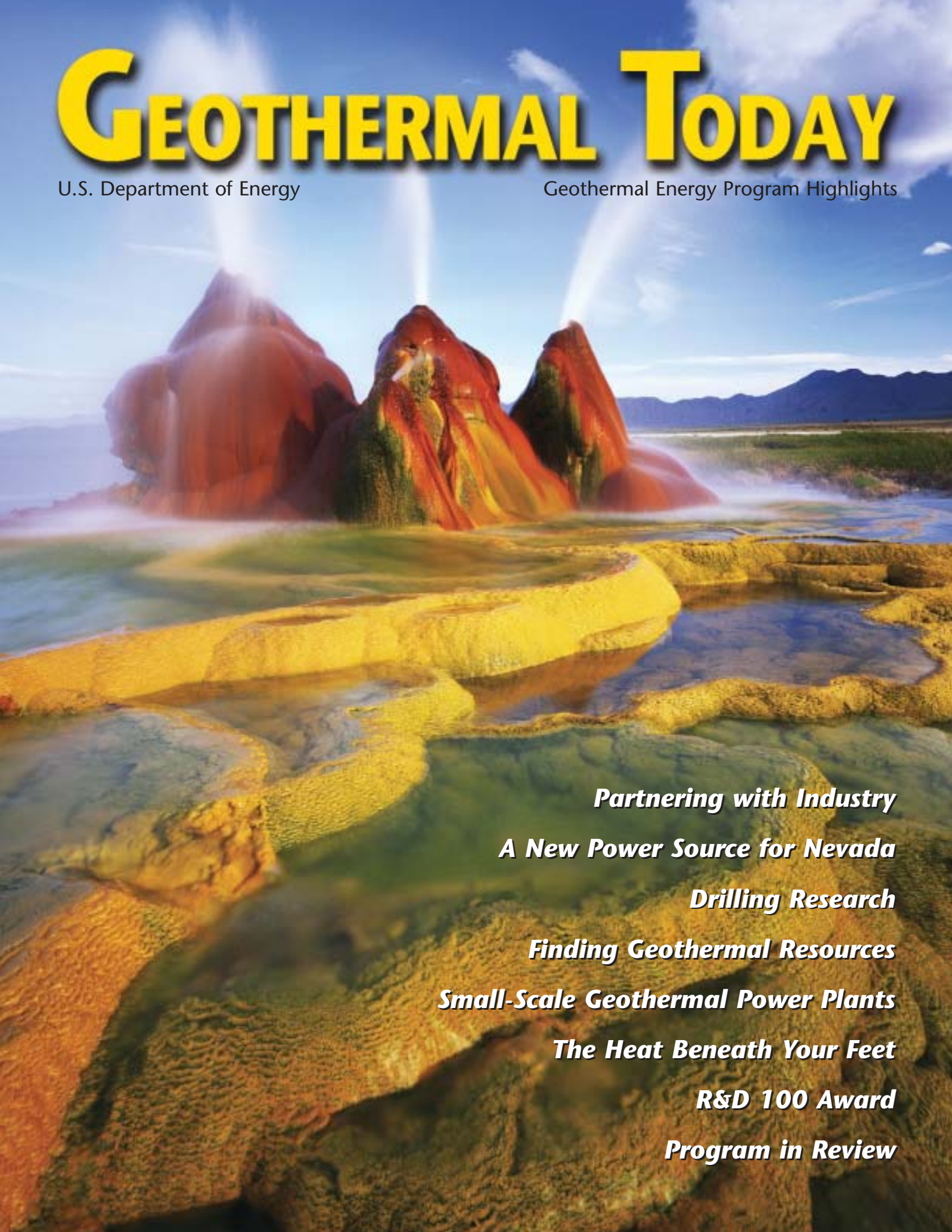


# **GEO THERMAL TODAY**

U.S. Department of Energy

Geothermal Energy Program Highlights



***Partnering with Industry***

***A New Power Source for Nevada***

***Drilling Research***

***Finding Geothermal Resources***

***Small-Scale Geothermal Power Plants***

***The Heat Beneath Your Feet***

***R&D 100 Award***

***Program in Review***

# Milestones

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## January 2000

The U.S. Department of Energy GeoPowering the West initiative was launched.

## February 2000

Grants totaling \$4.8 million were awarded in six western states, primarily for development of reservoir exploration, characterization, and management technologies.

## March 2000

Three DOE solicitations were released to accelerate moving new technology into the commercial arena. The solicitations targeted specific areas: field verification of small-scale geothermal power plants; enhancement of heat-delivery characteristics of geothermal reservoirs; and exploration for and definition of new geothermal resources.

## April 2000

Dr. Toshi Sugama of DOE's Brookhaven National Laboratory was honored with an R&D 100 award for developing a geothermal well cement. The cement resists deterioration by harsh geothermal fluids more effectively than previous cements.

## May 2000

The National Renewable Energy Laboratory received the 2000 Federal Laboratory Consortium Award for development of the Advanced Direct Contact Condenser for geothermal applications.

## July 2000

The GeoPowering the West kick-off meeting for Nevada was held in Reno, hosted by U.S. Senator Harry Reid. A Nevada Working Group, composed of industry, state, and Federal stakeholders, was established to identify the barriers to geothermal development, and to discover new opportunities.

## August 2000

The GeoPowering the West kick-off meeting for New Mexico was held in Albuquerque, and a New Mexico Working Group was formed.

## November 2000

DOE announced awards of 21 geothermal energy industrial partnerships totaling more than \$40 million over five years.

## March 2001

Solicitations were issued for innovative direct-use projects and drilling technology development.

## May 2001

The kick-off meeting for GeoPowering the West in Idaho was held in Boise, and an Idaho Working Group was formed.



# About “Geothermal Today”

The year 2000 marked a solid start of the U.S. Department of Energy’s (DOE’s) campaign to increase geothermal development and make full use of this abundant resource, especially in the western states. This issue of Geothermal Today describes how DOE’s research and development (R&D) efforts and industry partnerships are making progress toward establishing geothermal energy as a reliable and homegrown source of heat and power for the 21st century.

DOE’s Geothermal Energy Program focuses R&D efforts on technologies that can overcome primary technical barriers, and that can be moved quickly into the commercial sector.

Other facets of the Program are helping geothermal stakeholders commercialize the R&D products and resolve financial and institutional issues or barriers to development.

Several western states now have formal Geothermal Working Groups. Members include state energy officials, municipalities, geothermal industry members, utilities, Federal agencies, and the public – all working together to bring this energy choice to their states.

Welcome to Geothermal Today. We hope you’ll gain an appreciation of the tremendous potential and value of this Earth (geo) Heat (thermal).

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*At The Geysers power plants in California, DOE researchers partner with industry to improve power conversion and increase power output. One of the areas of focus is cooling strategies - researchers have designed advanced direct contact condensers that reduce steam consumption.*



# Partnering with Industry to Accelerate Geothermal Development



*DOE forms partnerships with the geothermal industry, utilities, state energy officials, municipalities, and the public to meet technical challenges, commercialize new technologies, resolve financial and institutional issues, and lower the cost of geothermal heat and power.*

In 2000, the U.S. Department of Energy (DOE) announced awards of more than \$43 million in geothermal projects cost-shared with industry over five years. The purpose of the projects is to advance newly developed technologies into commercial use, and ultimately lower the cost of geothermal heat and power.

DOE's three primary National Laboratories conducting research and development (R&D) on geothermal technology – Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho; National Renewable Energy Laboratory, Golden, Colorado; and Sandia National Laboratories, Albuquerque, New Mexico – focus their efforts on technologies that will answer the short-term and long-term needs of

industry and the U.S. When new tools are developed in the lab, DOE partners with industry to test them in real-world conditions.

The cost-shared project awards for 2000 were made in three primary technical areas. The areas and their awarded projects are described below.

## *Geothermal Resource Exploration and Definition*

This solicitation sought collaborative efforts to support exploration for and definition of new geothermal resources to increase electrical power generation from geothermal energy in the western United States. Seven awards were made for projects in California, Nevada, New Mexico, and Utah, with fiscal year 2000 funding of \$625,000.



*This geothermal power plant in the Imperial Valley in southeastern California generates electricity from steam produced underground in the Salton Sea geothermal reservoir. DOE was a partner in this project.*

PIX00426, Warren Gretz, NREL



*DOE partnered with Klamath Falls, Oregon, on this district heating project. Circulating geothermally heated water under the pavement keeps sidewalks clear of snow and ice.*

### **Enhanced Geothermal Systems Project Development**

In this solicitation, DOE looked for projects that would verify the electrical power generating potential of enhanced geothermal systems (EGS). EGS is a term applied to rock fracturing, water injection, water circulation, and fracture-mapping technologies. The goal of EGS is to collect heat from the unproductive areas of existing geothermal fields, or from new fields lacking sufficient production capacity. Nine projects for Phase One (concept definition) were awarded in New Mexico, California, Nevada, and Utah. Phase One funds were approximately \$2 million. Phase Two awards will be given to the most promising projects for field validation.

### **Field Verification of Small-Scale Geothermal Power Plants**

The objectives of this solicitation were to determine performance and operating characteristics of small-scale electric power plants, and to determine their applicability to providing distributed power in the western U.S. “Small scale” is defined as plants with approximate electrical outputs of between 300 kilowatts and one megawatt. Small-scale plants, if their feasibility is verified, would be an important part of a distributed power system – one that, instead of relying on a centrally located power plant and a transmission grid, uses many smaller plants located near end-users.





*Cost-shared projects to develop innovative drilling technologies will lower the cost of geothermal heat and power.*

### ***Innovative Direct-Use Concepts***

A solicitation was released seeking innovative direct-use applications and methods. Possible applications are district heating, greenhouse heating, fish farming, and others. Phase One funding for these projects is \$330,000.

### ***New Drilling Techniques***

DOE also issued a solicitation for near-term development of innovative drilling and well completion technologies. Proposals were sought

for projects involving drill bit design, drilling operations, lost circulation control, well remediation, handling of drilling effluent, and other topics related to construction and maintenance of geothermal wells. Available funds are \$200,000 – \$300,000. ■



*Geothermal power plant complex in Reno, Nevada, with a 48-MW capacity.*





# A New Power Source for Nevada

Nevada residents and businesses are now using geothermal waters to raise fish, dehydrate onions and garlic, soak aching muscles, heat their homes, and produce electricity. Only since the 1980s has use of this sustainable, reliable, and homegrown energy source really taken off in Nevada. As technology improvements and demand for electricity continue, geothermal is certain to become a major source of energy for Nevadans and people in surrounding states.

Nevada has the largest untapped, usable geothermal resource in the United States – 3700 megawatts (MW) – enough to supply electricity to 3.7 million households. Currently installed capacities of electric generation and direct heat uses in Nevada are 265 MW and 69 MW, respectively. That includes 14 power plants at 7 sites, 4 fish farms, 2 district (multiple buildings or houses) heating sites, 5 industrial sites, 13 spa and resort facilities, and 7 space heating sites.

As with many new things, it wasn't easy to sell the idea of geothermal electricity in the early days. In 1974, a major oil company was drilling in the well-known Brady area, which was the hottest known geothermal system in Nevada at that time. The head of the company's Reno office discovered a large thermal anomaly and proposed drilling a geothermal well. After he had conducted some exploration studies, company management decided that geothermal wells in that area would become clogged with scale buildup, rendering them unusable. Managers told the Reno people

to stop working in the area. In true western tradition, they simply renamed the project and kept working. A year or so later, the discovery well was drilled, and the result was a 9-MW power plant that has run for almost 20 years on the original three wells.







*This geothermal plant in Nevada blends well with its environment.*

Geothermal energy not only supplies Nevada with clean energy, it also brings money to the state coffers. Nevada is 86% Federally owned, and half of all royalties and production fees collected on Federal land goes back to the state. In 1999, almost \$2 million was returned to the state from geothermal sources. The Department of Energy currently supports 19 research/industry-partnership projects either in Nevada or involving Nevada-based partners. These initiatives are bringing in \$6 million to the state.

The geothermal energy industry is also a source of direct and indirect employment of Nevada residents in many areas, including drilling and well services, environmental services, construction contractors, plant operators, researchers, pipe and equipment suppliers, exploration geologists, and others.

As Nevada's U.S. Senator Harry Reid said at the inauguration of DOE's aggressive geothermal effort in the western states, "This modest investment by the Federal government has the potential to stimulate billions of dollars in investment and tens of thousands of new jobs, and in turn make Nevada the Saudi Arabia of geothermal energy."

Nevada is in the geologically active region known as the Basin and Range, a broad area characterized by extensive fracturing of the Earth's crust, which allows water to circulate in the hot, primarily volcanic rock formations. Northern Nevada has the highest-temperature geothermal resources, capable of generating electricity. Southern and east-central Nevada hold low- to moderate-temperature waters suitable for direct-use applications such as aquaculture, spas, crop-drying, and space heating.





*Warm geothermal waters provide excellent growing conditions. Aquaculture has become a popular industry in several western states. Nevada has four aquaculture facilities.*



# Nevada's Geothermal Historical Highlights

Ten thousand years ago, North American Paleo-indians used geothermal hot springs for cleansing, cooking, healing, and even negotiating. In the late 1800s, recreational spas were developed in northern California and Yellowstone National Park. By the 20th century, Nevada's geothermal resources were beginning to be recognized and used.

- In 1940, the first residential space heating in Nevada was installed in Reno. Today, nearly four hundred homes use geothermal resources for space heating or hot water.
- In 1974, the Arab oil embargo helped to reveal the benefits of geothermal energy as an indigenous resource, and a way to preserve

future energy supplies. Project development and research were accelerated, and public-land leasing laws and economic incentives reflected geothermal's growing importance.

- In 1978, the first crop-drying plant was opened at Brady Hot Springs.
- In 1980, an entrepreneur drilled a couple of wells into 210 °F water, hoping to pioneer the use of geothermal energy for fish farming or ethanol (alcohol fuel) production from corn byproducts. After a few years, those efforts worked marginally well, but he thought that a more lucrative use would be to generate electricity with waste heat from the water. He installed a 600-kW power

Today, geothermal energy provides about 5% of Nevada's electricity. A recently passed Renewable Portfolio Standard in the state requires that 15% of Nevada's power come from renewables (including geothermal) by the year 2013. Starting in 2003, the percentages will be gradually stepped up from 5% to 15%.

One of the issues hindering geothermal energy from supplying more than 5% of Nevada's electricity is its higher initial cost. Research being conducted at National Laboratories and universities, in partnership with industry, is developing new technologies for exploration, drilling, and plant operation. With these improvements in efficiency, the initial capital costs will continue to decrease, making geothermal energy even more cost-competitive with traditional sources.

What is the outlook for geothermal energy in Nevada? The research and development advances, coupled with the Renewable Portfolio Standard and other incentives, are attracting new power plant projects to Nevada. Many of Nevada's 20 Native American reservations are in geothermal areas. Leaders of one reservation recently began to explore development of a geothermal power plant. Another power project is being discussed for the Fallon Naval Air Station 90 miles east of Reno. Perhaps those "Top Gun" pilots will soon be flying over Nevada's newest geothermal power plant. ■



plant, power sales agreements were negotiated, and the plant is still providing geothermal electricity today.

- Nevada's first geothermal electricity was generated in 1984 at Wabuska, in Lyon County.
- In 1987, geothermal fluids were first used in enhanced heap leaching for gold recovery near Round Mountain.
- Nevada's first binary-cycle power plant was completed in 1993 in Steamboat Springs.
- In 1995, a food-dehydration facility was dedicated that processes 26 million pounds of dried onions and garlic per year at Empire, Nevada.

- By 2000, 14 power plants and more than 30 major direct-use facilities were operating in Nevada.

Geothermal electricity accounts for 5% of the total electricity generation in Nevada, ranking it #2 in the U.S. in geothermal electricity generation.

- Also in 2000, the U.S. Department of Energy, with Nevada's U.S. Senator Harry Reid, launched DOE's new initiative to encourage development of geothermal resources in the western U.S.

An initial group of 21 partnerships with industry in western states was funded to develop new technologies.

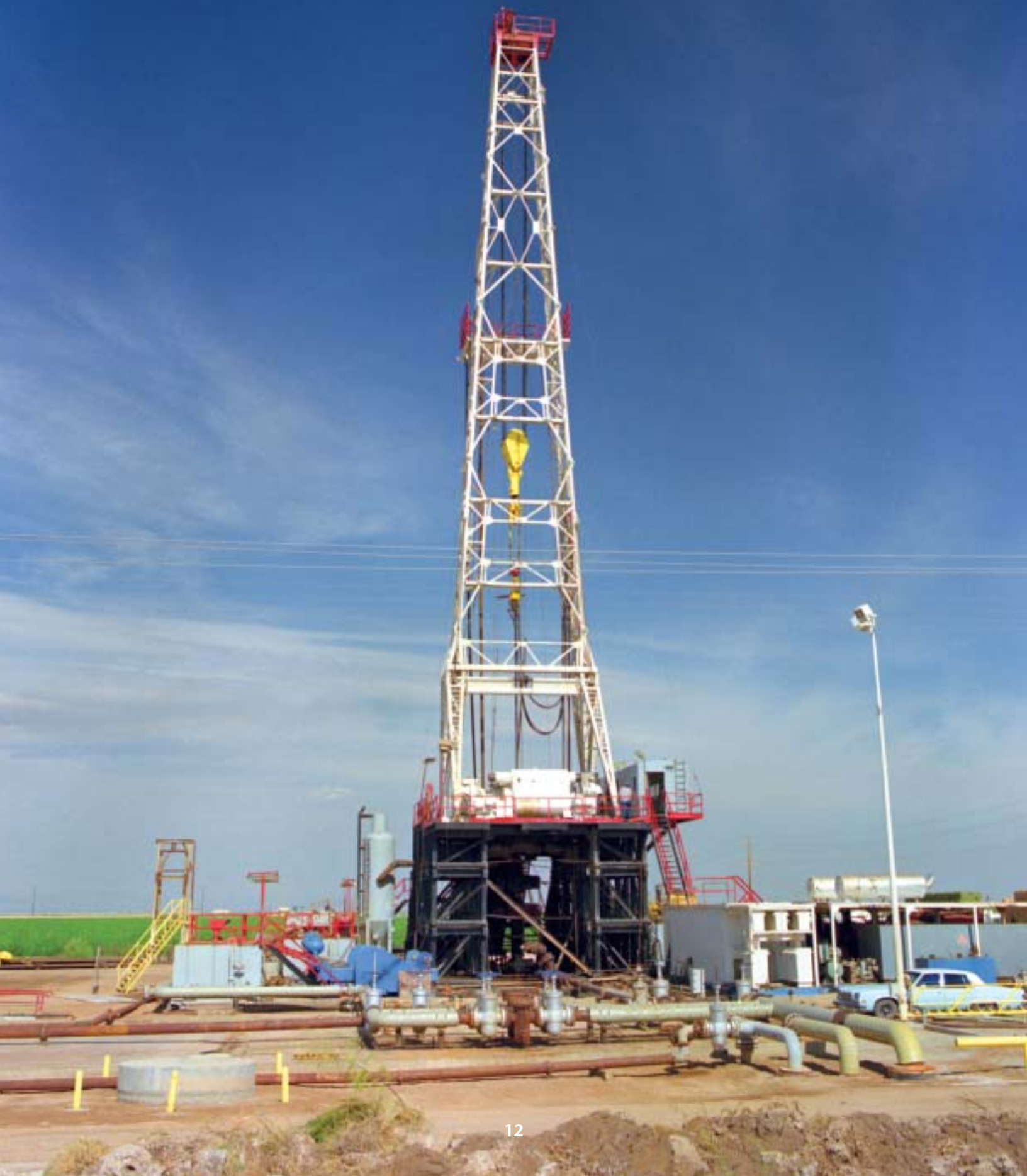


PIX07659, Joel Renner-INEEL

*The Soda Lake Power Plant No. 2 in Soda Lake, Nevada.*



*Well-field construction accounts for one-third to more than one-half of the cost of a geothermal project.*





# A Closer Look at Drilling Research

**T**he driller, hard hat and coveralls splashed with mud and grease, stands before the rig floor console and watches the drill string turn. Ten thousand feet below, at the other end of the spinning string of pipe, the bit chews away at a hot, hard layer of abrasive rock that lies above the pay zone. Operations like this are expensive — costing upward of \$15,000 a day for a small land rig to drill geothermal wells. Drilling and well completion can account for more than half of the capital cost of a geothermal power project; drilling costs can have a “make or break” effect on proposed geothermal development.

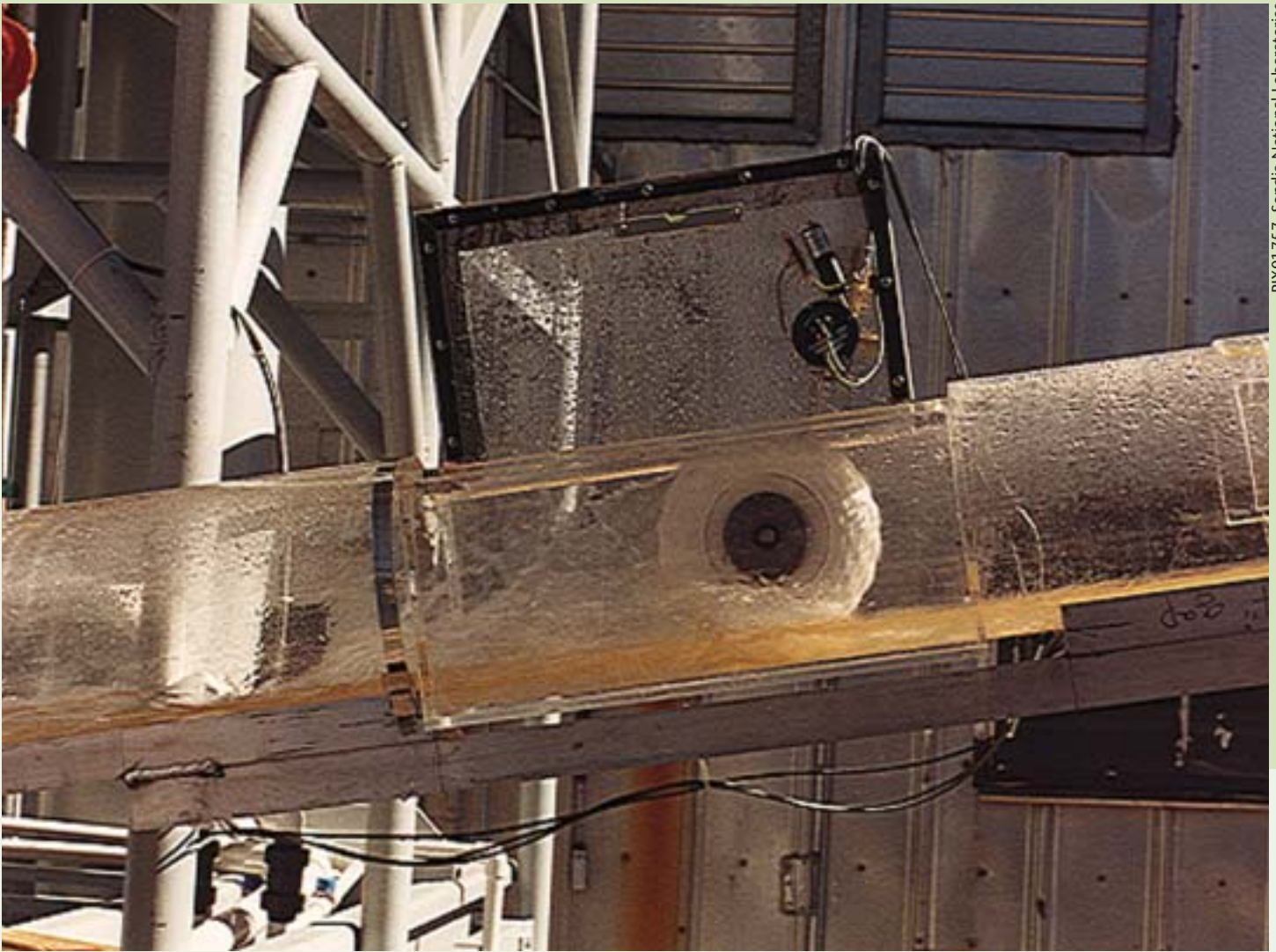
The potential pitfalls the rig can run into are many. For example, the bit can wear out quickly, causing the driller to spend hours pulling thousands of feet of drill pipe out of the hole to install a new bit. The drill string can twist off, or it can cause the drilling assembly to get stuck in the hole. The drilling fluid can leak off into formation fractures before it reaches the surface, causing stuck pipe and costly delays. New technology is being developed to minimize these problems so that geothermal wells can be drilled cost-effectively.

For more than two decades, the Department of Energy has been working to cut the costs of geothermal well drilling and completion, working closely with industry and holding quarterly meetings with industry advisors. “We’re very



*Researchers work on new drilling technologies to lower the cost of geothermal heat and power.*

conscious of the need for industry feedback. We want to ensure that we are trying to solve relevant problems and are doing so in an appropriate way, so we aim to maintain open lines of communication around our research developments,” said John Finger, Principal Member of



*This flowmeter will allow drilling companies to rapidly identify expensive lost-circulation events.*

the Technical Staff of Sandia National Laboratories in Albuquerque, New Mexico. Drilling cost reduction can be achieved in several ways — faster drilling rates, increased bit or tool life, less trouble (twist-offs, stuck pipe), higher per-well production through multi-laterals (horizontal offshoots), and others. Researchers are working in all of these areas to ultimately reduce the cost of drilling geothermal wells by 50%.

Working closely with the geothermal and drilling industries, DOE's efforts are focused on the following functions:

- Drilling systems analysis – understanding costs in order to focus R&D
- High-temperature instrumentation – developing high-performance electronics for down-

hole applications, reduced tool failure rates, and less expensive reservoir characterization

- Lost circulation technology – finding ways to prevent losses of drilling fluid, and thereby lower the cost of drilling
- Hard-rock drill bit technology – developing longer-lasting bits and better systems for faster, less expensive drilling
- Diagnostics-while-Drilling (DWD) – developing advanced systems for real-time data gathering based on high-speed data telemetry between the bit and the surface

Among the problems that plague all types of drilling, including geothermal, is a lack of timely information about what is happening downhole, where the bit is cutting the rock. This limited knowledge, combined with a lack of control, complicates the driller's job and adds to the cost.





PIX05933, Sandia National Laboratories

Even in trouble-free drilling, with the driller simply trying to optimize performance by changing weight-on-bit or rotary speed, it may be a few minutes to an hour before he can assess the effect of a change. Quick, reliable data communications from down-hole to the surface could revolutionize the drilling process.

Efforts to improve drillstring communication began more than half a century ago. For the past 20 years, a rudimentary technology called Measurement-while-Drilling (MWD) has helped get the measured data to the surface. MWD today is used primarily to control the path of wells. Data are transmitted via pressure pulses in the stream of mud that circulates in the well (also called mud-pulse telemetry). But the information travels relatively slowly, almost always under 10 bits per second (baud). (Common computer modems transfer data at 57,000 baud.) This technology also fails under high temperatures.

*Improved drill bits will substantially lower drilling costs.*

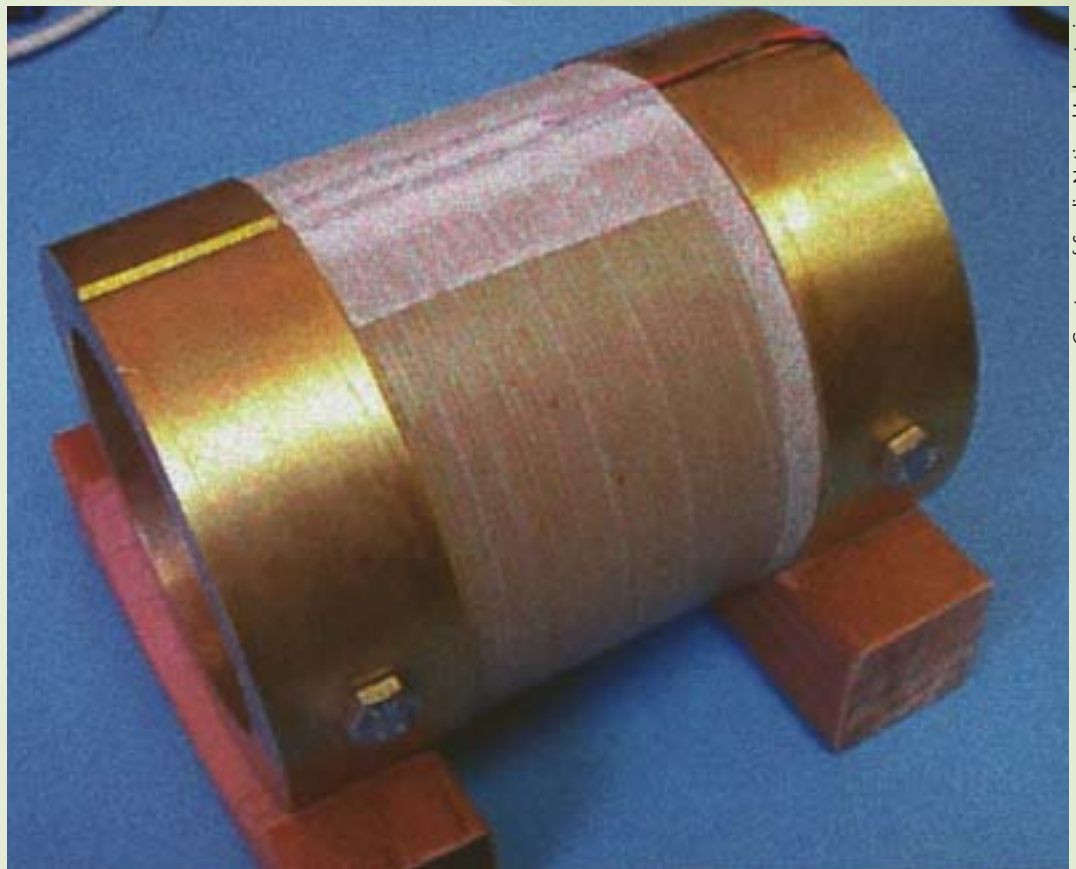
Drillers have few options in conventional drilling operations. They can only control weight-on-bit (the force that drives the bit into the rock), the rotary speed of the drill string, and the flow rate of drilling mud (the viscous liquid that circulates down the drill pipe through nozzles in the bit and back up the hole, cooling the hole while carrying the rock cuttings with it). The long, slender drill pipe gives the operator little information about what may be happening downhole. Is the bit bouncing off the bottom, breaking its teeth, soon to become unusable? Has the temperature of the rock suddenly risen? Has the bit penetrated a pocket of high-pressure fluid?

Diagnostics-while-Drilling technology will use a data loop, which will bring high-speed (100,000 bits per second or more), real-time data up the hole, combine it with measurements made at the surface, integrate and analyze these measurements to advise the driller, and then return signals downhole for control of “smart” tools. Sensors near the bit will measure such things as pressure, temperature, and vibration, and will show if the bit is turning smoothly. All signals will be sent uphole in real time.

When the DWD concept is put to commercial use, drillers will know immediately when problems arise, in time to take corrective action. They will know when the bit drills into a new kind of rock or, in many cases, even when it is about to fail. A prototype DWD system with



Acoustic data telemetry equipment works like the stereo system in your house. At the bottom of the well, a “microphone” picks up signals from various sensors in the drilling equipment. The weak signal from the “microphone” is sent to an amplifier, which transforms it into a high-power, high-voltage signal. The output of the amplifier goes to a “loud speaker,” shown below, which sends the sound into the drill pipe, where it travels from the bottom of the well to the surface. If the well is only about a half-mile deep, you can actually hear the pipe “sing” – one of the researchers likened the sound to a whale warbling! This sound is monitored by an accelerometer that can detect signals from deeper than 14,000 feet. The sound goes to a computer, which analyzes the tones, and then tells the driller what’s going on down at the bottom. All this happens at speeds many times faster than today’s traditional equipment.

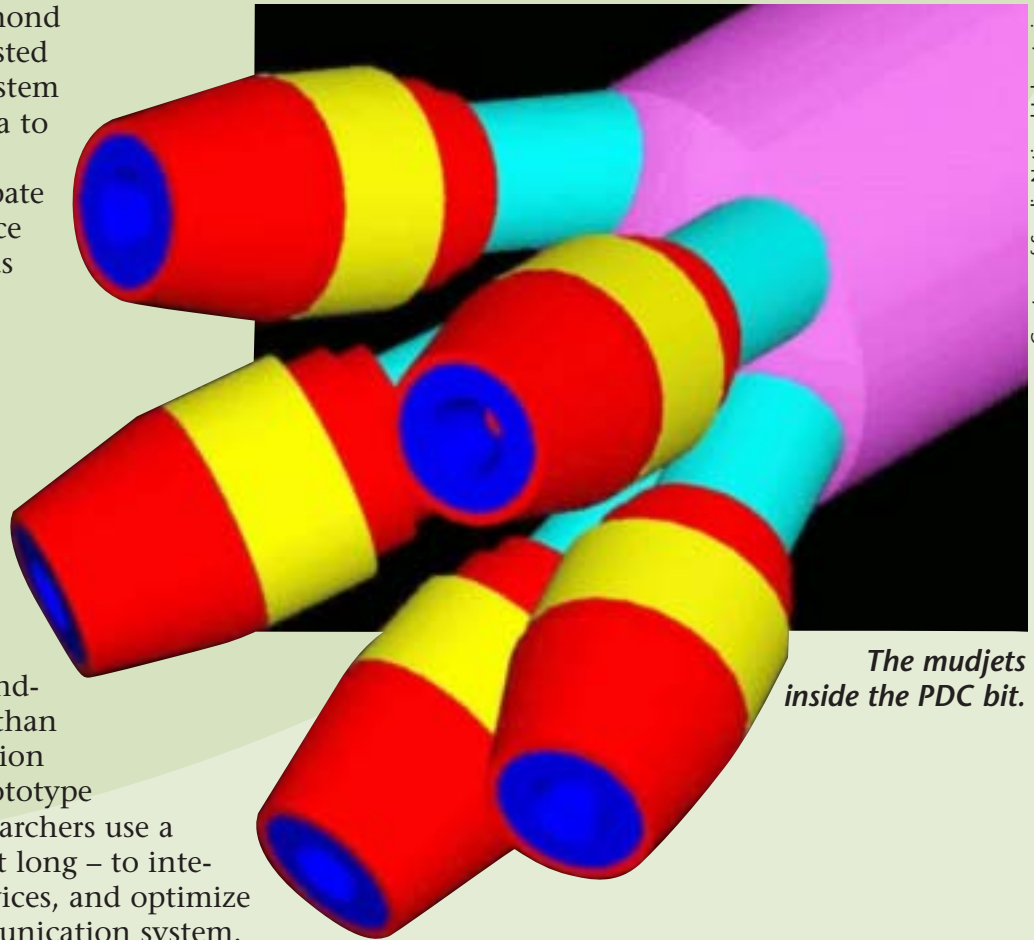


The heart of Sandia’s acoustic telemetry tool is this lead/zirconium/titanate (PZT) transmitter, capable of transmitting an acoustic signal more than 14,000 feet. This device directly converts electrical energy into axial pipe vibrations. It is only 5 inches long, but in combination with a power amplifier, it operates at 25% efficiency – about 100 times better than a typical home stereo system. This transmitter is placed into the telemetry equipment as shown at right in the top photo.



synthetic polycrystalline diamond compact (PDC) bits will be tested in hard, abrasive rock. The system will send bit-performance data to the surface at almost 200,000 baud. DWD's ability to anticipate problems should greatly reduce "flat time" (time the rig stands idle while the driller waits for data).

Acoustic telemetry — wireless data communication — also has great potential to reduce costs. This method sends a signal through sound waves that travel up the steel of the drill string. Acoustic telemetry will provide information at a much broader bandwidth — more data, faster — than mud-pulse telemetry. In addition to numerous field trials of prototype equipment in deep wells, researchers use a surface drill string — 1,400 feet long — to integrate operations, test new devices, and optimize operation of the entire communication system.



*The mudjets inside the PDC bit.*

Courtesy of Sandia National Laboratories



*This polycrystalline diamond compact drill bit has mud-jet nozzles built into it. The photo above shows a computer model of the jets inside the bit. This photo shows a face view of the entire drill bit.*

Courtesy of Sandia National Laboratories

Sandia project manager Douglas Drumheller says mud-pulse telemetry has been a useful tool, but more and more often it is failing to do the job. "Something more is needed, and that's why acoustic telemetry technology is so promising. Acoustic telemetry works when the mud isn't circulating, and the rate at which it sends data is at least one order of magnitude faster than mud-pulse signals," says Drumheller.

Comparing mud-pulse telemetry to acoustic telemetry is like comparing the telegraph to the telephone: because mud-pulse components are mechanical, the data transfer rate is thousands of times slower than the slowest computer modem, causing information bottlenecks. In acoustic telemetry, the electronic signal is transmitted by stress waves in the drill string. With a new component under development, the "repeater," acoustic communications will have an unlimited range capability with power from flashlight batteries. The communication range of the primary transmitter will operate down to 10,000 feet, and is capable of penetrating more than 15,000 feet.

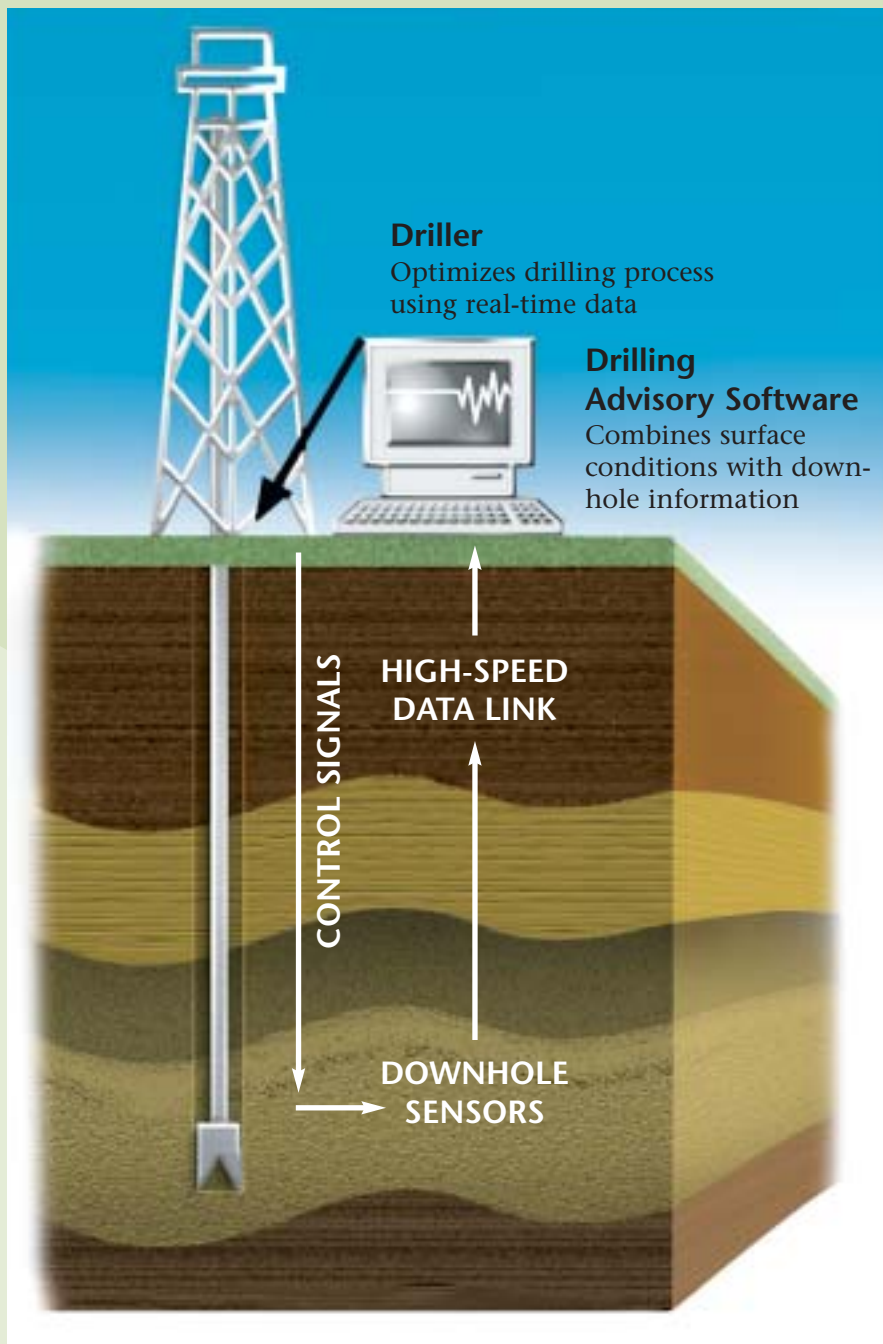
A leading drilling service company has been interested enough in the system to acquire a nonexclusive license for the technology, as has a Canadian venture capital firm.

Another promising method of getting signals to the surface is by transmitting them via optical fiber. Because optical signals have essentially unlimited bandwidth, they have enormous data-carrying capacity. Researchers are experimenting with ways to use optical fiber simply and more cost-effectively. In partnership with the Gas Technology Institute (formerly the Gas Research Institute), DOE is developing a system for deploying an optical fiber inside drill pipe to serve as a data link. After drilling, the fiber is disposed of easily and inexpensively.

In the area of high-temperature electronics, DOE is assisting private industry by developing tools that can withstand the high temperatures of geothermal wells. Hard, hot, abrasive rocks reduce the life span of bits and electronic tools to about eight hours. Almost 50 percent of conventional electronics fail at 150 °C, and of the remaining 50 percent, 80 percent fail before reaching 200 °C.

“A huge need exists for high-temperature electronics and sensors on drilling operations, but the relatively small market for geothermal energy gives equipment manufacturers little incentive to produce tools,” said Principal Investigator Randy Normann. “Commercial geothermal well-bore instruments capable of operating above 200 °C are almost nonexistent, and those that are available have a high price tag. Our target temperature is 300 °C, which is hot enough to cover 90 percent of the geothermal wells within the United States.”

Most common well-logging and well-bore measurements are performed using a custom, application-specific integrated circuit with silicon-on-insulator (SOI) technology. SOI technology



*A Diagnostics-while-Drilling system.*

hardens silicon electronic components so they can perform in extremely high temperatures, similar to the way electronic components are hardened to withstand radiation. Working with Honeywell’s Solid State Electronics Center, Sandia developed and demonstrated the industry’s first 300 °C microprocessor-based circuit, a device that ran for more than 200 hours through several temperature cycles. SOI prototypes have already been tested successfully in wells at temperatures above 250 °C.





Courtesy of Sandia National Laboratories

**Sandia's Hard-Rock Drilling Facility.**

- The Hard-Rock Drilling Facility, a laboratory drill rig used for studying the performance and durability of polycrystalline diamond compact (PDC) cutters under a variety of conditions
- The Linear-Cutter Test Facility for making detailed measurements of the forces acting on PDC cutters as they remove rock from samples characteristic of geothermal reservoirs
- The Orpheus Mobile Acoustic Lab, a fully equipped instrumentation trailer that houses sophisticated instrumentation and computers for gathering data in the field

“Lost circulation” of expensive drilling mud also frequently adds to drilling costs. A recent success in controlling lost circulation demonstrated the value of polyurethane foam for plugging problematic zones in geothermal wells. Researchers plugged a loss zone in a well in Nevada where more than 20 previous attempts with cement had failed. Since that successful field demonstration, several inquiries have been received from industry.

Twenty-two professionals with diverse technical backgrounds support the work at Sandia. Mechanical, petroleum, and electrical engineers, physical scientists, and skilled technologists work together to first understand the difficulties of geothermal drilling, and then develop systems to overcome these difficulties. “Taking drilling improvements from concept through development and laboratory validation, to field testing and commercialization is what makes the job fun — you get a real sense of accomplishment,” says Mike Prairie, leader of Sandia’s geothermal research program.

Sandia has a variety of tools for tackling the problems of geothermal drilling. Dedicated facilities and equipment include:

- The Engineered-Lithology Test Facility (ELTF), a 15’x15’x15’ structure where simulated geothermal lithologies can be built up around simulated well bores, mainly for lost-circulation experiments
- The Area III Geotechnical Range that houses the ELTF and 1,400 feet of horizontally mounted drill pipe of two diameters used mainly for telemetry system tests
- The Well-Bore Hydraulics Test Facility, a flow loop for testing mud-handling instrumentation (flowmeters, etc.)
- A fleet of vehicles for use in the field including a fully equipped logging truck, a mobile crane, a diesel tractor, and several 4WD trucks

As research brings drilling costs down, reliable geothermal energy will become more accessible to residents of the West. ■





*In the old days, geothermal reservoirs could be found by their steam vents, geysers, and fumaroles. Today, most of those reservoirs have been discovered and either developed or protected. New technology is needed to explore for new resources and assess their suitability for heat or power uses.*



# Finding and Characterizing New Geothermal Resources

The U. S. Geological Survey estimated that already-identified geothermal systems hotter than 150 °C have a potential generating capacity of about 22,000 megawatts (MW), and could produce electricity for 30 years. Additional geothermal systems waiting to be discovered have an estimated capacity of 72,000 to 127,000 MW. (A rough rule-of-thumb is 1 MW = power for 1000 homes.)

The current status of geothermal exploration has been likened to that of the oil and gas industry in the early 20th century.

Oil companies were drilling wells based on surface oil seeps, similar to the geothermal industry targeting hot springs.



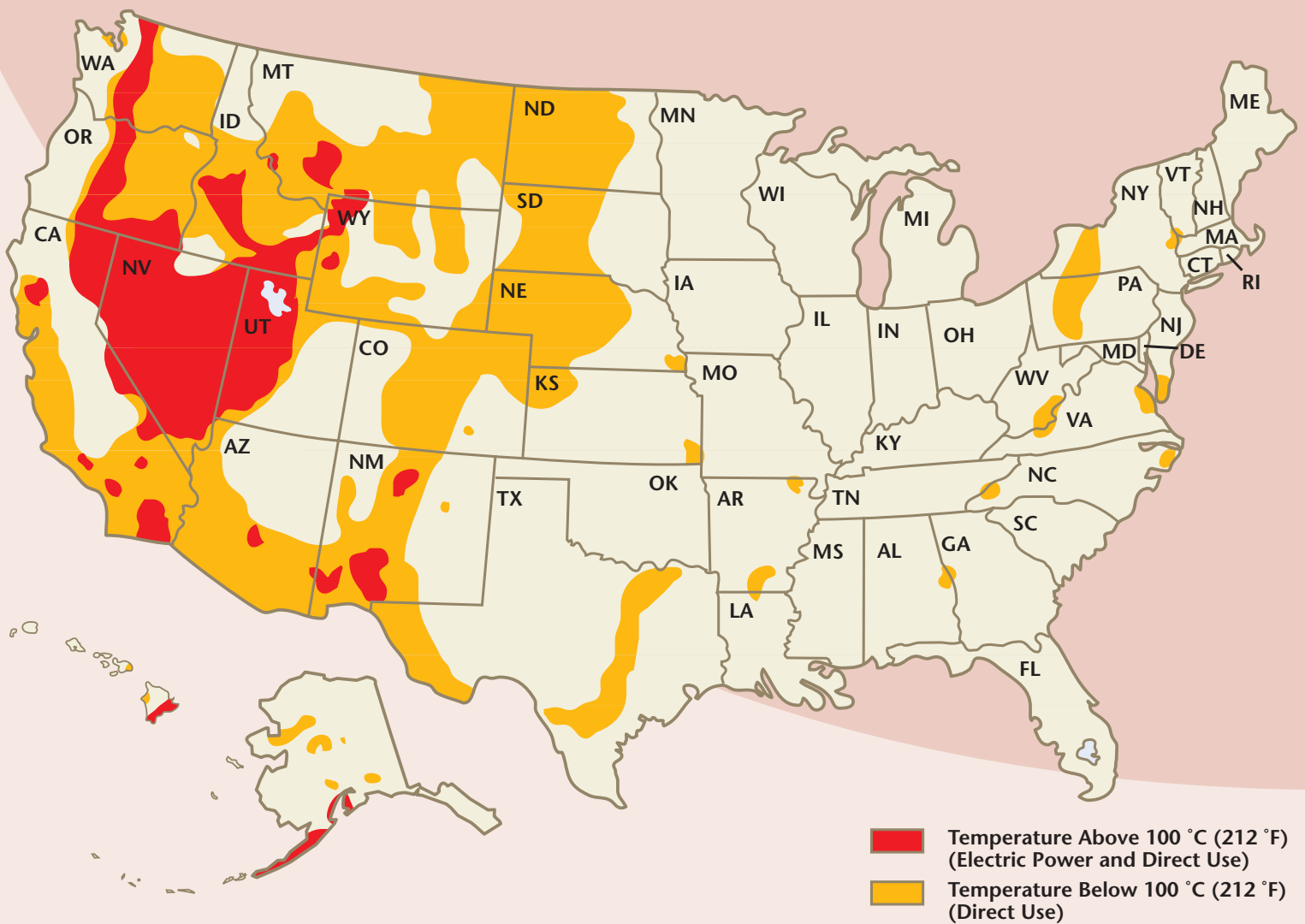
PIX05901, Warren Gretz, NREL

*Natural geothermal hot spring at Pagosa Springs, Colorado.*

Advances in exploration technology have enabled the oil industry to pursue exploration projects with no surface manifestations and targets at great depths. The geothermal industry still has only limited ability to target hidden systems.

DOE conducts research on exploration methods and the geologic settings of existing systems to assist the geothermal industry in discovering these hidden systems. National Laboratories and universities are developing improved geophysical tools and interpretation methods for exploration.

High-temperature logging tools are under development at several National Laboratories and universities, with industry and state partners. These tools will be able to withstand the elevated temperatures of



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

geothermal systems and determine if fractures are present near a well bore, indicating viable access to the hot water. Geochemists are investigating the possibility that minor concentrations of rare earth elements or carbon dioxide gases in soils may be indicators of hidden geothermal systems.

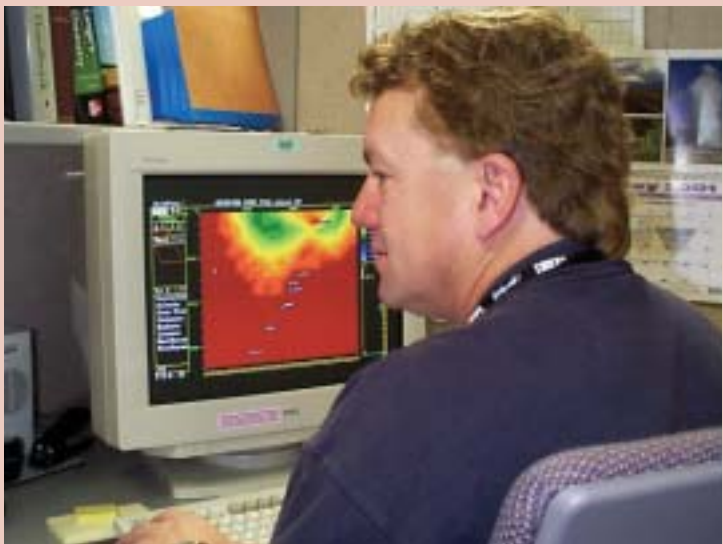
The oil industry's three-dimensional seismic exploration methods are being adapted to geothermal exploration. The generally poor seismic reflection properties of geothermal fields require extensive adaptation for geothermal use. If successful, the technology will become the tool of choice for precisely locating geothermal fields.

DOE also is developing innovative methods for characterizing geothermal resources and ascertaining changes in reservoirs during production.

As fluid is produced from a reservoir, mass is lost and the gravity signal decreases. Newly developed gravimeters provide more rapid and precise measuring of gravity, allowing researchers to monitor changes in fluid content in a reservoir over time to ensure maximum productivity. Withdrawal of fluid from a reservoir may cause the reservoir to compact, lessening production with a consequent change in the surface elevation of the reservoir. Space-based imaging systems allow rapid, remote sensing of these surface changes, which then can be correlated with areas of subsurface fluid withdrawal.

Also under development are new tracers for monitoring fluid flow. Tracers are chemicals whose flow path can be tracked in a reservoir, providing information that will improve the accuracy of reservoir management models.





Courtesy of Idaho National Engineering and Environmental Laboratory

These tracers and improved numerical, subsurface-flow computer models are important tools for characterizing geothermal reservoirs so that the resource is used most effectively and judiciously. DOE researchers are leaders in developing these numerical techniques.

Future projects will continue to develop new tools and exploration methods to reduce risks associated with exploration. Predicting the presence of a geothermal field without drilling, and managing the resource for long-term sustainability are the ultimate goals. ■

*A researcher at the Idaho National Engineering and Environmental Laboratory tests new computer models.*



Courtesy of Geothermal Education Office

*This researcher is analyzing a newly drilled rock core for reservoir characterization.*

# Small-Scale Geothermal Power Plants

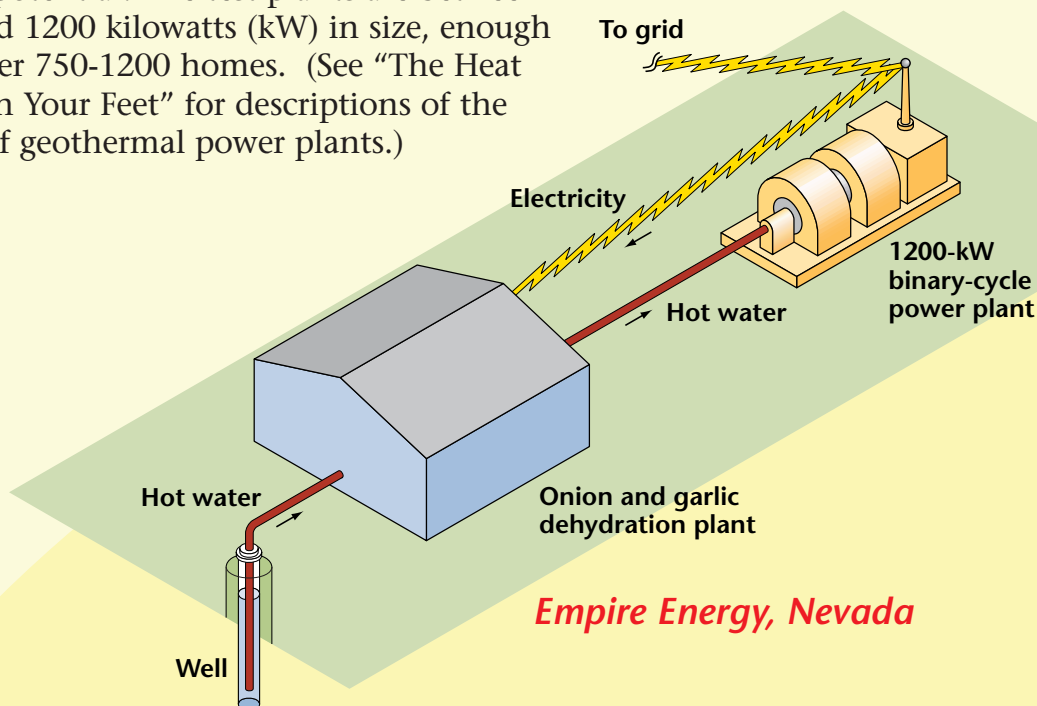
The combined output of the 20 geothermal fields in the U.S. is more than 14 billion kilowatt hours (kWh) per year of electricity. All but four of these plants are larger than 5 MW. (One megawatt serves about 1,000 houses.) Small-scale geothermal power plants (under 5 MW) have the potential for widespread application in rural areas. Achieving cost-effectiveness in small plants, however, presents a challenge. One way to meet this challenge is to pursue applications where the geothermal fluid can be used twice – once to generate electricity and again for direct heat uses, such as crop drying, fish farming, and greenhouse heating.

To evaluate the cost-effectiveness of small plants, DOE's Geothermal Energy Program, through the National Renewable Energy Laboratory (NREL) in Golden, Colorado, is partnering with industry on three test projects. All of the projects are in the western U.S., in states with the most geothermal electricity potential. The test plants are between 750 and 1200 kilowatts (kW) in size, enough to power 750-1200 homes. (See "The Heat Beneath Your Feet" for descriptions of the types of geothermal power plants.)

The projects are:

**Empire Energy, Nevada:** Located about 90 miles north of Reno, Nevada, this project involves design, installation, and operation of a 1200-kW power plant downstream of an existing geothermally heated onion and garlic dehydration operation. The geothermal fluid will be used first in the drying operation, and then it will travel to the power plant to boil a hydrocarbon fluid, the vapors of which will expand through a turbine to generate electricity. This project will also explore the use of evaporative cooling to enhance the plant's air condenser system on hot summer days.

**Exergy, Inc., New Mexico:** In southwestern New Mexico, near Cotton City, a 1000-kW geothermal power plant is being designed and built. The electricity will be provided to a tilapia fish hatchery. This plant will employ an innovative power cycle in which the geothermal fluid is used to boil an ammonia-water mixture whose vapors then



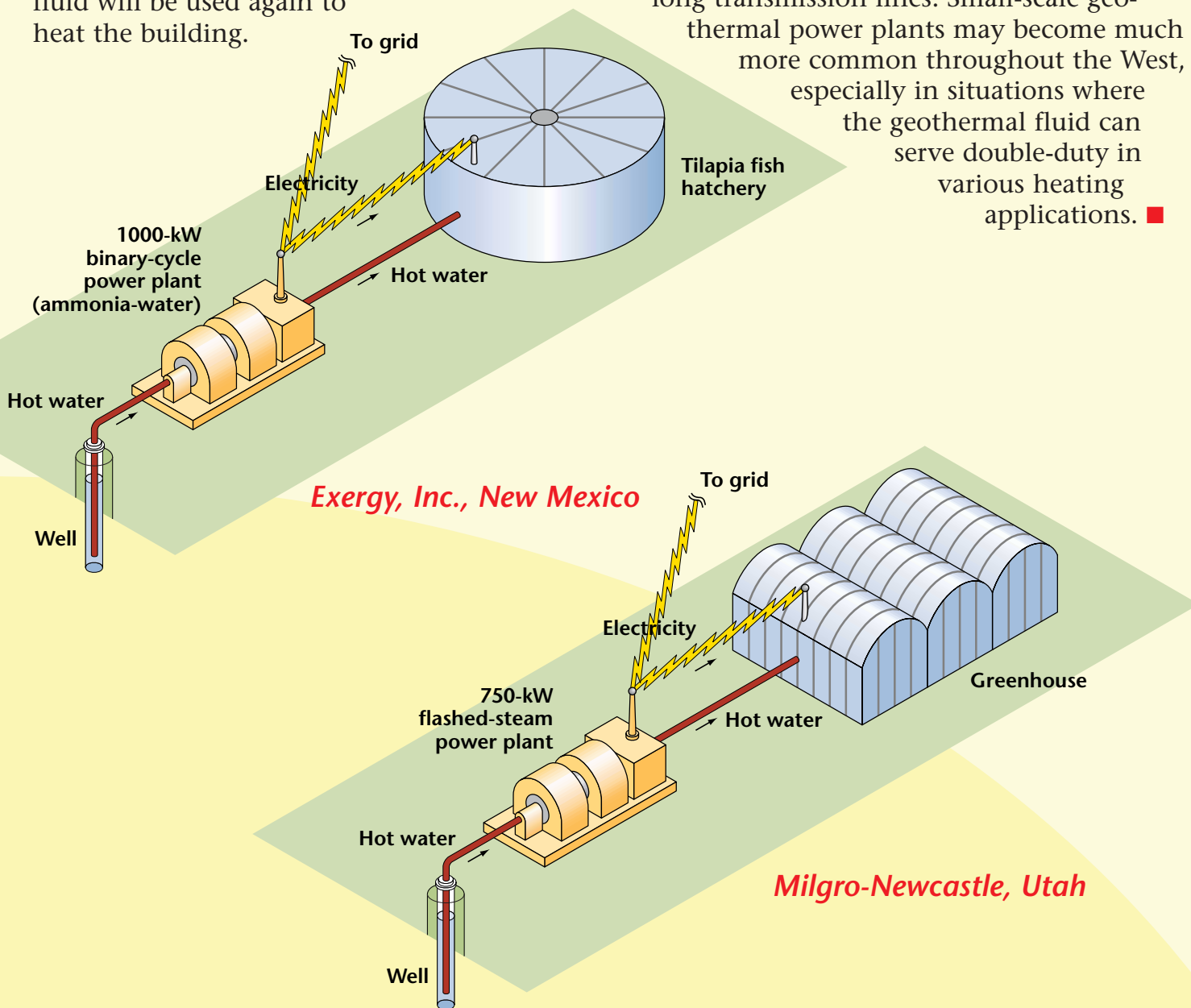
**Empire Energy, Nevada**



drive a turbine. After making electricity, the geothermal fluid will be used to heat the fish hatchery.

**Milgro Newcastle, Utah:** At Newcastle, Utah, 150 miles northeast of Las Vegas, Nevada, this project will involve a plant design in which the high-pressure geothermal fluid is rapidly boiled to steam in a low-pressure “flash” tank. Approximately 750 kW will then be delivered to a commercial greenhouse, where the geothermal fluid will be used again to heat the building.

Each project will be monitored for three years following plant startup. The performance and cost data collected will be used to extrapolate the expected technical and economic performance of the plants over their life cycle (usually 20 years). If the small-scale plants prove to be as economical as researchers believe, they could provide an additional power option for our electricity-hungry country. Small power plants could provide electricity right where it is needed, thus avoiding the losses associated with long transmission lines. Small-scale geothermal power plants may become much more common throughout the West, especially in situations where the geothermal fluid can serve double-duty in various heating applications. ■



*Our Earth holds an enormous amount of heat that can provide power for its inhabitants.*





# The Heat Beneath Your Feet

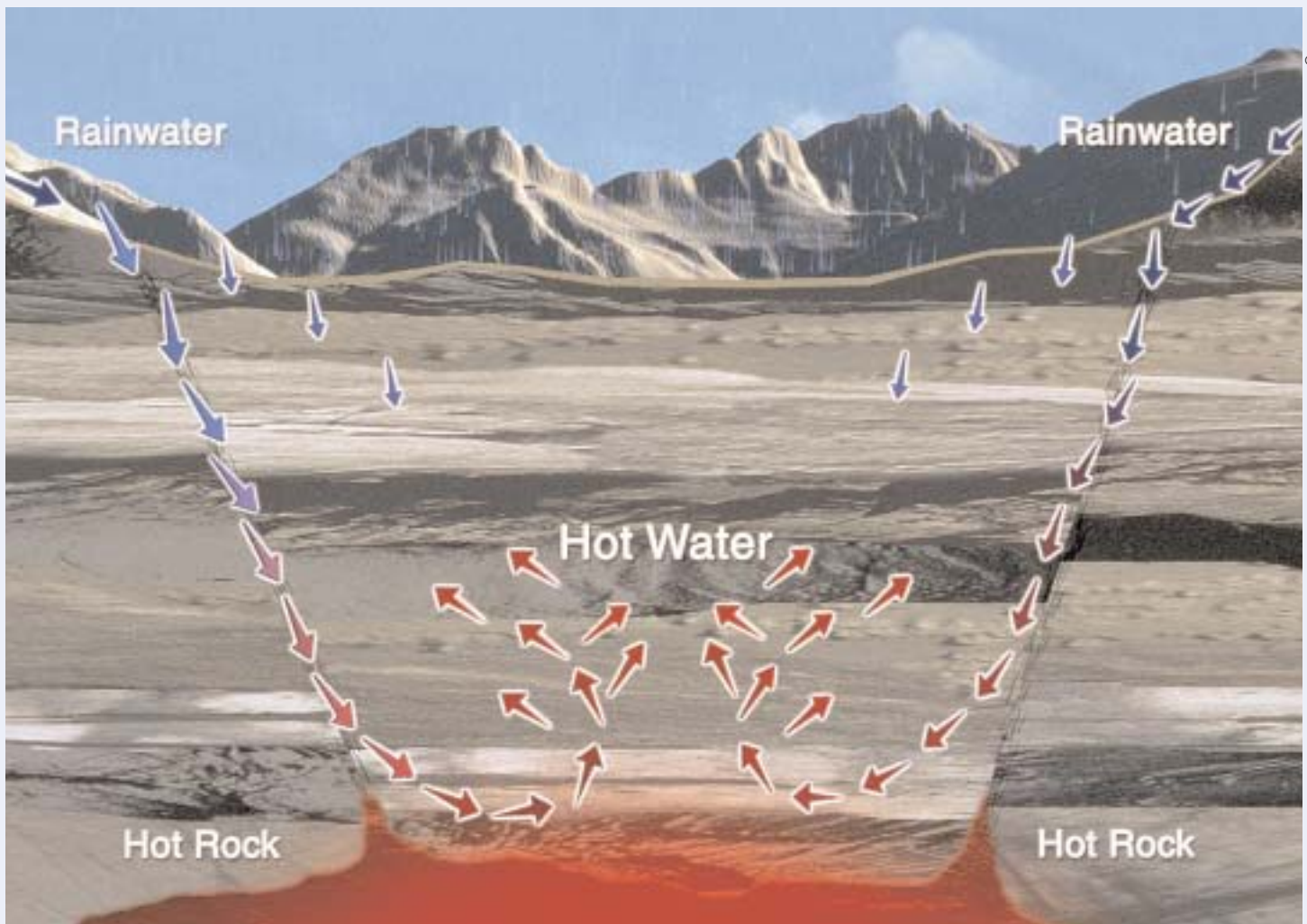
The Earth's crust is a bountiful source of energy. Nearly everyone is familiar with the Earth's fossil fuels — oil, gas, and coal — but fossil fuels are only part of the story. Heat, also called geothermal energy, is by far the more abundant resource.

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 overlying rock. At high enough temperatures, some rocks melt, transforming into magma. Magma can sometimes well up and flow to the surface as lava, but most of the time it remains below the

surface, heating the surrounding rock. Water seeps into the Earth and collects in fractured or porous rock heated by the magma, forming reservoirs of steam and hot water. If those reservoirs are tapped, they can provide heat for many uses, including electricity production.

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 known 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.



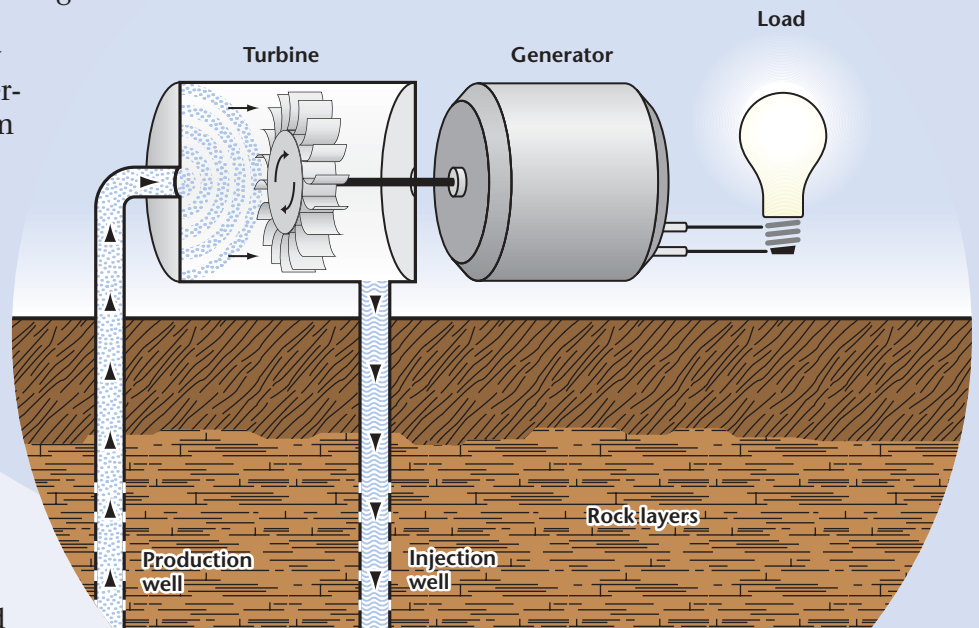
Courtesy of the Geothermal Education Office © 1999

*How a geothermal reservoir is formed.*

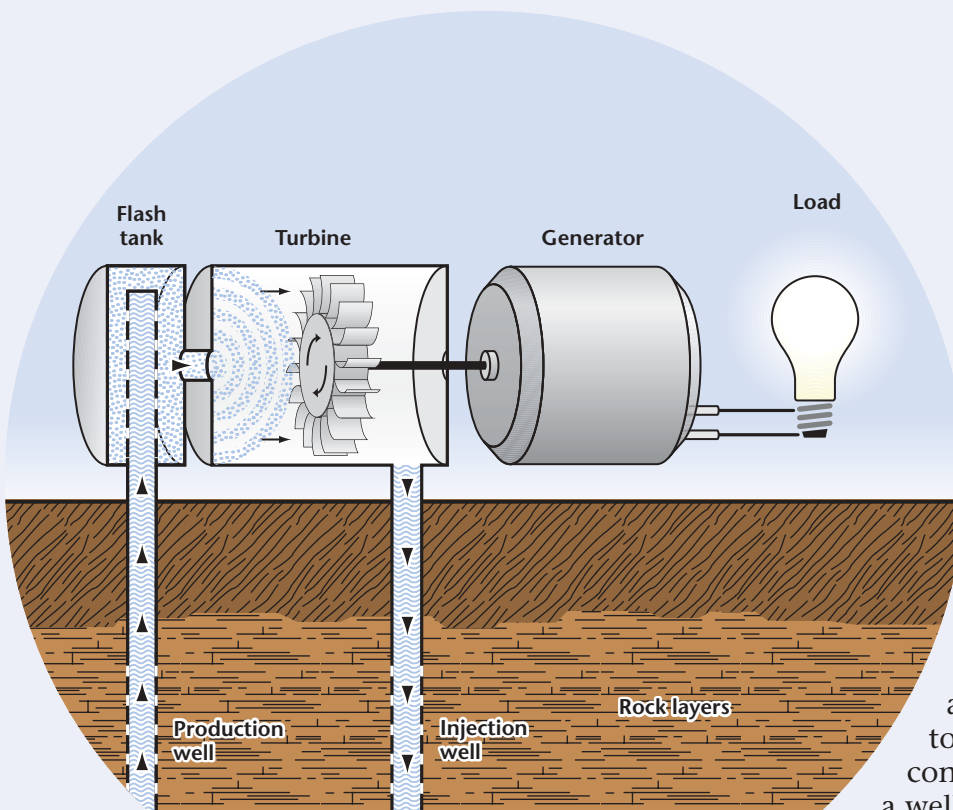
## Electricity Production

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 depends on a reservoir's temperature, pressure, and fluid content. There are three types of geothermal power plants: dry-steam, flashed-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 enters a turbine. The steam turns the turbine, which turns a generator. The steam is then condensed and injected back into the reservoir via another well. First used in Italy in 1904, dry steam is still very effective. The Geysers in northern California, the world's largest single source of geothermal power, uses dry steam.



**Dry-Steam Power Plant**

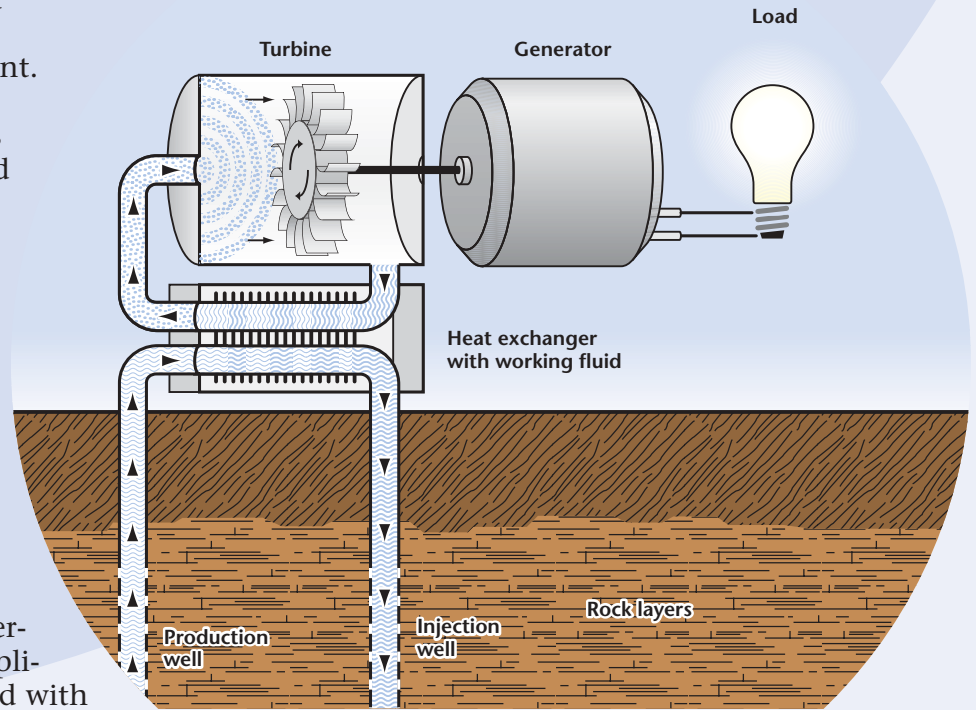


**Flashed-Steam Power Plant**

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



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



**Binary-Cycle Power Plant**

### Direct Use

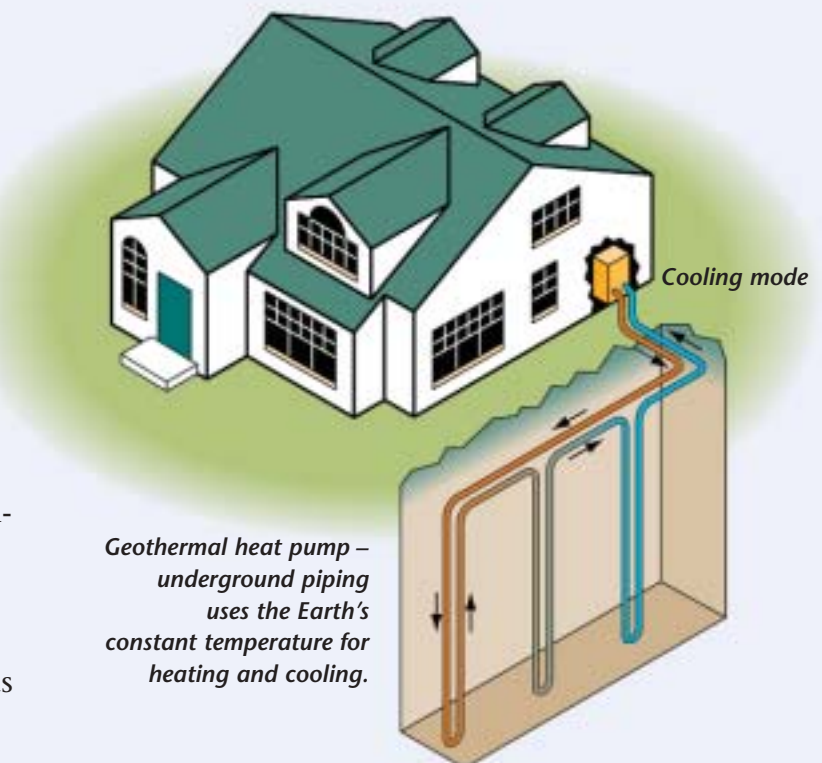
Hot water from geothermal resources can be used to provide heat for industrial processes, crop drying, or heating buildings. This is called “direct use.” In geothermal district heating, a direct-use application, multiple buildings are heated with a network of pipes carrying hot water from geothermal 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.

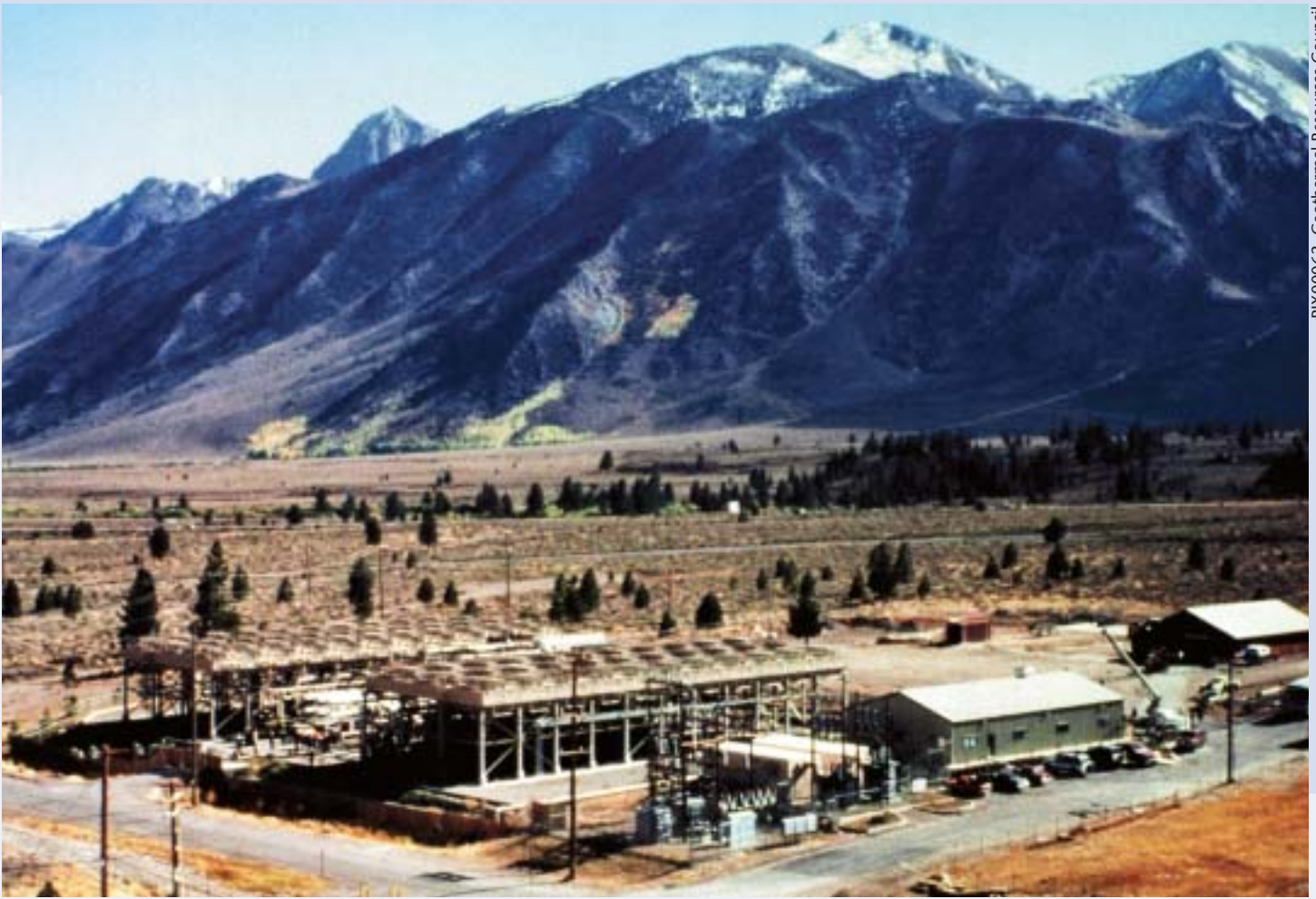
The consumer of direct-use geothermal energy can save as much as 80% over traditional fuel costs, depending on the application and the industry. Direct-use systems do require a larger initial capital investment compared to traditional systems, but have lower operating costs and no need for ongoing fuel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

### Geothermal Heat Pumps (GHPs)

Geothermal heat pumps use the ground as an energy storage device. GHPs transfer heat from a building to the ground during the cooling season, and transfer heat from the ground into a building during the heating season. GHPs marketed today also can provide hot water. More than 650,000 GHPs are in service today in the United States, including hundreds of systems in schools and colleges.



**Geothermal heat pump – underground piping uses the Earth’s constant temperature for heating and cooling.**



*Geothermal plants produce clean, sustainable, and homegrown power and require relatively little land.*

### **Market Potential**

Today's U.S. geothermal industry is a \$1.5 billion-per-year enterprise. Installed electrical capacity is nearly 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. Geothermal plants produce clean, sustainable, and homegrown power and require relatively little land.

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 deregulated power markets, the need for additional generating capacity will continue to grow in future years. And if renewable portfolio

standards (requiring that a certain percentage of energy come from renewables) 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.

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. GHPs account for about 4,000 megawatts (thermal) of annual energy savings today.



## Solutions Beneath Our Feet

Together, geothermal power plants and direct-use technologies are a winning combination for cleanly meeting our country's energy needs. Whether geothermal energy is used for producing electricity or providing heat, it's an attractive alternative for the nation. And geothermal resources are domestic resources. Keeping the wealth at home translates to more jobs and a more robust economy. 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. ■



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*Developing geothermal resources in the United States translates to more jobs at home and a more robust economy.*

## R&D Award

### Geothermal Well Cement Wins R&D 100 Award

The harsh, hostile environment of a geothermal well rapidly degrades conventional cements that are supposed to keep the well intact. **Dr. Toshifumi Sugama** of the U.S. Department of Energy's Brookhaven National Laboratory developed a high-performance cement that increases useful well life by a factor of 20 or more. That means savings of \$150,000 per well per year over a 20-year lifetime of the well!

The positive impact of this cement on industry was recognized when R&D Magazine presented Dr. Sugama with a prestigious R&D 100 Award, given annually to the world's one hundred most commercially significant new technologies. Named as co-winners were Lawrence Weber, PE, of Unocal Corporation, and Lance Brothers, PE, of Halliburton.



**Dr. Toshifumi Sugama**



The new calcium-aluminate-phosphate cement isn't just for geothermal wells. It can also be used in steam injection wells for secondary oil recovery. It will be effective in other areas that get a lot of wear and tear or stress: airport runways, bridge decks, and buildings with steel-reinforced concrete, for example.

This R&D 100 Award is the second presented to DOE's Geothermal Energy Program in the past two years. In 1999, Dr. Desikan Bharathan of the National Renewable Energy Laboratory was recognized for his patented design of an advanced direct contact condenser that improves the efficiency of geothermal power plants. ■

*Because geothermal plants do not burn fuel, they have an inherent environmental advantage over power plants that do. The geothermal plant below is emitting only water vapor.*





# The U.S. Department of Energy Geothermal Energy Program

The mission of DOE's Geothermal Energy Program is to work with the U.S. geothermal industry to establish geothermal energy as an economically competitive contributor to U.S. energy supplies. Currently installed U.S. geothermal electricity capacity is about 2800 megawatts (MW) (1 MW powers approximately 1000 households). Non-electric uses total an additional 570 MW thermal.

DOE-funded research and development (R&D) is carried out by National Laboratories and universities. DOE provides overall Program leadership, and a team of representatives from three of its National Laboratories — Idaho National Engineering and Environmental Laboratory, National Renewable Energy Laboratory, and Sandia National Laboratories — directs technical activities. R&D emphasis is on challenges that pose higher risks than can be addressed solely by industry, and which have a high potential

return. The primary goal of the Program is to reduce the levelized cost of geothermal electricity to 3 - 5 cents/kilowatt hour (kWh) from the current 5 - 8 cents/kWh. The three primary research areas are described below.

## *Geoscience and Supporting Technologies*

Geoscience and supporting technologies R&D focuses on core research in improved exploration methods and management of geothermal reservoirs. Cost-shared Enhanced Geothermal Systems projects develop injection and fracture-mapping technologies to ensure the most effective and judicious use of the reservoirs. University research is expanding knowledge of heat flow, reservoir dynamics, fracture stresses, and active faulting areas. The Idaho National Engineering and Environmental Laboratory leads DOE's efforts in this area.



Courtesy of Idaho National Engineering and Environmental Laboratory

*The Idaho National Engineering and Environmental Laboratory.*



*Sandia National Laboratories in Albuquerque, New Mexico.*

Recent accomplishments include:

- Liquid- and vapor-phase tracers (trackable chemicals placed in the geothermal fluid to show the path of the fluid through the reservoir) and test interpretation methods have been developed. Test results are incorporated into management models to ensure a long, productive reservoir life.
- Permeabilities and capillary pressures of fluids in reservoirs were measured. Measurements of these flow properties allow more accurate modeling (and, therefore, management) of geothermal reservoirs.
- New models were developed that improve our understanding of igneous events in the evolution of geothermal systems, which leads to more productive exploration and development.

### **Drilling Research**

Drilling R&D is developing cost-cutting technologies for accessing geothermal resources.

Well drilling and completion account for 30% – 50% of the initial capital cost of a geothermal power project, so reducing these costs is crucial if geothermal energy is to compete with conventional fuels.

Drilling R&D includes lost circulation control, hard-rock drill bits, high-temperature sampling and monitoring instrumentation, and wireless data telemetry. Cost-shared projects involve foam cements, percussive mud hammers, and downhole motor stator development. A major effort is Diagnostics-while-Drilling, using high-speed data links to provide real-time information for immediate and better decision-making by the drillers. Sandia National Laboratories leads DOE's efforts in drilling research.

Several recent accomplishments include:

- Demonstrated the value of polyurethane foam for plugging lost circulation zones in geothermal wells by plugging a loss zone in a Nevada well where more than 20 previous attempts with cement had failed.





*The National Renewable Energy Laboratory in Golden, Colorado.*

- Through collaboration with industry, developed a mud-jet polycrystalline diamond compact drill bit that drills moderately hard formations 30% faster than traditional bits.
- Began a collaborative project with industry to document and analyze geothermal drilling costs.

### ***Energy Systems Research and Testing***

Activities within the energy systems research and testing area focus on converting geothermal heat to electricity, and improving the efficiency of direct geothermal heating for space conditioning, industrial and agricultural processes, and other direct-use applications.

Specific emphasis is on the more widespread low-to moderate-temperature geothermal resources. DOE is working with industry to increase conversion efficiency, optimize plant design, validate combined-heat-and-power and small-scale plant feasibility, and reduce operation and maintenance costs. The National Renewable Energy Laboratory leads DOE's efforts in these areas.

Recent accomplishments include:

- Assisted with installation of a prototype hydrogen sulfide monitoring system at The Geysers in northern California. The new monitoring system will measure gas levels continuously so that expensive treatment compounds can be used more effectively, reducing operating costs.
- Investigated new air-cooled condenser fin designs that will lower plant costs by more efficiently handling the heat not used by the plant process. The new fin designs will allow the condenser to use significantly less electricity, a large portion of the cost of generated electricity.
- Developed a low-cost polymer coating to be applied to inexpensive carbon steel in heat exchangers. The coating can save many thousands of dollars per year in maintenance and capital costs.

DOE also is making a significant effort to alleviate non-technical barriers to geothermal development. Through DOE's GeoPowering the West education and outreach activities, stakeholders such as businesses, government organizations, Native American groups, and the general public are learning about the availability and benefits of geothermal energy throughout the western U.S., where geothermal resources are most readily accessible. DOE also supports industry's efforts for geothermal development overseas.



*(From left to right) Kathy Pierce, Director, DOE Seattle Regional Office; Peter Goldman, Director, DOE Office of Wind and Geothermal Technologies; Idaho's U.S. Senator Larry Craig; and Robert Dixon, Deputy Assistant Secretary, DOE Office of Power Technologies at the Idaho GeoPowering the West kick-off meeting.*

Courtesy of Idaho National Engineering and Environmental Laboratory

Recent accomplishments include:

- Hosted stakeholder meetings in Nevada, Idaho, and New Mexico. The meetings were attended by representatives from the geothermal industry; Federal, state, and municipal agencies; environmental groups; members of Congress; and the general public. Focused Working Groups were established in each state to pursue solutions to the non-technical barriers to geothermal development. Scheduled for the coming months are stakeholder meetings in Oregon, Utah, Alaska, and other western states.
- Brought together representatives from the Bureau of Land Management, the U.S. Forest Service, the geothermal industry, and other decision-making entities to discuss problematic issues regarding siting on Federal lands. The group's focus is on better communication among agencies, more efficient permitting processes, and other initiatives to promote geothermal development.

By working in partnership with industry in these areas, DOE is striving to have five million homes and businesses using reliable, sustainable, and homegrown geothermal energy by 2010. ■



Courtesy of Keith Gawlik, NREL

*Low-cost polymer coatings are tested in inexpensive carbon steel tubes.*



# KEY CONTACTS

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**GEOTHERMAL ENERGY PROGRAM WEB SITES:**

*U.S. Department of Energy GeoPowering The West*

<http://www.eren.doe.gov/geopoweringthewest/>

and

*Geothermal Energy Program*

<http://www.eren.doe.gov/geothermal/>

*Geo-Heat Center*

<http://www.oit.osshe.edu/~geoheat/>

*Idaho National Engineering and Environmental Laboratory*

<http://geothermal.id.doe.gov>

*National Renewable Energy Laboratory*

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