



## Renewable Energy Source: GEOHERMAL



### TERMS IN GLOSSARY

- binary power plant
- conduction
- crust
- dry steam power plant
- enhanced geothermal systems (EGS)
- fissure
- flash power plant
- fumarole
- geothermal reservoir
- groundwater
- heat exchanger
- hot dry rock
- hydrogen sulfide
- magma
- mantle
- modular
- mud pot
- porous
- subducting
- tectonic plates
- wastewater
- working fluid

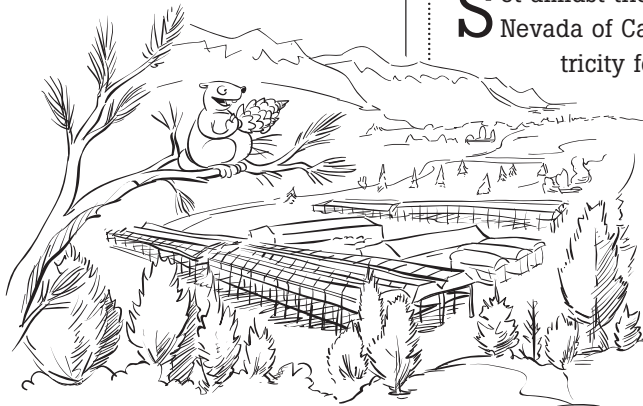
**P** EOPLE HAVE ALWAYS BEEN FASCINATED with volcanoes and their fiery displays of nature’s power. Many ancient societies believed volcanoes were homes to temperamental gods or goddesses. Today science tells us that volcanoes result from the immense heat energy – geothermal energy – found in Earth’s interior. This heat also causes hot springs, fumaroles (steam vents) and geysers.

Over the ages, humans have benefited from Earth’s geothermal energy by using the hot water that naturally rises up to the earth’s surface. We have soaked in hot springs for healing and relaxation and have even used them as instant cooking pots. Hot springs have also been an important part of cultural life and healthy lifestyles, especially in Japan and Europe.

Today we drill wells deep underground to bring hot water to the surface. We use the heat energy from this geothermal water to warm buildings, to speed the growth of plants and fish, and to dry lumber, fruits and vegetables. (See “Direct Use Geothermal,” page 149.) We use the energy from the hottest water to generate electricity.

### POWER SKETCH: Fine Neighbor

**S** et amidst the open vistas and forests of the eastern Sierra Nevada of California, a power plant churns out enough electricity for about 40,000 homes. The natural setting is not marred by smoky emissions, because there are none. This geothermal power plant uses hot water resources from an underground geothermal reservoir to power its turbine generators. Many tourists and residents of nearby Mammoth Lakes don’t even notice that the power plant is right there beside the main highway.



Mammoth Lakes geothermal power plant

## THE GEOTHERMAL RESOURCE

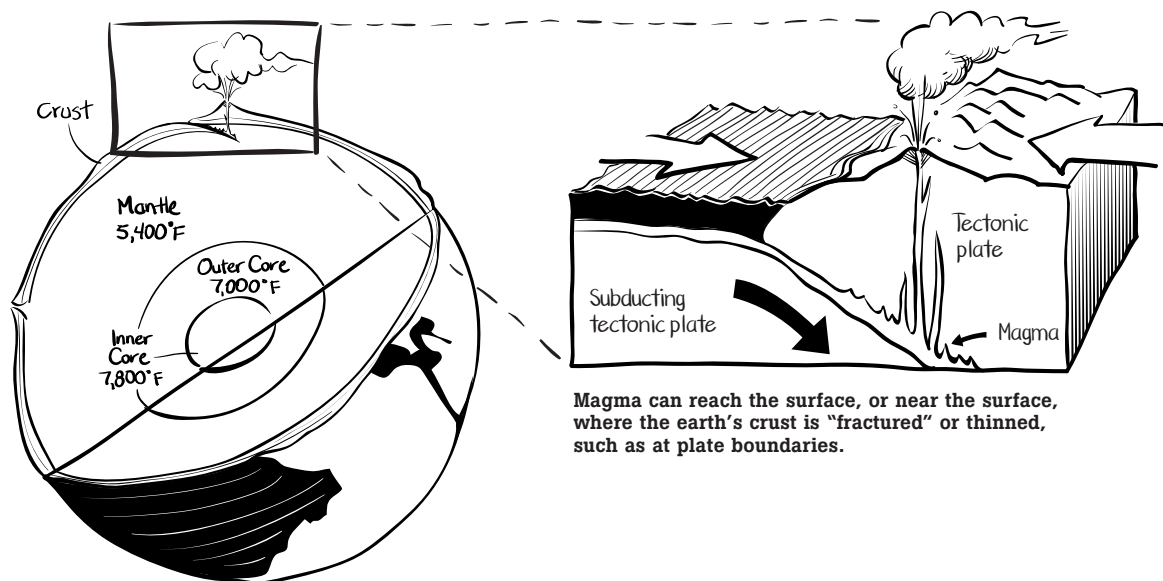
*Geo* means earth and *thermal* means heat. Geothermal energy is the earth's heat energy.

### The Inner Earth: Hot, Hot, Hot!

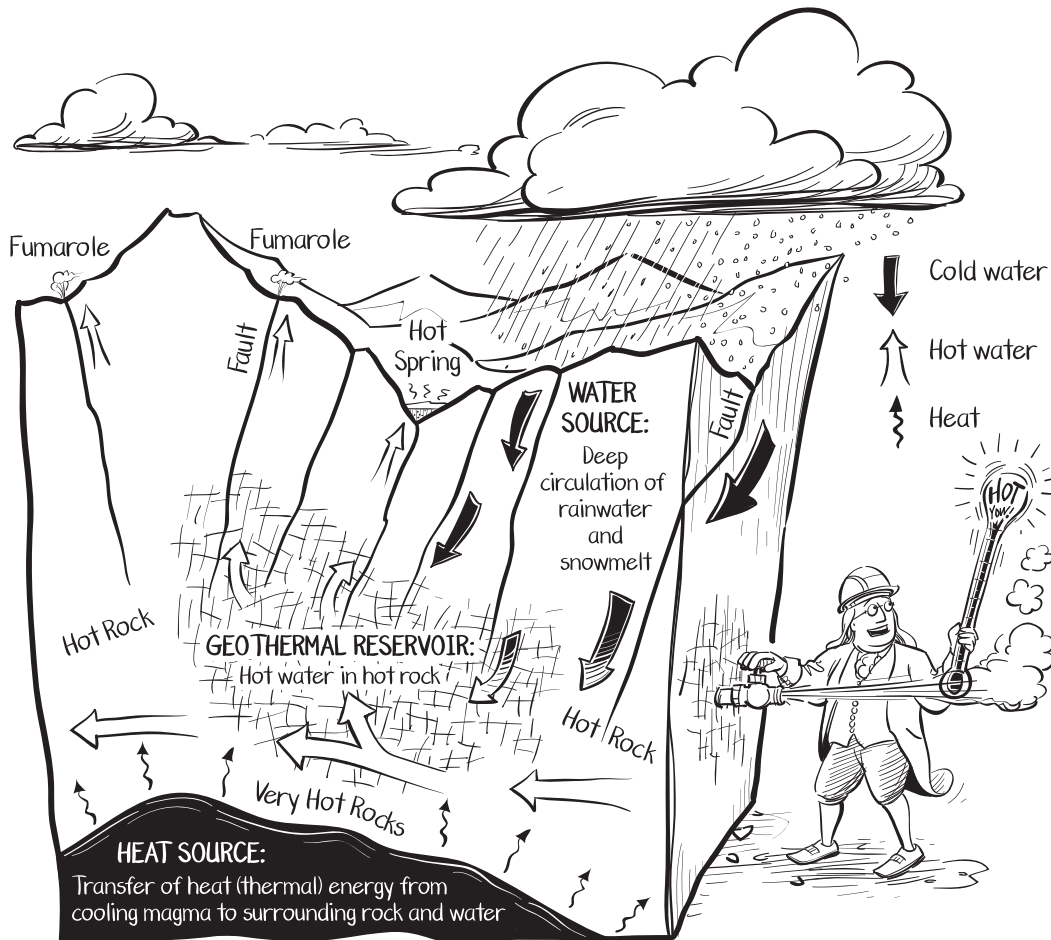
Billions of years ago our planet was a fiery ball of liquid and gas. As the earth cooled, an outer rocky crust formed over the hot interior, which remains hot to this day. This relatively thin crust "floats" on a massive underlying layer of very hot rock called the mantle. Some of the mantle rock is actually melted, or molten, forming magma.

The heat from the mantle continuously transfers up into the crust. Heat is also being generated in the crust by the natural decay, or breakdown, of radioactive elements found in most rocks.

The crust is broken into enormous slabs — tectonic plates — that are actually moving very slowly (about the rate your fingernails grow) over the mantle, separating from, crushing into, or sliding (subducting) under one another. The edges of these huge plates are often restless with volcanic and earthquake activity. (See "Hot Locations," page 56.) At these plate boundaries, and in other places where the crust is thinned or fractured, magma is closer to the surface. Sometimes magma emerges above ground — where we know it as lava. But most of it stays below ground where, over time, it creates large regions of very hot rock.



Magma can reach the surface, or near the surface, where the earth's crust is "fractured" or thinned, such as at plate boundaries.



A geothermal reservoir is a large underground area of hot permeable rock saturated with extremely hot water.

**Geothermal Reservoirs: Earth’s Natural Boilers**

Rainwater and melted snow can seep miles below the surface, filling the pores and cracks of hot underground rock. This water can get really hot. It can reach temperatures of 500°F (260°C) or higher – well above the normal boiling point of 212°F (100°C).

Sometimes this hot water will work its way back up (hot water is less dense than cold and so tends to rise). If it reaches the surface it forms hot springs, fumaroles, mud pots, or geysers. If it gets trapped deep below the surface, it forms a “geothermal reservoir” of hot water and steam. A geothermal reservoir is an underground area of cracked and porous (permeable) hot rock saturated with hot water. The water and steam from these super hot reservoirs are the geothermal resources we use to generate electricity.

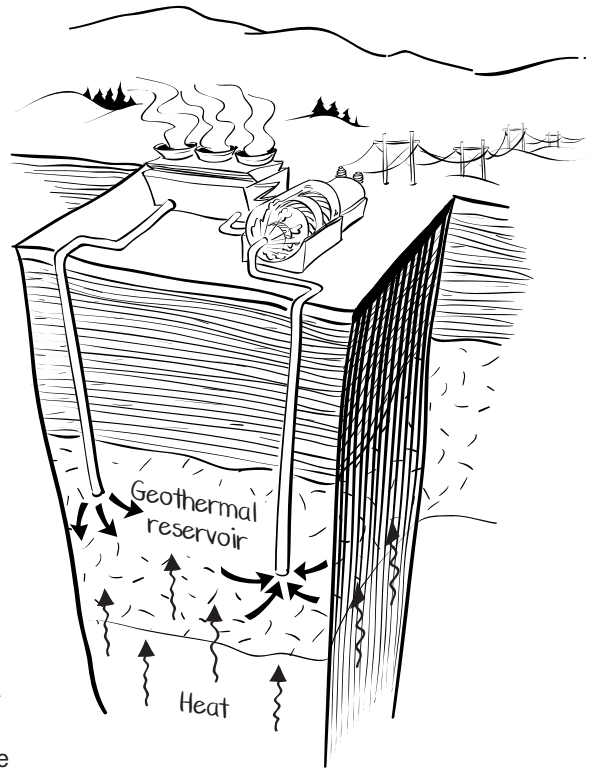
### GENERATING ELECTRICITY FROM GEOTHERMAL RESOURCES

Geothermal reservoirs can be found from a few hundred feet deep to two miles or more below Earth’s surface. To reach them, we drill wells and then insert steel pipe (casing). Now with an open passageway to the surface, the hot geothermal water or steam shoots up the well naturally or is pumped to the surface. From here it’s piped into a geothermal power plant.

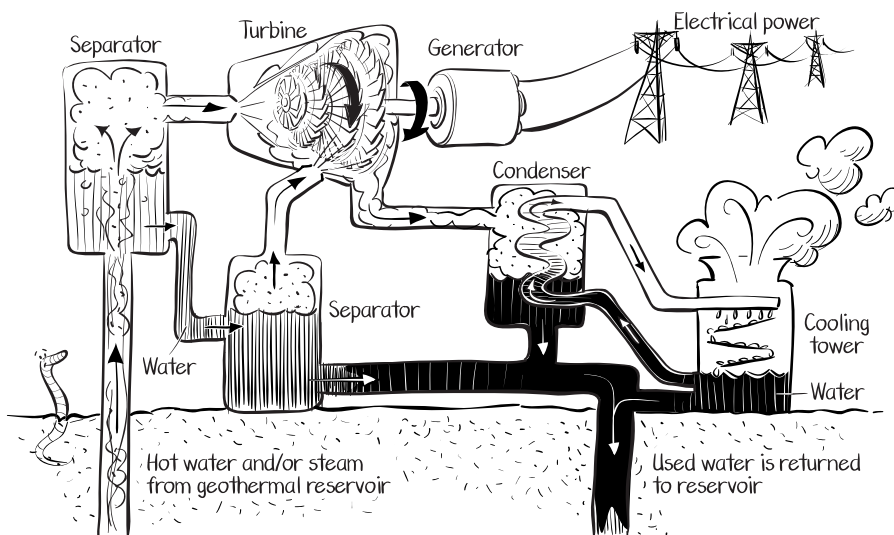
#### Geothermal Power Plants

There are different kinds of geothermal power plants, because there are different kinds of geothermal reservoirs.

**Flash Steam Power Plants.** Flash steam plants use really hot geothermal reservoirs of about 350°F (177°C) or higher. From the well, high-pressure hot water rushes through pipes into a “separator,” where the pressure is reduced. This causes some of the water to vaporize vigorously (“flash”) to steam, the force that drives the turbine-generators. After the steam does its work, it is condensed back into water and piped back down into the geothermal reservoir so it can be reheated and reused. Most geothermal power plants in the world today are flash plants.



Hot water or steam from a geothermal reservoir shoots up a geothermal well, spins the turbine-generator, and is returned to the reservoir.



Flash steam plants can include one steam/water separator or, more commonly, two separators (shown here).

**Dry Steam Power Plants.** Very few geothermal reservoirs are filled naturally with steam, not water. This means that the wells will produce only steam. The power plants that run on this steam are called “dry steam” power plants. Here, the steam blasts right into the turbine blades (they do not need separators), then is condensed to water and piped back into the reservoir. Though dry steam reservoirs are rare, they have been important to the development of geothermal power, especially in California, Italy, and Japan.

**Binary Power Plants.** In some geothermal reservoirs, the water is hot (usually over 200°F, or 93°C), but not hot enough to produce steam with the force needed to turn a turbine-generator efficiently. Fortunately, we can generate electricity from these “moderate temperature” reservoirs using binary power plants. Moderate-temperature reservoirs are more common than high-temperature reservoirs, so the use of binary power plants is expanding worldwide.

In the binary process, the geothermal water is used only to heat a second liquid. After passing through a heat exchanger, the geothermal water is pumped right back into the reservoir. It is that second “working fluid” that flashes to vapor and drives the turbine. (See sidebar.)

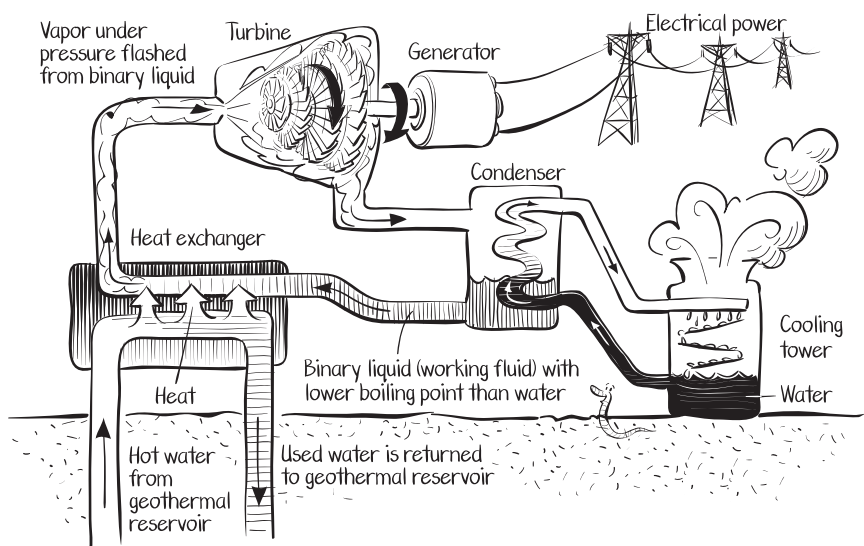
**HEAT EXCHANGERS**

**H**eat exchangers are used in electricity generation when the heat source is hot, but not quite hot enough to bring water to a boil to create forceful steam.

A heat exchanger transfers heat (thermal energy) from a hotter liquid (thermal energy) from a hotter liquid to a cooler one by conduction. The heat is conducted from the first (hotter) liquid into the second liquid (the “working fluid”) through metal pipes or plates that keep the two liquids separated.

The second liquid is usually one with a lower boiling point than water, so it vaporizes, or “flashes” to vapor, at a lower temperature than does water. Sometimes, such as in certain solar thermal power plants, where the first liquid is oil or another material, the second liquid can be water.

The force of the rapidly expanding vapor or steam spins the turbine blades that drive a generator. The vapor or steam can then be condensed back to a liquid and used over and over again.



**Binary power plant**

### All Shapes and Sizes

Geothermal power plants come small (200 kW to 10 MW), medium (10 MW to 50 MW), and large (50 MW to 100 MW and larger). A geothermal power plant usually consists of two or more turbine-generator “modules” in one plant. Extra modules can be added as more power is needed.

Binary plants are especially versatile because they can use relatively low reservoir temperatures. Small binary modules can be built quickly and transported easily. These little power plants are great for use in remote parts of the world, far from transmission lines. One interesting plant is installed in the rugged mountains of Tibet (People’s Republic of China). At a soaring 14,850 feet (4,526 meters), it is the highest geothermal power plant in the world.

Small binary plants are also popular in sometimes remote hot spring spas and health resorts. They add the convenience of electricity while maintaining an environmental and healthful appeal.



#### REMINDER

**W** = watt

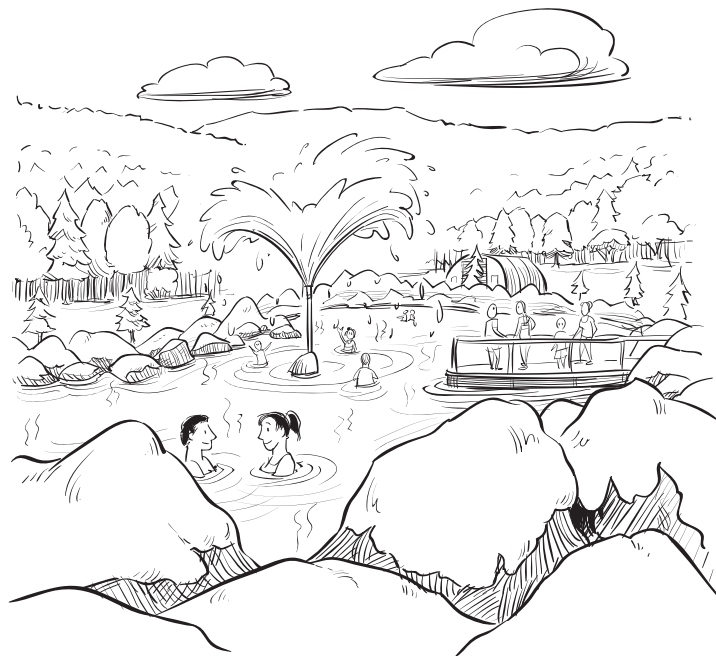
**kW** = kilowatt = 1,000 watts

**MW** = megawatt = 1,000 kilowatts

1 megawatt can serve about 1,000 homes in the United States.

#### HOT TIMES IN ALASKA!

**C**hena Hot Springs Resort has found an answer to high energy demands by tapping into the local geothermal resource. Chena is just east of Fairbanks – only 150 miles south of the Arctic Circle. Winters are extremely cold, with temperatures dropping to  $-50^{\circ}\text{F}$  and colder. This means a LOT of energy is required for heating as well as for electricity. Chena is using a small binary power plant to generate 400 kW of geothermal power with a resource that’s only  $165^{\circ}\text{F}$  – the lowest geothermal temperature ever used for making electricity. The resort is also using geothermal water to make ice, heat buildings and greenhouses, and – of course – for the natural hot springs pools that make Chena famous.

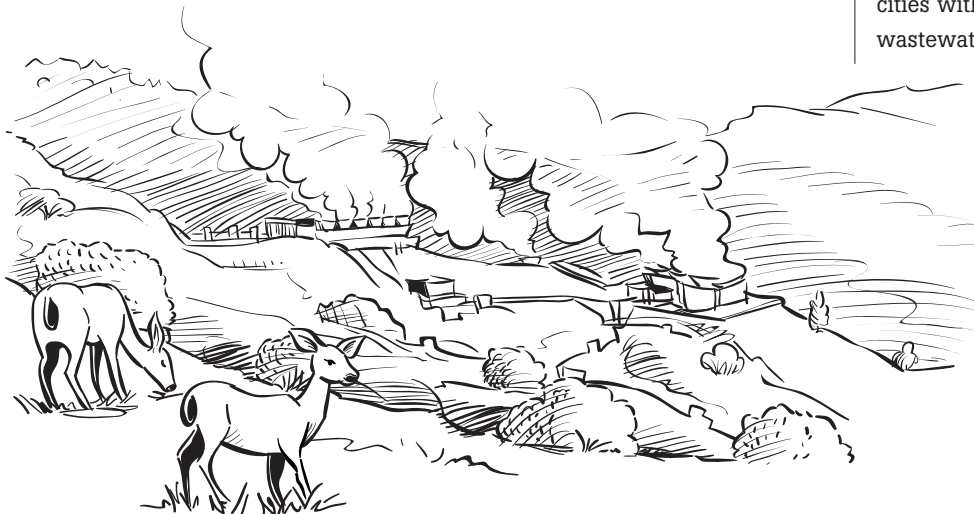


### Geothermal at Work Around the Globe

So far, the U.S. produces more electricity from geothermal energy than does any other country. Six states now have geothermal power plants. California has the most, followed by Nevada, Utah, Hawaii, Idaho, Alaska, Oregon, Wyoming, and New Mexico. More are planned in these states and are also being considered in Arizona, Colorado, Florida, Louisiana, Mississippi, and Washington.

U.S. geothermal power plant types vary widely. One little 300 kW geothermal powerhouse in northern California runs all by itself and automatically radios an operator when it needs maintenance. At one of Nevada's geothermal plants, the heat from geothermal water is used to dry onions and garlic before it is injected back into the reservoir. Hawaii's geothermal plants provide about 20 percent of the electricity used on the Big Island. And the world's largest single geothermal power plant, 185 MW, is nearing construction near southern California's Salton Sea.

The Philippines and Indonesia have abundant geothermal resources. Geothermal generates about one-fourth of the electricity in the Philippines, making this country the second largest user of geothermal electricity in the world (after the United States). Italy was the site of the first geothermal power development. Its beautiful dry steam field of Larderello, developed in 1904, is still generating electricity today. Other places with large geothermal power developments include Mexico, Iceland, New Zealand, Japan, and several Central American countries.



Geothermal power plants at The Geysers in California

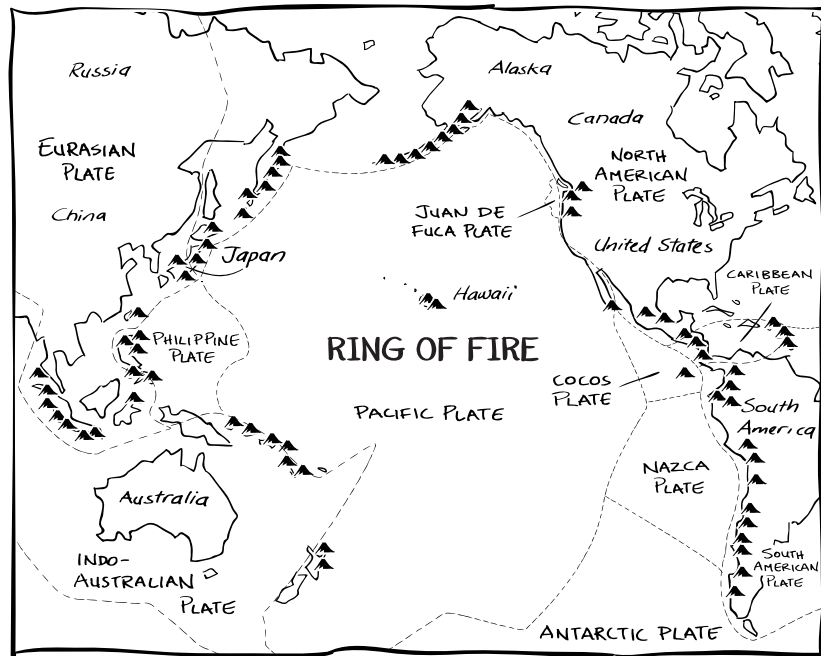
### "THE GEYSERS"

A geothermal field in northern California is named "The Geysers" (though it has no geysers — only fumaroles). It once was the site of a famous resort — attracting hardy travelers the likes of Jack London and Teddy Roosevelt. Today it is the world's largest single source of geothermal electrical power. Even its reservoir is rare, being one of the few in the world that produce steam (rather than mostly water). After over 50 years, The Geysers' 21 power plants still reliably generate enough electricity to power a city the size of San Francisco — about 900 MW.

To top it off, cities in Lake and Sonoma Counties are piping their cleaned wastewater many miles to The Geysers and injecting it deep into the geothermal reservoir. This practice helps sustain the productive life of the reservoir for electricity production while providing nearby cities with environmentally safe wastewater disposal.

### HOT LOCATIONS

The edges of the continents that surround the Pacific Ocean (the Pacific “Ring of Fire”) are prone to earthquakes and volcanoes and have some of the best geothermal resources in the world. This includes the western part of North, Central, and South America; New Zealand; Indonesia; the Philippines; Japan; and Kamchatka (eastern Russia). These countries all have coastlines that sit on or near the boundaries of tectonic plates. Some of the other prime geothermal locations include Iceland, Italy, the Rift Valley of Africa, and Hawaii.



This map shows the edges of the tectonic plates (they all have names) that form the “Ring of Fire.” Most countries in this area have lots of geothermal energy.

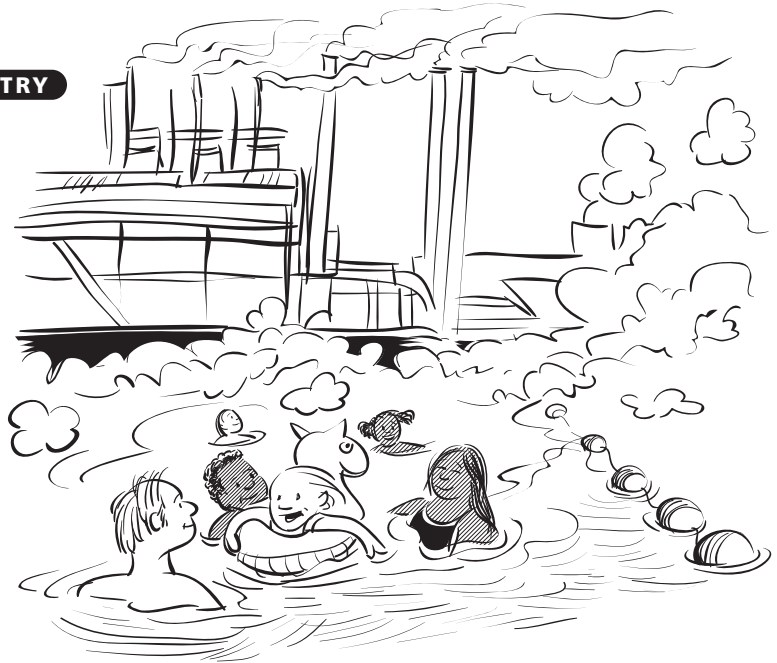
### Enhanced Geothermal Systems: New Energy from “Engineered” Reservoirs

There are many places underground where the rock is really hot but doesn’t naturally contain much water. Researchers are working on ways to pump water down into this hot rock, creating “engineered” geothermal reservoirs. Called “enhanced geothermal systems” (EGS) or (less often) “hot dry rock,” this method involves drilling a well into the hot rock and injecting high-pressure cold water to expand natural cracks (fractures) or to make new ones. Then more water is pumped down into the fractured rock. The heat from the rock transfers to the water, and the now-hot water is pumped up a separate well to generate electricity in a binary power plant.

A U.S. project at Los Alamos, New Mexico, first demonstrated that EGS can work. Japan, France, Germany, Switzerland, Australia, and other countries are also working on this method. In the United States and elsewhere, similar processes are being adapted to boost the production of already-developed natural geothermal reservoirs.

**HOT ENERGY FOR A COLD COUNTRY**

Iceland is such an active geothermal area that hot springs occasionally bubble up right into people’s living rooms! People in this cool-weather country make really good use of their abundant geothermal energy resource. They use it for everything from heating homes, offices, and greenhouses to warming swimming pools and generating electricity. In the middle of winter, it is not uncommon to see people soaking in the steamy hot pool found right outside a geothermal power plant.



Some spas in Iceland are located right next to geothermal power plants.



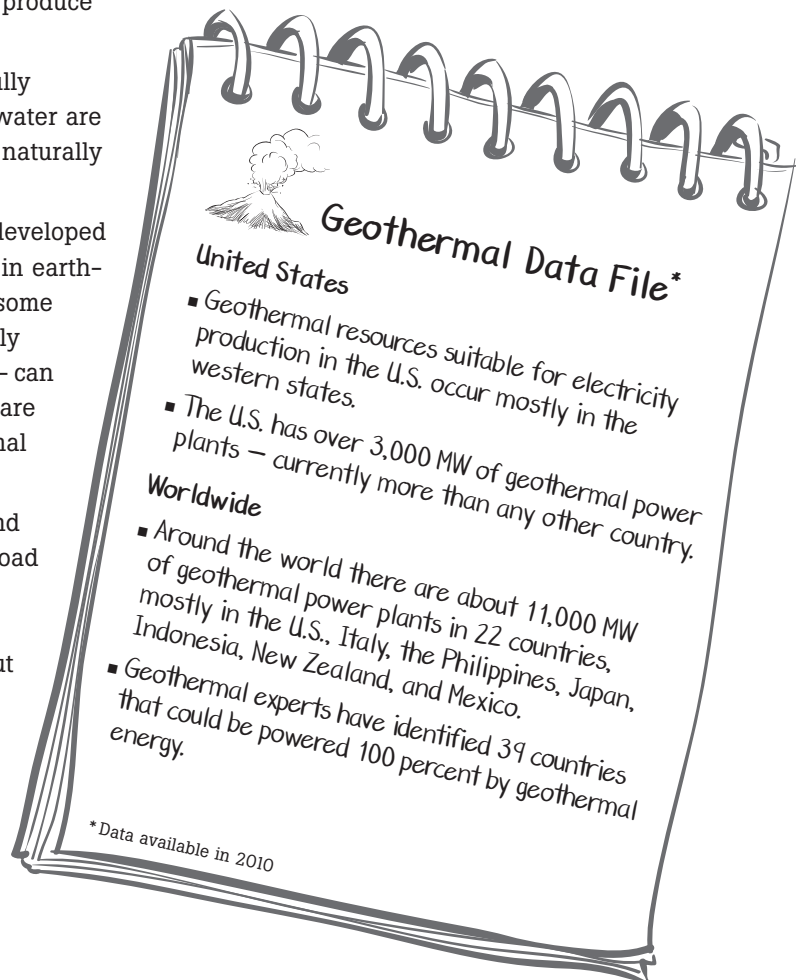
**CONSIDERATIONS**

- Geothermal power plants produce no smoke. What comes out the top of a geothermal plant cooling tower is steam (water vapor) with only trace amounts of natural minerals and gases from the geothermal reservoir. Flash and dry steam plants produce only a small fraction of air emissions compared to fossil fuel plants. (See page 135.) Binary power plants have virtually no emissions.
- Geothermal power plants use very little land compared to conventional energy resources and can share the land with wildlife or grazing herds of cattle. They operate successfully and safely in sensitive habitats, in the midst of crops, and in forested recreation areas. However, they must be built at the site of the geothermal reservoir, so there is not much flexibility in choosing a plant location. Some locales may also have competing recreational or other uses.
- Geothermal wells are sealed with steel casing, cemented to the sides of the well along their length. The casing protects shallow, cold groundwater aquifers from mixing with the deeper geothermal reservoir waters. This way the cold groundwater doesn’t get into the hot geothermal reservoir and the geothermal water doesn’t mix with potential sources of drinking water.

*(continued)*

**CONSIDERATIONS (continued)**

- Geothermal water contains varying concentrations of dissolved minerals and salts. Sometimes the minerals are extracted and put to good use. Examples are zinc (for electronics and for making alloys such as bronze and brass) and silica. At reservoirs with higher concentrations, advanced geothermal technology keeps the salty, mineralized water from clogging and corroding power plant equipment.
- Most geothermal reservoirs contain varying amounts of dissolved gases such as hydrogen sulfide. This gas smells bad (like rotten eggs), even at very low concentrations, and is toxic at high concentrations. Modern geothermal technology ensures that geothermal power plants capture these gases before they go into the air. Some gas removal processes can produce sulfur for use in fertilizers.
- Geothermal reservoirs must be carefully managed so that the steam and hot water are produced no faster than they can be naturally replenished or supplemented.
- Geothermal resources are generally developed in areas of high seismic activity, i.e., in earthquake country. Critics point out that some geothermal development – particularly with enhanced geothermal systems – can cause small earthquakes. Regulators are examining this issue where geothermal projects are near residential areas.
- Geothermal power plants run day and night, so they provide reliable baseload electricity. Most can increase their output of electricity to provide more power at times of greater demand. But geothermal power plants can't be used exclusively for peaking power; if geothermal wells were turned off and on repeatedly, expansion and contraction (caused by heating and cooling) would damage the wells.



## Creating Electricity from Geothermal Resources



### Finding Geothermal Resources

Abundant geothermal resources occur in the countries bordering the Pacific – the “Ring of Fire.” Geologists explore volcanic regions like this steaming hillside in El Hoyo, Nicaragua, and other regions of the world where resources can occur even with no volcanoes or other surface evidence. *(Photo courtesy of Trans-Pacific Geothermal Corporation)*



### Getting to the Geothermal Reservoir

If geologists find encouraging signs of deep heat, wells will be drilled. Drill rigs can be small water-well truck-mounted rigs, or large drill rigs like these, erected onsite. Geothermal wells can be drilled over two miles deep. *(Photo courtesy of Geothermal Education Office, Tiburon, CA)*



### Testing a Geothermal Well

If a geothermal reservoir is discovered, the well is flow-tested to determine the pressure, temperature, and chemistry of the reservoir. Large “separators” can be used to safely control the hot steam, such as for this well test at the Blue Mountain power project in Nevada. *(Photo courtesy of Nevada Geothermal Power, Vancouver, Canada)*



### Power Around the Clock

This turbine generator works fine outdoors at a geothermal project in California’s Imperial Valley. Geothermal power plants provide baseload power, so these turbine generators operate 24 hours a day. *(Photo courtesy of Geothermal Education Office, Tiburon, CA)*

## Creating Electricity from Geothermal Resources



### World-Record Power

The Geysers steam field in northern California is the largest producing geothermal development in the world, with 21 power plants. Those white plumes you see are steam (water vapor); geothermal plants do not burn fuel or produce smoke. *(Photo courtesy of Calpine Corporation, San Jose, CA)*



### Geothermal Plumbing

This flash steam plant is in East Mesa, California. Geothermal flash technology was invented in New Zealand. You can see the huge pipes bringing hot water and steam to the power plant, where it spins turbine generators. The used water is returned to the reservoir. *(Photo courtesy of Geothermal Education Office, Tiburon, CA)*



### Compact Model

This small binary power plant is in Fang, Thailand. By using a heat exchanger, binary technology creates electricity from lower temperature reservoirs. Worldwide, developers are working on ways to produce power at ever lower temperatures. *(Photo courtesy of Geo-Heat Center, Oregon Institute of Technology)*



### Generation without Emissions

This air-cooled binary geothermal power plant nestles in the mountains at Mammoth Lakes, California. It is emission-free and consumes no water or chemicals. *(Photo courtesy of Ormat Technologies, Inc., Reno, NV)*