RE Consumption*). In 2011 through early 2012, new geothermal capacity was installed in Hawaii, Nevada, and California (*GEA 2012 Annual*). As of early 2012, the GEA identified 3,187 MW of installed geothermal capacity. Geothermal plants and small power units are on line in nine states: California, Nevada, Alaska, Hawaii, Idaho, New Mexico, Oregon, Utah, and Wyoming.

In early 2012 there were 129 confirmed developing geothermal projects in various phases of project development in 14 states:

⁶Located 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.

Nevada, California, Oregon, Utah, Idaho, Alaska, Hawaii, New Mexico, Colorado, Louisiana, Arizona, Texas, Washington, and Wyoming. Bringing these projects on line could add 4,116-4,505 MW of geothermal energy to the existing 3,187 MW of geothermal power in use today in the U.S.

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 what is happening under the surface in states such as California and Nevada. Because more is known about the geology in these areas, and commercial operations have shown they can be successful, this is where geothermal has been studied and developed the most. 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 is dominated by geothermal energy; see data for the years 1983-2010 in Figure 11. Resource types, listed left to right, are represented in order on the y-axis from bottom to top. In 2011 the California Energy Commission (CEC) noted in its staff report that geothermal provided about 42% of California's commercial in-state renewable electricity generation -- about 6.2% of all power generated in-state.

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

Advances in geothermal technology are making possible the expansion of useable resources, improvements to the economics of generation, and new applications. New and better working fluids for binary power systems, on-site small power generation,

and using hot water produced by oil wells are just three non-conventional applications. For coproduction, enhanced geothermal systems (EGS), geopressed, and supercritical, see section 3.

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

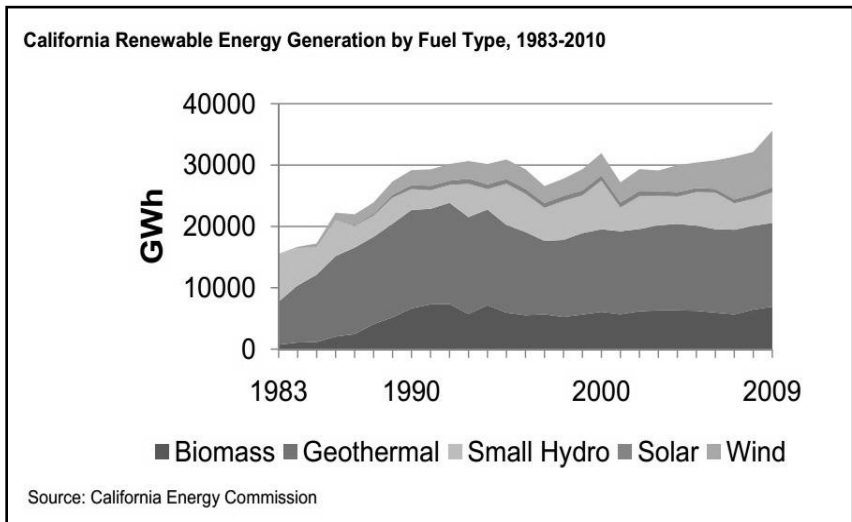


Figure 11 Source: California Energy Commission

Advances in new working fluids or mixed working fluids make it possible to achieve greater heat transfer efficiency and produce power at lower temperatures. Examples of these units include the Kalina Cycle and the Green Machine (*"Kalina Cycle"; "ElectraTherm"*). The Kalina Cycle, for example, uses an ammonia-water mixed working fluid to produce up to 50% more power from the same heat source compared to other existing technologies. Efficiency-improving units such as these have increased the development of lower-temperature geothermal resources in recent years, such as the Turbine Air Systems (TAS) project at the Beowawe Flash Plant in Nevada.

Distributed generation facilities produce geothermal energy on a small scale to provide local or on-site electricity needs of a facility. Energy not being used by the facility could be sold back to the grid. To do this, geothermal applications can be sized and constructed at geographically remote sites in order to meet on-site electricity demands. Examples of remote geothermal power systems are at Wendel-Amedee in northeastern California, Chena Hot Springs in Alaska; the Oregon Institute of Technology in Klamath Falls; and at the Rocky Mountain Oil and Gas Testing Center in Wyoming (*GEA “Chena”*; *Oreg. Inst. Technol. “Geo-Heat”*; *DOE “Rocky”*).

Combined heat and power (CHP) plants, also used in fossil fuel technologies, make more efficient use of the resource by using low-temperature resources in combination with binary or Organic Rankine Cycle (ORC) power units. The use of energy is cascaded, which in turn improves the economics of the entire system. Many CHP plants started as just a district heating project (*Oreg. Inst. Technol. 2005*).

2.3. How much geothermal energy is used internationally?

As of early 2012, GEA identified ~11,224 MW of energy on line at geothermal power plants in 24 countries around the world (Table 1).⁷

Additionally, at least 78 countries utilize geothermal direct use applications. Including GHPs, direct use capacity reached 51 GWt⁸ in 2010 (*Pike “Geo. Heat Pumps”*).

⁷In section 2 and Table 1, capacities of geothermal energy for individual countries and global totals use data from *Bertani 2010* plus additional capacity tracked by GEA between 2010 and 2012.

⁸1 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

Table 1. Countries Generating Geothermal Power as of May 2012

<i>Country</i>	<i>Installed Capacity (MW)</i>
United States	3,187
Philippines	1,904
Indonesia	1,222
Mexico	958
Italy	883
New Zealand	768
Iceland	661
Japan	535
El Salvador	204
Kenya	202
Costa Rica	208
Nicaragua	124
Russia	82
Turkey	93
Papua New Guinea	56
Guatemala	52
Portugal	29
China	24
France	16
Ethiopia	7
Germany	7
Austria	1
Australia	1
Thailand	0.3
Total	11,224.3

generated, which creates steam to drive a turbine. Electric power (as in MWe or GWe) is the amount of electricity generated.

Figure 12 shows the countries with the highest capacity growth (MW installed) between 2008 and early 2012, including: U.S., +336.94 MW; Indonesia, +292 MW; New Zealand, +263.3 MW; Iceland, +180 MW; Italy, +80 MW; and Kenya, +71 MW. The number of countries with projects under development or consideration grew by 52% in 3 years (46 countries in 2007 to 70 countries in 2010).

Figure 12: Top Countries for Geothermal Capacity Growth, 2008-2012

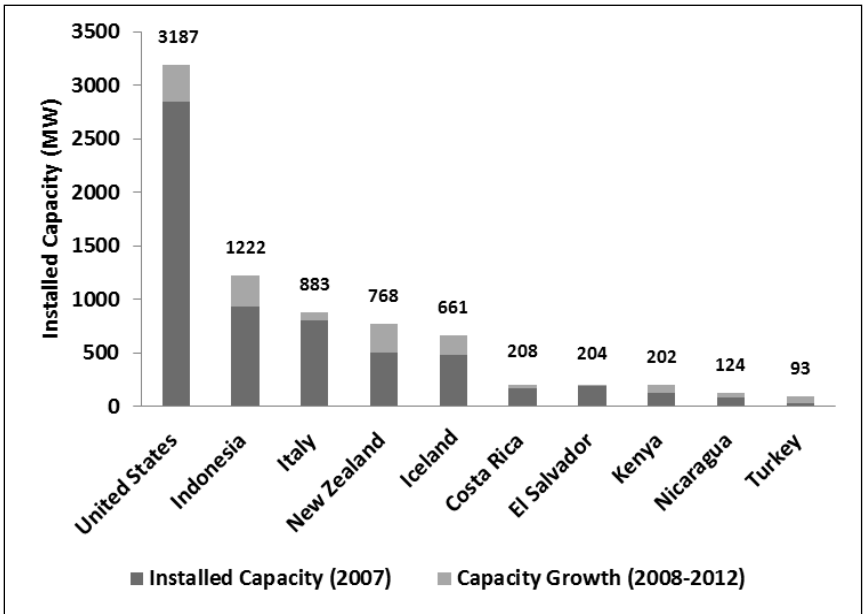


Figure 12 Source: Geothermal Energy Association

In 2012, more and more countries are announcing projects or policies to support them, or are otherwise interested in the growing market. Some regional initiatives focused on geothermal have made a difference, such as the African Rift Geothermal Energy Development Facility, which underwrites drilling risks in six African nations and is backed by the United Nations Environment Programme (UNEP); and the World Bank and the geothermal initiatives of the European Bank

for Reconstruction and Development supported by European Union climate policies (*GEA 2010 Int'l*, page 5).

Opportunities for U.S. geothermal companies abound in the global market. In the near term, according to the National Export Initiative (NEI), “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” (2010, pp. 18-19). NEI estimated U.S. exports totaled \$70.1 million worth of geothermal equipment in 2009.

The GEA produced an overview report of international geothermal markets in May 2012. Highlights from around the world include:

Known potential estimates of geothermal resources in the East African Rift System range between 10,000 and 20,000 MW and remain largely undeveloped; Kenya has ~202 MW on line.

Countries within Asia’s geothermal sector including Indonesia, the Philippines, and Japan are incentivizing the development of geothermal resources. Indonesia alone contains ~ 27,510 MW of potential geothermal resources, among the largest in the world.

The majority of countries in Central America have developed a portion of their geothermal resources for utility scale power production. El Salvador and Costa Rica derive 24% (204 MW) and 12% (163 MW) of their electricity production from geothermal energy, respectively. Additional potential in the region has been estimated between ~3,000 MW and 13,000 MW at 50 identified geothermal sites.

As of 2011, Europe had a total installed capacity of 1,600 MW for geothermal energy. There were 109 new power plants under construction or under investigation in EU member states. Within Europe, Italy is the market leader with over 50% of the European capacity. Iceland derives 25% of its electricity and 90% of its heating from geothermal resources and is often considered a model of transitioning indigenous practices to modern technology use.

3. Potential Use

The heat of the Earth is considered infinite; its use is only limited by technology and the associated costs. Natural geothermal reservoirs in the Western U.S. are some of the most conducive to traditional hydrothermal power production systems, and geothermal will continue to expand there. Production is also viable in more states and areas of the world as research and development uncovers additional new resources and proves new innovative technologies. Today, we are looking at new developments in coproduction at oil and gas wells, enhanced geothermal systems, geopressured resources, and supercritical cycles.

GEA resources for section 3: *Annual US Geothermal Power Production and Development Report (April 2012)*; *GEA Issue Brief: Geothermal Energy's Future Potential (August 2009)*; *Geothermal Energy Weekly (GEA's newsletter)*

3.1. What is the potential of using geothermal resources in the U.S.?

There is enough geothermal energy available from the Earth to meet the power needs of humankind many times over. A 2008 assessment by the USGS identified potential for geothermal energy production in 13 Western states⁹ 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 2).¹⁰

⁹ Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming

¹⁰ Not included in the USGS 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

Additionally, a 2006 estimate by the Western Governors Association (WGA) stated that by 2025, around 13,000 MW of identified geothermal resources could be developed in Western states.

In 2012 there are geothermal projects in development as far east as Texas and Louisiana. Furthermore, since the temperature at a depth of 6.5 km is above boiling nearly everywhere in the U.S. (Figure 13), the potential for generating electrical power from geothermal resources could be realized in every state in the country. In Figure 13, darker areas represent higher temperatures.

Table 2. Geothermal Resource Potential in Western States

<i>Category</i>	<i>Potential MWe (% probability)</i>	<i>Description</i>
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.

Figure 13: United States Heat Flow Map

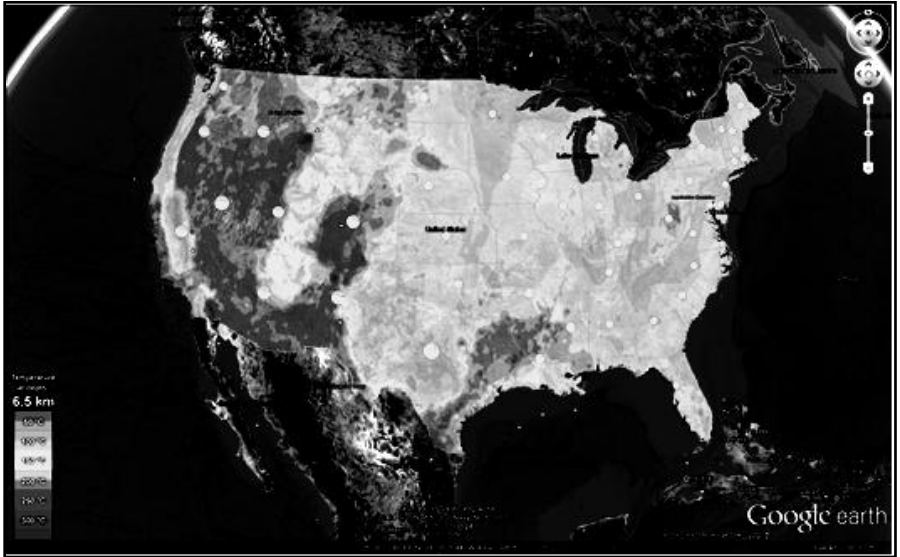


Figure 13 Source: Google Earth

The data in Figure 13, available via Google Earth, was collected by Southern Methodist University (SMU) in 2010 in a study funded by Google.org,¹¹ which showed EGS technology broadens geothermal potential across the U.S. to 2,980,295 MW -- a near 40-fold increase compared to traditional geothermal technology potential. As part of the study, SMU made the major discovery of sites in West Virginia with temperatures of ~392°F (200°C) at 5-km depths (a dark area representing this find is seen in Figure 13). Using this new data, SMU placed 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.

¹¹ Google's investment made it the top investor in geothermal energy in the U.S. at the time, outspending the federal government.

Production is already happening beyond the Western states and will continue to expand. Separate studies by the National Renewable Energy Laboratory (NREL; *DOE 2006*)¹² and the Massachusetts Institute of Technology (MIT; *MIT 2006*) 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.

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

Additional applications and technologies continue to emerge from the U.S. geothermal industry, often with support from the DOE. Sections 3.2.1-3.2.5 discuss mineral recovery, hydrocarbon coproduction systems, EGS, geopressured systems, and supercritical cycles. For discussion of mixed working fluids and distributed generation, see section 2: Current Use.

3.2.1. Mineral Recovery

Mineral recovery from geothermal water has been studied for years and is newly becoming practical. This is the practice of extracting minerals from water at existing conventional geothermal sites. Zinc, silica, and sulfur, for example, are now being extracted for sale (*DOE "Geo. FAQs"*). Recovering these materials from geothermal water thus reduces the environmental impacts of mining.

Some geothermal resources have water that is rich in needed elements such as lithium, manganese, and zinc, and can support these emerging and established markets. Lithium has been called an energy-critical element (*Am. Phys. Soc. 2011*), needed for high-

¹² The NREL report does not include hidden or undiscovered geothermal systems, which the USGS report estimates have substantial energy potential. Nor does the report specifically examine small power systems (distributed generation).

performance battery materials and electrolyte solutions in electric vehicles and other clean-energy storage applications.

A company called Simbol Materials is working to produce lithium from geothermal plants at a demonstration facility in Imperial Valley, California. 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.

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 (*Canty and Mink 2006*). Different geothermal sites contain different suites of minerals.

3.2.2. Enhanced Geothermal Systems

Enhanced 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. EGS technologies enhance existing fracture networks in rock, introduce water or another working fluid, or otherwise build on a geothermal reservoir that would be difficult or impossible to derive energy from using only conventional technologies.

EGS projects in the U.S.:

- At The Geysers, California, two pipelines from Lake County and from the nearby city of Santa Rosa replenish the reservoir using treated sewage water to improve the generation capacity of the wells.
- In the Deschutes National Forest in Oregon, AltaRock Energy, Inc. is preparing 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.

Table 3 shows demonstration projects in EGS that are funded by the U.S. DOE.

Table 3. DOE-Funded EGS Demonstration Projects

<i>Demo Performer</i>	<i>Demo Site</i>
AltaRock Energy, Inc.	Newberry Volcano, Oregon
Geysers Power Company, LLC	The Geysers, California
Naknek Electric	Naknek, Alaska
Ormat Technologies, Inc.	Brady Hot Springs, Nevada
Ormat Technologies, Inc.	Desert Peak, Nevada
TGP Development Co.	New York Canyon, Nevada
University of Utah EGI	Raft River, Idaho

3.2.3 Coproduction of Geothermal and Oil/Gas

Geothermal water is a natural byproduct of oilfield production processes that has long been considered unusable. But much of the 25 billion barrels of “wastewater” produced at oil wells each year in the U.S. is hot enough to produce electricity through geothermal coproduction. Many oil or gas wells could 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,” notes ElectraTherm in its 2011 Denbury white paper. “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.”

The Denbury project was a six-month demonstration at a Mississippi oil field in 2011. At the DOE’s Rocky Mountain Oil Test Center (RMOTC), Wyoming, geothermal company Ormat Technologies built a successful 0.25 MW geothermal and hydrothermal coproduction demo unit which ran in 2008 and was shut down for maintenance; it has since resumed operation and RMOTC is developing another site for the installation of a 0.28 MW unit (*GEA 2012 Annual*). Other DOE-funded coproduction demonstration projects are underway by ElectraTherm in Nevada, Universal GeoPower in Texas, and the University of North Dakota in North Dakota.

Figure 14: SMU Estimated Co-Produced Geothermal Potential

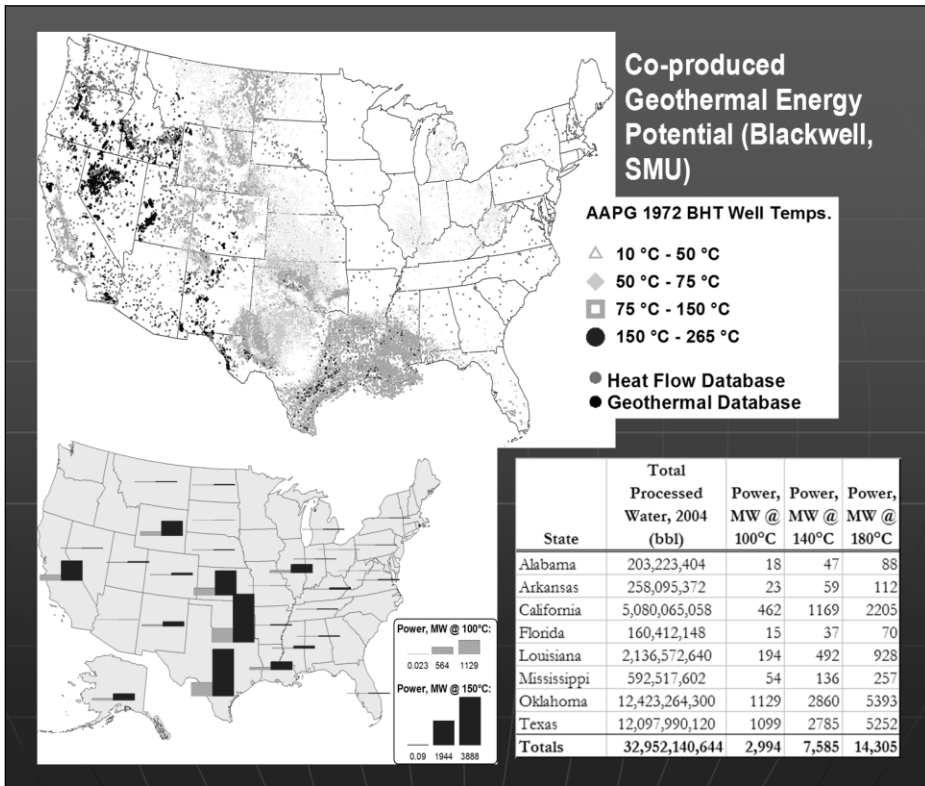


Figure 14 Source: Southern Methodist University and Massachusetts Institute of Technology

Figure 14 provides a perspective of the known estimated coproduced geothermal potential as of the 2006 report from MIT. An updated coproduction paper will be presented by NREL representatives at the Geothermal Resource Council's 2012 Annual Meetings ("An Estimate of the Near-Term Electricity Generation Potential of Co-Produced Water from Active Oil and Gas Wells," by Chad Augustine and Dave Falkenstern).

3.2.4. Geopressured Resources

Geopressured resources are reservoirs of naturally high-pressure hot water. Geopressured resources are known to be located in several areas of the U.S., with the most significant of these located in Texas, Louisiana, and the Gulf of Mexico. Figure 15 shows major oil-producing basins in the U.S., with known geopressured strata indicated by gray dotted shading and solid outline.

Figure 15: Geopressured Basins in the United States



Figure 15 Source: Department of Energy

A demonstration plant in Texas produced electricity from geopressured resources as part of a DOE research program from 1979-1983 (*Campbell 2006*). In 2012, DOE funded a Geopressure Demonstration Project by Louisiana Tank in Louisiana.

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 is used. When in a supercritical state, it 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.

An example of work in this area is a 2-MW demonstration plant being developed by GreenFire Energy. The project would compress and reinject naturally occurring CO₂ under the Arizona-New Mexico border region to carry heat to the plant (*DOE 2011 "Innovative"*). The technology has the potential not only to utilize natural carbon dioxide, but also to sequester human-made CO₂ from nearby power, resulting in net negative emissions.

The Iceland Deep Drilling Project (IDDP) is focused on supercritical hydrothermal fluids at temperatures of over 752°F (400-600°C), which are accessed by drilling 4-5 km deep. The project's first well was drilled in 2009, but was terminated when the drill bit hit molten rock. The IDDP intends to drill additional wells by 2015, according to their Web site.

3.3. What is the international potential of geothermal energy?

Since geothermal sources are considered essentially limitless, estimates of its potential focus on commercial possibilities using quantifiers such as available lands and technology limits.

Geothermal resources were estimated to potentially support between 35,448 and 72,392 MW of worldwide electrical generation capacity using technology available at the time of a 1999 GEA study. 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. Table 4 shows 1997 estimates of world geothermal resources for four different geologic regimes (*U of Utah 1997*).

Table 4. World Continental Geothermal Resources

<i>Geologic Regime</i>	<i>Joules (J)</i>	<i>bbl oil equivalent</i>
Magmatic Systems	15×10^{24} J	$2,400,000 \times 10^9$
Crustal Heat	490×10^{24} J	$79,000,000 \times 10^9$
Thermal Aquifers	810×10^{18} J	130×10^9
Geopressured Basins	2.5×10^{24} J	$410,000 \times 10^9$
Total Oil Reserves (for comparison) ¹³	$5,300 \times 10^9$ J	--

¹³ Includes crude oil, heavy oil, tar sands, and oil shale (*National Academy of Sciences 1990*).

4. Supporting Policies

Geothermal energy production and use are governed by numerous federal, state, and local laws ranging from environmental protection statutes to zoning regulations. Unique laws at the federal and state level govern the leasing and permitting of geothermal resources on federal and state land. Policies and incentives key to new geothermal development include tax credits, loan and grant programs, and research support.

Public policies play a significant role in energy development and production. For decades federal and state policies have shaped our utility and energy systems. Today, the drivers (or policy impediments) for geothermal power growth are usually said to be: (1) state renewable portfolio standards; (2) federal and state tax incentives; (3) geothermal leasing and permitting; (4) research and technology support; and (5) pollution and climate change laws.

Geothermal projects are subject to a variety of local, state and federal laws and regulations related to environmental protection. An excellent source to understand how these different requirements intersect with a geothermal project is the "Geothermal Permitting Guide" prepared by the California Geothermal Energy Collaborative.

GEA resources for section 4: *Geothermal Revenue Under the Energy Policy Act of 2005 (January 2009)*; *Geothermal Energy Weekly (GEA's newsletter)*

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

At the federal level, tax incentives are usually considered the most important incentive for driving growth in renewable energy. Geothermal power projects can qualify for either the federal Investment Tax Credit or the Production Tax Credit. In addition, there are loan and grant programs, research support, and other federal

measures encouraging geothermal and other renewable technologies (*DOE “DSIRE”*).

Federal research programs also support geothermal energy. 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. More recently, Congress has passed as part of HR 6 in 2007, the Advanced Geothermal Energy Research and Development Act of 2007. GEA Executive Director Karl Gawell said in April 2012:

“We’ve seen slow but steady growth for geothermal, even in a challenging economy. The drivers for that growth have been state renewable portfolio standards, federal tax credits, DOE demonstration project support, and the fact that utility scale geothermal energy offers clean baseload energy that’s competitive with other clean energy technologies. The geothermal industry looks to our policy leaders to provide a stable environment to foster growth that could lead the U.S. toward greater energy independence.

“With federal tax credits expiring at the end of 2013, many new geothermal power plants cannot count on federal help. Most plants need between four and eight years of lead time before the geothermal resource is on tap. As Washington debates whether or not to extend renewable energy tax incentives, the industry struggles to continue steady growth. Stable tax credit policies would further enhance this development. State policies also continued to support new development, but need to better recognize the full value of geothermal, particularly its contribution to the reliability of the power system.”

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. Geothermal leasing and permitting on federal lands 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 US in 2008 (*DOI 2008*).

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

In addition 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. The primary sources for geothermal research and technology support are the U.S. DOE's Geothermal Technologies Program and the CEC, 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. For California, the Air Resources Board leads their climate efforts.

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. About 43 states today have some form of RPS requirement. 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 (*DOE "DSIRE"*).

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 (GRDA). The GRDA account is funded from geothermal royalty revenues.

5. Environmental Benefits

Experts generally agree that effects of climate change pose significant environmental dangers, including flood risks, drought, glacial melting problems, forest fires, rising sea levels, loss of biodiversity, and potential health dangers (*IPCC 2001*). Geothermal power plants involve no combustion, unlike fossil fuels plants, so they emit very low levels of greenhouse gases. Binary and flash/binary plants produce nearly zero air emissions. Electricity generation from geothermal resources also eliminates the mining, processing, and transporting required for electricity generation from fossil fuel resources. Using geothermal energy helps to offset the overall release of carbon dioxide into the atmosphere, as well as its effects. Geothermal energy also takes up very little surface land – it has among the smallest footprint per kilowatt (kW) of any power generation technology, including coal, nuclear, and other renewables.¹⁴

In addition, 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.

GEA resources for section 5: *Why Support Geothermal Energy?* (February 2012); *GEA Issue Brief: Geothermal Energy and Induced Seismicity* (August 2009); *GEA Issue Brief: Geothermal Energy and Water Consumption* (August 2009); *A Guide to Geothermal Energy and the Environment* (April 2007); *Geothermal Energy Weekly* (GEA's newsletter)

¹⁴ 1 MW = 1,000 kW

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

As of 2011, energy-related carbon dioxide accounts for about 82% of greenhouse gas (GHG) emissions in the U.S. (*DOE 2011 Emissions*).¹⁵ The average rate of emissions for a coal-fired power plant is ~12 times greater than that of a geothermal power plant, as shown in Figure 16, and ~6 times greater than a geothermal power plant for a natural-gas-fired power plant.

Figure 16. Comparison of Coal, Natural Gas, and Geothermal CO₂ Emissions

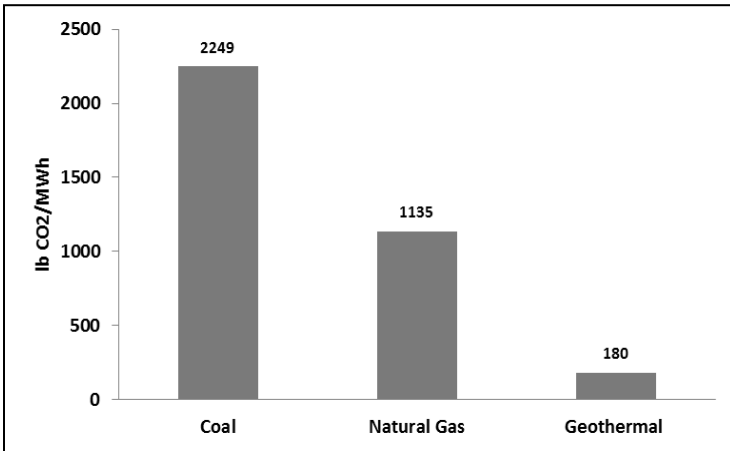


Figure 16 Source: GEA, CARB, EPA, CEC

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

¹⁵Energy-related carbon dioxide accounted for 5,359.6 million metric tons of greenhouse gas emissions in 2009, or 81.5% of the total.

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. Air emissions from geothermal are still considered environmentally benign compared with technologies that involve combustion of the primary energy resource (fossil fuels).

The exact relationship between human-caused and natural 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. Despite the difficulty in distinguishing between natural and human-caused emissions associated with geothermal power production, geothermal remains a low emitter.

In an international community increasingly worried about worsening effects of climate change, geothermal can play an important role in reducing air emissions from electricity production and heating and cooling. In Nevada alone, the state'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 CO₂ annually (*Nev. Geo. Council*).

In the example of Lake County, California, located downwind of The Geysers geothermal complex, the county has met all federal and state ambient air quality standards since the 1980s. Air quality has even improved because hydrogen sulfide, which would ordinarily be released naturally into the atmosphere by hot springs and fumaroles, instead passes through an abatement system that reduces hydrogen sulfide emissions by 99.9% (*GEA 2007 A Guide*).

Based on publicly available data for the State of California, GEA estimates an average emissions rate of approximately 180 pounds of CO₂ per megawatt-hour (lb CO₂/MWh) of electricity generated for geothermal power plants in the state. This is a relatively high estimate

for the larger U.S. geothermal industry, considering that many of the recent capacity additions and much of the future projected development involves binary technology, which results in near-zero emissions figures.

Additionally, because geothermal use offsets emissions of nitrogen, sulfur, and particulate matter produced by fossil fuel power plants, geothermal helps reduce the health effects of these emissions and their related costs (*GEA 2007 A Guide*). Estimates from the Clean Air Task Force in 2010 showed the healthcare costs for illness and premature death associated with impacts from coal plants in the U.S. to exceed \$100 billion per year. 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. Reducing power plant emissions has substantial benefits to public health and the associated costs.

5.2. How much land does geothermal energy use?

In its 2008 Programmatic Environmental Impact Statement, the BLM estimated that the total surface disturbance for geothermal power plants ranges from 53 to 367 acres. This range includes all activities involved in plant development, including 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. BLM notes that much of this land is reclaimed after the exploration, drilling, and construction phases of development, so the actual land footprint of an operational geothermal power plants is much less. Additionally, geothermal energy utilization results in fewer long-term land disturbance impacts compared to other electricity generation activities (*DOI 2008*, page ES-8). Figure 17 (Table 2-8 of *DOI 2008*) breaks out land use throughout geothermal plant development, assuming plant sizes of a range approximately 30-50 MW.

Figure 17. 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 may 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

Moreover, 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 on supports above ground, which allows small animals to roam freely and native vegetation to flourish. Additionally, natural color painting 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 (*DOE "Program Areas"*). Surface features such as geysers or fumaroles are not used during geothermal development; to prevent deterioration if located near a facility, sometimes special efforts are made to keep these thermal features intact if they are of cultural value.

5.3. How noisy are geothermal plants?

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 (*GEA 2007 A Guide*).

When noise issues arise, they can be dealt with effectively in ways that do not impact plant performance. For example, for GEA's 2011 Honors awards, Enel Green Power North America described how the company dealt with 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, 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.”

5.4. How do geothermal developers use water?

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 (*Farison 2010*, page 1025).

In 2011, Argonne National Lab (*DOE 2011 Water Use*, page 26) found:

“Average values of [life cycle water] consumption for coal, nuclear, and conventional natural gas power plant systems are higher than for geothermal scenarios. However, because consumption depends on cooling technology, it is not surprising that reported low consumption values for thermoelectric technologies including coal, nuclear, conventional natural gas, NGCC, EGS, and biomass are similarly near 0.3 gal/kWh. 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.”

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"*).^{16,17}

Water is a critical component of geothermal systems. The water used, which comes from the geothermal system, is reinjected back into the reservoir to maintain reservoir pressure and prevent reservoir depletion.¹⁸ Rainwater and snowmelt generally continue to feed underground thermal aquifers, naturally replenishing geothermal reservoirs. 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 ground water and fresh water sources to avoid 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.

Geothermal energy can make use of wastewater that might otherwise damage surface waters (see section 3.2.3.) Additionally, studies have

¹⁶These 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.

¹⁷Includes 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.

¹⁸Reinjection 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.

shown condensate at geothermal power plants could potentially be used to produce potable water, but no completed projects have thus far incorporated this.¹⁹ Additional benefits of geothermal energy to regional water use are possible: for example, section 3 includes a discussion of mineral recovery from geothermal water at power plant sites.

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

Seismicity is a natural geological phenomenon that occurs in geothermally active areas. Geothermal production and injection operations can create low-magnitude events known as microearthquakes, though these events typically cannot be detected without sensitive equipment.

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 (*DOI 2008*).

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 continue to monitor for induced seismicity throughout the life of the plant. According to BLM, "seismic risk is more likely to impact geothermal facilities than operation of geothermal facilities is to increase seismic risk" (pp. 4-18 of *DOI 2008*).

In order to address public concern and gain acceptance from the general public and policymakers for geothermal energy development, specifically EGS, the U.S. DOE commissioned a group of experts in induced seismicity, geothermal power development and risk assessment to write a revised induced seismicity protocol (*DOE 2012*). The authors met with the

¹⁹Geothermal Development Associates of Reno, Nevada worked on a design for a power plant in Djibouti, East Africa that would have produced potable water.

domestic and international scientific community, policymakers, and other stakeholders to gain their perspectives and incorporate them into the Protocol. They also incorporated the lessons learned from Basel, Switzerland and other EGS projects around the world to better understand the issues associated with induced seismicity in EGS projects. The protocol concludes that with proper study and technology development, induced seismicity will not only be mitigated, but will become a useful tool for reservoir management.

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

6. Economic Benefits

Geothermal energy is beneficial because it provides long-term answers to some of the most pressing issues in today's economy. Costs of traditional fuel and electricity are volatile, leading people to question where their power comes from and how rising energy costs will affect their communities. 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. Additionally, since geothermal energy production is domestic, it helps offset involvement in foreign energy affairs.

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

GEA resources for section 6: *Why Support Geothermal Energy?* (February 2012); *Energizing Southern California's Economy: The Economic Benefits and Potential for Geothermal Energy in Southern California* (October 2011)

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

While warning signs of climate distress and volatile fuel and electrical costs leave more questions than answers as to how nations will continue to power their communities and businesses, geothermal power is:

- low cost -- the average cost of geothermal plant over its lifetime is dramatically lower than that of traditional sources of power – see section 7, Power Plant costs

- reliable, helps to stabilize prices
- environmentally friendly – see section 5, Environmental Benefits
- locally produced -- using geothermal energy reduces foreign oil imports
- supported by federal and local grants and incentives
- boosts rural economies with royalties and taxes
- supplies thousands of quality jobs
- diversifies the fuel supply

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.²⁰

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 (*DOE 2008 Geo. Risk*).

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

²⁰ Assuming an average capital cost of a geothermal project corresponding to \$4000/kW.

construct, the capital investment in new U.S. geothermal projects would be in excess of \$10 billion.

“This is no longer just an interesting alternative, but a large scale transformation in global energy markets,” DOE wrote. Even so, geothermal remained in underdog status: “While the worldwide scale of available investment capital for renewable energy in 2006 is robust, the geothermal share of that capital was conspicuously small at less than 1%, or about \$66 million.”

In the U.S., the DOE has increased its public investment in renewable technologies, including geothermal. The geothermal energy budget request was \$65 million for FY2013, as compared to \$37.9 million enacted in FY2012. The Geothermal Technologies Program received \$368.2 million through the American Recovery and Reinvestment Act of 2009, and awarded 148 projects spanning 38 states and the District of Columbia.

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. The funding facilitated geothermal heat maps. Geothermal maps are now available free through Google Earth, with user-friendly panning and searching options (see Figure 13).

Table 5 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 5. 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?

Producible geothermal resources are often located in rural areas, which can suffer from economic depression and high unemployment. Geothermal developers bring significant economic advantages such as jobs and tax payments to local economies, and they also often benefit minority communities. Many geothermal companies provide additional voluntary contributions to the communities in which they exist. For example:

Nevada's geothermal power plants pay sales & 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 (*GEA 2012 Why Support*).

MidAmerican Renewables is the single largest taxpayer in Imperial County (page 16 of *GEA 2006*). Overall geothermal activities supply a full 25% of the county tax base, and over \$12 million in tax revenue.²¹

Since enactment of the 2005 Geothermal Steam Act Amendments, 25% of revenues from geothermal leasing and production are allotted to state and local governments, which can determine how the funds will be used. 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.

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 (*GEA 2009 Geo. Revenue*, page 5).

Geothermal power plants can even be a tourist draw when students, scientists, or interested individuals visit the site of a power plant, 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 has hosted more than 75,000 visitors from all 50 U.S. states and 79 countries since it opened in 2001.

²¹MidAmerican Energy Holdings Company operates geothermal energy through MidAmerican Renewables (formerly known as CalEnergy U.S.), as well as operating other power technologies.

6.4. How does geothermal energy benefit developing countries?

Developing countries that are seeking energy and economic independence are often already battered by the trade and subsidy practices employed by developed nations. Geothermal energy can provide answers to infrastructure needs while preserving the cleanliness of these regions. A growing number of countries, including Australia, China, Germany, Iceland, Italy, Japan, and the U.S., are facilitating geothermal development projects in developing countries around the world. Forms of support other than financing include technology sharing and training. Geological surveys are also being endorsed by outside governments (*GEA 2010 Int'l*).

Countries with abundant geothermal resources, such as Kenya, Indonesia, and many Caribbean islands, stand to directly benefit from developing those resources. This could go a long way to reducing both energy and economic poverty in developing nations and directly contribute to local energy infrastructure and economic development.

Indonesia, for example, 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 free up its portable energy fuels – such as coal and natural gas – for higher-markup export to other markets or overseas.

In Africa, biomass production has led to unwanted deforestation, and hydropower plants lack adequate resource due to climate-change-induced droughts. Recent years have seen increased dependence on expensive, imported petro-products and diesel supplies. The East African Rift System is another of the world's largest known geothermal reserves and could provide an indigenous generation system with a predictable supply and price in remote locations (*GEA 2012 "Budding"*).

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. According to Sanyal and Koenig (2011, p. 1):

“The resource risk in connection with the financing of geothermal projects can be subdivided into questions of: resource existence, resource size, deliverability, cost of development and operation, environmental constraints, management and operational problems, and resource degradation.”

The DOE’s new 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.

GEA resources for section 7: *Handbook on the Externalities, Employment, and Economics of Geothermal Energy (October 2006)*; *Factors Affecting Cost of Geothermal Power Development (August 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. There are many factors that influence the cost of a geothermal power plant. Some 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. 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. To fully explore a geothermal resource a developer leases exclusive rights to the geothermal resource (*DOI 2009*). Leasing and permitting can greatly influence the upfront costs and can contribute to time delays -- 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 will be profitable. Research also indicates that risks change over time, and for resource risk there is a learning curve effect on drilling success rates (*Sanyal and Morrow 2012*). The risks can be offset by certain tax incentives and federal sureties, which are discussed more in section 4: Policy.

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

A geothermal project competes against many other renewable and non-renewable power developments as well as all other projects that use similar commodities and services (*DOE 2008 Geo. Tomorrow*). Geothermal is capital intensive, which can present challenges to initial financing. The upside to this is that essentially the entire resource base is paid for upfront. Fossil fuel plants such as natural gas and coal have high fuel costs, especially if they are imported. But once a geothermal project is completed, the fuel is free.

This also means geothermal energy can act as a price stabilizer, offsetting effects of volatile fossil fuel power markets. 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.²² Figure 19 shows levelized costs of geothermal dual flash plants and geothermal binary plants as compared to several other technology types for projects starting in 2009 (data from Table 1 of *CEC 2010*). The levelized generation cost for an economically competitive geothermal merchant power plant can be as low as \$83/MWh for a 15-MW geothermal binary plant and \$79/MWh for a 30-MW flash plant.

Figure 19: Levelized Costs of Selected Technologies

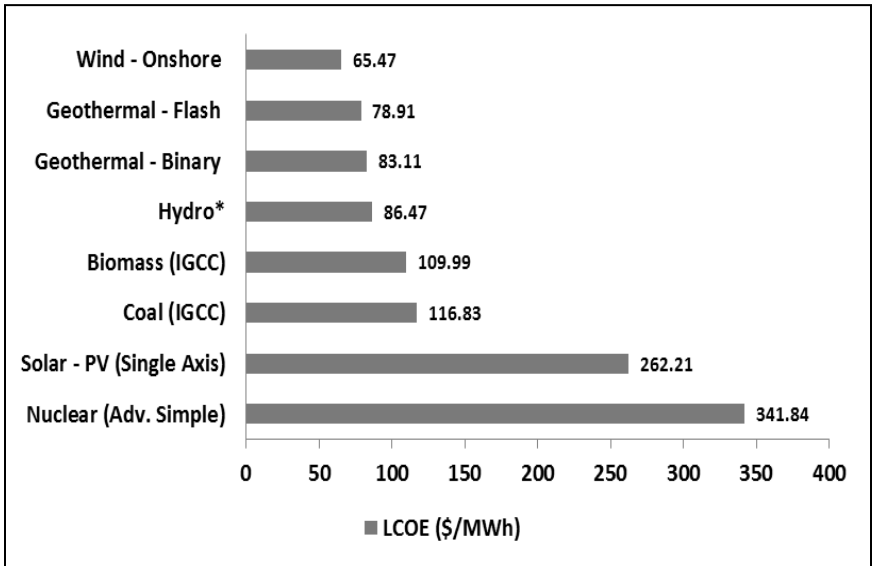


Figure 19 Source: California Energy Commission

²² 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.

Figure 20 lists the estimated cost of electricity by source for plants entering service in 2016 (*DOE 2010*).²³ 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. For geothermal, the average²⁴ levelized cost is an estimated \$101.7/MWh for a plant starting in 2016.

7.3. What is the cost of geothermal power?

In the U.S., geothermal plants can produce electricity for 5 to 11 cents per kilowatt-hour (kWh) including tax incentives, a rate competitive with traditional fossil fuel generation (*Calif. 2008*). 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 (*DOE "Geo. FAQs"*).

Whether the cost of power affects the customer, and by how much, could depend on the existing energy portfolio of the utility, which are 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, and just over 1% in Connecticut and Massachusetts. Additionally the U.S. Energy Information Administration in 2009 projected little difference in electricity rates through 2030 with or without a national renewable energy standard.

At its San Jacinto-Tizate project in Nicaragua, where renewable energy projects qualify for a power sales tariff, U.S. company Ram Power is in discussions as of mid-2012 for an increased power sales tariff that would result in an annual increase of approximately \$8

²³ No tax credits or incentives are incorporated in the table.

²⁴ Minimum \$91.8, maximum \$115.7, per Table 2 (not shown) of *DOE 2010*.

million to \$11 million of revenue once the full project is complete (*Ram Power*). The resulting tariff rate would be approximately 30% to 35% lower than the current oil-dominated energy matrix, thus providing cheap energy while still making it an attractive venture for the company.

Figure 20: Estimated Levelized Cost of New Generation Resources, 2016

Plant Type	Capacity Factor (%)	U.S. Average Levelized Costs (2009 \$/megawatthour) for Plants Entering Service in 2016				
		Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System Levelized Cost
Conventional Coal	85	65.3	3.9	24.3	1.2	94.8
Advanced Coal	85	74.6	7.9	25.7	1.2	109.4
Advanced Coal with CCS	85	92.7	9.2	33.1	1.2	136.2
Natural Gas-fired						
Conventional Combined Cycle	87	17.5	1.9	45.6	1.2	66.1
Advanced Combined Cycle	87	17.9	1.9	42.1	1.2	63.1
Advanced CC with CCS	87	34.6	3.9	49.6	1.2	89.3
Conventional Combustion Turbine	30	45.8	3.7	71.5	3.5	124.5
Advanced Combustion Turbine	30	31.6	5.5	62.9	3.5	103.5
Advanced Nuclear	90	90.1	11.1	11.7	1.0	113.9
Wind	34	83.9	9.6	0.0	3.5	97.0
Wind – Offshore	34	209.3	28.1	0.0	5.9	243.2
Solar PV ¹	25	194.6	12.1	0.0	4.0	210.7
Solar Thermal	18	259.4	46.6	0.0	5.8	311.8
Geothermal	92	79.3	11.9	9.5	1.0	101.7
Biomass	83	55.3	13.7	42.3	1.3	112.5
Hydro	52	74.5	3.8	6.3	1.9	86.4

¹ Costs are expressed in terms of net AC power available to the grid for the installed capacity.

Source: Energy Information Administration, Annual Energy Outlook 2011, December 2010, DOE/EIA-0383(2010)

Figure 20 Source: Department of Energy

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.

GEA resources for section 8: *Why Support Geothermal Energy?* (February 2012); *U.S. Geothermal Education and Training Guide* (2011); *Green Jobs Through Geothermal Energy* (October 2010); *GEA Issue Brief: Geothermal Energy and Jobs* (August 2009); *A Handbook on the Externalities, Employment, and Economics of Geothermal Energy* (October 2006); *Geothermal Energy Weekly* (GEA's newsletter)

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 21).

The most jobs involved in the construction of the plant and the manufacturing of the power system and equipment. Employment surges when projects are in active drilling stages because of the labor involved in drilling teams (Table 6).

The average wage at the proposed Telephone Flat geothermal facility in California will be more than double the average wage in surrounding counties, noted GEA (*GEA 2007 A Guide*). According to the U.S. Census Bureau, the average per capita income in 1999 in

the surrounding counties was around \$21,000, \$2,000 lower than the average California per capita income at the time. The average projected wage related to operation at the Telephone Flat facility would be higher than both the county and state averages, totaling between \$40,000 and \$50,000 (in 1998 dollars).

Figure 21: Job Types throughout the Project Timeline

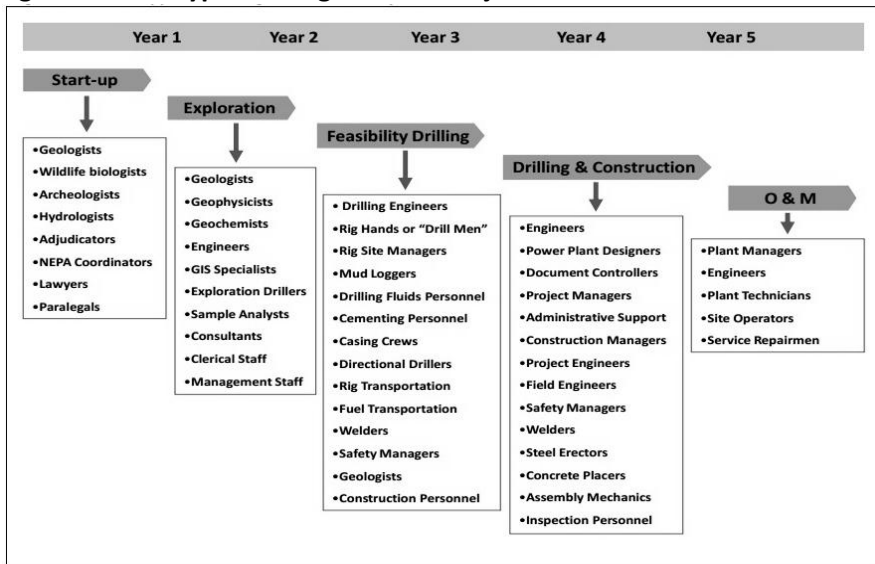


Figure 21 Source: Geothermal Energy Association

In the EIS of the Salton Sea Unit 6 Geothermal Power Plant, to be built in the Imperial Valley, total workforce for the construction period of a new 185 MW geothermal power plant is estimated to be 6,898 person*month, distributed through the construction period (Figure 22).

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

Estimates of the number of people employed today by the development and use of geothermal energy are not exact but can be extrapolated from past studies. Previous GEA analysis, widely

reviewed by industry, academic, and government experts, concluded (*GEA 2005 Geo. Industry*):

- Direct employment results in 1.7 full time positions and 6.4 person*years per megawatt.
- Induced and indirect impacts were 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 /MW.

Table 6. Jobs Involved in Geothermal Development for a 50-MW Plant

Stage of Development	No. of jobs
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

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 (*GEA 2010 Green Jobs*).

Figure 22: Number of Employees (y) per Month of Construction (x) at Salton Sea Unit 6

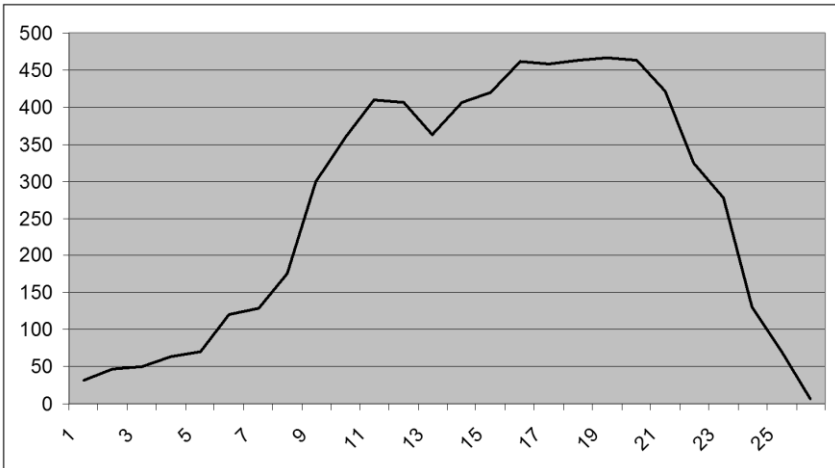


Figure 22 Source: CalEnergy, "Salton Sea Geothermal Unit #6 Power Project - EIS & EIR," July 2002

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

MidAmerican Geothermal's planned new 235-MW geothermal plant is 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. For example, Stanford University and SMU offer geothermal Master's and Doctorate degrees (*GEA Education 2011*). Research facilities and/or geothermal research opportunities exist at a growing number of institutions. 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. In 2012, a collaboration of instructors from universities across the U.S. offered the National Geothermal Academy (NGA), an 8-week intensive course funded by the DOE, for the second summer in a row. The NGA is hosted at UNR.

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