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THE POTENTIAL FOR ENERGY PRODUCTION FROM GEOTHERMAL RESOURCES

REPORT

OF THE

SUBCOMMITTEE ON WATER AND POWER RESOURCES

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS

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MEMORANDUM OF THE CHAIRMAN

To: Members of the Senate Committee on Interior and Insular Affairs:

This report is based upon hearings held by the Subcommittee on Water and Power Resources on June 13, 1973, in Washington, D.C., on August 10, 1973, in Idaho Falls, Idaho, and on August 11, 1973, in Klamath Falls, Oreg.

As the Interior Committee's extensive study of a National Fuels and Energy Policy has shown, the United States is experiencing tremendous increases in demands upon all of the conventional energy sources.

These demands, coupled with the environmental consequences of many energy production and conversion processes, have resulted in an energy crisis of major proportions. Fuel shortages, curtailments of electric power, and increasing energy costs have become commonplace. Our burgeoning demands for energy have overrun the limited supplies from many conventional domestic sources, making us increasingly dependent upon insecure and economically disastrous imports. The production, conversion, and use of energy are major causes of some of our most pressing environmental problems.

In this situation, greater attention must be given to the unconventional energy sources which have been largely ignored in the past. Geothermal energy, the energy of the earth's natural heat, is among the most promising of these unconventional sources.

Although, as this report reveals, estimates of the potential for development of the resource vary widely, it is certain that the United States possesses a vast geothermal resource which has been used for very small applications for many years. No real efforts have been made until very recently, however, to inventory the resource or to perfect technologies which would extend its utility to major powerplants and industrial applications.

Especially in the Western States, geothermal resources have the ability to provide a substantial portion of future electrical energy demands. It has been estimated that as much as 400,000 megawatts of electric generating capacity based upon geothermal energy could be installed in the United States by the year 2000 if an aggressive research and developmental effort were initiated quickly.

This amount equals the Nation's total present installed generating capacity of all types. The geothermal resource, therefore, is potentially an important part of the Nation's energy future.

The Senate Interior Committee has had an interest in the development of geothermal energy for many years. Many of the most attractive and readily accessible geothermal sources which are known to exist in the United States are on the public lands of the West, and the Interior Committee worked for several years on measures which led to the enactment of the Geothermal Steam Act of 1970 establishing a geothermal leasing policy for the public lands. More recently, the Water and Power Subcommittee conducted a series of hearings in

Washington, D.C., and in the field, to explore the potential for energy production from geothermal resources. The objective of the subcommittee's investigation was to explore the following:

The long-range potential for the production of electric power and heat from various types of geothermal resources;

The exploration, research, and development work presently in progress;

The technological and environmental problems of large-scale development; and

The exploration, research, and development activities which are necessary to achieve optimum progress toward large-scale applications.

The findings of the subcommittee's investigation and the Senate Interior Committee's recommendations based upon those findings are set forth in the attached report.

THE PROSPECT FOR GEOTHERMAL ENERGY

An important fact is that geothermal resources defy generalizations. There are a great many types of geothermal resources, and they represent varied opportunities and challenges. The most easily developed resource, easily accessible hot, dry steam, is not a speculative energy source. It is a reality today. In California, The Geysers power development of the Pacific Gas and Electric Co. is producing electricity approximately equal to the demands of the city of San Francisco, and it is producing it at costs which are easily competitive with the most attractive alternative sources.

The occurrences of dry steam sources, unfortunately, do not appear to be extensive. Most known geothermal resources will be more technologically difficult to develop. Where naturally occurring steam is of lower temperature and contains more water, for example, difficult corrosion and brine disposal problems are encountered and in some situations binary-cycle devices may be necessary to achieve efficient electric power generation.

There does appear to be a potential for early and significant development of such resources. Electricity is being produced from wet-steam systems in other nations, and a binary system is being constructed in California. Furthermore, there are numerous applications of geothermal brines as domestic and commercial heat sources, both in foreign countries and in the United States.

There appears to be an attractive potential for the development of small (10 to 25 megawatts) powerplants based upon wet-steam resources. Opportunities for such installations are particularly abundant in the West. If economical and reliable installations of small capacity are feasible, they would be an important accomplishment. Most modern fossil fuel plants for base-load operation must be very large to achieve the economies of scale. Many small electric utilities serving rural areas would welcome alternative installations of relatively small capacity, and the dispersal of generation would enhance the reliability of major regional power systems.

This type of geothermal development might become a reality within the next decade if real efforts are made by industry and government. Although it might represent only a small percentage of national energy

supplies, it could be very significant at local or regional levels. For example, the Pacific Northwest, which has traditionally relied upon hydroelectric power, is approaching the practical limits of that resource. The area has no appreciable reserves of fossil fuels and could benefit greatly from the development of geothermal technologies.

Dry geothermal resources are a form which, perhaps, offer the most exciting possibilities for the long-term future. Hot formations unusually close to the surface of the earth are known in a number of localities. If appropriate drilling and heat exchange technologies were developed, the energy of these geological anomalies could be used for electrical generation and industrial process heat. It is possible that some applications could be achieved in the near future. If the technologies could be brought to a very high degree of sophistication, moreover, the earth's natural heat would provide a virtually inexhaustible source of energy which occurs everywhere. Along with solar energy, hydrogen fuels, and nuclear fusion, it deserves study as a solution to the inevitable exhaustion of conventional fuels.

UNCERTAINTIES FACING DEVELOPMENT

The Water and Power Subcommittee's investigations have established that there is great interest in getting on with geothermal development and they have established that the possible value of development is great. But the hearings have also highlighted the tremendous uncertainties clouding early development of the resource.

The extent and nature of geothermal anomalies are not well established. No comprehensive exploration program is actively being pursued. Work has been done by some very good geologists in some regions, but it has been based almost exclusively upon surface indications and water and oil well data which are not suited to the purpose. No specific exploratory drilling program is underway to validate and extend this data base.

Lack of information about the resource, coupled with insufficient experience in drilling and production techniques, make geothermal development risky ventures. Those private firms which would like to undertake geothermal projects find financing difficult to obtain. Until more experience has been acquired through the construction and operation of demonstration facilities, private financing for geothermal exploration and development will probably remain difficult.

In the more technologically complex applications, a strong measure of Federal financial participation in research and development may be necessary. There is no assurance that early attempts to tap geothermal resources of new kinds will result in reliable or economic ventures. The probability is that they will not. As in any new technology, prototype plants will provide primarily a learning experience. Cost estimates will be unreliable and results uncertain. There is an understandable reluctance for private industry to embark upon such ventures, particularly the electric utilities which are presently sorely pressed to finance and construct sufficient conventional capacity to meet increasing energy demands.

The pace of experimental installations could be greatly accelerated by a Federal program of cooperative financing and construction of

prototype demonstration plants. The experience which would be gained from a number of such installations, based upon a variety of resources and technologies, would help to resolve such uncertainties as the environmental problems which might occur, the costs and reliability which might be expected of second generation plants, and the types of specific research which should be undertaken to improve performance.

Unfortunately, there is no concerted Federal program for research and development of geothermal resources. There are several agencies which are interested in the resource and there are some small, tentative, activities underway. These efforts lack a sense of urgency. They lack a lead agency with specific authority to coordinate Federal responsibilities for geothermal research and to cooperate with industry in a planned program of exploration, research, and development.

In the present energy situation, we cannot afford to overlook the potential of this attractive domestic resource.

The subcommittee offers the findings and recommendations of its investigation set forth in the attached report for the consideration of the Senate Interior Committee.

The preparation of this report was directed by Mr. Daniel A. Dreyfus, professional staff member for Water and Power Resources. The subcommittee appreciates the assistance of Dr. Daniel P. Beard of the Environmental Policy Division, Congressional Research Service, who assisted greatly in the analysis of the hearings and the preparation of the report.

FRANK CHURCH,
Chairman,
Subcommittee on Water and Power Resources.

I. Findings and Recommendations

A. FINDINGS

1. Electric power production from geothermal resources has been shown to be technically and economically feasible in certain locations and is presently providing 400 megawatts of electricity in the United States.

2. The geothermal resources of the United States hold a potential for the production of substantial amounts of energy in the form of heat and electric power. They hold special promise for making a significant contribution to regional power supplies.

3. Potential geothermal technologies offer the possibility of providing environmentally attractive energy production techniques.

4. The available information about the resource is not adequate to form reliable estimates on the nature and extent of geothermal resources or to support reliable estimates of the probable rate of geothermal energy development. There is a need for increased exploration and classification of geothermal resources.

5. There is a wide margin of uncertainty concerning the potential magnitude of geothermal energy development and the schedule of achievement of technological capabilities.

6. Geothermal resources occur in a variety of types and situations which pose widely different types of technological problems.

a. Dry-steam geothermal systems have been developed successfully but their total potential is believed to be limited.

b. Wet-steam geothermal systems have been harnessed for useful applications, but the ultimate utility of the resource depends upon development of methods to develop energy from low-temperature brines and the successful resolution of engineering and environmental problems.

c. Hot dry-rock systems may offer the greatest power potential over the long run, but significant research and development work (including drilling technology and advanced binary cycle heat exchange work) will be required to develop this resource.

d. Geopressured brines are believed to have potential for energy development, but exploration and research on this form of of geothermal resource are especially limited.

7. There is considerable interest on the part of private industry in developing geothermal energy. However, the lack of a Federal leasing program, financing impediments, and the risk involved in advanced technologies are inhibiting development.

8. There is a lack of aggresive governmental leadership in the development of geothermal energy. There is no lead agency and as a result research and development is sporadic and uncoordinated.

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9. The Department of the Interior's implementation of the Geothermal Steam Act, which has been law since 1970, has not yet resulted in regulations which will permit orderly development of attractive resources on the public lands.

10. The present Federal geothermal R.&D. program lacks clearly enunciated goals and objectives, coordinated management or adequate funding for the exploration, research, and development activities which are needed.

11. There is a need for small-scale demonstration projects which produce power from geothermal resources to provide experience with and confidence in the resource use.

12. There is a need for more Federal assistance in exploration, research, development, and demonstration of geothermal technology and for financial assistance to non-Federal developments.

B. RECOMMENDATIONS

1. The Department of the Interior should take steps to insure prompt issuance of the final environmental impact statement on its leasing regulations formulated pursuant to the Geothermal Energy Act of 1970.

2. A lead agency should be designated to take responsibility for advancing geothermal energy resources research and development.

3. Exploration activity for geothermal energy resources should be greatly accelerated.

4. The level of funding for Federal research and development activities in geothermal energy resources should be greatly increased from the present level.

5. In order to facilitate private development of geothermal resources, a financial assistance program should be initiated to overcome some of the uncertainties associated with new technology development.

II. BACKGROUND

The Senate Committee on Interior and Insular Affairs has actively encouraged the development of geothermal resources for over a decade. The Committee first held hearings on the potential for geothermal steam resources in July and October, 1963. Following these hearings, the Committee favorably reported S. 883, a bill that would have aided in developing the full potential of geothermal resources underlying public lands (Senate Report 88–1508). The Senate passed this measure on August 21, 1964, but the House did not take further action.

In the 89th Congress, a new bill, S. 1674, was introduced to authorize the Secretary of the Interior to develop geothermal resources through a leasing program. As the Committee observed in its report on this measure (Senate Report 89–683): "Although . . . the resources and uses of geothermal steam have been only slightly explored, particularly on the public domain, enough is known from experience on privately owned lands and from operations in other countries to warrant encouragement for further development." The full Senate concurred in this observation and passed S. 1674 on September 7, 1965.

The House reported S. 1674 the following year (House Report 89–2140). The only major difference between the two bills was the omission from the House measure of a "grandfather clause" or preference right for persons who had already undertaken exploration and/or development of geothermal resources on public lands. The Senate position on this section was maintained without a conference and S. 1674 was enacted with a grandfather clause in October, 1966.

S. 1674 did not, however, become law. On November 13, 1966, President Johnson pocket vetoed the bill saying that it was "flawed" in several respects. One significant objection was the "grandfather" provision which the President asserted would have constituted an unlimited and unwarranted free gift of valuable public property rights. The Committee on Interior and Insular Affairs did not agree with this interpretation, and it was to observe several years later: "The earlier provision was itself carefully limited, and in the committee's judgment the President's failure to approve the bill was ill-advised and unfortunate." (Senate Report 91–1160).

In the 90th and 91st Congresses, the Committee continued to hold hearings to resolve the issues surrounding the Presidential veto. These problems were resolved in 1970 and the Committee reported a new bill, S. 368 (Senate Report 91–1160). This measure was passed by the Senate on September 16, 1970, and reported and passed by the House in early October, 1970 (House Report 91–1544). Minor differences between the two measures were resolved in early December and the bill was signed into law on December 24, 1970 (P.L. 91–581, 84 Stat. 1566, 30 U.S.C. 1001–1025).

The major intent of the Geothermal Steam Act of 1970 was the prompt and orderly development of geothermal resources on public

lands. The major device for achieving this objective was the authorization to the Secretary of the Interior to issue leases for the development and utilization of geothermal steam resources on public lands in much the same manner that he is authorized to lease land for development of oil and gas deposits under the Mineral Leasing Act of 1920 (30 U.S.C. 22). The Secretary was instructed by the Act to survey the geothermal resources of the public lands and classify them into two types: "known geothermal resource areas" (KGRA) and other areas where there was potential for development. The Act called for leases to go to the highest qualified bidder in KGRA's and to the first qualified person making application for leases in other areas. A "grandfather" provision was included in the Act to give preference to persons holding leases, permits or claims under the Mineral Leasing Act to convert these to geothermal leases. Royalties from these leases and all other leases were to be not less than 10 percent nor more than 15 percent of the amount or value of the steam. Leases were to extend for not more than 10 years. If geothermal steam was produced or utilized in commercial quantities within this time, however, the leases would continue for 40 years after which time the lease would be reevaluated. The Act calls for each lease to embrace a reasonably compact area of not more than 2,560 acres. The Secretary is awarded authority to readjust, cancel or change the conditions of leases under certain conditions.

The Committee viewed the development of geothermal resources as an important program for meeting future energy needs. As the Committee observed in 1970:

> * * * geothermal power stands out as a potentially invaluable untapped natural resource. It becomes particularly attractive in this age of growing consciousness of environmental hazards and increasing awareness of the necessity to develop new resources to help meet the Nation's future energy requirements. The Nation's geothermal resources promise to be a relatively pollution-free source of energy and their development should be encouraged. (Senate Report 91-1160.)

The Committee backed this statement with several strong measures in the Geothermal Steam Act of 1970 to insure the speedy development of these resources. The requirement that the Secretary survey public lands and publish a map showing KGRA's and other areas of potential development within 120 days demonstrates this commitment.

In June, 1972, in conjunction with the national fuels and energy policy study, the Committee undertook oversight hearings to examine the progress in implementing the Geothermal Steam Act and to reassess the potential for geothermal resources. As Senator Bible stated in opening the hearings:

> There is an immediate need for alternative energy technologies which improve the efficiency of energy systems as well as minimize the environmental impact of energy production.
>
> There is also a need to provide an adequate and reliable power supply required to achieve the goals and aspirations of the American people. By all indications, geothermal energy offers a significant opportunity for meeting these objectives.
>
> In anticipation and recognition of the need to explore and develop the potential of geothermal energy resources on Federal lands, the Congress passed the Geothermal Steam Act of 1970...
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> Our purpose [at these hearings] is to review the available data concerning the potential of geothermal energy as an alternative power source, the technology needed to exploit it, the efforts already underway, and the status of future plans for the resource.

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Agreement was found among the witnesses testifying at these hearings on several points. First, all of the witnesses agreed that the potential contribution of geothermal steam to energy supply was large. Moreover, it was apparent that several private and public institutions were going forward with research and development plans. Finally, the several Federal agencies charged with implementing the Geothermal Steam Act were taking steps toward launching the leasing program. The U.S. Geological Survey had proceeded with the statutory classification of KGRA's, and the Department of the Interior had prepared a draft environmental impact statement as required by the National Environmental Policy Act. In addition, the Department had published proposed rules and regulations for leases in the *Federal Register* (36 *Fed. Reg.* 13722, 37 *Fed. Reg.* 25282 and 25300). The Department anticipated holding its first leasing sale in the fall of 1972.

III. PRESENT HEARINGS

On June 13, 1973, the Subcommittee on Water and Power Resources again held oversight hearings to evaluate and investigate the potential of geothermal steam resources and to consider the requirements for Federal programs in exploration, research and development of these resources. After observing the potential for power from geothermal resources, the Chairman of the Subcommittee hearings, Senator Church stated:

> Some types of geothermal resources are quite easily developed, and electric power generation from such sources has been in service in a few applications for many years. Other types of resources will involve more difficult and costly research and development efforts to perfect the technologies necessary for practical, large-scale applications.
>
> The hearing today is intended to compile a record on the status of the geothermal resources of the United States. The Federal agencies which have an interest in geothermal energy have been requested to testify on the following major points:
>
> The long-range potential for the production of electric power and heat from various types of geothermal resources;
>
> The exploration, research and development work presently in progress;
>
> The technological and environmental problems of large-scale developments; and
>
> The exploration, research and development activities which are necessary to achieve optimum progress toward large-scale applications.

IV. POTENTIAL OF GEOTHERMAL STEAM RESOURCES

Geothermal energy is, in the broadest sense, the natural heat of the earth. Because temperatures in the earth's crust rise with increasing depth, the entire planet could hold potential for development. However, most of the earth's heat is far too deeply buried to be tapped by man. Although drilling has reached 4.7 miles and may some day reach two or three times that depth, the depths from which heat might be extracted profitably with current or foreseeable technology are unlikely to be greater than 6 miles. Even within this range much of the geothermal heat is too diffuse to be recovered economically. Consequently a very large fraction of the heat within the earth, even at depths of less than 6 miles, cannot be considered an energy resource.

Geothermal energy, however, does have potential economic significance where heat is concentrated into restricted areas in the crust, in a manner analogous to the concentration of ore deposits or of oil in commercial petroleum reservoirs. At present, these concentrations are found in permeable rocks at depths less than 1.9 miles. The thermal energy is stored both in the solid rock and in water and steam that fill pores and fractures. Most geothermal reservoirs are found in zones of recent geologic activity (i.e., young volcanism and mountain building), and are localized near the margins of major crustal plates.

There are two major types of geothermal energy systems. The first type is "hot spots" where the flow of heat in the earth is one and one-half to five times the normal average. These hot spots can be broken down into dry-steam, wet-steam and hot dry-rock systems. The second form of geothermal resources are geopressured brine systems which occur in deep, sedimentary basins.

Dry-Steam Systems.—Dry-steam geothermal reservoirs produce superheated steam with only minor amounts of other gases and very little or no water. Within the reservoir, steam and water coexist. When this reservoir is tapped, this mixture of steam and water rises. As it does so, the surrounding rock dries the fluids and superheated steam is available at the surface. Here it is piped directly to a turbine where it can be used to generate electricity.

Dry-steam geothermal systems are a rare phenomenon. Drilling has revealed only three areas in the world where commercial dry-steam resources exist: Larderello, Italy; The Geysers, California; and Matsukawa, Japan. In these areas, commercial ventures are producing electric power. At The Geysers, Pacific Gas and Electric has eleven generating units, the largest of which has a capacity of 55 megawatts (MW). Present generating capacity in the field is more than 400 MW. The first geothermal development took place at the dry-steam field in Larderello, Italy in 1904, and today that field has a capacity of 358 MW. Generation from Japanese sources is now about 30 MW.

While dry-steam reservoirs can be easily developed, their long-range potential is smaller than any other geothermal resource. There are

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only two other areas in the world where dry-steam geothermal resources *might be* available in commercial quantities; both are in the Monte Amiata region of Italy. Furthermore, potential from existing fields is limited. According to the Department of the Interior, The Geysers is estimated to have only a potential for 1000 to 3000 MW. Thus, the future of geothermal steam resources lies with the development of wet-steam, dry-rock and geopressured resources.

Wet-Steam Systems.—In many parts of the world, thermally-driven convective systems of water are present in the earth's crust. In this reservoir, water is heated by surrounding rock and steam is produced when the water is tapped by a well. As the water moves to the surface, the decreased pressure produces a mixture of steam and water at the surface. There, the water and steam are separated before the steam is fed to a turbine. In other wet-steam systems, and especially where the temperature of the steam is low, a binary system which transfers heat from the water-steam mixture to a secondary source may be utilized.

There are several areas in the world which are now or will soon be producing electricity from wet-steam geothermal resources. Wairakai (160 MW) and Broadlands (100 MW proposed) in New Zealand and Cerro Prieto, Mexico (75 MW, 200 MW proposed) are the major areas. The Salton Sea field in California and the Yellowstone geyser basins in Wyoming are also areas of great potential for wet-steam geothermal energy. (It should be noted, however, that no development of geothermal resources can take place in U.S. national parks. Thus, Old Faithful and similar national treasures will never be harnessed to produce power. See: 30 U.S.C. 1014(c).)

Accurate estimates of the potential power from wet-steam geothermal resources are not available. Rough estimates, however, have been made. The Department of the Interior, for example, estimates that wet-steam systems are perhaps 20 times as common as dry-steam systems. Another witness, Dr. Gary H. Higgins of Lawrence Livermore Laboratories, estimated that the wet-steam systems could eventually supply one-fourth of the Nation's electrical generating capacity if they were successfully developed.

While there is optimism concerning the development possibilities of wet-steam systems, the realities are much different. As noted above, there are only two wet-steam systems now producing electricity—in Mexico and New Zealand. Moreover, these developments are using "flashed steam systems." In this process, a mixture of hot steam and water is fed from wells into intermediate pressure tanks where the vapor is separated from the liquid. Unfortunately, this system can only be used with wet-steam brines with a temperature range of 500° to 600° Fahrenheit (260° to 316° Centigrade), and such resources are rare. Most wet-steam geothermal resources have brines which occur at much lower temperatures.

Work is now underway, however, to develop systems for harnessing low temperature wet-steam brines. The first system is a binary system which transfers heat from the hot water to a secondary low-boiling point working fluid such as freon or isobutane which is used drive a turbine. The other system expands the total hot-water/steam mixture from the well-head through nozzles much like rocket exhaust

nozzles. The expanded high velocity mixture drives a turbine similar to a hydro-electric turbine. Successful development of these systems could greatly expand the potential for power recoverable from wet-steam geothermal resources.

The only attempt now underway in the United States to utilize either a binary or nozzle system is in the Imperial Valley. There, San Diego Gas and Electric, in cooperation with Magma Power Company, is constructing a 25 MW pilot plant utilizing a binary system. The Soviet Union is also constructing a pilot plant to develop hot-water resources through advanced means.

Hot Dry-Rock Systems.—The third form of "hot spot" geothermal resources are the hot dry-rock systems. These systems are found in regions where heat is contained in impermeable rock of low porosity. Water is not present in these formations to transfer that heat to the surface. Thus, to develop this resource, it is necessary to drill a hole and create a permeable fracture system in the rock. This reservoir of cracked rock could be created either hydraulically as in coventional oil field developments or by the detonation of an explosive device. A supply of water then would be injected into the voids and cracks in the rock heated to very nearly the temperature of the surrounding rock. The water then would be brought to the surface through another hole drilled into the reservoir. At the surface the heat would be extracted and the water reinjected into the underground system.

The potential energy recoverable from this type of system is, according to all estimates, very large. Representatives from the Atomic Energy Commission, for example, told the Committee that 40 cubic miles of hot rock contain energy equivalent to the entire oil reserves on the northern slope of Alaska if cooled by 360° F. (200° C.). Cooling only one cubic mile of rock by the same amount would provide an equivalent of one week's energy consumption in the United States. As Mr. Morton C. Smith of the Los Alamos Scientific Laboratory noted before the Committee on June 13, 1973:

> The heat in "dry" rock of the earth's crust is . . . by far our largest accessible reservoir of immediately usable energy. It is also by far our most broadly distributed energy sources; at sufficient depth it exists everywhere, and that, unfortunately, is not equally true even of sunlight. Hot rock is a completely reliable energy supply, which will not be disturbed by a storm or a pipeline failure or a shipping problem . . . It is, in fact, a most attractive energy source, although with two obvious disadvantages: (1) In most places it is a relatively low-temperature source of heat, and it is therefore not the ideal energy supply for all purposes . . . (2) the engineering methods required to extract energy from hot dry rock, economically and at a usefully high rate, appear to exist, but they have not yet actually been demonstrated together in this application.

Mr. Smith's last point is particularly germane. While hot dry-rock systems have great potential, these estimates are constructed on the basis of very little proven evidence. There is, for example, no working hot dry-rock geothermal system now producing power. While the Atomic Energy Commission's Los Alamos group has plans for a small pilot project on hot dry-rock, no funding has been secured for the system. The only active work in the United States has been carried out by the National Science Foundation. It has recently announced a new grant for research that could be the first step toward a proof-of-

concept experiment utilizing an apparent hot rock resource. This project will attempt to find out the extent of temperatures in a high heat flow region near Marysville, Montana. As the Department of the Interior noted:

> Hot dry rock represents a very large potential geothermal energy resource. Recovery of heat from this source is not economic at present. Determining its significance as a future energy source will depend, among other things, on (1) ascertainment of the availability of rock at sufficiently high temperature at depths less than 10,000 feet, assuming present drilling techniques, and (2) development of technology for recovering energy from dry hot rock.

Geopressured Brine Systems.—The final form of geothermal energy is geopressured brine systems. In many regions of the world, normal heat flow of the earth is trapped by insulating impermeable beds of deep sedimentary basins. Pressures in these formations are far above normal. In addition, water in these "geopressured zones" is not the normal circulating water; rather it is confined to the formation under higher pressure than ordinary for that depth. Geopressured deposits are hotter than normally pressured deposits because upward loss of water is stopped, and has been for millions of years. The specific heat of the water is about five times that of the minerals associated with it. Temperatures of this water range from 325° to 380° F. (163° to 193° C.) with ample production rates through wells that may tap this resource.

Sedimentary basins of this type are thought to have extremely high potential for development as geothermal energy. For example, along the Gulf Coast, temperatures of 325° to 550° F. (163° to 287° C.) are found at depths of 2.5 miles to 4.5 miles in geopressured zones. These facts, in addition to other evidence accumulated on the region, offers speculation that the Gulf Coast and other areas represent a significant resource potential. However, as the Department of the Interior cautioned:

> **The brines are cerainly hot enough and the pressures high enough that the generation of electricity could be effected by either, but a great deal remains to be learned about this resource through a systematic research program. Of prime concern is the capability of any given reservoir to supply a sustained source of steam or very hot water long enough to warrant the construction of a power plant.**

Overview.—This qualified optimism regarding the potential for geopressured brines must also be kept in mind when viewing the overall potential for geothermal resources. For example, the present *worldwide* generation of electricity from all geothermal sources is only 1000 MW—about the size of many individual nuclear and fossil fuel plants now under construction. The estimates made for the potential for all geothermal resources are just that—estimates. As such they must be qualified by the assumptions upon which they are based and upon the definitions utilized. Assistant Secretary of the Interior, Jack O. Horton, made an important point in this regard when he observed:

> **It was noted earlier that on a worldwide basis, the hot-water systems *may be*** 20 times as abundant as the dry-steam systems and that, in the opinion of some, **the hot-rock sources *may be* the most abundant of all. These estimates are based** upon: (1) a small statistical sampling (less than two dozen geothermal systems are currently under exploitation all over the world), and (2) geologic assumptions **and extrapolations that at present have too little foundation in observational fact. (Italics in original)**

The small statistical sampling and the differences in assumptions may be the reasons that the estimates for geothermal steam resources of the United States and of the world differ by as much as six orders of magnitude. The Department of the Interior, in its testimony before the Committee, provided the following survey of the estimates for geothermal resources:

Eight years ago, D. E. White (Geological Survey) stated that "existing worldwide utilization equivalent to about 1 thousand megawatts (MW) . . . probably can be increased at least 10 times (that is, to 10^4 MW) under present economic conditions and maintained for at least 50 years." Six years ago, C. J. Banwell (United Nations) estimated a potential heat production of 2×10^9 kg-cal/sec from geothermal energy associated with "Pacific type volcanism." At 14 percent thermal efficiency, this rate of heat production could sustain electrical generating capacity of about 10^6 MW. More recently, R. W. Rex stated that he and his colleagues ". . . are estimating the western (conterminous) U.S. geothermal potential from 10^5 to 10^7 megawatts." D. E. White and L. J. P. Muffler (U.S. Geological Survey) estimated that the world geothermal resources to a depth of 3 km (1.9 miles) for electrical generation by proven techniques is approximately 2×10^{29} calories (equivalent to 58,000 MW for 50 years). R. W. Rex later stated that ". . . the present recoverable (geothermal) resource for the western third of the continental United States, excluding Alaska, is of the order of 10^9 megawatt-centuries. This figure might be expanded by another factor of 10 by the inclusion of the eastern two-thirds of the United States and another factor of 10 (that is, to 10^{10} megawatt-centuries by improvements in technology." C. J. Banwell and Tsvi Meidav (United Nations) have stated optimistically that "the geothermal energy reserves of the world are orders of magnitude greater than the total reserve of any other form of fossil energy."

The diversity of estimates is also demonstrated in table 1. Here the estimates for geothermal energy from four sources are contrasted. The range of forecasts, while it is large, is not nearly so large when the bases for the forecasts are considered. The first Interior Department estimates are based on current available technology and known resources. The second, on increased research and exploration, particularly with the successful development of the wet-steam systems. The Hickel and Rex Reports are based on forecasts of potential developments on expanded research and exploration without regard to cost estimates. They are primarily based on heat gradients and on the assumption that most research and exploration will be successful.

TABLE 1.—COMPARISON OF ESTIMATES OF U.S. GEOTHERMAL ELECTRICAL POWER, 1985 AND 2000

Source	Estimate (megawatts)	
	1985	2000
Interior Department, II	4,000	40,000
Interior Department, I	19,000	75,000
Hickel report	132,000	395,000
R.W. Rex		400,000

Sources: R. W. Rex—Testimony of R. W. Rex before the Senate Committee on Interior and Insular Affairs, "Geothermal Energy Resources and Research," hearings, 92d Cong., 2d sess., June 1972, p. 49.
Hickel report.—"Geothermal Energy: A National Proposal for Geothermal Resources Research," final report of the Geothermal Resources Research Conference, Walter J. Hickel, chairman (Fairbanks: University of Alaska, 1972).
Interior Department, I—"Assessement of Geothermal Energy Resources," prepared for the Committee on Energy Research and Development Goals, Federal Council for Science and Technology, Dallas L. Peck, coordinator, Department of the Interior, September 1972.
Interior Department, II—Internal briefing report on geothermal resources, Department of the Interior, April–May 1973, unpublished.

Nevertheless, while there is disagreement concerning the exact contribution geothermal energy will make to future needs, it does remain one of the more promising of the unconventional energy sources now being considered.

V. CURRENT FEDERAL ACTIVITIES

There are nine Federal agencies or commissions *actively* involved with the research or development of geothermal resources. The Department of the Interior, the primary agency in this regard, has four agencies actively pursuing work in a number of diverse areas.

DEPARTMENT OF THE INTERIOR

U.S. Geological Survey.—The USGS is the Department's lead bureau in geothermal energy studies. The major elements of their program include exploration methodology, resource appraisal, reservoir development, utilization technology and environmental monitoring.

The objective of the USGS's exploration methodology is to locate areas underlain by geothermal systems and to estimate their volume, temperature and permeability. This work is carried out through geological and geochemical techniques from laboratory efforts to field tests. The resource assessment research is attempting to evaluate three different classes of geothermal resources: hydrothermal convection systems (both dry-steam and wet-steam types), geopressured brine systems and hot dry-rock resources. A large share of their current program involves studies of The Geysers and Long Valley, California.

The USGS environmental monitoring program attempts to assess possible geological hazards to the environment which are of most immediate concern; these include: subsidence potential, stimulated seismicity, and surface- and ground-water pollution. Research is directed toward an accurate determination and evaluation of the character and magnitude of these factors.

There is, according to the USGS, a great deal of research required to form a sound basis for reservoir development and production methods needed for optimal development of geothermal resources. The most important need is aimed at developing tools and techniques for evaluation of high temperature geothermal formations. This research is also followed by an effort to improve utilization technology. The USGS is attempting to identify the types and concentrations of solutes in a number of resevoirs to provide engineering design information. This work will be especially helpful in developing wet-steam geothermal steam resources.

Funding for USGS geothermal activities showed a small increase between FY 1973 and FY 1974. Appropriations for all activities in FY 1973 were $2.5 million while the budget request for this fiscal year was $2.53 million.

Bureau of Reclamation.—The principal effort of the Bureau of Reclamation is to investigate the technical and economic feasibility of producing fresh water from the saline brines contained in the wet-

steam geothermal systems. Secondary objectives of this program include geothermal reservoir evaluation, geophysical monitoring, including subsidence and micro-earthquake effects of geothermal production and evaluation of the environmental impact of production.

These objectives are being accomplished through research efforts in the Imperial Valley of California. According to the Bureau, extensive geological, geophysical, geohydrological and water chemistry investigations will be undertaken to fully evaluate the regions. Deep test wells will be drilled both for production and reinjection. A major portion of the research effort will be in the evaluation of geothermal desalting techniques and the most feasible desalting processes. These preliminary studies may culminate in the construction of a prototype desalting plant which would be operated in conjunction with the appropriate pretreatment and waste disposal system. The environmental aspects of geothermal development will also be analyzed through this program. The Bureau's estimated cost for completing its geothermal resource investigations is $9 million; its budget request for FY 1974 was $1.2 million.

Bureau of Mines.—The major emphasis of the Bureau of Mines activities is on the recovery of minerals and gases found dissolved in geothermal fluids. These investigations will also be focused on the geothermal fluids of the Imperial Valley. According to the Bureau's testimony, the program will consist of five elements: (1) developing a system for evaluating brines to determine constituents of potential economic value; (2) developing methods for recovering the constituents found; (3) developing methods for separating non-commercial constituents and for their disposal; (4) determining criteria for selecting materials of engineering construction needed in the handling of hot concentrated brines; and (5) finding new metallurgical processing uses for residual brine.

The estimated cost of completing the Bureau of Mines' geothermal program could be $5.9 million; its budget request for FY 1974 was $200,000.

Office of Saline Water.—The Office of Saline Water conducted geothermal desalting studies in FY 1972 and FY 1973. The program included: research on brine chemistry, process analysis and testing; environmental effects of the desalting process; effluent disposal techniques; materials; and construction. Two desalting test units have been developed and installed at the Bureau of Reclamation geothermal drilling site in the Imperial Valley. The amount of $8[illegible] was provided for this work in FY 1973. Funds were not reque[illegible] for FY 1974. The program has been terminated as a part of a gene[illegible] dismantling of the Department's desalination activities.

Bureau of Land Management.—The Bureau of Land Management's budget request for FY 1974 contains a request for $200,000 to expand the Bureau's program to stimulate the development of geothermal resources. Efforts will be concentrated in the states of California, Nevada, Oregon and Utah which contain the principal known geothermal resource areas. Major program features will include adjudication of the conversion rights established by Section 4 of the Geothermal Steam Act, analysis and selection of potential leasing tracts,

development of resource uses plans and environment analyses, coordination with other Federal agencies, and development of a leasing schedule.

ATOMIC ENERGY COMMISSION

The Atomic Energy Commission's role in geothermal energy development, according to Dr. Gerald W. Johnson, Director Division of Applied Technology, is "presently undefined." The AEC does not receive appropriated funds with which to carry out geothermal research and development. Nevertheless, it does feel that the agency and its laboratories can bring energy development experience and a strong scientific base to bear on the numerous technical problems in the development of geothermal energy.

One particularly promising plan involves research in the development of a hot dry-rock project. Under sponsorship of the AEC, the Los Alamos Scientific Laboratory has undertaken to investigate the possibilities, problems, and probable usefulness of man-made geothermal-energy system in hot dry rock. Their plans call for drilling into hot rock in the Jemez Plateau of New Mexico and developing a pilot project plant. The major research work will concentrate on thermal, mechanical and chemical behavior of the rock to demonstrate the feasibility of this system. Preliminary plans do not call for generating electricity at the site. The AEC has requested $4.7 million for FY 1974 to finance this project.

In addition, the AEC feels there are at least three ways that a joint government-industry program might be established to develop geothermal resources. The first would be a phased approach where the initial effort would be predominantly governmental, as in the development of the dry hot-rock concept at Los Alamos. The second might involve joint funding and management over the life of a program. Finally, joint government-industry programs might take the form of government-operated test facilities, where various industrial equipment components might be installed for the development of long-term operational experiments.

NATIONAL SCIENCE FOUNDATION

The major effort of the National Science Foundation in geothermal energy is the funding of research on wet-steam and hot dry-rock systems. The total budget request for FY 1974 to carry out these investigations was $1,080,000.

The Foundation has several projects underway on wet-steam systems. The first is an effort by the New Mexico Institute of Mining and Technology to investigate the thermal regime of the Rio Grande Rift System in New Mexico. Another project involves a study of the hydrothermal systems of the Kilauea Volcano on the island Hawaii under the direction of the Colorado School of Mines. The third project, initiated last year, is using electrical methods to delineate geothermal reservoirs. The final project involves investigations of the geothermal resources of the Imperial Valley, in cooperation with the State of California.

The major research effort now underway on hot dry-rock geothermal systems is now being funded by the Foundation in Marysville, Montana. Researchers from Southern Methodist University, Battelle Memorial Institute and other research centers are completing geophysical surveys of the area to determine where a test hole might be drilled to ultimately develop this system. The Foundation hopes this research can serve as a test area for technology development and as a model for exploration of similar hot dry-rock formations.

OTHER AGENCIES

There are three other agencies which are involved in developing geothermal energy resources: the Department of State, the National Aeronautics and Space Administration, and the Advanced Research Projects Agency.

Department of State.—The Department of State has a two-part program with respect of geothermal power. The first is a series of informal exchanges between scientist in the U.S. and overseas. For example, in Japan, the Department of the Interior has entered into a cooperative development program with Japan and the U.S. geothermal team has been assembled. In New Zealand, the Department has assisted the U.S. Geological Survey in exchanging scientists with that country.

A second part of the State Department program is the provision of direct assistance to developing countries through the Agency for International Development (AID). The AID, for example, has financed a preliminary reconnaisance of geothermal energy resources in the Dieng Plateau of Central Java. As a result of favorable indications, exploratory drilling is being carried out by private contractors for the Indonesian Government, with partial financial support from AID in the form of a development loan. AID is also assisting in the planning of a small pilot geothermal project in Southern Luzon, in the Philippines. The initial project is expected to be authorized in 1973 and is scheduled to bring into operation a single 10 MW generating plant. The total project cost of $4.5 million would be financed under a development loan from AID.

National Aeronautics and Space Administration.—While NASA does not obtain any direct appropriations for geothermal energy, some of its space programs could provide valuable information for inventorying and evaluating geothermal resources. These capabilities exist, according to NASA witnesses, in those space missions in which they carry out remote sensing using thermal infrared detectors or obtain photograph-like images of the earth's surface from very high altitudes. The Skylab mission, for example, could provide important information about the inventorying an devaluation of geothermal resources. The NIMBUS–5 mission, also carries instrumentation which has the potential to make a significant contribution to the inventory and evaluation process. The NOAA–2 mission, ERTS–1, and the Earth Observation Aircraft Program can also contribute to locating and evaluating geothermal resources.

Advanced Research Projects Agency.—The Advanced Research Projects Agency of the Department of Defense has started a study to investigate the potential applications of geothermal energy sources

to specific military needs. Possible military applications of geothermal energy of interest to the Department of Defense include: (1) primary source of reliable power at remote locations; (2) an emergency or back-up power source in case conventional power sources are disrupted; and, (3) a self-contained, stand-by power source for hardened underground or underwater facilities capable of providing space heating and cooling, and usable water as well as electric power. The Agency's effort is limited to the definition of Department of Defense needs.

VI. ISSUES DEVELOPED DURING THE HEARINGS

OVERVIEW OF THE FEDERAL EFFORT

As noted previously, the Committee on Interior and Insular Affairs has worked for over ten years in an effort to initiate an orderly and efficient, yet speedy Federal effort at developing geothermal resources. The Geothermal Steam Act of 1970 provides a workable means to obtain this goal through a leasing program on Federal lands by private industry while at the same time providing a fair return to the public for the use of these resources. These objectives cannot, however, be achieved without the proper implementation of the Act by the responsible Federal agencies.

The Department of the Interior has had the major responsibility for this task. It has the responsibility for carrying out the leasing program established under Section 4 of the Act and it also has authority to promote geothermal research and development through the Bureau of Reclamation, Bureau of Mines and the Geological Survey.

Considerable testimony at the hearings was devoted to the effectiveness of the Department's implementation of the Act. Assistant Secretary of the Interior, Jack O. Horton, provided the following summary of the agency's activities to date:

> Having been assigned the primary Federal role for carrying out the Act, the Interior Department has proceeded to translate its provisions into working regulations.
>
> While blending the legislative objectives and the requirements of technology, sound economics and the environment is complex, we are moving vigorously to assure that the Congressional purpose is carried out.
>
> In preparing regulations to supplement the Act, we have undertaken environmental studies, held public hearings and reviewed comments and views of others in accordance with the National Environmental Policy Act.

During questioning, the Department's effort to "vigorously" implement the Act was seriously questioned. Several witnesses pointed out that the only major steps taken to date have been the issuance of draft regulations for the leasing program and a draft environmental impact statement on the leasing program. Final leasing regulations have not been promulgated and the program is now more than two years behind schedule. The environmental impact statement is now over one year behind schedule. Last June, for example, the Department informed the Committee that the final environmental impact statement would be issued by September 1, 1972. In addition, the Department told the Committee that after waiting thirty days, they would be "in a condition to commence the leasing program." No action has taken place on either of these matters since this statement.

Several witnesses also felt that the present Federal effort suffered from a lack of leadership. The successful development of geothermal steam resources depends directly on the ability of government and

private industry to overcome the technological problems which are now hindering development. This could be greatly accelerated through leadership in coordinating public and private efforts. Several committee members felt the Department of the Interior had not fulfilled this role. For example, Senator Bible stated:

> The unhappy fact is that up to this point at least government itself has been a major barrier to progress. It has now been almost two and a half years since the Congress enacted the Geothermal Steam Act, opening the public lands to geothermal development the Administration has yet to promulgate the regulations needed to implement that act and place industry in a position to proceed with exploration and development.

Several other witnesses pointed out that the present Federal effort is more effective on the international front than domestically. The U.S. Agency for International Development reported to the Committee that it is undertaking projects in Indonesia and the Philippines. The latter project alone is expected to cost $4.5 million which is only $500,000 less than the total domestic geothermal research and development budget request for FY 1974 (see pg. 52a).

LEASING PROGRAM

Under provisions of the Geothermal Steam Act of 1970, the Secretary of the Interior is authorized to "issue leases for the development and utilization of geothermal steam and associated geothermal resources . . ." (30 U.S.C. 1002). The Act further stipulates that the Secretary can issue the leases ". . . (1) in lands administered by him, including public, withdrawn, and acquired lands, (2) in any national forest or other lands administered by the Department of Agriculture through the Forest Service . . and (3) in lands which have been conveyed by the United States subject to a reservation to the United States of the geothermal steam and associated geothermal resources therein" (*Ibid.*).

The Department of the Interior responded to this requirement with the publication of draft regulations covering leasing and operation of geothermal resources in July, 1971 (36 *Fed. Reg.* 13722). These regulations were revised as a result of comments received and, according to Department of the Interior spokesmen, they were to be published in final form as an attachment to the final environmental impact statement on the geothermal leasing program.

The draft environmental impact statement was completed and circulated in September, 1971. Four months later, the Department of the Interior delayed issuing the final statement in order to reexamine it in light of the decision handed down in *National Resources Defense Council* v. *Morton* (458 F. 2d 834 (D.C. Cir., 1972)). This case required a thorough examination of environmental risks incident to reasonable alternatives for any Federal project or program.

Six months later, Assistant Secretary John W. Larson informed the Committee that this evaluation was near completion and that the final environmental impact statement would be issued in the fall of 1972:

> Mr. LARSON. * * * I cannot tell you at this time when the statement will be completed, but I think a period of not more than 8 weeks from now would be adequate. * * *

Senator BIBLE. Well, August 1 is a good date. I will just write that down here.

Mr. LARSON. Fine; if you put my caveat next to it, I would appreciate it.

Senator BIBLE. Well, I penalized you, that isn't 2 months. We will give you a little leadtime. We will say right after the Republican Convention on September 1. We will give you a specific date. September 1.

Mr. LARSON. Thank you.

However, the final environmental impact statement was not issued by September 1, 1972. The only action taken between June, 1972 and June, 1973 was the issuance of modifications in the proposed regulation in November, 1972 (37 *Fed. Reg.* 25281 and 25300).

On June 13, 1973, Assistant Secretary Jack O. Horton again informed the Committee that the evaluation of the environmental impact statement was near completion and that a final statement would be issued in the fall of 1973:

Regulations to implement the Geothermal Steam Act of 1970 have undergone modification as a result of public comments and are expected to be published again as proposed rule making.

The final environmental statement should be released by the end of August. While we regret that there has been a delay in completion of the environmental impact statement and final promulgation of regulations, we will be pleased to appear again before the Subcommittee again when these matters are completed.

In the meantime, they have our highest priority.

Under questioning from Committee members, Secretary Horton identified compliance with the National Environmental Policy Act (NEPA) as the major factor in the delay of issuing the statement. As particular concern was fear of court tests on the final statement:

The draft statement is right here. We have had it analyzed at the Secretary's direction. It was determined that . . . it was open to valid legal challenge. . . . in terms of the alternatives that have been examined. . . .

The Secretary assigned five full-time people in the Department to amplify the present 102 statement task force. We are making a serious and determined effort to get through this . . .

It would be adverse to go out with a statement too, which in our judgment, was inadequate. If the Secretary's decision is to lease, he wants to do it on an instrument that is as valid and legal as he can possibly make it.

The delay in issuing the final environmental impact statement was a major point of controversy during the apeparance of departmental witnesses. The primary questioning focused on the inability of the Department to resolve the problem of alternatives in the statement. As several members indicated, this was most difficult to understand because other departments, agencies and programs faced with the same legal constraints, have fulfilled their requirements under NEPA without a two year delay. Without the issuance of the statement, the geothermal program cannot go forward. This being the case, geothermal resources remain untapped. Senator Bible expressed the disappointment of Committee members when he made the following observations regarding the lack of progress in the leasing program:

The bulk of the nation's available geothermal resources lie beneath or nearby public domained lands throughout the west and an action by the Department of the Interior has effectively stymied any meaningful progress by the private sector.

I think we have to recognize the fact that if geothermal power is going to be explored that the job would have to be done by private enterprise. This has been the case in every other major industrial field. There can be no forward movement if qualified developers are denied access to the land.

Geothermal power is not only trapped underground, it is also trapped in the bureaucratic pipelines.[1]

EXPLORATION AND RESOURCE APPRAISAL

Testimony before the Committee revealed a wide disparity between the estimates for all forms of geothermal energy (see table 1). The potential for hot dry-rock geothermal steam presents a good example of this disparity. As mentioned earlier, some experts maintain that hot dry-rock could have a power potential 20 times that of wet-steam. But as Dr. Gordon Eaton of the U.S. Geological Survey pointed out, this estimate ". . . is strictly guesswork at this point; we really don't have much of a national inventory so that these [figures] are guesses, they are not based on fact." He added that the ratio of 20 to one is based on a statistical sample of *less than* two dozen geothermal systems throughout the world.

Department of the Interior spokesmen indicated that the variations in estimates "reflect several factors—most importantly, a lack of hard knowledge and an appreciable difference in the definition of the term 'resources' as used by the respective authors." Assumptions regarding physical factors, technology, economics and governmental policy could also have an impact on the marked difference in the estimates. While these factors certainly can have an impact, it appears that our lack of concrete factual knowledge about each geothermal form has also influenced the estimates.

The lack of factual knowledge concerning geothermal resources results from the failure to implement a strong exploration and resource appraisal program. We do not know where geothermal resources are located, the amounts in which they occur, in what forms and what their economic life may be. The following description of domestic geothermal resources by the Department of the Interior offers a good example:

> The question of where the United States geothermal energy resources are is easy to answer in the broad geographic context. *Within this large region, however, the specific distribution, extent, and magnitude of geothermal resources are only sketchily known.* About 1.8 million acres of land in the western states have been classified as "being within Known Geothermal Resources Areas (KGRA's)," according to the Geological Survey. An additional 96 million acres are listed as having "prospective value" for geothermal resources (italics added).

The Geological Survey is attempting to overcome these deficiencies by carrying out a two-part program for geothermal exploration and appraisal. First, it is attempting to establish a reliable body of knowledge on the principles that control the occurrence, size, temperature, energy content, productibility, and economic life of geothermal fields. Second, the USGS is developing, refining and testing techniques for finding and evaluating geothermal areas. It should be pointed out, however, that the Geological Survey has undertaken limited appraisal work and no drilling to develop information on geothermal resources.

The compilation and analysis of this information and data is essential to the ultimate development of geothermal resources. It provides

[1] Subsequent to the hearings, the Department of the Interior issued draft revised guidelines for the leasing program; see: 48 *Federal Register* 19748–19779, July 23, 1973.

the necessary foundation upon which to base further development. As Gerald W. Johnson of the Atomic Energy Commission, noted: "all technology programs—public and private—will depend on USGS activities."

While all witnesses agreed on the importance of the exploration and resources appraisal studies, several witnesses felt that the present program has not provided the answers to a large number of questions. A great deal of information remains to be ascertained. In testimony before the Committee the Department of the Interior identified a number of short- and long-term objectives for geothermal resource exploration and appraisal.

The Department informed the Committee that there is a critical need for the development of tools to improve discovery and evaluation of geothermal resources:

> What is needed urgently is the development and testing of tools and techniques for finding and evaluating geothermal systems and their rapid application to the task of resource appraisal and national inventory. Until the Nation has fulfilled these missions, estimates of the total United States resource are just that—estimates.

In the long run, a large number of applied and basic geophysical research avenues must be pursued:

> Research is needed in: Chemical, physical, thermodynamic properties of aqueous solutions at temperatures of 100° C. to 400° C. (212°–752° F.), determination of chemical compositions of in-situ geothermal fluids as a function of in-situ rock temperatures; and isotopic relations among water and various dissolved constituents, particularly gases.

The Department of the Interior feels that additional research should focus on the thermally induced changes in the electrical resistivity of enclosing rocks in geothermal systems. In particular, "research should be directed toward: understanding the variation of porosity, water salinity, and temperature in actual geothermal reservoirs; improving electrical field techniques and procedures for extracting true resistivity values from field data; and developing complementary exploration techniques which will improve the interpretation of resistivity data."

Three other research areas on resource appraisal were identified. First, research on seismic techniques could provide assistance in delineating faults that may channel hot fluids to drillable depths. Second, research is needed on the gravity and magnetic signatures of geothermal resources to aid in detecting known geothermal areas. Third, expanded laboratory experimentation and modeling of geothermal system is needed.

Finally, as the Department of the Interior noted: "In addition to this applied research, basic research should be pursued on the physical properties of geothermal water-steam mixtures, thermal geophysics and hydrology, modern tectonic theories and geothermal anomalies, geothermal data processing and general interpretation theory, and computer modeling."

In the area of resource assessment, the Department feels that the institution of a national inventory is necessary; they observed:

> During the process of resource assessment research program, a national inventory of geothermal resources should be established. The program envisioned includes actual assessment studies as well as research on assessment methodology. In all cases, energy, water and minerals are to be considered.

Departmental witnesses also felt special attention should be given to dry-steam and hot-water geothermal systems. Two important research areas include the dynamics of representative convective systems, and geologic, geochemical, hydrologic and geophysical characteristics of representative geothermal systems.

Research programs are also necessary to determine the extent and characteristics of geopressured brines and hot-dry rock systems. For geopressured brines, the Department hopes to initiate a regional resource study in the Gulf of Mexico which will compile basic geologic data, in addition to identifying suitable sites for subsequent field research. For hot dry-rock systems, the hydrology and energy transfer characteristics of fracture systems should be analyzed to adequately assess the resource.

While the Department of the Interior's program could provide the answers to a number of unknowns, the National Aeronautics and Space Administration (NASA) would also provide valuable assistance in both exploration and resource assessment. As Mr. Charles W. Mathews, Associate Administrator for Application of NASA pointed out to the Committee:

> * * * we believe that space applications do provide valuable capabilities for inventorying and evaluating geothermal resources. Such capabilities exist in those space missions in which we carry out remote sensing using themal infrared detectors or obtain photograph-like images of the earth's surface from very high altitudes. Thermal infrared sensing can provide accurate surface temperature information either from aircraft or spacecraft and such information should enable the identification and inventorying of relatively warm areas underlain by geothermal sources. Imagery in the visible or near visible range obtained from very high altitudes in many cases facilitates recognition of surface geological features * * * With both the thermal infrared and photographic techniques, sensing from orbital altitudes permits observation of essentially all of the earth's surface. Thus, regional characteristics are established and recognition of anomalies is facilitated.

The direct application of this technology, while it is within the realm of possibility, has not been utilized to date. As Mr. Mathews observed:

> Although the missions flown to date have demonstrated a basis capability for geothermal sensing from space, none were optimally configured or deployed specifically for this purpose.

PROBLEMS IN DEVELOPING GEOTHERMAL RESOURCES

The ultimate contribution of geothermal energy will depend on its successful development by private and public institutions. The hearings on geothermal energy revealed several problems which could deter the development of each geothermal form. The following paragraphs outline these problems.

Dry-Steam.—The technology of utilizing dry-steam resources is reasonably well advanced and there is commercial exploitation of such resources; The Geysers, California and Larderello, Italy are the major fields. In these systems, the dry steam flows directly from the reservoir and is used as the working fluid in a turbine which drives an electric generator. While the technology for development is quite well known, there have been several institutional and technical impediments which have prevented development of dry-steam resources.

The major problem preventing development of dry-steam has been the lack of adequate exploration. There are very few *known* reservoirs

of dry-steam capable of commercial development. The only known domestic field, for example, is The Geysers. It is possible, however, that other commercial fields may be discovered and utilized if increased exploration and resource assessment activities could take place.

The second impediment to the development of dry-steam systems has been the failure of the Department of the Interior to implement the leasing program. There are a number of possible dry-steam areas on public lands which offer the possibility for development, but until the leasing program goes forward, these areas will remain unexplored and untapped.

A third deterent to development has been the curious institutional structure created by the resource. Dr. Gary H. Higgins of the Lawrence Livermore Laboratory explained the problem:

> * * * the technology dictates that resource development and power-generation be integrated. This integration creates a serious dilemma because the resource development industries and the utilities industries have grossly different financial policies and regulations.

For example, the electric utility industry has traditionally obtained money for capital investments through financial institutions. The development of geothermal steam, however, will necessitate expensive and risky drilling by utilities to find and harness these resources. Since electric utilities do not obtain the same tax benefits as other resource exploration industries (primarily oil and gas), they are reluctant to undertake this risky exploration. Dr. Higgins summarized the problem in the following way:

> The second factor which I think has inhibited development of geothermal power has been the absence of leasing, tax and depletion allowance regulations. Some of these problems are being resolved through efforts of your committee. I do not think technical problems have prohibited development even though they are formidable. In addition, there has been little stimulus to develop new power sources because, until recently, we have had all we needed.

In addition to these institutional problems, dry-steam systems also involve some technical problems. One such problem involves drilling technology. Geothermal drilling requires special equipment to withstand the temperatures encountered and the rock formations drilled. A National Science Foundation report edited by former Secretary of the Interior Walter J. Hickel, explained the problem of high-temperature drilling:

> Most conventional equipment will not stand up to the temperatures encountered. Some critical areas include rubber seals, valves, cements, muds, heat shields, sound muffiers, etc. Federal funding of research and development contracts on these types of problems with private industry could make a major contribution to the safety and efficiency of the drilling operations.

As Dr. James Bresee of the Atomic Energy Commission concluded: ". . . general geothermal drilling tends to be more expensive than drilling for oil wells since it is not in conventional sedimentary basins but it tends to be in areas of hard rock."

The Hickel report also pointed out a number of other technological problems which have hindered the development of dry-steam geothermal systems:

> The non-condensible gases in the steam can vary widely in consistency and quantity. Their removal is necessary to maximize plant efficiency, to minimize

corrosion of plant equipment, and for ecological considerations. The Pacific Gas and Electric Company has had a program under way for some time to abate the release of hydrogen sulfide from its plants, and this program should succeed. In other areas, ammonia, or other gases will require attention.

Particulates in steam cause erosion of turbine blading and valves. In order to minimize erosion and to maintain good performance from transfer equipment, it is very desirable to remove as much particulate matter as possible from the steam before it reaches the utilization plant * * *.

Dissolved salts may be carried into utilization equipment when any wet steam is present. Silica can cause fouling of turbines and decrease their performance; it can restrict the flow in pipes. Boron can be detrimental to plant life. Research should be conducted on preventing dissolved salts from entering the equipment.

Wet-Steam.—Wet-steam geothermal systems are produced from reservoirs containing hot water in which a number of dissolved salts exist. Heat is extracted for power generation by either separating the water and steam mixture before driving a turbine or by transferring the heat to a secondary working fluid. Wet-steam systems offer several other benefits besides power. There is the potential for the production of pure water by condensing and collecting the steam from these systems.

In addition, space heating by conducting the liquid to residences and other buildings is possible. Such systems are presently in use in Iceland, Klamath Falls, Oregon, Boise, Idaho, and other areas. Finally, wet-steam systems also offer potential for the extraction of minerals.

As noted earlier, there are only two areas in the world where wet-steam systems are producing power; these are New Zealand and Mexico. These projects, however, utilize a "flashed steam technology which uses wet-steam brines at temperatures greater than 380° F. (193° C.). The technology to harness wet-steam brines at lower temperatures are still in the developmental stage. It is important to note, however, that the successful application of these technologies will greatly expand the power potential of wet-steam systems. Dr. Higgins of Lawrence Livermore Laboratory detailed the types and estimated costs for each type of wet-steam technology now being considered:

* * * The first, called the flashed steam system, is most comparable to conventional steam-electric plants. * * * Efficiencies between 11 percent and 12 percent can be expected from plants presently costing about $275/kw, yielding power in the range of 10 mills/kwh from brines at 500° to 600°F.

The second method incorporates a heat exchanger to transfer heat from the hot water to a secondary low boiling point working such as freon, which is used to drive a turbine. This is called the binary fluid cycle method * * * such a system is not used commercially. It should operate at about 12 percent efficiency at a cost of about $300/kw and generate power for greater than 10 mills/kwh, according to estimates by others. * * *

The third method is called the total fluid flow method and consists of expanding the total hot steam-water mixture from the wellhead through nozzles much like rocket exhaust nozzles. * * * Because of its simplicity and intrinsic high thermal efficiency, about 16 percent, we expect the installation to cost $200/kw and to generate power for less than 10 mills/kwh.

The same impediments preventing the use of dry-steam systems are also preventing the development of wet-steam systems. There is very little knowledge, for example, concerning the location, size, characteristics and economic life of wet-steam systems. Second, the failure to implement the leasing program has effectively prevented any large-scale prospecting. Furthermore, there are a number of important tech-

nological problems which must be addressed before full scale development can take place (see discussion below). The development of this type of system is a venture involving a great deal of risk. Most companies are reluctant to undertake such ventures without some governmental assistance to help defray possible investment losses, especially when alternative energy forms are available at competitive prices and less risk. For these, and other reasons, there is only one company now involved in the active development of wet-steam resources; that company is San Diego Gas and Electric which is building, in cooperation with Magma Power Company, a 25 MW demonstration project in the Imperial Valley of California.

In addition to these problems, there are a number of technical problems which must be addressed in order to successfully develop wet-steam systems. Dr. Alfred J. Eggers, Jr., Assistant Director for Research Application, National Science Foundation, pointed out these difficulties to the Committee:

> Unlike the dry steam open system, the technology of [wet-steam] systems is quite complex * * *.
>
> One component of this system requiring further research is the heat exchanger for transferring heat from the hot brine to the working fluid of the power cycle. This unit must be designed to withstand the corrosive nature of the geothermal brines while operating at maximum efficiency for extended period of time * * *.
>
> A downhole pump is also required by this system to increase the production capacity of a well and to pressurize the hot brine to prevent its flashing to a two-phase mixture at the surface. This latter use would simplify heat exchange to a binary fluid. It could prevent scaling and salt deposition on the heat exchange equipment * * *.
>
> An alternative to the closed-binary fluid system involves passing the entire hot brine flow directly into a mechanical power generating device, designed to withstand both the corrosive and two-phase nature of the fluid. Potential devices for achieving this end include a rotary vane engine, a bladeless turbine and helical screw expander. Research will be supported to develop the technologies for these devices with a view to providing attractive alternatives for obtaining power from geothermal fluids.

Hot Dry-Rock.—Hot dry-rock systems represent a very large potential geothermal energy resource. However, technology for the economic recovery of heat from this source is not available at the present time. Testimony before the Committee revealed that there is no pilot project or demonstration plant now operating (or under construction) to utilize hot dry-rock resources in the United States or the world. As Dr. Gordon Eaton of the U.S. Geological Survey noted, we know very little about hot dry-rock systems: "* * * basically we don't know what one of these systems looks like and when you get right down to the hard fact of it, most of what [was shown to the Committee] is an inference from a lot of scientific data * * *"

A necessary first step toward development of hot dry-rock systems, according to testimony, is a thorough exploration program. The only research work now underway in this regard is being financed by the National Science Foundation. In FY 1974, they will undertake drilling to find hot rock anomalies near Marysville, Montana. If this drilling is successful, the NSF hopes it will "lead into a program of research and development for utilization that would be carried out in a close coordination with other government agencies and private industry."

The other important area of research on hot dry-rock will examine developmental technology with special emphasis on creating rock fractures. One area of investigation contemplates the use of remotely mixed chemical explosives to induce fracturing; recently a successful test of this concept in a situation simulating a well bore was carried out. Another method uses the standard petroleum technology of hydraulic fracture; this is a method experimented with by researchers at Los Alamos Scientific Laboratories. Finally, another group of researchers is utilizing mathematical simulation modeling to investigate fracturing systems.

Several witnesses were optimistic about the possibilities of developing hot dry-rock geothermal energy systems even though we have limited knowledge about some aspects of the resource. Dr. Eggers of NSF, for example, stated that "if the efforts in rock fracturing technology are successful, power plants using hot rock resources could be on line by the next decade." He cautioned, however, that "such a schedule will require the cooperative efforts" of a number of public and private institutions. The Geothermal Coordinator for the Department of the Interior, Mr. Reid Stone, stated that "the mechanical or technological equipment that we need to develop [hot dry-rock systems] is, I think, well established."

This optimistic tone was shared by the Hickel report which concluded that there is no significant need for research on surface technology of hot dry-rock systems assuming temperatures high enough to heat the fluids sufficiently are found. The report also commented that hot dry-rock systems "do not appear to pose any unique utilization technology problems" assuming that injected water is used as the heat transfer medium.

While witnesses were optimistic about the potential for hot dry-rock systems and the time frame within which it can be delivered, it was obvious from testimony that there has not been interest by private concerns in developing hot dry-rock systems. No private firms are now involved in research or development of such systems, and until more extensive research and development is undertaken by public institutions, it appears that there will be no private interest, since this R&D involves a high risk and uncertain returns on investments.

This state of affairs prompted one witness, Dr. Gerald Johnson of the Atomic Energy Commission, to state that "the missing ingredient [in the present geothermal development effort] is a broadly based engineering program aimed at planning and carrying out joint governmental/industrial geothermal energy development activities." Dr. Johnson expressed the need for a pilot project, involving the participation of the Federal Government.

Two government agencies are now on the verge of instituting such a project for hot dry-rock. The National Science Foundation's research is leading to the ultimate development of a pilot project. The Atomic Energy Commission, through its Los Alamos Scientific Laboratory, outlined for the Committee a proposal to construct a small (30 MW) hot dry-rock pilot project, Barring any major unexpected difficulties, the AEC feels that in less than five years, it could produce the evidence on which industrial development could be based. Funding required for this project would be $4.7 million.

Geopressured Brines.—The final geothermal energy form is geopressured brines. Testimony before the Committee revealed that this form could only be viewed as a long-term source since so little is known about it. Dr. Gordon Eaton of the USGS observed:

> There is, I should hasten to point out * * * quite an honest divided opinion as to how viable this resource will be. The main thing we do not know is how large are these reservoirs. If they are going to give up their pressure in heat in a very short period of time obviously it is not going to be economically feasible to construct a plant on the site of one of these.
>
> If on the other hand there are very, very large volumes, perhaps then it might be feasible. So the first order of business it seems to me is to determine how large these reservoirs are.

It was pointed out to the Committee that geopressured brines may be expensive to develop. Dr. Gary Higgins of Lawrence Livermore Laboratory made the following estimates of geopressured brines:

> Crude estimates suggest plants for generating electric power from geopressured water will cost between $500 and $1,500 per kilowatt [of installed capacity] and produce power between ten and thirty mills per kilowatt hour.
>
> These estimates include power from the pressure and heat and credit for 15 cubic feet of natural gas per barrel of water.
>
> The geopressured resource electricity costs are higher than those of geothermal because unit drilling costs increase so much with depth and each hole produces less power. Geopressured resources are found deeper than 10,000 feet, while hot water resources we have examined are 5,000 feet deep, or less.

While there is a lack of knowledge about this resource and while preliminary estimates suggest a high development cost, other witnesses warned against deferring exploration and resource appraisal. The Department of the Interior, for example, concluded in its testimony that "the geothermal energy in these sedimentary basins may represent a significant resource potential" and that resource assessment studies should go forward.

A large part of the resource assessment work will depend on the close cooperation of government and industry. As the Hickel report indicated, regional resource studies will be based on data which presently exists in petroleum company files. Because of the proprietary nature of these files, even though data on the geopressured resource itself is normally not considered proprietary, it will be necessary to derive these data through a cooperative endeavor.

The Hickel report also indicates that it will be necessary to develop models to characterize the dynamics of geopressured reservoirs and then apply these models to assess the reserves of this type. The models will need to relate size, recharge rates from neighboring formations, origin, natural life, and flow mechanisms of geopressured resources. The study estimated the cost for modeling and information gathering to be $30 million for a ten-year research program.

REALIZING DEVELOPMENT POTENTIAL

The present Federal geothermal program is based on the premise that private industry will lead the development effort. Assistant Secretary Horton enunciated this policy in the following manner: "Facilitating the orderly and efficient development of geothermal resources on the public lands by private industry while at the same time pro-

viding a fair return to the public for the use of those resources are the main objectives of the Geothermal Steam Act of 1970."

Testimony before the Committee revealed that achieving the active participation of private industry in extensive development of geothermal steam resources will be difficult. The Department of the Interior's failure to institute the leasing program is a major deterrent. Over and above this obstacle, however, there is a great deal of costly basic exploration, resource assessment, research, and development work which remains to be done. Private industry has not shown the willingness to undertake this work for reasons outlined earlier.

Witnesses agreed that the Federal Government should continue to perform its traditional role in resource exploration and assessment. There was, also, considerable support in favor of an expanded role by the Federal Government in the development of geothermal energy forms, specifically in the development of pilot projects in wet-steam and hot dry-rock systems.

The involvement of the Federal Government in joint private/public pilot projects is not a new concept. The Department of the Interior has undertaken a similar program with coal gasification and oil shale and these projects are important preludes to future development of the resources. Pilot projects, witnesses observed, could lead to demonstration plants which, in turn, could develop a general industrial confidence in the resource and the technologies.

The concensus among witnesses was that pilot projects could be implemented quickly. The developmental technology for wet-steam and hot dry-rock systems are available or close-at-hand. Witnesses testified that only through application could many technological problems be resolved and ultimate development take place. The following colloguy between Senator Church and Mr. Reid Stone regarding the development of hot dry-rock brought this point into sharp focus:

Senator CHURCH. May I just stop you there? * * * If I understand you correctly, you are saying that as far as the technology is concerned, drilling, fracturing and that kind of thing, we have already developed the technology. * * *

Does it follow then, that we are in a position, if we had the funding, to go forward with a pilot plant demonstration effort to get approval of the feasibility of this dry hot-rock system. * * * Are we, technologically speaking, in that position?

Mr. STONE. The mechanical or technological equipment that we need to do the job is. I think, well established, however, the understanding of the reservoir itself and the high drill rock system, as Dr. Eaton pointed out, is a very big question.

Senator CHURCH. How are you going to get that understanding? Are you going to have to experiment?

Mr. STONE. You are going to drill and find out.

It was the opinion of witnesses that we are at the same position with respect to wet-steam geothermal systems as well. In this cases, three different avenues of investigations were proposed to the Committee. First, several witnesses believed that some form of Federal assistance for financing (either through grant-in-aids, tax provisions, or depletion allowances) was a proper way in which to proceed. The number of projects available for funding is not the problem. As mentioned earlier, the Atomic Energy Commission has a proposal ready for the development of a hot dry-rock system. The National Science Foundation also testified that it had received research requests for

over $10 million in projects, one-half of which they would like to support. Magma Energy, Inc. and the Lawrence Livermore Laboratory also presented projects to develop wet-steam geothermal systems. Both groups are seeking financial assistance through the Federal Government. The Magma project would total $3 million, while the Livermore project would cost $8.6 million. Both projects would initiate a program leading to a pilot plant.

The second possible avenue for initiating a pilot project was the proposal to establish a National Geothermal Testing Station. The Atomic Energy Commission has for many years operated a National Reactor Testing Station to serve as a general purpose nuclear reactor and component test facility. The AEC suggested to the Committee that since this facility was located near numerous geothermal resources it could be expanded into a "National Geothermal Testing Station." According to testimony, this conversion could take place by administrative action if appropriations were obtained for the facility and staff.

The final suggestion for developing wet-steam systems was the proposal to develop joint public/private pilot projects followed by the gradual withdrawal of Federal participation. This suggestion is similar to the program instituted to develop nuclear power.

RESEARCH ON GEOTHERMAL ENERGY SYSTEMS

Testimony at the hearings revealed a number of fundamental and complex research-related questions. Since these problems are basic to successful development of geothermal energy, they are discussed below.

Research and Development Goals.—Geothermal research and development activities by Federal agencies are quite recent. The passage of the Geothermal Steam Act of 1970 marked the beginning of the present effort. The Department of the Interior pointed out that this newness has had a direct impact on the character of research to date.

At the present time, geothermal exploration, research, and development work is at an early stage in the United States, and the level of understanding is still relatively rudimentary. For example, the U.S. Geological Survey is attempting to develop and test tools and techniques for finding and evaluating any kind of geothermal system for any and all applications.

Dr. Gerald Johnson of the Atomic Energy Commission noted another effect: "all the people in the laboratories and the associated organizations have been developing programatic approaches on their research funds * * *" The Department of the Interior indicated that this "programatic" approach is the only valid course given our state of knowledge: "much of the current research can only be geared to the general, rather than the specific, case."

The "general" character of research was indicated in the Department's research and development goals outlined for its agencies and bureaus with geothermal responsibility. It envisions, for example, that the U.S. Geological Survey will concentrate on exploration methods and resource appraisal, and to a lesser extent, reservoir development, utilization technology, and environmental monitoring. The Bureau of Reclamation will focus on the technical and economic feasibility of

producing fresh water from saline brines contained in wet-steam systems. The Bureau of Mines will concentrate on the recovery of minerals and gases in geothermal fluids.

Missing from this testimony was any discussion of R&D goals for agency programs within the context of an overall R&D program. Witnesses did not, for example, outline the priority exploration should take over R&D on development technology or environmental assessment. Witnesses preferred to keep their recommendations on the "programatic" level. In addition, research and development recommendations did not contain any discussion of the priority one specific geothermal energy form should take over another. Thus, testimony did not discuss whether dry-steam should be investigated over wet-steam or geopressured brines. *Finally, there was no discussion or explanation of an overall Federal R&D program.* Only programmatic objectives of individual departments and agencies were discussed.

This discussion of goals and priorities is fundamental to the development of geothermal energy. By outlining the R&D activities which will be pursued by public and private institutions, investment decisions can be made and developmental programming undertaken. In some applications, for example, private industry may not be able to undertake highly risky and/or expensive R&D. In these areas, Federal involvement is necessary. Yet without enunciated R&D goals, public and private agencies may not be able to make decisions, or if they do, they may be incorrect decisions. Senator Buckley mentioned this dilemma when he observed that he hoped the hearings would "help us define the area of research and development which because its goals are so remote in point of time that the private sector cannot be expected to move in and to help define; in other words those areas where the Federal Government must move in."

Another difficulty with the research and development goals outlined by witnesses was the need to balance R&D objectives in light of changing economic conditions. Most forms of geothermal energy resources, at the present time, are more expensive to develop than alternative forms for generating electric power. The application of R&D to specific problem areas could, however, decrease the gap between geothermal energy and alternative power sources. Testimony on this problem was not extensive. But Dr. Gerald Johnson of the AEC did outline several technological problems with "economic" constraints which he thought should be emphasized in future research:

> Examples of other technological problems which are more economic than environmental and which should be emphasized in joint programs are: One, long term reservoir management. Both from the standpoint of conservation and realistic reserve depletion assessment, models must be developed which predict the rates of heat mining and reservoir recharge for various combinations of reinjection and heat removal.
>
> Two, precipitation and corrosion. Our knowledge of the causes and remedies of precipitation in the geologic formation and remedies of precipitation in the geologic formation and in the process equipment must be expanded . . .
>
> Three, advanced power cycles. Since geothermal energy is generally available at lower temperatures than used for present day electrical power generation, we need to improve the technology of power generation in this low temperature regime . . .
>
> Four, emission control. The technology of containment of pollutants is environmentally important, but advanced concepts can also be aimed at recovery of valuable by-products.

Research and Development Organization.—The present organization of Federal agencies involved in geothermal research and development is highly fragmented. According to the Hickel report, ten Federal agencies are involved in one phase or another of geothermal research, development or planning. Within these ten agencies, twenty-one separate bureaus or offices are involved (Table 2). In addition, the Hickel report stated that "in terms of current Federal activity alone, more than a dozen agencies have R&D programs either in the planning stage or already underway."

No formal mechanisms have been established within the Federal structure to guide the R&D effort or to avoid duplication. There is, however, an informal mechanism. According to testimony supplied by the Department of the Interior, the R&D work of the Department's four bureaus has been "loosely tied by an ad hoc interbureau committee that meets monthly." The other members of this ad hoc group are the National Science Foundation, Atomic Energy Commission, Environmental Protection Agency and Advanced Research Projects Agency.

TABLE 2.—LIST OF FEDERAL AGENCIES WITH GEOTHERMAL RESOURCES RESEARCH AND DEVELOPMENT RESPONSIBILITIES

I. Department of the Interior:
   - A. U.S. Geological Survey.
   - B. Bureau of Land Management.
   - C. Bureau of Reclamation.
   - D. Bureau of Mines.
   - E. Bureau of Outdoor Recreation.
   - F. Bureau of Sport Fisheries and Wildlife.
   - G. Office of Saline Water.
   - H. Office of Water Resources Research.

II. Atomic Energy Commission:
   - A. Division of Applied Technology.
   - B. Division of Research.

III. National Science Foundation:
   - A. Earth Sciences Section.
   - B. Energy Research and Technology Program.

IV. Federal Power Commission.

V. Department of the Treasury.

VI. Department of Defense:
   - A. Advanced Research Project Agency.
   - B. Naval Weapons Center.

VII. National Aeronautics and Space Administration.

VIII. Environmental Protection Agency.

IX. Department of State.

X. Executive Office of the President:
   - A. Office of Management and Budget.
   - B. Energy Policy Office.

Source: Adapted from, Walter J. Hickel, *Geothermal Energy: A National Proposal for Geothermal Resources Research*, (Washington: NSF, 1972).

Several witnesses questioned whether this form of R&D organization was leading to effective results. Dr. Johnson, for example, com-

mented that a major factor missing in the present R&D program was the "assignment of responsibility" for the various areas needing investigation. Mr. Reid Stone, Geothermal Coordinator for the Department of the Interior, commented that the Department hadn't supported the research efforts of the Atomic Energy Commission on hot dry-rock systems.

In addition to the problem of coordination, the present organization of R&D exhibits some overlap of responsibility. The Department of the Interior, for example, is involved in R&D on dry-steam, wet-steam, and to a lesser extent, geopressured brines. The National Science Foundation is also carrying out research on wet-steam systems, as well as hot dry-rock. While the Atomic Energy Commission efforts are limited, it has carried out work on wet-steam systems and hot dry-rock. As the Hickel report observed, some duplication is inevitable, but wasteful duplication can detract from a successful program:

> Although it is possible that wasteful duplication may not be occurring at the present time, duplication almost assuredly is eventually inevitable unless steps are taken to coordinate the national effort. Without effective coordination there can be no realistically achievable programs. * * *
>
> Some of the questions of the specific responsibilities of the private sector and government will have to be worked out and structured to some degree if the private sector and the government are to be meshed in a program that is both effective and efficient in relation to national need.

The witnesses offered few recommendations concerning alternative organizational schemes which might replace the present one. There was, for example, no mention of the possibility of establishing a more formal interagency mechanism to coordinate Federal R&D and no full discussion of designating a "lead agency," specifically instructed to pursue geothermal R&D. In addition, there was little comment about the possibility of creating joint industry/government research projects leading to the orderly development of the resource.

Financing Research and Development.—The present funding for Federal research and development is shown in Table 3. The level of funding has shown a marked increase since 1970 when no funds were appropriated for geothermal research and development. The major change between FY 1973 and FY 1974 was the deletion of funds for the Office of Saline Water research on wet-steam resources. This action was taken, according to the Department of the Interior, to consolidate desalination research in the Bureau of Reclamation, however, there has been no action taken to initiate any such effort in the Bureau. The Atomic Energy Commission does not appear on Table 3 because it has not requested funds specifically for geothermal R&D.

Some controversy developed at the hearings regarding the level of funding for geothermal research and development. Senator Bible, for example, took the position that current levels were far too low:

> The Administration has also taken a baffling attitude toward the funding of geothermal research and development. One case with which I am personally acquainted involves the AEC. The commission is uniquely qualified to make a meaningful contribution to geothermal research. Nevertheless, the Administration refused to apportion funds appropriated for AEC for geothermal research in both fiscal years 1972 and 1973; and again this year they rejected the Commission's request for such funds in the 1974 budget.
>
> I realize that this may be only one example but one notices frequent complaints in the geothermal literature about the lack of progress on geothermal is attributable to a lack of essential research and development funds.

TABLE 3.—APPROPRIATIONS FOR GEOTHERMAL RESEARCH AND DEVELOPMENT, FISCAL YEAR 1973 AND FISCAL YEAR 1974

Agency	Fiscal year 1973[1]	Fiscal year 1974[2]
U.S. Geological Survey	$2, 500, 000	$2, 530, 000
Bureau of Mines	200, 000	200, 000
Bureau of Reclamation	1, 432, 000	1, 270, 000
Office of Saline Water	800, 000	----------
National Science Foundation	1, 050, 000	1, 080, 000
Total	5, 982, 000	5, 080, 000

[1] Appropriated funds.
[2] Budget requests.

Assistant Secretary Jack O. Horton disagreed with this assessment. According to the Secretary, "the R&D funding for geothermal was based on successful technology which is now being used at the Geysers from which geothermal is being economically and commercially developed." He pointed out that "until the leasing program goes forward I think it is difficult for us to pre-judge what response in terms of R&D industry might be willing to come forward with when they have physically, geographically, the lands on which to experiment." Dr. Gordon Eaton of the U.S. Geological Survey added that R&D funding had undergone a 20-fold increase since 1970. In addition, Dr. Eaton questioned the results that would be obtained from increasing appropriations:

> The point that I wish to make is that there is a certain limit to how much money you can pour into something and get immediate results. In other words I think we can't just suddenly jump to a plateau of funding and hope to make optimum use of that. We have to build up the background of understanding.

The Subcommittee Chairman, Senator Church, strongly disagreed with the level of funding. He labeled the present level "tokenism" and also commented that Assistant Secretary Horton's testimony suggested a "non-program":

> It is tokenism in terms of really moving forward with the development of new technologies in this field. I know you have technical people who are going to talk about those technologies, but your statement suggests a non-program which I take it to be the position of the Administration.

Most witnesses did agree that the low level of funding for geothermal R&D had hindered the development of the program. Most were also in agreement that more money could be utilized and that the results obtained from added funds would be vital to future development. Senator McClure raised the issue that added research and development funds would also enable us to see if geothermal energy development was a good avenue to pursue for future energy supplies:

> The reason I asked that question is that we are not just talking here about what we may be able to do with the development of the geothermal, we are talking about the priority for the investment of dollars that are more scarce than we would like to have them. And unless we can demonstrate conclusively somewhere that the investment of money in geothermal research would yield as good a result as the investment of those dollars in alternative energy sources, we are not going to get to first base unless you can get the government to invest very much money.

Most witnesses, however, emphasized the need to increase research and development funding to help meet the growing problem of do-

mestic energy supplies. Senator Church made the following statement in this regard:

We have got an energy crisis, you know that; I don't have to emphasize it. We are running out of our own supplies—petroleum and natural gas. Nobody knows how we are going to solve the physical and economic problems associated with the importation of larger and larger quantities of petroleum from abroad.

Yet it seems to me there is no sense of urgency in connection with developing these other sources of energy that are available to us right within our country.

It just seems to me that we are grinding along in low gear.

The Congress would seem to be in agreement with this view. It has, for example, increased the geothermal research and development funds for the Bureau of Reclamation by $500,000 over the amount requested. There has also been an increase of $300,000 for the Geological Survey and $100,000 for the Bureau of Mines. In addition, the Atomic Energy Commission was appropriated $4.7 million to begin substantial R&D on hot dry-rock resources.

Additional funds also may be forthcoming through supplemental appropriations as a result of the President's energy message of June 29, 1973. In that message, the President directed that an additional $100 million for fiscal 1974 be appropriated for the "acceleration of certain existing projects and the initiation of new projects in a number of critical research and development areas." While the exact amount to be appropriated for geothermal energy has not been determined, it is hoped that it will be sufficient to lay a solid foundation for an expanded geothermal research and development program.

ENVIRONMENTAL PROBLEMS ASSOCIATED WITH GEOTHERMAL DEVELOPMENT

In addition to technological and economic considerations in geothermal resource development, there are certain environmental considerations associated with utilizing the resource.

One immediate problem will involve land use. Utilization of presently undeveloped Federal lands can be expected to require decisions involving land use between adjacent private landowners and between land use on nearby Federal lands. The Department of the Interior pointed out several other related land use problems:

Recreational use of both private and Federal lands poses a significant area requiring resolution to this factor. Geothermal development is expected to result in restricting the use of a small portion of land surface in the immediate vicinity of wells, pipelines, power plants and other related surface structures.

Of particular concern to many environmental groups is the alteration of aesthetic qualities of an area due to industrial development. It is expected that geothermal developments may be limited in certain areas to avoid or minimize major land use conflicts.

The withdrawal of geothermal fluids and reinjection of waste liquids may result in either land subsidence or increased seismic activity. The Department of the Interior explained this concern:

The withdrawal of fluids from oil and gas and water reservoirs has resulted in cases of land subsidence. Subsidence has also been measures in conjunction with geothermal fluid production of Cerro Prieto, Mexico and Wairakei, New Zealand. Reinjection of geothermal fluids, as practices at The Geysers field in California, is expected to be the normal operating procedure at other geothermal developments in the United States. Thus, the effect of fluid withdrawal may, in part, be offset by reinjection of liquids. If, however, desalination plants were used to

produce fresh water at a geothermal development, a greater net withdrawal would occur, unless makeup brackish waters are injected, and subsidence could have a significant effect.

An associated effect which may develop as a result of reinjection of geothermal fluids is an increase in seismic activity. * * * Changes in effective stress and lubrication of fault planes by reinjected fluids coupled with pressure buildup and related effects could result in movement along fault zones.

There are a number of gases and vapors which may be associated with the release of geothermal steam and could provide a problem. Gases such a hydrogen sulfide and vapors such as mercury and ammonia may be present. According to the Department, the geothermal power plant because it is fed by wells is the point at which the effect from such gases may become a problem. While some gases can be removed, noncondensible gases are released through the cooling towers. Technology has not been developed to remove some vapors, but methods are available to prevent overexposure to toxic elements.

Noise is another significant environmental impact associated with geothermal development. As the Department of the Interior noted:

Power sources for drill rigs, venting of air and cuttings through the return circulation line during air drilling, racking of drill steel, and other related sounds during the drilling process can be annoying. An unmuffled well with a capability of commercial production on open flow through the full well diameter has been compared to the noise of a jet plane on takeoff. Venting of a well upon completion is necessary to prevent condensation of the steam and flowback down the well which may result in the loss of the well. In order to suppress the noise, prevent damage to the well, and to conserve the natural resource, and at the same time to insure continuous venting of the well, a controlled venting device is usually required to be installed at the well head . . . Muffling devices have been developed and are in use in most geothermal fields.

A final environmental problem associated with geothermal development is water pollution. To prevent the contamination of ground and surface water, reinjection of used geothermal fluids is, according to the Department, expected to be a standard operating procedure in U.S. geothermal fields. As indicated earlier, however, the impact of reinjection upon reservoir life and seismic conditions is not known.

Consideration of environmental impact in development plans will place an added responsibility on American industry. As Dr. Gerald Johnson of the AEC noted: "one common element of all cooperative programs will be the need to adapt existing or develop new geothermal technology to meet the special requirements of the U.S." He also observed that "it is agreed that environmental constraints related to such problems as land subsidence, hydrogen sulfide release, noise pollution, and saline solution discharge, will be strictly construed and will challenge the engineer to develop improved approaches to their solution."

Any discussion of the environmental impact of geothermal energy should not, however, be taken out of perspective. Geothermal energy, even with its environmental problems, remains a relatively "clean" energy source. Because geothermal energy must be harnessed at the resource site, its environmental impact is lessened. Unlike fossil-fueled or nuclear power plants there will be no transportation of the energy source. As the Department of the Interior stated:

To understand properly the impact of the production of electric power on the environment, it is necessary to evaluate more than just the power plant, whether it is geothermal, nuclear, or fossil fueled; the entire fuel cycle from mining,

processing, transportation, and the disposal of spent wastes must be considered. When viewed in this light, the environmental impact of geothermal generation appears to be minor when compared with fossil-fuel or nuclear generation. The environmental impact of geothermal generation is restricted to the generating site, whereas much of the environmental impact of other power generation takes place at several locations (mines, processing plants, disposal sites).

GEOTHERMAL ENERGY AND WATER RESOURCES DEVELOPMENT

The desalination of geothermal fluids may be feasible under certain circumstances. Since a majority of geothermal resources are located west of the Rocky Mountains, this possibility could benefit many water-deficient areas in western states. The most active work in this area is being carried out by the Bureau of Reclamation in the Imperial Valley of California.

The Bureau and the University of California began a joint exploratory program to evaluate the geothermal potential of this area in 1968. In 1970, the Bureau became an active participant in the geothermal resource investigations of the Imperial Valley. Drillers, equipment, and technical personnel were employed and deep drilling and geophysical operations were conducted to find the most promising areas. A production well was drilled and completed in the summer of 1972. Two desalting plants using different technologies were installed at the well and testing is now underway to obtain definitive results. The quantities of geothermal water in storage in the Imperial Valley are known to be large and it could prove to be a significant augmentation to the fresh water supplies of the region.

The Department of the Interior cautioned, however, that geothermal brine desalination should not be viewed as a panacea to Western water problems. They stated that "although the technology of desalination of geothermal brines is being developed, the economic of fresh water production may only be attractive at certain locations."

The interface between geothermal energy development and water supplies was also brought into focus by Senator McClure. In questioning the Director of the Idaho Department of Water Administration, Mr. R. Keith Higginson, Senator McClure asked whether Mr. Higginson was "satisfied from the preliminary data which is available * * * that drilling through the Snake River Plain aquifer can be sufficiently isolated to guarantee the safety and integrity of the water supplies within the aquifer." Senator McClure cautioned that development of geothermal resources at the expense of other economic activity which are dependent on those water supplies would not be wise.

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