DRAFT

Geothermal Energy

Multi-Year Program Plan
FY 1993-1997

Geothermal Division
U.S. Department of Energy

January 1992

This material is for internal planning and management purposes. Budget figures, similarly, are for purposes of planning and for making assumptions explicit. They have not been approved as U.S. Government budget figures or projections.

DISCLAIMER

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I. INTRODUCTION

Geothermal energy is the most versatile and reliable renewable energy resource available today. It is a domestic resource contributing both to energy supply, through electric power generation, and to demand reduction, through the use of geothermal heat pumps and other direct use applications. Geothermal power plants are modular -- additional generating capacity can be installed incrementally -- and have very high on-line records. The resource is capable of generating electricity at a competitive price for baseload, peaking, or load-following operations without detrimental environmental effects. By cost-sharing and leveraging, investments in geothermal energy produce a greater return on federal R&D than any other renewable resource. This *Multi-Year Program Plan* summarizes the Geothermal Division's near-term efforts to expand the Nation's use of this flexible renewable energy option.

II. BACKGROUND

Status of Geothermal Development

Geothermal energy is commercially employed to produce electricity for utilities at 17 fields in California, Nevada, and Utah. Geothermal energy is a cost-effective and competitive resource at these locations with nearly 2800 MWe of capacity in operation. The resource provides about 8% of the power currently used in California. Further power development appears imminent in Hawaii and the Pacific Northwest.

The annual geothermal energy use for direct geothermal heat applications in the U.S. is over 18 trillion Btu or the equivalent of over 5 million barrels of oil at 60% conversion efficiency. It is estimated that about 150,000 geothermal heat pumps are in use and rapid growth in this technology is anticipated. In addition, 25 geothermal municipal and institutional district heating systems are in operation; many structures are heated/cooled with individual systems, and a number of commercial/industrial enterprises operate economically with geothermal heat.

The Investment

The Department of Energy (and its predecessors) has spent in excess of $1.3 billion in support of geothermal development in this country both for power generation and direct use. Industry and utilities have spent in excess of an estimated $5 billion for power projects alone.

In addition to expenditures for technology development, expenditures by both industry and government have been made to overcome institutional barriers to development. For example, early environmental and other regulatory requirements necessitated expensive remedial actions and loss of promising resource areas. Through an accelerated federal leasing program, the industry was able to acquire a good land position for geothermal development in the western states. In the case of the government, substantial effort was made to overhaul tax and regulatory aspects of geothermal development to reduce unnecessary construction costs and lead times.

Since 1982, virtually all of DOE's expenditures have been dedicated to improving technologies for locating and developing geothermal reservoirs and for managing the production of geothermal fluids and converting their thermal energy to electric power.

Benefits

The benefits of these investments are manyfold. First, there is an increase in the economic *supply* of geothermal energy to provide a benign energy source for power generation and direct heat applications. Second is a reduction in power ***demand*** through the widespread use of geothermal heat pumps and other direct heat uses. These applications, and the inclusion of geothermal energy in integrated resource planning, ~~may~~ will relieve demand pressure on some utilities, providing an opportunity to defer new capacity.

The use of geothermal power by utilities resulted in a $125-$250 million cost-savings to consumers in 1988, primarily due to the low cost of power from The Geysers (CA). New hot water plants are providing customers with reliable power supplies with availability ratios second to none. A majority of these geothermal electric power generating plants are sited on federal leases, and in 1990, the latest year for which data are available, these leases returned some $18 million in lease and rental fees to the federal government.

Geothermal power plants are modular and allow power producers to develop geothermal resources incrementally. Utilities can add generating capacity quickly to meet increases in demand and can avoid committing to large, capital-intensive projects with long lead times. Geothermal power is also flexible in terms of its availability as a source of baseload, peaking, and load-following electricity.

Using commercially available advanced technologies, geothermal energy assists a number of western metropolitan areas in meeting local air quality regulations. Nationally and globally, use of geothermal resources increases the energy supply without detrimental environmental effects; reduces the demand for imported oil and frees some domestic oil for other uses, such as chemical feedstocks; and reduces the clearing of rain forests or burning of fossil fuels in many developing countries with large untapped geothermal resources.

Geothermal facilities also can co-exist compatibly with highly scenic and recreational values -- e.g., the Mammoth Plant near Mammoth Lakes in the Mono-Long Valley area of California. This factor makes geothermal energy a prime candidate for increasing the power supply with the least impact in sensitive environments.

Stakeholders

The participants in geothermal development include utilities, field developers -- some of whom also own and operate power plants -- and other independent power producers. At The Geysers, 23 of 28 plants are owned by utilities -- investor-owned and municipal -- while the hot water industry is dominated by independent power operators, and only two of 36 plants are utility-owned. In addition to utilities, the industry is an amalgam of oil companies, geothermal energy entrepreneurs, and a mix of partnerships formed by representatives of other industries and the financial community. A number of newcomers have no previous energy investment experience.

A wide range of service and supply companies provide valuable support to geothermal developers and operators. These companies are engaged in a multitude of activities needed to bring a geothermal project online, such as conducting geophysical and other geoscience surveys; providing drilling expertise; supplying chemicals, piping, and other materials; and manufacturing turbines.

Additional stakeholders include researchers and others in the R&D community who are actively improving various geothermal-related technologies to advance geothermal development and the Public Utility Commissions and regulators whose efforts ultimately affect the utilization of the Nation's geothermal resources.

Government's Role to Date

The federal geothermal program was initiated in the early 1970's to investigate the feasibility of using this alternative energy source. The Atomic Energy Commission, the National Science Foundation through the Research Applied to National Needs program, and the U.S. Geological Survey were charged with directing the early resource and technical assessments. The program continued as a scientific/technical effort with only marginal commercialization interest until passage of the Geothermal Energy Research, Development, and Demonstration (RD&D) Act of 1974.

Subsequently, a formal commercialization program was initiated, and from 1977 to 1981 its budget was by far the largest element of DOE's total geothermal funding. Commercialization embraced expenditures for the cost-shared demonstration plants at Baca, New Mexico, and Heber, California; a program to expedite direct use; cost-shared resource assessments by industry and the states; a loan guaranty program; and studies on leasing, environmental regulation, and other institutional problems. The significance of these efforts is demonstrated by the fact that eight of 14 reservoirs explored under DOE's Industry-Coupled Drilling Program of the late 1970's are currently in production. Each of the producing reservoirs has additional undeveloped potential and, at some sites, plans to expand these reservoirs have been announced. A cost-shared inventory of low- and moderate-temperature resources in 22 states and cost-shared direct use demonstration projects led to an upsurge of these applications in the late 1970's; most projects that originated with DOE funds have since been expanded. Implementation of many of the recommendations made by the DOE-funded Interagency Geothermal Streamlining Task Force during that period have led to remedial regulatory and administrative changes that greatly reduced costs and accelerated geothermal development.

Commercialization dominated the program through 1983, reflecting the final federal outlays committed for the Heber plant. In 1981, however, a policy decision was made to rely on the market and on incentives of the National Energy Act of 1978 for geothermal energy commercialization, thus shifting the program's emphasis back to research and technology development.

In terms of site-specific results of government research, the technology for the economical use of hypersaline fluids in flash plants, developed at the cooperative government/industry Geothermal Loop Experimental Facility, is used today in six plants at the Salton Sea (CA) reservoir totalling 200 MWe in capacity. This technology has also been the subject of intensive follow-up by industry and, if technologies are available for efficient management of this field, another 1800 MWe may be developed. At Coso (CA), which today hosts 240 MWe of geothermal power, the developer started with DOE-funded data in the early 1980's and conducted a successful exploration effort. In addition, previous research on dealing with high-temperature environments has led to the industry-wide use of temperature-hardened materials and components. Even more important, in almost every instance of which the Geothermal Division is aware, industry development funds have been spent to further refine the research results.

The R&D program of the 1980's was characterized by decreased budgets and emphasis on long-term, high-risk R&D funded by the government and short-term efforts to encourage the commercial manufacture of the products of research, often cost-shared with industry. The government began to rely on industry facilities for testing new or improved equipment and materials developed by the DOE program. For example, Oxbow Geothermal Corporation provided existing field data and the use of their wells and geothermal field at Dixie Valley, Nevada, to DOE-sponsored researchers for an injection tracer test conducted to model fluid flow in the reservoir. More recently, industry has provided field operating data for use in validating or modifying reservoir models. For the past several years, hydrothermal R&D has been guided by quantified cost-of-power objectives determined through the use of IMGEO ("Impacts of Geothermal Research"), a model which uses actual plant experience to simulate interactions among the components of a hydrothermal electric plant.

Since 1988, the federal role has been changing again to emphasize applications research and development activities while continuing some long-term, high-risk research. By working cooperatively with industry and utilities, technologies capable of tapping geothermal energy's vast potential will be available for deployment in the near-, mid-, and long-terms.

When the Office of Conservation and Renewable Energy was reorganized to create an end-use oriented structure, the geothermal research program was adapted to respond to the needs of the utility sector. Currently, the program's objectives are more specifically focused on developing additional energy supplies, reducing energy demand, reducing institutional barriers that constrain renewable technologies, and accelerating market penetration by new technologies. The Geothermal Division, working as team leader of a group from the Office of Building Technologies and the Office of Technical and Financial Assistance, has been cooperating with various utilities in expanding the use of geothermal heat pumps and incorporating geothermal energy into their integrated resource plans. Industry has also been exploring the use of geothermal energy for thermally enhanced oil recovery, the detoxification of pollutants, and other innovative applications subsequent to earlier DOE research. Currently, the Bonneville Power Administration is negotiating with companies that submitted proposals to develop three 10-MW geothermal plants in the Pacific Northwest and is planning a geothermal pilot program. The DOE program has been a significant influence on these decisions.

Throughout the life of the federal program, R&D for geopressured and hot dry rock resource applications has been almost exclusively a government function. Technology to harness these resources lies beyond the present financial capabilities of the geothermal community, but the potential payoff in the long-term cannot be ignored. This R&D is consistent with the mandate of the RD&D Act of 1974 to determine and improve the scientific, engineering, and economic feasibility of using energy from all types of geothermal systems.

Given the stage of geothermal development today, what is the rationale for continued federal technology research and development? For oversight of institutional impediments to geothermal growth? For transfer of advanced technologies to industry? For continued contributions to geothermal education?

The answers to these questions appear to encompass issues beyond oversight responsibility, technology transfer, and educational advancement. Without continued substantive federal leadership and involvement, geothermal energy will play a much smaller role as a competitive energy supply option. Overall, the geothermal industry is appreciably smaller than the industries that supply fuel and generate electric power from conventional energy sources. This situation leaves geothermal companies in a position where they lack the financial resources to wholly fund essential research. They are still unable to take the substantial investment risks that accompany major geothermal development. Also, potential markets for geothermal-generated power are often located some distance from the resource, and construction of transmission lines to tie into the grid are costly. Federal support stimulated the initial commercialization and expansion of the abundant moderate-temperature hydrothermal resources, both in terms of R&D and institutional factors. That support must continue in order for geothermal resources to fulfill their potential as economic energy alternatives.

III. THE VISION

The challenge, or opportunity, confronting the Geothermal Division is to help increase the amount of our country's energy that can be economically recovered and used for beneficial purposes and to develop the best state-of-the-art technology to extract it. Simply stated, our mission is to increase geothermal reserves, reserves being defined as that portion of the identified resource which can be extracted economically under existing conditions.

The most recent estimate of U.S. geothermal reserves is 5,000 MWe and consists of hydrothermal energy predominantly from identified and producing fields. Based on USGS criteria (Circular 790), these locations have the potential of generating 12,000-13,000 MWe. By continuing geothermal research activities at the current level and discovering additional geothermal fields, the National Energy Strategy predicts that 4,500 MWe, 11,000 MWe, and

22,000 MWe of geothermal capacity can be available by 1997, 2010, and 2030 respectively. A more aggressive exploration and R&D program could potentially result in 48,000 MWe by 2030. Increasing geothermal reserves is largely a function of technology advancements and economics; thus, as circumstances permit, geopressured and hot dry rock systems could also contribute to geothermal reserves.

Technology Development Needed for Power Generation/Energy Supply

Expansion by the geothermal industry both within and beyond the 17 currently producing fields will require innovative technologies. There is little experience in this country in expanding the use of liquid-dominated fields that have been in production for several years. Thus, analytical tools are needed to determine the effects of existing operations on the reservoir and to optimize placement of new plants, new production wells, and new injection wells to reduce the risk of mismanagement or over-production of the reservoir.

The situation at The Geysers steam field in Northern California is a case in point. While operations at The Geysers have always been an industry pursuit, government is cost-sharing restoration of lost productivity of the field for two reasons. First, The Geysers complex offers the first opportunity in this country to study the behavior of a mature geothermal field. Second, the success of The Geysers, and now its decline, are so well-known worldwide that maintaining confidence in this field is critical to ensuring confidence in all proven and yet-to-be-proven geothermal fields. The situation at The Geysers has fostered an exceptional degree of cooperation between DOE and industry. In FY 1990, $3.5 million in funds or in-kind contributions were invested by industry; DOE provided $1.2 million. Industry committed $4.5 million in FY 1991 and DOE budgeted $2.5 million annually for both FY 1991 and FY 1992 for cost-shared research at The Geysers. Investments of this magnitude are expected to continue until the field's problems have reached resolution.

For expansion beyond producing fields, industry is seeking innovative methods to find and characterize new hydrothermal reservoirs and to identify the best sites for drilling. For example, remote sensing and biogeochemistry methods that have been used successfully in minerals exploration will be evaluated for geothermal exploration. In other geothermal regions, electromagnetic and passive seismic methods will be combined with existing geologic data and laboratory measurements to develop unified exploration strategies. The development of these strategies will result in the discovery of new fields, particularly those with no obvious surface manifestations of a subsurface heat source. Only one such area is in production today -- the Desert Peak field in Nevada.

While drilling technology is an integral part of all stages of geothermal development -- exploration, reservoir development, and production/injection -- the costs are still often 3 to 4 times those of oil and gas wells. Thus, new drilling technologies are needed to reduce the costs of exploratory wells to confirm hidden reservoirs and to increase the geologic data obtained from each well. The combination of new sensing and exploration methods and advanced drilling technologies would greatly improve the "dry hole" ratio, particularly in fractured reservoirs, and increase well productivity. This would cut the number of wells needed for each 100 MW of installed power.

Increases in conversion efficiencies can optimize the heat value of the resource and offset large investments in finding and producing the resource. In addition, more advanced modular technology than is available today will supply a better means of testing new reservoirs, allowing early power production and cash flow, encouraging step-by-step development, and reducing financing costs.

If geopressured and hot dry rock resources are to be commercially developed in the future, the Geothermal Division must transfer the knowledge that will permit decisions about the economic competitiveness and reliability of these new energy sources. In the case of geopressured brines, industry needs an understanding of how geopressured reservoirs behave over extended periods of time (e.g., drive mechanisms), including the ability to predict reservoir characteristics (reservoir size and longevity, hydrocarbon content, salinity) with high confidence. For hot dry rock, future developers will need definitive information on thermal lifetime, flow impedance, water consumption rates, production fluid chemistry and temperatures, and energy productivity on an extended basis. The long-term flow test of the man-made reservoir at Fenton Hill, New Mexico, which is planned for FY 1992-1993, is expected to provide this information. The future federal program will be defined after the industry has had an opportunity to respond to that information.

Potential Needs in U.S. Geothermal Infrastructure

The current favorable climate for development on federal land appears to be one result of earlier DOE outreach efforts to show that geothermal development can co-exist with competing interests in the forests. With only one major site-specific exception in Hawaii, the U.S. geothermal industry currently operates in a relatively friendly infrastructure in terms of official and public acceptance. However, as use of this resource expands into new areas, assistance or support in outreach activities may be warranted to inform cognizant regulatory officials and/or the public as to the nature of the impact of geothermal development on their communities or region.

The industry itself appears to have overcome, at least for now, the problem of the remote location of many geothermal reservoirs, vis-a-vis, the availability of transmission lines. This is illustrated by the transmission line built specifically for the geothermal power plants operating in the Imperial Valley of California. Similarly, Oxbow Geothermal found the resource at Dixie Valley, Nevada, sufficiently attractive to build its own 220-mile transmission line to a tie-in with existing lines. The key here, however, is a large, high-quality resource; lesser resources may not justify such expenditures. Eventually, some provision for guaranteed transmission access may be warranted at the utility, state, or regional level.

Changes in the marketing of geothermal power appear to be on the horizon through load-following operations. While hot geothermal wells cannot be shut-in for extended periods without risk of damage, the industry believes it has the capability to tailor production to meet variable power demands. One utility at The Geysers has been practicing load-following for over a year. Whether any DOE involvement will be sought by the industry as it expands from strictly baseload operations to supporting intermittent or peaking modes of operation is unclear at this time.

Obstacles to Geothermal Development

During the process leading to the National Energy Strategy, geothermal advocates noted that a concerted R&D effort by DOE is needed to solve technology problems which are hampering increased geothermal use. These problems were alluded to in the previous discussion. In addition, the following obstacles to geothermal development were identified:

- Energy prices have dropped so low that there are no incentives to make the large investments required to find and develop new resources.
- The market for geothermal power is primarily in the western states where there is currently an oversupply of generating capacity.
- Present tax regulations do not provide sufficient encouragement to geothermal development.
- Present energy policies do not reflect the external costs of energy conversion and use, or consider total fuel-cycle costs. Incentives for development of resources that are environmentally advantageous are needed.
- Major utilities deny free access to transmission lines and wheeling rights.
- Failure to plan cooperatively for geothermal development -- e.g., through unitization.
- Incentives (i.e., tied aid) by foreign governments reduce competitiveness of U.S. geothermal products and services in international markets.

Options for Removal or Alleviation of Obstacles

The reorganization of DOE's Office of Conservation and Renewable Energy is designed to accelerate the market penetration of new technologies to suitable end-use applications in several energy sectors. Applications research and development activities to "push" technologies to commercial maturity for both demand-side and supply-side approaches to energy supply are being emphasized under this arrangement. Reducing institutional and economic barriers allows market "pull" to enhance the use of these technologies. Within the new structure, the Office of Utility Technologies has been created to play a key role in addressing the challenges and opportunities facing the electricity sector, including the use of geothermal resources for power generation.

The reorganized renewable energy program is already focusing on the ~~known~~ previously identified obstacles to geothermal development. For example, ~~for the first time,~~ an effort is being made to integrate energy and environmental policies. A new working relationship with the Environmental Protection Agency should result, particularly in the arena of pollution prevention through policies that will encourage greater use of renewable energy. Consideration is being given to performing complete fuel-cycle cost analyses for energy systems as a whole which evaluate the economic, social, and environmental costs of competing technologies to help the private sector better assess the most cost-effective allocation of resources to meet energy needs. The new Clean Air Act amendments are being analyzed to determine their potential effect on geothermal energy in the U.S. power market. The impacts are expected to be economically favorable as the costs of more stringent regulations are applied to fossil-fired plants.

New programs to address issues regarding transmission pricing and access can make major strides toward maximum utilization of transmission systems. And various types of tax incentives are being analyzed to determine their potential impact on energy technologies. Amendments to PURPA were enacted in November 1990 which remove the cap on plant size for all energy technologies covered by the Act.

Legislation entitled the "Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989," signed by the President in December 1989, supports the goals of DOE's Renewable Energy Programs. It calls for authorization of renewable energy R&D budgets for three fiscal years at a time, a move that would lend considerable stability to research programs, and one which has long been advocated by the industry. In addition, the Act addresses the desire of the U.S. industry to increase its competitiveness in overseas markets. It directs the interagency Committee on Renewable Energy Commerce and Trade (CORECT) to "establish in consultation with representatives of affected industries, recommended administrative guidelines for federal export loan programs to simplify application by firms seeking export assistance for renewable energy technologies from agencies implementing such programs."

Key Participants Needed for Success

All elements of the U.S. geothermal community contribute to the success of the federal R&D program, as well as helping to assure an infrastructure in which geothermal development can flourish as more market opportunities become available. The community is an especially close-knit one and cooperation is the norm. This group includes other federal agencies -- the U.S. Geological Survey, the Bureau of Land Management, the U.S. Forest Service -- state energy and resource agencies, the national laboratories, utilities, and industry.

Two unique DOE/industry organizations, the Geothermal Drilling Organization (GDO) and the Geothermal Technology Organization (GTO), are critical to the successful transfer of technology to the marketplace. These organizations function similarly except that the interests of the GDO are centered on geothermal drilling technologies, whereas the GTO focuses on technology development related to reservoir performance and energy conversion. Both organizations support projects designed to market the products of research. Projects are jointly funded by DOE and the participating industry partners, with industry providing at least 50% of the total cost. Just recently, the GDO completed improvements to a rotary head seal for drilling and transferred the technology to industry for commercial production. The seal will have broad applications throughout the drilling industry. Both organizations frequently provide test sites for investigating new technology and methods. For instance, GTO members provided the premises for a cooperative research effort to monitor signals from an advanced seismic array at The Geysers.

IV. THE OBJECTIVES

The major objectives of the Geothermal Division for the FY 1993-1997 planning period are as follows:

Near-Term (until 1995)

- Reverse the pressure decline at The Geysers steam field in California and stabilize productivity by developing and applying improved reservoir management techniques in cooperation with industry.

- Develop and test innovative exploration methods and integrated strategies to locate and characterize the undiscovered hydrothermal reservoirs.

- Reduce the downtime due to lost circulation during drilling by developing an expert control system, various types of materials and packers, and advanced detection tools.

- Improve efficiency of binary cycle systems by 25-30% through experiments on mixtures of working fluids, supercritical vaporization, integral condensation, and supersaturated expansion in binary turbines.

- Decrease front-end costs of geothermal heat pumps by improving ground loop installation technology.

- Test the hot dry rock reservoir at Fenton Hill, New Mexico, to evaluate its performance characteristics over an extended period of time and arrange for industry participation.

- Increase a reservoir's economic value by conducting research on how to operate a geothermal reservoir in a peaking mode.

Mid-Term (1995-2010)

- Identify, in cooperation with industry, hidden geothermal resources and increase the number of fields for future development through the application of advanced exploration technology and confirmatory drilling.

- Reduce the number of exploratory wells needed to define a field by 15% and the dry hole ratio in fractured reservoirs by 20% by developing advanced sensing tools, improved dual-well seismic techniques, and fiber optic technology.

- Reduce well costs and extend well life using advanced non-metallic well casing liners and materials for the in situ conversion of drilling fluids into cements.

- Reduce plant maintenance costs by 10% by predicting scale formation from geothermal brines and developing low cost, environmentally sound waste disposal processes.

- Reduce front-end costs of power plants by identifying high-efficiency, standardized energy conversion technology.

Long-Term (post 2010)

- Determine if the performance of the Fenton Hill Phase II reservoir, when considered as a modular unit in a commercial-scale project, could support production of electricity at an economical busbar cost.

- Improve the ability to locate fractures in hot dry rock environments.

An overall technology cost reduction for hydrothermal of 30 to 40 percent for the mid-term was determined through the use of a quantitative cost-of-power model (IMGEO, "Impacts of Geothermal Research"). The model simulates interactions among the components of a hydrothermal electric plant and enables a comprehensive cost analysis of impacts from each element of the hydrothermal research program. For example, the impact on the cost of power of a 20% decrease in well drilling costs can be determined. Sensitivity analyses can be conducted to determine which technology improvements will have the greatest overall impact.

V. THE STRATEGY

The Geothermal Division has implemented a strategy which aims to increase the Nation's energy supply by markedly expanding the economically recoverable hydrothermal resource base through the discovery of new reservoirs; the development of improved, low-cost drilling techniques and electric generation systems; and the improvement of reservoir management methods. The strategy also strives to reduce power demand through the widespread use of geothermal heat pumps and other direct heat uses. Research priorities are industry-driven focusing on those projects promising the most benefit to industry and having the greatest commercial potential. The Division maintains a core research program through which investigations are conducted that the undercapitalized industry cannot afford. Research activities which can be cost-shared with industry partners, as well as other funding agencies, are emphasized to assist industry in eliminating near-term technical obstacles to geothermal development and exploitation. Efforts enabling geothermal energy to contribute to integrated resource planning activities will also be encouraged.

Primary Research Activities by Year and Expected Incremental Products

The primary research activities for the base-level funding program for FY 1993-1997 are identified in Appendix A for Exploration Technology, Reservoir Technology, Drilling Technology, and Conversion Technology, along with the expected incremental products of the research. These program activities are designed to accomplish the three levels of program objectives defined in an important companion program document entitled *Programmatic Objectives of the Geothermal Division, U.S. Department of Energy (1989)* (in revision). The objectives have been established such that the achievement of research objectives (Level III) results in improvements in the various geothermal-related technologies. These advancements, in turn, translate into changes in power plant performance (Level II objectives) affecting cost that reduce the overall cost-of-power (Level I objectives). As the objectives document also points out, analysis of technology performance is a critical step in determining geothermal objectives. Until recent years, the performance analysis was largely qualitative, necessitating considerable subjective judgment on the part of geothermal program managers. Now, however, the subjective approach has been modified by the introduction of the quantitative, cost-of-power IMGEO model.

The Level I objectives allow analysts and decision makers to estimate the future cost of power from geothermal energy systems. At this level, the objectives are expressed in terms of reducing the life-cycle costs of energy from a typical geothermal energy production project (e.g., a binary electric power plant including its geothermal fluid supply). Economies are the focus of the Level II hydrothermal objectives which provide direct input to the IMGEO model. This level of objective gives government and industry managers an impression of how much improvement is likely to occur within major project components as a result of federally funded research. The Level III objectives prescribe the technical direction of individual research projects. They facilitate communication among engineers and scientists and comprise the technical yardsticks by which progress can be measured.

Cost-of-energy models equivalent to the IMGEO hydrothermal model are not yet available for geopressured brines or hot dry rock. The objectives for these resource types, to which the R&D activities in Appendix A are addressed, were set by Geothermal Division staff through consultation with DOE field R&D managers and industry specialists.

INSERT (B)

Industry is actively participating in the planning and implementation of the R&D program objectives. Industry's response to the achievement of objectives -- i.e., whether or not industry expands beyond currently known hydrothermal reservoirs -- will be the final test of the success of this plan.

Monitoring of Infrastructure Conditions

The Geothermal Research, Development, and Demonstration Act of 1974 provides the authority for the Geothermal Division to identify "social, legal, and economic problems associated with geothermal development (both locally and regionally) for the purpose of developing policy and providing a framework of policy alternatives for the commercial utilization of geothermal resources." The Geothermal Division has exercised this authority in the past, largely through funding the Interagency Geothermal Streamlining Task Force and the Barriers Panel of the Interagency Geothermal Coordinating Council.

And, as discussed previously, the Geothermal Division, and its predecessors, have maintained close contact with all elements of the infrastructure in which the geothermal industry -- both utilities and developers -- operates. Thus, mechanisms are in place to monitor the status of the infrastructure elements and to identify problem areas as they develop. Regular dialogue among the entities is customary and the Geothermal Division is kept abreast of interaction between industry and its infrastructure through both formal means, such as the annual Stanford University Reservoir Engineering Workshop, the Geysers Research Consortium, and the annual DOE Geothermal Program Review, and on an informal basis.

Regular interaction with state geologists, state energy offices, and state energy commissions is maintained; frequent inquiries are directed to state regulatory agencies to ascertain their views on compliance by the geothermal industry; and dialogue continues between the Geothermal Division and regional power agencies such as the Bonneville Power Administration. Funding of geothermal research programs at Stanford University and other academic institutions provides "hands-on" experience for students who provide the professional workforce for the geothermal industry. In addition, the Geothermal Division participates in and actively supports the public information and educational programs of the Geothermal Resources Council.

Indications of Progress

Due to the nature of geothermal operations -- and the variability of the resource -- progress is not measured by "overnight" successes. Rather, progress toward competitiveness with other fuels is based on an evolutionary process, consisting of incremental improvements in methods, equipment, and materials, marked intermittently by exceptional advancements.

For example, R&D in reservoir technology to characterize geologic structures and the occurrences of viable resources within them is an ongoing process, requiring years of field operating data to evaluate, verify, or modify characterizations drawn from earlier data.

New Section

"The Program"

INSERT → "Objectives"

Add → R&D ~~Program~~ Activities

(See INSERT (C))

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R&D Activities

Research activities assuming a base level of effort during FY 1993-1997 are identified in Appendix A. The base level comprises projects and tasks currently in progress and expected to extend into the planning period. These program activities belong to one of two categories: (1) Core research aimed at reducing the cost of power, and (2) Development and Applications involving cost-shared practical applications of new technology. Enhancements to the base-level program in the form of new initiatives are also proposed as a means of making new technology advancements or accelerating technology applications. These initiatives include substantial cost sharing with the utility sector and related industries.

However, recent injection tests of new organic tracers confirmed the calculations of a numerical reservoir model on tracer breakthrough, thus providing significant evidence of a research success.

The overall results of the research activities outlined in this plan will be measured by reductions in the cost of geothermal power as determined by ~~the~~ IMGEO ~~cost model~~, appropriately adapted to analyze hydrothermal, geopressured, and hot dry rock resources. The actual cost benefits will accrue incrementally in subsequent years as industry adopts the new technology and gains operating experience with it. Assessments of the performance of the Geothermal Division's R&D program will be determined by the change in geothermal power plant capacity and other value-based factors such as the reduction in the Nation's vulnerability to oil supply disruptions, the cost reduction in meeting energy demands, the minimization of adverse environmental impacts, the improvement in market deployment, the management of technical risk, and the need for and amount of federal involvement.

Ancillary or Spin-Off Benefits

Based on previous experience, the oil and gas industry and others can be expected to benefit from various advancements in reservoir technology and innovative drilling techniques developed through geothermal R&D. The development of cements and materials for bonding high-temperature elastomers to metal can be expected to find application wherever heat and/or corrosion create major problems in the performance and durability of materials. In the waste and brine modeling areas, techniques developed for geothermal activities can be applied to a host of other industries, such as mining and environmental clean-up. Additionally, advancements in binary technology should have broad application to various industrial operations.

~~VI.~~ BUDGET ASSUMPTIONS

Renewable energy technologies received a great deal of visibility and support during the public hearing process for the National Energy Strategy. As a result, while the Department continues to analyze and evaluate the many energy options proposed, Secretary Watkins designated renewable energy for "fast track" consideration among the policy choices. This action, combined with greater budgetary support, indicates an enhanced emphasis on renewable energy programs. Recent threats to imported oil supplies appear to have further solidified public support for more expeditious development of renewable energy technologies.

The Geothermal Division has proposed two major scenarios for the FY 1993-1997 planning period. The base case scenario entails activities to achieve the current research objectives and assumes a 5-year budget of $142 million and Division staff of 12-14 full-time equivalents (FTE). Under the enhanced scenario, new initiatives for industry-coupled ~~drilling and resource confirmation~~, geothermal heat pump installation, ~~advanced~~ drilling technology, and ~~advanced energy conversion~~ are pursued; hot dry rock demonstration projects are initiated earlier to accelerate commercial development and potentially double geothermal power on-line after the year 2010. A 5-year budget of $220 million and Geothermal Division staff of 17-18 FTE are assumed. Table 1 presents the resource plan for the geothermal program for the FY 1993-1997 planning period.

Table 1

GEOTHERMAL RESOURCE PLAN*

Resource Plan (Dollars in Millions)	FY93	FY94	FY95	FY96	FY97	Total
Base Budget	24.4	27.2	28.6	30.0	31.5	141.7
Enhanced Budget	0.0	~~18.0~~ 21.0	~~19.0~~ 26.3	~~20.0~~ 23.5	~~21.0~~ 23.0	~~78.0~~ 93.8
TOTAL	24.4	~~45.2~~ 48.2	~~47.6~~ 54.9	~~50.0~~ 53.5	~~52.5~~ 54.5	~~219.7~~ 235.5

* Budget figures are for internal planning purposes. They have not been approved as U.S. Government budget figures or projections.

~~VII. THE MACRO~~-SCHEDULE

Technical milestones have been established for each of the research tasks in the R&D program. These milestones are used as targets and provide a basis for evaluating the accomplishments made to date. Periodic reevaluation is conducted to ensure that the milestones meet the latest program objectives and consider current budgetary constraints. ~~The~~ key milestones for the base case and new initiatives for FY 1993-1997 are shown in Table 2. ~~A more detailed set of milestones is provided in Appendix B.~~

Given the risks and uncertainties of research, the objectives expressed in this plan may be subject to change. In addition, the potential for changes in policy directives, 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.

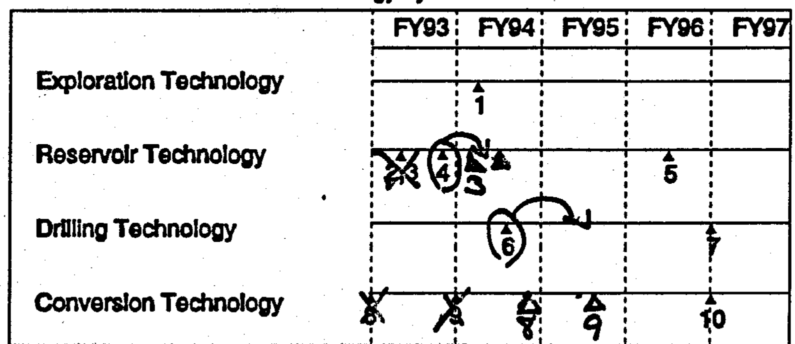
VIII. MANAGEMENT STRUCTURE

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 assistance of these offices, the Geothermal Division implements energy policy at the program level and allocates the necessary technical and budgetary resources for program activities. In addition, the Division works in cooperation with other offices within DOE (e.g., Office of Technical and Financial Assistance) on activities of mutual interest.

Table 2

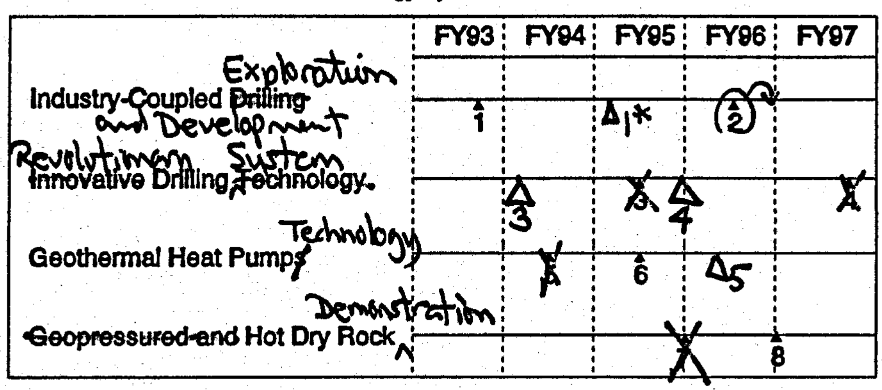
GEOTHERMAL KEY MILESTONES

Geothermal Energy Systems - Base Case



complete development of integrated exploration model
1 ~~Conduct Field Test of New Exploration Methods~~
2 Test New Injection Technology at The Geysers; ~~Complete Study of Peaking Mode Operations.~~
4 Complete Long-Term Flow Test of the Hot Dry Rock Reservoir
5 Complete Joint Testing of Production Strategies for Managing Reservoirs ('96 base or enhanced)
6 ~~Complete Development of Emplacement System for Geothermal Heat Pump Ground Loops and Conduct National Utilities Awareness Campaign.~~ Complete development of corehole drilling system
7 Field Test Measurement-While-Drilling Tools and Fiber Optic System
8 ~~Complete Studies to Improve Binary Cycle Technology;~~ Develop Elastomeric Well Casing Liners
10 Build Commercial-Scale Bioreactor with Industry
9 Test improvements in binary-cycle efficiency

Geothermal Energy Systems - Enhanced Case



1 Conduct Field Surveys and Exploratory Drilling at Selected Sites
2 Complete Cost-Shared Drilling of Most Favorable Sites
3 ~~Conduct Cost-Shared Drilling Using New Technology.~~ Initiate system design studies of alternatives
4 ~~Transfer Drilling Technology to Industry.~~ Select system for prototype development
5 Demonstrate One-Day Installation of Compact ~~Residential GHP Units~~ Geothermal Heat Pumps in Cooperation with Industry
6 Complete Ground Loop Design Manual for Commercial Buildings
~~7 Initiate Joint Geopressured Project with Industry/Utilities.~~
8 Initiate First Joint Hot Dry Rock Project with Industry/Utilities Partners

* Complete cost-shared surveys of Pacific Northwest geothermal areas

Under the guidance and leadership of the Geothermal Division, field organizations 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. 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, institutions specializing in various aspects of geothermal research have been established. ~~This unique geothermal expertise resides at Sandia National Laboratories, Idaho National Engineering Laboratory, Lawrence Berkeley Laboratory, Los Alamos National Laboratory, the University of Utah Research Institute, Stanford University, and Brookhaven National Laboratory.~~

Appendix A

PRIMARY RESEARCH ACTIVITIES OF THE GEOTHERMAL DIVISION FOR FY 1993-1997 AND EXPECTED RESULTS
– BASE PROGRAM ONLY –

Center – larger print

PROGRAM ELEMENT	RESEARCH ACTIVITIES	EXPECTED RESULTS
CORE RESEARCH		
Exploration Technology	Actively involve industry in technology development to produce the new generation of instruments necessary to discover hidden geothermal systems.	Enhanced superiority of U.S. industry in the international market for geothermal exploration and a competitive advantage for U.S. companies. Increased effectiveness of exploration tools and methods for identifying potential new geothermal fields.
	Publish a collection of geothermal development case studies based on geothermal systems in the western U.S.	Documented experiences of geothermal development in active, producing fields to use as a reference in the exploration, development, production and management of new fields.
	Complete study of collocation of heavy oil and geopressured-geothermal resources in Texas.	Delineation of areas where heavy oil and geopressured-geothermal fluids co-exist.
Drilling Technology	Transfer to industry technology for emplacing encapsulated cements and bridging materials to control lost circulation; develop and field test an expert system for lost circulation operations; field test the drillable straddle packer, porous packer, and rolling float meter; and develop borehole televiewer loss-zone characterization techniques.	30-50% reduction in cost due to lost circulation episodes.

PRIMARY RESEARCH ACTIVITIES OF THE GEOTHERMAL DIVISION FOR FY 1993-1997 AND EXPECTED RESULTS
– BASE PROGRAM ONLY –

PROGRAM ELEMENT	RESEARCH ACTIVITIES	EXPECTED RESULTS
Drilling Technology (Continued)	Conduct field tests to compare production in large and small wellbores; develop and field test slimhole coring exploratory drilling system; initiate development of measure-while-coring system with industry.	Development of relatively inexpensive coring holes which can assess reservoir productive potential at half the cost of conventional wells.
	Begin adapting subsurface dual-well seismic technology to locate fractures.	20% reduction in dry hole ratio in fractured reservoirs due to improved identification of well target.
	Develop fiber optic cables and sensors for high-temperature (above 300°C) logging.	Reduction in the number of exploratory wells needed through advanced measurement techniques.
	Measure durability, pumpability, and density of lost circulation control materials that harden like cements when they enter fractures in rock formations.	Commercialization of reliable in-situ lost circulation materials.
Reservoir Technology	Determine basic thermodynamics of hydrogen chloride gas in steam.	Ability to control HCl corrosion in valves and surface pipes at The Geysers and other geothermal fields.
	Investigate the mechanism of water adsorption on fractured rock surfaces.	Ability to determine water saturation in reservoir fractures and the longevity of production.

Appendix A

PRIMARY RESEARCH ACTIVITIES OF THE GEOTHERMAL DIVISION FOR FY 1993-1997 AND EXPECTED RESULTS
– BASE PROGRAM ONLY –

PROGRAM ELEMENT	RESEARCH ACTIVITIES	EXPECTED RESULTS
Reservoir Technology (Continued)	Investigate the development of integrated reservoir simulation that combines hydrology and geochemistry in a single computer model.	Ability to track the migration of injected geothermal fluids and to predict their thermal and chemical changes in both vapor- and liquid-dominated systems.
	Extend and refine existing brine chemistry model to include new experimental data to improve the capability to predict scaling tendency of geothermal brines and apply model to assist industry in solving on-site problems.	Reduction in plant maintenance costs by 10%.
	Shut-in Pleasant Bayou well for pressure buildup, complete final testing, and plug and abandon well.	Completion of well testing and restoration of Pleasant Bayou well site.
	Plug and abandon Hulin well.	Restoration of Hulin well site.
	Complete scientific tests at Pleasant Bayou well site and analyze data.	Identification of reservoir drive mechanisms and determination of the reservoir's long-term production capability.
	Continue monitoring of surface and ground water, microseismicity, and subsidence at geopressured well sites.	Verification of no adverse environmental effects from geopressured well testing activities.
	Coordinate final geopressured research reports.	Publication of final research reports in peer-reviewed journals to transfer findings to the private sector.

PRIMARY RESEARCH ACTIVITIES OF THE GEOTHERMAL DIVISION FOR FY 1993-1997 AND EXPECTED RESULTS
– BASE PROGRAM ONLY –

PROGRAM ELEMENT	RESEARCH ACTIVITIES	EXPECTED RESULTS
Reservoir Technology (Continued)	Conduct long-term flow test (LTFT) and analyze data.	Estimation of thermal lifetime; determination of reservoir productivity; compilation of reliable record of HDR engineering, operational, and maintenance factors, especially water consumption; validation of the commercial viability of HDR.
	Operate Fenton Hill HDR reservoir under alternative conditions.	Definition of governing criteria for optimum productivity.
	Collect and evaluate environmental monitoring data for Fenton Hill site.	Verification of the absence of adverse effects from sustained reservoir operations.
	Verify behavior of diagnostic tracers for HDR applications.	Demonstration that tracers can predict reservoir thermal lifetime for 10-20 years into the future.
	Continue microseismic monitoring and improve 3-D models of the HDR reservoir performance using seismicity and tracer data.	Determination of reservoir expansion parameters and improved accuracy of reservoir mapping technology for easier development of new HDR systems.
	Extend HDR modeling analysis to multi-well, multi-reservoir configurations that simulate full-scale commercial systems.	Enhancement of efficient reservoir operational modes and improved accuracy of forecasting production and cost.
	Conduct mineral dissolution studies.	Prediction of changes in flow impedance.

Appendix A

PRIMARY RESEARCH ACTIVITIES OF THE GEOTHERMAL DIVISION FOR FY 1993-1997 AND EXPECTED RESULTS
– BASE PROGRAM ONLY –

PROGRAM ELEMENT	RESEARCH ACTIVITIES	EXPECTED RESULTS
	Investigate zone isolation and impedance reduction technology.	Advanced techniques for reservoir enhancement and multi-reservoir facilities.
	Conduct HDR technology transfer activities in cooperation with the utility sector.	Dissemination of HDR technology to the private sector to improve commercialization potential.
	Evaluate enhanced power production modes for a HDR reservoir.	Determination of alternative modes of economic reservoir production.
Conversion Technology	Document field tests of heat-resistant, lightweight cements and complete technology transfer.	Development of materials which can be used in the completion of geothermal wells.
	Perform laboratory evaluations of chemical systems that will bond elastomers to steel.	Reduce cost of wells by the availability of advanced drilling equipment.
	Measure the resistance of ceramic-based cements to scaling and corrosion under simulated conditions at 300°C.	Extension of casing life by 10 years, costing one-third as much as metal alloys.
	Continue development of a system to detoxify geothermal wastes with bacteria; design continuous process prototype for commercial geothermal site; examine process economics.	Potential for over 25% reduction in waste disposal costs. Potential for mineral recovery to offset costs. Removal of 80% of the metals.

PRIMARY RESEARCH ACTIVITIES OF THE GEOTHERMAL DIVISION FOR FY 1993-1997 AND EXPECTED RESULTS – BASE PROGRAM ONLY –

PROGRAM ELEMENT	RESEARCH ACTIVITIES	EXPECTED RESULTS
Conversion Technology (Continued)	Develop advanced heat rejection system.	Reductions in consumptive water use for heat rejection.
	Develop advanced non-metallic well casing liners.	Reduction in well costs and extension of well life.
DEVELOPMENT & APPLICATIONS		
Industry-Coupled Drilling	Conduct joint ventures with industry to select the most innovative exploration methods and implement the best exploration techniques.	Characterization of the large number of undiscovered geothermal resources in the U.S., building an inventory of sites for future industry development.
Drilling Applications	With industry participation, field test advanced modular downhole memory tools and develop borehole instruments.	Reduction of 15% in number of exploratory wells needed.
	Begin new GDO projects on near-term technology improvements that are selected and cost-shared by industry on a 50-50 basis.	Accelerated technology advancement and technology transfer.
Reservoir Engineering Applications	Work with utilities and field operators at The Geysers to test and evaluate water injection strategies for maximum energy recovery.	Determination of the most effective method of water injection to reverse the pressure decline at The Geysers and return the steam field production closer to the installed 2,000 MWe capacity; if successful, extension of reservoir lifetime by an order of magnitude.

PRIMARY RESEARCH ACTIVITIES OF THE GEOTHERMAL DIVISION FOR FY 1993-1997 AND EXPECTED RESULTS
– BASE PROGRAM ONLY –

PROGRAM ELEMENT	RESEARCH ACTIVITIES	EXPECTED RESULTS
Reservoir Engineering Applications (Continued)	Field test surface-based high frequency seismic monitors for accurate measurement of fracture planes in The Geysers.	Improve ability to locate major producing zones and reduce the risk and cost associated with drilling production wells.
	In cooperation with the Geothermal Technology Organization, conduct industry-directed, joint-venture research to design the production wells and methods needed to operate a geothermal reservoir as a load-following energy source.	Significantly increased economic value of reservoirs through the ability to operate in a peaking mode.
Electric Conversion Applications	Test supersaturated expansions in binary cycle turbines.	Potential 5%-10% improvement in advanced binary plant performance.
Direct Heat Applications	Design drilling hardware for rapid emplacement of vertical heat exchangers and horizontal heat exchange loops for geothermal heat pumps.	Reduced installation costs and expansion of cost-effective market penetration of geothermal heat pumps in higher density urban markets.

~~Add: improved electric conversion – Energy night~~

Demonstrate commercial power generation by employing innovative technology with superior design or operating characteristics.

Improve the conversion of thermal energy to electric power at reduced cost.

Appendix B

GEOTHERMAL PROGRAM MANAGEMENT MILESTONES FOR FY 1993 - FY 1997
– BASED AND ENHANCED PROGRAMS –

MILESTONE	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997
CORE RESEARCH					
Exploration Technology					
Complete new analysis and interpretation of existing exploration data and select regional exploration areas for focused effort.	●				
Complete development of second generation chemical tracers.	●				
Develop integrated, comprehensive exploration model of geothermal fields.		●			
Drilling Technology					
Initiate field test of high-temperature lost circulation materials.	●				
Complete development of porous packer.	●				
Complete development of downhole injector, small-scale laboratory studies of cementitious muds, and wellbore hydraulic models.	●				
Identify needs and begin development of surface technology for coring rigs.	●				
Begin development of high-temperature drilling fluids.	●				
Initiate development of high-temperature core barrels.	●				

MILESTONE	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997
Drilling Technology (Continued)					
Begin design of advanced coring system for geothermal exploration.	●				
Initiate development of fiber optic cables for high-temperature logging above 300°C.		●			
Complete large-scale laboratory tests of cementitious muds.		●			
Initiate development of expert systems for lost circulation control.		●			
Complete development of SEA-MIST hardware.		●			
Initiate development of high-temperature slimhole drilling fluids and lost circulation materials.		●			
Initiate field test of cementitious muds, expert systems for lost circulation control, and SEA-MIST hardware.		●			
Initiate advanced drilling concepts for geothermal applications.				●	
Transfer cementitious mud lost circulation technology to industry.				●	
Develop measurement-while-drilling tools for geothermal wells.				●	
Transfer expert system technology for lost circulation to industry.					●
Transfer core drilling technology to industry.					●
Reservoir Technology					
Complete analysis of data obtained from Phase II drilling of the Long Valley Exploratory Well.	●				

MILESTONE	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997
Reservoir Technology (Continued)					
Complete study of peaking mode operations.	●				
Expand testing and application of brine model to field problems.	●				
Complete update of brine model user's manual.	●				
Initiate literature search and modeling of metal sulfides.	●				
Commence in-depth analysis of LTFT data.	●				
Complete study of HDR Phase II reservoir fluid mineralization.	●				
Complete initial studies on water-rock interactions.	●				
Demonstrate reliability of temperature-sensitive tracers for HDR applications.	●				
Begin evaluation of enhanced power production modes (multi-well, cyclic) for a HDR reservoir.	●				
Complete LTFT.	●				
Develop tracking methodology to account for disposition of all injected water in geothermal developments.		●			
Initiate development of reservoir computer simulation which includes geochemistry.		●			
Complete model of pH in high-temperature brines.		●			
Initiate preliminary model of aluminum specification as a function of pH.		●			
Complete preliminary model of bisulfate species in high-temperature program.		●			
Complete final report on environmental monitoring of geopressured sites.		●			

MILESTONE	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997
Reservoir Technology (Continued)					
Issue preliminary report on LTFT results.		●			
Complete metal sulfide modeling (0 - 100°C).			●		
Initiate comparative brine kinetic studies and modifications.			●		
Decommission Fenton Hill site or transfer to industry.			●		
Document economics of enhanced production modes for HDR reservoirs.			●		
Initiate investigation of zone isolation and impedance reduction technology.			●		
Issue final reports on LTFT.			●		
Complete integration of geochemical processes into reservoir simulators.				●	
Complete metal sulfide modeling (100°C - 250°C).				●	
Complete impedance reduction technology study.				●	
Demonstrate full-field reservoir strategy for location and flow rate control of injection wells.					●
Conduct a comprehensive HDR systems study.					●
Conversion Technology					
Complete advanced heat rejection system scoping studies and select one for field investigations.	●				
Conduct field tests of polymer concrete liners for heat exchanger tubes.	●				
Initiate construction of new generation bioreactor.	●				

MILESTONE	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997
Conversion Technology (Continued)					
Complete study of mineral recovery from geothermal residual waste.	●				
Complete investigations of condensation behavior of supersaturated turbine expansions.		●			
Conduct third-phase field test of polymer concrete-lined heat exchanger.		●			
Transfer polymer concrete heat exchanger technology to industry.		●			
Complete cementing activities in demonstration well.		●			
Complete development of elastomeric liners for well casing.		●			
Complete field demonstration of elastomeric liners.		●			
Complete construction of new generation bioreactor.		●			
Initiate process development studies.		●			
Complete investigations of advanced heat rejection systems.			●		
Close out operation of HCRF.			●		
Technical feasibility of cementitious lost circulation control materials established in field tests.			●		
Complete technical feasibility study for placement of ceramic liners.			●		
Complete biochemical process development studies.			●		
Initiate third biochemical economic study.			●		
Complete identification of best candidates for further bioreactor scale-up with industry.				●	
Complete downhole testing of prototype ceramic-lined sections.					●
Build commercial-scale bioreactor with industry.					●

MILESTONE	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997
DEVELOPMENT & APPLICATIONS					
Industry-Coupled Drilling					
Develop strategy to deepen Long Valley Exploratory Well to 14,000 feet in conjunction with participating groups.	●				
Conduct field surveys and exploratory drilling at selected sites.	●				
Conduct field test, with industry, of new exploration methodology.		●			
Complete joint regional exploration of initial areas and target deep drilling.			●		
Complete joint, cost-shared, deep drilling of most favorable exploration targets.				●	
Apply new exploration methodology at candidate sites.					●
Present unified concept for geothermal exploration technology.					●
Initiate first joint hot dry rock project with industry.					●
Drilling Applications					
Initiate fabrication of drilling hardware for heat pump installation.	●				
Complete development of emplacement system for geothermal heat pump ground loops.		●			
Drill cost-share exploratory corehole with industry.			●		
Field test fiber optic system.					●
Field test measurement-while-drilling tools.					●

MILESTONE	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997
Reservoir Engineering Applications					
Test new injection technology, with industry, to efficiently recycle scarce available water at The Geysers field.	●				
Conduct joint field tests of second generation chemical tracers for determining flow paths in geothermal reservoirs.		●			
Complete joint development, with industry, of automated well-field control for fast response to energy needs.			●		
Complete joint testing, with industry, of reservoir simulator for use as a production management tool.				●	
Electric Conversion Applications					
Award cooperative agreement for demonstration of economic benefits of improved electric generation systems for geothermal applications.	●				
Complete environmental assessment of electric generation system project.	●				
Direct Heat Applications					
Conduct geothermal heat pump National Utilities Awareness Campaign.	●				
Demonstrate one-day installation of residential geothermal heat pumps in cooperation with industry.			●		