Strategic

for the

Geothermal

Program

Plan

RECEIVED

JUN 29 1998

OST

Energy

U.S. Department of Energy
Office of Geothermal Technologies

June 1998

Preface

The Office of Geothermal Technologies (OGT) is the office within the U.S. Department of Energy (DOE) that manages the Federal program for research and development of practical and economic geothermal energy systems. OGT funds research to reduce the cost of geothermal components, systems, and operations. The program builds on a history of accomplishments that has facilitated a six-fold growth in geothermal power capacity in the United States. This Strategic Plan offers a perspective on what might be accomplished with a program that brings the full spectrum of geothermal energy resources into play.

Extensive interactions with the U.S. geothermal industry, researchers supported by OGT, and staff of other government offices took place in the preparation of this Plan. The Plan stems from a series of workshops conducted by the Geothermal Energy Association—the industry's trade association—during 1995, 1996, and 1997. Those meetings focused on areas of research that industry participants thought should be strengthened, in keeping with their relevance to actual industrial projects. Additional workshops were conducted by DOE during 1997 to assist in drafting the Plan, and the geothermal community reviewed a draft version in early 1998.

The “**Strategic Plan for the Geothermal Energy Program**” derives in large part from the current U.S. Department of Energy Strategic Plan and links to a number of objectives in that Plan. Similarly, the geothermal Plan represents a specific implementation of goals and objectives from DOE's Comprehensive National Energy Strategy (April 1998) at the program level. These precursor plans served as guideposts for the preparation of the geothermal program strategy presented in the following pages.

Table of Contents

Executive Summary	1
Introduction	3
Vision for Geothermal Energy	5
Strategic Goals	5
1. Domestic Electric Power	6
2. Direct Use Applications and Geothermal Heat Pumps	8
3. International Geothermal Development	10
4. Science and Technology	14
5. Future Geothermal Resources	15
Benefits of the Plan	17
Resource Needs	19
References and Notes	20
Appendix	
A Perspective on Benefits and Costs of the Plan	21

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Geothermal Program

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Geothermal Program

Strategic Goal 1—Electric Power Generation

- Supply the electrical power needs of 7 million U.S. homes (18 million people) from geothermal energy by the year 2010.

Strategic Goal 2—Direct Use Applications and Geothermal Heat Pumps

- Expand direct uses of geothermal resources and applications of geothermal heat pumps to provide the heating, cooling, and hot water needs of 7 million homes by the year 2010.

Strategic Goal 3—International Geothermal Development

- Meet the basic energy needs of 100 million people in developing countries by using U.S. geothermal technology to install at least 10,000 megawatts by the year 2010.

Strategic Goal 4—Science and Technology

- Accelerate the development of U.S. geothermal science and technology to ensure that the United States continues to lead the world.

Strategic Goal 5—Future Geothermal Resources

- By the year 2010, develop new technology to meet 10% of U.S. nontransportation energy needs in subsequent years.

Over the next decade, achieving the goals of this Strategic Plan would have the following cumulative effects:

- Stimulate \$61 billion of domestic investment in all geothermal facilities.
- Stimulate \$16 billion of U.S. investment in overseas geothermal power facilities.
- Create 1.6 million person-years of new employment in the United States.
- Reduce U.S. carbon emissions by 80 to 100 MMTC (million metric tons of carbon).
- Reduce global carbon emissions by 190 to 230 MMTC.
- Add \$180 million to government royalties from geothermal projects operating on Federal lands.

These benefits can accrue with an investment in the Geothermal Program of about one cent per day for each home that uses geothermal energy.

Introduction

Geothermal energy is heat from the Earth. The Earth's interior reaches temperatures greater than 4,000°C, and an immense amount of heat flows continuously to the surface. This flow of heat drives many geologic processes, some of which concentrate heat near the Earth's surface, where it can be extracted for productive uses.

Geothermal energy comprises a truly enormous amount of energy. U.S. geothermal resources alone are estimated at 70,000,000 quads, or the equivalent of a 750,000-year supply of energy at current rates of consumption. World geothermal resources are estimated to be 15,000 times the world's oil reserves!¹ Geothermal energy can be used to generate electrical power; for direct use applications such as district heating, greenhouse heating, and aquaculture; and for geothermal heat pumps (GHPs). The savings in emissions of atmospheric pollutants and reductions in environmentally hazardous wastes by displacing other, less desirable energy resources will be ever more important as the United States and the world strive to limit global warming and adverse environmental impacts. Geothermal energy is clean, reliable, and sustainable.

Geothermal resources are abundant. In the United States, alone, we have an estimated 750,000-year supply of geothermal energy at current rates of consumption.

Today, society uses only a small fraction of the geothermal energy resource base. The ultimate promise of geothermal energy is that a much larger fraction of the total resource can be tapped. New and improved technology is a major factor in making this happen.

Geothermal resources occur in a variety of forms, each of which requires advances in technology to ensure attainment of optimal benefits.

Hydrothermal (water or steam) resources usually occur above cooling bodies of once molten rock (magma) that have intruded into the upper crust from great depth. Hydrothermal convection occurs as ground water is heated, and rises upward in plumes through permeable pathways in the rock. Typically the hot water becomes concentrated in

Geothermal Program

reservoirs, somewhat similar to oil and gas reservoirs, that can be tapped by drilling wells. Such hydrothermal resources support almost all of the applications of geothermal energy in use today.

Hot dry rock resources are simply rocks at high temperatures, with little or no in situ water. Such resources usually lie at considerable depth compared to hydrothermal reservoirs. Hot dry rock comprises by far the largest portion of the total geothermal resource. Hot rocks are found at accessible depths everywhere. By circulating water through fractures in rock connecting two wells, the feasibility of extracting energy has been proven, but economical extraction technology currently does not exist.

In some areas, apparently unrelated to magmas, water at temperatures between 50° and 100°C or more occurs in some aquifers. Examples include the Madison aquifer system in the Dakotas, Wyoming, and Nebraska, and the extensive aquifer in the Paris basin, France. These *thermal aquifers* can often be tapped for direct use applications.

Normal gradient resources constitute those resulting from the normal heat flow from the Earth's crust. The relatively constant near-surface ground temperatures, maintained in part from the flux of heat from depth, allows geothermal (ground-source) heat pumps to serve as cost-effective sources of space heating in the winter and space cooling in the summer.

Each geothermal resource type has a contribution to make to meeting society's energy needs, and each has its unique technological problems. Although the present industry is based solely on hydrothermal resources, the long-term viability of geothermal energy lies in developing technology to enable use of the full range of geothermal resources.

Today's U.S. geothermal industry is a \$1.5-billion per year enterprise. Installed electrical capacity exceeds 2,800 megawatts (MWe) in the United States and almost 8,000 MWe worldwide. Geothermal power plants operate at high capacity factors (70%–100%) and have typical availability factors greater than 95%. These plants produce clean power and require very little land.

Over the years, an excellent working relationship has evolved between the U.S. Department of Energy (DOE) and the U.S. geothermal industry. DOE's program comprises research and development (R&D) that encompass consideration of the present and future energy security of the United States. Industry is mainly interested in R&D that will lead to solutions to immediate and pressing technological problems. As a result, DOE undertakes a program balanced between short-term goals, of greater interest to industry, and long-term goals, of importance to national energy interests. Nevertheless, DOE's long-term goals can often be reached in increments by satisfying industry's short-term goals. And industry has been most supportive by adopting DOE's technology improvements for practical applications. This Plan contains a careful appraisal of strategic issues that impede the Nation's ultimate realization of geothermal energy's potential, along with strategies for addressing these issues.

Vision for Geothermal Energy

The geothermal energy resource base is enormous and diverse. Removal of technical barriers will greatly accelerate development and use of that resource, providing a reliable alternative energy capable of supplying a significant fraction of the world's energy needs. The vision of DOE's Office of Geothermal Technologies (OGT) is

By 2010, geothermal energy will be the preferred alternative to polluting energy sources throughout the world.

As the vehicle to achieve its vision, OGT plans and implements a program of R&D dedicated to removing the barriers to more widespread uses of geothermal energy. The Program's mission is to work in partnership with U.S. industry to establish geothermal energy as a sustainable, environmentally sound, economically competitive contributor to the U.S. and world energy supply.

Strategic Goals

In moving forward with its mission, the Program has identified strategic goals for each of its five primary business lines:

- Domestic Electric Power
- Domestic Direct Use Applications and Geothermal Heat Pumps
- International Geothermal Development
- Science and Technology
- Advanced Geothermal Resources.

The goals that follow are supported by specific objectives that, in turn, lend themselves to the identification of program strategies. The strategies contained herein are illustrative of actions that may be undertaken to achieve objectives. They form the basis for subsequent implementation plans that logically follow from this Plan. Only by working in close cooperation with stakeholders, especially the geothermal industry, can we expect to achieve these goals and objectives.

1. Domestic Electric Power

The long-term sustainability of geothermal production has been demonstrated by continuous electrical power generation at the Larderello field in Italy since 1913, at the Wairakei field in New Zealand since 1958, and at The Geysers field in California since 1960. In fact, no geothermal field has been abandoned because of resource decline. Today, geothermal energy provides about 2,700 megawatts (MW) of electrical power in the United States and over 7,000 MW worldwide.

Historically, the demand for new electrical power in the United States has grown at annual rates of 2%–4%. Given an active and expanding economy and the pressures of competition from unregulated power markets, the need for additional generating capacity will continue to grow in future years. While competition from fossil fuels, especially natural gas, remains strong, good opportunities for geothermal power will become increasingly frequent, particularly in the western United States. And if renewable portfolio standards on power generation become common throughout the nation, new markets for geothermal power will open. To meet the increased demand, many operating geothermal fields could be expanded, and many new fields await discovery. The costs of producing geothermal power must be reduced further if the full potential of this clean resource is to be realized.

Pacific Gas and Electric Company / PIX 01759

If the costs and risks of developing geothermal resources for electricity production are lowered, existing geothermal fields can be expanded and new geothermal fields discovered. Pictured above: The Geysers, Calistoga, California.

Strategic Goal 1 *Supply the electrical power needs of 7 million U.S. homes (18 million people) from geothermal energy by the year 2010.*

Objective 1.1

Lower the costs and risks of developing geothermal resources.

Strategic Issues Geothermal power development is a capital-intensive enterprise, with the major expenses being incurred well before the plant begins to produce revenue. Today, capital costs for a typical geothermal power project average about \$1,600 per installed kilowatt. The highest-cost components of the project include (1) the drilling of exploration, production, and injection wells, and (2) plant equipment and construction. The primary risk in a geothermal project is confirmation of a viable reservoir, and this step requires extensive drilling and well testing to identify productive areas of the field. To reduce the primary risk in geothermal development, a better understanding is needed of the basic geologic conditions associated with hydrothermal systems. If the costs of drilling and testing wells can be substantially reduced, much of the risk is mitigated. Failure of the power plant presents less risk, but design challenges to minimize capital and operating costs are substantial.

The following program strategies illustrate the range of measures that may be taken to meet the objective.

Strategy 1. Improve technologies for exploration, detection of fractures and permeable zones, well siting, fluid production, and fluid injection.

Strategy 2. Decrease the cost of drilling and completing geothermal wells.

Strategy 3. Improve the cost-effectiveness of energy conversion systems, and reduce plant operation and maintenance costs.

Strategy 4. Develop multiple income sources from power plants, such as metals recovery or cascaded uses of heat.

Strategy 5. Decrease the time required from exploration to power-on-line.

Objective 1.2

Increase the quantity of identified high-grade geothermal resources.

Strategic Issues Due to technological barriers and the low cost of generating electrical power from natural gas, only the highest grade geothermal resources can be developed economically. High grade resources are defined as hydrothermal fluids with a combination of high temperature and pressure, low dissolved solids content, and shallow depth. Current economic conditions and shortcomings in technology make it difficult to carry out the exploration required for a continual supply of new high grade resources.

Strategy 1. Improve the basic knowledge of the nature and occurrence of U.S. hydrothermal reservoirs.

Strategy 2. Develop improved geothermal exploration techniques.

Strategy 3. Develop improved techniques for mapping additional high grade resources.

Strategy 4. Update assessments of the geothermal resource base in the United States.

Strategy 5. Document exploration successes and failures through case histories.

Objective 1.3

Remove market inequities inhibiting development of geothermal energy.

Strategic Issues Significant market inequities exist in developing geothermal energy compared with other forms of energy. Furthermore, the marketplace gives no credit for nonpolluting "green" energy sources. If energy markets truly reflected the value of geothermal energy to society, many more geothermal projects could be carried out economically today, using available technology. Environmental degradation due to energy

Geothermal Program

development and use will continue until energy markets offer equitable credit for nonpolluting sources.

Strategy 1. Support tax equity for geothermal projects.

Strategy 2. Include environmental and social externalities in the economics of energy projects with possible emissions credits trading, and increase public

awareness of the environmental compatibility of geothermal energy.

Strategy 3. Broaden the industry base by attracting more companies to geothermal development.

Strategy 4. Encourage a renewables portfolio standard applicable to all generators of electricity.

2. Direct Use Applications and Geothermal Heat Pumps

In the United States, direct use applications of geothermal energy with installed capacity of 500 thermal megawatts (MWt) contribute about 6.2 trillion British thermal units (Btu) per year to our energy needs. These applications include district heating, heating of individual homes, greenhouse heating, aquaculture, food processing, balneology, and many other uses. Geothermal heat pumps (GHPs) for heating and cooling in residential and commercial buildings, with 3,600 MWt capacity, provide 38 trillion Btu per year of end use energy in the United States. Worldwide, nonelectric geothermal uses total more than 12,000 MWt, and they have been an important part of many cultures for centuries.

Hydrothermal resources of sufficient temperature for direct heat use are much more plentiful and widespread than the hotter resources required for power generation. Today's geothermal direct use contribution is a very small fraction of what it could be. In a recent survey of 10 western states, over 270 geothermal sites were identified within 5 miles of a city or town, but few of these resources are being used. A significant reduction in carbon dioxide emissions could be achieved in the near term from accelerated use of lower-temperature hydrothermal resources.

GHPs move heat from the ground into buildings in the winter, providing space heating. In the summer, heat is pumped in the opposite direction, providing air conditioning; in addition, waste heat from air conditioning can provide hot water. About 350,000 to 400,000 were operating in the United States at the end of 1997. Between 1994 and 1996, about 55,000 new units (3-ton equivalent) were installed per year. A significant increase in annual GHP sales is anticipated for 1997. Accelerating the rate of deployment of GHPs in the United States could provide significant additional benefits in electric supply-system peak shaving and reductions in carbon dioxide emissions.

Strategic Goal 2 *Expand direct uses of geothermal resources and applications of geothermal heat pumps to provide the heating, cooling, and hot water needs of 7 million homes by the year 2010.*

Objective 2.1

Lower the costs and risks of developing low- and moderate-temperature geothermal projects and of installing geothermal heat pumps.

Strategic Issues Most nonelectric geothermal projects are small in total investment and return, compared to a geothermal electrical power project. Direct heat projects

cannot support a great deal of exploration or drilling expense and still remain economically viable. More efficient exploration techniques and less costly well drilling methods, specifically designed for smaller, lower temperature resources, are needed. The ground connection for GHPs requires advancements in many areas to reduce costs such as predicting soil thermal conductivity, developing grouts, and integrating other end uses.

John Lund, Geo-Heat Center / PIX 06192

Worldwide, nonelectric geothermal uses, including geothermal heat pumps, total more than 12,000 megawatts of thermal energy. Pictured above: Installation of a residential heat exchanger in Klamath Falls, Oregon.

Strategy 1. Reduce drilling costs for geothermal direct heat systems and GHPs.

Strategy 2. Improve low-cost geochemical and geophysical methods for evaluating low-temperature geothermal reservoirs.

Strategy 3. Develop cascading uses for geothermal direct heat projects.

Strategy 4. Develop advanced design and installation systems for GHP ground heat exchangers.

Objective 2.2

Increase the inventory of low- and moderate-temperature geothermal reserves for direct use.

Strategic Issues The vast majority of low- and moderate-temperature (50° to 150°C) geothermal occurrences in the United States have not been adequately defined through exploration, drilling, and testing, leaving the true extent and usefulness of the resource undetermined. Many undiscovered geothermal resources, which lack surface manifestations, such as hot springs, are believed to exist. A systematic exploration program and evaluation of water wells and oil and gas wells to locate and document the magnitude of these reservoirs is critical to continued growth.

Strategy 1. Cost share exploration and reservoir confirmation using new, advanced technology.

Strategy 2. Improve basic geologic knowledge about geothermal resources at the state and local level.

Strategy 3. Update assessments of domestic geothermal resources.

Objective 2.3

Remove market inequities that inhibit development of geothermal energy for direct use applications.

Strategic Issues Significant market inequities exist in developing low and moderate temperature geothermal projects. For instance, the market gives no credit for nonpolluting energy sources. If energy markets truly reflected all the costs (environmental, economical, political) of energy development projects, many more geothermal projects could be carried out economically today.

Strategies The strategies to meet this objective are essentially the same as those for geothermal electric systems (Objective 1.3), as described above.

Objective 2.4

Develop and expand the infrastructure available for direct heat uses of geothermal energy and for geothermal heat pumps.

Strategic Issues Although geothermal direct use systems and GHPs are often the most economic option on a life-cycle basis, most decision-makers are interested in the lowest first cost. In addition, most heating and cooling contractors, architects and engineers, building owners, and industrial plant managers lack the confidence to specify or request a direct use or GHP system. This lack of information hinders the rapid growth of the direct use and GHP markets. Significant amounts of information about the design and performance of geothermal direct use installations remain unpublished and inaccessible. This situation needlessly increases costs and risks and makes financing for new projects more difficult to obtain.

Strategy 1. Transfer technology to industry, including design and financial information, on direct use and GHPs.

Strategy 2. Support training of skilled workers to design, install, and operate direct heat systems and GHPs.

Strategy 3. Cost share the development of pilot or demonstration projects, and document and validate operational economics.

Strategy 4. Educate potential consumers about low- and moderate-temperature direct heat uses and GHP applications.

3. International Geothermal Development

Geothermal resources occur in many countries, especially developing countries, and their value is increasingly recognized by governments worldwide. By one estimate, over 80,000 MWe of potential for geothermal electrical power projects currently exist in developing countries using hydrothermal resources alone. The international market for geothermal power development could exceed \$25 billion for the next 10 to 15 years. At the present time, U.S. technology and business acumen is at the forefront of this international market. In the recent years, U.S. industry has won some 60% of geothermal electrical power projects in developing countries. By providing superior technology and focusing on the needs of customers, the partnership of U.S. industry and DOE can strengthen U.S. leadership in the international geothermal energy market. To the extent that our companies can succeed, the U.S. economy will benefit through jobs, exports of U.S. products and services, tax revenues, lower cost of geothermal technologies, and lower cost of electricity.

The chief competition in the large international geothermal market comes from Italy, Japan, and New Zealand, although the energy and utility sectors of several developing nations have begun gaining geothermal expertise of their own. The Japanese government alone dedicates well over \$150 million per year to geothermal R&D in support of its industry.

If the U.S. industry is to maintain its world-leadership position, create new jobs, and help to expand the U.S. economy, assistance from DOE will be vitally important. In addition to conducting research focused on cost-cutting technology improvements, DOE can help industry penetrate the international market through educational programs, technical advisory efforts, and country-to-country contacts.

Strategic Goal 3 *Meet the basic energy needs of 100 million people in developing countries by using U.S. geothermal technology to install at least 10,000 megawatts by the year 2010.*

Objective 3.1

Reduce the costs and technological risks of developing geothermal resources overseas.

Strategic Issues Although some commonality does exist among geothermal fields, each geothermal resource is unique. For example, many of the countries with potential to develop geothermal resources line the Pacific Rim. However, most of the geothermal systems in this "Ring of Fire" are found in volcanic terranes, unlike those found with most U.S. geothermal resources. Exploration and drilling in such geologic environments

require different considerations and often the development of new or improved technology.

Strategy 1. Improve understanding of geothermal systems in the world's diverse geologic environments and how to exploit them.

Strategy 2. Develop better reservoir simulation models and methods of siting production and injection wells in different geothermal systems.

Strategy 3. Develop technically improved and lower-cost drilling methods for use in various geologic environments.

Trans-Pacific Geothermal Corp. / PIX 00664

International geothermal development creates new jobs, expands the U.S. economy, and lowers the costs of geothermal technologies. Pictured above: William Teplow of Trans-Pacific Geothermal Corporation in the El Hoya-Monte Galán region of Nicaragua.

Objective 3.2

Increase market opportunity for U.S. industry by identifying geothermal resources in developing countries.

Strategic Issues Government agencies in developing countries—such as the Philippines, Indonesia, Mexico and other Latin American countries—have been working to assess their geothermal resources for two decades. In other countries there has not been adequate funding or technical expertise to address the problem in the way needed to spur development. Still other countries—most notably China—have huge trade potential and favorable geology, but poorly documented geothermal resources. They present a high risk to foreign investment. The United Nations, the World Bank, U.S. AID, and other U.S. and foreign agencies have established programs to help developing countries assess and develop their energy resources. However, quite often geothermal resources are overlooked because reliable information is not available, nor has sufficient drilling been done to confirm geothermal reservoirs. As a result, resource exploration has not progressed at a satisfactory rate. U.S. industry would benefit from knowledge of economic geothermal resources in developing countries whose policies favor increased use of their indigenous resources.

Strategy 1. Form partnerships with other DOE offices, U.S. agencies, the United Nations, the World Bank, country governments and foreign organizations to assist developing countries in assessing and publishing information on their geothermal resource base.

Strategy 2. Provide education to developing countries about U.S. geothermal resource assessment methods and techniques.

Objective 3.3

Educate key stakeholders in developing countries about the benefits of geothermal energy.

Strategic Issues Many key persons in developing countries—including scientists and engineers, government decision makers, bankers, and legal experts—lack knowledge of their countries' geothermal resources or how geothermal energy can help their social development in an economically sustainable and environmentally safe

way. In those cases in which key individuals do possess that knowledge, often it came from sources other than the U.S. National geothermal specialists trained in the geothermal training centers of Iceland, Italy, and New Zealand, tend to turn first to their teachers for advice on how to plan their large-scale development projects. This lack of a centralized training center, or at least a centrally organized training program, poses a barrier to training domestic and foreign managers, politicians, engineers and scientists in the implementation of U.S. technology. In general, the level of geothermal technical education and awareness of the value of geothermal energy needs to be increased. Better market opportunities for U.S. industry with its superior technology will result.

Strategy 1. Improve the level of technical education among scientists and engineers in developing countries so that they can reliably assess their own resources.

Strategy 2. Partner with U.S. Government agencies to educate relevant groups within developing countries on the potential of geothermal energy and the benefits of geothermal energy projects.

Strategy 3. Educate government officials in developing countries on the ease of application and benefits of using geothermal for rural electrification and direct use.

Objective 3.4

Improve U.S. competitiveness internationally.

Strategic Issues The very large international geothermal market encompasses electrical power generation, direct heat applications, and GHPs. Various countries are vying for a share of this market, with strong partnerships between government and industry, often with the government opening the initial doors for their industry. The U.S. Government has not kept pace with some other countries in this regard.

Strategy 1. Serve as an intermediary to promote closer relationships between the U.S. geothermal industry and government decision makers in other countries.

Strategy 2. Facilitate entry into the international market of small U.S. geothermal contractors and consultants.

Objective 3.5**Promote geothermal energy for rural electrification and development.**

Strategic Issues A universal problem in the developing world is the migration of people from rural areas, where there are few jobs, to already overcrowded cities. Many developing countries hope to provide jobs and amenities to rural peoples as a means of stemming such migration. Since many rural areas have no access to a power grid, the provision of electricity is a high priority. Small-scale and "micro" geothermal electric systems could readily serve as sources of "village power" and "mini-grid power" for rural, island, and other remote locations.

To date, U.S. Government agencies, banks, and other funding sources, (e.g., the World Bank) have not seen geothermal energy as a solution to the problem of rural electrification. The perception is that geothermal power plants are exclusively base load, costly, and unable to furnish the small amounts of power (100 kWe to 5 MWe) needed in many remote rural situations. This perception is incorrect. Further, these organizations do not appreciate that geothermal energy has simple and effective cascade uses as process heat for small industries and community-based ventures. Crop drying, greenhouses, and district heating are but a few examples.

As previously discussed, a centralized training center, or at least a centrally organized training program, would be an excellent tool to train domestic and foreign managers, politicians, engineers, and scientists in the implementation of U.S. technology. The level of geothermal technical education and awareness of the value of geothermal energy needs to be increased.

Strategy 1. Develop simple, robust equipment for export to countries where technical skills are scarce.

Strategy 2. Establish performance models for rural electrification, and direct use applications of geothermal

energy that U.S. industry can employ in developing countries.

Strategy 3. Advise developing countries in identifying their geothermal resources for rural development.

Strategy 4. Partner with other renewable energy technologies and programs to integrate geothermal energy into rural electrification plans.

Objective 3.6**Reduce the political and legal risks for U.S. industry in developing the geothermal resource of other countries.**

Strategic Issues Although the concept of private power is sweeping the world, most government agencies, utilities, financial institutions, and other entities in developing countries lack a practical basis in law to facilitate that change. Several governments, notably in Latin America, have requested assistance in devising geothermal laws and regulations that will encourage private investment in their countries. However, they are the exception rather than the rule. Many other countries remain unable to raise the capital necessary for rapid expansion of their energy infrastructure. They would benefit from new laws that make private investment easier and less risky.

Strategy 1. Assist U.S. industry in dealing with foreign governments on legal and regulatory issues.

Strategy 2. Enter into bilateral or multilateral cooperative agreements with interested countries, to support development of their indigenous geothermal resources.

Strategy 3. Compile a summary of U.S. laws, rules, and regulations relevant to finding, extracting, and using geothermal energy.

4. Science and Technology

At present, the U.S. industry leads the world in geothermal technology. However, that lead is threatened by the combination of low levels of support for geothermal R&D relative to competing nations and the current slowdown in domestic geothermal development. In the United States, reduced demand for new generating capacity and strong competition from natural gas have resulted in a poor market for new geothermal capacity, providing only limited opportunities for employment in geothermal. Therefore, there is little incentive for students in U.S. colleges and universities to seek an education related to geothermal energy. It is critical that in the future the U.S. industry has the knowledge base and technical expertise to develop geothermal resources in increasingly difficult geologic environments.

Warren Gretz, NREL / PIX 06152

The Office of Geothermal Technologies seeks to accelerate the development of geothermal science and technology to ensure that the United States leads the world in geothermal energy expertise. Pictured above: NREL researcher Desikan Bharathan working on a computer model of the advanced direct contact condenser designed to boost geothermal power.

Strategic Goal 4 *Accelerate the development of U.S. geothermal science and technology to ensure that the United States continues to lead the world.*

Objective 4.1

Support a diverse, well-trained community of geothermal energy specialists.

Strategic Issues Few students are being trained in geothermal technology in the United States. Geothermal training needs to be combined with other disciplines, such as hydrology or petroleum engineering, to augment the energy specialists' acceptance in the job market. The United States needs a continuous, core R&D program to maintain the expertise of these trained specialists.

Other countries, such as New Zealand, have college-level programs dedicated to training geothermal specialists. The United States has the opportunity to tap foreign expertise to enhance the training of U.S. geothermal specialists.

Strategy 1. In cooperation with the academic community, support one or more geothermal training centers.

Strategy 2. Expand graduate-level geothermal education and research.

Strategy 3. Develop educational materials about geothermal energy at the K-12 grade levels.

Strategy 4. Encourage industry and government agencies with modest cost-sharing to support a core group of geothermal energy specialists.

Objective 4.2

Expand the knowledge base in geothermal energy.

Strategic Issues An ever improving base of knowledge will be needed to develop geothermal resources from increasingly complex and difficult geologic environments. These environments provide major challenges in terms of understanding the resources and providing suitable technology to exploit those resources.

Strategy 1. Maintain a high-quality R&D infrastructure of instruments, equipment, and laboratories within industry, government, and academia.

Strategy 2. Expand technology transfer to speed private sector acceptance of new technology.

Strategy 3. Encourage industry and government agencies to support expansion of the geothermal knowledge base through cost-shared scientific research.

Strategy 4. Maintain diversity in the geothermal R&D portfolio to ensure advances in both basic and applied geothermal knowledge.

Strategy 5. Collect, maintain, and disseminate information about geothermal energy.

5. Future Geothermal Resources

The greatest potential of geothermal energy lies in the full development of hydrothermal resources and in the harvesting of heat from rocks that lack sufficient natural water. Many geothermal experts believe that with improved technology, heat may be economically extracted from hot, but dry rocks. When suitable technology is developed, a significant portion of the world's energy needs will be furnished from geothermal sources. This is the long-term promise of geothermal energy.

U.S. Department of Energy / PIX 06158

The Southeast Geysers effluent pipeline is transporting treated wastewater to The Geysers for enhanced steam production and power generation. This project, and others like it, can extend the power-generating lifetime of geothermal fields. Pictured above: (l to r) Mark Dellinger from Lake County Special Districts, and Raymond Fortuna and Allan Jelacic from the Office of Geothermal Technologies, at the dedication of the Southeast Geysers effluent pipeline project.

Strategic Goal 5 *By the year 2010, develop new technology to meet 10% of U.S. nontransportation energy needs in subsequent years.*

Objective 5.1

Reduce costs of locating and producing deeper hydrothermal resources.

Strategic Issues Current technology is inadequate to economically develop the deeper hydrothermal resource base. The major technical barriers to development are 1) a general inability to locate and define deep, permeable zones so that wells can be drilled into them, and 2) the high cost of geothermal drilling.

Strategy 1. Support creative partnerships of diverse groups in industry and academia to spawn new technological advances.

Strategy 2. Pursue revolutionary improvements in drilling technology.

Strategy 3. Increase accuracy of mapping deep, permeable zones in hydrothermal reservoirs.

Objective 5.2

Develop technology for economically producing energy from enhanced geothermal systems.

Strategic Issues The vast majority of the geothermal resource base exists in rocks that are hot but lack sufficient porosity, permeability, or fluid to produce geothermal fluids in economic quantities. A continuum in permeability exists in rocks, from those whose permeability is very high and can support production of geothermal fluids in the range of 250,000 or more pounds per hour from a single well (hydrothermal reservoirs), to rocks which are virtually impermeable and hold little or no natural water (hot dry rock). The term "enhanced geothermal systems" refers to geothermal systems with less than ideal permeability or fluid content that will require "enhanced" methods to be developed economically. At present, only higher grade (e.g., hot, permeable, and relatively shallow) hydrothermal systems can be developed economically. For geothermal energy to fulfill its greater potential,

technologies must be developed to enable industry to economically develop enhanced geothermal systems.

Strategy 1. Develop technology to extract energy from resources of progressively lower permeability and fluid content.

Strategy 2. Use unproductive portions of operating hydrothermal reservoirs as test beds for enhanced geothermal systems.

Strategy 3. Conduct resource assessments of high-temperature, nonhydrothermal resources suitable for development as enhanced geothermal systems.

Objective 5.3

Collaborate on R&D in advanced geothermal technologies with other countries.

Strategic Issues Significant progress is being made in advanced geothermal technology by several groups, most notably by several research groups in Europe and Japan. These groups have willingly shared results from their work. However, protocols for exchanging detailed technical information and leveraging funds to achieve maximum benefit to the United States need to be improved.

Strategy 1. Participate in bilateral and multilateral cooperative agreements with other countries.

Strategy 2. Participate in international workshops and meetings on topics relevant to major advances in geothermal technology.

Strategy 3. Sponsor international personnel exchange programs to remain current on new concepts and approaches to advanced geothermal technologies.

Benefits of the Plan

A geothermal project provides a wide array of benefits to society. The large amount of thermal energy in the Earth's upper crust allows geothermal projects to provide economic, reliable, and environmentally sound electric power, for applications ranging from grid-connected baseloads to off-grid remote demands. Electricity from geothermal energy provides an economic benefit to the nation because the electricity is dependable, has high availability, and is produced from a domestic source. Further, sales of electricity and of U.S.-made equipment and services, both within the United States and abroad, provide a significant revenue source for the geothermal industry. Lastly, in the United States, lease fees and royalties from geothermal power plants on Federal lands provide the U.S. Government and the states with more revenues than what is presently expended on Federal geothermal R&D.

In supporting geothermal R&D, we are strengthening the overall energy infrastructure of the United States. Innovative geothermal engineering developments, such as new drill bits, have greatly benefitted the oil and gas industry. Other products of geothermal R&D, such as corrosion-resistant cements, have been used in a variety of applications.

Recently, British Petroleum recognized that buildup of carbon dioxide in the atmosphere will alter the Earth's climate. International accords call for reductions in levels of carbon dioxide released to the atmosphere. Geothermal energy can rapidly bring large amounts of power on line in many countries without a significant contribution to carbon dioxide emissions or atmospheric pollution. Given the goals laid out in this Plan, by the year 2010, U.S. production of geothermal energy could displace as much as 19 MMTC emissions annually and substantially reduce the quantities of other atmospheric pollutants that are damaging to public health and the environment.

In the United States, royalties, rents, and bonus bids from geothermal energy operations generate more revenue than what is expended on Federal geothermal research and development.

Over the next decade the cumulative benefits of achieving the goals of this Strategic Plan will be to:

- Stimulate \$61 billion of domestic investment in all geothermal facilities.
- Stimulate \$16 billion of U.S. investment in overseas geothermal power facilities.
- Create 1.6 million person-years of new employment in the United States.
- Reduce U.S. carbon emissions by 80 to 100 MMTC.
- Reduce global carbon emissions by 190 to 230 MMTC.
- Add \$180 million to government royalties from geothermal projects operating on Federal lands.

Over the ensuing decades, the benefits would increase many fold as the use of enhanced geothermal systems becomes more prevalent.

Resource Needs

The strategies in this Plan provide a basis from which to estimate the funding resources needed to reach the strategic goals. However, the strategies can imply varied levels of support, and absent in-depth programmatic planning that specifies research priorities and timing, we cannot define a fixed budget level. Given the ambitious goals and scope of the Plan, increased budgets beyond current levels are likely. For comparison of resource needs, we have the recommendations of independent organizations who have studied research needs for geothermal development:

1. National Academy of Sciences (NAS) Study on Geothermal Energy Research—1987.

The NAS Committee on Geothermal Energy Technology reviewed the status of geothermal resources and technology, and progress made by the DOE Geothermal Research Program. The Committee suggested that the geothermal research budget should be raised by 60%, to \$34 million, which in 1998\$ would be \$47 million. The Committee also emphasized that the Geothermal Program should increase support for scientific studies of advanced geothermal resources (e.g., hot dry rock, geopressured, magma).

2. National Geothermal Association Recommendations—1993.

The National Geothermal Association (NGA), an interest group that promotes government policies conducive to private-sector geothermal development, developed a series of Federal R&D priorities that it presented to the Subcommittee on Energy and Water Development, of the House Committee on Appropriations in April 1993. The total recommended budget was \$61.4 million per year (1993\$).

The NGA identified priority research thrusts, including the Hydrothermal Base R&D Program, Industry-Coupled Drilling, Hard Hot Rock Project, Fluid Injection at The Geysers, and Advanced Energy Conversion.

3. PCAST Panel on Energy Research and Development—1997.

U.S. energy needs, technologies, and R&D programs were recently reviewed by the Energy Research and Development Panel of the President's Committee of Advisors on Science and Technology (PCAST) in a report published in November of 1997. The PCAST Energy Panel recommended that the DOE Geothermal Program should:

- Continue work on hydrothermal systems, including cost-shared work with the relatively small and somewhat fragile geothermal industry.
- Reactivate R&D for advanced geothermal energy concepts with the top priority given to high-grade hot dry rock systems.
- Increase participation of other DOE programs and other Government agencies in the National Advanced Drilling and Excavation Technologies Program, begun a few years ago with seed money from the DOE Geothermal Energy R&D Program. The NADET program will assist in the leveraged development of advanced drilling technology to lower costs—opening up a larger fraction of the massive U.S. geothermal resource base for competitive power production as well as making advanced drilling technology available to a host of other industries.
- Enhance R&D on reservoir diagnosis and modeling to better understand geothermal reservoir behavior, increase performance (productivity and system lifetime), and lower development costs.

Geothermal Program

Funding levels within the DOE Geothermal Program should be increased from \$30 million in FY 1997 to \$49 million in FY 2000, and slightly higher thereafter. The increment should include funding at a level of up to about \$5 million per year, with matching funds from DOE's Office of Energy Research (ER) directed towards fundamental research needs in identifying and exploiting advanced geothermal energy technologies. This fundamental research should be both cofunded and comanaged by the Geothermal Program and by ER.

Comparison of Recommendations

Besides an expanded R&D budget for the Program, some other common threads in these recommendations include:

- Core hydrothermal research should be expanded, with increased emphasis on advanced drilling systems and understanding of reservoir mechanics.
- DOE should reestablish some of the risk-sharing programs with industry that were so successful in the late 1970s and early 1980s.
- Hot dry rock R&D should continue to be pursued at 10% to 20% of the total budget, as an important long-range national energy resource.

These conclusions on the technical content of the program largely coincide with the strategies suggested by this Plan.

References and Notes

1. The U.S. geothermal resource base includes known heat in the crust down to a depth of 10 kilometers at temperatures above 100°C. Its size was estimated from various studies by the U.S. Geological Survey and DOE. The U.S. oil reserve includes crude oil, heavy oil, tar sands, and oil shale, as determined by the National Academy of Science in 1990.

Appendix

A Perspective on Benefits and Costs of the Plan

The DOE Geothermal Energy R&D Program is a modest investment in the future energy supply for the American people, with worldwide benefits.

If the current Geothermal R&D Program is expanded to achieve the goals outlined in this Plan:

- Commercial generation of geothermal power in the United States can quadruple by 2010 using known geothermal reserves;
- Installation by U.S. firms of geothermal power plants overseas would more than quintuple by 2010;
- GHPs and direct applications of geothermal heat will match in energy terms the production from conventional geothermal electric systems; and
- Technology can be developed to commercialize the currently untapped geothermal resources, leading to geothermal energy providing a significant portion (60,000–70,000 MWe) of U.S. electrical generating capacity.

1. What can we buy for one cent per day per home?

To gain a perspective on what the Strategic Plan buys, let us weigh the benefits to the American people derived from the strategic goals against the probable cost of the Plan.

Supply Seven Million U.S. Homes with Geothermal Electricity by 2010

The average American home uses about 10,500 kWh of electrical energy annually. Based on projected growth in demand and increased competitiveness, some 10,000 MWe of geothermal capacity can result by the end of 2010. That capacity would produce about 79 million megawatt hours (MWh) per year of geothermal electrical energy, equivalent to all the electricity consumed by 7.5 million homes, the residences of about 18 million people.

Supply Seven Million Homes with Geothermal Heat and Cooling by 2010

Another part of the Geothermal Energy R&D Program would be devoted to improving GHPs and direct use technologies. The detailed goal here is that 7.3 million GHP units (average 3-ton residential system) would be in operation at the end of 2010. Each 3-ton GHP unit, a typical residential size, would save about 3,700 kWh per year relative to its most direct competition, an air-source heat pump. The savings from 7.3 million units would be 27 million MWh per year, the equivalent of the output from four 1,000-MWe coal-fired power plants.

Heat 140,000 Homes Using Geothermal Direct Heat

Direct uses of geothermal heat, growing at 5% per year from the current installation base, will supply about 11 trillion Btu per year in 2010. That is equivalent to the annual heat use of 140,000 additional U.S. homes. The usage will be spread among residential, commercial, agricultural, and industrial uses.

Integration

The goals above are actually “residence equivalents.” We summed the 7.3 million and the 0.1 million into 7.4 million households, but rounded off to report 7 million residences for convenience. About 80% of the heating and cooling would

Geothermal Program

actually be used in residences. About 20% would be used in commercial and industrial settings, including stores, schools, offices, hospitals, and manufacturing. As many as 20 million people would be served in some way.

Summed Effect

Therefore, the approximate total number of homes served by this Plan would be $7.5 + 7.3 + 0.1 = 14.9$ million. If the investment in geothermal R&D were equivalent to a penny a day per household (i.e., \$3.65 per year), the annual budget would be on the order of \$54 million. This amount falls within the range of budget recommendations by independent organizations who have analyzed the Geothermal Program. The investment is remarkably cost effective when compared to the return from the strategic goals in terms of people served and new business generated.

2. Reduce Global Greenhouse Gas Emissions, Particularly Carbon Dioxide.

Greenhouse gas emissions will be avoided by overseas, as well as domestic, development of geothermal resources. To this end, the DOE Geothermal Energy R&D Program has supported the U.S. geothermal industry. Today that industry is busily building many new geothermal power plants in the Philippines, Indonesia, and Central America.

By the end of 2010, we expect emissions reductions to total about 42 MMTC per year, from the following:

- U.S. domestic geothermal power plants:	14.9 MMTC
- U.S.-built overseas geothermal power plants:	23.4 MMTC
- GHPs in the United States:	4.0 MMTC
- Geothermal direct use in the United States	0.2 MMTC

65,000 MWe of electric capacity from unconventional geothermal sources (e.g., hot dry rock) would reduce carbon emissions by 80 million metric tons of carbon per year, on a sustainable basis.

If the current DOE Geothermal Energy R&D Program is expanded to achieve its new goals, worldwide emissions of greenhouse gases will be significantly reduced.

3. Reduce the Use of Hydrocarbon Fuels by 400,000 Barrels of Oil Equivalent per Day.

The production of 79 million MWh/year of electricity from geothermal energy saves fossil fuels (oil, coal, natural gas) equivalent to 104 million barrels of oil each year, based on 0.756 MWh of electricity from each barrel of oil. The 27 million MWh/year of electricity saved by GHPs is equivalent to 35 million barrels of oil per year. Those two thrusts sum to 139 million barrels of oil equivalent in 2010, and continue to increase thereafter.

NOTICE: This report was prepared as a account of work sponsored by an agency of the United States government. Neither the United States government nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Printed in the United States of America

Available to DOE and DOE contractors from:

Office of Scientific and Technical Information (OSTI)
P.O. Box 62
Oak Ridge, TN 37831

Prices available by calling (423) 576-8401

Available from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

Information pertaining to the pricing codes can be found in the current issues of the following publications which are generally available in most libraries: *Government Reports Announcements and Index (GRA and I)*; *Scientific and Technical Abstract Reports (STAR)*; and publication NTIS-PR-360 available from NTIS at the above address.

Produced for the
U.S. Department of Energy

1000 Independence Ave., SW
Washington, DC 20585

by the
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
a DOE national laboratory

DOE/GO-10098-572
June 1998

Printed with renewable source ink on paper containing
at least 50% wastepaper, including 20% postconsumer waste