

DRAFT

**Multiyear Plan
FY 1992-1996**

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

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BACKGROUND

Status of Geothermal Development

Geothermal energy is commercially employed to produce electricity at 17 reservoirs in California, Nevada, and Utah. Geothermal energy is a cost-effective and competitive resource at these locations with nearly 2,800 MWe of capacity in operation. The resource provides about 7 percent of the power currently used in California. Further power development appears imminent in Hawaii and the Pacific Northwest.

The annual energy use of 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 percent conversion efficiency. It is estimated that about 110,000 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 geothermal power industry reports that the severe institutional impediments to geothermal development of the 1970's have largely dissipated. For example, the industry has acquired a good land position for development in the western states through an accelerated federal leasing program, and the most repetitive environmental regulations have been modified to reduce unnecessary construction costs and lead times at no penalty to the environment.

Cost

The Department of Energy (and its predecessors) have spent in excess of \$1.3 billion in support of geothermal development in this country, both for

power generation and direct use. It is estimated that industry has spent in excess of \$5 billion for power projects alone.

In addition to expenditures for technology development, some expenditures by both industry and government have been accounted for by institutional barriers to development. In the case of industry, it was extremely costly to meet early environmental and other regulatory requirements, and, in the case of DOE, support was given to the effort to overhaul tax and regulatory aspects of geothermal development. Since 1982, virtually all of DOE's expenditures have been dedicated to power generation technology advancement.

Benefits

The benefits of these expenditures are multifold. 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 uses and the inclusion of geothermal energy in integrated resource planning may relieve the pressure on some utilities, providing an opportunity to defer new capacity.

In addition, the advancements achieved through federal expenditures -- both technical and institutional -- continue to provide a favorable investment climate for geothermal technologies and improve the competitiveness of geothermal products and services to meet the 1995-2005 markets.

The use of geothermal power resulted in a \$125-\$250 million cost-savings to consumers in 1988, primarily due to the low cost of power at The Geysers. The new hot water plants are providing customers with reliable power supplies with availability ratios second to no other fuel. A majority of these geothermal electric power generating plants are sited on federal leases, and in

1989, the latest year for which data are available, these leases returned some \$14 million in lease and rental fees to the federal government.

Further, in local air quality terms, a number of western metropolitan areas will be assisted in meeting federal requirements. Nationally and globally, geothermal use:

- increases the energy supply without detrimental environmental effects
- reduces the demand for imported oil and frees some domestic oil for more valuable uses such as chemical feedstocks
- reduces the clearing of rain forests or burning of fossil fuels in many developing countries with large untapped geothermal deposits.

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

Spinoffs

Many spinoffs of geothermal technology are in use in other industries. They are exemplified by the following:

- Improved drill bits resulting in a \$300-\$500 million per year cost saving to the oil and gas industry.
- Adaptation of the radar fracture mapping tool for use in nuclear weapons treaty verification.
- Proposal by the Energy Research Advisory Board to designate geothermal geoscience management methods as a model for accelerated oil and gas R&D.

- Wide use in the petroleum industry of an elastomer compound (Y267 EPDM) developed by geothermal materials research.

Participants/Customers

The industrial participants in geothermal development include utilities, field developers -- some of whom also own and operate a power plant -- and other independent plant owners. 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.

The customers of geothermally-generated power are both utility electricity customers and the utilities themselves. The utilities purchase power from the independents under long-term contracts, many acquired with California Standard Offer No. 4, a California-specific mechanism for implementing the provisions of the Public Utilities Regulatory Policies Act. This mechanism has been phased out, and, at this juncture, no new pre-approved contracting procedures have been instituted.

Government Role

The federal geothermal program began as a mandate to the Atomic Energy Commission to broaden the technology base upon which use of this alternative energy source could be built. It continued as a scientific/technical program, with only marginal commercialization interest, until passage of the Geothermal Energy Research, Development, and Demonstration 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. It embraced expenditures for the Baca, New Mexico, and Heber, California, cost-shared demonstration plants; a program to expedite direct use; cost-shared resource assessment efforts by industry and the states; and studies on leasing, environmental regulation, and other institutional problems. This budget element remained high 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. Emphasis shifted back to research and technology development.

With greatly decreased budgets, the R&D program of the 1980's has been characterized by 1) long-term, high-risk R&D funded by the government, and 2) short-term efforts to encourage the commercial manufacture of the products of research, cost-shared by government and industry. However, the government has relied on industry facilities for testing new or improved equipment and materials developed by the DOE program, and, more recently, for field operating data for use in validating or modifying reservoir models. In recent years, the hydrothermal R&D has been guided by quantified cost-of-power objectives.

The federal role is now changing again to emphasize applications research and development activities, while continuing long-term, high-risk research. Thus, a balance in availability of technologies is sought among near-, mid-, and long-term objectives. The Office of Conservation and Renewable Energy has been reorganized to create an end-use oriented structure to address the usefulness of its program to:

- develop additional energy supplies
- reduce energy demand
- reduce institutional barriers that constrain renewable technologies
- accelerate market penetration by new technologies.

Throughout the life of the federal program, R&D of advanced systems for geopressured, hot dry rock, and magma application has been solely a government function. This approach is in accordance with the mandate of the RD&D Act to determine and improve the scientific, engineering, and economic feasibility of using energy from all types of geothermal systems.

Importance of Government Role to Date

The importance of the federal program in U.S. geothermal development to date cannot be underestimated, and is inherent in the benefits itemized above. Specific examples can be offered.

A major example of the general application of previous research results is the industry-wide use of high-temperature materials and components developed with federal dollars. Even more important, in almost every instance of which the Geothermal Division is aware, industry has in turn spent its own development resources to further refine the research formulations.

Eight of 14 reservoirs explored under DOE's Industry-Coupled Drilling Program are in production, and each one is acknowledged to have undeveloped potential. 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 originated with DOE funds have since been expanded. Implementation of many of the recommendations of the DOE-funded Interagency Geothermal Streamlining Task Force have led to

remedial regulatory and administrative changes that greatly accelerate and reduce the costs of geothermal development.

In terms of site-specific effects of government research, the technology for economical use of supersaline fluids in flash plants, developed at the cooperative government/industry Geothermal Loop Experimental Facility, is used today in six plants at the Salton Sea 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 appropriate management of this field, another 1800 MWe may be developed. At Coso, which today hosts 240 MWe of geothermal power, the developer started with DOE-funded data and built a successful exploration effort.

At the relatively mature stage of geothermal development today, what is the rationale for continued federal power generation 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 answer appears to be that without continued federal geothermal involvement, achievement of the national goals for energy security and a mix of competitive energy supply options will be extended much further into the future insofar as the use of geothermal is concerned. This industry alone is not yet prepared to reach the full geothermal potential in a timely manner.

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. Specifically, our mission is to increase the geothermal reserve, reserve being defined as that portion of the

identified resource which can be extracted economically under present conditions.

Geothermal energy accounts for nearly 40 percent of our total resource base of nearly 4 million quads, or about 660,000 billion barrels of oil equivalent. Yet, the geothermal reserve is estimated to drop to only 4 percent of the total reserve of 6,400 quads. In fact, the current reserve includes only two categories of geothermal energy -- hydrothermal convection systems with temperatures of 150°C or above and low-temperature (>40°C) hydrothermal fluids for direct use applications. The reserve excludes conduction-dominated thermal regimes, geopressured, hot dry rock, and magma. Clearly, increasing the geothermal reserve is largely technology-dependent, although a healthy infrastructure and available transmission facilities must also be maintained.

Technology Development Needed for Power Generation/Energy Supply

Expansion by the geothermal industry both within and beyond the 17 currently producing reservoirs 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, technologies 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.

In addition, while operations at The Geysers steam field are, and always have been, an industry pursuit, there is an apparent government obligation to cost-share restoration of the productivity of the field for two reasons. First, The Geysers complex offers the first opportunity in this country to determine the needs for managing mature geothermal fields, and this is seen as equally an important function as supporting the technology needed to open new fields.

Second, the success of The Geysers, and now its decline, are so well known worldwide that maintaining confidence in this field is critical to confidence in all proven and yet-to-be-proven geothermal fields. The importance of The Geysers field is further demonstrated by the participation of both DOE and industry. In FY 1990, \$3.5 million in funds or in-kind contributions were invested by industry; DOE provided \$1.2 million. For FY 1991, industry has earmarked \$4.5 million and DOE has budgeted \$2.5 million for cost-shared research on The Geysers.

For expansion to new reservoirs, industry is seeking innovative methods to locate and characterize undiscovered hydrothermal reservoirs, particularly those with no significant surface manifestations of a subsurface heat source. Only one such area is in production today -- the "blind" Desert Peak reservoir in Nevada.

While drilling technology is an integral part of all stages of geothermal development -- exploration, reservoir development, production, and use -- the costs are still up to 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. In addition, such innovations would greatly improve the "dry hole" ratio 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 are needed to optimize the heat value of the resource and to offset large investments in finding and producing the resource. In addition, better modular technology than is available today will supply an enhanced means of testing new reservoirs, allowing early power

production and cost 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 for future development.

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 reservoir lifetime, flow impedance, water consumption rates, production fluid temperatures, and energy production on an extended basis.

Potential Needs in U.S. Geothermal Infrastructure

As noted above, the U.S. geothermal industry currently operates in a relatively friendly infrastructure in terms of official and public acceptance with, at present, only one major site-specific exception in Hawaii. 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. For example, the prime geothermal prospect areas in Oregon lie in highly scenic national forests. As geothermal development began to approach reality in this area, public concern and opposition mounted. The U.S. Forest Service has undertaken, apparently successfully, through comprehensive public information programs, to protect the multiple interests of the public, other forest users, and the geothermal community. Without this

effort, it was felt that geothermal development might not have been able to expand into the Pacific Northwest.

However, this situation appears to be one result of earlier DOE outreach efforts to inform Forest Service personnel on the importance and benefits of geothermal use and the potential for successful co-existence of geothermal development with competing interests in the forests. This effort led to expedited decisions on the lands to be leased for geothermal development and under what conditions. Land use concerns, environmental mandates, and policy decisions at the federal and state levels affecting geothermal development will continue to be monitored.

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 and by the geothermal power plants operating in Imperial Valley. And, Oxbow Geothermal found the resource at Dixie Valley, Nevada, sufficiently commercially attractive to build its own 220 mile line to a tie-in with existing lines. The key here, however, is a large, high quality resource; a lesser resource may never justify such expenditures, and some form of governmental support may be warranted at the utility, state, or regional level.

Some change in the marketing of geothermal power appears to be on the horizon through load following operations. While hot geothermal wells cannot be shut-in for extended periods without considerable risk of damage, the industry is finding that it has the capability to reduce production over certain periods. One utility at The Geysers has indicated that it has been practicing load following for over a year. Whether the industry's desire to change from

straight baseload operations will call for any DOE involvement is unclear at this time.

Obstacles to Geothermal Development

During the National Energy Strategy process, geothermal representatives noted that a concerted R&D effort by DOE is needed to solve technology problems existing in increasing geothermal use. These problems are described in general above. In addition, these representatives identified the following obstacles to geothermal development although there is no apparent consensus that these problems exist industry-wide:

- Energy prices have dropped so low that there are no incentives to make the large investments required to find and develop new resources. The effects of subsequent actions in the Middle East on oil prices are not yet clear.
- 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.
- Lack of incentives for development of resources that are environmentally advantageous; present energy policies do not reflect the external costs of energy transformation and use, or consider total fuel-cycle costs.
- Denial of free access to transmission lines and wheeling rights by major utilities.
- Failure to plan cooperatively for geothermal development -- e.g., through unitization.

- Relative lack of support of U.S. government in enhancing exports of geothermal products and services as compared with the programs of competitor countries.

Options for Removal or Alleviation of Obstacles

The reorganization of DOE's Office of Conservation and Renewable Energy referred to above 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, along with reducing institutional and economic barriers to allow 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 electric sector, including geothermal use for power generation.

While the National Energy Strategy (NES) is not yet complete, the reorganized renewable energy program is already focusing on the enunciated obstacles to geothermal development. For example, for the first time, an effort is being made to integrate energy and environmental policies. In implementing related portions of the NES as it is finalized, the program foresees a new working relationship with the Environmental Protection Agency, particularly in the arena of pollution prevention through policies that will encourage greater use of renewable energy. Consideration is being given to mechanisms for performing complete fuel 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 impact of the new Clear Air Act amendments are being analyzed to determine their potential effect on geothermal energy in the U.S. power market. The impact is 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 have been enacted in November 1990 which remove the cap on plant size for all energy technologies covered by the Act.

New 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 add 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 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 our R&D program, as well as to 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 a critical factor in 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 percent of the total cost. Just recently, the GDO completed improvements to a rotary head seal and, during FY 1990, transferred the technology to industry for production. In addition, both organizations frequently provide test sites for investigating new technology and methods. For example, GTO members provided the premises for a cooperative research effort to monitor data from an advanced seismic array at The Geysers.

Geothermal Division Multiyear Objectives

The major objectives of the Geothermal Division for the FY 1992-1996 planning period are as follows:

- Near-Term
Enhance geothermal reservoir management technology and upgrade drilling and conversion technologies to expand the use of known hydrothermal reserves.

- Mid-Term

Improve reservoir, drilling, and conversion technologies to reduce hydrothermal costs to 3-7¢/kWh and discover new reserves.

- Long-Term

Provide industry with information on geopressured and hot dry rock technology adequate for informed decision-making.

The hydrothermal mid-term technology cost objective 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 percent decrease in well drilling costs can be determined. Sensitivity analyses can be conducted to determine which technology improvements will have the greatest overall impact. Models for geopressured and hot dry rock resources are under development.

NES Projections for Geothermal Power on Line

If the primary research goal to reduce the cost of hydrothermal power to 3-7¢/kWh is reached in the late 1990's, the economically available hydrothermal supply will increase to as much as 25,000 MWe by the year 2030. This goal will be accomplished with an R&D core program focused on the major cost-sensitive technology areas: reservoir engineering and management, drilling, and energy conversion. The core program augmented by two new initiatives -- one in exploration to expand the economic resource base and one in advanced drilling systems to reduce the cost of tapping these resources -- possesses the potential to expand geothermal power supplies to 45,000 MWe by 2030. These estimates are

derived from the NES modeling of potential market penetration and do not reflect ultimate geothermal production.

THE STRATEGY

Primary Research Activities by Year and Expected Incremental Products

The primary research activities for FY 1992 are shown in Table 1 for Hydrothermal Systems, Geopressured Research, and Advanced Systems, along with the expected incremental products of the research. This information for the outyears FY 1993-1996 is shown in Table 2.

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 (Revised). As that document 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 reduced 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).

The basis for the Level I hydrothermal objective is that the technology is not available for economic exploitation of the large bulk of the identified hydrothermal reservoirs in this country where the temperature is below the economic range of flash plants. Some very small binary units -- most around 2

Table 1

PRIMARY RESEARCH ACTIVITIES OF THE
GEOTHERMAL DIVISION FOR FY 1992
AND EXPECTED RESULTS

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
HYDROTHERMAL SYSTEMS		
Reservoir Technology	<p>Work with utilities and field operators at The Geysers to test and evaluate water injection strategies for maximum energy recovery.</p> <p>Field test surface-based high frequency seismic monitors for accurate measurement of fracture planes in The Geysers.</p> <p>Determine basic thermodynamics of hydrogen chloride gas in steam.</p> <p>Investigate the mechanism of water adsorption on fractured rock surfaces.</p> <p>Conduct joint ventures with industry to select the most innovative exploration methods and implement the best exploration techniques.</p>	<p>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, extend the reservoir lifetime by an order of magnitude.</p> <p>Ability to locate major producing zones and reduce the risk and cost associated with drilling production wells.</p> <p>Ability to control HCl corrosion in valves and surface pipes at The Geysers and other geothermal fields.</p> <p>Ability to determine water saturation in reservoir fractures and the longevity of production.</p> <p>Characterization of the large number of undiscovered geothermal resources in the U.S. Build an inventory of sites for future industry development.</p>

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PRIMARY RESEARCH ACTIVITIES OF THE
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AND EXPECTED RESULTS

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
Reservoir Technology (Continued)	<p>Actively involve industry in technology development to produce the new generation of instruments necessary to discover hidden geothermal systems.</p> <p>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.</p>	<p>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.</p> <p>Significantly increased economic value of the reservoir through the ability to operate in a peaking mode.</p>
Hard Rock Penetration	<p>Transfer to industry technology for emplacing encapsulated cements and bridging materials to control lost circulation; acquire data to aid the design of an expert system for lost circulation operations; begin fabricating prototype and developing software; field test the drillable straddle packer and velocity-level flow tools.</p> <p>Conduct field tests to compare production in large and small wellbores; build and test PDC coring bits; define needs for high-temperature slimhole drilling fluids.</p>	<p>Achieve 80 percent reduction in downtime due to lost circulation episodes which constitute 20 percent of well costs.</p> <p>Development of relatively inexpensive coring holes which can assess reservoir productive capacity at half the cost of conventional wells.</p>

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AND EXPECTED RESULTS

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
Hard Rock Penetration (Continued)	Field test with industry advanced modular downhole memory tools and develop borehole instruments with industry.	Adaptation of several key geophysical measurement techniques used for oil exploration to geothermal applications; 15 percent reduction in number of exploratory wells needed.
	Design drilling hardware for emplacement of vertical heat exchangers for geothermal heat pumps.	Expand cost-effective market penetration of geothermal heat pumps in higher density urban markets.
	Place new rotary head seal into commercial application through the Geothermal Drilling Organization.	Increase reliability and reduce costs of rotary head seals.
	Begin new GDO projects on near-term technology improvements that are selected and cost-shared by industry on a 50-50 basis.	Support of technology advancement and technology transfer.
Conversion Technology	Conduct condensation experiments on supersaturated expansions in binary turbines; select prototype advanced head injection system and begin HCRF modification design; incorporate advances into concepts for commercial wellhead generator system.	Potential 25-30 percent efficiency improvement in binary cycle systems.

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AND EXPECTED RESULTS

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
Conversion Technology (Continued)	<p>Document field tests of heat-resistant, lightweight cements and complete technology transfer.</p> <p>Measure the resistance of ceramic-based cements to scaling and corrosion under simulated conditions at 300°C.</p> <p>Perform laboratory evaluations of chemical systems that will bond elastomers to steel.</p> <p>Measure durability, pumpability, and density of materials that function as drilling fluids, but set up like cements when they enter fractures in rock formations.</p> <p>Extend existing brine chemistry model to include new experimental data to improve the capability to predict scaling tendency of geothermal brines.</p> <p>Continue development of a system to detoxify geothermal wastes with bacteria; design continuous process prototype for commercial geothermal site.</p>	<p>Development of materials which can be used in the completion of geothermal wells.</p> <p>Extension of casing life by 10 years, costing one-third as much as metal alloys.</p> <p>Reduce cost of wells by the availability of advanced drilling tools.</p> <p>In situ lost circulation materials.</p> <p>Assistance to industry in reducing plant maintenance costs by 10 percent.</p> <p>Potential for over 80 percent reduction in waste disposal costs.</p>

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PRIMARY RESEARCH ACTIVITIES OF THE
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AND EXPECTED RESULTS

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
GEOPRESSURED RESEARCH		
Well Operations	Shut-in Pleasant Bayou well for pressure buildup.	Acquisition of pressure buildup data for validation of reservoir model.
	Plug and abandon Pleasant Bayou well.	
	Construct production facilities at Hulin well site.	Prepare well site for flow testing.
Geosciences and Engineering Support	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 research activities for Hulin well.	Refinement of Hulin site geology.
	Continue monitoring of surface and ground water, microseismicity, and subsidence at well sites.	Verify absence of environmental effects from geopressured well testing activities.
	Interpret and analyze well logs for programmatic activities.	Support of Hulin well testing activities.
	Monitor and coordinate program well site activities and related university research.	Issuance of monthly management reports and an integrated research program.

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AND EXPECTED RESULTS

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
ADVANCED SYSTEMS - HOT DRY ROCK		
Phase II Energy Extraction System	Conduct Long-Term Flow Test (LTFT). Extend cooperative testing at the Fenton Hill site. Operate reservoir under alternative conditions. Establish baseline of long-term reservoir performance.	Provide estimate of thermal lifetime and determination of reservoir productivity. Confirmation of findings from initial reservoir analyses. Definition of governing criteria for optimum productivity. Tool for industry assessment of potential applications of hot dry rock technology.
Phase II Ancillary Activities	Secure and adjust water supplies to accommodate LTFT. Collect and evaluate environmental monitoring data.	Ensure sufficient water needed for the LTFT. Verification of the absence of effects from sustained reservoir operations.
Test Site Support	Continue site maintenance activities and conduct safety and emergency reviews.	Assure safe and efficient operation of test site.
Tools and Instrumentation	Improve logging tools for use in HDR environment.	More efficient logging and analysis of HDR wells and reservoirs.

Table 1

**PRIMARY RESEARCH ACTIVITIES OF THE
GEOHERMAL DIVISION FOR FY 1992
AND EXPECTED RESULTS**

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
Reservoir Engineering	Verify behavior of diagnostic tracers. Continue microseismic monitoring and improve 3-D models of reservoir performance using seismicity and tracer data. Extend modeling analysis to multi-well, multi-reservoir configurations that simulate full-scale commercial systems. Conduct fluid mineralization studies.	Demonstrate that tracers can predict reservoir thermal lifetime for 10-20 years into the future. Determine reservoir expansion parameters and improve accuracy of reservoir mapping technology for easier development of new HDR systems. Enhance models of efficient reservoir operational modes and improve accuracy of production and cost forecasting. Determine environmental characteristics of circulated water and predict changes in flow impedance.
Technology Applications	Conduct technology transfer activities in cooperation with the utility sector.	Dissemination of HDR technology to the private sector.

Table 2

PRIMARY RESEARCH ACTIVITIES OF THE
GEOHERMAL DIVISION FOR OUTYEARS 1993-1996
AND EXPECTED RESULTS

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
HYDROTHERMAL SYSTEMS		
Reservoir Technology	<p>Investigate the development of integrated reservoir simulation that combines hydrology and geochemistry in a single computer model.</p> <p>Publish a collection of geothermal development case studies based on geothermal systems in the western U.S.</p>	<p>Ability to track the migration of injected geothermal fluids and to predict their thermal and chemical changes in both vapor- and liquid-dominated systems.</p> <p>Provide industry with the collected experiences of geothermal development in active, producing fields.</p>
Hard Rock Penetration	<p>Transfer radar fracture mapping tool to industry upon completion of cost-shared field tests; with industry support, begin adapting subsurface dual-well seismic technology to locate fractures.</p> <p>Develop fiber optic cables and sensors for high-temperature (above 300°C) logging.</p> <p>Field test porous packer and borehole televiewer loss-zone characterization techniques; initiate development and field test expert system for lost circulation control.</p>	<p>Reduction in dry hole ratio in fractured reservoirs by 20 percent.</p> <p>Reduction in the number of exploratory wells needed through advanced measurement techniques.</p> <p>Achieve 80 percent reduction in downtime due to lost circulation episodes which constitute 20 percent of well costs.</p>

Table 2

**PRIMARY RESEARCH ACTIVITIES OF THE
GEOTHERMAL DIVISION FOR OUTYEARS 1993-1996
AND EXPECTED RESULTS**

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
Hard Rock Penetration (Continued)	Develop surface technology for exploratory coring rigs, slimhole drilling fluids, and lost circulation materials; initiate development of measure-while-coring system; field test slimhole coring exploratory drilling system.	Development of relatively inexpensive coring holes which can assess reservoir productive capacity at half the cost of conventional wells.
Conversion Technology	Complete testing advanced heat rejection system. Complete testing supersaturated expansions in binary cycle turbines. Terminate Heat Cycle Research Task. Complete development of advanced elastomers and chemical coupling systems.	Reductions in consumptions water use in heat rejection. Potential 5-10 percent improvement in advanced binary plant performance. Available technology for designing binary power plants with gains in fluid effectiveness as large as 25 percent. Reductions in capital costs and costs of power for binary plants by as much as 11 percent and 18 percent, respectively. Improve economics and reduce environmental impacts by the availability of advanced drilling tools and safety-related devices.

Table 2

PRIMARY RESEARCH ACTIVITIES OF THE
GEOHERMAL DIVISION FOR OUTYEARS 1993-1996
AND EXPECTED RESULTS

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
Conversion Technology (Continued)	Complete the development of materials for the in situ conversion of drilling fluids into well cements.	Reduce well completion costs and extend well life.
	Complete development of advanced non-metallic well casing liners.	Reduce well costs and extend well life.
	Refine existing brine chemistry model to improve the capability to predict scaling tendency of geothermal brines and apply model to assist industry in solving on-site problems.	Assist industry in reducing plant maintenance costs by 10 percent.
	Continue development of a system to detoxify geothermal wastes with bacteria; scale-up bioreactor operations; examine process economics.	Potential for over 80 percent reduction in waste disposal costs.
GEOPRESSURED RESEARCH		
Well Operations	Flow test Hulin well, then plug and abandon well or transfer to industry.	Determination of reservoir characteristics.
Geosciences and Engineering Support	Measure and interpret aromatic hydrocarbons at Hulin.	Determination of the source and flow mechanism of aromatic hydrocarbons.

Table 2

PRIMARY RESEARCH ACTIVITIES OF THE
GEOTHERMAL DIVISION FOR OUTYEARS 1993-1996
AND EXPECTED RESULTS

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
Geosciences and Engineering Support (Continued)	Interpret Hulin flow test data.	Validation of reservoir model and determination of the reservoir's long-term production capability.
	Continue monitoring surface and ground water, microseismicity and subsidence.	Verify absence of environmental effects from geopressured well testing activities.
	Coordinate final research reports.	Publication of final research reports in peer-reviewed journals.
ADVANCED SYSTEMS - HOT DRY ROCK		
∞ Phase II Energy Extraction System	Complete Long-Term Flow Test.	Compile reliable record of HDR engineering, operational, and maintenance factors.
Phase II Ancillary Activities	Assure water supply.	Provide water needed for reservoir test.
	Environmental monitoring.	Confirm environmental characteristics of HDR.
Test Site Support	Site maintenance, and health and safety activities.	Assure safe and efficient operation of test site and provide data for the operation of commercial HDR sites.
Reservoir Engineering	Analyze LTFT data.	Determine long-term operating characteristics and validate commercial viability of HDR.

Table 2

PRIMARY RESEARCH ACTIVITIES OF THE
GEOHERMAL DIVISION FOR OUTYEARS 1993-1996
AND EXPECTED RESULTS

<u>PROGRAM ELEMENT</u>	<u>RESEARCH ACTIVITIES</u>	<u>EXPECTED RESULTS</u>
Technology Applications	Investigate zone isolation and impedance reduction technology.	Advanced techniques for reservoir enhancement and multi-reservoir facilities.
	Evaluate enhanced power production modes.	Verify alternative modes of economic reservoir production.
	Support commercialization activities by industry and the implementation of enhanced production technology.	Commercial use of hot dry rock technology.

MWe or less in capacity -- are operating successfully with low-temperature brines. However, in these cases, economics are dictated by size and very favorable site-specific conditions -- e.g., sufficient heat at very shallow depths, use of existing wells -- that are not generally available. While the success of these small plants is to be applauded, even a multiplicity of installations of this size will not permit geothermal energy to reach its full potential as a viable energy supply option. While industry will profitably use small capacity facilities as "ice breaker" plants at undeveloped reservoirs, and such units are very useful in filling small incremental power demand, more favorable economics for larger binary plants (e.g., 10-100 MWe) are the key to meaningful expansion in geothermal utilization. To achieve the cost goal, it will be necessary to bring about economies across the board -- from reservoir characterization to drilling and field development to the binary power cycle itself.

These economies are the focus of the Level II hydrothermal objectives established through the use of 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; they comprise the technical yardsticks by which progress can be measured.

Since 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 Tables 1 and 2 are

addressed, were set by Geothermal Division staff through consultation with DOE field R&D managers and industry specialists.

Industry is actively participating in the planning and implementation of the R&D program objectives. Industry's response to the results of objective achievement -- i.e., whether or not industry's development planning and activities extend to more difficult geothermal resources in the 1990s and beyond -- 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 of the 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. There is regular -- formal and informal, scheduled and unscheduled -- dialogue between the entities, and the Geothermal Division is kept abreast of interaction between industry and the environment in which its operates.

Regular interaction with state energy offices is maintained; frequent inquiries are directed to state regulatory agencies to ascertain their views on

geothermal industry compliance; 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 manpower pool for the geothermal industry. In addition, the Geothermal Division expects to participate in and actively support the public information and educational program of the Geothermal Resources Council.

Thus, little need is foreseen for future major intervention by DOE in the forces that shape the environment of geothermal development. That effort is primarily behind us, although it is recognized that all problems solved do not necessarily remain solved in the long run.

Indications of Progress

Due to the nature of geothermal operations -- and the variability of the resource -- progress is not measured in "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 subsurface geologic structures and the occurrences within them is an ongoing process, requiring years of field operating data to evaluate, verify, or modify characterizations drawn from earlier data. 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 in reductions in the cost of geothermal power as determined by the

IMGEO cost model. The actual cost benefits will accrue incrementally in subsequent years as industry adopts the new technology and gains operating experience with it.

Side or Spin-Off Benefits

As has been the case in previous experience, the oil and gas industry and others may be expected to benefit from certain advancements in reservoir technology and innovative drilling techniques developed through geothermal R&D. In addition, the high-temperature 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 wearability and longevity of materials.

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. Annual reevaluation is conducted to ensure that the milestones meet the latest program objectives and consider current budgetary constraints. The milestones for FY 1992 and the outyears FY 1993-1996 are shown in Table 3.

ASSUMPTIONS

Renewable energy technologies received a great deal of visibility and acceptance during the NES process. As a result, while the Department continues to analyze and evaluate the many other energy options proposed, Secretary Watkins designated renewable energy for "fast track" consideration among the policy choices available. This action, combined with greater budgetary support, indicates an enhanced emphasis on renewable energy programs. More recent

Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
HYDROTHERMAL SYSTEMS								
Reservoir Technology								
Conduct joint, cost-shared testing of new, innovative exploration methods.			●					
Include geochemistry in current reservoir simulation programs to better predict reservoir lifetime.				●				
Field test second generation of chemical tracers for determining flow path in geothermal reservoirs.					●			
Develop integrated, comprehensive geologic model of geothermal fields.						●		
Demonstrate full-field reservoir strategy for location and flow rate control of injection wells.							●	

Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Hard Rock Penetration								
Conduct field test of velocity-level flow transducer.	●							
Initiate collection of cost data for conventional exploration.	●							
Initiate development of downhole injector and SEA-MIST hardware.		●						
Complete identification of needs for high-temperature slimhole drilling fluids.		●						
Initiate field test of drillable straddle packer.			●					
Initiate field test of high-temperature lost circulation materials.			●					

Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Hard Rock Penetration (Continued)								
Initiate development of borehole instruments with industry.			●					
Conduct field test of high-temperature positive displacement motor.			●					
Complete development of porous packer.				●				
Initiate field test to compare production in large and small wellbores.				●				
Build PDC coring bits and initiate testing.				●				
Initiate design of drilling hardware for cost effective emplacement of vertical heat exchangers for geothermal-based heat pumps.				●				

Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Hard Rock Penetration (Continued)								
Initiate field test of modular electronic tools in geothermal wells.				●				
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.					●			
Initiate fabrication of drilling hardware for heat pump installation.					●			

Table 3

GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Hard Rock Penetration (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.						●		
Begin development of measure- while-coring system.						●		

Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Hard Rock Penetration (Continued)								
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.								●
Conversion Technology - Heat Cycle Research								
Complete investigation of condensation behavior of isobutane in simulated supersaturated turbine expansions.	●							

Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Conversion Technology - Heat Cycle Research (Continued) Complete supercritical cycle investigations and report on imposed binary cycle designs producing 20% performance improvements. Complete advanced heat rejection system scoping studies and select one for field investigations. Complete investigations of condensation behavior of supersaturated turbine expansions. Complete INEL feasibility study of incorporating advanced plant concepts into a standardized modular binary plant design.				●				
				●				
					●			
					●			

Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Conversion Technology - Heat Cycle Research (Continued)								
Complete investigations of advanced heat rejection systems.						●		
Close out operation of HCRF.						●		
Solicit industrial interest in cost-shared development of modular binary plant which incorporates improved binary cycle design.						●		
Conversion Technology - Materials Development								
Complete downhole testing of CO ₂ -resistant cement samples.	●							
Complete technology transfer of drill pipe protectors.			●					
Complete cementing activities in demonstration well.				●				

Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Conversion Technology - Materials Development (Continued)								
Complete development of chemical coupling system.				●				
Technical feasibility of cementitious muds established in laboratory tests.					●			
Complete development of elastomeric liners for well casing.					●			
Initiate technology transfer of high-temperature cements to industry.					●			
Complete development of advanced elastomers.					●			
Complete pilot-scale flow tests of cementitious muds.						●		

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Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Conversion Technology - Materials Development (Continued)								
Complete field demonstration of elastomeric liners.						●		
Complete technical feasibility study for placement of ceramic liners.						●		
Complete technology transfer of Moineau stators and blow- out preventors.							●	
Complete well demonstration of cementitious muds and transfer technology to industry.							●	
Complete downhole testing of prototype ceramic-lined sections.							●	
Conduct field demonstration of ceramic-lined casing.							●	

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Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Conversion Technology - Brine Chemistry								
Initiate materials study for bioreactor design.	●							
Initiate testing and application of brine model to field problems.	●							
Initiate preparation of document on high-temperature pH-bioprocessors for peer review.		●						
Issue report on brine kinetics.			●					
Initiate study of mineral recovery from geothermal residual waste.			●					
Complete preliminary model of H ₂ S-H ₂ O solubility in brines.				●				
Initiate construction of upscale bioreactor.					●			

Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Conversion Technology - Brine Chemistry (Continued)								
Complete study of mineral recovery from geothermal residual waste.					●			
Complete testing and application of brine model to field problems.					●			
Complete update of brine model user's manual.					●			
Complete preliminary model of aluminum speciation as a function of pH.					●			
Complete construction of upscale bioreactor.						●		
Initiate process development/pilot plant design using best laboratory results.						●		

Table 3

GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Conversion Technology - Brine Chemistry (Continued)								
Complete process development/pilot plant design.						●		
Initiate third economic study.						●		
Complete preliminary model of bisulfate species in high-temperature program.						●		
Initiate literature search for metal sulfide data.							●	
Initiate comparative brine kinetic studies and modifications.							●	
Complete identification of best candidates for further bioreactor scale-up.								●

Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
Long Valley Experimental Well								
Note: Pending a decision on FY 1992 and outyear budgets, no plans can be made for the Long Valley Experimental well.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GEOPRESSURED RESEARCH								
Initiate facility design at Hulin well site.	●							
Initiate pressure buildup test of Pleasant Bayou reservoir.	●							
Complete construction of production facilities at Hulin well site.				●				
Complete pressure buildup test of the Pleasant Bayou reservoir.				●				

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Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
GEOPRESSURED RESEARCH (Continued)								
Complete data analysis and model development of the Pleasant Bayou reservoir.					●			
Complete scientific tests at Pleasant Bayou.					●			
48 Conduct flow test of Hulin reservoir.					●			
Plug and abandon Hulin well or transfer well to industry.					●			
Complete all research reports except environmental monitoring.						●		
Complete final report on environmental monitoring.							●	
ADVANCED SYSTEMS - HOT DRY ROCK								
Begin Long-Term Flow Test (LTFT).	●							

Table 3

**GEOHERMAL PROGRAM MANAGEMENT MILESTONES
FY 1992 - FY 1996**

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
ADVANCED SYSTEMS - HOT DRY ROCK - (Continued)								
Commence in-depth analysis of LTFT data.		●						
Complete study of Phase II reservoir fluid mineralization.				●				
Demonstrate reliability of temperature-sensitive tracers.				●				
Begin evaluation of enhanced power production modes (multi-well, cyclic).					●			
Complete LTFT.						●		
Issue preliminary report on LTFT results.						●		
Decommission Fenton Hill site.						●		

Table 3

GEOHERMAL PROGRAM MANAGEMENT MILESTONES
 FY 1992 - FY 1996

MILESTONE	-----FY 1992-----				FY 1993	FY 1994	FY 1995	FY 1996
	1	2	3	4				
ADVANCED SYSTEMS - HOT DRY ROCK - (Continued) Document economics of enhanced production modes. Initiate investigation of zone isolation and impedance reduction technology. Issue final reports on LTFT. Complete impedance reduction technology study.							●	
							●	
							●	
								●

threats to imported oil supplies appear to have further solidified public support for more expeditious development of renewable energy technologies.

At the current stage in the planning process, three scenarios have been proposed for the Geothermal Program (Table 4). The base case scenario entails activities to achieve the current research objectives and assumes a 5-year budget of \$113 million and Division staff of 11-12 full-time equivalents (FTE) for FY 1992-1996. To achieve these objectives sooner, a 5-year budget of \$274 million is assumed. Under a more accelerated scenario in which advanced geothermal systems are developed, a 5-year budget of \$474 million and Geothermal Division staff of 12-14 FTE are assumed.

Table 4
GEOHERMAL R&D PROGRAM
5-YEAR BUDGET SCENARIOS

(in Millions of Dollars)

	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	TOTAL
Base Case	\$ 21	\$ 22	\$ 22	\$ 23	\$ 25	\$ 113
Accelerated Case	\$ 49	\$ 70	\$ 105	\$ 119	\$ 131	\$ 474

UNCERTAINTIES

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.

Another significant source of uncertainty in the R&D planning process is the proclivity of congressional budget committees to respond to constituent pressure by mandating specific R&D activities that were not included in the original budget request. In some cases, additional funds are appropriated to support the add-on activities. This course, in most cases, does not necessitate a major reorganization of the plan for the funding year. However, in other instances, the research is mandated, but no additional funding is provided. In these cases, the program is left to "swallow" the added cost by deducting the dollars from the budgets of planned activities. This type of mandate can create havoc in the year-by-year R&D planning process, and greatly reduces Geothermal Division control of it.

MANAGEMENT DESIGN

DOE Headquarters

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 Director implements energy policy at the program level and allocates the necessary technical and budgetary resources for program activities.

Operations Offices

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.

Contractors

Actual implementation of the geothermal program research is performed by contractors, including the national laboratories, universities, and industry. The participating contractors are responsible for the conduct and day-to-day management of the activities and are directly responsible for ultimately meeting the technical goals of the program.

Substantial contractor investment in human, technological, and analytical resources, as well as for laboratory equipment and facilities, has been instrumental in establishing centers of excellence for geothermal research. These geothermal centers of excellence include Sandia National Laboratories, Lawrence Berkeley Laboratory, the University of Utah Research Institute, Stanford University, and Brookhaven National Laboratory.

PRINCIPAL FEATURES FOR THE UPCOMING YEAR

Hydrothermal Systems

Reservoir Technology - Development of integrated, comprehensive geologic models of geothermal fields will be continued to improve the effectiveness of energy recovery along with sophisticated well test, heat recovery, geochemical, and material/energy balance models for geothermal systems. Field testing and data analysis will be continued in a multiyear effort to verify the use of tracer techniques to track the migration of injected fluids. Rock-water interaction studies will be completed and validated. Improvements will continue to be sought in the analytical techniques for interpreting heat transfer, fluid transport, and chemical interaction data sets from active geothermal systems. Development of surface and borehole techniques to locate fracture zones and permeable formations in geothermal reservoirs and refinement of geophysical equipment and methods of interpretation will continue. Depending on funding,

a new initiative will be undertaken to cost-share development and testing of innovative methods for advanced geothermal exploration. The GTO and DOE will continue cooperatively funded research related to geothermal reservoirs and reservoir development.

Hard Rock Penetration - In its ongoing efforts to extend the economics and efficiency of drilling technology currently used in the geothermal industry, the FY 1992 activities of this task will focus largely on solutions to the problems created by the loss of drilling fluid from the system. Episodes of this occurrence are frequent in fractured reservoirs and represent the largest single cost in geothermal drilling. In addition to continuing research in and testing of lost circulation materials, FY 1992 activities will include field tests of:

- A drillable straddle packer, a tool that employs two inflatable packer elements that straddle the lost circulation zone and diverts cement into the zone, rather than allowing it to fall to the bottom of the hole. If tests are successful, this tool would reduce both the volume of cement that must be pumped downhole and the volume of hardened cement that must be drilled through to reach a new rock formation.
- A velocity level flow transducer for measuring drilling fluid flow rates in the field. In this concept, the outflow rate would be measured by detecting both the fluid level and the velocity in the inclined return line and combining the data to indicate flow rates.

In addition, development of a porous packer will be completed. This tool is a wireline-deployed packer unit that inflates to seal the loss zone in order to prevent wellbore fluid from entering the zone.

Two new activities will be initiated -- development of a downhole injector for lost circulation materials and the SEA-Membrane Instrumentation and Sampling Technique (SEA-MIST) hardware. The downhole injector concept is a potential alternative technique for emplacing cementitious mud downhole, a material that appears promising for lost circulation control, but which is still under study. The practicability of the injector concept will depend on the type of tubing or hose required and its cost.

The SEA-MIST concept, patented for other applications, would use a fabric tube that is inverted by internal pressure during emplacement to eliminate the need for sliding contact between the fabric and wellbore wall. The tube would be fitted with transducers for loss zone diagnostics and/or filled with setting fluid for lost circulation control.

Conversion - FY 1992 will see the completion of several long-term tasks of the Heat Cycle project. The resources available, primarily the Heat Cycle Research Facility and access to the Heat Transfer Research, Inc. (HTRI) "state-of-the-technology" heat exchanger codes, will be used to complete the validation of the assumptions/criteria necessary to achieve the projected 20 percent improvement in binary cycle performance. These performance improvements are projected to reduce the cost of power by 10 percent to 12 percent. The Heat Cycle Research Facility will also be utilized in the investigation of the condensation behavior of the supersaturated turbine expansions. If it can be demonstrated that when these expansions are used, condensate droplets do not form as the working fluid is expanded through the two-phase region, and there is minimal impact on turbine performance, an additional 8 percent to 10 percent performance improvement can be realized. This will correspond to an additional 3 percent to 8 percent reduction in the cost of power.

In materials development, technology transfer will be completed on CO₂-resistant lightweight cements with the cementing of a demonstration well as a cost-shared effort with industry. R&D efforts on advanced high-temperature elastomers for use in downhole drill motors, high temperature chemical coupling systems, and the mitigation of corrosion at The Geysers will be continued. Work will commence on the in-situ conversion of drilling muds into well cements and metallic or ceramic liners for well casing. In-situ conversion would simplify well completion procedures and extend well life; the metallic or ceramic liners would provide a lower cost alternative to high alloy steels currently in use to ameliorate the affects of corrosion.

The high-temperature elastomer development is also a cost-shared activity, and contingent on FY 1991 research results, a full-scale Moineau stator incorporating this material will be fabricated and laboratory tested. The most promising chemical coupling system for handling advanced elastomers to metals will be identified, and a cost-shared program with tool manufacturers (e.g., rotating head seals) will be arranged to build and field test full-size units.

The advanced brine chemistry activities for FY 1992 are divided into two categories: chemical models for optimizing geothermal power production and waste treatment biotechnology. In the former effort, computer models are being constructed which can evaluate the energy contents and the likelihood of scale formation of geothermal brines with their associated gas phases under a wide variety of operating conditions (e.g., species, temperatures, pressure). The present model has a temperature range of 0°-250°C and can predict calcium carbonate, calcium sulfate, and amorphous silica scale formation as a function of brine composition and partial pressure of CO₂. It can also predict the presence of other less common scales, such as sodium chloride. FY 1992

activities will be directed toward including new experimental data, such as aluminum and bisulfates, in the model to improve its capability to predict the scaling tendency of geothermal brines.

Some geothermal brines -- most notably those of the Salton Sea area in California -- contain naturally-occurring metals which in sufficient concentration are considered toxic and, under some conditions, may be regulated as hazardous wastes. Since the volumes of wastes are large and the metal content so relatively low, the use of conventional metal removal systems to reduce the toxicity would be prohibitively costly. Thus, while the technical feasibility of biochemical processes to reduce the metal content has been demonstrated, work aimed at optimization and scaling-up of the detoxification processes continues. The major activity for FY 1992 is the design of a continuous process prototype for a commercial geothermal plant site, based on the results of bench-scale experiments.

Geopressured Research

After 15 years of geopressured R&D, this program element is in the initial stages of transitioning to the commercial utilization of this undeveloped resource. Currently, three wells remain in the R&D effort. The Gladys McCall in Louisiana was shut-in in 1987, but is providing valuable information on pressure build-up to validate the McCall geopressured reservoir model. Flow tests of the Pleasant Bayou well are continuing subsequent to a 9-month test of a small hybrid power plant at the Pleasant Bayou well site in Texas. Both of these wells were designed and drilled specifically for geopressured brine production. The deeper Hulin well in Louisiana, an abandoned natural gas well contributed to the DOE program by industry, has been cleaned out, short-term flow tested, and is available for longer term testing.

In FY 1992, a pressure build-up test of the Pleasant Bayou will begin, and the data gathered will be used to confirm postulated reservoir drive mechanisms and to validate the reservoir model. The Hulin well production facilities will be constructed in preparation for the flow testing planned for the following year. The Geoscience and Engineering Support arm of the geopressured R&D, which was established to evaluate well operation data and to examine factors which affect geopressured production, will analyze and report the data gathered at both the Pleasant Bayou and Hulin wells. Environmental monitoring at the sites will continue to determine any effects related to subsidence, microseismicity, and water quality resulting from the well operations. This is an important activity for determining the acceptability of long-term brine production and injection.

Recent data from the two design wells and the information to be developed in FY 1992 will make it possible to complete the development of the McCall and Pleasant Bayou reservoir performance models. This should facilitate a more quantitative and accurate extrapolation of the test data to other reservoirs in the Gulf Coast area, thereby fostering realistic near-term resource utilization projections.

Advanced Systems

Hot Dry Rock - The major remaining activity of the hot dry rock project at the Fenton Hill, New Mexico, Phase II reservoir is the Long-Term Flow Test. Present plans are to begin the Long-Term Flow Test (LTFT) in FY 1992 providing adequate funding is available. The LTFT will be used to evaluate reservoir lifetime, flow impedance, water consumption rates, production fluid temperatures, and energy production on an extended basis. Long-term operational and maintenance conditions will be established, environmental effects will be

thoroughly assessed, and predictive models will be tested, adjusted and confirmed. Reactive tracers will be used to predict the ultimate useful lifetime of the reservoir on the basis of one to two years worth of data.

Upon completion of the LTFT, much of the data needed to validate the commercial viability of HDR should be in hand. Analysis and understanding of this information will provide the basis for future decisions regarding the exploitation of HDR resources at other locations throughout the world.

Magma - Due to funding constraints, research and development activities have been deferred on magma resources. The Long Valley, California well, which was originally designed to investigate the engineering and economic feasibility of utilizing molten or partially molten magma, will be devoted to basic science experiments and the evaluation of deep hydrothermal resources (if funded).

APPENDIX A: PLANS FOR CONSOLIDATION OF RESEARCH ACTIVITIES

In accordance with guidance issued by the Office of the Assistant Secretary for Conservation and Renewable Energy, the Geothermal Division is consolidating its various research activities under the management of one of the designated core National Laboratories. The impetus for this action is to improve the cost-effectiveness, management control, and administration of appropriated research funds. By reducing overhead costs and minimizing the duplication of resource expenditures for facilities and infrastructure at laboratories and Operations Offices, it is anticipated that more significant research results can be accomplished with the same funding. In addition, with research funds directed to a core group of research facilities, the resulting accumulation of human, technological, and analytical resources will provide the basis for the development of centers of excellence and position the research program to support the increase in growth expected during this and upcoming years.

The streamlining process, which is scheduled to get underway during FY 1991, will be accomplished over a period of 12 to 18 months. It is recognized that the transition from the use of numerous research organizations to the use of core laboratories will proceed at varying rates due to the impact that program consolidation will have on current and near-term project completion and the uniqueness of the specific program offices. Based on an assessment of such factors as the corporate mission of each organization currently being utilized for geothermal research activities, its capabilities with respect to the mid-to-long term research needs of the Geothermal Division, the investments that have been made in facilities, infrastructure, and equipment in support of the research activities, and the development and maintenance of significant human

and physical resources, the Geothermal Division will utilize Sandia National Laboratories as the primary core laboratory responsible for managing its future research activities.

The Geothermal Division intends to accomplish the objectives of the consolidation strategy before the end of FY 1993. The geothermal research being conducted at Lawrence Livermore National Laboratory and Oak Ridge National Laboratory will be essentially completed in FY 1992. During FY 1992, the management of materials research and biotechnology activities being conducted by researchers at Brookhaven National Laboratory will be transferred to Sandia National Laboratories, as will the geological and geophysical studies being conducted by the Lawrence Berkeley Laboratory. The geothermal activities currently being pursued by Los Alamos National Laboratory, predominantly hot dry rock research, and the various efforts in geopressured-geothermal energy, reservoir technology, and heat cycle research being conducted at Idaho National Engineering Laboratory will be integrated with the other geothermal activities at Sandia during FY 1993. By the end of FY 1993, the transition to the core National Laboratory strategy should be completed and the benefits of the streamlining approach should be achieved.