U.S. Department of Energy
Energy Efficiency and Renewable Energy
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Geothermal Technologies Program

Strategic Plan

August 2004

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Executive Summary

The Earth houses a vast energy supply in the form of geothermal resources. Domestic resources are equivalent to a 30,000-year energy supply for the United States. However, only about 2,600 MWe of geothermal power is installed today. Geothermal has not reached its full potential as a clean, secure energy alternative because of concerns or issues with resources, technology, industry commitment, and public policies. These concerns affect the economic competitiveness of geothermal energy.

The U.S. Department of Energy's Geothermal Technologies Program seeks to make geothermal energy the Nation's environmentally preferred baseload energy alternative. The Program's mission is to work in partnership with U.S. industry to establish geothermal energy as an economically competitive contributor to the Nation's energy supply.

The Program has three strategic goals that drive its activities:

1. Decrease the levelized cost of electricity from hydrothermal systems to less than 5 cents per kWh,
2. Increase the economically viable geothermal resource to 40,000 MWe, and
3. Decrease the levelized cost of electricity from Enhanced Geothermal Systems to 5 cents per kWh.

The strategies that the Program will use to achieve its goals include five focus areas or categories of work: Enhanced Geothermal Systems (EGS); Exploration and Resource Characterization; Drilling and Reservoir Management; Power Systems and Energy Conversion; and Institutional Barriers. Each area has objectives or measures by which to gauge progress.

The schedule for reaching the goals depends on the level of commitment by Government and industry. At the current rate of funding for the Program (Base Case), Goal (1) should be reached by 2010, but the remaining goals are long-term, circa 2040. Doubling the Program's budget (Accelerated Case) will enable the long-term goals to be attained by 2020, resulting in an overall budget savings of more than $100 million.

The goals will bring substantial benefits to the Nation, including large increases in economic activity, such as capital investment and jobs, along with considerable royalty payments and offsets in greenhouse gas emissions. The benefits would be multiplied by a factor of four to five if the Accelerated Case applied. Such benefits are well worth the modest investment needed to make the goals a reality.

I. The Promise of Geothermal Energy

The United States possesses vast underground stores of heat whose full potential has yet to be realized. The Earth's interior reaches temperatures greater than 4,000°C, and this geothermal energy flows continuously to the surface. The energy content of domestic geothermal resources to a depth of 3 km is estimated to be 3 million quads [1], equivalent to a 30,000-year supply of energy for the United States. While the entire resource base cannot be recovered, the recovery of even a very small percentage of this heat would make a large difference to the Nation's energy supplies.

Today, at select locations around the country, geothermal energy is used to generate electricity, or the heat is used directly for applications such as space heating, aquaculture, and industrial processes. In California, six percent of the state's power generation comes from geothermal plants. Cogeneration applications of geothermal resources, cascading from electricity production to direct uses, are also feasible. As a source of electric power, geothermal plants provide dependable, secure baseload generation at a predictable cost. Geothermal facilities are environmentally safe and rank among the best power sources for low emissions of greenhouse gases [2].

Geothermal resources could meet a substantial portion of the Nation's energy needs in the twenty-first century. All that is required is the technology to tap this energy economically on a large scale. This Strategic Plan lays out the means by which geothermal energy can achieve its considerable promise.

II. Background

Resource Fundamentals

Most high-temperature geothermal resources occur where magma (molten rock) has penetrated the upper crust of the Earth. The magma heats the surrounding rock, and when the rock is permeable enough to allow the circulation of water, the resulting hot water or steam is referred to as a hydrothermal resource. If the hot fluids are confined at pressure, the resource becomes a hydrothermal reservoir, analogous to an oil or gas reservoir. Such reservoirs are used today for the commercial production of geothermal energy. They benefit from continuous recharge of energy as heat flows into the reservoir from greater depths.

The U.S. Geological Survey estimated that already-identified hydrothermal reservoirs hotter than 150° C have a potential generating capacity of about 22,000 MWe and could produce electricity for 30 years [1]. Additional undiscovered hydrothermal systems were estimated to have a capacity of 72,000 – 127,000 MWe. Recent estimates by industry of hydrothermal potential range from 5,000 MWe with current technology to over 18,000 MWe with advanced technology [3]. These estimates (and others not cited here) indicate considerable uncertainty in the extent of hydrothermal resources. Given the current state of knowledge, hydrothermal resources appear limited compared to future energy needs.

But the heat content of the Earth is virtually limitless. At depths accessible with current drilling technology virtually the entire country possesses some geothermal resources (Figure 1). The best areas are in the western United States where bodies of magma rise close to the surface.

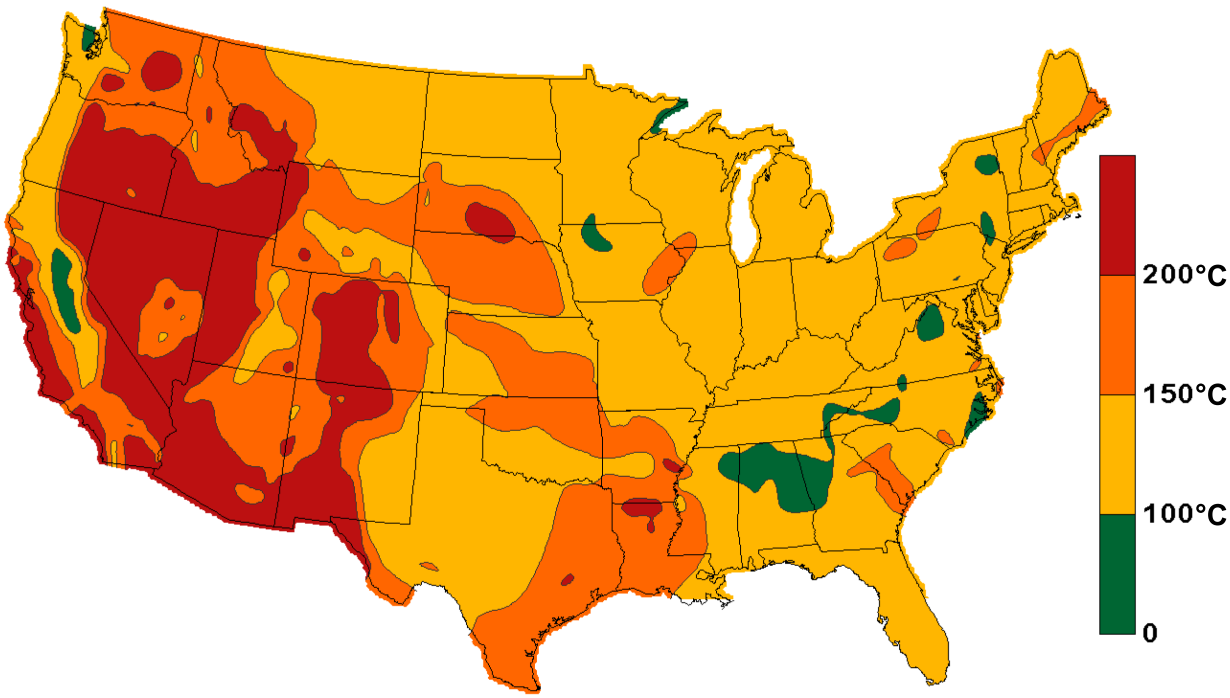


Figure 1: Estimated Earth Temperatures at 6 km Depth

However, geothermal resources often lack sufficient water and/or permeability to enable the economic production of energy. At present, only high-grade (shallow, hot, and permeable) hydrothermal reservoirs are economic for the generation of electricity.

Technology Fundamentals
Geothermal development begins with exploration, using a variety of techniques, to locate an economic reservoir. Wells are drilled to measure subsurface temperatures and flow rates and to produce and inject the hydrothermal fluid. Once the reservoir has been proven, the site is developed either for power generation or a direct use application.

Geothermal projects are capital-intensive, and the major expenses are incurred before the project produces revenue. Exploration represents only about 10 percent of the total cost of a successful project, but many projects can fail at this stage. A high degree of risk evolves from the need for success of the first wells drilled into the reservoir. The extent to which these wells produce hot fluids can influence subsequent investment decisions. Although the most expensive element of a power generation project is surface plant construction, drilling to create a well field involves higher risk due to uncertainties in reservoir characteristics. Direct use applications are usually less costly than power generation, because the resource is shallower, the fluids are less difficult to manage, and the technology less complex.

Typically, geothermal power plants are baseload facilities, but they may be operated in a load-following mode. Power conversion options include (1) the transformation (flashing) of hot geothermal fluids to steam which drives a turbine or (2) transfer of heat from the geothermal fluids to a secondary (binary) working fluid which drives a turbine. Geothermal plants have very high availabilities and capacity factors, often exceeding 90 percent. Liquids produced from the reservoir are reinjected to sustain production pressures. After mitigation, air emissions are in full compliance with applicable air quality standards.

For cases in which reservoir flow rates are inadequate due to low permeability or lack of fluids, reservoirs may be engineered to increase productivity. Such engineered reservoirs are called Enhanced Geothermal Systems (EGS.) Much EGS technology is still in the experimental stages, but a number of countries are pursuing this technology because of its potential to tap the large amounts of heat contained within geothermal resources of low permeability.

Industry Fundamentals

The U.S. geothermal power industry underwent a boom in the 1970s and 1980s, followed by consolidation in the 1990s. The industry, once dominated by large oil companies and utilities, is now made up of independent power producers. During the 1990s industry focused on international markets, and only minimal new domestic development occurred. Since 2000, industry has shown renewed interest in domestic development thanks to reduced production costs, an improved competitive position due to increased prices for power generation from gas, and incentives such as state renewable portfolio standards. New projects totaling about 400 MWe have been announced since 2002.

Domestic geothermal energy production is currently a $1 billion a year industry that accounts for almost 20 percent of all non-hydropower renewable electricity production, and about 0.35 percent of total U.S. electricity production [4]. Installed nameplate geothermal electricity generating capacity in the U.S. has grown from about 500 MWe in 1973 to over 2,600 MWe today. Geothermal electric generation is currently limited to sites in California, Nevada, Hawaii, and Utah. Other states with significant near-term potential include Alaska, Arizona, Idaho, New Mexico, and Oregon.

The Energy Information Administration's Annual Energy Outlook [4] projects geothermal installations totaling 6,800 MWe (electric) by 2025, based on the assumption that natural gas prices will remain relatively stable. The projection does not take into account the potential of EGS.

Direct use systems are currently in use throughout the western United States and in a few locations in the East. In northern Nevada, for example, one of the nation's largest onion-drying facilities uses geothermal energy to provide both process heat and electric power. Direct use projects tend to be developed on an ad hoc basis, and a domestic industry specific to direct heat applications has not evolved. The direct heat installed capacity in the United States is about 600 MWt.

Policy Fundamentals

The energy security goal of the Department of Energy (DOE) Strategic Plan [5] is to "Improve energy security by developing technologies that foster a diverse supply of reliable, affordable, and environmentally sound energy …" The DOE has a long-term vision of a zero-emission future in which the nation does not rely on imported energy. One of DOE's strategies for achieving this goal is to work on renewable energy technologies such as geothermal energy and to work with the private sector in developing domestic renewable resources. Furthermore, the National Energy Policy Plan [6] recognizes the potential of geothermal resources on public lands and recommends reducing barriers to accessing and leasing Federal lands for geothermal development.

Just as the Public Utility Regulatory Policy Act (PURPA) of 1978 provided a vital incentive for the expansion of renewable technologies in the 1980s, a production tax credit for geothermal energy would foster rapid growth in the number of new power generators. Industry believes this incentive, coupled with state-based renewable portfolio standards, would provide the competitive edge needed to bring large amounts of the hydrothermal resource base into the marketplace. Other policy incentives, such as loan guarantees, could also be considered.

Since the late 1970s, the Federal Government has sponsored a geothermal research program as authorized by the Geothermal Energy Research, Development and Demonstration Act of 1974 (P.L. 93-410). At present, the

Geothermal Technologies Program supports research focused on exploration, drilling, reservoir engineering, and energy conversion (i.e., electricity production.). In recent years, annual Program funding has been stable in the range of $25-$30 million.

Federal royalties from geothermal leases on public lands currently total about $40 million annually, including payments to the U.S. Navy for power generation at the Coso (CA) geothermal field [7, 8]. States receive one half of the royalties from Federal leases as well as payments from leases on state lands.

III. Vision and Mission

The Geothermal Technologies Program has a vision of geothermal energy as the Nation's environmentally preferred baseload energy alternative. Geothermal power plants have a proven track record of performance as baseload facilities, with capacity factors and availabilities frequently exceeding 90 percent. Modern energy conversion technology enables geothermal facilities to operate with only minor emissions. These factors, combined with the considerable size of the resource, argue for a large share of geothermal energy in the future U.S. energy economy.

However, the question remains: How can large amounts of geothermal energy be produced at competitive costs? The Program's mission is to answer this question by w*orking in partnership with U.S. industry and others to establish geothermal energy as an economically competitive contributor to the Nation's energy supply*. The vision and mission are primary drivers for the Program's strategy.

IV. Strategic Goals

Today, some 2,600 MWe of geothermal electricity is installed in four states. While the Program's research has reduced the cost of developing high-quality resources, further expansion will require the use of resources that are currently uneconomic. These resources include the heat energy that underlies much of the country as well as undeveloped and undiscovered hydrothermal reservoirs. Accordingly, the Program's goals revolve around the need to improve the economic competitiveness of geothermal energy while at the same time enlarging the economic resource.

The cost of geothermal power facilities has varied dramatically over time, but the trend has been toward reduced costs. Given available information, the estimated current cost of most projects falls in the range of 4-6 cents per kWh, a substantial reduction from 10-12 cents per kWh in the 1980s [9]. And a recent analysis of commercial hydrothermal systems indicates that costs as low as 3.4 cents/kWh are feasible [10]. As a result, the following goal has been adopted for the research program:

- **Decrease the levelized cost of electricity from hydrothermal systems to less than 5 cents per kWh (in 2004 dollars)**

For this goal, hydrothermal systems are taken as those indicative of the more challenging geothermal conditions likely to be encountered by future developers in large portions of the country: moderate fluid temperatures (circa 150°C) and depths (3 km or greater). Such conditions will require substantial drilling, a binary conversion system and air-cooling, all of which add to development costs. These costs are estimated to exceed 6 cents per kWh. A reduction in overall cost of at least 20 percent requires major improvements in technology affecting every element of power production. However, this goal is achievable, given historic performance.

Thirty years of experience suggest that the estimates of the hydrothermal resource base (discovered and undiscovered) by the U.S. Geological Survey may have been optimistic. While a new, comprehensive resource assessment has not been done, the likely outcome would yield smaller estimates. However, this does not take into account resources that can be produced using EGS technology. EGS technology has the potential to make a sizeable portion of the Nation's geothermal resources available for production. Consequently, a goal of the Program is to:

- **Increase the economically viable geothermal resource to 40,000 megawatts**

Identifying 40,000 MWe of economic resources will require major improvements in exploration practices and development of technologies that either do not currently exist or are unproven. Approximately 30,000 MWe of the resource is expected to come from EGS, with the remainder from conventional hydrothermal systems. This amount of resource will provide adequate stimulus to assure continued long-term growth in geothermal development.

The key to a robust resource lies in the ability to reduce the cost of energy using EGS technology to levels comparable to those for hydrothermal resources. Therefore, the third Program goal is to:

- **Decrease the levelized cost of electricity from Enhanced Geothermal Systems to less than 5 cents per kWh (in 2004 dollars**)

This goal represents a long-term target indicative of the broadest range of geothermal conditions (low permeability, unsaturated, deep rock formations). The goal will require a 30 to 50 percent reduction over the most recent estimates of current EGS costs [11].

Achievement of the three strategic goals will provide the technology push needed for sustained industry expansion in future energy markets.

V. Strategic Directions

Only a small portion of the Nation's identified geothermal resource is economic today. Costs must be lowered to bring more resources into production. Discovering, accessing and developing the deep geothermal resources with lower permeability and fluid content will require significant improvements in both the technology and economics of geothermal development. The Program's goals also require addressing institutional issues that affect costs and inhibit development such as Federal leasing practices, regulation, and public acceptance.

Consequently, the Program has shifted its emphasis to longer-term, high-payoff research with cost-shared field applications, as opposed to nearer-term incremental improvements in technology with laboratory-based studies. All types of resources are now considered as targets for development, including those with relatively low fluid content and permeability.

The Program has used stakeholder input and peer review to identify program priorities and select projects for funding. This outreach and communication approach has worked well for sponsoring fundamental research, making near-term technological improvements, and ensuring that the results of research are known and useful to industry. Roadmapping will be used to identify targets and investment requirements for long-term research within the context of meeting the goals. A multiyear plan is being developed to better align research activities with program goals.

The Program's activities are organized to support both technology development and technology application. That is, the Program has some involvement in all stages of its products' evolutionary cycle: from problem formulation to basic and applied research to field testing of prototypes to final deployment in the marketplace. Industry plays a key role as a cost-sharing partner in the cycle, especially as products move toward deployment.

A priority activity is the collection of baseline data on all aspects of geothermal development against which to measure improvements. The Program needs comprehensive baseline information for some technologies on which to base decisions about priorities and funding levels. Collection and analysis of industry data, along with observations of technology performance, can provide a baseline and measure progress.

Specific programmatic strategies aimed at achieving the Program's goals fall into several categories:

A. Enhanced (Engineered) Geothermal Systems (EGS)

While industry has focused on the best hydrothermal resources – shallow, hot, and highly permeable – the Program's goals depend foremost on new technology that enables cost-effective use of all geothermal resources. Resources without associated water, or where the permeability of the rock is too limited to allow fluid production at economic rates, can be changed into functional geothermal reservoirs. In the long term, tapping the energy in hot, low-permeability rock at depths that are not economic today is essential for geothermal energy to fulfill its promise. The objective of EGS research is to develop the technology to create commercial-scale hydrothermal reservoirs at sites that lack economic hydrothermal resources.

Although the procedures for creation of an engineered reservoir are understood conceptually, progress on filling in the details has been slow, in part because field experiments are expensive and time-consuming. Drilling a well field is costly, and the system must be monitored and managed over long periods. A series of field experiments over the past 30 years, both in this country and abroad, has not yet led to development of reliable techniques for creating, measuring, modifying, and controlling an engineered reservoir.

The pathway to success for EGS involves these strategies:

- Conduct research on improved and innovative technologies for creating and managing EGS in a variety of geothermal environments. The result will be a "tool bag" of techniques that can be used as needed.

- Apply the tools in partnership with industry to enhance production at selected field locations. Experimentation in the field will be conducted at different types of sites determined by their developmental condition: (1) productive hydrothermal reservoir; (2) unproductive hydrothermal reservoir; (3) no hydrothermal reservoir.

- Leverage Program funds by incorporating oil and natural gas industry experience with reservoir stimulation, and collaborating with EGS research and development projects in other nations.

B. Exploration and Resource Characterization

Only about one exploratory well in five discovers a viable hydrothermal resource. At costs usually exceeding $1 million per well, investors are often reluctant to assume the risk of an exploratory drilling program. Developers need better assurances that their initial wells will be successful. The Program's objective is to improve the 20% success rate for finding economic resources at previously undrilled sites to 40%. Steps to meeting the objective include:

- Establish which exploration techniques are most effective, and work to improve these techniques. Much past work in this area has been done by industry, and analysis of the results has been either insufficient to clarify the value of specific techniques, or held proprietary by a given company. As a result, the Program must strive to assess and document this experience for the public record.

- Update characterizations of known resources. Information on individual sites is scattered among separate databases, and varies in quality. This information will be collected, checked for quality, updated, and used as a baseline for future efforts. The known resource can be used to develop an economic supply curve and identify the prospects with the highest priority for development. An early target is to develop a portfolio of geothermal resource prospects in the Western United States. DOE will collaborate with the U.S. Geological Survey to update the Survey's national assessment of geothermal resources.

- Develop collaborative efforts with industry to support exploration for and definition of new hydrothermal resources. These efforts involve geotechnical exploration to locate sites that industry can develop, and drilling and flow testing of slim holes to determine the reservoir's productivity. The target is to find 20 new hydrothermal fields.

C. Drilling and Reservoir Management

Because of their volcanic origins, most geothermal rock formations are typically hot, hard, corrosive, abrasive, and fractured, leading to rapid wear of drilling equipment and early failure of typical electronic components. Improved components and electronics have the potential to reduce costs. The capital costs associated with developing a typical geothermal well field range from $200 to $800 per kilowatt of installed electric capacity. These costs can represent up to 40 percent of the total capital cost of a project.

Field management costs, which make up a significant fraction of overall operating costs, can increase sharply when reservoir-related problems occur. In some fields, severe reservoir degradation has been stopped by optimization of the production/injection strategy. Predicting and avoiding problems through reservoir engineering and performance monitoring can significantly reduce operating costs.

The Program is pursuing four strategies to reduce the costs and attendant risk associated with specific hydrothermal reservoirs and their well fields:

- Improve understanding of the characteristics of the rock and the geothermal reservoir to be drilled, leading to application of varying technologies and practices to compensate for subsurface conditions. This learning experience will produce a steady reduction in drilling costs for each successive well. As knowledge about the reservoir is gained, the number of wells needed to produce a unit of energy will decrease, resulting in lower drilling costs for the well field as a whole.

- Improve the component parts of a drilling system to perform essential functions quickly, efficiently, and cheaply. Near-term improvements to drill bits, drilling fluids, and cements, and implementation of the 'Diagnostics-While-Drilling' concept, are expected to reduce the nominal cost of drilling by 25% (for a given geothermal site) relative to costs in 2000.

- Investigate long-term revolutionary advances in drilling materials and techniques with the target to drill twice as deep for the same cost. These advances are essential to making a significantly larger portion of the deep resource base (>3 km) economically viable.

- Increase hydrothermal reservoir performance through better tools and techniques for managing reservoirs over extended periods of time. The intent is to reduce the number of makeup wells in the field by one half.

D. Power Systems and Energy Conversion

The power plant is typically the largest project expense (both capital cost and O&M costs). Because the temperatures of most geothermal resources are low relative to the combustion temperatures of fossil fuel, the size and cost of surface plant equipment are greater. Almost all geothermal plants to date have been built specifically for individual sites. While this may permit optimal energy capture, it also prevents the economic gains from mass production. Furthermore, the chemically reactive nature of typical geothermal fluids requires protective measures to prevent equipment damage from scaling and corrosion. Mitigating these problems can be expensive. However, some of these fluids contain commercially valuable minerals that may be recovered to offset costs.

The Program's objectives in power systems research are to decrease capital investment requirements by 20 percent and operations and maintenance costs by 20 percent. These objectives are essential to meeting the overall cost goals. Four strategies for improving power plant economics include:

- Investigate advanced cooling technologies that offer the potential for major efficiency improvements, especially for low-temperature resources. High ambient air temperatures can reduce the efficiency of air-cooled heat exchangers, reducing power output and plant income. Mitigating this effect will improve the viability of marginal projects. These improvements will increase conversion efficiency by 25%.

- Cut operations and maintenance costs through optimized maintenance schedules, better construction materials, and hardier instruments. Improved operating procedures can lead to greater plant automation and reduced effluent treatment. Increased component, plant, field, and operational flexibility and control schemes can maximize power production during periods of high power demand, thus increasing revenue. Standardization and modularization of plant designs into a few categories would reduce costs for successive plants.

- Reduce costs by using geothermal resources for multiple applications in series, such as mineral recovery or cascading uses for hot water passed from high-temperature applications to progressively lower-temperature ones. Some analyses have shown that recovery of high-quality silica from certain geothermal brines could generate a revenue stream equivalent to as much as 1.1 cents per kWh [12].

- Develop advanced conversion cycles, such as those using mixed working fluids, that offer the potential for major efficiency improvements especially for lower temperature resources. These cycles are currently untested, but they offer potential for large cost reductions.

E. Institutional Barriers

Despite its many advantages over traditional extractive resources (e.g., relatively minimal environmental and operational impacts, high capacity factor, and diversification as a regional alternative source of power), geothermal energy lags behind other technologies in public awareness, perception, and support. Delays in the processing of leases and permit applications have impeded the development of geothermal energy. Often these constraints exist because authorities, stakeholders, and the public lack adequate information for making decisions.

Consequently, the Program's GeoPowering the West initiative targets stakeholders such as businesses, government organizations, Native American groups, and the general public with communication, education, and outreach activities. This approach emphasizes the economic development benefits of geothermal energy in order to support a "market pull" to complement the "technology push" from research and development. By identifying barriers to development and working with others to eliminate them, GeoPowering the West helps a state or region create a regulatory and economic environment that is more favorable for geothermal and other renewable energy development.

The objective of these communication and outreach activities is to remove barriers by providing timely information about geothermal resources, their development, and relevant technologies to all interested parties through the following strategies:

- Provide information on the costs and benefits of geothermal energy.
- Sponsor educational forums on key issues involving Federal agencies, states, tribes, industry, and other stakeholder organizations.
- Work with regulatory agencies to identify alternative approaches for addressing regulatory constraints and accelerate the approval processes for developing geothermal resources.
- Assemble working groups of stakeholders and other interest groups at the state and local levels to facilitate geothermal development. These groups will work to double the number of states with geothermal power facilities.

VI. Timeframe

The programmatic goals laid out in this Plan and the strategies to achieve them will require substantial effort and funding. The extent to which the goals can be attained within a given timeframe will depend on the annual budget devoted to the Program and the commitment on the part of Government and industry to meeting the goals.

At the current level of funding (Base Case - assumed to be about $25 million for research) with only allowance for inflation, two of the three goals are long-term, circa the year 2040. The goal to reduce the levelized cost of hydrothermal systems to less than 5 cents per kWh would be achievable by 2010. With increases in budget and commitment (Accelerated Case – assumed to be a doubling of funding levels), the Program's long-term goals would be achievable by 2020. The funding increase would produce not only a substantial acceleration in the adoption of geothermal energy, but a reduction in the total cost of the Program of more than $100 million. Further funding increases would allow new technologies to be adopted even more quickly and enable the Program to pursue a wider range of technology options.

The target dates to achieve the goals outlined by this strategic plan for the two cases described here are compared in Table 1. These targets include interim, biennial decision points for the Program to determine whether progress is sufficient to warrant continuation.

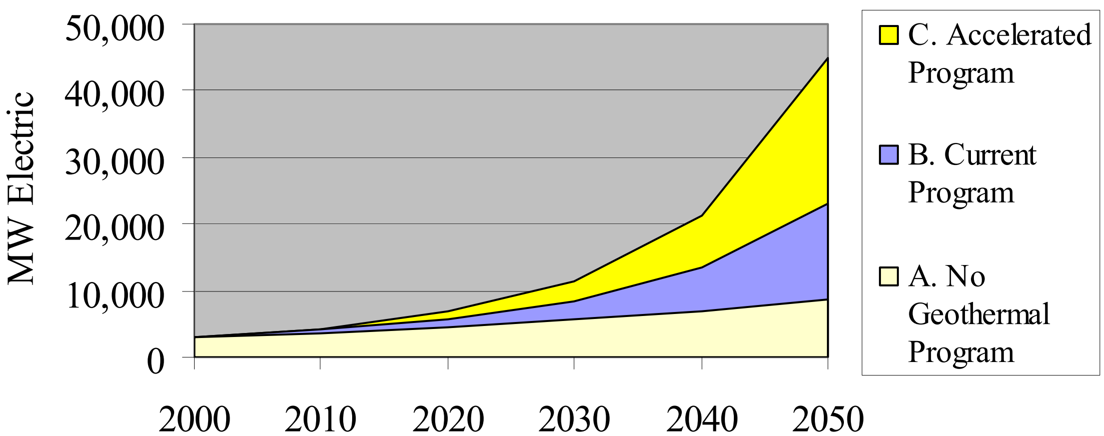
Table 1: Program Goal Milestones

	Performance Target	**Base Case**	**Accelerated Case**
Program Goal 1	Decrease the levelized price of electricity from hydrothermal resources to less than 5 cents/kWh	2010	2010
Program Goal 2	Increase the economical domestic resource to 40,000 MWe	2040	2020
Program Goal 3	Decrease the levelized price of electricity from EGS to less than 5 cents/kWh	2040	2020

VII. Outcomes

In the absence of a Geothermal Program, growth in geothermal deployment is expected to reflect projections by the Energy Information Administration [4]. Only very modest growth is predicted for the years beyond 2010--due entirely to conventional hydrothermal systems--with a doubling of installed capacity by about 2040 (Figure 2). With Program funding at the current level (Base Case), growth resulting from achieving cost reductions for hydrothermal systems (Program Goal 1) will be resource limited. Conventional hydrothermal systems will peak at just over 10,000 MWe, and the remainder of the growth will result from EGS coming online after 2040. With increased funding (Accelerated Case), rapid growth in geothermal deployment is projected after 2030 as additional economic resources become available sooner and EGS technology comes into common use after 2020. These cases are compared in the following chart:

Figure 2: Range of U.S. Geothermal Deployment Possibilities



A. The "No Program" case represents industry-only business as usual for hydrothermal, with no contribution from EGS, for a total of 8,700 MW by 2050.
B. The "Base" case estimates slightly accelerated hydrothermal (to 10,400 MW) and a substantial contribution from EGS (12,564 MW), for a total of 23,000 MW by 2050.
C. The "Accelerated Program" case estimates slightly accelerated hydrothermal (to 10,400 MW) and a substantial contribution from EGS (34,400 MW), for a total of 44,800 MW by 2050.

Some of the tangible results obtained by achieving the program's goals for both the base and accelerated cases are shown in the following table:

Table 2: Cumulative Outcomes from Geothermal Deployment by 2050*

Outcome	Units	No Program	Base Case	Accelerated Program
Installed Capacity	MWe	8,700	23,000	45,000
Generation	Billion kWh	1,000	2,200	4,100
Capital Investment	$Billion	13	31	56
Jobs	FTE	190,000	554,000	960,000
Sales	$Billion	48	108	200
Federal Royalties	$Billion	1.7	3.9	7.4
Greenhouse Gases Offset	MMTC	180,000	410,000	780,000

*GPRA metrics

The accelerated case gives a multiplier factor of 4-5 in outcomes over the case with no Geothermal Program. These economic and social benefits justify the relatively modest investment required to make the goals a reality.

VIII. Conclusion

As a clean, sustainable, baseload technology, geothermal energy has promising potential for addressing energy price volatility, long-term energy security, and environmental issues. To date, however, geothermal energy has achieved only a fraction of its potential.

Hydrothermal resources that can be economically developed today may support only a three-fold increase in capacity, which is not sufficient to justify a large-scale Federal research program. The vast majority of potential is in resources that cannot be effectively tapped using existing technology. Further research is required to determine whether Enhanced Geothermal Systems technology can provide a competitive solution to development of these resources.

This strategic plan is based on the premise that geothermal energy can provide a significant fraction of the United States' domestic energy needs for the future. To be considered a player in the U.S. energy market, geothermal energy will have to expand significantly over the next three decades. Such an expansion will require a strong, sustained commitment from the public and private sectors. This is a daunting challenge, but the past three decades of research and commercial development of geothermal energy have provided a solid base on which to move forward.

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A Strong Energy Portfolio for a Strong America
Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

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