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# *REPORT TO THE CONGRESS*

# Problems In Identifying, Developing, And Using Geothermal Resources

Department of the Interior
Energy Research and Development Administration

*BY THE COMPTROLLER GENERAL OF THE UNITED STATES*

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COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-178205

To the President of the Senate and the
Speaker of the House of Representatives

This report concerns problems associated with the identification, technological development, and use of geothermal resources.

We made our review pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

We are sending copies of this report to the Director, Office of Management and Budget; the Administrator, Energy Research and Development Administration; the Secretary of the Interior; and the Director, National Science Foundation.

Comptroller General
of the United States

# Contents

ABBREVIATIONS

| | |
|---|---|
| AEC | Atomic Energy Commission |
| BLM | Bureau of Land Mananagement |
| ERDA | Energy Research and Development Administration |
| GAO | General Accounting Office |
| KGRA | known geothermal resource area |
| NASA | National Aeronautics and Space Administration |
| NSF | National Science Foundation |
| R&D | research and development |
| USGS | United States Geological Survey |

COMPTROLLER GENERAL'S
REPORT TO THE CONGRESS

# PROBLEMS IN IDENTIFYING, DEVELOPING, AND USING GEOTHERMAL RESOURCES
Department of the Interior
Energy Research and
Development Administration

## D I G E S T

### WHY THE REVIEW WAS MADE

Geothermal resources--the natural heat of the earth--include dry steam, hot mineralized water, hot dry rock, and geopressured zones. These resources can be used to produce energy, fresh water, and minerals.

GAO assessed the potential and progress of developing geothermal resources as a source of energy and water and identified problems being encountered.

### FINDINGS AND CONCLUSIONS

The Federal budget for fiscal year 1975 requested about $49 million for geothermal exploration, research, and development.

The Atomic Energy Commission, the Department of the Interior, and the National Science Foundation have been involved in developing geothermal resources. The Foundation was the lead Federal agency for planning and running the comprehensive geothermal research and development program.

The Geothermal Energy Research, Development, and Demonstration Act of 1974 established the Geothermal Energy Coordination Management Project.

The act provides a loan guaranty program to encourage and assist in commercial development of energy from geothermal resources. Except for the loan guaranty program, funds for carrying out project activities subsequently must be authorized. (See p. 6.)

Project activities, including the loan guaranty program, were transferred to the Energy Research and Development Administration, which was created by the Energy Reorganization Act of 1974 (effective January 19, 1975). The Administration will bring together most Federal activities relating to research and development of energy sources. (See p. 8.)

Geothermal activities were transferred from the National Science Foundation and the Atomic Energy Commission; however, the Department will retain its activities.

#### Development of electrical power from geothermal resources

The potential for developing large quantities of electric

power from geothermal resources varies because of

--a lack of reliable information on the extent and locations of resources and

--unsolved technological and environmental problems.

Estimates of electric power that may be produced from such resources in the United States by 1985 range from 4,000 to 132,000 megawatts. A large nuclear or fossil fuel electric plant can produce about 1,000 megawatts. (See pp. 10 and 11.)

The only electrical energy being developed from geothermal resources in the United States is at The Geysers, California, a dry-steam field which is producing about 400 megawatts. Ultimate capacity of The Geysers has been estimated at 2,000 megawatts. No other major dry-steam fields suitable for commercial production have been identified in the United States. (See p. 15.)

Geothermal leasing program

The U.S. Geological Survey classifies as known geothermal resource areas those Federal lands with good enough prospects for extracting geothermal resources to warrant expenditures by private interests. (See p. 12.)

Under the geothermal leasing program, these areas are leased to private interests through competitive bidding; other Federal lands having potential value are leased by noncompetitive applications.

The program has not proceeded as rapidly as anticipated, due partly to the little-known characteristics of the resources and partly to the early state of the technology.

The lack of information used in designating lands as known geothermal resource areas is another problem impeding progress of the leasing program. Geological Survey criteria for designating such areas are based on geological, geophysical, and geochemical data and do not require drilling to obtain subsurface data. Geothermal experts, even within the Geological Survey, disagree about the value and even the existence of geothermal resources within some designated areas. (See p. 34.)

Under the geothermal leasing regulations, if two applications for noncompetitive leases are received during any monthly filing period for lands which overlap by 50 percent or more, the area will be designated as a known resources area and will later be considered for competitive leasing. Designating the lands in these cases is not based on a geological survey. (See p. 36.)

Under the geothermal leasing regulations, each lessee is to diligently explore the resources until commercial quantities are produced. Minimum expenditures required of the lessee in the 10-year primary lease term could be insufficient to cover the cost of drilling one exploratory well, and no minimum expenditures are required in the first 5 years of a lease. (See p. 40.)

Because different laws deal with ownership and control of minerals, gas, and water, issuing leases on certain lands within known geothermal resource areas may be delayed or precluded pending adjudication of legal issues. These problems are being examined as part of the geothermal research program. (See p. 42.)

There is indication that, pending determination of ownership of geothermal resources, some land owners would be willing to have the resources leased with the understanding that all rents, royalties, and bonuses would be held in escrow. This would facilitate development of resources at an earlier date than would otherwise be possible. (See p. 43.)

The classification problem also has added to doubts concerning the Department's authority to lease offshore lands for geothermal exploration in geopressured zones. (See p. 46.)

Developing potable water from geothermal brines

The Bureau of Reclamation is involved in the first stage of a potential three-stage program for producing from geothermal brines as much as 10,500 megawatts of power and 2.5 million acre-feet of fresh water a year to augment the flow of the Colorado River. (See p. 50.)

The program, being carried out on federally owned lands in Imperial Valley, California, originally was based on the assumption that the Bureau would control use of these lands. In April 1973 the Department made these lands available for leasing to private firms for power development. (See pp. 51 and 53.)

The Bureau is to receive the residual geothermal brines after the lessees have developed power. However, temperatures and pressures of these residual brines may be too low for economical water production and the quantity of recoverable brines may be much less than originally estimated.

Although the Bureau's program is yielding valuable data on the potential for geothermal development in the Imperial Valley, the Bureau might not obtain as much water in the Imperial Valley from geothermal resources as originally hoped for in augmenting the flow of the Colorado River.

This technology, however, can be transferred to other areas with more potential. Further exploration and research may show improved potential for concurrent development of power and potable water in the Valley. (See pp. 58 and 59.)

RECOMMENDATIONS

The Secretary of the Interior should:

--Improve the methods for designating a known geothermal resource area by obtaining subsurface data when practicable and, in the case of areas designated as known geothermal resource areas because of overlapping noncompetitive

lease applications, analyzing the geology of any area before a value is assigned and it is offered for lease.

--Strengthen leasing regulations by increasing the level of expenditures required of lessees during the primary 10-year lease term to an amount more closely approximating the cost of drilling at least one deep exploratory well and by providing more specific requirements as to the minimum developmental actions required during the initial 5 years of a lease.

--Consider making special arrangements for leasing lands where ownership of geothermal resources is in dispute by providing for issuing leases with the understanding that all rents, royalties, and bonuses would be held in escrow, pending resolution of the title question.

--Propose legislation to classify geothermal resources in a special class, if the lack of such clear classification hampers development.

--Propose legislation to clarify the Department's authority for offshore geothermal leasing if offshore geothermal sites are considered worth developing. (See p. 48.)

AGENCY ACTIONS AND UNRESOLVED ISSUES

The Department said that recommendations in this report pertinent to the legal problems involving resources development will be considered with the implementation of the Geothermal Energy Research, Development, and Demonstration Act of 1974. (See p. 48.) The Department does not agree at this time, however, that it needs to improve its methods for designating known geothermal resource areas or to strengthen its regulations for promoting early exploration and development of leased lands. (See pp. 39 and 41.)

The Geothermal Energy Research, Development, and Demonstration Act of 1974 places on the Geological Survey responsibility for using innovative geological, geophysical, geochemical, and stratigraphic drilling techniques to develop improved information on geothermal resources. Exploratory drilling should remain the province of private industry, but the Department should make the necessary effort, including obtaining subsurface data, to improve its technique for locating and evaluating geothermal resources. (See p. 39.)

To encourage early drilling of exploratory wells and development of geothermal resources and to discourage speculation, leasing regulations should be

strengthened by (1) increasing the level of expenditures by lessees during the primary 10-year lease term to an amount more closely approximating the cost of drilling at least one deep well and (2) providing more specific requirements as to the minimum developmental actions required during the initial 5 years of a lease. (See p. 41.)

## MATTERS FOR CONSIDERATION BY THE CONGRESS

The report should help the Congress in considering funding levels and priorities for Federal programs designed to develop geothermal resources.

# CHAPTER 1

## INTRODUCTION

Geothermal energy, in its broadest sense, is the natural heat of the earth. Where heat is concentrated in restricted volumes in the earth's crust in a manner analogous to concentrations of oil in commercial petroleum reservoirs, the heat, or geothermal resource, becomes accessible and has potential economic use. Geothermal reservoirs have been found primarily in the Western United States; more than half are on Federal land.

Providing electrical power with geothermal energy began in 1904 when power was first produced from natural steam at Larderello, Italy. Since then the world's total production of electrical power from geothermal sources has reached only about 1,000 megawatts, 1/ or about the output of one large, modern, fossil-fueled or nuclear generating plant. (See app. I for list of geothermal resources uses.) Although experts predict that individual geothermal fields may have the capacity to produce extremely large amounts of power, geothermal energy remains a minor factor in the world's energy picture.

Geothermal resources are classified as dry steam, hot mineralized water, hot dry rock, and geopressured zones. 2/ Active volcanic regions, rare in the United States but found in other nations, also are a source of geothermal energy, referred to as molten magma. These resources can be used to produce energy, fresh water, and minerals, as shown below.

| | Geothermal resources | | | |
|---|---|---|---|---|
| Use | Dry steam | Hot water | Hot dry rock | Geo-pressured zones |
| Energy | X | X | X | X |
| Fresh water | | X | | X |
| Minerals | | X | | X |

Currently energy extracted from geothermal resources is used primarily to generate electrical power; however, other energy uses include heating, refrigeration, and

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1/ One million watts equals 1 megawatt.

2/ These zones, which contain methane gas, consist of sand and clay saturated with water at temperatures up to 273°C and at very high pressures.

industrial processing requiring heat. Unlike facilities using coal, oil, or other fuels, geothermal powerplants and associated facilities must be constructed at or near the wellhead because transporting steam is difficult.

In the United States, geothermal resources have been used to generate electrical power from dry steam at The Geysers, California--the only commercial dry-steam field 1/ in the United States--and to heat homes and buildings in Idaho and Oregon. The United States is the world's leading producer of geothermal electrical power due to the production at The Geysers.

## FEDERAL ACTIVITIES

To stimulate geothermal resources development, the Federal Government has recently begun programs to (1) gain a better understanding of the nature and extent of the resources, (2) develop technology to generate power, produce fresh water, and extract minerals, and (3) lease public lands for exploration and development. As shown in the following table, Federal funding for geothermal research and development (R&D) programs has been increased considerably in recent years.

Federal Funding for Geothermal
Exploration, Research, and Development

| Agency | Through FY 1973 | FY 1974 | FY 1975 |
|---|---|---|---|
| | ----------(000 omitted)---------- | | |
| Atomic Energy Commission | $ 591 | $ 5,167 | $12,700 |
| National Science Foundation | 1,120 | 3,700 | 22,300 |
| Department of the Interior: | | | |
| Bureau of Land Management | - | 550 | 1,230 |
| " " Mines | 310 | 280 | 500 |
| " " Reclamation | 2,165 | 1,750 | 1,270 |
| United States Geological Survey | 3,915 | 2,947 | 10,064 |
| Office of Saline Water (note a) | 1,355 | 2 | - |
| " " the Secretary (note b) | - | - | 250 |
| Department of Defense | 105 | 193 | 400 |
| Total | $9,561 | $14,589 | $48,714 |

a/ Functions relating to the geothermal program have been assumed by the Bureau of Reclamation.

b/ Funds to be used for an international geothermal conference.

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1/ Yellowstone Park is another dry-steam field, but it is not available for commercial development because it is a national park.

The Chairman of the Atomic Energy Commission (AEC) submitted a report to the President in December 1973 proposing a geothermal R&D program that would need the following Federal funding for the period 1976 through 1979.

| | Fiscal years | | | | |
|---|---|---|---|---|---|
| | 1976 | 1977 | 1978 | 1979 | Total |
| | (millions) | | | | |
| Operating expenses | $30.7 | $30.1 | $27.3 | $21.6 | $109.7 |
| Equipment | 7.3 | 5.4 | 4.4 | 3.1 | 20.2 |
| Construction | 3.0 | 5.3 | 4.0 | 2.8 | 15.1 |
| Total | $41.0 | $40.8 | $35.7 | $27.5 | $145.0 |

This program is planned to culminate in the construction and operation of several demonstration powerplants. If shown to be economically feasible, the geothermal technology could then be used by private industry for commercial power projects in the 1980s and later.

The National Science Foundation (NSF), the lead Federal agency responsible for formulating and executing a comprehensive geothermal R&D program, has integrated and coordinated the geothermal R&D effort.

Current Federal activities are discussed below.

Identifying the nature and extent of the resources

The United States Geological Survey (USGS) is the Department's lead bureau in geothermal energy studies. Its research program includes exploration methods; resource appraisals; and, to a lesser extent, resource development, utilization technology, and environmental monitoring. Until 1971, USGS did not receive any appropriated funds specifically for geothermal resource studies, but, as part of ongoing energy and mineral investigations, it had investigated hot springs since 1945.

Much of the USGS research program in fiscal years 1972-74 was directed toward detailed study of the dry-steam field at The Geysers and the geothermal hot water area of Long Valley, California. Several other geothermal areas in Western States are being studied on a smaller scale, and the geopressured zones along the gulf coast are being mapped on the basis of data obtained from industrial sources.

Additional geothermal exploration is being carried out or planned through NSF and AEC programs. To gain better understanding of geothermal resources, NSF has funded studies

at (1) a hot water geothermal area in Imperial Valley, California, known as the Dunes Anomaly, (2) the Kilauea Volcano in Hawaii, and (3) a thermal anomaly near Marysville, Montana, believed to be a large, hot dry rock formation. Along with programs to develop geothermal technology, AEC is also planning to explore ways of extracting energy from geothermal resources.

Developing the technology to generate power, produce fresh water, and extract minerals

Until fiscal year 1973, the Bureau of Reclamation was the primary agency involved in developing geothermal technology under the Colorado River Basin Project Act of 1968 (43 U.S.C. 1501-56). The Bureau's work consisted of applied research to develop methods of desalting geothermal brines and producing fresh water while producing electrical power. The initial phase of this work is to continue through fiscal year 1979. (See ch. 4.) The Department's policy has been to leave the development of geothermal power to the private sector.

In fiscal year 1974, AEC began work on a geothermal energy development program which includes developing technology for energy extraction from dry hot rock. Before fiscal year 1974, AEC conducted research under several other programs which had geothermal application.

Several of the technology development programs will culminate in demonstrations of power-generating systems using energy from various types of geothermal resources. These demonstrations are to be carried out by scientific laboratories under contract with AEC.

The AEC geothermal plan covering fiscal year 1975 through the early 1980s includes resource use projects involving R&D related to, and construction and operation of, approximately 10-megawatts pilot plants representative of one or more different types of geothermal resources--high temperature, low salinity; high temperature, high salinity; geopressured sedimentary; moderate temperature, low salinity; and hot dry rock. The success realized in these concept validations will help determine the long-range potential of using geothermal resources as a source of power.

According to NSF, its strategy for the geothermal program is to remove barriers to the rapid development of geothermal resources by industry. The program focuses on four areas: (1) advanced research and technology, (2) resource use, (3) environmental, legal, and institutional research, and (4) resource exploration and assessment. Implementing this program involves research on specific environmental,

legal, and technical questions and establishing several regional facilities, each associated with a specific type of geothermal resource.

The Bureau of Mines' geothermal research program deals mainly with developing new and improved corrosion-resistant materials and developing the technology for recovering materials from geothermal brine. In fiscal year 1975, the Bureau's main effort is to develop superior-performance materials needed to withstand serious scaling and the corrosive attack of high-temperature, high-pressure saline fluids expected to be encountered at most domestic geothermal facilities.

This materials development research is done at the College Park (Maryland) Metallurgy Research Center. Along with this research, field testing has been initiated at the San Diego Gas and Electric Company's geothermal well near Niland, California. The Bureau of Mines is focusing attention on developing methods and systems for separating, extracting, and recovering potentially valuable mineral salts and chemicals from geothermal brine.

The Bureau's Boulder City (Nevada) Metallurgy Research Laboratory is concerned primarily with developing environmentally acceptable techniques for disposing of nonusable brine constituents. Contracts and research grants were awarded to two non-Federal laboratories in 1973 and 1974 to develop information for evaluating domestic geothermal brines as potential mineral resources.

## Leasing public lands for exploration and development

The Geothermal Steam Act of 1970 (30 U.S.C. 1001-25), effective December 24, 1970, authorizes the Secretary of the Interior to lease Federal lands for geothermal resource exploration, development, and production of energy as well as any useful byproducts. The Department, through the Bureau of Land Management (BLM) and USGS, conducts the Federal leasing program, which is under the act's authority. BLM is responsible for selecting lands for lease and holds lease sales. USGS classifies the lands according to its appraisal of the land's geothermal value before issuing leases and supervises development of the lands.

The lands which can be leased include (1) lands--public, withdrawn from public use, and acquired--administered by the Secretary of the Interior, (2) national forest or other lands administered by the Forest Service, Department of Agriculture, and (3) lands for which the Government has given title to qualified people while retaining rights to geothermal resources.

## GEOTHERMAL ENERGY RESEARCH, DEVELOPMENT, AND DEMONSTRATION ACT OF 1974

The Geothermal Energy Research, Development, and Demonstration Act of 1974 (Public Law 93-410) was enacted on September 3, 1974. The act established the Geothermal Energy Coordination and Management Project which is composed of six members--one appointed by the President, an Assistant Director of NSF, an Assistant Secretary of the Interior, an Associate Administrator of the National Aeronautics and Space Administration (NASA), the General Manager of AEC, and an Assistant Administrator of the Federal Energy Administration. The President is to designate one of the members as Chairman of the project.

The project is responsible for effectively managing and coordinating a national geothermal resources program that includes

--determining and evaluating the resource base;

--research and development for exploration, extraction, and utilization technologies;

--demonstrating appropriate technologies; and

--a loan guaranty program.

The project has exclusive authority to establish or approve programs initiated under the act, but such programs will be administered and operated by other Federal agencies specified in the act; generally, programs may be carried out under cooperative arrangements with non-Federal entities.

The Chairman of the project, acting through the Administrator of NASA, is to prepare and submit to the President and each House of the Congress a comprehensive program definition of an integrated effort and commitment for effectively developing geothermal energy resources. The comprehensive program definition is to include a schedule and objectives for the inventorying of geothermal resources, which are to be prepared by the USGS. Interim reports are to be submitted not later than November 30, 1974, and January 31, 1975, and a final report not later than August 31, 1975.

The act authorized for NASA for fiscal year 1975 an amount not to exceed $2.5 million to prepare the program definition. Funding for carrying out other activities under the act--other than the loan guaranty program for which an amount not to exceed $50 million annually is authorized--must be subsequently authorized by law.

The act designates the following program areas:

--A resource inventory and assessment program designed to improve techniques for locating and evaluating geothermal resources, to develop better methods for predicting the power potential and longevity of geothermal reservoirs, to determine and assess the nature and power potential of the deeper unexplored parts of high temperature geothermal convection systems, and to survey and assess regional and national geothermal resources of all types.

--A research and development program designed, among other things, to develop drilling methods to operate at high temperatures; to explore new concepts for fracturing rock; to improve equipment, technology, and methods for extracting and converting geothermal resources and for controlling emissions and wastes; to provide an adequate supply of scientists; and to encourage States to establish and maintain geothermal resources clearinghouses.

--A demonstration program designed, among other things, to develop economical geothermal resources production systems and components which meet environmental standards, to design plants to produce electric power and byproducts, to provide an adequate supply of trained geothermal engineers and technicians, and to construct and operate pilot and demonstration plants.

--A scientific and technical education program to encourage the development and maintenance of programs to provide the necessary trained personnel to perform required geothermal research, development, and demonstration activities.

--A loan guaranty program designed to encourage and assist in the commercial development of practicable means to produce useful energy from geothermal resources with environmentally acceptable processes by guaranteeing lenders against loss of principal or interest on loans made by lenders for the purpose of (1) determining and evaluating the resource base, (2) researching and developing extraction and utilization technologies, (3) acquiring rights in geothermal resources, or (4) developing, constructing, and operating facilities for the demonstration or commercial production of energy from geothermal resources.

The act also provides for transferring the project's research, development, and demonstration functions (including

the loan guaranty program) to a permanent Federal organization having jurisdiction over energy R&D functions. Such an organization, the Energy Research and Development Administration (ERDA), was created by an October 11, 1974, act.

## ERDA

The Energy Reorganization Act of 1974 (Public Law 93-438) was enacted on October 11, 1974. It established ERDA which consists of an Administrator, a Deputy Administrator, and six Assistant Administrators, one of whom will be responsible for solar, geothermal, and advanced energy systems. ERDA is to bring together and direct Federal activities relating to R&D of various energy sources--including geothermal. ERDA will encourage and conduct energy R&D, including demonstration of the commercial feasibility and practical applications of the extraction, conversion, storage, transmission, and use phases related to the development and use of energy from geothermal resources as well as from other energy sources.

The act transferred to the Administrator the geothermal power development functions of NSF. The act established a Nuclear Regulatory Commission and abolished AEC, transferring its nonregulatory functions to ERDA. Therefore, the NSF and AEC geothermal programs and activities discussed in this report were transferred to ERDA effective January 19, 1975. The Department will retain its activities.

## SCOPE OF REVIEW

We reviewed legislation and legislative history and examined documents relating to the Department's participation in the geothermal program. We discussed with officials of various Federal and State agencies, including the Department, AEC, NSF, and the State of California, the potential uses of geothermal resources and the possible methods used to develop them. We obtained pertinent information regarding geothermal resources from these officials. In addition, we met with officials of private industry and academic institutions interested in geothermal development.

We made our review at the offices of the Bureau of Reclamation, Boulder City, Nevada; USGS, Menlo Park, California; and BLM, Sacramento, California, and at the Washington, D.C., headquarters offices of these agencies and NSF. We visited the geothermal development projects at The Geysers and Imperial Valley, California; Cerro Prieto, Mexico; and selected AEC laboratories.

In letters of September 26 and November 12, 1974, AEC and NSF, respectively, commented on the report and made certain suggestions. Their comments were considered in preparing this report.

The Department commented by letter dated December 13, 1974 (see app. IV), and pertinent parts of these comments are shown starting on pages 38, 41, 48, and 57.

## CHAPTER 2

## DEVELOPMENT OF ELECTRICAL POWER FROM GEOTHERMAL RESOURCES

The potential for developing large quantities of electrical power from geothermal resources is uncertain, except at The Geysers, because of the lack of reliable information on the extent and locations of the resources and of unsolved technological and environmental problems associated with obtaining and converting resources. Although the solutions to these problems probably will vary in degree of difficulty, depending on the form of the geothermal resource, the type of problems generally are common to all forms. The Federal Government is increasing its efforts to solve these problems.

### ENERGY POTENTIAL OF GEOTHERMAL RESOURCES

The technology for producing electrical power from the energy contained in geothermal dry steam has been successfully applied at The Geysers, which was producing about 396 megawatts of power as of May 1, 1974.

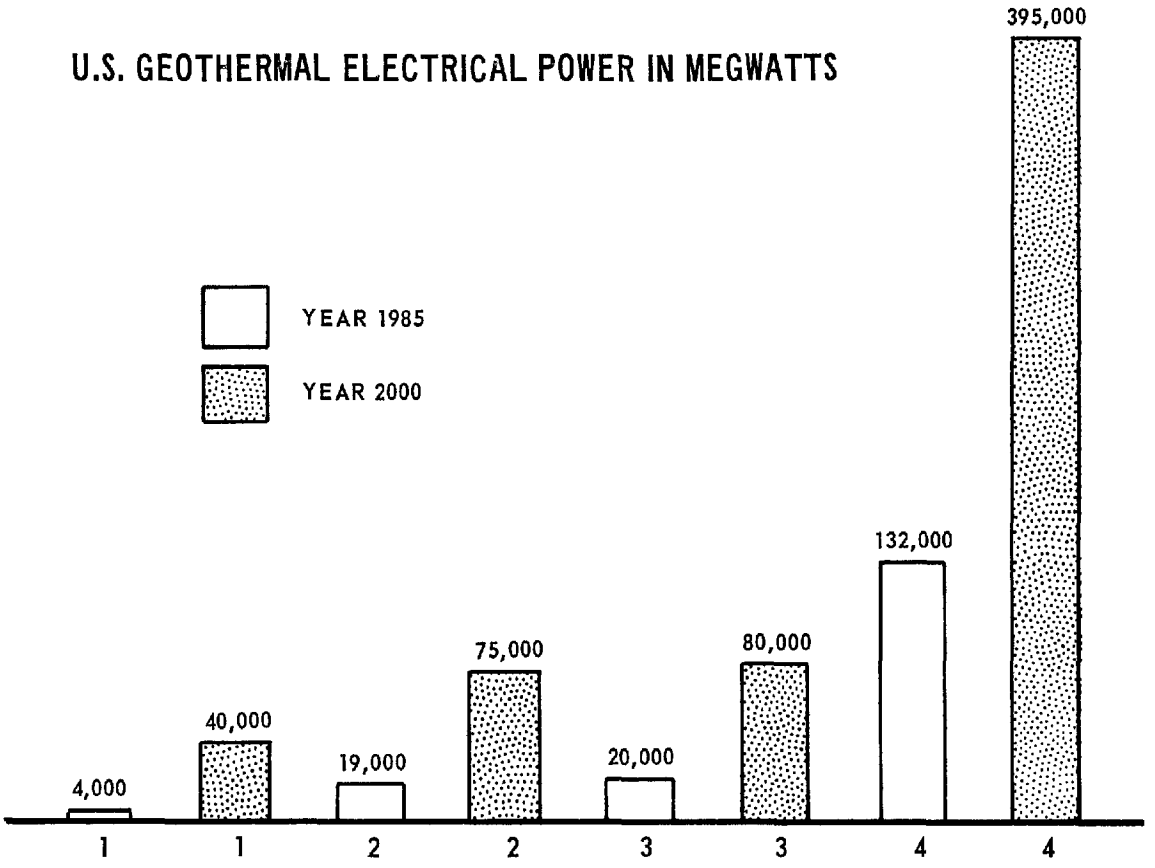
The potential of producing energy from all geothermal resources cannot be easily determined. The scientists, industrialists, and researchers covered in our review were optimistic about the resources' potential. But differing opinions exist about the quantity and temperatures of recoverable fluids, the rate at which the heat of the fluids will be depleted, and the success which can be expected in overcoming production problems.

The cost of geothermal power production is also uncertain. Cost estimates at this time would be highly speculative and would vary depending on which opinions of the above-mentioned factors are considered.

Although the Government is now involved in an extensive geothermal research program, the Federal policy has been to leave the production of commercial quantities of power to the private sector. Regardless of the theoretical potential of the resources, commercial production will probably not occur unless the cost of geothermal power is competitive with available alternative energy sources. The cost of production will remain uncertain until further exploration and R&D is carried out.

Estimates of the electrical power to be generated from geothermal resources in 1985 range from 4,000 to 132,000 megawatts. Estimates for the year 2000, which project

energy developed from hot dry rock as well as from hot water and dry steam, range from 40,000 to 395,000 megawatts. These estimates are shown below.




1. Bureau of Mines analysis, 1973.

2. "Assessment of Geothermal Energy Resources," Department of the Interior, 1972.

3. "The Nation's Energy Future," a report to the President of the United States submitted December 1, 1973, by the Chairman, AEC.

4. "Geothermal Energy," a special report by W. J. Hickel, University of Alaska, 1972.

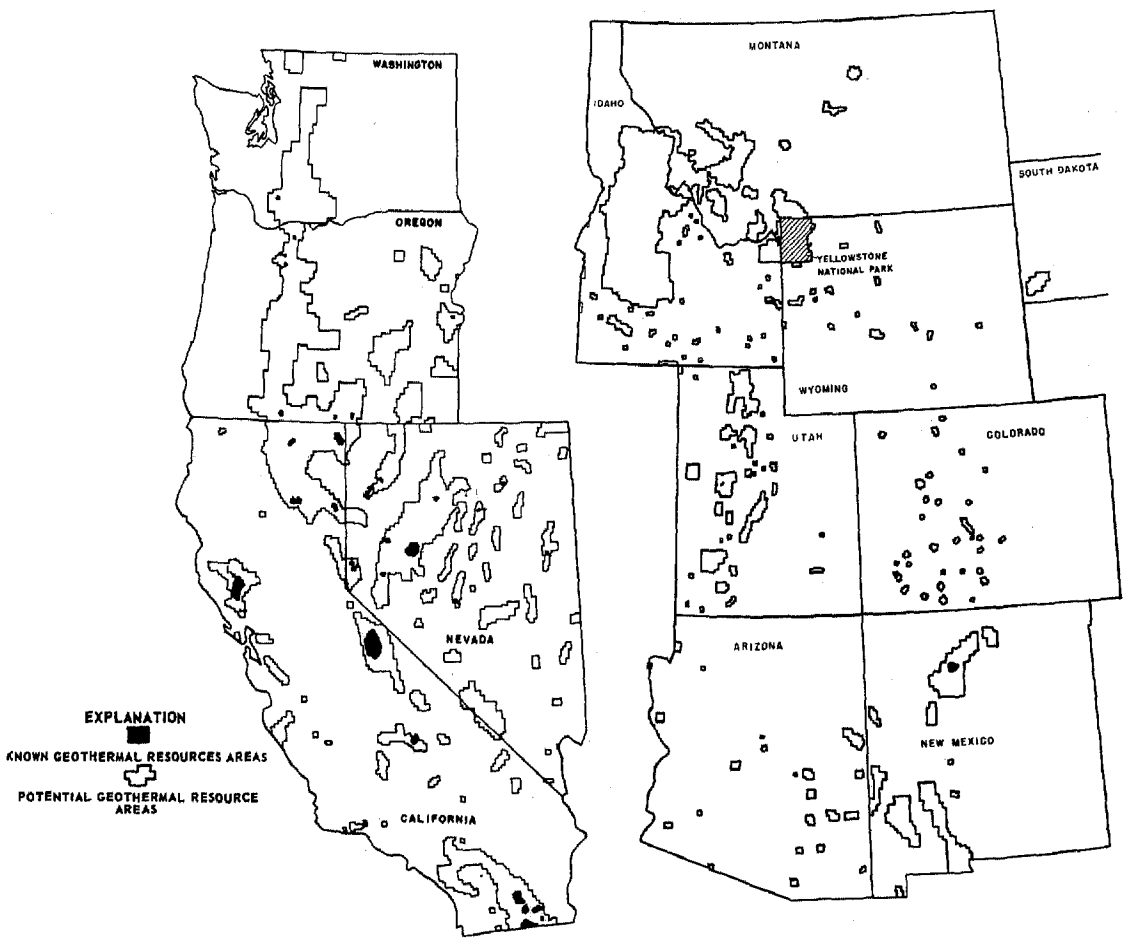
The total estimated electrical requirements for the United States in 1985 will be about 865,000 megawatts. Therefore, geothermal energy could supply 0.5 to 15 percent of the requirements. However, the highest estimate assumes development of apparently feasible but unproved technologies and recovery of large quantities of resources.

## LOCATION OF GEOTHERMAL RESOURCES

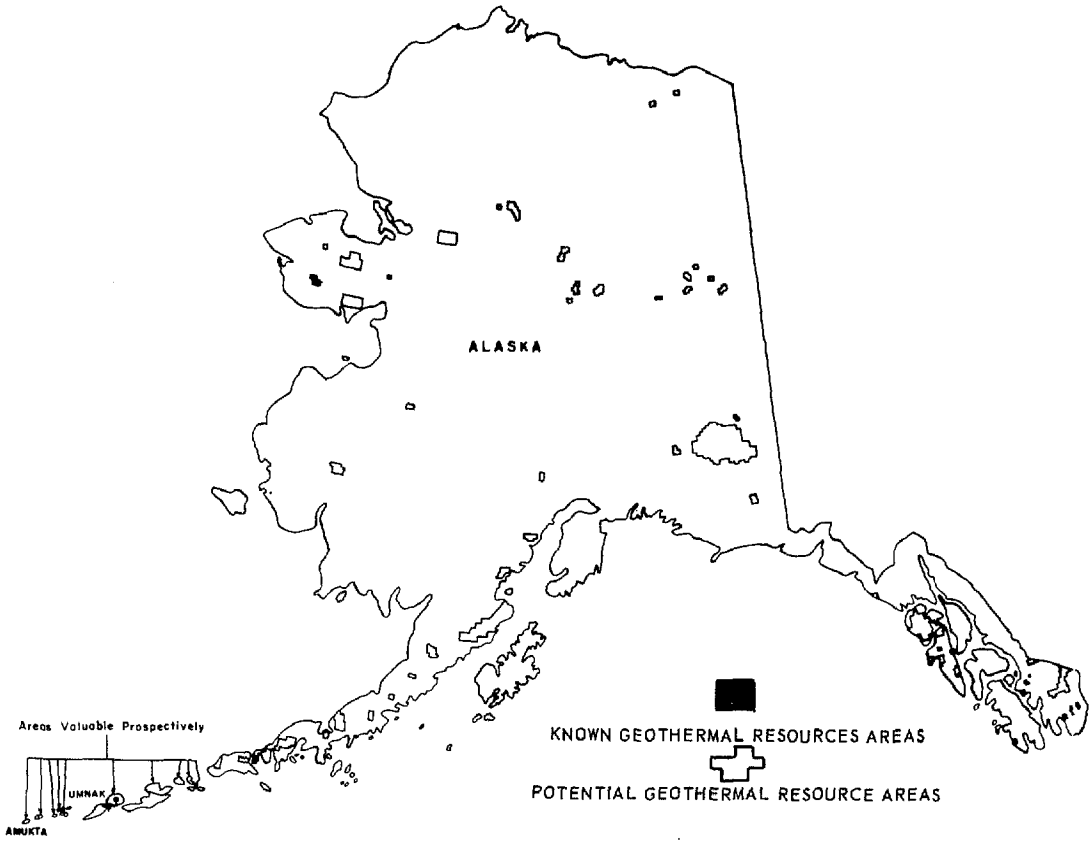
Scientists have identified the locations of geothermal resources in the United States in terms of large geographical areas. Within these areas, however, little is known about the specific distribution, extent, or magnitude of the resources.

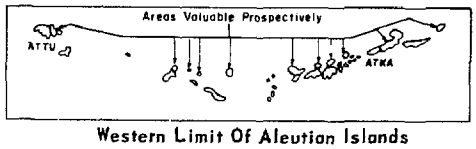
USGS has classified about 1.9 million acres of land in the Western States as known geothermal resource areas (KGRAs) where the prospects of extracting geothermal resources are good enough to warrant expenditures of money. Of the 1.9 million acres, about 1 million acres (about 56 percent) are on Federal lands. An additional 96 million acres are listed as having potential value for geothermal resources. Of these, about 58 million acres (about 60 percent) are on Federal lands. (See maps below showing these areas in the Western United States and in Alaska and the Aleutian Islands.) Although geothermal steam, hot water, and hot rock are concentrated in the Western States, geopressured zones are located along the gulf coasts of Texas and Louisiana. (See p. 14.)

**KGRAs AND POTENTIAL GEOTHERMAL RESOURCE AREAS**



# KGRAS AND POTENTIAL GEOTHERMAL RESOURCE AREAS

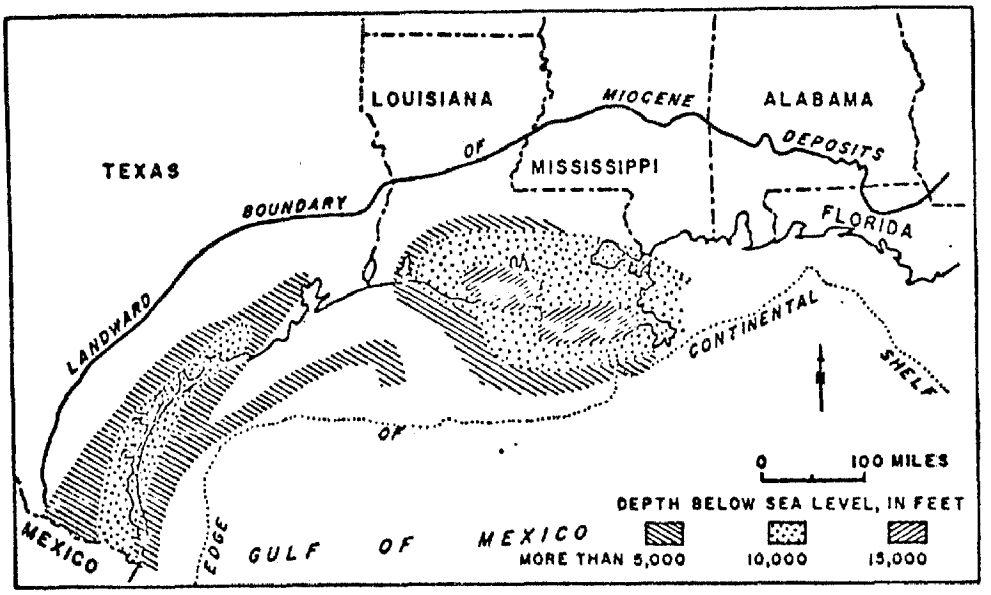



Western Limit Of Aleutian Islands

| | ACRES | |
|---|---|---|
| | KGRA | POTENTIAL GEOTHERMAL RESOURCE AREAS |
| CALIFORNIA | 1,051,533 | 15,737,000 |
| NEVADA | 344,027 | 13,468,000 |
| OREGON | 84,279 | 15,048,000 |
| WASHINGTON | 17,622 | 5,759,000 |
| ARIZONA | 88,160 | 1,473,000 |
| COLORADO | – | 1,014,000 |
| IDAHO | 21,844 | 14,845,000 |
| MONTANA | 12,763 | 3,834,000 |
| NEW MEXICO | 152,863 | 7,482,000 |
| SOUTH DAKOTA | – | 436,000 |
| UTAH | 13,521 | 4,511,000 |
| WYOMING | – | 824,000 |
| ALASKA | 88,160 | 11,277,000 |
| TOTAL | 1,874,772 | 95,708,000 |

# LOCATION AND DEPTH OF GEOPRESSURED ZONES IN THE NORTHERN GULF OF MEXICO BASIN




Because heat dissipates rapidly, geothermal fluids cannot be transported far from their point of recovery without significantly losing heat. The maximum transport distance depends on the initial heat content of the fluids and the use for which the fluids are intended. For steam used to generate electric power, the maximum lateral distance is about 1 or 2 miles. Hot water for agricultural use or space heating can be transported farther--the longest reported distance is about 12 miles. When heat energy is converted to electric power, it can be distributed throughout a power transmission grid. Conversion to electric power is a practical means of transferring heat energy from often-remote geothermal fields to population centers.

## PROCESSES USED TO GENERATE ELECTRICAL POWER

The technology for obtaining power from geothermal resources, except for dry steam, has not been successfully demonstrated in the United States. Technical, environmental, and administrative problems had impeded progress in converting the energy in hot water and brines to usable power, and research and exploration of the other forms of geothermal resources were not emphasized until recently.

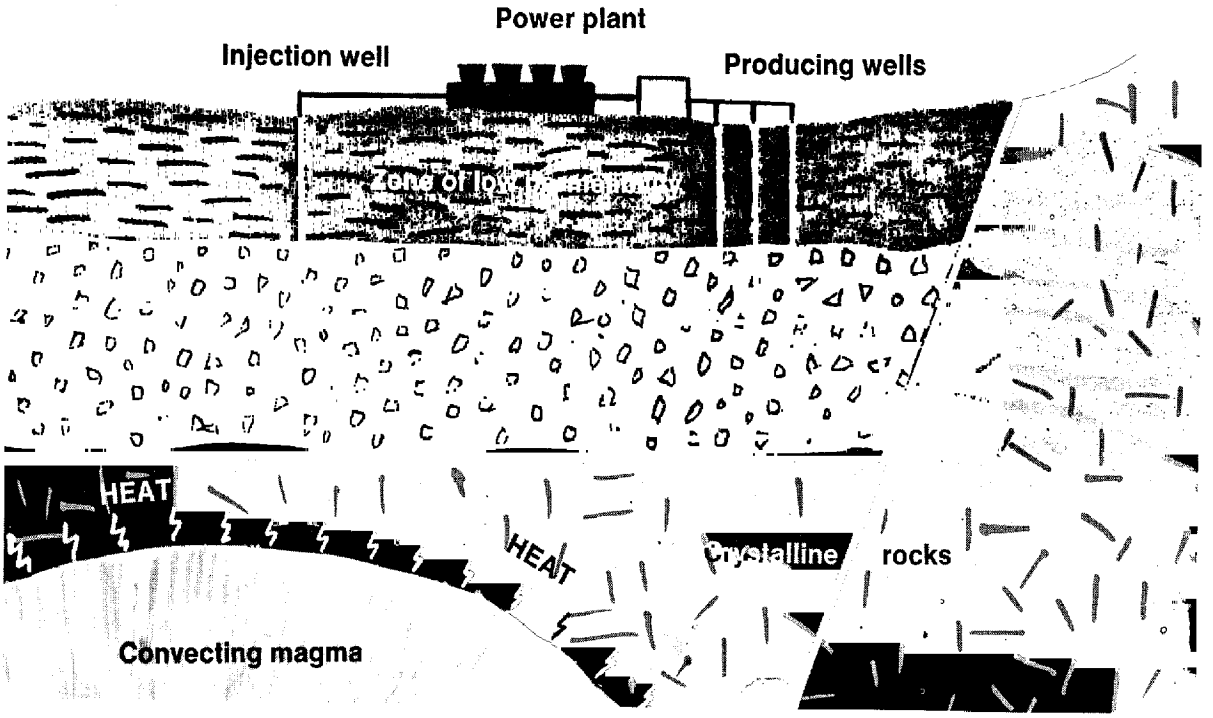
### Geothermal energy from dry steam

Producing energy from geothermal steam is a relatively simple process. Environmental problems, such as noise and

air pollution, have not yet been satisfactorily resolved, but progress is being made.

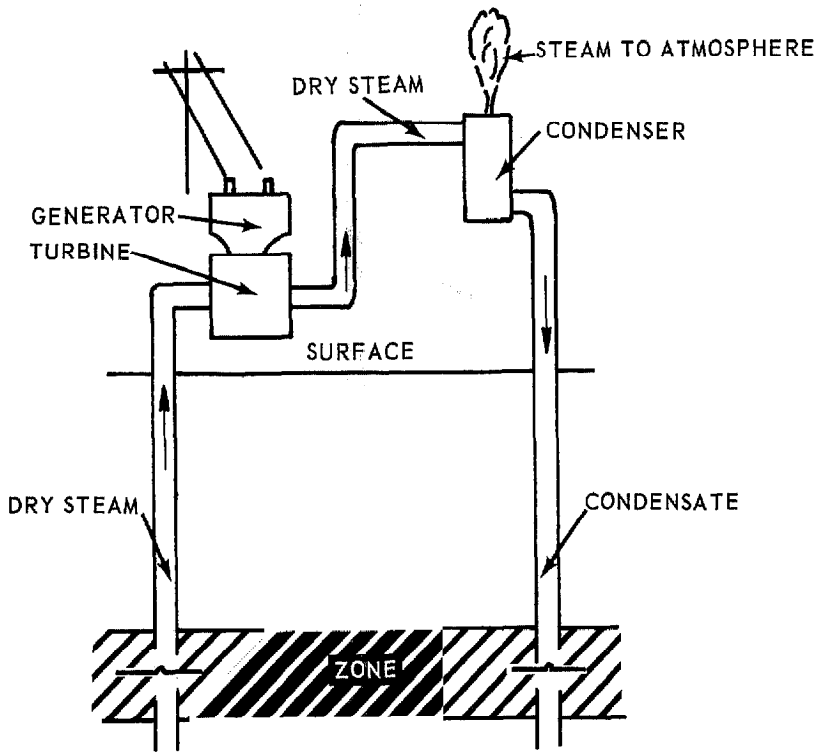
Dry steam geothermal systems contain both water and steam in underground reservoirs. When a geothermal well is drilled into a reservoir, steam heated from molten rock material within the earth (magma) rushes to the surface through the well and can be piped directly into a turbine for power generation. (See illustrations below.)

The Geysers' geothermal steam field, located about 85 miles north of San Francisco, has an electrical generating capacity of 396 megawatts--enough power to supply more than half the power requirements of San Francisco. (See picture on p. 17.) USGS has not identified any other major dry-steam fields suitable for commercial production in the United States. Unless such fields are found, the potential for dry steam as a source of energy will lie primarily in the development of The Geysers to its ultimate capacity. Pacific Gas and Electric Company told us that the ultimate capacity will approach 2,000 megawatts.



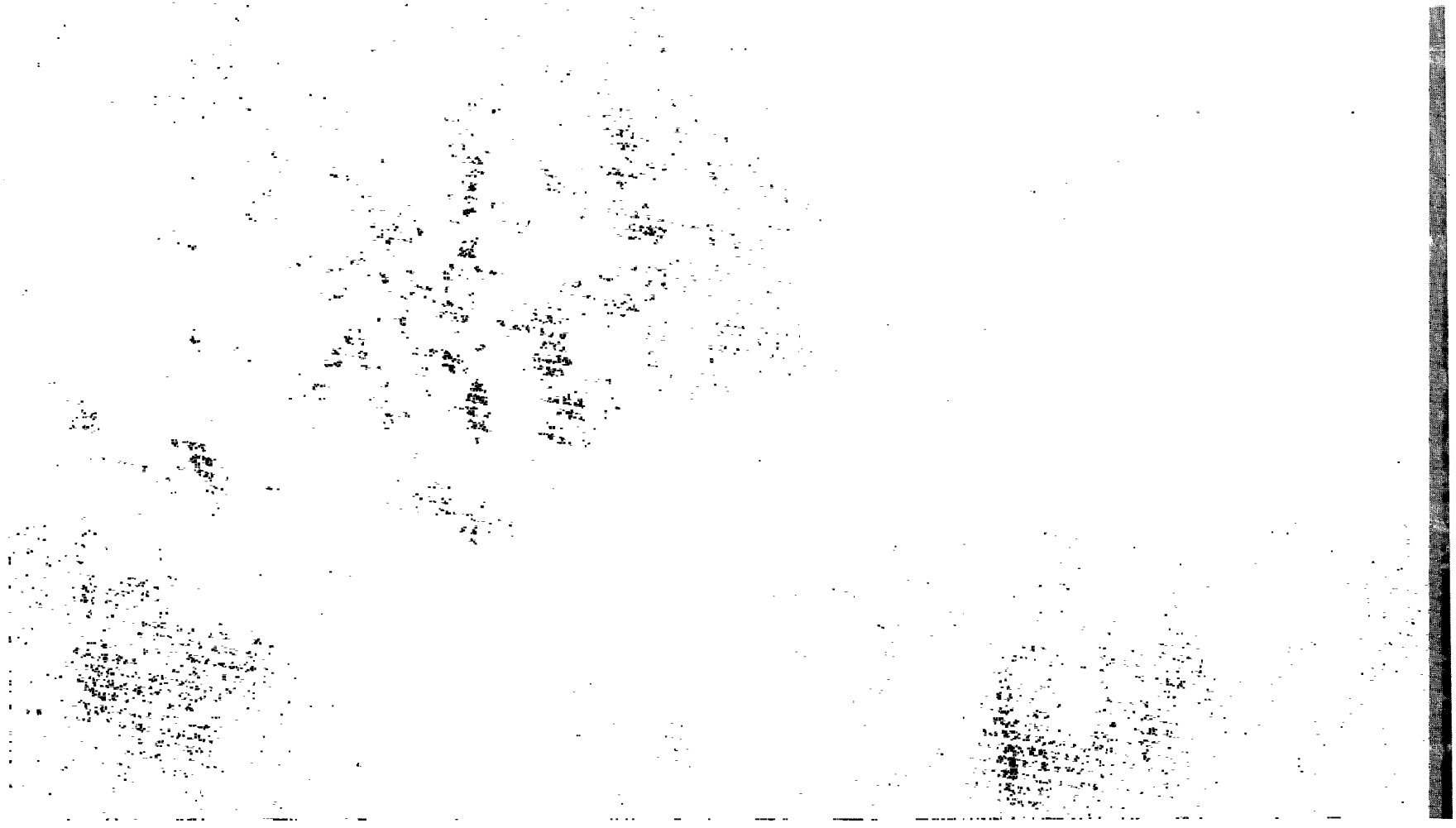

Source: The Pacific Gas and Electric Company

# DRY-STEAM SYSTEM (GEYSERS USA)




The first attempt to develop The Geysers' power potential was made in 1922. In 1956, the Magma Power Company and the Thermal Power Company, working jointly, found that geothermal steam could be produced economically. The Pacific Gas and Electric Company contracted to build a powerplant and buy steam from the Magma-Thermal wells. In 1967 the Union Oil Company of California joined with Magma-Thermal in a project to drill for and produce steam.

The Pacific Gas and Electric Company has installed, contracted for, or planned the following geothermal generating units at The Geysers.



The Geysers geothermal steam field. Source: The Pacific Gas and Electric Company

| Date | Units | Capacity of units | Cumulative capacity |
|---|---|---|---|
| | | (megawatts) | |
| 1960 | 1 | 11 | 11 |
| 1963 | 2 | 13 | 24 |
| 1967 | 3 | 27 | 51 |
| 1968 | 4 | 27 | 78 |
| 1971 | 5,6 | 106 | 184 |
| 1972 | 7,8 | 106 | 290 |
| 1973 | 9,10 | 106 | 396 |
| 1975 | 11 | 106 | 502 |
| 1977 | 12 | 106 | 608 |
| 1977 | 13 | 135 | 743 |
| 1977 | 14 | 110 | 853 |
| 1977 | 15 | 55 | 908 |
| 1979 | (a) | 110 | 1,018 |
| 1980 | (a) | 110 | 1,128 |
| 1981 | (a) | 110 | 1,238 |

a/Not yet identified.

About 20 to 24 wells are required to support a 110 megawatt generating plant, and each well has a life of 2 to 30 years; the average lifetime is about 15 years. As individual well pressures decrease, new wells must be drilled to maintain an adequate steam supply to the turbines.

The Pacific Gas and Electric Company told us that the cost of electric power produced from dry steam at The Geysers varied from plant to plant. The company provided us with information which shows that the cost of power produced from units 9 and 10 averages 5.325 mills 1/ per kilowatt-hour at an 80-percent capacity factor. 2/ This figure can be broken down as follows:

| | Mills per kilowatt-hour |
|---|---|
| Annual cost of steam | 2.599 |
| Annual operating costs | 0.223 |
| Annual fixed costs | 2.503 |
| Total | 5.325 |

1/ One mill equals one-tenth of one cent.

2/ Capacity factor is the ratio of the average capacity required from a plant to the capacity of the plant.

In March 1974, however, the company estimated that the unescalated cost of power from unit 13 will average about 10.36 mills per kilowatt-hour at an 80-percent capacity factor. Although the cost of geothermal power appears to have risen significantly, it remains considerably lower than the cost of power produced from nuclear fuel plants, which AEC estimated to be about 15.2 mills per kilowatt-hour. Union Oil officials told us that the charge for geothermal energy was comparable with the charges for fossil fuels.

The Geysers is a KGRA consisting of 163,428 acres; 11,450 acres are federally owned. In January 1974, a competitive lease sale was held for 8,755 acres and bids totaling $5,526,728 were offered. Leases on these lands were issued in July 1974. The Federal Government holds mineral rights on an additional 14,000 acres within the KGRA which were granted under the Stock Raising Homestead Act of 1916. Whether the retention of mineral rights includes geothermal steam is a legal problem needing resolution. (See ch. 3.) In January, February, and March 1974, numerous private interests applied for Federal geothermal leases on potentially valuable lands adjacent to The Geysers KGRA; none had been issued as of November 1974.

Technical and environmental problems at The Geysers include the high noise levels of the wells and air pollution from hydrogen sulfide gas escaping into the atmosphere. Operators of The Geysers told us that both problems were expected to be resolved soon by newly designed noise mufflers and chemical scrubbers.

Recent studies indicated that geothermal powerplants in The Geysers emit small amounts of radioactive material into the atmosphere. According to the Union Oil Company's geothermal program director, the amount of radiation measured is well below the permissible levels established by AEC and California. Nevertheless, the Union Oil Company and the Pacific Gas and Electric Company have contracted with the Lawrence Berkeley Laboratory to study The Geysers field's radiation levels and their effects on the environment.

Although dry steam represents a technically and economically acceptable energy source, its potential may be severely limited by its availability, since dry steam is not a replenishable resource and no commercial dry-steam fields have been identified in the United States, except The Geysers.

## Geothermal energy from hot water

The private sector, mainly in Imperial Valley in Southern California, is developing the technology to produce energy economically from brine or hot geothermal fluid. The Federal Government is involved in research for resolving technical problems and stimulating the development of critical hardware technology needed in geothermal power generation processes. Department officials expressed the opinion that the greatest geothermal energy resource potential in the short term is in the form of liquid-dominated or hot-water systems.

No electrical power is currently being produced from hot-water fields in the United States, but hot geothermal fluids are providing heat to more than 400 buildings in Klamath Falls, Oregon, and to about 200 homes in Boise, Idaho.

The amount of electrical power which can be generated from such systems depends on resource characteristics, which are largely unknown, and available technology. The important resource characteristics are the temperature and pressure at which the brines are found--often at depths up to 10,000 feet--and the concentrations of salts and minerals that they contain. The useful life of the field is determined by (1) the total quantity of brines in the field and (2) the rate at which reinjected brines would be reheated after being extracted and cooled during the power generating cycle. These resource characteristics are largely unknown for hot-water fields in the United States.

Imperial Valley is one of the largest and most intensively studied hot-water fields in the Nation. USGS; the Bureau of Reclamination; the University of California, Riverside; and several oil companies have carried out geochemical and geophysical exploration. Estimates of Imperial Valley's geothermal power potential have changed over the years, as shown below.

| Estimator | Date of estimate | Power potential 1985 (megawatts) | Power potential 2000 (megawatts) |
|---|---|---|---|
| Stanford Research Institute | 1973 | 200 | 1,000 |
| California Division of Oil and Gas | 1972 | 710 | - |
| Bureau of Reclamation (note a) | 1972 | 420 | 10,500 |
| University of California | 1970 | - | 20,000 to 30,000 |

a/ The Bureau estimate of the power potential of 10,500 megawatts is contained in a document entitled "Geothermal Resource Investigations, Developmental Concepts." A Bureau regional official provided the estimate by years.

The Stanford Research Institute estimate was based on a 1972 USGS appraisal; the other estimates were based on earlier appraisals. Although the deep geothermal wells drilled to date appear to support the USGS appraisal, the potential of the resource will remain uncertain until more exploration, drilling, and well production are carried out.

Technological uncertainty also contributes to the wide variance in estimates of hot water power potential. The methods for generating power from hot water or brines also need more study. These methods--the flashed-steam system, the binary-cycle system, and the total-flow system--involve technical and environmental problems which must be overcome before they can be successfully applied in the United States.

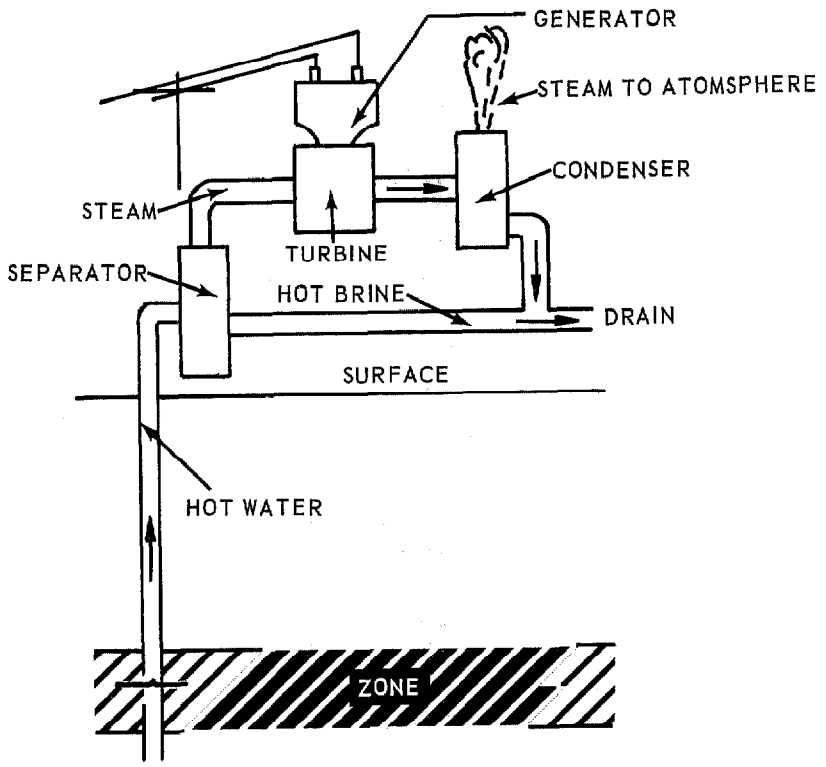
Flashed-steam system

In the flashed-steam system, the geothermal fluids boil, or flash, as they move up a well and a mixture of water and steam surfaces. The steam can then be separated from the fluids and fed to a steam powerplant similar to those used at The Geysers. (See illustration on p. 22.) The Bureau is investigating the feasibility of desalting the geothermal fluid and producing fresh water concurrently with power. (See ch. 4.)

The flashed-steam system is capable of producing power only from that portion of the hot fluids which flash to steam at the surface. In high-temperature hot-water fields, this portion is approximately 20 percent of the fluids. The heat in the remaining fluids is essentially wasted, unless it is used for desalination, heating, or reinjection.

Flashed-steam powerplants are operating in New Zealand, Mexico, and Japan; however, no such plants are operating in the United States. Because the geothermal fluids found in Imperial Valley are generally believed to be at lower temperatures than those in the other nations, a smaller portion of the fluids would flash to steam. Since Imperial Valley's fluids also contain higher concentrations of salts and minerals, problems of scaling (formation of a solid film on the metal surface) and corrosion of powerplant equipment could be expected if the flashed-steam system were used. Private industry, the Department, and AEC are studying these problems. Furthermore, the foreign installations have not yet faced the environmental problems which need to be resolved if development is to take place in the United States. (See p. 26.)

## FLASHED-STEAM SYSTEM (MEXICO)




Binary-cycle system

The binary-cycle system would make it possible to generate electrical power from fluids above or below the boiling point. In this system, the fluids do not flash to steam; instead, they are kept under pressure and pumped to a heat exchanger where they are used to heat a secondary fluid, such as isobutane or freon, which--when vaporized--drives a power turbine. The fluids, which are at a lower temperature after passing through the heat exchanger, are pumped underground through a reinjection well. 1/ (See illustration on p. 23.) A small binary-cycle plant is operating in the Soviet Union.

Several American firms are doing development work on components of a binary-cycle system. The San Diego Gas and Electric Company, along with the Magma Power Company and the Standard Oil Company of California, is currently engaged in a

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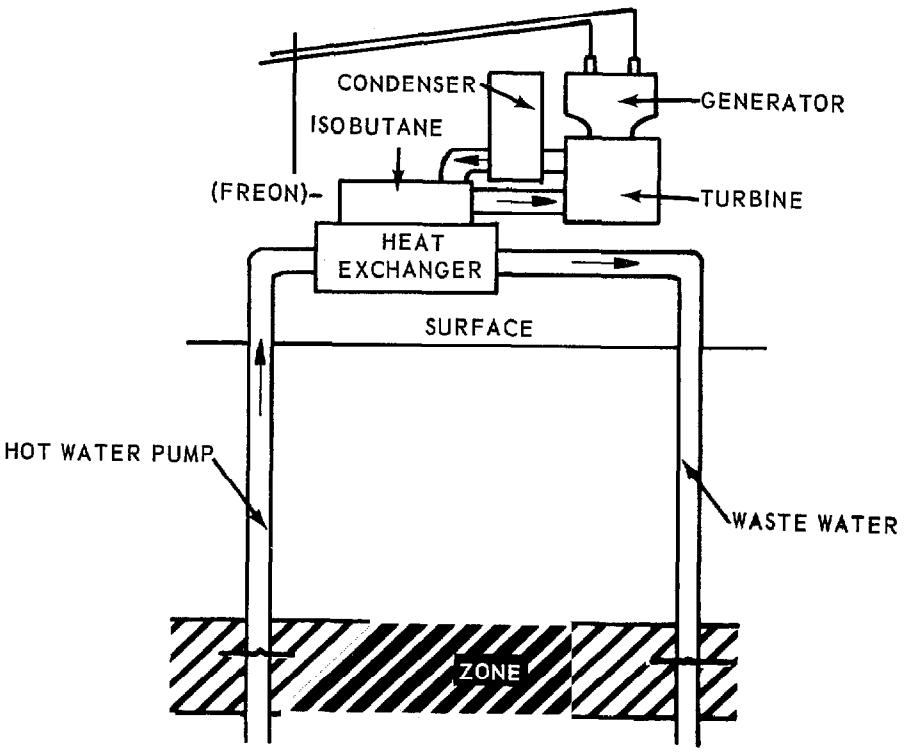
1/ In a variation on this system, steam is separated from the fluids and fed to a heat exchanger. The fluids which do not flash to steam are used for cooling or are reinjected to the reservoir.

project to install and operate prototype plants at two sites in Imperial Valley. An official of the San Diego Gas and Electric Company told us that scaling was the most persistent problem encountered. At one site the concentration of minerals dissolved in the geothermal fluids reaches 200,000 to 300,000 parts per million--nearly 10 times that of sea water. Clogged pipes and heat exchangers have been serious enough at this site to necessitate redesigning the powerplant. Modifications are expected to be completed and power produced by the end of 1975.

In a cooperative 5-year program with private industry, AEC plans to develop improved methods of extracting energy from geothermal hot-water reservoirs. An official of the Lawrence Berkeley Laboratory, where the program is being carried out, said that research would focus on the binary-cycle system and would lead to the construction of a 10-megawatt power system in 1978. AEC's estimated budgets for the program in fiscal years 1974 and 1975 are $800,000 and $1.1 million, respectively.

Lawrence Berkeley Laboratory scientists have begun exploring various geothermal areas in Nevada to find the best site for the pilot plant. In December 1973 they asked BLM

**BINARY-CYCLE SYSTEM**



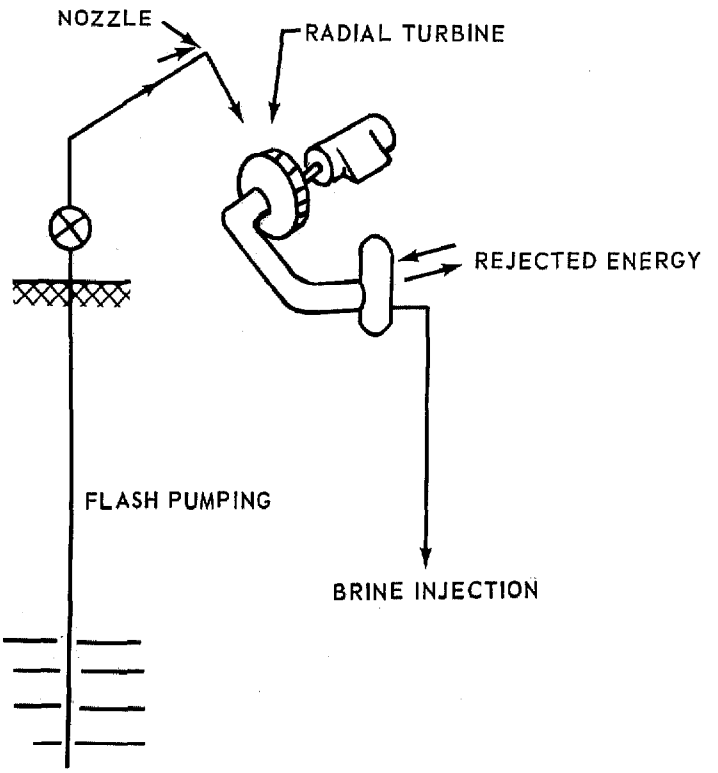
to withdraw 88,000 acres of land in Nevada from the geothermal leasing program for a maximum exploration period of 2 years. Within the 2 years, a 5,000-acre site was to be chosen for the project. As of mid-December 1974, the Department had not yet reached a decision on the proposed withdrawal.

If binary-cycle technology proves to be economically viable, more of the heat could be used than a flashed-steam system allows, and the power potential of reservoirs with temperatures too low for steam production could also be used. Since high-pressure water retains its gases in solution and can be reinjected to an underground reservoir, atmospheric pollution could be avoided. Furthermore, the binary-cycle steam involves less noise and offers greater efficiency than the flashed-steam system. For these reasons, industry officials expect it to play a dominant role in developing the potential of hot-water reservoirs.

Total-flow system

AEC's Lawrence Livermore Laboratory has proposed a third system for generating power from hot-water fields. Using the total-flow system, hot geothermal fluids would be passed through a nozzle into a turbine, similar in some respects to a water wheel. (See illustration below.)

**TOTAL-FLOW SYSTEM**



By making use of the mechanical energy as well as the heat energy of the fluids, the Lawrence Livermore Laboratory scientists believe the system could be more efficient than the flashed-steam and binary-cycle methods. They expect to begin testing a small total-flow system in fiscal year 1975. A site for a pilot powerplant--perhaps in the Salton Sea area of California--is to be chosen later. The scientists anticipate arranging a joint venture with private industry for demonstrating the system. AEC's estimated operating budgets for the total-flow concept in fiscal years 1974 and 1975 are $419,000 and $1,600,000, respectively.

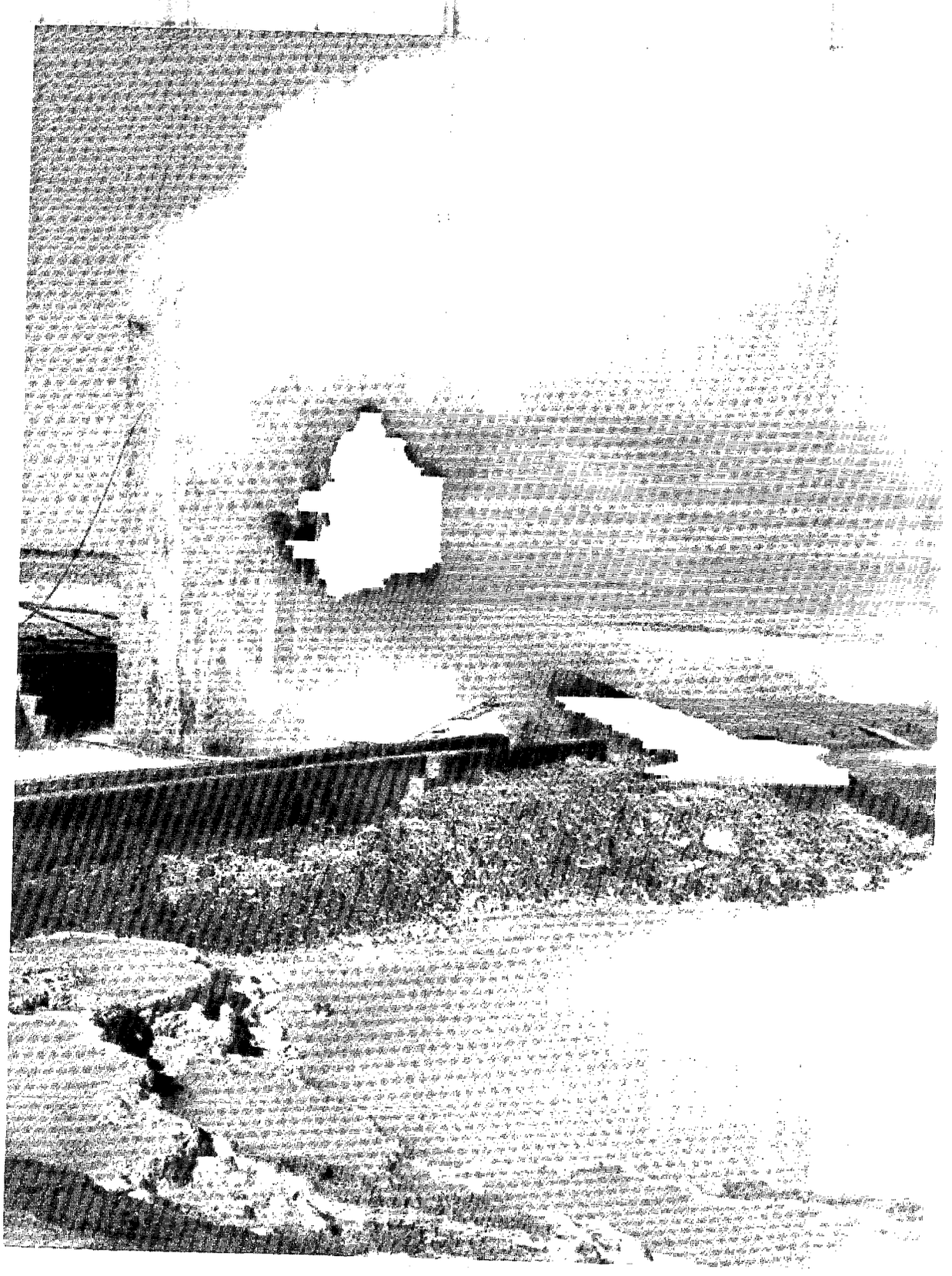
Since the system is only in a conceptual stage, it is too early to predict whether it will prove feasible. Scaling and corrosion of the nozzle and turbine may be serious obstacles that will have to be overcome. Federal funds have been made available to AEC for continuing this research, and a demonstration of the process is expected by 1979.

### Environmental concerns affecting all hot-water systems

Environmental problems created by developing geothermal hot-water resources stem primarily from the large quantities of fluid which must be brought to the surface to produce power. The Geysers can produce a kilowatt-hour of power from about 20 pounds of dry steam, but between 75 and 150 pounds of hot water, depending on the temperature, is needed to produce a kilowatt-hour of power. The environmental problems include sinking of the land, disposal problems, and faults and earthquakes.

Sinking of the land has occurred at the geothermal hot-water fields at Cerro Prieto, Mexico, and Wairakei, New Zealand, where the fluids, after being used to produce power, are dumped into local water systems. USGS reported that the land at Cerro Prieto has sunk as far as 7 miles extending from the well field and that over 25 square miles of land at Wairakei--mostly outside the production field--has sunk. In some areas the land has sunk about 10 feet.

In many undeveloped areas, sinking would not cause serious adverse effects. However, in such fields as Imperial Valley, it could cause damage to geothermal wells, pipelines, and buildings. It could also seriously impair the areas's extensive irrigation networks, which support a large agricultural industry. Releasing corrosive fluids into the area surrounding a geothermal field could contaminate surface streams and ground waters and could pollute the land area with chemical deposits. (See picture p. 26.) Consequently, fluids must be adequately and safely disposed of to meet environmental standards.



Source: Department of the Interior

**Effects of corrosive brines on equipment and pollution of surrounding area at Cerro Prieto, Mexico.**

Fluids can be disposed of in many ways, but one method which is expected to minimize sinking and avoid adverse environmental problems is reinjecting the fluids into the producing reservoir. The problem with reinjection is that most geothermal waters contain dissolved salts and minerals which tend to separate from the solution when temperatures and pressures are reduced. The salts and minerals could clog the wells and plug fractures in the reservoir.

Because the unstable conditions in the earth's crust that produce geothermal phenomena are also the conditions that produce faults and earthquakes, geothermal and seismic phenomena are inseparable. In fact, high seismic activity is one of the clues used in finding geothermal reservoirs. Lubricating fault planes by reinjecting fluids, coupled with pressure buildup and related effects, could result in movement along fault zones. Little is known about the phenomena, and considerable monitoring and research will be necessary to resolve the cause and effect relationships involved.

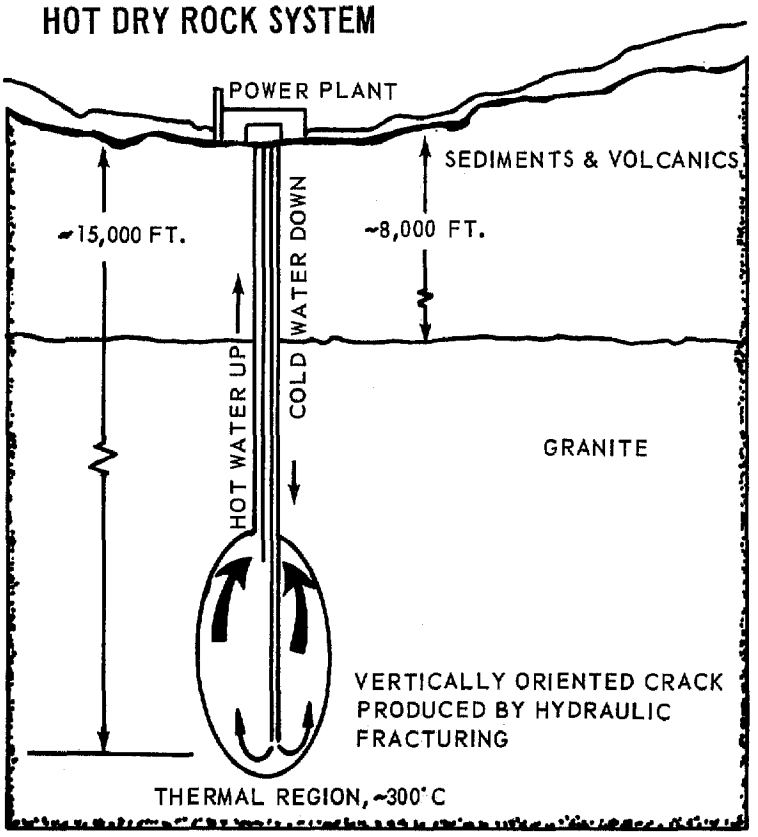
The Bureau of Reclamation and USGS are conducting research in Imperial Valley on the sinking and seismic effects of geothermal production. The Bureau is also planning to experiment during fiscal year 1975 with reinjecting geothermal fluids. This research is aimed at resolving many of the environmental problems. According to NSF, it will conduct a workshop on the environmental aspects of geothermal development as part of its fiscal year 1975 program. The workshop should provide a forum for full discussion of these issues.

Geothermal energy from hot dry rock

The potential and economics of developing the hot dry rock resource are uncertain. Technical problems will have to be solved before energy can be developed from hot dry rocks. AEC's Los Alamos Scientific Laboratory initiated a program in fiscal year 1974 to determine the technical and economic feasibility of recovering geothermal energy from hot dry rock. The estimated operating levels for this effort were $3 million in fiscal year 1974 and $2.7 million in fiscal year 1975. During the period between fiscal years 1972-73, AEC conducted research in the geosciences under several broader program areas which had application to the development of geothermal energy extraction technology from hot dry rock resources. The Laboratory spent about $591,000 in this period for geophysics and geochemistry research having geothermal application. Although the economics associated with hot dry rock are unknown, this resource is believed to be a potential energy source.

Hot dry rock differs from other geothermal resources because it does not contain a fluid to carry heat to a powerplant. Therefore, water must be introduced to the reservoir, where it is heated by the surrounding rock, and brought to the surface. The hot water is then used to generate power as in other hot-water systems. A deep well is then fractured by pumping high-pressure water into the well. A second well is drilled to intercept the fracture. (See illustration below.) When water is pumped down the first well, it is filtered through the fracture, picking up heat, and returned to the surface through the second well. There it is passed through a binary fluid power system where the heat of the circulating water is converted to electrical power. After leaving the power system, the water, now at much lower temperature, is returned to the first well and the circulation cycle is repeated.

A site for the first test of the system has been chosen near Los Alamos, New Mexico. Scientists at the Los Alamos Scientific Laboratory expect to complete drilling of the first well to a depth of 7,500 feet in fiscal year 1975 and then hydrofracture the rock and drill a second well to complete the



circulation system. A heat exchanger (not a powerplant) will be installed to dissipate the heat extracted from the rock. If equipment delivery and installation schedules permit, the system will begin operation by the end of fiscal year 1975. After testing the system for about a year, Los Alamos scientists expect to begin constructing a larger system which will include a powerplant. An operational prototype system is expected to be demonstrated by 1981.

If the process is successful, it could have wide commercial application. The Los Alamos Scientific Laboratory concluded that dry-rock temperature levels over 290°C (550°F)--a very appropriate temperature for electrical power generation--could be obtained by drilling about 16,400 feet in about 7 percent of the surface area of the Western States (20,000 to 30,000 feet in the Eastern States). This area, which is not identified, is over 30 times larger than the total KGRAs listed by USGS for potential hot water or steam geothermal development. Hot dry rock geothermal development, however, is faced with potential problems which are briefly described below.

--Hydrofracturing the rock at the bottom of deep wells may not produce fractures adequate for water circulation and heat removal.

--Cooling the reservoir would occur rapidly and therefore may not result in the necessary thermal stress cracking. This phenomenon, caused by cold water coming in contact with hot rock, is expected to extend the original fractures in outward directions and to allow the circulating water to contact additional hot surfaces. However, it is not certain that such thermal cracking will occur or that the cracking will proceed rapidly enough to sustain adequate heat transfer for commercial production.

--Many rocks may contain stress patterns which, upon hydrofracturing, may cause earthquake disturbances.

--Large amounts of water may be required to maintain water circulation in a commercial system. This will depend on the rate at which water escapes from the underground system through cracks and fissures. In areas with little water, this requirement could be a limiting factor.

AEC is studying these problems and has drilled exploratory wells to obtain data which it will use in trying to resolve them.

Much of the hot dry rock resources at temperatures high enough to permit useful extraction of heat are found below 15,000 feet, which presently are too deep for economical drilling. A new drill, known as the subterrene or rock-melting drill, is being developed by the Los Alamos Scientific Laboratory. AEC is funding this activity in fiscal year 1975; previously it was funded under a separate NSF grant. The drill, which has been successfully tested on a small scale, can bore a hole in the earth by melting, rather than grinding, the rock in its path. If technical problems are overcome, the drill could help to decrease well costs and could make the hot dry rock found at greater depths accessible. But first, drilling costs will have to be reduced and deep-drilling technology developed.

NSF said that it was supporting research on other non-conventional drilling techniques and systems.

Geopressured zones

USGS is doing limited research in the geopressured zones along the gulf coasts of Louisiana and Texas. The zones consist of sand and clay saturated with water, temperatures up to 273°C, and very high pressure. The water contains considerable amounts of methane gas which can be extracted. Information is being accumulated about this resource and, although many scientists are skeptical about its potential, others believe the possibilities for useful exploration are good.

The zones are generally found about 9,000 to 15,000 or more feet below the surface. They are known to cover an area of about 160,000 square miles along the gulf coast; about two-thirds of which lie offshore.

Over the past several years, USGS has made studies of the zones using data supplied by oil companies exploring for petroleum. The oil companies have encountered many geopressured zones in their drilling operations and have made records of temperature and pressure characteristics. USGS and AEC plan further study. NSF said that its fiscal year 1975 program included a major geopressure effort. Geophysics data on thousands of gulf coast wells will be transferred to a computer and will be available for information about the location, extent, and characteristics of geopressure resources in the region. NSF said that it expected construction to start by fiscal year 1977 on a "test bed" facility for further developing geopressure technology.

USGS has not classified the geopressured zones of the gulf coast as KGRAs, or even as potentially valuable areas. The reasons given for this were:

--It has not yet been shown that the resource has any power potential.

--There are little, if any, leasable Federal lands in the area of the zones.

--Although any zones lying offshore beyond the 3-mile limit would involve Federal ownership, the technical problems associated with harnessing the geothermal potential are enormous.

--Private firms have not expressed interest in acquiring geothermal leases in Federal offshore areas. Furthermore, the Geothermal Steam Act may not cover leasing offshore. (See p. 46.)

Some researchers claim that, if technical and environmental problems can be overcome, 500 wells could economically produce 13 trillion cubic feet of methane gas over a 30-year period and sustain 7,500 megawatts of energy. In addition, fluids could be processed through desalting plants and recovered as fresh water to supply water to deficient areas, such as parts of Texas and Western Oklahoma.

The most critical questions influencing the successful development of the zones appear to be:

--How long can production from a geopressured zone be sustained without decreases in temperature and pressure?

--How much will the land sink if large quantities of geopressured fluids are removed?

Additional research is needed to determine whether geopressured zones constitute a practical, economical energy source.

## CONCLUSIONS

It appears that through 1985 geothermal resources will not offer a major alternative source of energy, and projections to the year 2000 involve great uncertainty. The development of power from geothermal hot water, geopressured zones, and hot dry rock is hindered by technical and environmental problems.

Federal R&D programs as well as industry programs are aimed at solving these problems and determining the economic feasibility of producing power from geothermal resources. Certain programs--under current schedules--would

have demonstration pilot powerplants operational between 1978 and 1983. If successful, the program could greatly affect long-range geothermal potential.

## CHAPTER 3

## GEOTHERMAL LEASING PROGRAM

The Federal program for leasing public lands to private interests for developing electrical energy from geothermal resources has not proceeded as rapidly as had been anticipated. As discussed in chapter 2, the lack of reliable information on the extent and location of geothermal resources and the need for improved technology for developing such resources in an environmentally sound way are the two key areas requiring progress before any sizable portion of the Nation's electrical energy requirements can be met through development of geothermal resources. Problems in the Federal program for leasing public lands to private interests to develop geothermal resources stem in large measure from the lack of reliable information regarding such resources, even on lands designated as KGRAs. Other problems in the leasing program relate to

--insufficient requirements for early exploration and development of leased lands and

--legal problems involving the ownership and control over use of geothermal resources.

### NEED FOR A SOUNDER BASIS IN DESIGNATING FEDERAL LANDS AS KNOWN GEOTHERMAL RESOURCES AREAS

Under the Geothermal Steam Act of 1970, lands identified as KGRAs and offered for lease must be leased on a competitive basis. Federal lands authorized for geothermal explorations and not designated as KGRAs may be leased through noncompetitive applications.

In addition to paying initial (bonus) fees for the land, all lessees must pay rent until they produce power or other geothermal resources in commercial quantities. The act sets the annual minimum rent at $1 an acre. For the three KGRAs offered for competitive leasing--The Geysers, Mono-Long Valley, and East Mesa (all in California)--the annual rent is $2 an acre.

After the lessees produce power or other geothermal resources in commercial quantities, they are required to pay the Government royalty fees which are 10 to 15 percent of the amount or value of energy sold or used. The royalty fees established by the Secretary of the Interior are 12.5 percent for The Geysers and 10 percent for Mono-Long Valley and East Mesa. We were told that The Geysers has a higher royalty fee because its known potential for geothermal development is

better than that for the other areas. The act has established a maximum 5-percent royalty for certain byproducts (e.g., minerals and water) sold or used.

Section 2 of the act defines a KGRA as

> "* * * an area in which the geology, nearby discoveries, competitive interests, or other indicia would, in the opinion of the Secretary [Interior], engender a belief in men who are experienced in the subject matter that the prospects for extraction of geothermal steam or associated geothermal resources are good enough to warrant expenditures of money for that purpose."

Department regulations define a competitive interest as existing when two or more applicants make noncompetitive lease applications during the same applications period--1 calendar month--for land which overlaps by 50 percent or more. Such land is automatically classified as a KGRA subject to competitive leasing.

Improved information on geothermal resources on Federal lands is essential to develop a sound and orderly leasing program. The method the Department used to identify and designate lands as KGRAs are not widely accepted, and experts do not agree that geothermal resources exist in some areas designated as KGRAs. The requirement that noncompetitive lease applications whose land areas overlap by 50 percent or more be designated as KGRAs apparently will result in additional land being so classified on the basis of the existing competitive interests. This situation and the associated risks to the prospective bidders could hamper the timely development of geothermal resources.

Competitive bidding to lease land in KGRAs

After the act was passed, USGS initially classified 43 areas as KGRAs in 9 Western States, including 2 in Alaska. These KGRAs have a total area of about 1.8 million acres. All leasable lands within these KGRAs are to be leased to the highest responsible qualified bidder. USGS establishes the minimum acceptable bid for each tract on the basis of information concerning the tract and surrounding area. BLM generally rejects high bids failing to meet this minimum.

In designating lands as KGRAs, USGS uses criteria based upon geological, geophysical, and geochemical data, which are to indicate those KGRAs good enough to warrant expenditures for extracting geothermal resources.

USGS officials told us, however, that geothermal experts, even within USGS, disagreed about the value and existence of geothermal resources within some areas designated as KGRAs. These officials and officials of some firms interested in leasing Federal land said that the USGS criteria for designating KGRAs are not sufficient. The officials contended that subsurface data should be acquired by drilling, and they strongly urged that KGRAs be limited to areas of proven or strongly indicated potential. According to one USGS official, only The Geysers is clearly a KGRA.

The differences in opinion over the value of KGRAs are indicated by the following table which summarizes the bids received on the California KGRAs offered for lease in January 1974 and the information which follows.

| California KGRAs | Land offered | | Bids received | | | |
|---|---|---|---|---|---|---|
| | Acres | Number of tracts | Acres | Tracts bid | Number of bids | Acceptable high bids |
| The Geysers | 8,755 | 12 | 8,755 | 12 | 42 | 10 |
| Mono-Long Valley | 13,714 | 7 | 5,483 | 3 | 10 | 3 |
| East Mesa | 30,169 | 14 | 9,210 | 5 | 5 | 5 |
| Total | 52,638 | 33 | 23,448 | 20 | 57 | 18 |

Bids on two tracts at The Geysers were unacceptable because they failed to meet the minimum bid set by USGS, and no bids were received on certain tracts in the hot-water fields in Mono-Long Valley and East Mesa. The bids submitted on the five adjoining tracts in East Mesa were $2.25 an acre (three tracts), $130.91 an acre, and $169.80 an acre. The bids of $2.25 an acre equaled or exceeded the minimums established by USGS. The bids received on tracts offered in Mono-Long Valley and in The Geysers also varied greatly.

The prospective bidders on tracts of land in Mono-Long Valley and East Mesa were faced with risks not associated with bidding on lands near the producing steam field at The Geysers. For example, two major obstacles must be considered: (1) the unproven technology for generating electrical power from geothermal fluids extracted from hot-water fields and (2) the lack of encouraging data as to the nature, extent, and quality of the geothermal resources available at each tract.

These differences, together with the lack of agreement among geothermal experts as to the value and existence of geothermal resources within designated KGRAs, point up the need for the Department to improve the methods for designating KGRAs and thereby enhance the development of geothermal resources.

To improve the methods for designating KGRAs, the Department might consider a Federal program for drilling deep exploratory wells on selected lands which are classified as potential or known geothermal resources areas but in which little interest has been shown by the private sector.

Noncompetitive leasing of lands

The Geothermal Steam Act of 1970 states that:

> "If the lands to be leased are not within any known geothermal resources area, the qualified person first making application for the lease shall be entitled to a lease of such lands without competitive bidding."

Under the leasing regulations, however, if two applications for noncompetitive leases are received during the same monthly filing period for lands which overlap by 50 percent or more, neither applicant will be issued the lease. Because of the competitive interest, the area will instead be designated as a KGRA and will be considered for competitive leasing. The designation of such land as a KGRA is not based on a geological survey.

Although 2,456 noncompetitive applications to lease land were received in January 1974, no leases had been issued as of November 1, 1974. We were told that the delay was due to (1) the requirement to reclassify some lands as KGRAs because some applications covered land areas which overlapped by 50 percent or more and (2) required environmental analyses.

Environmental analyses of areas to be leased are necessary to determine the impact of the lessee's activities on the surface of the land. The matters considered in such analyses include the building and location of roads, pipelines, and powerplants. If it is determined that the lease and lessee's activities will not significantly interfere with the environment, the lease can be issued.

In California, 528 noncompetitive lease applications were filed during January 1974--the first 30-day filing period following the effective date of the leasing regulations. At the end of April, BLM determined that about 200 of these applications involved lands that overlapped by 50 percent or more. The overlapping lands amounted to approximately 180,000 acres, or about 20 percent of the acreage for which applications were received. These overlapped areas are to be reclassified as KGRAs and held for competitive leasing at a later date.

Since there is no limitation on acreage held under application, many firms or persons filed for more than 20,480 acres. Consequently, applications for lease of certain lands duplicated the lands of other applicants. Some applicants filed for over 100,000 acres in a State. However, 20,480 acres is the maximum which the act authorizes one lessee to hold in any one State. 1/

The Chief, Branch of Leasing, BLM, said that after January 1974 noncompetitive applications had not been received in large quantities and that overlapping applications had not continued to be a problem. He agreed with our view, however, that this aspect of the leasing program should be closely monitored and that corrective action should be taken if it becomes a problem again.

Although these overlapping applications should prompt USGS to analyze the geology of these areas, we believe that such areas should not be automatically designated as a KGRA without enough evidence to support such a designation.

Provisions of recently enacted legislation

The need for improved methods for locating and evaluating geothermal resources are recognized in recently enacted legislation--the Geothermal Energy Research, Development, and Demonstration Act of 1974 (Public Law 93-410, approved Sept. 3, 1974). The act authorizes a resource inventory and assessment program which includes the goals of (1) improving techniques necessary for locating and evaluating geothermal resources and (2) developing better methods for predicting the power potential and longevity of geothermal reservoirs.

Under the act, Geological Survey and others are responsible for, among other things,

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1/Although 20,480 acres is the maximum which one lessee can hold in any one State, section 18 of the Geothermal Steam Act of 1970 provides that lessees may unite with each other in a unit plan for development or operation of a geothermal pool or field whenever this is determined and certified by the Secretary of the Interior to be necessary or advisable in the public interest. Lessees committed to any unit plan are not included in computing the acreage limitation.

"* * * using innovative geological, geophysical, geochemical, and stratigraphic drilling techniques, 1/ which will lead to a national inventory of geothermal resources in the United States."

This act authorizes Federal agencies to participate with non-Federal entities in research to develop, improve, and test technologies for the discovery and evaluation of all forms of geothermal resources. The act provides also that Federal agencies recommend legislation, as necessary, to make Federal leasing policy for geothermal resources consistent with (1) known inventories of various geothermal resources, (2) the current state of technologies for geothermal energy development, and (3) current evaluations of the environmental impacts of such development.

Effective implementation of this act should, in the long term, result in a sounder basis for designating Federal lands as KGRAs, provide better assurances to prospective lessees concerning the value of such geothermal resources and thereby contribute to the orderly development of the resources. Consistent with the intent of this act, we believe the Department should move as rapidly as possible to improve its knowledge about lands designated as KGRAs.

Agency comments

In commenting on the report in a December 13, 1974, letter (see app. IV), the Department stated that if it limited competitive auctions to those tracts on which estimates have been made of proven reserves, it would be required to either essentially eliminate the KGRA designation and rely completely on noncompetitive leasing or initiate an extensive exploratory drilling program, in effect taking over the exploration function from industry.

The Department recognized that stratigraphic drilling might provide important data in addition to that currently collected but stated that before doing such drilling consideration will have to be given to whether the expected payoff is enough to justify the added costs or preparation for lease sales. In addition, the Department noted that, in the case of hot mineralized water and dry rocks geothermal resources, there was no standardized technology available for harnassing geothermal energy and, thus, even a common understanding of the geothermal resource characteristics for a given tract leaves ample room for disagreement on its commercial value.

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1/Drilling techniques used to determine the nature, distribution, and relations of the stratified rocks of the earth's crust.

In conclusion, the Department stated that its

> "* * * current position is that geologic and geophysical data can provide sufficient grounds for designating KGRAs with the remaining uncertainty on resource characteristics inherent in developing subsurface resources appropriately dealt with by industry in the context of competitive auctions and subsequent development efforts."

Moreover, the Department stated that exploratory and development drilling are felt to be an integral part of industry efforts and not an appropriate function for the Government. The Department noted that this view was consistent with the Conference Report (H. Rept. No. 93-1301, Aug. 19, 1974) on the Geothermal Energy Research, Development, and Demonstration Act of 1974, which specifically stated that drilling activities

> "* * * should be to establish the extent and nature of geothermal resources, and should not involve any exploratory drilling, which is, and should remain the province of private industry."

The act places on the Geological Survey the responsibility for using innovative geological, geophysical, geochemical, and stratigraphic drilling techniques to develop improved information on geothermal resources. Although we do not suggest that the Department take over the type of exploratory drilling which the Conference Report on the act states should remain the province of private industry, we believe it should make the necessary effort, including obtaining subsurface data, to improve its techniques for locating and evaluating geothermal resources.

We recognize the improvements in such designations will not solve all the disagreements on the commercial value of geothermal resources resulting from technological uncertainties, but, in our opinion, improvements in designating KGRAs would appear to be a first step in promoting the orderly development of geothermal resources.

## LEASING REGULATIONS CAN BE STRENGTHENED TO PROMOTE EARLY EXPLORATION AND DEVELOPMENT OF LEASED LANDS

The Department's leasing regulations do not require lessees to drill exploratory wells to evaluate the area's potential for heat, power, minerals, or fresh water. Under the geothermal leasing regulations, however, each geothermal

lease is to provide for the diligent exploration of the leased resources until there is production in commercial quantities. Failure to perform such exploration may subject the lease to termination. In addition, the regulations provide the following incentives to lessees for early exploration and development.

--Rental fees on the leased acreage can be increased after the fifth year if there is no production.

--Rental fees will be eliminated once production begins.

--Certain expenditures for diligent exploration may be credited against rental fees after the fifth year.

A USGS official responsible for supervising geothermal leases told us that USGS had not established a firm guideline on the required level of diligent exploration in the first 5 years of the lease and would probably not terminate leases in the first 5 years if no developmental actions were taken. He agreed that the regulations and leases probably should contain more specific requirements as to the minimum developmental actions required during the initial 5 years of a lease.

For succeeding years, however, the regulations provide a formula for computing the minimum expenditures necessary to qualify as a diligent exploration. The following table summarizes the minimum rents and expenditures necessary to maintain a lease for 2,560 acres, 1/ if no commercial production takes place during the 10-year lease.

| Year of the primary lease | Rent (note a) | Minimum expenditures for diligent exploration (note a) | Total |
|---|---|---|---|
| 1 to 5 | $12,800 | $ - | $ 12,800 |
| 6 | 5,120 | 10,240 | 15,360 |
| 7 | 7,680 | 15,360 | 23,040 |
| 8 | 10,240 | 20,480 | 30,720 |
| 9 | 12,800 | 25,600 | 38,400 |
| 10 | 15,360 | 30,720 | 46,080 |
| Total | $64,000 | $102,400 | $166,400 |

a/No minimum has been established for diligent exploration during the first 5 years. After the fifth year, the minimum expenditure is twice the rent.

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1/The law provides that a geothermal lease shall embrace a reasonably compact area of not more than 2,560 acres.

According to USGS officials, drilling geothermal exploration wells up to 10,000 feet is the only way to determine actual geothermal reservoir characteristics and to quantitatively evaluate the potential for heat, power, minerals, or fresh water. Since the cost of an 8,000-foot geothermal production well would be about $800,000 ($100 a foot), according to an AEC official, the total required expenditures for diligent exploration of 2,560 acres over the 10 years apparently would be less than the cost of one deep well.

The Chief, Branch of Leasing, BLM, said that the required minimum expenditures probably should be higher but that he believed more experience was needed before this could be definitely concluded. In our view, the signing of leasing agreements with the present requirements for diligent exploration will make it difficult to require a higher level of expenditure in the future, if experience shows that a higher level is needed.

To encourage early drilling of exploratory wells and development of geothermal resources and to discourage speculation, leasing regulations should be strengthened by (1) increasing the level of expenditures by lessees during the primary 10-year lease term to an amount more closely approximating the cost of drilling at least one deep well and (2) providing more specific requirements as to the minimum developmental actions required during the initial 5 years of a lease.

Agency comments

In its December 13, 1974, letter (see app. IV), the Department said that, although it considered drilling costs at the time that provisions were placed in the regulations for increased rental fees and for minimum expenditures in the second half of the 10-year primary lease term, there is disagreement now over the current cost of drilling an exploration well. The Department said that experience with existing leases can give it better information on that problem.

Even if the $166,400 in minimum expenditures and rental fees for an average geothermal tract does not cover the costs of an exploration well, the Department said that current regulations provide incentives for diligent development. The Department said that a lessee's basic options are:

--Putting down the amount of money bid and $166,400 in minimum expenditures and rental fees to maintain rights to the lease. At the end of the 10 years, no return will have been realized on the investment, and exploratory drilling will still be required to determine whether the lease is worth developing.

--Putting down the amount of money bid and spending $210,000 to $520,000 on an exploration well. The lessee can then decide to abandon the lease--and take a tax writeoff on the acquisition and exploration costs--or start production and begin to realize a return on his investment.

Although we agree that the lessee's options cited by the Department should provide some incentive for exploratory drilling, their principal impact would be on lessees who hold large tracts of leased lands or who have sufficiently high taxable income to obtain large benefits from tax writeoffs.

The $166,400 minimum expenditure referred to by the Department and cited by us (see p. 40) is for tracts of land comprising 2,560 acres--the maximum-sized tract authorized by law. Most of the tracts leased by the Department are less than 2,560 acres; many have less than 1,000 acres and several have less than 200 acres. Since the amount of required minimum expenditures is computed on the basis of the number of acres in a tract, the incentives cited by the Department may not be adequate to cause timely development of the smaller tracts.

## LEGAL PROBLEMS INVOLVING GEOTHERMAL RESOURCES DEVELOPMENT

Ownership and control over use of geothermal resources on certain lands is in question because of the lack of a definite classification of geothermal resources as minerals, gas, or superheated water. Because various laws deal with ownership and control over use of minerals, gas, and water, issuing leases on certain lands within known geothermal resource areas will be delayed or precluded, pending adjudication of legal issues. Present laws do not clearly provide for the Department to lease offshore geothermal zones and, therefore, the Department has not initiated leasing of these zones.

### Classification of geothermal resources

Although geothermal steam and associated geothermal resources have been defined by the Geothermal Steam Act of 1970, the resources are referred to in the act as (1) steam and some other gas, (2) heat or some other associated energy, and (3) hot water. The differing classifications have added to the problems concerning the ownership of the resources and may affect the control over use of the resources.

The ownership problem is illustrated by a case involving the Stock Raising Homestead Act of 1916 (43 U.S.C. 291-302). This act permitted qualified people to obtain lands that the Secretary of the Interior determined to be valuable chiefly for grazing and raising forage crops. Under this act, the Government gives up title to the lands while reserving coal and other mineral rights. The Government has such rights on approximately 40 million acres of land, of which 14,000 acres are at The Geysers KGRA. Some of the 14,000 acres were developed for geothermal energy before the Geothermal Steam Act was passed.

In October 1972 the Government brought suit 1/ against the Union Oil Company of California and others to determine ownership rights to the geothermal resources being produced on lands granted under the act. The United States district court considered the Department's opinion that geothermal steam is merely superheated water and concluded that water is not a mineral within the meaning of the act. The district court determined that the Government had no right to, or interest in, geothermal resources discovered on land granted by the Government under the act because such resources did not come within the definition of "minerals" in use when the act was passed.

The case is being appealed and the Government cannot legally issue geothermal leases on lands granted under the act until the courts reach a final decision. A geothermal development company official told us that private industry would not attempt to develop the geothermal resources on these lands until the issue is resolved. However, there is some indication that certain surface owners, as well as grandfather preference right holders, 2/ would be willing to have the geothermal resources leased with the understanding that all rents, royalties, and bonuses be held in escrow, pending final resolution of the title question. This would facilitate development of the resources at an earlier date than would otherwise be possible.

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1/ United States v. Union Oil Co. of Calif., 369F. Supp. 1289 (N.D. Calif. 1973).

2/ The grandfather clause provision of the Geothermal Steam Act gave preference to persons holding leases, permits, or claims under the Mineral Leasing Act of 1920, as amended (30 U.S.C. 181-287), or the Mineral Leasing Act of Acquired Lands, as amended (30 U.S.C. 351, 358), who could convert these to geothermal leases.

The particular problem of mineral ownership being dealt with in the Union Oil case exists only with regard to land conveyed before the Geothermal Steam Act was enacted. With regard to land conveyed by the Government after enactment of the Geothermal Steam Act, section 25 of the act (30 U.S.C. 1024) provides that all laws that provide for conveying land subject to a mineral reservation shall be deemed to embrace geothermal resources as a substance that must be reserved.

Other potential ownership problems, however, stem from the classification problem. For example, geothermal resources, depending upon how classified, could belong to the owner of water rights. Ownership problems exist because different resources--water, minerals, etc.--are subject to different ownership ramifications.

Another issue stemming from the classification problem is control over use of geothermal resources. Once ownership of the resources has been determined, there remains a question as to what extent States may maintain control over the use of geothermal resources on Federal lands.

To illustrate this potential problem, if geothermal resources are classified as water, depending on the extent to which State water laws apply to geothermal resources located on Federal lands, it could hamper development of the resources. Various States, including California, have laws which control the use of water, including, in some cases, a prohibition against transporting water out of a State. Resolution of this issue could have an impact on the Bureau of Reclamation's program for using geothermal water to augment the flow of the Colorado River. (See ch. 4.)

Examples of State laws dealing with the control over use of water are as follows:

--Oregon Revised Statutes §537.810 (1953): "No waters located within this State shall be diverted, impounded, or in any manner appropriated for diversion or use beyond the boundaries of the State except upon the express consent of the Legislative Assembly."

--Colorado Revised Statutes 148-1-1 (1963): "* * * it shall be unlawful * * * to divert, carry, or transport * * * the water * * * of this State into any other State for use therein."

--California Water Code §104 (Deering 1954): "* * * the State shall determine what water of the State, surface and underground, can be converted to public use or controlled for public protection."

Geothermal resources have been classified in different ways under different circumstances. In the Union Oil case, referred to above, the geothermal resource was treated as being similar to water. In another Federal case, Reich v. Commissioner of Internal Revenue, 454 F. 2d 1157 (9th Cir. 1972), which involved geothermal steam, the court held the geothermal resource to be a gas within the meaning of the Internal Revenue Code provisions for depletion allowance and intangible drilling costs. In these cases, the court apparently attempted to categorize the resources on the basis of the substance being withdrawn or extracted from the land.

Several States have classified geothermal resources by statute, but the classifications have not been consistent. For example, California defines geothermal resources as:

> "* * * the natural heat of the earth, the energy, in whatever form, below the surface of the earth present in, resulting from, or created by, or which may be extracted from, such natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases and steam, in whatever form, found below the surface of the earth, but excluding oil, hydrocarbon gas or other hydrocarbon substances."

Thus, under California law, geothermal resources are not specifically defined as water, minerals, or gases, but rather as a combination of resources. On the other hand, Hawaii considers them minerals.

Conclusion

Classification is a problem that could be an obstacle to the rapid and orderly development of geothermal resources. There are various laws dealing with ownership and control over the use of water, minerals, and gas, and it is difficult to determine whether and when to apply which laws. A specific classification placing a geothermal resource within one or more of these resources might necessitate litigation.

Since geothermal resources have characteristics of water, minerals, and/or gas, they do not, in our opinion, readily fit within any resource classification. To avoid the ambiguity which could result from existing laws, legally classifying geothermal resources in a special class of their own (sui generis) may be helpful. Idaho has provided for such a classification (sec. 42-4002 of the Idaho Code), as follows:

"(c) Geothermal resource means the natural heat energy of the earth, the energy, in whatever form, which may be found in any position and at any depth below the surface of the earth present in, resulting from, or created by, or which may be extracted from such natural heat, and all minerals in solution or other products obtained from the material medium of any geothermal resource. Geothermal resources are found and hereby declared to be sui generis, being neither a mineral resource nor a water resource, but they are also found and hereby declared to be closely related to and possibly affecting and affected by water and mineral resources in many instances." (Underscoring supplied.)

The Department should monitor the problems with the resources' classification and should propose clarifying legislation to the Congress if the problems hamper development of the resources.

Lack of a clear provision for offshore geothermal leasing

Present law does not clearly provide for leasing of offshore geothermal zones. Since about two-thirds of the geopressured zones are reported to lie offshore, this could pose a problem to their future development.

Section 3 of the Geothermal Steam Act states:

"* * * the Secretary of the Interior may issue leases for the development and utilization of geothermal steam and associated geothermal resources (1) in lands administered by him, including public, withdrawn, and acquired lands * * *."

The act does not specify whether the above provision provides for leasing offshore lands. The Government claims jurisdiction over and administers offshore lands (Outer Continental Shelf Lands Act, 43 U.S.C. 1331, 1332 (1953)). However, since it does not claim title to the offshore lands, such lands do not appear to be within the meaning of "public, withdrawn and acquired lands," which are lands owned by the Government.

Although "public, withdrawn and acquired lands" does not appear to include offshore lands, section 3 of the act might be construed to include offshore leasing because offshore lands are generally administered by the Secretary of the Interior. Section 3 refers to lands "administered by him, including public, withdrawn and acquired lands." If the law

merely stated that the Secretary could issue geothermal leases in lands administered by him, offshore lands would probably be included.

However, the term "including," followed by a list of types of land, was added. The term "including" has various uses, "in some instances operating as a restriction upon and in others as an enlargement of the general language that precedes it, and in still others simply as connoting illustrative examples." In Re Midas Coin Company, 264 F. Supp. 193, 198 (E.D. Mo. 1967). Since it is not clear how the term "including" is used in section 3, it is not clear whether the Geothermal Steam Act provides for offshore leasing.

The only other Federal law that might provide for offshore geothermal leasing is the Outer Continental Shelf Lands Act, (43 U.S.C. 1331-1343). Section 4 of the Outer Continental Shelf Lands Act (43 U.S.C. 1333) provides that "* * * mineral leases on the Outer Continental Shelf shall be maintained or issued only under the provisions of this subchapter." Whether geothermal leases qualify as mineral leases (defined at 43 U.S.C. 1311(c) as "any form of authorization for the exploration for, or development or removal of deposits of oil, gas, or other minerals") would appear to depend on whether geothermal resources qualify as "oil, gas, or other minerals," within the meaning of the Outer Continental Shelf Lands Act.

The question of legal authority to lease offshore lands for geothermal development is further complicated by section 23(b) of the Geothermal Steam Act (30 U.S.C. 1022(b)), which provides:

> "Rights to develop and utilize geothermal steam and associated geothermal resources underlying lands owned by the United States may be acquired solely in accordance with the provisions of this Act."

Thus, the authority to lease offshore lands for geothermal development is not clearly established by law.

USGS officials said that they had not designated offshore lands as KGRAs because they did not know if (1) offshore geopressed zones had any power potential and (2) they had the legal authority to lease the zones for geothermal development. We believe that, if the offshore zones were considered worthy of development, the Department should propose legislation clarifying its authority for offshore geothermal leasing.

NSF told us that, as part of its geothermal research program, it was examining these legal problems.

## Agency comments

In its December 13, 1974, letter (see app. IV), the Department told us that the recommendations in this report pertinent to special arrangements for leasing land where ownership of geothermal resources is in dispute, and legislation to clarify the classification of geothermal resources as well as the Department's authority for offshore geothermal leasing, will be considered in the implementation of the Geothermal Energy Research, Development, and Demonstration Act of 1974.

## RECOMMENDATIONS TO THE SECRETARY OF THE INTERIOR

We recommend that the Secretary:

--Improve the methods for designating a KGRA by obtaining subsurface data when practicable and, in the case of areas designated as KGRAs because of overlapping noncompetitive lease applications, analyze the geology of any area before a value is assigned to the area and it is offered for lease.

--Strengthen the leasing regulations by increasing the level of expenditures required of lessees during the primary 10-year lease term to an amount more closely approximating the cost of drilling at least one deep exploratory well and by providing more specific requirements as to the minimum developmental actions required during the initial 5 years of a lease.

--Consider making special arrangements for leasing lands where the ownership of geothermal resources is in dispute by providing for issuing leases with the understanding that all rents, royalties, and bonuses would be held in escrow, pending resolution of the title question.

--Propose legislation to classify geothermal resources in a special class of their own, if the lack of such a clear classification hampers their development.

--Propose legislation to clarify the Department's authority for offshore geothermal leasing, if the offshore geothermal sites are considered worthy of development.

## CHAPTER 4

## DEVELOPING POTABLE WATER FROM GEOTHERMAL BRINES

The potential problems discussed in chapters 2 and 3--resources characteristics, technology, and the leasing program--could hinder the development of geothermal resources for power production and the Bureau of Reclamation's program for obtaining potable water by desalinating geothermal brines. Although the program is providing valuable information on resource characteristics and technology, data obtained during the early exploration and research stage has raised doubts about whether it will be economically feasible to implement a coordinated program to obtain power and potable water from the brines in Imperial Valley. The technology being developed in Imperial Valley, however, can be transferred to other areas which might have more potential. Further exploration and research may improve the potential for concurrent development of power and potable water.

As a result of the problems discussed in this chapter, the Bureau might not obtain as much water in Imperial Valley as originally hoped for to implement one objective of the Colorado River Basin Project Act of 1968 (43 U.S.C. 1501)--augmenting the flow of the Colorado River by 2.5 million acre-feet a year.

The Colorado River Basin Project Act of 1968 requires the Secretary of the Interior to make reconnaissance studies on meeting future water needs of the Western United States and to determine the most economical method of augmenting the flow of the Colorado River by 2.5 million acre-feet a year. This mission has been delegated to the Bureau.

The flow of the Colorado River needs to be augmented because:

--There is an international obligation to deliver 1.5 million acre-feet of water annually to Mexico to satisfy the requirements of the Mexican Water Treaty.

--The salinity level of the Colorado River is rising. Without a major water quality improvement program by the year 2000, this water will increase to a salinity level unsuitable for many of its present uses. The poor quality of the water supplied to Mexico from the Colorado River has already become a matter of international dispute.

--The Colorado River Compact has allocated more water per year for consumptive use by the seven basin States than the runoff records of recent decades indicate is

available. Bureau of Reclamation investigations concluded that by the year 2000 a deficiency of about 2.42 million acre-feet will exist in the Colorado River without augmentation.

The Bureau is investigating methods of augmenting the Colorado River, including weather modification, sea water desalting, canal lining, and the desalination of geothermal brines in Imperial Valley.

## BUREAU'S PROGRAM FOR DESALINATING GEOTHERMAL BRINES

The Bureau is involved in the first stage of a potential three-stage geothermal program 1/ to produce as much as 2.5 million acre-feet a year of fresh water and 10,500 megawatts of power from Imperial Valley's brines found on federally owned lands in Imperial Valley.

Through June 1973 the Bureau spent about $2.34 million for geothermal exploration and resource development in Imperial Valley. Five deep geothermal wells have been drilled at East Mesa KGRA, and two small test desalting units have been installed which produce small amounts of high quality potable water. (See picture on page 52.) In addition, other benefits have accrued from this program. For example, (1) information on heat flow, resistivity, and seismic activity was obtained and disseminated to all interested parties, (2) private industry recently expressed interest in testing equipment at the Bureau's facility, and (3) almost all information gathered applies as much to power development as to water development. During fiscal year 1975, the Bureau plans to begin experimenting with reinjection of geothermal brines.

Funding requirements through completion of the program, as estimated by the Bureau, are summarized in the following table.

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1/ This program is described in a January 1972 Bureau of Reclamation report entitled "Geothermal Resources Investigations, Imperial Valley, California, Developmental Concepts."

| Development program | Estimated amount required through completion |
|---|---|
| | (000,000 omitted) |
| R&D stage (1972-79) | $ 13 |
| Demonstration stage (1980-90) | a/ 209 |
| Large-scale implementation (1990) | a/6,340 |
| Total | $6,562 |

a/ These amounts would be shared with private firms if joint-venture agreements to produce both power and fresh water from the same system of wells could be worked out.

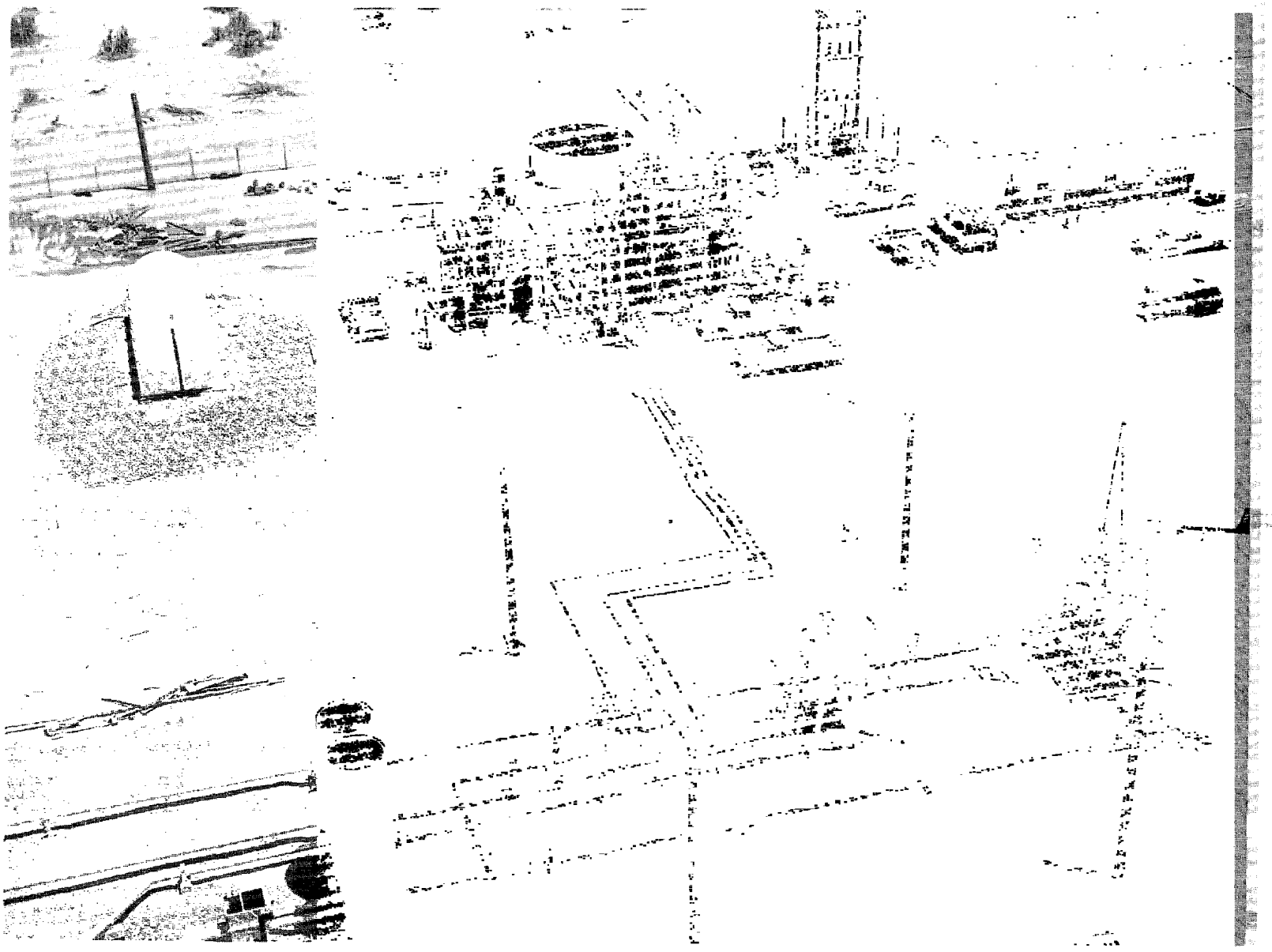
After completing the R&D stage, the Bureau plans to issue a feasibility report and to decide whether the demonstration stage of the program is justified.

Bureau officials told us that it is still too early in the program to accurately determine the quantity of water and power that could eventually be produced from Imperial Valley geothermal resources. However, the Bureau has developed a representative plan for the second and third stages so that prospective costs of augmenting the Colorado River waters can be estimated. This plan was also used as a basis for cost analysis and program description. (See app. II.)

The cost estimates made in 1971 for the demonstration and large-scale implementation stages are only rough approximations which will be greatly influenced by the technology developed in the R&D stage. However, some developments which have occurred since the estimates were made--such as the geothermal leasing program, the possible use of the binary-cycle power system, and lower resource estimates--tend to make the original estimated program results high.

## IMPACT OF THE GEOTHERMAL LEASING PROGRAM

The Bureau's original geothermal program was based on the assumptions that the production of large quantities of both water and power was possible on its withdrawn lands and that the Bureau would control its withdrawn lands in Imperial Valley. To obtain leases under this program, power companies would have been required to enter joint-venture agreements with the Bureau for developing combined waterpower systems. On April 20, 1973, however, a Department geothermal leasing policy made Federal lands, including Bureau-withdrawn lands



Source: Department of the Interior

**Bureau of Reclamation geothermal test site at East Mesa, California.**

in Imperial Valley, available for leasing to private firms for power and other resources development under the Geothermal Steam Act. (See ch. 3.)

USGS has identified six KGRAs in Imperial Valley, four of which include lands subject to the act as shown below.

| KGRA | Acres subject to the act |
|---|---|
| Salton Sea | 18,914 |
| Glamis | 23,425 |
| Dunes | 7,680 |
| East Mesa | 32,725 |
| Heber | - |
| Brawley | - |

Much of the Salton Sea KGRA in Federal ownership is under the sea and involves complex problems in extracting and using the geothermal fluids. The remaining KGRAs subject to the act lie mostly on Bureau-withdrawn lands. However, the Glamis and Dunes areas are used as part of a BLM desert recreation program and therefore BLM has not recommended them for geothermal development.

The East Mesa was one of the three KGRAs included in the first geothermal lease sale in January 1974. Bids were received for 5 of the 14 tracts offered on East Mesa; all 5 were accepted. A second lease sale was held in June 1974, and one bid was received on one of the remaining tracts.

To maintain the viability of the Bureau's program in Imperial Valley, the notice of geothermal lease sale contained special stipulations and conditions for the East Mesa KGRA, as follows:

> "* * * The Lessor reserves the ownership of brines and condensates and the right to receive or take possession of all or any part thereof following the extraction or utilization by Lessee of the heat energy associated therewith subject to such rules and regulations as shall be prescribed by the Secretary of the Interior." (Underscoring supplied.)

The special stipulation and conditions give the Bureau the right to test and evaluate the leased lands and to erect and operate any facilities necessary for desalination research.

The proposed leasing agreements contain a provision that gives the Government the options to take products or

byproducts of geothermal development--if the lessee's activities under the lease would not be impaired and if such taking would otherwise be consistent with field and operational requirements--if the lessee does not initiate a program to produce commercially demineralized water where feasible from such products or byproducts.

These stipulations would be adequate to protect the Bureau's interests in the East Mesa area if the brines had enough heat energy after being used for power generation to allow for economical desalination; however, as explained in the next section, this may not be the case.

## IMPACT OF LOWER TEMPERATURE AND PRESSURE THAN ORIGINALLY ASSUMED

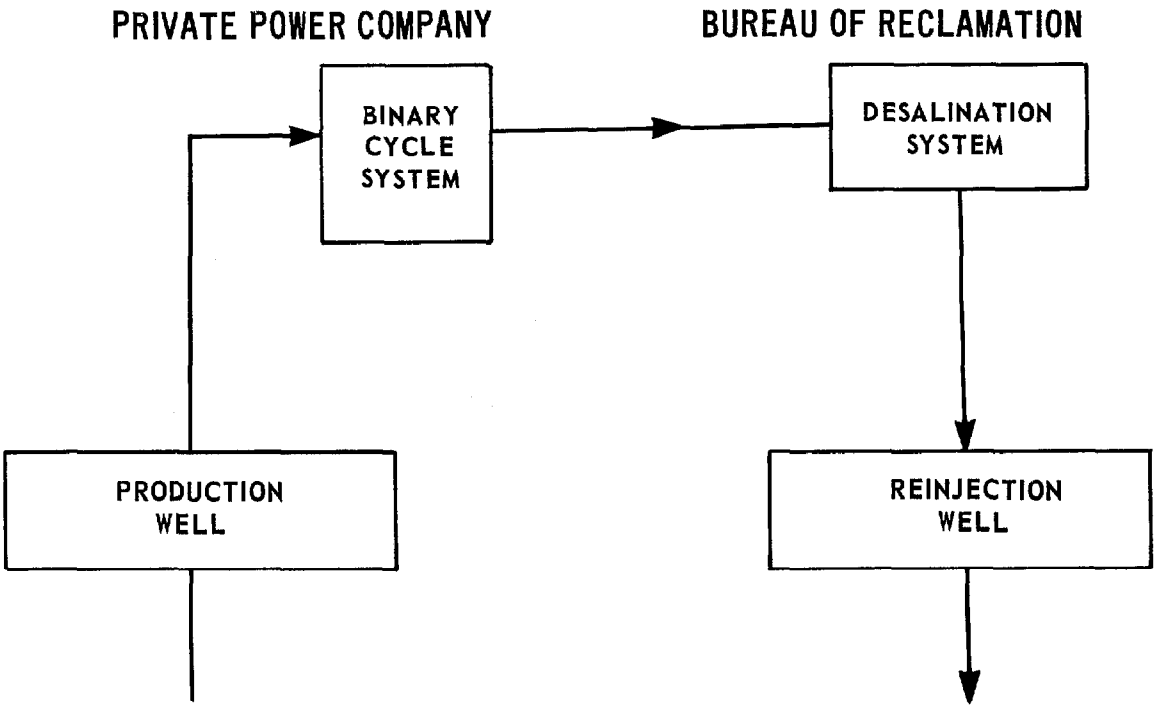
The temperature and pressure characteristics of geothermal resources on the Bureau's lands in Imperial Valley were originally assumed to be much the same as those found at Cerro Prieto, Mexico, 30 miles to the south. The Bureau estimated that, by coupling flashed-steam powerplants (see illustration on p. 22) with desalination units, 80 percent of the brines obtained could be recovered as fresh water with no major sacrifice in the amount of power generated. However, Bureau exploration on the East Mesa KGRA has indicated that the temperatures and pressures of geothermal fluids at East Mesa are considerably lower than assumed, as shown in the following table.

| | January 1972 estimate | Actual results (note a) | |
|---|---|---|---|
| | | Mesa well 6-1 | Mesa well 6-2 |
| Well depth (feet) | 4,500 to 6,000 | 8,030 | 6,005 |
| Temperature in bottom hole | 600°F | 400°F | 370°F |
| Temperature at surface | 398°F | b/ 300°F | b/ 310°F |
| Flowing pressure (pounds per square inch) | 242 | b/ 56 | b/ 96 |

a/ In January 1974, Mesa 6-1 was perforated at shallower depths; conditions approximated Mesa 6-2. Also, from April through July 1974, the Bureau completed three more geothermal wells to depths of about 6,000 feet. Bureau officials said that the temperatures and pressures of brines obtained from these wells were similar to or lower than those obtained from the Mesa 6-1 and Mesa 6-2 wells.

b/ Maximum obtained; some tests indicated much lower figures.

Both Government and industry officials told us that instead of using flashed steam generators, as in the Mexican field, power companies are most likely to attempt to use the binary-cycle system in Imperial Valley because of the lower temperatures and pressures. The binary-cycle system (see p. 22) offers environmental advantages over other systems because gases do not escape to the atmosphere and all the fluid can be reinjected into the reservoir to limit subsidence effects. The kind of system which Bureau officials told us would be used under these circumstances is shown below.




According to industry data, the binary-cycle system, if designed to produce maximum power, would extract maximum heat from the brines and yield effluents at relatively low temperatures. For example, if brines at temperatures of 350°F are obtained and delivered, the temperature of the output brines from the power system would be about 170°F. Bureau officials told us that brines at temperatures of at least 240°F would be needed for economical desalination and that higher temperatures would be preferable. Furthermore, the hotter the brine put into the desalination unit, the more fresh water can be recovered from it, and the more economical the process would be.

Bureau officials agreed with our observation that power systems designed to yield output brines at a temperature of 240°F, rather than 170°F, would sacrifice large amounts of power and allow for the recovery of only small amounts of

fresh water. To obtain greater amounts of fresh water, more power must be sacrificed. Therefore, a trade-off is involved. The officials said that the desalination project might still be feasible if power companies would agree to redesign the binary-cycle system to extract less heat from the brines and yield effluents at the necessary higher temperatures. To compensate for the reduction in power production, the Bureau would assume the responsibility for reinjecting and disposing of residual brines to prevent sinking and meet environmental requirements.

## IMPACT OF LOWER RESOURCE ESTIMATES

The Bureau's 1972 report on geothermal developmental concepts includes the following statements:

> "Based on data available to date, it is estimated that it may be possible to develop as much as 2.5 million acre-feet of desalted water per year from geothermal well fields in Imperial Valley.
>
> "Preliminary estimates by the Geological Survey indicate that 1.1 billion acre-feet of water are usable and recoverable at feasible drill hole depths in the Imperial Valley."

USGS made the most recent appraisal of the quantity and temperature of recoverable brines in Imperial Valley in 1971. The appraisal, published in 1972 as USGS Circular 649, came to several important conclusions, two of which are stated below.

> "Although the estimates of recoverable water in the Imperial Valley area were based on an assumption that all water in storage would be recoverable through wells by some means, production of much of the water may not be economically feasible.
>
> "In summary, economic studies are needed to determine the feasibility of recovering the 1.1 billion acre-feet of water estimated * * * as being recoverable. Such studies may indicate that recoverable water is only about 100 million acre-feet at a temperature less than 100°C (212°F), less than 100 million acre-feet at higher temperature, and less than 200 million acre-feet from all sources."

Although the USGS circular stated that additional water could be recovered through pumping, it showed that the costs would be very high. The study indicated that, without such

costly techniques, the recoverable geothermal brines would be only about one-tenth the amount estimated previously.

As mentioned earlier, the Bureau's original goal in Imperial Valley was to produce as much as 10,500 megawatts of power and 2.5 million acre-feet of fresh water a year. However, on the basis of the USGS study, the Stanford Research Institute concluded in a May 1973 report that "the maximum electric power capacity from geothermal resources in the Imperial Valley would appear to be from 2,000 to 3,000 MW [megawatts]." Bureau officials agreed that, if the USGS appraisal proves correct, the scope of the Bureau's proposed program would have to be considerably reduced.

## AGENCY COMMENTS

In its letter of December 13, 1974 (see app. IV), the Department pointed out that the Bureau's program was the first Federal development-oriented program, and considering the program's limited resources, it has contributed greatly to advancing the state of the art in both desalting and power production as well as in environmental problems associated with geothermal resource utilization.

The Department emphasized that its report on developmental concepts for obtaining 2.5 million acre-feet a year of fresh water from Imperial Valley to augment the flow of the Colorado River was designed to demonstrate the cost of such augmentation if it were done entirely from geothermal brines. The Department stated that its report was not intended to be an estimate that such a quantity of fresh water actually was capable of being produced in the Valley and that such production from geothermal brines is not required to comply with the Colorado River Basin Project Act of 1968. This act requires that augmentation of the Colorado River by 2.5 million acre-feet a year be done by the most economical means and, according to the Department, at least 1.5 million acre-feet a year can probably be provided at nominal cost by the Bureau's Weather Modification Program, barring environmental or legal restraints. Thus, less than 1 million acre-feet per year would need to be provided by desalting geothermal brines should that source be the second most economical method of augmentation.

The Department said that only a fraction of Imperial Valley had been explored in adequate detail to hazard an estimate of the geothermal potential and, in any event, the question of how large a resource is available in the Valley should not be a deterrent on a program that is aimed at development of a new technology.

The Department also said that development of the binary-cycle system for producing power will not necessarily preempt desalting of geothermal brines for the following reasons.

--Binary-cycle power development is still in the experimental stage and lacks proven technical and economic feasibility, as does desalting geothermal brine technology. Either, neither, or both may survive the research stage.

--Even if the binary-cycle power system should prove to be feasible, the resource could well prove to be more valuable as a water source. Water at one hundred dollars per acre-foot equates to a cost of only about 5 cents per barrel of oil if the water is used for oil shale production. It is possible that water will prove to be a limiting factor in oil shale production, as almost the entire oil shale resources are located in the water-short Colorado River Basin.

--The binary-cycle power system, if feasible, would probably be limited to the cooler-type geothermal anomaly, such as the Mesa Anomaly. On hotter types of anomalies, direct steam power production would probably be utilized and the hot brines would be available in a joint water/power system such as that presented in the Developmental Concepts Report.

--Recent studies show that multipurpose water-power development is still possible and probably economical, using 400°F geothermal brines and a binary-cycle power system.

In summary, the Department said that there was a possibility that much hotter anomalies 1/ remain to be discovered and that there is no basis for considering the Bureau's program as deficient because of concurrent research in the binary-cycle type of geothermal powerplant.

## CONCLUSIONS

Although the Bureau's program is yielding valuable data to the scientific and industrial community on the potential for geothermal development in Imperial Valley, information based on early exploration and research efforts has raised doubts that geothermal resources in the Valley have as much potential for supplying large amounts of water to the Southwest as originally hoped. This view is supported by the

---

1/ Areas of the earth where the temperatures are higher than the average.

recent estimates of water supply by USGS, the Stanford Research Institute study, and the trade-off involved in the coordinated development of power and potable water at the brine temperatures being found. As a result, the Bureau might not obtain as much water from geothermal resources in Imperial Valley as originally hoped for in meeting the objectives of the Colorado River Basin Project Act of 1968.

The technology being developed by the Bureau in Imperial Valley, however, can be transferred to other areas which might have more potential. In addition, further exploration and research may improve the potential for concurrent development of power and fresh water from geothermal brines in Imperial Valley and other locations.

GEOTHERMAL ACTIVITY BY NATION

| | Electrical power in megawatts (note a) | Space heating | Manufacturing and processing | Agriculture and green houses | Refrigeration | Byproduct chemicals |
|---|---|---|---|---|---|---|
| UNITED STATES: | | | | | | |
| The Geysers, California | 396 | | | | | |
| Klamath Falls, Oregon | | X | | | | |
| Boise, Idaho | | X | | | | |
| ITALY: | | | | | | |
| Larderello | 365 | | | | | |
| Monte Amiata | 25 | | | | | |
| MEXICO: | | | | | | |
| Cerro Prieto | 75 | | | | | |
| Pathe | .5 | | | | | |
| NEW ZEALAND | 170 | X | X | X | | |
| ICELAND | 3 | X | X | X | | |
| JAPAN | 33 | X | | X | | |
| SOVIET UNION | 29 | X | X | X | X | X |
| HUNGARY | | X | | X | | |

a/ 1973 figures.

APPENDIX II

BUREAU OF RECLAMATION CONCEPTUAL PLAN FOR

GEOTHERMAL DEVELOPMENT OF IMPERIAL VALLEY, CALIFORNIA

| Features | Stage 1<br>R&D stage | Stage 2<br>Demonstration stage | Stage 3<br>Large-scale development |
|---|---|---|---|
| NUMBER OF GEOTHERMAL WELLS: | | | |
| Production | - | 72 | 1,800 |
| Injection | 11 | 100 | 2,400 |
| Total | 11 | 172 | 4,200 |
| DESALTING PLANTS: | | | |
| Number | 2 | 6 | 150 |
| Annual production capacity (acre-feet) | 2,000 to 3,000 | 100,000 | 2.5 million |
| WATER DELIVERY SYSTEM: | | | |
| Destination | local | All American canal | Colorado River |
| Miles | - | 8 | 150 |
| WATER IMPORT SYSTEM: | | | |
| Source | Groundwater | Salton Sea | Pacific Ocean |
| Miles | - | 48 | 126 |
| POWERPLANTS: | | | |
| Number | - | 6 | 150 |
| Capacity in megawatts | - | 420 | 10,500 |
| COST: | | | |
| Water | $13,000,000 | $120,913,000 | $4,303,138,000 |
| Power | - | 88,387,000 | 2,036,862,000 |
| Total | $13,000,000 | $209,300,000 | $6,340,000,000 |
| COST IN DOLLARS PER ACRE-FOOT OF DESALTED WATER | - | $85 to $130 | $100 to $150 |

# LIST OF PRINCIPAL REPORTS AND STUDIES CONSIDERED IN PREPARING THIS REPORT

"Classification of Public Lands Valuable for Geothermal Steam and Associated Resources," Geological Survey Circular 647 (Washington, D.C.; 1971, U.S. Geological Survey).

"Final Environmental Statement for the Geothermal Leasing Program," U.S. Department of the Interior. (Washington, D.C.; U.S. Government Printing Office, 1973).

"Geothermal Energy: Resources, Production, Stimulation." Edited by Paul Kruger and Carel Otte, Stanford, California (Stanford University Press, Stanford University, 1973).

"Geothermal Resource Investigations, Imperial Valley, California: Developmental Concepts," Bureau of Reclamation, Jan. 1972.

"Meeting California's Energy Requirements, 1975-2000," Stanford Research Institute, May 1973 (SRI Project ECC-2355).

"Preliminary Appraisal of Ground Water in Storage with Reference to Geothermal Resources in the Imperial Valley Area, California." Prepared in cooperation with the Bureau of Reclamation by USGS (Geological Survey Circular 649).

R. G. Bowen "Environmental Impact of Geothermal Development," Geothermal Energy Resources, Production, Stimulation, Op. Cit.

James B. Koenig "Worldwide Status of Geothermal Resource Development," Geothermal Energy, Resources, Production, Stimulation, ed., Paul Kruger and Carel Otte, Stanford University Press, 1973.

# United States Department of the Interior

OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20240

DEC 13 1974

Mr. Henry Eschwege
Director, Resources and Economic
Development Division
General Accounting Office
Washington, D. C. 20548

Dear Mr. Eschwege:

This responds to your request for comments on your proposed report to the Congress entitled "Problems Associated With Identification, Technological Development, and Use of Geothermal Resources".

As the report notes, the Geothermal Energy Research, Development and Demonstration Act of 1974 (P.L. 93-410) established an organizational framework and broad guidelines for developing policy on geothermal energy. It is expected that the work of the mandated Geothermal Energy Coordination and Management Project (GECMP) will consider and provide programmatic responses to the issues raised and the recommendations in the report covering such matters as leasing, R&D effort within the Department and others.

Pending the results of the Project efforts, it is appropriate at this time to provide a more general response to several of the issues raised in the report.

GEOTHERMAL LEASING PROGRAM

Designating Known Geothermal Resource Areas (KGRA). The report states that the Secretary should, before designating a KGRA, require that sufficient subsurface data be obtained to better indicate whether or not there is a commercially exploitable geothermal reservoir.

The basic point of the GAO is that industry is discouraged from entering competitive auctions for geothermal tracts because of inadequate data underpinning the KGRA designation. Competition could be focused on good prospects if more care was taken in making this designation.

Currently, Geological Survey relies on surface geology and geophysical data. Stratigraphic drilling might provide important data in addition

to that currently collected. Consideration will have to be given to whether or not the expected payoff is enough to justify the added costs or preparation for lease sales.

Beyond these efforts, making substantial inroads into the disagreement among "geothermal experts" on the value of designated KGRA's would require drilling and completion of wells so that estimates of proven reserves could be made. Were Interior to limit competitive auctions to those tracts on which estimates have been made of proven reserves, we would be required to:

-- essentially eliminate the KGRA designation and rely completely on noncompetitive leasing

or

-- initiate an extensive exploratory drilling program, in effect taking over the exploration function from industry.

The Department's current position is that geologic and geophysical data can provide sufficient grounds for designating KGRA's with the remaining uncertainty on resource characteristics inherent in developing subsurface resources appropriately dealt with by industry in the context of competitive auctions and subsequent development efforts. Moreover, exploratory and development drilling are felt to be an integral part of industry efforts and not an appropriate function for the Government. This view is apparently held by the Congress also as the Conference Report for the Geothermal Energy Research, Development, and Demonstration Act of 1974 specifically stated that drilling activities "should be to establish the extent and nature of geothermal resources, and should not involve any exploratory drilling, which is, and should remain the province of private industry."

Finally, it should be noted that--especially in the cases of hot mineralized water and dry rocks--there is no standardized technology available for harnassing geothermal energy. For this reason, even a common understanding of the geothermal resource characteristics for a given tract leaves ample room for disagreement on its commercial value.

Diligence Requirements. The report recommends a strengthening of leasing regulations by including an option to require an increased level of expenditures by lessees during the 10-year primary lease term and by providing more specific requirements as to the minimum developmental actions required during the initial 5 years of a lease.

The report does not note that the Interior Department took drilling costs into consideration at the time that provisions were placed in the regulations for increased rental fees and minimum expenditures in the second

half of the 10-year primary lease term. There is disagreement now over the current cost of drilling an exploration well. Experience with existing leases can give us better information on that problem.

Even if the report is correct in its assertion that the $166,400 in minimum expenditures and rental fees for an average geothermal tract does not cover the costs of an exploration well, current regulations provide incentives for diligent development. The lessee's basic options are:

-- Put down the bonus money and $166,400 in minimum expenditures and rental fees to maintain rights to the lease. At the end of 10 years, no return will have been realized on the investment and exploratory drilling will still be required to determine whether or not the lease is worth developing.

-- Put down the bonus money and spend $210,000 to $520,000 on an exploration well. The lessee can then decide to abandon the lease--and take a tax writeoff on the acquisition and exploration costs-- or start production and begin to realize a return on his investment.

Other Recommendations. The other recommendations in the report pertinent to special arrangements for leasing of land where ownership of geothermal resources is in dispute, and legislation to clarify the classification of geothermal resources as well as Interior's authority for offshore geothermal leasing will be considered in the implementation of the Geothermal Energy Research, Development and Demonstration Act of 1974 (P.L. 93-410).

DEVELOPING POTABLE WATER FROM GEOTHERMAL BRINES

This Bureau of Reclamation program also will be addressed by the GECMP. Certain facts about the program and the report commentary require clarification.

This program was the first Federal development-oriented program and, when one considers the limited resources devoted to it, has contributed significantly to advancing the state of the art in both desalting and power production as well as in environmental problems associated with geothermal resource utilization. We believe the report does not adequately credit the innovations of the Bureau in this evolving energy technology. The Bureau believes that its views on the two principal criticisms of its program should be presented in some detail.

1. The report repeatedly asserts that there may be less potential for water production from Imperial Valley than originally estimated, and implies that this is a serious shortcoming of the program.

The Bureau states that it has never estimated the geothermal potential of Imperial Valley. Only a tiny fraction of the Valley has been explored in adequate detail to hazard an estimate. The report credits the Developmental Concepts Report of 1972 which developed only estimated costs of fresh water if the resource should prove to be as large as 2,500,000 acre-feet per year. The report did not estimate that the resource was capable of that volume of production. Reclamation believes that the GAO report could be construed as meaning that production of 2,500,000 acre-feet per year was self evident as being the Public Law 90-537 requirement for augmentation of the Colorado River.

Actually, Public Law 90-537 requires that augmentation be done by the most economical method. Barring environmental or legal restraints, at least 1,500,000 acre-feet per year probably can be provided at a nominal cost of only several dollars per acre-foot by Reclamation's Weather Modification Program. If this program is implemented, less than 1 million acre-feet per year will be provided by desalting geothermal brines, should this source be the second most economical method of augmentation.

[See GAO note, p. 69.]

The principal reason for placing a stage III concept of 2,500,000 acre-feet per year production of fresh water in the Developmental Concepts Report was to demonstrate a maximum cost of augmentation if all of the augmentation were from geothermal brines. Reclamation's program is in no way deficient if less than 2,500,000 acre-feet per year are obtainable from desalting geothermal brines. Neither is there a need to give greater consideration to other alternatives as Reclamation has been diligently pursuing all alternatives within funding limitations and will continue to do so.

As stated in the report, geothermal desalting technology developed in the Imperial Valley program could and is expected to be used in other arid areas in the Western United States and in other parts of the world

to furnish needed fresh water supplies. Thus, the question of how large a resource is available in the Imperial Valley should not be deterrent on a program that is aimed at development of a new technology.

2. The report indicates that binary-cycle power development will probably preempt desalting of geothermal brines. This is not a valid assumption for several reasons.

a. Binary-cycle power development is still in the experimental stage and lacks proven technical and economic feasibility, as does desalting geothermal brine technology. Either, neither, or both may survive the research stage.

b. Even if the binary-cycle power system should prove to be feasible, the resource could well prove to be more valuable as a water source. Water at one hundred dollars per acre-foot equates to a cost of only about 5 cents per barrel of oil if the water is used for oil shale production. It is possible that water will prove to be a limiting factor in oil shale production, as almost the entire oil shale resources are located in the water-short Colorado River Basin.

c. The binary-cycle power system, if feasible, would probably be limited to the cooler-type geothermal anomaly such as the Mesa Anomaly. On hotter types of anomalies, direct steam power production would probably be utilized and the hot brines would be available in a joint water/power system such as that presented in the Developmental Concepts Report.

d. Recent studies show that multi-purpose water/power development is still possible and probably economical, using 400° F geothermal brines and a binary-cycle power system.

In summary, since the Mesa Anomaly is the only anomaly that has been substantially explored on Federal lands in the Imperial Valley and as less than 10 percent of the Federal lands in the Imperial Valley have been explored even partially, there is a possibility that much hotter anomalies, such as that at Cierro Prieto, Mexico, in the southern part of the Valley, remain to be discovered. Also there are many totally unexplored geothermal areas in the Colorado Basin outside of the Imperial Valley that would be available for development of water. Results from Reclamation's research program in the Mesa Anomaly, Imperial Valley, can be transposed to any other anomaly in the United States or the rest of the world where a critical need for supplemental water exists.

Because of the current state of the art in geothermal energy technology, there is no basis for considering Reclamation's program as deficient because of concurrent research in the binary-cycle type of geothermal power plant.

[See GAO note.]

We appreciate the opportunity to review your draft report.

Sincerely,

A L Reynolds

Allan L. Reynolds
Director of Audit and Investigation

Attachment [See GAO note.]

GAO note: The attachment is not included here, but was considered in this report. Material no longer related to this report has been deleted.

APPENDIX V

PRINCIPAL OFFICIALS OF THE ATOMIC ENERGY COMMISSION, THE DEPARTMENT OF THE INTERIOR, THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, AND THE NATIONAL SCIENCE FOUNDATION RESPONSIBLE FOR ADMINISTERING THE ACTIVITIES DISCUSSED IN THIS REPORT

| | Tenure of office | |
|---|---|---|
| | From | To |
| **ENERGY RESEARCH AND DEVELOPMENT ADMINISRATION** | | |
| ADMINISTRATOR: | | |
| Robert C. Seamans, Jr. | Jan. 1975 | Present |
| **ATOMIC ENERGY COMMISSION** | | |
| CHAIRMAN: | | |
| Dixy Lee Ray | Feb. 1973 | Jan. 1975 |
| James R. Schlesinger | Aug. 1971 | Feb. 1973 |
| Glenn T. Seaborg | Mar. 1961 | Aug. 1971 |
| GENERAL MANAGER: | | |
| John A. Erlewine | Jan. 1974 | Jan. 1975 |
| Robert E. Hollingsworth | Aug. 1964 | Jan. 1974 |
| **DEPARTMENT OF THE INTERIOR** | | |
| SECRETARY OF THE INTERIOR: | | |
| Rogers C. B. Morton | Jan. 1971 | Present |
| Walter J. Hickel | Jan. 1969 | Jan. 1971 |
| DIRECTOR, GEOLOGICAL SURVEY: | | |
| Vincent E. McKelvey | Dec. 1971 | Present |
| William A. Radlinski (acting) | May 1971 | Dec. 1971 |
| Dr. William T. Pecora | Jan. 1966 | May 1971 |
| DIRECTOR, BUREAU OF MINES: | | |
| Thomas V. Falkie | Mar. 1974 | Present |
| Dr. John D. Morgan (acting) | Sept. 1973 | Mar. 1974 |
| Elburt F. Osborn | Oct. 1970 | Sept. 1973 |

| | Tenure of office | | | |
|---|---|---|---|---|
| | From | | To | |
| **DEPARTMENT OF THE INTERIOR (continued)** | | | | |
| DIRECTOR, BUREAU OF LAND MANAGEMENT: | | | | |
| Curtis J. Berklund | July | 1973 | Present | |
| Burton W. Silcock | June | 1971 | July | 1973 |
| Lloyd L. Rasmussen | Jan. | 1966 | June | 1971 |
| COMMISSIONER, BUREAU OF RECLAMATION: | | | | |
| Gilbert Stamm (note a) | Apr. | 1973 | Present | |
| Ellis L. Armstrong | Nov. | 1969 | Apr. | 1973 |
| **NATIONAL SCIENCE FOUNDATION** | | | | |
| DIRECTOR: | | | | |
| H. Guyford Stever | Feb. | 1972 | Present | |
| Raymond L. Bisplinghoff (acting) | Jan. | 1972 | Feb. | 1972 |
| William D. McElroy | July | 1969 | Jan. | 1972 |

a/ Served as Acting Commissioner from April to May 1973.

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