Clean Energy for the 21st Century

GEOTHERMAL TODAY

U.S. Department of Energy

1999 Geothermal Energy Program Highlights

The Hot Facts

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Turning Wastewater into Clean Energy

Producing Even Cleaner Power

Drilling Faster and Cheaper

Program in Review

1999: The Year in Review

January

CalEnergy announced sale of Coso geothermal power plants at China Lake, California, to Caithness Energy, for $277 million. U.S. Export-Import Bank completed a $50 million refinancing of the Leyte Geothermal Optimization Project in the Philippines.

February

U.S. Department of Energy (DOE) selected five energy service companies to finance and manage contracts valued at up to $500 million for the installation of geothermal heat pumps at federal facilities.

March

Calpine Corporation and Unocal Corporation announced the sale of Unocal's Geysers geothermal steam fields to Calpine for $101 million.

April

Barber-Nichols, Inc., Pacific Gas & Electric Co., Unocal Corp., and DOE announced the development of a new turbocompressor offering a more efficient and reliable way to remove noncondensable gases from geothermal process steam.

May

Calpine announced completion of its acquisition of Pacific Gas & Electric Company's 14 geothermal power plants at The Geysers in northern California. The facilities have a combined capacity of about 700 megawatts. The purchase price was $212.8 million, financed with a 24-year operating lease.

July

El Salvador's national electric utility (CEL) dedicated a 56-megawatt single-flash, condensing geothermal power plant at the Berlin Geothermal Field, which has an estimated capacity of 100 megawatts (electric). The project was partially financed by the InterAmerican Development Bank.

September

CalEnergy Minerals, a subsidiary of MidAmerican Energy Holdings Co., announced an agreement to sell all zinc produced by CalEnergy's Mineral Recovery Project in California's Imperial Valley to metals refiner Cominco, Ltd.

October

The Geo-Heat Center hosted people from 30 countries at the International Geothermal Days in Klamath Falls, Oregon. The Geothermal Resources Council held its annual meeting along with the Geothermal Energy Association Trade Show in Reno, Nevada.

About "Geothermal Today"

The energy potential beneath our feet, in the form of geothermal energy, is vast. This tremendous resource amounts to 50,000 times the energy of all oil and gas resources in the world. And geothermal energy development represents a clean energy solution as people, businesses, and governments become ever more concerned about the impacts of global climate change and other forms of pollution.

The word that best describes geothermal today is potential. Today's U.S. geothermal industry is a $1.5 billion per year enterprise, with substantial domestic and international growth potential. Market growth in the western United States should be particularly vigorous during the next few years as more and more indigenous geothermal resources are tapped. The international market for geothermal power development could exceed $25 billion (total) for the next 10 to 15 years. At the present time, U.S. technology and business acumen stand at the forefront of this international market.

Increased development of geothermal energy gives people the potential to gain better control of their own local energy resources and use a secure, safe, domestic source of energy.

The U.S. Department of Energy's Geothermal Energy Program continues to support the geothermal industry with research and development to reduce costs and help geothermal energy fulfill its potential. One major objective of the program is to reduce the levelized cost for geothermal electric power generation from the current $0.05 to $0.08 per kilowatt-hour to $0.03 to $0.05 per kilowatt-hour by 2007.

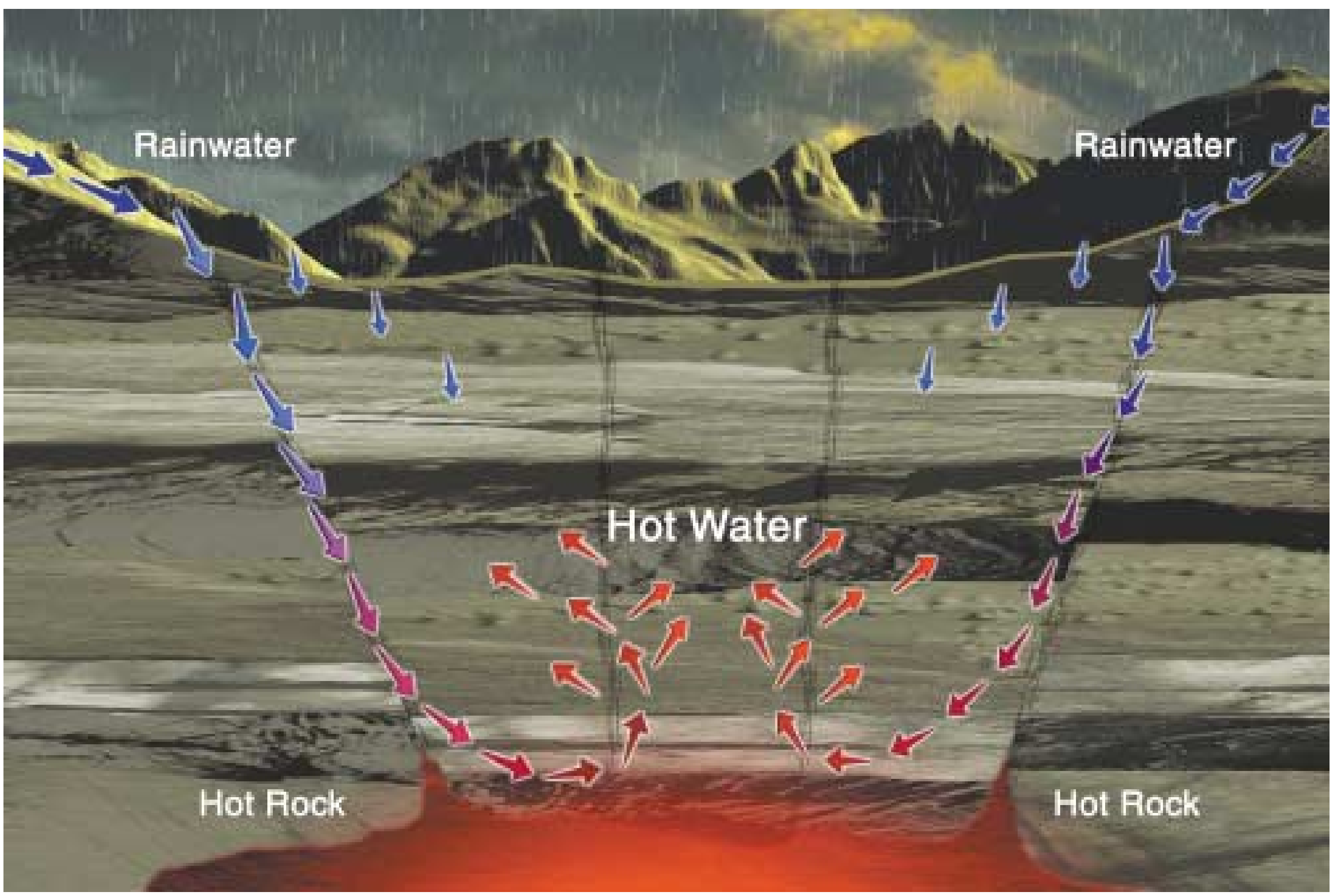
Contents

Old Faithful geyser at Yellowstone National Park in Wyoming

Geothermal Energy Explained

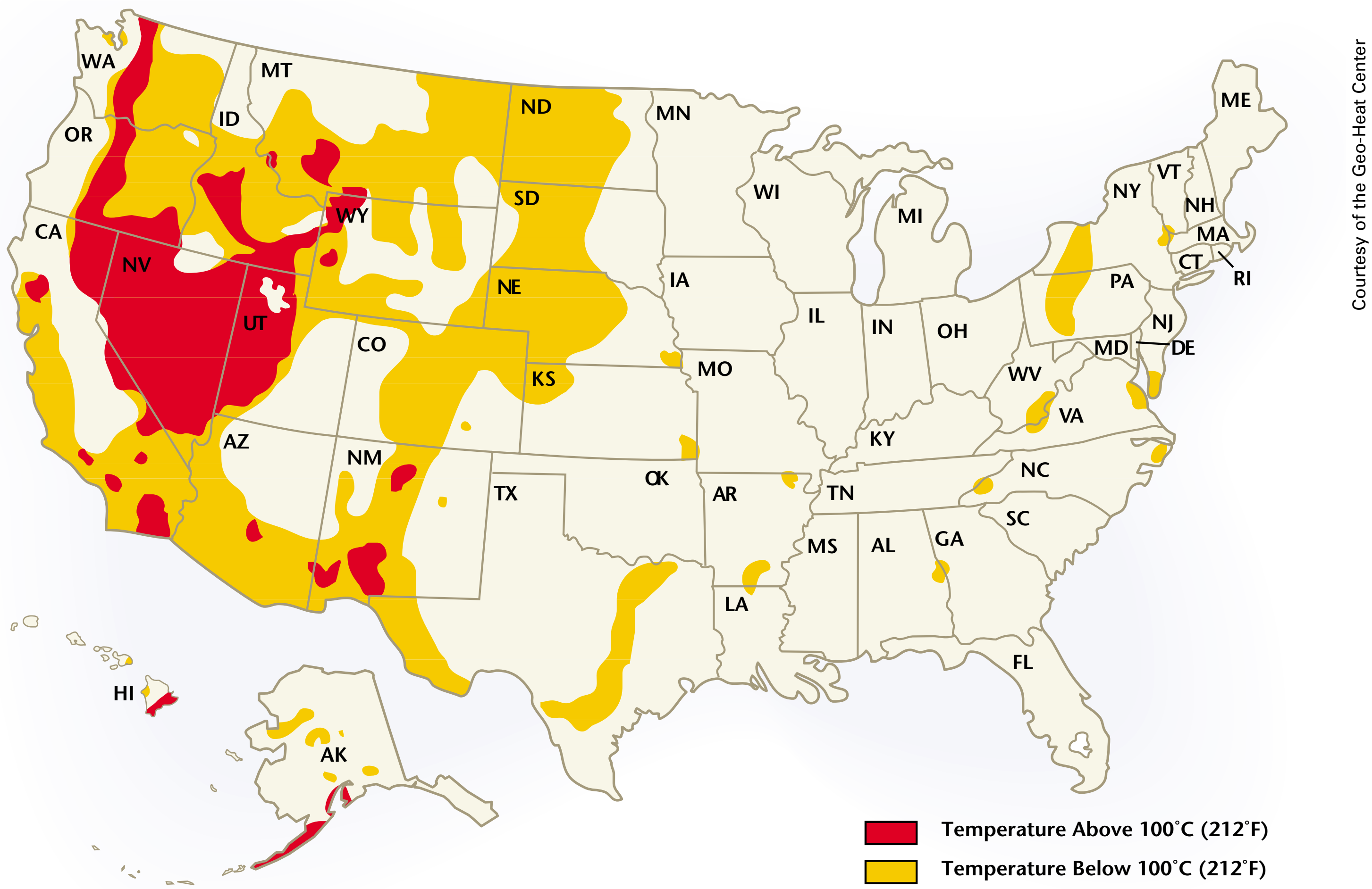
The Hot Facts

The Earth's crust is a bountiful source of energy. Nearly everyone is familiar with the Earth's fossil fuels—oil, gas, and coal—but fossil fuels are only part of the story. Heat, also called thermal energy, is by far the more abundant resource. The Earth's core, 4000 miles (6437 kilometers) below the surface, can reach temperatures of more than 9000°F (4982°C). The heat—geothermal energy—constantly flows outward from the core, heating the surrounding area. Nearby rock melts at high temperatures and pressure, transforming into magma. Magma can sometimes well up to the surface as lava, but most of the time it remains below the Earth's crust heating nearby rock. Water seeps into the Earth and collects in fractured or porous hot rock, forming reservoirs of steam and hot water. If those reservoirs are tapped for their fluids, they can provide heat for many uses, including electricity production.



Courtesy of the Geothermal Education Office © 1999

How a geothermal reservoir is formed



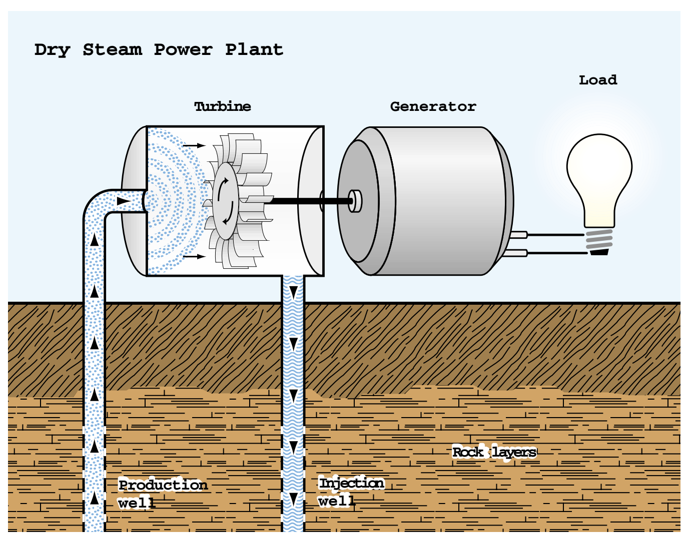
Geothermal power and direct-use resources in the United States (geothermal heat pumps can be used nearly everywhere in the United States)

To add some perspective, the thermal energy in the uppermost six miles of the Earth's crust amounts to 50,000 times the energy of all oil and gas resources in the world. There are three primary ways of using geothermal energy: for electricity production, for direct-use applications, and with geothermal heat pumps.

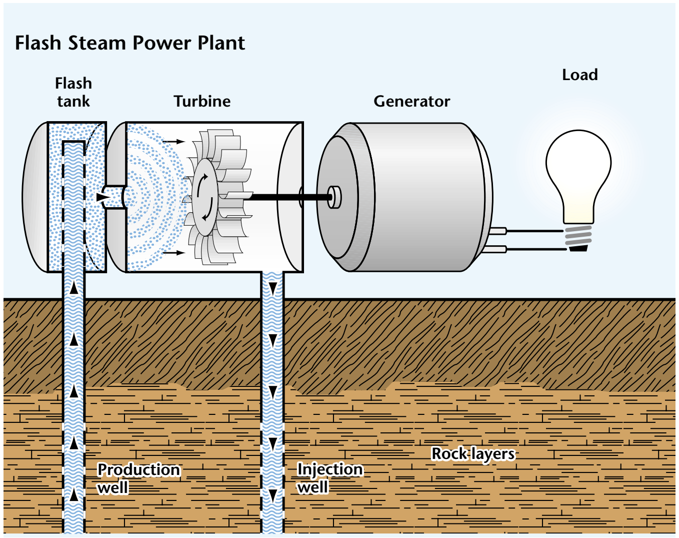
Electricity Production

Electricity production using geothermal energy is based on conventional steam turbine and generator equipment, where expanding steam powers the turbine/generator to produce electricity. Geothermal energy is tapped by drilling wells into the reservoirs and piping the hot water or steam into a power plant for electricity production. The type of power plant constructed depends on a reservoir's temperature, pressure, and fluid content. There are three types or geothermal power plants: dry steam, flash steam, and binary cycle.

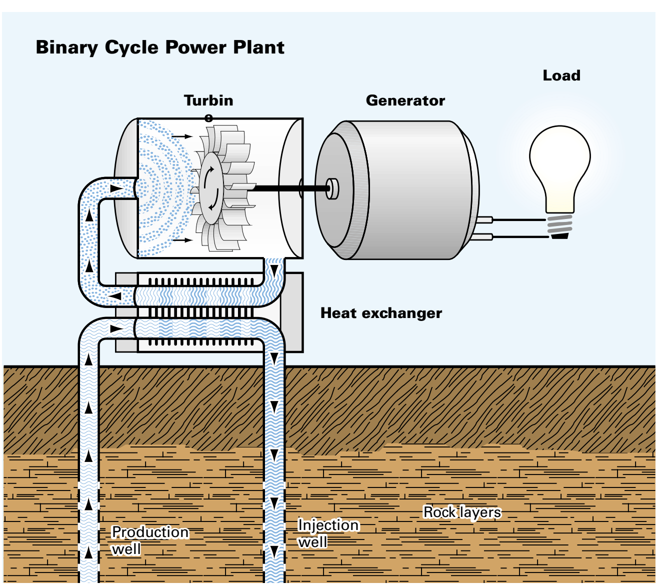
Dry steam power plants draw from underground reservoirs of steam. The steam is piped directly from wells to the power plant, where it is directed into a turbine. The steam turns the turbine, which activates a generator. The steam is then condensed and injected back into the reservoir via a well. Dry steam is the oldest type of plant—first used in Italy in 1904—but it is still very effective. The Geysers in northern California, the world's largest single source of geothermal power, uses dry steam.



Flash steam power plants tap into reservoirs of water with temperatures greater than 360°F (182°C). This very hot water flows up through wells in the ground under its own pressure. As it flows, the fluid pressure decreases and some of the hot water boils or "flashes" into steam. The steam is then separated from the water once at the surface and is then used to power a turbine/generator unit. The remaining water and condensed steam are injected through a well and back into the reservoir.



Binary cycle power plants operate on water at lower temperatures of about 225° to 360°F (107° to 182°C). These plants use the heat from the geothermal water to boil a working fluid, usually an organic compound with a low boiling point. The working fluid is vaporized in a heat exchanger and used to turn a turbine. The water is then injected back into the ground to be reheated. The water and the working fluid are confined to separate closed loops during the whole process, so there are little or no air emissions.



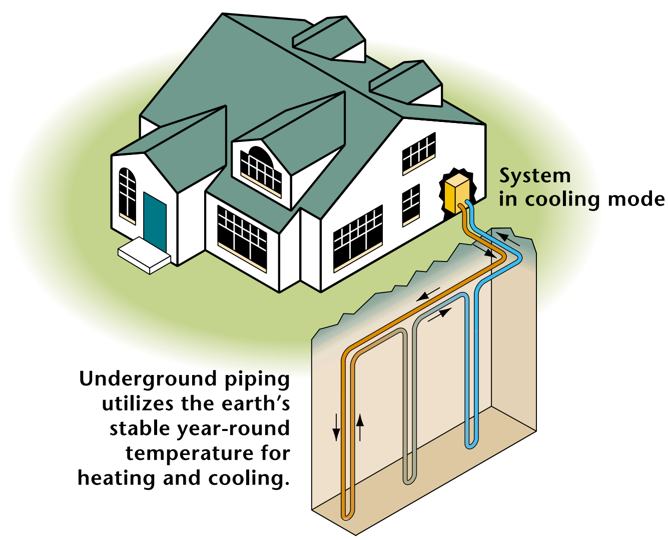
Direct Use

Hot water from geothermal resources can be used directly to provide heat for industrial processes, crop drying, or heating buildings. This is called direct use. Geothermal district heating, a direct-use application, is where multiple buildings are heated with a network of pipes carrying hot water heated from geothermal energy sources. People at more than 120 locations (some of which include as many as 500 wells) are using geothermal energy for space and district heating. These space, industrial, agricultural, and district heating systems are located mainly in the western United States.

The consumer of direct-use geothermal energy can count on savings of as much as 80 percent from traditional fuel costs, depending on the application and the industry. Direct-use systems do require a larger capital investment compared to traditional systems, but have lower operating costs and no need for ongoing fuel purchases.

Geothermal Heat Pumps

Geothermal heat pumps, also known as GHPs, enable the ground to serve as an energy storage device. GHPs are similar to conventional air conditioners or refrigerators. GHPs discharge heat to the ground during the cooling season and extract useful heat from the ground during the heating season. GHPs marketed today also provide hot water. There are over 500,000 GHPs in service today in the United States, including about 600 systems at schools and colleges.



A GHP system

Market Potential

Today's U.S. geothermal industry is a $1.5 billion per year enterprise. Installed electrical capacity exceeds 2,800 megawatts (electric) in the United States and almost 8,000 megawatts (electric) worldwide. Geothermal power plants operate at high capacity factors (70 to 100 percent) and have typical availability factors greater than 95 percent. These plants produce clean power and require very little land. The savings in pollution emissions by displacing other, less desirable energy resources will be ever more important as the United States and the world strive to limit adverse environmental impacts, such as global warming. Geothermal energy is clean, reliable, and sustainable.

Historically, the demand for new electrical power in the United States has grown at annual rates of 2 to 4 percent. Given an active and expanding economy and the pressures of competition from unregulated power markets, the need for additional generating capacity will continue to grow in future years. And if renewable portfolio standards on power generation become common throughout the nation, new markets for geothermal power will open. To meet the increased demand, many operating geothermal fields could be expanded, and many new fields await discovery.

With growing concerns about global climate change, the market potential for a clean power source that provides electricity at $0.03 to $0.05 per kilowatt-hour is expanding. Geothermal power plants are located in the western part of the United States, an area that is characterized by a steadily increasing population and industrial base that requires reliable sources of electric power.

International markets also have shown huge potential. During the next 20 years, foreign countries are expected to spend $25 to $40 billion constructing geothermal power plants, creating a significant opportunity for U.S. suppliers of geothermal goods and services.

Direct-use applications and use of GHPs are also growing rapidly and have considerable market and energy-savings potential. For example, the GHP market grew at an impressive 22 percent during 1997, and accounts for about 4,000 megawatts (thermal) of annual energy savings today.

PIX# 07215 Photo courtesy of Sierra Pacific

Hot springs in Steamboat Springs, Nevada

Solutions Beneath Our Feet

Together, geothermal power plants and direct-use technologies are a winning combination for meeting our country's energy needs while protecting the environment. Whether geothermal energy is used for producing electricity or providing heat, it's a clean alternative for the nation. And geothermal resources are domestic resources. Keeping the wealth at home translates to more jobs and a more robust economy. And not only does our national economic and employment picture improve, but a vital measure of national security is gained when we control our own energy supplies.■

PIX#00664 Photo courtesy of Trans-Pacific Geothermal Corporation

Steam escapes from the El Hoyo volcano in Nicaragua.

On a cold morning, steam rises from a geothermal fish-breeding pond in Alamosa, Colorado.

Getting into Hot Water

Direct Use Proves Its Worth

Geothermal direct use dates back thousands of years, when people began using hot springs for bathing, cooking food, and loosening skin from game. Today, geothermal reservoirs can also directly provide heat for homes, raising livestock, growing crops, and even for melting snow on sidewalks.

The geothermal temperatures required for direct use—70° to 302°F (21° to 150°C)—are lower than those for electric power generation. Geothermal resources at these low-to-moderate temperatures, located within a mile below the Earth's surface, are also more abundant. The Geo-Heat Center has identified reservoirs with the potential for direct use near 271 cities and communities throughout 10 western states: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, and Washington. The United States already has more than 1,300 direct-use systems in operation.

"Geothermal direct use in this country has increased about 8 percent annually," said John Lund, director of the Geo-Heat Center. "It's a domestic, nonpolluting, renewable energy source that can be used by homeowners and ranchers, as well as businesses, institutions, and municipalities, to reduce energy costs. At present, the direct use of geothermal energy is utilized in at least 20 states, including Georgia, New York, Alaska, and Hawaii."

In a direct-use system, a well is drilled into a geothermal reservoir, providing a steady stream of hot water. While some of these systems directly use the geothermal water, most of them pump the water through a heat exchanger. The heat exchanger keeps the water separate from a working fluid (usually water or a mixture of water and antifreeze), which is heated by the geothermal water. The working fluid then flows through piping, distributing the heat directly for its intended use. The geothermal water is usually injected back into the reservoir through another well.

The most common direct-use applications are used for recreational, heating, agricultural, and industrial purposes.

Recreational

More than 200 resorts and spas in the United States offer their guests the use of hot springs for bathing, swimming, or therapy. Geothermal waters have been used recreationally for a very long time, even before the word "spa," derived from a Belgium hot spring called "Espa," found its way into the English language during the 1300s. The U.S. National Park Service estimates that humans have bathed in the Arkansas hot springs for at least 10,000 years. Native American tribes revered the hot springs area—which they called the "Valley of Vapors"—as a sacred place where the Great Spirit lived and brought forth Mother Earth's healing warmth. The tribes established these hot springs, like many others throughout the New World, as neutral ground. Tribal warriors could rest and bathe at the springs, taking refuge from their battles, without the threat of attack.

PIX#07931 Photo by Warren Gretz, NREL

The Hot Springs Resort in Glenwood Springs, Colorado, features the world's largest, outdoor geothermal swimming pool.

When Europeans began to settle in the New World, many Native Americans tried to keep the existence of hot springs a secret. But these early settlers eventually discovered them. And by the 1800s, some settlers realized the commercial potential of the hot springs and began to develop them into spas and resorts, which were very popular in Europe at the time.

In 1860, a party of geologic explorers discovered the Yampah Spring in what is now Glenwood Springs, Colorado. More than 20 years later, a Civil War veteran staked his claim on the hot spring. He sold it in 1886 to a group of investors who envisioned a world class resort with the largest hot spring pool ever. In the beginning, the resort consisted of a sandstone bathhouse and a brick-paved pool. Today the resort operates the world's largest outdoor mineral pool—holding more than 1 million gallons (3.78 million liters) of 90°F (32°C) water—and a 107-room lodge, which also directly takes advantage of the hot spring as Colorado's largest geothermally heated building.

Heating

In the early 1890s, a few pioneering individuals in Boise, Idaho, constructed a wooden pipeline for distributing geothermal water to an extravagant building, called the Natatorium, to provide it with hot water. The geothermal water supply was also extended to large homes along Warm Springs Avenue. It became the first such direct-use system in the United States. Unfortunately, a windstorm destroyed the Natatorium, and the wooden pipeline has long since been replaced. The direct use of the geothermal resource, however, evolved into a modern system that today provides space and domestic water heating throughout the city of Boise to many homes, businesses, and government buildings.

The hot water from a geothermal well can replace the traditional heat source—often natural gas—of a boiler, furnace, and hot water heater. Geothermal water can also heat a working fluid that melts snow as it flows through piping installed underneath pavement. Generally, an individual home or building only needs one geothermal well for a heating system. In larger applications, like in Boise, a district heating system can be used to supply heat from a central location of one or more wells through a network of pipes to entire blocks of buildings.

PIX#06192 Photo by John Lund, Geo-Heat Center

A well is drilled at a residence in Klamath Falls, Oregon, for geothermal direct-use heating.

Currently, the United States has 18 geothermal district heating systems, most of which are owned and operated by municipalities. A district heating system is either designed for open or closed distribution. Open distribution systems deliver geothermal water to buildings, which have their own heat exchangers. Closed distribution systems, on the other hand, employ a central heat exchanger, and buildings are connected to a pipe or loop that runs from the exchanger.

When compared to conventional gas or electric systems, direct-use heating systems require a greater capital investment, involving the location and drilling of wells; and the purchase and installation of pumps, distribution piping, and heat exchangers. But they make up for it with lower operating costs. For example, geothermal district heating systems save consumers about 30 to 50 percent compared to the cost of natural gas heating. The savings are much higher when compared to electric, propane, or fuel oil heating systems.

Agricultural

In the United States, more than 80 agribusinesses are applying geothermal direct use to their operations. And this number continues to rise as word spreads about the benefits of direct use in agriculture, such as lower operating costs and increased growth rates. These can be significant competitive advantages.

Many crops—like cucumbers, tomatoes, flowers, houseplants, tree seedlings, and cacti—flourish in geothermally heated greenhouses. Direct-use heating significantly reduces a greenhouse's operating costs, which can account for 35 percent of the product cost. Most direct-use greenhouse operators claim total operating cost savings of about 5 to 8 percent, or up to 90 percent savings in fuel costs. Using a direct-use system to heat 75,000 square feet (7000 square meters) of greenhouse space, a rose-growing operation in Helena, Montana, actually reduced heating costs by 80 percent and overall operating costs by 35 percent.

Several fish farms and other aquaculture operations have found success using geothermal water as a habitat for their livestock, making it the fastest-growing direct-use application in the country. Even nonnative aquatic species can thrive in geothermally heated ponds under the sometimes harsh winter conditions of the western states. Geothermal energy can actually help raise catfish, shrimp, tilapia, eels, and tropical fish faster than conventional solar heating. Geothermal heat allows for better control of pond temperature, which optimizes growth. Growth rate increases range from 50 to 300 percent.

Livestock that don't live in the water, such as pigs and chickens, can benefit from geothermally heated facilities as well. According to the Geo-Heat Center, these facilities can help lower newborn mortality rates, enhance growth rates and litter sizes, control disease, and make waste management easier. Geothermal water can even be used directly for cleaning and drying animal shelters.

Geothermal Greenhouse Operation in Utah Experiences Continued Growth

In the early 1990s, Milgro Nurseries, Inc., of California decided to expand its greenhouse operation at a site in Newcastle, Utah, to take advantage of a cost-saving resource—an abundant supply of geothermal hot water for direct-use heating. The south-western Utah operation started off with one 400,000 square foot (37,000 square meter) greenhouse. Today, it has 1 million square feet (92,900 square meters) of geothermally heated, commercial growing space, where several million flowers are grown each year.

PIX#03700 Photo courtesy of the Geo-Heat Center

Milgro Nurseries has about 1 million square feet (92,000 square meters) of geothermally heated greenhouse space in Newcastle, Utah.

According to Bill Gordon with Milgro, the direct-use system was worth the capital investment, especially since business continues to grow along with the flowers. The direct-use system's low operating costs enable the company to add about 200,000 square feet (18,500 square meters) of growing space annually at its 400-acre (161-hectare) site in Utah. In turn, the growth of the operation helps the local economy in southwestern Utah by providing jobs. The Utah operation currently has around 70 employees.

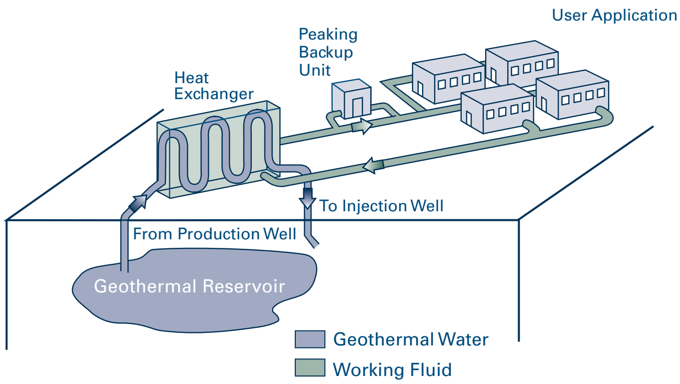
Milgro's direct-use system is simpler than most geothermal greenhouse applications. "The geothermal water here is clean and non-corrosive," Gordon said. "We can use it directly without using heat exchangers and a working fluid." The water is pumped through piping under the rolling benches where the flowers are grown. The system produces a hot water flow of more than 2000 gallons (7500 liters) per minute.

The system was also designed to operate under the extreme weather conditions of Utah. During the winter, the geothermal water keeps the temperature in the greenhouse space at about 70°F (21°C) even when the outside temperature drops below freezing. Fog-cooling and ventilation systems help maintain a moderate temperature during the summer when outside temperatures can reach 95°F (35°C).

Following the success of the direct-use system, Milgro is now considering the installation of a small-scale geothermal power plant at the Utah site to generate its own electricity.

PIX#03703 Photo courtesy of the Geo-Heat Center

Milgro Nurseries annually grows several million flowering plants, like these geraniums, at its geothermal greenhouse operation in Newcastle, Utah.



A geothermal district heating system

Industrial

Geothermal direct use continues to show great commercial potential and competitive advantages for a variety of industries. Throughout the western United States, industrial applications already include food dehydration, gold mining, laundries, milk pasteurizing, mushroom culture, and sewage digestion.

Geothermal direct-use resources are especially well suited to vegetable dehydration operations, such as in the production of dried onions or garlic. The dry climates throughout much of the West also assist in the process. The dehydration process begins with geothermal water flowing through a heat exchanger, which warms the air to temperatures ranging from 100° to 220°F (38° to 104°C). The warm air is blown on the sliced vegetables as they proceed along a conveyor belt. The moisture eventually evaporates from the vegetables, drying them. Using geothermal heat in the process instead of natural gas results in cost savings of 30 percent for a typical plant and prevents "hot spots." Hot spots produce a lower-quality product.

Geothermal heat can also enhance a process called heap leaching used in gold mining, a major industry in many parts of the western United States. In leaching, the gold is dissolved in a dilute cyanide solution that is sprinkled over an outdoor pile of ore. During the winter months, however, the solution can freeze, halting operations. But geothermal water can be used to inexpensively heat the solution, allowing the mining operations to continue year-round. Two mining operations in Nevada have used this geothermally enhanced process, and at least one-third of the other mines in the state have the potential to use geothermal resources for the same process.

Direct Use Potential

As fossil fuel resources continue to dwindle and their costs rise, geothermal direct use will prove to be a competitive, viable, and economic alternative source of renewable energy, especially in the western United States. Throughout the world, the United States already rates as one of the top four countries in the use of geothermal direct-use applications. The installed energy capacity of direct-use applications in the United States is about 566 thermal megawatts—the equivalent of saving about 4 million barrels of oil for electricity production. By 2010, the U.S. Department of Energy's Geothermal Energy Program wants to expand the direct use of geothermal resources to heat and provide hot water for 7 million homes—the equivalent of saving about 46.5 million barrels of crude oil or nearly six days worth of imported oil.

For information on direct use, visit the Geo-Heat Center's Web site at *http://www.oit.osshe.edu/~geoheat/*.

PIX#05928 Photo by Warren Gretz, NREL

These tomatoes were grown in a geothermally heated greenhouse.

PIX#03706 Photo courtesy of the Geo-Heat Center

This dehydration plant (e.g. onions and garlic) in Empire, Nevada, benefits from the use of geothermal energy as its heat source.

District Heating is a Hot Topic in Klamath Falls, Oregon

PIX#08827 Photo courtesy of Geo-Heat Center

The geothermal district heating system in Klamath Falls can melt snow on more than 50,000 square feet (4645 square meters) of sidewalks and crosswalks.

Beneath the city of Klamath Falls, Oregon, lies a vast underground resource of geothermal water, which has been tapped to provide district heating for many local buildings.

In the northeast part of Klamath Falls, the Oregon Institute of Technology has been using a geothermal district heating system on campus since 1964, making it the first modern system. Today, the system heats 11 buildings (600,000 square feet/55,742 square meters), provides domestic hot water, and melts snow on 2300 square feet (214 square meters) of sidewalk. The district heating system saves the Institute around $225,000 each year in heating costs, as compared to the previous fuel-oil boiler system.

The city of Klamath Falls constructed its own district heating system in 1981 to heat 14 government buildings, including the county museum, fire station, post office, city hall, library, courthouse, and jail. The system has now expanded to include other buildings, such as churches and small businesses, for a total of nearly 30 buildings. In 1995, the city began to use the system to also melt snow on more than 50,000 square feet (4645 square meters) of sidewalks and crosswalks.

"The city's district heating customers are very happy with the system," said Brian Brown, consulting engineer. "They're saving money on heating costs. Their buildings stay warmer because the system heats more efficiently than a conventional, natural gas system. And they're especially thrilled when they don't have to shovel the snow off their sidewalks all the time, unlike their neighbors who aren't hooked up to the system."

For more information on district heating systems, visit the Geo-Heat Center Web site at http://www.oit.osshe.edu/ ~geoheat/.

PIX#08810 Photo by Mary C. Smothers, Oregon Institute of Technology

The Oregon Institute of Technology has used a geothermal district heating system for almost 40 years.

Alligators in Mosca, Colorado

Alligators Thrive in the Geothermal Waters of Colorado

Not only are there spectacular views of snowcapped mountains during the winter in Mosca, Colorado, but considering the cold weather and an elevation at 7500 feet (2286 meters), there's also a most unusual sight—alligators. More than 150 alligators call this town in southern Colorado home thanks to a geothermal direct-use aquaculture system.

"In 1987, we brought 100 baby alligators here from Florida to use as garbage disposals for the carcasses and byproducts from our fish processing activities," said Erwin Young, owner of the alligator and fish farm, which also uses geothermal water to raise tilapia. "Our goal was to recycle resources in an environmentally friendly way."

PIX#05874 Photo by Warren Gretz, NREL

This alligator is able to live in Colorado, far from its native habitat, thanks to a geothermal aquaculture system.

The aquaculture geothermal system consists of one artesian well, 2000 feet (610 meters) deep, with a water temperature of about 87°F (31°C) and a flow of about 500 gallons (1,893 liters) per minute. First, the water flows into an aeration pond, allowing for the dissipation of entrained gases. The water then flows into 10 indoor fish tanks. From there, it flows outside into a 1-acre (0.40-hectare) alligator pen. For disposal, the water eventually ends up in a wetlands area spanning across 65 acres (26 hectares). Young also uses a geothermal direct-use system to heat a 50-foot by 100-foot (15-meter by 30-meter) building, and as a result, he estimates savings of about $800 a month in heating costs during the winter.

The fish farm produces about 1 million tilapia annually. And in 1997, the alligator farm celebrated the first-ever hatching of an alligator in Colorado. "Since alligators had never been hatched at this elevation," Young said, "we didn't even know if it was possible. But we couldn't give up." According to Young, alligator eggs can't hatch outside in Colorado even during the summer. Therefore, when the alligators started laying fertile eggs in 1996, Young began to collect the eggs from the nests and put them in incubators.

Today, about 30 alligators hatch in the incubators each year. The original alligators have grown between 6 to 11 feet (1.8 to 3.3 meters) long, weighing up to 600 pounds (272 kilograms), and they're still growing. "The alligators have adjusted well to Colorado because of the warm geothermal waters we can provide them with," he said.

Besides the fish farm, the alligator operation has become a successful business for Young. "We didn't plan on it," he said, "but the alligators have become quite a tourist attraction."

Steam waste-heat escapes from a geothermal power plant located at The Geysers in northern California.

Turning Wastewater into Clean Energy *Effluent Injection at The Geysers*

California has the world's first wastewater-to-electricity system. The system provides both an environmentally sound method of wastewater disposal and a resource for clean energy—geothermal electricity production—at The Geysers.

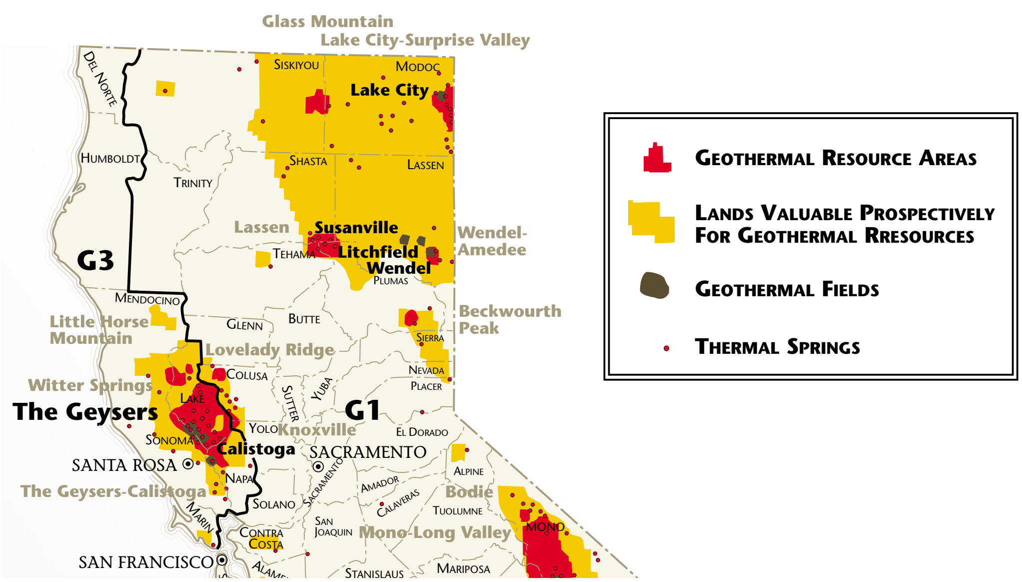
The Geysers geothermal field spans across three northern California counties—Sonoma, Lake, and Mendocino—through a landscape of rolling mountains, steep canyons, green valleys, and vineyards. The first commercial power plant in the United States to generate electricity from a geothermal resource was constructed at The Geysers in 1960. Since the 1970s, following the construction of more power plants, The Geysers has generated about 5 percent of California's electricity, a capacity greater than any other geothermal field in the world.

But by the 1980s, the power plants at The Geysers were using steam at a rate exceeding the geothermal field's natural recharge rate. Steam production fell. The geothermal heat source remained constant, but injection of additional water was needed to replenish the steam resource. A 1990–91 survey of potential injection water sources concluded that since surface and groundwater sources in the area were already committed to other uses, wastewater might be the best source.

As it turned out, the nearby Lake County Sanitation District (LACOSAN) needed to upgrade its wastewater treatment and disposal systems in the communities of Clearlake, Lower Lake, and Middletown because of growth. LACOSAN was looking for an environmentally acceptable and affordable effluent disposal method. Effluent injection at The Geysers would not only provide a continuous supply of recharge water for steam production, it was also found to be environmentally superior to conventional surface disposal methods, such as surface water discharge or land irrigation. For instance, surface disposal methods consume land. And methods like spray irrigation, according to Mark Dellinger with LACOSAN, have issues concerning aerosols and odors that effluent injection wouldn't have.

An effluent injection system would also cost less to construct and operate than other wastewater disposal methods, saving LACOSAN's customers money. "Customer rates typically rise anytime a wastewater

Geothermal Activity in California



Courtesy of California Department of Conservation treatment system is upgraded," Dellinger said. "If we had selected a method other than effluent injection, rates would have gone up much more."

A Partnership Develops

In 1991, the idea of effluent injection at The Geysers evolved into a public/private partnership among LACOSAN and the geothermal power plant operators in the southeast portion of The Geysers. The operators included Northern California Power Agency, Calpine Corporation, Unocal Corporation, and Pacific Gas & Electric Company.

The partners, known as the Joint Operating Committee, spent four years confirming the feasibility of and designing an effluent injection system. Engineers and geothermal researchers examined the impact of effluent injection on The Geysers reservoir. They also conducted analyses of the pipeline that would carry the effluent. Environmental surveys were conducted to identify potential design and construction conflicts with environmental resources.

Construction of the effluent injection system—now called the Southeast Geysers Wastewater Recycling System—began on October 6, 1995, and was completed about two years later. The total cost of construction was $45 million: $37 million for the pipeline and $8 million for wastewater system improvements.

Joint Operating Committee members shared the construction costs, but they also secured additional funding from the California Energy Commission, California Water Resources Control Board, U.S. Department of Energy, U.S. Department of Commerce, U.S. Department of the Interior, and the U.S. Environmental Protection Agency. Geothermal industry partners also invested several million dollars for secondary pipelines, which distribute the effluent from the main pipeline to injection wells in The Geysers steamfield.

In 1998, the project received three state awards: the California State Association of Counties Challenge Award of Merit; the California Governor's Environmental and Economic Award of Recognition; and the Water Reuse Association of California Award of Merit.

Through an operating agreement, the Joint Operating Committee partnership will continue at least another 25 years. LACOSAN will operate the pipeline as far as the Middletown Wastewater Treatment Plant. From there, geothermal industry partners take over the pipeline's operation up to The Geysers geothermal field. LACOSAN pays an annual operation and maintenance cost-share equivalent to conventional surface water discharge of effluent, while industry partners pay any remaining operation and maintenance costs based on the quantity of effluent they each receive for injection.

Pacific Gas & Electric has sold all of its power plants at The Geysers to Calpine, and Unocal sold its steamfield interest at The Geysers to Calpine. So now there are only two operators at The Geysers—Calpine and the Northern California Power Agency.

How it Works

The Southeast Geysers Wastewater Recycling System begins at Clear Lake, where make-up water is piped three miles from the lake to the Southeast Regional Wastewater Treatment Plant. From there, the pipeline carries the water and effluent 20 miles (32 kilometers) to the Middletown Wastewater Treatment Plant, where additional effluent is

PIX#04132 Photo by Mark Dellinger, LACOSAN

The Southeast Geysers Wastewater Recycling System begins here at the Southeast Regional Wastewater Treatment Plant in Clearlake, California.

added. The effluent and water then flows another 6 miles (9 kilometers) through the pipeline to the southeast portion of The Geysers. Finally, the treated effluent and water is injected into several wells, connected to the geothermal reservoir.

The system delivers about 2.8 billion gallons (10.6 billion liters) of effluent and make-up water annually to The Geysers. By 1999, effluent injection had already constituted about 65 to 80 percent of the steam produced in the geothermal reservoir, stabilizing the average power generation at about 1000 megawatts. At an expected steam recovery rate of about 50 percent, the electrical output capacity should eventually increase by at least 70 megawatts.

The power plants at The Geysers distribute the electricity generated from effluent-derived steam to the three wastewater-producing communities—Clearlake, Lower Lake, and Middletown—along with other parts of Calpine's service area and 15 jurisdictions that comprise the Northern California Power Agency. As a result, about 13 million consumers in California receive a portion of their electricity from Lake County's recycled wastewater.

Environmental Benefits

Environmental monitoring of the wastewater recycling system will continue during its operation. Both the pipeline and injection operations are inspected and tested on a regular basis.

While monitoring, it was discovered that injection of

TRACER TESTS CONDUCTED AT THE GEYSERS

Injection flow from the Southeast Geysers Wastewater Recycling system needs to be traced through the geothermal reservoir to help optimize injection for maximum steam production and to verify improvements in power plant capacity.

Through research funded by the U.S. Department of Energy (DOE), the University of Utah's Energy & Geoscience Institute is developing chemicals—called tracers—that can be injected into a reservoir to trace the flow of water. Effective tracers are compatible with the environment, stable at high temperatures, and detectable in minute quantities. The Institute selected hydrofluorocarbon (HFC) refrigerants as tracers for tests at The Geysers. These tracers contain no chlorine that could damage the ozone layer.

Tracer tests are designed to evaluate the length of time for flow through the reservoir and the amount of injection-derived steam produced. Tests can also provide data to help determine which production wells receive steam derived from a particular injection well.

The first tracer test at The Geysers was conducted in January 1998, about three months after the wastewater recycling system began operation. This test, along with others that followed, have been jointly funded by DOE, the Northern California Power Agency, Calpine Corporation, and Unocal Corporation.

During tests, the Institute discovered that the HFC tracers had remained stable at high temperatures, up to 464°F (240°C), and that they could travel rapidly through the geothermal reservoir, providing data. Researchers are refining the tracers even more to provide optimal data on the injection-derived steam at The Geysers.

PIX#09054 Photo by Joe Moore, EGI, University of Utah

Researchers with the University of Utah's Energy & Geoscience Institute conduct a tracer test at The Geysers.

treated effluent has actually reduced the amount of contaminants typically found in the steam at The Geysers. According to the Northern California Power Agency, the amounts of noncondensable gases in the steam have dropped significantly since effluent injection began. Hydrogen sulfide, the gas of greatest concern, requires costly processing and waste disposal during power plant operation. Less hydrogen sulfide has resulted in lower abatement costs and a reduction in heavy truck traffic on local roads.

The recycling of wastewater also helps conserve water resources, which is of great concern in California. And since geothermal power plants emit very low amounts of carbon dioxide, the wastewater recycling system helps offset the combustion of fossil fuels, which contribute to global warming.

Economic Benefits

In addition to saving money on pollution abatement and wastewater disposal, the Southeast Geysers Wastewater Recycling System supports the local economy through job retention in the geothermal industry and economic growth opportunities in the communities served by the pipeline.

The extension of the reservoir's life at The Geysers also benefits the state of California financially as it owns about one-third of the geothermal resources. All state royalties from steam production supplement the state's Teachers Retirement Fund. "We'll support all projects that enhance revenue," said Mike Morrison with the California State Lands Commission. "The Geysers is one of them."

The Future

Phase 2 of Lake County's wastewater recycling system, called Clear Lake Basin 2000, will connect two additional wastewater treatment plants on the lake's north shore into the existing system. The project includes a 20-mile-long (32 kilometers), recycled water interconnection pipeline and a series of constructed wetlands at numerous locations adjacent to the pipeline. When completed, Phase 2 will not only allow dual recycling of effluent through wetlands and The Geysers, but also provide drought protection for the existing system. In February 2000, 3.5 miles (5.6 kilometers) of the pipeline were completed, connecting the Clearlake Oaks Wastewater Treatment Plant.

Following the success of the Southeast Geysers Wastewater Recycling System, final approval was received in January 2000 for another pipeline route that will carry effluent from a wastewater treatment plant in Santa Rosa, California, for injection 41 miles (65 kilometers) away into the central portion of The Geysers. This wastewater recycling system is expected to provide 11 million gallons (41 million liters) of treated effluent daily for geothermal power plants located in northeast Sonoma County. It should be operational in 2002.

Much can be learned from the increased application of effluent injection at The Geysers, especially since the central and southeastern portions have differences in steam production. It will help further extend the life of The Geysers, an important clean energy resource in California and now also an important method of wastewater disposal. This is recycling at its best.

Visit the S.E. Geysers Wastewater Recycling System Web site at *http://geysers-pipeline.org/* for information.■

PIX#00063 Photo courtesy of Pacific Gas & Electric

Geothermal power plants use the steam at The Geysers to produce clean energy.

Award-Winning Geothermal Technology Tested at The Geysers

PIX#01079 Photo by David Parsons, NREL

Condensers and cooling towers rise above a power plant at The Geysers.

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) received a R&D 100 Award in 1999 for developing advanced technology that condenses spent steam from geothermal power plants. R&D Magazine gives this award each year for the 100 most significant innovations.

Condensation of spent steam is an important step in a power plant's cycle. A geothermal power plant typically condenses spent steam through a cooling process for injection back into the reservoir. NREL's award-winning technology—the advanced direct-contact condenser or ADCC—speeds up this cooling process for greater production efficiency and generating capacity in power plants. The ADCC even costs less to design than other condensers.

Conventional steam condensers, known as shell-and-tube condensers, circulate spent steam from power plants around coolant pipes to condense the steam. Direct-contact condensers mix cooling water directly with the spent steam in an open chamber. Simple perforated plates provide the surface area upon which condensation occurs. The ADCC, however, uses sophisticated geometric shapes, called packing structures, which provide the best surface area for condensing steam. The packing structures also channel the steam and cooling water for maximum contact with each other.

The Pacific Gas & Electric Company installed the ADCC in one of its geothermal power plants at The Geysers. The power plant, known as Unit #11, has experienced a 5 percent increase in production efficiency, a 17 percent increase in total power generation, and about a 50 percent reduction in the costs for emissions treatment.

The ADCC can also be used cost-effectively in fossil-fuel power plants and for any other industrial process that needs to condense steam.

Alstom Energy Systems has licensed the ADCC technology for commercialization.

PIX#06152 Photo by David Parsons, NREL

NREL researcher Desikan Bharathan works on a computer model of the ADCC used at The Geysers, which was designed to boost geothermal electricity production.

The Salton Sea in southeastern California

Coproduction

Producing Even Cleaner Power

Removing minerals from geothermal brine while also making electricity—a process called coproduction—from an environmentally attractive energy source like geothermal power is a win-win situation, as shown with the Salton Sea geothermal resource in California.

An Unusual Beginning

The Salton Sea was formed between 1905 and 1907 when the Colorado River burst through poorly built irrigation canals south of Yuma, Arizona. Almost the entire flow of the river ran unchecked into the Salton Sink for about a year and a half, flooding communities, farms and the main line of the Southern Pacific Railroad. The Salton Sink is an area of geothermal activity that is located at the southern end of the San Andreas Fault.

In 1907, the continuous river flow into the Salton Sea was finally stopped when a line of protective levees was built by boxcars dumping boulders into the breach from Southern Pacific tracks. When the flow of water stopped, a huge lake remained in the middle of Southern California's desert. By then, this inland lake stretched about 40 miles (64 kilometers) long and 13 miles (21 kilometers) wide, covering an area of nearly 400 square miles (1035 square kilometers). The Salton Sea is California's largest lake, and the third largest saline lake in the nation.

A Big Challenge

The Salton Sea geothermal reservoir went undeveloped for years because the geothermal fluid contains high amounts of dissolved salts. To solve this problem, industry, with help from DOE, developed a process for crystallizing the salts, which could then be separated from the fluid. Eight power plants at the Salton Sea now supply 330 megawatts of power to southern California.

Research has shown that geothermal fluids from the Imperial Valley, where the Salton Sea is located, can be removed and processed to yield amorphous silica in a form suitable as raw material in other industrial processes. Industry uses silica, especially high surface area amorphous silica, as paper and rubber additives, in cements, as pigments and inert fillers. For example, an independent commercial analysis, in which amorphous silica was used directly in the production of acrylic wall paint, showed that the paint which used the geo-silica product compared favorably with regular acrylic wall paint.

CalEnergy's Salton Sea geothermal field currently produces about 143 tons (130 metric tons) of silica every day. A substantial revenue can be generated if silica can be sold as a rubber additive at the current market price of around 70 cents per pound. Silica-enhanced rubber produces tires that bond better with steel wire, have higher tear strength, and have lower rolling resistance. CalEnergy also avoids the cost of disposing of this former waste product in a landfill.

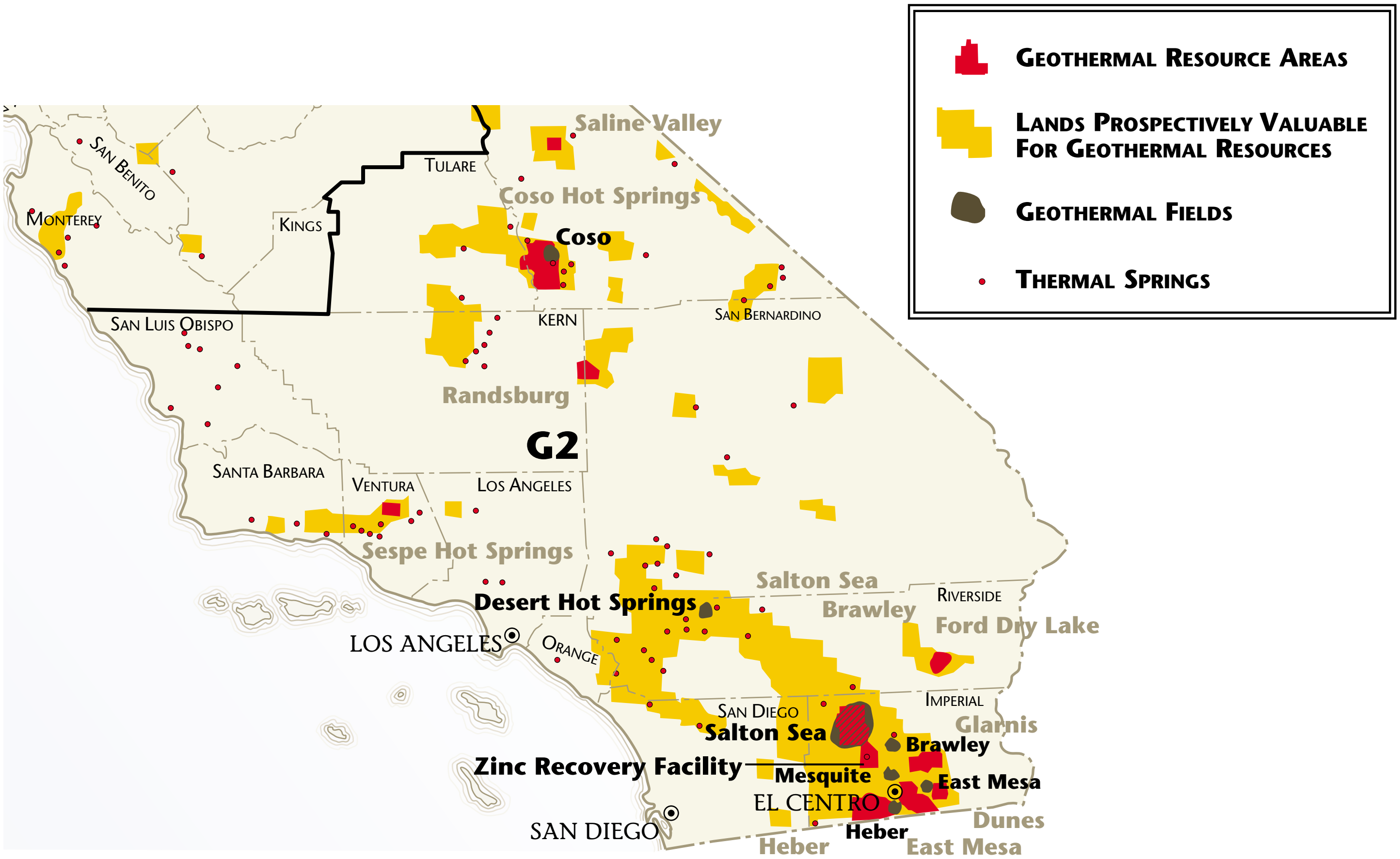
The solid waste produced by some geothermal power plants may contain just enough heavy metals to require special disposal. Part of the challenge is to remove the toxic metals (e.g., chromium, arsenic, and mercury) so that the waste sludge is not considered a mixed hazardous waste requiring special treatment. Disposal costs are considerably less if the waste is classified as nonhazardous.

Plants in the Salton Sea geothermal field produce as much as 100 pounds (45 kilograms) of solids per megawatt-hour of electricity generated, but recent technical advances are greatly reducing the amount requiring disposal. Some plants now dewater the byproducts and rinse them to remove the heavy metals. The rinse water is injected back into the reservoir, and the remaining solids—mostly silica—are used as filler in concretes for building roads and flood-protection levees.

The latest development in mineral recovery from geothermal power plants is zinc production. Manufacturers, especially in the construction and automobile industry, use zinc primarily as a coating on steel to protect against corrosion. CalEnergy Minerals, LLC, a subsidiary of MidAmerican Energy Holdings Co., announced an agreement to sell all zinc produced by CalEnergy's Mineral Recovery Project in California's Imperial Valley to metals refiner Cominco Ltd. Cominco, incorporated in 1906, is the world's largest zinc concentrate producer and the fourth largest zinc metal producer.

The innovative recovery process uses advanced technology to recover zinc from the brine used to generate electricity at the company's Salton Sea geothermal power plants. The technology for zinc extraction involves ion

Geothermal Activity in Southern California



Courtesy of California Department of Conservation

exchange and solvent extraction to remove minerals from geothermal fluids. Successful commercialization of end products are helping generate revenues, which offset the overall costs of geothermal power production, thus improving the cost-benefit ratios for geothermal power-plant owners and operators.

"We are delighted to be associated with a company of Comico's stature in the minerals business," said Cal-Energy President and CEO Robert Silberman. "We will be providing zinc in an environmentally sensitive manner, and the agreement will clearly create value for both CalEnergy and Cominco."

MidAmerican Energy Holdings Company's new Zinc Recovery Facility will produce approximately 33,000 tons (30,000 metric tons) per year of high-quality zinc for sale to the galvanizing industry, with associated facilities producing 49 megawatts (net) of geothermal electricity. Currently, the West Coast galvanizing industry imports about 110,000 tons (100,000 metric tons) of zinc per year from outside the United States. This new facility also brings jobs and money to the local community.

Because there is neither mining nor emissions in the process, the plant represents the cleanest and most environmentally benign zinc-producing method. It will also be the lowest cost producer of zinc in the world and the first and only facility specifically designed to harvest minerals from high-temperature geothermal brine.

PIX#05128 Photo by Warren Gretz, NREL

The Magma Power Leathers Plant in Imperial Valley, California

The Future

The beauty and promise of coproduction is that it reduces solid waste, saves valuable landfill space, and reduces operations and maintenance costs while producing a valuable product. Meanwhile, the public benefits from reduced demand on quickly filling landfills and less air and water pollution typically associated with fossil-fuel power generation. As the technology to extract useful minerals from geothermal brine continues to improve, the economic attractiveness of geothermal power at these sites will improve.■

PIX#00414 Photo by Warren Gretz, NREL

Transmission lines from a geothermal power plant at the Salton Sea carry electricity to consumers in California.

PIX#00415 Photo by Warren Gretz, NREL

This power plant in southeastern California uses the Salton Sea geothermal resource to generate electricity.

After drilling, geothermal fluid is released from a well in Valles Caldera, New Mexico.

Geothermal Drilling

Faster and Cheaper is Better

Before the Earth's heat can be used for purposes such as generating electricity or heating buildings, conduits between the geothermal reservoir of hot water or steam and the Earth's surface must be provided. This is done by drilling production and injection wells, which are often thousands of feet deep, into the reservoir. Drilling of exploratory wells also helps collect data to define the size and productivity of the geothermal reservoir. Construction of wells is clearly essential, but it is also expensive, accounting for 15 to 30 percent of the total cost of a geothermal power project.

The U.S. Department of Energy (DOE), in partnership with the geothermal industry, is helping improve well drilling technologies and thus lowering geothermal development costs. DOE research focuses on those aspects that have the greatest potential for substantially reducing costs, including more effective drill bits, improved downhole measurements such as Diagnostics-While-Drilling, better detection and treatment of lost circulation zones, and lower-cost slimhole drilling.

Geothermal Drilling

To drill almost any well, a drill bit is mounted on the end of a long metal pipe called the drill string, which is rotated from the surface by machinery called a drill rig. New 30-foot lengths of pipe are added to the top of the drill string as the borehole gets deeper. To cool and lubricate the drill bit and to carry away the chips of rock cut by it, a viscous fluid called drilling mud is pumped down the drill string. The mud passes through holes in the drill bit and then flows back up the hole in the space between the borehole wall and the drill string.

Geothermal drilling is more challenging than drilling water, oil, or gas wells because the reservoir rocks are hotter, harder, and more fractured. Because of these differences, there has been a significant learning process, going back almost 80 years, in geothermal drilling. In 1922, a homemade drill rig was used at The Geysers in California to drill the first successful geothermal well in the United States. The first drilling attempt failed, however, because it was done in the hottest part of the steam reservoir—a place called the Witches' Cauldron. When the hole reached a shallow depth, "the well blew up like a volcano," recalled the drilling rig operator, so the second attempt at drilling a well was moved to another area. In the new area, steam was located just below 200 feet (61 meters).

PIX#00450 Photo by Warren Gretz, NREL

The drilling of production wells, such as this one in southeastern California, can result in up to 30 percent of the costs of a geothermal project.

"At this depth," the drilling rig operator said, "everything came flying up—mud, tools, rocks, and steam. After things settled down, there was just clean steam. But the noise was loud enough to hear all over the valley."

Even though knowledge and technology have advanced greatly since those early days, geothermal reservoirs continue to present unique challenges because of the high temperatures, hard rock formations, corrosive reservoir fluids, and problems with lost circulation (i.e., the loss of drilling mud into fractures in the surrounding rock). DOE-sponsored research is aimed at improvements in each of these areas.

Drill Bits

Drilling costs are greatly affected by how quickly the drill bit can penetrate the hard, abrasive, fractured rocks of a geothermal location, and by how long it can last before the drill string needs to be taken out of the hole to replace the bit. If both penetration rate and bit life were doubled, drilling costs would drop an average of 15 percent.

Two kinds of bits are used for virtually all drilling in either geothermal or oil and gas wells—roller-cone bits and polycrystalline diamond compact (PDC) bits. Roller-cone bits have toothed cones that roll on the bottom of the hole as the bit rotates, each tooth crushing the small area of rock beneath it. The first roller-cone bit was patented in 1912, so this technology is very mature and reliable. It is, however, inherently less efficient than the PDC bit, which uses fixed cutters to shear rock in the same way that a machine tool cuts metal.

The PDC bit uses thin layers of synthetic diamond bonded to tungsten carbide-cobalt studs or blades. The diamond layer gives the cutter extreme resistance to abrasive wear in the shearing action of cutting. PDC bits are especially well suited to drilling through hot rock because they have no moving parts, so high-temperature seals, bearings, and lubricants are not an issue.

DOE contributed markedly to development of the PDC bit, which has had a dramatic impact on the geothermal, oil, and gas industries. Introduced in the 1970s by General Electric, development of PDC bits was significantly aided by a collaboration, under the DOE Geothermal Energy Program, with the U.S. geothermal industry and Sandia National Laboratories. Sandia worked with General Electric, bit manufacturers, and geothermal operators to design and test PDC bits in hard-rock formations, and research with industry continues today.

Today, PDC bits account for over one-third of the total footage drilled worldwide, with annual sales by U.S. manufacturers exceeding $260 million. They have gained this tremendous market acceptance because they have consistently drilled faster and lasted longer than roller-cone bits. Over its useful lifetime, a single PDC bit can save more than $100,000 compared with a roller-cone bit.

For geothermal drilling, however, PDC bits do not work reliably well in rock that is more than moderately hard. Research funded and managed by DOE has led to a better understanding of basic rock-cutting physics, allowing researchers to model the performance and wear of PDC bit designs. A computer code based on this modeling was released in 1986 and is still being used by the drill bit industry. Research continues to evaluate and better understand self-induced bit vibration, or chatter, and how variables such as weight-on-bit, rotary speed, bit and cutter configuration, and fundamental vibration modes can be controlled to minimize chatter. In combination with this work, DOE and Sandia have teamed with seven companies on five projects, ranging from new PDC cutter and bit designs to thermally stable polycrystalline diamond and impregnated-diamond bit development. These efforts will lead to enhanced performance, extending full application of PDC bits, with its attendant cost savings, to the hot, hard rocks of geothermal reservoirs.

PIX#05933 Photo courtesy of SNL

The performance of PDC drill bits, such as this one developed at Sandia National Laboratories, continues to improve for hard rock geothermal drilling.

Borehole Measurements

Measurements in the borehole are used both to evaluate the reservoir once the well is drilled and to provide data during drilling that will make the process faster, cheaper, and safer. To function effectively for geothermal drilling, this instrumentation must be adapted for slimhole drilling and high-temperature conditions. Sandia has developed tools that meet these temperature and size requirements, including a promising new self-contained, battery-powered, memory-storage system. Several of these tools have been used extensively in the field and are available for application or have been commercialized; others are in the late stages of testing.

Baker Hughes has signed a licensing agreement with DOE for use of downhole instrumentation, and Boart Longyear, a supplier of drilling equipment for geothermal and mineral exploration, recently commercialized core-tube data logging equipment.

Lost Circulation Increases Costs

DOE is also working to detect and mitigate problems where drilling mud is lost into the rock formations during drilling. This loss can add 20 to 30 percent to the total cost of a well because it requires more drill rig time (at a typical cost of $10,000–$20,000/day), uses more drilling mud, and risks severe problems, such as borehole instability or stuck drill strings. Because early detection of lost circulation is crucial in minimizing problems, researchers have developed a rolling float meter for mud outflow and an advanced, acoustic Doppler flowmeter for mud inflow to detect and quantify lost circulation. The rolling float meter has gained wide acceptance by industry and is now being commercialized.

Work is also being done to integrate both meters into an expert system that will diagnose drilling problems and recommend action. DOE also supports field-testing of new high-temperature cements that can be used for plugging lost circulation zones at lower costs.

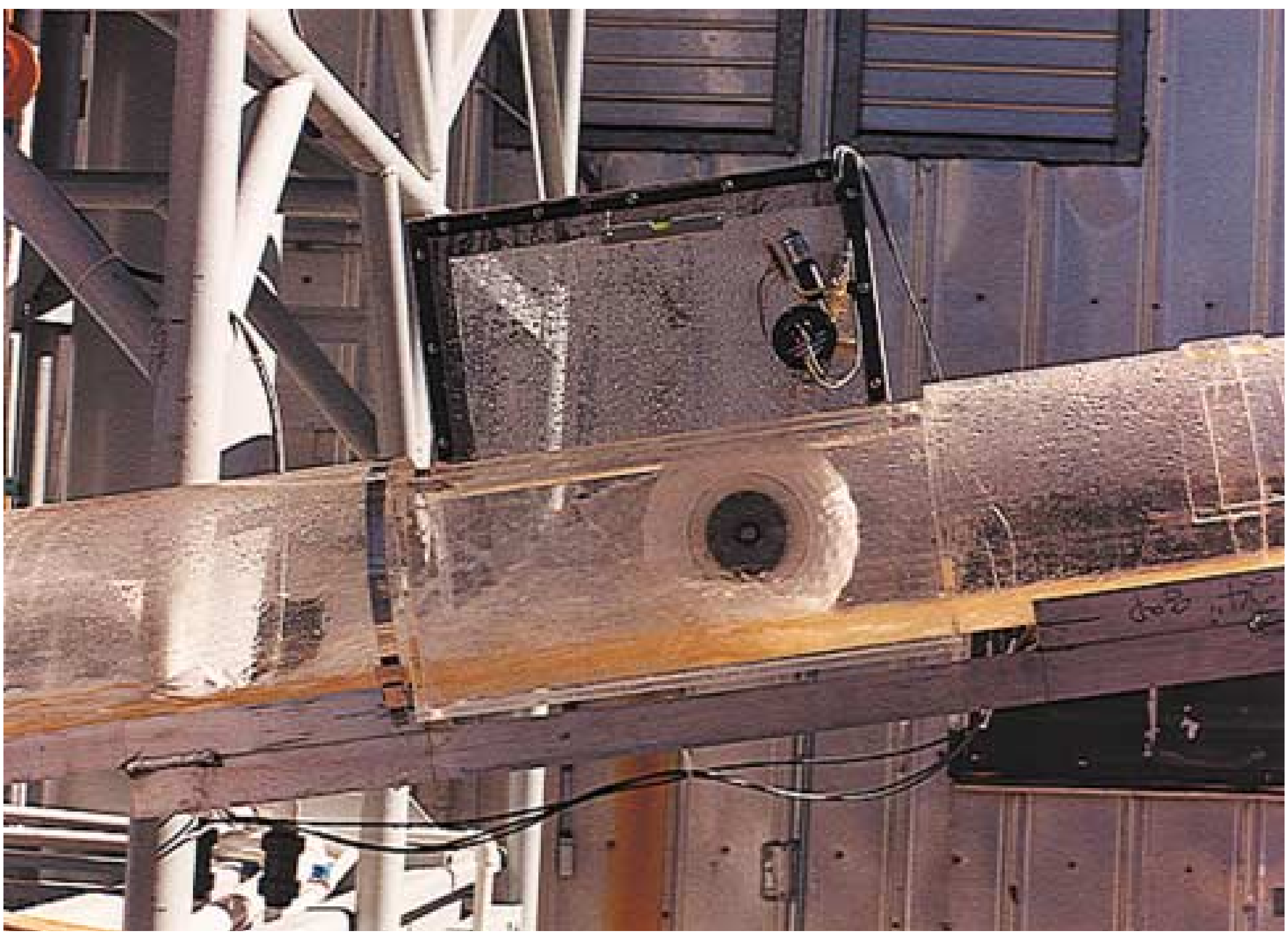
Slimhole Drilling Lowers Costs

The use of smaller-than-standard-diameter drilling bits and pipe, referred to as slimhole drilling, has been demonstrated to reduce oil and gas exploration costs by 25 to 75 percent. DOE-supported researchers have investigated whether slimhole drilling can provide sufficient data to characterize a geothermal reservoir, and how slimhole-drilling costs compare with conventional-sized holes. There is very convincing data that both of these questions have positive answers that encourage slimhole exploration of geothermal resources.

Diagnostics-While-Drilling

Although faster drilling and problem mitigation are clearly important for reduced cost, truly cost-effective drilling also requires that all functions of the overall process operate optimally.

Even the best drill bit will not significantly reduce the costs of a well if it is not compatible with, or does not



PIX#01757 Photo courtesy of SNL

DOE-sponsored research has led to new geothermal drilling technologies, such as this flowmeter that measures the outflow rate of fluid from a well.

enhance, the complete drilling system. DOE has sought an enabling technology that links all drilling functions and improves all component parts of the drilling process.

One such enabling technology is Diagnostics-While-Drilling (DWD). DWD is a concept that uses a closed information loop—carrying data up and control signals down—between the drilling platform at the surface and tools at the bottom of the hole. Upcoming data gives a real-time report on drilling conditions, bit and tool performance, and imminent problems. The drilling operators can then use this information to either change surface parameters (e.g., weight-on-bit, rotary speed, and mud flow rate) with immediate knowledge of their effect, or to return control signals to active downhole components.

DWD will reduce costs, even in the short-term, by improving drilling performance, increasing tool life, and avoiding trouble. For example, Baker Hughes INTEQ used surface-mounted equipment to monitor downhole vibration while drilling and cut 33 days off of a 90-day drilling job.

The longer-term potential of DWD includes variable-damping shock subs (analogous to a shock absorber) in the drill string for smoother drilling, reservoir characterization for locating the pay-zone while drilling, bit wear DWD, and self-steering directional drilling. Ultimately, DWD will lead naturally to autonomous-smart-drilling systems that analyze data and make drilling decisions downhole, without the driller's direct control.

Cost reductions will be realized through improved penetration rate, increased bit life, diminished tool failures, and reduced completion cost. The sum of the projected near-term savings is 25 percent, but advanced technology, that can only be dimly visualized now, has the potential to drive this savings even higher. DOE

PIX#07213 Photo courtesy of Sierra Pacific

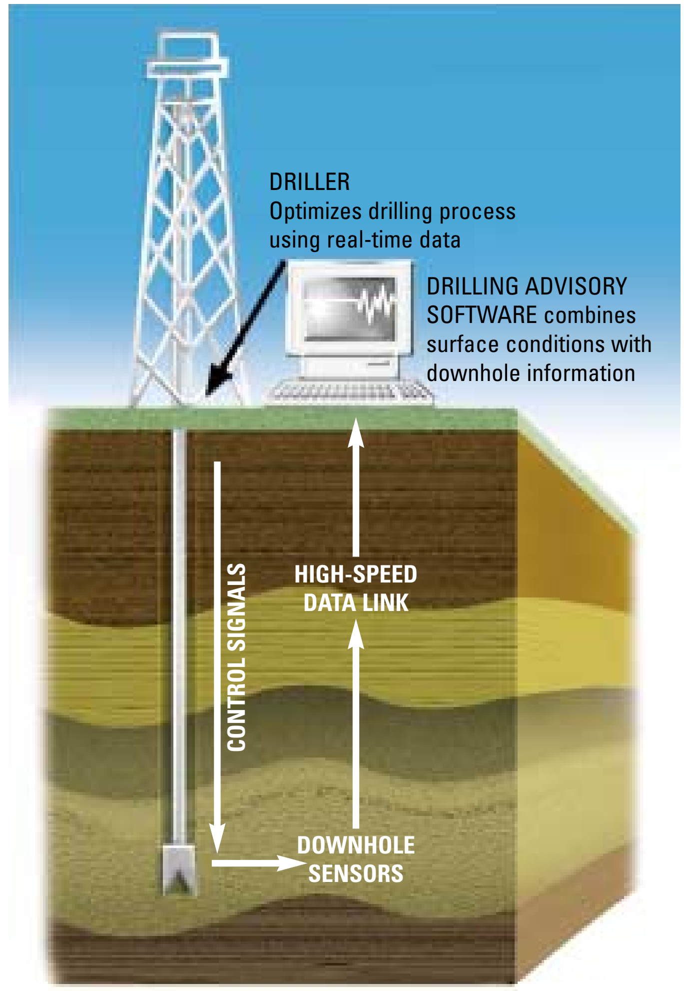
A drilling rig in northern Nevada

researchers are currently planning proof-of-concept tests that will demonstrate the inherent value of DWD for optimized drilling.

The Future

Reducing drilling costs will substantially cut the costs of geothermal development, thus helping the domestic geothermal industry to maintain its world-leader status and to expand its markets.

Today, society uses only a small fraction of the geothermal energy resource base. The ultimate promise of geothermal energy is that a much larger fraction of the total resource base can be tapped. New and improved drilling technologies can make this happen.■



Courtesy of SNL

A Diagnostics-While-Drilling system

The Geothermal Energy Program

Clean Energy from the Earth for the 21st Century

The U.S. Department of Energy (DOE) Geothermal Energy Program builds on a history of accomplishments that has facilitated a *six-fold growth* in geothermal power capacity in the United States. DOE funds research to reduce the cost of geothermal components, systems, and operations. The DOE program helps the industry maintain its technical edge in world energy markets, thereby enhancing exports of U.S. goods and services, and encouraging U.S. job growth.

During the last year, a reorganization of DOE's Office of Power Technologies went into effect. With this reorganization, the Office of Geothermal Technologies was combined with the Wind Energy Program. In addition, research and development (R&D) activities pertaining to geothermal heat pumps have been curtailed due to the market success that has been realized by this technology during the last decade.

The mission of the Geothermal Energy Program is to work in partnership with U.S industry to establish geothermal energy as an economically competitive contributor to the U.S. energy supply. Although the present industry is based on hydrothermal resources, the long-term viability of geothermal energy lies in developing technology to enable use of the full range of geothermal resources.

Industry is interested in R&D that will lead to solutions to immediate and pressing technological problems. As a result, DOE undertakes a program balanced between short-term goals of greater interest to industry, and long-term goals of importance to national energy interests.

Geothermal facilities use the natural heat in the earth's interior to produce electricity or to satisfy other heat energy needs. Currently, the installed commercial geothermal electric capacity in the United States is about 2,800 megawatts. Other, non-electric uses of geothermal energy total 800 megawatts. The potential to produce sustainable, environmentally sound geothermal energy is much greater, especially in the western United States.

The Program's R&D activities closely align with its mission and goals. With improved

in Review

Program Goals and Objectives

- Double the number of states with geothermal electric power facilities to eight by 2006.
- Reduce the levelized cost of generating geothermal power to $0.03 to $0.05 per kilowatt-hour by 2007.
- Supply the electrical power or heat energy needs of 7 million homes and businesses in the United States by 2010.

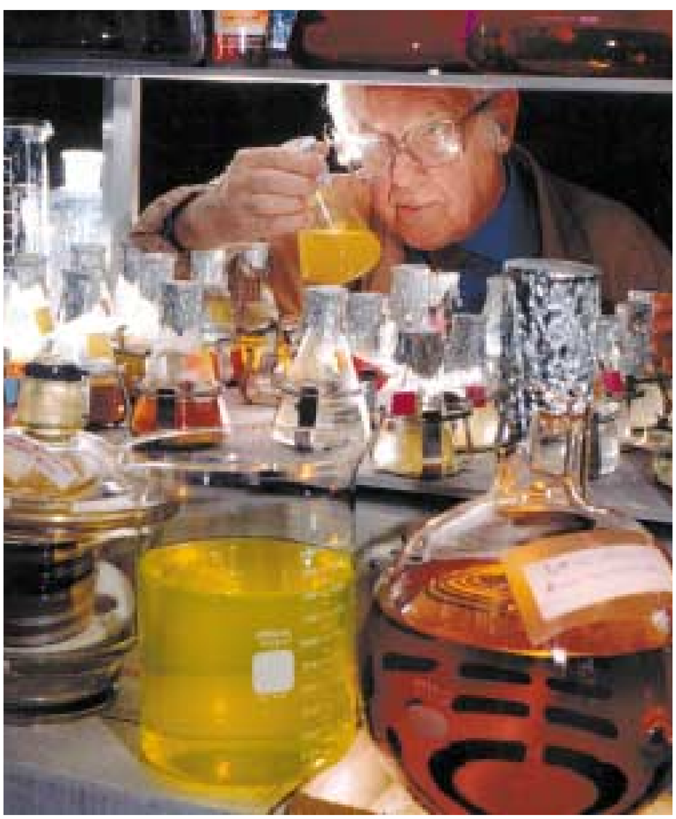
exploration methods, industry will locate and characterize new geothermal fields more accurately, reducing the high cost and risk of development. Better technology for drilling wells will make it possible to access deeper resources and reduce costs, thereby expanding the economic resource base. Advances in energy conversion will establish air-cooled binary technology as a means of generating competitively priced electricity from more plentiful lower-temperature resources. Studies of reservoir behavior will improve management of geothermal fields, allowing fields to operate for over 100 years as sustainable commodities. These activities all contribute directly to reducing the cost of geothermal development and enabling the installation of more geothermal facilities.

Geothermal electric generation projects are capital-intensive enterprises, with the major expenses being incurred before the plant begins to produce revenue. The high-cost components of a geothermal development project include: drilling exploration, production, and injection wells; and plant equipment and construction. The primary risk in a geothermal project is confirmation of a viable reservoir, which usually requires extensive drilling and well testing. To help reduce the risks and costs in geothermal development, the Program's research strategy involves:

- Improving technologies for exploration, detection of fractures and permeable zones, well siting, and fluid injection
- Decreasing the cost of drilling and completing geothermal wells
- Reducing the capital, operation, and maintenance costs of geothermal power plants.

A new initiative announced in January 2000, GeoPowering the West, will lend strong support toward achieving the Program's goals. The initiative will provide federal leadership, public awareness and education, technology development, and policy support that will enable broad expansion in the use of geothermal resources throughout the western United States.

The R&D program is based upon DOE's interaction with industry stakeholders and geothermal experts at universities and the national laboratories to create a balanced portfolio of core research and well-focused technology development thrusts. Cost-shared activities in geoscience, drilling, and energy systems research leverage the federal funds and facilitate technology transfer. These three key activity areas are described below.



PIX#08876 Photo courtesy of BNL

A researcher analyzes geothermal fluids

Geoscience and Supporting Technologies

Core Research—Core research is being conducted in the areas of materials, geofluids, geochemistry, geophysics, rock properties, and reservoir modeling. The work ensures that the United States continues to lead the world in geothermal science and technology, while expanding the geothermal knowledge base. Core research provides the understanding of complex geothermal processes and facilitates development of suitable technology for exploiting geothermal resources.

Enhanced Geothermal Systems—The Enhanced Geothermal Systems (EGS) project will apply hydraulic injection and fracture mapping technologies to both new and operating geothermal fields in the United States. The project applies EGS technology (i.e., rock fracturing, water injection, and water circulation) to sweep heat from the unproductive areas of existing geothermal fields, or new fields lacking sufficient production capacity.

University Research—The Program supports researchers at universities to expand their geothermal knowledge base in the areas of heat flow and temperature gradient research; reservoir dynamics and two-phase flow; the stress and thermal history of fractures; active faulting areas; and the history of plutonic hydrothermal systems. This research complements core research conducted by national laboratories and industry.

Seismic Exploration—Building on the design and testing of seismic source instruments to generate seismic energy, researchers in collaboration with industry are developing 3-D seismic exploration methods. The technology is used routinely in the oil and gas industry, but the generally poor seismic reflection properties of geothermal fields requires extensive adaptation for geothermal use. If successful, the technology will become the tool of choice for precisely locating geothermal fields.

Detection and Mapping—Mapping of geothermal fields and detection of open fractures and permeable zones are critically important to the overall productivity of a geothermal well field. Exploration projects with industry are used to find and confirm new geothermal resources in the United States. Researchers use tracers to determine the flow paths of injected water through a geothermal reservoir, analyze fractures with a borehole televiewer which takes pictures of the fractures in a well, and analyze rock cores for correlation with seismic exploration data. In addition, researchers detect fractures with seismic shear-wave splitting, develop new software to interpret downhole electromagnetic data, and conduct geologic mapping of existing geothermal fields.

Drilling Research

Innovative Subsystems—When completed, the Geothermal Advanced Drilling System will provide dramatic improvements in the economics of drilling wells in deep, hard, and fractured hot rock. This system will consist of a number of unproven and innovative subsystems. Subsystems currently under development include lost circulation control, hard-rock drill bits, high-temperature well sampling and monitoring instrumentation, and wireless data telemetry. Work on subsystem development is performed with careful attention to integration of components into a complete advanced drilling system.

Near-Term Technology Development—Incremental improvements to existing technology continues while development of the Geothermal Advanced Drilling System takes place. These drilling improvements, which involve cost-shared projects with industry, include a valve-changing assembly, downhole motor stator, foam cements, and a percussive mud hammer.

Diagnostics-While-Drilling—The principal subsystem component of the Geothermal Advanced Drilling System is a high-speed data link that can provide drilling data and information about rock characteristics to the surface in real time for better decision making by drillers. With the completion of a reliable data link, other components of the subsystem that rely on the flow of high-quality data, such as bit sensors, can be developed.

PIX#07224 Photo by Sue J. Goff, LANL

The eruption of the first water entry of a geothermal reservoir

Energy Systems Research and Testing

Advanced Plant Systems—Development of new technology for generating electricity from geothermal resources continues. Areas of investigation include air-cooled condensation of binary working fluids, control of heat exchanger fouling, and instrumentation for process monitoring.

Small-Scale Field Verification—Several prototype systems will be constructed and field tested to establish the performance characteristics of small-scale geothermal power plants and the economic benefits of improved electric power generation technology in geothermal applications.

GeoPowering the West—GeoPowering the West is a major new initiative that will foster awareness of the availability and benefits of geothermal energy throughout the western United States where geothermal resources are most readily accessible. The initiative will begin with education, awareness, and outreach activities aimed at a variety of stakeholders, such as businesses, government organizations, Native American groups, and the general public.

International Clean Energy Initiative—Exceptional opportunities exist for increased use of geothermal resources in overseas markets. Combined heat and power, hybrid systems, distributed power, and off-grid applications all present means for harnessing more geothermal energy. The Program assists U.S. industry in identifying

PIX#00413 Photo by Warren Gretz, NREL

A geothermal power plant in Imperial County, California potential new markets in developing and transitional countries.

Industry Support—The Program provides support to the U. S. geothermal industry in resolving near-term technical and institutional problems and enhancing technology transfer for both low and high temperature systems. Geothermal applications in a variety of situations, ranging from small-scale systems to traditional central stations, will be assessed for technical, economic, and institutional feasibility.

Geothermal resources are domestic resources. Keeping the wealth at home translates to more jobs and a robust economy. And not only does our national economic and employment picture improve, but also a vital measure of national security is gained when we control our own energy supplies.

Together, geothermal power plants and direct-use technologies are a winning combination for meeting our country's energy needs while protecting the environment. Whether geothermal energy is used for producing electricity or heat, it's a clean alternative for the 21st Century.■

Photo by Ann Lundy

These elementary students in Lincoln, Nebraska, enjoy superior classroom comfort from a geothermal heat pump system installed in their school.

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