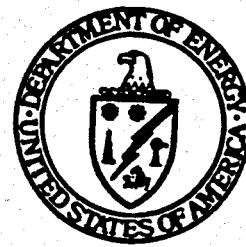


Geothermal Energy Draft Multi-Year Program Plan

FY 1996-2000



**Geothermal Division
U.S. Department of Energy**

March 3, 1995

NOTICE

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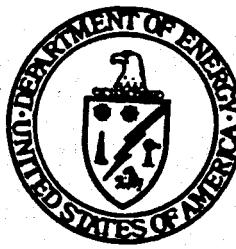
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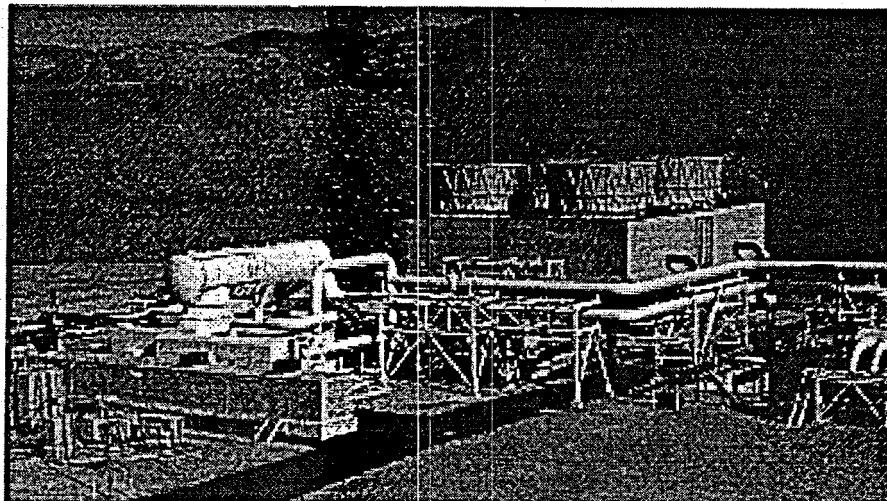
I. INTRODUCTION

Geothermal and other renewable energy technologies are expected to play an increasingly important role in meeting the nation's and the world's future energy needs. Domestic electricity consumption in the United States, projected to increase 26% by the year 2010, will require construction of an additional 172,000 megawatts (MW) generating capacity^{1,2}. International electric capacity is expected to increase to an even greater degree. As technology continues to improve, geothermal energy, with its abundant resources, competitive costs, and minimal environmental impacts, will become an attractive alternative to conventional sources that dominate today's energy mix.

Geothermal energy is the nation's most versatile, reliable, economic, and environmentally benign renewable energy resource, capable of both meeting supply needs and managing demand. The Integrated Resource Plans of electric utilities, state regulatory agencies, and regional power authorities reflect a continuing trend of gradual geothermal capacity expansion. The geothermal heat pump, a demand-side management option, is gaining a growing share of home and commercial heating and cooling markets nationwide. Other direct uses of geothermal heat serve to conserve energy and reduce utility loads.

The Geothermal Division of the U.S. Department of Energy serves as the national Federal technical expert for formulating and implementing national energy policies and programs relating to geothermal technology. The mission of the Geothermal Division is: *"In partnership with industry and other stakeholders, plan and manage a balanced program for technology research, development, testing, and evaluation that will stimulate an expanding use of geothermal energy for environmentally-sound electric power generation and direct use applications."*

The Division's partnership with the U.S. geothermal industry and other stakeholders in geothermal energy development is critical for the success of all of the Program's activities. It is industry that discovers and develops geothermal reservoirs and designs and constructs geothermal power plants and direct heating systems. Other stakeholders influence and mold both industry's and the Division's plans and activities, to ensure that geothermal energy projects provide optimal benefits to society as a whole. The Division's main role is to support the design and development of technology to reduce system costs, and to improve the environmental and social benefits and acceptability of geothermal energy use.



Geothermal resources can provide reliable and environmentally sound electrical energy. This is a 28 MWe flashed-steam plant at Coso, California.

To accomplish its mission, the Geothermal Division works to achieve several general, yet measurable, goals embodied in its vision statement. The vision of the Geothermal Division is to:

- Improve the competitive status of the U.S. geothermal technology in domestic and global electricity markets;
- Help the U.S. industry maintain leadership in world geothermal electricity markets;
- Promote geothermal heat pumps as a significant domestic demand side management option; and
- Gain recognition of geothermal energy as an abundant, reliable, economic, and environmentally-beneficial energy source for the nation and the world.

In this Multi-Year Program Plan, the Geothermal Division outlines its strategy for developing and transferring technology that will enable industry to realize these energy supply and demand management opportunities. The Plan describes the status of geothermal energy systems and the general plan for research to improve such systems. It identifies the stakeholders involved and the market and institutional realities that they now face. It describes the steps the Division will use to achieve significant technological progress to enhance the economic competitiveness of geothermal energy systems in both domestic and international markets.

THE RESEARCH STRATEGY

Changes in energy market forces in past few years (especially low prices of natural gas) and improved prospects for privatized electricity generation in many foreign countries, have turned the near-term focus of the U.S. geothermal electric industry to exports rather than domestic sales. Concurrently, strong market signals have emerged that geothermal heat pumps could make very significant contributions to domestic energy efficiency in the near term.

Such events have induced the Geothermal Division to focus its strategic outlooks on:

- Accelerated efforts to markedly reduce the cost of both geothermal wells and power plants, to enhance both domestic competitiveness and export sales of geothermal electric systems.
- A new emphasis on helping U.S. firms to condition and develop additional international markets for geothermal energy electricity production.
- A strong new collaborative effort with the electric utility industry and environmental groups to markedly accelerate domestic installations of geothermal heat pumps, as an important Climate Change action.
- Continuing to pursue heat mining as the large geothermal long-term option. Many energy system analysts believe that heat mining is as important as a long-term energy option as nuclear fusion and solar energy.

EXPECTED PAYOFFS

The expected payoffs from the Base Research Program are shown in Table 1. For geothermal electric power systems through 2000, U.S. industry will find most of its business offshore. Significant domestic growth is expected to occur after 2000. Heat mining applications could be extensive after 2010. Geothermal heat pump usage will accelerate markedly in the near term.

Table 1. Expected Payoffs from BASE R&D Program
(Values by end of year)

Performance Measure:	1995	2000	2005	2010	2015
A. Domestic Hydrothermal Electricity, MWe	2,100	2,500 to 2,600	4,900 to 5,700	6,600 to 9,000	8,500 to 13,000
B. Domestic Heat Mining Electricity, MWe	0	3 to 5	35 to 65	190 to 350	1,900 to 3,500
C. U.S. - Built Overseas Electric Power, MWe	1,210	3,000 to 3,400	4,100 to 5,500	5,400 to 8,000	6,500 to 11,000
D. Geothermal Heat Pumps, (Domestic) 1000 units	180 to 200	1,300 to 1,600	4,100 to 5,600	8,800 to 13,600	12,700 to 21,800
E. Other Direct Heat (Domestic), Trillion Btu/year	6.7	7.7 to 9.2	9.1 to 12	11 to 16	13 to 21

The payoffs from an Enhanced Research Program are estimated to exceed those of the Base Program, as follows:

- Domestic Hydrothermal Electric Capacity: Enhanced program produces a 60 percent increase by end of 2015.
- Heat Mining (Domestic): Enhanced program produces 85 percent higher capacity installed by end of 2015.
- International Electric Capacity: Enhanced program produces 30 percent higher capacity installed by U.S. firms through 2010, and about 50 percent higher through 2015.
- Geothermal Heat Pumps: Enhanced program reduces by one year, the year in which penetration reaches 50 percent of the market. The most noticeable effect is 20 percent higher installed capacity by 2005. Overall, the effect is increased electricity and global warming savings during the 2005 to 2015 period.
- Other Direct Heat: Enhanced program could increase installations through 2015 by as much as 200 percent.

II. BACKGROUND

GEOTHERMAL RESOURCES AND TECHNOLOGIES

Geothermal energy - the heat of the earth - is a very large and widespread resource and is one of the most reliable and environmentally-friendly energy sources available. The resource is already making a significant contribution to the nation's energy needs - as both heat and electricity - and its future is even more promising.

Geothermal heat originates from the earth's molten interior and from the decay of radioactive materials in the earth's crust. In some places, this heat comes to the surface in natural streams of hot water or steam, which have been used since prehistoric times for cooking and bathing. Most geothermal resources lie beneath the surface. Man-made wells convey the heat from deep in the earth to homes, farms, factories, and electric generators.

To date, all commercial development of geothermal energy, for both power generation and direct use, has employed hydrothermal resources. The advanced technology needed for economically extracting power from hot dry rock resources is under development.

Hydrothermal systems can be categorized as liquid-dominated (hot water) or vapor-dominated (steam) based on the dominant fluid phase trapped in fractured and porous rocks. The highest quality U.S. resource areas are located in the western states, where relatively young volcanoes or a thinning of the earth's crust are associated with many shallow high-temperature sites. A large number of low-temperature systems — <90°C (194°F) — are found in the western, eastern, and central U.S.

Three discrete energy conversion technologies may be used for generating electricity with geothermal resources. The resource characteristics that dictate the use of a particular technology are the form in which it occurs (vapor or liquid), its temperature, and its chemistry.

Conventional turbine generators are employed to generate power from vapor-dominated resources where the naturally occurring dry steam eliminates the need for a boiler. While these are the simplest geothermal energy conversion systems, vapor-dominated resources are relatively uncommon.

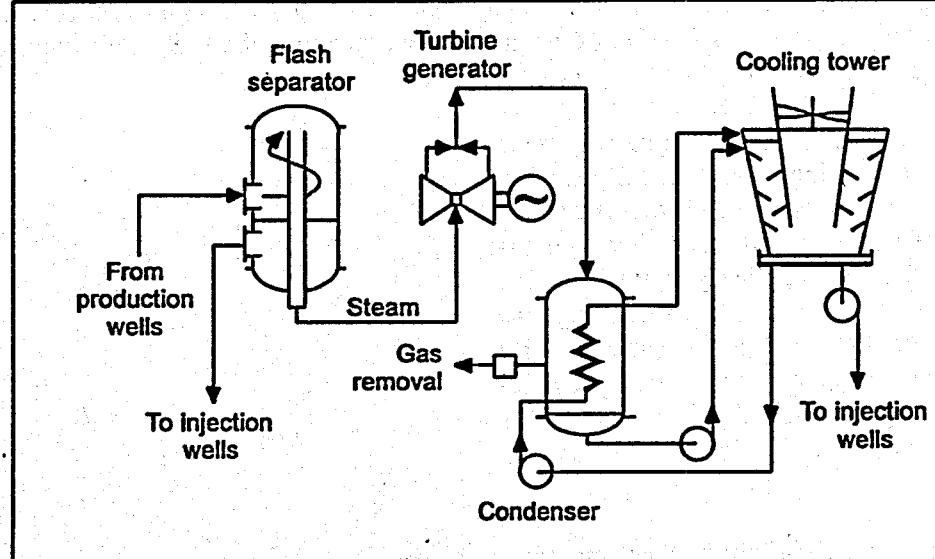
For liquid-dominated resources with temperatures of 200°C (400°F) or higher, the flash-steam technology illustrated in Figure 1 may be used. The liquid is allowed to flash to steam under reduced pressure as it reaches the ground surface. The steam is separated from the remaining liquid and used to drive a turbine generator. The economics of geothermal flash plants can be improved by using a double-flash cycle, which produces additional steam by flashing the steam a second time, and produces up to 20 percent more power than a single-flash system.

Lower-temperature hydrothermal liquids are more suited to the binary cycle units shown in Figure 1. In this technology, the heat of the geothermal liquid vaporizes a secondary working fluid for use in the turbine. These units may be used to generate electricity from resources with temperatures in the range of 110°C to 200°C (300° to 400°F).

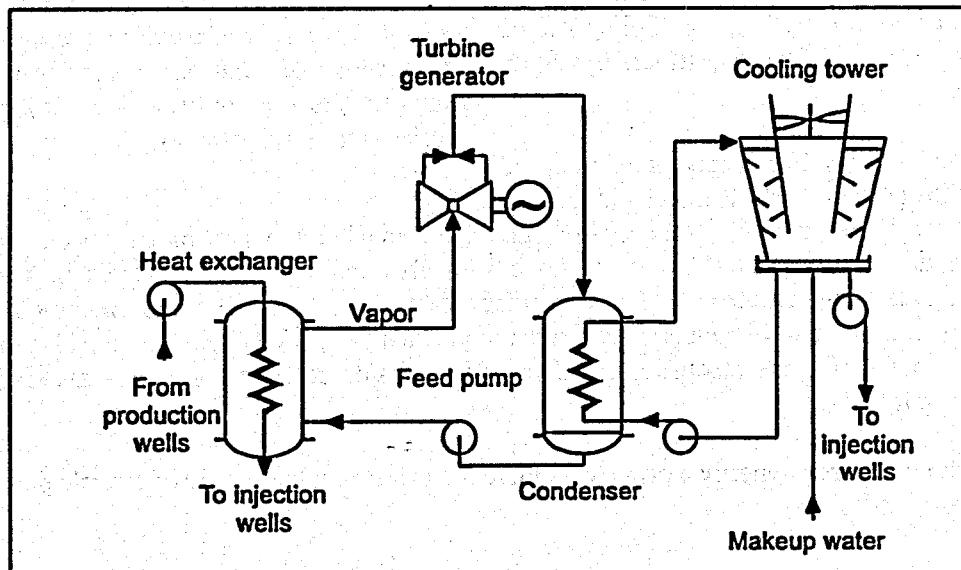
Geothermal resources cooler than 150°C (300°F) are suitable for applications that require large amounts of heat such as district heating systems, industrial processes, and crop drying. The technology for direct

use applications is drawn mainly from conventional hot water and steam handling and heat transfer equipment.

Some rock formations are hot but contain no fluid. To mine heat from them, drillers create a man-made reservoir within the rock. Water is injected down one well, circulated through the hot rock, and recovered through a production well. The most accessible "heat mining" resources of sufficient temperature to produce electricity are found mostly in the western states near young volcanic centers, many of which also contain hydrothermal reservoirs.



Flash-steam technology for high-temperature liquids.



Binary cycle technology for moderate-temperature liquids.

Figure 1. Geothermal Generation Technologies

GENERAL BENEFITS OF GEOTHERMAL ENERGY

The promise of geothermal energy is that it is a very large and relatively clean source of electricity and heat. In particular, geothermal energy systems emit extremely low levels of greenhouse gases compared to fossil-fueled sources. Over the long term, geothermal energy offers an opportunity as great as that of nuclear energy or fusion energy for forestalling global warming, whether used in the U.S. or elsewhere in the world.

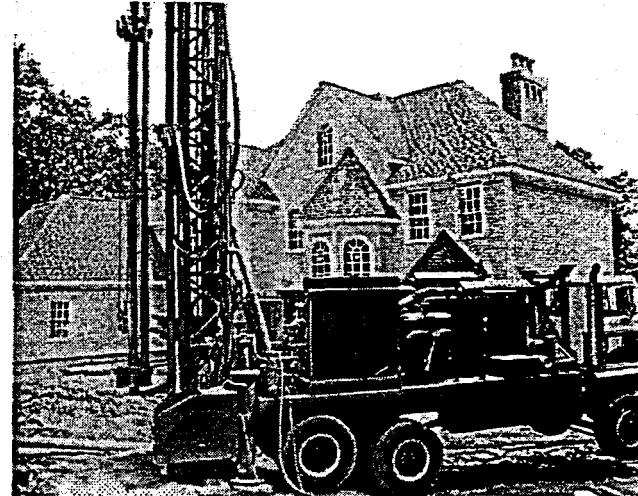
The primary product of DOE's partnership with the geothermal industry has been the commercial adoption of hydrothermal electric-power-related technologies developed through the Geothermal Division's R&D programs. The Division has had, and continues to have, a significant role in shaping an industry responsible for over 2,000 MWe of net generating capacity in the U.S. This industry is now making good progress in exporting that technology overseas.

Direct application of geothermal heat to processes such as space heating, greenhousing, and mineral recovery provide alternatives that assist load reduction and conservation measures. Geothermal heat pumps (GHPs) and other direct use applications are providing demand-side management and conservation options designed to manage the need for electricity. By offering a nationwide option for reducing overall demand and managing peak-period power loads, GHPs are expanding geothermal applications on a nationwide scale.

Geothermal energy also contributes other important benefits, such as reducing the nation's dependence on imported oil and improving the environment -- both major objectives of the National Energy Policy Act of 1992 and the Department's Energy Partnerships for a Secure Economy.

Use of geothermal energy has helped a number of western U.S. metropolitan areas to meet air quality standards. Nationally and globally, geothermal resources can contribute to meeting energy demands with minor effects on the environment. Geothermal facilities also can exist unobtrusively in scenic and recreational areas, as demonstrated by three geothermal power plants near the Mammoth Lakes, California, resort area. In newly emerging international energy markets with untapped geothermal resources, development of these resources could provide a major economic stimulus and reduce the consumption of fossil fuels.

These factors make geothermal energy a prime candidate for increasing the supply of electric power, both nationally and worldwide.



Small truck-mounted drill rigs such as this find extensive use in installing geothermal heat pumps and other direct heating systems. They are also used in drilling wells for micro-geothermal power systems.

The Environmental Promise

A major reason to pursue the development of geothermal energy technology and resources is that the environmental emissions associated with electricity production from geothermal resources are very low compared to most conventional energy sources. This is especially true with release of greenhouse gases that contribute to global warming -- the release of these from geothermal systems is very small compared to fossil-fueled systems.

- Geothermal carbon dioxide releases are much smaller than those from fossil-fueled electric plants -- typically less than 5 percent of that from coal, or about 10 percent of that from natural gas. Some types of geothermal plants emit no carbon dioxide at all.
- Geothermal systems release no nitrogen oxides. Nitrogen oxides are formed in high-temperature combustion processes, which do not occur in geothermal systems.
- The release of sulfur oxides from geothermal power plants is well below the minimum for air quality standards, even in the strictest jurisdictions.
- Geothermal fluids from a few reservoirs are noteworthy for their content of hydrogen sulfide. The geothermal industry has developed a variety of effective and safe hydrogen sulfide abatement technologies.

OPPORTUNITIES

Electric Power Generation

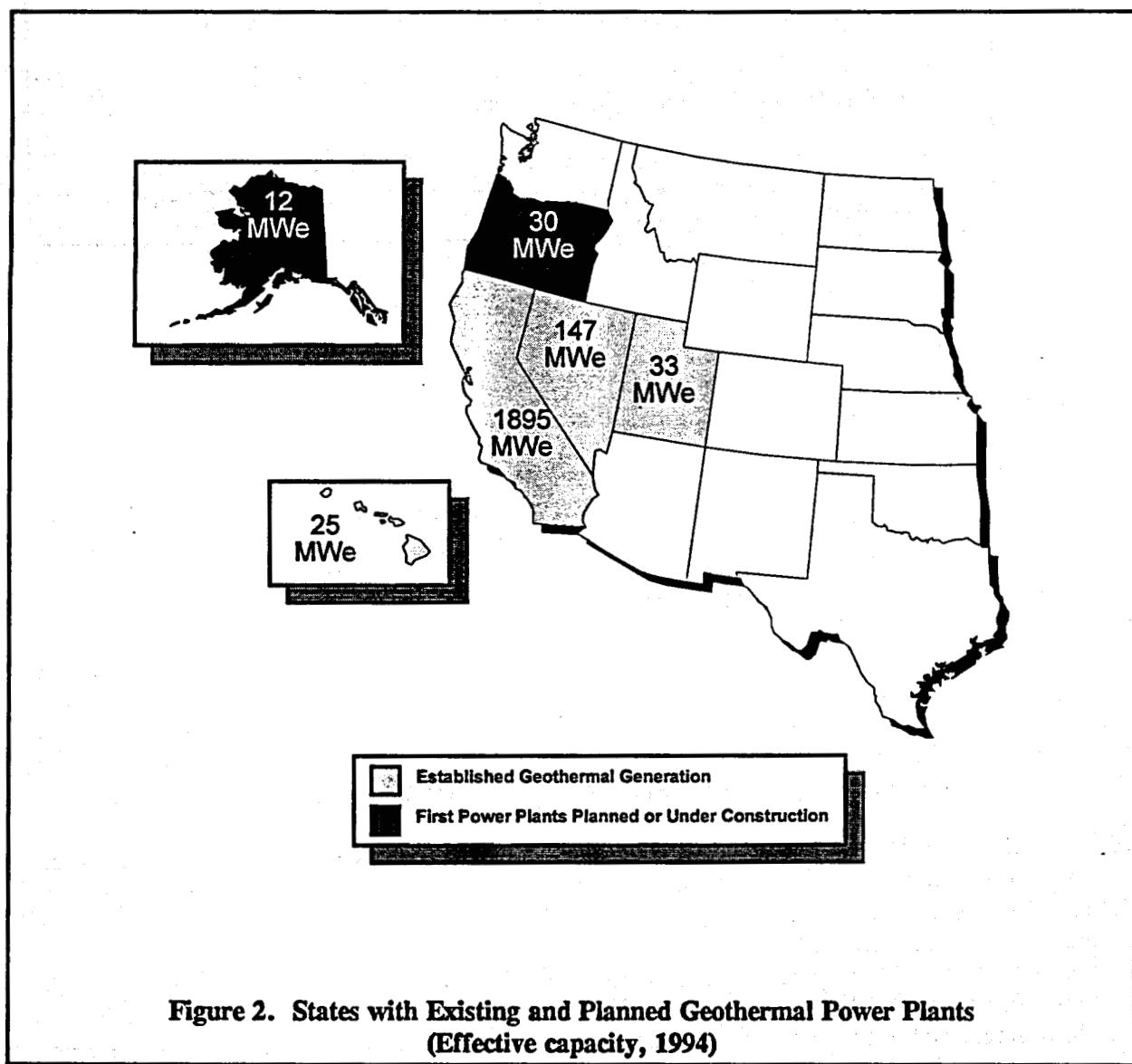
Seventy geothermal plants now operate at 19 geothermal fields in California, Hawaii, Nevada, and Utah (Figure 2), and new plants are planned for the Pacific Northwest and Alaska. About five percent of California's power needs in 1994 were supplied by geothermal plants. Utility generation of geothermal power resulted in a \$125-\$250 million cost savings to consumers in 1988, primarily due to the low cost of power from The Geysers field in California.

Since 1976, the Federal Government, through DOE and its predecessors, has invested about \$1.3 billion in developing and encouraging geothermal power generation and direct use applications. This Federal investment has leveraged substantial technology-improvement contributions from industry through collaborative, cost-shared research and demonstration projects. The geothermal construction industry and electric utilities have invested an estimated \$5 billion in U.S. electric power projects.

In 1979, the U.S. Geological Survey estimated that 23,000 megawatts of electricity could be supported by discovered geothermal resources and that undiscovered resources could potentially support an additional 72,000 to 127,000 megawatts in the long term³. A 1992 study by Sandia National Laboratory estimated that approximately 27,000 MW of electric power from already-identified hydrothermal resources will be available over the next 40 years. Including undiscovered resources increases this estimate to 50,000 MW. While only a portion of these resources are economic today, the study also found that incremental technology improvements could decrease the cost of developing the more expensive geothermal resources by as much as 53 percent⁴.

A very large additional long-term potential exists from resources accessible by heat mining techniques. As much as 1,900,000 MWe could be made economic in the 2010 - 2020 time frame if sufficient technology improvement occurs ⁵. That amount is about three times the total electric capacity now installed in the U.S.

The U.S. Energy Information Administration (EIA) has projected growth in geothermal electricity capacities (net summer capability) to range from 7,300 to 9,700 MW by 2010, with a reference case projection of 8,500 MW ^{6,7}. EIA also estimated that a very-aggressively-funded Federal geothermal exploration and R&D program could result in almost 18,000 MWe capacity installed by 2010 ⁸. These estimates are now deemed to be relatively high, given the substantial reductions in the cost of natural gas after the projections were made.



Potential for geothermal electricity generation outside the U.S., using current technology, is in the range of 80,000 MW⁹. (That amount is commensurate with the 23,000 to 27,000 MW of identified U.S. resources mentioned above.) The U.S. industry faces considerable competition to supply goods and services for this market. Continuing improvements in U.S. technology will contribute to the competitive position of U.S. industry. The very recent successes of U.S. geothermal firms in the Philippines and Indonesia will open doors to other markets in the Americas, the western Pacific Rim, and in the long run, Africa and elsewhere.

The challenge and opportunity facing the Geothermal Division is

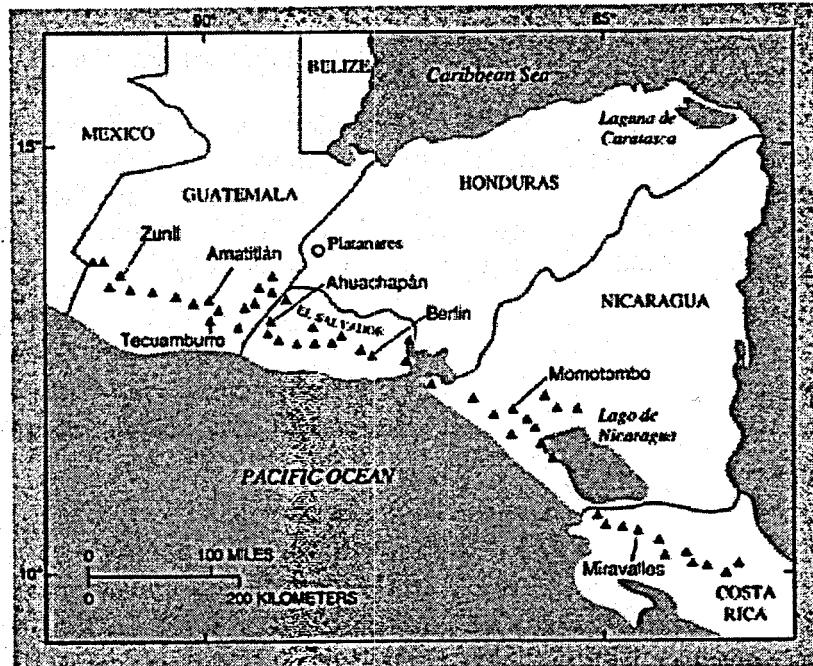
to assist the U.S. to take full advantage of this abundant, reliable, clean, indigenous domestic resource, and to promote the U.S. geothermal industry in international markets for new geothermal electric systems, thereby benefitting the nation via creation of high-tech jobs and improved balance of trade.

The Geothermal Division believes it is likely that an enhanced program of appropriately targeted research to improve technology, and to assist U.S. firms in opening new international markets could increase the rate of U.S. geothermal power systems overseas by an average of 200 MWe per year over the next 20 years. This would return at least \$4 billion (in nominal dollars) to the U.S. economy over that period.

Demand-Side Options

The annual energy saving from geothermal direct heat applications in the U.S. is over 10 trillion Btu, the equivalent of over 5 million barrels of oil.

An estimated 150,000 to 200,000 geothermal heat pumps are currently in use, with large growth rates expected in the near-term and mid-term. The total market for GHPs has been estimated to be about 25 million units¹⁰. The U.S. Environmental Protection Agency has endorsed GHPs as a technology that can both save consumers money and reduce atmospheric pollution¹¹. A series of nationwide GHP teleconferences, cosponsored by DOE, have stimulated a high level of interest among utilities and HVAC manufacturers in this renewable energy demand-side management technology. A few U.S. electric utilities currently provide incentives to spur GHP use, including: installation cost rebates to residential



These geothermal zones in Central America present a nearby and favorable market for export of U.S. geothermal goods and services.

and commercial customers, low-cost loans, and discounted electric rates. Growth rates for GHPs could reach 20 to 25 percent annually for at least the next few years.

Other geothermal energy direct use applications include space heating, aquaculture, greenhouse heating, industrial process heat, and balneology (therapeutic baths). Twenty-five geothermal municipal and institutional district heating systems are in operation, while individual systems serve a growing number of commercial and industrial enterprises. These applications are expected to grow annually at a rate of 4 to 11 percent, depending on the rate of technology development and market opportunities ¹².

Geothermal Export Potential

Working from a diverse base of solid technology developed and proven in domestic installations, U.S. geothermal electricity development companies have competed very successfully, as international contracts for new electric power systems soared upward in 1993 and 1994.

- Firm contracts to U.S. firms for about 2,000 MWe of geothermal capacity to be installed by about 2000 in the Philippines and Indonesia dominate current activities. Additional smaller contracts are in place elsewhere (e.g., in Nicaragua) and being negotiated in other countries.
- These international geothermal contracts will keep the major firms in the U.S. geothermal industry occupied and intact through at least 2000, thereby preserving and strengthening the system design and project management expertise these firms built domestically during the 1980's.
- Near-term overseas markets for small non-grid-connected geothermal power stations, especially in newly emerging markets, total many thousands of megawatts.
- Overall identified international geothermal resource potential is on the order of 80,000 MWe for 30 years. U.S. cumulative geothermal-electric technology exports might be as high as 7,000 MWe by 2005 and 10,000 MWe by 2010.

The Geothermal Program will:

- Continue to sponsor technical R&D to maintain and improve the international competitiveness of U.S. geothermal firms.
- Continue to study and promote the use of small geothermal electric systems (0.1 to 5 MWe capacity) for village, small city, and other off-grid powering, and as "ice-breaker" plants for the initial opening of new geothermal reservoirs.
- Accelerate market-conditioning, promotional, and technology demonstration activities, for Central and South America, and the Western Pacific Rim, the Rift Valley in east Africa, and the Indo-Asiatic continental boundary.

THE STAKEHOLDERS

A diverse group of stakeholders has an interest in the development of our nation's geothermal resources.

The U.S. geothermal industry is comprised primarily of geothermal developers and a broad array of suppliers and service companies that support them. A national trade association, the Geothermal Energy Association (GEA), has been formed by the industry to improve business conditions in the geothermal industry through public education, research, and advocacy of legislation favorable to the increased use and development of geothermal resources. The GEA also publishes statistical information and data to improve efficiency in the industry and encourage research and development¹³.

Geothermal developers include utilities (investor-owned and municipal), and independent power producers (IPPs). IPPs may be small firms specializing in geothermal development, large conglomerate-type firms, or financial firms, either working independently or in partnership with each other. Currently, utility-owned steam plants at The Geysers geothermal steam field in California dominate the capacity mix (Figure 3). Hot water plants (using flash and binary conversion technologies) represent the current trend in geothermal power generation. IPPs already produce nearly 40 percent of geothermal electric power generated in the U.S. IPPs are expected to install the majority of future geothermal capacity, as demonstrated by their dominance outside The Geysers (Figure 3). Some geothermal facilities are owned and operated by independent utilities or consortia of municipal utilities. Also, some non-regulated subsidiaries of utility holding companies own interests in geothermal facilities.

A variety of service and supply companies support geothermal developers. These companies provide services such as geoscientific surveys and contract drilling. They supply the chemicals, piping, materials, equipment, and services needed in power plant construction and operation.

Geothermal resource owners include individuals, corporations, municipalities, states, and the Federal Government. A geothermal resource is often controlled through a lease arrangement in which the lessee pays an annual rental fee plus additional fees based on production of the resource. The Federal Government leases geothermal resources on public lands to numerous private parties and has collected annual fees ranging from \$13 million to \$17 million in recent years.

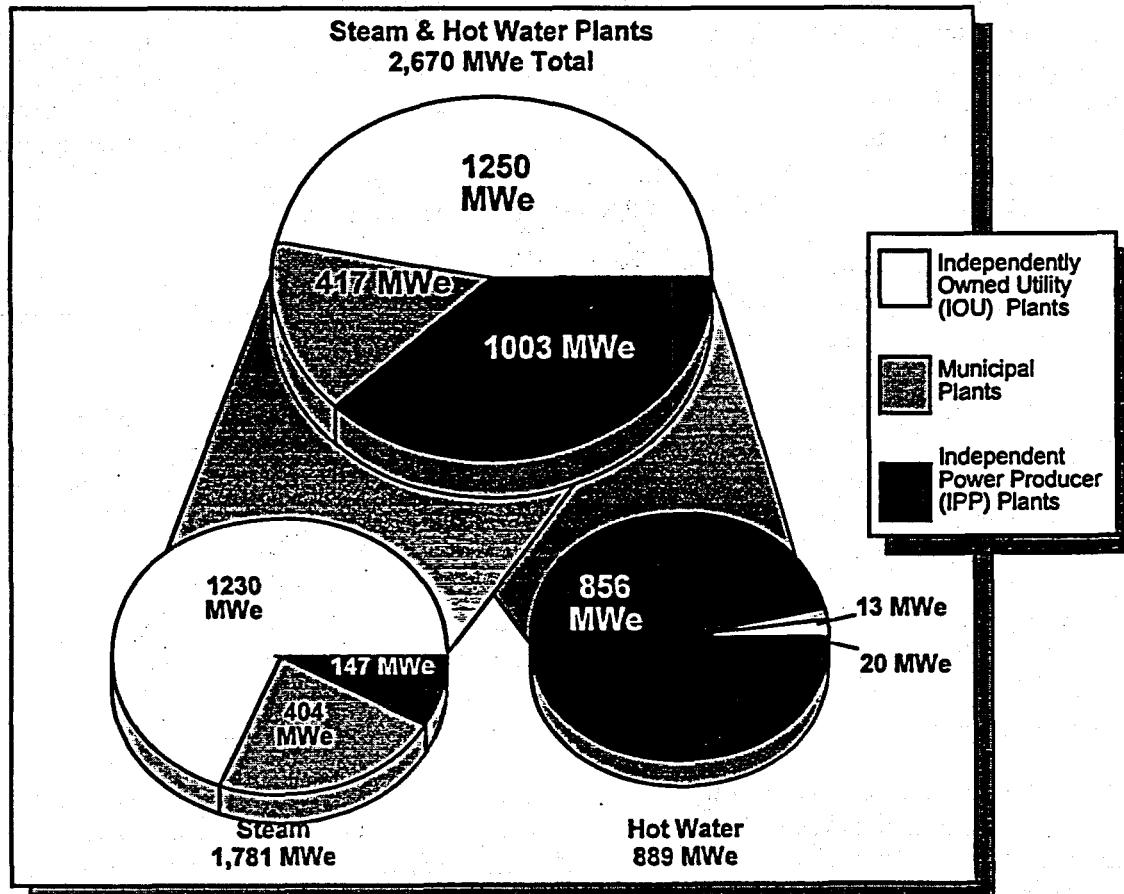
The environmental impacts of geothermal development are of interest to environmental organizations. Power production from geothermal resources has minimal environmental impacts compared to other baseload generation technologies. Current installed geothermal generating capacity reduces CO₂ emissions by approximately 15 million tons per year, based on displaced coal generation.

Local, state, and Federal government agencies ensure that geothermal facilities are developed and operated in such a way as to maximize their benefit to society. This includes involvement with a diverse array of issues such as research and development, taxation, safety, regulatory compliance, consumer protection, and electric power system reliability. The states with active geothermal facilities are California, Nevada, Oregon, Hawaii, Utah, Alaska, and New Mexico.

Other stakeholders include the research and development community (e.g., universities, national laboratories) involved in actively improving technologies to facilitate geothermal development, and financiers and investors who provide the private capital investment essential to geothermal development. National laboratories active in geothermal R&D include Sandia National Laboratories, Idaho National

Engineering Laboratories, Los Alamos National Laboratory, and the National Renewable Energy Laboratory.

Electric power consumers benefit from reliable, competitively-priced geothermal electricity. The citizens of areas where geothermal resources exist are important stakeholders. Geothermal facilities can significantly increase local tax revenues and provide an important stimulus both directly and indirectly to local economies. The general public benefits from the lower environmental impacts of geothermal energy as compared to competing fuels.



**Figure 3. Ownership of Geothermal Electric Power Facilities
(Installed capacity, 1994)**

Major Accomplishments of the Government-Industry Geothermal Partnership

- Establishment of a technology base for the economic and environmentally-sound commercial use of geothermal energy resources.
- 2,100 MWe of geothermal electric capacity operating in the U.S. Of this, about 1,100 MWe is from dry steam turbines at The Geysers field, 700 MWe is from flashed steam plants in California, Nevada, and Utah, and 300 MWe is from binary plants in California and Nevada.
- 150,000 residential-scale units of geothermal heat pumps installed nation-wide.
- 430 MW (thermal) of geothermal direct use capacity operating in western states.
- Exploration - R&D projects developed fluid samplers, logging equipment, and various other downhole instruments capable of withstanding the high temperatures and corrosive environments of geothermal wells. A cost-shared drilling program completed exploratory wells in 14 geothermal fields, leading to commercial development of 8 of these fields.
- Reservoir Engineering - Improved computer models have reduced the risk of resource development by permitting optimized well siting and resource management techniques.
- Drilling - New elastomer seals solved a common failure of drill bit bearing seals. New cements for well completions now withstand high temperatures and CO₂ corrosion. New packers, materials, and methods are used to control the common, expensive problem of lost circulation of drilling fluids. Polycrystalline Diamond Cutter (PDC) drilling bits, initially developed for geothermal service in the early 1980's, have markedly reduced the cost of drilling for oil and gas, saving the U.S. an estimated \$3 billion in drilling costs by since 1985.
- Brine Processing - Previously-severe problems of corrosion and scale formation associated with high temperature geothermal brines have been reduced. Crystallizer-clarifier technology, which removes dissolved solids from brines, was instrumental in opening the Salton Sea geothermal field in California. This important field now produces 236 MWe. New computer models capable of characterizing the chemistry of geothermal brines under variable thermodynamic conditions enable geothermal plant designers and operators to optimize processes for minimal corrosion and scale formation.
- Power Conversion - Research in the thermodynamic properties of hydrocarbons and supercritical Rankine power cycles has resulted in improved efficiencies and reduced costs for binary geothermal systems.
- Direct Use - Exploration surveys have located and characterized geothermal resources suitable for additional direct use applications. The Geo-Heat Center at the Oregon Institute of Technology was established to provide technical assistance and information on direct use technology.
- Environmental Control Technologies - Many new technologies are now available to minimize surface effluents from geothermal operations, and to abate the moderate hydrogen sulfide emissions that historically accompanied geothermal energy.

III. RESEARCH STRATEGY AND OBJECTIVES

While geothermal resources are very widespread in the U.S., the most useful resources are concentrated in the western states. The decade of the 1980's saw extensive technology development and installation of about 2,000 MWe of new geothermal electric capacity, and the emergence of what is likely to be a very large market for geothermal heat pumps in space-conditioning services.

However, economic conditions for geothermal energy development in the United States have changed markedly since 1990. Accordingly, some major shifts are timely in the research and development strategy pursued by the Geothermal Division.

Changing Conditions

Since the late 1980's, significant changes have occurred in a number of conditions that had supported the emergence and growth of geothermal use in the U.S. These include:

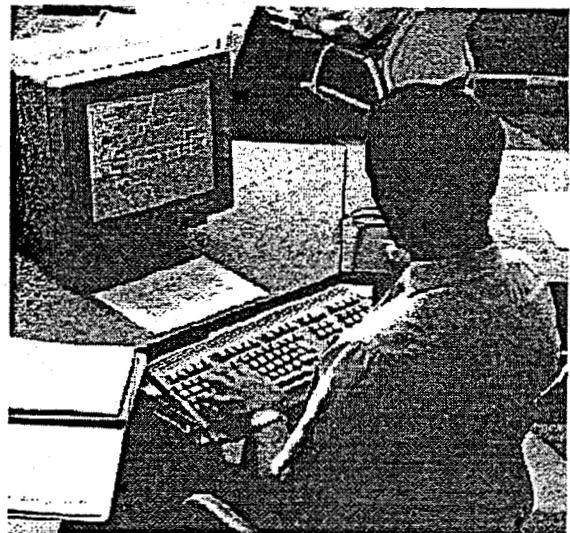
- Domestic Hydrothermal Electric Systems:

Even though the cost-effectiveness of geothermal hydrothermal-electric technology had been significantly improved by joint DOE-industry efforts during the 1974 - 1990 period, since the late 1980's the advent of very inexpensive baseload electricity (from combined-cycle systems fueled by unusually inexpensive large new supplies of natural gas) has made it difficult for current geothermal technology to compete in the domestic electricity marketplace.

There is no way to predict if, when, and how much the price of natural gas might increase in the near to mid-term. The Energy Information Administration predicts small but steady increases in gas price sufficient to make electricity from the best of the known geothermal hydrothermal resources competitive in the 2000 to 2005 period, using current commercial technology. Thus, domestic geothermal electric development will be nearly stagnant for the foreseeable near term, unless the industry can find ways to markedly reduce its capital and operating costs.

- International Hydrothermal Electric Systems:

Although the recent changes in domestic energy markets constitute quite a blow to the U.S. geothermal industry, large international development contracts (especially in the Philippines and Indonesia) awarded in 1993 and 1994 will maintain the large U.S. geothermal firms through the end of the 1990's



Computer-assisted design of geothermal turbines and power stations represents just one wave of change that is sweeping the industry. Such changes reflect increased competition, as well as cost-saving advantages.

and somewhat beyond. These projects will provide a continuing testbed for technology improvement for U.S. firms, and maintain their financial stability and system-design expertise.

- New Questions about Geothermal Energy Systems:

In the past few years, questions have intensified about two issues:

- How sustainable is production of geothermal energy? How should "sustainability" be defined and measured for financing and policy-making purposes? These technical questions have surfaced in part because of the earlier-than-anticipated decline in the rate of steam production from The Geysers, California field.
- Is the U.S. domestic resource base for hydrothermal electricity production large enough to warrant continued Government investment in this technology? This question has arisen in part because of recent estimates that have sparked skepticism concerning the likelihood of huge deposits of hydrothermal fluids in the Cascades mountain range (in northern California, Oregon, and Washington), despite the existence of large volcanic heat sources.

- Geothermal Heat Pumps:

GHPs are beginning to emerge as an important "demand side management" option for electric utilities. Besides offering advantages with respect to load reductions relative to the common air-source heat pumps, GHPs are additionally favored by electric utilities because they can compete with natural gas furnaces in some regions. The awareness of the potential of GHPs by Federal agencies can be traced to analyses for the National Energy Strategy of 1991. These estimated that under reasonable assumptions, 15 million GHP units might be installed by 2020 ¹⁴. Relative to air-source heat pumps, this level of installation of GHPs would prevent the emission of 55 million tons of carbon dioxide per year. That is about 60 percent of the entire CO₂-reduction goal for the residential and commercial sectors under the Administration's initiatives for Energy Partnerships for a Secure Economy ¹⁵.

- Other Geothermal Direct Heat Applications:

Outside of GHPs, the adoption of geothermal energy in direct heating applications has been relatively slow. At many, but not all, of the sites where it has been tried, the cost of the wells has been relatively expensive compared to the energy obtained. Geothermal direct heating has caught on mainly where reasonably large populations are situated directly above a geothermal reservoir, and rarely otherwise.

Geothermal Resource Assessment

Estimating the amount and quality of local, regional, and national geothermal resources of various types is a complex process. The intrinsic difficulty lies in the need to make estimates of physical properties of extended volumes of rock and fluid lying fairly deep within the earth, from measurements based on surface effects and samples of only a few points within that volume.

- For a commercial geothermal developer, the emphasis is at first regional: comparing the geology of a region to that surrounding previously discovered geothermal reservoirs. This is done to find highly promising "prospects" where drilling an expensive wildcat exploration well will have a high likelihood of discovering a high quality new reservoir. Once an exploration well is successful, the emphasis becomes extremely local: the drilling and flow testing of four to ten deep wells to gather enough information to convince investors and lenders that a power production project is economically feasible.
- The results of such industry efforts are often kept highly secret. This contributes to the difficulty that policy makers have in estimating how much high-quality resource has been discovered. Estimates at the national-aggregate level are very important, since they influence perceptions of the degree to which private and public sector investments should be applied to develop resources and technology for using the energy. The estimates are affected by what is known about the resources from a physical point of view, and by what is known about how well various grades of resource might compete economically and environmentally with other energy supplies.
- Estimates for all U.S. geothermal resources have been put into rather severe flux in the past few years. In the late 1970's, many hoped that the active volcanoes in the Cascades Range of Oregon and Washington might hold copious hydrothermal resources. That possibility has been discounted in the past few years by indications that while much hot rock exists in the range, only rarely is the rock contacted by extensive zones of fluid-filled permeability from which energy could be extracted cheaply.
- Recent estimates of the amount of hydrothermal resources in the continental U.S. from which new electric capacity could be installed economically within the next 20 to 30 years range from as low as 4,800 MWe¹⁶ to as high as 40,000 MWe¹⁷. This disparity clearly needs to be resolved, and the Geothermal Division will exert all reasonable efforts to do so during the next few years.

● Unconventional Geothermal Resources:

Research supported by the Geothermal Division has resulted in findings in the early 1990's that energy production from two of the three unconventional (non-hydrothermal) resources are unlikely to become economic in any reasonable time frame:

- Geopressured resources are not economic in today's energy markets because of the cost of drilling deep high-pressure wells.
- The rock temperatures associated with magma energy resources are so high that adapting available drilling and completion equipment to withstand those temperatures would be too expensive and time

consuming to warrant a high priority in geothermal research. It seems clear that magma-energy extraction technology will not be developed until technology for hot dry rock becomes commercial.

In contrast, other results of research indicate strongly that the third major unconventional resource, heat in dry rock, although not commercially developed today, is likely to be amenable to technology improvement in the long term. It is possible that heat mining technology can be developed as a significant non-greenhouse-gas electricity for use in the next century.

A number of energy system analysts believe that heat mining is as important as a long-haul energy option as nuclear fusion and solar energy. These options all require substantial technological development before they can be major contributors to economic world energy supplies. The Geothermal Division believes that heat mining will reach wide-spread commercial use before solar or fusion, simply because the technological improvements needed for heat mining are modest improvements in mechanical systems, rather than fundamental breakthroughs in solid state and nuclear physics.

The Research Strategy

Hydrothermal Electricity Systems, Generally:

The goal of the strategic thrusts described here is to help the U.S. geothermal industry compete better in both domestic and world markets:

- Support R&D to push the costs of these systems down markedly and rapidly. Prioritize R&D initiatives rigorously through portfolio analysis of where the largest cost reductions can be made for the least R&D investment. In the very near term, it is deemed likely that the best cost-reduction opportunities will be in the areas of: a) Geothermal power plant cycle designs; b) Geothermal well drilling and completion technology; and c) New materials for construction and maintenance to markedly reduce operating costs associated with corrosion, scaling, and other materials failures. Near term opportunities for marked cost reduction in the areas of exploration and reservoir management are less obvious.
- Continue to support technology-improvement R&D identified as critical on a near term basis by U.S. industry, whether needed for use at U.S. or world geothermal fields. This tactical approach led to a number of important strategic technology breakthroughs during the last decade, and will be continued.
- Begin a new research thrust to clarify the technical, economic, and social issues concerning "sustainability of production" among geothermal energy developers, electric utilities, utility regulators, other policy makers, and the general public. Define "sustainability" in the geothermal context, including consideration of economics and finite time-frames. E.g., The Geysers still supports over 1,000 MWe after a 34-year production period.

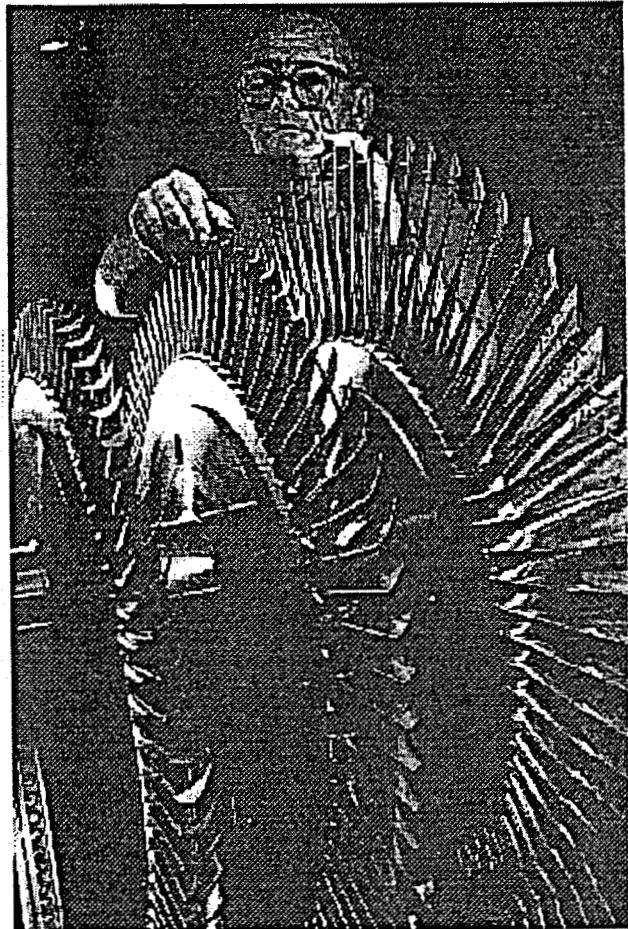
Hydrothermal Electricity Systems, Domestic:

The goal here is to improve domestic acceptance of geothermal electric systems, and to ensure that the world's premier geothermal-technology-development industry remains on U.S. shores.

- Reassess the status of U.S. hydrothermal resources. There are two conflicting trends in recent assessments. The first trend has been a concentration on identified sites that could produce relatively low cost power today and in the near term — these assessments tend to produce low estimates of what is possible. The second, opposite, trend has attempted to widen assessments to include geothermal sites that have not yet been well-characterized — these assessments tend to produce high estimates of what is possible. Some middle ground needs to be found, to clarify both the near-term and mid-term potential for new capacity from geothermal fields.
- Encourage electric utility executives and regulators to continue to establish small set-asides for new geothermal capacity. The set-asides should be focused jointly on opportunities for the opening of new geothermal fields and opportunities for the testing and refinement of improved technologies.

Similarly, encourage Federal Regional Power Marketing Authorities (WAPA, BPA) to provide transmission access to wheel geothermal power across State boundaries.

- Seek the continuation and expansion of Federal and State incentives for producing geothermal power. These moderate-cost outlays are a social investment in the mid-term and long-term opportunities for significant displacement of greenhouse gas emissions in the western U.S. and elsewhere in the world.



Turbines play the key role in converting the energy in geothermal fluids to electricity. Special sizes and materials of construction are needed for geothermal service.

Sustainability of Production from Geothermal Reservoirs

The degree to which production of energy from geothermal resources is sustainable has recently become a topic of some importance. The interest has occurred in part because of recent declines in the rate of steam production from The Geysers, California, field, the world's most highly developed geothermal reservoir.

"Sustainability" encompasses both marketplace and social issues. Geothermal resources tend to be "renewable" on scales of a few centuries, rather than a few years or a human lifetime. Within a one-century time frame, each discovered reservoir is best construed as containing a finite amount of heat and geothermal fluid. The rate at which energy is extracted from the reservoir is to some extent constrained by physical factors, but to a large extent is based on business decisions. For example, a particular reservoir might produce electricity for 50 years if 200 MWe capacity is operating, but only for 25 years if 400 MWe were installed.

At The Geysers, the USGS estimate of the potential was 1,600 MWe for 30 years. No regulations restrained development, and about 2,000 MWe was installed there by 1988. Given that those power plants expend water from the reservoir, it is now clear that even 1,600 MWe might have been too much capacity, under conventional energy conversion paradigms. But that became obvious only after 2,000 MWe had been installed.

Industry and some regulators are adapting to the realization that the hot fluid in most geothermal reservoirs should be viewed as a heat transfer medium to be recycled, rather than an energy-containing resource to be consumed and expended. If the fluid is recycled, then much more heat can be extracted from the reservoir rocks over time. For example, at The Geysers, it has been estimated that by the end of 1992, about 50% of the fluid in the reservoir had been expended, while only about 5% of the useful energy in the reservoir rocks had been used. It is likely that if all of the produced geothermal fluid had been reinjected into the reservoir, little decline in power production rates would have occurred so far.

The Geothermal R&D Program will:

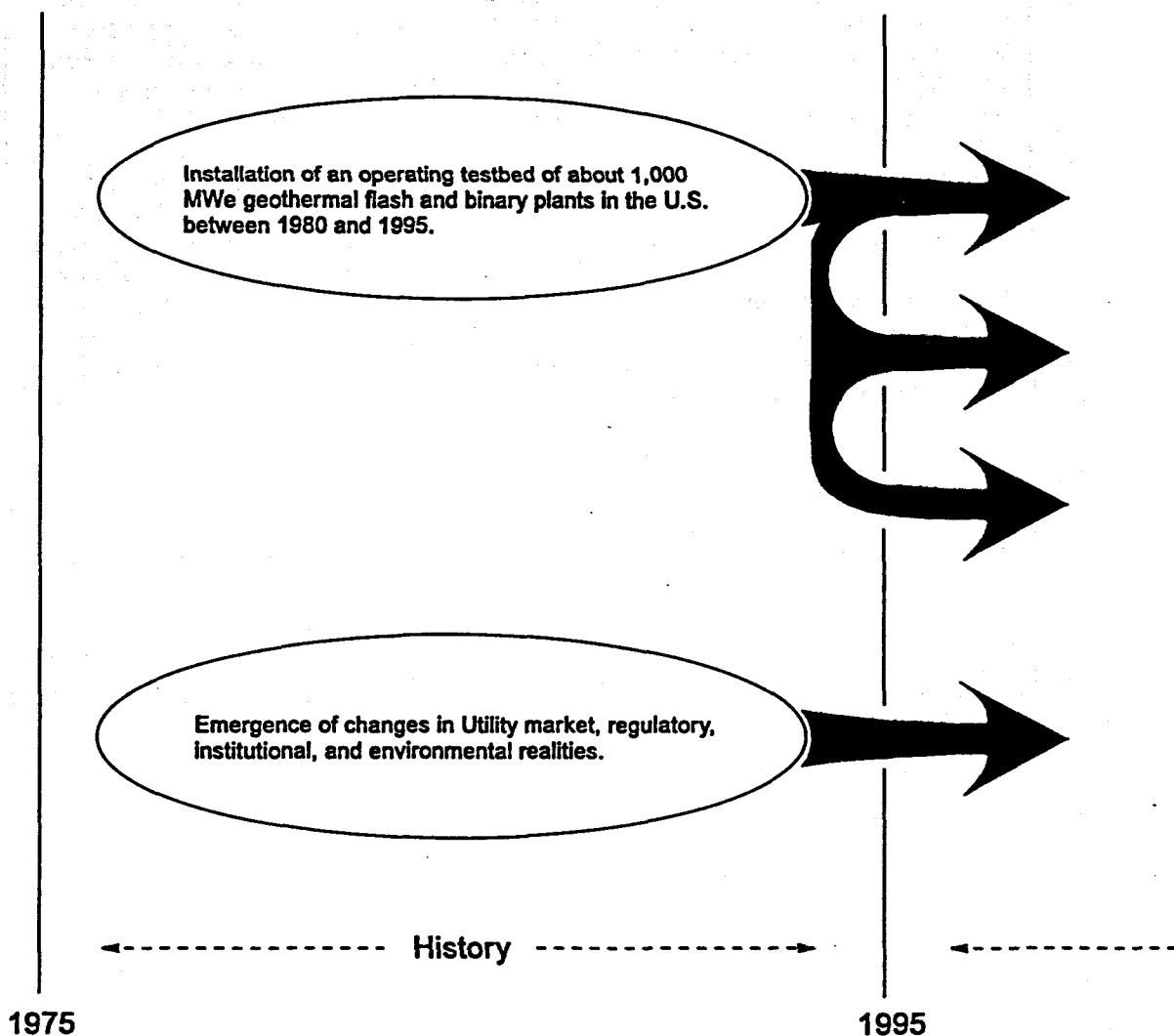
- Continue to support research to improve industry's methods for estimating the rate at which energy can be extracted without compromising investments.
- Work with industry to clarify how capacity-limit decisions are made, and how they are communicated to industry stakeholders and others affected by geothermal development.

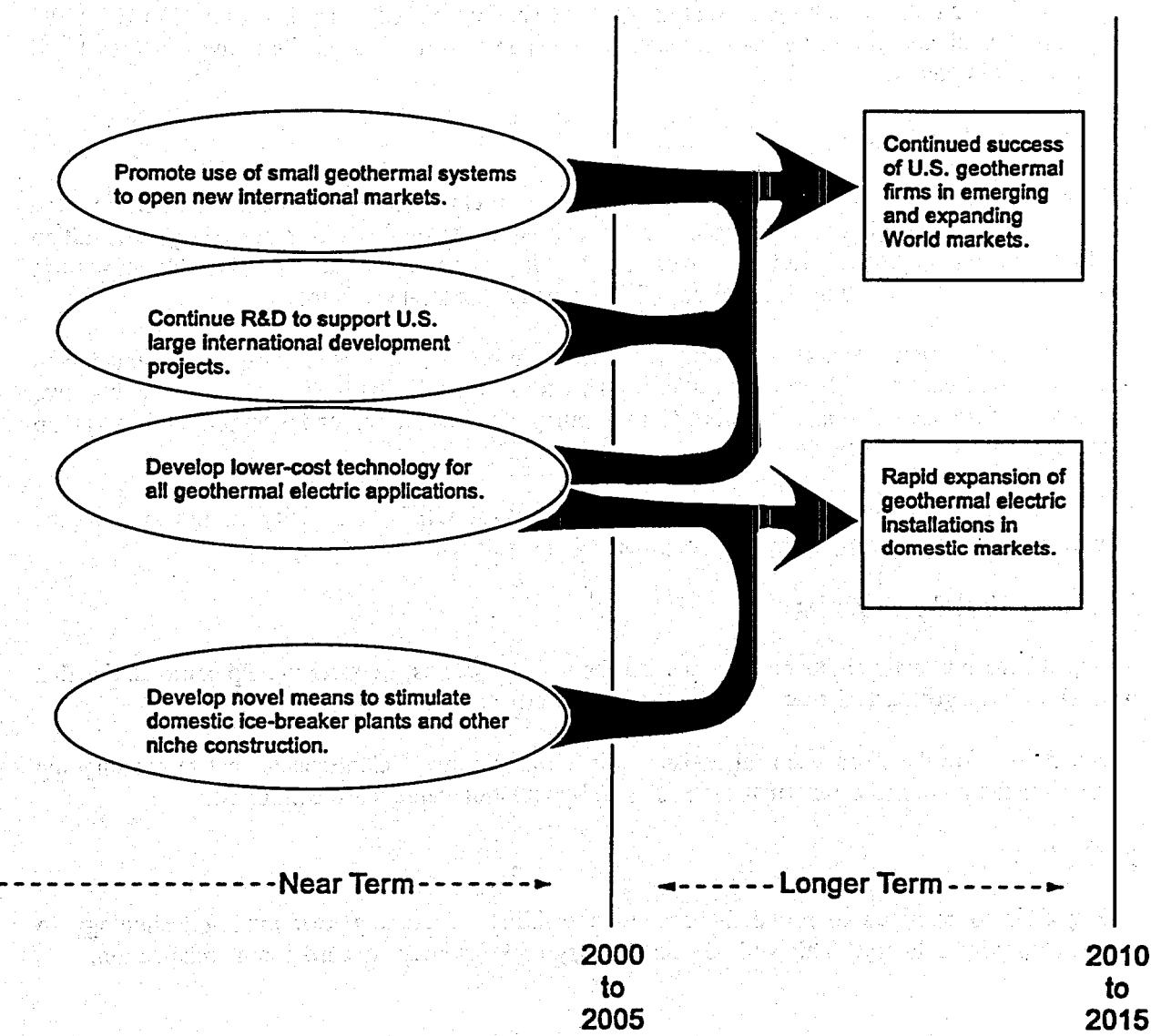
Strategy for Geothermal Electric Technology and Resource Development

Major strategic thrusts are shown here. The strategy is founded on two concepts:

- Both domestic and international markets are important for the continued expansion of geothermal electric deployment and improvement of U.S. geothermal expertise.
- Continued industry experience and R&D on these systems will drive their costs down so that they will be increasingly competitive with other fuels.

It is impossible to know exactly when new domestic geothermal electricity will again cost less than electricity from natural gas. For planning purposes the Geothermal Division estimates that will happen in the 2000 - 2005 time frame.





Hydrothermal Electricity Systems, World:

The goal here is to: a) Promote U.S. competitiveness and exports; b) Maintain the skills and expertise of U.S. geothermal project developers and equipment vendors; c) Increase world awareness of the very significant potential value of geothermal systems with respect to forestalling global warming; and d) Provide direct local social benefits from the actual installations.

- Promote the opening, conditioning, and development of new markets for geothermal system exports. There is substantial interest among U.S. firms in expanding exports into Central America, Southeast Asia, and the Rift Valley of Africa. Many nations in these areas are beginning to experiment with the privatization of portions of their electricity generation systems. American firms and consortia need help in pursuing opportunities for sales of goods and services in these newly emerging markets.
- Promote development of equipment and marketing strategies for small geothermal power systems (100 to 5,000 kWe) for use in village power and other remote markets. There are many places where electricity from such systems, although somewhat more costly than that from 50 to 100 MWe geothermal plants, would be very competitive compared to traditional alternatives of diesel and photovoltaic power.

Geothermal Heat Pumps:

The goal here is to avoid significant greenhouse gas emission by markedly accelerating the commercialization of GHPs. The peak-shaving consequences of this effort are likely to result in avoiding the construction of 22,000 MWe of new electric generation capacity by 2011, a direct savings to the U.S. economy of about \$25 billion. Consequently, the strategy is to:

- Participate in a new major consortium, the "Earth Comfort Program," to increase both demand and supplier/servicers for GHPs very rapidly. The consortium includes electric utility companies, electric utility associations, geothermal heat pump manufacturers, and geothermal heat pump vending and servicing firms.
- Continue research to improve the cost effectiveness of GHPs, especially in the area of the performance and cost of the ground-loop part of the systems.

Other Direct Heat Applications:

The goal here is to maintain technical expertise about such systems, in order to help communities that have significant geothermal resources use them more effectively.

- Maintain a low level of technical assistance in western states. Continue to update the ongoing assessments of where geothermal reservoirs and population centers are collocated.

Heat Mining:

The goal is to continue to prove the economic viability of existing heat mining technology in partnership with industry. This will advance hot dry rock resources toward commercialization.

- Keep heat mining resource and technology options visible at the National level. This R&D thrust will emphasize continued refinement of technology analyses, economic analyses, and technology development plans.
- Attempt to establish a Government-industry collaborative to produce heat-mined electricity at sub-commercial scales in the near term. The purpose is to maintain a cost-effective test bed for refining the technology.

The major thrusts of the revised strategy are summarized in Table 2.

Table 2. Major Strategic Thrusts of the Geothermal R&D Program

Strategic Thrust	Description
1. Domestic Electric Systems	<ul style="list-style-type: none"> ● Use technology-improvement R&D to drive costs down as rapidly as possible ● Resolve ambiguities in perceptions about geothermal systems ● Broaden set-asides and incentives
2. International Electric Systems	<ul style="list-style-type: none"> ● Open markets in additional countries ● Focus some technology R&D on improvements of export systems ● Develop and promote small geothermal systems for remote village powering
3. Heat Mining	<ul style="list-style-type: none"> ● Continue technology development of heat mining as a long-term option
4. Geothermal Heat Pumps	<ul style="list-style-type: none"> ● Collaborate with electric utility associations and the Environmental Protection Agency on intensive commercialization effort ● Improve cost-effectiveness of the technology
5. Other Direct Heat Systems	<ul style="list-style-type: none"> ● Maintain technical assistance and resource/market collocation studies

Research Program Objectives

In pursuing these strategic goals and thrusts, the Geothermal Division's primary objectives are to:

- Make geothermal electricity systems fully competitive in U.S. and World commercial markets at a cost of electricity ranging from 4 to 6 ¢/kWh. This is to be accomplished primarily by developing technology that will reduce the costs and risks of developing and operating geothermal facilities.
- Promote the rapid expansion of the use of geothermal heat pumps in the U.S. as a significant Demand Side Management and CO₂-reduction option. This will be accomplished through modest technology improvements, and substantial support of technology transfer operations.

Specific technical objectives, most to be accomplished by the end of 2000, support the Division's primary objectives.

For electricity systems, the specific objectives include:

- Identifying 25 new high-quality geothermal resource areas;
- Reducing power plant costs by 15 to 20 percent for high-temperature reservoirs, and 25 to 35 percent for moderate-temperature reservoirs;
- Reducing well drilling costs by about 25 percent by 2005, and by 40 to 50 percent by about 2010;
- Helping industry open eight new producing geothermal reservoirs in the U.S.;
- Achieving 5,000 to 7,500 MWe of operating domestic geothermal electric generating capacity by the end of 2005;
- Helping U.S. firms open five to eight new countries to exports of U.S. geothermal power projects, thereby adding 2,900 to 5,500 MWe of new capacity worldwide.
- Reducing electricity-related CO₂ emissions by 36 to 56 million (short) tons per year domestically, and 31 to 50 million tons/year internationally.

For geothermal heat pumps and other geothermal direct heat uses, the objectives include:

- Reduce the installed cost of geothermal heat pumps by about 15 percent.
- Through equipment efficiency improvements, decrease the annual operating cost for GHPs by about 20 percent.
- Markedly accelerate the market penetration rate for GHPs by participating in the "Earth Comfort" consortium of electric utilities, GHP manufacturers and installers, and government agencies.
- Provide resource analysis support and technical assistance to establish new geothermal district heating systems in eight to ten cities.

Details of how the technical objectives of the R&D projects that are focused on improving the cost and performance of geothermal electricity generating systems are shown in Table 3. These estimates are taken from a recent analysis of performance and cost improvements that are expected to result from the R&D projects currently being supported by the Geothermal Research Program.¹⁸

It is clear from Table 3 that significant breakthroughs in costs are anticipated in the near term. Across the mix of reservoir characteristics examined in this study, the average estimated reduction in the life-cycle cost of power is 40 percent.

Table 3. Expected Impacts of Research Program Technical Objectives on the Cost of Power from U.S. Liquid-Dominated Sites

A. Impacts Within Specific Research Areas				
Research Area	Project Major Components Affected	Portion of Life-Cycle Costs Due to Components, % [a]	Estimated Decrease in Cost of Components, %	Consequential Reduction in Life-Cycle Costs, % [b]
1. Exploration Technology	Exploration Surveys and Wells	3	47	1 to 2
2. Drilling Technology	All Wells	31	25	5 to 9
3. Reservoir Technology	Fluid Supply	38 [c]	30 to 40	10 to 17
4. Conversion Technology	Fluid Supply Power Plant	38 [c] 57	35 25	17 to 35
B. Impacts Integrated Across all Research Areas				
Estimated effects of entire R&D Program:				25 to 45
Notes:				
[a] This column sums to more than 100% due overlaps of impacts among some of the research areas.				
[b] Varies with geothermal reservoir characteristics.				
[c] Fluid supply includes wells and other geothermal field components, such as pipes and downhole production pumps.				

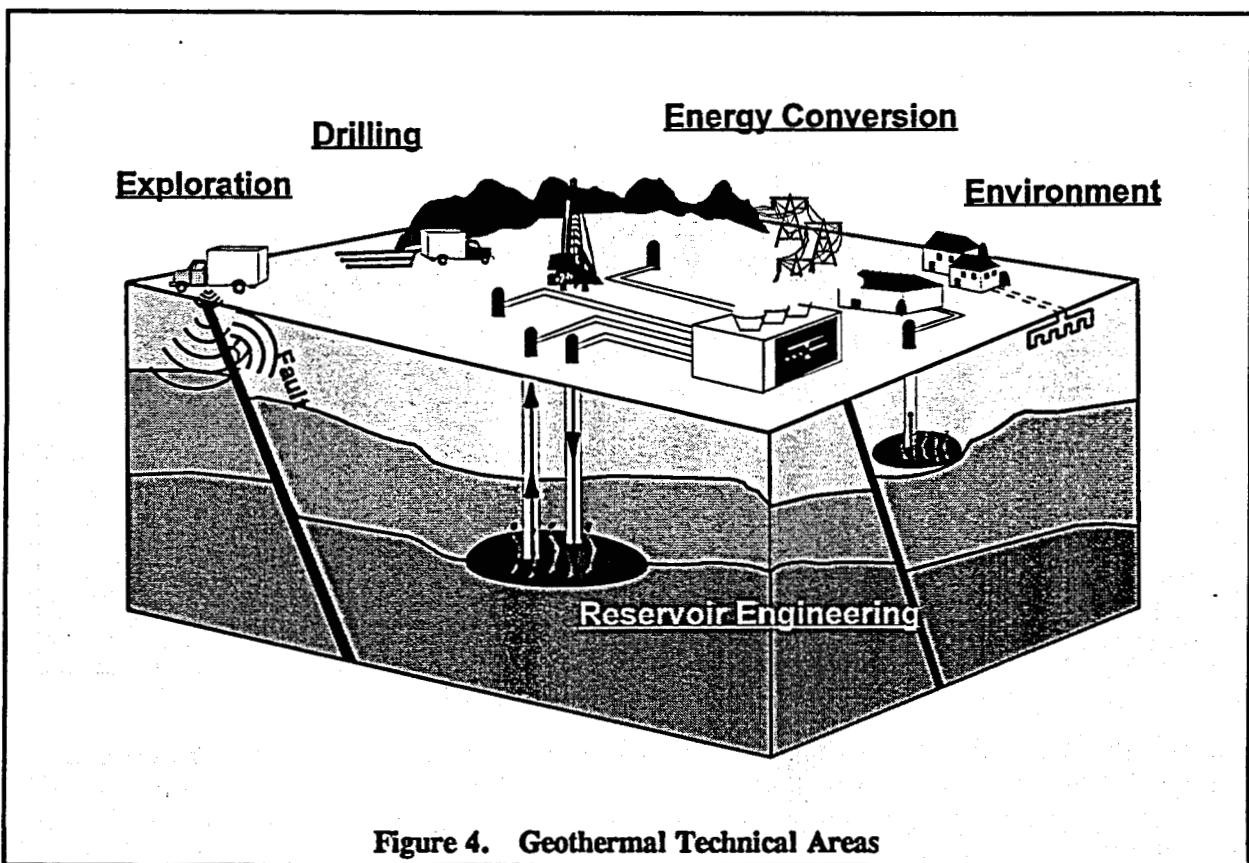
Given the risks of research, coupled with the uncertainties of funding, the objectives expressed in this plan are subject to change. In addition, the potential for changes in policy, industry needs, new concepts for technology improvement, and funding levels requires that the Geothermal Division maintain a degree of flexibility in its R&D approach.

IV. THE BASE R&D PROGRAM

The Geothermal Division's strategy involves a balanced program of applied research leading to development and application of technologies with strong commercial potential. The applied research is primarily continuing research that improves the technology base available to the geothermal industry. Typically, this research cannot be funded by industry due to industry's required focus on activities with a large potential for near-term commercialization. Nevertheless, the Division's development and applications research projects are targeted to key priorities identified by industry. The strategy for development and applications research leverages DOE funding by involving industry and other agencies in collaborative, cost-shared R&D projects.

The structure of the research program derives from the four technology areas that parallel the components (or stages) of a commercial geothermal project. These are: exploration, drilling, reservoir technology, and energy conversion (Figure 4).

The strategy encompasses both a Base program, described here, and an Enhanced program, described in Section V. The Base program continues support of current projects at levels consistent with current funding, with significant budget increases for several new initiatives in out years. The proposed Enhanced program expands the Base program with new initiatives and joint ventures, as recommended by the geothermal industry. Projected timelines for the Base program activities are given in Appendix A.



A. Exploration

Most of the U.S. geothermal systems with obvious surface manifestations have been explored. Discovery of new geothermal resources will require exploration in frontier areas where the reservoirs are either concealed or lie at greater depths. Exploration technology research focuses on developing new methodologies, instruments, and techniques for industry to locate and evaluate new and hidden geothermal fields. Application of new and improved exploration techniques will increase the geothermal reserve base in the U.S. and worldwide.

- **Integrated Exploration Strategy**

The fusion of exploration data from different geoscientific techniques allows superimposing results to identify or indicate zones of high resource probability and reduces ambiguities that can arise from the use of one individual method or technique. Research efforts already underway seek to develop a new integrated geothermal exploration strategy that will reduce costs and increase the success of exploration. Studies to assess the relative value of geothermal exploration methods and heat flow studies are in progress. Remote sensing and biogeochemistry approaches for exploration will continue to be pursued.

- **Improvement of Geophysical Exploration Methods**

Improved geophysical methods for locating and characterizing reservoirs will lower exploratory drilling costs, which account for much of the pre-development costs. Further, refined geophysical methods will be instrumental in locating hidden geothermal resources with few or no surface manifestations. Various geophysical methods including self-potential, remote sensing, and magnetotellurics are being investigated for further improvements.

- **Slim Hole Exploration**

Slim hole drilling has been shown to reduce oil and gas exploration costs by 25 to 75 percent. Drilling production-size exploration holes adds a large expense at the beginning of a geothermal project, incurring substantial debt servicing before costs can be recaptured from the sale of power. If a geothermal reservoir can be adequately defined and proved by drilling smaller, cheaper slim holes, production drilling can be delayed until the power plant is under construction, reducing interest costs substantially.

A recent thrust in drilling research includes efforts to use slim-hole drilling more effectively. Currently however, slim-hole-generated data do not provide sufficient reservoir-related information to determine if a geothermal resource will support electric power generation. Today, obtaining such data requires flow testing one or more full-diameter production wells. Slim hole measurement equipment, flow testing methods, and data interpretation techniques are under development, and are now being used to gather reservoir-related information from such holes. If these correlation studies succeed, slim hole drilling will reduce geothermal exploration costs by about 50 percent and could reduce some other field development costs and risks.

- **Industry-Coupled Drilling**

Since the yet-to-be-identified U.S. geothermal resources usually lack obvious surface manifestations, finding these resources will require exploration efforts that are major from both technical and financial points of view. The Base program adds funding in F.Y. 1995 for a new exploration program, Industry-Coupled Drilling. This new initiative will be a cost-shared cooperative effort with industry to explore for, discover, and delineate new geothermal fields in order to rebuild the nation's inventory of discovered fields. Examples of potential industry participants and areas of interest include: California Energy Company at the Coso and Roosevelt fields; Oxbow Geothermal at Dixie Valley; Caithness and Far West at Steamboat Springs; California Energy Company, Magma Power, and Oxbow for Basin and Range exploration; and OESI for Hawaii exploration.

B. Drilling Technology

The hard rock, high-temperature geothermal environment raises drilling costs to two to four times that of similar oil and gas wells. Lost circulation, the loss of fluids circulated to cool and lubricate drill bits, aggravates the problem. Drilling and well field development costs comprise about one-third the cost of typical geothermal electric projects. Thus, reductions in drilling costs are important for the expansion of the geothermal industry.

- **Geothermal Drill Bit Technology**

The hard, abrasive, and fractured rock formations drilled to access most geothermal reservoirs are generally beyond the capabilities of current polycrystalline diamond compact (PDC) bit technology. Roller bits, which are generally used for this application, suffer from inherently low penetration rates, accelerated bit wear, and often severe loss of gauge and roller bearing failure. Both PDC and another promising technology, thermally-stable polycrystalline (TSP) synthetic diamond bits, will be improved through cost-shared research with industry. The absence of moving parts in PDC and TSP bits makes them particularly attractive to production well drilling in harder rocks. Predictions are that advanced PDC and TSP bits are likely to reduce the cost of drilling most deep geothermal wells by about 20 percent, by increasing both penetration rates and bit longevity.

- **Lost Circulation Control**

Lost circulation is the loss of expensive drilling fluids into fractures in a well bore during drilling. Problems related to hole stability and well bore completion also arise due to such loss. Consequently, lost circulation accounts for 10-20 percent of the total cost of drilling a typical geothermal well.

Continued research is addressing the development of adequate technology to correct the problems associated with lost circulation. Downhole and surface tools, and fast-setting corrosion resistant cements are under development to detect, diagnose, and treat lost circulation zones. The objective is to reduce lost circulation costs by 30-50 percent. Recent R&D has produced a number of devices to speed diagnosis and mitigate lost circulation problems, including: the high-temperature borehole televIEWer, rolling float meter, drillable straddle packer, and the porous packer.

DOE/Industry Cost-Shared R&D

Geothermal technology development is further strengthened through cooperative DOE/Industry partnerships. Such cooperation has allowed the establishment of three technology organizations: the Geothermal Technology Organization (GTO), the Geothermal Drilling Organization (GDO), and the Geothermal Power Organization (GPO). Such an arrangement provides a mechanism by which the geothermal industry pools its resources to develop a product or service of direct (and usually broad) use and can be commercialized. These organizations are similar in structure and facilitate joint funding of projects by DOE and industry partners, with industry providing at least 50 percent of the total cost.

The GTO encourages technology development related to reservoir performance and energy conversion projects. The GDO concentrates on the transfer of new drilling technology to industry. The GPO focuses on improvements in power plant technology. The organizations have selected and cost-shared numerous projects including:

- Development of a high temperature acoustic borehole televiewer for fracture identification in open holes and for casing inspection in cased wells — currently two televiewers are being used by UNOCAL in their worldwide operations.
- Development of a real-time gas monitoring system for production well testing.
- Development of a high-temperature rotary head seals — a new line of head seals has been commercialized by A-Z Grant International.
- Improved Positive Displacement Motors for operation at high temperature with air — under development by Baker Hughes INTEQ.
- Development of a detailed chemistry modeling computer program to predict interactions of gases with piping and turbines.
- Development of new cement formulations for better casing protection in corrosive geothermal environments — being developed by Brookhaven National Laboratory, Halliburton, and Unocal.

● Advanced Drilling Instruments and Materials

Instruments and materials capable of withstanding the high-temperature geothermal environment will reduce the uncertainties associated with downhole measurements and improve well completions. Acoustic telemetry research seeks to advance measurement-while-drilling technology in response to industry needs. Development of memory tools and applications of fiber optics system is also underway. Such tools are required for better identification of fractures and major flow zones, and to reduce the cost of drilling.

● Advanced Drilling Systems

The National Advanced Drilling and Excavation Technologies (NADET) Program is an initiative begun in 1995 to bring together a consortium of stakeholders from industry, academia, and government who share a common need for more economic means of penetrating rock. NADET will produce a revolutionary system to access underground resources, such as oil and gas, geothermal energy, minerals, and groundwater. In 1994, the National Academy of Sciences released a study that assessed

the state-of-the-art and made recommendations for developing a revolutionary drilling system ¹⁹. The recommendations will be pursued in collaboration with industry and other Federal Agencies. NADET will also assist in maintaining international competitiveness and regaining world leadership in drilling and excavation technologies. NADET's goal is reduce the cost of deep drilling by 40 to 50 percent by about 2010.

Advanced Drilling Technology: Button Bits, TSP's and NADET

Geothermal drilling encounters conditions of high temperature, and hard and/or abrasive rock that are much more difficult to deal with than conditions encountered in drilling oil and gas wells in typical sedimentary formations. Consequently, the cost of a geothermal production or injection well is routinely on the order of two to four times the cost of the average gas and oil well of equivalent diameter and depth.

The geothermal industry and the Geothermal Research Program have since the mid-1970's been constantly searching ways to reduce geothermal drilling costs. The search has met with partial success so far, with exciting possibilities looming in the near future.

- Over the years, tricone button bits, the mainstay of the U.S. deep drilling industry, have been modified many ways to increase their rates of penetration and especially their longevity under extreme conditions.
- Shearing-action (drag) bits using polycrystalline diamond cutters (PDC's), developed first in the 1970's by the Geothermal Research Program, have saved U.S. oil and gas drillers literally billions of dollars, but have not proven suitable for routine geothermal drilling.
- A multi-sponsor R&D thrust coordinated by Sandia National Laboratories is developing thermally stable PDC's (called "TSP's"), which should be available for effective geothermal drilling service within two to three years. TSP's have been estimated to be likely to reduce the cost of most deep geothermal wells by about 20 percent. Other advanced bits are also being developed.
- For the longer haul, the Geothermal Division is investing in coordinating a number of other Government agencies and private firms in the National Advanced Drilling and Excavation Technologies (NADET) Program. NADET's goal is to develop revolutionary rock-removal technologies that could reduce the cost of most deep wells by 50 percent within the next 10 to 15 years.

These initiatives reflect the Geothermal Program's consistent attention to improving drilling technology as one of the main avenues by which the overall cost of using geothermal energy can be markedly reduced.

C. Reservoir Technology

Uncertainties remain in assessing the productivity of geothermal reservoirs and the extent of fluid reserves. These require development of new reservoir-related technologies for managing and projecting the long-term behavior of commercial geothermal fields.

- **Reservoir Evaluation Strategies**

To mitigate the risks of reservoir uncertainties, new analytical and interpretative methods are used for predicting reservoir performance and resource evaluation. Optimum resource management techniques will aid in arresting or slowing production declines at The Geysers and other geothermal fields. Such measures are critical to ensure utility and investor confidence in geothermal projects. Under the Base program, efforts underway include an ongoing cost-shared program to stabilize production at The Geysers, a major priority of industry. The Geysers complex offers the first opportunity in the U.S. to study and to improve the behavior of a mature geothermal field.

Several other investigations are also underway, including: development of a coupled model incorporating both fractured and porous media for geothermal reservoirs; and studies of the mechanical properties of Geysers rocks and of the effects of adsorption on vapor-dominated geothermal fields.

- **Geophysical Methods**

High-resolution, multi-component microearthquake data can be used to monitor the effects of liquid injection in real time, locate high-permeability paths for fluids, and aid in the siting of in-fill well drilling. Understanding the reservoir dynamics and the nature of fluid paths will help reduce operating costs. Projects in progress include: microearthquake monitoring at The Geysers; seismic imaging of geothermal systems; and characterizing subsurface fracture patterns by analyzing seismic waves. Advanced seismic interpretation methods for locating fractures are under continuing development.

- **Geochemical Methods**

The acidity and corrosivity of some geothermal fluids increases operation and maintenance costs of surface facilities and reduces equipment life. Solutions to these problems can be found by understanding the chemical composition and origin of geothermal fluids. This enables the analytical modeling of chemical interactions and prediction of changes over time. To this end, investigations underway include: a study of magmatic vapor evolution; corrosion mitigation and oxygen isotope studies at The Geysers; and geothermal fluid modeling.

- **Production and Injection Evaluation**

The fluid in geothermal reservoirs serves as the heat transfer medium. The fluid is used to extract and transport heat from the reservoir rock to the surface. Injection of the produced fluid facilitates continued recovery of heat and maintains reservoir pressures to support production. The Geothermal Division will continue work with industry to develop methods to understand, model, and manage the movement of fluid in geothermal reservoirs. Joint, cost-shared R&D programs have been established with operators at The Geysers to investigate key issues related to maximizing the useful output of the

reservoir. These include the testing of various injection schemes to identify the most effective methods for replenishment of steam in the reservoir.

- **Reservoir Modeling**

Computer-based modeling of reservoir processes improves the selection of production strategies and the prediction of production trends. On a cost-shared basis with industry, DOE will develop real-time reservoir management methods, using tested and proven reservoir simulators. Efforts are underway to incorporate geophysical processes into reservoir numerical simulators and to couple them with well-bore simulators. Reservoir simulators will be modified to run on personal computers to increase user access. Investigations are underway to develop improved dual-porosity models for simulating the behavior of fractured reservoirs. A detailed model of the Coso, California, geothermal system has been developed as one basis of ongoing reservoir modeling efforts. Major improvements in reservoir models are being made to help industry evaluate different field development strategies.

- **The Geysers R&D and Injection Pipeline**

Substantial research has been conducted at The Geysers since 1990 to improve the understanding of conditions within the reservoir. The more basic aspects of that research will conclude in 1995.

To slow the rate of decline in steam production, Lake County, California, is working closely with the geothermal operators to construct a pipeline to supply treated municipal wastewater for injection into The Geysers reservoir. Injection has been used successfully in several recent tests at The Geysers and other at geothermal areas worldwide as an effective practice for sustaining production.

The primary activity is the construction of a 24-mile, 24-inch diameter pipeline to carry seven million gallons per day of treated wastewater effluent to three Geysers steam suppliers. The steam suppliers will construct and operate secondary pipelines to distribute the effluent to injection wells. Power plants operated by Calpine, NCPA, and Pacific Gas and Electric (PG&E) will receive steam supplies created by the effluent injection. The injectate is expected to sustain between 50 and 100 MWe of capacity at these power plants.

A public/private cost-shared financing plan is proposed that uses County wastewater funds, Federal and state financial assistance, and Geysers operators' funding. The Government's investment will



This downhole ultrasonic tool measures the structural integrity of well casings. Other sensors of similar configuration provide information about deep reservoir conditions.

ensure the continued production of economic energy from the resource in an environmentally-compatible manner, thus securing the jobs of those employed at the site, maintaining the regional business base associated with the plant complex, and accruing benefits of clean, economic power for the consumers served. In addition, the experience gained at The Geysers will be applicable to management of reservoirs at other sites.

- **Heat Mining Systems**

Resources accessible by heat mining technology are by far the largest and most widespread of geothermal resource types with a resource base exceeding one million quads. Heat mining can potentially supply a vast new class of geothermal resources within the technical and economic grasp of the U.S. geothermal industry by 2005 to 2015. Prototype heat mining technology has been demonstrated at the experimental facility at Fenton Hill, New Mexico. To accelerate the commercialization of heat-mining, the Base program includes preparatory efforts to conduct a joint-venture demonstration project at a site to be named by a potential industrial partner.

D. Energy Conversion Technology

The conversion component (power plant) comprises about two-thirds of the cost of typical geothermal electric power systems. Electric power generation using the nation's moderate-temperature geothermal resources is not now competitive with the cheapest alternatives (natural gas combined-cycle systems). Research efforts in electric conversion technology will seek to reduce plant costs, improve geofluid utilization, optimize heat rejection systems to conserve water, develop better designs and materials that mitigate corrosion and scaling, and develop more efficient energy conversion cycles.

- **Incremental Electric Systems Improvements**

Continued improvements in thermodynamic efficiency result in incremental gains in output and overall cycle efficiency, leading to reductions in the cost of power. Heat cycle research in the Base program involves a cooperative demonstration, with industrial partners, of supersaturated hydrocarbon expansions at a commercial power plant to reduce operating costs. Application of direct contact condensers, which can handle non-condensable gases and improve the efficiency of the condensation process, is being investigated. A prototype advanced heat rejection system will be designed and tested through a cooperative field test which will include an analysis of improved designs for condensing two-component mixtures of working fluids.

- **Advanced Geothermal Electric Systems**

The economic benefits and improved efficiency of advanced power conversion concepts need to be investigated and proven to develop state-of-the-market technologies. To this end, investigations are underway on the applications of the Biphase Topping Turbine, the Kalina Cycle, and advanced low-temperature cycles.

The Biphase turbine extracts useful energy by capturing kinetic energy during flashing. A nozzle directs the two-phase geothermal fluid tangentially onto the inside of the Biphase turbine. The force of the fluid causes the turbine to rotate, transferring kinetic energy from the fluid to the turbine. A sub-scale Biphase turbine is being tested on a slip stream from a geothermal production well. Results

from this test will establish the operating parameters and efficiencies of a full size Biphase turbine. Addition of the Biphase turbine to a flashed steam plant is expected to produce approximately 20 percent more electricity.

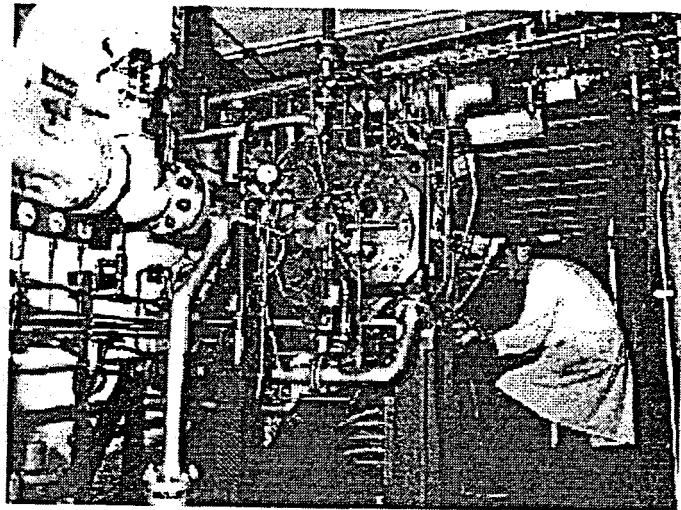
A project is underway to demonstrate an advanced binary geothermal plant utilizing a Kalina cycle. The Kalina cycle uses an ammonia-water mixture as the working fluid and takes advantage of regenerative heating. The ammonia-water mixture has a low boiling point, therefore, the excess heat coming from the turbine's exhaust can be used to vaporize a substantial portion of the working fluid. This technology is estimated to be about 20 percent more cost effective than current state-of-the art binary geothermal power plants.

Researchers are also developing innovative methods of economically producing electrical energy from quite low-temperature geothermal resources. Different approaches to improving low temperature systems will be prioritized by assessing the impact each would have on decreasing the cost of producing electricity relative to a "state-of-the-art" base case. This task will provide a strong set of innovative technology options for economically producing electricity from low-temperature resources.

Systems integration in this technical area is being provided by the "Next Generation Geothermal Power Plant" study. Jointly funded by the Geothermal Division and the Electric Power Research Institute (EPRI), this study is conducting comparative performance and cost evaluations of a number of new geothermal power conversion cycle designs that have been proposed in the past few years. The results of the study are expected in early 1995, and will identify the most promising energy conversion technologies for various applications.

- Chemistry and Materials for Electric Systems

Materials withstanding the hostile chemistry of geothermal fluids will increase lifetimes of equipment whereas adequate corrosion and scale control will reduce operation and maintenance costs. Development and testing of CO₂-resistant coatings is underway in collaboration with industry. A cooperative effort with industry is in progress to design, construct, and test a bioprocess unit capable of removing hazardous chemicals from geothermal wastes. This unit is expected to reduce the costs of disposing undesirable end products from geothermal operations by as much as 50 percent. Brine chemistry models are being applied at selected field sites to address existing scaling and corrosion problems.



Biphase Turbine test stand at Douglas Energy. Rotary separators can increase the power output from some flash plants by 20 percent.

Dealing with Chemicals in Geothermal Fluids

In some circles, geothermal fluids have a reputation for being exceptionally difficult from the point of view of high concentrations of problematic chemicals. Such reputations are founded on partial truth. All geothermal fluids contain some chemicals that have been leached from reservoir rocks over long periods of time. Some of these chemicals are toxic if found in high concentrations, and require treatment and/or carefully controlled disposal. Others, if left untreated, are conducive to scaling of pipes and power plant equipment. Some fluids contain small amounts of noxious gases. Others can corrode metals or cements.

Nevertheless, in every instance where a geothermal brine has had such undesirable tendencies, the U.S. geothermal industry — often with research support from the DOE Geothermal Program — has come up with economic technological fixes. This is true of all of the following:

- H_2S control — The best systems produce elemental sulfur that is sold for reuse, rather than sludges that must be disposed of in expensive landfills.
- Silica scaling — Crystallizer-clarifier and pH-modification technologies prevent silica precipitates on pipe and vessel walls, and reduce the clogging of injection wells.
- Carbonate scaling — Upstream injection of minute amounts of scale-inhibiting compounds essentially eliminate this problem, at low cost.

The Geothermal Program will continue to:

- Support the improvement of sophisticated computer models of geothermal fluid chemistry. These are being used very successfully to predict scaling and corrosive tendencies at various conditions in power systems, and to design technological fixes for novel problems as they are detected at new geothermal reservoirs.
- Continue the work of the extraordinarily successful Geothermal Materials Development Center at Brookhaven National Laboratory.

Additional research activities are designed to accelerate adoption of geothermal heat pumps and other direct applications of geothermal energy. Geothermal heat pumps are proving to be excellent energy conservation and demand reduction tools. GHPs are also becoming household names because of their efficient residential heating and cooling capabilities. However, the initial high installation costs of GHPs must be reduced to facilitate market penetration and increase the marketability and effectiveness of this technology.

● Geothermal Heat Pump Systems Evaluation

A survey to evaluate the performance of residential and commercial heat pump installations concluded that GHP technology is effective in saving energy over all other electrical heating systems, typically on the order of 15 to 20 percent over air-source (ASHP) systems and 25 to 60 percent over electric resistance systems. Compared to non-electric heating systems, the GHP was found to save significant energy costs (35 to 58 percent) over liquified petroleum gas (LPG) systems.

Results from a peak power reduction survey indicate that a significant peak power (kW) reduction can be achieved for winter peaking utilities, on the order of 2 to 7 kW per home. Utilities are accepting

GHPs as a peak-reducing demand-side-management tool and many offer incentives of some kind. Incentive programs include: average rebates of \$382 per unit to residential and \$132 per ton to commercial customers, low cost loans, discounted electric rates (about \$0.01/kWh), and add-on rebates for de-superheaters. Barriers to market entry of GHPs are higher initial costs (\$2,000 to \$3,000 for a 3-ton unit) than other HVAC systems, due to incremental cost of the ground loop and lack of an infrastructure of ground loop contractors and dealers.

The Base research program will expand a data acquisition program to provide statistically valid GHP load data. Using this GHP load data, models will be developed to enable utilities evaluate the benefits of GHPs on their system load characteristics and to facilitate the incorporation of GHPs as a viable demand-side management option.

- **Geothermal Heat Pump Ground Loops**

Devising ways to install geothermal heat pumps more economically is a continuing research project under the Base program. In an effort to maximize ground loop heat exchanger performance, a grouting materials study will be completed. A design manual for commercial-sector heat pumps will also be prepared.

- **Geothermal Heat Pump Commercialization**

A utility/industry consortium led by the Edison Electric Institute has developed an aggressive commercialization program. The "Earth Comfort Program" is targeted at overcoming economic, regulatory, and awareness barriers for GHP deployment. The Geothermal Division helped to establish this partnership and supports it with substantial funds. The Earth Comfort Program will focus first on improving the cost-competitiveness of GHPs, and then increasing the level of confidence in the technology and awareness of GHP benefits among potential users. Extensive training of marketing, installation, and service personnel is included in the Program.

- **Low-Temperature Resource Assessment**

In 1991, Congress appropriated funds for the Department of Energy to begin a new program to evaluate and use low- to moderate-temperature geothermal resources. To undertake resource assessments, State Geothermal Resource Teams were established in ten western states including: Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, and Washington. These state teams have completed their resource evaluation and database compilation efforts to update their resource inventories. The states are not selecting priority sites from the new inventories for further study.

- **Geothermal Direct Heat Systems Commercialization**

The Geo-Heat Center at the Oregon Institute of Technology will continue to supplement the efforts of DOE by providing technical assistance and coordinating technology transfer efforts. Educational materials and technical information will be published and a library will be maintained to aid researchers and developers of geothermal direct use projects. Appropriate research will also be conducted to reduce the cost of installing and operating direct use projects.

E. Environment

Environmental activities under the Base research program fall into two main categories: (a) Environmental compliance and restoration of inactive geothermal field sites formerly operated by the Division and (b) the Administration's Energy Partnerships for a Secure Economy (EPSE).

Restoration of several geothermal sites will occur during the Base program planning period, e.g., the Heat Cycle Research Facility and the Fenton Hill site (if the Fenton Hill site is not converted to a commercial plant). Other work concerning preparation of environmental analyses and site monitoring will be conducted as needed.

The overall goal of EPSE Action 26 is to accelerate the market acceptance of renewable technologies through collaboration with industry, in order to achieve significant reductions in greenhouse gas emissions. The collaboration will involve partnerships with organized groups of stakeholders working with DOE to achieve improved market acceptance of geothermal technologies. The intent of the Geothermal Division's activities under EPSE Action 26 is to enlist the active cooperation of the geothermal industry and the organizations and companies that influence geothermal purchasing decisions to exploit more of the competitive geothermal resource in the U.S. To date, collaboratives have formed to advance four geothermal components:

- The Earth Comfort Program to promote geothermal heat pumps,
- The Geysers Research Consortium and Geysers Pipeline project,
- Development of small geothermal power plants for use as field-opening exploration projects, and
- State Outreach Partnerships for geothermal resource development.

F. Electric Systems Market Conditioning

As described above, several U.S. geothermal development firms are constructing new grid-connected power plants, usually in the 50 to 110 MWe size range, in the Philippines and Indonesia. Furthermore, these firms have in place contracts for substantial additional U.S. geothermal developments in those countries. These agreements envision capacity additions of about 1,500 to 2,000 MWe by the year 2000, and 4,000 to 7,400 MWe by 2015. The outstanding success of these U.S. firms is due in no small measure to the superior geothermal technology they bring to this market. That technology is largely a consequence of two decades of shared research and development by the industry and DOE's geothermal programs.

Through its GT-World (Geothermal-World) program, the Geothermal Division will continue to support the improvement of geothermal technologies for export, and efforts to expand international markets for U.S. geothermal technology and services. The Division will work with U.S. industry to apply the most important advances in reservoir, drilling, and conversion technology to expand international geothermal development. GT-World activities will enhance the competitiveness of U.S. industry in the expanding international market for geothermal electrical generation to international customers. GT-World will also work with industry to aid market penetration that will support a more aggressive program in the future. The activities described here cross-cut the primary technology-development categories.

- **Geothermal Export Technology Development**

The focus of this effort is coordination of research program thrusts and specific R&D projects to adapt U.S. large-scale geothermal technology to export needs. The R&D projects are those described under other headings above.

- **Geothermal Exports Acceleration**

The development of specific country markets will be supported by direct and reverse trade missions to establish working relationships with host country officials. To assist U.S. businesses in opening international markets, technical assistance will be granted to host countries under terms that emphasize helping U.S. firms to establish concessionary development positions, so that U.S. investments in field exploration can be converted more directly into U.S.-built power projects.

- **Geothermal Village Power Technology**

In addition to the sale of geothermal power plants in the 50 to 110 MWe size range, there is a second major international market for the advanced geothermal technologies of U.S. firms. The electric power grids in many developing nations will not reach remote rural populations for decades. Because electric power is so crucial to economic development, national governments often provide locally generated power using diesel engines or other costly and environmentally undesirable sources. These areas, usually towns or villages, typically require modest amounts of power, less than three megawatts. Vast areas in the western Pacific, Africa, and South and Central America are endowed with abundant geothermal resources of moderate grade that coincide with such rural power needs.

The U.S. geothermal energy community has the technical capability to address these large and untapped markets. Various U.S. firms are able to construct economic, durable and portable energy conversion units in the one-megawatt size range, that can operate from geothermal resources as cool as 100°C. This embryonic U.S. technology, coupled with recent and pending advances in the technologies for geothermal exploration, drilling, and reservoir management, form the foundation for a potentially large and lucrative near-term export business for numerous small and medium-sized geothermal companies. This business would provide numerous U.S. jobs in both the service and manufacturing sectors.

The competition from other nations in these overseas geothermal markets is substantial. Financial incentives that U.S. companies cannot offer, give a substantial edge to companies from nations like Japan, Italy, France, New Zealand, and Iceland in capturing the rural power business. The major competitive advantage U.S. firms have is their superior technology. In order to bring the new technology for small geothermal power plants to that market, and keep ahead of the competition, these U.S. firms must build on continuing technical development. Most U.S. geothermal companies are unable to support a robust enough R&D effort.

The Department's contribution in this circumstance is the sharing of the R&D load. This effort, in which the geothermal industry will share costs, will yield:

- Less expensive, faster and more accurate methods and instruments for locating promising geothermal sites for drilling,

- Improved drilling technologies to speed up projects and cut costs,
- Advanced techniques for managing the production from geothermal reservoirs to maximize yield and reduce cost,
- Modular power generation units that can be manufactured in the U.S., shipped to rural overseas destinations, and assembled on site with very short lead times. These systems could accommodate a variety of power demand levels and resource conditions, including wide ranges of temperature, chemical composition, and depth. Self diagnostics and satellite communication capability would be built in.
- Materials that reduce costs of well and plant components, while improving resistance to scaling, corrosion, and temperature degradation.

- **Geothermal International Training Program**

U.S. training programs for geothermal planners, engineers, and technicians from export-target countries will be expanded as an essential part of this larger technology transfer and marketing program.

Additional Geothermal Division initiatives are underway to condition domestic electric markets, to accelerate deployment of geothermal electric systems within the U.S. These thrusts include:

- Working with Government Power Marketing Administrations (e.g., Bonneville Power Administration) and other power sellers or wheelers to establish field-opening plants of use in specific regions.
- Within-Government efforts to clarify and improve financial incentives and environmental-related cost adders for geothermal development. This will include new analyses of the relative fairness of the Federal and State tax burdens on geothermal and other renewable energy projects, compared to projects that use fossil fuels.

G. Research Program Integration

The Geothermal Division supports a number activities that cut across resource types and technology categories to promote technology transfer and support R&D program planning.

- **Technology Transfer Activities**

The Division supports a variety of technology transfer activities. It conducts an annual Program Review of progress and near-term plans of research projects, and disseminates the findings in a *Proceedings*. It develops and disseminates fact sheets and brochures about various aspects of geothermal energy resources and technologies. It supports the information dissemination, training, and outreach activities of a few geothermal industry associations. It supports technical assistance to industry and user groups on a case-by-case basis.

● Geothermal Research Program Strategic Planning

Strategic planning activities are in progress continually, both to adjust the R&D project mix to current industry needs and market realities, and to ensure that the activities of the program support general Government and Department of Energy goals and directives. The Geothermal R&D Program's past and present experiences are assessed to help assist in R&D program planning and project selection:

- Primary data about geothermal resources, including cost and performance of existing geothermal operations, are collected and analyzed.
- Technical and economic feasibility studies of incremental and advanced technology improvements are conducted and evaluated.
- Issues and interests regarding the sustainability of geothermal resources are being studied.
- The R&D program will continue to refine its Technology Characterizations of Hydrothermal Electric, Geothermal Heat Pump, and Heat Mining systems, studies that evaluate the status of these technologies, and expectations of the improvement of system cost-effectiveness via technology development R&D.

Longer-term Geothermal Division planning activities focus on:

- Refinement of Geothermal Research Program strategy, and
- Preparation of DOE/Energy Efficiency Quality Metrics assumptions, estimates, and goals.

V. ENHANCED R&D PROGRAM

The Geothermal Energy Association (GEA), the U.S. geothermal industry trade association (formerly named the National Geothermal Association), believes the programs of the Geothermal Division have been highly successful and have substantially assisted the U.S. geothermal industry in the development of resources for electrical power generation and direct uses of the earth's heat. The GEA proposed to DOE's Office of Utility Technologies and Congress a \$61.4 million Federal geothermal research budget for FY 1995, to be leveraged by an additional \$51.8 million in industry cost sharing and \$25 million in industry in-kind contributions. The industry-proposed program forms the basis of the Enhanced research program. The program is divided into four main categories: core research, advanced applications, advanced systems, and market acceleration.

Core Research

"Core" research includes those essential activities for which industry lacks the resources to share costs or which possess long lead times. Core research focuses on the four principal cost-sensitive technology areas: 1) exploration technology to locate the highest potential reservoirs; 2) drilling technology to reduce costs; 3) reservoir engineering and management to prolong reservoir lifetimes; and 4) conversion technology to reduce plant operating costs. Moreover, the program will provide the research needed to enhance U.S. technological competitiveness in domestic and foreign geothermal markets, and promote economic recovery and creation of jobs by expediting the growth of power on line domestically and internationally.

The Enhanced program will increase funding for ongoing core research activities. Also, the ongoing cost-shared activities transferred from the core program will increase in scope and budget. The broader scope of these cost-shared activities are briefly described below.

Advanced Applications

Advanced applications research will employ new technology and industry collaboration to address the key concerns facing the geothermal industry in exploration, drilling, and reservoir engineering.

- **Advanced Exploration Technology** — Currently, the geothermal industry is hampered by outmoded, ineffective, and expensive exploration technology that is derived from the petroleum industry. New techniques are needed to find geothermal systems in areas where there are no hot springs, steam vents, or other manifestations on the surface. Drilling of expensive production wells is the only exploration method currently available to confirm the discovery of geothermal resources. Industry leaders have identified the critical need for new and improved exploration methods to find and develop the potential of geothermal energy. Cost-shared joint ventures with private industry to develop and test innovative methods for advanced geothermal exploration will lay the cornerstone upon which the geothermal industry could develop an estimated 15,000 to 25,000 megawatts of electric capacity over the next 30 years. Technology developed for geothermal exploration will most likely be transferrable to the petroleum and mineral industries and perhaps aid basic earth science research.
- **Industry-Coupled Drilling** — Rapid geothermal development during the late 1980s was based on exploration and discovery done during the 1970s. The inventory of geothermal reserves is now at an all-time low, and new discoveries are needed to sustain future development. High-risk

exploratory drilling is currently needed to discover and confirm the existence of new geothermal resources. In the present economic climate, the Government will have to share this risk to attract private investment. A similar DOE program in the late 1970s had a 60% success rate for resource development. The impact of a joint-venture program in exploratory drilling is projected by industry to accelerate the growth of electrical generation from geothermal resources, resulting in almost doubling geothermal generation to an estimated 4,000 MWe within five years.

- **Fluid Injection at The Geysers** – Joint, cost-shared R&D programs have been established with operators at The Geysers to investigate key issues relating to maximizing the useful output of the reservoir. Examples of such programs are testing the use of seismic signals to locate undeveloped areas of steam, developing chemical tracers to aid in determining reservoir flow patterns, and testing various injection schemes to identify the most effective methods for replenishment of steam in the reservoir. In addition, a new effort, cost-shared with industry, has been initiated to obtain deep core samples to establish the geological characteristics of the reservoir. The Government's investment in helping industry to understand The Geysers will ensure the continued production of economic energy from the resource in an environmentally-benign manner, thus securing the jobs of those employed at the site, maintaining the regional business base associated with the plant complex, and accruing benefits of clean, economic power for the consumers served. In addition, the experience gained at The Geysers will be applicable to management of reservoirs at other sites.

Advanced Systems

Research in advanced systems will develop new technology to reduce the cost of geothermal power by lowering the cost of well fields and power plants, increasing power plant efficiency, and demonstrating heat mining technology.

- **Revolutionary Drilling Systems** – This activity is the National Advanced Drilling and Excavation Technologies (NADET) Program described under the Base program. The Enhanced program would more than double the budget for NADET activities from the Base program, thereby increasing the number of technological options and accelerating the commercialization of a new drilling system.
- **Advanced Energy Conversion** – This program will seek out new technology to provide continued improvement to the performance and cost of geothermal power plants. The goals are to reduce plant costs, improve geofluid utilization, optimize heat rejection systems that conserve water, develop better designs and materials that mitigate corrosion and scaling, and develop more efficient energy conversion cycles for power plants. This initiative will enable the development of the vast reserve of untapped, low-temperature geothermal resources resulting in industry expansion and creation of new jobs. Such expansion will also decrease U.S. dependence on imported oil and



Smoothly-bent loops like this compensate for thermal expansion in geothermal steam collection lines. Novel inductive heating methods allow such bends to be made at lower cost.

Advanced Geothermal-Electric Conversion Designs

Some bold schemes are afoot to reduce the cost of the power plant portions of geothermal electric systems by 15 to 30 percent. Almost all of the proposals involve new insights about improving the thermodynamic efficiency of cycle designs. Ways to reduce the cost of manufacturing and installation are also being studied. The concepts for most of the projects originated from industry. Only two of the projects are currently receiving Government funding. Some of the systems have already undergone some degree of field testing.

- **Organic Rankine Cycle (ORC) Improvements:** The largest manufacturer of these systems, ORMAT, estimates it has reduced the cost of these by 30 percent over the past eight years, mostly through packaging and manufacturing optimization rather than thermodynamic cycle changes.
- **Topping Cycles:** The Biphase Rotary Separator turbine and other topping turbines capture available work from liquid-vapor mixtures as they flash into steam. That energy is ordinarily lost in the steam-separation process.
- **Ammonia-water mixtures:** Ammonia and ammonia-water mixtures have certain advantageous heat-transfer properties compared to organic working fluids. Barber-Nichols has estimated 20 percent cost reductions possible from using pure ammonia. The Kalina cycle being developed by Exergy, Inc. adds additional heat recuperation. Exergy estimates that overall geothermal system costs for moderate-temperature reservoirs might be reduced by as much as 40 percent if Kalina cycle designs are used.
- **Vacuum-Flash Cycles:** Cycles that generate steam at very low pressures have been proposed as a means to generate electricity from fairly-low temperature resources (e.g., 110°C). Barber-Nichols recently described an innovative low-pressure turbine design whose installed cost would be 35 percent less than a conventional ORC binary plant optimized for the same inlet temperature. A Japanese firm has built a vacuum-flash system, but reportedly at substantially higher cost than the Barber-Nichols estimate.
- **Flash-Binary Combined Cycles:** Engineering studies of these are in progress. They would use either an ORC binary or a Kalina-cycle plant in place of the second-stage flash tank and low-pressure steam turbine. Overall system efficiencies are estimated to be higher. Another advantage is a large reduction in the amount of metal now used in the condensers that handle turbine-exhaust steam at very low pressures and high specific volumes.

reduce environmental impacts from carbon dioxide emissions and acid rain. Structured as a cooperative government, utility, and industry effort, significant support and funding will come from organizations representing utilities (e.g., EPRI), independent power producers, and manufacturers.

- ***Heat Mining Demonstration Project*** – This project involves the competitive selection of industrial partners to develop the first commercial heat mining facility, either at Fenton Hill, New Mexico, or another site. A fundamentally-revised management approach would retain the scientific and technical capability of Los Alamos National Laboratory, while assigning the major responsibility for field work to industry. If the joint venture generates promising data for industry use, development of a second project at another site could emerge under industry leadership. The second project would assist industry in integrating heat mining technology into their operational base, and accelerate commercialization by the first decade of the twenty-first century. Heat mining potentially can supply a vast new class of geothermal resources within the technical and economic grasp of the U.S. geothermal industry by the year 2000, with a resource base exceeding one million quads.

Market Acceleration

Market acceleration activities will expedite the market penetration of U.S. geothermal energy and direct use systems, both domestically and abroad.

- ***Geothermal Heat Pumps*** – This activity, under the Enhanced program, is much like the geothermal heat pump effort under the Conversion Technology elements of the Base program, but with a slightly increased budget.
- ***Pacific Northwest Initiative*** – Electric energy shortfalls are now emerging in the four-state Pacific Northwest region ^{20, 21}, due in part to the premature shutdown of nuclear reactors and the reduction of hydropower generating capacity to accommodate endangered species of fish. The Bonneville Power Administration (BPA) has competitively selected three geothermal proposals in the 10 to 30 MWe range for negotiation of favorable power contracts. BPA's intention is to initiate development at these sites with the expectation that unsubsidized geothermal development to at least 100 MWe will follow in each case. Hopefully, success at these sites will stimulate independent geothermal development throughout the region. Under this new initiative, the Geothermal Program will contribute to the achievement of regional energy goals by testing advanced technical concepts such as slim-hole drilling and advanced heat rejection technology at the BPA sites. This initiative would be a stimulus to the geothermal industry and result in expansion of the industry and the creation of jobs. The site developers would share the cost of the heat rejection equipment and slim-hole drilling.
- ***International Initiative*** – The growing worldwide demand for geothermal power represents a large potential market for U.S. technology and equipment. This Enhanced program international initiative will build on the GT-World initiative described under the Base program. A program of cost sharing and loan guarantees for projects will be implemented to secure U.S. participation in this emerging international market. Additional enhanced efforts will be devoted to increasing the rate at which various countries are privatizing and accepting foreign investments for their electricity generation needs. The Enhanced program is estimated to produce average annual sales of about 600 MWe per year over the next 20 years. At \$2.5 million average cost per MWe, this would total about \$30 billion in sales, of which somewhere between \$12 and \$18 billion would return directly to the U.S. economy.

VI. EXPECTED PAYOFFS

The practical commercial effects of this Plan are estimated for both the Base R&D Program (Section IV) and an Enhanced R&D Program (Section V). The estimated five-year budget requirement for the Base Program is \$370 million; for the Enhanced Program the estimate is \$612 million. Annual budget breakdowns are presented in Section VII.

The estimated effects of the Base Program are shown in Table 4. Those of the Enhanced Program are shown in Table 5. These effects were estimated using selected market penetration models and a degree of expert opinion. Most of the assumptions about future technology improvements from which the effects were estimated are documented in the *Technology Characterizations* prepared for the Geothermal Division ². All domestic projections are based on studies underlying the stipulation of DOE Quality Metrics for Geothermal Energy Research in Fiscal Year 1996.

A. BASE PROGRAM

Domestic Electric Systems

It is estimated that around 2005, the cost-reduction effects of the planned research and continued experience-based learning on the part of the geothermal industry, should enable new geothermal electric projects at relatively high-temperature reservoirs (flashed steam plants and their technological successors) to compete with other sources of power, notably natural gas combined cycles plants. For technical and cost reasons, many of these plants are likely to be "flash - binary combined cycle" plants, rather than today's standard dual-flash plants. The "binary" component will be based on either organic working fluids (as now) or ammonia-water mixtures. Substantial additional capacity will be added in the 2005 to 2015 period, some of this from moderate-temperature reservoirs (where Organic Rankine Cycle binary plants are used today) as this technology continues to be reduced in cost.

Through 2015, effective capacity additions (allowing for expected declines in production at some existing plants, and estimated retirements) will range from 6,400 to about 11,000 MWe.

Heat mining systems will require a protracted period of engineering development to reach acceptable cost levels. Reaching a 4 cent/kWh target, by about 2010, will require both the power plant advances mentioned above, and attaining a reduction of 40 to 50 percent in the cost of the geothermal wells, as expected from the NADET advanced drilling technology program (Section VI). All capacity from heat mining systems through about 2005 - 2008 will be in the form of technology-development experimental systems.

International Electric Systems

As mentioned elsewhere, a number of U.S. geothermal field firms have contracts for substantial new field development and power plant construction in the Philippines and Indonesia. The activities of the Geothermal Research Program will be geared to supportive technology-improvement R&D, and efforts to open additional sites in those countries and others to geothermal electric development, particularly through the refinement of highly reliable and relatively inexpensive small geothermal power plant designs for remote and off-grid applications.

**Table 4. Expected Payoffs from BASE R&D Program
(Values by end of year)**

Performance Measure:	1995	2000	2005	2010	2015
A. Domestic Hydrothermal Electricity, MWe	2,100	2,500 to 2,600	4,900 to 5,700	6,600 to 9,000	8,500 to 13,000
B. Domestic Heat Mining Electricity, MWe	0	3 to 5	35 to 65	190 to 350	1,900 to 3,500
C. U.S. - Built Overseas Electric Power, MWe	1,210	3,000 to 3,400	4,100 to 5,500	5,400 to 8,000	6,500 to 11,000
D. Geothermal Heat Pumps, (Domestic) 1000 units	180 to 200	1,300 to 1,600	4,100 to 5,600	8,800 to 13,600	12,700 to 21,800
E. Other Direct Heat (Domestic), Trillion Btu/year	6.7	7.7 to 9.2	9.1 to 12	11 to 16	13 to 21

**Table 5. Estimated Payoffs from ENHANCED R&D Program
(Values by end of year)**

Performance Measure:	1995	2000	2005	2010	2015
A. Domestic Hydrothermal Electricity, MWe	2,100	2,800 to 3,000	5,700 to 7,500	8,200 to 12,400	11,800 to 20,500
B. Domestic Heat Mining Electricity, MWe	0	3 to 5	40 to 100	300 to 700	3,000 to 7,000
C. U.S. - Built Overseas Electric Power, MWe	1,210	3,400 to 3,800	4,900 to 6,700	7,000 to 10,500	10,000 to 16,000
D. Geothermal Heat Pumps, (Domestic) 1000 units	180 to 200	1,600 to 2,000	4,900 to 6,700	9,800 to 15,100	13,200 to 22,500
E. Other Direct Heat (Domestic), Trillion Btu/year	6.7	10 to 12	16 to 22	26 to 38	40 to 67

Capacity additions through 2005 will range from 2,900 to 5,500 MWe. Through 2015, capacity additions are likely to range from 5,000 to as much as 15,000 MWe.

Geothermal Heat Pumps and Other Direct Heat

Annual sales of geothermal heat pumps are projected by the U.S. Environmental Protection Agency to increase from less than 50,000 units today to over 400,000 units by 2005²³. Market penetration of this extent would avoid the need for construction of about 30,000 MWe of new capacity to meet summer electricity demand.

Other direct uses of geothermal energy are expected to double or triple by 2015.

B. ENHANCED PROGRAM

The payoffs from the Enhanced Program are estimated to exceed those of the Base Program, as follows:

- Domestic Hydrothermal Electric Capacity: Enhanced program produces a 60 percent increase by end of 2015.
- Heat Mining (Domestic): Enhanced program produces 85 percent higher capacity installed by end of 2015.
- International Electric Capacity: Enhanced program produces 30 percent higher capacity installed by U.S. firms through 2010, and about 50 percent higher through 2015.
- Geothermal Heat Pumps: Enhanced program reduces, by one year, the year in which penetration reaches 50 percent of the market. The most noticeable effect is a 20 percent higher installed capacity by 2005. Overall, the effect is increased electricity and global warming savings during the 2005 to 2015 period.
- Other Direct Heat: Enhanced program could increase installations through 2015 by as much as 200 percent.

VII. PROGRAM MANAGEMENT

PROGRAMMATIC MANDATE AND ROLES

The Geothermal Steam Act of 1970 authorizes the Secretary of the Interior to issue leases for the development and utilization of geothermal resources on Federal lands. The act requires competitive bidding for such leases of Federal lands within "known geothermal resource areas."

Initiated in the early 1970's, the Federal Geothermal Program was first administered by the U.S. Atomic Energy Commission, the National Science Foundation, and the U.S. Geological Survey. The program started as a scientific/technical effort with only marginal commercialization interest.

The Geothermal Energy Research, Development, and Demonstration Act of 1974 recognizes the nation's geothermal resources as a potentially significant source of environmentally-acceptable energy. The Act established the Geothermal Energy Coordination and Management Project, which authorized:

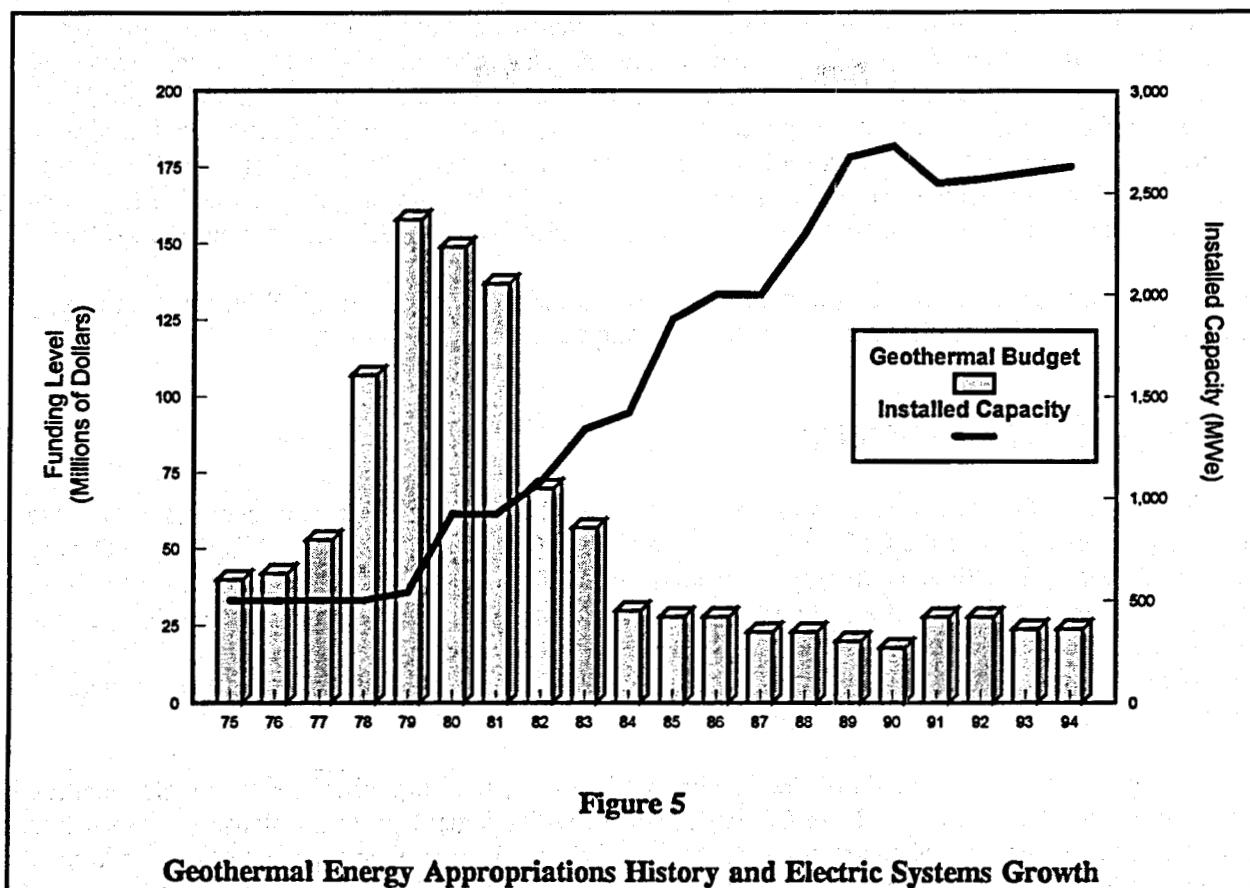
- Determination and evaluation of the geothermal resource base;
- Research and development of exploration, extraction, and utilization technologies;
- Demonstration of appropriate technologies; and
- A geothermal loan guarantee program.

The Act initiated a formal commercialization program. The resulting projects, located in Idaho, New Mexico, and California, were cost-shared cooperative ventures in partnership with industry.

During the early 1980's, policy shifted away from near-term commercialization toward longer-term, fundamental research and technology development. The R&D program was characterized by lower budgets (Figure 5) and emphasis on high-risk research with long-term payoff.

Since 1988, the Federal role has shifted to emphasize applications research, while continuing some long-term, high-risk research. DOE's Office of Energy Efficiency and Renewable Energy was reorganized based on energy end-use sectors, and the Geothermal Program was adapted to respond to the needs of the Utility sector. Currently, the Program's objectives are focused on bringing additional economic energy supplies on line, reducing energy demand, and accelerating market penetration by new technologies.

Timely cooperative efforts between the Federal Government and industry were key to overcoming early institutional barriers to development. These barriers included exclusion of promising resource areas and expensive remedial actions to satisfy environmental regulations. Solutions such as an accelerated Federal leasing program in the western states and revision of taxation and regulatory procedures opened new areas for development and reduced construction costs and lead times. Major technological barriers overcome through past government and industry partnership include the lack of credible models to manage production from geothermal reservoirs, failure of drilling equipment and downhole instruments at high temperatures, and corrosion and scaling problems associated with some geothermal fluids. Due to efforts to overcome these barriers, geothermal energy has become a competitive, reliable supply option with relatively little adverse environmental impacts.



The most recent legislative mandate for continuing Federal involvement in geothermal research and development is the Energy Policy Act of 1992 (EPACT). It contains nearly forty provisions related directly or indirectly to geothermal energy. Three Federal programs authorized by the Act include: (1) a five-year, Renewable Energy Research, Development, Demonstration and Commercialization, and Cost-Sharing Program; (2) a provision for Federal cost sharing of demonstration and commercial applications projects; and (3) a five-year program to improve energy efficiency and renewable energy use in the buildings, industry, and utility sectors. A limited geothermal production incentive and a permanent extension of the geothermal tax credit are also part of the Act. EPACT contains one section specifically designed to encourage the use of geothermal heat pumps.

Other EPACT provisions are designed to assist geothermal and other renewable energy technologies when competing in international markets. These include two international technology transfer programs: one to promote export of renewable energy technologies and the other to transfer environmentally-sound energy technologies. Additionally, EPACT contains a U.S. renewable-energy-technology training provision targeted for newly emerging overseas markets.

Geothermal energy also plays a significant role in the Energy Partnerships for a Secure Economy (EPSE) actions. EPSE Action 26 directs the Department of Energy (DOE) to "Form Renewable Energy Market Mobilization Collaborative and Technology Demonstrations." Partnerships will be established with organized groups of stakeholders working with DOE to overcome commercialization barriers, and participate in cost-shared projects and purchases of near-commercial renewable energy systems.

The geothermal industry is considerably smaller than the industries that supply fuel and generate electric power from conventional energy sources. Because the industry is small, it lacks the financial resources to wholly fund essential research. Past Federal support of R&D and institutional incentives has stimulated the commercialization and expansion of the abundant moderate-temperature hydrothermal resources (Figure 5). Widespread commercialization of new technologies typically lags their development by several years. Substantial Federal spending for geothermal technology development in the late 1970s and early 1980s contributed to the high growth rates for new geothermal capacity throughout the 1980s.

Without continued substantive Federal involvement as outlined in EPACT and EPSE, geothermal energy will not reach its full potential as a clean, reliable, indigenous energy resource.

MANAGEMENT STRUCTURE

The Geothermal Division is responsible for overall program management and operates under the administrative oversight of the Office of Renewable Energy Conversion under the Office of the Deputy Assistant Secretary for Utility Technologies. With the oversight of these offices, the Geothermal Division implements energy policy at the program level and allocates technical and budgetary resources for program activities. In addition, the Division works in cooperation with other offices within DOE (e.g., the Office of Energy Research, and the Office of Technical and Financial Assistance) on matters of mutual interest.

Under the guidance and leadership of the Geothermal Division, field organizations at the Albuquerque and Idaho Operations Offices and the Golden Field Office implement program plans, execute prime contracts for research, direct contractors and review their performance, and provide the Geothermal Division with recommendations on program needs and direction. Industry is involved through close liaison with coordinating committees organized by the national laboratories. Actual implementation of the geothermal research program and day-to-day management of the research activities are performed by contractors, including the National Laboratories, universities, and industry. As a result of substantial contractor investment in human, technological, and analytical resources, as well as for laboratory equipment and facilities, centers of excellence specializing in various aspects of geothermal research have been established.

KEY PARTICIPANTS CONTRIBUTING TO SUCCESS

The various elements of the U.S. geothermal community contribute to the success of the Federal R&D program. The geothermal community is a diverse, yet close knit group of organizations and individuals committed to promoting the use of geothermal energy. This group includes the geothermal industry, utilities, the R&D community including academia and the national laboratories, state energy and resource agencies, and Federal agencies such as the Department of Energy, Department of Defense, U.S. Geological Survey, Bureau of Land Management, and U.S. Forest Service.

The Geothermal Drilling Organization (GDO) and the Geothermal Technology Organization (GTO) are collaborative industry organizations that cooperate with DOE in the transfer of technology to the marketplace. The GDO focuses on geothermal drilling technologies and the GTO focuses on other aspects of geothermal technology. These organizations support projects designed to market the products of research. Projects are jointly funded by DOE and participating industry partners with industry

providing at least 50% of the total cost. The Geothermal Power Organization (GPO) was recently formed to address the R&D needs of energy conversion technology. Another, more narrowly-focused, DOE/industry organization, the Geysers Research Consortium, is working on solutions to the problem of reservoir decline at The Geysers steam field.

The Geothermal Division is kept apprised of the industry's status and needs through various channels of communication: the annual DOE Geothermal Program Review, the annual Stanford University Reservoir Engineering Workshop, and ongoing personal contact between Division staff and geothermal industry personnel. Contact with state geologists, energy offices, energy commissions, and other regulatory agencies is maintained to exchange information and interact when necessary.

Organizations such as the Geothermal Resources Council, the recently formed Geothermal Energy Association, and the Geothermal Education Office provide important public relations and educational functions. In addition, the Geothermal Resources Council provides valuable forums for technology transfer such as annual technical meetings, short courses, and periodicals.

BUDGET ESTIMATES

The Geothermal Research Program strategy encompasses both a Base program and an Enhanced program. The Base program continues support of current projects at levels consistent with current funding, with significant budget increases for several new initiatives in out years. The proposed Base program includes a Division staff of 16 full time equivalents and a budget of \$370.2 million over the planning period (Table 6). The proposed Enhanced program is an expansion of the Base program with new initiatives and joint ventures, as recommended by the geothermal industry, requiring a budget of \$611.9 million for FY 1995-1999 (Table 6). Projected timelines for the Base program activities are given in Appendix A.

Table 6
GEOTHERMAL RESOURCE PLAN ***

Resource Plan (Dollars in Millions)	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	Total
Base Program Budget	37	40	43	46	50	126
Enhanced Program Budget	62	92	142	155	162	613

*** Base Program budget figures are for internal planning purposes and reflect current DOE policy. Enhanced Program Budget figures are from the Geothermal Energy Association, an industry consortium. None of these figures have been approved as U.S. Government budget figures or projections.

VIII. CONCLUSION

The proposed Base research program contains an optimal mix of technology development and demonstration derived from the current program. Funding levels consistent with recent budgetary trends are assumed. Given success, this program will lower costs and risks of developing and operating geothermal facilities, increase U.S. geothermal reserves, contribute to the nation's air quality, increase market penetration of geothermal heat pumps, maximize resource recovery at The Geysers, demonstrate the technical feasibility of heat mining, increase U.S. competitiveness in foreign geothermal markets, and contribute to increasing U.S.-installed foreign capacity to 1,700 MW by the year 2000.

The proposed Enhanced research program accelerates the Base program and augments it with additional initiatives at funding levels approximately twice that of the Base program. The Enhanced program would accelerate and multiply the benefits anticipated from the Base program. The Enhanced program has a greatly increased likelihood of meeting national goals for energy independence, a cleaner environment, economic growth, and increased competitiveness of U.S. industry in international markets, and balanced trade.

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APPENDIX A.

MILESTONES for the BASE PROGRAM

Appendix A
Primary Research Activities FY 1996 - 2000 Base Program

Research Activities	Project Timeline					Expected Results
	FY96	FY97	FY98	FY99	FY2000	
Exploration Technology						
Integrated Exploration Strategy						
A. Complete development of Integrated Exploration Model (IEM).						
B. Field verification of IEM.						
C. Transfer technology to industry.						
Industry-Coupled Exploration and Development at Selected Sites						
A. Continue exploratory drilling at Long Valley.						
B. Complete cost-shared drilling.						
C. Demonstration of new reserves (5 new fields).						
Develop Slimhole Coring System						
A. Cost-shared demonstration of advanced slimhole coring.						
B. Assist industry in technology transfer.						
C. Future projects.						
Drilling Technology						
Revolutionary Drilling Systems (NADET)						
A. Establish cost-shared joint ventures.						
B. Develop and test revolutionary drilling technologies.						
C. Transfer technology to industry.						
Lost Circulation Control (LCC)						
A. Develop technology for emplacing encapsulated cements and bridging materials to control lost circulation.						
B. Transfer to industry.						
Advanced Drilling Instruments & Materials						
A. Field test memory-logging tools.						
B. Develop advanced synthetic-diamond drill bits.						
C. Future projects.						

Appendix A (continued)
Primary Research Activities FY 1996 - 2000 Base Program

Research Activities	Project Timeline					Expected Results
	FY96	FY97	FY98	FY99	FY2000	
Reservoir Technology						
Reservoir Management						
A. Test new reservoir simulators incorporating geochemical processes.						
B. Investigate water adsorption on fractured rock surfaces.						
C. Design wells and methodology for operating reservoir for load-following.						
D. Develop well location strategy for optimum production and injection						
The Geysers						
A. Conduct joint demonstration of new injection technology/strategy.						
B. Determine thermodynamic properties of hydrogen chloride gas in steam.						
C. Monitor reservoir changes due to new injection fluid pipeline.						
Heat Mining -Hot Dry Rock						
A. Commercialize Fenton Hill with industry, or decommission.						
B. Develop commercialized site.						
C. Conduct heat extraction tests.						
Conversion Technology						
Heat/Power Cycle Research						
A. Test supersaturated expansions in binary cycle turbines.						
B. Improve scavenging of non-condensable gases in direct-contact condensers.						
C. Develop advanced heat rejection system.						
D. Develop alternative advanced power cycles.						
E. Demonstrate economic benefits of improved technologies.						
Materials Development						
A. Develop thermally conductive polymer linings for heat exchanger tubes.						
B. Field test CO ₂ -resistant, lightweight cements and complete transfer of technology.						
C. Evaluate high-temperature electrical insulators.						
D. Develop non-metallic materials of construction.						

Appendix A (continued)
Primary Research Activities FY 1996 - 2000 Base Program

Research Activities	Project Timeline					Expected Results
	FY96	FY97	FY98	FY99	FY2000	
Conversion Technology						
Biochemical Processes						
A. Complete cost-shared testing of pilot bioreactor.						Potential for over 25% reduction in waste disposal costs.
B. Transfer brine chemistry models.						Potential for mineral recovery to offset costs. Removal of 80% of toxic metals.
Geothermal Heat Pumps (GHP)						
A. Develop low-cost, portable drilling system.						
B. Complete grouting materials study.						
C. Prepare commercial design manual.						
D. Future projects.						
Direct Use Applications						
A. Complete State resource assessments.						
B. Continue technical assistance program.						
Environment						
Environmental Compliance and Restoration						
A. Heat Cycle Research Facility.						
B. Monitoring, impact analysis.						
Energy Partnerships for a Secure Economy						
A. Implement power generation action plan with industry consortium.						
B. Start geothermal heat pump (GHP) mobilization partnership.						
C. Conduct GHP market mobilization in six regions						
D. Transfer GHP market mobilization to utilities and other industry groups.						
GT-World						
A. Contact newly emerging markets and establish working relationship with applicable ministries.						
B. Formulate plans to apply the most important advances in reservoir technology and energy conversion.						
C. Working with selected countries, implement plan.						
D. Using lessons learned, implement plan in other emerging markets.						