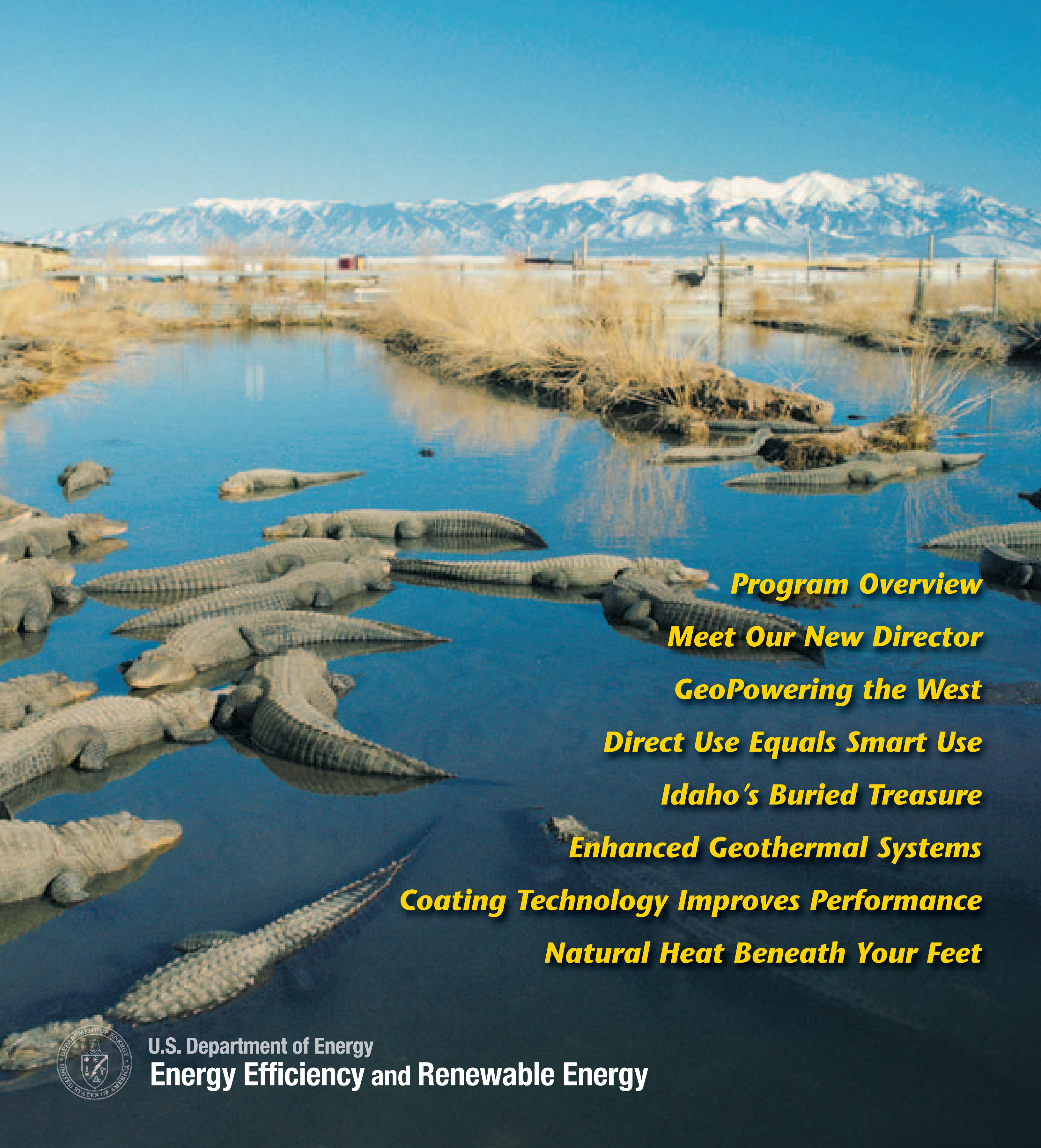
GEOTHERMAL TODAY

U.S. Department of Energy

2003 Geothermal Technologies Program Highlights



U.S. Department of Energy
Energy Efficiency and Renewable Energy

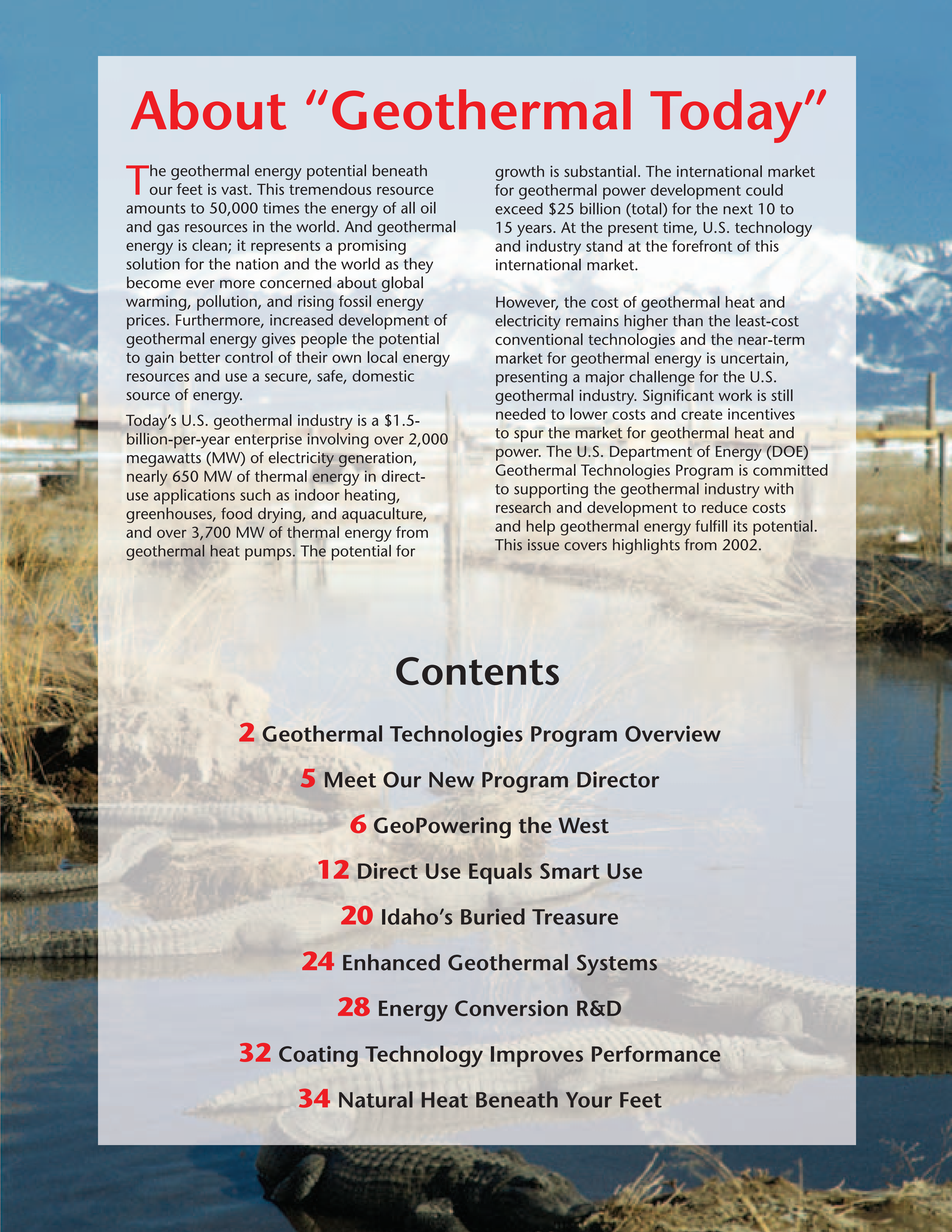
As charged by Secretary Abraham, the Office of Energy Efficiency and Renewable Energy provides national leadership to revolutionize energy efficiency and renewable energy technologies, to leapfrog the status quo, and to pursue dramatic environmental benefits.

The Geothermal Technologies Program, a critical part of our overall effort, is making great strides toward increasing the viability and deployment of geothermal heat and power. The peer reviewed, focused R&D and supporting outreach activities conducted by this program will enable broad expansion of the use of geothermal resources throughout the western United States. Through federal leadership and partnership with states, communities, industry, and universities, we will ensure that geothermal energy is established as an economically competitive contributor to the U.S. energy supply. Our program's success will mean a stronger economy, a cleaner environment, and a more secure energy future for our nation.

"Pursuing a prosperous future where energy is clean, abundant, reliable, and affordable...."

David K. Garman
Assistant Secretary
Energy Efficiency and Renewable Energy

Cover image PIX05876 Warren Gretz, NREL



About "Geothermal Today"

The geothermal energy potential beneath our feet is vast. This tremendous resource amounts to 50,000 times the energy of all oil and gas resources in the world. And geothermal energy is clean; it represents a promising solution for the nation and the world as they become ever more concerned about global warming, pollution, and rising fossil energy prices. Furthermore, 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.

Today's U.S. geothermal industry is a $1.5-billion-per-year enterprise involving over 2,000 megawatts (MW) of electricity generation, nearly 650 MW of thermal energy in direct-use applications such as indoor heating, greenhouses, food drying, and aquaculture, and over 3,700 MW of thermal energy from geothermal heat pumps. The potential for growth is substantial. 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 industry stand at the forefront of this international market.

However, the cost of geothermal heat and electricity remains higher than the least-cost conventional technologies and the near-term market for geothermal energy is uncertain, presenting a major challenge for the U.S. geothermal industry. Significant work is still needed to lower costs and create incentives to spur the market for geothermal heat and power. The U.S. Department of Energy (DOE) Geothermal Technologies Program is committed to supporting the geothermal industry with research and development to reduce costs and help geothermal energy fulfill its potential. This issue covers highlights from 2002.

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The Federal Geothermal Technologies Program — An Overview

The National Context

The United States needs clean and secure energy, maybe now more than ever. Geothermal energy sources have shown an increasing ability to help meet our homeland energy needs, through proven and expanding technologies, and using domestic resources. Geothermal energy is homegrown — it reduces our need to import oil, reduces the trade deficit, and adds jobs to the U.S. economy.

The Bush Administration's National Energy Policy (NEP) and its goals have become an important focus of the Federal Geothermal Technologies Program. The NEP report cites the critical shortage of new electricity generating capacity in the United States. With the integration of new, Federally supported technology at operating geothermal fields, an additional 100 to 300 megawatts (MW) of generating capacity can come online within two years. Geothermal resources are plentiful in most western states, and would go far in alleviating capacity shortfalls.

The next generation of geothermal technology, enhanced geothermal systems (EGS), promises to at least double the amount of geothermal resources that can be developed for electricity production over the next 20 years. Strong support for this technology is consistent with the NEP's recommendation to develop next-generation power technology.

Finally, the NEP notes that renewable technologies such as geothermal can help industry achieve compliance with the Clean Air Act and other environmental regulations. In fact, this is especially true for geothermal, which uses emissions control technology that meets or exceeds the most stringent Federal and state regulatory standards. And with the use of fluid-injection coupled with binary-cycle technology, some geothermal plants have virtually no emissions other than rejected heat.


PIX00001 Warren Gretz, NREL

Electricity is vital to our nation's economic health. Reliable, local resources can help.

The Federal Program

The mission of the U.S. Department of Energy's (DOE) Geothermal Technologies 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 over 2,000 megawatts (MW – 1 MW powers roughly 1,000 households). Non-electric uses total about 650 MW of thermal energy.

The U.S. Geological Survey estimates that the potential of this clean energy amounts to 50,000 times the energy of all oil and gas resources in the world. Today's 1.5-billion-dollar-per-year geothermal industry has great potential for growth.

However, the cost of geothermal heat and electricity remains slightly higher than the least-cost conventional technologies. Significant work is needed to lower costs and create market incentives for geothermal heat and power.

The DOE Geothermal Technologies Program conducted more than 40 projects in fiscal year 2002. The goal of these projects is to improve technology (and thereby lower costs) for finding, characterizing, accessing, and producing geothermal resources, with strong involvement by industry partners.

The three major research areas are:

- Geoscience and Supporting Technologies
- Exploration and Drilling
- Energy Systems Research and Testing

DOE-funded research and development (R&D) is carried out by national laboratories and universities. DOE provides overall program leadership and management, and a team of representatives from three of its national laboratories – Idaho National Engineering and Environmental Laboratory (INEEL), National Renewable Energy Laboratory (NREL), and Sandia National Laboratories (SNL) – implements technical activities. R&D emphasis is on challenges that pose higher risks than can be addressed solely by industry, and which have a higher potential return. The primary goal of the program is to reduce the levelized cost of geothermal electricity to 3 to 5 cents/kilowatt-hour (kWh) from the current 5 to 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 (including seismic) and management of geothermal reservoirs. Cost-shared EGS projects develop injection and fracture-mapping technologies

PIX05933 Sandia National Laboratories

Performance of PDC drill bits, like this one developed at Sandia National Laboratories, helps improve hard rock geothermal drilling.

PIX09054 University of Utah

Geoscience researchers conduct tracer tests at The Geysers, northern California.

to ensure the most effective use of the reservoirs. University research is expanding knowledge of heat flow, reservoir dynamics, fracture stresses, and active faulting areas. 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. Test results were incorporated into resource 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 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.

Exploration and Drilling Research

Exploration and drilling R&D is developing cost-cutting technologies for accessing geothermal resources. Well drilling and completion account for 30 to 50 percent of the capital cost of a geothermal power project, so reducing these costs is crucial if geothermal energy is to compete with conventional fuels.

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 the Diagnostics While Drilling project, using high-speed data links to provide real-time bottom-hole information about rock characteristics for immediate and better decision-making by the drillers. Recent accomplishments include:

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

- Through collaboration with industry, developed a mud-jet polycrystalline-diamond compact drill bit that drills moderately hard formations 30 percent faster than traditional bits.

- Began a collaborative project with industry to document and analyze actual 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.

To complement its geothermal R&D, DOE is conducting a significant effort, called GeoPowering the West, to remove non-technical barriers to geothermal development. Through 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.

Recent accomplishments across the program include:

- Installed a 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-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.

PIX10991 Sandia National Laboratories

The Mammoth Pacific geothermal plant (northern California), with air-cooled condensers on either side of the plant generators, located in the center.

- Developed a low-cost polymer coating (e.g., PPS) to be applied to inexpensive carbon steel in heat exchangers. For more information, see *Coating Technology Improves Performance* in this issue.
- Brought together energy stakeholders in several Western states for a GeoPowering the West state summit to discuss and resolve non-technical barriers to development.

The DOE Geothermal Technologies Program is already contributing tangibly and substantially to efforts that will help meet the important goals of the Bush Administration's National Energy Policy. And the potential for even greater contributions is more evident than ever before. By working in partnership with industry in these R&D areas, DOE is striving to have seven million homes and businesses using reliable, sustainable geothermal energy by 2015. ■

Meet Our New Program Director

In February 2003, Leland ("Roy") Mink became the new Director of the U.S. Department of Energy's (DOE) Geothermal Technologies Program. In Dr. Mink's new role, he will manage one of the eleven technology program offices that were created when the Office of Energy Efficiency and Renewable Energy (EERE) was reorganized.

Dr. Mink has held a wide range of positions in the public and private sectors, academia, and industry. He began his career as a hydrogeologist with the Idaho Bureau of Mines and Geology (1972-1975), and was associate professor of hydrogeology at Boise State University (1975, 1982-1985). Dr. Mink also served as a research geohydrologist for the U.S. Environmental Protection Agency in Las Vegas (1976).

DOE, Susan Norwood

The new program director is no stranger to the federal government, having served with DOE as a geothermal energy project manager in Washington, D.C., and Idaho Falls (1977-1980). He also has industry experience, working as a hydrologist and project engineer for Morrison-Knudson in Boise for most of the 1980s. Prior to accepting the DOE directorship, Dr. Mink was professor of hydrogeology at the University of Idaho-Moscow, and director of the Idaho Water Resources Research Institute.

Dr. Mink has a B.S. in math and science from Idaho State University, and an M.S. in hydrology and Ph.D. in geology from the University of Idaho.

Mammoth Pacific Power Plants, located in the eastern Sierra Nevada mountain range in California, showcases the environmentally friendly nature of geothermal power. PIX00062 Geothermal Resources Council

GeoPowering the West

GeoPowering the West is a commitment to dramatically increase the use of geothermal energy in the western United States.

The American West has been called our nation's "energy treasure chest" by some. If so, geothermal resources may be one of the largest and most valuable treasures in that chest. Western states including Alaska and Hawaii, hold a tremendous reserve of clean, reliable, renewable geothermal resources that can be used for both heat and power. According to testimony given by the United States Geologic Survey, known geothermal resources could provide more than 20,000 megawatts of clean power and more than five times that amount may be available from undiscovered geothermal resources in the United States.

In California, a state with the fifth largest economy in the world, 6 percent of the state's electricity is supplied by geothermal power plants. Beyond power, lower temperature geothermal resources that exist in every state can supply much needed heat without price volatility often associated with traditional fuels. This heat can be used for residential and commercial buildings, commercial greenhouses, fish farms, food processing facilities, gold mining operations, and a variety of other applications.

We've just begun to scratch the surface, so to speak, in tapping our reserve of geothermal resources. Only four states, California, Hawaii, Nevada and Utah, currently have geothermal electric power production. Across the West, there are 18 district-heating systems in seven states, 45 aquaculture facilities in eleven states; 40 greenhouse operations in nine states; and a handful of industrial or crop drying operations in Nevada, all using geothermal heat. A 1999 survey of 16 western states identified more than 12,000 thermal wells and springs, more than 1,000 low- to moderate-temperature geothermal resource areas, and hundreds of direct-use sites. The survey also

Geothermal plant located at Steamboat Springs, Nevada. PIX07211, Sierra Pacific

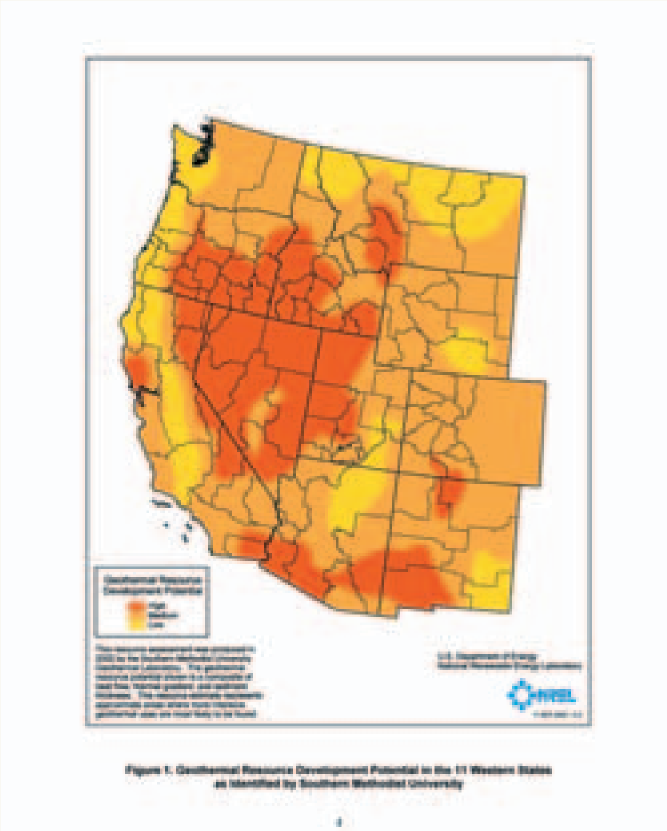
identified 271 collocated sites – cities within 5 miles (8 kilometers) of a resource hotter than 122°F (50°C) – that have excellent potential for near-term direct use. The potential for increased use of geothermal resources for direct heat applications is enormous.

To increase the use of U.S. geothermal resources, the Department of Energy (DOE) launched GeoPowering the West (GPW) in 2000. GPW is an education and outreach effort conducted through a partnership among the federal government, states, local communities, tribes, industry, and others to dramatically increase the use of geothermal heat and power in the U.S. GPW activities complement the DOE Geothermal Technologies Program R&D efforts by improving the market, fostering awareness, building policy support, and addressing institutional barriers to new geothermal development. GPW activities support the vision of the Geothermal Program to:

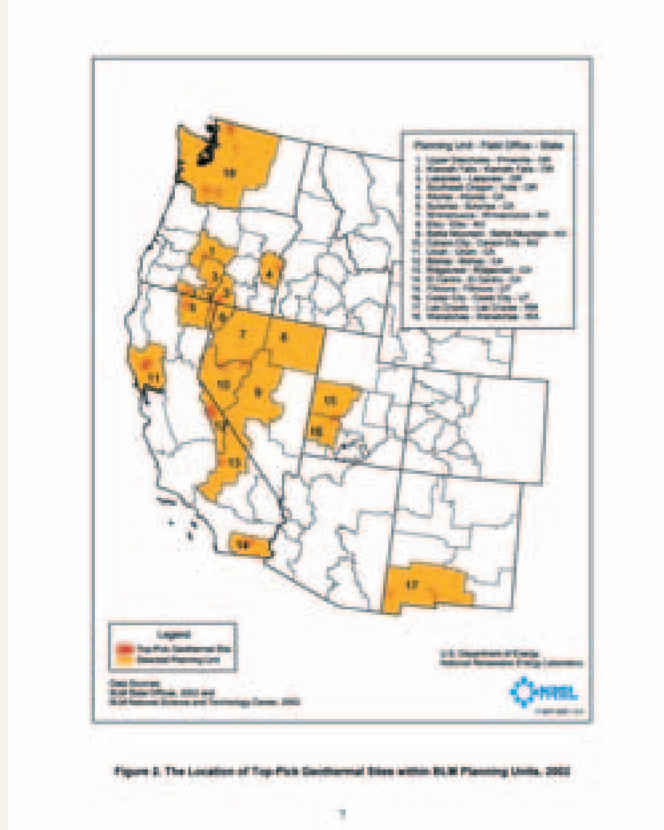
- Double the number of states generating geothermal electricity from four to eight by 2006; and
- Supply the heat or power needs of seven million Western homes and businesses by 2015.

A major emphasis of GPW is support to state geothermal working groups. In addition, GPW also supports public power partnerships, tribal geothermal development, and streamlining public land access. Susan Norwood, DOE coordinator for GeoPowering the West, says, "GPW is a critical component of our geothermal program. It supports the technical efforts of our laboratories and R&D partners by bringing together policy and decision makers to resolve the many institutional and non-technical barriers facing the geothermal community."

GPW is lead by a team of DOE staff who represent the Geothermal Technologies Program, three national laboratories (Idaho National Engineering and Environmental Laboratory – INEEL, National renewable Energy Laboratory – NREL, and Sandia National Laboratories – SNL), two EERE regional offices (Denver and Seattle), and the Western Area Power Administration (WAPA). Laboratory experts provide much of the technical assistance to stakeholders through GPW, but GPW also works



Source: Opportunities for Near-Term Geothermal Development on Public Lands in the Western United States (CD), page 4.



Source: Opportunities for Near-Term Geothermal Development on Public Lands in the Western United States (CD), page 7.

closely with other organizations in the geothermal and energy communities. The Geothermal Energy Association, the Geothermal Resources Council, the Geothermal Education Office, Bob Lawrence and Associates, the National Geothermal Collaborative, Washington State University, the National Council of State Legislators, and the Geo-Heat Center are all collaborators in helping DOE and GPW meet its goals of expanding geothermal development across the West.

State Geothermal Working Groups

Since its inception in 2000, GPW has sponsored several workshops and community meetings to educate the public about the benefits of geothermal and to foster discussion of issues that face geothermal stakeholders. GPW brings together experts in a variety of areas to address subjects including geothermal resource mapping, the state of geothermal technologies, economics and financing of geothermal projects, public lands, and state level policies and regulations affecting geothermal development. The audience is often policy-makers, state energy officials, utilities, advocacy groups, other federal officials, and industry.

The GPW team provides both technical and non-technical support for these workshops.

The outcome for the workshops is the formation in each state of a geothermal working group with the primary goal of advancing geothermal development in that state. To date, GPW has sponsored the formal development of geothermal working groups in Nevada, New Mexico, Idaho, Oregon, Utah, and Arizona and is looking forward in the near future to the establishment of working groups in Alaska, Hawaii, Washington, and California.

To provide information about geothermal resources, GPW works with technical experts and state geothermal working groups to define the needs of stakeholders in understanding the resource and the factors that affect access to it, such as transmission grids, roads, and political boundaries. The Idaho National Engineering and Environmental Laboratory has completed 13 state maps for the GPW effort: Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

Tribal Geothermal Development

Indian lands have long held known supplies of natural energy resources and geothermal energy is no exception. Scattered across the western states are many tribes who have geothermal springs and wells. A few of these tribes have built spas or heated

Roger Hil, Sandia National Laboratory

Idaho GPW Working Group tour of the Edwards Greenhouse in Boise.

pools or raised fish. But many more are aware of this resource and have considered its use, but have not taken the next step. This is where GPW helps.

By example, GPW has supported the Council of Energy Resource Tribes and other organizations at various workshops. At these events, tribal officials learn about the characteristics of geothermal applications. GPW has on several occasions even sent teams to tribal lands to assess first-hand the resource and ways to use it. This has happened with Jemez Pueblo, Eastern Shoshone, and the Walker River Paiute, all of who have direct geothermal use possibilities and the Pyramid Lake Paiute who also have a power generation opportunity. The Pyramid Lake Paiute have even teamed with the geothermal industry after a GPW team visit. Geothermal energy enables economic development while offering advantages over the use of fossil types of energy. Like land management officials with other types of governments, tribal leaders seek to take advantage of natural resources with an appropriate balance of economics and environment.

Public Power Partnerships

Many would agree that the lack of understanding of the impacts and benefits of geothermal energy to utility systems is a significant barrier affecting the future of geothermal development. It is one that must be addressed if GPW is to realize its goal of doubling the number of states generating electricity using geothermal sources. Utility stakeholders are often represented in the state geothermal working groups, but GPW also works directly with utilities and utility interest organizations such as the Power Marketing Administrations (WAPA and the Bonneville Power Authority/BPA) and the Public Renewables Partnership (PRP) to overcome transmission constraints and other utility issues related to geothermal energy.

There is an important message GPW brings to utilities in terms of the benefits of geothermal energy. Geothermal electricity can provide baseload electricity. It is not limited by the intermittent nature of other renewable energy sources and, therefore, is much more reliable in meeting fluctuations in energy demand. Geothermal plants typically operate at capacity factors of 90 percent. This means that a geothermal power plant is delivering close to its maximum output most of the time.

In 2002, GPW partnered with the Center for Resource Solutions, WAPA and others to form the Public Renewables Partnership. The PRP was organized to enable public utilities, co-operatives, and Tribal utility authorities to effectively integrate all forms of renewable energy into their power portfolios and business strategies. PRP's primary objective is to better inform utility decision makers about renewable energy technology options and potentials.

In addition to the efforts organized by PRP, the Western Area Power Administration is leading activities on behalf of GPW such as conducting workshops and studies that deliver the message of geothermal energy to public utilities. GPW is looking forward to developing new partnerships with organizations in the utility community to carry the message even further.

The National Geothermal Collaborative

A U.S. consensus-based collaborative, the National Geothermal Collaborative (NGC), was formed in 2002, with assistance from DOE, to identify issues that impede the use of geothermal power, establish dialogue among key stakeholders, and catalyze activities to overcome obstacles to appropriate development.

The NGC is led by a Steering Committee whose membership to date includes representation from both investor-owned and public utilities, academia, state energy offices, White House Task Force on Energy Project Streamlining, Center for Energy Efficiency and Renewable Technologies, Council of Energy Resource Tribes, Geothermal Resource Council and Geothermal Energy Association, Departments of Interior, Agriculture and Energy, and the National Conference of State Legislatures (workgroups convene around issues identified as important to address).

The NGC encourages stakeholders to learn more about its activities. For more information, see the NGC website at: ***www.geocollaborative.org.***

Public Land Access

In the past, access to the enormous amount of our nation's geothermal resource that exists on public lands has been a barrier to new geothermal development. This situation has improved dramatically in the last few years. Particularly in states like Nevada, where public lands comprise nearly ninety percent of the state, the federal government has made great efforts to improve and streamline the process for gaining access to geothermal resources.

In November 2000, GPW sponsored a workshop on geothermal siting issues on public lands to examine the issue more closely. Representatives of the geothermal industry and state and federal land agencies participated and concluded that actions should be taken to improve geothermal siting processes on public lands. In addition, the President's National Energy Plan of May 2001, recommended "that the President direct the Secretaries of Interior and Energy to re-evaluate access limitations to public lands in order to increase renewable energy production, such as biomass, wind, geothermal and solar."

To meet these recommendations, the DOE, through GeoPowering the West, formed a partnership with representatives of the Bureau of Land Management (BLM) Geothermal Program.

In April 2001, the two agencies published a joint report entitled Opportunities for Near-Term Geothermal Development on Public Lands in the Western United States.

The report is an assessment identifies 35 public-land sites in the West as having good potential for near-term development of geothermal power. There were two objectives for this assessment:

1. To assess the potential for geothermal, wind, solar, biomass, and low-impact hydropower resources on BLM lands; and

2. To identify BLM planning units in the western United States with the highest potential for development by industry of power production facilities based on renewable energy.

This report provides information to BLM in order to kick-start industry's access to public lands for renewable energy development. Paul Dunlevy, National Geothermal Program Leader of BLM, said, "Geothermal energy can significantly contribute to our national energy supply. This joint DOE/BLM report shows that the Department of Energy and the Department of Interior are working together to accomplish something positive for the nation. It demonstrates the initiative of both departments to advance progress of President Bush's National Energy Policy."

Lake Mead

The 35 sites were selected upon analysis of the existing data and determined to have the highest and easiest potential for private sector development of renewable resources. The report is based on existing information and does not represent all good potential sites. Ten sites were identified in Nevada, nine in California, seven in Oregon, and three each in New Mexico, Utah, and Washington. Jointly released by DOE Assistant Secretary David Garman and Assistant Interior Secretary Rebecca Watson, the report is "part of a broader effort to reduce U.S. dependency on foreign energy," said Watson.

Two-thirds of the 35 sites either have been environmentally reviewed or are currently under review. Nevada Senator Harry Reid, a long-time supporter of geothermal energy, said at the press conference, "I have been saying for years that Nevada is the Saudi Arabia of geothermal energy, and I am pleased that the Interior and Energy Departments have reinforced that claim."

The DOE/BLM geothermal report is a companion to a broader DOE/BLM report titled, Assessing the Potential for Renewable Energy on Public Lands. The purpose of that report is to help federal land managers make decisions on prioritizing land-use activities that will increase development of renewable energy resources on public lands in the West (except Alaska). BLM and the National Renewable Energy Laboratory prepared the report. In announcing the report, Energy Secretary Spencer Abraham said,

> *"The Department of Energy is pleased to provide the technical renewable energy expertise to our national laboratories to the Bureau of Land Management. Federal agencies can lead by example to improve America's energy security by helping renewable industries bring domestic energy resources to market."*

Sources of renewable energy addressed in the report include wind, solar (photovoltaic and concentrating), biomass, and geothermal. The report found that 63 BLM planning units in 11 western states have high potential for power production from one or more renewable energy sources. Twenty BLM planning units in seven Western states have high potential for power production from three or more renewable energy sources.

(For a downloadable copy of the geothermal report on the 35 highest-potential sites, including its many full-color maps, charts, and posters, please go to ***www.eere.energy.gov/geothermal/geopressroom.html.***) ■

Direct Use Equals Smart Use

PIX13000 NREL, Robb Williamson

Many communities and businesses in the western United States are showing the way, saving large sums of energy and money while using "direct-use" geothermal resources.

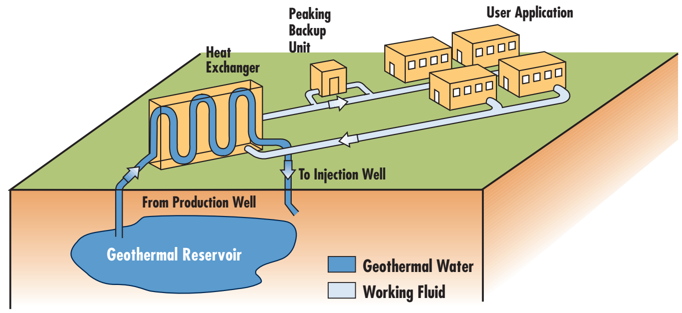
Heat that Comes Directly from the Earth

Low-temperature geothermal resources exist throughout the western U.S., and there is tremendous potential for new direct-use applications. A recent survey of 16 western states identified almost 12,000 thermal wells and springs, more than 1,000 low- to moderate-temperature (68° to 302°F, or 20° to 150°C) geothermal resource areas, and hundreds of direct-use sites.

Direct use of geothermal resources is the use of underground hot water to heat buildings, grow plants in greenhouses, dehydrate onions and garlic, heat water for fish farming, pasteurize milk, and for many other applications. Some cities pipe the hot water under roads and sidewalks to melt snow. District heating applications use networks of piped hot water to heat buildings in whole communities.

Directly using geothermal energy in homes and commercial operations is much less expensive than using traditional fuels. **Savings can be as much as 80 percent over fossil fuels.** It is also very clean, producing only a small percentage (and in many cases none) of the air pollutants emitted by burning fossil fuels.

The Idaho State Capitol Building (Boise) uses the city geothermal district-heating system.



Graphical representation of a geothermal district-heating system.

Direct-use systems are typically composed of three components:

- A production facility – usually a well – to bring the hot water to the surface;
- A mechanical system – piping, heat exchanger, controls – to deliver the heat to the space or process; and
- A disposal system – injection well, storage pond, or river – to receive the cooled geothermal fluid.

According to the Oregon Institute of Technology's Geo-Heat Center (DOE-funded), there are nearly 2,500 potential geothermal wells located within five miles of towns and medium-sized cities throughout 16 western states. If these "collocated" resources were used only to heat buildings, the cities have the potential to displace 18 million barrels of oil per year!

Historically, most of the communities that were identified have experienced some development of their geothermal resources. However, depending on the characteristics of the resource, the potential exists for increased geothermal development for applications such as space and district heating, resort/spa facilities, aquaculture, industrial and greenhouse operations, and possible electrical generation in some areas.

Use of heat pumps with low-temperature geothermal resources can be very cost-effective, and can really extend the usefulness of the resource. For example, the College of Southern Idaho (CSI) uses two 36-ton heat pumps to provide supplemental space heating in a building that houses CSI's Health and Human Services Program. These two heat pumps have performed so well that an additional sixteen 36-ton heat pumps have been installed in another facility to extract more useful energy from the school's geothermal resource.

Two 36-ton heat pumps being used for space heating at the College of Southern Idaho.

District and Space Heating

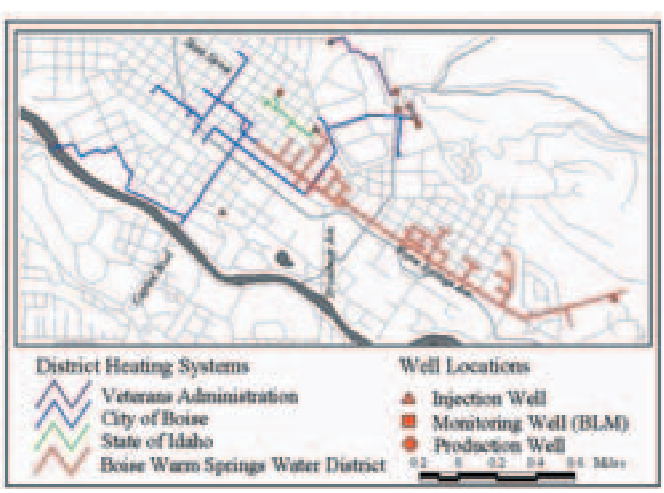
A growing and attractive use of low-temperature geothermal resources is in district and space heating. District heating systems distribute hydrothermal water from one or more geothermal wells through a series of pipes to numerous individual houses and buildings, or blocks of buildings. Space heating typically uses one well per structure, but can use more than one well. In both district and space heating systems, the geothermal production well and

PIX08827 Geo-Heat Center

In Klamath Falls, Oregon, a geothermal district-heating system keeps the sidewalks clear and dry at the Basin Transit station after a snowfall.

distribution piping replace the fossil fuel–burning heat source of the traditional heating system.

Savings are achieved not only by eliminating the need for conventional heating energy, but also through elimination of the need for equipment (e.g., boilers and gas vents) and interior space for this equipment. Most district systems also provide chilled water for building cooling (using conventional, but high-efficiency, modular equipment), and these savings can be substantially greater than heating bill savings because of the greater cost of electricity compared to heating fuels.



Boise geothermal district-heating system map.

Boise District Heating, Idaho

In 1892, two companies competed furiously for Boise's water system contract. One company, the Boise Water Works, sweetened its proposal by declaring the preposterous idea that it would distribute both cold and hot water. They got the contract, and Boise has used its geothermal resources ever since.

Today, that system is one of four geothermal district heating systems in Boise: the Boise Warm Springs, Water District System (the original), the Boise City System, the Veterans Administration Hospital System, and the State of Idaho Capitol Mall System (all three installed in the 1980s). Three hundred and sixty-six buildings are heated by these four geothermal systems. That's 4,426,000 square feet (411,189 square meters) – equal to about 1,770 houses. Boise has the only state capitol building in the U.S. that is heated by geothermal water.

In 1998, the city of Boise signed a Cooperative Agreement with DOE that provided $870,000 for the construction of an injection well for the city's geothermal heating system. The goal of the project is to hydraulically replenish the geothermal aquifer the city shares with the Boise Warm Springs Water District, the Veterans Administration hospital, and the state of Idaho Capital Mall buildings, and to reduce the discharge of spent geothermal water to the Boise River.

The people of Idaho also use geothermal resources for other direct uses (see *Idaho's Buried Treasure*). In 1930, Idaho's first commercial greenhouse use of geothermal

PIX03694 Geo-Heat Center, Oregon Institute of Technology

Heat exchangers and circulation pumps for the geothermal district-heating system in Klamath Falls, Oregon.

PIX03706 Geo-Heat Center, OR Institute of Technology

Geothermal energy is ideal for dehydration operations (onions and garlic), as seen in Empire, Nevada.

energy was undertaken. The system still uses a 1,000-foot (305-meter) well drilled in 1926. At least 14 other greenhouses now operate in Idaho. Geothermal aquaculture is also popular. Nine fish farms raise tilapia, catfish, alligators, and other fauna. “Using geothermal resources makes sense because they are clean, less expensive than other sources, and renewable,” says Ken Neely of the Idaho Department of Water Resources, “Geothermal resources could become even more important in Idaho as demands for energy increase.”

Klamath Falls District Heating, Oregon

The city of Klamath Falls, Oregon, geothermal district-heating system was constructed in 1981 to initially serve 14 government buildings, with planned expansion to serve additional buildings along the route. The original and continuing municipal purpose of the district heating system is to serve building space heating requirements.

The district heating system was originally designed for a thermal capacity of 20 million Btu/hr (5.9 MW thermal). At peak heating, the original buildings on the system utilized only about 20 percent of the system thermal capacity, and revenue from heating those buildings was inadequate to sustain system operation. This led the city to begin a marketing effort in 1992 to add more customers to the system. Since 1992, the customer base has increased substantially, with the district heating system serving several additional buildings.

PIX04133 Jeff Hulen

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

Geothermally heated sidewalks and crosswalks have been incorporated into a downtown redevelopment project along Main Street, starting with the 800 block in 1995. That same snowmelt system has been extended to cover nine blocks of sidewalks and crosswalks. The heated sidewalk and crosswalk area currently served by the city snowmelt system is over 60,000 square feet (18,288 square meters).

Reno and Elko, Nevada

Nevada is also a hotbed of geothermal development, with applications growing rapidly in this resource-rich geothermal state. Modern geothermal energy use in Nevada began in 1940 with the first residential space-heating project in Reno. Today, almost 400 homes use geothermal energy for heat or hot water in Warren Estates and Manzanita Estates. These two housing developments, located in southwest Reno, Nevada, comprise the largest residential geothermal space-heating district in Nevada.

Production well depths range from 700 to 800 feet (213 to 244 meters) with temperatures in excess of 200°F (98˚C). Geothermal water is pumped at a rate of 250 to 350 gallons-per-minute (gpm) (1,137 to 1,591 liters-per-minute) from one of two production wells to flat-plate heat exchangers at the surface. Hot water at about 180°F (82°C) is circulated from the heat exchangers to the subdivisions via underground pipes. All geothermal water is injected back into the reservoir through a well located on the premises.

Elko is another Nevada community with a long-standing history using geothermal heating. In 1978, the first geothermal food-processing plant was opened in Brady Hot Springs. More than 25 million pounds (11.3 million kilograms) of dehydrated onion and garlic are being processed annually.

Elko Heat Company has been operating a geothermal district heating system in Elko, Nevada, since December 1982. The Elko Heat Company project was funded by DOE in the late-1970s, and continues to operate successfully today. This system is a direct-use application and serves 17 customers, and distributes approximately 80 million gallons (364 million liters) of 178°F (81°C) geothermal water annually. Customers are primarily using the geothermal water for space heating and domestic hot water heating. Two customers are using their return water for wintertime snow and ice melting on walkways, and one is using a heat pump system.

Cactus production at the Southwest Technology Development Institute (SWTDI), Las Cruces, New Mexico.

Aquaculture and Horticulture

Greenhouses and aquaculture (e.g., fish farming) are the two primary uses of geothermal energy in the agribusiness industry. Most greenhouse operators estimate that using geothermal resources instead of traditional energy sources saves about 80 percent of fuel costs – about 5 to 8 percent of total operating costs. The relatively rural location of most geothermal resources also offers advantages, including clean air, few disease problems, clean water, a skilled and available workforce, and, often, low taxes.

New Mexico is appealing to the greenhouse industry for several reasons, including a good climate, inexpensive land, a skilled agricultural labor force, and the availability of relatively inexpensive geothermal heat. New Mexico has taken the nation's lead in geothermal greenhouse acreage with more than half of the state's acreage now heated by geothermal resources. And there are also many successful, thriving geothermal direct-use greenhouses in other western states (see Geo-Heat Center website at: ***geoheat.oit.edu/***).

New Mexico has the nation's two largest geothermal greenhouses and a total of 50 acres (20.2 hectares) of greenhouses that are heated with geothermal energy. This represents a payroll of more than $5.6 million and sales of $20.6 million. Nearly all of the greenhouse sales are to out-of-state buyers. In addition, the largest geothermal greenhouse pays royalties to the state for geothermal production, and the smallest geothermal greenhouse pays Federal royalties for geothermal heat.

Altogether, the projected new greenhouse acreage and business startups by 1997 represented a capital investment of more than $21.5 million, with sales of nearly $26.1 million. Nearly 500 new jobs are the result. Annual energy savings to the greenhouse operators, using geothermal energy, approaches $1 million.

The largest geothermal greenhouse in the nation is the Burgett Geothermal Greenhouse near Animas in southwestern New Mexico. This 32-acre (13-hectare) facility produces high-quality cut roses that are marketed widely, contributing substantially to county tax receipts, and creating local jobs.

PIX13097 NREL

This is an example of a geothermal "direct-use" application in horticulture in Idaho (Mountain States Plants, Flint Greenhouses).

Aquaculture

AmeriCulture Fish Farm

AmeriCulture Inc., located in Animas in southwest New Mexico, is among the largest domestic suppliers of tilapia fingerlings and is able to produce between four and seven million fingerlings annually. AmeriCulture markets and sells a disease-free tilapia fry to growers and researchers nationwide for grow-out to full size. Tilapia is a fish that is growing in popularity for its taste. AmeriCulture ships male tilapia fingerlings by UPS throughout the country. In recent years, local Red Lobster™ seafood restaurants have added tilapia from AmeriCulture to the menu.

Tilapia is growing in popularity for its mild taste.

Geothermal offers several advantages for fish culture. For example, AmeriCulture facilities are heated at much lower costs, compared to fossil fuels like propane, with a downhole heat exchanger installed in a 400-foot (122-meter) depth well. Many species have accelerated growth rates in warm water, adding to energy-saving advantages.

Horticulture

Masson Radium Springs Farm

The Masson Radium Springs Farm geothermal greenhouses are located on private land in southern New Mexico 15 miles (24 kilometers) north of Las Cruces. The operation started in 1987 with four acres of geothermally heated greenhouses. Masson selected New Mexico and the Radium Springs area to take advantage of the sunshine, ease of climate control because of the dry desert air, a willing and trainable work force, and geothermal heat. Today, the greenhouses employ 110 people, and cover

Masson Radium Springs Farm greenhouse in New Mexico. NREL, Rob Williamson

16 acres (6.5 hectares) in two major modules, each with shipping and warehousing buildings attached. The Masson Radium Springs Farm geothermal greenhouses produce more than 30 groups of potted plant products, including seasonal products such as poinsettias and carnations.

The greenhouse space is heated by geothermal energy from three wells that are located on private land. Two are shallow wells less than 350-foot (107-meter) depth, and produce 165°F (74°C) water. The third well was drilled about two years ago to 800-foot (244-meter) depth, and produces water at 199°F (93°C). The water is stored in a newly constructed 167,000-gallon (760,000-liter) storage tank used mainly for nighttime heating. After use, the geothermal water is injected back into three shallow (less than 250-foot/76-meter depth) injection wells.

Mountain States Plants

Flint Greenhouses, owned and operated by Mountain States Plants, and located in the Hagerman Valley of southern Idaho, uses geothermal fluid ranging in temperature from 98° to 110°F (37° to 43°C) for greenhouse heating. The two-acre (0.8-hectare) greenhouse facility achieves an estimated annual savings of about $100,000 over propane gas, representing a significant competitive advantage on operating costs. Compared to Mountain States Plant's other two greenhouse operations (not geothermally heated), the Flint Greenhouses delivers the best cost-per-square-foot operating performance. About 20 permanent employees and 10 to 15 seasonal employees work at the Flint Greenhouses raising potted plants.

DOE Support and Assistance

Through its support of the Geo-Heat Center (website at *geoheat.oit.edu/*) at the Oregon Institute of Technology in Klamath Falls, Oregon, DOE conducts research, provides technical assistance, and distributes general information on a wide range of geothermal direct-use applications. The center is the primary source of data and information about all types of direct-use operations. Those interested are encouraged to contact this organization by the Internet or by phone (541-885-1750) for technical assistance and consumer information. ■

Idaho's Buried Treasure – Geothermal Energy

Homegrown, abundant, secure energy right beneath the ground.

Idaho holds enormous reserves – among the largest in the United States – of this clean, reliable form of energy that to date have barely been tapped. According to U.S. Geological Survey estimates, Idaho ranks seventh among the 50 states in geothermal energy potential. **These resources could provide up to 20 percent of Idaho's heat and power needs.**

Idaho State Historical Society (73-2.52)

The Natatorium was a landmark in Boise.

Geothermal resource map of Idaho, showing areas in pink with potential for direct-use applications (mostly lower half of State).

Idaho's history of geothermal use begins with Native Americans who congregated at hot springs, as indicated by artifacts and petroglyphs on nearby rocks. Settlers, miners, and trappers also used hot springs by the mid 1800s. In 1892, the nation's first district heating system was birthed in Boise (see *Direct Use Equals Smart Use*). Geothermal water was put to use along Warm Springs Road to heat over 200 buildings including homes, businesses, and the Boise Natatorium, a 65 by 125-foot (20 by 38-meter) swimming pool.

The district heating system is still in operation and has been joined by three more district heating systems in the Boise area. The current city system is used to heat about 2.7 million square feet (250,838 square meters) including the City Hall, the new Ada County Courthouse, and over 40 businesses. The water is extracted from several wells that range in depth from 880 to 1,900 feet (268 to 580 meters). Water production temperature is about 175°F (80°C). Most of the used geothermal water is re-injected about a mile to the southwest of the wellfield.

In 1930, Edward's Greenhouses became the first commercial greenhouse operation in the United States to use geothermal water for a heat source to grow plants. The facility still exists and prospers today. Several other greenhouse businesses were developed throughout southern Idaho in the next half-decade to take advantage of the natural hot water available in many places.

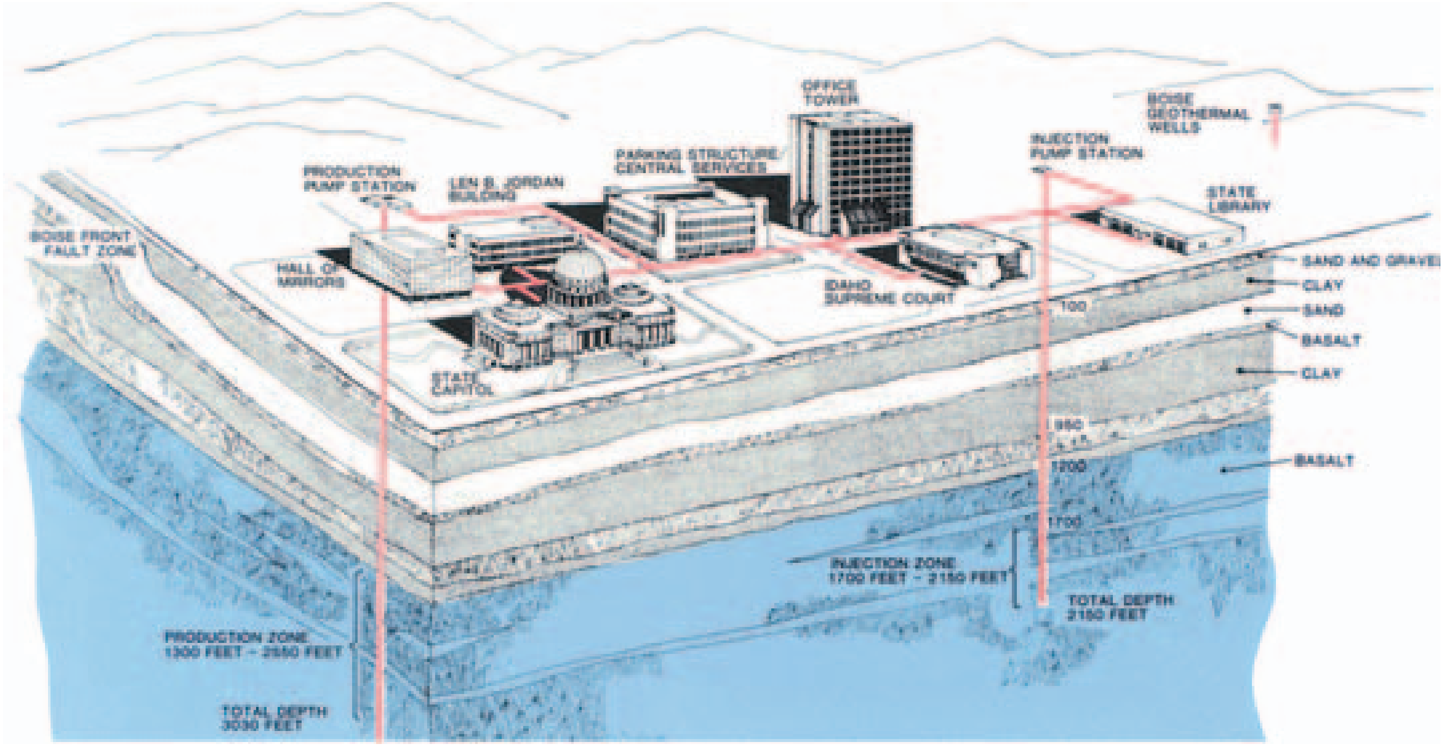
In 1979, the College of Southern Idaho (CSI) drilled the first geothermal well on its campus in Twin Falls. During the 1980s, district heating operations were put in place in Twin Falls and Ada counties.

The Ada County Courthouse in Boise, Idaho, uses the city geothermal district-heating system. PIX13078 NREL

The Idaho State Capitol Building in Boise is heated by the city geothermal district-heating system. PIX13100 NREL

CSI drilled a second geothermal well in 1981. Throughout the 1980s, CSI converted their existing heating system into a geothermal heating system by laying the underground supply and return lines, retrofitting the existing buildings, and installing heating systems in the new buildings. The heating system serves 12 buildings and 4 greenhouses, with over 440,000 square feet (40,877 square meters) of facilities kept warm by geothermal energy. About 35,000 square feet (3,252 square meters) of this area is conditioned with two 36-ton heat pumps using geothermal fluid. Water temperature from the two production wells is about 101°F (38°C). The system currently produces about 209 million gallons (950 million liters) per year. The spent water is discharged over the south rim of the Snake River Canyon.

In the early 1980s, the State of Idaho drilled two wells in the vicinity of the Capitol Building. By 1982, the State of Idaho geothermal system was supplying heat to nine buildings in the Capitol Mall complex, including the State Capitol. Currently, the system is used to heat about 4,426,000 square feet (411,189 square meters).



The Capitol Mall geothermal district-heating system, Boise, Idaho.

PIX13108 NREL

Geothermal production well at the College of Southern Idaho, Twin Falls. This district-heating system now heats nearly half a million square feet (46,450 square meters), with more area reached by this winter with 16 heat-pump units.

Geothermal interest has grown in Idaho since the early 1990s. In the mid 1990s, a computer modeling study was conducted for the Boise geothermal system in an effort to predict how different production scenarios might affect water levels and temperatures. In 1999, the City of Boise began re-injecting its used geothermal water into the aquifer through a newly completed (cost-shared with DOE) injection well. Since 1999, water levels in a nearby monitoring well have risen significantly and in a manner similar to modeling predictions.

These resources could provide up to 20 percent of Idaho's heat and power needs!

Although there has been a great deal of development of geothermal energy in Idaho, considering its small population and large land mass, the potential for further use of this resource is great. Development of geothermal energy resources for various applications has proven to be a positive economic impact for Idaho. ■

Fish Breeders of Idaho

In 1973, Leo Ray became the first person to use geothermal water to raise catfish in the Hagerman Valley near Buhl, located in the Snake River Valley in southern Idaho. In fact, Mr. Ray may have been the first person in Idaho to put geothermal resources to work for fish farming, raising tilapia, sturgeon, blue-channel catfish, and rainbow trout.

Mr. Ray's site has hot artesian wells that produce abundant quantities of 95°F (35°C) water. Mixing this hot water with crystal-clear cold springwater produces the ideal temperature for growing these fish. The climate is too cold and the growing season too short to grow these aquatic species without hot water. Geothermal water changes a non-commercial area into a 365-day optimum growing season.

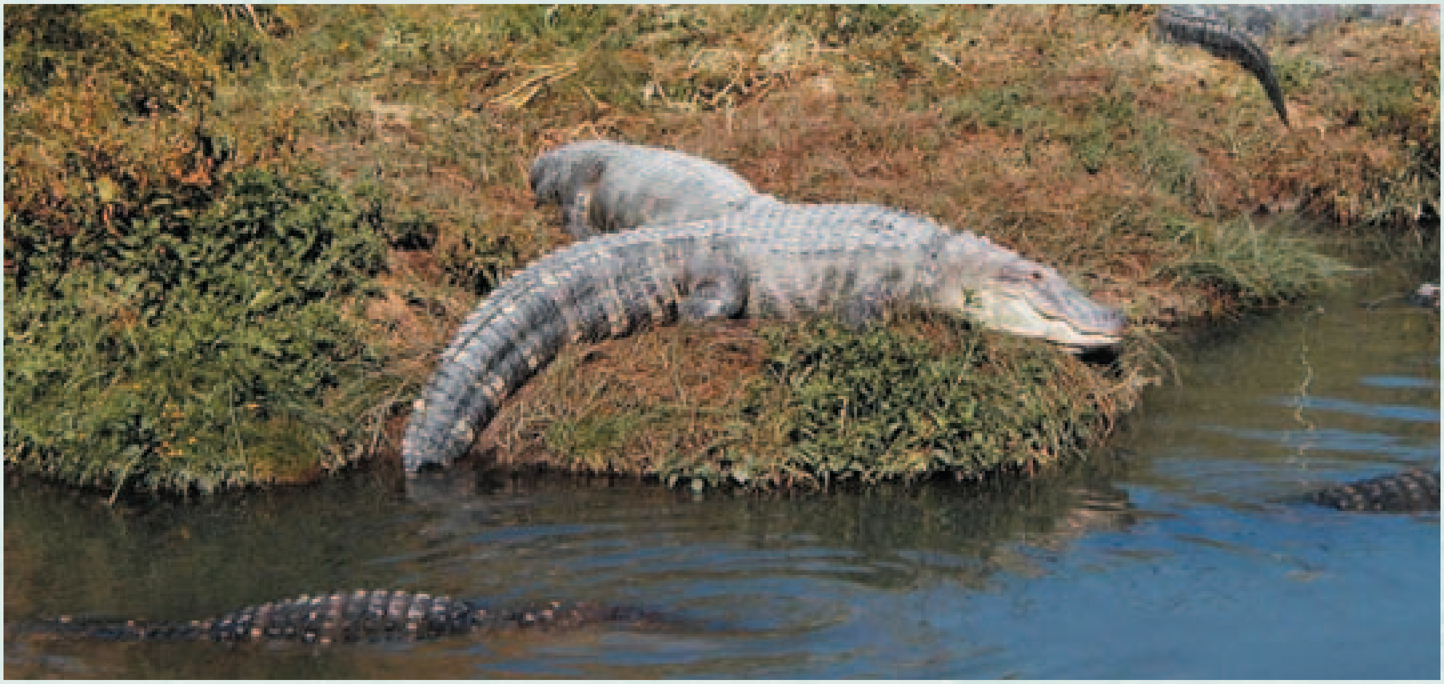
After processing onsite, the fish are shipped daily to supermarkets and restaurants throughout the United States and Canada. Mr. Ray also raises alligators with geothermal water – 2000 alligators! Some of the alligator hides are even sold to Gucci™ for women's purses. (For more details, see GATORS IN THE SAGE, *geoheat.oit.edu/bullletin/bull23-2/art2.pdf*, Geo-Heat Center Quarterly Bulletin, Vol. 23 #2.)

PIX13089 NREL

Leo Ray in front of geothermally heated cascading fish raceways. Geothermally heated water accelerates fish growth.

PIX13018 NREL, Rob Williamson

Tilapia fingerlings being raised in Idaho with the aid of geothermal energy.



NREL, Bruce Green

Mature alligators at Fish Breeders of Idaho – without geothermal heat, they could not survive in Idaho.

Enhanced Geothermal Systems

The Navy I geothermal power plant near Coso Hot Springs, California.

PIX07667 J.L. Renner, INEEL

How to extract more energy and power from geothermal resources

The Coso geothermal project, located in California's Coso volcanic field and about 100 miles (161 kilometers) north of Los Angeles, produces 260 megawatts of geothermal energy. Without tapping into any new geothermal resources (just by fracturing the existing reservoir), Coso will soon produce another 20 megawatts of electricity. The additional power will come from applying technology designed to improve the production of fields like Coso. Known as enhanced geothermal systems (EGS), this technology should more than double the amount of recoverable geothermal energy in the U.S., as well as extend the productive life of existing geothermal fields.

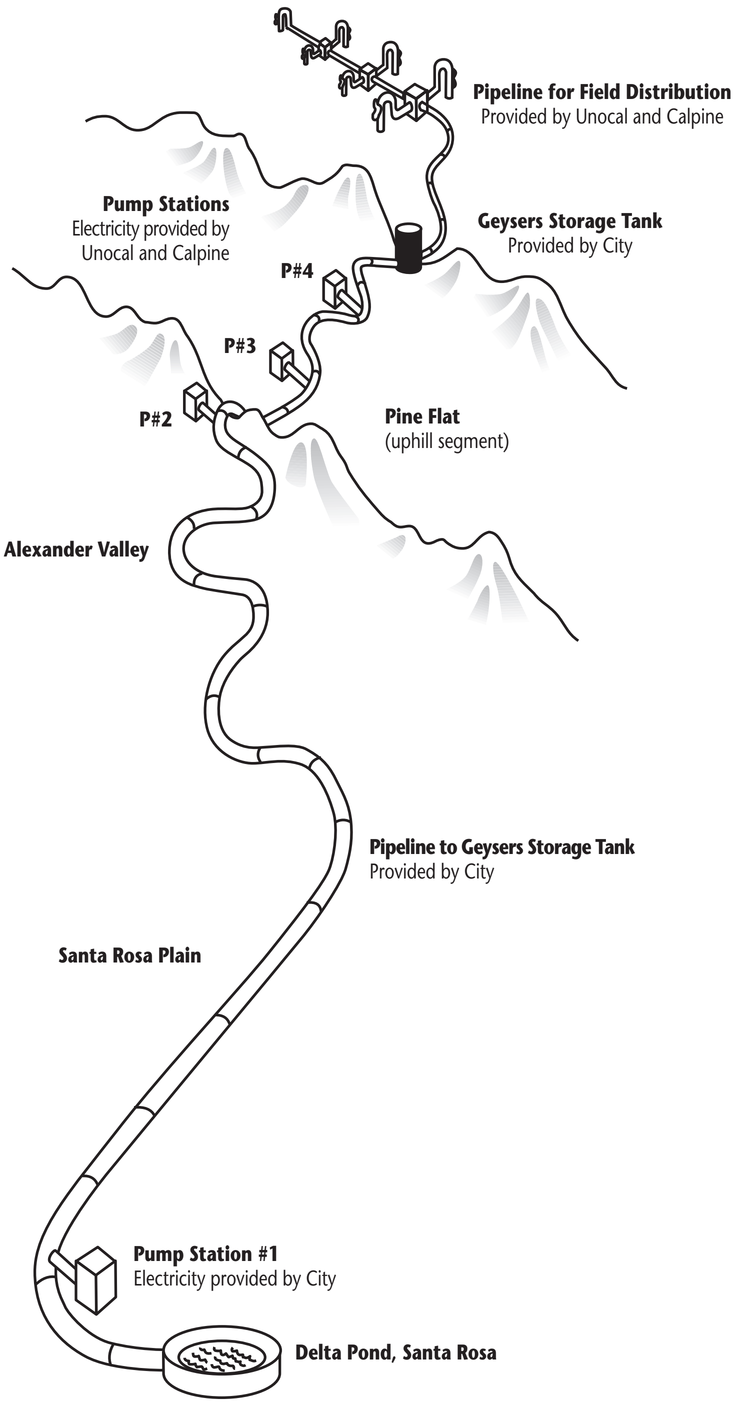
EGS Benefits
- Increased Productivity
- Extended Lifetime
- Expanded Resources
- Siting Flexibility
- Sizing Flexibility
- Environmental Advantages

With EGS, a new reservoir is targeted within a volume of rock that is hot, tectonically stressed, and fractured. However, due to secondary-mineralization processes, those fractures have sealed over time, resulting in low permeability and little or no production of fluids. Through a combination of hydraulic, thermal, and chemical processes, the target EGS reservoir can be 'stimulated,' causing the fractures to open, extend, and interconnect. This results in the creation of a conductive fracture network and a reservoir that is indistinguishable from conventional geothermal reservoirs. EGS technology could serve to extend the margins of existing geothermal systems or create entirely new ones, wherever appropriate thermal and tectonic conditions exist.

The enhanced production at Coso will come as DOE's partners at the University of Utah's Energy & Geoscience Institute (EGI) and Caithness Corporation pump water under high pressure into a portion of the Coso field to reopen sealed fractures in subsurface rocks. Water pumped into the ground from injection wells will then circulate through the fractured rocks, flow to the surface through existing geothermal wells, and drive steam turbines. The process, called "hydrofracturing," is commonly used in oil and gas production. "We are attempting to tap into less permeable and less productive margins of existing geothermal systems," according to Peter E. Rose, coordinator of the Coso EGS project at EGI. For up-to-date information on this project, see the Coso EGS website at: ***egs.egi.utah.edu/indexcoso.htm***.

Geysers Project, California
The Geysers, about 120 miles (193 kilometers) north of San Francisco, is the world's largest dry-steam geothermal steam field, reaching peak production in 1987, at that time serving 1.8 million people. Since then, the steam field has been in gradual decline as its underground water source decreases. Currently, The Geysers produce enough electricity for 1.1 million people.

EGS techniques will also increase the production and extend the life of The Geysers geothermal steam field. At The Geysers, Calpine Corporation and the Northern California Power Agency have found a way to generate more electricity without tapping additional geothermal resources. They are recharging existing reservoirs with treated wastewater from nearby communities. The companies, in partnership with the City of Santa Rosa, have built about 40 miles (64 kilometers) of pipeline to carry treated city wastewater to The Geysers.



PIX00060 Pacific Gas & Electric

A view of several geothermal power plants at The Geysers, northern California (showing water-vapor emissions during normal cooling operation).

The wastewater from the Santa Rosa project will be injected into underground wells at a depth of 7,000 to 10,000 feet (2,134 to 3,048 meters), and at a rate of 11 million gallons (50 million liters) a day for the next 30 years. This water will be naturally heated in the geothermal reservoir, and the resulting steam will be used in nearby power plants to produce electricity. The project should increase electrical output by 85 megawatts, enough for about 85,000 homes.

A similar project with the Lake County Sanitation District called the Southeast Geysers Wastewater Recycling System has been operating successfully since 1997. This system delivers about 2.8 billion gallons (10.6 billion liters) of effluent annually, and has delivered more than 16 billion gallons (60.5 billion liters) of fluid to The Geysers since operations began. This project was described in the 1999 *Geothermal Today* in an article titled *Turning Wastewater into Clean Energy.*

EGS seeks to tap a continuum of geothermal resources, ranging from conventional hydrothermal resources to hot dry rock. Nature has been prolific in providing large quantities of heat in the earth's crust, but fluids and permeability are less abundant. With EGS, we hope to "engineer" new and improved reservoirs, and foster the economic production of that heat over long periods of time. Similar research and demonstration efforts are well underway in Europe (websites at **www.dhm.ch/dhm.html** and **www.soultz.net**) and Australia (website at: **hotrock.anu.edu.au**), and show the promise of EGS technology worldwide.

EGS technology will initially enable greater efficiency and sustainability in the extraction of heat energy from producing hydrothermal fields. The technology developed will also set the stage for eventually recovering the abundant heat contained in areas not associated with commercial hydrothermal fields, but with huge resource potential. This broadening use of geothermal resources will strengthen security and develop needed, clean, domestic energy resources. ■

DOE Program Goal – Enhanced geothermal systems should increase geothermal production to 20,000 MW by 2020.

EGS Around the West

Located in Siskiyou County, California, about 30 miles (48 kilometers) south of the Oregon border, Calpine Siskiyou Geothermal Partners is developing and demonstrating new EGS techniques. Specifically, they are developing stimulation technology to extract energy from reduced permeability zones around geothermal wells. This EGS project is part of a larger development that could result in two geothermal power plants that each produces 50 megawatts of electricity. The plant goes online in 2004, and Calpine already has a power purchase agreement with Bonneville Power Administration.

PIX 07655 Joel Renner, INEEL

The Steamboat geothermal power plant, originally built and now owned by ORMAT, in Steamboat Springs, Nevada.

ORMAT Nevada, Inc., a major geothermal operator, plans to apply EGS techniques at a prospective geothermal site east of the operating Desert Peak geothermal field in Churchill County, Nevada. They will fracture a low permeability zone under the ground to enable production of an estimated 2 to 5 megawatts of electricity. If successful, this project could have wide application to other geothermal sites in the Great Basin, due to the many similarities of subsurface features throughout this geologic province.

The DOE will share the cost of the Phase I feasibility study of a three phase, five-year program to develop a commercial EGS power plant project. ORMAT's objective will be to develop and demonstrate EGS techniques at its geothermal leasehold area, east of the existing Desert Peak Geothermal Facility in Churchill County, Nevada. The objectives of subsequent phases of this project will be the drilling, logging, hydraulic fracturing, and testing of the reservoir, followed by the construction and operation of a facility employing EGS technology for commercial power generation.

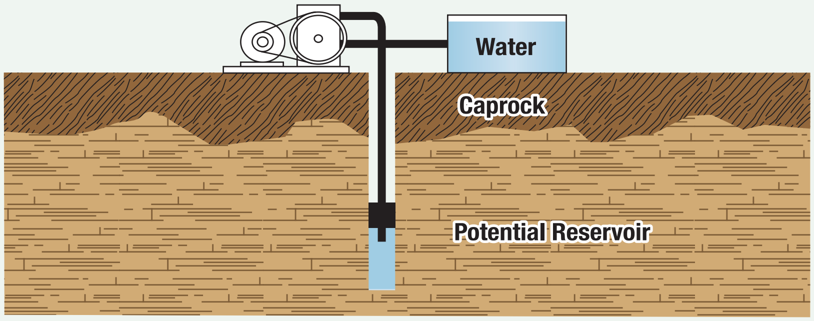
The project seeks to demonstrate that: 1) hydraulic fracturing technology can be applied commercially to geothermal systems; 2) adequate analytical techniques (such as subsurface stress analysis, fracture definition through seismic monitoring, numerical simulation of fluid flow and heat transfer in fractured media, etc.) required for an EGS project are already available; 3) neither water loss nor cooling of the produced fluid is a prohibitive barrier to a well-designed EGS project; and 4) commercial power can be generated reliably from an EGS project. The project relies upon proven technology for reservoir characterization and routine wellfield/power plant operation, and the application of existing fracturing technology to EGS.

How

an Enhanced Geothermal System works

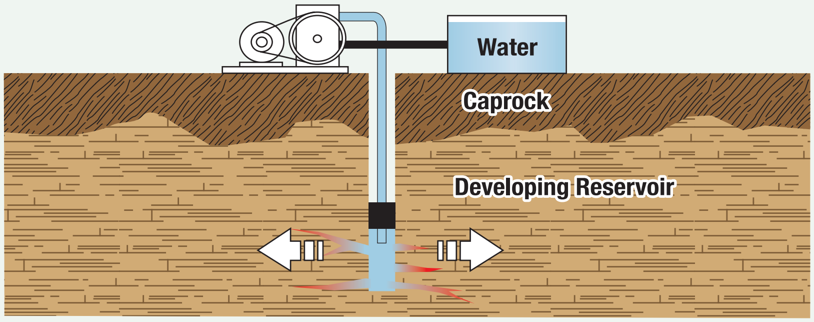
1 Drill an Injection Well

A production-injection well is drilled in hot rock that has limited permeability and fluid content.



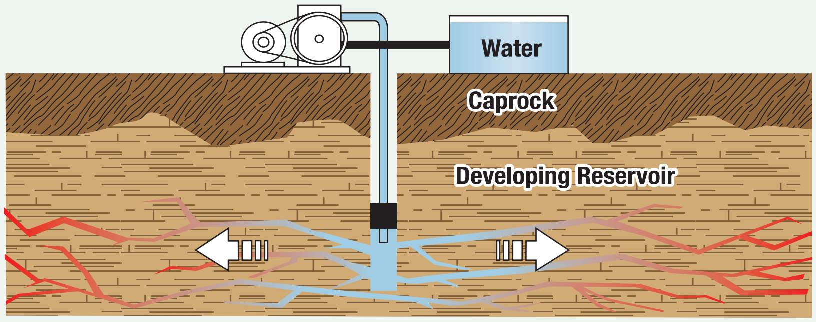
2 Inject Water

Water is injected at sufficient pressure to induce fracturing, or open existing fractures within the rock mass.



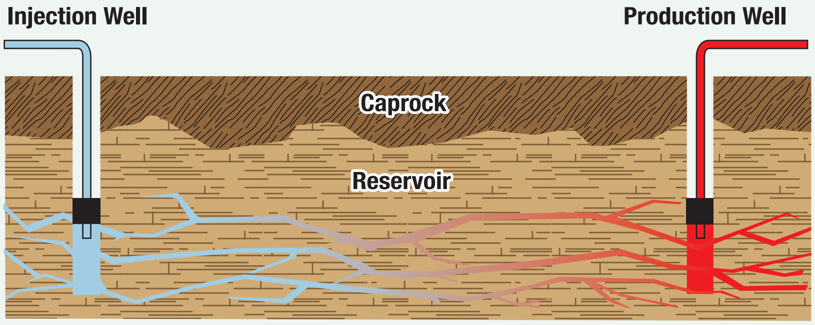
3 Hydro-fracture

Pumping of water is continued to extend fractures some distance from the injection wellbore.



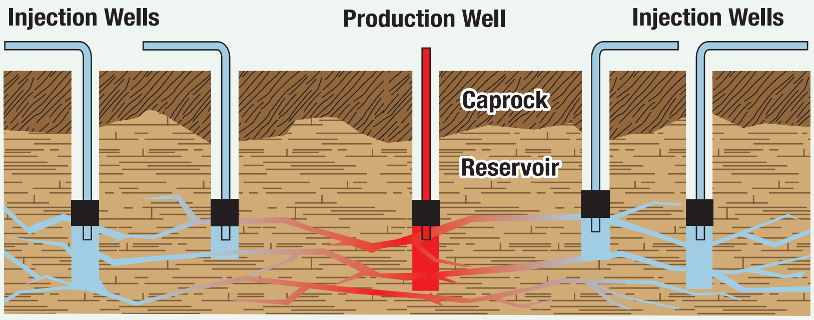
4 Doublet

A second production well is drilled with the intent to intersect the stimulated fracture system, and circulate water to extract the heat from the rock.



5 Multiple Injection Wells

Additional production-injection couplets are drilled to extract heat from large volumes of rock to meet power generation requirements.



Geothermal Energy Conversion R&D

One of the many geothermal power plants at The Geysers, northern California (showing water-vapor emissions during normal cooling operation). PIX00061 Lewis Stewart

Maximizing the power produced from a geothermal plant is crucial for cost-effective operation.

Converting the Earth's Heat to Electricity

Most power plants – whether fueled by coal, gas, nuclear power, or geothermal energy – have one feature in common: they convert heat to electricity. In the field of geothermal energy, the term "energy conversion" refers to the power-plant technology that converts the hot geothermal fluids into electric power.

Geothermal power plants have much in common with traditional power-generating stations. They use many of the same components, including turbines, generators, heat exchangers, and other standard power generating equipment. However, there are important differences between geothermal and other power generating technologies.

Every geothermal site has its own unique set of characteristics and operating conditions. For example, the fluid produced from a geothermal well can be steam, brine, or a mixture of the two; and the temperature and pressure of the resource can vary substantially. The fluid can contain dissolved minerals, gases, and other hard-to-manage substances. Geothermal power plants are designed to optimize power generation by taking these site-specific conditions into account. In addition, geothermal power plants operate at much lower boiler temperatures than conventional plants. Thus, they require different operating strategies and specialized heat-rejection systems.

The U.S. Department of Energy funds critical energy conversion R&D that meets near- and long-term needs at the National Renewable Energy Laboratory (NREL) in Colorado, and the Idaho National Engineering and Environmental Laboratory (INEEL). The quest to lower the cost of producing geothermal energy has led to five specific areas of research concentration:

- Condensation of mixed working fluids
- Heat exchanger linings
- Enhancement of air-cooled condensers
- Alternative non-condensable gas removal methods
- Field verification of small-scale geothermal power plants

Condensation of mixed working fluids – Studies have shown that using hydrocarbon fluid mixtures in binary-cycle geothermal power plants can reduce inefficiencies in the boiler and condenser. Researchers are performing laboratory experiments to study condensation and generate heat transfer formulas that can be used in equipment design. This work is currently focused on water-ammonia, a mixed working fluid that has application in certain advanced binary-power cycles.

Heat exchanger linings – Heat exchangers in geothermal power plants are used to transfer energy from geothermal fluids to other fluids that are then used to mechanically drive conventional power-generation equipment. Heat exchangers used at geothermal power plants are often exposed to highly corrosive fluid. Such corrosion can significantly decrease thermal conductivity – the heat exchanger can't extract heat as efficiently as it should. And the corrosive fluids require the use of expensive materials such as stainless steels, nickel-based alloys, and titanium.

This project is developing polymer-based coatings that can be applied to inexpensive carbon steel. The coatings provide corrosion and scaling resistance equal to or better than that demonstrated by conventional, high-cost materials. This work entails developing coatings and methods of application, lined heat-exchanger design, and field tests. The coating has become a commercial success, saving refinery operations a significant amount of money. Both Brookhaven National Laboratory (BNL) and NREL were research partners on this successful project. For more information, see *Coating Technology Improves Performance*.

Air-cooled condensers – Laboratory researchers have developed and licensed an advanced direct-contact condenser for water-cooled power plants. Because of their low operating temperatures, geothermal power plants must reject approximately 90 percent or more of the heat energy in the geothermal fluid.

The power output from some plants can vary by about 1 percent for every degree of change in the condensing-air temperature. Less heat rejection can have a significant impact on overall plant performance. This is especially true in binary plant applications, many of which use air-cooled condensers due to the lack of make-up water. Because binary plants use lower-temperature hydrothermal resources, the performance of these plants is more sensitive to air temperature and condensing temperature.

PIX01079 NREL, David Parsons

At The Geysers power plant, DOE researchers are studying ways to improve power conversion and increase power output. Researchers have designed advanced direct-contact condensers that reduce steam consumption.

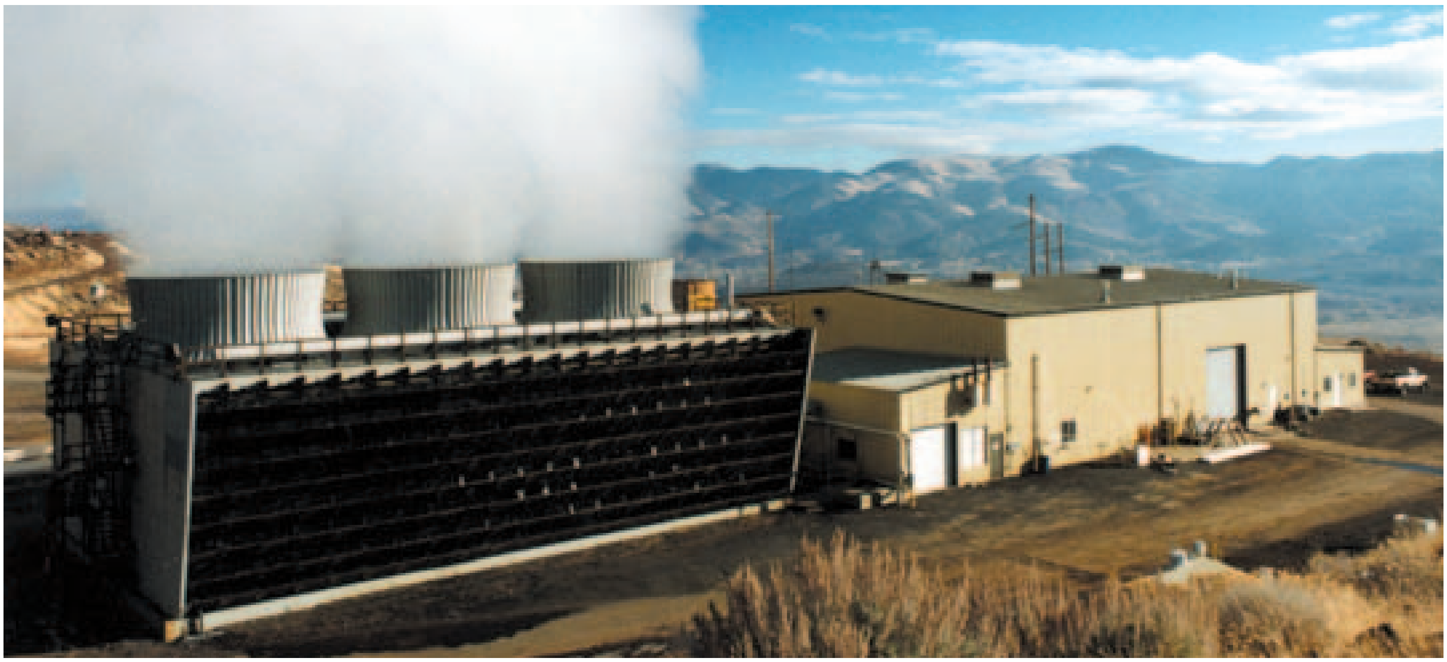
Air-cooled condensers use large airflow rates, requiring significant fan power – on the order of 10 percent of the plant output. Better-performing air-cooled condensers improve plant output, lower costs, and reduce the fan power requirement.

NREL and INEEL are working together to investigate ways to improve the heat transfer effectiveness of air-cooled condensers. One concept involves using perforated fins, where air flows through the perforations. Tests of two prototypes and associated computer modeling indicated that 30 to 40 percent more heat transfer could be obtained for the same fan power. Another concept employs tiny "winglets" on the fins, which provide similar gains in heat transfer.

Researchers also are investigating ways to combine some degree of evaporative cooling with air-cooling during hot weather when air-cooled condenser performance drops, and therefore the power output drops, just when it is needed most. Evaporative cooling is used in low-humidity areas. Water evaporates into incoming air, providing a natural, energy-efficient means of cooling. This process causes a cooling effect much like the process when evaporating perspiration cools your body on a hot (but not too humid) day.

Alternative non-condensable gas removal methods – Non-condensable gases accumulating in the condenser can decrease heat transfer and raise turbine backpressure, thereby lowering turbine performance and plant output. Although not typically associated with the operation of binary geothermal power plants, non-condensable gases are present in commercial plants, requiring removal on a periodic basis.

Researchers at INEEL are trying to determine the potential of innovative separation technologies, such as selective membranes, for low energy removal of non-condensable gases from binary-cycle power plants. Use of such membranes enhances the removal of the working fluid from the vent gas, which significantly reduces the fluid loss, and allows non-condensable gases to be continuously vented. Bench-scale testing during 2001 identified those membranes best suited for the working fluid–air separation. Test performance data was used to construct a prototype system during 2002. This gas removal system was then installed at a binary plant that uses an isopentane working fluid. Testing at this plant focused on developing an improved understanding of the performance of the membranes, and identifying operating issues associated with a commercial application of this technology. Testing will also provide data that will be used to verify increases in power output, and quantify reductions in working fluid losses.



PIX07658 Joel Renner, INEEL

Normal water-vapor emissions from the Steamboat Hills geothermal power plant in Steamboat Springs, Nevada.

Field verification of small-scale geothermal power plants – The primary objectives of this project are (1) to determine and validate, in various locations, the performance and operational characteristics of small-scale geothermal electric power plants and (2) to determine their ability to provide localized power to increase their use in the western United States. "Small-scale" geothermal power plants are those with net electrical outputs of between 300 kilowatt (kW) and 1 MW. They can be automated and operated without full-time, on-site care.

Researchers selected several representative geothermal sites from the Geo-Heat Center's survey of collocated geothermal resources in Western states (see "Where are Geothermal Resources Located?" available at the ***geoheat.oit.edu/colres.htm*** website) for analysis using NREL's Cycle Analysis Software Tool (CAST). The analysis was of a binary-cycle geothermal power plant operated in two modes: only generating electricity, and electrical production in series with a direct-use application. For example, the hot fluid would first be used to generate electricity, and then the cooler water (but still quite warm!) would be piped to a greenhouse to warm flower bedding.

The AmeriCulture project (also refer to the article titled *Direct Use Equals Smart Use*), located near Cotton City, New Mexico, involves the design, installation, and operation of a 1,420-kW gross (approximately 1,000-kW net) water-cooled Kalina-cycle geothermal power plant that uses ammonia-water as the working fluid. Electricity will be provided to the AmeriCulture fish hatchery. The project will use an existing 400-foot (122-meter) production well to provide approximately 1,000 gpm (4,546 liters-per-minute) of 240˚ to 245˚F (115˚ to 118˚C) brine to the power plant. The plant's exit brine will be used to heat the tanks of a tilapia

PIX07656 Joel Renner, INEEL

The 4.8 MW Empire Energy geothermal power plant in the San Emidio Desert, Nevada.

Two projects that are part of this energy conversion R&D program should be noted. **The Empire Energy project,** located in Empire, Nevada (about 90 miles/ 150 kilometers north of Reno), involves the design, installation and operation of a 1,300-kW (gross) air-cooled, binary geothermal power plant downstream from a geothermally heated dehydration plant that produces 26 million pounds (11.8 million kilograms) of dried onion and garlic annually. The plant, which will be located within a few hundred feet of the dehydration plant, will use 1,200 gallons (5,455 liters) per minute (gpm) of 295˚F (146˚C) geothermal fluid from an existing 1,800-foot (550-meter) production well, and will deliver 1,300 kW of power (net) for sale to Empire Foods, LLC. This project will use evaporative cooling enhancement of the air-cooled condensers to improve summer performance. Also, the direct use will occur upstream, rather than downstream of the plant because of the dehydration process temperature requirements.

fish hatchery on the site. The estimated total project cost is $3,370,000, fifty percent of which is provided by NREL.

The Future

These and other DOE-sponsored energy conversion research projects are helping the geothermal industry develop the more abundant lower-temperature resources into practical sources of electrical power. Continued progress will allow us to tap a greater percentage of geothermal reservoirs and increase the amount of clean, renewable energy used in our power generation network.

For more information, please visit the NREL Geothermal Technologies Program website at: ***www.nrel.gov/geothermal/georandd.html.*** ■

Coating Technology Improves Performance

Preventing corrosion and inhibiting scale buildup reduces downtime and maintenance costs.

How can geothermal power plants and chemical refineries save many thousands of dollars a year? By coating heat exchangers and other process equipment with a revolutionary material developed by the National Renewable Energy Laboratory (NREL) and Brookhaven National Laboratory (BNL) geothermal programs. The coating prevents corrosion and inhibits buildup of scale from mineral-rich geothermal brines and caustic industrial fluids, reducing maintenance and capital expenditures.

Keith Gawlik of NREL and Toshi Sugama of BNL have already won an R&D 100 Award and a Federal Laboratory Consortium award for the coating, and industry is beginning to reap the benefits. Refineries throughout the U.S. had installed tens of thousands of heat exchanger tubes coated with the material by mid-2002, and that number may be in the hundreds of thousands by now.

Keith Gawlik, NREL

PPS coating on the left and a failed coating on the right.

Testimonial letters confirm that the companies are very pleased with the results they're getting. One executive writes, "Our tubes were failing an average of every 17 weeks. We've now used the coating for 13 months at 350˚F (177˚C) with no tube failure or loss of heat transfer. We've recovered the cost of the coating application many times over."

The remains of a steam vent pipe made of uncoated carbon steel, after five years of exposure to corrosive water vapor and gases at the Cove Fort geothermal power plant in Utah.

The PPS system can be exposed to production geothermal fluid at 350˚F (177˚C).

Research and development on the coating began as an effort to reduce the cost of geothermal electricity. Geothermal power plant heat exchangers have traditionally used expensive stainless steel or other corrosion-resistant materials, such as titanium, to withstand aggressive environments. These materials would provide corrosion protection, but no resistance to scaling. NREL and BNL tested polyphenylenesulfide (PPS) with different fillers, such as carbon fiber, silicon carbide, Teflon™, and calcium aluminate, in a variety of harsh geothermal environments on relatively inexpensive carbon-steel tubing.

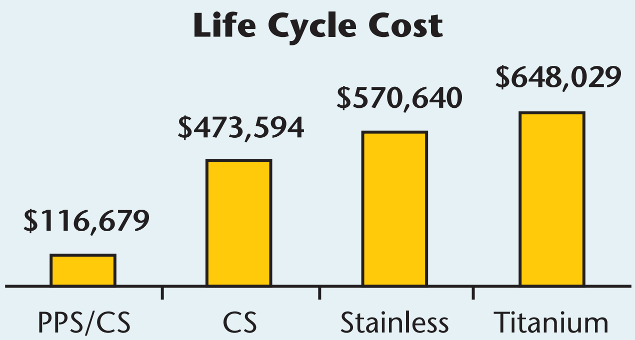
After years of exposure testing in a number of different environments, the formulations were developed such that the tubes were virtually new looking at the end of a test. Formulations can be developed for abrasion resistance, thermal conductivity enhancement, and scale inhibition.

To launch the coating system into the commercial arena, researchers worked closely with Curran International (formerly Bob Curran and Sons), an established company that had been successful with epoxy and phenolic coatings. After learning basic techniques of working with the new PPS coating, Curran went on to develop their own innovative techniques and perfected large-scale application of the coating system, which they have trademarked as CurraLon™.

Only the slow rate of new geothermal power plant construction has prevented more widespread application of the coating in geothermal environments. The coating has, however, been used in the replacement of failed components at existing geothermal plants.

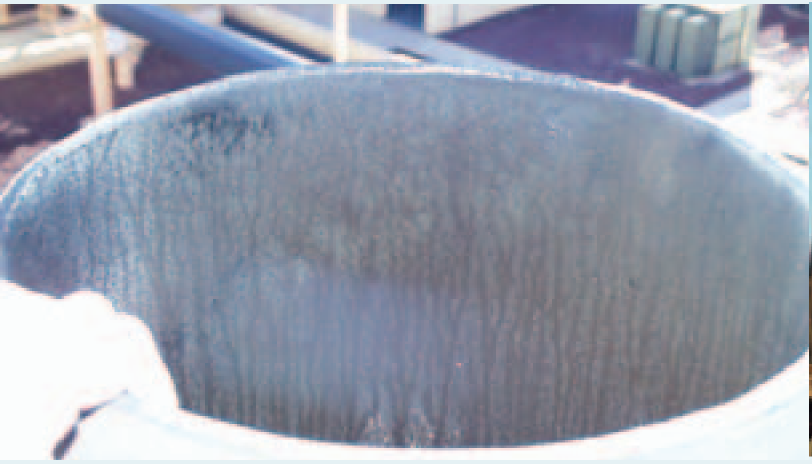
Coating technology R&D continues at NREL and BNL. Gawlik and Sugama are testing PPS formulations in extremely high-temperature geothermal brines, thus making the coating suitable for all known geothermal resources, in acidified and non-acidified fluids, and even in low-temperature applications plagued by algae buildup, such as cooling towers. Research is beginning on development of a new low-temperature organometallic polymer coating that would protect steel tubing with aluminum fins, commonly used in air-cooled geothermal plants, from attack by brine sprays, a proposed method of increasing the power output of these plants during hot weather.

The graph below compares life-cycle cost estimates of a typical geothermal shell-and-tube heat exchanger in which the tubes and other wetted components are made of PPS-coated carbon steel, uncoated carbon steel, stainless steel, and titanium. ■



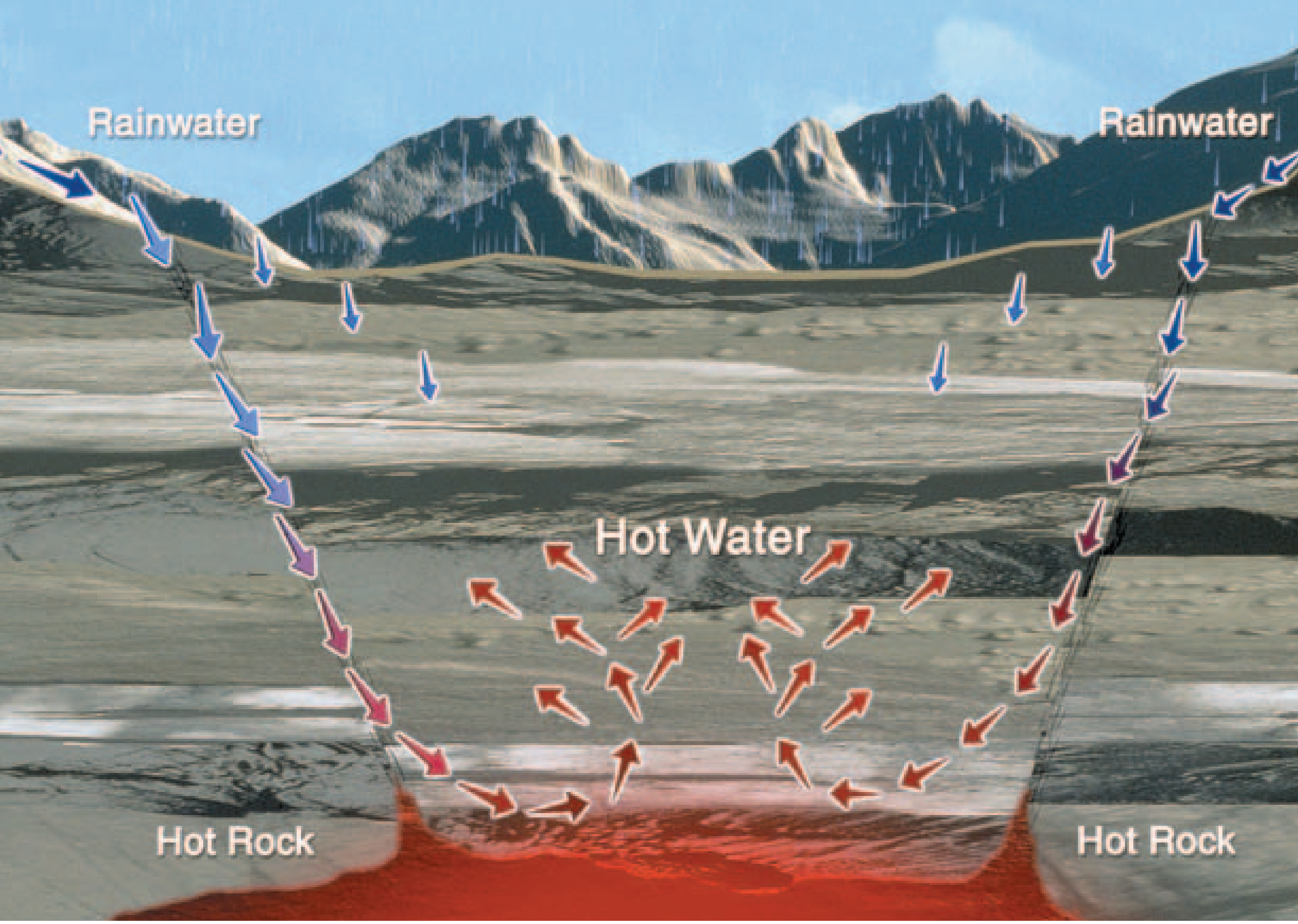
Thirty-year life-cycle cost comparison between the new coating technology and traditional corrosion-resistant materials for a typical brine/working fluid heat exchanger having 800 40-foot-long tubes.

All four pictures by Keith Gawlik, NREL



PPS-coated pipe after seven months of operation, showing no damage. (Rivulets are condensed acidic steam.) Uncoated pipe would show extensive corrosion by now.

Cove Fort – Installation of the new steam-vent pipe made of carbon steel coated internally and externally with the PPS system.



Courtesy of the Geothermal Education Office

Natural 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.

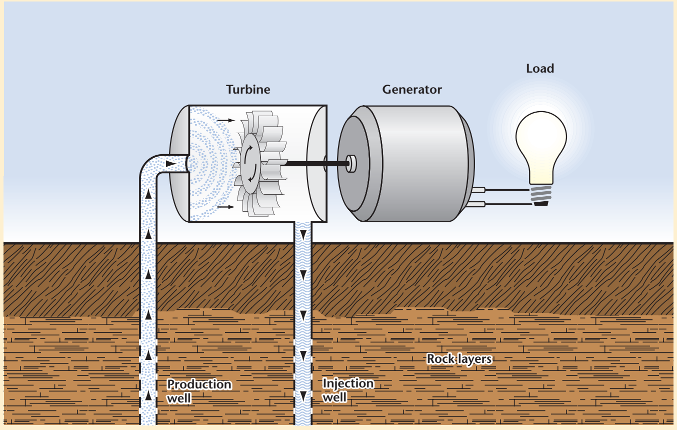
The Earth's core, 4,000 miles (6,437 kilometers) below the surface, can reach temperatures of more than 9,000°F (4,982°C). The heat — geothermal energy — constantly flows outward from the core, heating the overlying rock. At high enough temperatures, some rocks melt, transforming into magma. Magma can 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.

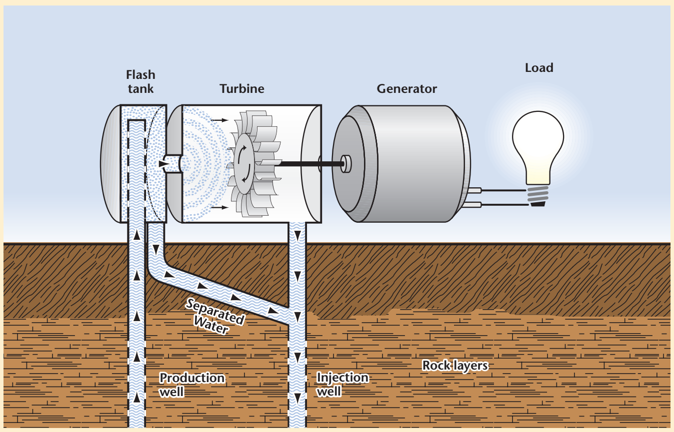
There are three primary ways of using geothermal energy: for electricity production, for direct-use applications, and with geothermal heat pumps.

Electricity Production

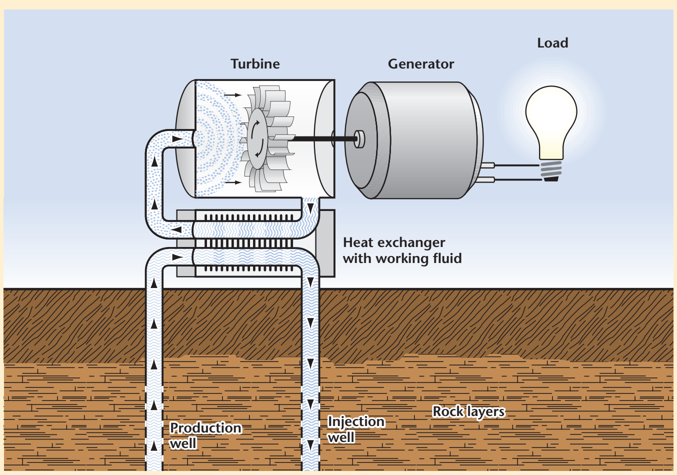
Electricity production using geothermal energy is based on conventional steam turbine and generator equipment, where expanding steam powers the turbine/generator to produce electricity. Geothermal energy is tapped by drilling wells into the reservoirs and piping the hot water or steam into a power plant for electricity production. The type of power plant depends on a reservoir's temperature, pressure, and



***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.*



***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° to 360°F (107° 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.*

fluid content. There are three types of geothermal power plants: dry-steam, flashed-steam, and binary-cycle.

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 percent over traditional fuel costs**, depending on the application and the industry. Direct-use systems often 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 750,000 GHPs are in service today in the United States, including hundreds of systems in schools and colleges. Technical improvements can yet be achieved in ground-coupling and excavation procedures.

Market Potential

Today's U.S. geothermal industry is a $1.5 billion-per-year enterprise. Installed electrical capacity is over 2,000 megawatts (electric) in the United States and over 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.

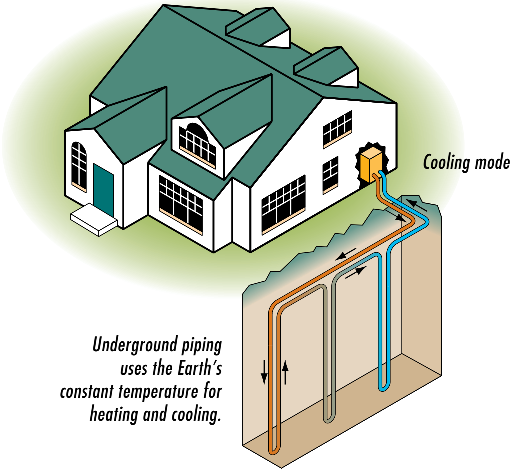
Residential application of a geothermal heat pump in Colorado.

PIX 06537 NREL, Warren Gretz

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 eneration become common throughout the

PIX13096 NREL

Greenhouse commercial growing is a big user of geothermal direct use. (Mountain States Plants, Flint Greenhouses, Idaho)



Geothermal heat pump - underground piping uses the Earth's constant temperature for heating and cooling.

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 3,700 megawatts (thermal) of annual energy savings today.

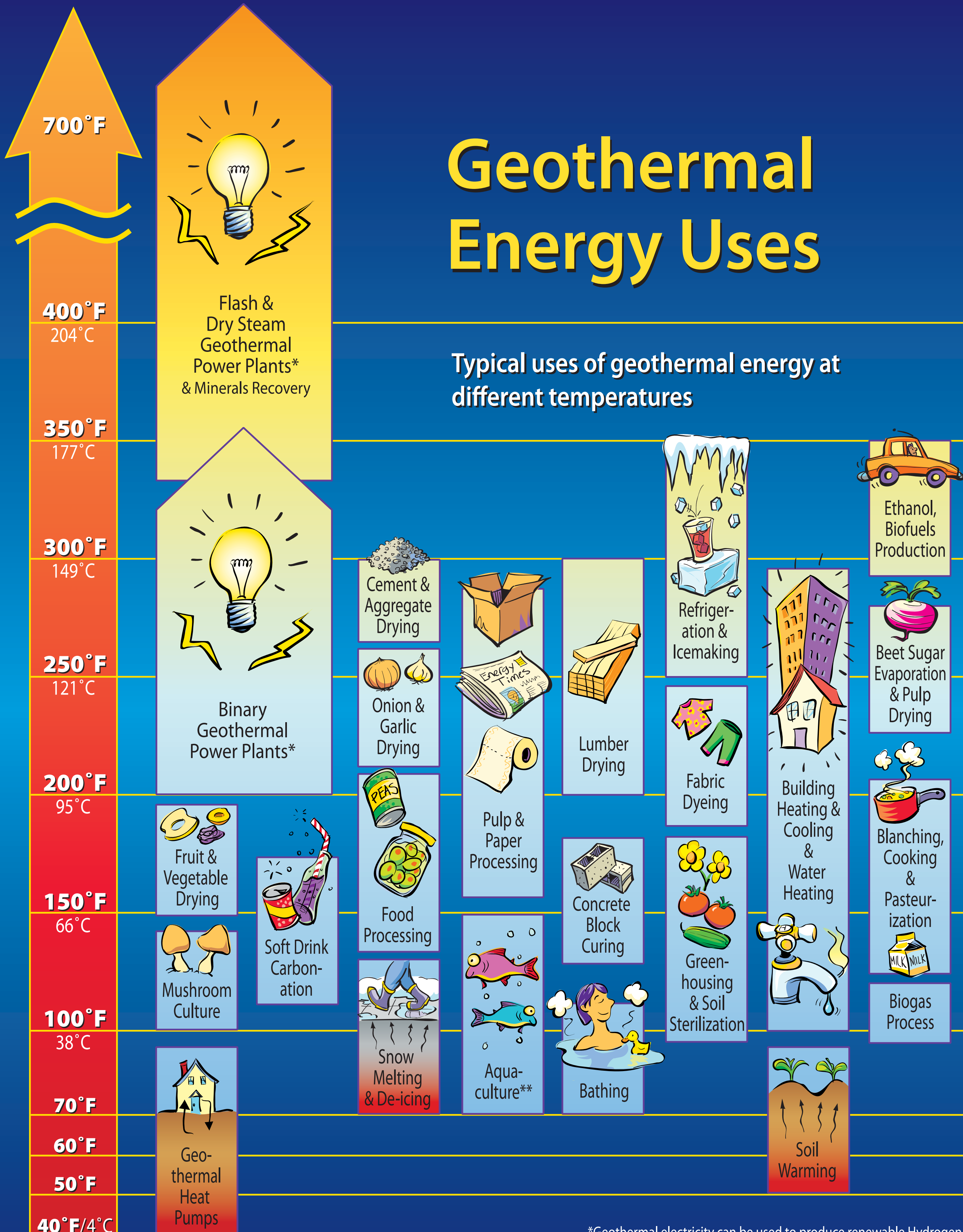
Solutions Beneath Our Feet

Together, geothermal power plants, direct-use technologies, and GHPs 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 also a vital measure of national security is gained when we control our own energy supplies. ■

DOE is working with industry to realize the vast potential of geothermal energy (volcanic vent on the Big Island, Hawaii).

Geothermal Energy Uses

Typical uses of geothermal energy at different temperatures



*Geothermal electricity can be used to produce renewable Hydrogen.
**Cool water is added to make the temperature just right for the fish.

KEY CONTACTS

U.S. Department of Energy
Roy Mink, Director
Geothermal Technologies Program
1000 Independence Avenue, SW
Washington, DC 20585
202.586.5348
www.eere.energy.gov/geothermal

Idaho National Engineering and Environmental Laboratory
Joel Renner, Manager
Geothermal Program
2525 Fremont Ave.
Idaho Falls, ID 83415-3830
208.526.9824
rennerjl@inel.gov
geothermal.id.doe.gov

National Renewable Energy Laboratory
Gerry Nix, Program Leader
303.384.7566
gerald_nix@nrel.gov

Bruce Green, Communications Contact
303.275.3621
bruce_green@nrel.gov
Geothermal Program
1617 Cole Boulevard
Golden, CO 80401-3393
www.nrel.gov/geothermal

Sandia National Laboratories
Craig Tyner, Manager
Geothermal Research Department
P.O. Box 5800
Albuquerque, NM 87185-0708
505.844.3340
cetyner@sandia.gov
www.sandia.gov/geothermal

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. By investing in technology breakthroughs today, our nation can look forward to a more resilient economy and secure future.

Far-reaching technology changes will be essential to America's energy future. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a portfolio of energy technologies that will:

* Conserve energy in the residential, commercial, industrial, government, and transportation sectors
* Increase and diversify energy supply, with a focus on renewable domestic sources
* Upgrade our national energy infrastructure
* Facilitate the emergence of hydrogen technologies as vital new "energy carriers."

The Opportunities

Biomass Program
Using domestic, plant-derived resources to meet our fuel, power, and chemical needs

Building Technologies Program
Homes, schools, and businesses that use less energy, cost less to operate, and ultimately, generate as much power as they use

Distributed Energy & Electric Reliability Program
A more reliable energy infrastructure and reduced need for new power plants

Federal Energy Management Program
Leading by example, saving energy and taxpayer dollars in federal facilities

FreedomCAR & Vehicle Technologies Program
Less dependence on foreign oil, and eventual transition to an emissions-free, petroleum-free vehicle

Geothermal Technologies Program
Tapping the Earth's energy to meet our heat and power needs

Hydrogen, Fuel Cells & Infrastructure Technologies Program
Paving the way toward a hydrogen economy and net-zero carbon energy future

Industrial Technologies Program
Boosting the productivity and competitiveness of U.S. industry through improvements in energy and environmental performance

Solar Energy Technology Program
Utilizing the sun's natural energy to generate electricity and provide water and space heating

Weatherization & Intergovernmental Program
Accelerating the use of today's best energy-efficient and renewable technologies in homes, communities, and businesses

Wind & Hydropower Technologies Program
Harnessing America's abundant natural resources for clean power generation

To learn more, visit www.eere.energy.gov

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