GEOHERMAL ENERGY R&D PROGRAM

SUMMARY

GEOHERMAL TECHNOLOGY DIVISION

**U.S. Department of Energy
Office of Renewable Energy Technologies**

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INTRODUCTION

Technical Description

Geothermal energy -- the heat of the earth -- is one of the cleanest, safest, and most reliable energy sources available. It is also a very large resource as can be seen in Exhibit 1. The resource is already making a significant contribution to the nation's energy needs -- both as heat and electricity -- and its future is even more promising.

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

It can be seen in Exhibit 2 that there are four types of geothermal energy which vary in character according to the form in which they occur. These differences necessitate the variations in production technologies described in Exhibit 1, and they also dictate the uses to which geothermal energy can be put economically. All forms of the resource are potentially capable of electric power generation if sufficient heat at a high enough temperature can be obtained for economic operation. However, at the current state-of-the-art, the power conversion technologies employed vary according to the temperature range of the resource. The heat of the resources that are not commercially exploitable for this purpose -- those with temperatures below approximately 300°F -- can be used effectively for space heating and cooling, commercial greenhouses and fish hatcheries, and industrial processes.

EXHIBIT 2

CHARACTERISTICS OF FOUR TYPES OF GEOTHERMAL RESOURCES AND METHODS OF ENERGY EXTRACTION

<u>Type of Reservoir</u>	<u>Form of Energy</u>	<u>Typical Depth (feet)</u>	<u>Temperature Range (°F)</u>	<u>Method of Energy Extraction</u>
Hydrothermal	Hot water and/or steam	Several hundred to 14,000	70-600	Conventional oil and gas rotary drilling equipment modified to withstand heat, hard rock, and corrosive geothermal environment
Geopressured	Moderately hot water under high pressure containing dissolved methane	10,000-16,000	212->400	High pressure oil and gas rotary drilling equipment and gas-liquid separators to extract methane from the produced brines
Hot Dry Rock	Relatively water-free hot rock	13,000-20,000	Highly variable	Modified conventional equipment, capable of high directional accuracy in very hard rock and creating artificial heat exchange fissures between pairs of well-bores
Magma	Molten or partially molten rock	10,000-33,000	1650-2200	Experimental drilling system, which will chill, solidify, and fracture magma through which a working fluid will be circulated for direct contact heat transfer (theoretical only at present)

Progress to Date

Power generation with naturally-occurring dry steam has been a commercial reality since the early 1900's and since 1960 in this country. Almost 2000 MWe of generation capacity is currently on line at The Geysers steam field in California. Thus, progress in geothermal utilization for power generation is measured most effectively in the status of power generation with the hot water resource, a primary goal of both industry and government since the early 1970's.

Beginning in the early 1980's, three 10 MWe demonstration plants in the Imperial Valley of California and a 3 MWe wellhead generator in Hawaii became the vanguard of "hot water" plants in this country. They were followed in 1985, despite many technological and institutional impediments, by the birth of a hot water power industry in the U.S. By the end of 1989, some 45 plants are expected to be in operation in six states with a total capacity of nearly 780 MWe.

The greatest hot water development remains centered in Imperial Valley where geothermal power plants co-exist harmoniously with the Valley's prolific agricultural industry. In the Salton Sea area alone, seven plants are in operation or under construction with a total capacity of over 200 MWe. To the north of the Valley in the Coso Hot Springs area, significant development is underway, with 230 MWe expected to be on line by the end of 1989. In Nevada, seven areas have been developed for a total of over 100 MWe, and two plants in Utah continue to perform with high reliability after several years of operation.

Where fluid temperatures are in excess of 400°F, "flash steam" power generation technology is employed. This term derives from the fact that the liquid resource is permitted to flash to steam as it reaches the surface under reduced pressure, and the steam is used to drive the turbine/generator. This is a relatively well developed technology and competes economically with power generated by

conventional means when a high quality resource is used.

At lower resource temperatures, binary cycle units are used to generate electricity. In this technology, the heat of the geothermal fluid is transferred to a secondary fluid which is vaporized and fed to the

turbine. A number of binary plants are in operation in the U.S. ranging in size from units of less than 1 MWe to 30 MWe. The larger capacities are made up of multiples of the small units - e.g., the 30 MWe binary plant comprises 26 1.2 MWe modules. Single binary units in the larger size range have not yet proven to be economic.

Geothermal resources with even lower temperatures have been used directly in district heating systems in this country since before the turn of the century. Although the initial costs of direct use systems may be quite high in some cases, considerable operating economies are generally achieved over the use of fossil fuels, 30 to 50 percent reductions being common for heating system customers. Currently, the total installed capacity of geothermal direct use projects in 44 states is 5.7 billion Btu/hour, or 1,700 thermal megawatts, with an annual energy use of nearly 17,000 billion Btu/year which displaces 4.5 million barrels of oil. Geothermally-heated commercial greenhouses and fish farms are growing rapidly in popularity in the western states; most of the 23 district heating systems in operation are expanding with new customers; and growth in groundwater heat pumps is expanding beyond all expectations. Vegetable processing remains the major industrial use of geothermal fluids today.

There is no commercial use to date of geopressed brines, hot dry rock, or magma to generate electricity or to provide the heat for direct applications. However, experiments to use both the thermal energy and methane in geopressed brines for power generation are to begin in 1989, and a small hot dry rock system has been successfully tested for this purpose in previous experiments.

Federal/Industry Cooperation

The driving force for geothermal development is industrial: the opportunity to profit by meeting local and national energy needs. The role of the government is to develop, assemble, and disseminate knowledge in cooperation with industry that will support increased geothermal energy production. The relationship of these roles is portrayed in Exhibit 3.

Extensive government/industry technical cooperation has existed since the inception of the federal geothermal research and development program in the early 1970's. The cooperative

mechanisms have ranged from "in-kind" contributions by industry -- e.g., availability of plant facilities to field test the products of Department of Energy research -- to the full financial and technical partnership in the Geothermal Loop Experimental Facility in the Salton Sea area. Cooperative R&D at this facility produced the crystallizer/clarifier technology which today permits the economic use of the chemically hostile, but attractively hot, brines of this reservoir, effectively opening its estimated 2000 MWe capacity to power generation.

More recently, the DOE Geothermal Program and industry have formalized their efforts to bring R&D

products to the marketplace at a faster pace than can be accomplished by federal R&D alone. In recognition that the market for geothermal services, systems, and components is too small to attract manufacturer participation, the Geothermal Drilling Organization and the Geothermal Technology Organization were formed to identify and fund projects that will have an immediate impact on industry's efficiency and costs. Each project is jointly funded by DOE and participating industry partners, with industry providing at least 50 percent of the total cost.

PROGRAM FOCUS

Objectives

Three levels of quantitative programmatic objectives are defined in the 1988-1992 Multiyear Plan of the DOE geothermal R&D program. Level I objectives are directed toward reducing the life-cycle costs of energy from geothermal power production projects (e.g., a binary power plant including its geothermal fluid supply), as shown in Exhibit 4.

The Level II objectives indicate how much improvement is likely to occur within major power project components as a result of federally-funded research. In this way, the degree to which improvements in each component -- e.g., fluid production -- will contribute to reductions in the total cost of a project can be determined. The Level III objectives prescribe the technical direction of each research project and provide the technical yardstick by which progress can be measured. For example, a need to improve the accuracy of siting geothermal wells will drive a research project to develop the technology needed to bring about such improvement.

Industry is actively participating in the planning and implementation of the program objectives. Its 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 1990's and beyond -- will be the final test of the Multiyear Plan.

Program Strategy

The Geothermal Program strategy is to select and implement both mid- and long-term research activities that will collectively, over time, permit the achievement of the program objectives. For example, the objective to reach a 25-35 percent total reduction in hydrothermal power generation costs reflects percentage reductions in each of the technologies employed in field development and power plant operation. However, some percentage reductions have more impact on total capital expenditures than others -- i.e., if the plant represents 60 percent of total costs and the field represents 40 percent, reductions in the plant will

EXHIBIT 4

LEVEL I OBJECTIVES FOR THE GEOTHERMAL PROGRAM

(Energy cost target range is expressed as levelized in 1986 constant dollars.)

- o Reduced the life-cycle cost of producing electricity with liquid-dominated, moderate-temperature (150-200°C) hydrothermal fluids by 25-35 percent by 1992. (This will place the life-cycle cost in a range of 3-10 c//kWh across 8 typical site cases.)
- o Improve geopressed technology to the point where electricity could be produced commercially from a substantial number of sites via wells of opportunity* in a cost range of 6-10 cents/kWh by 1995.
- o Improve hot dry rock technology to the point where electricity could be produced commercially from a substantial number of known hot dry rock sites in a cost range of 5-10 cents/kWh by 1995.
- o Advance magma technology to the point where electricity could be produced experimentally from one or more inferred magma resource sties in a cost range of 10-20 cents/kWh in the period of 1995-2000.

* Usually abandoned oil and gas wells.

have the greater impact. Taking the example a step further, since wells for injecting waste fluids account for only about 10 percent of total field costs, reductions in injection costs will have a lesser impact. However, reservoir confirmation and characterization are the areas of greatest financial risk in geothermal development, and injection is potentially the greatest environmental risk. Thus, the hydrothermal strategy is balanced to address costs directly through engineering improvements -- e.g., drilling, power cycle -- and indirectly through reduction of risk.

In the case of the advanced systems -- geopressured, hot dry rock, and magma -- such precise calculations of the impact of technology on costs are not yet possible with sufficient accuracy. Thus, the objectives guided the selection of program activities which will result in more reliable cost estimates for industry's use in longer-term decisions on the economics of expanding into markets for advanced systems.

Technology Transfer

Technology transfer is an inherent program activity. The Geothermal Program's investment in research activities is of little value unless the results are promptly transferred to the private and public sectors. Systematic means are in place to assure that geothermal developers, utilities, materials and components manufacturers, and other members of the geothermal industry readily acquire and implement the output of the Geothermal Program research effort.

Technology consumers are informed about and stimulated to adopt improved technology through: (1) general awareness programs, e.g., technical conferences and publications; (2) topical seminars about selected improvements in technology; (3) participation in or observation of field experiments with prototype technologies; and (4) technical assistance to new users of geothermal technologies. Whenever possible, and especially with respect to promoting general awareness of geothermal resources and technology, the Program works cooperatively with major private sector associations and established federal generic mechanisms for technology transfer.

CURRENT STATUS

While commercial geothermal development has occurred at the best understood and most favorable hydrothermal reservoirs, cost-effective technology is not yet available for industry to compete with conventional power generation using lower-temperature hydrothermal reservoirs or geopressured brines, hot dry rock, or magma. By examining the status of the state-of-the-art technologies for exploiting each of these resources, the research opportunities for the Program are identified.

Hydrothermal

While industry is using DOE-developed techniques for characterizing hydrothermal reservoirs, a major impediment in this component of a power generation project is the lack of reliable techniques for locating and mapping fractures in the subsurface rock. This significantly inhibits the ability to tap the areas of greatest fluid production without considerable costly drilling.

Effective techniques are also needed for identifying hydrothermal systems in regions of abundant precipitation which effectively masks the underlying heat with shallow cool groundwater. This is particularly important in the Cascades Range of the Pacific Northwest where the presence of a very large hydrothermal resource is suspected.

While injection of spent fluids is practiced by virtually all power plant operations, industry is still fearful of prematurely cooling the fluids in the production zone due to insufficient knowledge on where to site injection wells. Another problem is that removal of solids from the fluids prior to injection creates large amounts of sludges which require disposal as hazardous wastes. However, nearly all spent hydrothermal fluids must be injected back to the subsurface, both as a means of acceptable disposal and to prevent potential subsidence due to the withdrawal of fluids.

Other major deterrents to increased hydrothermal use remain. A principal one is that the capital costs for drilling production and injection wells are still a significant fraction of the costs of a geothermal project due to the heat, hard rock, and harsh fluid chemistry encountered. While large binary technology has been tested at a government/industry 45 MWe plant, the costs of this research project are

subeconomic for commercial application. The effects of the complex chemistry of hydrothermal fluids still takes too costly a toll on materials and equipment, and more cost-effective surface and downhole components are needed.

Geopressured

Long-term production tests have shown that the geopressured reservoir will produce more brine than conventional oil reservoir models would predict. While this result is desirable in one sense, it is due to unknown causes, and some potential causes may result in eventual reservoir failure. The reservoir drive mechanisms are not yet sufficiently understood, and more confidence is needed in techniques for locating and evaluating geopressured reservoirs.

Hot Dry Rock

The HDR resource is known to be very large, but the characteristics and limits of a resource reservoir need to be more clearly understood. In addition, more cost effective technology for creating heat exchange fractures and completing and logging HDR wells under high-temperature conditions is needed to develop more economical HDR systems.

Magma

The scientific feasibility of extracting energy from molten rock has been proven by experiments at a shallow lava lake in Hawaii. However, the scientific and engineering technology to locate subsurface magma chambers and to extract energy from them has yet to be developed and tested.

TECHNICAL PLAN

The research projects of the Geothermal Program are driven by specific technology needs to achieve reductions in the cost of geothermal power. Before a project is considered for funding, a preliminary quantitative estimate is made of its impact at three levels -- the overall cost of power projects (Level I objective), cost and/or performance of a major component (Level II), or a technology improvement (Level III).

Specific ongoing research can be summarized as follows:

Hydrothermal

Reservoir Technology

Reservoir definition R&D activities are being devoted to reservoir technology research areas that have a direct impact on the characterization and assessment of geothermal reservoirs. Typical activities include testing of geophysical methods for fracture mapping and developing and verifying models for fractured reservoirs. Two areas of research will be emphasized: two-phase flow testing and tidal/ barometric analyses.

The study of the Cascades region, performed through drilling of deep thermal gradient wells cost-shared with industry, will be completed with the publication of data gathered through well logs and cores and the results of the gradient tests. The purpose of this effort was to develop analytical and interpretative tools for locating and evaluating geothermal reservoirs within young volcanic regions.

The brine injection R&D is addressing techniques for predicting the chemical, thermal, and hydrologic effect of injection on the reservoir. The research activities directed to the preparation of these simulators include laboratory and field studies of tracer species needed to delineate fluid in reservoirs and development of surface geophysical techniques to monitor subsurface fluid movement. The emphasis of the research is on fractured and dual-permeability reservoirs.

Hard Rock Penetration

R&D efforts are directed at those aspects of

geothermal drilling that continue to elevate the cost of this project component. By industry consensus, loss of circulation in the drilling fluid system is the single most expensive consideration because of the time and expense incurred in recovery circulation. Thus, R&D is underway to design, field test, and evaluate materials and techniques that will prevent this phenomenon. Insulated drill pipe is in development for high-temperature drilling to reduce drill pipe wear and cost, and, in cooperation with industry, models to predict the drilling environment are being completed to optimize drilling hardware and design. The Geothermal Drilling Organization is in the process of commercializing several technologies including a high-temperature borehole televiewer.

Conversion Technology

The Program's heat cycle R&D is focused on improvement of the performance of binary cycle technology to levels approaching the practicable thermodynamic maximum. The purpose of this effort is to extend the economics of commercial geothermal power generation to the more abundant, lower quality reservoirs whose temperatures are not suitable for flash steam technology. In pursuit of performance improvement, supercritical cycle tests are being conducted at the Heat Cycle Research Facility at East Mesa, California, involving mixed working fluids, variations in condenser attitude, and supersaturated turbine expansion.

Two approaches are being pursued to define the expensive operating problems associated with brine chemistry. First, numerical modeling of complex brines will allow improved prediction of the thermodynamic conditions under which problems will occur in geothermal power plants from scale deposition, corrosion, and suspended solids. The second approach is to monitor brine flow lines to detect these problems before they result in plant failure.

Experiments are also underway on the use of two biochemical techniques to concentrate and remove toxic metals from wastes. One is the solubilization of metals by microorganisms which leach out the metals, and the other is concentration and removal of the metals by their sorption on cellular materials. Both processes are applicable in situations where

metals are present in large volumes of waste at concentrations unsuitable for conventional technology.

Research and development efforts are also aimed at further cost reductions in technologically and economically viable materials of construction for use by the geothermal industry and in extending their service life. Projects include:

- o Nonmetallic heat exchanger tubing
- o Chemical systems for lost-circulation control
- o Very high temperature well completion materials
- o Metallic liners for well casing.

Geopressured

The major current focus of geopressured R&D is flow testing of the Pleasant Bayou well in Brazoria County, Texas, in preparation for conducting a power generation experiment using geopressured brines. Co-sponsored by the Electric Power Research Institute and DOE, the experiment will utilize equipment that will incorporate both combustion of the methane separated from the brine and geothermal heat in a hybrid system. This type system can produce in excess of 15 percent more electricity than the same amount of fuel and geothermal fluid in separate power plants. Research on reservoir drive mechanisms will continue as the well is produced over a one-year period during the power experiment.

Hot Dry Rock

Preparations are underway for a long-term flow test of the large, deep, and very hot Phase II man-made hot dry rock reservoir. Research is concentrating on those efforts which will aid eventual interpretation of the long-term test and reservoir assessment. These efforts include development of chemically-reactive tracers, which allow estimation of internal temperatures within a reservoir, and development of three-dimensional models of fluid, heat, and tracer transport, and seismic analysis focusing upon fault plane analyses. Field experiments will be continued to learn more about the nature of the Phase II reservoir as well as developing and improving reservoir interrogation techniques.

Magma

The R&D activities of the magma energy extraction project are focused on determining the engineering feasibility of locating, accessing, and utilizing magma as a viable energy resource. An exploratory well will be drilled to 20,000 feet, in phases over about four years, in the Long Valley caldera of California. This well will permit estimates of the crustal magma resource base and test the adequacy of current geophysical techniques for locating magma. Drilling hardware is in development that will permit entry into the harsh magma environment where temperatures may range up to 2200°F. The geochemical environment of a magma heat exchanger system is being studied so that engineering materials can be selected that will survive for several years. The phased drilling will allow opportunities for scientific experiments between drilling operations with access to an open hole deeper than any ever available in this unique location.

The Geothermal Program budget is summarized in Exhibit 5.

EXHIBIT 5
GEOHERMAL PROGRAM BUDGET SUMMARY
(\$000)

ACTIVITY	OPERATING BUDGET		
	FY 1988	FY 1989	FY 1990
Geopressed Research.....	\$ 4,955	\$ 6,000	\$ 2,900
Hydrothermal Industrialization.....	455	0	0
Geothermal Technology Development			
Hard Rock Penetration Research.....	1,775	2,300	2,830
Reservoir Technology.....	3,975	2,500	2,153
Conversion Technology.....	1,580	1,935	2,110
Hot Dry Rock Research.....	5,770	3,500	3,500
Magma Energy.....	1,380	1,700	2,200
Capital Equipment.....	0	795	450
Program Direction.....	835	826	881
Total, Geothermal Technology.....	\$20,725	\$19,556	\$17,024

PROGRAM IMPLEMENTATION

Program Management

The responsibilities of DOE Headquarters, Operations Offices, and national laboratories in managing the program are summarized as follows:

Headquarters

The Geothermal Technology Division has overall management responsibility including program planning, budgeting, allocating funds, providing guidance to the field, and serving as the focal point for intra- and interagency coordination, required interaction with Congress, and technology transfer. Operations Offices

The Idaho (IDO) Operations Office is the principal field office for the Geothermal Program and is responsible for the technical and operational management of specific program areas. The Albuquerque Operations Office provides field management for specified projects.

Contractors

Actual implementation of the Geothermal Program objectives is performed by contractors, including the national laboratories. The contractors are responsible for the conduct of day-to-day management of geothermal research activities. They assist in the management of program activities, perform some projects in-house, and subcontract other work in areas assigned to them. Consequently, the contractors are directly responsible not only for conducting and managing federal geothermal research, but also for ultimately meeting the technical goals of the Program.

Organization

The Geothermal Program is managed by the Director of the Geothermal Technology Division (GTD) at DOE Headquarters, Washington, D.C. GTD is responsible to the DOE Assistant Secretary for Conservation and Renewable Energy, through the Director, Office of Renewable Technologies and the Deputy Assistant Secretary for Renewable Energy.

The Director of GTD provides the centralized

leadership necessary to ensure that Geothermal Program activities are consistent with national energy policy, priorities, and directives. Management of technical activities is decentralized among DOE Field Offices and national laboratories to ensure that specialized technical expertise is available to supervise the research.

Management Control

Due to the decentralized nature of the Geothermal Program, processes for management control are required at three levels: at Headquarters to provide mechanisms to ensure program success and adherence to program policy; at Operations Offices to ensure that contractual requirements are met and Quality Assurance plans implemented; and at the prime contractor level to ensure that operations in each respective area of responsibility are consistent with guidance and technical goals.

To ensure the continuing exchange of technical and programmatic concerns, the Division sponsors an annual program review during which the Operations Offices, national laboratories, and other contractors, and other industry representatives provide updates on their activities. Twice a year the participants in each research category gather for a program review to report on category-specific activities. At Headquarters, the Director holds monthly informal conferences where Program Managers report on current technical and programmatic issues and problems in their respective areas.