A TECHNOLOGY ASSESSMENT OF GEOTHERMAL ENERGY RESOURCE DEVELOPMENT

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Preface

This report deals with some potential futures for geothermal energy in the United States, evaluates these, and makes recommendations based on these evaluations which can help policy-makers capture the desirable aspects of this energy source while avoiding its pitfalls. Because such considerations often involve a high level of uncertainty, the conclusions of this work necessarily depend on assumptions and judgments; therefore, the report documents the assumptions which were involved, separates opinion from fact.

Many people were involved in this study. The methodology which was employed drew heavily on interviews with experts in geothermal energy and its potential social, environmental, political, and economic effects. Participants in these interviews are identified in the report with their permission; but particular statements are not attributed, in accordance with our understanding with these contributors. An Oversight Committee made extremely valuable suggestions to the study team. Numerous consultants were employed. Bechtel Corporation, the major study subcontractor, furnished most of the material dealing with potential technological impediments, environmental aspects, and resource development. The Futures Group is responsible for the work as a whole, and in particular, the social, economic, political, and legal material, some technical and environmental material, and the development of the simulation model. And, finally, The Futures Group is responsible for the definition and assessment of impacts and for the framing of recommendations.

The Futures Group team consisted of Theodore J. Gordon, Frank Maslan, Lillian Deitch, David Weinstein, John Stover, and Elihu Fein. Theodore J. Gordon was the study director and Frank Maslan was assistant director. The Bechtel team consisted of Meir Carasso, Larry Beaulaurier, Michael Gallagher, and Jerome Hankin. Meir Carasso headed the Bechtel effort.

Special thanks must also be given to reviewers of the original manuscript and to Joseph Coates, the National Science Foundation study monitor, who, through artful inquiry, helped the study team sharpen its views.

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1. INTRODUCTION

1.1 Study Objectives and Framework

Geothermal energy, energy derived from the intrinsic heat of the earth, may become an important element of the energy inventory of the United States and throughout the world over the next few decades. In some of its earliest applications, it has proven to be relatively economic, and if not completely "pure" environmentally, then at least relatively acceptable. How important it will become, and what effects it will have on the nation, the economy, the environment, and people, depends on many factors, including the extent of the resource and the length of time any particular field will last when tapped. Estimates of the extent of the resource vary widely. Participants at the Hinkel Geothermal Resources Research Conference [1] estimated the developable potential as 132,000 MW of electric power by 1985. (For comparison, the Federal Power Commission anticipates a demand of about 930,000 MWe for the United States in 1985.) The National Petroleum Council [2] on the other hand estimated that the level of power generated from geothermal sources would range between 3500 MW and 19,000 MW by 1985. These estimates, separated by almost two orders of magnitude, indicate that by 1985 geothermal energy may be able to supply between 0.4 percent and 14 percent of the power consumed in the United States. With the lower estimate geothermal energy would be interesting; with the higher estimate it would be extremely important.

For the most part current geothermal installations in the United States and elsewhere exploit resources relatively near the surface of the earth in the form of natural steam or hot brine. In many places, however, it appears that deep geological formations exist which have abnormally high heat content. These formations are known as "hot dry rock"; these formations exist because they are relatively impervious to meteoric or magmatic waters which, if present, would provide a cooling heat transport mechanism. Such formations may exist within 20,000 feet of the surface in the western United States; in the East their depth may be on the order of 40,000 feet. In addition, very extensive deep (5,000-20,000 feet) zones of hot pressurized water with widely varying salinity have been found to exist in the northern Gulf of New Mexico basin along the Texas, Louisiana, and Mississippi coasts, and beneath the Gulf Continental Shelf. If technology can be developed to utilize these deep resources safely, geothermal sources could well satisfy a large portion of the energy demand of the United States before the year 2000.

Energy derived from geothermal sources must be bought by a relatively narrow set of users: in most instances, the electric utility industry and other users of heat. The potential buyers of geothermal energy will view the resource in context with other resources. Are they cheaper? Do they have advantage by virtue of their lesser environmental impact? Are they reliable? Has that reliability been proven? Does geothermal energy, more than other energy sources, promise abundance and relative independence of supply interruption caused by natural or political events?

Clearing institutional and political hurdles in the identification and development of geothermal resources is a particularly complex problem. Most Known Geothermal Resource Areas (KGRA) [3] exist on federal lands and a leasing program has recently been established by the U.S. Department of the Interior. The industry which will pursue the development and sale of these

resources is only now being formed and its interface with the body of law and practices largely established for other purposes must yet be clarified.

Most environmental impacts of geothermal installations have seemed relatively innocuous. However, for certain types of wells, some experts have felt that the environmental impacts may include land subsidence. In addition, it has been suggested that when geothermal installations involve injection or removal of fluids near active fault lines, seismicity must be considered.

Certainly there are a host of other issues: to what degree will geothermal resources be useful in providing fresh water supplies and minerals? The technology for removing or preventing some kinds of scale formation in high salinity hot water fields is not yet well known; can it be developed effectively? Is the required deep-hot drilling technology likely to be available to exploit "hot dry rock" energy resources? If the high resource estimates are correct, can a new industry with its concomitant demand for capital, manpower, and materials be put into place fast enough?

Out of this mix of scientific, technological, social, economic, and political issues emerges these considerations: there is a potential for geothermal energy to provide an appreciable portion of our energy needs; its growth may be shaped by institutional policies; and its impacts may affect not only those who provide and service the new installations and those who live nearby, but essentially all people who use energy. The central objectives in this study were to determine the plausible levels of energy which can be produced using the intrinsic heat of the earth, the effects on society of doing so, and the consequences of policies available for modulating the evolution of the technology and its impacts.

Fundamental to this work is the notion that not only can man shape his future, but he has the obligation to do so, both to avoid stumbling into a potentially disastrous situation and to gain the best of what is possible.

More specifically, the objectives of this study were to:

1. Identify potential constraints to the development of geothermal power, including technological constraints, and should the source be found potentially beneficial, develop action options which can be helpful in removing the constraints.
2. Determine technologically feasible levels of geothermal energy resources development in the United States in the 1973-2000 time period.
3. Determine the impacts of the wide use of geothermal energy on the nation as a whole as well as on the energy industry and other groups which would be importantly affected.
4. Analyze the social, political, economic, and environmental impacts associated with possible future geothermal energy developments before this source comes into wide use in this country. Both favorable and unfavorable effects are included in the term "impact."
5. Provide an understanding of the interplay of environmental consequences with prospective policy actions and resource development.
6. Provide input to the policy process regarding this technology and its impacts so that the chances of achieving its intrinsic benefits are improved and its disfunctional aspects avoided, to the greatest extent possible.

7. Foster development and application of systematic technology assessment methods for potential use in other policy-related studies.

Over the past year these objectives have been pursued by a study team composed of members of the staff of The Futures Group and its major subcontractor, the Bechtel Corporation. The study team was ably assisted by distinguished consultants whose skills ranged from geology to urban design, and an oversight committee which not only reacted to ideas presented by study team members but also provided advice and furnished much needed information throughout the study period. The contribution of both the consulting group and the oversight committee is gratefully acknowledged; participants are listed in Figure 1.1.1.

3. With a plausible range of geothermal energy in the United States defined, the study next moves to inquire about the potential primary and higher order impacts of this evolution, including effects on the economy and society, cities and dwellings, environment, and on the institutions which are likely to serve and be served by the new energy source. These impacts are evaluated in terms of their perceived desirability from the standpoint of various interest groups. Finally, conclusions and recommendations are stated.

Throughout, it has been the intent to make assumptions explicit and, where possible, to test conclusions for sensitivity to these assumptions. Numerical and methodological detail is included in a series of Appendices to this report.

REFERENCES

- [1] Denton, J. C. (ed.), Geothermal Energy, A Special Report by Walter J. Hickel (Fairbanks, Alaska: University of Alaska, 1972), p. 95.
- [2] Committee on U. S. Energy Outlook, A Summary Report of the National Petroleum Council (National Petroleum Council, Washington, D.C., 1972), p. 52.
- [3] KGRA is defined in the Geothermal Steam Act of 1970 as "an area in which the geology, nearby discoveries, competitive interests, or other indicia would, in the opinion of the Secretary of the Interior, engender a belief in men who are experienced in the subject matter that the prospects for extraction of geothermal steam or associated geothermal resources are good enough to warrant expenditures of money for that purpose."

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Figure 1.1.1

The presentation of the material in this report is divided into three major segments:

1. After the introductory sections, which describe study objectives and study design, the report concentrates on a description of the geothermal state-of-the-art including geothermal resources, technology, and institutional, legal, and environmental considerations.
2. With this information in hand the report describes how geothermal energy may evolve in the United States; a series of plausible scenarios and the factors and policies which control the rate of growth of the resource are described.

1.2 An Overview of Geothermal Energy

In terms of systematic commercial exploitation of geothermal resources for general societal benefit, the chemical plant at Larderello (Tuscany), Italy, which was producing boric acid in 1818, predates all others. In 1904 the first attempt to generate electrical energy from geothermal energy was made on a small scale. By 1913 a capacity of 250 kWe had been installed. During World War II, a large part of the Larderello plant was destroyed by the retreating German Army; however, the plant has been fully restored and its capacity expanded to its present 384 MWe.

In the 1930's the Hungarians began using geothermal water from Margit Sziget Island (in the Danube) for district heating in Budapest.

The Icelanders began heating of a few of their homes and greenhouses with geothermal hot water in 1925. They started drilling for steam in 1928, but it was not until December 1943 that a hot water pipeline to Reykjavik and a distribution system were commissioned for district heating (which is now provided to almost the entire city). The Icelanders currently have a 3 MWe unit in operation and are studying the possibility of generating electric power from their resource on a large scale.

In New Zealand the commercial development of geothermal resources started in 1955 when the Tasman Pulp and Paper Company, Ltd. undertook using geothermal steam to provide process heat and to drive a 10,000 kWe generator at their Kawerau paper mill. This was followed in March 1960 by the commissioning of 69 MWe of geothermal electric generating capacity by the State Electricity Department, which has since been increased to 192 MWe. A much greater potential exists and further expansion continues.

The Soviet Union has pursued a vigorous geothermal exploration program for the past decade or more, and currently has two operating geothermal electric generation plants of 440 kWe (net) (Paratunka, 1967) and 5 MWe (Pauzhatka, 1967), respectively. The former is the only geothermal plant in the world operating on a binary cycle (steam/freon). Thousands of homes and commercial facilities are space-heated by district heating systems in several areas of the Soviet Union.

The Mexican Government has been conducting an intense exploration program for approximately 20 years, which has culminated in the recent completion of a 75 MWe flashed steam plant (2-37.5 MWe units) at Cierro Prieto.

In Japan private interests have developed electric power generation from geothermal resources. A 20 MWe unit at Matsukawa (Honshu I) was commissioned in September 1966 and a 7 MWe unit at Otake (Kyushu I) was commissioned in 1972. The Japanese are also using their geothermal resources for district heating, desalination, agricultural heating, and industrial process heat. Because of the extreme sensitivity of the Japanese economy to energy availability and the heavy dependence of Japan on imported oil, the Japanese are embarking on a major research enterprise designed to achieve as much energy as possible from indigenous geothermal sources.

The Philippine Government has had a 3 MWe unit producing electric power at reduced capacity for some four to five years at their Tiwi Hot Springs, Bicol District, Luzon Island, which is currently being followed by an aggressive drilling, testing, and feasibility program. The government is now planning a larger commercial capacity station.

The Turkish Government, assisted by the United Nations, is currently conducting evaluative studies and physical tests of their Kizildere Field, with the stated intention of using it for electric power production.

Explorations, test and production drilling, and feasibility studies, some under the auspices of the United Nations, are also being conducted in Kenya, Ethiopia, Afar and Issa Territories (East Africa), Indonesia, New Hebrides, Algeria, Greece, Israel, Yugoslavia, Chile, Columbia, Guatemala, Nicaragua, El Salvadore, and India.

At The Geysers, California, a well was drilled in 1921 (by J. D. Grant of Healdsburg, California) for the purpose of generating electric power; however, large-scale production of electric power from this resource did not occur until 1960 when the Pacific Gas & Electric Company commissioned their Unit No. 1 (12.5 MWe). Total installed capacity of this installation is now 396 MWe (net), with an additional 110 MWe (net) under construction, and an additional 406 MWe (net) committed for construction. Magma Power Company and Thermal Power Company, developers, and the Union Oil Company, which operates the field, are increasing The Geysers' production capacity at a rate equivalent to 100 MWe yearly. The Pacific Energy Corporation and the Burmah Oil & Gas Company have, under separate agreements, also contracted to supply The Pacific Gas & Electric Company with steam. The total capacity scheduled for installation at The Geysers is 900 MWe by 1976. [1]

In the three years following issuance of the Geothermal Steam Act of 1970, the U.S. Department of the Interior prepared an environmental impact statement for the geothermal leasing program. With this statement, issued in December 1973, leasing of federal lands for geothermal exploration began in January 1974. The first competitive lease sale was held by the Bureau of Land Management on January 22, with 52,000 acres of land in California put up for bid in three Known Geothermal Resource Areas (KGRA)—The Geysers, Mono-Long Valley and East Mesa in Imperial County. Bids were higher than expected in the already proven Geysers area and all units offered there drew competitive bids from several companies. In the Mono-Long Valley KGRA, three out of the seven units offered received bids and in the East Mesa KGRA, five out of fourteen. The 23,000 acres leased brought in \$6,813,000 in high bids at an average bid per acre of \$290. The average bid per acre in The Geysers was \$631.

Monthly bidding on a non-competitive basis for approximately 57 million acres of federal lands designated as Potential Geothermal Resource Areas (PGRA's) also began in January 1974. The Department of the Interior defines a Potential Geothermal Resource Area as "an area containing an inferred geothermal reservoir within a geothermal resource province which has not been determined to be a Known Geothermal Resource Area." As of the end of February, bids had been filed for over 6 million acres, with heaviest concentrations in California, Oregon, and Nevada. These bids must now be assessed for overlapping claims, which according to law constitute competitive interest, and may entail reclassification of the tract in question as a KGRA, requiring competitive bidding.

Worldwide, the total installed electric generating capacity deriving from geothermal sources at the present time is about 1100 MWe. This is approximately the same as one large nuclear generating unit.

Resource Base

Geothermal energy can be defined in the broadest terms as heat emanating from the earth. The major source of this heat is believed to be the gradual decay of radioactive elements within the earth.[2] Temperatures in the earth increase with depth, and range from about 400-1800°F at the base of the Continental crust, 80,000-160,000 feet deep.[3] At the center of the earth, at a depth of some 21 million feet, the temperature range is approximately 6500-8000°F.[4] Nevertheless, the rate of outward flow of heat at the earth's surface is so thinly dispersed (low heat flux) that in most locations it is of no practical value.[5] However, highly localized thermal anomalies exist at many sites where high heat flows are produced near the earth's surface by geologically recent intrusive flows of molten rock or magma through massive fractures in the earth's crust. As the magma solidifies, its heat is conducted to the surface through the overlying geological formation. This often results in the heating of groundwaters which are sometimes ejected through surface vents to form thermal springs, geysers, fumaroles, or mud pots. By their very nature these phenomena are closely associated with seismic and volcanic activity and are widely distributed over the earth's surface. An example of this close relationship is the consistency with which geothermal activity is found along the volcanism belt (so-called Ring of Fire) that surrounds the Pacific Ocean. This accounts for the fact that the preponderance of geothermal surface manifestations in the United States occurs in the western states. Similarly, geothermal manifestations in Kenya, Ethiopia, Afar and Issa territories closely follow the Great Rift Valley of East Africa.

Geothermal resources can be classified in accordance with their geological, hydrological, and thermodynamic characteristics in the following manner:[6]

1. **Vapor-dominated:** Naturally occurring primarily single-phase thermodynamically saturated or super-heated steam. To date only six major vapor-dominated reservoirs have been located. These are The Geysers, California; Larderello, Italy; Matsukawa, Japan; Onikobe, Japan; The Monte Amiata Region, Italy.
2. **Liquid-dominated:** A naturally occurring two-phase mixture of liquid water (or brine) and steam at an elevated temperature and corresponding saturation pressure. Most hydro-thermal sites throughout the world are of the liquid-dominated type, perhaps twenty times as many as vapor-dominated sites.[7]
3. **Hot Dry Rock:** A geological formation having an abnormally high heat content but not containing meteoric or magmatic waters to act as a heat transport medium.

Due to volcanism and tectonic activity, there are excellent prospects for finding enormous amounts of hot dry rock, particularly in the western United States. Vast amounts of energy stored in this form have been discovered in such locations as The Crater of the Moon, Idaho, and Marysville, Montana.

4. **Geopressured:** Very extensive deep (5000-20,000 feet) zones of pressurized water with widely varying salinity, the pressure in which exceeds the corresponding hydrostatic pressure of the fluid at depth. This is caused by the weight of the overlying higher density geological formation on

the trapped fluid. Fluid temperatures in the reservoir have been measured in the range from approximately 140-360°F. Corresponding fluid pressures vary from about 3000 psig to 14,000 psig.[8]

At present, the most extensive known geopressured zones in the United States exist in the Northern Gulf of Mexico Basin which lies along the Texas, Louisiana and Mississippi coasts, and beneath the Gulf Continental Shelf. There are also other geopressured zones of lesser extent in the United States such as the Anadarko Basin of Oklahoma and Texas, the Rocky Mountain Basin, and the Los Angeles Basin.

5. **Magma:** Formations comprising molten rock in the range of approximately 1000°F.-3000°F. Although magma systems exist at levels that are accessible to current drilling equipment in active volcanic areas such as the western United States, Hawaii, and Alaska, very deep drilling, 100,000 feet or more, will be required to reach these resources in most regions of the continental United States.

Resource Estimates

Section 2.2 of this report summarizes in detail the available estimates of geothermal resources throughout the world and in the United States in particular. Uncertainty about the extent of geothermal resources is very great. Figure 1.2.1 displays some estimates of electricity production through the use of geothermal energy which have been made in the recent literature. Note that the estimates range over almost two orders of magnitude by 1985.

ESTIMATES OF ELECTRICITY
WHICH COULD BE PRODUCED BY GEOTHERMAL ENERGY
(1000 MWE)

SOURCE	1985	2000
ROBERT REX - SENATE HEARINGS, 1972 [9]	--	400
BUREAU OF MINES, 1972 [10]	4	40
DEPARTMENT OF THE INTERIOR, 1972 [10]	19	75
NATIONAL PETROLEUM COUNCIL, CASE I, 1972 [11]	19	--
NATIONAL PETROLEUM COUNCIL, CASE IV, 1972 [11]	3.5	--
W. HICKEL, <u>GEOTHERMAL ENERGY</u> , 1972 [12]	132	395
DR. D. L. RAY - ENERGY POLICY OFFICE, 1973 [13]	20	80

Figure 1.2.1

Exploration

Historically, geothermal sites have been located from obvious surface manifestations, such as hot springs, fumaroles, mud pots, geysers, and the like, or through accidental discovery while exploring or drilling for other natural resources. This approach is rapidly being replaced by more scientific and productive prospecting methods, such as remote infrared sensing, detection of anomalies in the earth's magnetic and gravity fields, and electric resistivity of strata. Earth noise emanating from microseismic activity is also recorded and correlated with data from the above sources. If a natural effluent is apparent at the surface, its chemical composition (constituents and concentrations) can be analyzed relative to the potential thermal and chemical productivity. Boring test-holes to production depths (3000-8000 feet) is an expensive proposition, but in the final analysis it is necessary to establish quantitatively a field's potential. As the drilling proceeds, core samples are recovered from the hole for logging and for physical and chemical analysis.

Temperature profiles are measured (top to bottom of hole) and where natural effluents occur, the bottom-of-hole static pressure and wellhead static pressures (over a range of flow rates) are recorded. From the latter data, the energy potential of the well can be inferred, and to a lesser extent, the field potential. To fully explore a field in an attempt to determine its geographical limits (both horizontally and vertically) is a protracted and expensive affair, often requiring years to accomplish with present methods. Even then, the anticipated longevity of the field remains a speculative matter.

Drilling

The basic techniques used in drilling for geothermal resources are essentially those employed in the petroleum business and, in fact, they were developed by and borrowed from that long established industry. While the hazards of fire and hydrocarbon gas explosions generally do not exist, great care must be exercised in securely anchoring (cementing) the well casings into the upper geological formation in order to withstand high pressures, severe mechanical vibrations, and thermal cycling. Drilling rates can vary greatly, depending on the hole diameter, frequency of sampling, and formation hardness, density, and temperature. Drilling costs can vary from \$20/ft. to \$60/ft., exclusive of mobilization and moving on and off the site.

Hypothetical Energy Recovery Methods

Similar to the practice employed in the oil fields, it has been widely suggested that by artificially fracturing a heat bearing formation (wet or dry) it may be possible to realize a more favorable release of geothermal energy by creating channels through which a heat recovering medium (water) can flow. Hydrofracturing, a procedure common to the petroleum industry which consists of pumping very high pressure water into the formation to fracture the rock, has been suggested as one method of field stimulation. Deep underground detonation of chemical or nuclear explosives to achieve the same purposes has also been suggested, but is not currently in favor. It has been hypothesized that subsequent to fracturing, energy recovery could be accomplished either by a natural effluent, or by injecting water into a hot, dry formation through one or more riser shafts. AEC Los Alamos Laboratories have begun an experiment with this design, which should be operative in four years. Others have proposed an interesting but untried method of heat recovery in which a long double-pipe, concentric heat-exchanger, having a closed outer envelope, is embedded in the heat bearing formation. A designer's choice working fluid would then be pumped down the center pipe, emerging at the bottom into the closed outer pipe and rising back to the surface in the annular space between the two pipe walls. Heat exchange between the working fluid and the surrounding formation is intended to occur at a sufficiently high rate to justify the installation. One obvious advantage of this method, if it can be proven to be practical, is the fact that the working fluid would remain uncontaminated with deposit-forming dissolved solids, and would not bring polluting constituents to the surface because it would never come in direct contact with the geological formation.

Electric Power Generation

At present there are three power sites in the world which produce saturated or superheated steam (single phase; no liquid). The best known sites are Larderehko,

Italy, The Geysers, California, and Matsukawa, Japan. In all three cases the steam is fed directly from the wellheads to steam turbines, with only minor pretreatment to remove particulate matter and occasional slugs of water. These plants employ relatively simple, low pressure Rankine steam cycles to drive the electric generators. In the case of the much more common wells which issue hot water (or brine) mixed with steam (two phase), such as at Cerro Prieto, Mexico, or Wairakei, New Zealand, steam is produced by flashing the hot liquid at a reduced pressure, separating the two phases, and feeding the steam to a turbine. When effluent is fed directly to the turbine the process is commonly referred to as the direct process. In contrast to this, the binary process employs a designer-selected secondary working fluid which circulates through the turbine (producing mechanical work) and passes through a heat exchanger in which it absorbs heat from the natural well effluent (steam and/or water), without becoming contaminated by the effluent itself. Although the binary process requires a more complex plant, it has the advantage of protecting the turbine from the corrosive, erosive, deposit forming constituents of natural well effluents. Only one such plant has been constructed in the world to date, namely the USSR Paratunka plant (Kamchatka Peninsula) of 440 kWe capacity, which was commissioned in September 1967. This plant employs Freon 12 as the secondary working fluid.

At least two proprietary binary processes are presently being advanced by their proponents in the United States. These are the "MagmaMax" process by Magma Energy Corporation of Los Angeles, California, and the "Hutchinson-Holt" process by the Ben Holt Engineering Company of Pasadena, California. Details of the latter have not been made public. Both of these processes are in the developmental state at the present time.

A number of proprietary novel heat engines have been proposed for directly converting the geothermal energy in a two-phase effluent into shaft work without separation. One of these is the "Keller Rotary Oscillating Vane" (KROV) engine by the Keller Corporation of Fort Worth, Texas, and another concept is the "Helical Screw Expander" offered by the Hydrothermal Power Company Ltd. of Pasadena, California. In addition, a bladeless turbine is under development. Prototype models of these engines have been built and are currently undergoing evaluative performance tests.

Present heat rejection systems for geothermal power plants are essentially the same as for fossil fueled plants, with certain important differences. In nearly all cases the condenser cooling water mixes intimately with the condensate and both return to either a natural water course or a cooling tower. For all geothermal plants employing evaporative cooling towers, the amount of water produced from the wells exceeds the water requirements of the cooling tower, thus imposing no demand on local water supplies for make-up. In the case of The Geysers plant, the excess is approximately 25 percent of the effluent rate.

The steam and/or liquid effluent from geothermal wells always contains varying percentages of entrained or dissolved non-condensable gases (NCG) of varying composition. These gases continuously flow into the condenser and must be removed by a gas ejector or vacuum pump at rates much higher than in a fossil fueled plant, in order to preserve minimum discharge pressure for the turbines.

As with fossil fueled or nuclear plants, the cooling system can be based on use of evaporative cooling towers, cooling ponds, or in certain cases, once-through flow.

Due to the relatively low available pressure and temperature of geothermal effluents, power plants energized by them are

inherently low efficiency conversion systems, having overall plant efficiencies of 10-14 percent.

All presently operating geothermal power plants produce waste products of varying toxicity and nuisance effect. The residual liquid fractions usually are charged with a high concentration of dissolved solids which preclude discharge of the liquids into natural water courses. Consequently, reinjection of the liquid back into the formation is presently being used as a disposal method, and in many cases appears to be the only practical available method. Gaseous emissions of the H_2S , and to a lesser degree, ammonia, are commonly associated with geothermal effluents. Historically, these have been discharged directly to the atmosphere since they were regarded as of minor consequence. Recently, however, due to statutory and public opinion pressures, control treatments are being developed to maintain emissions at legally acceptable levels. Disposal of large volumes of solid wastes, such as the chloride salts in the Imperial Valley, pose a problem at the present time.

Control of solids deposition (carbonates, silicates, etc.) in the production bore-holes and in plant piping and equipment is a major design problem in geothermal plants. One patented procedure, the "EEP System" by Rogers Engineering Company of San Francisco, proposes injection of CO_2 gas into the effluent stream deep in the well to inhibit precipitation of calcium carbonate in the system; this scheme is theoretical only at this point and has not yet been proved physically. Above ground, long established techniques of chemical cleaning and mechanical chipping or reaming to remove deposits from pipe, separators, heat exchangers, turbine casings, and other equipment are readily available. Practical techniques for rejuvenating deposit plugged production wells are not yet well developed.

Because of the inherent inertia of a geothermal power plant (relatively long start-up and shut-down time) and its low operating costs (no fuel), it is economically and technically advantageous to operate the plant base-loaded. Integrating the plant into the power network may require construction of extensive transmission lines; otherwise, the electrical characteristics are the same as for any other power plant.

Time required to develop sufficient producing and reserve wells (in an already explored field) to energize a 150 MWe plant presently requires from 18-24 months.

Figure 1.2.2 presents energy cost comparisons for geothermal installations which have appeared in the literature and Figure 1.2.3 presents a comparison of geothermal costs with the costs of generating electrical energy using other primary energy sources as reported to the FPC in 1974. Because accounting systems vary, these figures should be utilized only as a general indication of the price range of geothermal electricity.

REFERENCES

- [1] Pacific Gas and Electric Week (August 24, 1973).
- [2] Rex, R.W., Investigation of Geothermal Resources, Imperial Valley, and Their Potential Value for Desalination of Water and Electricity Production (Riverside, Calif.: University of California, June 1, 1970). See also E. Bullard, "Basic Theories -- Geothermal Energy," UNESCO, Earth Science, Vol. 12 (1973).
- [3] Lachenbruch, A.H., "Crustal Temperature and Heat Production--Investigations of the Linear Heat Flow

ENERGY FROM GEOTHERMAL RESOURCES

POWER PLANT TYPE	PLANT SIZE MWe	CAPITAL COST \$/kWe	THERMAL HEAT COST	GENERATION COST Mill/kWh
Dry Steam - Operational				
Geysers, California unit No. 11 under construction [14]	106	132	2.7 mill/kWh	5.71
No. 14 on line 1976 [15]	110	148	4.8 mill/kWh	8.35
Larderello, Italy [16]	25		3.2c/MMBtu	2.96
Hot Brine - Operational				
Cerro Prieto, Mexico 1973 [17]	75	264		8.00
Otake, Japan 1970 [18]	30	288		6.50
Wairakei, New Zealand 1970 [19]	192		6.9c/MMBtu	5.14
Rotorua, New Zealand, district heat, 1970 [19]			3.36c/MMBtu	
Reykjavik, Iceland, district heat, 1970 [19]			7.5-14/MMBtu	
Hot Brine - Estimates				
Armstead 1970 [19]	100	270	4-5c/MMBtu	3.90
Green & Laird 1973 [20]	20-42	330-297		12.77-4.77
Austin, Higgins, Howard 1973 [21]	220	180		3.20
Stanford Research Institute 1973 [22]	215			7.75-9.35
Kaufman, 1973 [23]	260			9.00
Hot Dry Rock Estimates				
Brown, Smith, Potter, 1973 [24]				
300°C, dual cycle	100	186		4.70
175°C, isobutane cycle	100	316		8.00
Battelle Northwest 1973 [25]	200			6.87
Geopressure				
Durham, 1973 [26]	45	380	1.25 mill/kWh	

Figure 1.2.2

Relation," Journal of Physical Research, Vol. 75, No. 17 (1970), pp. 3291-3300.

- [4] Muffler, L.P.J., "Geothermal Resources," U.S. Geological Survey, Professional Paper 820 (1973).
- [5] White, D.E., "Geothermal Energy," U.S. Geological Survey Circular 519 (1965).
- [6] Hickel, W.J., Geothermal Energy--A National Proposal for Geothermal Resources Research (Alaska: University of Alaska, 1972). See also D.E. White, "Characteristics of Geothermal Resources," in Kruger and Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973).
- [7] White, D.E., "Geochemistry Applied to the Discovery, Evaluation, and Exploitation of Geothermal Energy Resources," Geothermics, Special Issue 2, Vol. 1 (1970).
- [8] Jones, P.H., "Hydrodynamics of Geopressure in the Northern Gulf of Mexico Basin," Journal of Petroleum Technology (July 1969). See also P.H. Jones, "Geothermal Resources in the Northern Gulf of Mexico Basin," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).

ESTIMATED COST OF ELECTRIC ENERGY GENERATION⁵
IN DIFFERENT TYPES OF POWER PLANTS, JULY 1974

	Gas-Fired ^{1, 3}	Coal-Fired ¹	Hydroelectric	Nuclear	Geothermal ² (Dry Steam)	Oil-Fired (September 1973)	Oil-Fired ¹ (February 1974)
Unit Investment Cost of Plant, Dollars per Kilowatt	125.	225	390.	400.	100.	185.	185.
Annual Fixed Charge, Percent of Investment	17.	17.	17.	17.	17.	17.	17.
Kilowatt-Hours Generated per Year per Kilowatt Capacity	7,000.	7,000.	7,000.	7,000.	7,000.	7,000.	7,000.
Heat Rate, Btu/kWh	9,100	8,800	—	10,500.	22,000.	8,900.	8,900.
Cost of Fuel:							
Cents per Million Btu	35.7	49.0(est.)	—	17.5	14.3	79.7	150.0(est.)
Dollars per Unit	0.37 (mcf)	10.86(est.) (ton)	—	—	0.35 (ton)	4.89 (bbl.)	9.20(est.) (bbl.)
Quality of Fuel, Btu/Unit	1,022 (cu. ft.)	11,084 ⁴ (lb.)	—	—	1,210. (lb.)	145,816. (gal.)	145,996. ⁴ (gal.)
Cost of Electricity, mills/kWh							
Plant Investment	3.0	6.2	9.5	9.7	2.4	4.5	4.5
Operation and Maintenance	0.6	0.8	0.1	0.4	0.5	0.7	0.7
Fuel	3.6	4.7	—	1.9	3.1	8.4	15.8
TOTAL	7.2	11.7	9.6	12.0	6.0	13.6	21.0

References: FPC Form 423

FPC Form 1

Finney, J. P., "Design and Operation of The Geysers Power Plant," in Paul Kruger and Carel Otto (eds.), Geothermal Energy: Resources, Production and Stimulation (Stanford, Calif.: Stanford University Press, 1973), pp. 145-161.

Stone, R., testimony before Senate Subcommittee on Water and Power Resources in Washington, D.C., June 13, 1973, pp. 107-116.

1. Fuel costs are preliminary averages for February 1974 computed from FPC Form 423, Monthly Report on Cost and Quality of Fuels.
2. All numbers for Geothermal are reported by Pacific Gas & Electric on FPC Form 1 for 1973 operations at The Geysers Steam Plant.
3. FPC policy presently discourages construction of gas-fired steam-electric plants.
4. Average energy contents of fuels reported on FPC Form 423 for November 1973.
5. Personal communication, Dr. Charles F. Reusch, Federal Power Commission, May 20, 1974.

Figure 1.2.3

- [9] U.S. Senate Committee on Interior and Insular Affairs, Hearings on the Role of Geothermal Energy Resources in our Nation's Future Energy Economy, June 15 and 22, 1972 (92nd Congress, 2nd session).
- [10] U.S. Dept. of the Interior, Final Statement for the Geothermal Leasing Program, Washington, 1973.
- [11] U.S. Energy Outlook, A Summary Report of the Natural Petroleum Council, Washington, December 1972.
- [12] Hickel, W. J., Geothermal Energy (Alaska: University of Alaska, 1972).
- [13] The Nation's Energy Future, A Report to Richard M. Nixon, President of the U.S., submitted by Dr. Dixy Lee Ray, Chairman U.S. Atomic Energy Commission, December 1973.
- [14] Pacific Gas and Electric Company, "Application Before the Public Utilities Commission of the State of California, Unit 11 at The Geysers Power Plant."
- [15] Pacific Gas and Electric Company, "Application Before the Public Utilities Commission of the State of California, Unit 14 at The Geysers Power Plant," July 1973.
- [16] Armstead, H.C.H., "Geothermal Economics," Geothermal Energy, UNESCO, Review of Research and Development (1973).
- [17] Parades, S., Superintendent Planta Geotermoelectrica, Commission Federal de Electricidad, speech El Centro, California, October 17, 1973.
- [18] Hayashida, T., "Cost Analysis on Geothermal Power," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [19] Armstead, H.C.H., "Geothermal Economics," Geothermal Energy, UNESCO, Review of Research and Development (1973).
- [20] Green, M.A., and A.D.K. Laird, "Comparison of Elementary Geothermal--Brine Power--Production Processes," Report LBL-2102 (University of California, Lawrence Berkeley Laboratory, August 2, 1973).
- [21] Austin, A.L., G.H. Higgins, and J.H. Howard, "The Total Flow Concept for Recovery of Energy from Geothermal Hot Brine Deposits," UCRL-51366, TID-4500, UC-51, April 3, 1973.
- [22] "Meeting California's Energy Requirements 1975-2000," SRI Project ECC-2355 (Stanford Research Institute, May 1973).
- [23] Kaufman, A., Letter to Congressman Mike McCormack, Chairman, Subcommittee on Energy, U.S. House of Representatives, December 6, 1973.
- [24] Brown, D.W., M.C. Smith, and R.M. Potter, "A New Method for Extracting Energy from Dry Geothermal Reservoirs," LA-DC-72-1157 (Los Alamos Scientific Laboratory, July 1, 1973).

- [25] American Oil Shale Corporation, Battelle Northwest, Westinghouse Electric Corporation, and U.S. Atomic Energy Commission, "A Feasibility Study of a Plowshare Geothermal Power Plant," April 1971.
- [26] Durham, C.O., Jr., Louisiana State University, Statement on "Proposed Geopressure Energy Investigation" on the Geothermal Energy Research, Development, and Commercial Demonstration Act of 1974, H.R. 11212.

1.3 Overall Study Design

Technology assessment may be defined as "the systematic study of effects on society that may occur when a technology is introduced, extended, or modified, with special emphasis on the impacts that are unintended, indirect, and delayed...technology assessment is a policy generation and analysis or decision oriented tool. Its aims, techniques, and methods are best conceived as yielding systematic inputs into the larger political economic decision process." [1]

There is no codified set of techniques which can be followed to satisfy these objectives. The methods of technology assessment which have been used in past studies have been drawn from many different disciplines, including, most prominently, economics, social psychology, statistics, engineering, and operations research. The choice of the appropriate technique depends on the judgment of the researcher as well as the nature of the problem and the level of funding of the project. As Joseph F. Coates of the National Science Foundation recently put it:

Technology assessment is an art form...It is separate, distinct, different from [existing disciplines] and as in any other art form, implies both a degree of creativity as well as the use of techniques. It also implies that not everyone is talented in undertaking or understanding the art forms. [2]

Martin V. Jones, in an early set of technology assessments performed for the Office of Science and Technology, defined seven major steps in making a technology assessment. These steps included:

1. Defining the assessment task, in which relevant issues and major problems are discussed, project ground rules established, and the scope of the inquiry is set.
2. Describing relevant technologies including not only the technology being assessed, but other technologies supporting or competing with the technology under study.
3. Developing state of society assumptions, involving the identification and description of major non-technical factors which could influence the application of the technology.

4. Identifying the impact areas, that is, societal characteristics that will be most influenced by the technology.
5. Making preliminary impact analysis: tracing and integrating the process by which the assessed technology makes its societal influence felt.
6. Identifying possible action options through the development and analysis of various programs for obtaining public advantage of the technology.
7. Completing the impact analysis through study of the ability of each action option to alter the previously established societal impacts. [3]

Most technology assessments go somewhat further than these seven steps. The identification of interest groups is an important facet of most studies. It is not enough simply to identify impact areas; the questions of who is affected, when, and how, must also be addressed. In addition, the study of action options and state of society assumptions must include at least macro-level alternatives to the technology under study. A technology assessment of geothermal energy, for example, should probe not only the means for producing and using geothermal energy and the effect of this technology on society as a whole and groups within it, but also whether geothermal energy or some other energy form is more appropriate, as well as the consequences of reducing energy demand.

Given the objectives of technology assessment and the major elements of such studies, a logic flow chart such as that shown in Figure 1.3.1 can be prepared.

Beginning at the left of the diagram:

Task 1. State-of-the-Art. The state-of-the-art is defined first. In this task, the major question is, "What do we know about the technology or problem under study?"

Task 2. Other Conditions. Here the focus is on other aspects of change which impinge on the subject under investigation. For example, this task may address concomitant technologies which, if successful, would limit or in some way amplify the basic technology. In addition, this task might center on external social

Figure 1.3.1 TECHNOLOGY ASSESSMENT LOGIC FLOW

conditions which could change the impacts of the technology or the values by which the impacts are to be judged.

Task 3. Forecast. This task involves generating an image or set of images of the future of the technology under study. How might it evolve? What are the most important breakthroughs? When might they occur? What paces them?

Task 4. Policies for Modifying the Technology or Problem. In this task, policies are nominated and defined which might change the time scale or nature of the technology. Typically, the definition of a policy might include identification of the agency which could perform the action, the cost of the policy, its timing, and its intended consequences. Note that the output of Task 4 provided an input to Task 3; that is, the policies generated here are designed to amend the technological forecast.

Task 5. Scenarios. In this task, forecasts are grouped into self-consistent sets, alternative futures depicting the evolution of the technology or problem under study in the presence of policies considered in Task 4. In effect, the output of Task 5 is a statement of what the world might be like in the particular domain of the assessment. The remainder of the analysis is devoted to an identification of the consequences of these alternative worlds and means for improving them.

Task 6. Interest Groups. Here the groups likely to be affected by the emerging technology or problem are identified.

Task 7. Impact Description. Given the interest groups and the alternative futures produced in Tasks 6 and 5, respectively, this task defines and estimates specific impacts. Thus, at this point in the study, an array can be constructed of interest groups, how they are likely to be affected in the various worlds depicted by the scenarios, each scenario having been determined by a particular technological or problem-oriented policy set.

Task 8. Assessment. Now the problem is: Are the forecasted impacts likely to be seen as good or bad? Of course, such judgments are value-laden and multi-dimensional. An impact seen as good for one group might be bad for another. Furthermore, "good" and "bad" can be defined only in terms of a value framework. Yet despite these difficulties, the assessment accomplished in this task necessarily must deal with these issues.

Task 9. Modifying the Impacts. The object of Task 9 is to invent policies which seem likely to improve the future state of affairs, that is, the conditions identified in Task 8. Nominated policies are fed back to Tasks 7 and 3. The loop to Task 7 is designed to test policies which are supposed to modify the technology itself. When policies have been found which produce the "best" world for the interest groups and society as a whole, they form the basis for action recommendations.

In accomplishing the geothermal technology assessment, both conventional and relatively novel analysis techniques were used. Literature searches were employed in reviewing the state-of-the-art of geothermal energy and other potentially competing sources of energy, such as coal, natural gas, petroleum, nuclear, and solar. As in the two preceding sections, 1.1 and 1.2, the bibliography of sources reviewed is

listed at the end of the section.

Technological forecasts, information about constraints to technological progress, and suggestions of means for removing those constraints were obtained in interviews and in responses to questionnaires by technological experts. This portion of the study was conducted by Bechtel Corporation personnel.

Briefly, the interviews involved careful preparatory steps, including:

1. Description of the content of geothermal technology down to the component level, using relevance tree techniques (the relevance tree is presented in Appendix B). A relevance tree is a hierarchical structure in which lower levels, in the aggregate, completely describe the higher levels to which they are connected, in some particular respect.
2. Compilation of an initial list of impediments to the evolution of geothermal technology; this list was checked and extended later by comparison against the completed relevance tree. Impediments to technological developments are described in Section 3.3.
3. Identification of respondents with expertise needed to span the spectrum of disciplines--from geology to rotating machinery--relevant to the picture of geothermal technology. In all 28 experts participated.

The members of the panel were interviewed in person, by mail, and by telephone. They responded about their view of technological impediments to identifying geothermal resources, bringing them to the surface of the earth, and converting them to electricity. In recognition of the fact that government actions by way of choosing directions, goals, and financial support levels directly affect the timing and magnitude of technological capabilities, responses were solicited from the panel members for two research and development program scenarios, defined as follows:

1. "Normal Development Program: Geothermal technology continues to develop on the same basis that is presently developing, without additional externally-applied stimuli."
2. "Crash Development Program: Geothermal technology develops under the stimulus of a declared national policy and massive government support, in which case cost is virtually no impediment."

Information produced by this interview sequence included independent assessments of technologically feasible levels of identified resources and levels of electricity production, as well as information on the nature of the associated technological impediments, and how and under what conditions the impediments could be removed, for each of the five types of geothermal resources and for the two research and development program scenarios.

The detailed technology forecasts produced by these interviews were synthesized into overall technology forecasts, quantitative energy system flow diagrams, and resulted in estimates of technologically feasible levels of development of geothermal energy for normal and crash program scenarios. The design and results of this portion of the study are summarized in Sections 3.1 and 3.3 and are provided in detail in Appendix A.

Having produced forecasts based on technological feasibility it was then necessary to consider and synthesize non-technological factors to arrive at an overall picture of the likely evolution of geothermal energy in the United States.

Several approaches were utilized. In the first, the study team added socio-political developments suggested in the literature to the two scenarios used previously in the technical interviews.

While these scenarios seemed intuitively consistent, a more structured approach was felt necessary to synthesize the available data and to provide a systematic basis for comparing the consequences of contemplated policies. A model was constructed to fill this need; it is described in detail in Appendix E and its operation is summarized in Section 3.4.

There are subtle benefits which often flow from the construction and use of such simulation models. First of all, a discipline is imposed which requires that the system being described be broken down into its elemental components. The interaction among these components should be understood in order to be simulated well. When used in a "futures" mode, modeling requires an explicit consideration of potential forces which can make a difference. In policy analysis applications, analysts can often define the range of control which actually can be exerted and can learn the range of outcomes which may result from actions or inactions.

The model used here involves many assumptions about relationships and the values of various initial parameters. As a forecasting tool, the model produces results which reflect and depend on these assumptions. In this study the assumptions and values of initial input parameters were largely based on judgments of The Futures Group with inputs from the literature and consultants; therefore, the model output reflects those judgments.

Basically, the model described the rate of growth of geothermal electricity production in the United States based on a simulation of utility company decision-making. It was capable of describing factors such as:

- A. The amount of electricity produced from geothermal sources in both the eastern and western United States.
- B. Total capital costs required for geothermal activities.
- C. Installed capacity in both the East and West in coal, petroleum, and nuclear power plants.

The assumptions on which the model was based could be tested by varying them one at a time. In this way, the assumptions to which the output of the model was most sensitive could be identified. In addition, policies designed to improve or diminish the rate of introduction of geothermal energy could be tested, at least within the framework of the simulation.

Interest groups were identified through review of the literature, informal discussions with the Oversight Committee members, and, most importantly, through a careful review of comments submitted in response to the U.S. Department of the Interior Environmental Impact Statement of 1973. The interest groups are summarized in Sections 2.3, 2.4, and Section 5.

Given the scenarios, it now became necessary to identify the impacts which might result. A primary tool here

was, once again, a series of carefully structured interviews. Now the respondents were selected because of their interest and expertise in the socio-political, environmental, or economic implications of geothermal energy. In all, 17 people were interviewed. These people included utility company executives, environmentalists, geothermal advocates, affected land owners and homeowners, local government officials, etc. They were first asked to comment on the scenarios and correct them where they felt necessary. In the second part of the interview, they were presented with a set of prospective impacts of geothermal evolution; they were asked to judge the relative significance and probability of these impacts and to add to the set other impacts which they felt should be included. These newly added impacts were also judged for importance and probability. Finally, for the important impacts, each respondent was asked to invent policies which they felt could mitigate adverse impacts or help assure the positive impacts which they saw.

Emerging from the interviews was a set of impacts of varying probabilities and relative significance which had to be assembled into a cohesive structure before assessment could be performed. The impact statements were carefully reviewed and organized into a second set of relevance trees.

Eight primary impact areas were identified; the relevance trees depicted how secondary and tertiary impacts might flow from these primary impacts. The impact relevance tree is contained in Appendix D; the impacts themselves are described in detail in Section 4.

Now given the results of the second set of interviews and a structure for displaying the "impact space," the question remained: How can one assess the impacts? The study team utilized three approaches. The first was a conventional comparison of costs and benefits. For example, in determining the consequences of the evolution of geothermal energy on the economy, estimates were made of the capital investments required, and these were compared to expected improvements in import/export ratio.

The second approach, Trend Impact Analysis, was used where it was important to describe the potential development of some particular parameter.

Trend Impact Analysis is a new forecasting method that permits extrapolations of historical trends to be modified in view of expectations about future events which could influence the trends. This technique permits including and systematically examining the effect of possible future events which are believed to be important on trends which depict the consequences of the technology being assessed. The events may be technological, political, social, economic, or value-oriented changes.

After making surprise-free extrapolations, a list of potentially important and relevant unprecedented future events is prepared. These events are plausible and potentially powerful in impact. The source of this list of events was the literature search, the two sets of interviews, and recommendations from consultants.

The TIA program combines impact and event-probability judgments with the results of the surprise-free extrapolation to produce an adjusted extrapolation, plus estimates of upper and lower quartile limits. The expected value of the combined impacts is computed by summing the products of the probabilities of the impacting events for each year in which they are possible with the magnitude of their expected impacts,

taking into account the specified impact lags. The TIA program is described in detail in Appendix F; the forecasted parameters are included in Section 4.

A third tool was used in the assessment task. Whereas conventional analysis and Trend Impact Analysis were useful in describing future conditions likely to affect various interest groups, it remained to describe how the various groups would perceive the changes brought about by the evolution of geothermal energy and policies implemented to shape it.

To analyze potential group impacts, a series of "value matrices" were constructed in which interest groups were listed along the abscissa of a matrix depicting geothermal-induced changes and developments important to the interest groups were listed on the ordinate. Each cell of the matrix contained a number depicting the relative importance, either positive or negative, of the development. By summing the products of the development probability and the cell entries, along a row, the relative importance of each of the developments could be established. By summing in the column, impact of the technology on the interest group could be deduced. Statistical analysis of these data could be used to indicate relative agreement or disagreement among groups. Furthermore, when impact shaping policies were tested, these matrices could indicate whether turmoil or tranquility was likely to be promoted. This portion of the analysis is included in Section 5.

When apparently inappropriate impacts were discovered, policies suggested in the interviews or invented by the study team were introduced in an effort to change the evolutionary scenario and its impacts. These policies were tested in the simulation model produced in Task 5, in the impact descriptions produced in Task 7, and by changing factors involved in the cost/benefit, trend impact and value matrix analyses. From the three iterative loops involved, a series of potentially desirable policies emerged. These policies were related to the evolution of the technology, as well as to means for mitigating impacts. They ranged from suggestions for needed research to suggestions for modifying the institutional arrangements by which geothermal energy would be pursued. The action recommendations are described in Section 1.4 of this report.

REFERENCES

- [1] Coates, Joseph F., "The Identification and Selection of Candidates and Priorities for Technology Assessment," Technology Assessment (February 1974).
- [2] Coates, Joseph F., "Institutional and Technical Problems in Risk Analysis," Proceedings of a Conference on Bulk Transportation of Hazardous Materials by Water in the Future, sponsored by the Committee on Hazardous Materials, College Park, Maryland, July 9-10, 1973.
- [3] Jones, Martin V., A Technology Assessment Methodology, MITRE MTR6009, 7 vols. (McLean, Va.: The Mitre Corporation, 1971).

1.4 Study Conclusions and Recommendations [1]

Overall Potential

Geothermal energy can be a relatively important energy source in the United States by the year 2000. It could supply on the order of 185,000 to 250,000 MWe, or more, compared to an expected U.S. total capacity of 2 million MWe. (For comparison, the State of California currently has a total generating capacity of 37,000 MWe.) At these levels, by 2000 geothermal sources will be contributing more to our energy supply than hydroelectric sources (Section 3.5).

Because geothermal sources are located primarily in the western part of the United States, the effects of geothermal energy will be considerably greater there than elsewhere in the United States. For example, total expected electricity generation capacity in the western part of the United States is expected to reach about 480,000 MWe by the year 2000; geothermal sources can constitute 25 percent or more of the total supply in that region (Section 3.5).

There is a great deal of uncertainty about the true extent of the total resource and the relative potential of its various forms (vapor-dominated, liquid-dominated, hot dry rock, geopressured, and magma). During the study, experts were asked to express their opinions about the likely extent of identified resources, resource development, and the level of energy conversion which could be realized in various years, constrained only by technology (Section 3.1). Ranges of estimates of identified resources were the widest, varying for the year 2000 from the lowest level of 50,000 MWe to almost infinite supply. The higher level was predicated primarily on the potential discovery of large quantities of hot dry rock resources. The mid-range of opinions of participating experts about the level of technologically feasible utilization of these resources for the generation of electricity was between 55,000 and 200,000 MWe in a normal program, and 270,000 and 800,000 MWe if a program unlimited by costs were implemented (Section 3.1).

The contribution of geothermal resources to U.S. energy supplies seems likely to increase continuously; by 1985 it is reasonable to expect that geothermal sources will be producing 7000 to 20,000 MWe or so out of a total of about 1 million MWe in the United States. After 1985, growth could be more rapid (Sections 3.1 and 3.5).

Impediments to Development

To achieve a high level of geothermal energy development, certain technological, institutional, and political issues will have to be resolved (Section 3.3). The timing of the actions which resolve these issues will determine the pace and the extent of utilization of geothermal energy.

Technological Issues

The present state of knowledge of the extent, distribution, and quality of geothermal resources in the United States is fragmentary, uncoordinated, and, on the whole, undeveloped. This fact is a major impediment to the rapid development of an energy industry based on the use of geothermal resources (Section 3.1).

Development of vapor-dominated reservoirs and liquid-dominated reservoirs of moderate salinity has reached

the level of large-scale energy production. However, energy extraction methods have not yet been demonstrated on a large scale for high-salinity brines, nor for hot dry rock, geopressured, or magma resources. Serious experimentation is being conducted on energy recovery techniques for high-salinity brines and for hot dry rock. However, little or no experimentation is being conducted on energy recovery from geopressured zones and magma (Section 2.1).

Technology for conversion of geothermal energy from vapor-dominated and moderate salinity liquid-dominated geothermal systems is fairly well in hand. However, conversion processes and equipment for high salinity systems and moderate to low temperature systems are still experimental. Conversion processes for hot dry rock have not yet been developed, but will probably be similar to vapor- or liquid-dominated geological systems. Processes for geopressured resources are only conceptual at this time. The possibility of extracting and converting energy from magma is so remote that little or no serious thought has been given to this problem (Section 2.1).

Figure 1.4.1 summarizes the most important currently perceived technological issues and indicates whether they are expected to exist as developmental impediments as late as 1985 (Sections 3.1, 3.3, and Appendix A).

The technological problems listed in Figure 1.4.1 seem amenable to solution.

The environmental issues deserve particular mention. Some of these issues have important local but temporary significance and others have potentially lasting significance (e.g., contamination of groundwater supplies, seismicity, and subsidence). The extent of the potentially irreversible environmental impacts is not known with precision; however, similar activities in the oil and gas industries have proven manageable. Clearly, research and development, incentives and sanctions are necessary in this area (Sections 2.6, 4.5, and 4.8). Such incentives and sanctions are discussed later in this section.

Non-Technical Issues

A number of regulatory and institutional impediments to the development of geothermal energy also exist. None of these seems likely to prevent the development of this energy source, but in the aggregate, they will pace its growth as certainly as the technological issues (Sections 3.3 and 4.5). The issues are associated with the encouragement of exploration and development, assuring a market for geothermal steam or hot water, and accomplishing the required research and development in a timely manner (Section 4.5). These issues are summarized in Figure 1.4.2.

Impacts of Development

The development of geothermal energy in the United States at the level described above is apt to cause both favorable and unfavorable, though manageable, impacts which can be grouped into eight major areas.

1. It will change the electric utility fuel mix by substituting for nuclear and coal generating plants (Section 4.1). The development of geothermal resources could lead to (by 2000) fewer nuclear plants (about 100,000 to 150,000 MWe could be saved) and fewer coal-fired plants (about 90,000 to 120,000 MWe could be saved). For comparison, a modern nuclear plant generates about

ISSUE	TIMING		DEVELOPMENT PHASE				RESOURCE				
	NOW	1985	RESOURCE EXPLORATION	RESOURCE DEVELOPMENT	ENERGY CONVERSION	ENVIRONMENTAL CONCERNS	VAPOR	LIQUID	HOT DRY ROCK	GEOPRESSURE	MAGMA
LACK OF INFORMATION ON THE EXTENT, DISTRIBUTION, AND QUALITY OF GEOTHERMAL RESOURCES IN THE UNITED STATES.	X	X	X				X	X	X	X	
LACK OF A PRACTICAL TECHNIQUE FOR CONDUCTING GROSS EXPLORATION (I.E., REMOTE THERMAL I.R. [INFRARED] SCANNING FROM EARTH RESOURCES SATELLITE).	X		X				X	X	X		X
LACK OF GEOTHERMAL DATA INFORMATION CENTER DESIGNED TO RECEIVE, STORE, PROCESS, AND DISSEMINATE EXISTING AND FUTURE RESOURCE AND RESERVOIR DATA (GEOLOGICAL, GEOPHYSICAL, GEOCHEMICAL, ETC.) WHICH IS IN THE PUBLIC DOMAIN FOR USE IN RESOURCE APPRAISAL, RESOURCE DESIGN, AND MANAGEMENT.	X	X	X				X	X	X	X	X
NEED FOR IMPROVEMENT IN PROCEDURES, EQUIPMENT, AND DATA INTERPRETATION OF THE VARIOUS GEOPHYSICAL EXPLORATION AND APPRAISAL TECHNIQUES.	X		X				X	X	X		X
LACK OF DEMONSTRATED METHOD FOR CONTINUOUS RECOVERY OF ENERGY FROM HOT DRY ROCK RESERVOIRS.	X		X						X		
PRESENT ACUTE SHORTAGE OF TUBULAR GOODS (DRILL STEEL AND WELL CASING) WHICH ARE ESSENTIAL TO DRILLING AND CASING OPERATIONS.	X	X		X			X	X	X	X	X
LIMITED AVAILABILITY OF DRILL RIGS FOR DEEP TO VERY DEEP DRILLING (I.E., BELOW 25,000 FT.) AND VERY HOT DRILLING (I.E., GREATER THAN 800°F).	X	X		X			X	X	X	X	X
LACK OF LONG-TERM CASE HISTORY DATA ON WHICH FIELD LONGEVITY PREDICTIONS CAN BE BASED.	X			X			X	X	X	X	X
NON-EXISTENCE OF A DEMONSTRATED, PRACTICAL DOWN-HOLE HEAT EXCHANGER OF SUFFICIENT CAPACITY TO BE USEFUL IN LARGE-SCALE ENERGY EXTRACTION OPERATIONS.	X			X				X			
NON-EXISTENCE OF A LARGE-SCALE DEMONSTRATION ELECTRIC POWER PLANT FOR LIQUID-DOMINATED RESOURCES TO MEDIUM- TO LOW-THERMAL QUALITY.	X				X			X		X	
NEED FOR DEMONSTRATION ELECTRIC POWER PLANT FOR CONVERSION OF ENERGY FROM HEAVY BRINE RESERVOIRS.	X				X			X		X	
LACK OF DEMONSTRATION ELECTRIC POWER PLANT FOR CONVERSION OF ENERGY FROM HOT DRY ROCK.	X				X				X		
LACK OF A PROVEN PRIME MOVER CAPABLE OF CONTINUOUS OPERATION ON A PREDOMINANTLY LIQUID TWO-PHASE FLUID.	X				X			X	X	X	
LACK OF AN EFFECTIVE METHOD FOR PREVENTING SCALE DEPOSITS ON INTERNAL SURFACES OF MECHANICAL EQUIPMENT, I.E., HEAT EXCHANGERS, PIPES, TURBINES, ETC.	X				X		X	X	X	X	
LACK OF DEMONSTRATION ELECTRIC POWER PLANT FOR CONVERSION OF ENERGY FROM GEOPRESSURED ZONES.	X				X					X	
NECESSITY FOR DEVELOPING PRACTICAL TECHNIQUES FOR PREVENTING GROUNDWATER CONTAMINATION.	X					X		X		X	
NECESSITY FOR DEVELOPING TECHNIQUES OF EFFECTIVELY CONTROLLING HARMFUL OR NUISANCE GASEOUS EMISSIONS.	X					X	X	X		X	
NECESSITY FOR DEVELOPING BROADLY APPLICABLE TECHNIQUES FOR LIQUID AND SOLID WASTE DISPOSAL.	X					X	X	X		X	
NECESSITY FOR DEVELOPING PRACTICAL AND EFFECTIVE TECHNIQUES FOR NOISE CONTROL DURING INITIAL DRILLING AND TESTING OPERATIONS, AS WELL AS DURING OPERATING LIFE OF THE PLANT.	X					X	X	X		X	
LACK OF CONFIRMED UNDERSTANDING OF CAUSE/EFFECT RELATIONSHIP BETWEEN FLUID INJECTION INTO THE FORMATION AND THE OCCURRENCE OR SUPPRESSION OF EARTHQUAKES, WITH RESPECT TO ENVIRONMENTAL EFFECTS ON THE SURROUNDING AREA AND POPULACE.	X	X				X	X	X	X	X	
NECESSITY OF DEVELOPING PREDICTIVE, PREVENTIVE, AND CORRECTIVE TECHNIQUES FOR DEALING WITH LAND SUBSIDENCE CONSEQUENT TO GEOTHERMAL FLUID WITHDRAWAL.	X					X	X	X		X	

Figure 1.4.1 TECHNOLOGICAL ISSUES

ISSUE	DESCRIPTION	DEVELOPMENT PHASE			
		RESOURCE EXPLORATION	RESOURCE DEVELOPMENT	ENERGY CONVERSION	ENVIRONMENTAL CONCERNS
CLASSIFICATION OF GEOTHERMAL RESOURCES--MINERAL RESERVATIONS	VARIOUS HOMESTEAD ACTS RESERVE MINERAL RIGHTS TO THE UNITED STATES; DEFINITION OF THE RESOURCE CONTAINED IN CURRENT LAWS DOES NOT CLARIFY THE RIGHTS OF LAND OWNERS AND THE UNITED STATES.	X	X		
CLASSIFICATION OF GEOTHERMAL RESOURCES--ACQUISITION OF RIGHTS	THE CURRENT BROAD DEFINITION OF GEOTHERMAL RESOURCES LEAVES OPEN THE POSSIBILITY THAT THESE RESOURCES COULD BE CLAIMED UNDER THE PROVISIONS OF STATE LAWS WHICH GOVERN THE ACQUISITION OF WATER RIGHTS ON UNRESERVED FEDERAL LANDS. WITHOUT A CLEAR DEFINITION OF GEOTHERMAL FLUIDS, VIS-A-VIS THE MINERAL AND WATER LAWS, COMPLEX REGULATORY AND LEGAL ISSUES SEEM CERTAIN TO ARISE.	X			
CLASSIFICATION OF GEOTHERMAL RESOURCES--TAX TREATMENT	THE DEPLETION ALLOWANCE AND DEDUCTIONS WHICH PERMIT WRITE-OFF OF INTANGIBLE COSTS ASSOCIATED WITH DRILLING AND DEVELOPING WELLS HAVE NOT YET BEEN APPLIED TO GEOTHERMAL DEVELOPERS EXCEPT IN A SPECIAL CASE. FEDERAL LEGISLATION IS REQUIRED TO DEFINE AN APPROPRIATE METHOD OF TAXATION OR SUBSIDY; OTHERWISE, UNCERTAINTY WILL PROVE INHIBITING.	X	X		
AVAILABILITY OF LANDS FOR DEVELOPMENT--EXCLUDED LANDS	THE FEDERAL GEOTHERMAL STATUTE EXCLUDES LARGE PARTS OF THE FEDERAL DOMAIN FROM GEOTHERMAL DEVELOPMENT; IT IS NOT CLEAR WHETHER SOME OF THESE AREAS COULD NOT BE MADE AVAILABLE FOR GEOTHERMAL DEVELOPMENT AND YET BE USED FOR THE PURPOSES FOR WHICH THEY ARE CURRENTLY RESERVED.	X	X		
AVAILABILITY OF LANDS FOR DEVELOPMENT--ACREAGE LIMITATIONS	THE GEOTHERMAL STATUTE LIMITS EACH LESSEE TO 25,000 ACRES. IT IS NOT YET CLEAR WHETHER THIS LIMITATION WILL PROVE TO BE A SUBSTANTIAL BARRIER TO DEVELOPMENT, OR WHETHER COOPERATIVE CONTROL AMONG LESSEES WILL SUBVERT THE INTENT OF THE STATUTE.	X	X		
AVAILABILITY OF LANDS FOR DEVELOPMENT--ADMINISTRATIVE DISCRETION TO WITHDRAW LANDS FROM GEOTHERMAL DEVELOPMENT	THE SECRETARY OF THE INTERIOR AND OTHER AGENCIES RESPONSIBLE FOR MANAGEMENT OF FEDERAL LAND HAVE VIRTUALLY UNRESTRICTED DISCRETION TO WITHDRAW LANDS FROM DEVELOPMENT; THE INHIBITING AFFECT OF THIS PROVISION IS UNKNOWN.	X	X		
AVAILABILITY OF LANDS FOR DEVELOPMENT--MULTIPLE USES OF PUBLIC LANDS	PRESSENT FEDERAL LAND USE POLICY IS GOVERNED BY THE MULTIPLE-USE PRINCIPLE: THAT IS, A SERIES OF USES SHOULD BE PERMITTED ON A SINGLE TRACT OF PUBLIC LAND, IF POSSIBLE. WHILE THIS IS A DESIRABLE PRINCIPLE, GENERALLY, GEOTHERMAL DEVELOPMENT MAY BE CURTAILED BECAUSE OF THE REQUIREMENT OF ACCOMMODATING OTHER USES OF THE PUBLIC DOMAIN.	X			
LAND ACQUISITION--EXPLORATION RIGHTS	THE FEDERAL LAW DOES NOT PROVIDE FOR PROTECTION OF THE DISCOVERY OF GEOTHERMAL PROSPECTORS OR EXPLORERS. IF A PROSPECTOR MAKES A DISCOVERY ON NON-KGRA LAND, HE CAN APPLY FOR A NON-COMPETITIVE LEASE. HOWEVER, IF ANOTHER PARTY FILES A LEASE APPLICATION AND THE SECRETARY OF THE INTERIOR FINDS A COMPETITIVE INTEREST EXISTS, THE NON-KGRA LAND WOULD BE RECLASSIFIED TO KGRA LAND AND THE SITE WOULD BE OPEN FOR THE NORMAL COMPETITIVE BIDDING PROCESS.	X			
LAND ACQUISITION--BONUS BIDDING	THE REQUIREMENT THAT BONUS BIDS BE "PUT UP" IN ADVANCE OF DEVELOPMENT TENDS TO INHIBIT THE PARTICIPATION OF SMALL FIRMS FOR TWO REASONS: THEY MAY NOT HAVE THE MONEY TO COMPETE WITH LARGE FIRMS AND THEIR DEVELOPMENT CAPITAL MAY BE DEPLETED BY THE REQUIREMENT OF PAYING LARGE SUMS OF MONEY IN ADVANCE. WHILE THE BONUS BIDDING SYSTEM PRODUCES THE LARGEST REVENUE IMMEDIATELY FOR THE FEDERAL GOVERNMENT, IT MAY, IN THE LONG RUN, DISCOURAGE DEVELOPMENT AND PRODUCE LESS NET REVENUE THAN A NON-BONUS BIDDING SYSTEM TIED TO HIGHER ROYALTIES.	X	X		

Figure 1.4.2 NON-TECHNOLOGICAL ISSUES

ISSUE	DESCRIPTION	DEVELOPMENT PHASE			
		RESOURCE EXPLORATION	RESOURCE DEVELOPMENT	ENERGY CONVERSION	ENVIRONMENTAL CONCERNS
LAND ACQUISITION--PUBLIC VS. PRIVATE DEVELOPMENT	THE FEDERAL GOVERNMENT SHOULD CONSIDER WHETHER THERE ARE TO BE DIFFERENT POLICIES REGARDING THE DEVELOPMENT OF PUBLICLY OWNED RESOURCES BY PRIVATE OR PUBLIC ORGANIZATIONS.	X	X	X	
SECURITY OF TENURE--LEASE TERMS	THE LEASE TERMS ESTABLISHED BY THE FEDERAL STATUTE ARE RELATIVELY SHORT AND IN MANY INSTANCES, SHORTER THAN STATE LEASE TERMS. THE SHORT TIME PERIOD WAS INTENDED TO ENSURE THAT GEOTHERMAL LAND WOULD BE PUT INTO PRODUCTION AND NOT HELD BACK FOR SPECULATION. IT IS TOO EARLY TO TELL WHETHER THE PRIMARY LEASE TERM IS TOO SHORT.		X	X	
SECURITY OF TENURE--RENEGOTIATION RIGHTS	THE SECRETARY OF THE INTERIOR HAS RIGHTS TO RENEGOTIATE BOTH LEASE TERMS AND CONDITIONS AS WELL AS RENTS AND ROYALTIES; THE POSSIBILITY OF DISPUTE AND TERMINATION IN THE NEGOTIATION PROCESS MAY INHIBIT PERSONS FROM INVESTING SUBSTANTIAL AMOUNTS OF CAPITAL.	X	X	X	
ENVIRONMENTAL CONCERNS-- TRADE-OFFS WITH DEVELOPMENT	ENVIRONMENTAL REGULATIONS SHOULD RECOGNIZE THAT ENVIRONMENTAL IMPACTS ASSOCIATED WITH GEOTHERMAL DEVELOPMENT CAN BE DIVIDED INTO TWO CATEGORIES: THOSE WHICH HAVE IMPORTANT LOCAL AND TEMPORARY SIGNIFICANCE, AND THOSE WHICH HAVE POTENTIALLY LASTING SIGNIFICANCE. IN THE CASE OF TEMPORARY IMPACTS, CONTROLLING MECHANISMS COULD RANGE FROM INDEMNIFICATION BY THE GOVERNMENT FOR DAMAGES CAUSED BY GEOTHERMAL EXPLORATION AND DEVELOPMENT, TO SELF-INSURANCE BY THE GEOTHERMAL OPERATORS.				X
ENVIRONMENTAL CONCERNS-- ADMINISTRATIVE COMPLEXITY	ADMINISTRATION IN THE AREAS OF LAND USE, ENVIRONMENTAL AFFAIRS, AND THE PRODUCTION AND DEVELOPMENT OF GEOTHERMAL RESOURCES SEEMS TO BE OVERLY COMPLEX AND REDUNDANT. EFFORTS MUST BE MADE TO COORDINATE VARIOUS REGULATORY RESPONSIBILITIES BOTH AT STATE AND FEDERAL LEVELS TO ENSURE THAT THE IMPORTANT VALUES EMBODIED IN THE REGULATORY PROCESS ARE PRESERVED AND TO REDUCE THE BURDEN ON THE GEOTHERMAL DEVELOPER TO OBTAIN THE APPROVALS NECESSARY TO INITIATE AND CONTINUE WITH DEVELOPMENT PROJECTS.	X	X	X	X
EFFECTS ON THE ELECTRIC UTILITIES-- INCENTIVES FOR THE PURCHASE OF STEAM	GEOTHERMAL ENERGY WILL BECOME AN IMPORTANT SOURCE OF ENERGY IN THE UNITED STATES IF THE UTILITY COMPANIES BUY IT. A MAJOR OBSTACLE IN THEIR ACCEPTANCE OF THIS RESOURCE IS THE UNCERTAINTY ABOUT THE LENGTH OF TIME WHICH A GIVEN FIELD WILL BE PRODUCTIVE. PARTICULARLY POWERFUL INCENTIVES WOULD BE TO PROVIDE "RESOURCE INSURANCE" AND "RELIABILITY INSURANCE", THAT IS, INSURANCE AGAINST THE RISK OF EARLY DEPLETION AND LACK OF CONTINUITY OF SUPPLY.	X	X	X	
EFFECTS ON THE ELECTRIC UTILITIES-- IMPACTS ON TRANSMISSION	GEOTHERMAL RESOURCES ARE OFTEN LOCATED OUTSIDE OF A MAJOR UTILITY'S AREA AND A LARGE DISTANCE FROM EXISTING LOAD CENTERS. THE PATTERNS OF JOINT OWNERSHIP OF TRANSMISSION LINES HAVE TO BE ESTABLISHED. NEW INSTITUTIONAL PROBLEMS WILL ARISE IF GEOTHERMAL ENERGY IS TRANSPORTED FROM WEST TO EAST IN THE FORM OF ELECTRICITY OVER TRANSCONTINENTAL LINES. THE ALTERNATIVE INSTITUTIONAL FORMS INCLUDE: COOPERATIVE ARRANGEMENTS AMONG UTILITIES, A FEDERAL AGENCY, A PRIVATE VENTURE (ANALOGOUS TO THE GAS PIPELINE COMPANY), AND A QUASI-PUBLIC ORGANIZATION MODELED AFTER THE COMMUNICATIONS SATELLITE CORPORATION.				X

Figure 1.4.2 (Cont.)

ISSUE	DESCRIPTION	DEVELOPMENT PHASE			
		RESOURCE EXPLORATION	RESOURCE DEVELOPMENT	ENERGY CONVERSION	ENVIRONMENTAL CONCERNS
EFFECTS ON THE ELECTRIC UTILITIES-- DIVERSIFICATION	IN SOME INSTANCES, UTILITIES MAY WISH TO PARTICIPATE IN GEOTHERMAL DEVELOPMENT THROUGH DIRECT INVESTMENT. IF THE UTILITY IS CLASSED AS A UTILITY HOLDING COMPANY, SEC REGULATIONS PROBABLY WOULD NOT PERMIT THE COMPANY TO DEVELOP GEOTHERMAL RESOURCES FOR SALE TO OTHERS. FURTHERMORE, THE CASE IS CERTAIN TO ARISE IN WHICH A GEOTHERMAL DEVELOPER WISHED TO UTILIZE THE RESOURCE FOR THE GENERATION OF ELECTRICITY RATHER THAN SELLING STEAM. THESE SITUATIONS WILL CHALLENGE THE EXISTING REGULATING STRUCTURE.	X	X	X	
EFFECTS ON GOVERNMENT--PENDING LEGISLATION	THERE ARE A NUMBER OF LEGISLATIVE PROPOSALS PENDING WHICH WILL HAVE IMPACT ON GEOTHERMAL ENERGY DEVELOPMENT. THESE IMPACTS INCLUDE, MOST PROMINENTLY, THE ESTABLISHMENT OF A NATIONAL PROGRAM FOR RESEARCH, DEVELOPMENT, AND DEMONSTRATION IN FUELS AND ENERGY.	X	X	X	X
EFFECTS ON GOVERNMENT--R & D PLANNING	SHOULD A CENTRAL FEDERAL AGENCY BE ESTABLISHED FOR ENERGY RESEARCH AND PLANNING, THE CURRENT FEDERAL INTER-AGENCY PANEL RESPONSIBLE FOR GEOTHERMAL R & D WOULD UNDOUBTEDLY BE REPLACED. THE PERIOD OF TRANSITION COULD INVOLVE UNNECESSARY DELAYS.	X	X	X	X
EFFECTS ON FINANCIAL INSTITUTIONS	LOAN GUARANTEES BY THE FEDERAL GOVERNMENT WILL ENCOURAGE CAPITAL INVESTMENT IN GEOTHERMAL DEVELOPMENT.	X	X	X	X

Figure 1.4.2 (Cont.)

1200 MWe. In total, these savings amount to about 15 percent of the country's coal and nuclear generation capacity by the end of the century; thus, while geothermal development has an important effect on these generating sources, it is by no means pre-emptory.

These shifts in fuel mix are likely to bring a number of secondary impacts, such as reduction in the number of nuclear and coal-fired generation sites, reduction in the amount of radioactive material to be stored, reduced need for mining of coal for use in electrical generation, and so on.

2. Two business sectors will be stimulated by geothermal development (Section 4.2). These are businesses involved in the exploitation of geothermal energy and businesses which can uniquely utilize geothermal resources.

- The total investment in geothermal development (materials, land, equipment, and so on) could be on the order of \$95 billion by the year 2000.
- The businesses affected by the advent of geothermal energy will be largely those which can utilize geothermal heat directly.

While the following applications are interesting, they are not likely to be of great economic importance. These applications include:

- (a) Agriculture (e.g., utilizing geothermal heat for soil warming, hothouse heating, treatment of animal wastes, drying, soil sterilization, and so on).
- (b) Process heat for certain classes of manufacturing (e.g., paper production, lumber drying, and so on).
- (c) Desalination, in which geothermal heat serves as an energy source for distillation.

A business which utilizes low grade geothermal heat is, in effect, utilizing hot water. Hot water can come from many other sources (e.g., power plant effluent); thus, development of a technology which permits the use of waste heat is directly applicable to geothermal fluids. Businesses which utilize geothermal electricity could, as well, utilize electricity from other sources; one kilowatt is indistinguishable from another. The effect on such businesses will be only that realized as the result of increased availability of electricity.

A major consequence of direct use of geothermal heat will be to bring certain industrial plants near the source of geothermal heat. Flowing from this impact will be a host of higher order impacts associated with land use, demographic shifts, regional economics, and so on. Since the extent of geothermal resources is not yet clearly known, and since it is apparent that the first major use of geothermal energy will be for the production of electricity, it is difficult to project the intensity of these impacts; however, the effect of these impacts probably will not be large when viewed on a national scale. From the standpoint of the affected localities, however, impacts could be similar to those associated with mild industrialization and therefore could be viewed by various interest groups as being beneficial or detrimental as a result of changing land use patterns, increasing population density, creation of the need for new public services, increasing the tax base, increasing the number of jobs, and so on.

3. Macroeconomic and societal factors will be affected (Section 4.3). It seems certain that the demand for electricity will increase; development of geothermal energy provides a way of helping to meet that demand. However, since geothermal sources may furnish about 10 percent of the total demand for electricity by the end of the century, the effect of its price "dilution" will be small.

Most of the specific societal impacts flowing from the development of geothermal energy will evolve from significant characteristics: the small size of prime installations and the location of the resources which, in most cases, are in outlying areas.

Federal royalty income from geothermal development could amount to \$1 billion per year by 2000, and local governments could realize about \$475 million per year from local taxes by 2000. These sums are helpful but not overwhelming; for comparison, federal tax revenues in 1971 were \$137 billion and local tax revenues, \$43 billion.

4. The development of geothermal energy will encourage the development of a national electrical grid (Section 4.4). Using preliminary estimates of the cost of constructing and operating a transcontinental high voltage DC transmission line, electricity derived from geothermal sources in the West can probably be supplied to the Mid-West and eastern portion of the United States at a cost of about 25 mills (1973 dollars) per kWh in 2000. Based on considerations of reliability, continued supply, diversity, and capital requirements, it is plausible to expect mid-western and eastern utility companies to purchase on the order of 56,000 MWe (out of a demand of 1.6 million MWe in the East) of geothermally-generated electricity from western sources by the year 2000.

Transportation of electrical energy from west to east could take advantage of intercontinental lines which may be in place in support of coal minemouth generation plants. The important secondary impacts flowing from this development include increased R&D development in the fields of high efficiency, high capacity transmission lines, and esthetic effects which seem likely to arouse conflict. Cost considerations seem to preclude placing transmission lined underground; however, the use of hydrogen produced from electrolysis of geothermal electricity may be an economic alternative to high voltage DC transmission.

5. Institutional arrangements will be affected (Section 4.5). It is essential that certain institutional arrangements change if the development of geothermal energy is to be accelerated. Currently, federal, state, and local regulations, particularly environmental regulations, overlap and cause delays.

At the federal level, research and development and programmatic planning is being accomplished by an Inter-agency Panel for Geothermal Energy Research composed of the National Science Foundation, the Department of the Interior, the Department of Defense, and the Atomic Energy Commission. As the geothermal program develops, these groups may have some divergent and conflicting interests; the implementation of an energy R&D agency (ERDA) will also make this panel obsolete.

The geothermal law, as presently constituted, encourages the participation of large companies and discourages small companies. For this reason a significant institutional impact is expected to be the increasing participation in geothermal development of major petroleum companies.

Arrangements developed in the past for selling other forms of energy may not be adaptable to this form and indeed may hinder its development. As the system is presently constituted, utility companies are the only major buyers of geothermal energy.

6. Geothermal development will affect regions, cities, and buildings (Section 4.6). The impacts on regions and cities stem from industrialization resulting from the development of the geothermal resource itself and from the potential influx of businesses which support geothermal development and which can utilize the heat and mineral content of the geothermal fluids. At the secondary level this results in changing population levels, population density, and land use patterns. However, these changes also bring an increased tax base, a potentially cleaner environment, and increased employment. Cities near geothermal resources will have the opportunity to develop district heating and cooking; Reykjavik, Iceland, which now supplies almost all of its residents with inexpensive geothermal heat, can serve as an example. District cooling systems have not yet been attempted anywhere in the world, but cooling of a tourist hotel in New Zealand using geothermal heat as an energy source establishes the feasibility of such an approach, at least on a small scale.

7. Geothermal energy will affect international relations (Section 4.7). At least 70 countries have geothermal potential. Some of these countries have already developed a portion of their geothermal resources; others have not. Development of geothermal technology in the United States will not only create the opportunity for technological aid, particularly to countries with relatively low GNP per capita, but it will lead to the creation of new markets throughout the world. Technological aid and geothermal markets can be expected to develop as early as the late 1970's. When foreign countries develop indigenous geothermal resources, their demand for imported fuel will diminish. Similarly, as the United States develops geothermal energy, fuels which might have been used for the generation of electricity can be put to other uses (or not mined or imported at all). The impact is significant: Geothermal energy could "free up" enough coal for export to bring into the United States a total of between \$13 and \$20 billion (cumulative) by the year 2000.

8. Geothermal energy will have certain environmental impacts (Section 4.8). Environmental impacts can be classed into two general categories: those of local or short-term importance, and those of regional lasting significance. In the former category fall local noise, gaseous emissions, and blowouts. These impacts have some danger associated with them and will undoubtedly be offensive to nearby residents. Good engineering practice can reduce these impacts. Regulations should clearly impose penalties for not adhering to such state-of-the-art practices.

There are three important potentially irreversible environmental impacts: contamination of groundwater, seismicity, and subsidence. The extent of these environmental impacts is not known today except by inference from activities similar to geothermal exploitation currently being pursued in the petroleum and gas industry. These such problems have proved manageable; in the case of geothermal energy, they will probably respond to research and development and a growing body of geophysical knowledge.

Impact on Interest Groups

Detailed assessment of selected potential impacts indicates that the interest groups in society most likely to support geothermal development because of the benefits it provides are the financial community, the U.S. Government, businesses that supply the geothermal industry, the geothermal industry itself, and the new research community involved in geothermal research. The groups likely to react to the threats of geothermal energy are environmentalists, the Environmental Protection Agency, groups of homeowners near geothermal installations, and the utility companies affected by the transcontinental grid. The policies likely to be viewed most desirable (that is, policies which increase the perceived positive consequences, minimize the perceived detriments, and promote agreement among the groups involved) are those which address the environmental implications of the use of the resource and help to resolve potential land use conflicts (Section 5).

Policy Recommendations

Policy is defined as "a definite course of action adopted for the sake of expediency, facility, etc.; prudence, practical wisdom...." This definition brings several questions immediately to mind: How can the best definitive courses of action be identified from among the myriad alternatives? By what dimensions can a course of action be defined? Policies which appear "prudent" to one group may appear reckless to another: How can such value questions be handled?

Because of such basic philosophical issues, it is important to define the frame of reference to be used.

In the discussion which follows,

- Recommended policies are those which, on the basis of analyses conducted by The Futures Group or, where necessary, judgments seem the "best" answer to issues identified during the study.

- The dimensions involved in defining a recommended policy are:

- What is to be done?

- By whom is it to be done: What level of government, the private sector, citizen groups?

- When would it be best to do it?

- Why is it being done?

- What is it likely to cost?

- What are the consequences of not doing it?

- The value orientation to be employed in the use of the term "best" or "prudent" will, for the most part, be that of a national planner seeking to ensure and improve the economic conditions and quality of life of people in the country. Where conflict exists between these dual objectives, or when conflict exists between the national orientation and the orientation of specific groups within the country, this will be identified if at all possible.

The key policy issue is whether or not the development of geothermal energy should be encouraged in the United

States. On the basis of this research, we believe it will be useful and important to the United States to encourage the expeditious development of indigenous geothermal resources, not only for the generation of electricity, but to exploit the heat, and possibly the water and mineral potential of the resource, as well. We expect that development of geothermal resources could, under prudent policies, provide about 10 percent of the country's total generation capacity by the end of the century.

The aggregate expenditures for geothermal power through the remainder of the century, including capital, operating costs, taxes, and royalties, are likely to be on the order of \$95 billion; if the amount of electricity anticipated from geothermal sources were to be generated by petroleum, cumulative expenditures for fuel alone would amount to at least \$100 billion by 2000, assuming an average cost of oil of \$10/bbl.

If the coal which geothermal energy can replace is exported, it will improve the import-export balance by a total of more than \$13 billion over the next two and a half decades; diminish by 100-150 the number of new 1000 MWe nuclear reactors required; diminish by 90-120 the number of new 1000 MWe coal-fired generators required; and provide new opportunities for international cooperation leading toward economic improvement of certain developing nations. These benefits will not be achieved without cost or conscientious effort. There are important uncertainties still connected with this resource including, most particularly; identifying the extent of the resource and the length of time over which particular installations could operate; solving the remaining problems of scaling when utilizing high salinity two-phase geothermal fluids; and handling potential environmental effects such as the potential for subsidence and seismic effects in some instances; and the possibility of groundwater contamination which could result from improper operations. Land use issues will also be vexatious. Incentives will be necessary to encourage utility companies to buy geothermal energy before field longevity is accurately known. Pilot plants will be required to help resolve some of these technical uncertainties as well as to develop operating experience. Government R&D programs must be introduced to help resolve these uncertainties. Certain crucial defects in federal regulations must be corrected if the development is to be encouraged in favorable directions.

We believe, further, that after a period of federal involvement in the development phase and after the necessary regulatory changes are accomplished, the development and use of the resource is likely to prove attractive enough economically to private investors so that normal market mechanisms will bring geothermal energy into prominence.

Recommended policies are discussed in the remainder of this section. These policies are divided into the following major categories:

- Those which stimulate exploration and development.
- Those which provide incentives to potential users of the resource.
- Those which will lead to the required technological developments.

Figure 1.4.3 summarizes the recommended policies.

Policies Which Stimulate Exploration and Development

Legal Classification of the Resource

The appropriate legal classification of geothermal resources for some purposes is as yet unclear: Are these resources minerals, water, or should they be considered sui generis (i.e., a new area of law)?

Geothermal resources are encumbered by legislation developed for other purposes. The lack of clear definition particularly impedes geothermal development by perpetuating uncertainty of treatment under income tax and public land laws. Investors do not have any assurance that they will be entitled to tax incentives similar to those provided for the oil and gas industry. These incentives currently include depletion allowances and deduction of intangible drilling costs. There is uncertainty as to the effect of mineral reservation in past federal deeds and land grants.

We believe that it is appropriate to consider geothermal energy as sui generis and therefore to define a body of law appropriate to this field. In particular, consideration should be given to stimulating exploration and development since the analytic work of this study has tended to show that reducing the uncertainty about the level of identified resource will be an important stimulant to the overall development of geothermal resources. It is recommended that a special subcommittee of the American Bar Association be formed, in conjunction with appropriate congressional representatives, within the next year, to review the current legal issues associated with geothermal energy and to make recommendations to Congress for appropriate legislation.

Land Availability

Are current provisions of the federal geothermal statute with respect to the availability of federal lands for leasing apt to encourage geothermal development?

There are two important restrictions in the law which limit the availability of federal land for leasing. One provision removes federal lands used for a variety of other purposes from the leasing process. The other limits the acreage which any one developer can hold in a single state. Taken together, these provisions have the effect of (a) removing large blocks of the federal domain from geothermal development and (b) discouraging the formation of large-scale concerns which could economically exploit the geothermal resources.

At present, given the state of knowledge about the location, exploitation, and practicality of using geothermal energy, it is probably unwise to open up more land to geothermal development than is presently planned. However, as the program progresses, Congress should reconsider some of the restrictions it has placed upon use of the public domain. Similarly, it is not clear whether the acreage limitations in the geothermal statute are too large or too small. Since the thrust of the rest of the statute is to encourage competitive bonus bidding and perhaps thereby encourage large firms to dominate the geothermal development industry, the acreage limitation may not be sensible. It may be that for energy development purposes it would

POLICY AREA	RECOMMENDED POLICY	RESPONSIBLE AGENCY
1. STIMULATION OF EXPLORATION AND DEVELOPMENT--CLASSIFICATION OF RESOURCE	CONSIDER GEOTHERMAL AS <u>SUI GENESIS</u> (A NEW AREA OF LAW).	CONGRESS AND AMERICAN BAR ASSOCIATION
2. STIMULATION OF EXPLORATION AND DEVELOPMENT--LAND AVAILABILITY	RECONSIDER RESTRICTIONS ON USE OF PUBLIC DOMAIN AND ON ACREAGE LIMITS.	CONGRESS
3. STIMULATION OF EXPLORATION AND DEVELOPMENT--LAND TENURE	MODIFY LAW TO ELIMINATE UNREASONABLE ARBITRARY GOVERNMENT ACTION AND TO INTRODUCE LEASE NEGOTIATION PROCEDURES, POSSIBLY RE-QUIRING ARBITRATION.	CONGRESS
4. STIMULATION OF EXPLORATION AND DEVELOPMENT--BIDDING SYSTEM ON KGRA	A. DETERMINE WHETHER IT IS IN THE NATIONAL INTEREST FOR LARGE COMPANIES TO DOMINATE GEOTHERMAL DEVELOPMENT. B. CONSIDER A ROYALTY BIDDING SYSTEM FOR ENCOURAGING THE SMALLER ENTREPRENEUR.	CONGRESS CONGRESS
5. STIMULATION OF EXPLORATION AND DEVELOPMENT--PROTECTION OF EXPLORERS AND PROSPECTORS	AMEND STATUTES TO PROTECT RIGHTS OF EXPLORERS ON NON-KGRA LANDS.	CONGRESS
6. STIMULATION OF EXPLORATION AND DEVELOPMENT--ADMINISTRATIVE COMPLEXITY	A. UTILIZE A SINGLE ENVIRONMENTAL IMPACT STATEMENT FOR LARGE BLOCKS OF LAND. B. ADAPT THE LEAD AGENCY CONCEPT TO MINIMIZE FEDERAL, STATE AND LOCAL GOVERNMENT REGULATION OVERLAP; ORGANIZE SYMPOSIA TO PROBE ADMINISTRATIVE PROBLEMS AND RECOMMEND LEGISLATION.	CONGRESS FEDERAL, STATE, AND LOCAL AGENCIES; NSF; AND EPA
7. STIMULATION OF EXPLORATION AND DEVELOPMENT--CAPITAL AVAILABILITY	MONITOR CAPITAL AVAILABILITY; IF LIMITED, STRENGTHEN LOAN GUARANTEES AND INITIATE OTHER INCENTIVES.	FEA, CONGRESS
8. INCENTIVES TO RESOURCE USERS--PURCHASE OF GEOTHERMAL STEAM; IMPROVEMENT IN RELIABILITY	A. BUILD AND OPERATE DEMONSTRATION PLANTS (10 - 100 MWE)--LIQUID DOMINATED, HOT DRY ROCK, GEOPRESSURE. B. INITIATE "RESOURCE RELIABILITY INSURANCE" TO REDUCE RISK ASSOCIATED WITH FAILURE OF GEOTHERMAL SUPPLY.	NSF, AEC CONGRESS
9. INCENTIVE TO RESOURCE USERS--ASSURING LONGEVITY	INITIATE "RESOURCE LONGEVITY INSURANCE" TO MINIMIZE RISK OF EARLY FIELD DEPLETION.	CONGRESS
10. RESEARCH AND DEVELOPMENT--GENERAL CONSIDERATIONS	A. ACCORD PRIORITY TO HIGH-RISK AREAS, REMOVING IMPEDIMENTS AND ADDRESSING POTENTIALLY ADVERSE ENVIRONMENTAL IMPACTS. B. APPOINT R & D ADVISORY GROUP FROM INDUSTRY AND PUBLIC.	NSF, AEC, DOI NSF
11. RESEARCH AND DEVELOPMENT--RESEARCH AGENDA	A. ACCORD PRIORITY TO LIQUID DOMINATED, HOT DRY ROCK, AND GEOPRESSURED RESOURCES. B. INCLUDE SPECIFICALLY: (1) SYNOPSIS SENSING TECHNIQUES (2) EXPLORATION INSTRUMENTATION (3) REGIONAL APPRAISALS (4) MEANS FOR PREDICTING RESOURCE POTENTIAL (5) ENERGY EXTRACTION METHODS FOR MODERATE TO HIGH SALINITY BRINES AND FOR LOW TEMPERATURE BRINES (6) 10 - 100 MWE DEMONSTRATION PLANTS	NSF, AEC, DOI
12. RESEARCH AND DEVELOPMENT--DATA BANK	ESTABLISH A DATA EXCHANGE CENTER WITH MANDATORY DATA REPORTING REQUIREMENTS.	USGS
13. RESEARCH AND DEVELOPMENT--ENVIRONMENTAL CONCERNS	A. REVIEW CURRENT REGULATIONS TO INSURE APPLICABILITY TO PRESENT AND FUTURE GEOTHERMAL OPERATIONS. B. INITIATE HIGH-PRIORITY RESEARCH FOR ENVIRONMENTAL AREAS WHICH HAVE POTENTIALLY LASTING CONSEQUENCES.	EPA NSF

Figure 1.4.3 Summary of Recommended Policies

be better to encourage a much larger scale of development by fewer firms and attempt to deal with a monopoly situation created thereby to regulation. Again, Congress has made a conscious policy of attempting to encourage some competition in the geothermal industry. It is too early to tell whether this is the correct decision or not.

Tenure

Are provisions in the federal geothermal statute relating to security of tenure adequate?

Geothermal development, especially if it is to be devoted to the generation of electric power, requires that the developer and producer of geothermal energy have enough security of tenure to be willing to make long-term investments. Electric generating companies, for example, normally require at least 20 to 30 years of active production before they will commit themselves to the construction of power plants. Against the required security for the developer one must weigh the need to keep geothermal land in production and out of the hands of speculators. It is not yet possible to tell whether the lease renewal and renegotiation periods specified in the law are long enough to give the geothermal developer the kind of security he will require to develop the resources. Several of the state laws are, however, somewhat more generous in this regard than is the federal law.

Of particular concern is the power of the Secretary of the Interior to renegotiate lease terms and conditions after a 35-year interval. If the geothermal developer refuses to accept the Department of the Interior's offered renegotiated condition, then the Department of the Interior may terminate the lease. This, in essence, gives the Department of the Interior the right to terminate the lease since it may impose such conditions on the developer that he cannot reasonably agree to.

The law and regulations in this regard should be modified to make clear that the geothermal developer or producer will not lose his lease if the Department of the Interior attempts to impose unreasonable conditions upon him. Provision for forced arbitration may be required in the statute. This will at least offer the geothermal producer or developer protection against arbitrary administrative action. On the other hand, it would seem reasonable that there should be some right to renegotiate lease terms and conditions as well as rents and royalties, since, over a 35-year period, there may well be considerable changes in both the energy situation, the economic situation, and attitudes with respect to use of public lands which would require that the United States reconsider its position. It should not be possible, however, to have terms and conditions change without adequate justification and due process.

The Bidding System

Is the bidding system now in effect for geothermal lands appropriate?

The federal thrust toward competitive bonus bidding gives firms with access to relatively large amounts of capital an advantage. The results may be better-financed development by firms with more skills and better equipment but perhaps less aggressive exploration if large companies begin to dominate geothermal resource development process. In an era in which the largest firms are beginning to dominate many phases

of energy extraction and production, it may not be desirable to add geothermal energy to the list of resources they control. Firms which are engaged in the development of many energy sources may tend to concentrate on developments which are the most profitable at the moment. If geothermal energy is not in the optimum mix, it may not be developed as rapidly or as completely as one would desire.

To encourage the small entrepreneur, it would be necessary to move toward non-competitive leasing of lands and to eliminate the bonus-bidding system with respect to competitive lands. Appropriate amendment to the definition of KGRA would be to follow the state statutes by defining a KGRA in purely physical terms and eliminating the "competitive interest" provision. As an alternative to the bonus-bidding system, some kind of variable royalty bidding system might be considered. That firm which offered the highest royalty combined with an adequate work plan might be awarded the geothermal lease without the necessity of depositing the cash bonus in advance. The funds that might otherwise be tied up in the cash bonus would be available for geothermal development. In the short run, this policy may contradict the Department of the Interior's established goal of obtaining the largest immediate cash resources in exchange for public land; in the longer run, a higher variable royalty without a bonus-bidding might produce greater revenues for the United States.

Furthermore, the notion that monies collected through leasing and royalties should flow to general revenues may be obsolete; in this instance it may be more appropriate to use these funds for geothermal research, indemnification, data collection, etc., at least until the industry is firmly in place.

Protection of Explorers and Prospectors

How can the protection given to geothermal explorers or prospectors be made more adequate?

Under federal law the explorer or developer who does not first acquire a geothermal lease is not protected. If other persons file applications for the same land, then, according to the Department of the Interior policy, the land will be classified as a KGRA and therefore it will become subject to competitive bidding. State law does, in some instances, offer the prospector more protection. Since the explorer is not protected under federal law, it will be incumbent upon all persons who wish to protect their rights to first secure a lease to lands which they wish to explore. This will require an initial investment in a non-competitive geothermal lease with a risk that at any time during the lease application process the land could be declared a KGRA and therefore subject to competitive bidding.

The study team recommends that consideration be given to amending the federal geothermal statute so as to provide explicit protection for prospectors or "wildcatters" working on non-KGRA lands.

Administrative Complexity

How can the current overlap of regulatory jurisdictions among various levels of government which control geothermal resources be eliminated without sacrificing important values?

Federal, state, and local governments have not yet sorted out their respective responsibilities with

respect to geothermal development. Estimates are that in California it may take up to one year to obtain necessary approval before geothermal land can be developed. Not only is the processing time long, but the cost is high. The developer and the regulatory agency are both faced with the necessity of preparing environmental impact statements for federal and state governments if federal lands are involved and also complying with a variety of state and local regulatory requirements with respect to air and water quality and land use.

Since each leasing operation has been determined to be a major action requiring an environmental impact statement or environmental report, the process of preparing such statements or reports is repeated over and over again as the geothermal leasing process progresses. A provision should be made for a single environmental impact statement to cover large blocks of land, requiring only that each developer report to the regulatory agency concerning any additional impact on the environment that his developmental activities will create. In the long run the goal should be "one-step" administrative clearance. Ideally, the agencies which are responsible for regulating various aspects of environmental control and geothermal development on federal, state, and private lands should agree that one agency will be the lead and that lead agency will be responsible for ensuring that the proposed geothermal developer or explorer complies with all applicable regulations of all agencies. This process will be difficult and will probably involve federal legislation eventually. The process might be started, however, through a series of symposia involving affected governmental agencies. These symposia could be organized by NSF or EPA.

Is adequate capital available for geothermal development?

Probably not, as things stand, because geothermal development is viewed as high risk, and in general, has a long time to pay off. Federal loan guarantees which are included in recent legislation, however, should ease this situation considerably. Furthermore, as geothermal development accelerates, its potential to attract capital will improve. We recommend that capital availability be monitored continuously and should capital availability be limiting, loan guarantees should be strengthened and other incentives such as direct subsidies to explorers and developers should be considered. [2]

Policies Which Provide Incentives to Potential Users of the Resource

Why should a utility company choose to purchase geothermal steam as an energy input?

There are likely to be two primary concerns on the part of the utility companies when they face the decision about whether or not to buy geothermal steam. These are reliability and longevity of the supply. Without assurance that the supply is reliable and that it will last at least over a 20-30-year time period, utilities will look elsewhere for primary energy inputs. Since the utility company is the primary customer for geothermal steam, these concerns must be taken very seriously.

Confidence in operational reliability can be improved through the use of demonstration plants. Demonstration plants operating at a level of about 10-100 MWe, using high salinity liquid-dominated resources, hot dry rock resources, and geopressed resources, seem to be quite appropriate. These plants would provide test beds for new technology as well as reliability demonstration vehicles.

In addition, the government should consider "resource reliability insurance" which would compensate utility companies for extra losses incurred as a result of their decision to utilize geothermal resources, in the event of failure of geothermal supply.

With respect to longevity, it is impractical to plan on demonstration plants which illustrate the length of time that a field will be productive. Rather, scientific research programs which include the development of geophysical models and data collection systems to enable the prediction of field lifetime and maximum heat extraction rates should be supported.

Furthermore, the government should initiate "resource longevity insurance" which would help minimize the risk to utility companies which choose to buy geothermal steam as a primary energy source. This insurance could take the form of expedited depreciation in the event of resource depletion, reimbursement of additional expenses incurred as a result of early field depletion, or other similar mechanisms.

Policies Which Will Lead to the Required Technological Developments

Government vs. Private Technological Development

Should the government intervene in the process by which geothermal technologies are developed?

Government policies could range from laissez faire (as in the case of innovation in the petroleum industry) to complete government development of new geothermal technology (as in the case of the early nuclear industry).

Although the study team believes that geothermal energy will become economically attractive and self-supporting, government intervention in several technological areas seems warranted. Three specific areas are:

- Technologies which are pivotal to further development.
- Technologies which, if available, would remove currently discernible impediments.
- Technologies required to remove potentially adverse environmental impacts.

Priority for government development in such technological areas should be increased if the technology under consideration is intrinsically high risk, but in the national interest because of long-term and indirect desirable national effects.

As in other areas of government-sponsored research, there are two dangers which should be considered: First, government-sponsored research may cause private firms to avoid engaging in similar research because of concern about their ability to compete with the government. Second, potential users of the research may simply wait until government programs are complete before initiating programs which could have utilized somewhat more primitive technology--thus producing a slower growth than might have otherwise been the case.

Private industry performs research because of the promise of a competitive advantage and economic return which it brings. If the government research program removed this promise, then the government would find itself performing almost all of the required R&D.

Clearly, the government has a battery of tools available to stimulate geothermal research in the private sector; these tools include expedited write-off of R&D, contracts which do not require public disclosure of proprietary information, patent protection, and so on.

Because of the need for government sponsorship of high risk technological research and the programmatic pitfalls which might accompany ill-chosen research agendas, the study team concurs with the present government intention to form an advisory group composed of representatives from electric utilities (perhaps through the Electric Power Research Institute), the resource extraction industry, the supply and services industry, agriculture, mining, financial institutions, state and local governments, and regulatory agencies. This group should have the authority to help formulate and review the government's research agenda. The group will bring to government research planning an industry and operational orientation which might otherwise be absent; such an orientation is necessary to ensure a rapid and efficient transfer of government developed technology to the user. While the study team does not believe it is necessary to provide this group with veto power, they should be able to publish reports of their findings which might be useful in governmental planning and budgetary processes.

The Research Agenda

Specifically, what pivotal technologies and technological impediments should form the focus of the government's research and development program?

The choices are quite broad: The research agenda might concentrate on a single resource type, or could cover high risk issues in all resources simultaneously. Furthermore, the range of possible targets within the domain of each resource is very large. We believe a phased program should be established which concentrates initially on the parallel development of energy extraction methods and conversion processes for moderate to high salinity brines and for low temperature brines, and which would lead to the identification of the extent, distribution, and quality of geothermal resources in the United States as soon as possible. Most geothermal sites throughout the world are of liquid-dominated type; perhaps as many as twenty times as many liquid-dominated sites exist as vapor-dominated sites.

The potential of hot dry rock and geopressed resources is also extremely large. Therefore, research priority should also be accorded these resource types. While magma resources are also likely to be very large, environmental and technical problems suggest that research priority should be placed elsewhere. (Note that magma applications in Hawaii may be a special case.)

More specifically, the research agenda should probably include:

- Development of synoptic remote sensing techniques.
- Development of geochemical, geological, geophysical instrumentation for the identification of geothermal resources.
- A systematic and well planned series of regional appraisal designed to identify the extent of geothermal resources in the western states, including Hawaii and Alaska, first, followed by the central and eastern states.
- Development of methods for predicting the energy potential of specific reservoirs,

including, at lower priority, deep geothermal reservoirs.

- Development of energy extraction methods and energy conversion processes and equipment for moderate to high salinity brines and of low temperature brines. This work would involve solving problems of scaling of pipes and heat exchangers which contain geothermal fluids.
- Initiating a series of demonstration plants (10-100 MWe) for moderate to high salinity, liquid-dominated resources; hot dry rock resources; and geopressed resources to develop and demonstrate new technology and to improve levels of confidence in the reliability of these energy sources.

The current federal program seems to be moving generally in these directions. However, whether a cohesive, efficient, and fast moving program can be maintained by an interagency panel (Section 4.5) remains to be seen.

Information Data Bank

Respondents in the technological interview endorsed the idea of establishing a geothermal data exchange center for the dissemination of existing and future resource and reservoir data obtained from both governmental and industrial programs. The concept of this data exchange center as an instrument for stimulating resource exploration and geothermal development was first proposed at the National Science Foundation seminar conducted under W. J. Hickel.[3] Such a data exchange center would have the following functions:

- Providing up-to-date information in the public domain about reservoir location and quality.
- Collecting and publishing operation data, particularly concerning field longevity, accidents, and environmental effects of geothermal operations.
- Acting as a repository for all environmental impact statements and comments about the statements.
- Compiling and making publicly available all detailed information about the status of federal leases, including, for example, published bids, lessees, and the status of leased federal property.
- Publishing bulletins about new technologies available to meet specific problems and government research plans and results.

The data exchange center would serve two primary purposes: a focus of information for public review and a reference center for professionals in the field. Having such information readily available, communications in the field would be improved, the process of "reinventing the wheel" would be diminished, and the development process would be expedited. Many of the functions defined for the data exchange center are already being performed by the United States Geological Survey. It is suggested that their role be expanded to include all of the elements listed above.[4]

Environmental Technologies

What research and development programs should the

government initiate in order to minimize potential adverse environmental impacts of geothermal energy?

We believe that current environmental regulations, both at the federal and state level, should be reviewed with special attention to areas likely to be affected by geothermal operations, and extended where necessary. Specifically, seismic effects, subsidence, and potential contamination of ground and surface water by geothermal fluids should be considered. In parallel, the government should initiate research programs tailored particularly to the various geothermal media to determine the potential for damage and means for exploring, developing, and operating with minimum damage. This program should be high priority and should focus on the following objectives:

- Develop and demonstrate practical techniques for preventing ground and surface water contamination by geothermal fluids.
- Obtain an understanding of the cause/effect relationship between fluid injection into a rock formation and earthquake occurrences.
- Develop predictive, preventative, and corrective techniques for dealing with land subsidence consequent to geothermal fluid withdrawal.

In addition, this environmental research program should include certain other priority objectives:

- Develop technology for effectively controlling potentially harmful or nuisance gaseous emissions such as hydrogen sulfide or ammonia.
- Develop practical effective techniques for noise control during geothermal drilling and plant operation.
- Reconcile design of surface geothermal power systems with preservation of local esthetic values.
- Develop a design safety code dealing with hazards to workers and to the public which is specific to the geothermal industry.

The successful accomplishment of these objectives may be key to the development of certain vapor- and liquid-dominated, hot dry rock, and geopressured resources in the United States. In addition, this environmental technology may be an important element of international technology transfer programs.

REFERENCES

- [1] The estimates of the future geothermal generating capacity are sensitive to a number of assumptions about the extent of the resource, technological developments, and removal of socio-economic impediments, which are described in detail in later sections of this report.
- [2] Following completion of this section of this report, Congress, on September 3, 1974, adopted the Geothermal Energy Research, Development and Demonstration Act of 1974 (P.L. 93-410). The Act (reproduced in Appendix J) provides for guidance of geothermal R&D by a Geothermal Energy Coordination and Management

Project composed of one presidential appointee and representatives of NSF, Department of Interior, NASA, AEC, and FEA. The project was assigned "overall responsibility for the provision of effective management and coordination with respect to a national geothermal energy research, development, and demonstration program" (P.L. 93-410, Section 101). The Project is also responsible for administering a loan guarantee and interest assistance program. The legislation directs that the Project be transferred to a permanent energy R&D agency when one is created.

The R&D program is to be carried out through the constituent agencies with the Project acting as overall coordinator. Its elements include: comprehensive program definition of an integrated effort and commitment for effectively developing geothermal energy resources; resource inventory and assessment; technical and environmental research and development; information collection and dissemination; scientific and technical education; and pilot and demonstration projects.

A loan guarantee may cover up to 75 percent of the aggregate cost of any program for which it is made. Interest payments may be made by the federal guarantor if the borrower cannot do so and the project is worth continuing. Guarantees are limited to \$25,000,000 for a single project and \$50,000,000 for a single borrower. A Geothermal Resources Development Fund was created for carrying out the loan guarantee and interest assistance program.

- [3] Hickel, W. J., Geothermal Energy--A National Proposal for Geothermal Resource Research (Alaska: University of Alaska, 1972).
- [4] P.L. 93-410 mandates an inventory of geothermal resources and publication of maps, etc. It also encourages development of state geothermal resources clearing houses.

2. STATE OF THE GEOTHERMAL ART

2.1 Geothermal Resources: Identification, Development, and Use

Resource Exploration and Appraisal

As mentioned in Section 1.2, geothermal sites have usually been identified from obvious surface manifestations such as hot springs, fumaroles, mud pots, and geysers, or through accidental discoveries while exploring or drilling for other natural resources. Figure 2.1.1 on the following pages illustrates the location of KGRA's in the western United States. This approach is rapidly being replaced by more scientific prospecting methods and techniques for appraising the volumetric extent as well as the physical and thermodynamic properties of the reservoir. Development of these techniques has emanated from established disciplines such as geology, geochemistry, geophysics, and hydrology. A great amount of further research and development work is needed in these areas as well as in drilling, well logging and testing, and modeling in order to simplify and speed up the process of exploration and appraisal. Since each prospective geothermal formation has unique characteristics which differ over a wide range, a number of different techniques are normally employed and the data obtained are correlated to form the final result. A logical progression of steps or phases has been recommended for exploration with each step being more sophisticated and/or expensive [1]. Such a progression might begin with a literature search for existing information and then progress to airborne surveys, geologic and hydrologic surveys, geochemical surveys, geophysical surveys, and finally to drilling.

The various techniques for exploring and appraising geothermal sites are described below under the major categories involved:

Geological. Geological studies consist of field work, aerial surveys, and subsurface investigations. Field work involves mapping the rock types and their distribution as well as any thermal manifestations and performing petrological studies [2, 11]. Structural maps and subsurface cross sections which identify the reservoir are prepared from structural and fracture analyses of the formation. Aerial surveys are made using visible light, infrared, and microwave photography. These are used for geological mapping, structural analysis, and topographic mapping. Cores or cuttings from wells are identified as a function of depth and serve to refine the structural model developed from surface data.

Geochemical. In prospecting for geothermal fields, geochemical analyses provide a guide to selecting specific drilling sites. They are used to determine the physical and thermodynamic properties of the reservoir fluids and the origins of these fluids [1, 3, 4, 5, 6]. Information on water drainage, storage and recharge is also obtained from geochemical techniques. To obtain this information, analyses are performed on solid, liquid, and gaseous samples obtained from surface manifestations during exploration and later from downhole and effluent samples obtained during the drilling phase. In analyzing the solids, rocks are age dated, bulk and trace elements are delineated, isotope studies are performed, and the mineralogical composition is determined. This information is used in modeling the geology of the reservoir that is being evaluated. Analysis of liquids and gases includes isotopic studies which yield information on the origin of the water and regional patterns of

water circulation. An estimate of the reservoir temperature at depth can be obtained from a determination of the constituents or ratios of constituents dissolved in the effluent. This technique of geochemical analysis has been termed geothermometry.

The chemical composition of liquids and gases in the reservoir fluid is a major factor in determining appropriate uses for geothermal resources from a given reservoir and in designing the specific processes and equipment to be employed. For instance, the fluids may contain large amounts of dissolved solids that would precipitate and obstruct the flow when its thermodynamic state is altered, by such means as expansion or temperature decrease, during a particular process. On the other hand, it may be economically advantageous to recover these minerals. Equipment must be designed to handle non-condensable gases and methods for controlling corrosion and erosion must be included. Solid, liquid, and gaseous waste materials must be disposed of in an environmentally appropriate manner. Geochemical analyses provide the basis for such evaluations.

Geophysical. Most geophysical methods measure various physical parameters at depth, such as temperature, electrical conductivity, the propagation velocity of elastic waves, density, and magnetic susceptibility, primarily by indirect means [1, 7, 8]. These methods may be used for prospecting, for selecting drilling sites, for mapping the geothermal reservoir, and for predicting the thermodynamic properties of the resource.

Heat flow measurements provide a direct means for predicting the reservoir temperature and for determining the three-dimensional extent of the reservoir. These measurements involve drilling, measuring the temperature gradient in the drill hole, and measuring the thermal conductivity of rock samples taken at various depths. Heat flow is the product of temperature gradient and thermal conductivity.

Electrical and electromagnetic reconnaissance techniques measure electrical conductivity at depth. In interpreting the results of such surveys, care must be taken to include factors other than temperature, such as porosity, fluid salinity, and clay content, which also affect resistivity. The primary electrical method used to date has been DC resistivity. This involves placing electrodes in contact with the ground in prescribed arrays, such as linear or dipole-dipole. Other electrical methods include self-polarization, induced-polarization, and telluric. Electromagnetic methods used to date include a two-loop method (the EM gun), a long-wire source with a loop detector, and an audio-frequency magneto-telluric system. Seismic surveys, both active and passive, are useful in locating faults and delimiting fractured and permeable zones. Active seismic methods, both reflective and refractive, use explosives to produce elastic waves. Passive seismic techniques involve recording either naturally generated micro-earthquakes or acoustic noise patterns within prescribed frequency ranges.

Thermal infrared surveys from aircraft [9, 10] or satellites may be used to map surface temperature anomalies. However, care must be taken in

Source: U.S. Department of the Interior, Final Environmental Statement for the Geothermal Leasing Program, 1973 (Hereafter called Final Environmental Statement, 1973)

Figure 2.1.1 KNOWN GEOTHERMAL RESOURCE AREAS IN THE WESTERN UNITED STATES

Source: U.S. Department of the Interior, Final Environmental Statement, 1973.

Figure 2.1.1 (cont.) KNOWN GEOTHERMAL RESOURCE
AREAS IN THE WESTERN UNITED STATES

Source: U.S. Department of the Interior, Final Environmental Statement, 1973

Figure 2.1.1 (cont.). KNOWN GEOTHERMAL RESOURCE AREAS IN THE WESTERN UNITED STATES.

interpreting the data since such apparent anomalies can be caused by many factors other than geothermal heat flow. Other frequencies, primarily microwave, have been used to improve results by increasing the depth of penetration into the earth. Magnetic and gravimetric surveys aid in interpreting structural features.

Hydrological. Surface hydrological investigations are normally carried out during the early stages of exploration along with geological field studies [1, 11]. Recharge and discharge studies are made by investigating the movement of surface waters. This includes estimating the discharge rates from springs as well as studying the drainage patterns in rivers, lakes, and watersheds. Water temperature is measured and samples are collected for chemical analysis. Water table studies are made from measurements in existing wells. As the exploration program proceeds to the drilling phase, subsurface hydrological investigations are made. These include studies of subsurface water flow which give information on local aquifers. The porosity and permeability of rock at various depths are measured. These properties control the flow of water, which is the heat transport medium. Water temperature and water chemistry at depths are useful in evaluating the thermal characteristics of the reservoir and chemical reactions that occur in the formation.

Drilling. Geothermal wells are currently drilled with the standard rotary rigs that are used in the oil and natural gas industries. Research is being conducted on a number of novel drilling methods in order to increase drilling rate, decrease cost, and increase the ultimate depth attainable. The current method, as well as novel ones, employs one or a combination of four basic mechanisms for excavating rock. These include mechanically induced stresses, thermally induced stresses, fusion and vaporization, and chemical reactions [12]. Mechanically induced stresses may be produced by equipment such as standard rotary drills, explosive drills, and ultrasonic drills. These methods induce mechanical stresses by impact, abrasion, or erosion. Brittle fracturing or plastic yielding occurs when these stresses exceed the tensile or shear strength of the rock. Thermally induced stresses may be produced by forced-flame drills, microwave drills, induction drills, etc. These devices generate thermal stresses that fracture rock by producing differential thermal expansion. Rocks may be fused or vaporized by applying heat at a sufficiently rapid rate to produce local temperatures that exceed the melting temperature or vaporization temperature of the rock. This principle is employed by techniques such as electric heater drills, electron beam drills, and laser drills. Chemical drills use highly reactive chemicals to dissolve rock. Chemicals may also be used to alter rock hardness in order to increase the drilling rate of mechanical methods.

Well Logging and Testing. Well logging refers to measurements that are made as a function of depth during and after the drilling operation. Measurements normally included are temperature and pressure, bore inclination, sonic logs to investigate cement bonding to the casing, and radioactivity, electrical and gravimetric surveys to aid in the study of the formation [13, 14]. After comple-

tion of the well, the thermodynamic properties and chemical composition of the fluid are determined at various depths. Flow tests are conducted to determine the effluent mass flow rate as a function of wellhead pressure, and the thermodynamic properties of the fluid at the wellhead as a function of flow rate [15, 16]. These tests are conducted over a period of time, normally several months, in order to evaluate the effect on reservoir lifetime. During flow testing, the chemical composition of the effluent is monitored and materials testing is conducted to determine the corrosion, erosion, and scaling properties of the fluid.

Modeling. Regional and national models of geothermal resources are needed as the first step in appraising the total resource. These models would map geological and geophysical data, such as temperature gradients or heat flow [17]. The data must be compiled by statistical analysis after being gathered by systematic methods. Statistical analysis is needed to eliminate erroneous or false data while treating a very large sample and to eliminate false thermal anomalies [18].

A different class of models is used to describe the dynamic behavior of a specific reservoir during its utilization. These models describe the heat source, unsteady-state heat and mass transport, and single and two-phase flow through porous and fractured media. They also describe the relationships between pressure and temperature at depth and at the wellhead and the rates of fluid discharge, injection or reinjection, and recharge (in-flow of cold ground water to the reservoir). The models may take the form of theoretical analyses having relationships in any convenient form such as curves, matrices, tables, or equations. Alternatively, the models may consist of computer programs, either digital or analog. Although a considerable amount of work has been accomplished in simulating reservoir dynamics [19, 20, 21, 22, 23, 24, 25, 26] further effort is needed to fully define all necessary parameters. Reservoir models are used to appraise the capacity and predict the longevity of a field. They are also important in several aspects of developing and managing reservoirs, such as determining well spacing and investigating the effects of fluid production and reinjection on the formation.

Reservoir Development and Operation

The development and operation of a reservoir is discussed below in terms of reservoir design, production well design, drilling and construction, well stimulation, the design and construction of the gathering system, and engineering and management during the years of production.

Reservoir Design. A reservoir is designed to provide a certain thermal energy production rate for a specific number of years. Generally, the criterion is that the field longevity must be at least long enough to amortize the capital expenditure for the field and plant. To accomplish this, studies are made of fluid production, reinjection, and recharge rates and field layout. These studies include production and reinjection well diameter and depth, reservoir recharge rate, and water-mineral reactions that may occur in the formation and adversely affect the system porosity and, consequently, the effluent flow rate. Input

information to these studies is derived from production well test data and from reservoir models which include hydrological, geological, geochemical, and geophysical test data. After these studies have been completed, the next task is to lay out the field. This involves, primarily, the arrangement of production and reinjection wells. The number of wells, well spacing, and amount of reserve area to be set aside for future drilling are site dependent and are determined from such considerations as expected flow rates and thermodynamic conditions of the effluent from the wells to be drilled, and from system requirements including the production rate of thermal energy and field and plant lifetime. In determining specific well locations, such considerations as terrain, access roads, and underground pipe or cables that are in existence or planned are taken into account. In some instances, a given field may have multiple owners. In this case, provision must be made for cooperative reservoir development.

Production Well Design, Drilling and Construction.

To date, geothermal wells have been drilled with conventional drill rigs that are normally used for oil or gas wells [14, 17, 29, 31, 33, 35]. Special high-temperature drilling "mud," water, or compressed air circulation is used to cool the bit and remove solid particles from the bore hole [30, 32]. Although directional drilling has been well developed in oil field practice, vertical drilling is far less expensive and, therefore, normally employed. Safety equipment includes blow-out preventers at the wellhead, an adequate supply of cooling water for quenching, and also gas detection equipment and gas masks since gas emitted may contain poisonous hydrogen and arsenic sulphides [13]. Future drill rigs using advanced techniques, such as described above under Resource Exploration and Appraisal, may increase the depths that are economically attainable.

Well casing design normally calls for steel casing with diameters that decrease as depth increases [15, 28]. The production zone may be bare (no casing), have a slotted liner, or the solid liner may be perforated after setting in place. The casing is cemented to the formation to prevent vibration, to insure that steam and/or hot water do not erupt in the annulus between the casing and the drill hole, and to prevent the casing from being ejected from the drill hole. Special high-temperature cements, and in special cases acid resisting cements, are used. At the wellhead, a concrete collar or pad is normally poured before drilling commences. In special instances, where the surface of the formation is not well consolidated, grout may be injected into the ground in the area of the drilling site [34]. Equipment attached to the top of the well casing includes the various shut-off and bleed valves.

Well Stimulation. Well stimulation techniques may be used to increase the flow in hydrothermal systems or to create cracks in impermeable hot dry rock formations. Stimulation techniques may prove beneficial in hydrothermal systems that have initially poor formation permeability or those that have decreased in production during use because of solids deposition in the formation [36]. Stimulation techniques include the use of hydraulic fracturing, chemical solvents, chemical explosives, and nuclear explosives. Hydraulic fracturing, or hydrofracturing, is common practice in oil and gas fields. It involves pumping water down the well with a sufficiently high

pressure to produce cracks in the rock at the bottom of the well [37]. These cracks extend as pumping continues.

In hot dry rock, controlled hydrofracturing creates a system of cracks that resembles a pancake on edge [38]. By injecting water into this pancake shaped system of cracks, or an array of such systems through one or more wells and recovering hot water through one or more other wells, heat may be extracted from hot dry rock formations. Although the cracks created by hydraulic fracturing may extend for several thousand feet, they are only about one-half inch wide and tend to close when the hydraulic pressure is removed. Propping material, such as sand, is injected in order to maintain the cracks in an open position.

After a period of production, a hydrothermal system may decrease in flow because of solids deposition in the formation which decreases permeability. Injection of chemical solvents through the well may be effective in dissolving these solids and restoring the well to its original rate. Chemical and nuclear explosives may prove useful in creating rubble chimneys in hydrothermal systems to improve fluid flow to a well or produce an artificial reservoir in impermeable hot dry rock formations [39, 40].

Gathering Systems. The piping network that transmits hot fluid from the wells to the point of use is called a gathering system. In a commercial size operation, the gathering system normally collects fluid from a number of wells and manifolds it to the plant [15, 34, 41, 42]. The system consists primarily of insulated piping, suitably anchored to the ground and having expansion loops or bellows. It also contains cyclone separators, screens, and filters to remove rock particles and in the case of vapor-dominated reservoirs, slugs of water that occasionally are emitted from the well. Mufflers, safety valves, and steam traps are also installed. In designing a gathering system, the objective is to maximize the flow and minimize cost and heat loss. These objectives are somewhat opposed, since large diameter piping will decrease pressure loss and maximize flow, but will also increase the surface area for heat loss, as well as pipe cost [15]. Instrumentation useful in operating a field would include flow meters, fluid sampling equipment, and instruments for measuring the thermodynamic properties of the fluid such as temperature, pressure, and enthalpy.

An alternative to transporting heat to the surface by extracting fluid from the reservoir is the use of downhole heat exchangers, heat pipes, or direct energy conversion devices. A downhole heat exchanger consists of a long concentric double pipe with the outer pipe closed at the bottom and the inner pipe open. A working fluid, probably water, would be pumped down the center pipe and rise back to the surface in the annular space between the two pipes. Heat from the formation would be transferred to the fluid as it rises in the annular space of the heat exchanger. A heat pipe consists of a closed pipe containing a small amount of volatile fluid which would absorb heat and vaporize at the bottom of the well, then rise to the top where it would condense, transfer its heat, and return to the heat source region by gravity. A direct energy conversion device, such as a thermoelectric converter, would produce electrical energy when inserted in a hot geothermal

well. Although simple downhole heat exchangers made of U-shaped tubes (not concentric pipes) have been successfully used in shallow wells for space heating [43], neither the downhole heat exchanger, the heat pipe, nor the direct energy conversion devices have been commercially demonstrated for electric power production.

Production Engineering and Management. After the wells have been drilled and the gathering system and utilization plant have been constructed, the field must be operated in a manner that will ensure a uniform flow of hot fluid having consistent properties over a period of time that is at least long enough to amortize the capital investment. Operating procedures covering start-up, production, and shut-down must be developed for the wells and the gathering system. These procedures are important in avoiding the entrainment of particulate matter in the geothermal fluid and subsequent transmission of particles to the turbine or other processing equipment in the plant. They are also designed to prevent thermal shock in the formation, the well casing and the gathering system. Implementation of these procedures requires close communication and cooperation between the personnel operating the field and those operating the plant [15].

As a field is being produced, a number of measurements must be continuously or periodically made and corresponding records maintained [44]. Typically these should include mass flow rate, wellhead pressure, thermodynamic and chemical properties of the fluid delivered to the plant, the net mass withdrawal from the field, and any ground subsidence that may occur. Accumulation of such information in a central data bank would be of mutual benefit to all field operators as well as to the geothermal industry in general. Pooling of this information may, however, be restrained because of proprietary considerations.

In order to effectively manage the operation of a field, studies of the effect of exploitation on field behavior and available reserves should be made periodically. Such possible effects as pressure decline, depletion of fluid, and changes in the chemical composition of the fluid would be evaluated. Reservoir models describing the availability and distribution of energy at a given point in time, as well as the overall system dynamics during steady operation, would be most useful to these studies. Based upon the results of the studies, decisions may be made regarding the discharge rate from individual wells, reinjection of cooled fluids, and possible recharge of the reservoir from ground water sources. Of course, in the case of a hot dry rock reservoir, groundwater must be initially injected before hot fluid can be produced. If a field has multiple users, there must be some agreement between them on such matters as the rates of fluid discharged from and injected into the formation, since the operation of each will affect all others.

Fluids discharged from geothermal wells contain minerals and noncondensable gases which vary in amount over a wide range between geothermal sites. These cause corrosion and scale deposition which must be controlled by the proper selection of construction materials and maintenance operations such as well workover

[45, 46, 47, 48, 49, 50]. Other maintenance operations would include ensuring that abandoned wells are safely secured, and drilling and constructing new wells in reserve areas.

Figures 2.1.2 and 2.1.3 summarize locations within the United States where governmental or commercial geothermal development is taking place.

Resource Utilization

Since hot fluids cannot be transported economically by pipeline over long distances, geothermal energy must be converted to electric energy or otherwise utilized at sites that are in close proximity to geothermal reservoirs. In most instances, geothermal fields are remote from population centers. For this reason the primary utilization of geothermal energy has been to generate electrical energy which can be transmitted to locations that require energy. However, in some regions geothermal provinces exist near population centers and have been successfully used for space heating and air conditioning. Other applications of geothermal resources, such as process heating and mineral extraction, are reported in the literature. Depending upon the chemical and thermodynamic properties of the geothermal fluid and the site location, it may be economically advantageous to construct a multipurpose plant. For instance, geothermal fluid from a given field could be used to generate electricity and also provide process heat, desalinated water, and salable minerals.

Electric Energy. Several different processes are currently being used to commercially produce electrical energy from geothermal energy. Still other processes are in the experimental or theoretical stage of development. The process selected for a particular site will depend upon the chemical and thermodynamic properties of the effluent. For instance, a different process must be considered for a liquid-dominated reservoir that produces a mixture of steam and hot brine than for a vapor-dominated site that produces only steam. In order to introduce a new technology such as geothermal energy, the most prudent first step would be the construction and operation of a demonstration scale plant for each of the basic conversion processes. This would normally be required before a utility company or other user would invest in a commercial scale plant.

Several conversion processes are shown schematically in Figure 2.1.4 on a following page. The first shown is a direct single-phase flow of steam from the well to the turbine which turns a generator to produce electrical energy [45, 51, 52, 53]. Vapor dominated sites which produce single-phase saturated or superheated steam without liquid are presently producing electrical energy on a commercial scale in the United States, Italy, and Japan. These plants employ relatively simple low pressure Rankine steam cycles and require only minor pretreatment of the steam to remove particulate matter and occasional slugs of water. Although steam could be exhausted from the turbine to the atmosphere, a condenser is normally employed which substantially increases the turbine efficiency. Heat rejection systems such as cooling towers provide cooling water for the condenser. Ejectors or vacuum pumps are used to remove noncondensable gases from the condenser.

In the case of liquid dominated reservoirs which issue hot water (or brine) mixed with steam (two-phase), steam is produced in a separator by flashing

LOCATION OF SELECTED NON-GOVERNMENTAL
GEOTHERMAL DEVELOPMENTS

CALIFORNIA

The Geysers

- Current power output - 396 MWe
- PG&E plants scheduled for operation - total of 908 MWe by late 1976
- Exploration and test wells (Union Oil, Pacific Energy, Magma, Geothermal Kinetics, Burmah Oil and Gas (Signal Co.), Shell Oil, Sun Oil/Aquitaine

Mono-Lake - Casa Diablo

- 10 MWe generating plant planned for 1975 (Southern California Edison & Magma)

Surprise Valley (northeastern corner of California)

- Exploration (Magma, Gulf Oil, American Thermal Resources, Hunt Oil)

Imperial Valley

- Production test wells, binary system development (Chevron, Magma, San Diego Gas & Electric)
- 25 MWe power plant planned (San Diego Gas & Electric)
- 50 MWe power plant planned (San Diego Gas & Electric)
- Tests on brine reinjection systems (Phillips Petroleum, Southern Cal. Edison)

ARIZONA

- 2 test wells (Geothermal Kinetics)
- Test well (Nix Drilling Co.)

NEVADA

- Test well (Chevron and American Thermal Resources)
- Test well (Phillips Petroleum and Southern Pacific Land Co.)
- Test well (Union Oil, Magma)

NEW MEXICO

- 12 wells drilled since 1960
- Baca 11, planned, power capacity of 6.5 MW (Union Oil)

OREGON

- Test well (Gulf Oil)
- 2 greenhouses utilizing geothermal heat under construction (Boise Cascade)

UTAH

- Test well (Geothermal Kinetics and Utah Power and Light)
- Test well (Nix Drilling Co.)

Figure 2.1.2

LOCATION OF GOVERNMENT GEOTHERMAL DEVELOPMENT

U.S. GEOLOGICAL SURVEY - exploration and research evaluation techniques

- Clear Lake - Geysers, California
- Long Valley, California
- Imperial Valley, California
- Northwest Nevada
- Southwestern Oregon
- Yellowstone National Park
- Jemez Mountain Area, New Mexico
- Southern Idaho

ATOMIC ENERGY COMMISSION

- Los Alamos, New Mexico - hot dry rock experiment
- Nevada - field exploration leading to hot water pilot plant (high temperature - low salinity)
- Imperial Valley - equipment design and testing at Lawrence Livermore Lab, Cal. leading to hot water pilot plant (high temperature - high salinity)

- Raft River Valley, Idaho - exploratory drilling leading to hot water pilot plant (moderate temperature - low salinity)

NATIONAL SCIENCE FOUNDATION

- New Mexico - heat flow measurements
- Hawaii - nature and extent of resource
- Imperial Valley, California - nature and extent of resource
- Montana - hot dry rock evaluation
- Nevada - delineation of reservoirs
- (does not include basic research not geographically oriented)

U.S. BUREAU OF RECLAMATION

- Imperial Valley, California - pilot desalination plant

U.S. NAVAL WEAPONS CENTER

- China Lake, California - exploration and drilling

Figure 2.1.3

the hot liquid at a reduced pressure and separating the two phases [35]. The steam is then fed to a turbine. If the first flash pressure is sufficiently high, the remaining liquid can be economically flashed again, producing steam at a secondary pressure which can be fed to a lower pressure turbine or a lower-pressure stage of the same turbine. This system also employs a Rankine steam cycle and, since the natural effluent is fed directly to the turbine, it is referred to as a direct process (Figure 2.1.4). Commercial plants are currently operating with this type of process in Mexico, New Zealand, Japan, Iceland, and the USSR.

In contrast to direct processes, the binary process (Figure 2.1.4) employs a designer-selected secondary working fluid, such as isobutane or freon, which expands through the turbine and passes through a heat exchanger in which it absorbs heat from the natural well effluent (steam and/or water), without becoming contaminated by the effluent itself [54]. The binary process is potentially more efficient than the single-stage flashed steam process where the wellhead temperature is less than about 400°F. Since the great majority of known hydrothermal reservoirs fall into this class, the binary process appears important to the utilization of this large source of energy.

Although research and development effort has been devoted to the development of binary processes by private industry and universities in the United States, only one binary plant, a demonstration scale plant located in the USSR [55], has been constructed in the world to date.

Several proprietary novel heat engines have been proposed for directly converting the geothermal energy in a two-phase effluent into shaft work without separation (Figure 2.1.4). Engines of this type such as the "rotary oscillating vane," the "helical screw expander," and the "bladeless

turbine" are being developed in the United States by private industry [56].

Although it is possible to directly convert geothermal energy to electrical energy by inserting such devices as thermoelectric converters into wells, there are many technical problems associated with the production of a sufficient amount of electrical energy to make a commercial plant of this type economically viable. For this reason, direct energy conversion of geothermal resources has received little attention to date.

The effluent from geopressed resources contains a sufficient amount of natural gas to separate and burn in a power plant to produce electrical energy. This can be done with equipment such as modified gas turbines or steam turbines powered by boilers.

Another energy extraction process using a low grade two-phase fluid has been suggested. Suppose the fluid were simply heated (after appropriate treatment) in a conventional boiler. The amount of energy required to raise the temperature of the fluid to high quality steam would clearly be less than the case in which cold water was used. This possibility is evaluated further in Section 2.2 of this report [68].

Process Heat. Geothermal energy currently provides process heat for industry and agriculture in a number of countries [57, 58, 59]. Present processes include the production of paper, the evaporation of sea water to produce salt, and the production of diatomite. Agricultural applications involving the heating of greenhouses and soil warming in the open are of major importance in several countries. Additionally, the warm waters from geothermal sources have been widely used for bathing, recreational, and therapeutic purposes for many years. Undoubtedly, a great many additional commercial processes could operate with geothermal energy. Suggested uses include sugar processing, heavy water production, mining and upgrading of minerals, ice melting, refrigeration, and freeze drying.

GEOHERMAL CONVERSION PROCESSES

Figure 2.1.4

The appropriateness of using geothermal energy for process heat in a particular process depends upon the temperature as well as the other thermodynamic and chemical properties of the effluent fluid. It is quite feasible to extract process heat from single-phase flow of steam, two-phase flow with flash separation, two-phase total flow, and heat exchange with secondary fluid, using the same processes and equipment as described previously in this section under Resource Utilization, Electric Energy. In addition to these, single-phase hot water which is too low in temperature to flow up the well by flashing may also be used for industrial and agricultural purposes by inserting deep well pumps. It is not considered economically feasible to produce electrical energy from water at this low temperature.

Space Heating and Air Conditioning. In areas where geothermal resources exist in close proximity to population centers, the natural energy from the earth has been successfully extracted for space heating and air conditioning [60]. Large-scale use of geothermal energy is currently being made for this purpose in Iceland, Hungary, the USSR, New Zealand, Japan, and the United States. Heating may be accomplished with single-phase flow (either steam or hot water), two-phase flow with flash separation, two-phase total flow, or heat exchange with secondary fluid, as described above in Resource Utilization, Electric Energy and Process Heat. Air conditioning to date has been produced with absorption cooling units. Steam jet (vacuum) cooling units are also theoretically applicable. It is also feasible to decrease fuel consumption by using geothermal heat in conjunction with heat pumps and either direct or reversed mechanical refrigeration cycles.

Desalinated Water. The mineral content of water in hydrothermal reservoirs varies over a wide range from site to site and may be sufficiently pure for drinking, industrial, or agricultural purposes. On the other hand, it may contain up to ten times the salt content of sea water. Self-desalination of geothermal brines [61, 62] is considered in this section. The application of geothermal energy to desalinate sea water or other brackish water is considered to fall into the category of process heat. Electric energy produced from geothermal energy may, similarly, be used at remote locations to desalinate sea water. Membrane desalting is more appropriate than distillation when electrical energy is applied.

In an electric generation plant, condensate from the steam turbine may be used as a source of fresh water. Two well-known conventional methods for desalting water are multiple-effect distillation and multistage flash. Either of these methods may be used to desalt geothermal brines and no fuel will be required.

Reportedly, geothermal resources provide a great potential supply of desalted water [63, 64]. The U.S. Department of the Interior is currently operating a geothermal desalination plant in the Imperial Valley, California [65].

Mineral Extraction. Generally, the technology for recovering minerals from geothermal fluids exists. Methods for extracting minerals such as potassium, lithium, and calcium have been described [57, 58, 66, 67]. Geothermal brines contain large amounts

of such minerals. They may be recovered by precipitation which requires clarifying tanks and chemicals to increase the rate of this process or simple evaporation in ponds or evaporators. From 1810 to 1966 large amounts of boron were produced from geothermal resources in Italy. Also, calcium chloride was successfully produced in the Imperial Valley, California, but this operation was discontinued for economic considerations.

Natural Gas Extraction. Fluids from geopressured reservoirs commonly contain 10 to 16 standard cubic feet of natural gas per barrel of geothermal fluid, and concentrations as high as 30 standard cubic feet per barrel have been reported. Since each geopressured well will produce perhaps a million standard cubic feet of natural gas per day, recovery of these dissolved hydrocarbon gases would be a valuable by-product [64]. These gases could be recovered in standard fractionating towers. Other classes of geothermal reservoirs do not contain sufficient quantities of natural gas to make their recovery economically viable. However, all classes may contain noncondensable gases such as argon, helium, and carbon dioxide that may prove to be valuable by-products and, therefore, their recovery should be considered. The natural gas recovered from geopressured reservoirs could be pipelined to load centers or burned at the site to produce electrical energy, provide process heat, or space heating and air conditioning.

REFERENCES

- [1] Combs, J., and L. P. J. Muffler, "Exploration for Geothermal Resources," in Kruger and Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973).
- [2] Healy, J., "Pre-Investigation Geological Appraisal of Geothermal Fields," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [3] Tonani, F., "Geochemical Methods of Exploration for Geothermal Energy," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [4] Ellis, A. J., "Quantitative Interpretation of Chemical Characteristics of Hydrothermal Systems," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [5] Fournier, R. O., and A. H. Truesdell, "Chemical Indicators of Subsurface Temperature Applied to Hot Spring Waters of Yellowstone National Park, Wyoming, U.S.A.," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [6] Sigvaldason, G. E., "Geochemical Methods in Geothermal Exploration," Geothermal Energy, Vol. 12 (1973).
- [7] Banwell, C. J., "Geophysical Methods in Geothermal Exploration," Geothermal Energy, Vol. 12 (1973).
- [8] Grose, L. T., "Geothermal Energy: Geology, Exploration, and Developments," Mineral Industries Bulletin, Vol. 14, No. 6 (November 1971).
- [9] Hodder, D. T., "Application of Remote Sensing to Geothermal Prospecting," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).

- [10] Valle, R. G., "Photogeologic and Thermal Infra-red Reconnaissance Surveys of the Los Negritos-Ixlan de Los Hervores Geothermal Area, Michoacan, Mexico," Geothermics, Special Issue 2, Vol. 2 Part 1 (1970).
- [11] McNitt, J. R., "The Role of Geology and Hydrology in Geothermal Exploration," Geothermal Energy, Vol. 12 (1973).
- [12] Maurer, W. C., Novel Drilling Techniques (Elmsford N.Y.: Pergamon Press, 1968).
- [13] Matsuo, K., "Drilling for Geothermal Steam and Hot Water," Geothermal Energy, Vol. 12 (1973).
- [14] U.S. Department of Interior, Bureau of Reclamation, Geothermal Resource Investigations, Imperial Valley, California (Washington, D.C.: U.S. Government Printing Office, February 1973).
- [15] Budd, C. F., Jr., "Steam Production at The Geysers Geothermal Field," in Kruger and Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973).
- [16] Dench, N. D., "Well Measurements," Geothermal Energy, Vol. 12 (1973).
- [17] Blackwell, D. D., "The Thermal Structure of the Continental Crust," Geophysical Monograph Series, Vol. 14, American Geophysical Union (1971).
- [18] Kehle, R. O., R. J. Schoeppel, and R. K. Deford, "The AAPG Geothermal Survey of North America," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [19] Donaldson, I. G., "The Simulation of Geothermal Systems with a Simple Conductive Model," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [20] Nogucki, T., K. Nishikawa, T. Ito, and K. Ushijima, "Some Theoretical Considerations on Hydrothermal Systems Due to Cracks," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [21] Mundry, E., "Mathematical Estimation Concerning the Colling of a Magmatic Intrusion" Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [22] Marshall, D. C., "Development of a Theory of the Wairakei Geothermal Field by the 'Simplest Cases First' Technique," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [23] Donaldson, I. G., "The Estimation of Subsurface Flows and Permeabilities from Temperature Pressure Data," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [24] Whiting, R. L., and H. J. Ramey, Jr., "Application of Material and Energy Balances to Geothermal Steam Production," Journal of Petroleum Technology (July 1969).
- [25] Miller, F. G., "Theory of Unsteady-State Influx of Water in Linear Reservoirs," Journal of the Institute of Petroleum, Vol. 48, No. 467 (November 1962).
- [26] Miller, F. G., "Steady Flow of Two-Phase Single-Component Fluids Through Porous Media," Petroleum Transactions, AIME, Vol. 192 (1951).
- [27] Cromling, J., "How Geothermal Wells are Drilled and Completed," World Oil (December 1973).
- [28] Stilwell, W. B., "Drilling Practices and Equipment in Use at Wairakei," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [29] Cirni, U., and A. Giovannoni, "Planning Methods in Geothermal Drilling," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [30] Fabbri, F., and M. Vidali, "Drilling Mud in Geothermal Wells," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [31] Brunetti, V., and E. Mezzetti, "On Some Troubles Most Frequently Occurring in Geothermal Drilling," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [32] Cigni, U., "Completion of Producing Geothermal Wells," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [33] "Larderello and Monte Amiata: Electric Power by Endogenous Steam," Ente Nazionale per l'Energia Elettrica (ENEL).
- [34] New Zealand Electricity Department, "Power from the Earth: The Story of a Wairakei Geothermal Project."
- [35] Otte, C., "Productions and Disposal Technology in Salton Sea Geothermal Area, Imperial County, California," presented to the Geothermal Resources Board of the State of California in the Imperial Valley geothermal hearings, October 22-23, 1970.
- [36] Ewing, A. H., "Stimulation of Geothermal Systems," in Kruger and Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973).
- [37] Smith, M., "Introduction and Growth of Fractures in Hot Rock," in Kruger and Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973).
- [38] Smith, M., "Geothermal Resources," Hearings before the Subcommittee on Water and Power Resources of the Committee on Interior and Insular Affairs, U.S. Senate (June 13, 1973).
- [39] Burnham, J. B., and D. H. Stewart, "Recovery of Geothermal Energy from Hot Dry Rock with Nuclear Explosives," in Kruger and Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973).
- [40] Ramey, H. J., Jr., P. Kruger, and R. Raghaven, "Explosive Stimulation of Hydrothermal Reservoirs," in Kruger and Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973).
- [41] Pollastri, J., "Design and Construction of Steam Pipelines," Geothermics, Special Issue 2, Vol. 2 Part 1 (1970).
- [42] Armstead, H. C. H., "Geothermal Economics," Geothermal Energy, Vol. 12 (1973).
- [43] Peterson, N. V., and E. A. Groh, "Geothermal Potential of the Klamath Falls Area, Oregon," The Ore Bin, Vol. 29, No. 11 (November 1967).

- [44] Bolton, R. S., "Management of a Geothermal Field," Geothermal Energy, Vol. 12 (1973).
- [45] Finney, J. P., "Design and Operation of The Geysers Power Plant," in Kruger and Otte (eds.) Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973).
- [46] Ham, W. C., "Materials and Corrosion, Geysers Geothermal Power Plant," presented at the National Association of Corrosion Engineers Western Regional Conference, San Francisco, Calif., October 3-5, 1972.
- [47] Krikorian, O. H., "Corrosion and Scaling in Nuclear-Stimulated Geothermal Power Plants," in Kruger and Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973).
- [48] Marshall, T., and W. R. Braithwaite, "Corrosion Control in Geothermal Systems," Geothermal Energy, Vol. 12 (1973).
- [49] Ricci, G., and G. Viviani, "Maintenance Operations in Geothermal Power Plants," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [50] Allegrini, G. and G. Benvenuti, "Corrosion Characteristics and Geothermal Power Plant Protection," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [51] Corti, R., et al., "New Trends in the Planning and Design of Geothermal Power Plants," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [52] Dal Secco, A., "Turbocompressors for Geothermal Plants," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [53] Ciapica, I., "Present Development of Turbines for Geothermal Application," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [54] Anderson, J. H., "The Vapor-Turbine Cycle for Geothermal Power Generation," in Kruger and Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973).
- [55] Hibben, S. G., Soviet Geothermal Electric Power Engineering, Report 2 (Informatics Inc., 1972).
- [56] Geothermal Energy Magazine, Vol. 1, No. 1 (August 1973).
- [57] Muffler, L. P. J., "Geothermal Resources," Professional paper 820 (Washington, D.C.: U.S. Geological Survey, 1973).
- [58] Lindal, B., "Industrial and Other Applications of Geothermal Energy," Geothermal Energy, Vol. 12 (1973).
- [59] Komagata, S., "The Status of Geothermal Utilization in Japan," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [60] Einarsson, S. S., "Geothermal District Heating," Geothermal Energy, Vol. 12 (1973).
- [61] Laird, A. D. K., "Water from Geothermal Resources," in Kruger and Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973).
- [62] Wong, C. M., "Geothermal Energy and Desalination: Partners in Progress," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [63] Rex, R. W., Investigation of Geothermal Resources, Imperial Valley and their Potential Value for Desalination of Water and Electricity Production (Riverside, Calif.: University of California, June 1, 1970).
- [64] Hickel, W. J., Geothermal Energy--A National Proposal for Geothermal Resource Research (University of Alaska, 1972).
- [65] "Will Geothermal Steam Projects Sizzle or Fizzle?" Chemical Week (August 22, 1973).
- [66] Lindal, B., "The Production of Chemicals from Brine and Sea Water Using Geothermal Energy," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [67] Glassett, J. M., "Mineral Recovery from Concentrated Brines," R&D Progress Report 593 (Washington, D.C.: U.S. Department of the Interior, December 1970).
- [68] Joseph Coates, NSF Study Director, suggested this concept.

2.2 Geothermal Technology: Special Considerations

Introduction

This section describes in more detail than in Section 2.1, some specific geothermal technologies and the economics of production in geothermal plants. The technologies discussed in this section are geopressure power, hot dry rock power, hot water total-flow concept, and geothermal power cycles. While the technology of commercialized geothermal power from steam is not discussed here because it is described adequately in other sections of this report, the economics of production are examined in detail. Finally, the concept of dual geothermal-fossil fuel power plants is described.

Geopressured Water as an Energy Resource

Formation of Geopressured Water

Water in geopressured strata zones is one of the important geothermal energy sources described in this report. In the United States the only major known geopressured area is in the northern Gulf of Mexico basin. As shown in Figure 2.2.1 there are two main areas of geopressured strata, south Texas and southern Louisiana, extending into the offshore in both areas. Figure 2.2.1 also shows the depths at which geopressures generally occur in each of these two areas. [1] Geopressured strata have also been reported in Mississippi.

Very large bodies of sand and shale containing saline waters under high pressure have long been known to exist along the northern shore of the Gulf of Mexico. Drillers, exploring for oil, have encountered the "geopressured zones" in an area stretching from Texas to Florida and extending from approximately 100 miles inland to the edge of the continental shelf. Due to extensive oil exploration along the Texas and Louisiana coasts, a great deal of data concerning the nature of

the zones in this area is available and has been studied extensively; unfortunately, much of this information is proprietary.

The geology of the Gulf Coast, particularly from Brownsville to New Orleans, is predominantly that of a sedimentary geosyncline. [2,3,4] Sediment transported from the eastern flanks of the Rocky Mountains by ancestral Rio Grande and Mississippi rivers and the intervening sister streams within the past 40 million years has resulted in roughly one million cubic miles of deposits, mainly sand and clay, in the northern Gulf basin. As these deposits in the form of river deltas grew to massive proportions, they eventually slid off into the deeper waters of the Gulf, carrying with them the entrapped saline water plus the water of hydration of the primarily montmorillonite clay. This movement along planes (referred to as "growth faults") resulted in the sealing off of sand zones and the entrapment of the contained waters.

Continued deposition and subsidence brought more and more weight upon the earlier layers. With the water unable to escape, the normal compaction of the sands could not occur and the water became the load-bearing element of the formations, resulting in the high pressure known as "geopressure."

Heat continually rising from the earth's interior has been absorbed by the waters of these geopressured zones as a result of the low thermal conductivity of water as compared to normal sands and clays. Thus the temperatures of these waters are much higher than normal for their depth of occurrence. [5]

Another interesting property of these waters is their much lower than normal salinity. [6] (Figure 2.2.2.) A total dissolved solids content of 3 to 6 percent is normal in the geopressured zone sands, while in normal zones immediately above, 15 to 20 percent solids is the rule. No intentional production of these geopressured waters has been attempted, but the geopressured strata

Figure 2.2.1 LOCATION AND DEPTH OF OCCURRENCE OF GEOPRESSURES IN THE NORTHERN GULF OF MEXICO BASIN (AFTER JONES, 1969) [1]

SOURCE [2]

Figure 2.2.2 CHARACTERISTICS OF THE GEOPRESSURED ZONE

have been accidentally tapped numerous times. Continued flow has resulted in a steady decrease in salinity [7] with purities approaching that of fresh water on occasion. It appears that as the water contained in the sand is withdrawn, it is replenished by water from the surrounding clay layers. These clays, under the influence of the increased temperatures, have undergone diagenesis to shale, releasing much of the bound water. They are now composed of 30 to 40 percent (by volume) free water which can migrate into the sands. This water appears to be of very low salinity due to the membrane qualities of the shale which acts as a reverse osmosis membrane to desalinate the water.

The migration and desalination of the shale waters is very important because the hot water resource then becomes that of both the sands and the shales and makes possible high rates of production over many years.

A second significant feature of these waters is the presence of dissolved hydrocarbons. Many hundreds of analyses have indicated that they are in general saturated with natural gas. [2] The gas content may be expected to be in the range of 10 to 40 standard cubic feet of gas per barrel of water. [2] This gas is recoverable. On the basis of 30 cubic feet per barrel, a 3000 gallon per minute well would yield 2.5 million cubic feet of gas per day. This materially increases the incentive to bring these waters into production. If the fluids are hotter than 450°F, the natural gas is likely to be absent and carbon dioxide and hydrogen sulfide are likely to be found.

Thus there are uncompacted zones of sand and shale of high, hot, and gas-bearing water content stretching some 800 miles along the Gulf Coast. [1] The top of these zones varies from as shallow as 4000 feet to as deep as 16,000 feet, while the bottom is known to exceed 25,000 feet. These exist in eight parallel belts corresponding to eight ancient shorelines or tertiary deposit episodes of which seven are major deposits. The areas within these belts, which have been cut off

by the faults and become geopressed, are individually large but are discontinuous and occur at various levels. [8] Oil well data indicate that these zones occur almost everywhere in the area at some depth and overlay one another in most cases.

High temperatures (up to 500°F) occur as well as high pressures. High well flow rates (4000 gallons per minute) have been observed [10] but no long-term flows have been demonstrated. Sustained flow requires continued migration of water from the thick shales into the broad sand layers and this remains to be tested.

Producing Energy

Three kinds of energy may be obtained from water produced from geopressed strata: (a) geohydraulic energy from the high pressure water arriving at the surface at pressures in excess of 2000 psig; (b) natural gas dissolved in the water; and (c) geothermal energy from the heat in the produced water. Figure 2.2.3 shows schematically a proposed surface energy recovery system based on a medium temperature aquifer which is described in Figure 2.2.4.

Figure 2.2.3 SCHEMATIC OF SURFACE INSTALLATIONS USED TO CAPTURE ENERGY FROM GEOPRESSURED WATER WELLS [10]

DEPTH OF RESERVOIR	12,000 FT
INITIAL PORE PRESSURE	10,000 PSIG
STRATUM THICKNESS	200 FT
ROCK POROSITY (PERCENT)	20
ROCK PERMEABILITY	100 MD
ROCK COMPRESSIBILITY (EFFECTIVE)	10^{-5} PSI ⁻¹
RESERVOIR TEMPERATURE	260°F
WATER VISCOSITY (AT 260°F)	0.30 CP
WELL DIAMETER (PIPE I.D.)	9 IN
WELL RADIUS	0.375 FT
RESERVOIR RADIUS	10 MILES

SOURCE: [10]

Figure 2.2.4 WELL AND AQUIFER DATA

Water leaves the well at 2000 psig and 260°F, after which some gas is removed by the high pressure separator. High pressure water then runs a water turbine to generate electricity, after which the remainder of the solution gas is removed by the low-pressure separator. This water, still near 260°F, is then passed through a Freon boiler which generates Freon "steam" to run a gas turbine, generating more electricity. The Freon emerging from the turbine is cooled, liquefied, and recirculated to the boiler. Water leaving the boiler is reinjected into shallow normally-pressured sands; or, where possible, released to the Gulf of Mexico. [10]

There is much that is not known about waters in the geopressed strata. One important unknown is the amount of dissolved gas in the water. Figure 2.2.5 shows that water at 260°F at 8000 to 10,000 psi can hold about 30 cubic feet of gas in solution in each barrel of water. There is general consensus among petroleum engineers that geopressed water is saturated with natural gas but data supporting this opinion are somewhat limited. Other unknowns are (a) the extent and interconnection between geopressed water-bearing reservoirs and (b) the rates at which wells can be expected to produce.

Figure 2.2.5 SOLUBILITY OF METHANE IN WATER (AFTER CULBERSON AND MCKETTA, 1951) [10]

Using well and aquifer data given in Figure 2.2.4, Parmigiano [10] predicts the performance of a typical Gulf Coast geopressed water well as shown in Figure 2.2.6. As indicated, such a well will flow at 80,000 barrels per day, or more, and at surface pressures above 2000 psig for a period of 15 years. It will flow for at least another 30 years at 80,000 barrels per day but at surface pressure below 2000 psig as the aquifer gradually loses pressurization. These data (summarized in Figure 2.2.7) were used by Durham [10] to estimate the well power production; a summary of his findings is presented in Figure 2.2.8. This figure illustrates the three kinds of energy which one well could produce, a total of 15 megawatts, assuming all forms are converted into electricity. In preparing Figure 2.2.8 it was assumed that all of the energy would be used to produce electricity, and the conversion efficiencies have been based on this premise.

Figures 2.2.9 and 2.2.10 present estimated data on the economics of producing electricity from geopressed water. For the data in Figure 2.2.9 it was assumed that three geopressure energy wells can be located in a cluster; these wells terminate in three different

Figure 2.2.6 SURFACE PRESSURE AND FLOW RATE HISTORY PREDICTED FOR A GEOPRESSED WELL [10]

WELL FLOW RATE	80,000 BMD
FLOWING SURFACE PRESSURE	2,000 PSIG
WELLHEAD WATER TEMPERATURE	260°F
NATURAL GAS CONTENT OF WATER	30 SCF/BSL
GAS PRODUCTION RATE	2,400 MCF/DAY
GAS HEATING VALUE	1,000 BTU/SCF
WATER TEMPERATURE AT DISCHARGE	100°F

Figure 2.2.7 DATA FOR POWER PRODUCTION ESTIMATE [10]

KIND OF ENERGY	CONVERSION EFFICIENCY (PERCENT)	ELECTRIC POWER (MEGAWATTS)
NATURAL GAS	25	7.5
GEOHYDRAULIC	75	1.5
GEO THERMAL	11	<u>6.0</u>
TOTAL		15.0

Figure 2.2.8 POWER PRODUCTION ESTIMATE [10]

ASSUME 3 WELLS FOR A PLANT =	45 MEGAWATTS
3 WELLS AND DISPOSAL FIELD =	\$10,000,000
SURFACE POWER STATION =	\$ 7,000,000
TOTAL COST =	\$17,000,000
COST PER KW =	\$380

Figure 2.2.9 GEOPRESSURE INSTALLATION ECONOMICS [10]

geopressure reservoirs (total of 45 megawatts). It is estimated that the geopressure source wells and a disposal well field will cost some \$10,000,000. The cost of the surface facilities is estimated at \$7,000,000, which is approximately equal to the cost of a 45 megawatt generating plant designed to burn natural gas. The design of the geopressure plant would be considerably different, but much of the electrical machinery would be similar to a conventional power plant. Based on these concepts, the installed cost of a geopressure facility to generate electricity is about \$380 per installed kilowatt. This compares favorably with costs for nuclear power in the \$350 to \$700 per kilowatt range.

Figure 2.2.10 presents an estimate of operating costs for a geopressure power installation. For the purposes of comparison, the geopressure energy source is treated as a "fuel" for the electrical generating plant. On this basis it is estimated that the geopressure energy sources will cost about 1.25 mils/kWh as compared to an expected cost of fuel for nuclear power on the order of 1.5 mils/kWh. [10] In summary, it would appear that geopressure energy for electricity generation is economically competitive with nuclear power. If environmental factors (discussed in Section 4.5) require the use of additional equipment when using this energy source, costs could be higher than those presented above.

OPERATING COST FOR 3 SOURCE WELLS PLUS DISPOSAL FIELD = \$500,000/YR	
RAW POWER PRODUCED	400 X 10 ⁶ KW-HR/YR
RAW POWER COST (FUEL COST)	1.25 MILS/KW-HR

Figure 2.2.10 GEOPRESSURE OPERATING ECONOMICS [10]

Figures 2.2.11 and 2.2.12 add additional perspective to the amount of energy that might be available from geopressured water. Figure 2.2.11 shows a comparison of the natural gas production possible and provides a comparison with current production for Louisiana and the United States. Figure 2.2.12 shows a comparison of the electrical power potentially available from geopressure sources with present power consumption in Louisiana and the United States.

500 WELLS	.447 TCF/YR	
TOTAL GAS OVER 15 YR. LIFE	= 6.50 TCF	
TOTAL GAS OVER 30 YR. LIFE	= 13.00 TCF	
CONVENTIONAL SOURCES	PRODUCTION RATE (TCF/YR)	RESERVES (1-72) (TCF)
STATE OF LOUISIANA (INC. OFFSHORE)	8	80
UNITED STATES	23	280

Figure 2.2.11 NATURAL GAS FROM GEOPRESSURE WATER [10]

Maasberg and Osborn [2] have also made an estimate of geopressure power development. The known geopressured Gulf Coast area covers 150,000 square miles. If only one-third, or 50,000 square miles, is assumed productive and sites consisting of ten wells each are assumed, then some 500 sites are practical. Using the assumptions for a well performance given in Figure 2.2.13,

500 WELLS @ 15 MW/WELL = 7500 MEGAWATTS	
CONVENTIONAL POWER CAPACITY	
INSTALLATION	CAPACITY (MEGAWATTS)
STATE OF LOUISIANA	4,100
UNITED STATES	410,000

Figure 2.2.12 GEOPRESSURE POWER [10]

	MEGAWATTS OF POWER	CUBIC FEET OF GAS PER DAY
ONE WELL	9	1.6 MILLION
ONE POWER SITE	90	16.0 MILLION
500 POWER SITES	45,000	8.0 BILLION
ASSUMPTIONS		
- 1600 GAL/MINUTE/WELL		
- 450°F WATER		
- 30 CU.FT. OF GAS/BARREL		
- 20 YEAR PRODUCTION PERIOD		

Figure 2.2.13 ENERGY POTENTIAL OF THE GULF COAST GEOPRESSURE ZONE [2]

they calculated a power potential of 9 Mwe and gas production of 1.6 million cubic feet per day per well. This gives an estimated total production potential of 45,000 Mwe and 8 billion cubic feet gas per day for at least 20 years.

Durham [10] in his estimate (7500 Mwe) did not claim his total as a maximum possible for the Gulf Coast. Using either his estimate or the estimate of Maasberg and Osborn (45,000 Mwe), the potential of the resource is clearly very high and of potentially great importance to the national energy capability. Interestingly, the estimates for the year 2000 given by experts interviewed in this study for the geopressure potential (Section 3.1) agree closely with Maasberg and Osborn.

Power Extraction from the Hot Dry Rock Geothermal Resource

In many places, such as in the western United States, Alaska, and Hawaii, useful hot rock is close enough to the earth's surface to be easily accessible using conventional drilling techniques.

At present, however, geothermal energy from this source is used only in the relatively few places where here the natural circulation of groundwater in permeable reservoirs overlaying the basement hot rock causes the heat to be conducted upward and then to be trapped in the form of steam.

However, the reservoir of geothermal energy contained by hot dry rock is so vast, so broadly distributed, and in many accessible places so hot that it constitutes a geothermal reservoir deserving very serious technical attention. Based on many recent heat flow measurements, the Los Alamos Atomic Energy Laboratory [11,12] and the Battelle Pacific Northwest Laboratory [13] have started research projects aimed at extracting and utilizing this geothermal heat.

Studies by Potter [14,15] and Blackwell [16] based upon measured heat flow data and temperature versus depth data, have been used to estimate in a semi-statistical fashion the probability of finding a given temperature at a given depth. Using this technique, Figure 2.2.14 was calculated, listing the estimated probability, in the form of a percentage distribution, of a given temperature range for two specified depths, 5 and 6 km (16,400 and 19,700 feet), for the 13-state western region being considered. In making this calculation, a mean depth to basement rock of 2.5 km (8200 feet) was used, along with the appropriate thermal conductivity values for sedimentary and crystalline basement rock.

PROBABLE AREAL DISTRIBUTION	HEAT FLOW RANGE HFU ²	RESERVOIR TEMPERATURE RANGE CORRESPONDING TO A DRILLED HOLE DEPTH (DEEPER HOLE) OF: 5 KM(16,400 FT)	6 KM(19,700 FT)
20%	< 1.6	< 158°C (316°F)	< 180°C (356°F)
30%	1.6-2.1	158-203°C (316-397°F)	180-233°C (356-451°F)
33%	2.1-2.6	203-248°C (397-478°F)	233-285°C (451-545°F)
10%	2.6-3.1	248-293°C (478-560°F)	285-337°C (545-639°F)
7%	> 3.1	> 293°C (560°F)	> 337°C (639°F)

²HFU - $\mu\text{CAL}/\text{CM}^2\text{-SEC}$, CORRECTED FOR PLEISTOCENE CLIMATIC EFFECTS.

Figure 2.2.14 PROBABLE DISTRIBUTION OF HOT ROCK RESERVOIR TEMPERATURES FOR THE WESTERN THIRD OF THE UNITED STATES (BASED ON A MEAN SEDIMENTARY THICKNESS OF 2.5 km OVERLYING THE TOP OF THE CRYSTALLINE BASEMENT ROCK [17])

From an examination of Figure 2.2.14 it may be concluded that a hot rock reservoir temperature level in excess of 290°C (550°F) (a very appropriate reservoir temperature level for surface electrical power generating power plant) can be achieved by drilling to a depth of about 5 km anywhere within a 95,000 square mile broadly distributed region of the western United States, Alaska, and Hawaii. This area is over 30 times greater than the present total KGRA area listed by the USGS for potential geothermal hot water and steam development.

Hot dry rock contains a vast amount of heat energy. Morton Smith [12] gives an example of this by considering a quantity of this rock four miles by five miles in horizontal area and two miles thick. This 40 cubic miles of granite, when cooled from 290 to 90°C, a Δt of 200°C, would give 6.8×10^{16} Btu. This is the total amount of energy used for all energy purposes in the United States in 1970. Obviously, if a practical and economical method for extracting energy from these known reservoirs of hot dry rock can be developed, then this geothermal resource is very, very large.

Power Plant Site

Both the Los Alamos Atomic Energy Laboratory and Battelle Pacific Northwest Laboratory are developing hot dry rock power plant concepts which are similar and are illustrated by Figure 2.2.15. Such a power site would probably be developed in the following manner.

The accessible and available land near a specified load center would be surveyed for suitable near surface heat

Figure 2.2.15 TYPICAL DRY-ROCK GEOTHERMAL-ENERGY SYSTEM PRODUCED BY DRILLING AND HYDRAULIC FRACTURING [17]

flow and favorable geology. From a geological standpoint, it would be desirable for the potential power plant site to be in an area free of major active faults or other obvious geological structural complexities, and with reasonably competent rock at the projected reservoir depth. Having done this, the first hole (the deeper one) would be drilled with a diameter of 9 to 12 inches to the projected depth of about 15,000 feet. Since this rock would be either granite or basalt, the drilling will be much tougher than the conventional oil well drilling which is usually in sedimentary rocks such as limestone and sandstone. Nevertheless, the testing which has been done so far indicates that conventional diamond drilling techniques can be used in the hot dry granite and basalt even though the drilling rate is one-third to one-fourth that for sedimentary rocks. [17]

After completing the drilling of the first hole, a large hydraulic series of fractures would be formed at or near the bottom of this hole using methods that are common in the oil well service industry. This is done, using a high pressure pump at the surface, by pumping water down a high pressure line extending through a seal inserted just above the bottom of the hole. Field experience and mathematical analysis indicate that the resulting series of fractures would be in the form of thin vertically oriented discs of elliptical cross section as shown in Figure 2.2.15. Diagnostic measurements obtained during the hydraulic fracturing operation will be used to determine the orientation of the fracture system. It is possible to obtain hydraulic fracture cracks 4000 feet away from the bottom of the hole.

The second hole will be drilled several hundred feet away from the first (deeper) hole. This second hole will be on a line perpendicular to the orientation of the fracture system formed at the bottom of the first hole. This hole will be the same diameter as the first hole but several thousand feet shallower. It will be drilled parallel to the first hole until adjacent to the upper portion of the fracture system, and then slanted (whipstocked) to intersect the fracture system using directional drilling techniques. After sufficient connection has been established through the fracture system connecting the two vertical drill holes, the entire fracture system will be enlarged to its final dimensions by pumping additional quantities of high pressure water.

Following this final fracturing operation, the two wells will be connected at the surface with high pressure piping, thus forming a complete flow loop. Circulation would be initiated with an auxiliary pump down the deeper hole through the fracture system up the shallower hole, through the surface heat transfer system, and finally back down the deeper hole. Once a moderate temperature difference has been established between the ascending and descending legs of the loop, the auxiliary pump will not be required due to the density difference between the hot and cold water legs which will create a natural flow system.

A pressure of approximately 200 psia will be maintained at the surface of this flow system and obviously the pressure at the bottom will be considerably higher. This high pressure water offers a very large heat transfer capability in extracting thermal energy from the thin cracks in the hot rock and gives a high heat transport rate through the pipe to the surface heat transfer equipment.

One of the critical parameters which has yet to be determined in a full-scale test is the heat transfer characteristics through the surrounding hot dry rock to the cracks and then into the pressurized hot water. The present experimental data and analysis indicate that the thermal conductivity of the surrounding rocks is high enough so that the hot water loop can draw on heat contained in the rock as far as two miles away from the base of the deeper hole.

Hydraulic Fracturing

Hydraulic fracturing is a very common production stimulation technique used in the oil industry to improve reservoir flow characteristics by creating a set of cracks in the producing formations adjacent to the well bore. Although there does not appear to be any depth limitation, hydraulic fracturing heretofore has been done in sedimentary rock. However, a series of rock mechanics experiments recently completed at the Los Alamos Scientific Laboratory has demonstrated that hydraulic fracturing works equally well in igneous and metamorphic rock. [12]

The observed breakdown levels for this igneous and metamorphic rock were of the order of the corresponding overburdened compressive stress (about 1 psi per foot of depth). The resulting fractures are essentially vertical, and more importantly, capable of containing pressurized water with little if any observed leak-off at the desired pressure levels. Therefore, this data indicate hydraulic fracturing offers a method of producing a large crack surface area in the hot dry rock for heat transfer, and is relatively inexpensive.

Thermal Stress Cracking

Extraction of heat from the rock penetrated by the hydraulic fractures will create thermal contraction stresses that should eventually be sufficient to extend the initial crack system in three dimensions. Initially, the cooler rock next to the fracture surfaces will be restrained from contracting by the adjacent hot rock. These restraints will cause tensile stresses to be developed which after sufficient cooling has occurred will exceed the tensile strength of the rock; new cracks will then form along the surfaces of the initial hydraulic fracture system which will probably propagate far beyond the initial cooled region. Both the amount of heat transfer surface and the total amount of heat available to the pressurized water circulating through the crack system should therefore increase continuously as heat is withdrawn from the geothermal reservoir. Calculations done on a typical well system show the variation of geothermal power with time as given in Figure 2.2.16. [17]

Figure 2.2.16 POWER VS. TIME AT CONSTANT CALCULATION RATE [17]

Hot Dry Rock Commercial Power Plant Concept

A concept for a hot dry rock geothermal energy system is shown in Figure 2.2.17. [12] The Los Alamos group has selected a dual cycle power generating system as most appropriate. This uses a conventional steam cycle for the higher temperatures and an isobutane vapor cycle for the lower temperatures. Also, due to the shortage of cooling water in the West, the plant is shown using air cooled condensers. Figure 2.2.17 gives the heat and material balances for the system. This indicates a total net power production of 50.7 MW at a net efficiency of 18.8 percent.

Electricity Production Economics

The economics of an electrical power generating system in the western United States based on this hot dry rock geothermal energy concept appear to be very favorable based on preliminary analysis. However, it should be remembered that no dual cycle power plant has been built so that the estimated costs given are speculative. On the other hand, geothermal power generating plants operating at a turbine inlet steam condition somewhat lower than those shown in Figure 2.2.17 are now operating at The Geysers in the United States and at Cierro Prieto in

Figure 2.2.17 POSSIBLE DUAL-CYCLE POWER GENERATION SYSTEM [17]

Mexico. The capital costs of the surface power plant for both of these installations was about \$110 per kW installed capacity (1974).

Although no actual cost data are available for organic vapor cycle power generating plants, estimates have been made. These estimates give a projected capital cost for a 100 MWe plant size of \$125 per kW installed capacity (1970 dollars). [17] Using these data the estimated capital cost for a 100 MWe dual cycle hot dry rock power plant are estimated at \$185 per kW for a unit coming on-line in 1975. The associated drilling and fracturing costs for two pairs of holes is estimated to be \$6.2 million, giving an overall capital cost of \$247 per kW, as shown in Figure 2.2.18. The holes would be drilled to depths of 4.2 km (13,000 feet) and 5 km (16,400 feet), respectively. The estimated overall electricity generating costs for this system are 6.3 mills per kWh as calculated by the Los Alamos group. This is a low figure and very competitive with the electricity generating costs by other methods such as nuclear and coal. Indeed, even if the actual cost is twice this, 12 mills per kWh, the cost would still be competitive.

POWER PLANT TYPE	POWER PLANT SIZE MWE	SYSTEM CAPITAL COST DOLLARS/KW	GENERATING COST MILLS/KWH
DRY ROCK GEOTHERMAL ENERGY SOURCE (>290°C ROCK, DUAL CYCLE, 4 DRILLED HOLES):	100	247	6.3
BASIS: 0.17 ANNUAL CAPITAL CHARGE RATE. USE FACTOR = 80% OF RATED CAPACITY.			

Figure 2.2.18. ESTIMATED PLANT AND GENERATING COSTS FOR THE YEAR 1975 [17]

Environmental Problems [11,12]

In drilling the holes for a hot dry rock system, the same precautions normally taken in drilling for oil and gas should result in no contamination of groundwater in the rocks and soil above the granite. Therefore, the pressurized water energy system will be completely contained and should be entirely non-polluting.

Since the energy extraction loop is relatively narrow, deeply buried in strong, competent rock, and always full of water under a pressure at least equal to the pore pressure of any fluid originally in the reservoir, it should produce no subsidence of the earth's surface either during operation or even after abandonment.

Small earthquakes have been stimulated in the Denver and Rangely areas of Colorado by the injection of large volumes of pressurized water into active fault systems. However, there have been no earthquakes in these areas when the fluid was injected into the same formation at places short distances away from the active faults. Therefore, the evidence is good that by simply avoiding active faults, seismic risk associated with a manmade hot dry rock geothermal power system can be reduced to essentially zero. However, the geothermal system should be continuously monitored.

Hot Water Total Flow as an Energy Source

The geothermal research group at Lawrence Livermore Laboratory [18] has proposed a "total flow" concept for recovering the energy from the hot concentrated brines of the Imperial Valley, California. These brines are very corrosive and contain 5 to 30 percent dissolved salts. These adverse conditions have prevented the use of a Wairakei, New Zealand type steam flash system so far because of numerous problems associated with scaling, corrosion, plugging, and concomitant low efficiency.

The proposed method consists of allowing the brine to expand to the surface as is now being done at Wairakei and at Cerro Prieto, and then expanding the total fluid stream through a convergent/divergent nozzle. The kinetic energy of the entire fluid stream would then be used in a corrosion-resistant impulse turbine, modeled after typical hydroelectric devices, to drive an electrical generating system. Theoretically, this method should produce about 1.6 times as much power from a given well as either the flashed steam system or the binary fluid system. Since fewer mechanical components are required at the surface, capital costs should be less, despite the need to protect against corrosive brines.

The enthalpy drop is calculated by subtracting the enthalpy at the nozzle exit from the inlet enthalpy (562 Btu/lb. and 360 psia). The exit value is found by assuming an isentropic expansion to the turbine operating pressure, which is set by the condensing temperature. For the wellhead conditions shown in Figure 2.2.19, the ideal velocity is about 2400 fps for a condenser temperature of 120°F at 3.5 in. Hg. The ideal power output

PRESSURE, p	360 PSIA
VOLUME, v	0.259 FT ³ /LB
TEMPERATURE, T	434°F
ENTHALPY, h	562.5 BTU/LB
QUALITY, x	0.189
DEPTH	5100 FT
FLOW RATE, w/A	500 LB/SEC/FT ²
VELOCITY, v = w/A	130 FT/SEC
VAPOR VOLUME/LIQUID VOLUME, v _v /v _l	16

Figure 2.2.19 WELLHEAD PRODUCT CHARACTERISTICS [18]

in terms of MW/ft^2 of wellbore area is a function of condenser pressure. For a backpressure of 3.5 in.Hg at 120°F—a practical value for this application—the ideal power output is 63.1 MW/ft^2 . For other wellhead conditions, the ideal power output will, of course, have other values.

The point is that the thermal energy in the entire wellhead product is converted to kinetic energy which is then converted to electrical energy by an impulse turbine. The advantage of this method is that most of the thermal energy is used for power production. In comparison, the flashed steam system uses only the energy contained in the flashed vapor to drive a turbine, with the remaining energy discarded with the separated hot brine.

The ideal power output of 63.1 MW/ft^2 assumes a perfect turbine and an isentropic nozzle. The actual power output, however, will be less because of non-ideal flow in the nozzle and losses in the turbine. The wheel efficiency should be about 0.9 (nozzle coefficients of about 0.9 are not unreasonable even for the two-phase flow, in which the mass of vapor is 20 percent of the total). Hence an overall efficiency value of 0.73 is a reasonable design goal and would lead to an expected power output of 46.0 MW/ft^2 of well cross section.

Figure 2.2.20 shows the expected power output/ ft^2 of well cross section area. The total flow system is compared to a steam flash system (Wairakei) and to a binary fluid (isobutane) system. All three systems were estimated on the same inlet well conditions as given in Figure 2.2.19. The system efficiency in Figure 2.2.20 is defined as the ratio of the electric energy generated to the recoverable energy from the wellhead product. Thus, 60 percent more power is likely to be available from a given well using the total flow system than from either alternate system.

SYSTEM	IDEAL POWER (MW/FT ²)	EXPECTED POWER (MW/FT ²)	ESTIMATED PRACTICAL SYSTEM EFFICIENCY (%)
FLASHED STEAM	39.5	27.7	11
BINARY FLUID	40.4	28.3	11
TOTAL FLOW	63.1	44.2	18

Figure 2.2.20 EXPECTED POWER OUTPUTS [18]

This increased power is expected because the total flow system uses the entire mass flow and, hence, gives a higher conversion efficiency. The flashed steam system uses only 29 percent of the mass as steam to drive the turbine while discarding the remaining as hot brine at 338°F. The two-fluid system rejects all of the brine at 300°F. Reinjection of the hot brine is possible with all systems, so part of the rejected energy is returned to the reservoir.

Turbine Choice

While there is a wide variety of turbines, they generally can be divided into two classes. In an impulse turbine thermal energy is converted to kinetic energy by a pressure drop through a nozzle only. The fluid's kinetic energy is then converted to rotational energy when the steam impinges on a vane or bucket attached to a wheel. There is almost no pressure drop through the rotating components. The reaction turbine, usually used to recover energy from high pressure gases, operates by allowing the gas to expand as it passes through the rotating vanes, and this expansion is accompanied by a pressure drop. Very close tolerances are used between the vanes and housings or stators to prevent the fluid from bypassing the rotating components.

Therefore, there are two possibilities for recovering energy from the full fluid stream: expanding the two-phase mixture through a nozzle to obtain high velocity jets that are used to drive an impulse turbine, with the entire pressure drop occurring in the nozzle, or expanding the two-phase mixture through a reaction turbine where both a velocity change and a pressure drop occur. An axial flow reaction turbine has a higher efficiency, normally operates at higher speeds, requires multiple stages, and is generally more complex requiring very small clearances to maintain the pressure drop/stage. But a multi-stage turbine cannot be expected to function reliably when driven directly by a mixture of vapor, brine, silica, and, probably, sand and other extraneous materials.

This nature of the geothermal working fluid requires that the turbine be simple and easily maintained; the impulse turbine therefore appears to be the better choice. The most common impulse turbine is the axial flow configuration in which the fluid is fed through a series of nozzles located around the wheel periphery. Blade friction, leakage past the blade, turbulence, and fanning will reduce efficiency. In addition, large axial forces can be developed, and control of vibration is always a serious factor in axial flow turbine design.

Other impulse turbine alternatives include radial and tangential flow configurations, and these appear to be most promising for the brine application. They are shown schematically in Figure 2.2.21. The radial flow device shown is similar to the Francis hydraulic turbine except that nozzles are used in place of inlet guide vanes. Proper selection of the rotor inlet and outlet vane angles will direct the exit fluid radially inward with no tangential velocity component (whirl). In principle, the blade efficiency for this condition can be 100 percent. This is unlikely, however, since turbulence losses will occur, and it may be necessary to select vane angles to give some whirl to the exit fluid. The advantages of the radial flow impulse turbine are high efficiency, reduced fanning losses, flexibility in choice of nozzle angle, reduced losses by jet dispersal, and minimal vibration problems. There are few vibration problems because the nozzles lie in the plane of the wheel, producing low axial forces.

The tangential flow turbine shown in Figure 2.2.16 is modeled after the Pelton wheel. Although it has only

Figure 2.2.21 TOTAL FLOW IMPULSE TURBINE CONCEPTS [18]

been used as a hydraulic turbine, there is no fundamental reason why it cannot be operated with a two-phase fluid. This device can have an efficiency as high as 95 percent, depending on bucket splitter angle and exit angle. Blade friction, of course, may be important, but the major losses (and disadvantages) will probably result from fanning and jet dispersal, since the nozzles must be placed some distance away from the buckets. The major advantages, however, are inherent high efficiency, simplicity of fabrication (and resultant low cost), low potential for vibration, and ready maintenance of the buckets. This latter point may be very important since the working fluid may be very corrosive.

Typically, hydraulically-operated devices of these types exhibit wheel efficiencies greater than 90 percent. No data exist for operation in the two-phase

flow regime, and it is not possible to report efficiencies for this operating condition. Nevertheless, there is no fundamental reason why gross differences should exist, so it seems reasonable that a two-phase total flow turbine could be developed which yields on the order of 90 percent efficiency. The efficiencies reported for the impulse turbines do not include the nozzle efficiency. Hence, nozzle efficiency is a critical factor. For wet steam, the nozzle coefficient may be low because of the difference in velocities of water droplets and vapor. Some data have been gathered for low quality steam flowing through a converging-diverging nozzle. The results indicate that mixtures containing 20 percent vapor can be expanded with nozzle coefficients of about 0.9. Hence, it appears possible to achieve high nozzle coefficients (0.9) by careful experimentation and testing to determine the optimum nozzle configuration. Therefore, it is reasonable to expect that impulse turbines could be constructed for two phase brine which will have an overall efficiency of about 80 to 85 percent.

The Concept [18]

To illustrate the nature of the design problem, one particular system is examined in some detail. It should be recognized that this example is intended only for illustrative purposes, and is not necessarily an optimum design. Figure 2.2.22 is an elevation view of an installation with a radial inflow turbine. A nozzle coefficient of 0.9 is assumed, with wellhead conditions taken from Figure 2.2.18 as the input data for calculating nozzle exit conditions. For a condensing temperature of 120°F at 1.7 psia, Figure 2.2.23 describes the exit conditions from nozzle to turbine and from turbine to condenser.

EXIT CONDITION	P (PSIA)	x (%)	h (BTU/LB)	(FT ³ /LB)	V (FPS)	A (FT ²)
WELLHEAD	360	0.19	562.5	0.26	130	1
NOZZLE OUTLET	1.7	0.37	465.7	75.2	2205	17.1
TURBINE OUTLET	1.7	0.37	465.7	75.2	965	17.1

Figure 2.2.23 EXIT CONDITIONS FROM NOZZLE AND TURBINE [18]

Figure 2.2.22 SCHEMATIC OF A TOTAL FLOW SYSTEM

Since the jet area is 17 times the inlet area, multiple nozzles and/or wheels will be necessary. The particular system chosen for this example is a single generator operated by two turbines with six nozzles per wheel. In this case the turbines have a diameter of 6.8 feet, rotate at 3600 rpm, contain nine equally spaced vanes, and (with an assumed turbine efficiency of 90 percent) produce about 44 MW/ft² of wellbore area. Hence, this power output requires two 9-5/8 in. i.d. wells, each flowing at 250 lb/sec.

This is not a large system compared to conventional hydraulic installations; however, the peripheral wheel speed is much higher than usual and will result in high stress levels, somewhere between 50,000 and 70,000 psi for a steel wheel. The stresses would scale down linearly with desntly for lighter materials, but it may prove more effective to develop design alternatives that either use lower mass flow rates per turbine or smaller nozzle angles or require pressure staging as a means of lowering peripheral wheel velocity. A two-stage device, for example, would reduce the peripheral velocity enough to lower the stress to 40 percent of its former value, but this requires a more complex and possibly less efficient system. Nevertheless, many alternatives exist, and arriving at an optimized system should be a fundamental goal of a research and development program.

The barometric condenser can do the cooling (see Figure 2.2.22) and could be modified as indicated to allow return of the cooling water without excessive contamination by the exhaust brine. The cooling water can be fed through either a cooling tower or a spray pond. Calculations indicate that for a cooling range of 20°F, each 44-MW module (500-lb/sec flow) requires about 9000 lb/sec of cooling water flowing between the condenser and pond. This includes 170 lb/sec added from the condensed vapor. The evaporative cooling loss is calculated to be 172 lb/sec. Depending on drift losses, there will be either a small net gain or loss in cooling water flow. Disposal of the concentrated brine outflow from the barometric condenser will be accomplished by injection through a number of wells equal to the number of production wells and extending to about the same depth.

Cost Estimates

Estimating costs of an operating geothermal total flow system is difficult, since neither the materials nor machine design problems are solved and the optimum cooling system is unknown. Nevertheless, it is desirable to make a crude economic evaluation to determine the relative range of geothermal costs.

Assumptions

Assume the plant module is served by ten producing wells of 9-5/8-in. nominal production diameter driving 3 to 5 alternators, each with 2 turbines. In case the radial flow machine is used, each turbine would be driven from one well and 2 turbines could be used to drive one alternator, so there would be 5 turbine alternator combinations in the module. With the tangential flow turbine, each wheel would be driven by one well, with 4 wheels for each alternator. Peak capacity of the module would be 220 MW and with a load factor of 80 percent, the annual power production, 1.53 billion kWh.

Capital Costs

The major capital requirements include the production and reinjection wells, powerhouse and plant that houses and services the wells and turbo-generators, the turbine-alternators, and a high voltage substation. A hole loss factor of 0.2 has been assumed; that is, it is assumed that during drilling one of each five attempts to complete a hole will be unsuccessful. These lost holes were distributed against the drilling costs of the completed wells at a value equal to 75 percent of the base drilling cost without the completion tubing. The well life is assumed to be 20 years. The estimates are shown below in Figure 2.2.24.

DRILLING AND CASING 20 WELLS, 5000 FT EACH @ \$20/FT	\$2,000,000
LOST HOLE ALLOWANCE, 20,000 FT @ \$15/FT	300,000
SPECIAL TUBING, 100,000 FT @ \$22/FT	2,200,000
CONTINGENCY @ 15%	675,000
SUBTOTAL	\$5,175,000

Figure 2.2.24 [18]

The capital investment for the remainder of the facility was estimated from New Zealand experience, approximately inflated to 1973. Note that all these costs (Figure 2.2.25) are higher than current fossil fired plants.

POWER HOUSE AND PLANT FACILITY @ \$49.50 KW	\$10,791,000
TURBINE AND GENERATOR @ \$56.54/KW	12,325,700
COOLING SYSTEM @ \$17.62/KW	3,841,100
HIGH VOLTAGE SUBSTATION @ \$11.11/KW	2,421,900
CONTINGENCY @ 15%	4,406,900
SUBTOTAL	\$33,786,800

Figure 2.2.25 [18]

The drilling costs totaling \$51.75/ft compare favorably with the costs in New Zealand, which are \$51.10/ft when inflated to 1972-1973 dollars. Figure 2.2.26 shows the total capital costs. Note that tubing costs are highly uncertain. However, even if these costs were multiplied fivefold, the total capital costs increase to only \$214/kW, which is still less than current systems. All capital construction costs include architect and engineer fees, land, utilities, and services.

DRILLING	\$ 5,175,000
POWER HOUSE, PLANT, AND HIGH VOLTAGE SUBSTATION	15,194,927
TURBINES, GENERATORS, AND COOLING SYSTEM	18,591,912
TOTAL CAPITAL	\$38,961,839 (OR \$40,000,000)
CAPITAL COSTS/KW	\$180

Figure 2.2.26 CAPITAL COST SUMMARY [18]

Operating Costs

A well production life of 20 years was assumed, but replacement of the production tubing was assumed every 5 years. This tubing cost was allocated by using an annual cost equal to 20 percent of the initial capital cost of production tubing. Maintenance was estimated at 1 percent per year of original capital cost of the power house, plant, and high voltage substation, and at 5 percent per year for the units subject to corrosion: turbines, generators, and cooling systems. To calculate operating labor and supervision, it was assumed that two operators would be required on each shift and that there would also be two craftsmen required on each weekday shift. A 30 percent supervision cost was added. State and local taxes were calculated as 5 percent of the assessed valuation, which was estimated at 25 percent of the depreciated capital value of the whole facility. This is shown in the cost summary for the average year at 0.625 percent of the initial capital cost. Insurance is shown as 1 percent of the initial capital cost and a contingency of 30 percent is included because of the gross method used in calculating maintenance and operating expenses. Corporate management is included in the maintenance costs. Figure 2.2.27 summarizes the operating costs.

PRODUCTION WELL MAINTENANCE	\$506,000
POWER HOUSE, PLANT, AND SUBSTATION MAINTENANCE	151,949
TURBINES, GENERATORS, AND COOLING SYSTEM MAINTENANCE	929,596
LABOR AND SUPERVISION	190,362
STATE AND LOCAL TAXES	243,511
INSURANCE	389,618
CONTINGENCY @ 30%	723,310
TOTAL COSTS OF SALES	\$3,134,346 (OR \$3,000,000)

Figure 2.2.27 ANNUAL OPERATING COST SUMMARY [18]

Cash Flow and Profitability

There are a number of uncertainties that prevent a rigorous cash flow analysis. These include lease royalty rate, depletion allowance, regulated permissible rate of return, method of financing, and corporate tax structure for calculating federal income tax. Assumed in this example were: an 80 percent load factor; lease royalties of either 12.5 percent or 5 percent of gross sales; internal financing; and a computed internal rate of return as a function of power sales price.

Figure 2.2.28 shows the cash flow using 6 mills/kWh, 12.5 percent royalty, no depletion allowance, and 48 percent federal income tax.

Figure 2.2.29 shows the rate of return on investment for various power sales prices. The upper curve is calculated with 5 percent royalty and no federal income tax; the lower curve is calculated with 12.5 percent royalty, no depletion allowance, and 48 percent federal income tax. Depreciation has been calculated as straight line for 20 years and the investment and plant life are assumed to be 20 years, with no recoverable value at the end of the 20th year. The actual profitability should fall between these two curves.

POWER SALES @ \$0.006/KWH	\$9,180,000
ROYALTY @ 12.5%	1,147,500
COST OF SALES	3,134,347
GROSS PROFIT	\$4,898,153
DEPRECIATION	\$1,948,092
NET PROFIT BEFORE FEDERAL INCOME TAX	2,950,061
FEDERAL INCOME TAX	1,416,029
NET PROFIT AFTER TAXES	1,534,032
TOTAL CASH FLOW	3,482,124
YEARS TO RETURN INVESTMENT	11.9
INTERNAL RATE OF RETURN	6.4%

Figure 2.2.28 CASH FLOW [18]

Figure 2.2.29 ESTIMATED RANGE OF EFFECT OF POWER SALES PRICE ON INTERNAL RATE OF RETURN [18]

Figure 2.2.29 shows that this system can provide a rate of return of 7.5 percent or greater for power prices greater than 6.5 mills/kWh.

The method for converting brines to electrical power using the whole fluid stream appears to be technically reasonable and economically attractive. An experimental program is needed to select materials that will withstand the corrosive brines, to find the best form of production tubing and well operation, to identify acceptable turbines, and to demonstrate commercial feasibility of a power plant. None of these problems seem intractable, although few if any of the conventional methods and materials appear to be workable.

Geothermal Power Cycles Analysis

Introduction

A number of power cycles have been proposed for extracting thermal energy from geothermal medium and high temperature brine resources, such as those of the Imperial Valley, California. Differences in these processes result from attempts to increase efficiency, reduce costs, or avoid one or another of the severe corrosion, erosion, and solids deposition problems associated with processing high salinity brines. The geothermal power study

OPTION	ADVANTAGES	DISADVANTAGES	DEVELOPMENT POTENTIAL
1. STEAM TURBINE OPERATING ON STEAM FLASHED FROM THE BRINE.	SIMPLEST FLOW ARRANGEMENTS. HIGH CYCLE EFFICIENCY. LOW CAPITAL COST. FLASH EVAPORATORS LESS SUSCEPTIBLE TO BRINE FOULING AND CORROSION THAN HEAT EXCHANGER SURFACES.	ADDITIONAL STEAM PURIFICATION EQUIPMENT REQUIRED TO PROTECT TURBINE FROM CORROSION AND DEPOSITION. TURBINE DESIGN MODIFICATIONS MAY BE REQUIRED TO ACCOMMODATE IMPURITIES IN THE STEAM. MULTI-FLASH STAGING REQUIRES A MULTI-STAGE ADMISSION TURBINE.	HIGH DEVELOPMENT POTENTIAL WITH LOW DEVELOPMENT RISKS.
2. STEAM TURBINE OPERATING ON CLEAN STEAM GENERATED BY A SECONDARY BRINE-TO-STEAM HEAT TRANSFER SYSTEM.	TURBINE SEES ONLY CLEAN STEAM. CONVENTIONAL STEAM CLEAN-UP EQUIPMENT IS ADEQUATE.	FOULING AND CORROSION PRESENTS A PROBLEM IN TUBULAR STEAM GENERATOR. LOWER TURBINE THROTTLE TEMPERATURE AND PRESSURE THAN OPTION 1. INCREASED CAPITAL COST DUE TO SECONDARY STEAM GENERATOR LOOP. SURFACE CONDENSER REQUIRED. LARGER CAPITAL COST AND LOWER POWER CAPABILITY THAN OPTION 1.	HIGH DEVELOPMENT POTENTIAL WITH LOW DEVELOPMENT RISK. DEVELOPMENT RISK IS PROBABLY LOWER THAN OPTION 1, BUT ECONOMICS ARE LESS FAVORABLE.
3. ISOBUTANE TURBINE, FLASHED STEAM-TO-ISOBUTANE HEAT TRANSFER SYSTEM.	POTENTIALLY SMALLER (AND LOWER COST) TURBINE THAN STEAM CYCLES.	ALL OF OPTION 2 (EXCEPT TURBINE THROTTLE PRESSURE) PLUS: LARGER STEAM GENERATORS DUE TO POOR THERMAL CONDUCTIVITY OF ISOBUTANE. LARGE ISOBUTANE PUMPS AND PUMP POWER. HIGH WORKING PRESSURES INCREASE HEAT EXCHANGER COSTS. DEVELOPMENT OF LARGE SECONDARY FLUID TURBINE REQUIRED.	HAS ALL OF THE DEVELOPMENT PROBLEMS OF OPTION 2 PLUS UNAVAILABILITY OF ISOBUTANE TURBINES IN THE DESIRED SIZE RANGE.
4. N-BUTANE TURBINE, FLASHED STEAM-TO-N-BUTANE HEAT TRANSFER SYSTEM.	POTENTIALLY SMALLER TURBINE THAN STEAM CYCLES.	ALL OF OPTION 3 PLUS LOWER POWER CAPABILITY.	LOW.
5. FREON-TURBINE FLASHED STEAM-TO-FREON HEAT TRANSFER SYSTEM.	POTENTIALLY SMALLER TURBINE THAN BUTANE OR STEAM CYCLES.	ALL OF OPTION 3. FREON DECOMPOSITION MAY LEAD TO CORROSION.	LOW.
6. AMMONIA TURBINE, FLASHED STEAM-TO-AMMONIA HEAT TRANSFER SYSTEM.	POTENTIALLY SMALLEST TURBINE.	ALL OF OPTION 3.	LOW.
7. TOTAL FLOW CONCEPT.	ELIMINATES SEPARATORS, FLASH EVAPORATORS, AND STEAM GENERATORS. USES RUGGED TURBO-MACHINERY WITH REPLACEABLE PARTS. HIGH EFFICIENCY. POTENTIALLY A SIMPLE, LOW-COST SYSTEM.	MORE SEVERE CORROSION/EROSION FOULING PROBLEMS THAN OPTIONS 1 AND 2. REQUIRES DEVELOPMENT OF NOVEL TURBO-MACHINERY CONCEPTS AND DEVELOPMENT OF BASIC ANALYSIS METHODS FOR HIGH-VELOCITY, TWO-PHASE BRINE FLOW.	DEVELOPMENT POTENTIAL UNCERTAIN. REQUIRES FURTHER ANALYTICAL EVALUATION.
8. ISOBUTANE TURBINE, FLASHED STEAM-TO-ISOBUTANE PLUS BRINE-TO-ISOBUTANE HEAT EXCHANGER.	RELATIVELY SIMPLE FLOW ARRANGEMENT, SINGLE FLASH VESSEL AND NO DOWNHOLE PUMP.	ALL OF OPTION 3 PLUS SCALE DEPOSITION ON TUBES OF BRINE HEAT EXCHANGER.	LOW DEVELOPMENT POTENTIAL DUE TO SCALE DEPOSITION PROBLEMS.
9. ISOBUTANE TURBINE AND DOWNHOLE PUMP, TOTAL WELL FLOW TO ISOBUTANE HEAT TRANSFER SYSTEM.	SIMPLE FLOW ARRANGEMENT, STEAM SEPARATOR NOT REQUIRED. HIGH EFFICIENCY POSSIBLE. SCALE DEPOSITION IN WELL IS MINIMIZED.	ALL OF OPTION 3 PLUS DEPOSITION ON HEAT EXCHANGER TUBES. LARGE EXPENSIVE ALLOY HEAT EXCHANGER REQUIRED DUE TO LOW COEFFICIENTS AND CORROSIVENESS OF BRINE.	LOW DEVELOPMENT POTENTIAL DUE TO SCALE DEPOSITION PROBLEMS.
10. DOWNHOLE HEAT EXCHANGER.	TURBINE SEES ONLY CLEAN STEAM. MAY EASE HEAT EXCHANGER CORROSION AND FOULING PROBLEMS.	THERMAL REFLUXING PROBLEM WITH CONCENTRIC TUBE IN WELL CASING, I.E., COLD DOWNSTREAM MUST BE THERMALLY INSULATED FROM HOT UPSTREAM. UNCERTAIN KNOWLEDGE OF HEAT EXTRACTION MECHANISM FROM GEOTHERMAL DEPOSITS. OUTSIDE SCALING OF CASING AND PLUGGING OF FORMATION MAY BE A PROBLEM.	DEVELOPMENT POTENTIAL IS
11. INJECTED HYDROCARBON INTO HOT BRINE WITH VAPOR PASSED TO MIXED VAPOR TURBINE.	SIMPLE FLOW ARRANGEMENT. HIGHER HYDROCARBON TEMPERATURE THAN 3. MAY EASE WELL CASING CORROSION AND/OR SCALE DEPOSITION PROBLEMS.	REMOVAL OF BRINE DROPLETS FROM MIXED HYDROCARBON-STEAM VAPOR PRESENTS PURIFICATION PROBLEMS. THERMAL REFLUXING IN WELL. LARGER FLUID FLOW REQUIREMENTS IN WELL. REQUIRES SPECIAL TURBINE DEVELOPMENT. LOSS OF HYDROCARBON WITH BRINE, CONDENSATE, AND NON-CONDENSABLE GAS STREAMS.	REQUIRES FURTHER EVALUATION TO ESTABLISH DEVELOPMENT POTENTIAL.

Figure 2.2.30 COMPARISON OF ALTERNATIVE GEOTHERMAL POWER OPTIONS [19]

group at Atomics International, Inc. [19] has conducted a preliminary study of a number of alternative approaches to geothermal power generation. The merits of several proposed systems relative to each other with respect to thermodynamic performance, current development problems, and potential for future growth were analyzed.

A tabulation of the various options is given in Figure 2.2.30. This figure summarizes a qualitative evaluation of the technical problems and indicated economics for each of these concepts.

Seven basic power production cycles were analyzed by Atomics International. These cycles incorporate direct steam turbine operation or heat exchange between flash steam and a secondary fluid (including pure water). These performance analyses consider both single- and multi-stage flashing of the brine. Uniform wellhead and heat sink temperatures are assumed for all cycles in order that comparisons would be independent of other influences. The wellhead conditions used in these studies are shown in Figure 2.2.31. The seven cycles considered in the analysis are listed in Figure 2.2.32.

STEAM FLOW	494,000 LB/HR
BRINE FLOW	2,326,000 LB/HR
BRINE TEMPERATURE	426°F
BRINE PRESSURE	265 PSIA
SALT CONCENTRATION	270,000 PPM (327,000 IN BRINE FRACTION)

Figure 2.2.31 WELLHEAD CONDITIONS USED IN THE CYCLE STUDIES [19]

1. STEAM TURBINE OPERATING ON STEAM FROM THE FLASHED BRINE.
2. STEAM TURBINE OPERATING ON CLEAN STEAM GENERATED BY A SECONDARY FLASHED STEAM-TO-WATER HEAT TRANSFER SYSTEM.
3. ISOBUTANE TURBINE WITH A STEAM-TO-ISOBUTANE HEAT TRANSFER SYSTEM.
4. TOTAL FLOW CONCEPT IN WHICH THE SATURATED BRINE SOLUTION IS EXPANDED TO HIGH VELOCITY THROUGH A CONVERGING-DIVERGING NOZZLE AND THEN IS USED TO DRIVE A HYDRAULIC IMPULSE TURBINE.
5. ISOBUTANE TURBINE WITH A BRINE-TO-ISOBUTANE HEAT TRANSFER SYSTEM.
6. DOWNHOLE HEAT EXCHANGER.
7. DOWNHOLE, DIRECT-CONTACTING HYDROCARBON VAPOR GENERATION WITH MIXED VAPOR TURBINE.

Figure 2.2.32 CYCLES CONSIDERED IN ANALYSIS [19]

The results of the cycle performance studies are summarized in Figures 2.2.33 and 2.2.34.

The direct steam cycle shows the highest performance of all the cases considered. Somewhat surprisingly, the steam-to-steam cycle shows a performance capability approximately equal to that of the isobutane cycle. If the difference in pump work between these two systems is considered, as shown in the last column of Figure 2.2.34, even the high temperature and pressure isobutane cycle (380°F, 1050 psia) shows little

CYCLE	GROSS GENERATOR OUTPUT, MW		
	1 STAGE	2 STAGE	3 STAGE
DIRECT STEAM, WET TOWER	42.9	49.0	54.7
DIRECT STEAM, DRY TOWER	34.6	41.0	45.8
STEAM-TO-WATER, WET TOWER	35.0	42.9	47.0
STEAM-TO-WATER, DRY TOWER	30.2	37.4	41.3
STEAM-TO-ISOBUTANE, 600 PSI SYSTEM	—	38.0	42.0
STEAM-TO-ISOBUTANE, 1050 PSIA SYSTEM	—	—	49.0
STEAM-TO-N BUTANE	30.6	—	—
STEAM-TO-FREON 114	30.8	—	—
STEAM-TO-AMMONIA	27.0	—	—
TOTAL FLOW CONCEPT, 90% EFFICIENCY	62.0	—	—
85% EFFICIENCY	57.0	—	—

Figure 2.2.33 SUMMARY OF CYCLE STUDIES (POWER PRODUCTION FROM 2,820,000 lb/hr WELL FLOW) [19]

CYCLE	REQUIREMENTS			
	WELL PRODUCTION 10 ⁶ LB/HR	COOLING WATER		POWER CYCLE FLUID PUMPING MW
		CIRC. 10 ⁶ LB/HR	MAKEUP 10 ⁶ LB/HR	
DIRECT STEAM, WET TOWER				
1 STAGE	6.6	120.0	1.6	—
2 STAGE	5.8	123.3	1.7	—
3 STAGE	5.2	111.1	1.5	—
DIRECT STEAM, DRY TOWER				
1 STAGE	8.2	—	—	—
2 STAGE	6.9	—	—	—
3 STAGE	6.2	—	—	—
STEAM-TO-WATER, WET TOWER				
1 STAGE	8.1	150.9	2.1	0.15
2 STAGE	6.6	139.9	1.9	0.25
3 STAGE	6.0	130.4	1.8	0.30
STEAM-TO-WATER, DRY TOWER				
1 STAGE	9.3	—	—	0.17
2 STAGE	7.5	—	—	0.29
3 STAGE	6.8	—	—	0.34
STEAM-TO-ISOBUTANE				
2 STAGE - 600 PSIA	7.4	162.1	2.3	13.32
3 STAGE - 600 PSIA	6.7	163.1	2.3	13.38
3 STAGE - 1050 PSIA	5.8	125.0	1.8	21.27
STEAM-TO-N BUTANE	9.2	190.5	2.7	7.78
STEAM-TO-FREON 114	9.2	189.3	2.6	19.45
STEAM-TO-AMMONIA	10.3	218.3	3.1	13.85

Figure 2.2.34 COMPARISON OF POWER CYCLE REQUIREMENTS (BASIS 100 MW GROSS ELECTRICAL OUTPUT) [19]

or no performance advantage over the steam-to-steam cycle. Taking into account the higher capital costs due to higher pressure pipes and heat exchanger tubes, the larger pump requirements, the considerably higher mass flow rates (which entails larger pumps and pipes), the substantially larger heat transfer surface requirements due to the poor thermal properties of isobutane,

and the unavailability of a proven turbine design in the size range required for geothermal plants, it becomes difficult to consider selecting the isobutane system in preference to a proven steam-to-steam or direct steam cycle. However, a developed isobutane turbine should be appreciably lower in cost than a low pressure steam turbine operating over the same temperature range because of the much smaller volume of isobutane vapor involved. All of the other binary cycles show relatively poor performance capability and do not yet appear to warrant more serious consideration.

Important technical features of the cycles analyzed in Figures 2.2.33 and 2.2.34 are discussed in the following paragraphs.

Direct Steam Cycles

In these cycles the steam turbines operate on steam flashed directly from the brine. Highly efficient separators and steam purifiers are required, since even a minor carry-over of high salinity brine accelerates corrosion and leads to deposition of solids on the turbine blades. Non-condensable gases present in the flashed steam also contribute to corrosion and result in the requirement for non-condensable gas removal from the steam condenser. Some minor modifications in turbine design, such as elimination of crevices and labyrinth seals between stages, can ease some of the problems resulting from impurities in the steam.

Saturated steam turbines have to deal with increasing moisture content in the expanding steam. This problem is reduced somewhat with multi-admission turbines because the steam introduced into the lower pressure stages does not expand to as high a moisture content. Moisture separator stages can be considered if necessary to keep wetness within manageable limits. Another approach which should be considered for multi-admission turbines is the superheating of low pressure steam using a portion of the higher pressure steam for the purpose. Moisture content is not a problem with isobutane and Freon cycles since the vapor does not expand into the wet region in the turbine.

Special designs must be developed for multiple inlet turbines when two or three stage flashing is applied. Discussions with turbine designers indicate this is not a problem. They feel that as many as four inlet stages are feasible. A potential limitation is the large inlet ducts required for the lowest pressure stage. In some cases, separate turbines for each pressure may be the best compromise.

Indirect Steam (Steam-to-Water) Cycles

In these cycles steam flashed from the brine in one or more flash stages is condensed in tubular heat exchangers in which pure water is heated and boiled to produce pure steam. This permits the use of "conventional" low pressure steam turbines operating on pure steam. In order to maintain the purity of the secondary steam circuit, direct contact condensers using cooling tower water are not practical and it is necessary to provide surface condensers to separate the recycled pure water and cooling water streams. The two sets of heat exchangers (steam generators and condensers) decrease the temperature range of the steam-to-water cycles compared to direct steam cycles and thereby cause a decrease in efficiency.

Although the impure flashed steam is kept out of the turbine, it must be handled in a large heat exchanger. This heat exchanger must be resistant to corrosion by

H₂S, CO₂, ammonia, boric acid, and other corrosive constituents of the brine. It must also be designed for ease of cleaning because of the possibility of fouling on the flashed steam side.

A further source of inefficiency in indirect cycles is the need to pump the feedwater from the condenser to the steam generator. Such pumps are not required in direct steam cycles.

Steam-to-Secondary Fluid Cycles

These cycles are very similar to the steam-to-water cycles described above and many of the same considerations apply. The difference is that a second fluid is selected which has thermodynamic properties particularly well suited to the temperature interval available. Specific criteria are a reasonable pressure at the top temperature (e.g., less than 2000 psi) and a vapor pressure slightly over atmospheric at the temperature of condensation. Other requirements are a low cost and high level of stability. After reviewing a number of candidates, four were selected in the Atomic International study for detailed analysis: isobutane, N-butane, Freon 114, and ammonia.

Steam generators and heat exchangers between the flashed steam and working fluid must be designed to accommodate cleaning. The drop in temperature of any brine droplets carried by the steam can lead to precipitation of chemicals and scaling of the brine-side heat transfer surface. This problem is compounded in the isobutane and Freon systems because of their substantially larger heat transfer areas relative to the all-steam system.

Turbines for isobutane and the other secondary fluids in the size required for geothermal power are beyond the state-of-the-art as developed to date. Designs can be extrapolated from existing smaller units, but the lack of a successful long-time operating history for units of this size introduces a degree of uncertainty in the application of such units to geothermal power.

Expansion turbines for isobutane and other secondary fluids have been discussed with a major manufacturer who claims that there is no basic size limitation. They have built hundreds of units; most are in the 1000 to 2000 hp range. These units have included six frame sizes; the largest being 12,000 hp (8-9 MW). One more step would, they feel, take them to a size equivalent to a 50 MW generator. They see no problem doing this; only a demand is required. The bigger turbines will turn at lower speeds, and thus, actually be easier to design and operate. They favor the 50 MW as the initial geothermal power unit size. It would turn at 3600 rpm and therefore match available two pole generators.

Efficiencies are as good or better than steam turbines—82 to 85 percent. Expansion rates of 1:2 or 1:2-1/2 are quite good; 1:3 is acceptable if a few percent efficiency loss can be tolerated. For greater expansions, two or three stages (usually separate machines) can be used.

Total Flow Concepts

In the total flow concept, the entire output of a geothermal well is expanded through a prime mover which is used to drive a generator. Several prime mover concepts have been proposed including Pelton wheels, radial inflow turbines, bladeless turbines, helical screw expanders, and rotary-oscillating vane machines.

It appears that the adaption of turbine concepts already developed in large sizes for hydraulic power generation would require a less extensive development effort than the development of radically new concepts.

Although hydraulic impulse turbines for the total flow concept are within the present state-of-the-art with respect to size, a substantial development effort will be required to adapt these to the erosive-corrosive scaling environment of high velocity, two-phase hot brine solutions. Multi-staging of Pelton wheels or radial inflow turbines introduces unique hydrodynamic design problems which are compounded in two-phase flow systems. Lack of an analytical model for two-phase brine flow in the turbine buckets and nozzles compounds the experimental problems and increases the development time and development costs.

The development program would require a supporting experimental study of the dynamic corrosion of materials under flashing flow before a turbine design can be attempted. Also, the dynamic properties of flashing brine solutions are not known, and probably would be required before the nozzle and turbine designs could be optimized. Preliminary studies of exit nozzle velocities and peripheral wheel speeds indicate a need for at least a two-stage hydraulic turbine. This could present a difficult design problem since bucket and radial inflow impulse hydraulic turbines are inherently single-stage machines. Nevertheless, because of the potential for achieving high performance at low cost, the total flow energy recovery device deserves further consideration. A more detailed discussion of this concept appeared previously in this section.

Brine-to-Secondary Fluid Cycles

The isobutane turbine plus downhole pump concept permits total well flow of the brine to an isobutane heat transfer system. It is a simple flow arrangement, since steam separators are not required. High cycle efficiency is possible and scale deposition in the well is minimized. A once-through heat exchanger can be considered.

However, severe corrosion and scaling problems may occur in the tubular heat exchangers. Certainly silica deposition will be a problem and the downhole pump and isobutane turbine need to be developed.

The hybrid isobutane turbine with a flashed steam plus brine heat transfer system does not need a downhole pump. However, it retains the deposition and corrosion problems associated with tubular brine heat exchangers. Isobutane turbine development is also required.

Downhole Heat Exchanger

One downhole heat exchanger which has been studied has a concentric tube arrangement in which injection water is carried down the wellhole through a central pipe and hot steam is brought up in the annular space between the pipe and the well casing. In this concept, it is desirable to minimize thermal refluxing between the injection water and the process steam which lowers the availability of the steam at the wellhead. The effectiveness of the concept depends on maintaining refluxing to a low level.

A number of typical designs were evaluated in the Atomics International study using injection pipe diameters of 4, 6, and 8 inches, with and without thermal insulation. Injection pipe lengths of 4000

and 6000 feet were considered to establish the effect of pipe length of refluxing. The temperature of the well bottom was assumed to be 600°F, and the injection water was assumed to enter the well at a temperature of 100°F. A flow rate of 300,000 lb/hr was assumed. The results of the analyses are shown in Figure 2.2.35.

PIPE DIAMETER (INCHES)	PIPE LENGTH (FEET)	WELLHEAD EXIT STEAM TEMPERATURE (°F)
4	4000	332
6	6000	384
6	4000	259
UNINSULATED	4000	129
1/2" INSULATION (K = 0.08 BTU/FT-HR-°F)	4000	562
1.0" INSULATION	4000	581

NOTES: WELL-BOTTOM TEMPERATURE = 600°F
WELLHEAD INJECTION TEMPERATURE = 100°F
300,000 LB/HR FLOW
SPECIFIC HEAT STEAM/SPECIFIC HEAT WATER = 0.7

Figure 2.2.35 THERMAL REFLUXING IN A DOWN-HOLE HEAT EXCHANGER [19]

For the case of an uninsulated 4-inch diameter injection pipe 4000 feet long, the exit steam temperature is calculated to be 332°F. The degradation in temperature at the wellhead due to loss of heat from the hot steam to the cold water was $600 - 332 = 268^\circ\text{F}$. This produces a 53 percent reduction in heat flow from the well. A 6-inch pipe of the same length would produce steam at a temperature of 259°F, resulting in a 68 percent loss in heat flow from the well. The effect of applying a small amount of thermal insulation between the hot and cold streams is significant. One-half inch of thermal insulation reduces the heat loss to less than 2 percent. A suitable insulation material probably can be found for application to the inside of the downcomer pipe where it sees only relatively pure water. However, the structural integrity of the insulation and its resistance to spalling with a 500°F temperature differential needs evaluation.

A more serious problem with the downhole heat exchanger concept is the uncertainty associated with the mechanisms by which the heat is transported from the geothermal strata to the well casing in the absence of large-scale mass transport of the hot brine to the production zone. The only known mechanism available for driving the brine toward the casing is thermal convection of the brine through the geothermal rock or sand formation. The driving heat that can be provided by small density differences is small compared to that generated by vapor pressure or hydrostatic liquid heat. It does not appear that the large flow requirements of the well can be established by small density differences generated by temperature gradients. In any event, these will be significant only in the immediate neighborhood of the well casing.

There is also the problem of scale formation on the outside of the casing and its deleterious effect on well production. A 1/2-inch thick deposit ($k=0.5$ Btu/ft-hr-OF) on the outside of a 12-inch diameter well casing will transfer 2×10^7 Btu/hr for each 1000 feet of casing with a 300°F ΔT between the geothermal brine and the wall of the casing. Ten production wells (2000 ft

casing) would therefore produce about 40×10^7 Btu/hr and 300°F water temperature. Comparing this to the 124×10^7 Btu/hr, 420°F brine used for the previous cycle analysis studies in this section, it indicates that significantly more production wells would be required in the downhole heat exchanger system.

The precipitation of silica, both as a scale on the casing and as colloidal particles which may plug the formation is quite possible. A thorough study of the potential flow and scaling problems which can arise with this concept is advisable.

Direct Contact Hydrocarbon Vapor Generation

The direct contact cycle vaporizes the hydrocarbon by injecting it into the hot brine, either in the well or in a high pressure vessel. The mixture of steam and hydrocarbon vapor then passes through a steam purification system to remove the brine droplets that have been entrained by the vapor. If the contacting is done outside the well, the brine must be compressed to the hydrocarbon vapor pressure, assumed to be isobutane at 100 to 600 psia, before it can enter the pressure vessel.

This concept does not show any potential performance advantages over the direct steam cycle. All of the technical problem areas external to the well still remain. A high performance mixed vapor purification system is required to remove the brine droplets before the vapor can enter the turbine. The purification problem will be magnified only if a few percent of brine blows out of the well with the mixed vapor. Binary turbine development must consider the flow of mixed vapors through the turbine.

The injection pipe, which must be insulated to limit thermal refluxing area limitations in the well hole, may present a flow problem. The isobutane process calculations show that 4.5×10^6 lb/hr of isobutane are required for the turbine system as compared to 2.82×10^6 lb/hr of brine and steam from the well. If the isobutane were introduced directly into the well, the downcomers would have to flow 4.5×10^6 lb of liquid down into the well and the annular upcomer space would have to flow 4.5×10^6 lb of isobutane vapor out of the well. Thus, the mass flow requirements for each casing would increase by at least a factor of four relative to a brine-steam flow. The economic effect of an increase in well costs needs to be evaluated.

Availability of suitable hydrocarbons for this application may be limited. The well bottom temperatures of 500 to 600° F are well above the permissible operating limit of Freon and well above the desirable operating temperature for ammonia vapor. Hydrocarbons that are suitable for the well may not be effective for the turbine.

Inert Gas Injection at Bottom of Well

As an alternative to injection of an immiscible volatile fluid, gas injection has been proposed as a means of bringing geothermal brine out of a well while maintaining pressure (and temperature). The object of such an approach would be to minimize flashing and thereby minimize brine cooling and consequent silica deposition in the well.

At ordinary rates of production, flashing occurs about half way to the surface in geothermal wells. As a result, the fluid in the upper half of the well weighs much less than pure liquid, and hydrostatic pressure in

the formation at the bottom drives the brine out. The rate stabilizes when wellhead pressure, plus the weight of the fluid in the well, plus friction losses in well and formation equal formation pressure.

With the proposed technique, a small amount of gas (e.g., nitrogen) is injected at the very bottom of the well. The bubbles of gas and water vapor decrease the density of the entire fluid column in the well. If the production flow rate is kept sufficiently low so that the frictional losses do not mask the effect of density reduction, an increase in pressure (and temperature) should be seen at the wellhead. The nitrogen and water vapor mixture would be separated from the hot brine, recompressed, and reinjected. Probably some heat would be extracted first to decrease the volume being compressed.

It appears that the injection of an inert gas at the bottom of a geothermal brine well may permit the production of a higher temperature brine and thereby inhibit scale formation in the well. Another benefit could be the availability of some of the heat at a relatively high temperature which may increase conversion efficiency and permit steam superheating to be practiced. The disadvantages of such a system include higher capital and operating costs (due to the gas compression step), possibly higher well corrosion (due to elevated temperatures near the surface), and greater scale formation in surface equipment. The concept represents an interesting possibility and may warrant a simple test or additional study.

Economics of Production in Geothermal Power Plants

Although geothermal power plants have been built for some years, their size continually increases as the demand for power becomes more pressing. Generally, the economy of scale should make the unit costs decrease by some exponential factor as size increases. However, with geothermal systems, the piping and steam gathering costs can become more important in the larger systems and tend to make larger plants more costly. In an effort to identify an optimum plant size, the capital and electrical production costs were computed for a range of power plant sizes. In performing this computation, assumptions had to be made about geothermal field life, well life, and the probability of drilling a successful well. Until more data are on hand in these areas, cost projections must be considered quite preliminary.

Dry Steam Wells

The calculation of the capital investment for a geothermal producing site is outlined in the top section of Figure 2.2.36. Four basic blocks of information were needed to sum together for the required capital investment. They are turbine and generator costs, exploration costs, well costs, and piping costs.

Turbine and Generator Costs. Some turbine-generation cost information for steam producing wells is available for The Geysers installations.[20,21,22,23] The Geysers field has been expanded several times, each time adding on larger units. The Geysers plant cost is plotted in Figure 2.2.37 indicating a scale-up factor of .085 which agrees with the assumption of Armstead.[20,24] The line through The Geysers' data was used in succeeding calculations rather than the higher cost curve of Armstead. This cost is assumed to include everything located at the plant site, principally the generators, turbines, transformers, and cooling towers. Once the capacity of the plant is assumed in MW, then the turbine-generator costs can be calculated.

Figure 2.2.36 CALCULATION FLOW SHEET

Well Costs. To determine well costs, of course, the number of wells must be first determined and this number is governed by many unknown factors about which certain assumptions must be made. The steam requirements of the plant must first be calculated. For this system, 110 psig steam is assumed to be available at the turbine inlet, while the turbine exhaust is under vacuum. The amount of steam required from The Geysers field is 2,000,000 lb/hr per 110MWe or 18.2 lb/kWe. This value is within the general range of 15 to 20 lb/kWe reported from steam wells. After the steam requirements are determined, a number of assumptions regarding the well must be made, the two most important of which are well production capacity and well placing density. The steam production rate from The Geysers field varies between 40-300,000 lb/hr per well at about 125 psig. For this system, 110,000 lb/hr per well was assumed, thus giving a well energy yield of 5.5 MWe per well. A reserve capacity of 20 percent in the number of wells was assumed.

The output of two Geysers wells [25] with time were plotted on semi-log paper, and the wells' output was found to decrease at 14 percent per year. Therefore the reserve would be used up within the first year, necessitating a constant drilling of new wells at the rate of 14 percent per year. The well life is assumed to be 20 years, after which the output would have become negligible.

The initial number of wells is,

$$N = \frac{\text{capacity, MW}}{5.5 \text{ MW/well}} \times 1.20 \quad (1)$$

The total number over 20 years is,

$$N_T = \frac{\text{capability, MW}}{5.5} (2.8 + 1.20) \quad (2)$$

After the number of wells has been determined, the initial well cost becomes

$$\text{Well cost} = \frac{N (\text{cost/drilled well})}{\# \text{ producing wells}/\# \text{ drilled wells}} \quad (3)$$

Assuming a cost of \$200,000/wellhole and 80 percent success of drilling a producing well,

$$\text{Well cost} = \$250,000 \times N \quad (4)$$

Piping Costs. It is assumed that as new wells are needed they are drilled at the perimeter of the existing field. In addition, it is assumed that the wells are drilled at a density of one well/40 acres, which is typical for The Geysers field. (A grid network for wells in a typical field is shown in Figure 2.2.38). Therefore the piping cost will increase for the later wells and as the capacity of the plant increases. This increase will work to the disadvantage of larger plants.

The distance of each well from the station as well as the cumulative distance of all wells to the station are given in Figure 2.2.39. The distance of each well from the central turbines was predicted by circular geometry to be

$$N = \text{area} \times \frac{\text{number}}{\text{area}}$$

Figure 2.2.37 CAPITAL COSTS FOR DRY STEAM TURBINE-GENERATOR ELECTRICITY GENERATING PLANT

☒ 10 ACRE PLANT SITE

• WELL SITE (WELL NO.)
(IN ORDER OF INCREASING DISTANCE FROM PLANT SITE)

EACH SQUARE = 40 ACRES

Figure 2.2.38 GRID FOR WELL PLACEMENT

Figure 2.2.39 WELL DISTANCES FROM POWER STATION

$$= \pi r^2 \times \frac{1}{40 \times 43,560}$$

$$= 1.80 \times 10^{-6} r^2 \quad (5)$$

Equation (5) gives the radius of the circle necessary to contain the N wells, or the distance out to the Nth well. As seen in Figure 2.2.39, the line has a slope of 2 on the log-log paper as predicted from the above equation, where the points are the measured distances on Figure 2.2.38.

The cumulative distance may be obtained by solving Equation (5) for r

$$r_1 = 745 \sqrt{n_1}$$

$$\sum_{i=1}^N r_i = 745 \sum_{i=1}^N \sqrt{n_i}$$

$$\sum_{i=1}^N r_i = 745 \left(\frac{2}{3} N^{3/2} + \frac{\sqrt{N}}{2} - 0.245 \right) \quad (6)$$

Equation (6) is plotted in Figure 2.2.39 and the sum of the well distances approached it closely for N 4.

The pipe mains were assumed to be 30-inch diameter and to service four wells at full capacity. The laterals from the well to main were assumed to be 16-inch diameter. The 30-inch pipe was assumed to be installed at a cost of \$88/ft while the 16-inch pipe was \$43/ft. It was also assumed that 200 feet of 16-inch pipe was needed per well to connect to the 30-inch main. The pipes' cost becomes

$$\text{Piping cost} = \$22 \times \sum_{i=1}^N r_i + (\$43 \times 200) \times N \quad (7)$$

These cost figures are averages for reported piping costs. [20,24,26,27,28]

Field Exploration Costs. The cost for developing a field is relatively constant at between 0.5 and 1.25 million dollars [28,29,30], although one reference [20] quotes several U.N. studies at 3.0 million dollars. The \$1.25 million figure was chosen since it represents costs more in line with The Geysers field. Since the exploration costs are fixed and must be written off against the producing wells, it becomes a major capital item in small plants.

Well Flow Characteristics

Since the well has a performance curve similar to a centrifugal pump, it may be approximated by

$$\frac{H}{H^0} = \frac{G}{G^0} = k \quad (8)$$

where H^0 = wellhead pressure at no flow

G^0 = well flow rate at atmospheric pressure

n = exponent characteristic of a particular well, $1.5 \leq n \leq 1.85$; $n=1.7$ for Geysers

If the well is located sufficiently far from the turbines, it is possible that the wellhead pressure could be sufficiently above the 110 psig at the turbines to cause an appreciable decrease in flow rate below the assumed 100,000 lb/hr. Taking $G^0 = 110,000$ lb/hr and H^0 at 480 psig, by differentiation:

$$\frac{dG}{dH} = - \left(\frac{G^0}{H^0} \right)^n \cdot \left(\frac{H}{G} \right)^{n-1} \quad (8)$$

$$= -88 \text{ lb/hr/psig}$$

For a 16-inch pipeline carrying 100,000 lb/hr of steam the pressure drop at 110 psig is about 0.25 psig per 100 feet of pipe. Considering lengths of 10,000 feet to be the maximum distance from a well, the maximum pressure drop between well and plant becomes 25 psig. Therefore, from Equation (8), the maximum drop in capacity for a well is $88 \times 25 = 2200$ lb/hr or about 2 percent, which is assumed to be negligible.

Total Capital Costs for Dry Steam. The capital investment for N wells to satisfy the first year production is shown in Figure 2.2.40. The required capital investment continues to decrease over the capacity range of 10-400 MW. However, it is very insensitive to capacity over the range of 100 to 400 MW, reaching a plateau of \$180/kWe. Therefore, there is very little incentive to expand to larger scale plants above 100 MWe. It should be emphasized that these figures are the capital investment for only the first year of operation, after which the well capacity should be expanded by 14 percent per year and that these additional wells will be further from the turbines and hence more expensive than the wells they replace. Therefore, if N_T wells are considered, the required total capital investment over 20 years is summarized in Figure 2.2.41. Here we have a minimum between 50 and 100 MW in contrast to the previous case where no minimum occurred.

Figure 2.2.40 INITIAL CAPITAL COST

There are several ways to budget future capital investments reserved for the new wells. [30] They can be treated as an operating expense and charged against production costs in the year in which they were spent. They also can be discounted to give their present worth

Figure 2.2.41 TOTAL CAPITAL INVESTMENT FOR 20 YEARS STEAM PRODUCING WELLS (GEYSERS)

and the discounted value can be added to the initial amount. This study utilized the latter method. If the discount factor is taken to be 8 percent, the total capital cost of the plant over the future 20 years in present dollars is given by Figure 2.2.41. It is interesting to note that after several scale-ups, Pacific Gas and Electric Company (PG&E) has settled on module units of 100 to 110 MW for several additional units through 1976 which would indicate that they are designing near the optimum.

Production Costs for Dry Steam. Current projections of future production costs and methods of accounting for them are outlined in the application of PG&E to the Public Utilities Commission of the State of California, dated July 24, 1973, for Unit No. 14 at The Geysers. [22] Their costs are based upon purchasing the steam necessary to run the turbine-generators and therefore the well and piping costs must be accounted for in the manufacturing cost analysis of a grass roots plant. Figure 2.2.42 gives the calculated manufacturing cost of electricity at the generation site for a 110 MW plant running at a 90 percent operation factor. The cost of electricity is largely determined by the required capital investment per kilowatt, and as such, only one production cost is necessary near the minimum in Figure 2.2.41, of 110 MW. (This is the same size as in the PG&E application.)

The projected cost of 6.33 mills/kWh compares with that of 8.35 mills/kWh from the PG&E application. The difference between the two figures is due to the method of calculating the steam cost to the generators. The cost of steam to PG&E is set by contract to fluctuate with the price of crude oil, and may bear no direct relationship to the cost of steam production in the field. The recent rise in crude oil prices may have been antici-

BASIS: 110 MW PLANT WITH 90% OPERATION FACTOR

1. TOTAL CAPITAL INVESTMENT	\$21.45 MILLION	
2. DIRECT COSTS		MILLION/YEAR
A. INSTALLATION OF NEW WELLS	1.073	
B. EFFLUENT DISPOSAL (0.5 MILL/KWH)	.434	
C. ADDITIONAL DEPRECIATION OF INITIAL WELLS (10 YEAR-STRAIGHT LINE)	.77	
3. FIXED CHARGES (% OF CAPITAL INVESTMENT, [7])		
A. RETURN AND DEPRECIATION	9.79	
B. TAXES AND INSURANCE	2.22	
C. PROPERTY TAXES	2.03	
D. INSURANCE	0.09	
	14.13	3.035
4. GENERAL, (THOUSAND \$)		
A. OPERATION	55	
B. MAINTENANCE	80	
C. GENERAL EXPENSE	40	
	175	.175
TOTAL ANNUAL COST	\$ 5.487	
5. PRODUCTION COST FOR GENERATED POWER = 6.33 MILLS/KWH		

Figure 2.2.42 CALCULATED PRODUCTION COST FOR DRY STEAM WELLS

pated in PG&E's application. In Figure 2.2.42, the steam costs are listed under Direct Costs as covering the installation of new wells, as well as the depreciation of the initial wells over a 10-year period. A charge for effluent waste disposal is also included. Since the amount of depreciation under (3a) of Figure 2.2.42 is based upon a 29 year life, the additional depreciation over ten years of the initial wells was included in line (2c) to more truly reflect the useful life of the well. If a company owns its own wells, the cost of electricity should be in the 6-7 mill range instead of the 8-9 mill range projected by PG&E. In any case, these costs are well below the 1980 projected costs for all sources of power except enriched uranium fuel, where costs of 5.1 mills/kWh are projected. As a result, geothermal power will be very competitively priced relative to other energy sources.

Hot Brine Wells

The chances of discovering a hot brine field as opposed to a dry steam field (e.g., Geysers) are estimated at 20:1 and therefore, they represent a larger source of potential geothermal energy. Unfortunately, the corrosion and scaling of equipment by the hot brines have seriously limited their utilization. In order to extract the energy from the hot brines, three general recovery methods have been considered: flashing the brine to obtain 20-30 percent of the brine water as steam, heat transfer to a secondary fluid such as isobutane or Freon for use in the power cycle, and the total flow of the flashed steam and hot brine to a turbine capable of handling the two-phase flow. Since the basic elements of capital cost in all of these processes is similar to that for the dry steam units and power output characteristics are similar (Figure 2.2.43), the effect of size on capital investment should be similar and should plateau out around the 100 to 200 MW range. The initial capital investment required for the geothermal plants with brine wells are comparable to that for the dry steam wells as seen in Figure 2.2.40.

LOCATION	FLASHED STEAM (LB/HR)	MM/WELL	REF.
IMPERIAL VALLEY, CALIFORNIA (21,000 BRINE BBL/DAY @ 125 PSIG)	118,000		31
WAIRAKEI, NEW ZEALAND	43,700	3.2	32
CERRO PRIETO, MEXICO	110,000	5.0	
GENERAL		3.8	34
"	100,000	5.0	20
GEYSERS, CALIFORNIA (DRY STEAM WELL--FOR COMPARISON)	96,800	5.3	20

Figure 2.2.43 POWER OUTPUTS FROM BRINE WELLS

Several detailed cost estimates have been prepared for those three brine methods and are summarized in Figure 2.2.44. The reports referenced in this figure assume a wide range of depreciation rates and hence a range of production costs were found for similar size plants. However, the electric generation costs for all schemes was below that predicted for the dry steam wells, primarily because the brine wells to date have not decreased their output with usage. In the dry steam wells, the production has been observed to decrease about 14 percent per year, while the rate of brine flow has remained constant. This decreased replacement cost can show up directly as lower electrical energy costs. The amount of flashed steam available per well from brine wells is very close to that found in the dry steam fields, such as The Geysers, California.

Hot Dry Rock Wells

Methods to extract energy from hot dry rock are largely centered around the method proposed by the Los Alamos Scientific Laboratory.[36] Two holes are to be drilled into the hot rock regions of the earth's crust, and the region between the holes will be hydrofractured, a common practice in the oil industry. Water will be pumped down one hole, permeate through the hot rock, and exit the other hole heated to about 300°C. The pressurized water would be heat exchanged with either

steam or isobutane in secondary cycles with the secondary fluid sent to the same type of turbine-generator system as for a dry steam plant. If a secondary fluid is not desired, the hot water could be flashed, and the steam sent to the turbine generators. Since no hot rock wells have been drilled and operated, it is difficult to project power costs using this method. The well depths are projected to be between 20,000 and 60,000 feet, about 4 to 10 times the depth of present dry steam or brine wells. The present limit to drilling technology is about 30,000 feet and therefore poses some constraint on regions of the country to be examined. In addition, little is known about the heat recharge rate to such a rock formation which will sustain a steady removal of heat from it. Recognizing these uncertainties, some projections of hot rock power costs have been made, nevertheless, and are given in Figure 2.2.45.[36] Capital and electrical generating costs are comparable to both the dry steam and hot brine systems. Until actual hot rock wells are drilled and evaluated, a large degree of uncertainty will govern hot rock costs.

TYPE	PLANT SIZE MW	CAPITAL COST \$/KW	GENERATING COST MILLS/KWHR
300°C ROCK, STEAM AND ISOBUTANE CYCLES, 4 HOLES	100	186	4.7
175°C ROCK, ISOBUTANE CYCLE, 10 HOLES	100	316	8.0

Figure 2.2.45 POSSIBLE ELECTRICAL COSTS FROM HOT ROCK GEOTHERMAL PLANTS [10]

Conclusions

1. The initial capital investment required for dry steam geothermal plants changes little from \$180/200-kW for plants above 100 MW. Therefore, there is no economic advantage to installing larger units.
2. When the total investment in replacement wells over 20 years is added to the initial capital investment, the total reaches a minimum for plants between 50 and 100 MW.

PROCESS	SIZE, MW	CAPITAL INVESTMENT \$/KW	OPERATING COSTS \$/YR	PRODUCTION COSTS MILLS/KWHR	REF.
<u>BRINE FLASH</u>					
BRINE @ 600 BTU/LB	28	214	677,000	2.8	35
BRINE @ 600 BTU/LB	22.6	251	838	4.77	23
BRINE @ 550 BTU/LB	192 (WAIRAKEI)			5.14	20
BRINE @ 510 BTU/LB	75 (CERRO PRIETO)	208 @ 17% OVERHEAD		8.0	
	30 (OTAKA)	288	1,427,000	6.53	
<u>SECONDARY FLUID</u>					
BRINE @ 600 BTU/LB	14.1	354	761,000	6.82	23
<u>TWO-PHASE TURBINE</u>					
BRINE @ 600 BTU/LB	28	264	1,050,000	4.70	23
BRINE @ 562 BTU/LB	220	180	3,134,000	3.30	34

Figure 2.2.44 GEOTHERMAL BRINE ENERGY COSTS

3. Since the amount of flashed steam per well obtained from hot brine wells is close to that obtained from dry steam wells, and their initial capital investments are the same, conclusions 1 and 2 also hold for hot brine wells.
4. Since the level of capital investment determines 80 to 90 percent of the electrical production costs, electrical production costs are a minimum for plants around 100 MWe in size.
5. The electrical production cost for a 110 MW plant is between 6 and 8 mills/kWh for both dry steam and hot brine systems.
6. The hot rock well systems are projected to have electrical costs between 4 and 8 mills/kWh, although these costs are largely conjecture.

Dual Fuel Cycle (Geothermal-Fossil Fuel Combined Cycle)

It has been suggested by Joseph Coates [37] and others [38,39] that the geothermal energy resource in the form of hot water can be combined with fossil fuel energy into an efficient combined cycle. Elements of this general concept have been studied by James [38] and by Armstead [39].

James, in a study of the Wairakei installations investigated superheating the geothermal steam in order to improve the power system. It was found that the optimum turbine pressure was 50 psig, and at this condition about 300 MWe could be generated at the total field fluid draw rate. If this saturated 50 psig steam were superheated with oil to 1000°F before entering the turbine, the power output could be boosted from 300 MWe to about 500 MWe for the same geothermal field output conditions. This would give a 67 percent increase in power capacity.

Another benefit would be improved turbine conditions. Because of superheating at low pressure, the turbine steam would never become wet at the final row of blades, hence, problems associated with wet steam erosion vanish and the speed of the turbine may be increased from 1500 rpm to 3000 rpm. All of this would give a less costly turbine. On the other hand, of course, a superheater has to be included in the cost of the plant, and this would about counterbalance the savings. James [38] made a cost analysis of all the additional equipment required for an oil superheating unit added onto the geothermal unit. He concluded that an examination of the thermodynamic cycle indicates that the thermo efficiency of the fuel-fired fraction of the unit would be in the range of 33 to 37 percent, depending on the superheater's efficiency, and is therefore not greater than that of a modern thermal plant which is in the range of 40 percent. Therefore, fuel costs are about the same for a dual geothermal-oil superheat system as for separate geothermal and oil fuel fired stations of equivalent total power. However, because of reduced capital investment, the dual composite system has apparently lower total generating costs. James emphasizes that this analysis is only for the Wairakei field. He believes that since every geothermal field is unique, the concept of an oil fuel fired superheating of geothermal steam will have to be analyzed for every separate field in order to determine the economics.

In the cycle suggested by Armstead [39], the geothermal steam power plant is used for base loading, and peak system demand is satisfied by superheating the geo-

thermal steam in a oil superheater before sending it to the turbines. Geothermal steam power plants normally use steam that is either saturated, as in liquid fields, or only slightly superheated, as in steam fields. By adding superheat from a fossil fuel, the cycle efficiency can be improved, as pointed out above, and a larger number of kilowatts can therefore be generated from a given quantity of steam. For example, steam at 100 psig could yield about 25 percent more power per pound of steam when superheated to 650°F, than when saturated at 338°F. Hence, a base-load plant designed to carry 80 percent of the maximum system load with saturated steam at 100 psig could also carry the full peak load of 20 percent more if the steam were superheated to a maximum of 650°F. To achieve this, it would be necessary to add 162 Btu per pound of steam when the turbine is carrying the full peak load. As the period of peak load demand (over 80 percent of the peak) would be only a few hours per day, only a small amount of fossil fuel (oil or coal) would be required ordinarily to provide the superheat.

In evaluating this dual fossil fuel-geothermal steam power plant, Armstead found that the capital costs of adding an oil-fired superheater for peak load purposes to a base load geothermal steam plant gives a lower capital cost than a straight expansion of the geothermal power plant. On the other hand, the cost of the oil is greater than the cost of the geothermal steam. In the cases which he examined, which were based largely on the geothermal field in New Zealand, it was shown that an oil-fired superheater would give slightly lower overall electrical generating costs than straight expansion of the geothermal plant. He points out that all that can be concluded from these samples is that oil-fired superheating can sometimes be an economic method of supplying peak loads in combination with a base-loaded geothermal power plant. However, each case will have to be examined carefully to determine its individual characteristics and merits.

It might well be asked: Why not feed the two-phase brine-steam mixture from a liquid geothermal field directly to the boiler of a fossil fuel fired plant? The answer is that the tubes would scale up in a very short time, thus stopping operation of the boiler. This corrosion problem has been discussed previously in this section and in the previous section. It is well known that the water in a steam boiler must be very pure.

This leads to another concept; that is to use the geothermal hot water as a heating medium for boiling pure boiler feedwater in a special heat exchanger or for preheating the boiler feedwater of a fossil fuel boiler. This concept has been examined slightly by several groups in the geothermal power business. They found that it is extremely difficult and expensive to design a heat exchanger to withstand the scaling and corrosion of the hot brines. So far, attempts to build economic units of this kind have been stymied.

The derivation of successful plant operating economics for a dual cycle geothermal-fossil fuel power plant will depend a great deal on a coincidence of location of geothermal and fossil fuel resources. Oil, of course, can be transported fairly easily to certain geothermal fields in the United States. For example, this could be done fairly easily for the Imperial Valley area. On the other hand, transportation of coal is much more expensive and it would be desirable to have coal fields near the geothermal fields. The maps given in a later section (Section 4.4) show that in many western areas, e.g., Wyoming and Utah, coal fields are very close to promising geothermal resource areas.

Therefore, the possibility of developing a combined cycle utilizing these western coal and geothermal resources should be examined further to determine their possible merits.

In conclusion, the concepts of dual cycle power plants combining the good features of geothermal and fossil fuel power cycles show some potential. However, at present only a small amount of study has been given to these concepts. The results to date indicate that further study is well justified.

REFERENCES

- [1] Jones, P. H., "Geothermal Resources of the Northern Gulf of Mexico Basin," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970).
- [2] Maasberg, A. T., and O. Osborn, "Statement on the Geothermal Energy Research, Development and Commercial Demonstration Act of 1973 H.R. 11212" (Midland, Mich.: The Dow Chemical Company, February 4, 1974).
- [3] Burst, J. F., Jr., "Postdiagenetic Clay-Mineral Environmental Relationships in the Gulf Coast Eocene," Earth Science, Vol. 2 (1959), pp. 327-341.
- [4] Jones, P. H., Hydrology of Neogene Deposits in the Northern Gulf of Mexico Basin, Louisiana Water Resources Research Institute Bulletin GT-2 (Baton Rouge, La.: Louisiana State University, 1969).
- [5] Schoeppe, R. J., and S. Gilarranz, "Use of Well Log Temperatures To Evaluate Regional Geothermal Gradients," Journal of Petroleum Technology, Vol. 18 (June 1966), pp. 667-673.
- [6] Schmidt, G. W., "Interstitial Water Composition and Geochemistry of Deep Gulf Coast Shales and Sandstones," American Association Petroleum Geol. Bulletin, Vol. 57, No. 2 (February 1973), pp. 321-337.
- [7] Wallace, W. E., "Water Production from Abnormally Pressured Gas Reservoirs in South Louisiana," Journal of Petroleum Technology Vol. 21 (August 1969), pp. 969-983.
- [8] Jones, P. H., "Hydrodynamics of Geopressure in the Northern Gulf of Mexico Basin," Journal of Petroleum Technology, Vol. 21 (July 1969), pp. 113-125.
- [9] A Feasibility Study of Power Production from Overpressured Reservoirs, ARPA Contract 72-2395 (Department of Geological Sciences, Southern Methodist University, n.d.).
- [10] Durham, C. D., "Proposed Geopressed Energy Investigation, Statement on the Geothermal Energy Research, Development and Commercial Demonstration Act of 1973 H.R. 11212," Director, School of Geoscience (Baton Rouge, La.: Louisiana State University, February 4, 1974).
- [11] Smith, M. C., "Geothermal Energy," LA-5289-MS (Los Alamos, N.M.: Los Alamos Scientific Laboratory of the University of California, May 1973).
- [12] Smith, M. C., "The Potential for the Production of Power from Geothermal Resources," LA-UR-73-926 (Los Alamos, N.M.: Los Alamos Scientific Laboratory of the University of California, June 13, 1973).
- [13] Burnham, J. B., and D. H. Stewart, "Recovery of Geothermal Energy from Hot Dry Rock with Nuclear Explosives," in Paul Kruger and Carel Otte (eds.), Geothermal Energy, Resources Production, Stimulation (Stanford, Calif.: Stanford University Press, 1973).
- [14] Potter, R. M., "Geothermal Resources Created by Hydraulic Fracturing in Hot Rock," paper presented at the Geothermal Research Conference (sponsored by the National Science Foundation through a research grant to Walter J. Hickel, University of Alaska) (Washington, D.C.: Battelle Seattle Research Center, September 1972).
- [15] Potter, R. M., "Assessment of Some of the Geothermal Resources of the Eastern United States" (Los Alamos, N.M.: Los Alamos Scientific Laboratory, 1973).
- [16] Blackwell, D. D., "The Thermal Structure of the Continental Crust," Geophysical Monograph Series Vol. 14 (1971), p. 169.
- [17] Brown, D. W., "The Potential for Hot-Dry-Rock Geothermal Energy in the Western United States," LA-UR-73-1075 (Los Alamos, N.M.: Los Alamos Scientific Laboratory, University of California, July 25, 1973).
- [18] Austin, A. L., G. H. Higgins, and J. H. Howard, "The Total Flow Concept for Recovery of Energy from Geothermal Hot Brines Deposits," UCRL-51366 (Livermore, Calif.: Lawrence Livermore Laboratory, University of California, April 3, 1973).
- [19] Power Generation from Imperial Valley Geothermal Brine--Preliminary Cycle Screening (Canoga Park, Calif.: Rockwell International Corp., Atomics International Division, 1974).
- [20] Armstead, H. C. H., "Geothermal Economics," Geothermal Energy (Paris: UNESCO, 1973), pp. 161-174.
- [21] Kaufman, A., "The Economics of Geothermal Power in the United States," Geothermics, Special Issue 2 (1970), p. 967.
- [22] Application of the Pacific Gas and Electric Company before the Public Utilities Commission of the State of California for Unit 14 (1973).
- [23] Green, M. A., and A. D. K. Laird, Comparison of Elementary Geothermal-Brine Power-Production Processes, Report LBL-2102 (Berkeley, Calif.: Lawrence Berkeley Laboratory of the University of California, 1973).
- [24] Armstead, H. C. H., "Geothermal Power for Non-Base Load Purposes," Geothermics, Special Issue 2 (1970), p. 936.
- [25] Budd, C. F., in Paul Kruger and Carel Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973), p. 129.
- [26] Hayashida, T., "Cost Analysis in the Geothermal Power," Geothermics, Special Issue 2 (1970), p. 950.
- [27] Smith, J. H., "Collection and Transmission of Geothermal Fluids," Geothermal Energy (Paris: UNESCO, 1973), pp. 97-105.

- [28] Greider, R., "Economic Considerations for Geothermal Exploration in the Western United States," Bulletin, Geothermal Resources Council, Davis, Calif., May/June 1974.
- [29] Reed, M. J., "The Economics of Geothermal Exploration, presented at the Geothermal Short Course in Sacramento, Calif., May 9, 1973.
- [30] Greider, R., excerpt from seminar on geothermal energy held at United Nations Headquarters, January 1973.
- [31] Otte, Carel, "Drilling, Production and Disposal Technology in Salton Sea Geothermal Area, Imperial County, California," presented to the Geothermal Resources Board of the State of California, October 22-23, 1970.
- [32] Wairakei, Commissioner, Ministry of Energy Resources, Wellington, New Zealand.
- [33] Paredes, S., Superintendent Planta Geotermoelectrica, Commission Federal de Electricidad, speech presented at El Centro, California, October 17, 1973.
- [34] Austin, A. L., G. H. Higgins, and J. H. Howard, The Total Flow Concept for Recovery of Energy from Geothermal Hot Brine Deposits, Report UCRL-51366 (Livermore, Calif.: Lawrence Livermore Laboratory, University of California, n.d.).
- [35] Ranking Research Problems on Geothermal Development, R&D Progress Report 711 (Washington, D.C.: U.S. Department of the Interior, Office of Saline Water, 1971).
- [36] Brown, D. W., M. C. Smith, and R. M. Potter, A New Method for Estimating Energy from "Dry" Geothermal Reservoirs, Report LA-DC-72-1157 (Los Alamos, N.M.: Los Alamos Scientific Laboratory, 1972).
- [37] Coates, Joseph, private communication, December 1973.
- [38] James, R., "Power Station Strategy," Geothermics, Special Issue 2, Vol. 2, No. 2 (1970), p. 1676.
- [39] Armstead, H. C. H., "Geothermal Power for Non-Base Load Purposes," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970), p. 936.

2.3 Institutional Considerations

Introduction

The exploration, development, exploitation, use, and regulation of geothermal energy has involved a host of institutions, government and corporate, formal and informal. These institutions sometimes support one another, but more often than not overlap in their functions; they act either in their own interest or in a manner which they view as representing the broad social interest; they are carving out their areas of responsibility or have had them defined by law. Out of this complex mix will come the future geothermal industry, its constituents, and its public. The purpose of this section is to review the groups and institutions with interest in geothermal energy and the nature of their interests.

The relationship of the institutions involved in the development of geothermal energy is illustrated in Figure 2.3.1. Each of the primary functions of land ownership, resource exploration, resource development, energy distribution, and energy consumption involve several different institutions, some of which have primary and active roles, and others, secondary and passive. The institutions discussed are major federal government agencies, other federal organizations, the geothermal industry, residents and environmentalists, and foreign institutions. The more important of these institutions and the nature of their involvement is described below.[1]

Federal Government Agencies

Within the Federal Government, the main agencies involved in the evolution of geothermal energy are: the U.S. Geological Survey, which has the responsibility for the identification and leasing of geothermal resources; the National Science Foundation, which has embarked on a broad and important program of research and which is currently serving as lead agency within the government; and the Atomic Energy Commission, which has initiated certain crucial geothermal research projects.[2]

The U.S. Geological Survey

This is the Department of the Interior'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 Department has carried out cooperative studies with private industry focused on the geochemistry and petrology of the hydrothermal system. Such studies have been going on in the Salton Sea geothermal field since 1963. In 1966, the Geological Survey began a major investigation of all aspects of the geology of Yellowstone National Park, including intensive studies at the Hot Springs area. Several other hot springs systems in the western United States have been investigated by the Survey, including Sulfur Bank on Clear Lake, California, and the Lake City area. With increased appropriations in 1971, the Geological Survey expanded its geothermal program. Projects were started at The Geysers, Clear Lake, and Long Valley, California, using detailed geologic and geophysical, geochemical, and hydrologic techniques. Reconnaissance geologic, geochemical, and hydrologic surveys were started in north-west Nevada and southeastern Oregon, and a program was begun for developing and testing new geophysical techniques.

The USGS is responsible for the supervision of operations under all federal geothermal leases, including approval of exploration and development plans; inspection of operations, and collection of royalties due the government.[2]

National Science Foundation

The major effort of the Foundation in geothermal energy is the funding of research on liquid-dominated and hot dry rock systems. The Foundation has several exemplary projects underway, one being 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 the study of the hydrothermal systems of the Kilauea Volcano on the Island of Hawaii under the direction of the Colorado School of Mines; while a third project, initiated last year, is using electrical methods to desalinate geothermal reservoirs. A major area of investigation sponsored by the Foundation involves the evaluation of the geothermal resources at the Imperial Valley in cooperation with the State of California.[2,3]

Research into the stimulation of geothermal aquifers is also being subsidized. This research has three major objectives: (1) development of experimental and numerical data to evaluate optimum performance of explosion stimulated geothermal aquifers; (2) development of a geothermal steam reservoir model to evaluate the thermal physical hydrodynamic and chemical parameters involved; and (3) development of a laboratory model of an explosion-produced chimney to produce experimental data on the processes of in-place boiling, moving flash fronts, and two-phase flow in high porous media. The Foundation has embarked on a research effort on hot dry rock geothermal systems in Marysville, Montana. Here, research teams from Southern Methodist University, Battelle Memorial Institute, and several other research centers are completing a geological survey of the area. Plans are to drill a test hole to develop appropriate technology as a model for exploration of similar hot dry rock formations and to ultimately develop this particular area to an economic productive source.

The Atomic Energy Commission

This Commission's research and development authority was revised in 1971 by a statutory amendment to the Atomic Energy Act of 1954. This amendment authorizes the AEC to conduct research and development activities related to "...the preservation and enhancement of a viable environment by developing more efficient methods to meet the nation's energy needs." In particular, this means that the AEC's efforts in R&D are no longer limited to the nuclear area.[2]

Studies were undertaken, in 1970 and 1971, at Battelle Northwest Laboratory, American Shale Company, Westinghouse Electric Company, the Lawrence Livermore Laboratory, and the Los Alamos Scientific Laboratory of the AEC. These studies concerned the technical and economic feasibility of extracting thermal energy from relatively dry geothermal reservoirs through the use of nuclear explosives to fracture the rocks and the subsequent injection of water to provide a carrier of heat.

A particularly promising project currently is the possibility of developing hot rock geological systems. This project will be carried out at Los Alamos Scientific Laboratory, where 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 rock to demonstrate the feasibility of such a man-made system. The AEC has requested \$4.7 million for 1974 to finance this project.[3]

Figure 2.3.1

The Los Alamos Scientific Laboratory is developing a thermal drill using electrically generated heat. A prototype of the drill has been successfully tested in the laboratory in the field.

The AEC has recommended three different paths that may be followed in a government industry geothermal development program. The first, a phased approach, would be one in which the initial research effort would be predominantly governmental as in the development of the hot dry rock concept at Los Alamos. The second could involve joint funding in management over the life of a program. The third could be a joint government industry program taking the form of government operated test facilities where various industrial equipment components might be installed for the development of long-term operational experiments. Such techniques, of course, have been applied successfully to the commercialization of reactor technology.

Other Federal Organizations

Bureau of Land Management

As manager of the public land, the Bureau of Land Management is responsible for leasing of federally-owned geothermal resources. The Bureau identifies potential geothermal leasing tracts based on geological surveys and on information provided by the U.S. Geologic Survey and the Bureau of Mines, as well as their own data and evaluation. Lands to be withdrawn, offered for competitive bidding, and marked for non-competitive leasing, are identified by the Bureau of Land Management.

The Bureau of Land Management recommends to the Secretary of the Interior exemption of those lands from leasing where the issuance of the lease might be contrary to the public interest. Such areas are those (a) administered under the national park system; (b) within a national recreation area; (c) in a fish hatchery administered by the Secretary, a wildlife refuge, wildlife range, game range, wildlife management area or water fowl production area, or for lands acquired or reserved for the protection and conservation of fish and wildlife which are threatened with extinction; and (d) individually owned Indian trust or restricted lands within or without the boundaries of Indian reservations. The Sierra Club has already indicated their belief that the provision for exempted areas falls short and should include, in addition: (1) the national wilderness preservation system; (2) units of the system of national wild and scenic rivers; (3) units of the national trails system; (4) areas reserved by the Secretary of the Interior or the Secretary of Agriculture for ecological, scenic, natural wildlife, geological, educational, historical, or scientific value, including primitive areas, roadless areas, back country areas, natural areas, and pioneer areas; (5) areas of de facto wilderness under study by the Secretary of the Interior or the Secretary of Agriculture for reservation as part of the national wilderness preservation systems; and (6) areas within one mile of the exterior boundaries of geothermal pools, hot springs, geysers, fumaroles, and mud pots [4]. It is quite apparent that should the issue be pressed, the larger policies addressed will probably go beyond the Department's confines and may require further legislative acts.

National Aeronautics and Space Administration

For several years NASA has carried out cooperative research with the U.S. Geological Survey in remote sensing of geothermal areas. In this program, data

from the geologic survey field and laboratory studies and aerial photographs were augmented by infrared scanning data and high altitude aerial photographs provided by NASA.[2]

The Bureau of Reclamation

The Bureau of Reclamation has the statutory responsibility to investigate alternate water supplies to supplement the Colorado River and to desalinate the river water. Under the Colorado River Basin Project Act (P.L. 90-537, 82 Stat. 885, September 30, 1968), the Bureau began an extensive, ambitious, 20-year project in 1971.[5]

First, the Bureau is to investigate the technological and economic feasibility of producing fresh water from the saline brine contained in the liquid-dominated systems of the Imperial Valley (East Mesa), California. Extensive geological, geophysical, geohydrological, and water chemistry investigations will be undertaken to fully evaluate those regions. Deep test wells will be drilled for both production and reinjection, and a major portion of the research effort will be in the evaluation of geothermal desalting techniques and the most feasible desalting processes. These studies may culminate in the construction of prototype desalting plants which would be operated in conjunction with the appropriate pre-treatment and waste disposal systems.

The components of the Bureau of Reclamation's geothermal program are (1) exploration, (2) production and injection wells, (3) research and development, and (4) appraisal. The exploration program is currently designed to secure estimates of the quantity and quality of geothermal resources in the Imperial Valley on reclamation withdrawn land. These estimates will be needed at an early date for a decision on the source of replacement water to prevent subsidence due to fluid withdrawal. If the resource proves to be large, the most economical source may be the ocean. In the case of large scale importation of replacement water from the ocean, the entire resource might be developed as a joint venture by federal and non-federal interests. If the source is moderate or small, local replacement water from such sources as near surface groundwater, the Salton Sea, and the Welton-Mohawk Drain would be used.

Finally, if the resource is found to be large and saltwater is therefore piped in from the Pacific for replacement, the Bureau has further plans. The imported saltwater can be distilled and, like the desalinated geothermal water, be piped on to the Colorado River. Since the full implementation of this plan would produce 2,500,000 acre feet of fresh water per year, very large quantities of steam and pumping power would be required. The Bureau expects to be able to contribute an amount of fresh water equal to approximately 25 percent of the present Colorado River flow at the Imperial Dam. In addition, with this throughput at the East Mesa installation, the Bureau studies indicate that 10,500 MWe could be developed jointly. About 2000 MWe would be required for water production and conveyance pumping, and the balance of 8500 MWe could be available to sell to the Pacific Southwest.[5]

As it proceeds with its project, the Bureau will also estimate environmental aspects of geothermal development, including effects such as seismic activity, subsidence, and air pollution.

The development of the Colorado River and its water quality are both national and international problems. The Federal Government (and, in particular, the Bureau of Mines) is bound by treaty to guarantee Mexico 1.5

million acre feet of Colorado River water per year. The government is also morally bound to supply this water at reasonable quality. With the gradual deterioration of quality of water available from the lower Colorado River, the multi million dollar agricultural industry in Coachella, Imperial, and Mexicali Valleys is at stake. The water supply is essentially fully utilized at the present time, and unless augmented by external sources as may be derived from geothermal development, only a modest increase in the amount of irrigated acreage can be expected in the future.

The Office of Saline Water

This office began a seven-year geothermal program in 1972 aimed at developing technology necessary to the desalting of geothermal brine. Their program included research on brine chemistry, materials of construction, process analysis and testing, environmental effects of the desalting processes, and effluent disposable techniques. Particular attention was directed towards finding economical and reliable materials of construction for the potentially corrosive geothermal fluid, a hot, acidic brine containing sulfide or carbonic gases. Funds were not requested for 1974 and it appears that the program has been terminated as part of a general dismantling of the department's desalination activities. The work in the Imperial Valley will shift entirely to the Bureau of Reclamation, as described above.[2]

Bureau of Mines

The major emphasis of the Bureau of Mines' activities centers on the recovery of minerals and gases found dissolved in geothermal fluid. The Bureau's program consists 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.

Research investigation will concentrate on the geothermal fluids of the Imperial Valley in addition to other promising geothermal resource areas. If research indicates the presence of mineral and gas constituents of sufficient economic value in the brines, a pilot plant for their recovery may be built in close proximity to a desalination plant in order to receive and process the plant effluents.[2]

The Department of State

Besides being involved in treaty negotiations with Mexico over the development of the Colorado River, the Department of State has a two-part program of its own with respect to geothermal power. The first is a series of informal exchanges between scientists in the United States and overseas. For example, through this program the Department of State has entered into a cooperative development program with Japan. Beyond information and scientific exchange, the State Department has a provision for direct assistance in developing countries through the Agency for International Development. This program has financed, for example, a preliminary reconnaissance of geothermal energy resources in the Diang Plateau of Central Java. AID is also assisting in the planning of a small pilot geothermal project in southern Luzon in the Philippines. The development of geothermal resources will become of increasing importance to certain underdeveloped countries which have sparse supplies of fossil fuels.[2]

The Advanced Research Project Agency of the Department of Defense

This agency is conducting studies of potential application of geothermal sources for specific military needs. Applications of concern to the military include (1) providing a primary source of reliable power at remote locations, (2) an emergency or back-up power source in the event that conventional power sources are disrupted, and (3) a self-contained standby power source for hardened, underground or underwater facilities capable of providing space heating and cooling and potable water, as well as electric power. While the ARPA effort is limited to the definition of Department of Defense needs, their work will be appropriate to the technological development of a small geothermal power station.[2]

The Bureau of Sport Fisheries and Wildlife

A division of the U.S. Fish and Wildlife Service (Department of the Interior), the Bureau's objectives include the perpetuation, use, understanding, and enjoyment of sportfish and wildlife resources in the United States. The Bureau operates over 100 fish hatcheries and stocks public waters and farm fish ponds. Wildlife programs are designed to protect and enhance the values of the nation's wildlife species.

The Bureau studies environmental impact statements proposed by federal or private agencies in order to assess the effects on fish and wildlife resources, and recommends appropriate measures for their conservation and development. Thus, it would be the role of the Bureau to evaluate the effects of brine, siltation, and subsidence in freshwater ponds and lakes near geothermal extraction operations. It may also advise in the placement of power lines, taking into account bird nesting, feeding, and migratory patterns. In addition, the Bureau may assist in the relocation of displaced ranges and hunting grounds. The Bureau presently maintains a fishery research station on Hot Creek, a tributary of the Owens River in Long Valley, California. Development of that region for geothermal power resources may lead to relocation of this station or perhaps its monitoring role could be expanded to assess the impact of geothermal development on the fish in that particular area.[4]

The Bureau of Outdoor Recreation (Department of the Interior)

This Bureau is responsible for the maintenance of public parks, recreation areas, and wildlife and waterfowl refuges. In some instances, geothermal power plant installations may lead to closing down some of these areas to ensure the public's safety. The Bureau might play a significant role in relocating the wildlife and waterfowl refuges which have been displaced and for providing alternate parks and recreation areas to the public in the affected region. The Bureau reviews proposed transportation projects for the possible adverse effects on parks, recreation areas, and wildlife and waterfowl refuges. Under the National Environmental Policy Act, the Bureau also reviews all projects having an impact on outdoor recreation. Geothermal leasing in areas designated as wild or wilderness areas must be compatible with the designation and purpose of these areas. However, under the Wilderness Act, these areas are not excluded from development of power projects or transmission lines if such use or uses are determined by the President to better serve the interests of the United States than would denial of such use.[4]

Environmental Protection Agency

EPA was established in the executive branch as an independent agency in 1970. Its role is to maintain water and air quality standards throughout the United States. It sets standards for major types of air purity in order to protect public health, as well as soil, water, vegetation, materials, animals, weather, visibility, and personal comfort and well-being. EPA has the role of enforcing environmental quality standards; this includes the gathering and preparing of evidential data and conducting enforcement proceedings. This agency made several significant comments in response to the Department of the Interior's draft environmental impact statement. EPA was concerned that dewatering active faults may result in a lessening of seismic frequency but an increase in the magnitude of severity when earthquakes do occur. They also mentioned that long-term subsidence control in the Imperial Valley trough (the areas between the Sea of Cortez in the Gulf of California and the Salton Sea) may be needed.[4]

The EPA suggested further examination of the possible radiological hazards resulting from geothermal fluids and the dangers of asbestos dust. It also commented that the environmental impact statement should address itself to the problem of clearance, debris disposal, and clean-up operations.

State Governmental Agencies

Within each state and locality there are numerous agencies originally constituted for other purposes which exert control over patterns of geothermal exploration, development, and use.

A flow chart of agencies involved in California is presented in Section 3.3. Some of the agencies involved are utility commissions, land zoning boards, water commissions, environmental agencies, mineral resource commissions, security and exchange boards, parks and recreation agencies, and so on. Some specific problems associated with this multiplicity of regulating agencies are redundant requirements, overlapping jurisdictions, and conflicts resulting from differing federal, state, and local regulations.

These problems are discussed in detail in Legal Considerations, Section 2.4.

State Agencies Concerned with Appraisal and Research

In California the State Geothermal Resources Board presently disseminates information about geothermal resources through publication, conferences, and discussions. Represented on the California Geothermal Resources Board are the federal agencies, in particular the Bureau of Land Management, the Bureau of Reclamation, and the U.S. Geological Survey. Coordination is provided for geothermal activities where they bear upon the jurisdiction of the Division of Oil and Gas, the State Water Resources Control Board, and the State Land Commission. (About 45 percent of the land in California is government owned. Government ownership is high in all of the western states, and the percentage of geothermal resources on state owned land is, of course, much smaller than on land owned by the Federal Government.) [6]

Natural resource agencies of many western states are currently engaged in geothermal research studies. The Division of Mines, as well as the Department of Water Resources and the Division of Oil and Gas in the State of California, have been appraising the

state's resources and conducting geologic investigations of the producing field at The Geysers and several other promising areas in the state for many years. The Oregon Department of Geology and Mineral Industries and the New Mexico Bureau of Mines and Mineral Resources have conducted geothermal programs, as have the Nevada Bureau of Mines and Geology, the Idaho Bureau of Mines and Geology, and the natural resources agencies of Alaska, Arizona, Colorado, Montana, Utah, and Washington. While the effort up to now has been relatively modest and primarily aimed at resource appraisal, interest in resource exploitation may grow to the point where joint ventures with private industry may be undertaken to develop promising resources on state land.

A recent report prepared by the Geothermal Resources Board of the State of California emphasizes research on the state level. While primarily directed at exploration and economic analysis of geothermal resources in California, this research is seen as providing "the basis for a sound development of geothermal resources as well as the basis for prediction of revenues to be derived from leases and royalties on state lands."

With the need increasing for wise management of natural resources, it becomes more necessary that research into geothermal resources be better coordinated. Several state-supported institutions, including the state university and the state college systems, are presently engaged in basic research in several phases of geothermal exploration and development.[6]

Response to Environmental Impact Statement

Several state agencies commented on the Department of the Interior's environmental impact statement. A review of their comments indicates some of their specific interests.

The State of California. California asked that federal geothermal leases include provision for power plant and transmission line construction without the requirement of a separate permit. The multiplicity of permits and approvals required is a continuing problem (see Section 3.3).

The California State Water Resources Control Board. This board has jurisdiction over the western Colorado River basin. Among the water quality indicators they are concerned with are: color, turbidity, bottom deposits, floatables, oil and greases, odors, pesticides, pH level, biostimulants, coliform bacteria, toxicity, radioactivity, temperature, dissolved oxygen, and dissolved solids. Their monitoring of the river basin could interact with geothermal exploration and development.

The California Department of Fish and Game. A trout hatchery on Hot Creek, a tributary of the Owens River (Long Valley), is maintained by the department. The hatchery depends on constant temperature cold water springs for water supplies. Should thermal pollution, siltation, or other adverse environmental impacts on the creek take place from geothermal development, the trout hatchery could be affected.

The Oregon Environmental Council. The Council responded to the impact statement by pointing out that issuance of standards for erosion control, noise control, waste disposal, wildlife protection, and others on a site-to-site basis could result in cases of permissive standards. This raises the issue of whether or not state regulations (in many cases far more restrictive than federal standards) are applicable to federal properties. The OEC also requested mandatory public hearings be held prior to any approval of unitization. Such hearings

are now at the discretion of the Director of the Bureau of Land Management.

The State of Colorado. Colorado objected to a USGS supervisor determining what measures are necessary to protect wildlife and wildlife habitat. The state feels that the USGS supervisor is not a professional wildlife man and the decision should be made by the Bureau of Sport Fisheries and Wildlife in cooperation with state wildlife agencies.

Oregon and Washington. Both states submitted that officially classified wild and wilderness areas should be excluded from proposed leasing programs, along with wildlife or game range areas. They felt that leases should not be issued in recreational areas, near national wild and scenic rivers, national trail systems, or primitive, roadless, or national pioneer areas.

Geothermal Industry

Field Development at The Geysers

The Geysers, California, is the only U.S. geothermal installation producing electricity. Its production is expected to grow from 400 MWe in 1974 to 908 MWe in 1977. In 1974 The Geysers contributes 5-6 percent of the electric capacity of the Pacific Gas and Electric Company; by 1977 this will increase to 10 percent. But, as mentioned earlier, like most infant industries, geothermal development at The Geysers had a slow, faltering beginning.

The Geysers' development began with the pioneering of Barkman C. McCabe, a Los Angeles stockbroker, and a friend of his, Dan McMillan. In 1955 they purchased about 5500 acres of property in Southern California, and after drilling several successful test wells, persuaded Pacific Gas and Electric to set up a pilot generating plant using an old 12,000 kW generator. Their efforts resulted in the creation of two firms, Magma Power, in Los Angeles, and Thermal Power, in San Francisco.

The most difficult technological hurdle they encountered was that of proving the potential of the field. The utility company was reluctant to build a generating plant unless assured of sufficient steam to run the plant for at least 30 years. Until recently, this meant that all the wells in the field had to be drilled and tested over roughly a five-year period before orders would be placed for the generating equipment. Generation began in 1960. The major breakthrough came when the Pacific Gas and Electric Company decided to accept reserve estimates based on criteria developed for natural gas fields. Dr. Carel Otte, a geologist who heads Union Oil's geothermal division, has observed that it was the acceptance of the principles of gas reservoir engineering applied to an underground steam field which provided the breakthrough for estimating the lifetime of The Geysers. [7]

Profits, Leasing, and Joint Ventures

Can geothermal development for electricity satisfy corporate demand for profits? Some observers say yes. They point to the venturesome efforts of Magma Power Company and Thermal Power Company, and proprietary interests at The Geysers who sell to utility companies such as Pacific Gas and Electric Company.

In 1971, when 192,000 kilowatts were being generated at The Geysers, Thermal showed a loss of 18¢ per share and Magma, 3¢ per share. In 1972, the joint venture yielded 37¢ a share for Thermal [7] and 7¢ a share

for Magma. With the addition of another 110,000 kilowatts of power in mid-1973, earnings were forecast by the brokerage firm, Henry F. Swift & Company, to be 60¢ a share for Thermal and 85¢ for Magma in 1974.

Negotiation for a \$13.4 million straight bank loan with the Welles Fargo Bank of San Francisco is held as proof of the increasing stature of geothermal activities in California. Of this, some \$4 million are slated for further expansion and drilling development in The Geysers field, and some half a million dollars set aside for other exploration. [7]

However, the story of the successful rise of these two firms should not be given without some cautions. The Geysers have proven to be a particularly fertile geothermal resource area; other areas may not prove as useful. Furthermore, certain hazards become apparent with time. One is the risk of subsidence and the other, reduced longevity of the field.

Magma and later Thermal Power became the holders of leases on geothermal land. Pure Oil Company, which later merged with Union Oil, entered into a joint venture with Magma and Thermal in 1967. Under this arrangement, Union Oil performs all the required drilling. Costs and profits are shared under a formula whereby the first 200,000 kilowatts of generating capacity belong to Magma and Thermal on a 50/50 basis, the second 200,000 kilowatts is shared equally by all three partners, and the third 200,000 kilowatts belongs entirely to Union, everything being shared equally again in excess of that. Steam sold to Pacific Gas and Electric is tied to the utility's other fuel costs and is thus not controlled by the supplies of steam. The utility, having accepted assurance of the productivity of the wells for a 30-year period, is, of course, attracted by the low cost of electric production. [7]

Magma and Thermal holdings, together with those of Union Oil, in The Geysers amount to about 13,000 acres. Other companies have now bought up leases in the area, including Signal Company, holding a large tract in lake country northeast of The Geysers; Pacific Energy Corporation, a subsidiary of Hughes Aircraft, which has 1120 acres to the southwest; and Geothermal Kinetics Systems Corporation, owned by a Canadian mining firm, United Cisco Mines Ltd., which has a 409-acre tract lying between joint venture property and that of Pacific Energy. In addition to these companies, there are a number of smaller concerns which are entering the geothermal development area actively, including American Thermal Resources, Incorporated, of Bakersfield, California, and Calvert Exploration Company, of Tulsa, Oklahoma. Calvert has bought leases on over 100,000 acres in New Mexico, including 2000 acres of known geothermal resource areas known as the Valles Caldera. Geothermal Kinetics has drilled two successful wells near Phoenix, Arizona, which are now being tested and evaluated. Geothermal Kinetics appears to be one of the most active of the independents; they have taken out leases on some 100,000 acres and are currently negotiating for considerably more acreage. [7]

In addition to Pacific Gas and Electric, other utilities have begun to take geothermal energy seriously. In 1971, San Diego Gas and Electric, in a joint venture with Magma, dug two wells. In 1972 the utility let contracts for the design of a \$3 million pilot plant, though at this point corrosion problems have postponed construction until procedures can be developed to cope with them. A consortium, including Southern California Edison and Southern Pacific and Phillips Petroleum Corporation, together with Union and Signal, are seriously exploring the possibility of developing geothermal

resources for feeding electricity into Southern California's grid, and New Mexico and Utah public utilities have indicated interest in buying steam or hot water from Geothermal Kinetics. [7]

Geothermal Development by Utilities

The development of geothermal resources by private entrepreneurs rather than by the utilities who will be the major customers for geothermal energy, is due, in large part, to utility economics and utility regulation. An electric utility concerned with raising large sums of money for its expansion relies upon the stability of its rate of return to secure its long-term debt. The uncertainties of geothermal development make it a venturesome business, and, therefore, probably unattractive from the point of utility investment. While its product is, of course, of vital interest to utility growth, the uncertainties of development will probably keep utilities in the role of purchasers of steam from proven fields.

Utilities are also limited by regulation in the services that they can perform. The development of multi-purpose utilization of geothermal resources would present problems to a utility, particularly one regarded as a utility holding company under SEC regulations. The structure of a utility as an organization marketing a single product would be significantly altered should the utility engage in the marketing of minerals produced from geothermal resources, for example. The profitability of the utility in terms of its investment is controlled by the regulation of revenues as a function of the utility rate base. The utility is non-competitive; should it engage in the competitive marketing of products, the relation of these activities to its non-competitive sale of electricity might prove difficult to balance.

The prospective role of the publicly owned utility, however, may be somewhat different from that of the privately owned utility. In the testimony pertaining to the Department of the Interior's geothermal leasing program, states and municipalities asked for preference in the issuing of leases. These leases, presumably, could be passed on to publicly owned utilities, a situation similar to the preference provisions for hydroelectric site permits as established in the Federal Power Act. The broad powers inherent in publicly owned utilities and their relative freedom from regulation might allow them to pursue geothermal resource development directly, rather than as purchasers of steam from privately developed resources. In those states heavily dependent upon hydroelectric power, the percentage of generation by publicly owned electric utilities is very high, being over 90 percent in Washington, over 70 percent in Oregon, and almost 30 percent in California. In Oregon, for example, the powers of a People's Utility District are very broad, including that of eminent domain, permitting even acquisition of property outside the District if that property is needed to serve the District. A People's Utility District may enter into contracts with the U.S. Government or with the State of Oregon, or with any other state, municipality, or utility district. In Washington, a first-class district is a public utility district which may obtain a license from the Federal Power Commission to construct major hydroelectric projects. Precedent is set, therefore, in several western states for active participation of publicly owned utilities in the generation of electricity.

Federal Government Involvement

As described previously, through the Bureau of Reclamation the Federal Government runs the project at East Mesa in the Imperial Valley of California. [5] Other federal projects could be forthcoming if the government chooses to upgrade an entire area through geo-

thermal development. This could be a TVA-like undertaking, an integrated land/river project committed on a regional scale to the development of low-cost power as an essential motivation for industrial expansion within the area. In the case of the TVA, which is primarily a wholesaler of power, preference is given to municipalities and cooperatives.

Residents and Environmentalists

The visual and olfactory impact of geothermal energy manifestations can be unpleasant. When William Bell Elliott was hunting grizzly bears in 1847 and stumbled upon the fumaroles at The Geysers, he thought he had arrived in Hades. It is generally acknowledged that the geothermal area near Larderello, Italy, was the inspiration for the Inferno segment of Dante's Divine Comedy of 1310. And in 1973, some of the residents in areas near geothermal sites were voicing similar complaints.

Resident Complaints During Early Development

In many ways, these residents are more fortunate than those located near other energy sources. Geothermal energy is relatively "clean" energy. It does not produce atmospheric particulate pollutants and does not require fuel to be mined or transported, handled or consumed. For the most part, the primary environmental effects are local. Yet the adverse environmental impacts may alter the quality of life for nearby residents. Such impacts are described in more detail in Section 4.8. In summary, during the exploration phase of geothermal development, environmental damage may result from field parties moving across access roads, generating dust, noise, and vehicular pollution. Vegetation is often lost resulting in patchy areas of dirt across the terrain. During the exploration, work forces must be housed and supported locally. Sometimes new public facilities are built to house large numbers of workers. After construction is completed, these facilities can be utilized for recreation and tourist needs, although their proximity to wells and drilling equipment may render them unsuitable for that purpose.

If exploration proves encouraging, test drilling is begun. This stage of development is often said to be the worst by many homeowners. The atmosphere becomes more polluted by cars, trucks, and other vehicles for transporting men and equipment. Diesel-powered trucks and drill rigs intensify the problem. The movement of vehicles on untreated or unsurfaced roads generates a considerable amount of dust. The settling of this particulate matter on plant life in the surrounding area may affect their growth and survival.

Blowouts, or uncontrolled release of the hot water and steam to the atmosphere, are extremely noisy, contaminate the air with gases, and may pollute surface and groundwater resources. The 1957 blowout at The Geysers in California has emitted more than 9 million tons of steam, about 4000 tons of hydrogen sulfide, 5000 tons of ammonia, and 6000 tons of methane to the atmosphere. In August 1972, three wells in Beowawe, Nevada were dynamited by vandals. Fortunately, the water ejected was of low salinity and has been successfully routed for use in pasture irrigation. [4]

In the third stage of development, production testing, non-condensable gases and vapors are released which may pose a health hazard to employees and disagreeable odors to residents. Asbestos is used as an insulation material around pipes; the fibers can be inhaled by workers.

Wells are vented into the air for periods up to 24

hours to avoid turbine blade damage from small rocks or stones which may be present in the steam. The noise level is a local nuisance and may present a health hazard. At a distance of 25 feet, the noise level reaches 126 dB. Barkman McCabe, President of Magma Power Company and Magma Energy Company, is partially deaf from working around "those banshees." In addition, noise from trucks and other vehicles and racking of drill pipe contributes to the problem. Besides being hazardous and objectionable to residents and visitors, this noise could disturb wildlife distribution and breeding patterns. [4]

The land is physically modified during this third phase of development. Roads and ponds are constructed. Drill sites are leveled. Erosion from this construction can lead to coverage of fish spawning and feeding areas and shallowing of streams. Wildlife directly within the area of development is either physically altered or removed completely. Releases of heated effluents to aquatic habitat could alter it by creating intolerably high temperatures and/or fostering the growth of nuisance algae.

In addition to the environmental and aesthetic results, there may be a reduction of hunting, angling, and camping opportunities on the land. Plant siting can affect mining and mineral operations, timber production, grazing, fish and wildlife habitat, and outdoor recreation. These effects may be especially objectionable in a resort or recreational community dependent upon the surrounding unspoiled beauty for its economic survival.

Resident Complaints During Final Development

The last three stages of geothermal development are field development, power plant and powerline construction, and full-scale operations. Now access roads are improved and service and living quarters constructed. The beneficial economic effects for the community include increased tax monies, royalties and rental fees, and some spending by construction workers, drilling crews, and employees.

Nevertheless, negative impacts are felt; complaints are voiced during these later development stages. Listed below are some specific examples of how these developmental steps may impinge on communities.

Members of the Anderson Springs (California) Homeowners Association, located 100 miles northwest of San Francisco in Lake County, have complained of noise, odor from hydrogen sulfide ("smells like rotten eggs"), threats to the creek, fish and wildlife, and water pollution. [4]

Clear Lake is the largest and most important warm water fishery lake in California. Angling is estimated at 200,000 man-days per year. Although the effect of geothermal development on the lake is not clear yet, any disturbance of this fishery would foster further regulation of power plant development and siting. [4]

Possible Future Resident Complaints. Some towns are expecting development problems. One such town is Lee Vining, the only town in the Mono Lake-Long Valley area. The population is approximately 400. Residents are concerned that development by Geothermal Resources International, Inc. will bring an influx of people and equipment. These newcomers will be associated with contractual firms of various kinds involved in the drilling and development of the geothermal reservoir, its operation and maintenance, and the construction of a power-generating station. Most of these people would be temporary residents but would increase the short-term use of utilities, housing, and so on. [4]

The Town of Cedarville, California is located on the western slope of Surprise Valley. This area is known for its hunting, fishing, camping, vacationing, and range land attractions. Should a geothermal plant be installed here, there is the possibility of a high noise level until the electric generating plant is completed, noxious odors of hydrogen sulfide, steam blown to the air causing certain damage to plant life, and drilling activities generating some dust. [4]

Olancho, California, population 150, is located near the south end of Owens Lake Basin in Inyo County. Getty Oil Corporation is prospecting for geothermal resources there. Presently, tourism and recreation-oriented services form the economic base of this community; geothermal development may impinge upon this or may offer an acceptable means of augmenting the economic base. [4]

Concerns of Interested Groups

Various groups, of course, voice concern over possible geothermal development. Following are the responses some groups gave to the Department of the Interior's draft environmental impact statement. [4]

The Sierra Club. Members said that the statement treats the scenic impact and possible solutions too lightly. This is a particularly difficult issue to come to grips with because of the lack of well-defined paradigms like those in air pollution.

Trout Unlimited. The Nevada Chapter wrote that provisions should be made to protect fish habitat from thermal pollution and detrimental dissolved solids. Maintenance of fish habitat is primarily their concern, but it is also important that this be done in its "natural" setting so as to allow the fisherman or recreationist other aesthetic pleasures.

The California Farm Bureau Federation. The concern of the Federation was that the tone of the statement was negative and could result in unnecessary delay of the resource. Clearly, this group is concerned that this source of additional irrigation water be developed and implemented.

The Audubon Society. The Society felt that transmission lines and destruction of natural habitat may result in unnecessary deaths, changing patterns of bird migration, and restriction of related bird watching and photography activities.

The comments of utility companies who responded to the U.S. Department of the Interior geothermal environmental impact statement are summarized below.

The Pacific Gas and Electric Company. PG&E commented that if the estimated level of 1000-2000 MW at The Geysers field is not achieved, the company would be obligated to generate the equivalent power by other means. It mentioned that subsidence was not a demonstrated problem at The Geysers and that the issue depends on the underlying rock types. PG&E was concerned that the power vested with the Department of the Interior officials is so restrictive as to discourage entrepreneurial geothermal resource development. Another suggestion was that federal geothermal leases should include provision for power plants and transmission line construction without requiring separate permits. And the company commented that noise level standards should be applied only to certain locations (e.g., residential areas) to be specified by PG&E.

The company responded to the environmental impact statement by stating that the danger of microearth-

quakes from fluid injection has been overemphasized. They also mentioned that the statement should emphasize tectonic setting of geothermal areas; much subsidence could be naturally occurring due to dynamic crustal processes.

Foreign Institutions

The development of geothermal resources in most countries other than the United States has been either a governmental undertaking or a joint undertaking between government and industry.

New Zealand [8,9,10,11,20]

An example of this governmental involvement is found in the control of the Wairakei Stations by the Electricity Department. This department is also responsible for all government-owned power stations and for distributing electricity through the national grid to electricity supply authorities in various centers. The Ministry of Works is in charge of the overall administration of construction on the Wairakei project. This department is charged with investigating and developing geothermal areas in which the government is directly interested, and performs all drilling and associated field work.

The Department of Scientific and Industrial Research is called on by the Ministry of Works to provide scientific services, mainly in geology, geophysics, chemistry, physics, and metallurgy. Actual construction has been done almost entirely by contract with consulting engineers aiding in design and supervision of the construction of the power stations and of the steam collection and transmission systems.

New Zealand industry has thus far been slow to develop and use geothermal energy, according to J. H. Smith, formerly chief geothermal engineer in the Ministry of Works. [8] This is partly due to the location of geothermal fields, which are remote from sources of raw materials, centers of consumption, or ports. The timber industry in the central region of North Island is a potential major user; other minor uses being currently investigated are geothermal heat for crop drying and the extraction of sulfur by the Frasch process (Section 4.2).

The Geothermal Energy Act (1953) in New Zealand originally provided for a rental payable to the government proportional to the value of the benefit derived from the uses of geothermal energy. Smith has observed that this has proved unworkable because of the difficulty in assessing the value of the benefit relative to other resources of energy. The basis was changed therefore to a charge of 2.5 New Zealand cents (approximately 3 U.S. cents) per million Btu in excess of ten thousand million Btu per 12 months. The rate was kept low in order to promote exploitation. At present, there is no rental payable for domestic use, and the only user which exceeds the exempted amount is a paper and pulp company. [10]

The City of Rotorua in the Wairakei area has been empowered by the Rotorua City Geothermal Energy Empowering Act (1967) to grant authority for licensing and control of geothermal energy in the city and for the sinking of bores for the purpose of obtaining geothermal energy in the city. Hot water is provided for space heating, bathing pools, for commercial heating in hotels, hospitals and offices, and some for industrial uses. This has required close association with the local authority regarding the control of possible problems arising from the discharge of hot waters and

atmospheric pollution and noise arising from operation of the wells. [11]

Iceland [12,19]

Iceland has pioneered in the use of hot water for municipal heating since the 1930's. Approximately 50 percent of the 200,000 population receives geothermal heating, and this is to rise to over 60 percent in this decade. Nine out of ten homes in Reykjavik, the nation's capital, received geothermal water for home heating distilled by the Reykjavik Municipal District Heating Service (Section 4.6).

Italy [18]

In Italy at the Larderello fields generating capacity has now grown to over 390,000 kilowatts. In Italy, Ente Nazionale per l'Energia Elettrica (ENEL) is the sole national agency which has been entrusted by law with the exploitation of geothermal energy for generation of electricity. An agreement, however, has been established between ENEL and the National Research Council of Italy for cooperating in the basic research of geothermal resources.

Japan [13,14,15,16,17]

The Japanese have a major program in geothermal development; the National Natural Resources Committee has reported that it is possible to develop geothermal energy in Japan in a range between 30,000 and 50,000 megawatts, and perhaps up to 60,000-140,000 megawatts (Section 4.7). [13]

An interesting example of the private exploitation of geothermal resources in order to develop cheap electric power may be seen in the case of the Japan Metals and Chemicals Company of Morioka, Japan. Plans for a large thermal power station, which had included an electrochemical works as a joint project were abandoned in the face of the projected high costs for electricity. Consideration of other methods of power led the Japan Metals and Chemicals Company to choose to develop power from the hot springs in the Matsubawe area. Since 1952, hot water from these springs had been used as a health center built by Matsuo village for its inhabitants. Cooperative studies were begun in 1956 by both the company and the Geological Survey of Japan. By 1966, 9500 kW were being generated; today, 20,000 kW is being consumed at full load operation. Present plans call for the construction of an additional 40,000 kW by 1975. [14]

Mexico [21]

Mexico has pushed the development of geothermal resources vigorously. Under the National Electricity Authority, a 75 MWe power plant at Cielito Prieto (northwest Mexico) was successfully completed in October 1973. It is being doubled in size now. Geothermal areas in other parts of the country are being explored for future exploitation.

Other Nations

Research is reported from the Somali Democratic Republic where plans are underway to commence drilling operations in the geothermal areas of Afars and Issas in order to provide geothermal power for Djibouti, and in order to stimulate the development of local industry. In India, a planned project is to start in late 1973 and will concentrate on exploration of favorable areas in the northwestern Himalayan region and western India, areas where alternative power schemes are considerably more expensive than in other parts of the country.

The United Nations and the government of Nicaragua are jointly studying a project to rebuild the ruined city of Managua with geothermal heating and air conditioning, as well as electricity.

REFERENCES

- [1] The Geothermal Energy Research, Development, and Demonstration Act of 1974 (P.L. 93-410) adopted after this section was written, redefines the responsibilities of NSF, Department of Interior, NASA, AEC, and FEA. It establishes a Project Committee to manage and coordinate research and development efforts. Under P.L. 93-410, Department of Interior is assigned responsibility for evaluation and assessment of the resource base, including development of exploration technologies. NASA is charged with overall program definition as well as contract management, resource evaluation and assessment, and development of technologies. AEC has technology development responsibilities and NSF is charged with basic and applied research and technical and scientific education. These delegations are not exclusive and all agencies may participate in the pilot and demonstration projects.
- [2] Hearings on Geothermal Energy Resources and Research, U.S. Senate Committee on Interior and Insular Affairs, Washington, D.C., June 15 and 22, 1972, p. 86.
- [3] Ray, D. L., The Nation's Energy Future--A Report to Richard M. Nixon, President of the United States, WASH-1281 (Washington, D.C.: United States Atomic Energy Commission, December 1, 1973).
- [4] Final Environmental Statement for the Geothermal Leasing Program, Vol. IV (Washington, D.C.: U.S. Department of the Interior, 1973), pp. 1-134.
- [5] Geothermal Resource Investigations--Imperial Valley, California--Developmental Concepts (Washington, D.C.: U.S. Bureau of Reclamation, January 1972).
- [6] The Economic Potential of Geothermal Resources on California (Sacramento, Calif.: The Geothermal Resources Board, January 1971), pp. 29-30.
- [7] Baron's (September 15, 1973), p. 3.
- [8] Smith, J. H., private communication, Wellington, New Zealand, January 10, 1974.
- [9] New Zealand Electricity Department, Wairakei--Power from the Earth (1970).
- [10] Statutes of New Zealand, "The Geothermal Energy Act 1953" and "Geothermal Energy Amendment Act 1957," Vol. 5, p. 637. "An Act To Amend the Geothermal Energy Act 1953," No. 50 (October 19, 1966).
- [11] Statutes of New Zealand, "An Act To Enable the Rotorua City Council To Make Provisions for the Control of the Tapping and Use of Geothermal Energy in the City of Rotorua," No. 2-Local, 1967.
- [12] City of Reykjavik, A Smokeless City, Report on the Reykjavik city geothermal district heating system (May 1972). National Energy Authority, "Recent Geothermal Developments in Iceland," Geothermics, Vol. 2 (March 1973), p. 38.
- [13] Japan Agency of Industrial Science and Technology, "Sunshine Project" (May 1974). Japan National Natural Resources Committee, "Geothermal Development in Japan," Geothermics, Vol. 2 (March 1973), p. 39.
- [14] Japan Geothermal Energy Association, Annual Information on Development and Utilization for Geothermal Energy in Japan--1971, Denkiyokai Building, 1-3 Yurakucho Chiyoda-ku, Tokyo.
- [15] Mori, Y., "Recent Plans of Geothermal Exploitation," Geothermics, Special Issue 2, Vol. 2, Part 2 (1970), p. 1150.
- [16] Sato, K., "The Present State of Geothermal Development in Japan," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970), p. 155.
- [17] Komagata, S., I. Iga, H. Nakamura, and Y. Minohara, "The Status of Geothermal Utilization in Japan," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970), p. 185.
- [18] Cataldi, R., P. Ceron, P. Di Mario, and T. Leardini, "Progress Report on Geothermal Development in Italy," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970), p. 77.
- [19] Palmason, G., and J. Zoega, "Geothermal Energy Developments in Iceland 1960-1969," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970), p. 73.
- [20] Smith, J. H., "Geothermal Development in New Zealand," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970), p. 232.
- [21] Banwell, C. J., and R. G. Valle, "Geothermal Exploration in Mexico 1968-1969," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970), p. 27.
- [22] Kaya, S., Chairman, Industrial Technology Council to Y. Nakosone, Minister of International Trade and Industry, "On Ways To Promote Development of New Energy Technology," ITC, No. 44 (December 18, 1973).

2.4 Laws and Regulations Applying to Geothermal Development

Introduction

Ideally, the legal structure for regulation of geothermal resource development should be logically and explicitly related to the nature of the resource and the institutional arrangements most appropriate to its development. Unfortunately, the legal regime not been as rationally structured as one might desire. The legal aspects of geothermal resource development today are a product of the past history of state and federal mining, mineral leasing, mineral disposal, water resources, environmental, and public land laws. The attempt to fit geothermal resource development into legal structures created for other purposes has inhibited its full exploitation.

This section of the study examines from an historical perspective the legal context in which geothermal resource development has taken place and efforts that have been made to develop a more rational legal foundation for future development. It includes a review of the history of mineral and water laws, limitations encountered in applying these laws to geothermal development, the development of new state and federal regulatory regimes, and the remaining legal barriers to geothermal resource exploitation. Other sections discuss what new legal incentives might be created to accelerate geothermal development while maintaining other important values.

Historical Context

While interest in the development of geothermal resources is of comparatively recent origin, laws dealing with the development of mineral and water resources have existed for many years. These laws differ somewhat depending on the location of the resources and whether private or public lands are involved.

If the resources are located upon private lands then the law is relatively clear: the owner of the surface of the land owns all that is under it. With respect to hard rock minerals, the owner is free to exploit these minerals as he sees fit subject to only the broadest restrictions such as those against creating a nuisance which injures his neighbor's lands.

With respect to underground water resources the surface owner is subject to additional restrictions especially in the arid western states. The use and enjoyment of resources underlying his land are often tempered by the requirement that he not trespass upon or unreasonably interfere with his neighbor's enjoyment of their underground water resources. The "law of capture" of a common underground water source which holds that one could use what one could take has been qualified by the doctrine that adjoining users have some "correlative rights" which limit one's ability to interfere with a neighbor's use.

In the arid West, early law relating to underground waters was further modified if the exploitation of underground resources interfered with the flow of surface waters. In such a case the surface owner's use of underground waters was limited by the rights of persons who had previously acquired rights in the flow of the surface waters.

As the West became more populated, the state governments assumed an even larger role in the development and use of water resources. Today in most western

states the surface owner must obtain state permission to exploit the water resources underlying his lands. The extent to which state water regulations govern geothermal resource development is explored below.

The Mineral Resources Model

In the earliest period of the development of the West, there was no comprehensive legislation dealing with mineral resource development. A variety of state, territorial, and private "miners" laws governed. In 1872 Congress passed the General Mining Law [1] governing the extraction of minerals. Intended to apply primarily to hardrock or metallic minerals, the 1872 Mining Law permitted:

1. Open exploration of the federal domain.
2. Acquisition of rights to minerals on public lands by discovery and filing of a claim.
3. Acquisition of title to the surface by acquisition, for a nominal sum, of a federal deed known as a "patent."
4. Production of minerals without a patent and without payment of any rents or royalties.

The size of the claims was limited to 20 acres. For a variety of reasons this system was not appropriate to all types of minerals.

A second system was established in 1920 when specific minerals were removed from the General Mining Law's "location-patent" system and placed under a leasing plan. Under the Mineral Leasing Act of 1920 [2] and subsequent related legislation, oil, gas, oil shale, phosphate, sulfur (in two states), potassium, sodium, native asphalt, and solid and semisolid bitumen and bituminous rock (e.g., tar sands) on public lands were made subject to leasing by competitive or noncompetitive bid. The competitive bidding system applied when minerals were known to exist in workable deposits. With respect to oil and gas, the test was whether or not the land sought to be leased was within a "known geologic structure" of a producing oil or gas field.

Under the competitive bidding system, appropriate notice is given and all interested parties are invited to submit bids. Sales of leases are made on the basis of royalty bidding. The highest cash bonus wins the bid. With respect to offshore oil and gas leases, the lump-sum bonus bidding system has generated billions of dollars in federal revenues.

Non-competitive leases are generally awarded to the first qualified applicant on a first-come, first-served basis except in certain circumstances in which a drawing is used to resolve competing claims. With the exception of oil and gas, exploration permits are issued for leasable minerals on a first-come, first-served basis and carry with them the right to lease minerals once a discovery has been made.

More recently Congress has provided for outright sale of certain minerals. The Materials Act of 1947 [3] authorizes sale of common materials, such as sand and gravel, usually by competitive bidding.

Much of the early congressional debate about the most appropriate legal arrangements for development of geothermal resources involved discussion of which of these three systems of mineral rights acquisition should apply to geothermal resources. As the debate progressed it became increasingly apparent that the three systems

were deficient even in the contexts in which they were being applied and needed significant modification prior to application to geothermal resources.

The location-patent and leasing systems per se were criticized by the prestigious Public Land Law Review Commission in its final report [4].

The Commission found with respect to the 1872 General Mining Law that:

1. It permitted individuals not primarily interested in mineral development to acquire rights in the public domain.
2. Inadequate filing procedures prevented federal land managers from locating claims.
3. Inadequate controls permitted filing of millions of claims, many of which were dormant and remained as clouds on title.
4. There were no revenues to the government except the nominal fee for acquisition of a patent.
5. The claims were too small in size and there was inadequate provision for acquisition of land for mining-related purposes.
6. There were no provisions by which the Federal Government could control environmental impacts.
7. There was no certainty of tenure prior to a discovery even if large expenditures were made and no certainty as to what constituted a discovery.
8. The claim holder was required to show actual possession of the claim or be subject to the rights of third parties.
9. The claim holder had to comply with state laws regarding location and maintenance of a claim.
10. The law was only applicable to specifically defined public lands and lands could be withdrawn administratively for other uses thereby upsetting mining claims.

Some Commission members were so unhappy with the location-patent system that they urged its replacement with a leasing system for all minerals. While the majority would not go this far, the Commission did recommend substantial modification of the system to provide for better filing procedures for claims; systematic review and granting of exploration permits; limitations on exploration rights; environmental regulation; development and production rights; patents to minerals only; payment of fair market value for the land surface; payment of royalties for minerals; uniform federal requirements for location and maintenance of claims; and elimination of dormant claims.

The work of the Public Land Law Review Commission postdated some of the debate over the legal structure to govern geothermal resource development. Its objections to the location-patent system of mineral exploitation were, however, widely shared and undoubtedly influenced

the Congress' decision to seek an alternative system for geothermal resources.

One such system was that of the Materials Act, which provided for outright sale of certain materials. This system was at one time considered by the Department of Interior to be applicable to geothermal resources. This position was soon reversed and the outright sale of geothermal resources was viewed as inappropriate to the complicated geothermal exploration and development process.

The ultimate choice narrowed, then, to selection of some sort of leasing system for geothermal resources. The most closely related resources were oil and hydrocarbon gas, so most Congressional attention focused on how the leasing system applicable to these resources should be modified to apply to geothermal resources.

Two basic sets of issues faced the Congress in selecting a workable leasing plan. The first related to the deficiencies in the Mineral Leasing Law itself, and the second related to the peculiar nature of geothermal resources. The Public Land Law Review Commission found the mineral leasing system to be inadequate in a number of ways [5].

The provisions for competitive sale of gas and oil exploration permits and leases were a major area of concern. The law provides that competitive bidding (in the case of oil and gas) need take place only when the area in question is within the known geologic structure of a producing oil or gas field. The Commission wanted to broaden competitive bidding to include cases in which: (1) the land is in the general area of a producing well; (2) the land is covered by relinquished or forfeited leases or permits; or (3) where past activity and general knowledge suggest reasonably good prospects for success. The purely physical test of a "known geologic structure" would be eliminated in favor of the more flexible tests listed.

A second set of deficiencies in the leasing system involved granting of exploration permits. The Commission in its report recommended:

1. Limiting the area covered by a single exploration lease or permit and the aggregate acreage held by any one explorer.
2. Specifying the time period for which the exploration right is granted.
3. Establishing performance requirements designed to ensure diligent exploration.

These recommendations were designed to encourage competition and prevent lands from being held for speculation. Oil and gas leases, for example, have only limited performance requirements.

Another recommended modification designed to encourage competitive bidding was the modification of the cash bonus system. The requirement of deposit of a percentage of the cash bonus serves to eliminate small developers without significant capital. The Commission recommended that federal authorities have the discretion to employ a combination of bonus, royalties, and rentals to encourage bidding by smaller firms.

Another problem with the leasing system was the ability of administrators either to withdraw lands from leasing or modify lease and operational conditions. The Commission recognized that excessive discretion led to lack of confidence in the developer's tenure. The resultant

insecurity led, in turn, to an inability to raise investment capital and/or an unwillingness to invest available capital in ventures which were viewed as uncertain. The Commission recommended that unilateral authority to modify operational and payment requirements be limited under guidelines to be specified by Congress.

Another area of concern was environmental protection. The Commission recommended that administrators operating under congressional guidelines establish environmental controls for protection of surface values. They recommended that the controls cover all phases of development from exploration through development and production to restoration and rehabilitation of the land after cessation of extraction operations.

A closely related issue is the use of conservation measures to protect development of the resource itself. The Commission came down strongly in favor of having federal law alone rather than federal and state law together or state law alone govern conservation activities.

The Water Resources Model

The foregoing discussion has assumed that one of the three major systems of mineral exploitation should serve as the model for geothermal development. There is, however, another possible model--water resource development. The elusive nature of the geothermal resource has led some to urge that geothermal resources be regulated as a water resource [6]. The argument is that geothermal energy is found, in nature, in an exploitable form only in association with water in its liquid or gaseous forms.

If geothermal resources in the federal domain are to be treated as water for regulatory purposes, then several unique problems arise. With respect to the eleven arid western states, Congress, in the Desert Land Act [7], decreed that state water laws would determine rights to use of all surplus unappropriated waters "upon the public lands." This grant of authority to the states was tempered by a major exception. The term "public lands" has a specialized meaning. It refers to lands that have not been reserved or withdrawn by the federal government for public purposes. Following a reservation no further rights to water can be obtained under state law which are superior to federal rights [8].

If geothermal resources were "water" within the meaning of applicable federal statutes, then prior to federal reservation it would be possible for a private citizen to acquire rights to such "water."

In the early 1960's some persons began to assert claims to geothermal resources on the federal public domain under state water laws. The Department of the Interior resolved these claims in two ways. First, it claimed that the lands in question had previously been "reserved" by President Hoover in 1930 under the authority of the Pickett Act [9] (governing reservations) and the Mineral and Hot Springs Act of 1925 [10] (governing leasing of hot springs). Second, it proceeded to execute extensive withdrawals of potential geothermal lands and resources from public acquisition. The reliance on President Hoover's reservation is somewhat doubtful since he purported to withdraw "springs" and not untapped heated waters or steam obtainable only by drilling.

Another argument which could have been made is that state water law governed acquisition of rights to waters "upon" the public lands. Since geothermal waters or steam are beneath the surface they would not be subject to appropriation under state law. At least one state court rejected this argument with respect to "artesian waters" which may explain the Federal Government's reluctance to rely on this argument [11].

The failure to agree on the nature of geothermal resources has given rise to yet another conflict. In making the public domain available for private settlement under various homestead and related acts, the federal government reserved the right to minerals in the lands conveyed to private persons. In due course, the question arose as to whether or not the federal government had reserved to itself the rights to geothermal resources. The Department of the Interior ruled that reservation of minerals did not include reservation of waters. It concluded that geothermal steam is essentially just subterranean water heated to a high temperature and, therefore, rights to it passed to the land owner and were not held by the federal government.

One of the arguments the Department of the Interior made was that geothermal steam is primarily the product of meteoric rather than connate or magmatic waters. Such latter waters are not only non-renewable and, hence, are "mineable," but they also tend to have a high mineral content. The result of this federal ruling may be that the waters belong to the land owner but that the mineral by-products in them belong to the Federal Government.

The present federal geothermal resource leasing act does not resolve this uncertainty.

The statute does, however, authorize test litigation to clear up the question of the mineral reservation. One such case has been decided by a United States District Court in the Northern District of California [12]. The court there held that a mineral reservation under the Stock Raising Homestead Act [13] did not include geothermal water or steam. The land owner is therefore free to use or dispose of geothermal resources without fear of any superseding federal rights. The court decided the case on the grounds that accepted definitions and past federal interpretation indicated that water is not a mineral. This case is presently upon appeal in the U.S. Court of Appeals.

Geothermal Steam Act of 1970 (Reprinted in Appendix I.)

Beginning in the early 1960's Congress attempted to construct a rational leasing scheme for geothermal resources. The early efforts culminated in passage of legislation by the Congress in 1966. The bill was vetoed by President Johnson on November 13, 1966. He found the legislation to be deficient in a number of ways: (1) it gave overly generous "grandfather rights" to early geothermal prospectors; (2) it provided for maximum lease acreages of 51,200 acres which was too extensive; (3) it provided for royalties only on steam sold or utilized, thereby encouraging waste; (4) it failed to give the government clear authority to readjust lease terms and conditions; (5) it provided for perpetual leases to developers of steam produced in commercial quantities; (6) it gave the developer 20 years to begin production and thereby encouraged holding land for speculative purposes.

The Congress returned to the drafting process and successfully resolved these and other pressing issues. 1970 President Nixon signed into law the federal Geothermal Steam Act [14]. This Act, which remains on the books in its original form, resolved a number of open questions about geothermal energy development on federal lands but left some issues unresolved. This section reviews the legislation and some of the issues which require further resolution.

Definition of Geothermal Resources. The initial task facing the Congress was to produce an acceptable definition of geothermal resources. As the discussion above reveals, the particular legal regime to be applied to geothermal resources could depend on the definition of the physical character of the resource. Congress defined "geothermal steam and associated resources" to include all products of geothermal activity, including steam, water, gases, brines, heat, and associated energy in geothermal formations; energy from artificially injected fluids was also covered. By-products derived from the above were included in the definition.

By adopting such a broad definition the Congress intended the federal leasing statute to supersede other leasing or mineral exploitation arrangements which might be applicable to geothermal resources. Neither the location-patent nor other mineral leasing systems would, henceforth, apply to geothermal resources.

What the definition did not do, however, is resolve all the questions as to how other aspects of mineral and water law applied to geothermal resources. By not stating explicitly that geothermal resources are either minerals, water, or sui generis, Congress left open several issues which from the developer's perspective might better have been resolved.

One such issue concerns mineral reservations by the United States in patents (deeds) issued under the various homestead acts. The definition does not clarify the respective rights of landowners and the United States with respect to geothermal resources under lands patented by the United States subject to mineral reservations. Indeed, Congress, in Section 21(b) of the Act instructed the Attorney General to institute appropriate proceedings in the courts to test out the scope of such mineral reservations. As noted above, one such suit has been instituted and the court held that the mineral reservations in the patents did not include geothermal resources. This case (and possibly others) will have to proceed through the courts until an "authoritative judicial determination" of the issue is received. In the meantime uncertainty will exist as to who has the rights to geothermal resources on land formerly owned by the United States. The Act does make clear that future patents and land restrictions will include reservations of geothermal resources as well as minerals. (Section 23).

A second major uncertainty not resolved by the definition is the degree of applicability of state water laws to geothermal resources on federal lands. By not clearly excluding geothermal resources from waters "upon the public lands," Congress left open the possibility that some persons might claim to have perfected rights to geothermal resources under the provisions of the Desert Land Act [15] which permits state laws to govern acquisition of water rights on unreserved federal lands. Congress clouded the issue in Section 22 of the Act by providing that "nothing in the Act shall constitute an express or implied claim or denial on the part of the Federal Government as to its exemption from State water laws." But in Section 23 it made its

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

This section may be sufficient to overcome the equivocal statement with respect to state water laws in the preceding section. In any event the Secretary of Interior has undertaken to withdraw lands from the public domain which might contain geothermal resources. Under prior case law this withdrawal should effectively prevent use of state water laws to perfect geothermal rights.

The inclusion of "by-products" in the definition of geothermal resources raises several questions. The first concerns the rights to non-leasable minerals subject to location under the mining laws. The geothermal lessee, upon termination of his lease, is given the rights to locate under the mining laws all minerals which are not leasable and which would constitute a by-product if commercial production or utilization of geothermal steam continued (Section 6(e)). The geothermal lessee must complete the location of mineral claims within 90 days after termination of his lease. While the lessee is producing geothermal steam, the minerals would constitute a "by-product" subject to leasing under the Act.

These provisions would seem to protect the geothermal lessee. There is, however, one ambiguity in this section (and other sections of the Act). Section 6(e) refers only to "geothermal steam" leases and production. There is no reference made to "associated geothermal resources." As the section now reads a lessee of "hot waters" or "hot brines" would not have the same rights to file mineral claims as would the lessee of "geothermal steam." It is doubtful that Congress intended to treat lessees differently depending on the form of the geothermal resources underlying their lands, but this may be what has occurred.

A second possible problem area concerns the rights to locatable minerals lying within the land covered by the geothermal lease which are not by-products associated with geothermal steam and associated geothermal resources, and hence are subject to acquisition under the mining laws. The geothermal lessee is given no preference to such minerals. This means that another person could obtain rights to minerals on the same tract held by the geothermal lessee. The possible conflict between the parties would have to be resolved under the principles of the Multiple Mineral Development Act [16], possibly to the detriment of the geothermal lessee.

A related set of issues arises with respect to minerals subject to leasing under the general Mineral Leasing laws. During production of geothermal resources rights to leasable minerals which constitute a "by-product" belong to the geothermal lessee. When geothermal resource production is no longer commercially feasible, the geothermal lessee may convert his geothermal lease to a mineral lease under the appropriate act. Such leases are subject to such terms and conditions as normally apply to the particular leasable mineral (Section 6(3)).

These provisions do not, however, apply to oil, hydrocarbon gas, and helium. Section 2(d) explicitly excludes them from the definition of geothermal resources and by-products. Section 27 of the Act reserves to the United States the ownership and right to extract these leasable minerals. The exercise of such rights probably will not, in most instances, interfere with production of geothermal steam and associated resources; except, however, complications may arise in the case of geopressured resources where it is not uncommon to extract large

quantities of dissolved natural gas with the geothermal fluids.

The definition of the term "by-product" raises one other potential problem. A by-product is any mineral or minerals associated with "geothermal steam" and which have value of less than 75 percent of the value of "geothermal steam" or, are not, because of quantity, quality, or technical difficulties in extraction or production, of sufficient value to warrant extraction and production by themselves. This definition refers only to "geothermal steam." Since the more valuable by-products are likely to be found in association with hot brines, there is some question as to whether or not the lessee of hot brines owns the rights to the by-products. Second, if market conditions change during the course of a lease so that the extractable minerals are worth more than 75 percent of the value of the geothermal steam or are worth extracting alone, who owns the rights to them? They are, by definition, no longer "by-products," therefore, they must be either leaseable or locatable minerals under the mining or mineral leasing laws. The geothermal lessee may, under certain circumstances, have to perfect additional rights to these minerals.

Lands Available for Leasing. The availability of federal lands for geothermal leases was a subject of continuous debate before the Congress in the hearings associated with the Geothermal Steam Act. Producers and potential developers urged broad availability; persons concerned with conservation and environmental matters argued for restrictions on availability of certain federal lands. The final resolution was to remove from leasing: the National Parks; national recreation areas; fish hatcheries; wildlife refuges; wildlife ranges; game ranges; wildlife management areas; water fowl production areas; and lands acquired or reserved for the protection and conservation of fish and wildlife that are threatened with extinction. Tribally or individually-owned Indian trust or restricted lands, within or without the boundaries of Indian reservations, were also removed by Congress from geothermal leasing (Section 15(c)).

Lands withdrawn or acquired in aid of a function of the Department of Agriculture (e.g., National Forest lands) can only be leased with consent of the head of that department. Lands subject to Federal Power Commission jurisdiction can only be leased with consent of that commission and subject to conditions concerning its use for power and related purposes.

A major issue in the congressional hearings was the degree to which the Secretary of Interior might use his discretionary powers to withdraw other lands potentially valuable for geothermal development. Industry spokesmen urged that this discretionary power be limited; they feared that investment in exploration would be limited because lands of interest would be removed from active development and production.

Competitive and Non-Competitive Bidding. One of the single biggest issues faced by Congress in establishing the geothermal legislation was definition of a competitive bidding system for geothermal resources. Industry representatives argued that competitive leasing would discourage exploration and deny security of tenure to those persons who made investment in the exploration and discovery of geothermal resources. The Department of Interior argued consistently for a wholly competitive geothermal leasing system. Its representatives opposed any non-competitive leasing system. Congress, in Section 4 of the Act, adopted a bifurcated system which has elements of both competitive and non-competitive leasing. The key factor in determining whether or not

geothermal lands will be leased on a competitive basis is whether or not the lands to be leased are within a "Known Geothermal Resource Area" (KGRA). If the lands are within such an area, they can only be leased to the highest responsible qualified bidder by competitive bidding. If lands are not within a Known Geothermal Resource Area, the qualified person first making application for the lease is entitled to a lease of such lands without competitive bidding.

The key decisional variable, then, is whether or not lands are within a "Known Geothermal Resource Area." Section 1(e) of the Act defines a KGRA as "one in which the geology, nearby discoveries, competitive interests, or other indicia would, in the opinion of the Secretary of the Interior, engender a belief in men who are experienced in the subject matter, that the prospects for extraction of geothermal steam or associated geothermal resources are good enough to warrant expenditures of money for that purpose."

As adopted, the definition of Known Geothermal Resource Area, unlike the definition of a "known geologic structure" in the oil and gas leasing system, is not purely a question of geology. Rather, in addition to geology, one must consider factors such as nearby discoveries, competitive interests, or other factors that indicate that people are willing to spend money to develop geothermal resources. The net effect of this definition is to push all geothermal leasing toward competitive bidding. The regulations adopted by the Department of Interior make even clearer the thrust toward competitive bidding. Nearby discoveries are defined in these regulations as "any well deemed to be capable of producing geothermal resources in commercial quantities" and where the geological structure is not known, "nearby" will be considered to be 5 miles or less from any such discovery." Hence, lands near new discoveries will be classified as KGRA's unless geological surveys determine that the lands are on a different geologic structure from the discovery. "Competitive interest" is defined to exist if at least one-half of the land covered in an application for a geothermal lease is also covered by another application which was filed during the same application filing period. Therefore, if one puts these definitions together it would appear that if two or more persons file for the same parcel of land, a competitive interest can be found to exist and competitive bidding will be required. This procedure should be contrasted with the procedures under the oil and gas leasing regulations which indicate that when there is a competitive filing the lessee will be selected by lot.

Of special concern to the industry was the revision that permitted the Secretary of Interior to determine that a Known Geothermal Resource Area existed when men experienced in geothermal development determined that prospects were good enough to warrant expenditure of money for that purpose. This provision gives the Secretary of the Interior considerable discretion to put areas which are subject to exploration and investment in the category of Known Geothermal Resource Areas, thereby prompting competitive bidding.

Since the thrust of the Act and enabling regulations is toward competitive bidding, the net effect will be to discourage "wildcat" exploration. The wildcatter may not be protected if he makes a discovery, and some other person, within the same filing period, also files with respect to those lands. (In this case this land would be classified as a KGRA and competitive bidding would follow.) The premium will be on secrecy, so that a developer can have some security that his investment in exploration will lead to a geothermal lease and not to competitive bidding.

These provisions will undoubtedly discourage small independent companies from the geothermal leasing process, in part because they may not be rewarded for their exploration activities, and in part because the bonus bidding system used to award competitive leases discriminates against small firms which do not have the capital to put up before the award of the lease. The Act itself is silent as to the bidding system which shall be used. It merely provides that lands shall be leased to the highest responsible, qualified bidder by competitive bidding under regulations formulated by the Secretary of Interior. In his regulations the Secretary of Interior has provided that each bidder must submit with his bid a certified or cashier's check, bank draft or money order, or cash, in the amount of one-half the amount bid. Upon award of the lease the bidder must pay the first year's rental and the balance of the bonus bid. This means that the bidder must submit, in cash, before he has started his work the entire amount of the first year's rental and the entire amount of his bonus cash bid. This system operates to favor those who have available cash to invest in bonus bids.

There is some question whether the bonus bidding system is properly applicable to geothermal resources as it is to other resources whose characteristics and market are known. The offshore oil leasing system produces billions of dollars in bonus revenues for the Department of Interior. With respect to the recent geothermal bids in a known geothermal resource in California, the highest amount bid for a single lease was only about \$350,000. The revenues to the federal government through the bonus bidding system appear small when compared to the potential value of development of the geothermal resource. The net result, however, is that the major oil companies tend to be the winning bidders for the largest and potentially most valuable tracts of land in the California KGRA's which were opened up for initial bidding. If these recent bids established a trend, then one would believe that the major energy producers, be they oil companies or others, will tend to dominate the geothermal industry. If one wishes to open up this infant industry to more independent talent, then some change in the bidding system will probably be required.

Conversion Rights. Section 4 of the Act carved out a major exception to the bidding system outlined above. A number of so-called "pioneers" had explored federal lands potentially valuable for geothermal leasing, and had attempted to establish claims under federal mining and leasing statutes. The Department of Interior consistently opposed the validity of any claim for geothermal resources based on mineral leases or mining claims. The Department argued that these statutes were limited to minerals specified therein or resources which qualified as minerals. The Department argued that geothermal resources did not qualify as minerals within the meaning of the General Mining Act, and, therefore, were not subject to location under that act.

Congress, however, felt that some consideration should be given to the so-called pioneers, and, therefore, provided that persons holding mineral leases, mining permits or applications, or mining claims, could convert these leases, permits and claims, or applications for leases and permits, into geothermal leases or applications for such leases, respectively. The conversion right is conditioned on a showing that the person who wished to convert had made substantial expenditures for exploration, development, or production of geothermal steam on the lands for which the lease is sought or on adjoining, adjacent, or nearby federal or non-federal lands. Conversion rights are limited to 10,240 acres. If there were more than one claimant for a particular

piece of land, that claimant who filed first had priority. September 1965 was used as the cutoff date. It was the congressional intent that claims filed after September 7, 1965, would not have priority, presumably because the claimant was on notice that the federal government intended to restrict the development of geothermal resources under a new leasing statute.

There was an exception stated for lands within any Known Geothermal Resource Area which were subject to a right to convert to a geothermal lease. Section 4(f) of the Act provides that a competitive geothermal lease shall be issued to the person owning the right to conversion if he makes payment in an amount equal to the highest bona fide bid for the lease in the Known Geothermal Resource Area. Therefore, the Act requires competitive bidding for geothermal leases in such areas but permits the holder of prior rights to convert his right to a geothermal lease if he matches the highest bid. The recent leases in California covered some lands for which there were conversion rights. It is not clear whether any of the applicants choose to exercise their right to meet the highest bid.

While the question of a "grandfather" clause absorbed considerable time and energy in the congressional hearings on the geothermal leasing statute, such conversion rights will probably be of minor importance in years to come, since out of the millions of acres of federal land potentially available for geothermal development, only about 80,000 acres were subject to conversion rights. However, in the short run, these conversion rights may be important since they may apply to lands of the highest potential which had been explored early.

Rents and Royalties. Section 5 of the Act provides that there be a royalty of not less than 10 percent nor more than 15 percent of the value or amount of steam or any form of heat or energy derived from production under a geothermal lease and sold or utilized by the lessee or reasonably susceptible to sale or utilization by the lessee. Some industry spokesmen argued that with respect to a resource whose characteristics were unknown that it would be unwise for Congress to establish any fixed royalty or, at least, peg it at a rate so high that the producer could not make a profit. Other industry spokesmen urged Congress to establish a royalty so that the producers would not be subject to the uncertain discretion of the Secretary of Interior to fix royalties. As the statute presently reads the royalty applies to the amount or value of steam or other form of heat or energy sold or utilized by the lessee or reasonably susceptible to sale or utilization by the lessee. It should be noted that even if the lessee does not engage in commercial production or sale of geothermal resources, he is still subject to payment of the royalty for any resources which are utilized by him, presumably at the site, or which he reasonably could have utilized or sold. This language removes one of the grounds for the presidential veto of the 1966 bill. The net effect of this provision is to encourage lessees to engage in commercial production and sale, because they will have to pay the royalty whether or not they, in fact, sell the resource. In addition, lessees will have to be very sure that they have customers for their steam.

The royalty on by-products derived from production under the lease and sold or utilized or reasonably susceptible of sale or utilization by the lessee is set at 5 percent of the value. There is an exception, however, for any by-product which is a mineral named in the Mineral Leasing Act. The rate of royalty is the same as that provided in that statute.

The Act does not address the question of royalties on commercially demineralized water. The regulations do, however, specify that the royalty on commercially demineralized water shall be at a rate of not more than 5 percent for value of such water which has been sold or utilized by the lessee or is reasonably susceptible to sale or utilization. However, no payment of the royalty is required if the water is used for plant operation, for cooling, or in the generation of electrical energy.

The regulations provide that in no event shall a royalty on any producing lease for any lease year be less than \$2 per acre, or fraction thereof, after the commencement of production in commercial quantities. This minimum royalty in lieu of rental is payable at the expiration of each lease year.

Section 5(c) of the Act also provides for payment of annual rental for lands leased under the Geothermal Steam Act. The rental is payable in advance at a rate of not less than \$1 per acre or fraction thereof for each year of the lease. If there is no producing well on the land, then the failure to pay the rental on or before the anniversary day terminates the lease by operation of law. The Secretary of the Interior has been given some discretion to continue the lease if payment is deficient but there is adequate justification for failure to pay on a timely basis. The lessee may pay, in lieu of rent, a minimum royalty of \$2 per acre, or fraction thereof, at the expiration of each lease year for each producing lease, commencing after the production of geothermal resource in commercial quantities.

The Secretary is given the right to determine the value of any geothermal steam and by-products used by the lessee and not sold and reasonably susceptible to sale. He is mandated to take into consideration the cost of exploration and production and the economic value of the resource in terms of its ultimate utilization. Here, again, the valuation question and the discretion which resides with the Secretary of Interior to establish value has troubled industry representatives. They feel that they are dealing in the dark with respect to value of steam not sold but which may be reasonably susceptible to sale. Economic decisions are made on the basis of production expectations which can be upset by the Secretary of Interior determining that the resources have been utilized or are reasonably susceptible to sale and then establishing a value for those resources upon which the royalty must be based.

The regulations contain a provision not in the statute for escalating rental rates. They state that to encourage orderly and timely development of geothermal resources all leases issued pursuant to the regulations will provide that beginning with the sixth year and for each year thereafter until the lease year beginning on or after commencement of production of geothermal resources in commercial quantities, the rental will be set by the authorized officer as the amount of rental for the preceding year plus an additional rental of \$1 per acre. The authorized officer may, upon a showing of sufficient justification by the lessee, waive the payment of any or all of the portion of additional rental. The intent of this section is to encourage production by continually escalating the rental rate. For the first five years, the lessee can engage in development activities at a fixed rate. Beginning with the sixth year and until commercial production, he must pay rental at an escalating rate. Therefore, it is in his interest to get to commercial production as soon as possible so that the lands themselves will begin to cover the cost of operation and the developer will not be forced to finance them out of pocket.

Lease Term and Renewal. The term of the lease and periods of renewal and discretion to alter terms upon renewal were another series of issues which once again divided industry spokesmen and the Department of the Interior. The Department of Interior wanted optimum flexibility in terms of lease term and conditions. Predictably, industry spokesmen wanted long fixed term and limited governmental discretionary powers. Section 6(a) of the act was a compromise. It provides that geothermal leases extend for a primary term of ten years. If geothermal steam is produced or utilized in commercial quantities within the ten-year period, the lease continues for so long thereafter as geothermal steam is produced and utilized in commercial quantities, but not to exceed an additional 40 years. Establishment of the 10-year and 40-year time periods was to permit the developer adequate time to develop the resource, and then ensure him some measure of security of investment in those resources.

Many industry spokesmen appearing before Congress argued against the leasing system and for outright transfer of title to geothermal land to developers on the model of the location-patent system. Once Congress determined that geothermal leasing rather than outright sale would be the mode of exploitation of geothermal resources, then the industry spokesmen shifted their argument and tried to get as long a primary term as possible and automatic renewals not subject to renegotiation. Many producers argued that the ten-year primary term was too short and that it was unrealistic with respect to a resource whose location and characteristics were not well known to expect commercial production within ten years after commencement of the lease. On the other hand, the Department of the Interior argued that longer than a ten-year primary term would permit lessees to withhold land from production and to slow down developmental activities. The Department of the Interior also argued that the renewals should not be automatic but should be subject to appropriate renegotiations between the Secretary of Interior or his representatives and the lessee. The Department wanted to protect the public domain and federal revenues where appropriate. The producers wanted as much security as possible.

The 40-year time period seems to be a reasonable compromise between the two objectives. The statute does not provide for renegotiation of terms and conditions at the end of the ten-year period. Therefore, the lessee is entitled to continuation of the lease on the same terms and conditions subject to other sections of the act which provide for renegotiation of lease terms.

The regulations stated that if at the end of 40 years, geothermal steam is "produced or utilized in commercial quantities" and the lands are not needed for another purpose, then the lease will be renewed upon renegotiation of terms and conditions. Production or utilization of steam in commercial quantities is defined to include the completion of one or more wells producing or capable of producing geothermal steam in commercial quantities and a bona fide sale of such geothermal steam for delivery to or utilization by a facility or facilities not yet installed but scheduled for installation not later than 15 years from the date of commencement of the primary term of the lease. This provision which appears in Section 6(d) of the act is to deal with the case in which the geothermal producer has entered into negotiations with an electric utility for utilization of his steam but because of the lead times involved in construction of electric power generating facilities, the facility cannot be completed at the end of the ten-year primary term. The lessees are given the right, if they have achieved production, to renew for a second 40-year term. However, this renewal is subject to such

terms and conditions as the Secretary of the Interior then deems appropriate.

Section 6(d) of the Act provides for extension of leases for land on which or for which, under an improved cooperative or unit plan of development or operation, actual drilling operations were commenced prior to the end of its primary term and which are being diligently prosecuted at the end of the primary term. The lessee is entitled to five-year extensions but not more than 35 years total as long as geothermal steam is produced or utilized in commercial quantities. This provision was necessary because an individual lessee may not be able to show production under an approved cooperative or unit plan of development or operation, since the actual development may be taking place on adjoining property.

Area of Geothermal Leases. Of particular concern to geothermal developers, both large companies and independents, was the area which a geothermal lease may embrace. An important related question was the amount of land which could be under the control of any single developer. The major companies argued that geothermal leases should be of large size and that a developer should be able to control hundreds of thousands of acres as under the oil and gas leases. The independents and, also, the Department of the Interior, which was interested in promoting some competition within the geothermal industry, argued that leases should be small, relatively speaking, and that no person or association should be able to monopolize the industry. President Johnson's veto of the earlier version of the Act was based, in part, on the fact that the Act permitted too large an acquisition by a single developer.

The compromise which resulted is embodied in Section 7 of the Act. It provides that a geothermal lease shall embrace a reasonably compact area of not more than 2560 acres, except where there is an irregular subdivision. No individual or corporation, except as otherwise provided in the act, can hold or control directly or indirectly more than 20,480 acres, including conversion leases. At any time after 15 years from effective date of the Act, the Secretary of the Interior, after public hearing, may increase the maximum holding in any one state to an area not to exceed 51,200 acres.

At this stage of development it is not yet clear whether these acreage limitations are too large or too small. In a single state, 20,480 acres is a fairly significant holding considering that the producing geothermal leases in The Geysers area of California encompass no more than a few thousand acres. However, until more is known about the nature and location of the resource, and its general availability, it will not be possible to draw a definitive judgment as to whether or not these acreage limitations are too large or too small. It may well be that Congress, by authorizing use of the bonus bidding system, has limited active participation to well financed energy producers; therefore, the acreage limitation may not be an effective way of encouraging competition.

Readjustment of Lease Terms and Conditions. Of particular concern to industry personnel is the amount of discretion given to the Secretary of the Interior. One area in which there was particular objection to the Secretary's discretion is the readjustment of lease terms and conditions. Industry spokesmen argued that if the Secretary of the Interior were given broad powers to reduce or otherwise adjust the terms and conditions, he would use that power to the detriment of the producers.

This, in turn, would reduce the security of tenure and, therefore, the willingness to make investments. The Secretary of the Interior argued that he needed authority to modify lease conditions as the character of the industry changed and more information was obtained about the exact nature of the geothermal development process.

Section 8(a) of the Act, which was a compromise between these positions, provides that readjustment of lease terms may be done at not less than ten-year intervals beginning ten years after geothermal steam is produced. The lessee is given the option of filing objections to any proposed lease terms and conditions. If the lessee files objections and an agreement cannot be reached between the authorized officer and the lessee within a period of 60 days, the lease may be terminated by either party subject to provisions of the law.

The Act is somewhat more stringent with respect to readjustments of rents and royalties as distinguished from other terms and conditions of the lease. It provides, in Section 8(b), that the Secretary may readjust the rents and royalties of any geothermal lease at not less than 20-year intervals beginning 35 years after the date that geothermal steam is produced. In the event of any such readjustment, neither the rent nor royalty may be increased by more than 50 percent over the rental or royalty paid during the preceding period, and in no event shall the royalty exceed 22-1/2 percent. The lessee may object and if his differences with the Secretary of Interior are not resolved, he may lose his lease. Because of the longer time periods for readjustment of rents and royalties and the upper ceiling on royalty payments, these provisions are probably not going to be a major factor in upsetting investors' expectations.

Section 12 of the Act also provides that the leases may be terminated outright by the Secretary of the Interior for any violation of the regulations or lease terms after appropriate notice and opportunity for the lessee to correct any defaults. The lessee is given the right to a hearing on any claimed violation or proposed termination of the lease provided he requests the same. Again, this section offers the lessee some limited protection. However, it does give the Secretary of Interior considerable discretion to determine what is a violation of the lease and then to act after hearing on that violation. It gives the lessee no recourse rights with respect to the Secretary's termination of the lease because of an alleged violation.

Miscellaneous Lease Provisions. There are also a number of sections of the Act which deal with various lease provisions. For example, Section 10 permits the holder to relinquish the lease if he determines that he no longer wishes to continue with development or production of geothermal resources. However, he must make all payments of accrued rents and royalties and act to restore the surface lands prior to complete relinquishment.

Compatibility of Multiple Uses of Land. A continuing problem with respect to all mining and mineral leasing statutes is the question of what principles should govern the use of land and resources when multiple uses are possible. Section 17 of the Act adopts the general principle that the Geothermal Steam Act shall allow for coexistence of other leases of the same lands for deposits of minerals under the laws applicable then, for location and production of claims under the mining law, and for other uses of the areas covered by them. The net result of this provision is that there is really no set of priorities established other than that the leases or uses of land shall not unreasonably interfere with each other. This, again, raises the question of administrative discretion, since the Secretary of the Interior, who is responsible for administration of this Act, may find

that there is some conflict of uses and subordinate the geothermal development to the development of other resources. This could endanger the lessee's use of the lease premises for geothermal development. It does not give priority to development of geothermal resources, and, therefore, does not offer the lessee complete security in its tenure.

Cooperative or Unit Plan and Drilling Agreements. Section 18 of the Act replaces the law "of capture" with a more rational system of development of geothermal resources in a pool, field or area where there are more than one lessee or landowner. This section provides that for the purpose of properly conserving the natural resources of any geothermal pool, field or area, or part thereof, lessees and their representatives may unite jointly or separately with others in collectively developing, adopting, and operating under a cooperative or unit plan of development. The Secretary of the Interior may in his discretion and with consent of the holders of the leases involved establish, alter, change, or evoke and make such regulations with reference to such cooperative leases as he deems necessary or proper to secure reasonable protection of the public interest. He may even include in geothermal leases a provision requiring the lessee to operate under such a reasonable cooperative or unit plan, and may prescribe such a plan. The compulsory unitization of leases again places the Secretary of the Interior in a key role in determining the investment and production decisions of private parties. Compulsory unitization may result in protection of individual lessees and of the resource pool, but possibly at the expense of delaying the development process, for, now, a bureaucratic chain of decisions may be included in the private investment decision.

Section 18 also provides that when separate tracts cannot be independently developed and operated in conformity with an established well spacing or development program, any lease or portion thereof may be pooled with any other land whether or not owned by the United States under a communitization or drilling agreement providing for apportionment of production or royalties among the separate tracts of land comprising the drilling or spacing unit. The Secretary may require such communitization or drilling agreements if the lessees cannot voluntarily agree among themselves. In this section, interestingly enough, the Secretary is given the power to apportion production of royalties among separate tracts of land including lands which are not federal lands and not subject to geothermal leasing under the Act. It is not clear how this provision relates to state laws which purport to give state oil and gas or geothermal officers the power to regulate drilling.

The Act does provide as a "bonus" to lessees that leases operated under an approved operating, drilling or development contract, and unitization or cooperative agreement, shall not be counted in determining maximum allowable holdings under other provisions of the Act. This provision of the law encourages lessees to engage in cooperative activities rather than competing activities if they are close to holding the maximum allowable lands in any single state.

Administration of the Act. The Act also contains a number of administrative provisions, the most important of which is contained in Section 24: the Secretary shall prescribe such rules and regulations as he may deem appropriate to carry out provisions of the Act. The scope of the regulations is large, including provisions for prevention of waste, development and

conservation of geothermal and other natural resources, protection of the public interest, assignments, segregation, extension of terms, relinquishment of leases, development contracts, unitization, pooling and drilling agreements, compensatory royalty agreements, suspension of operations of production and suspension or reduction of rents or royalties, filing of surety bonds, use of the surface by the lessee, maintenance by lessee of an active development program, protection of water and other environmental qualities.

Section 23 of the Act provides that all leases shall be subject to conditions: the lessee will, in conducting his exploration development and producing activities, use all reasonable precautions to prevent waste of geothermal steam and associated resources in the leased land. Section 21 provides that within 121 days after effective date of the Act the Secretary shall cause to be published in the Federal Register a determination of all lands which were included within any known geothermal resource area on the effective date of the act and shall add such determination in the Federal Register from time to time as he specifies.

Section 19 of the Act provides that upon request of the Secretary, other federal departments and agencies shall furnish him with any relevant data then in their possession or knowledge concerning or having bearing upon fair and adequate charges to be made for geothermal steam produced or to be produced for conversion to electric power or other purposes: the data so provided shall be confidential.

Exploration rights. The federal Act is silent with respect to granting of exploration rights. The Secretary of Interior, in accordance with his rule-making authority, has established a procedure whereby persons who wish to search for geothermal resources upon the public lands must file a notice of intent to engage in exploration operations. The notice of intent gives the holder the right to engage in non-exclusive exploration for geothermal resources. The explorer gains no preferential rights to geothermal resources or any lease. There are requirements with respect to bonding, environmental maintenance, and the like. The way that the exploration process is presently structured, a person coming upon the public domain does so at his own risk. All expenditures for geothermal exploration may be vitiated either by a prior filing of a non-competitive lease application by another person or by a declaration by the Secretary of Interior that the lands explored are within a KGRA and therefore subject to competitive bidding.

The net result of this provision will be to discourage independent exploration of the public domain for geothermal resources. The investor would do so at his own risk. Those persons who wish to protect their investment will first have to obtain a geothermal lease. These procedures should be contrasted with those under state law, where in California, for example, a geothermal explorer can obtain an exploration permit from the State of California for exploration on state land and, therefore, have a preferential right to a geothermal lease if geothermal resources are discovered as a result of the exploration operation.

State Geothermal Leasing Laws

Nine states, Wyoming, California, Arizona, Alaska, Oregon, New Mexico, Utah, Montana, and Idaho, have adopted geothermal laws. Figure 2.4.1 summarizes the current laws and Appendix I contains an analysis of air quality standards in thirteen states. Only three of these states, California, Alaska, and New Mexico, have specific geothermal leasing statutes with respect to state lands.

State	Geothermal Law	Geothermal Regulation	Geothermal Regulation State Lands	Water Well Permit Required	Drilling Fee Required	Drilling Bond Required (Thousands \$)	Impact Statement to Drill Required
Alaska	Yes	No	Yes 1972	Yes/No	\$100	Yes 15	No
Arizona	Yes 1972	Yes 1972	Yes	No	\$25	Yes 15	No
California	Yes 1965	Pend. (1973)	Yes 1967	No	\$25-1,000	Yes 15	No
Colorado	No	No	No	UD	UD	UD	UD
Hawaii	No	No	Pend.	Yes	Nom.	No	Yes
Idaho	Yes 1972	Yes (1973)	Yes 1972	Yes	\$500	Yes 110	No
Montana	Yes (7/73)	Yes (7/73)	Yes (7/73)	Yes	\$75-150	Yes 15	Cond.
Nevada	No	No	No	Yes	\$25+	No	No
New Mexico	Yes (6/73)	Yes (6/73)	Yes 1967	Yes	UD	UD	No
Oregon	Yes 1971	Yes 1971	Yes 1972	Yes	\$25	Yes 15	No
Utah	Yes 1973	No	Yes	Yes	\$10+		No
Washington	No	No	No	UD	UD	UD	No
Wyoming	Yes (5/73)	No	No	Yes	\$2	No	No
() - Pending date UD - Undecided							

Source: State of California, Division of Oil and Gas, Department of Conservation, April 1973 (Updated)

Figure 2.4.1 OVERVIEW OF GEOTHERMAL LAWS AND REGULATIONS IN THE WESTERN UNITED STATES

While these statutes are modeled on the federal statutes, they do differ in some respects. California's statute was adopted prior to enactment of the federal law and therefore served as a model for several other states. The statutes are administered by a variety of state agencies--illustrating the uncertainty about the nature of geothermal resources. In California, for example, the supervisor is the State Oil and Gas supervisor. In Arizona, it is the Oil and Gas Conservation Commissioner. In Alaska, it is the Director of the Division of Lands and Department of Natural Resources; in Oregon, the state geologist; in New Mexico, the Commissioner of Public Lands; and in Idaho, the Director of the Idaho Department of Water Administration.

Generally, these statutes are written so as to govern all leasing of state lands for geothermal purposes. All the statutes draw a distinction between competitive and non-competitive bidding lands, and basically parallel the federal statute in this regard.

Definition of Geothermal Resources. The state statutes use differing definitions of geothermal resources. Of particular interest are the Arizona and Oregon statutes which explicitly recognize that geothermal resources include energy resulting from artificial stimulation or induction of fluids into geothermal formations. Oregon also, perhaps in order to resolve some conflict with its water laws, indicates that geothermal resources include hot waters which have a bottom hole temperature of more than 250°F. Idaho indicates in its statute that geothermal resources are declared to be *sui generis*, neither a water resource nor a mineral

resource, but the legislation goes on to indicate that they are also found and declared to be closely related to and possibly affected by water and mineral resources in many instances. This tag clause appears to leave some uncertainty with respect to the nature of geothermal resources in Idaho.

Definition of Geothermal Resource Area. The nine states which have adopted geothermal statutes have in five cases defined "geothermal resource area" or "Known Geothermal Resource Area." It is interesting that the states which have so defined these areas have used what appears to be, in essence, a physical definition. That is, they refer to surface areas which are underlaid or reasonably appear to be underlaid by geothermal resources. This definition should be distinguished from the federal statutory definition which indicates that a KGRA is an area which is, in effect, suitable for investment purposes. The use of a purely physical definition removes some discretion from the state administrative officers with respect to classification of lands, and thereby encourages non-competitive leasing of state lands, whereas the federal statute has the distinct tendency to encourage competitive leasing of lands.

Prospecting Permits. California and Alaska have dealt explicitly with the problem of exploration and prospecting for geothermal resources on lands which are not classified as geothermal resource areas. The first qualified applicant, upon payment of a fee of \$1 per acre or more, may obtain the right to an exclusive prospecting permit for lands not classified as a KGRA. If before the permit is issued the lands are classified as a KGRA, the application will be denied. If the permit is awarded, the prospector has an exclusive three-year period of prospecting which may be extended administratively for an additional two years. This prospecting permit includes a preferential right to lease lands. If while the prospecting permit is still valid and, in effect, the state authorities reclassify lands in a KGRA, the permittee is given a preferential right to lease the lands. Permits are subject to cancellation for non-performance or failure to use diligence and care in prospecting and development. Any single person, association, or corporation may obtain a prospecting permit for an area of not more than 25,600 acres within the California state domain. California, interestingly enough, provides for preferential rights for the surface owner with respect to prospecting. In lands sold to private persons by the state with a mineral reservation in the state, the owner may, if any other person applies for an application for a prospecting permit, himself file an application within six months and obtain preferential rights. The failure to apply terminates the landowner's rights and the original applicant is permitted to proceed with his application.

State Leasing Provisions. State leasing provisions are very similar to those in the federal law. They do, however, differ in some particulars. For example, in California the primary leasing term is 20 years and renewals of up to 99 years are permitted as long as there is commercial production of geothermal resources. This should be contrasted with the federal law which has a ten-year primary term and 40-year renewal periods. Alaska has a ten year primary term and 40-year renewals up to a total of 99 years. New Mexico provides for a 5-year primary term and 5-year renewals thereafter as long as the resources are produced in commercial quantities. The developer would appear to have more security in California than under the federal statute, but more under the federal statute than he would in New Mexico. The rental provisions are similar to the federal law with roughly \$1 per acre required at a minimum. The

royalty provisions differ somewhat. California provides for 10 percent of gross revenue on steam and brine, and between 2 and 10 percent on gross revenue of other resources found in geothermal fluids. This should be contrasted with the federal law which provides for a royalty of from 10 to 15 percent for steam, 5 percent or less on by-products, and 5 percent or less on commercially demineralized water. Alaska provides for royalties of 10-15 percent of gross revenue from sales of steam and brine, and 2-10 percent of gross revenues of minerals and chemicals sold. Oregon puts the authority for setting royalties in the Division of State Lands and has no statutory maximum or minimum. New Mexico is similar to California and Arizona, but does, however, provide for a royalty of 8 percent of net revenue from energy-producing plants, and 2-10 percent of gross revenue for use of lands for recreational purposes. The state statutes also have provisions with respect to termination of leases; suspension; transfer ability; and waiver, suspension and reduction of rents and royalties which are similar to the federal statute. The state laws have provisions for adjustment of rents and royalties and terms and conditions of the lease which are basically the same as the federal statute, although California does provide for readjustment of terms and conditions after 20 years, whereas the federal statute provides for readjustment of terms and conditions at ten-year intervals beginning ten years after commercial production.

Protection of Resources and Environment. The state statutes, as well as the federal statute, provide for prevention of waste and safeguarding of life, health, property and the environment. The terms of conservation and waste prevention provisions are essentially similar to those in the federal statute. California, Alaska, and New Mexico also provide that where land is used for some other state purpose, the state lease requires the consent of the agency which has reserved the land for its own purposes. The state statutes provide that in future leases the state authorities have the right to reserve minerals or geothermal resources in the leasing and selling of state lands. State statutes have provisions for cooperative development and drilling agreements to conserve the resource pool; the emphasis here is on conservation of the resource and protection of the public interest in those resources.

Overlapping Regulatory Jurisdictions [17]

A problem which is going to plague the geothermal resource industry in years to come is the sorting out of overlapping regulatory jurisdictions with respect to acquisition of rights to geothermal resources, exploration, drilling, development, production, and utilization of those resources. Federal, state, county, and local governments are involved with respect to regulation of private lands, state lands, and federal lands. Figure 3.3.1 depicts schematically the complex regulatory system in California.

Federal Lands

In order to obtain rights on federal land the prospective geothermal developer must pass through a series of procedures established by regulatory agencies. First, the lands must be made available for leasing by the Bureau of Land Management of the Department of the Interior. Secondly, prior to a lease sale, the Bureau of Land Management must prepare an environmental impact statement which must then itself go through a series of review processes.

Following availability of lands for leasing and acceptance of the environmental impact statement (which may include litigation by persons opposed to geothermal development in a particular area), the bidder must then determine whether or not the lands are available for competitive leasing or non-competitive leasing. If the lands are available for non-competitive leasing, and the potential developer wants to go upon the lands prior to development or bidding, he must file a notice of intent to engage in geothermal resource exploration. This notice of intent is filed in the office of the Bureau of Land Management for the district in which the lands are located. The prospector must also obtain a bond. Assuming that the developer is reasonably confident there are geothermal resources under the land and wishes to engage in exploratory drilling, he must do so after obtaining administrative approvals from the USGS conservation division and the applicable office of the Bureau of Land Management. He must not only have appropriate bonds but he must give appropriate assurances that he will not affect the environment adversely or will restore the land if he will have such an effect. As noted earlier, this exploratory drilling is solely at the developer's risk, since he may find that the lands are reclassified as a KGRA or he may find that the lands are withdrawn from leasing at any time prior to granting of a non-competitive lease to him.

If the developer wishes to proceed with a non-competitive lease, he must file an application and provide a year's rent in advance. If the land is not classified as a KGRA and he is the only applicant, he will in due course receive such lease unless the Department of the Interior determines otherwise. If the land is reclassified as a KGRA, then the developer must engage in a competitive bidding process. He stands a substantial risk that persons with more capital will, because of his exploratory work, feel free to invest larger sums of money than he can afford to obtain a competitive lease to the land. The risk is particularly great for the small developer since the Bureau of Land Management uses the cash bonus bidding system for the development of geothermal lands.

If an environmental impact statement has not previously been filed with respect to those lands, then the law seems to require that such a statement be produced, although it is less clear with respect to non-competitive lands than it is with respect to competitive lands. In addition to filing an application for a non-competitive lease, the applicant must file a proposed plan, consisting of a map and a narrative statement. The statement must describe the operation the developer intends to conduct, the method he intends to use, and the way in which he will protect the environment, wildlife, and other natural resources.

If after this process, the developer is able to acquire a lease to promising land, he is then in a position to engage in developmental drilling. This drilling process requires, according to applicable regulations, clearances by the U.S. Geological Survey with respect to all drilling plans and proposals. The developer must comply with a number of production and drilling regulations. It appears (but is by no means completely clear) that the developer must in addition comply with state regulations pertaining to exploration, exploratory drilling and developmental drilling on federal land. California state law, for example, purports to bring actions on federal lands under California jurisdiction. The Bureau of Land Management has indicated that it intends to comply to the extent possible and consult with state regulatory agencies. However, it has not taken the step of firmly committing itself to state or local regulation.

Once a developer gets into the development stage, he

must concern himself about additional regulations with respect to resource production and utilization. The Federal regulations require that the developer take a number of steps with respect to soil and resource conservation and production on leased land as determined by the supervisor of the USGS. These steps include safe reinjection of fluids, monitoring of land for subsidence, and precautions that will facilitate the restoration of disturbed lands to their original condition. The production regulations also require the developer to file periodic monthly production and financial reports and obey all geothermal resource operational orders issued by the supervisor of the USGS.

At the production stage, the developer may either voluntarily or upon order of the supervisor have to enter into a unit or cooperative drilling arrangement with other developers in the area. The extent to which these arrangements will be required will depend upon experience with development of geothermal resource pools.

If the resource is to be used for production of electricity, the Federal Power Commission enters the picture. The Commission must grant a permit before a power plant is constructed on federal land or transmission lines are developed over navigable waters. The extent to which this provision will be used is not yet clear since there has been no actual production on federal land. If the developer should produce valuable mineral by-products, then he is subject to additional regulations with respect to the use and disposition of those by-products.

State Lands

California, which is the only state in which there is active production and utilization of geothermal resources for the generation of electricity, provides a model for other states with respect to state regulation of geothermal activity on state lands. In order to conduct exploration operations on lands owned by the State of California, the prospective developer must apply to the State Lands Commission for a prospecting permit. The permit must include a description of the land as well as statements of the methods proposed for developing deposits, the quality and use of underlying groundwaters and adjacent surface waters, and waste disposal methods. Fees, deposits, and bonds are required at this stage. Additional information is required by the permittee before drilling any exploratory wells.

The State Land Commission must grant permission before any exploratory drilling commences. There are also provisions for environmental protection of fish and wildlife resources, and reimbursement to the state for timber damaged and destroyed. State law requires that the permittee comply with all valid ordinances of cities and counties applicable to his operation, and to submit periodic reports and logs showing his developmental activities.

Before exploratory drilling can begin, the developer must apply to the Oil and Gas Supervisor of the Division of Oil and Gas of California's Department of Conservation. He must submit a work program and appropriate bonds which comply with the rules and regulations of that department. His intent must be filed before any drilling is actually commenced. The Division of Oil and Gas is directed by law to enforce various operating standards, including standards with respect to casing and safety devices and environmental protection. Abandonment of a well also requires state approval and restoration of lands. Overseeing these

exploratory and developmental activities is the California Geothermal Resources Board of the Division of Conservation which has general oversight of all agency activities dealing with geothermal resources development in the state.

In accordance with the California Environmental Quality Act of 1970, an environmental impact report must be prepared before any geothermal exploration projects on state lands can be undertaken. The State Land Commission must prepare an appropriate environmental report before granting a prospecting permit. The developer must cooperate in preparation of that report. The environmental impact report is also required at other stages of the development process. It must, under California law, include a description of the environment in the vicinity of the project, an account of the direct and indirect impacts of the proposed project on the environment; it should include specifics with respect to the area resources involved, physical changes, alteration of ecological systems and changes introduced into population distribution, population concentration, human uses of land, and other aspects of the natural resource base such as water, scenic quality, and public services. Avoidable environmental impacts must be described and mitigation measures imposed. The statement must contain a description of the relationship between the local short-term uses of man's environment and the maintenance and enhancement of long-term productivity and any irreversible environmental changes which could result.

In addition to the state environmental impact statement, the developer must also obtain a permit from the appropriate local or regional air pollution control board. If the operation intends to discharge waste waters from the well, the operator must also file a report with the local regional water quality control board. Operations, of course, must not violate air or water control provisions.

With respect to leasing, the California system is similar to the federal law, except that no leases at all are granted upon non-KGRA lands--only prospecting permits are allowed. Lands must be converted to a KGRA before the permittee can obtain a lease. However, the prospecting permittee may obtain a lease without competitive bidding if the land is so classified. The State Land Commission must prepare an environmental impact report before it grants any leases for geothermal development. Once a geothermal lease has been obtained and developmental drilling is contemplated, the developer must go through substantially the same procedures for developmental drilling as are required with respect to exploratory drilling. The same types of information and clearances are required. The Division of Oil and Gas has general regulatory jurisdiction over both developmental drilling and exploratory drilling.

In California, the State Land Commission plays an active role in regulating resource production and utilization on state lands. It can determine the rate of development in production of wells to promote their maximum economic recovery and conservation of resources in each resource basin. All sales of geothermal resources must be approved in advance by the State Land Commission. There must be state approval of generating plants, buildings, structures, production equipment, metering system, pipeline, and roads prior to installation. The Commission has the authority to require production of by-products. Monthly reports must be submitted to the Division of Oil and Gas.

If a developer intends to enter into a contract or construct a power generating plant, additional approvals must be obtained from the California Public Utilities Commission. The applicable statutes and regulations also require an environmental impact report when the plant is

to produce more than 50 megawatts of electric power. Regional or local Air Resource Control Boards and Regional Water Quality Control Boards must also give their permission when any power plant or other plant is likely to emit air contaminants or water contaminants. If the power plants on state lands come under FPC regulation, then they will also have to obtain Federal Power Commission permission. This could occur if they sell power across state lines or sell into a federal power net.

Local government is also involved in regulating those stages of geothermal development likely to present land use problems. California counties, for example, are authorized to minimize the effects that geothermal operations will have on other economic activities and on recreation. They will also check to see that noise is not produced near businesses and homes. It is not clear whether counties will be able to regulate federal lessees operating within their jurisdictional limits. It appears likely that this matter will have to be worked out by consultation between state, federal, and local authorities.

In some instances county regulations are quite extensive. For example, in Imperial County, the county requires a permit for geothermal exploration activities if they involve drilling a well. The county requires indemnity bonds and liability insurance. If the development is to be near populated areas or other areas of existing development, then more stringent regulations are imposed, including the use of sump ponds, noise level limitations, and participation in a subsidence detection program. Minimum distance criteria exist which control well sitings with respect to residences, schools, hospitals, and the like. The closer that the development activity is to existing residences, businesses, or other land uses, the lighter the level of regulation with respect to noise, sound, esthetics, and other possible environmental impacts.

The county also requires permits with respect to buildings upon lands within the county and facilities to produce, process, transport, and sell geothermal resources. The county also has other areas of regulatory jurisdiction. For example, they can regulate the location of power lines, the restoration of environment, the location of collection and sewage pipes, and so on. A summary and comparison of state and federal regulations is presented in Figure 2.4.2.

Private Lands

The leasing of private lands is essentially an individual transaction between the developer and the owner of the land. However, public bodies still play a significant role. The Division of Oil and Gas in California's Department of Conservation has been given power to regulate geothermal operations on private lands. The state sees its role as safeguarding life, health, property, and the public welfare, and encouraging maximum economic recovery of the resource. The regulations issued by the Division of Oil and Gas concerning development on private lands are similar to those applicable to state lands. While no environmental impact statement is required with respect to private lands, these lands are nonetheless subject to jurisdiction of the Air Pollution Control Board and the Regional Water Quality Control Boards in the area. County land use regulations also apply to development on private property.

It is not yet clear how federal and state officials intend to deal with resource pools which underlie state, federal, and private lands at the same time. It appears that some consensus will be required to obtain unitization or drilling agreements with respect to these jointly underlaid lands. It is interesting to note that the

federal regulations provide that when leased lands are being drained of geothermal resources due to activities of developers on non-federal lands, the lessee of the federal lands is required to drill and produce all wells necessary to protect the leased land from drainage, or in lieu of such drilling may pay a compensatory royalty. It is generally conceded to be undesirable that individual federal, state, and private lessees engage in competitive activity, therefore it is anticipated that some resolution of this problem will be worked out on a cooperative basis. State regulations with respect to utility regulation also apply to creation and operation of electric generating facilities on private lands.

Conflicting Regulatory Jurisdiction. State, county, and federal regulations overlap in several areas, and there are several areas of uncertainty with respect to regulatory jurisdiction. Federal lands, of course, lie within both state and county boundaries, but it is not clear that the county or state governments have any authority to bind the Federal Government. California state law purports to exert jurisdiction over federal lands. It is not yet clear that the Federal Government will accept such jurisdiction.

Within the state, there is a comparable problem since it is not clear the extent to which county regulation can overrule conflicting state regulation. Until geothermal development occurs on federal lands, the debilitating effect of overlapping and conflicting regulatory jurisdictions will not be known. At the very least, it appears that the regulatory processes will be quite time consuming, expensive, and to all but the most persevering, discouraging.

Tax Treatment of Geothermal Resources

The taxation of geothermal resources is a problem which has not yet been resolved. Geothermal developers would like to obtain the favorable tax treatment both under federal and state law which is given to hydrocarbon, oil, and gas developers. Oil and gas companies may deduct a percentage (currently 22 percent) of their gross income as a depletion allowance. This allowance is not related to the rate at which the resources are being used up; rather, it is in the nature of a subsidy for the producer. The oil and gas people are also entitled to deduct in a single year intangible costs of drilling and developing wells. These intangible drilling and development costs include the cost to operators of any drilling or development work (excluding amounts payable only out of production and amounts properly allowable to cost of depreciable property) done for them by contractors under any form of contract, including "turnkey" contracts. It is to the advantage of the developer to be able to deduct these so-called intangible costs in a single year rather than have to depreciate them over the life of the resource. In 1969 precedent was established in a significant tax case, *Reich vs. U.S.* [18]. The taxpayers in that case had participated in ventures to develop geothermal resources at The Geysers. They had taken the depletion allowance and intangible drilling expense deductions applicable to hydrocarbon oil and gas.

The court was faced with several different questions. First, it had to determine whether the resource was classified as one of the substances for which the depletion allowance was applicable. In practical terms this meant that the resource had to be classified as a "gas." Secondly, the resource could not be one for which a depletion allowance was specifically denied by the Internal Revenue Code, and, third, the resource had to be one which is exhaustible as provided in the Internal Revenue Code regulations.

TOPIC: OPERATIONS	FEDERAL	CALIFORNIA	ARIZONA	ALASKA	OREGON	NEW MEXICO	IDAHO
SUPERVISOR'S DUTIES (in some cases, title is different, e.g., director, super- visor)	Empowered to re- gulate operations and to perform other duties; approval of plans, operations, etc.	Supervise drilling, operation, mainten- ance of well in a manner calculated to achieve state objectives. Also, to supervise owners, operators of well so as to best ex- tract geothermal resources.	Approves of opera- tion plan bearing in mind objectives of resource devel- opment, and gen- eral environmental protection.	Commissioner's duties are passive, approves or dis- approves of opera- tion plans.	Same as California	Commissioners can prescribe develop- ment program, for best realizing state interests while producing resource, to lessee.	Basically same as California. Objec- tives similar; duties start earlier since jur- isdiction starts from moment appli- cant applies for permit.
DISTRICT DEPUTY	---	Gathers informa- tion for proper supervision of operations.	---	---	---	---	---
SUPERVISOR'S AUTHORITY TO ORDER	Can regulate operations.	Implied in duties the right to order particular methods	Can change approval in emergency, basically a pas- sive supervisor role.	Can suspend or ter- minate for cause, can disapprove of operation plans.	Same as California	Implied that in pre- scribing program, power is similar to supervisor's in California, can suspend production, or terminate for cause.	General supervision.
CONTENTS OF NOTICE OF INTENT TO DRILL	A. Location of well by survey. B. Altitude of ground & derrick. C. Plan of opera- tions, "details of work."	A. Location & ele- vation of floor of derrick. B. Identification & designation of well. C. Estimated depth for production. D. Any further in- formation that supervisor may require.	Commission specifies infor- mation it wants.	---	Same as California	---	A. Names of inter- ested parties. B. Particulars of incorporation if necessary. C. Location of well by survey. D. Operation plan in entirety. E. Purpose of drilling. F. Any further in- formation requested.

Figure 2.4.2 GEOTHERMAL REQUIREMENTS IN SIX STATES
COMPARED WITH FEDERAL REQUIREMENTS

TOPIC	FEDERAL	CALIFORNIA	ARIZONA	ALASKA	OREGON	NEW MEXICO	IDAHO
INTENT TO DRILL	Must first apply to supervisor for a permit to drill.	Must notify deputy 10 days prior of intent to drill	Shall notify commissioner prior to drilling.	---	Must notify supervisor prior to drilling, re-drilling, or widening well.	---	Must apply to dept. for a geothermal resource well permit.
FEES FOR DRILLING NEW WELL	---	\$25 or \$200 or \$500 or \$1000, depending on supervision required.	\$25.00	---	\$25 filing fee with every notice except for prospect well.	---	Filing fees: \$500 for well \$50 for injection well \$50 to amend
PREVENTION OF FIRES AND EXPLOSIONS	---	Where well is operated in area of high or unknown pressure, casings of sufficient strength will be used, as approved by supervisor.	Basically same as California	General duty to conduct operations in a manner calculated to protect environment, avoid waste & pollution.	Same as California	---	In applying for permit, spec's must be given on casing and methods used (to be) for best realizing combination of prod. of geothermal resources while preventing waste & environmental damage of all kinds.
WATERPROOFING	Must meet Federal and State standards on water quality & safety.	Casing shall be watertight & adequate to prevent environment & agricultural damage.	Basically same as California.	---	Basically same as California.	---	---
REMEDIAL WORK	Lessee must provide for restoration of disturbed lands.	Supervisor shall require tests & remedial work to meet objectives of geothermal policy.	---	Same as California	---	---	Dept. may order correction of practices that might cause damage to life, property, under, on, and/or above ground.
STATEMENT OF PRODUCTION	Must file in duplicate each month, last day of, quantity of production and any by-products obtained.	Shall file with supervisor a statement of production on 10th day of each month.	Shall file a statement of production on 25th day of each month.	Lessee must install measuring devices to ensure proper measurement of production.	Same as California	---	---

Figure 2.4.2 (Cont.)

TOPIC: OPERATIONS	FEDERAL	CALIFORNIA	ARIZONA	ALASKA	OREGON	NEW MEXICO	IDAHO
REMOVAL OF CASING	May not make casing tests or alter casing after completion of well without first getting approval of plans from supervisor.	Supervisor must have 5 days notice for written approval. Failure to respond = approval.	---	---	Same as California	---	---
WELL LOCATION AS PUBLIC NUISANCE	---	Within 100 ft. of outer boundary, or 100 ft. of public road, street, or highway, built prior to well commencement, is public nuisance.	---	---	---	---	---
ABANDONMENT OPERATIONS	Lessee must plug & abandon useless or unused wells. Plans, reasons for, proof of reasons for abandonment, must first be submitted to supervisor.	Supervisor must be satisfied that underground & surface waters will not be endangered for irrigation, that fluids will not escape to surface. 5-day notice of intent.	---	Implied that abandonment operation must return area to a "proper condition."	Basically same as California. 24-hour notice.	---	5-day notice to director, must be approved, with a plan giving condition of sight. Must comply with objective of avoiding waste, damage, property, and natural resources.
REPORT BY SUPERVISOR, ETC. ON PROPOSED ABANDONMENT	Supervisor must first approve manner & method of abandonment.	Supervisor, before proposed commenced abandonment, will furnish owner or operator a report giving: A. approval or B. necessary steps to gain approval C. request for information necessary to gain approval.	---	---	Same as California	---	Department may approve or disapprove orally or written, in part or in whole, on proposed operation.

Figure 2.4.2 (Cont.)

TOPIC: OPERATIONS	FEDERAL	CALIFORNIA	ARIZONA	ALASKA	OREGON	NEW MEXICO	IDAHO
DESIGNATION OF AGENT FOR CONTACT FROM SUPERVISOR OR COMMISSION, ETC.	Supervisor may require designa- tion of agent, local, empowered to receive notices & orders of supervisor.	Owner or operator shall designate agent, state resi- dent, for receipt of orders, notices, processes, etc.	---	---	Same as California	---	Same as California
GENERAL LOGS AND RECORDS	Lessee shall keep log records & history.	Owner or operator shall keep core & log record, well history.	Commission may require any infor- mation necessary to supervise.	---	Same as California	Commissioner may require report, samples, logs, assays, or cores as necessary for administration.	Logs, records, and histories may be required by director.
LOG RECORD PARTICULAR	Geologic informa- tion, formation samples, electric logs, temperature surveys, water, steam analysis, heat flow tests, etc.	Character & depth of formation passed through, size & weight of casing, location, depth, & temperature of water bearing strata, & chemical characteristics of fluids encountered.	---	---	Same as California	---	---
CORE RECORD	---	Depth, character, & fluid content of cores obtained.	---	---	Same as California	---	---
HISTORY	---	Location & amount of sidetracked casing, tools, other material, depth & quantity of cement in plugs, dynamite usage, production, tests, & completion data.	---	---	Same as California	---	
PROGRAMMING OF PROSPECT WELLS: INFORMATION IN PLAN	---	Wells numbers, locations & eleva- tions, geological interpretation of area, data required by supervisor.	---	---	---	---	---

Figure 2.4.2 (Cont.)

TOPIC: OPERATIONS	FEDERAL	CALIFORNIA	ARIZONA	ALASKA	OREGON	NEW MEXICO	IDAHO
FEES	---	\$25 per well, \$250 per program, whichever is less.	---	---	---	---	---
APPROVAL BEFORE COMMENCEMENT	---	Supervisor or district deputy must first approve. 10 days of no response equals approval.	---	---	---	---	---
FILING OF LOGS, CORE RECORD, HISTORY, ON COMPLETION, ABANDONMENT, SUSPENSION, ETC.	Within 30 days after completion of each well.	Within 60 days after completion, abandonment, suspension of well, must file data with district deputy.	Must file within 30 days of completion.	---	Basically same as California. 20-day limit to file. Suspension to apply here must have been for 6 months.	---	Director may require such data within reasonable time after well completion.
FILING OF LOGS, CORE RECORD, HISTORY ON REQUEST	---	Supervisor or district deputy can request such data be furnished by personal notice or by registered mail.	Commissioner specifies intervals at which data must be supplied.	---	Basically same as California.	As necessary for administration of Act.	Basically same as New Mexico
REQUEST FOR ORDER, SUPERVISOR'S ORDER, APPEAL	---	If given written direction, owner or agent can request definite order be given within 5 days for purpose of appeal. (Seeming conflict §3743, §3762.	---	---	Same as California	---	Can appeal order within 30 days.
COMMENCEMENT OF WORK ORDERED; APPEAL	Within 30 days after order, adversely effected party may appeal.	30 days after order. 10 days after affirmation of appealed order.	---	---	Order of supervisor must be complied with (commencement of) or appealed within 5 days.	---	---

Figure 2.4.2 (Cont.)

TOPIC: SUSPENSION	FEDERAL	CALIFORNIA	ARIZONA	ALASKA	OREGON	NEW MEXICO	IDAHO
CAUSE FOR SUSPENSION	By application of lessee to secretary, secretary can suspend for conservation reason.	---	---	Application of lessee, conservation interests.	Application in good cause by permittee.	Application of lessee, on motion of commissioner in interest of conservation.	---
EFFECT ON LEASE	Where supervisor approves, rentals or minimum royalties shall be suspended.	---	---	Lease may be extended for period of suspension; rental & royalties may be reduced or waived.	---	---	---
EXTENSION OF SUSPENSION	---	---	---	---	If, before suspension time is up, permittee can get extension by application and show of good cause.	---	---
EFFECT OF FAILURE TO RESUME OPERATIONS	---	If, after suspending operations for 6 months, drilling operations are not resumed or application for extension is made, prima facie case of desertion is created.	---	---	Failure to resume operation within 6 months after suspension ended or suspending production for 6 months without proper application raise presumption of unlawful abandonment.	---	---

TOPIC: ADMINISTRATION	FEDERAL	CALIFORNIA	ARIZONA	ALASKA	OREGON	NEW MEXICO	IDAHO
COMPLAINTS, REPORT & ORDER	---	Upon receipt of specified complaint, supervisor or district deputy must investigate and make a report.	---	---	---	---	---
EFFECT OF REPORT	---	Report may dismiss complaint or state order for corrective measures.	---	---	---	---	---
DELIVERY OR ORDER PURSUANT TO COMPLAINT	---	If corrective measures are necessary, owner, operators, or agents in charge of wells will be delivered each a copy of said order.	---	---	---	---	---

Figure 2.4.2 (Cont.)

TOPIC: CANCELLATION OR TERMINATION	FEDERAL	CALIFORNIA	ARIZONA	ALASKA	OREGON	NEW MEXICO	IDAHO
REPORT BY OWNER/ OPERATOR AFTER ABANDONMENT IS COMPLETED	---	Within 5 days after completion of abandonment operations on work are done.	---	---	Same as California	---	Same as California
REPORT BY SUPER- VISOR, ETC. AFTER ABANDONMENT IS COMPLETED	---	Within 10 days after owner/operator report giving either approval or disapproval with reasons.	---	---	Same as California	---	---
CANCELLATION AND TERMINATION CAUSES	Unexcused failure to pay rent, violation of regulations and failure to timely correct. Supervisor deems operations unsafe or dangerous to environment.	Failure to exercise diligence in search for resources and development and failure to timely correct violations of lease terms.	---	Violation of lease or permit and failure to timely correct. Failure to pay rent when no well is producing. Well where violations do not exist unaffected.	---	Non-payment of rents, royalties; violation of lease terms or conditions	---
REMOVAL OF MATERIALS AFTER TERMINATION	Must be within 90 days after termination (any materials, tools, structures, etc. except for improvement needed for producing wells). After 90 days, lessor may claim property left.	---	---	Reasonable time to remove equipment owned or operated by lessee or permittee.	---	Can remove all equipment & improvements as long as rents & royalties have been paid and premises are not damaged. 2 years for removal.	---

TOPIC: TRANSFER OF INTEREST	FEDERAL	CALIFORNIA	ARIZONA	ALASKA	OREGON	NEW MEXICO	IDAHO
NOTICE OF SALE OR ASSIGNMENT ETC. OF WELL AND LAND BY CONVEYOR	Both parties must file in proper BLM office within 90 days of execu- tion of transfer. If title is as- signed, separate filing must be filed.	Owner or operator must notify com- missioner or dis- trict deputy with- in 5 days after sale, transfer, lease, conveyance, assignment, or exchange, etc.	Same as California Notice time is 10 days.	---	Same as California	Commissioner must approve.	No transfer allow- ed unless an application to amend well permit has first been approved by de- partment.
NOTICE OF PURCHASE, TRANSFER, ETC. BY CONVEYEE OF WELL AND LAND	Both parties must file in proper BLM office within 90 days of execu- tion of transfer. If title is as- signed, separate filing must be filed.	Owner or operator must notify com- missioner or dis- trict deputy with- in 5 days after sale, transfer, lease, conveyance, assignment, or exchange, etc.	Same as California Notice time is 10 days.	---	Same as California	Commissioner must approve.	No transfer allow- ed unless an application to amend well permit has first been approved by de- partment.
INFORMATION NOTICE OF CONVEYOR	Description of lands, terms and conditions in contract.	1. Name & address of conveyer. 2. Name & location of well. 3. Date of trans- action. 4. Date when pos- session was re- linquished. 5. Land description	1. Name & address of conveyer. 2. Name & location of well. 3. Date of trans- action.	---	Same as California	---	---
INFORMATION NOTICE OF CONVEYEE	Description of lands, terms and conditions in contract.	1. Name & address of conveyer. 2. Name & location of well. 3. Date of acqui- sition. 4. Date of posses- sion. 5. Land description	1. Name & address of conveyer. 2. Name & location of well. 3. Date of acqui- sition. 4. Date when oper- ations are as- sumed or resum- ed by new owner.	---	Same as California	---	---
PROGRAMMING OR PROSPECT WELLS	---	Must submit plan to supervisor to drill wells for observa- tion; program.	---	---	---	---	---
LIMITATIONS	---	25 wells per pro- gram, 250 ft. depth limit.	---	---	---	---	---

Figure 2.4.2 (Cont.)

The opinion of the court dealt largely with the physical nature of the resource. It determined that with respect to The Geysers area the resource existed in the ground as superheated steam and at no time was in a liquid water form. This was an important determination since the Internal Revenue Code explicitly prohibited a depletion allowance for water. The court held that water was intended to have its common meaning of liquid H₂O rather than its chemical meaning of H₂O in all states. The court therefore held that the steam in The Geysers was not water and, secondly, that it was a gas and, therefore, if the third condition were met, entitled to a depletion allowance.

The third condition is that the resource be exhaustible. The argument was made by the U.S. Government that The Geysers steam reservoir was constantly being replenished by groundwater and that the heat of the earth was turning this water into steam, and as long as the heat of the earth remained, the resource was, in essence, inexhaustible. The taxpayers argued that at The Geysers there existed, underground, a steam reservoir which through a slow geologic process had become sealed off and incapable of replenishment. They also argued there was no water in this reservoir so that the steam was being taken from a closed volume and was gradually being depleted. There was evidence as to reduction of pressure of steam at The Geysers offered on behalf of the taxpayers.

The Court agreed with the taxpayers' contention and concluded that with respect to the facts of the situation at The Geysers, that the resource was exhaustible and was a gas, and therefore the developer was entitled to a deduction of 22 percent depletion allowance and was entitled to deduct his intangible drilling costs in a single year rather than amortizing them over the life of the project.

The Reich case was limited to its own facts by the Court of Appeals. That is to say it does not apply generally to all geothermal resource developers. The Court relied heavily on the specific geologic structure of The Geysers area and the fact that it contained a closed volume of steam. The finding would not, for example, apply to an area where there is a wet basin characterized by an active groundwater system. The result of the case has been that developers of geothermal resources in an area other than The Geysers are not certain at this time whether they may, in fact, claim the depletion allowance and deduct their intangible drilling expenses in a single year. Because of the limitation of the case to its own facts, it is anticipated that there will be considerably more litigation with respect to depletion allowance and expense deduction with respect to geothermal resource development, and, second, there will be considerable pressure on Congress to define an appropriate scheme of tax or other subsidy to the infant geothermal resource development industry [19].

The problem is not limited to the federal tax laws. There are state, business, income, and franchise taxes which also depend upon the characterization of the resource as a gas. These taxes should also be re-examined in light of the economic and institutional necessities for development of the geothermal resource industry and appropriate rules adopted.

An Experience With the Leasing Process

In order to become more familiar with the leasing process, in practice as well as in theory, Michael Belzer, a third-year student at the University of Connecticut School of Law, was asked to submit a

lease bid in the January 1974 competition and to write a description of his experiences. His report follows.

On January 22, 1974, I bid \$1394 for a tract of land in California known as "Geysers KGRA, Lease Unit" which had been released for competitive bidding by the Bureau of Land Management in Sacramento, California.

The bidding process was really quite simple since all that was required was the filling out of a simple form, bidding at least the minimal amount acceptable per acre, and submitting a certified check for one-half the amount bid. Under the Federal Rules and Regulations, no filing or application fee was required. Moreover, I was able to submit my bid by mail. Thus, the dollars and cents cost of bidding was \$1.82 for the registered letter, plus the interest value on \$697, from the time the certified check was made out, approximately January 18, 1974, until the check came back, on March 1, 1974. This convenience would seem to encourage participation in the bidding system, since a qualified bidder can submit his bid from any place on earth as long as it arrives at the proper Bureau of Land Management office in time.

I should note that I did not expect to win the bid. When William Buckley ran for mayor of New York, he was asked what he would do if elected. He supposedly replied that he would ask for a recount. If my bid had carried the day, my sentiments would have been quite similar. At any rate, to ensure against winning the bid, I bid the absolute minimal amount permitted on a piece of land which I knew had the interest of another party, since it was subject to so-called "grandfather" conversion rights. In the notice of the lease bidding, descriptions of each lease unit were given. Under some of the land descriptions, names of people or corporations were given which owned conversion rights on that particular unit. As will be discussed, that interest would have had great significance if I had chosen to submit a truly competitive bid. The owner of the right to convert to a geothermal lease would have had 30 days to match a higher bid. Doing so would give him the right to the lease if otherwise qualified.

As it was, my bid of \$1394 on the 697 acres lost to Signal Oil and Gas Company, which bid \$56,666.

Interestingly, the bid was taken and opened on January 22, 1974 with all the other bids, and while I learned through second-hand sources that I had been out-bid, I did not get direct word from California until March 1, 1974, when my check was returned along with a letter informing me as to who made the winning bid and how much was the winning bid. This represented 41 days, during which funds were tied up. In my case, this represented no great hardship since the amount bid was relatively small. A bid of larger magnitude, say, several hundred thousand dollars or more, will increase the cost of submitting a bid; perhaps making it a significant factor.

I should note here, and will discuss later, once a bid has been accepted, all other bids are considered rejected. However, the officer reviewing the bids has the right to reject any

or all bids. This could have considerable impact on the bidder whose bid came in second.

While my experience represented a starting point, in many senses it just scratched the surface. It did not cover non-competitive leasing, it did not cover all aspects of competitive bidding, nor did it cover all aspects of the matter on conversion rights.

Figure 2.4.3 summarizes the results of the competitive bidding in January 1974.

FEDERAL GEOTHERMAL LEASE SALE

JANUARY 22, 1974

BIDDING RECAP

TOTAL MONEY EXPOSED (ALL AREAS)	\$12,499,494.60
TOTAL OF HIGH BIDS (ALL AREAS)	6,812,679.79
AVERAGE BID/ACRE (ALL AREAS)	290.54
AVERAGE BID/ACRE GEYSERS K.G.R.A.	631.00
AVERAGE BID/ACRE MONO-LONG VALLEY K.G.R.A.	115.00
AVERAGE BID/ACRE EAST MESA K.G.R.A.	71.00

FEDERAL GEOTHERMAL LEASE SALE

JANUARY 22, 1974

MAJOR BIDDERS

SHELL OIL
THERMOGENICS, INC.
UNION OIL
SIGNAL OIL & GAS
OCCIDENTAL PETROLEUM CORPORATION
CHEVRON OIL COMPANY
GETTY OIL COMPANY
MONO POWER COMPANY
REPUBLIC GEOTHERMAL

Figure 2.4.3

Several statements are required by the applicant for a lease. They include a statement of citizenship and that the applicant's interests, direct or indirect, in federal geothermal leases does not exceed the acreage limitations outlined in S3201.2 of the lease. Violation of this regulation could result in automatic rejection of the bid, or eventual forfeiture of the lease(s) which brought the applicant over the limit (20,480 acres in any state, 10,240 acres through conversion of mineral leases, permits, applications or claims).

Additionally, an association or corporation must show with its application (1) authority to hold a geothermal lease; (2) authorization of the officer executing the lease application; (3) state of incorporation along with the names and addresses of 10 percent-plus stockholders, owners, and interests in the corporation; (4) a statement from each person owning or controlling 10 percent, plus, giving his holding and citizenship.

Requirement (4) above raises the possibility of a minority stockholder thwarting the

majority wishes of the stockholders and owners by refusing to give a statement. Even if the corporate by-laws dealt with the matter, one could prevent the corporation from making the bid in a timely manner.

A municipality or governmental unit application must include (1) authority to hold leases, (2) authority of officer executing application, and (3) a copy of the regulation by which the government unit authorized such action.

Primarily, land can be leased on two bases: non-competitive and competitive.

An application for a non-competitive lease (one that does not involve KGRA) must be filed in duplicate at the BLM (Bureau of Land Management) for public lands, and in triplicate for acquired lands.

Figure 2.4.4 summarizes the non-competitive lease applications on federal land through January 31, 1974.

FEDERAL GEOTHERMAL NON-COMPETITIVE LEASE APPLICATIONS

PERIOD ENDING JANUARY 31, 1974

STATE	NUMBER OF APPLICATIONS	NUMBER OF APPLICANTS*	ACREAGE
CALIFORNIA	528	200	1,071,277
OREGON	458	61	1,003,691
NEVADA	433	58	907,248
NEW MEXICO	274	50	637,073
IDAHO	265	83	582,590
UTAH	207	30	453,548
WASHINGTON	151	41	344,000
COLORADO	64	14	125,906
MONTANA	55	8	105,444
ARIZONA	18	3	42,783
WYOMING	3	3	6,973
	2,456		5,280,534

*INCLUDES OIL COMPANIES, GEOTHERMAL COMPANIES, A STATE UNIVERSITY, A RURAL ELECTRIC COOPERATIVE, AND A NUMBER OF INDIVIDUALS. MANY HAVE FILED IN MORE THAN ONE STATE.

Figure 2.4.4

The application is submitted in a sealed envelope with the following information on it:

1. "Application for lease pursuant to 43CFR 3210."
2. Name and address of applicant. On the application the following: name and address of the applicant, statement of citizenship, and qualifications.
3. An accurate description of the land from a survey, or if not available, by metes and bounds.
4. A plan including maps, makeup of land, topography, pertinent land conditions, narrative on proposed exploration, and steps to be taken to prevent damage to the environment.

5. Statement of citizenship.

6. Compliance with acreage limits.

One will note that, whereas a competitive bid requires little more than the bid itself, a non-competitive application for a lease requires much advance preparation.

Not that a non-competitive lease is a sure thing! First of all, the earliest application in the filing period (30 days) will have priority. Moreover, if the land area applied for is overlapped by one half or more, a competitive interest is created which in effect causes the overlap to be treated constructively as a KGRA, and, thus, not subject to a non-competitive application.

In an application including a KGRA, an opportunity to amend to just non-KGRA is allowed with priority assigned according to the original lease date.

An application submitted simultaneously to another for the same land is decided by a public draw.

One can withdraw his application provided the request to the BLM arrives before the application has been signed on behalf of the United States.

If land applied for properly is not included in the lease for any reason, and later becomes available, the original lease will automatically amend to include that land unless a withdrawal is first submitted or the land is KGRA. This would seem important where a lessee, having given up on leasing a tract of land, reallocated his resources not used on the land he did receive, only to find himself later "stuck" with a piece of land he no longer wants nor can properly develop.

The issuance of a lease cannot be made before considering (1) prior application(s), (2) subsequent applications based on preferential rights, and (3) petition for renewal or reinstatement of an existing or former lease.

Finally, before a lease is issued, a final determination as to whether a KGRA is involved. KGRA parts of the application are rejected, as are applications on lands reclassified as KGRA between the time of filing and issuance. Non-KGRA parts of application retain validity.

Another type of non-competitive leasing involves the releasing of land formerly leased. The BLM must give notice in the Federal Registrar when such lands become available: (1) a listing of the units, (2) time for application, and (3) place to apply, terms, and conditions. For this type of lease, only one lease unit per application is allowed.

Within 15 days of acceptance the applicant must furnish a plan of operation. The application period is 30 days; all applications submitted within that period are treated as simultaneous.

The application envelope must be marked "Application for a lease pursuant to 43CFR

subpart 3211." Here, a \$50 application fee, service charge for each unit bid for, is included. While a plan is not immediately required, the accepted applicant must pay his advance rental within 15 days or else the applicant with the next highest priority gets consideration.

Competitive leases involve bidding on lands which have been determined to be KGRA. This can happen by several ways. The Geological Survey, a federal agency, can declare certain lands to be KGRA on the basis of evaluating the land. As mentioned before, a competitive interest on a piece of land originally offered non-competitively as a non-KGRA can create a KGRA. Also, before issuance of a lease on a non-competitive land, a final determination as to whether a KGRA is involved is made.

The leasing process on a KGRA is very simple. The process goes into motion when the Secretary of Interior (or his agent) based on information given him by the Geological Survey and other government agencies, decides to offer KGRA for competitive bid leasing.

The Secretary gives notice by publication in a newspaper, published in an area near the KGRA, the following information:

1. Time and place of bidding.
2. Manner of bidding.
3. Description of land.
4. Terms and conditions of sale.
5. Proper BLM to which bids should be submitted.
6. Notice that a proposed plan of operation is necessary before the lease will be issued.
7. Where applicable, after each unit description, the names and addresses of those holding conversion rights (to be discussed) of mineral leases on the land.

On the envelope for the bidding must be "Bid for Geothermal Resources Lease in (name of KGRA)." Inside the envelope must be a description and identification of the lease unit bid upon; only one lease unit can be bid for in any one envelope. A statement of citizenship and qualifications to hold a lease is included in the bidding form. The amount of the bid must be indicated along with a certified or cashier's check, bank draft payable to the BLM, or cash or money order equaling one-half the amount bid.

At the same time specified in the notice, all bids are broken open and the highest qualified bidder gets the lease except where conversion rights permit the owner of those rights 30 days in which to match the highest qualified bid.

The authorized officer has 30 days during which he can reject any or all bids. Once a bid is accepted, though, all other bids are rejected for all intents and purposes. If the accepted bidder fails to comply with the rules and regulations (i.e., execution of lease, advance payment of rental and balance of bid, file bonds,

submit operation plan), he forfeits. The land then goes back to the status of a KGRA, possibly to be reoffered in the future.

Summing the above up, it would seem that until the highest bid is accepted as being made by a qualified bidder and no other extenuating circumstances crop up, all the other bids remain in contention. Once a bid is accepted, the losers no longer have to think about the matter; their deposits are returned eventually and they can start making new plans.

At times, I have mentioned the phrase, "conversion rights." This is an important phrase and can be explained in its several aspects without too much difficulty. When I bid on the piece of property in California, that piece was subject to the conversion rights of the Signal Oil Company. In my case, it meant that, even if mine had been the highest qualified bid, the owner of the conversion rights would have had 30 days to match my bid, and, thus, get the bid.

Conversion rights involve leases, permits, and applications valid on September 7, 1965, issued under the Mineral Lease Act of 1920, 30U.S.C. 181-287, 351-358.

If someone applied for a mineral lease under the 1920 act on or before September 7, 1965, he could convert the application to one for a geothermal lease and get priority by having it dated by the original application date. This would not help where a KGRA was involved but for a non-competitive bid, this could be decisive.

Where someone actually owned a lease, on September 7, 1965, on a piece of property classified as a KGRA, his rights would not hold off a bid. He would have 30 days, if needed and wanted, to top the highest bid. The lease owner must bid if he wants the geothermal lease conversion. Even if no one else bids, if he does not, he forfeits his conversion rights.

Those who wanted to convert their leases of applications had to apply on or before June 22, 1971.

Where a non-KGRA is involved, the owner of a convertible mineral lease only has to apply, and if qualified to hold, his lease becomes a geothermal lease.

In choosing land for leasing, knowledge of conversion rights owners should have a high priority, especially where a KGRA is involved since here you could have your funds tied up for a considerable time. For example, your bid is read, let's say, on January 22, 1974. The owner of the conversion lease right can wait 30 days and then top your bid. Then the officer who evaluates the bid could take up to 30 days to decide if the bid is acceptable. Finally, the losing bids must be processed and returned. In other words, one could have a lot of money tied up for over two months with absolutely nothing to show for it.

REFERENCES

[1] Act of May 10, 1872, 17 Stat. 19, now codified

largely in 30 U.S.C., Sec. 21 et seq.

- [2] Mineral Lands Leasing Act, 41 Stat. 4371, now codified with amendments in 30 U.S.C., Chs. 2 and 3.
- [3] Materials Act of 1947, 61 Stat. 681, as amended 30 U.S.C. 601 et seq.
- [4] U. S. Public Land Law Review Commission, One Third our Nation's Land (Washington, D.C.: U.S. Government Printing Office, 1970).
- [5] U. S. Public Land Law Review Commission, One Third our Nation's Land (Washington, D.C.: U.S. Government Printing Office, 1970), pp. 121-138.
- [6] A small number of articles and papers have addressed the legal aspects of geothermal resource development including those applicable to water and mineral law. The following is the bulk of the small literature on the subject:

Allen, Donald, "Legal and Policy Aspects of Geothermal Resource Development," Water Resources Bulletin, Vol. 8, No. 2 (April 1972), pp. 250-255.

Brooks, John W., Jr., "Legal Problems of Geothermal Industry," Natural Resources Journal, Vol. 6, No. 4 (October 1966), pp. 511-541.

Olpin, Owen, "The Law of Geothermal Resources," Rocky Mountain Mineral Law Institute, Vol. 14 (1968), pp. 123-165.

Note, "Acquisition of Geothermal Rights," Idaho Law Review, Vol. 1, No. 1 (1964), pp. 49-67.

Abbott, George W., Address to Rocky Mountain Minerals Conference, Society of Mining Engineers of AIME, Salt Lake City, Utah, September 11-13, 1963.
- [7] Desert Land Acts, 43 U.S.C., Sec. 321 et seq.
- [8] FPC v. Oregon, 349 U.S. 435 (1955).
- [9] Pickett Act, 16 U.S.C., Sec. 471; 43 U.S.C., Sec. 141 et seq.
- [10] Mineral and Medicinal Springs Act of 1925, Act of March 3, 1925, 43 Stat. 1133, 43 U.S.C. 971, implemented by Executive Order No. 5389, July 7, 1930.
- [11] State Ex. Rel. Bless v. Dority, 55 N.M. 12, 225 P.2d1007 (1950), App.dism. 341 U.S. 924 (1951).
- [12] U.S. v. Union Oil Co. of California, U.S. District Court, Northern District of California (October 1973; civil No. 72-1866 GBH).
- [13] Stock Raising Homestead Act, 43 U.S.C., Sec. 291 et seq.
- [14] Geothermal Steam Act of 1970, 30 U.S.C., Sec. 530, 1001 et seq. (Hereafter referred to as the Act.) All text references are to section numbers of the original Act appearing in 84 Stat. 1566 et seq.
- [15] Desert Land Acts, 43 U.S.C., Sec. 321 et seq.
- [16] Multiple Use Law, 30 U.S.C., Sec. 521 et seq.
- [17] This section was drawn directly from a paper pre-

pared by Thomas H. Cahrman, entitled "The Inter-relationship between Federal, State and Local Regulatory Agencies on the Development of the Geothermal Resource in California," which was presented at a geothermal conference in California in April 1973. In some instances, direct quotations were made from this paper, but the quotation marks were eliminated to preserve continuity of the text. Full indebtedness to Mr. Cahrman is acknowledged.

- [18] U.S. v. Reich, 52 Tax Court 700 aff'd 454 F2d1157 (9th Cir., 1972).
- [19] H. R. 13856, introduced on April 1, 1974, would amend the Internal Revenue Code to extend the deductions for intangible drilling and development expenses and for depletion to geothermal resources.

2.5 Overview of Environmental Considerations

The technical aspects of alleviating the environmental impacts that result from the commercial development of geothermal resources are summarized in this section in terms of land use, gaseous emissions, waste disposal, groundwater contamination, heat rejection, land subsidence, noise emissions, induced earthquakes, safety, fog plumes and aesthetics [1, 2]. More thorough and quantitative discussion of the potential environmental impacts which may result from the development of geothermal resources is contained in Section 4.8 of this report.

Land Use. In terms of land surface area occupied, the geothermal power plants themselves use no more space than other types of power plants. However, the wells may be widely scattered, requiring an extensive gathering system of feeder pipes and trunk lines to convey the effluent (steam and/or water) to the plant. It is feasible to use the land occupied by the wells and gathering systems for compatible types of agriculture such as orchards, or animal grazing; this is being done in the geothermal fields at Larderello, Italy. A necessary adjunct to any electric power generation station is the electric transmission lines leading to the load centers, which occupy dedicated rights-of-way. Apart from the land surface occupied, the question of conflict of land use has arisen from time to time. Geothermal reservoirs are often located in remote or primitive areas which have historically been used for recreational purposes. Introduction of an industrial plant into such an area is a marked departure from the preexisting land usage and, in general, does not enhance the recreational value of the region.

Gaseous Emissions. Geothermal effluents carry a variety of noncondensable gases, either in solution in the liquid phase, or as a gas mixed with the steam. The most common and abundant species are carbon dioxide (CO_2), hydrogen sulfide (H_2S), ammonia (NH_3), and methane (CH_4). Release of CO_2 to the atmosphere is relatively harmless. However, H_2S diluted by the atmosphere can be a significant nuisance because of its objectionable odor, and a potential danger to human and animal life when in high concentration. Methods are currently being developed for chemically oxidizing the H_2S while in solution and disposing of it as a solid precipitate. However, this approach is being developed specifically for The Geysers plant and may not be transferable to other sites. Incineration of the H_2S , possibly at each wellhead, has also been proposed as a possible solution, but its practicality has not yet been demonstrated. Methane is in solution in substantial amounts in the liquids of most geopressured zones, and boils out of solution when the pressure is released. Methane is an energy source itself (21,120 Btu/lb), and it has been proposed in some cases that it be burned, possibly in a gas turbine, as an adjunct to the geothermal energy conversion process. Radon 223 has been detected in very small quantities in isolated cases.

Liquid and Solid Waste Disposal. In general, liquid wastes from geothermal plants are charged with dissolved solids such as sodium chloride, calcium chloride, potassium chloride, boron, arsenic, and other chemicals in a wide range of combinations and concentrations, which in most instances preclude direct disposal into natural water bodies or water courses. Presently, the most acceptable and commonly used disposal method is to re-inject the liquid waste back into the geological formation at a depth and stratum which, hopefully, will not permit contamination of surface and groundwaters. Disruption of the integrity of groundwater aquifers can permit migration of higher-pressure saline fluids into zones of sweet groundwater, producing cross-contamination of one aquifer by another. Much investigation and experimentation remains to be done to develop construction and operating methods as well as monitoring techniques

to assure that groundwater contamination does not occur. Although the sale of mineral salts would be an ideal method for disposing of such solid wastes, their extraction has not proved economical to date. Mineral extraction would require construction of processing equipment, storage facilities, evaporation ponds, and other ancillary facilities. Landfill disposal of insoluble precipitates has been proposed, but this does not appear to be a viable solution for readily-soluble chloride salts. No universally acceptable method for disposal of solid wastes, such as precipitated salts and chemically precipitated sulfur (from H_2S), has been identified.

Surface and Groundwater Contamination. Surface and groundwater contamination would result from geothermal operations in which solid wastes or mineral-charged liquid wastes were discharged into natural water courses or water bodies. Avoidance of these problems is often a matter of good housekeeping practices during drilling operations and provision for adequate disposal of liquid and solid wastes. Liquid wastes can be reinjected deep into the formation. Disposal of solid wastes has not yet been fully solved; appropriate solutions are dependent upon the particular constituents involved. A thorough knowledge of the formation in which the drilling is being conducted and well-engineered casing and cementing operations are required to prevent inter-aquifer contamination.

Heat Rejection. Heat rejection is an essential feature of all thermodynamic power cycles, including those used in geothermal power plants. Any of the conventional heat rejection methods can be applied, but the most common method used to date has been the evaporative cooling tower. Because of their inherently low overall conversion efficiency, geothermal power plants reject a higher percentage of heat than do fossil-fueled or nuclear plants. Typical overall plant efficiencies for geothermal power plants have been in the range of 10-14 percent, due to the relatively low initial temperatures and pressures of the steam and/or hot water. It should be noted that vapor dominated plants such as The Geysers in California and Larderello in Italy produce all the water required by their evaporative cooling towers by condensing steam and do not draw upon local water sources. However, hot dry rock or magma plants may require a continuous supply of water unless effective dry cooling towers can be designed.

Land Surface Subsidence. Land surface subsidence has been noted in some oil and gas fields. Where it occurred, it was due to massive withdrawal of gas and crude petroleum without application of appropriate preventive measures. Land surface subsidence can also be caused by massive withdrawal of geothermal fluids from liquid-dominated systems. This has occurred at Wairakei, New Zealand. Presumably, it could occur in a similar manner in geopressured zones. On the other hand, subsidence has not been observed at vapor-dominated sites such as The Geysers, California and Larderello, Italy [3].

Subsidence is a long-term phenomenon which does not occur suddenly. Re-injection of waste liquids or substitute liquids (such as brackish water) on a one-for-one volume basis has been proposed as a preventive measure. In the case of geopressured zones, re-injection would have to be into aquifers of relatively shallow depths and low pressure, otherwise there would be no net gain of extracted energy. Extraction of heat from a hot dry rock formation will cause a gradual temperature decline of the formation and, therefore, a thermal contraction of the rock. It is not known at this time whether subsidence can be caused by this effect. Monitoring and detection of subsidence is accomplished by setting up a system of precise leveling benchmarks

within the affected area and reference controls outside the affected areas. Periodically, sets of leveling measurements are made to determine the degree and extent of any settlement or horizontal movement.

Noise. Noise emissions from geothermal operations are most serious and prevalent during drilling of vapor-dominated wells, which are usually drilled with compressed air as the drilling fluid (instead of drilling "mud"). When the well is being blown for cleanout, there is sudden release of compressed air and natural steam, resulting in very intense noise. Specialized muffling devices are being developed to hold these noise emissions within acceptable limits. Compounded "drilling muds" are used for washing out the cuttings when drilling liquid-dominated wells and the same noise problem does not exist. Under normal operating conditions, noise emissions from the geothermal power plants themselves are no different than from any other steam power plant, and are within acceptable limits.

Induced Earthquakes. Minor earthquakes have been triggered in a number of instances by injection of high pressure fluids into the geological formations [4]. These occurrences were not associated in any way with geothermal developments. However, the implication is clear that a problem may result from reinjection of liquid wastes, reinjection to control land surface subsidence, or injection of liquids to exploit a hot dry rock field. Recent experimental work by Dr. Barry Raleigh of the USGS near Rangely, Colorado, indicates that injection may trigger minor earthquakes if there is hydraulic communication with an active fault zone. [5] Although additional investigation and confirmatory work are needed, it is fairly clear that reinjection operations should avoid active faults.

Safety. Problems of public safety and safety of geothermal workers are moderate to minimal, in comparison with other similar industries. In general, these operations are subject to federal and state industrial safety codes. One problem peculiar to geothermal operations is the possibility of a well blowout, which is a failure of the well casing and attendant valving to contain the pressure, resulting in the casing being blown out of the well. It is expected that adherence to long-established safe drilling, casing, and cementing practices will virtually preclude this type of accident.

Fog Plumes. Evaporative cooling towers associated with geothermal power plants, like all evaporative cooling towers, will develop fog plumes under certain conditions of atmospheric temperature and humidity. For geothermal plants this poses no problem except possibly one of aesthetics, where the cooling towers are not large and are widely dispersed. Minor weather modification is of some concern where dense clustering of cooling towers over a sizeable region is contemplated.

Aesthetics. The problem of preserving the aesthetic values of an area in which an industrial facility is being constructed is essentially the same for a geothermal plant as for any other type of plant. In this respect, problems peculiar to geothermal plants would include the appearance of an extensive piping system for gathering geothermal steam and water and for returning the reinjected liquid wastes. It is technically feasible to bury these insulated pipes and their valving and thermal expansion loops; however, this would greatly increase the capital costs.

REFERENCES

- [1] Muffler, L.P.J., "Geothermal Resources," U.S. Geological Survey, Professional Paper 820 (1973).
- [2] Bowen, R.G., "Environmental Impact of Geothermal Development," in Kruger and Otte (eds.), Geothermal Energy (Stanford, Calif.: Stanford University Press, 1973). (Hereafter called Bowen, 1973.)
- [3] Bowen, 1973.
- [4] Healy, J.H., et al., "The Denver Earthquakes," Science, Vol. 161 (1968), pp. 1301-1310.
- [5] Raleigh, C.B., "Earthquakes and Fluid Injection," Underground Waste Management and Environmental Implications, Memoir 18 (American Association of Petroleum Geologists, 1972).

3. HOW GEOTHERMAL ENERGY MAY EVOLVE IN THE UNITED STATES

3.1 The Technical Inquiry

The geothermal energy industry is in its infancy in the United States. Foreign experience, operating data collected at The Geysers, engineering estimates for other systems, and informed speculation all indicate that the infant industry may well have an important, perhaps vital, future in furnishing energy in the decades ahead. The study began by defining the nature of the technology on which this industry depends, the technological impediments which, if uncorrected, might block its growth, the means available to overcome the impediments, and the range of energy production levels which might possibly be expected from this source. Several analytic tools were employed in the pursuit of these objectives:

1. A technical relevance tree was constructed depicting in detail the elements of geothermal technology. The purpose of this activity was to help assure that all important subsystems and components were considered.
2. A set of sequenced interviews involving a broad spectrum of well-informed individuals throughout the geothermal industry was conducted to solicit opinions about the seriousness of individual impediments, forecasts about when the impediments could be substantially removed, and the types and quantities of inputs (in terms of capital, manpower, or material resources) which would be required to effect the removal of the impediments.
3. Energy system diagrams were produced to help synthesize judgments about technologically feasible levels of geothermal resources development as functions of time, resource type, and research and development programs.

These elements of the technological inquiry are discussed in more detail below and in Appendix A.

The Technological Relevance Tree

A relevance tree is a hierarchical structure; at each level in the structure, mutually exclusive elements are displayed which, in the aggregate, completely define the next higher level. In effect, a relevance tree is merely an outline, and it should conform to the same rules of development. A relevance tree, properly accomplished, requires that the analyst explore alternative ways of making the structure of his topic explicit and in doing so helps assure that the topic itself is defined to the appropriate level of detail. In this case, the relevance tree formed a systematic, visual framework for describing geothermal technology, and aided in identifying impediments to the development and utilization of geothermal energy. The relevance tree which was produced in this task is displayed in Appendix B.

The relevance tree was limited to the technologies involved in exploration, development, utilization, and environmental aspects of geothermal systems, and at its lowest level, specified major system components such as steam turbines or specific techniques such as resistivity measurements used in exploration. While the inquiry included consideration of process heating, space heating and air conditioning, water desalination, and mineral extraction, the emphasis was on electrical energy production.

The relevance tree consists of six levels, with each succeeding level describing the preceding one in greater detail. These levels were built by answering the six questions shown in Figure 3.1.1 below.

RELEVANCE INTERROGATION	
LEVEL I	WHAT NATURAL RESOURCES ARE AVAILABLE?
LEVEL II	WHAT PRIMARY ENERGY FORMS CAN BE DEVELOPED FROM THESE NATURAL RESOURCES?
LEVEL III	WHAT MAJOR TECHNOLOGIES ARE ASSOCIATED WITH THE DEVELOPMENT OF THESE ENERGY FORMS?
LEVEL IV	WHAT APPLIED TECHNOLOGICAL AREAS ARE INVOLVED IN THESE MAJOR TECHNOLOGIES?
LEVEL V	WHAT SYSTEMS, PROCESSES, OR METHODS ARE INVOLVED IN THESE APPLIED TECHNOLOGICAL AREAS?
LEVEL VI	WHAT MAJOR COMPONENTS COMPRISE THESE SYSTEMS AND PROCESSES, OR WHAT SPECIFIC TECHNIQUES ARE USED IN THESE METHODS?

Figure 3.1.1

Geothermal energy itself comprises level one. At level two, five classes of geothermal resources are identified: vapor-dominated, liquid-dominated, hot dry rock, geopressured, and magma. At the next level, each class of resource branches into four major subsystems of the technology: resource exploration and appraisal, reservoir development and operation, resource utilization, and environmental systems. Figures 3.1.2 through 3.1.5 on the following page illustrate one particular branch of the tree (components involved in field surveys, aerial surveys, and subsurface investigations germane to geologic methods of resource exploration and appraisal of vapor-dominated resources).

The work involved in building such a structure is a task which requires much time and the strenuous mental effort of a group of technical people. However, the explicitness and organizational thinking demanded by this task led to a level of precision and completeness in later work which would have been difficult to achieve in other ways. At level six, the questions could be asked: Where do we stand with respect to these components? What impediments are likely to develop as the technology moves forward?

As technical impediments to geothermal development and utilization were identified, they were assigned specific numbers which were cross-referenced to the relevance tree.

Interview Sequence

This task began with the formulation of a preliminary impediment list. In this context, an "impediment" is defined as any technical condition or deficiency which will materially impede the development of geothermal resources in the United States to its fullest potential within the next 25 years or so. An example of an impediment would be lack of adequate definition of the location, distribution, energy content and class segregation of the natural resource, or lack of a demonstrated method for continuous recovery of thermal energy from hot dry rock reservoirs. It should be noted that the impediments considered in this portion of the inquiry dealt only with technical problems and were not concerned with legal, institutional, societal, or other aspects of technology; these questions are treated elsewhere in the study.

The preliminary impediment list was compiled from inputs of consultants to the study team, members of the team itself, and a detailed review of the literature. The relevance tree provided an important means of checking the impediment list. This preliminary list formed a major input to the technical interviews. In essence, the geothermal consultants were asked to modify and

Figure 3.1.2

Figure 3.1.3

Figure 3.1.4

(To Point (A) Figure 3.1.4)

Figure 3.1.5

extend the list and to contribute ideas as to how the impediments which were either provided to them or which they themselves added might be overcome.

Early in this task, the impediment list was divided into four categories, called subsystems, as follows:

1. Resource exploration and appraisal.
2. Reservoir development.
3. Energy conversion.
4. Environmental technology.

The first of these included all identified impediments associated with gross and localized exploration, and exploratory drilling and data gathering for the purpose of discovering and appraising the extent of a reservoir in the energy content, quality, and distribution.

The second category included all impediments relating to the commercial development of identified reservoirs, including production drilling, formation fracturing, fluid injection, installation of well casing and well-head valving, and gathering systems.

The third category included the technical impediments which inhibit the manufacture and construction of all above-ground facilities from the gathering system discharge forward through the energy conversion or mineral recovery plants.

The fourth category encompassed the technical impediments to the alleviation of the adverse environmental effects which may follow from exploration for utilization of geothermal resources.

These impediments were reviewed in interviews by a selected group of experts in geothermal technology and the geothermal industry.

Candidate interviewees were chosen because of their widely-recognized knowledgeability about one or more of the impediment areas. The criteria for "knowledgeability" in this context were the extent to which an individual had published on a particular topic related to one or several impediments, or whether the individual was known to be actively engaged in a particular segment of industry which put him in a "position to know" with respect to forecasting the status of given impediments. Figure 3.1.6 on the following page summarizes the participants and their affiliations.

Prospective participants were first contacted by telephone. The initial response, in every case, was favorable and often reflected considerable enthusiasm. Of the 31 prospective interviewees solicited, only one declined (conditionally) at the outset, and six additional individuals who originally agreed to act as interviewees either declined subsequently or failed to respond. Consultants to Bechtel Corporation in this portion of the study also acted as interviewees on certain specific impediments.

Interview Procedure

After ascertaining that the prospective interviewee would, in fact, like to participate, a selected group of questionnaires was mailed, accompanied by an introductory cover letter and a supplementary sheet which defined the essential terms and presented an example of the types of answers desired. (Appendix A includes examples of these documents.) The cover letter included an approximate date by which the interviewee would be recontacted for the purpose of discussing the questionnaire and soliciting replies. During the course of the initial phone contacts, the study team promised to supply all participants with a summary of the results of all of the interviews. This inducement to participate was confirmed in the cover letter. Additionally, each prospect (also confirmed in the cover letter) was assured that their contribution would remain anonymous, if they so desired; that is, no

Mr. David M. Anderson Geothermal Officer Department of Conservation Division of Oil and Gas State of California	Dr. Paul Kruger Professor of Civil Engineering Stanford University
Mr. Winston H. Bishop Vice President, Marketing General Ener-Tech, Inc.	Mr. James T. Kuwada Vice President Rogers Engineering Company, Inc.
Dr. David D. Blackwell Adjunct Professor Southern Methodist University	Dr. Alan D. K. Laird Professor of Mechanical Engineering University of California
Dr. James B. Combs Professor of Geology University of California at Riverside	Mr. Peter McClure Department of Engineering Research Pacific Gas & Electric Company
Dr. R. O. Fournier Research Geologist U.S. Geological Survey	Dr. L. P. J. Muffler Coordinator, Geothermal Research Program U.S. Geological Survey
Mr. William A. Glass Executive Vice President Big Chief Drilling Company	Dr. Carel Otte Manager of Geothermal Division Union Oil Company
Mr. Robert Greider Consulting Geologist Chevron Oil Company	Dr. Samuel O. Patterson Principal Investigator Tetra Tech, Inc.
Mr. Tom C. Hinrichs Manager, Fuel Planning San Diego Gas & Electric Company	Dr. C. Barry Raleigh Chief of Earthquake Tectonics Program National Center for Earthquake Research U.S. Geological Survey
Mr. Ben Holt, President Ben Holt Company	Dr. John C. Rowley Subterranean Coordinator Los Alamos Scientific Laboratory
Dr. Paul H. Jones Research Hydraulicist Division of Water Resources U.S. Geological Survey	Mr. Howard Schultz Asst. Manager of Marketing REDA Pump Company
Dr. George V. Keller Professor of Geophysics Colorado School of Mines	Mr. Morton C. Smith Project Manager Los Alamos Scientific Laboratory
Mr. Leonard J. Keller, President The Keller Corporation	Mr. Roger S. Sprankle General Partner Hydrothermal Power Company, Ltd.

Figure 3.1.6 THE TECHNICAL PANEL

specific comment would be attributed to any particular individual, without prior authorization.

In general, the method of responding to the questionnaire was determined by the preference of the interviewee; i.e., by mail, phone, or person-to-person. The process of receiving and recording phoned replies was usually a protracted affair, requiring from 45 minutes to an hour and a half per interview to complete. As expected, person-to-person interviews were less burdensome and usually more productive of desired information. (A later task in the study required that a similar set of interviews be conducted, but in this case, focusing on social, political, and economic factors. Almost all of these later interviews were conducted person-to-person.)

Individual questionnaires were prepared for each of the first three subsystems. The basic intent of these questionnaires was to solicit the interviewees' forecasts of what geothermal developments they thought could be accomplished in terms of what was perceived as technically possible; political, competitive, regulatory, and environmental considerations notwithstanding.

In essence, the questionnaire was divided into two major

parts. The first dealt with specific individual impediments; most respondents were given a number of impediments to address. The second dealt with the more general questions of resource appraisal, reservoir development, and resource conversion. The comprehensiveness of these general questions, the request for quantitative replies, and general low state of knowledge about these issues, made the questions rather difficult ones to answer and limited the possible number of respondents. The respondents were asked not only to complete these questionnaires, but also to contribute, in view of their own experience and judgment, other impediments which they felt might have been omitted.

For each impediment the questionnaire sought judgments as to:

1. Present status of the impediment.
2. Future status (in 1985 or 2000 under the assumption of either a "normal" or "crash" program) in terms of performance, availability, and policies which might be necessary to overcome the impediment being considered.

Overview of Interview Findings

The results of the technical interview sequence were utilized as inputs to almost all later tasks in the study. The interviews produced information on attitudes and expectations of various experts about technological impediments which could, if uncorrected, pace the development of geothermal energy. The impediments which they defined, the areas to which those impediments applied, and the expected schedule of the resolution, are presented in Figures 3.1.8 through 3.1.15. Detailed discussion generated in the interviews about each of these impediments is included in Appendix A; Section 3.3 discusses these impediments in more detail and, in particular, probes their implication for the accelerated evolution of geothermal energy in the United States.

Energy System Diagrams

The purpose of this activity was to integrate the forecasts produced in the technological interviews to produce estimates of the amount of geothermally-generated electricity which is, in the minds of the respondents, technologically feasible under various program definitions between the present time and the end of the century. It should be noted in the discussion which follows that other estimates were produced later in the study of the amount of electricity produced from geothermal sources. These later estimates were, in general, more conservative than the estimates produced by the technical panel. This is reasonable since the technical panel was answering the question: How much electricity could be produced if only technological impediments paced either a "normal" or "crash" program?

In order to provide a uniform basis on which impediment questions could be answered, it was necessary to define essential terms used in the questionnaire. Important terms used in this portion of the study are defined in Figure 3.1.7 on the following page.

Any of the first three subsystems may limit the electric power potential of a geothermal energy resource. Consistent with the search for technical feasibility levels, rather than economic viability, the level of identified resources (as opposed to reserves) has been used to determine the upper limit on technically feasible levels of geothermal energy which can be extracted and converted to electric energy. It was assumed that field lifetime is 25 years, and identified resources are adequate to support a given reservoir development capability if

DEFINITION OF TERMS:		
Normal Program	Research and development program whereby geothermal technology continues to develop on the same basis that it is currently developing, without additional externally applied stimuli.	Reservoir Development
Crash Program	Research and development program whereby geothermal technology develops under the stimulus of a declared national policy and massive governmental support, in which case cost is virtually no impediment.	A geothermal energy subsystem which includes activities associated with bringing the resource to the surface of the earth, including producing, drilling, formation fracturing, fluid injection, installation of well casing and wellhead valving, and gathering systems.
Identified Resources	Heat in identified geothermal reservoirs that may or may not be economically recoverable. (Definition excluded resources not yet discovered.)	Energy Conversion
Reserves	Economically recoverable resources in identified geothermal reservoirs.	A geothermal energy subsystem which includes activities associated with the conversion of geothermal energy into electrical energy, including all facilities from the gathering system discharge forward through the energy conversion plant.
Energy System	Includes all technological subsystems and components necessary to identify a given type of geothermal resource, bring it to the surface of the earth, and convert it to electrical power.	Impediments
Subsystem	Technological component of geothermal system necessary either to identify the resource, bring it to the surface of the earth, or convert it to electricity.	Technological components of subsystems, which represent technical conditions or deficiencies which will materially impede the development of the geothermal resource in the United States to its fullest potential within the next 27 years.
Resource Exploration and Appraisal	A geothermal energy subsystem which includes activities associated with identifying resources.	Energy System Flow Diagram
		Flow diagram of geothermal energy system which links all technological subsystems necessary to bring resource from its natural state to a place and into a form in which it is finally utilized.
		System Throughput
		Technologically feasible amount of geothermal energy which can flow through the energy system to consumers, defined in terms of installed electric generating capacity.

Figure 3.1.7 DEFINITION OF TERMS

- A1 DOWNHOLE SAMPLING TECHNIQUES AND DEVICES
- A2 GROSS EXPLORATION TECHNIQUES
- A3 CORRELATION OF GEOPHYSICAL DATA
- A4 SIGNIFICANCE OF GEOCHEMICAL DATA
- A5 DATA BANK FOR INFORMATION POOLING
- A6 DYNAMIC RESERVOIR MODELS
- A7 IMPROVED GEOPHYSICAL TECHNIQUES AND EQUIPMENT
- A8 DEEP DRILLING RIGS
- A9 REGIONAL GEOLOGICAL MODELS

[illegible]

LEGEND

- - MINOR IMPEDIMENT
- - MAJOR IMPEDIMENT
- - NO IMPEDIMENT

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- B1 VERY DEEP DRILLING TECHNIQUE
- B2 TUBULAR GOODS SHORTAGE
- B3 ENERGY RECOVERY METHOD FOR HOT DRY ROCK
- B4 ENERGY RECOVERY METHOD FOR MAGMA
- B5 DOWNHOLE HEAT EXCHANGER
- B6 SOLIDS DEPOSITION IN FORMATION AND CASING
- B7 DEEP-WELL PUMPS
- B8 RESERVOIR FLUID RECHARGE
- B9 FIELD STIMULATION METHODS
- B10 REINJECTION OF LIQUID WASTES
- B11 THERMAL STRESS INDUCED IN HOT DRY ROCK
- B12 RELATIONSHIP BETWEEN FLUID INJECTION AND EARTHQUAKES
- B13 AVAILABILITY OF DRILL RIGS FOR DEEP DRILLING
- B14 PORTABLE TWO-PHASE FLOW METER
- B15 DYNAMIC RESERVOIR MODELS
- B16 CASE HISTORY DATA FOR FIELD LONGEVITY PREDICTIONS

TIME FRAME	VAPOR-DOMINATED	LIQUID-DOMINATED	HOT DRY ROCK	GEOPRESSURED ZONES	MAGMA
	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
PRESENT 1973	● ○ ○ ● ○ ●	● ○ ○ ○ ● ○ ● ● ● ●	○ ○ ● ○ ● ● ● ●	● ● ● ● ●	● ● ● ● ●
NORMAL 1985	● ○ ○ ● ○ ○	● ○ ○ ○ ● ○ ● ●	○ ○ ● ○ ○ ●	● ○ ● ●	○ ● ● ●
NORMAL 2000	○ ○ ○ ○	○ ○ ○ ○	○ ○ ○	○	○ ○
CRASH 1985	○ ○ ○ ○	○ ○ ○ ○	○ ○	○ ○	○ ○ ○ ○
CRASH 2000					○

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C. ENERGY CONVERSION	
(ABBREVIATED STATEMENT OF IMPEDIMENTS)	
C1	DEMONSTRATION POWER PLANT FOR LIQUID-DOMINATED RESERVOIR OF MEDIUM TO LOW THERMAL QUALITY
C2	DEMONSTRATION POWER PLANT FOR HEAVY BRINE RESERVOIRS
C3	PRIME MOVER FOR TWO-PHASE FLUID
C4	SCALE DEPOSITION
C5	EMPIRICAL DATA FOR SELECTION OF PLANT MATERIALS
C6	DEMONSTRATION POWER PLANT FOR GEOPRESSURED ZONES
C7	DEMONSTRATION POWER PLANT FOR MAGMA
C8	DEMONSTRATION POWER PLANT FOR HOT DRY ROCK

Figure 3.1.12 IMPEDIMENT LIST

TIME FRAME	VAPOR-DOMINATED								LIQUID-DOMINATED								HOT DRY ROCK								GEOPRESSURED ZONES								MAGMA											
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8				
PRESENT 1973				○					●	●	○	○					○	○			●	●	●	●	●					●								●	●					
NORMAL 1985												○						○												○								○	●					
NORMAL 2000																																									○			
CRASH 1985												○						○												○							○	●						
CRASH 2000																																									○			

LEGEND
○ = MINOR IMPEDIMENT
● = MAJOR IMPEDIMENT
- = NO IMPEDIMENT

Figure 3.1.13 FORECASTS OF TECHNICAL IMPEDIMENTS IN ENERGY CONVERSION

D. ENVIRONMENTAL TECHNOLOGY (ABBREVIATED STATEMENT OF IMPEDIMENTS)	
D1	GROUNDWATER CONTAMINATION
D2	GASEOUS EMISSIONS
D3	LIQUID AND SOLID WASTE DISPOSAL
D4	NOISE EMISSIONS
D5	EARTHQUAKE INDUCTION
D6	SAFETY CODES
D7	LAND SUBSIDENCE
D8	AESTHETICS

Figure 3.1.14 IMPEDIMENT LIST

TIME FRAME	VAPOR-DOMINATED								LIQUID-DOMINATED								HOT DRY ROCK								GEOPRESSURED ZONES								MAGMA							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
PRESENT 1973		●	○	○			○	○		●	○				○	○		●	○				○	○		○	○			○								○		○
NORMAL 1985							○								○									○							○						○		○	
NORMAL 2000																																					○		○	
CRASH 1985							○								○									○							○								○	
CRASH 2000																																								

LEGEND
 ○ = MINOR IMPEDIMENT
 ● = MAJOR IMPEDIMENT
 = NO IMPEDIMENT

Figure 3.1.15 FORECASTS OF TECHNICAL IMPEDIMENTS
IN ENVIRONMENTAL TECHNOLOGY

they are greater than or equal to the amount of geothermal resources which would be extracted in 25 years by the reservoir development capability estimate. Using this convention the potential of each geothermal resource in terms of added installed electric capacity was computed as follows:

The technologically feasible level of geothermal energy resources development which flows into the energy conversion subsystem is the lower of the two subsystem capabilities for (a) identification of resources and (b) reservoir development. The technologically feasible geothermal energy development level determined from resource and reservoir development considerations is adequate to support a given energy conversion capability if it is greater than or equal to the amount of thermal energy which could be converted to electric energy at a 10 percent conversion efficiency.

Thus, the technologically feasible level of installed electric power capacity which flows from the energy system (system throughput) is the minimum of the three subsystem capabilities:

- (1) "Resource equivalent,"* defined as the amount of electrical generating capacity which can be supported by the forecasted level of identified resources for 25 years, assuming 10 percent overall conversion efficiency.
- (2) "Reservoir development equivalent," defined as the amount of electrical generating capacity which can be supported by the forecasted level of reservoir development capability, assuming 10 percent overall conversion efficiency.
- (3) Energy conversion capability.

*This definition of resource equivalent assumes that all identified resources would be depleted in 25 years if they were developed at the resource equivalent rate. However, no value judgment has been made as to the advisability of this procedure as a national policy, and it is a relevant concern only in those cases when resource equivalent is a more limiting subsystem than reservoir development equivalent or energy conversion capability.

The resource information requested during the interviews can be summarized as follows:

1. "What do you think could be the level of identified resources in Mwt-years?" This question was asked for 1985 and 2000, for "normal" and "crash" development programs and for five resource types (20 questions.)
2. "What do you think could be the level of developed geothermal reservoirs within the entire United States in Mwt?" (For 1985 and 2000, "normal" and "crash" programs, five resource types; 20 questions.)
3. "What do you think could be the installed geothermal electric generation capacity within the entire United States in MWe?" (For 1985 and 2000, "normal" and "crash" programs, five resource types; 20 questions.)

Of the set of 24 respondents, 14 were asked to respond to these questions; 8 were asked to provide resource estimates; 6 were asked for reservoir development capability forecasts; and 3 for energy conversion capability forecasts.

The quality of the responses generally met expectations in view of the comprehensive and difficult nature of the subsystem questions and the state of knowledge. In some cases, the respondents queried either failed to respond or failed to give quantitative forecasts. In addition, some interviewees responded only to a portion of the questions asked (for example, some respondents discussed fewer than all five resource types or a regional section of the entire United States) as their expertise dictated. An overview of the responses is given in Figure 3.1.16.

RESPONDENT	RESPONSES		
	RESOURCE EXPLORATION AND APPRAISAL	RESERVOIR DEVELOPMENT	ENERGY CONVERSION
1	X		
2	X		
3	QUALITATIVE		
4	QUALITATIVE		
5	QUALITATIVE*	QUALITATIVE*	X*
6	X	QUALITATIVE	X
7		X	X
8		X	
9		X**	
10			QUALITATIVE

*NONE RESOURCE TYPE ONLY.

**REGIONAL SUBSECTION OF UNITED STATES.

KEY X = QUANTITATIVE FORECAST OF TECHNICALLY FEASIBLE LEVEL.
QUALITATIVE = QUALITATIVE FORECAST OF TECHNICALLY FEASIBLE LEVEL.

Figure 3.1.16 OVERVIEW OF RESPONSES TO SUBSYSTEM-LEVEL QUESTIONS

During the course of the interview sequence, it became apparent that the majority of respondents found it difficult to isolate reservoir development capability estimates from energy conversion capability considerations and vice-versa, and that the independent forecasts obtained for these two technological capabilities would be more representative of the respondents' state of information if they were considered as forecasts of the combined reservoir development and energy conversion capability of industry. Accordingly, the energy system flow diagrams have been modified to include only two independent forecasts for geothermal energy systems, one for the level of identified resources, and one for the reservoir development and energy conversion capability of industry. Thus, the technologically feasible level of geothermal energy resources development was determined from the energy system flow diagrams as the minimum of the two numbers for:

- (1) Resource equivalent (GWe)
- (2) Reservoir development and energy conversion (GWe)

and the forecasts provided by the respondent were aggregated as shown in Figure 3.1.17 on the following page. As can be seen from the figure, only 3-4 estimates for level of identified resources and 3-5 estimates for reservoir development/energy conversion capability were obtained. Clearly, these data cannot be given any statistical significance; the value accorded them is derived solely from the high level of expertise of the contributors. Figure 3.1.18 illustrates the process which was followed.

Analysis of results from the interview sequence indicates that any attempt to achieve a consensus in describing the potential of geothermal energy by a single deterministic value would have probably failed, with the exception of a few specific cases. A range of forecasts has been obtained both for the technological subsystems and for electric power throughput from geothermal energy systems. In the treatment of results, this range of throughput

RESPONDENT [‡]	RESOURCE EXPLORATION AND APPRAISAL	RESOURCE DEVELOPMENT/ ENERGY CONVERSION
1	X	
2	X	
3	X*	
4	X	X**
5		X
6		X
7		X***

[‡]RESPONDENTS NUMBERED 1-7 HERE DO NOT CORRESPOND TO THOSE NUMBERED 1-7 IN FIGURE 3.1.16 PRECEDING.

*LOWER LIMIT ONLY FOR ONE RESOURCE TYPE ONLY.

**ONE RESOURCE TYPE ONLY.

***FOR ONE REGIONAL SECTION OF THE COUNTRY ONLY.

Figure 3.1.17 INDEPENDENT QUANTITATIVE FORECASTS

forecasts will be presented in various forms:

- (1) full range (all data)
- (2) midrange, calculated by eliminating forecasts which led to extreme points of full range, and
- (3) median, calculated by integrating median subsystem forecasts

The median values are calculated for convenience of results presentation only; the range and midrange forecasts reflect the present state of knowledge.

The fullrange resource estimates are presented in Figures 3.1.19 and 3.1.20 on the following page. Figure 3.1.21 summarizes the results for fullrange, midrange, and median estimates.

Some general trends are reflected by the median forecasts. The present installed geothermal electric generating capacity is 0.396 GWe (1973). The technically feasible level of geothermal energy resources development is forecasted to be 10 GWe in 1985 and 200 GWe in 2000 (median forecasts), under normal program conditions. If a crash program is implemented, the corresponding values are 35 GWe in 1985 and 770 GWe in 2000.

The potential relative contribution of each of the various types of geothermal resources to electric power supply is illustrated by Figures 3.1.22 and 3.1.23, which plot the median forecast for each resource for 1985 and 2000,

respectively. Additional analysis indicates that hot dry rock and liquid-dominated resources are relatively abundant, whereas vapor-dominated and to a lesser degree geopressured zone resources are relatively scarce. Accordingly, the year 2000 results indicate small contributions from the two resource-limited types. On the other hand, it is the technology associated with the development of the hot dry rock resources, rather than a resource limitation, which will cause the development of this resource to lag behind that of the liquid-dominated resources, according to most experts. The technological problems associated with development of magma resources restrict their utilization to negligible amounts.

Results of the analysis also indicate that the greatest impact of a crash development program, in terms of potential additions to the national fuel supply mix, will be on increased development of liquid-dominated and hot dry rock resources, due primarily to the fact that resources for these two types are abundant and can support greater exploitation.

A strategy suggested by these results for allocating crash program R & D efforts to geothermal programs would be to concentrate on programs related to development of liquid-dominated and hot dry rock resources. The degree of success of this effort, both in terms of mapping of the resource and appraisal of its qualities, should yield data for required R&D efforts in reservoir development and power conversion technology. In the case of hot dry rock, concentration of R&D effort on development and conversion technologies should yield data on the technological feasibility of large-scale development of the resource.

Figure 3.1.18 SAMPLE ENERGY SYSTEM FLOW DIAGRAM

Figure 3.1.19 SUMMARY OF SYSTEM THROUGHPUT RANGES, YEAR 1985

Figure 3.1.20 SUMMARY OF SYSTEM THROUGHPUT RANGES, YEAR 2000

Year	Level of Development Program	Technologically Feasible Electric Power Capacity (GWe)		
		Range (all data)	Midrange+	Median*
1973	-	0.396		0.396
1985	Normal	5-24	9-11	10
	Crash	12-142	27-40	35
2000	Normal	25-600	55-200	200
	Crash	55-3430	270-800	770

+ Calculated by eliminating two forecasts which led to low and high extremes of range forecasts.

* Median values are given here for convenience. The range of forecasts reflect better the present state of knowledge.

Figure 3.1.21 GEOTHERMAL TECHNOLOGY FORECASTS (ALL RESOURCES)

MEDIAN²² FORECASTS OF GEOTHERMAL POTENTIAL, YEAR 1985

²²MEDIAN FORECASTS ARE USEFUL SOLELY FOR SHOWING THE RELATIVE POTENTIAL CONTRIBUTIONS OF THE VARIOUS RESOURCE TYPES TO TOTAL GEOTHERMAL RESOURCE UTILIZATION. THE ABSOLUTE VALUE OF CONTRIBUTIONS FROM THE DIFFERENT RESOURCE TYPES IS BEST GIVEN BY THE RANGE AND MIDRANGE FORECASTS.

Figure 3.1.22

MEDIAN²² FORECASTS OF GEOTHERMAL POTENTIAL, YEAR 2000

²²MEDIAN FORECASTS ARE USEFUL SOLELY FOR SHOWING THE RELATIVE POTENTIAL CONTRIBUTIONS OF THE VARIOUS RESOURCE TYPES TO TOTAL GEOTHERMAL RESOURCE UTILIZATION. THE ABSOLUTE VALUE OF CONTRIBUTIONS FROM THE DIFFERENT RESOURCE TYPES IS BEST GIVEN BY THE RANGE AND MIDRANGE FORECASTS.

Figure 3.1.23

3.2 The Social and Political Inquiry

The Role of the Interview

As described in Section 1.3, the basic logic flow of the study required that technological capacities be addressed first. Having described what seemed possible, recognizing technological constraints, the study then focused on the nature of the impacts likely to emerge from the evolution of geothermal energy. Using the technological forecast as a quantitative framework generated in Section 3.1, background material in the geothermal and general energy literature was synthesized to construct scenarios depicting potential evolutionary paths of geothermal energy development. These scenarios were then used as interview springboards to elicit from representatives of various interest groups their opinions about the probable future course of geothermal development and the impacts which could be expected as a result of this development on their specific group, on other interest groups, and on the nation as a whole. In addition, this phase of the study was designed to identify and define various policies which might be implemented to mitigate or improve potential impacts of geothermal development.

Seventeen experts were selected for in-depth interviews from groups interested in various aspects of geothermal energy and representing a broad range of attitudes and opinions. Included were representatives of federal agencies and legislative bodies, state agencies, research institutions, oil companies, commercial geothermal developers, public utilities, environmental organizations, land developers, and financial institutions. Figure 3.2.1 summarizes the participants and their backgrounds.

PARTICIPANT	AFFILIATION
Mr. Joseph Aidlin	Counsel, Magma Power Company
Mr. Daniel Beard	Environmental Policy Specialist Library of Congress
Mr. Richard Bowen*	Economic Geologist Oregon Department of Geological and Mineral Industries
Dr. R. D. Doctor	Rand Corporation
Mr. Daniel Dreyfus	Staff Professional U.S. Senate Interior Committee
Professor Hamilton Hess	University of San Francisco and Sierra Club
Mr. Donald Everitts	California State Lands Div.
Mr. William House	Signal Oil & Gas Company
Mr. Alvin Kaufman	Director, Office of Economic Research New York State Public Service Commission
Mr. Owen Malone	Legislative Assistant to Senator Bible of Nevada
Mr. Carl McCulloch	Chief Geologist Southern Pacific Land Co.
Dr. Patrick Muffler	U.S. Geological Survey
Mr. Alex Raden	General Manager American Public Power Association
Mr. Fred Searles	Commercial Development Dept. Bechtel Corporation
Mr. Barton W. Shackelford	Vice President-Planning Pacific Gas & Electric Co.
Mr. C. Malvin Swinney	Manager, Energy Resources Group Southern California Edison Co.
Mr. Joseph Wilson	Manager of Lands Geothermal Division Union Oil Company

*Telephone interview

Figure 3.2.1 SOCIO AND ECONOMIC PANEL

A modified Delphi interview approach developed by The Futures Group was employed to obtain the desired information in a face-to-face meeting of 2-3 hours. The b Delphi technique, used extensively in forecasting since the mid-60's, attempts to crystallize group judgments of experts unidentified to each other through use of written questionnaires in an iterative process. The modified approach used in this study substitutes interviews for written questionnaires.

There are at least five advantages to this alternative: (1) the information is gained in a much shorter time; (2) personal contact with the respondents makes it possible to obtain a first-hand sense of their confidence and competence in handling the questions; (3) the interview sequence can be modified readily to accommodate the thought process of the respondents; (4) the personal interest shown on the part of the interviewers tends to enhance the cooperativeness of the panelists (this is, if the study is important enough to warrant sending professional researchers to gather the information, the panelists generally feel a stronger obligation to take the questions seriously;) and (5) the interviewers have the opportunity to learn at first hand about the respondents' organizations, to observe their actual day-to-day environment, and to see their answers more fully in the context of this environment.

Interview Procedure

Copies of the "normal" and "crash" scenarios (Figures 3.2.2, 3.2.3, 3.2.4, and 3.2.5) were sent to each respondent prior to the interview when time permitted.

NORMAL SCENARIO

PRESENT TREND OF GEOTHERMAL GROWTH CONTINUED.
MODERATE GOVERNMENT R&D FOR EXPLORATION AND OPERATIONS TECHNOLOGY.
GRADUAL DEVELOPMENT OF INVESTMENT INCENTIVES.
GRADUAL DEVELOPMENT OF REGULATORY COOPERATION.

CRASH SCENARIO

NATIONAL COMMITMENT TO INTENSIVE GEOTHERMAL DEVELOPMENT.
GREATLY INCREASED GOVERNMENT R&D.
GOVERNMENT FUNDING OF PILOT AND DEMONSTRATION PLANTS.
INTENSIVE EFFORT TO ELIMINATE REGULATORY DELAYS.
GOVERNMENT PROVISION OF TAX INCENTIVE AND CAPITAL GUARANTEE PROGRAMS.
PROMOTION OF CROSS-COUNTRY TRANSMISSION LINES.

Figure 3.2.2 SCENARIO DEFINITION

If not, they were presented on arrival. The levels of installed geothermally derived power included in these scenarios correspond to estimates obtained in the technical interviews; the events included in the scenarios were meant to depict a potentially plausible sequence of steps leading to the power estimates. Each participant was asked to comment on their content in general and/or in detail, and to present his own appraisal of the course of development and his underlying assumptions. Where relevant, the interviewer directed the discussion to areas of the respondent's expertise or particular interests.

The respondent was then presented with a set of 36 cards, each a possible impact of the development of geothermal energy. These impact statements are listed in Figure 3.2.6 later in this section. The objective of this part of the interview was to have the respondents evaluate these impacts as to their perceived desirability and their probability of occurring under the pattern of geothermal development which the respondents believed most

NORMAL DEVELOPMENT OF GEOTHERMAL ENERGY

The energy crisis of 1973 necessitates a changing pattern of input fuels for electricity generation. Shortages of low-sulfur oil and natural gas preclude the continuing substitution of these fuels for coal. Nuclear energy supplies are less than anticipated because of siting problems and long lead times involved in nuclear plant construction. Appropriate environmental accommodations are made allowing coal to fill the generating gap until additional nuclear plants become operative by the mid-1980's. By the early 1980's oil supplies are available from shale, tar sands, and Alaska, but are primarily used for transportation, heating, and petro-chemicals rather than for electricity generation.

By 1974 intensive prospecting for geothermal resources is underway, spurred by the open leasing of federal land. Supported by venture capital, utility development funds, and governmental pilot projects, exploration for geothermal steam and hot water resources begins in the western regions. This exploration, spurred by new developments for assessing the resource longevity of fields, indicates that most identified geothermal resources are liquid-dominated hot water systems. Potential development of these hot water resources, however, is slowed due to difficulties with high brine content. It is 1978 before any commercially viable plants utilizing hot water are operative.

Legal and institutional impediments are gradually removed during the mid- to late 1970's. By 1980 geothermal resources are treated as unique and statutes are clear regarding what can be developed and in what manner. Specific guidelines are instituted to assure that the physical sites of geothermal systems are developed in a manner compatible with existing land use patterns.

Due to the large risk factor, substantial capital outlay involved, and long lead times which characterize geothermal developments, it becomes evident that private initiative must be supplemented by federal incentive programs (tailored depreciation allowances, investment guarantees, and/or production subsidies). Federal and state policies regarding geothermal resource development are coordinated and most conflicts resolved.

As hot water systems are being developed, work commences on possible utilization of hot rock resources. In the 1970's research efforts focus on hydraulic fracturing and also on possible seismic effects of fluid injection into hot dry rock.

By 1985 there is an electrical output capability of about 7500 megawatts from geothermal energy in the West. Of this total 3000 is from steam, 3500 from hot water, and 1000 from hot dry rock. This accounts for 6 percent of the generating capacity of the West. The only other significant geothermal production is on the Gulf coast where geopressured fields produce some 3000 megawatts.

The utilization of geothermal resources proceeds rapidly since it has cost and environmental advantages over coal and in many instances over nuclear powered plants as well. The growth of nuclear development slows somewhat in the West as geothermal power is clearly demonstrated as a practical energy source.

As the year 2000 approaches geothermal energy is a major factor in the West and a minor, though significant, factor in the Gulf states. Prospecting for geothermal reserves in the East begins, spurred by new advances in drilling and resource locating technology.

By the year 2000 geothermal resources supply over one-third of the generating capacity of the West. Of this total of 140,000 megawatts, 6000 are from steam, 100,000 from hot water, and 34,000 from hot dry rock. Plans to export electricity from western regions await the development of additional capacity and adequate transmission technology.

Other uses of geothermal energy being implemented on a relatively large scale include space heating and air conditioning, supplying irrigation water from desalinated wastes, and provision of minerals recovered from fluid wastes. Some geothermal systems are multi-purpose combining electrical generation with one or more of the above-mentioned uses.

Figure 3.2.3 NORMAL SCENARIO NARRATIVE

CRASH DEVELOPMENT OF GEOTHERMAL ENERGY

After the opening of federal lands for leasing in 1974 interest in geothermal energy intensifies. Congress, spurred by an awareness of private industry interest, acts to stimulate geothermal development through a variety of measures. By 1975 and 1976 legislation is passed which coordinates federal research and development activities on geothermal energy; and in addition, funding and guarantees for new programs are passed. Since it has been demonstrated that private industry is unable or unwilling to bear all early risks of geothermal development, the federal government funds entire projects for mapping, exploration, and the development of hot water, hot rock and geopressure technology. To hasten the development of commercially feasible resources (steam and hot water), the Federal Government utilizes loan guarantees to private industry and actually participates with some utilities and municipalities in joint pilot projects.

The combined actions of federal, state, and local agencies are successful in preventing duplication of effort by establishing standardized procedures regarding the development and definition of geothermal resources. A national data bank for geothermal information is established by 1977 to facilitate orderly research and exploration.

These programs, plus additional federal activity in granting depreciation allowances and instituting manpower training projects, have a significant effect on the pace of development of steam, hot water, and geopressure resources. Exploratory techniques advance rapidly and the scale deposit problem is solved by 1980.

Most major technical impediments to the development of hot water reservoirs have been removed by 1985. In addition, hot dry rock and geopressure technology is developing rapidly, especially in the area of deep drilling techniques (commercial rigs are available for depths up to 30,000 feet and temperatures of 800°F). Despite the lack of adequate field longevity data some regional utilities have been encouraged through federal incentive programs to base a large part of their new capacity on geothermal energy. This increased utilization is encouraged since geothermal energy has been shown to have cost and environmental advantages over coal and in many instances over nuclear powered plants as well. Production has reached a level of 35,000 megawatts: 3500 in steam, 16,500 in hot water, 5000 in hot dry rock, and 10,000 in geopressure.

While further development of steam and geopressure resources is limited by the extent of these resources, hot water and hot rock resources have been identified in very substantial quantities. Whether these resources are to be fully developed depends on the possibility of exporting excess electricity from the West to other regions. In other areas increased demand for electricity is being met through the construction of additional nuclear plants since fossil and synthetic fuels are largely reserved for other uses. As the use of nuclear power increases so do the perceived environmental problems of siting, safety, and wastes. In dealing with these problems the cost of nuclear power rises and it becomes cost-competitive to transport electricity from geothermal developments via high voltage transmission lines from the West to the rest of the country.

After a prolonged national debate which weighs the advantages of more abundant energy versus possible environmental damage, Congress proclaims a national policy to promote this transmission of geothermal electricity. In addition, legislative action provides funding and incentives to minimize any undesirable environmental and economic effects of this policy.

By the year 2000 the geothermal industry is a major source of income in western regions. Formerly isolated areas are now populated as jobs open at geothermal plants and surrounding industries. Geothermal generating capacity in the West totals 660,000 megawatts: 10,000 in steam, 500,000 in hot water, and 150,000 in hot dry rock. The Gulf coast states are supplied with 50,000 megawatts from geopressured resources, while hot rock resources utilized for space heating provides the equivalent of 50,000 megawatts in other regions. This crash program, which has eliminated major constraints and accelerated geothermal development, results in geothermal energy supplying about one-third of the electricity produced in the United States.

Figure 3.2.4 CRASH SCENARIO NARRATIVE

DEVELOPMENT OF GEOTHERMAL ENERGY	
1974 1975 Liquid-dominated and vapor-dominated resource exploration is intensified after opening of federal lands; drilling begins in several areas. Experimentation continues with Imperial Valley brines. Hot dry rock drilling experiment starts. Level of federal R&D is: 1973, \$3.8 million; 1974, \$11 million; 1975, \$40 million.	
NORMAL DEVELOPMENT	CRASH DEVELOPMENT
Moderate level of federal R&D--\$40 million/year. Techniques begin to be gradually developed for exploration and reservoir development for steam and hot water. U.S. Geologic Survey starts an overall survey and exploration of U.S. geothermal resources. 1976	Intensified federal R&D--\$100 million/year. Stepped-up exploration and development. 1976
Research geopressure plant. 1978	Formation of overall coordinating federal geothermal agency. 1976
Experimental downhole heat exchanger in hot brine. 1978	Programs instituted to train scientists and engineers. 1976
Scale deposit and corrosion problems solved. 1979	Tax incentives allowed. 1977
Resource legally defined; procedural leasing conflicts settled. 1979	Cooperative task force achieves early resolution of leasing and regulatory conflicts and environmental procedures. 1977
Depreciation and depletion schedules defined. 1979	Capital made available through loan and guarantee programs. 1977
Thermal stress cracking technology available. 1979	Joint data banks started. 1977
Geopressure and hot rock drilling technology available for up to 15,000 ft.--a few rigs for 30,000 ft. 1979	Federal-state-industry projects funded. 1978
Environmental procedures finalized. 1979	Hot rock programs advanced by a year--additional demonstration sites added. 1978
Binary fluid plants in operation in hot brine field. 1980	Binary fluid plant operations and heavy brine installations speeded up by capital availability. 1978
Demonstration brine plant solves scaling and corrosion. 1980	Crash program has greatest effect on hot water and geopressure. 1979
Environmental problems under control. 1980	Utilities given incentives to utilize unproven resources. 1979
Geopressure demonstration plants recover electricity and natural gas. 1980	Geopressure demonstration plants recover electricity and natural gas. 1979
Demonstration hot rock plant makes 100 MW electricity. 1981	Demonstration hot rock plant makes 100 MW electricity. 1980
Administrative overlaps straightened out. 1982	Exploration techniques advanced by 5 years; scale deposit problem solution advanced by several years. 1980
Longevity data not yet adequate but can predict performance of variety of reservoir types 5 years in advance. 1982	No further technical impediments to development of hot water: low brine, 1978; high brine 1980
Geopressure geology fairly well explored and understood. 1982	Geothermal measuring and interpretation services available commercially. 1980
Number of new steam plants limited only by discovery rate. 1985	Hot rock and geopressure commercial development advanced by 3 years over normal. 1982
Many low salinity hot water plants in operation. 1985	Geopressure geology well explored and understood. 1982
	Heavy government funding to finance reservoir models. 1983
	Publicly available data bank for dissemination of resource and reservoir data. 1985
	Deep drilling capacity developed through national priority program and capital infusion. Rigs available commercially for 20,000 ft. at 800°F. 1985
1985 Capacity: 10,500 MW	1985 Capacity: 35,500 MW
Vapor-Dominated: 3,000 MW	Vapor-Dominated: 3,500 MW
Liquid-Dominated: 3,500 MW	Liquid-Dominated: 17,000 MW
Hot Dry Rock: 1,000 MW	Hot Dry Rock: 5,000 MW
Geopressured Zones: 3,000 MW	Geopressured Zones: 10,000 MW

Figure 3.2.5 CHRONOLOGICAL AND QUANTITATIVE SCENARIOS

NORMAL DEVELOPMENT BY 2000	CRASH DEVELOPMENT BY 2000
<p>No major technical impediments.</p> <p>Geophysical measuring and interpretation services available commercially.</p> <p>Deep drilling technology available up to 40,000 ft., 800°F.</p> <p>Longevity predictable up to 10-20 years in advance.</p> <p>Hot water major producer.</p> <p>Hot rock commercially acceptable--spreading to East.</p> <p>Production limited to absorption capacity of West--one-third of West's electrical capacity geothermal.</p> <p>Little export of geothermal to other parts of country.</p> <p>Direct use of hot water for space heating and air conditioning.</p> <p>Multi-purpose installations--generation, desalination, mineral extraction, space heating.</p>	<p>Congress making national policy to export geothermal energy from West to the rest of the country via cross-country transmission grid.</p> <p>Western states allowing geothermal production to increase for export.</p> <p>Geothermal an important means of producing electricity for the whole country.</p> <p>Hot rock furnishing increasing amounts of energy in eastern areas.</p> <p>Multi-purpose installations basis of new population centers.</p>
2000 Capacity: 200,000 MW	2000 Capacity: 770,000 MW
<p>Vapor-Dominated: 6,000 MW</p> <p>Liquid-Dominated: 100,000 MW</p> <p>Hot Dry Rock: 50,000 MW</p> <p>Geopressed Zones: 40,000 MW</p>	<p>Vapor-Dominated: 10,000 MW</p> <p>Liquid-Dominated: 500,000 MW</p> <p>Hot Dry Rock: 200,000 MW</p> <p>Geopressed Zones: 54,000 MW</p>

Figure 3.2.5 (cont.) CHRONOLOGICAL AND QUANTITATIVE SCENARIOS

likely to unfold. A matrix was physically laid out through the use of heading cards, with the desirability scale as the abscissa and the probability scale as the ordinate, as shown in Figure 3.2.7. The respondent was asked to place each of the impact statement cards at the matrix intersection which he considered appropriate. He was instructed to make his judgment from the point of view of the national interest, and was encouraged to comment on the reasons for his choices, particularly for those impacts seen as "very desirable" or "very undesirable."

If time permitted, the scale of desirability alone was laid out and the respondent was asked to reclassify the impact cards from the point of view of his own self--or group--interest as contrasted to the national interest assumed above. An alternative approach utilized was to ask if there was any area of impact which, if judged from the respondent's own or professional point of view, might be in conflict with any judgments made from a national point of view.

As the final point of the interviews, the respondent was asked to suggest any additional impacts of geothermal development which he could foresee and policies which he would like to see implemented. This question usually resulted in a summing up of the respondent's overall attitudes and projections.

Overview of Interview Findings

The results of the socio-political interview sequence were utilized as inputs to the impediment definition (Section 3.3), impact definition (Section 4), and impact evaluation and policy assessment (Section 5). The interviews produced information on attitudes and expectations of the various interest groups and on specific current activities in the field. The format was designed to encourage free discussion and the respondents were able to concentrate on their particular area of

expertise in commenting on the scenarios and possible impacts. Appendix C contains a compilation of individual responses to each impact question along with additional comments made to clarify the matrix placement. Figure 3.2.7 illustrates the format used to present the judgments about each impact considered.

The major area of agreement among respondents was that the normal scenario represented a much more likely level of development than the crash scenario, which was judged far too optimistic. Although the pattern of the normal scenario was in general thought to be fairly realistic through 1985, a number of respondents considered it to be at too high a level for 2000. Some emphasized uncertainties as to the extent of resources and the possibility of their utilization at the projected levels (particularly for hot dry rock) within the given time frame.

An underlying theme appeared to be that geothermal energy will evolve as a supplementary source of power, playing a role perhaps comparable to that of hydro-electric power. As such, it could help provide an important portion of the energy input for electrical generation and thus help possibly avert both electricity shortages and shortages of fuels replaced by geothermal energy. Several respondents felt that the electrical load growth would be so great that all available energy resources would have to be developed to their fullest, and that only in the case of a hot dry rock breakthrough would geothermal development impinge on development of other resources. References were made in many cases to anticipated nuclear bottlenecks, and one researcher advanced the thesis that strict conservation of electrical energy combined with use of geothermal resources could drastically cut the need for nuclear power plants in the West.

There was a general agreement that the cost of geothermal steam at present is competitive with other fuels used to generate electricity. A utility source felt that by the

POSSIBLE IMPACTS OF GEOTHERMAL DEVELOPMENT

1. Air pollution due to electric generation in western regions reduced.
2. Land subsidence disrupting agricultural production.
3. Noise from geothermal systems disrupting land use patterns (i.e., wildlife habitation, residential, agricultural, etc.).
4. Increased seismic activity in western regions due to fractures and fluid withdrawal.
5. Localized climatic modification in areas where vapor-dominated geothermal systems are developed.
6. Development and construction of nuclear power plants slowed markedly in western regions.
7. Contamination of water tables in many localities by geothermal wastes.
8. Previously inaccessible areas opened for recreational use.
9. The development of agriculture in previously unfarmed areas stimulated by the availability of irrigation water from desalinated geothermal wastes.
10. Revitalization of the drilling industry.
11. Other primary energy sources (oil, coal, and natural gas) freed for use other than the generation of electricity.
12. Exclusion of small firms from geothermal development.
13. Large integrated companies dominating the development of geothermal resources.
14. Reduced needs for imported petroleum improving the U.S. balance of trade.
15. The construction of transcontinental transmission lines requiring new rights of way.
16. Tax revenues and royalties from geothermal developments providing the basis for tax reductions in municipalities and states in western regions.
17. Increased industrial development due to the availability of low-cost electricity.
18. Implementation of anti-poverty programs based upon municipal development and administration of geothermal resource areas.
19. Alteration or modification of home construction techniques to utilize geothermal potential for space heating.
20. The construction and development of new towns near geothermal resource systems.
21. Commercial market for minerals and mineral salts extracted from geothermal liquids.
22. Eastern electricity demand met in part by electricity exported from western geothermal developments.
23. Improved living standards.
24. Energy intensive industries located in the East migrating to western regions.
25. Real GNP growth higher than it might have been without geothermal power.
26. Population migration from East to West stimulated.
27. Shortage of skilled manpower.
28. Slowdown in the growth of the synthetic fuel industry.
29. Increased government regulation of resource development by private enterprise.
30. Despoilation of land by coal strip mining essentially terminated.
31. Recreational space in western states reduced.
32. The state of geological science advanced markedly.
33. Multi-purpose industrial/agricultural complexes developed in the West.
34. Natural gas supplies increased.
35. Creation of tax shelters for investment in geothermal developments.
36. Formation of many new federal, state, and municipal agencies to oversee geothermal resource development.

Figure 3.2.6 POSSIBLE IMPACTS OF GEOTHERMAL DEVELOPMENT

	Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
Almost Certain	1	7	13	19	23	31
Very Likely	2	8	14	20	26	32
As Probable As Not	3	9	15	21	27	33
Very Unlikely	4	10	16	22	28	34
Almost Impossible	5	11	17	23	29	35
No Opinion	6	12	18	24	30	36

Figure 3.2.7 IMPACT CLASSIFICATION MATRIX

1980's steam costs could be in the same range as nuclear costs because of additional environmental protective equipment. Although the use of hot water resources will inevitably cost more than steam, it also was generally projected to be competitive unless very serious problems develop. One operator pointed out that each hot water reservoir will have a different fluid composition and consequently will require individually designed plants. Under these circumstances, costs from plant to plant could differ by a factor of two or three. Several respondents criticized the present arbitrary method of pricing geothermal steam by tying its cost to other fuels, stating that this provides economic incentive to utilize geothermal resources. It was suggested that pricing be based instead on the cost of production plus a reasonable rate of return.

Opinions on other aspects of development were wide-ranging. For instance, one respondent involved in field operations considered the brine problem of hot water resources almost solved, while another stated it might be insoluble for up to ten years. Federal legislative experts see the basic problem as financing of development, while a representative of an operating company stated that government aid was not needed to finance exploration and should be limited to true research and development. One respondent felt that utilization of minerals from geothermal brine would be of great commercial importance, but most did not think that desalination either for minerals or water would prove practical.

Pessimism generally prevailed on the possibility of coordination and simplification of government regulatory procedures. Particularly singled out for criticism were leasing procedures, complexity of permits, and duplication of environmental impact statements.

One official of a development company strongly emphasized his view that the principal obstacle to development lies in the circumscribed nature of the electricity market, where, by law, there can be only one buyer of energy, the local franchised utility.

Assessments of the list of possible impacts by the respondents depended, of course, on their view of how the development scenario would unfold. Their perception of the degree of impact on other energy sources, for instance, varied with the level of geothermal energy expected to be utilized. Opinions varied as to whether a slowdown in building of nuclear plants was desirable and whether geothermal development seemed likely to cause this to happen. The majority thought that the use of other geothermal energy would free other fuels, particularly petroleum, for uses other than the production of electricity, but all agreed that geothermal development would not cause a slowdown in the synthetic fuel industry or the cessation of strip mining. There was a wide range of views about whether imports of petroleum and the balance of trade would be affected.

Several respondents emphasized that industries would be attracted more by the availability of process heat than by electricity. There was a diversity of views on the possibility of development of new towns. Most respondents did not expect a noticeable impact on national GNP or living standards. Environmental impacts were generally viewed as locally controllable.

Almost all respondents considered the exclusion of small firms from geothermal development undesirable, but most felt there was a likelihood of this happening. There was also a general expectation of increased government regulation of private industry and establishment of new geothermal agencies, but different views on the desirability of this development.

Most respondents agreed that transcontinental transmission lines would be built in the future but disagreed as to whether the development of geothermal energy would be a causal factor. About half thought there was an even or greater probability that eastern electricity demand would be met by the export of geothermal-generated electricity. One participant theorized that only the development of hot dry rock resources could cause an excess of electricity in the West; but if hot dry rock technology were perfected it could be utilized in the East, even though it involved deeper drilling. Eastern development would thereby eliminate the need for transcontinental transmission.

Several important additional impacts of geothermal development were suggested by the participants. These included a change in the character of management and ownership of electrical systems, a change in the electricity marketing structure, and the effect on electrification of railroads.

Representatives of the varying interest groups offered suggestions as to government policies which they would like to see implemented. Among the recommendations were preference for: publicly-owned power companies in

geothermal leasing; establishment of a federal geothermal development corporation to serve as an economic barometer; elimination of bonus payments of leases in favor of royalties; government loan guarantee programs; government allocation of pipe casing and drilling rigs; allowance of more rapid plant amortization; government pilot programs to ameliorate present environmental problems; and limitation of government aid to cover only basic research and development.

Figure 3.2.8 summarizes the interview results and Appendix C presents the findings in more detail.

In addition to the structured in-depth interviews discussed here, at least 50 telephone interviews of varying lengths were conducted with informed persons on various specific topics. These conversations were initiated at various points throughout the course of the study when expert opinion or unpublished information on a particular subject was needed. Those contacted included, among others, utility officials, government administrators, suppliers of geothermal equipment, researchers in geothermal and allied scientific fields, and representatives of trade associations. Their particular inputs are referenced in the sections of the report in which they appear.

INTERVIEW PANEL EVALUATION OF GEOTHERMAL IMPACTS

	DESIRABLE	NEUTRAL	UNDESIRABLE	DISAGREEMENT ON DESIRABILITY
LIKELY TO OCCUR	1. Reduction in air pollution 11. Other energy sources freed from use for electricity 32. Geological science advanced 33. Multi-purpose complexes developed		13. Large integrated companies dominate development	29. Increased government regulation of private development 36. Formation of new government agencies
EVEN CHANCE OF OCCURRENCE	21. Commercial market for minerals 6. Nuclear plants slowed			
UNLIKELY TO OCCUR	18. Implementation of anti-poverty based on development of geothermal resources 23. Improved living standards	24. Energy-intensive industries migrating to West 20. Construction of new towns 26. Population migration to West 35. Geothermal tax shelters	2. Land subsidence 4. Increased seismic activity 7. Contamination of water tables 31. Recreation space reduced	28. Slowdown in growth of synthetic fuels 30. Strip-mining despoilation terminated 16. Geothermal tax revenues permit reduction of municipal tax
DISAGREEMENT ON OCCURRENCE	8. Inaccessible areas opened for recreation 9. Agriculture development stimulated by geothermal irrigation water 10. Revitalization of drilling industry 14. Improved balance of trade 15. Construction of transcontinental transmission lines 17. Increased industrial development 19. Alteration of home construction techniques 22. Electricity exported to East 25. Higher GNP growth 34. Natural gas supplies increased		3. Noise disrupting land use patterns 5. Localized climatic modification 12. Exclusion of small firms 27. Shortage of skilled manpower	

Figure 3.2.8 INTERVIEW PANEL EVALUATION OF GEOTHERMAL IMPACTS

3.3 Technical, Social, Political, and Economic Impediments

The purpose of this section is to summarize and record critical problems and technical unknowns which may act to varying degrees as constraints on the development of geothermal energy. This list of critical factors was developed from literature in the field and data collected in the two interview sequences described in Sections 3.1 and 3.2. The listing almost certainly will be modified as experience grows. Nevertheless, it represents a compendium of issues which currently constrain the development and use of geothermal energy.

The impediments are summarized below by principal categories, and are then repeated in more extended form with a detailed discussion of each issue and its significance in the pattern of geothermal development.

Technical Issues--Summary

A. Resource Exploration and Development

1. Need for developing more sophisticated deep sampling techniques and devices.
2. Lack of a practical technique for conducting gross exploration.
3. Lack of understanding of the correlations between sets of geophysical data.
4. Lack of understanding of a geochemical profile.
5. Lack of geothermal data exchange center.
6. Lack of coherent, verified, dynamic reservoir models.
7. Need for improvement in geophysical exploration and appraisal techniques.
8. Limited availability of deep drilling rigs.
9. Lack of generalized, coherent static geological models.

B. Reservoir Development

1. Lack of practical technique for very deep and very hot drilling.
2. Present acute shortage of tubular goods.
3. Lack of demonstrated method for recovery of energy from hot dry rock.
4. Lack of demonstrated method for recovery of magma.
5. Non-existence of a demonstrated downhole heat exchanger of sufficient capacity.
6. Lack of effective method for inhibiting and correcting solids deposition in the formation.
7. Non-existence of proven high-temperature deep-well pumps.
8. Unknown effects of reinjection on the producing formation.

9. Lack of knowledge of thermal stress-field inducted in a hot dry rock formation by massive injection and withdrawal of cold water.
10. Lack of confirmed understanding of cause/effect relationship between fluid injection into the formation and the occurrence of earthquakes.
11. Limited availability of drill-rigs for deep to very-deep drilling.
12. Lack of coherent, verified, dynamic reservoir models.
13. Lack of long-term case history data needed for field longevity predictions.

C. Energy Conversion

1. Need for demonstration electric power plant for liquid-dominated moderate temperature resources.
2. Need for demonstration electric power plant for heavy-brine reservoirs.
3. Non-existence of a proven prime mover on a predominantly liquid two-phase fluid capable of continuous operation.
4. Lack of effective method for preventing scale deposits on internal surfaces of equipment.
5. Lack of demonstration electric power plant for geopressured zones.
6. Lack of demonstration electric power plant for hot dry rock.

D. Environmental Technology

1. Need to prevent groundwater contamination.
2. Need to control harmful gaseous emissions.
3. Need to dispose of liquid and solid wastes.
4. Need for noise control.
5. Need to understand relationship between fluid injection and earthquake induction.
6. Need for developing techniques for dealing with land subsidence.

Non-Technical Issues--Summary

A. Lack of Uniform Definition of Geothermal Resource And Consequent Tax and Other Uncertainties

1. Need for classification as water, mineral, or sui generis.
2. Need for clarification of income tax treatment.
3. Need to define allowable depreciation schedules.

B. Land Use Problems Arising from Private Development of Public Lands

1. Lack of certainty as to use of federal land and operation of leasing regulations.
 2. Need to resolve problems arising from patch-work of government and private lands.
 3. Need to resolve question of bonus bidding vs. greater emphasis on royalties.
- C. Overlaps in Administrative and Environmental Regulations
1. Need for simplification of costly and delaying regulatory maze resulting from multiplicity of agencies at many government levels.
 2. Necessity to provide assurance to developers of proceeding to production stage.
 3. Need for clarification of which level of government's regulations are binding on federal and state lands.
- D. Reluctance of Private Financial Institutions, Utilities, or Investors to Back Projects Entailing High Risks, Long Waits for Return, or Unproven Resources
1. Lack of incentive to encourage investment in inherently high-risk, long-wait geothermal projects.
 2. Lack of legal right to include geothermal exploration and development in utility rate base.
- E. Commercial Institutional Arrangements
1. Lack of institutional flexibility in producing and marketing electricity.
 2. Lack of provision in current utility regulations for multi-purpose geothermal complexes.
- F. Availability of Materials, Manpower, and Capital
1. Present shortage of drill rigs and tubular goods.
 2. Need for geothermal experts and trained drill crews.
 3. Difficult geothermal competitive position in high-interest, tight capital market.
- G. Previous Commitment of Utilities to Other Fuels
- Need to evaluate long-term expansion demand for electricity relative to lead-time for plant construction.
- H. Conflicting Local, Regional, and Federal Interests
- Need for cost/benefit trade-offs in environmental areas.

Technical Issues--Discussion

A. Resource Exploration and Development

1. Need for developing more sophisticated sampling techniques and devices which are capable of retrieving unaltered representative samples of solids, liquids, and gases at depth. Sampling procedures are divided into two basic groups: those conducted during drilling operations and those conducted after well completion.

Sampling during drilling can be partially characterized as follows:

- a. Solids samples (cores) can most conveniently be retrieved during drilling. These are required to determine physical variations in rock types (such as porosity and permeability).
- b. Bulk chemical composition is often difficult to determine because soluble fractions and clays are usually washed away by the drilling fluid (water or drilling mud).
- c. "Slim holes" (2-3" diameter) yield more useful data because they do not disturb the sample to nearly the same extent as production drilling. Slim holes are practical to an approximate maximum depth of 3000 ft.; their sole purpose is to gain information. Slim hole technology was developed for minerals exploration.

Sampling after well completion can be partially characterized as follows:

- a. Solids sampling is almost impossible to perform after well completion because the well casing prevents it and present samplers are not capable of scooping solid samples from the wall of an unlined hole.
 - b. Liquid sampling of groundwater at moderate depths is conducted in order to acquire baseline data against which to compare future composition of groundwater in order to monitor possible contamination.
 - c. Samplers can be sent to the bottom of a hole to retrieve an in-situ liquid sample under no-flow conditions, or a "grab" sample can be taken at the well-head while the well is flowing.
 - d. One fairly effective in-situ liquid sampler has been developed which is capable of going to approximately 1000 ft.
 - e. A small submersible pump has been suggested as an effective sampling device.
2. Lack of a practical technique for conducting gross exploration (i.e., remote thermal I.R. (infrared) scanning from Earth Resources Satellite.

Knowledge of the location of geothermal sources is important to growth in the use of the resource. If reliable synoptic methods for remote identification could be developed, KGRA's could be specified and development encouraged. The present thermal infrared scanning instruments appear to be ineffective for the purpose of conducting gross geothermal exploration. The minimum heat flow that can be detected is at least 10 times greater than the necessary minimum value for exploration. Instrumentation explicitly for this purpose is not currently included in the Earth Resources Satellite Program. Micro-earthquake location techniques may be an alternate synoptic exploration candidate. Certainly, ambitious but potentially useful would be the compilation of a comprehensive set of geological-heat-flow/surface manifestation maps of the entire United States, based on existing uncorrelated data; these data would be expanded by further extensive surface and sub-surface physical measurements.

3. Lack of understanding of the correlation between sets of data obtained from the numerous geophysical measurement techniques. Geophysical measurement techniques include electric surface resistivity, seismology, magnetic, gravimetric, magneto-telluric, deep electrical resistivity and heat flow measurements. Each has been used to greater or lesser extent in surveying for geothermal sources. There is no clear and general understanding of the degree to which data produced by the various methods correlate with each other and with geologic structure at depth.

4. Lack of understanding of the inferential significance of a geochemical profile (identification and concentration of constituents).

A chemical profile is needed to predict important characteristics of a particular formation. It is important in determining the hydrology and porosity, and can be used to determine the expected levels of productivity. The availability of accurate geochemical profiles would also hold the key to assessing the economically recoverable mineral values. The geochemical profile for each field should be determined before the conversion system is designed. In terms of downhole solution chemistry, measuring pressure, as well as temperature, is critical. Much more research is required in order to relate quantitatively the geochemical analysis to the geothermal resource characteristics.

5. Lack of geothermal data information center designed to receive, store, process, and disseminate existing and future resource and reservoir data (geological, geophysical, geochemical, etc.) which is in the public domain for use in resource appraisal, reservoir design and management.

Much data are gathered by private companies and are not available for public release because of the proprietary nature of the data. The industry urgently needs feedback of data from exploration programs (both successes and failures) to a centralized data bank so it will be available for general public dissemination and correlation. Substantial incentives will probably be necessary to compensate

for the proprietary value of data. Also much of the effort will have to be made by government agencies such as the U.S. Geological Survey and National Science Foundation.

6. Lack of coherent, verified, dynamic reservoir models. To date there are no simulation models available which allow accurate prediction of dynamic reservoir behavior—with increased drilling data, the formation of such models will become more practical. Models predicting behavior of reservoirs will be useful in determining the optimum rate of heat extraction and reservoir lifetime.
7. Need for improvement in procedures, equipment, and data interpretation of the various geophysical exploration and appraisal techniques. The presently available techniques for making geophysical measurements are essentially laboratory methods which have been adapted to field use, and they are often cumbersome, time-consuming, and require the use of highly trained personnel. Therefore, acquisition of data is an expensive and drawn-out affair. Greatly improved techniques, procedures, and instruments are needed which will reduce both required time and costs.
8. Limited availability of drill rigs and knowledge for deep to very deep drilling (25,000 ft. and greater).

Geothermal drilling to date has not exceeded the 10,000 ft. depth. The few existing ultra-deep wells are natural gas wells. Experience in planning and drilling deep, hot, igneous, wide-diameter geothermal wells is lacking. There are only eight to twelve rotary drill rigs in the United States today that are capable of drilling to depths greater than 25,000 ft. The geothermal drilling industry can expect strong and increasing competition from the deep oil and gas well drilling industry. Production lead time for this type of drill rig is currently three to five years. Geothermal drilling requires specially modified petroleum industry equipment. At the present time there is a short-term shortage of trained personnel, an acute shortage of tubular goods (drill steel and well casing), and keen competition for drill rigs of all capabilities. The geothermal industry occupies a poor competitive position because of present lack of continuity of the drilling work (The Geysers is an exception), i.e., no long-term drilling contracts of two to three years in the same general location. This situation can be changed by instituting an organized geothermal drilling program.

There are rigs available today which can penetrate to 30,000 ft.; but what will be most needed are investors and/or sponsors for more research. A thorough systems analysis and planning of all the components of deep geothermal development appears to be needed.

9. Lack of generalized, coherent, regional geothermal geological models (static).

Regional geologic, geophysical, hydrologic, and geochemical studies can yield maps indicative of resource dispersion throughout a particular region. Such maps could provide insight into the formation of three-dimensional underground models depicting heat and water flow. If models of this sort were available, forecasting the extent of the resource, available reserves, and disposal well

location and projecting the consequence of fluid removal, would all become more feasible and precise.

B. Reservoir Development

1. Lack of practical, broadly-applicable technique for very deep drilling (i.e., below 25,000 ft) or to temperatures above 800°F for the following reasons:

- a. Compounded drilling fluids ("mud") begin to break down chemically and physically at about 600°F. Until now, there has been no compelling reason to break through this temperature limit.
- b. The water in casing cements boils out of the cement at 600°F. A 700°F setting cement is now being developed.
- c. Data measuring and recording instrument packages (logging tools) generally fail when subjected to temperatures above 500°F.

Research should be directed toward the temperature and depth goals, proof-of-concept experiments (POCE), and field demonstrations.

Eventually sources will be required for drill bits and associated heavy-duty drill rigs capable of making holes to depths of 40,000 ft. into formations having temperatures greater than 800°F. Availability will be shown by one demonstration in the field.

First demonstration of the energy extraction technology for hot dry rock as a practical energy resource will be at the lower temperature levels (430°F). Then the potential of very hot rock resources (800°F) for expanded electric power production will generate the impetus for the development of a high-temperature drilling technology to the state of commercial field equipment.

2. Present acute shortage of tubular goods (drill steel and well casing) which are essential to drilling and casing operations.

Geothermal drilling operations must compete with oil and gas drilling operations, both domestic and foreign, for tubular goods (i.e., for drill steel and well casing). Fabrication plants have been able to keep up with the demand until recently. However, the shortage has now become acute, and is due to a rapidly increasing domestic and foreign demand. Foreign buyers prefer U.S. casing and drill pipe because it is cheaper than foreign fabricated tubular goods because of the devaluation of the U.S. dollar. This situation was exacerbated under Phase IV since price controls prevented raising of the domestic prices; therefore, a very substantial fraction of the supply flowed out of the country.

In the United States alone, there are 85-100 offshore drill rigs being built at any one time. Each of these requires approximately 40,000 ft. of drill steel (two complete strings).

Prior to development of the shortage, normal delivery time was 30-60 days from date of placement of order, with a present slippage rate of 2-3 months per calendar month. The industry believes this situation is temporary and will return to normal in about two years.

3. Lack of demonstrated method for continuous recovery of energy from hot dry rock reservoirs. The recovery of energy from hot dry rock is an unproven concept. While large-scale technological problems remain yet to be solved, initial results from the laboratory and field experiments are very encouraging.

If the present funding is expanded and the research programs are continued until 1985, commercial feasibility may be demonstrated with a 50-100 MWe power plant. Within five years from now, demonstrated continuous energy recovery for the western United States is possible.

Hot dry rock is ubiquitous and therefore development of practical methods for its utilization will be extremely significant for the whole country.

4. Lack of demonstrated method for continuous recovery of energy from magma reservoirs.

The use of this resource is extremely speculative and of low priority. Potential applications may be found in Alaska and Hawaii near active volcanoes, but the technology required is ill defined and very poorly understood.

5. Non-existence of a demonstrated, practical downhole heat exchanger of sufficient capacity to be useful in large-scale energy extraction operations.

Within two years, a downhole heat exchanger system (Van Huisen concept) will be full-scale tested in the Imperial Valley, California. If this system is proven to be feasible many units will be installed in the Imperial Valley. The approach will require an adequate source of cooling water, or other satisfactory heat rejection schemes.

Control of deposition of dissolved solids on the exterior of the heat exchanger may be achieved by judicious management of well production.

6. Lack of effective methods for inhibiting and correcting solids deposition in the producing formation and in the production casing.

Presently the hydraulic, chemical and thermal mechanisms of deposition are understood but are difficult to deal with and to control. Deposition of calcium carbonate and calcium sulfate is a major problem. Silica deposition is a problem at temperatures of 240°C and higher, and is a major problem at 280°C and above. No information is available on silica or calcium carbonate deposits in the formation. Field studies and laboratory studies on the kinetics and

solubilities are much needed, as well as on methods of inhibiting scale formation.

Close control of well production rate is required to avoid well draw-down, causing flashing and subsequent salt deposition in the formation which may be irreversible, or at least expensive to correct. The effects of mechanical pumping must be well-understood and carefully applied.

A good possibility exists for a breakthrough within six years. Work will be done to determine effects on the formation, as this is much needed. A required input for solving the silica deposition problem will be good field studies with strong laboratory support. For the calcium carbonate deposition problem, the work will parallel that for silica.

7. Non-existence of proven deep-well pumps (for geothermal applications at 500-700°F.

Electric cable and motor windings are presently available for 300°F operation on a routine basis, but at reduced useful life and increased maintenance costs. Electric insulation is temperature-limited. One experimental air-cooled electric motor has been operated continuously at 500-700°F. Experimental work in the next few years is expected to improve the technology. Requirements for production will include: a strong demonstrated demand; development of improved lubricants, such as silicones, etc.; development of high-temperature electric insulation for cables and motor windings; and development of high-temperature bearings and seals.

Hydraulic pumps for this high temperature duty are also being researched. The main problems are finding a longlife high temperature hydraulic fluid, a lubricant, and a workable mechanical design.

A third suggested pump is a steam driven centrifugal. The most apparent basic problems are mechanical design, seal design, and lubrication.

The development of these three types of high temperature deep well pumps will be difficult, expensive, and require much innovative research.

8. Unknown effects on the producing formation resulting from reinjection of solids-bearing liquid wastes (cooling tower blowdown or flash tank liquid).

Damage to the producing formation from this cause, if any, has not been investigated and therefore is essentially unknown. Liquid wastes can be cleaned up (pretreatment) on the surface before disposal or reinjection. It is essential to know the geochemical profile of the liquid wastes, the undisturbed liquids in the formation, and the solids in the reinjection zone, especially with respect to calcium carbonate, silica, clays, zeolites, and sulfate ions. There is too little thermochemical data presently available to

permit prediction of the effects on the formation caused by reinjection. The small amount of available data is not well characterized with reference to temperature and pressure. It will be necessary to collect much new thermochemical data, and to develop new computer models with inputs which characterize the various geological systems, i.e., the chemical composition of liquids and solids which are already in place. Modeling of solution-solution reaction dynamics is also required. Experimental drilling should be conducted in which core sampling is done before reinjection and some years after reinjection, to assess the extent of buildup on the formation. It may be necessary to pretreat before reinjection.

9. Lack of knowledge of thermal stress-fields induced in a hot dry rock formation by massive injection and withdrawal of cold water.

The successful operation of a geothermal hot rock resource depends on the scientific understanding of the behavior of the formation when subjected to injection and flow of colder water. The presence of the cold water will set up temperature gradient fields in the surrounding rock. In turn, this will cause the formation of differential thermal stress-fields. Very little is known about the hot dry rock characteristics and how it will act under the conditions of the proposed operation.

Laboratory experiments with cast concrete have begun and are yielding some important results. Further laboratory work with igneous rock (granite) similar to that found in actual rock formations is required. This should be followed by proof-of-concept experiments (POCE) at selected field sites.

This successful research is vital to the effective engineering of a hot dry rock power system. A good engineering understanding of the rock thermal mechanics can be used in rock fracturing and creation of the required heat transfer surface and channels. The entire concept can only be proven in a full scale field test.

10. Lack of confirmed understanding of cause/effect relationship between fluid injection into the formation and occurrence of earthquakes with respect to possible damage or destruction of the wells, gathering system, power plant or surrounding land.

This mechanism is better understood than is generally believed, and is presently being studied intensively by the U.S. Geological Survey. Field experiments are very advanced at this time. State-of-the-art of locating earthquakes is also far advanced, i.e., with a network of inexpensive seismic stations. A present impediment is the inability to predict the magnitude of earthquakes. Based on results of recent field experiments by Dr. B. C. Raleigh (USGS) in the oil field near Rangely, Colorado, triggering earthquakes by injection of fluids into the formation can be avoided by not injecting where the pressurized fluid can communicate with active seismic faults.

11. Limited availability of drill-rigs for deep to very deep drilling (i.e., below 25,000 ft.) and

very hot drilling (i.e., greater than 800°F).

Geothermal drilling must compete with oil and gas drilling operations for the available drill rigs, skilled personnel, and tubular goods (drill steel and well casing). At present, there is a shortage of trained personnel, an acute shortage of tubular goods, and keen competition for drill rigs of all capabilities. Present geothermal drilling technology depends completely upon the oil and gas industry developed drilling equipment. Deep drilling requirements imply an extended geothermal drilling development beyond present trends which today require only relatively shallow (approximately 5000-10,000 ft.) steam and hot water wells. There are only eight to ten drill rigs in the United States capable of drilling to depths greater than 25,000 ft. Current drill rig production lead time is three to five years. The geothermal industry has a poor competitive position because of present lack of continuity of the drill work, i.e., it cannot provide long-term drilling contracts of two to three years in the same general location.

The three largest rigs available in the United States today were developed in response to U.S. AEC drilling requirements.

The near-term situation is strongly influenced by the general demand for gas and oil in the United States and the foreign value of the U.S. dollar. In terms of performance, drill rig capability can be expected to extend to 40,000 ft. with ability to handle normal geothermal gradient temperature problems (i.e., less than 390-520°F). Present trends in oil and gas exploration and production indicate that deeper capabilities will evolve but it is likely that very few drill rigs of this capability will exist. Availability of drill rigs, trained crews, and tubular goods for geothermal will depend on the geothermal industry's ability to stimulate these essential items with higher prices and long-term contracts. Among the incentives which should be considered are: (a) Government established priorities for drilling equipment; (b) depletion allowance for geothermal steam; (c) means of assuring continuity of work (i.e., two to three year drilling contracts), or the ability to pay premium prices for a one- or two-hole drilling effort.

12. Lack of coherent, verified, dynamic computer reservoir models to understand and manage field development. A concerted, well-financed scientific program should be instituted to obtain data on which to base sufficient dynamic reservoir models.

Private companies probably will not initiate the necessary programs of scientific data recovery because it is difficult to demonstrate that this kind of investment is either recoverable, or profitable. Nevertheless, geothermal reservoir models are badly needed now and in the future in order to effectively understand and manage field development. A government supported research program could make computer programs and data publicly available. These will be a valuable

and necessary tool in the rational development of geothermal energy.

13. Lack of long-term case history data on which field longevity predictions can be based. There is a serious need to correlate geophysical signatures with reservoir characteristics at depth and to develop test methods that allow prediction of reservoir longevity without waiting until the field is exhausted. The only data available at present is on The Geysers, Wairakei, and Larderello. Declines in pressure and fluid discharge rates have been noted, but no information about the ultimate significance of these changes is yet at hand.

This situation is likely to be serious because ten years or more of data may be required to form a good idea of field performance. This will lead, hopefully, to the ability to predict the behavior of a variety of types of fluid reserves for at least five years in advance.

C. Energy Conversion

1. Non-existence of a large-scale demonstration electric power plant for liquid-dominated resources of medium to low thermal quality.

There are no plants now operating on medium to low temperature brines (hot water). Since large quantities of geothermal resources of this type are available, there is a great incentive for overcoming this impediment. The problem really has two parts: (1) the plant thermodynamic efficiency, and (2) the brine corrosion, scaling, and deposition due to dissolved salts.

The plant thermodynamic efficiency tends to be low and is limited by the temperature of the brine. The present high temperature brine power cycle (Mexico and New Zealand) which only uses the single flashed steam and discards the remaining hot water is not usable simply because not enough energy is contained in the small amount of flashed steam. Most of the heat will remain in the discarded water, so a cycle is required which will use more of the heat in the initial brine. Two general methods are now proposed to do this.

In the first method, the inlet brine is flashed successively, two or three times, at decreasing pressures and each flash is sent through an optimum turbine stage. Such a system would recover most of the available energy and have a fairly good efficiency. Some of the equipment for this cycle will have to be developed. The low pressure steam turbine design will be a problem but probably can be solved. This cycle avoids most of the scale and corrosion problems as the inlet dissolved salts remain in the portion of brine which does not flash and is sent to waste.

The second method is also potentially capable of an economically viable plant efficiency (10-15 percent) because it would use all of the available energy contained in the inlet brines. In this cycle, the inlet hot brine is sent through a heat exchanger in which isobutane or freon is boiled as the cycle working fluid. This isobutane vapor, of

course, is at an elevated pressure and temperature. This is then sent through a turbine generator to make electricity.

There are a series of problems to be overcome in developing this cycle. First, a heat exchanger must be developed which has a good efficiency and does not scale up. Second, an efficient large size turbine design must be developed for the isobutane or Freon. It does not exist now. Third, and finally, severe scaling and corrosion caused by the inlet brine in the heat exchanger, pumps, pipe, and other equipment, must be controlled.

When all of this is accomplished, medium to low temperature geothermal brines may be utilized to generate very large amounts of electricity and space heat.

2. Need for demonstration electric power plant (of any size) for conversion of energy from heavy-brine reservoirs.

While no technical impediments are known to exist in building 50-100 MWe plants using the binary process, no expander of this size has yet been built for a geothermal application. The major technical impediment is knowledge of how to control (or live with) the heat exchanger scaling problem. Possibly scaling can be overcome by multi-stage flash and steam clean-up processes. Employing multi-stage flash systems will permit construction of binary plants of any size. Control of scaling in heat exchangers has yet to be demonstrated. Plans exist (e.g., Magmax process in the Valley) for a small-scale demonstration plant to be built in five years, plus three years of testing, for a total of eight years.

3. Lack of a proven prime mover capable of continuous operation on a predominantly liquid two-phase fluid.

The liquid dominated brines are essentially two-phase systems, vapor-liquid at the turbine inlet temperature-pressure conditions. Since a conventional turbine cannot withstand liquid material without breaking, new design machines are required. This new machine must be capable of converting the energy in the vapor-liquid brine at elevated pressure and temperature to mechanical work and then to electricity. Thermodynamically, this is an adiabatic isentropic expansion of the entire geothermal vapor-liquid mass. Of course, the process and machine must operate continuously. Such an energy conversion machine (turbine) does not exist now. A large research effort is required to solve this problem and build a reliable machine. At present there is a small industry effort to develop a machine capable of handling a two-phase fluid. A prototype KROV (Keller Rotating Oscillating Vane) engine is presently being built. Test plans call for a full range of mechanical and performance tests by personnel from M.I.T. Hydrothermal Power Company has accumulated approximately 1000 hours of operational experience on a machine which functions directly on high-energy brine, employing a helical-screw type expander. Considerable development experience has been accumulated by General Ener-Tech, Inc., in bladeless turbines utilizing superheated steam, and also in various hot gas applications in

ranges from 3-1600 hp. Additionally, General Ener-Tech has developed several two- and three-phase pumps in performance ranges to 1000 gpm which also utilize this principle. Currently undergoing development testing is a 250 hp, 300 gpm, 500 psig geothermal reinjection pump which is scheduled for testing on a geothermal well in the Imperial Valley, California.

4. Lack of effective method for preventing scale deposits on internal surfaces of mechanical equipment, i.e., heat exchangers, pipes, turbines, etc.

Hot saline brines are well known for their corrosiveness. However, there are some reasonably good methods and materials for dealing with low salinity water. These methods are for 10,000 ppm dissolved salts and for fairly low sulfate ions and dissolved silica. A combination of selected non-corrosive metals and design methods can be used to give a successful geothermal unit. However, hot saline brines containing large amounts of salts, such as those of the Imperial Valley, California (300,000 ppm) present a very difficult set of problems. The only known non-corrosive materials of construction are expensive and must be used in combination with improved engineering design in order to make the plant economical. Such designs will have to be developed, as well as improved with less costly metals.

The fouling and scaling of the internal surfaces is mainly due to the deposition of calcium sulfate and silica. This is a set of problems, not just one. New techniques will have to be developed to control the water chemistry, the heat transfer, the mass transfer, and the engineering design. This set of problems is formidable. They have been attacked slowly and piecemeal in the past. A well thought-out coordinated research program is now required to solve this critical problem.

5. Lack of a demonstration electric power plant of any size for conversion of energy from geopressured zones.

The geopressured resource is extensive but relatively little is known about environmental and technological issues associated with its use. Most important among environmental concerns is the possibility of land subsidence; prominent among technical issues are techniques for reinjection of waste fluids, recovery of the mechanical energy from the pressurized fluid, and, finally, efficient conversion of the low temperature heat to electrical energy.

6. Lack of a demonstration electric power plant of any size for conversion of energy from hot dry rock.

A 10 MWe demonstration plant will be built at the Los Alamos Scientific Laboratory test site, possibly by 1978. Among the important problems yet to be resolved in the use of this potentially important energy source are:

- a. Determining the rate at which heat can be extracted from the heat source.
- b. Developing effective methods of increasing the heat transfer surface through hydrofracturing and other means.

- c. Ascertaining the effect of this energy extraction form on seismicity.
- d. Determining the available heat resource contained in the surrounding rock strata.
- e. Researching, developing, and demonstrating the whole system of machinery required to continuously circulate water through the rock fractures, extract heat, carry it to the surface power plant heat exchangers, boil the turbine working fluid, and convert it to mechanical and then electrical energy.

D. Environmental Technology

1. Necessity for developing practical techniques for preventing groundwater contamination. The importance of this issue will be a function of the type of geothermal reservoir, its hydrological setting, and the means employed for fluid recharge or disposal of geothermal fluids.

Research is needed to show whether it is possible to recharge an underground reservoir at an acceptable rate at the appropriate depth and stratum and still prevent contamination of any groundwater aquifers which are likely to be used as a water supply source.

2. Necessity for developing techniques of effectively controlling harmful or nuisance gaseous emissions (H_2S , CH_4 , ammonia, etc.).

Hydrogen sulfide is present in very small amounts in both steam and hot water wells. Research to control H_2S emissions from power generating units with an open cycle, wet cooling tower, and with dry steam, as at The Geysers, is fairly well understood. Demonstration at the prototype and operational levels is scheduled for 1974. Control of NH_3 and CH_4 emissions is not necessary at The Geysers and therefore should be the subject of future research, although neither presents much of an environmental problem.

3. Necessity for developing broadly applicable techniques for liquid and solid waste disposal.

Disposal of liquid waste brine by reinjection has already been demonstrated and is commercially reliable at The Geysers. Means of disposal of solid waste products are now being investigated at The Geysers and a solution is expected during 1974.

Techniques for disposal of both liquid and solid wastes must be fully developed and commercially reliable. Disposal of solid wastes may require landfill sites.

However, liquid waste brine disposal still is a very formidable problem in liquid geothermal fields such as the Imperial Valley, California. Extensive research is required to solve the many problems associated with chemistry, corrosion, pumps, geochemistry, geophysics, reservoir engineering, and environmental chemistry, among others. The solution of these problems will require a large effort.

4. Necessity for developing practical and effective techniques for noise control during initial drilling and testing operations, as well as during operating life of the plant.

A noise problem exists for high-pressure steam wells during drilling and clean-out blow, which is due to the use of compressed air as a drilling fluid, and the uncontrolled release of the natural steam. At present, drilling mufflers are in an experimental stage of development. A clean-out blow lasts from 6-48 hours, depending on the characteristics of the well. For hot water systems, noise is not a problem at the well during drilling, because drilling mud is used instead of compressed air, and there is no uncontrolled release of the geothermal fluid.

During operation there are several places in a field at which some steam is blown off, creating a considerable noise. This, of course, is localized. Research is required to develop good functional sound muffling equipment.

5. Lack of confirmed understanding of cause/effect relationship between fluid injection into the formation and occurrence or suppression of earthquakes, with respect to environmental effects on the surrounding area and populace.

Dr. B. C. Raleigh (USGS) has demonstrated in the oil fields near Rangely, Colorado that earthquakes can be triggered as a result of injection of fluids into regions which contain active seismic faults. Clearly a requirement for geothermal operations will be the avoidance of active seismic faults. When deep wells, either primary or reinjection, are utilized it may prove difficult to identify faults a priori. Therefore, what is required is a more basic understanding of the mechanism by which fluid injection relates to earthquakes; and a means of more positively identifying the course of faults, particularly deep faults.

6. Necessity of developing predictive, preventive, and corrective techniques for dealing with land subsidence consequent from geothermal fluid withdrawal.

Subsidence is of most concern in the use of geopressured zones and shallow hot water resources. In the latter case, reinjection of fluids after heat removal should virtually eliminate any potential subsidence threat. (However, if the fluids which are removed are used to supplement local water supplies, and the net amount returned is less than the amount extracted, subsidence may result.) In the case of geopressured resources, the situation is more complex. The under surface fluids exist at very high pressure, therefore, reinjection in the same strata would require high pumping pressures and, therefore, could potentially eliminate an appreciable portion of the advantages which might accrue to the use of this energy source.

Much more research in geophysics and geology is required to understand the phenomena involved in subsidence and reinjection of water into rock strata. At this time very little is actually known, in a scientific sense, about the factors involved and their interrelationships.

A. Lack of Uniform Legal Definition of Geothermal Resources and Consequent Tax and Other Uncertainties

1. A state of uncertainty exists as to whether geothermal resources should be legally classified as water, minerals, or *sui generis*. The Geothermal Steam Act of 1970[1] (see also Appendix K) clarifies this matter to some extent. It does, however, leave to be settled the question of whether reservation of minerals to the United States in prior land grants and patents included the geothermal resources. Ownership of resources is therefore in question in many cases. No unique legal definition of geothermal resources has been provided by Congress and current conflicts must now be settled through litigation.
2. The lack of clear definition particularly impedes development by perpetuating uncertainty of treatment under income tax laws. Investors do not have any assurance that they will be entitled to tax incentives similar to those provided for the oil and gas industry. These incentives include the depletion allowance and deduction of intangible drilling costs. The Reich case[2] in 1969 established that steam produced at The Geysers in California could be classified as a "mineral gas" for tax purposes. Consequently, participants in drilling ventures in that area are entitled to deduct the depletion allowance from gross income received from steam production and to expense the intangible costs of drilling and developed wells. Tax treatment is still uncertain, however, for steam in other places and for non-steam resources. The question remains whether they are depletable resources or continually renewable. Depreciation schedules have also not been defined to fit special geothermal conditions.
3. It is probable that the present situation will lead to time-consuming court cases turning on the definition question. Research into legislation which could be recommended to speed up the process could result in earlier removal of this impediment. Studies are also needed to evaluate the effects of various tax treatments and depreciation schedules, and to expedite their adoption so that private developers will be able to proceed with greater assurance.

B. Land Use Problems Arising From Private Development of Public Lands

1. About 60-70 percent of geothermal resources are on government-owned land, and in many promising exploratory areas a patchwork of public and private land exists. These conditions have led inevitably to a number of conflicts and uncertainties. The most basic difficulty centers around which land can be developed. The opening of federal lands for leasing in 1974 removed the greatest obstacle to exploration, but some aspects of the leasing law have been subject to criticism or remain to be clarified.

Including the element of "competitive interest" in the definition of a KGRA, it is

claimed by some private developers[3], will inhibit acquisition of leases in areas not currently designated as KGRA's by allowing the Secretary of the Interior the option of reclassification for competitive bidding if more than one bid is received in an area with more than 50 percent overlap. In contrast, if this type of situation occurs on federal land in non-competitive oil and gas areas, the choice is made solely by order of application or by lottery. The criterion is purely physical, i.e., whether the land is within a known geological structure. Reduction or elimination of this administrative discretion and redefinition of KGRA's on a purely scientific basis would clarify this situation. Other ambiguous items in the leasing regulations are provisions for duration and renewability of leases and the definition of land subject to leasing because of environmental factors. This latter definition may take a number of years because of the necessity to balance the diverse interests involved.

2. A related land-use problem is the need for joint development of areas where government-owned land, either federal or state (or both), are intermingled. There is provision in the leasing law for unit or cooperative agreements for such areas, but questions remain as to whether federal, state, or local land-use regulations would govern such developments.
3. There has been some criticism of the use of the bonus bid system for competitive leasing on the grounds that it favors larger companies over the small operator who does not have the financial capability to tie up a large amount of money prior to production. Emphasis on larger royalty payments rather than prepaid bonuses would also tend to maximize long-term rather than short-term income to the government.

Ambiguities in the leasing law can be clarified by amendment or by changes in regulatory action, but studies are needed to determine what type of emphases (e.g., competitive vs. non-competitive bidding, or bonus vs. increased royalty payments) would best serve the needs of the industry and the public.

C. Overlaps in Administrative and Environmental Regulations

1. A multiplicity of agencies with some responsibilities in the development and use of geothermal energy exist on the federal, state, county, and local level, each with its own standards, requirements, and time schedules. This situation is compounded by confusion as to the nature of the resources and by the involvement of various types of regulatory bodies on all levels. These include agencies with jurisdiction over public lands, geothermal resources per se, oil and gas, water, building inspection, public work, public utilities, and specific environmental areas such as land planning, air pollution, fish and game, and forestry. Figure 3.3.1 (on the following page) charts the regulations which must be met in California for each phase of the development.
2. Different regulations must be complied with at each stage of exploration and drilling, and there is no assurance that the developers will

FLOW CHART OF CRITICAL PATH IN GEOTHERMAL EXPLORATION (CALIFORNIA)

Source: David Anderson, Division of Oil and Gas, State of California.

Figure 3.3.1

be able to continue on to production. As many as three environmental impact statements can be required for each project. It is difficult for developers to be aware of all required procedures, and the necessary compliance involves costly duplication of effort and time delays. There is also a lack of administrative finality in the environmental area.[4]

3. In addition, there is the problem of what regulations are binding on what land; that is, if state regulations can apply on federal land, and county zoning and environmental regulations on state and federal land.

As more exploratory drilling is done and environmental knowledge of the resource is augmented, necessary standards will become more clearly defined and duplications may be able to be gradually eliminated, although all levels of government will maintain their concern. Immediate measures to enlist the cooperation of all agencies and interests involved could speed up the simplification process. Study teams could determine the best way for this to be accomplished. Statewide geothermal regulatory clearing houses could be established for instance, to work for standardization of laws and regulations, coordinate processing of forms and public hearings, disseminate information to developers, and encourage counties to establish land use and zoning plans which give developers some assurance that their projects can be carried to completion. California has made a start in coordination of federal and state agencies through its Geothermal Resources Board.

An additional possibility for simplified requirements is amendment of the National Environmental Protection Act to allow one impact statement for all levels of government. This could still allow local input, since present statements are not generally conflicting, but repetitive.

This one statement might be more extensive than any of the former separate ones because of the need for some different information by different levels of government. It has been suggested that some limitations be put on rights of appeal in order to ensure some degree of administrative finality, but some political conflict can always be expected to exist in this area.

Another contribution to unraveling the regulatory maze could be made through establishment of multi-level commissions to prepare model laws and standard operating procedures for states. In addition to streamlining procedures, such measures could enable developers to operate in different states without having to become familiar with entirely different regulations.

Although it will be possible through coordinated efforts of all involved to make regulatory procedures more clearly defined and easier to fulfill, a large number of regulations will always have to be met in order to accommodate the interests of all levels of the public.

D. Reluctance of Private Financial Institutions, Utilities, or Investors To Back Projects Entailing High Risks, Long Waits for Return, or Unproven Resources

1. Even after basic research has shown that a process can be commercially viable, financing may be difficult to obtain. Especially in the high-interest capital market which prevails today, with many competing demands for money, high risk and long-term projects are hard to finance. These high risk and long wait factors are inherent in geothermal development. Several years can elapse between the time a producing well is drilled and the time purchase contracts are negotiated with utilities and generating plants are built. Developers, particularly small operators with limited resources, are being constrained by these conditions.
2. Utilities are also discouraged from undertaking investment in geothermal field exploration, appraisal, and development, and equipment and process research and development because of uncertainties as to whether utility commissions will allow costs of these activities to be included in utility rate bases.

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Without some sort of government incentive programs, these investment factors will be major constraints on development.[5] Development would at first be limited to those few projects which would be judged to have an immediate chance for commercial success. Any steam resources found would be most easily financed because of their proven capability. At least several years of production and convincing geological evidence that the resource would continue might be necessary before a utility would commit itself to utilize a hot water resource. Hot dry rock and geopressured resources, because of their greater uncertainties, would probably require a longer time to attract venture capital.

Several proposals have been advanced in Congress to provide utility and investor assurance, though none has been yet enacted. Title II of S1283[6] authorizes a loan guarantee for geothermal development. It guarantees banks or other financial institutions against loss of principal or interest on loans to acquire rights in geothermal resources and to perform exploration, development, and construction and operation of commercial production facilities. The guarantee extends up to 75 percent of the cost of the project, up to \$25 million for any project, and up to \$30 million for any borrower. The government is authorized to pay the interest if the borrower is unable to do so. The bill authorizes up to \$50 million to be appropriated to a Geothermal Resources Development Fund.[7]

Another approach is contained in Title I of S1283, applying to all energy research. It provides for federal purchases or price guarantees for products of demonstration plants. Another possibility is for local governments to declare a moratorium on property taxes between the time a well is drilled and returns are realized.

An additional avenue is for utilities to offer loans for development drilling, with utility commissions permitting the costs to be included in rate base formulation. In return, the utility could receive an option to purchase steam. Utilities presently use this method with the oil and gas industry.

E. Commercial Institutional Arrangements

1. One of the most fertile areas for innovative research lies in the area of institutional arrangements for marketing the products of geothermal energy, both electrical and non-electrical. Arrangements developed in the past which were suitable for utilization of other forms of energy may not be adaptable for this form and may indeed hinder its development.

The primary area of concern is the structure of the electric utility industry and its transmission network. Privately held public utilities are granted monopoly status in their areas and are closely regulated by public utility commissions. They are generally allowed to sell no product other than electricity, gas, or water, and no competing firm may operate in their franchised territory. Transmission lines are owned by the companies and are not common carriers. (In publicly-owned systems, such as exist in the Pacific Northwest, transmission lines are common carriers.)

Any private geothermal company which develops a geothermal resource therefore has only one customer for his product--the local utility. Selling it to another utility would require permission to use the local utilities transmission system or building of new lines. A recent Supreme Court decision (Otter Tail vs. U.S., February 1973), [8] may modify this situation. The court in this case ruled that a power company is not exempt from antitrust regulation and cannot refuse to "wheel" (transfer) wholesale power from another producer to another consumer. Until the precedent is well established, however, this factor may deter development.

2. The possibility of multiple uses of geothermal energy may also pose a problem. [4] If chemicals or desalinated water are developed from geothermal resources along with electrical power in a multi-purpose complex, the utilities may not be allowed to sell the non-electrical product. Conversely, an industrial company developing such a complex would not be allowed to sell electricity. Use of geothermal water for district heating and cooling or for industrial process heat might involve similar institutional problems.

As the capability for such installation grows, it must be accompanied by investigation of legal changes necessary to permit efficient marketing methods.

F. Availability of Materials, Manpower, and Capital

Even though an estimated level of geothermal capacity may be attainable technologically and institutionally, its feasibility must still be judged on a production basis. Materials, manpower, and capital must be available to implement the projections.

1. Major considerations in materials needs for geothermal development are the availability of drill rigs and tubular goods (well casing and drill steel). These materials are essentially the same as are used in the oil industry. At the present time, there is an intensification of exploratory oil drilling. For a number of years, this drilling has been in a down-trend, but the recent higher prices for crude oil triggered a surge in activity. The total number of wells drilled is expected to rise from an estimated 26,600 in 1973 to 30,500 in 1974 (Figure 3.3.2).

NUMBER OF GAS AND OIL WELLS DRILLED
IN THE UNITED STATES

1974	30,500 (EST.)
1973	26,596
1972	28,755
1971	27,300
1970	29,464
1969	34,853
1968	32,914
1967	33,818
1956	58,000

SOURCE: AMERICAN PETROLEUM INSTITUTE

DRILLING RIGS IN USE IN THE UNITED STATES

1974	1,600 (EST.)
1973	1,435
1972	1,376
1971	1,235
1970	1,506
1969	2,074
1968	2,110
1967	2,308
1956	4,845

SOURCE: WORLD OIL

Figure 3.3.2

With this rise in drilling has come a scramble for materials. Although the supply of rigs is tight, the major constraint on current activity is a shortage of tubular goods. According to officials of equipment supply and drilling associations, [9,10] this shortage may be a short-term one, stemming primarily from distortions of steel price relationships and problems of allocation which particularly affect independent drillers.

Steel executives predict general steel shortages in the United States for at least two to three years before additional capacity can meet overall demand. However, they anticipate a greater supply of oil country goods (comprising certain types and grades of pipe) resulting from diversion of production from cold rolled sheet production, which is down because of decreased demand from the auto industry. [11] Steel companies have assured the government that shipments of oil country tubular goods will increase by 25 percent in 1974. In addition, steel imports from Europe increased approximately 25 percent over the previous year during the first

five months of 1974, although prices were 25-30 percent above domestic levels.[12] Thus, it appears that by the time geothermal development enters an intensive phase, an easing of material shortages can be expected, although current operations are being delayed by the limited availability of casings.

In the next few years, probably around 15-20 drilling rigs will be required for geothermal exploration and production wells, with about 200 MWe per year being added to production capacity. This assumes a combination of a 10 percent success rate for wildcat wells and a 90 percent success rate for development and production wells, an average production of 5 MW per well, and a drilling rate, including downtime, of four 6000-ft. wells per year per rig. After 1985, assuming the rate of expansion of geothermal capacity has gradually increased to about 2000 MWe a year, and the installed capacity is about 7000 MWe, approximately 150 rigs will be needed; in the early 1990's, assuming expansion averaging 5000 MWe a year, about 375 rigs a year; and by 2000, when capacity has reached 190,000 MWe and expansion is proceeding at 20,000 MWe a year, about 1500 rigs will be required.

By comparison, there are currently approximately 1600 drill rigs operating in the United States[13] and about 100 additional rigs are being produced annually.[9] In the 1950's, however, there were several years where over 4800 were in use. The historical pattern for tubular goods parallels that for drill rigs. In 1956, over 2.3 million tons of oil country goods were sold to the oil industry, 50 percent above the current market.[10] A condition of excess capacity existed in the industry for 15 years until the energy crisis reactivated exploration.

The estimated expansion of about 10 percent above current levels by 1985 in drill rigs and accompanying materials to meet geothermal requirements and 100 percent by 2000 would seem to be within the long-term capacity of supply industries. The consensus of equipment industry spokesmen is that if a geothermal market is defined and there is reasonable expectation that demand for equipment will last for at least five years to provide an adequate amortization period, probably normal geothermal demand could be met along with the expanding needs of the oil industry.[9,10]

Although the accelerated level of drill rig production and the necessary accompanying production of tubular goods seems within long-range feasible limits, government incentive or guarantee programs, plus some sort of allocation program might be required for shorter-term expansion. As mentioned above, a market must be defined with a reasonable expectation of sustained demand before manufacturers can be expected to increase their output. Tax incentives or low interest loans to expand capacity for geothermal materials would speed up the free market process. In addition, an allocation program could ensure that geothermal developers, especially those with no historical records of purchases, could receive their share of tight supplies. This provision would be of particular benefit to independent operators, especially those with no connection to the oil industry.

2. It has been estimated that there are in the country today only about 50 trained geothermal explorers and 50 engineers with direct experience in the development and utilization of geothermal power.[14] There are, however, earth scientists and engineers in other fields whose skills are adaptable to this area, and a large pool of college students who could be directed into the field. Past experience in development of other new technologies indicates that the supply of scientific manpower increases to meet the demand if well-paying jobs are available.[15] When the aeronautical field opened up, for instance, there were no specifically trained engineers, but mechanical engineers switched to the field. Similarly, at the inception of the nuclear industry, many chemical engineers chose this new opportunity. If good salaries and opportunities are available in geothermal enterprises, the same type of change-over can be expected to occur. If other industries are simultaneously experiencing shortages of scientific personnel and competition is keen, the worst that can be expected is a four-year lag to allow colleges to produce the needed manpower. A recent M.I.T. study of engineering manpower[16] concludes that the supply of new entrants to engineering is highly responsive to economic conditions. These conditions were measured by starting salaries and by various factors that determine job opportunities, salaries, and the state of the market.

The Bureau of Labor Statistics[17] projects a record number of college graduates through the mid-1980's. The available supply is estimated at 15.3 million from 1972-1985, about 750,000 above projected job requirements, even after including the assumption that there will be an increasing trend toward specifying college graduates for jobs formerly filled by less-educated workers. The gap will be greatest in the latter part of the period, 1980-1985, because of projected slowdowns in the growth rate of the economy in those years. The BLS does not project unemployment for college graduates, but rather conditions of underemployment at occupational levels lower than anticipated and consequent job dissatisfaction and increasing occupational mobility. In the face of this situation, availability of engineering and geological job openings will certainly induce college students to prepare for them. Declines in engineering enrollment in recent years were attributed to the perceived lack of opportunities rather than to any shortage of scientifically inclined students. According to the College Placement Council, 59 percent of all business and industry job offers to 1974 B.A. graduates were made to engineers, who comprise only 5 percent of total graduates.[18] The Scientific Manpower Commission recommends that a program be set up to assess long-term scientific manpower needs to avoid the successive periods of shortages and oversupply which have existed in the recent past.

Some outside stimulation may be required to accelerate the process of developing scientific personnel. Programs could be instituted to alert colleges and professional groups to geothermal opportunities more quickly. Examples are government grants for seminars to spread geothermal information, grants to universities for work involving graduate students, and provision of student internships on geothermal projects. In addition, premium pay scales

might be necessary to immediately attract talent from allied fields.

There is currently a shortage of trained manpower for operating oil drilling rigs. This appears to be a short-range condition, however, precipitated by the sudden surge in drilling activity brought on by the energy crisis. It takes four to five months to train a crew member, according to the International Association of Drilling Contractors, and intensified training programs are now underway. In addition, some workers who were laid off during the period of declining oil well drilling activity from 1968-1973 can be expected to return to this occupation if it appears to offer continuing opportunities. The trend towards more highly automated equipment also reduces the former need for crew members of unusual strength or stamina.

At an average of 17 workers per crew for each drilling rig, the 150 rigs estimated to be needed around 1985 for an expansion rate of 2000 MWe per year could require about 2500 workers, and the 1500 rigs in the year 2000, about 25,000.

Labor has historically been attracted to areas where job opportunities offering good pay are available, and can be expected to move in from outside the area if it is not available in the West. In addition, California, the expected site of a large proportion of geothermal activity, has its climatic advantages to offer. From 1960-1970, the population of California increased by over 4 million persons. In relation to this growth, additions of 2,500-25,000 geothermal workers to the labor force of the whole West area by 2000 are minimal.

In addition to drilling crews, of course, workers will be required to operate the production facilities and the electrical generating plants. These can be considered as transfers from other types of plants which would be operated in the absence of geothermal facilities, however, and would not exert any net additional demands on the labor market.

3. Capital markets are highly competitive today, and will continue to be so into the foreseeable future. Shortages of energy and a number of basic materials point to the need for expanded capacity. Manufacturers Hanover Trust Company projects annual capital spending by American industry of \$147 billion from now through 1985 as compared to \$90 billion in 1973 (in 1971 dollars). Electric utility requirements are particularly heavy both in absolute and percentage terms[19,20] since growth in electricity consumption has in recent years been almost double the real growth rate of the economy as a whole. Electrical World forecasts a total of \$266 billion needed for investment in electricity generation alone (excluding transmission and distribution facilities) from 1973-1990.[21] Projecting this ten years further gives a total of \$506 billion needed from 1973-2000. On a proportional basis, about \$100 billion of this sum would be required for electrical generation in the western regions. If it is assumed that geothermal energy will replace other fuels for electrical generation and that costs will be comparable or less, then total expenditure needs would

not be increased by geothermal development. As a practical matter, however, geothermal projects have to compete in the capital market place with more traditional forms of investment at a time when it seems improbable that all capital demands can be met. At the present time, a number of utilities which had planned to finance facilities through sale of common stock have deferred new issues because of unfavorable stock market conditions and have switched to debt funding instead. This has led to sluggish sales of recently issued bonds.

As discussed in Section 3.5, a level of 190,000 MWe of geothermal capacity in 2000 would require a cumulative investment of \$95 billion. (This figure is not comparable with the Electrical World forecast above since it includes exploration and drilling expenditures as well as investment in generating facilities.) In order to receive the necessary financing, either from financial institutions or individual investors, geothermal investment vehicles will have to be made as or more attractive than competing forms. Since exploration is a high-risk enterprise and development drilling, though less risky, is still unproven, either high rates of return must be expected or government guarantees provided to reduce risk of default. High prevailing interest rates can destroy the economic viability of a project if there is a long lead time between exploration and production, and since this is a common situation in geothermal development, government subsidization of interest payments may be necessary. Government subsidized loans are provided for geothermal development in Title II of S1283, as described in Section D.2 above, and if a measure of this type is passed, it will greatly expand the funds available.

Ralph Saul, Chairman of the First Boston Corporation, describes new methods for utility financing,[22] which appear to be applicable to geothermal development. He points out that traditional methods of financing will no longer be adequate in the face of massive need for capital. Utilities will have to finance fuel sources or even assume ownership of production facilities and finance long-distance transportation of fuel. They will form joint ventures to further these projects, with several methods of financing described which could be used for geothermal projects. In the first, the participating companies will guarantee the debt incurred by the joint company. Another method is the "take-or-pay" contract, in which each utility commits itself to purchase a specific percentage of the output and pay the same percentage of the costs. Alternatively, the project company can lease the facilities from the financial institution providing the funds.

In addition to funds raised through federal government guarantee programs and innovative private investment approaches, there may be some local government financing provided for geothermal development. The City of Burbank, in conjunction with a private developer, has already leased federal land for exploration.

G. Previous Commitment of Utilities to Other Fuels

Demand for electricity will double every ten years if recent historical growth rates continue. The National Power Survey of the Feder

Power Commission projected an increase in national capacity from 390,000 MWe in 1970 to 1.26 billion MW in 1990 in order to meet demand.[23] Projecting this curve at the same rate would give a level of about 2.5 billion MWe in 2000. In light of recent emphasis on conservation, it seems appropriate to reduce these demand estimates by 10 percent or so to account for energy-saving measures. Some may argue that 10 percent is not enough, that conservation will be much more powerful. Perhaps so, but there are also forces likely to come into prominence which will tend to increase electricity consumption, most notably the drive toward self-sufficiency. This objective leads inevitably to increasing relative use of coal and uranium, probably in the form of electricity.

Using the FPC estimates, generating capacity in the west region, comprised of 11 states, would increase from 64,900 MWe in 1970 to over 400,000 MWe in 2000, even with the 10 percent reduction. Using these assumptions, utilities will have to plan for enormous expansion.

Because of shortages of natural gas and oil, the choice for new facilities appears to lie between coal and nuclear. The pollution problems of coal, both in the mining stage and in the generating stage, indicate that nuclear facilities will be deemed by many utility companies to be the long-range desirable alternatives. Industry forecasts made by Electrical World indicate that nuclear power plants will rise from about a quarter of the new capacity coming on line in the mid-1970's to close to one-half in the 1980's.[23] The FPC estimates that nuclear energy will supply half the total U.S. generation by 1990.[23]

Since nuclear plants presently require lead times of seven to ten years because of siting and licensing problems, the question arises of whether utilities would be able to absorb geothermal energy when available if their needed capacity additions are already committed. This lead-time factor may be modified somewhat in the near future by the adoption of standardized nuclear plants requiring less individualized design time. However, installation of nuclear plants is now about five years behind projected schedules, and, in some cases, crash installation of alternative fossil-fueled generation has been necessary.

The Atomic Industrial Forum recently announced that a record number of orders for nuclear reactors were placed in 1973 and that U.S. utilities now have a total commitment for 213 reactors for a total capacity of 204,470 MWe.[24] It added, however, that a number of nuclear plant construction and licensing schedules have continued to slip, and that there is also a shrinking inventory of acceptable power plant sites. According to the Federal Power Commission, 42 of 47 nuclear plants planned for operation in 1974-1978 are behind schedule by an average of 25 months.[25]

In the west region, the FPC estimated that about 25,000 MWe of nuclear power would be on-line by 1980. At the present time, however, according to Electrical World, only 11,500 MWe of nuclear capacity is committed for that area for installation by 1982, in addition to the currently existing 1628 MWe. It does not seem feasible, then, considering the lead times involved, that the projected levels can be met.

In the West, at least, geothermal energy may come on line in some instances as a stop-gap for slipping nuclear schedules. It is unreasonable to expect utilities to drop current and near future nuclear commitments in favor of geothermal sources. If the resources are present, and utilities are convinced of the resource's reliability, cost, and longevity, geothermal sources can provide in the next decade a partial augmentation, easing the impact of slipping nuclear schedules in the West.

H. Conflicting Local, Regional, and Federal Interests

These problems are just beginning to develop and will grow increasingly severe, particularly if a crash geothermal policy is followed. In opening federal lands for leasing, for instance, there are the questions of which land to open first and which should not be opened at all. Some local areas may want development and others may be against it for environmental reasons. Even though a whole area may need power, a particular locality may not wish to be chosen as its site. When it comes to a question of providing energy for other areas of the country, one region may not want to bear the environmental costs.

Areas of conflict are also becoming apparent in the case of geothermal water, particularly in the Imperial Valley. Several states plus Mexico use the waters of the Colorado River; and, if desalinated water is used to reduce the salinity of the river as planned, there will be questions of where to introduce the new water and who will reap the greatest benefits.

Transportation of geothermal energy may engender the greatest conflicts of interest. Since geothermal resources are in scattered areas, utilization other than at the site will require transmission networks, and the localities on the way to load centers may not wish to be transversed. Interstate and cross-continental transmission can be expected to engender even more controversy.

Land and water problems will probably be gradually ironed out through litigation and negotiated agreements. Environmental siting problems and transmission rights may involve extensive public hearings, with federal, regional, and state planning commissions or other bodies arbitrating conflicts of interest. Acceptance of local undesirable effects may be encouraged by consideration of the alternative effects of nuclear siting. In the last analysis the decisions made will be political and governed by a trade-off of costs and benefits among various areas of the country.

REFERENCES

The Technical and Social Interview Panels as listed in Sections 3.1 and 3.2 provided extensive materials for this section in addition to the references listed below.

- [1] Geothermal Steam Act of 1970, 30 U.S.C., Sec. 530, 1000 et seq.
- [2] U.S. v. Reich, 52 Tax Court, 700 aff'd 454 F 2nd 1157 (9th Cir.1972).
- [3] Finn, Donald F. X., private papers, 1974.
- [4] Proceedings, National Conference on Geothermal Energy (Riverside, Calif.: University of California, August 1973).
- [5] The Potential for Energy Production from Geothermal Resources, Report of the Subcommittee on Water and Power Resources, Committee on Interior and Insular Affairs (Washington, D.C.: U.S. Government Printing Office, December 1973).
- [6] S. 1283, National Energy Research and Development Policy Act of 1973, 93 rd Cong., 1st Sess. Passed Senate December 7, 1973.
- [7] See p. 25 for a discussion of the Geothermal Energy Research, Development and Demonstration Act of 1974 (P.L. 93-410, Appendix J), which enacted a loan guarantee and interest assistance program.
- [8] Otter Tail Power Co. v. U.S., 410 U.S. 366, 35 L. Ed 2d 359, 93 S Ct. 1022 (1972).
- [9] Private communication, Warren L. Baker, International Association of Drilling Contractors, 1974.
- [10] Private communication, William J. Sallans, Petroleum Equipment Supplies Associates, 1974.
- [11] "A Grim Forecast for Steel Users," Business Week (May 11, 1974).
- [12] Farnsworth, Clyde H., "Europe Sells More Steel Here," The New York Times (June 20, 1974).
- [13] Private communication, World Oil Magazine (1974).
- [14] Fuchs, Robert L., and W. Westphal, World Oil Magazine (December 1973).
- [15] Private communication, Alan E. Harger, Center for Policy Alternatives, Massachusetts Institute of Technology, 1974.
- [16] Freeman, R. B., Changes in Engineering Manpower, 1948-1972 (Cambridge, Mass.: Massachusetts Institute of Technology, Center for Policy Alternatives, September 1973).
- [17] Johnston, Denis F., "The U.S. Economy in 1985-- Population and Labor Force Projections," Monthly Labor Review (December 1973).
- [18] Vetter, Betty M., "Assessing the Demand for Scientists and Engineers," Science, Vol. 184, No. 4132 (April 5, 1974).
- [19] Archbold, Pamela, "Utilities Money Shortage," The New York Times (March 17, 1974).
- [20] "Utilities Face Pricing Dilemma," Business Week (February 2, 1974).
- [21] Electrical World, 1974 Annual Statistical Report (March 15, 1974).
- [22] Saul, Ralph, "Energy and the Capital Markets," Public Utilities Fortnightly (January 31, 1974).
- [23] The 1970 National Power Survey (Washington, D.C.: Federal Power Commission, December 1971).
- [24] Smith, Gene, "Industry Report Asserts Nuclear Power 'Came into Own' in 1973," The New York Times (January 16, 1974).
- [25] Schorr, Burt H., "Bottlenecks Hinder U.S. Plans To Boost Supplies of Energy," Wall Street Journal (May 9, 1974).

The following are other references, not numbered in the text, used as background for this section.

Private communication, Robert Platte, American Iron and Steel Institute, 1974.

Private communication, David Anderson, California Division of Oil & Gas, 1974.

U.S. Senate, Hearings on S. 2465 before the Subcommittee on Water and Power Resources of the Committee on Interior and Insular Affairs, 93rd Congress, Washington, D.C.; November 7, 1973.

U.S. Senate, Hearings on S. 2465 before the Subcommittee on the Potential for the Production of Power from Geothermal Resources, 93rd Congress, Washington, D.C., June 13, 1973.

U.S. Senate, Hearings before the Committee on Interior and Insular Affairs, 92nd Congress, on the role of geothermal energy resources in our nation's future energy Washington, D.C., June 15 and 22, 1972.

3.4 A System Dynamics Model of the Electric Utility Decision Process

Introduction

One of the major determinants of the rate of growth of geothermal energy in the United States is whether or not the utility companies will wish to buy energy from this source. If they do there will be a "pull" on the development of the resource; if they do not, there will be little economic incentive to pursue the enterprise. Therefore, it is important to ask about the factors likely to be involved in the utility company decision process, how these factors may change with time, and when geothermal energy sources seem likely to measure-up to competing energy sources.

Imagine a situation in which a utility company executive is faced with a decision about what type of generation capacity to add to his system. He sees a gap between presently available generation capacity and projected demand. Suppose there are several alternative systems from which he might choose. What factors would enter his decision process? The literature in the field, informal discussion with a number of utility company executives, and the socio-economic interviews suggest that competing systems might be compared on the basis of:

Reliability: (Is the rate of unplanned repair and maintenance likely to be higher for one than the other?)

Environmental Hazards: (Clearly systems must comply with environmental regulations; nevertheless it may be easier to do so with one than with the other.)

Fuel Availability: (Is fuel likely to be equally available for both systems over its anticipated life?)

Capital Costs: (Is one system likely to be less expensive than the other?)

Operating Costs: (Is the manufacturing cost of electricity higher for one system than the other?)

Construction Time: (Is the planning and construction process more lengthy for one system than the other?)

The relative importance of these factors has changed somewhat with time. For example, economists Harvey Averch and Leland Johnson assumed and demonstrated in a widely discussed theoretical paper in 1962 [1,2,3,4] that utilities with regulated rates of return would find it to their stockholders' advantage to overcapitalize. Whether this was done in the past is not clear. [2,5] However, the current inflationary climate, lagged regulatory action, and conditions in the capital markets, in which utilities are hard-put to raise needed money by either equity or debt financing, appear to have made the "A-J Bias" thesis currently untenable.

Decisionmaking in the utility industry has been the focus of a recent study. [5] This shows that plant investment has usually been guided by a judicious evaluation of the listed factors. There seems to be little doubt that criteria are changing; and all the factors in the list presented above are now of primary concern in the selection of generation facilities.

Geothermal energy could be evaluated on the basis of any of the factors in the list; how it will fare depends

not only on the state of prior development but on perceptions about its performance vis-a-vis competing energy sources.

This statement of the problem suggested that a model could be constructed to simulate the utility company decisionmaking process. (See Appendix E.) Such a model was developed and used to explore sensitivity of geothermal development to prospective policies designed to influence the rate of development and to initial assumptions. It is worth repeating the caveat presented in Section 1.3:

The model used here involves many assumptions about relationships and the values of various initial parameters. As a forecasting tool, it produces results which reflect and depend on these assumptions. In this study the assumptions and values of initial input parameters were largely based on judgments of The Futures Group and its consultants; therefore the output reflects those judgments.

The model is not expected to serve as a substitute for other forms of detailed analysis. Although it necessarily produces estimates of the consumption of coal, nuclear, solar, and other energy forms used in generating electricity in the United States, these should be regarded only as artifacts of the input assumptions. Nevertheless, the model was useful in several ways: It resulted in the development of a coherent set of assumptions concerning those factors apt to influence the rate of growth of geothermal electrical generation systems and, based on those assumptions, it provided a means for beginning the analysis of the consequences of contemplated policies. It also provided a means for exploring the sensitivity of certain conclusions to changing input assumptions.

Simulation modeling is one of the most useful of policy analysis techniques. The general concept behind mathematical models is simply that the model can serve as a surrogate for the real system. A mathematical model is a detailed, mathematical description of the relationships among the most important variables within a specified system. Thus, given values of these variables at one point in time (the condition of the system at that time), the state of the system at some later time can be calculated. The usefulness of mathematical models stems from the fact that human judgment is not capable of reliably determining how complex systems are apt to change with time or in response to external influences. Although a person may have detailed knowledge about particular parts of a system, the number of interactions taking place may be too large to handle on an aggregated judgmental basis. Mathematical modeling assumes that by using human judgment to specify the parts of the system and the nature of their interactions (a simpler task with fewer variables involved) a model can be constructed that will display the behavior of the system in a more reliable manner.

System dynamics is one method of mathematical simulation. It was developed during the 1950's by Professor Jay W. Forrester of the Massachusetts Institute of Technology. This technique is based on information feedback within closed systems. An example of a simple information feedback loop in a closed system is a television cameraman who views a scene through the eyepiece of the camera. Using this information, he makes a decision about how to move the camera to bring the scene into the center of the picture. If he overshoots, the projected scene conveys this information and corrective action is taken. Often many such simple loops interact with each other, producing complex systems.

Figure 3.4.1 depicts one of the feedback loops in the electric utility model. Projected electrical demand is compared with present generating capacity to determine the need for new capacity. This leads to new plants being planned. After planning and construction delays, present capacity is increased by the completion of these new plants.

Figure 3.4.1

When system dynamics modeling is applied to a specific problem, the first task is to identify the feedback loops that appear to have bearing on the problem. The next step is to study these feedback loops to determine the decision points and, once these are identified, to describe the decision process, including the information used in these decisions. Building on this information, a simulation model is defined and tested by comparing its behavior with actual historical system behavior. The model may be refined until it appears to represent the real system accurately. This model is then used as a tool for experimentation to identify methods of improving the system behavior which can then be studied in more detail before introduction.

The Electric Utility Model

The electric utility simulation model developed in this study is primarily a model of the decision mechanism involved in the construction of new central station generating capacity. Given a certain level of future demand and information concerning future costs and other characteristics of the various generating alternatives, the model calculates on-line capacity for each alternative through the year 2000. Separate calculations are made for the western region of the United States (as defined by the Federal Power Commission) and the remainder of the country.

Figure 3.4.2 illustrates the calculation of the need for new capacity. Demand for electricity is supplied to the model as an input. FPC projections [6] have been used through 1990 and extrapolations of those trends have been used to simulate demand projections through 2010. These projections are presented in Figure 3.4.3. In the model, projected demand is read from the table, ten years in the future.

Figure 3.4.2 Determination of Present Capacity and Need for New Capacity

YEAR	EAST	WEST
1970	109	44
1975	374	94
1980	536	129
1985	710	181
1990	1005	255
1995	1281	340
2000	1558	406
2005	2045	533
2010	2532	660

Figure 3.4.3 Demand for Electrical Capacity (1000 MWe)

The need for new capacity is the difference between projected demand and expected capacity, the capacity that will be on-line in ten years if no new capacity is planned. Expected capacity is found by subtracting the capacity of plants that will be retired during the next ten years from present capacity and adding the capacity of plants that are already planned or under construction. The initial values of present and planned capacity are shown in Figure 3.4.4. The amount of new capacity that is needed to meet projected demand is then allocated among the various generating alternatives as planned capacity which, after construction and planning delays, becomes on-line capacity.

YEAR	E A S T			W E S T			
	COAL	OIL	NUCLEAR	COAL	OIL	NUCLEAR	GEO-THERMAL
PRESENT CAPACITIES	137.5	50.4	12.5	13.2	6.5	1.6	.396
AMOUNT OF NEW CAPACITY BEING COMPLETED							
1974	14.343	3.333	14.001	.400	.379	--	.110
1975	9.569	8.331	13.560	1.100	.060	.916	.110
1976	11.106	7.435	9.801	2.521	.300	1.066	.110
1977	8.884	7.375	4.952	1.522	.239	2.183	
1978	11.099	5.553	11.825	.360	.240	--	
1979	4.384		13.678			2.199	
1980			19.546			3.322	
1981			30.910			--	
1982			6.503			1.767	
1983			8.324			.765	

SOURCE: NEW CAPACITY ADDITIONS PLANNED OR IN CONSTRUCTION AS OF JUNE 1, 1973, COMPILED BY ELECTRICAL WORLD (NEW YORK: MCGRAW HILL, 1973).

Figure 3.4.4 Present and Planned Capacities Used As Initial Model Values (1000 MWe)

The process by which needed capacity is allocated to the various alternatives is shown in Figure 3.4.5. The alternative generating plants included in the model are coal, oil, nuclear, geothermal, solar, natural gas, hydroelectric and, for the East only, imports of energy from the West via a transcontinental grid. Natural gas and hydroelectric capacities are input to the model, following National Electric Reliability Council [7] and FPC projections, and do not enter into the allocation process. Figure 3.4.6 presents the projections used.

The decision value for each alternative is a measure of the perceived desirability of that alternative to the utility. It is assumed that the desirability is based

YEAR	E A S T		W E S T	
	NATURAL GAS	HYDRO-ELECTRIC	NATURAL GAS	HYDRO-ELECTRIC
1970	55	22	22	30
1975	43	21	19	35
1980	37	23	16	42
1985	30	25	13	47
1990	24	27	10	52
1995	20	30	9	55
2000	16	32	7	58
2005	14	34	6	61
2010	12	36	5	64

SOURCES: PROGRESS REPORTS OF THE REGIONAL ORGANIZATIONS TO THE EXECUTIVE BOARD OF NATIONAL ELECTRIC RELIABILITY COUNCIL (PRINCETON, N.J.: NERC, APRIL 1973); FEDERAL POWER COMMISSION.

Figure 3.4.6 Projected Natural Gas and Hydroelectric Capacities (1000 MWe)

on the six criteria previously listed:

1. Perceived reliability.
2. Perceived environmental hazards.
3. Perceived fuel availability.
4. Perceived capital costs.
5. Perceived operating cost of electricity (at the busbar).
6. Perceived construction time.

Initially, the selection of the factors themselves, the weights accorded them and the other judgmental inputs to the model were provided by the study team. As mentioned earlier the study team was strongly guided in these choices by the literature and informal

NOTE: DECISION FACTORS ARE SHOWN FOR NUCLEAR ONLY; CONSIDERATIONS ARE SIMILAR FOR COAL, OIL, GEOTHERMAL, SOLAR, AND TRANSCONTINENTAL TRANSMISSION; HYDRO AND NATURAL GAS CAPACITIES ARE EXOGENOUS INPUTS.

Figure 3.4.5 Allocation of New Capacity

discussions with utility company executives. Early runs of the model were conducted with only these inputs. When it appeared that the model could indeed serve a useful purpose in the study, a small panel of experts familiar with or involved in utility company decisionmaking was assembled to provide the required judgments.[8]

Total decision values for particular alternatives were found by multiplying the weight for each decision factor by the perceived value of that factor for that alternative and summing the products for all six decision factors. (This is shown for nuclear only in Figure 3.4.5.)

For example, the total decision value for nuclear in 2000 is found by summing the following products:

Perceived nuclear reliability (.9) x reliability decision weight (.5) = .45

Perceived nuclear capital cost factor (.43) x capital cost decision weight (1) = .43

Perceived nuclear environmental impacts (.9) x environmental decision weight (.6) = .54

Perceived nuclear electrical cost factor (.56) x electrical cost decision weight (1) = .56

Perceived nuclear fuel availability (.95) x fuel availability decision weight (2) = 1.90

Perceived nuclear construction delay factor (.5) x construction delay decision weight (.1) = .05

Total: 3.93

The sum of these products, 3.93, is the total decision value for nuclear in 2000. Dividing the value by the total decision value for all fuels in the year 2000 (this figure is 14.32) yields the amount of new capacity needs that will be met by new nuclear plants. In this case 27 percent of the capacity gap would be filled with new nuclear plants.

Thus, the most important factor in the decision is fuel availability, with capital investment and electricity costs also having high importance.

The values of the decision factors for the various alternatives are expressed as numbers from zero to one, with one denoting the most desirable. The actual estimates used for each alternative are presented in Figures 3.4.7 through 3.4.11. The estimates for environmental impact, reliability, and fuel availability are expressed directly as numbers from zero to one. Estimates for capital costs, electricity costs, and construction delay time are expressed in real units. These values were converted to numbers from zero to one by dividing the value (of electricity costs, for example) for a particular alternative into the value (of electricity costs) for the least expensive alternative. Thus, if nuclear electricity costs are 32 mills/kWh in 2000 and the least expensive alternative is geothermal at 18 mills/kWh, the nuclear electricity cost factor would be 18/32 or 0.56.

In the estimates of perceived reliability (Figure 3.4.7) the transcontinental grid is assumed to be the most reliable since it is connected to a number of different plants. The reliability of coal plants is assumed to decline somewhat as complicated pollution abatement equipment is added.

YEAR	COAL	OIL	NUCLEAR	GEO-THERMAL	SOLAR	TRANS-CONTINENTAL GRID
1973	.8	.9	.6	.7	—	1
1985	.7	.9	.9	.7	.55	1
2000	.7	.9	.9	.8	.65	1

Figure 3.4.7 Estimates of Perceived Plant Reliability (The scale is from 0 to 1, with 1 denoting the most reliable plants.)

Capital cost projections (Figure 3.4.8) were prepared by using actual engineering estimates through 1982 and escalating at 1.5 percent per year (constant December 1973 dollars) thereafter.[9] Solar central station capital costs in the West were based on estimates by the Arthur D. Little Company study team conducting a technology assessment of solar energy.[10] Solar central station capital costs in the East were assumed to be double those in the West because of a lower incidence of solar energy per square mile and higher land costs.

YEAR	COAL	OIL	NUCLEAR	GEO-THERMAL	SOLAR EAST	SOLAR WEST	TRANS-CONTINENTAL GRID
1973	240	220	354	264	—	—	—
1975	359	260	385	272	—	—	—
1980	550	299	615	292	—	—	—
1985	615	332	734	315	3000	1500	467
1990	662	358	791	339	2667	1334	503
1995	713	386	852	365	2334	1167	542
2000	768	416	918	394	2000	1000	583
2005	882	447	989	424	2000	1000	629
2010	892	482	1065	456	2000	1000	677

Figure 3.4.8 Capital Cost Projections (1973 dollars/kW)

Perceived environmental impacts (Figure 3.4.9) assume that the transcontinental grid will have the least negative impact on the environment. Coal, oil, and geothermal are all assumed to improve with time as the introduction of new technologies reduces the impact of these fuels on the environment.

YEAR	COAL	OIL	NUCLEAR	GEO-THERMAL	SOLAR	TRANS-CONTINENTAL GRID
1973	.5	.7	.9	.75	.8	1
2000	.8	.85	.9	.9	.8	1

Figure 3.4.9 Environmental Impacts (The scale is from 0 to 1, with 1 denoting the least impact on the environment.)

Electricity costs (Figure 3.4.10) were prepared by using actual engineering estimates through 1982.[10] Estimates past 1982 were based on capital cost increases of 1.5 percent per year and average fuel cost escalations of 3 percent per year (constant December 1973 dollars).

YEAR	COAL	OIL	NUCLEAR	GEO-THERMAL	SOLAR EAST	SOLAR WEST	TRANS-CONTINENTAL GRID
1973	12	21	12	7			14
1975	18	23	18	8			16
1980	21	27	19	9			18
1985	23	30	21	10			19
1990	26	33	23	12	196	98	21
1995	29	37	25	13	180	90	23
2000	32	42	27	14	180	90	26
2005	35	47	29	16	180	90	28
2010	39	53	32	18	180	90	31

Figure 3.4.10 Cost of Electricity (Mills/kWh)

Perceived fuel availability (Figure 3.4.11) represents the likelihood that a particular fuel will be available for the lifetime of a new plant (30 to 40 years). Coal, nuclear, and solar are assumed to be the most abundant energy sources. Importation of electricity via a transcontinental grid is also assumed to be based on abundant resources. Initial uncertainty about the lifetime of geothermal reservoirs leads to lower estimates for this source before 1985. In the case of oil, it was assumed that without major breakthroughs in recovery technology and with rapidly increasing world demand, the perceived availability of petroleum in the United States for long term planning (30 to 40 years) will drop to very low levels by 2000. (For example, a plant built in 1990 would require petroleum until about 2030.)

YEAR	COAL	OIL	NUCLEAR	GEO-THERMAL	SOLAR	TRANS-CONTINENTAL GRID
1973	.95	.75	1	.75	1	1
1985	.95	.4	.95	.75	1	1
2000	.95	.2	.95	.95	1	1

Figure 3.4.11 Projected Perceived Fuel Availability

Construction delay times were assumed to be the following:

Coal	- 6 years
Petroleum	- 5 years
Nuclear	- 10 years in 1973, decreasing to 6 years by 2000
Geothermal	- 3 years
Solar	- 8 years
Transcontinental Grid	- 6 years

There are four other considerations that may limit the development of any alternative. First, some alternatives (such as central station solar plants) are not

yet technically feasible. Thus, they become generating alternatives only at some future time when the technology is sufficiently developed. In the base run of the model, the first year that solar plants begin to come on-line is assumed to be 1995. (The first plants are actually planned eight years earlier, in 1987.)

Second, the perceived value of one of the six decision factors may be sufficiently undesirable for a particular alternative that no new capacity will be allocated to that alternative no matter how desirable it otherwise appears.

For example, if a continued supply of petroleum were to become unlikely, no new petroleum-fired plants would be constructed. The threshold value in the case of fuel availability was assumed to be .5. Thus, when perceived petroleum availability drops below .5, as it does in 1985, no new petroleum plants are planned. A limitation on the cost of electricity generated is also included.

The third limitation simulates a "learning process" in the introduction of new generating alternatives. It is assumed that when new generating alternatives become available there is initial hesitation on the part of the industry to choose that new alternative until some initial use has been demonstrated by a few pioneering utilities. The model includes the effects of this learning process through the use of a learning curve multiplier which reduces the total decision factor for the generating alternative in question by a factor which rises from 1/10 in the first year that the alternative becomes technologically available to 1 in the tenth year. This learning process affects geothermal in the West (beginning in 1970), geothermal in the East (beginning in 1985) and solar, East and West, (beginning in 1987).

The fourth restriction is a limitation that applies only to geothermal. The total amount of potential resources that will be available is based on the technologically feasible capacity described in Section 3.1. If at any particular time more geothermal energy is called for by the model than is actually available, geothermal development is limited to the resources available and the shortfall is made up by coal, oil, and nuclear plants.

The amount of geothermal energy potentially available is a key input assumption. The median estimates of the technologically feasible level of geothermal power, derived in the technology interviews, were used as this assumption. Figure 3.4.12 presents these estimates (divided by The Futures Group between East and West). As will be recalled, these estimates represented the levels of geothermally derived electricity viewed as possible by the technology and resource experts, given only technological constraints. The model has the effect of adding other consultants' opinions.

YEAR	BASE PROGRAM CASE		CRASH PROGRAM CASE	
	EAST	WEST	EAST	WEST
1985	3,000	7,000	10,000	25,000
2000	40,000	160,000	54,000	716,000

Figure 3.4.12 Resources Available Estimates (MWe)

To illustrate some of the model calculations the model output for the year 1979 can be used. In this year installed capacity in the West is about 101,000 MWe. The demand for electricity in ten years, 1989, is projected to be 240,000 MWe. The present capacity of 101,000 MWe, minus plants that will be retired over the next ten years, yields a value for that portion of present capacity which is expected to be on-line in ten years of 98,000 MWe. Currently planned capacity additions (all of which will be on-line in ten years) equal 122,000 MWe. Thus, the sum of these two represents the amount of capacity expected to be on-line in ten years, or 220,000 MWe. Comparing this figure with projected demand, 240,000 MWe, yields the amount of new capacity that must be added in order to meet demand, in this case 20,000 MWe. This needed capacity will be allocated among the various alternatives: coal, petroleum, nuclear, and geothermal (solar is not available for planning in 1979). The decision values for each of the alternatives determine the amount to be allocated to each. The decision value for coal (which is the result of considerations of reliability, environmental factors, construction time, fuel availability, electricity costs and capital costs) is calculated to be 3.64. The values for nuclear and geothermal are 3.84 and 4.25, respectively. The decision value for petroleum is only 1.33. This low value is a result of a perceived fuel availability that is very low. (Were it not for a low fuel availability the decision value would have been about 3.3.) The decision value for all four alternatives is 13.06. The percentage of needed capacity that will be allocated to coal is found by dividing the coal decision value by the total decision value: $3.64/13.06$ or 28 percent. New coal plants are then assumed to be 28 percent of the projected capacity gap, or 5,600 MWe. Calculations are similar for the other alternatives. In the case of geothermal, however, not enough resources are available to supply the demand for geothermal.

The model tests desired geothermal additions against resource availability 3, 6, and 10 years in the future. In the case described here, this limit was reached 6 years in the future, in 1985. In 1979, 2800 MWe of geothermal power were installed and an additional 4340 MWe were planned to be available by 1985. The computation in 1979 called for a further addition of 2000 MWe by 1985, yielding a total of 9140 MWe. This figure exceeded that expected to be available. Thus no new geothermal plants are planned for that year, of course, plants planned earlier can still be built in that year since resources have already been allocated to those plants. The geothermal shortfall is distributed among the other alternatives according to their respective decision values.

As mentioned earlier, a detailed discussion of model equations and assumptions is presented in Appendix E.

REFERENCES

- [1] Averch, H. and L. Johnson, "Behavior of the Firm under Regulatory Constraint," The American Economic Review, Vol. 52, No. 5 (December 1962).
- [2] Baumal, W., and A. Klevorich "Input Choice and Rate of Return Regulation: An Overview of the Discussion," The Bell Journal of Economics and Management Science, Vol. 1, No. 2 (Autumn 1970).
- [3] Bailey, Elizabeth E., and Roger D. Coleman, "The Effect of Lagged Regulation in an Averch-Johnson Model," The Bell Journal of Economics and Management Science, Vol. 2, No. 1 (Spring 1971).
- [4] Spann, R. M., "Rate of Return Regulation and Efficiency in Production: An Empirical Test of the Averch-Johnson Thesis," The Bell Journal of Economics and Management Science, Vol. 5, No. 1 (Spring 1974).
- [5] Gray, John E., "A Study of Energy Industry Decision-Making," Draft Report, Ford Foundation Energy Study Project, 1973.
- [6] The 1970 National Power Survey (Washington, D.C.: Federal Power Commission, 1970).
- [7] Estimated Fossil Fuel Requirements for the Electric Utility Industry of the United States 1973-1982, National Electric Reliability Council, February 12, 1974.
- [8] The following people were involved: Mr. Sidney Law, Director of Research and System Studies, Northeast Utilities Service Company; Mr. James Smith, Director of New England Planning, Western Mass. Electric Company; and Mr. Edward Pawlak, Stone & Webster Management Consultants.
- [9] A Study of Base Load Alternatives for the Northeast Utilities System (Cambridge, Mass.: A.D. Little, Inc., July 1973).
- [10] A Technology Assessment of Solar Energy, Preliminary Report (Cambridge, Mass.: A.D. Little, Inc., 1974).

3.5 The Model Results

A projection of the rate of growth of geothermal energy, various hydrocarbon and nuclear fuels, and other energy sources was made using the model described in the previous section. This projection had several uses in this study:

1. It provided a basis for exploring the relative importance of the assumptions included in the model which can affect electricity generation fuel mix.
2. The model served as a means for testing the potential effect of some candidate policies and established, within the limitations of its assumptions, the levels of some impacts.

The results of the run based on the assumptions outlined in the previous section are presented in Figures 3.5.1 and 3.5.2. In essence, the model output can be considered a scenario in which assumptions and projections are consistent.

There are several important observations to be made about this scenario:

1. Petroleum utilization in the generation of electricity peaks in the early 1990's (227,000 MWe) as a result of uncertainty about continued supply.
2. Indigenous geothermal energy sources in the East (which are not tapped until early

Figure 3.5.1 ELECTRICITY FUEL MIX - TOTAL U.S.

Figure 3.5.2 ELECTRICITY MIX - WESTERN U.S.

in the 1990's) account for 40,000 MWe of installed capacity by 2000.

3. In the West, however, geothermal sources are more significant, yielding 147,000 MWe out of a total of 495,000 MWe in the year 2000, or about 30 percent of the installed capacity. By 2000, geothermal energy equals the contribution of the other primary energy sources in the West: coal and nuclear.
4. In both the East and the West, nuclear energy provides more power than other sources after about 1990.
5. In the early 1990's, geothermal energy is transported from the West to the East and is distributed with energy generated by other means; by 2000, 56,000 MWe is handled in this way.

Validation of this kind of model is quite difficult. Of course, it can duplicate historical data if model coefficients are chosen so as to fit these data, hence a "match to history" offers little in the way of confidence. With respect to projected future conditions, the absolute accuracy of the model need not be great in order for it to be quite useful in testing the expected effects of simulated policies or the sensitivity of conclusions to changing initial conditions, since in both instances overall system behavior and differences from the base run are used to form conclusions. Nevertheless, the projections provided by the model seem quite plausible for several reasons:

1. The input assumptions about decision criteria, on which the model depends, are consistent with judgments provided by utility company executives and utility regulators. These judgments agree qualitatively with recent research performed by John Gray in his work in the Ford Foundation Energy Policy Study. [1]
2. The projections obtained, assuming zero geothermal development, were compared with forecasts prepared by the Federal Power Commission in the 1970 National Power Survey. [2] As shown in Figure 3.5.3 the two estimates are in relatively close agreement.

REFERENCES

- [1] Gray, John, "A Study of Energy Industry Decision Making," Draft report to the Ford Foundation Energy Policy Project (1974).
- [2] Federal Power Commission, The 1970 National Power Survey 3822 (Washington, D.C.: December 1971).
- [3] National Petroleum Council, U.S. Energy Outlook (Washington, D.C.: December 1972).
- [4] Office of Planning and Analysis, Nuclear Power 1973-2000 (Washington, D.C.: Atomic Energy Commission, December 1972).
- [5] Bureau of Mines, An Energy Model for the United States (Washington, D.C.: Department of the Interior, July 1968).
- [6] Associated Universities, Inc., Reference Energy Systems and Resource Data for Use in the Assessment of Energy Technology (New York: Upton, 1973).

YEAR = 1980

SOURCE	TOTAL ELECTRICAL CAPACITY	COAL	PETROLEUM	NATURAL GAS	NUCLEAR	HYDRO ELECTRIC	GEOTHERMAL
MODEL BASE RUN	584.6*	229.0	120.8	53.3	113.5	65.0	3.1
MODEL NO FURTHER GEOTHERMAL	584.6*	229.7	121.4	53.3	113.5	65.0	1.8
FPC (2)	598.0*	231.7	80.0	78.4	140.0	68.0	0
NPC (3)	672.0	288.6	81.8	78.5	153.0	65.3	2.5 TO 10.3
AEC (4)	---	---	---	---	131.6	---	---
DOI - BUREAU MINES (5)	523.0	TOTAL OF 377.5			69.7	75.8	0

YEAR = 2000

SOURCE	TOTAL ELECTRICAL CAPACITY	COAL	PETROLEUM	SOLAR	NATURAL GAS	NUCLEAR	HYDRO ELECTRIC	GEOTHERMAL
MODEL BASE RUN	2022.6*	695.9	180.7	3.5	23.2	841.1	90.0	188.1
MODEL NO FURTHER GEOTHERMAL	2048.9*	787.2	183.1	5.5	23.2	958.7	90.0	2.2
FPC (2) & AU (6)**	1964.1*	704.5	138.1	0	95.0	829.0	98.0	0
AEC (4)	---	---	---	---	---	1200.0	---	---

*EXCLUDES PUMPED STORAGE HYDRO, INTERNAL COMBUSTION, AND GAS TURBINES.

**FPC ESTIMATES FOR 1990 PROJECTED TO 2000 BY AU TREND.

Figure 3.5.3 A COMPARISON OF FORECASTS OF ELECTRICAL GENERATING CAPACITY IN THE UNITED STATES (1000 MWe)

3.6 Some Policies and Their Anticipated Effects

An important use of the model described in Section 3.4 is to test sensitivity to policy; to explore and illustrate the effects of certain policies designed to control the rate of introduction of geothermal energy, within the limits of accuracy of the simulation. A systematic attempt was made to define a range of activities designed to influence geothermal development and to understand their significance and power by testing them with the model. Figure 3.6.1 lists the policies considered and the means employed to simulate them. The paragraphs which follow describe the candidate policies in more detail.

POLICY	METHOD OF SIMULATING
1. GEOTHERMAL RESOURCES NOT DEVELOPED.	GEOTHERMAL OPTION REMOVED FROM MODEL DECISION SIMULATION.
2. GEOTHERMAL RESOURCES NOT EXPORTED FROM WEST TO EAST.	IMPORTATION OPTION REMOVED FROM MODEL EAST DECISION SIMULATION.
3. BASE RUN.	TECHNOLOGICALLY FEASIBLE GENERATION CAPACITY (FROM TECHNOLOGICAL INTERVIEWS) PER "NORMAL" PROGRAM.
4. INCENTIVES CREATED TO REDUCE PERCEIVED RISK ASSOCIATED WITH FIELD DEPLETION RATE.	PERCEIVED AVAILABILITY FACTOR FOR GEOTHERMAL INCREASED TO 1.
5. GOVERNMENT-FUNDED HOT DRY ROCK DEVELOPMENT PROGRAM.	TECHNOLOGICALLY FEASIBLE GENERATION CAPACITY (FROM TECHNOLOGICAL INTERVIEWS) FOR HOT DRY ROCK "CRASH" PROGRAM USED WITH "NORMAL" CAPACITY ESTIMATES FOR OTHER RESOURCE TYPES.
6. TECHNICAL "CRASH" PROGRAM.	TECHNOLOGICALLY FEASIBLE GENERATION CAPACITY (FROM TECHNOLOGICAL INTERVIEWS) PER "CRASH" PROGRAM.
7. ACCELERATED (TECHNICAL AND NON-TECHNICAL "CRASH") PROGRAM WHICH INCLUDED: - STEAM COST SUBSIDY. - DEMONSTRATION PLANTS. - ENVIRONMENTAL PROGRAMS.	AS IN 4 AND 6 ABOVE PLUS: - STEAM COST REDUCED TO 25% OF ITS INITIAL LEVEL. - PERCEIVED GEOTHERMAL RELIABILITY FACTOR INCREASED TO UNITY. - PERCEIVED ENVIRONMENTAL FACTOR INCREASED TO UNITY.

Figure 3.6.1 POLICIES STUDIED USING SIMULATION MODEL

Geothermal Resources not Developed. This case is designed to simulate a program which cuts off all further geothermal development. This simulation involves removing the option of deciding to purchase geothermal steam from the present through the year 2000. This option is included to produce estimates of how load would be met without geothermal energy so that the effect of geothermal development on fuel mix can be estimated.

Geothermal Resources Not Exported from West to East. As explained in Section 3.4, the model includes an option for the simulated East Coast utility decision-maker to develop geothermal energy in the East and to buy geothermal energy transported from the West via transcontinental transmission lines. In this policy simulation, the importation option is removed from the model; however, the possibility of developing both East coast and West coast geothermal resources is retained.

The Base Case. This case is identical to the run described in the previous section. Estimates of the geothermal energy available were derived from the technological interviews and were equivalent to the levels of power judged to be technologically feasible by the panel under "normal" circumstances; that is, no additional political action to create development incentives, and technology evolving as a result of private initiative and a plausible conservative continuation of government technology programs currently in effect.

Depletion Uncertainty Removed. This case simulated a situation in which incentives were created to reduce the perceived risks associated with geothermal field depletion. Such incentives might take the form of guarantees to utility companies which would reimburse them for losses incurred should a geothermal resource on which they depended for energy be depleted before an arbitrary cut off time, say 25 years. In order to simulate this policy the factor associated with perceived availability was increased to unity.

Government Funded Hot Dry Rock Development Program. This case was designed to simulate a set of policies intended to expedite the development of hot dry rock resources. Among the specific actions included here might be the increase in the tempo of exploration, vigorous funding of R&D programs associated with hot dry rock drilling and utilization and early hot dry rock proof-of-concept plants. These actions were simulated by increasing the available resource level from the base case values to levels which corresponded to the hot dry rock "crash" program identified in the technological interviews.

Technical "Crash" Program. This case assumed that all possible effort was placed on the technical development of geothermal technology. It was simulated by employing the technologically feasible generation capacity corresponding to a "crash" program as defined by the technological interviews. It did not include non-technical actions which might have been viewed as pacing.

Accelerated Technical and Non-technical "Crash" Program. This case was intended to represent a situation in which all reasonable action which could be taken was in fact initiated. It included not only the technological factors of the case listed above, but also simulated other actions such as the initiation of a steam cost subsidy, the construction of demonstration plants, and the initiation of a set of environmental programs. The subsidization of the purchase of steam would presumably be an inducement to the utility company since its cost would be artificially reduced through federal programs. This policy was simulated by reducing steam costs to 25 percent of their initial level. Demonstration plants would be designed to improve perceptions of reliability and to expedite the development of appropriate technology. This policy was simulated by increasing the perceived geothermal reliability factor to unity. The environmental programs were simulated by increasing the perceived environmental factor in the model to unity. In the remainder of this report, this program is called "Case 7" or "the accelerated program."

The results of the runs using the simulated policies as well as the base case described in the previous section and a no geothermal case are presented in Figure 3.6.2.

POLICY	NO GEOTHERMAL	NO IMPORTS TO EAST	BASE RUN	DEPLETION UNCERTAINTIES REMOVED	HOT DRY ROCK DEVELOPMENT	TECHNICAL CRASH	ACCELERATED
GEOTHERMAL EAST	0	43.4	41.3	40.2	41.3	54.8	57.0
GEOTHERMAL WEST	2.2	90.04	146.8	148.2	155.6	181.1	192.2
IMPORTED BY EAST	0	0	56.4	56.0	57.5	57.5	57.2

Figure 3.6.2 EFFECT OF SELECTED POLICIES ON THE LEVEL OF GEOTHERMAL DEVELOPMENT IN YEAR 2000 - 1000 MWE

Some observations about these policies are:

1. If all of the simulated technical and non-technical policies designed to expedite geothermal development are implemented simultaneously, the amount of electricity produced from this source could be increased about 30 percent over a "normal program" of geothermal development (249,000 MWe vs. 188,000 MWe in 2000).
2. The policies which seem most effective in stimulating the development of geothermal energy are those which improve the level of available technologically feasible development.
3. As the amount of geothermal energy is increased by various policies, the other electricity sources which are most affected are nuclear energy and coal. Figure 3.6.3 compares, for example, the power generated by various sources in 2000, under the base case assumptions and under accelerated program assumptions. Comparing the technical policy crash case to the no-geothermal case, some 51,000 MWe of coal generation and 62,000 MWe of nuclear generation would be replaced in the West. Generating sources using petroleum are limited by uncertainty about the continued availability of oil and, thus, are little affected by geothermal growth. Solar energy from central generating plants becomes available too late in the simulation to be much affected by geothermal before 2000.
4. A run was made in which petroleum availability was increased by 10 percent; the amount of electricity from that source by 2000 almost doubled over the base case; neither coal-fired nor nuclear generation develop as rapidly as before. Geothermal and solar development were affected only slightly.

The reason that petroleum was affected to such a large extent by a relatively small change in perceived fuel availability is that, in the base run, the perceived availability drops so low that petroleum ceases to be considered a viable alternative after 1985. Increasing the perceived availability by 10 percent resulted in petroleum existing as a viable alternative a few years longer, which, when coupled with rapidly growing demand, resulted in a large increase in new petroleum generation capacity.

5. The amount of geothermal energy exported from the West to the East is not affected significantly by the policies considered.

	E A S T								W E S T						
	COAL	PETROLEUM	NUCLEAR	GEOTHERMAL	SOLAR	HYDRO	NATURAL GAS	IMPORT	COAL	PETROLEUM	NUCLEAR	GEOTHERMAL	SOLAR	HYDRO	NATURAL GAS
NO GEOTHERMAL (CASE 1)	640	150	777	0	2.9	32	16	0	147	33	181	2.2	2.6	58	7
ACCELERATED (CASE 7)	576	151	691	57	1.7	32	16	57	96	28	119	192	1.2	58	7
DIFFERENCE (CASE 1 - CASE 7)	64	-1	86	-57	1.2	0	0	-57	51	5	62	-190	1.4	0	0

Figure 3.6.3 EFFECT OF GEOTHERMAL DEVELOPMENT ON OTHER FUELS IN 2000 (1000 MWE)

3.7 Sensitivity of the Model to Input Assumptions

The assumptions which form the basis for the model were described in previous sections. It is possible to vary these assumptions systematically to determine input points at which large changes in output can be induced. When such points are discovered they can suggest particularly effective policies, the need for increasing confidence about input assumptions (which might in turn be reflected as research projects), or parameters to be monitored as the geothermal program progresses in order to improve the accuracy of such simulations and the quality of the decision-analysis process.

In the paragraphs which follow, the specific variations tested and the results achieved are described. In general the variations in model assumptions could be grouped into six major categories:

- The decision weights
- The level of technologically feasible geothermal development
- The demand for electricity
- Electricity and capital costs
- Availability of petroleum
- Parameters associated with the introduction of solar energy.

Decision Weights

As explained in Section 3.4, a "decision" about which type of generating capacity to build was reached each year of the simulation. The amount of generation capacity was based on a ten year projection of load and a set of six decision factors.

- Capital investment
- Environmental criteria
- Cost of electricity
- Perceived fuel availability
- Reliability
- Construction time

These factors did not contribute equally to the decision; rather weights were assigned to each factor. In the first set of sensitivity runs, the weights assigned to these factors were systematically varied. For example, in the first run, reliability weight was doubled; in the second run reliability weight was halved; in the third run capital investment weight was doubled; and so on. It was found that the model was quite insensitive to changes of this magnitude in the assumed weighting. The most extreme fluctuations in this series of runs amounted to only about three percent of the total amount of geothermal energy expected in the year 2000.

The Level of Technologically Feasible Geothermal Development

In testing the sensitivity of the model to assumed level of resources, two runs were made. The first assumed a factor of two increase in technologically feasible resources and the second assumed that resources were only one-half as great as the base case. The results achieved in the first run are shown in Figure 3.7.1 and the second, 3.7.2. Clearly, this is a major point of sensitivity of the model. It suggests that early policies be concentrated on identifying the proven resources.

(1000 MWE)

CONDITION		GEO THERMAL WEST	GEO THERMAL EAST	GEO THERMAL IMPORTS - EAST
BASE CASE	1973	0	0	0
	1985	7	0	0
	2000	145	40	56
RESOURCES DOUBLED	1985	14	0	0
	2000	158	73	57

Figure 3.7.1 EFFECT OF DOUBLING RESOURCES

(1000 MWE)

CONDITION		GEO THERMAL WEST	GEO THERMAL EAST	GEO THERMAL IMPORTS - EAST
BASE CASE	1973	0	0	0
	1985	7	0	0
	2000	145	40	56
RESOURCES DIMINISHED BY .5	1985	3	0	0
	2000	80	20	23

Figure 3.7.2 EFFECT OF HALVING RESOURCES

The Demand for Electricity

A series of runs was conducted to explore the effect of changing assumed levels of electricity demand. The base case used a level of demand projected by the Federal Power Commission in 1970. Five variations on the FPC assumption were tested: demand increased by 25 percent; demand increased by 50 percent; demand increased by 50 percent with resources associated with the "Technological Crash" case (case 6--Section 3.6); demand decreased by 25 percent; and change in the demand growth curve which presumed no growth after the year 1990. The results of these runs are presented in Figures 3.7.3 through 3.7.7. The effect of demand is relatively important. Figure 3.7.8 shows how effective demand is in stimulating the development of geothermal energy and in changing importation levels of geothermal energy by the East. As demand increases, the amount which can be furnished from geothermal sources is constrained by the amount of resources available. Comparison of Figures 3.7.4 and 3.7.5 also makes this point. In the former case demand increased by 50 percent but resources were limited to the level assumed in the base run. In the latter case, resources were raised to the "crash" program level and the amount of geothermal energy utilized was about 50 percent more than the resource-constrained, high-demand example.

(1000 MWE)				
CONDITION		GEO THERMAL WEST	GEO THERMAL EAST	GEO THERMAL IMPORTS - EAST
BASE CASE	1973	0	0	0
	1985	7	0	0
	2000	145	40	56
DEMAND INCREASED BY 1.25	1985	6	0	0
	2000	155	40	60

Figure 3.7.3 EFFECT OF INCREASING DEMAND BY 25%

(1000 MWE)				
CONDITION		GEO THERMAL WEST	GEO THERMAL EAST	GEO THERMAL IMPORTS - EAST
BASE CASE	1973	0	0	0
	1985	7	0	0
	2000	145	40	56
DEMAND DECREASED BY .25	1985	7	0	0
	2000	116	40	43

Figure 3.7.6 EFFECT OF DECREASING DEMAND BY 25%

(1000 MWE)				
CONDITION		GEO THERMAL WEST	GEO THERMAL EAST	GEO THERMAL IMPORTS - EAST
BASE CASE	1973	0	0	0
	1985	7	0	0
	2000	145	40	56
DEMAND INCREASED BY 1.5	1985	6	0	0
	2000	160	40	52

Figure 3.7.4 EFFECT OF INCREASING DEMAND BY 50%

(1000 MWE)				
CONDITION		GEO THERMAL WEST	GEO THERMAL EAST	GEO THERMAL IMPORTS - EAST
BASE CASE	1973	0	0	0
	1985	7	0	0
	2000	145	40	56
NO DEMAND GROWTH AFTER 1990	1985	7	0	0
	2000	80	11	8

Figure 3.7.7 EFFECT OF LIMITING DEMAND TO NO GROWTH AFTER 1990

(1000 MWE)				
CONDITION		GEO THERMAL WEST	GEO THERMAL EAST	GEO THERMAL IMPORTS - EAST
BASE CASE	1973	0	0	0
	1985	7	0	0
	2000	145	40	56
DEMAND INCREASED BY 1.5 AND RESOURCES EQUIVALENT TO "CRASH"	1985	26	0	0
	2000	264	55	86

Figure 3.7.5 EFFECT OF INCREASING DEMAND BY 50% RESOURCES AVAILABLE EQUIVALENT TO "TECHNOLOGICAL CRASH"

Figure 3.7.8 VARIATION IN GEOTHERMAL ENERGY PRODUCED IN 2000 AS A FUNCTION OF DEMAND (WITH CONSTRAINED RESOURCES)

The demand limited example, which assumed no growth after 1990 (Figure 3.7.7) produced some very interesting results. The demand assumptions involved in both the base case and the "no growth" case are shown in Figure 3.7.9. Using these assumptions, the model forecasted significantly lower demand for all fuels involved in the generation of electricity. Figure 3.7.10 summarizes this effect. The energy source affected the least is petroleum since, in the decision sector of the model, a relative uncertainty about continuous supply became less important for this fuel, and demand was lower. Geothermal is affected greatly because of the fact that, in the base case, most of the geothermal development takes place after 1990. In the no growth case the only opportunity for geothermal development after 1990 is in replacing retired capacity, thus its growth is severely restrained.

Electricity and Capital Costs

A series of twelve simulation runs were made in which the costs of electricity associated with various fuels and capital costs associated with the use of various fuels were increased and decreased by 50 percent compared to the base run. The simulated situations were as follows:

- Coal electricity costs increased by 50 percent
- Coal electricity costs decreased by 50 percent
- Coal electricity and capital costs increased by 50 percent
- Coal electricity and capital costs decreased by 50 percent
- Nuclear electricity costs increased by 50 percent
- Nuclear electricity costs decreased by 50 percent
- Nuclear electricity and capital costs increased by 50 percent
- Nuclear electricity and capital costs decreased by 50 percent
- Geothermal electricity costs increased by 50 percent
- Geothermal electricity costs decreased by 50 percent
- Geothermal capital costs increased by 50 percent
- Geothermal capital costs decreased by 50 percent

Figure 3.7.9 DEMAND ASSUMPTIONS

RUN		WEST					EAST					
		COAL	PET.	NUC.	GEO.	SOLAR	COAL	PET.	NUC.	GEO.	SOLAR	IMPORT
BASE	1973	13	6	2	0	0	137	50	12	0	0	0
	1985	45	32	39	7	0	262	163	220	0	0	0
	2000	112	29	141	145	2	582	145	708	40	2	56
CONSTRAINED DEMAND	1985	27	16	22	7	0	207	113	164	0	0	0
	2000	78	14	97	80	1	231	99	275	11	0	8

Figure 3.7.10 SENSITIVITY TO DEMAND GROWTH CONSTRAINTS (1000 MWe)

These runs showed that the amount of geothermal energy generated in the year 2000 was not sensitive to changes in cost assumptions; within the range tested the maximum fluctuation was on the order of 6 percent. Figure 3.7.11 summarizes these runs. Changing the cost factors associated with coal had the effect of changing the

amount of coal capacity installed in the expected direction; the same effect was noted for nuclear generation capacity. This shift with changing costs was not observed to any large extent for geothermal energy because the constraint on development in the model was primarily the level of resources assumed to be available.

RUN	WEST					EAST					
	COAL	PET.	NUC.	GEO.	SOLAR	COAL	PET.	NUC.	GEO.	SOLAR	IMPORT
BASE	112	29	141	145	2	583	146	708	40	2	56
COAL ELECTRICITY COSTS INCREASED BY 50 PERCENT	109	29	143	145	2	570	147	718	40	2	56
COAL ELECTRICITY COSTS DECREASED BY 50 PERCENT	120	28	136	142	2	617	141	681	40	2	56
COAL ELECTRICITY AND CAPITAL COSTS INCREASED BY 50 PERCENT	106	30	145	146	2	556	149	730	40	2	56
COAL ELECTRICITY AND CAPITAL COSTS DECREASED BY 50 PERCENT	129	27	131	139	2	652	137	652	40	2	56
NUCLEAR ELECTRICITY COSTS INCREASED BY 50 PERCENT	114	30	138	146	2	594	147	695	40	2	56
NUCLEAR ELECTRICITY COSTS DECREASED BY 50 PERCENT	107	28	151	140	2	551	141	745	40	2	56
NUCLEAR ELECTRICITY AND CAPITAL COSTS INCREASED BY 50 PERCENT	116	30	135	146	2	604	149	684	40	2	56
NUCLEAR ELECTRICITY AND CAPITAL COSTS DECREASED BY 50 PERCENT	103	27	159	137	2	528	137	772	40	2	56
GEOHERMAL ELECTRICITY COSTS INCREASED BY 50 PERCENT	112	29	142	141	3	581	145	709	40	4	57
GEOHERMAL ELECTRICITY COSTS DECREASED BY 50 PERCENT	111	29	140	146	0	584	147	707	40	1	56
GEOHERMAL CAPITAL COSTS INCREASED BY 50 PERCENT	114	30	141	142	2	585	150	703	40	2	57
GEOHERMAL CAPITAL COSTS DECREASED BY 50 PERCENT	110	28	141	145	2	580	140	715	40	2	56

Figure 3.7.11 EFFECT OF CHANGING COST ASSUMPTIONS (YEAR 2000--1000 MWe)

Availability of Petroleum

The base model assumed that petroleum availability will be perceived as diminishing significantly through the turn of the century. A sensitivity run was conducted in which it was assumed that the current petroleum availability would be maintained. Figure 3.7.12 illustrates that increasing petroleum availability has a relatively minor effect on the amount of geothermal energy developed. However, this change has a major effect on the petroleum generating capacity itself and on the generating capacity using other fuels. The effect is a major one: as petroleum generating increases, coal and nuclear diminish significantly.

Parameters Associated with the Introduction of Solar Energy

The sensitivity of geothermal development to different assumptions about solar energy was also tested because of the great uncertainty about the amount of central station solar generating capacity that might be installed by 2000. The base run has assumed that the solar option could be included in the decision process after 1987. The four sensitivity runs were:

- The solar option is available after 1982.
- The solar learning process is accelerated (solar gains widespread acceptability four years after first introduction rather than ten years).
- The solar option is available after 1982, the learning process is accelerated, and perceived reliability is increased to unity.
- The solar option is available after 1980, the learning curve is accelerated (to immediate acceptance), reliability is increased to unity, capital costs are halved, and the cost of solar electricity is halved.

These runs are summarized in Figure 3.7.13. These runs are not intended to be forecasts of central station solar development. They do show, however, that the amount of geothermal that is developed is not very sensitive to the level of solar development. Solar substitutes for coal and nuclear, primarily.

Conclusions

The level of geothermal energy projected by the model is quite sensitive to assumptions about available geothermal resources and insensitive to decision weights and costs assumptions within the range tested.

Increasing or decreasing the level of assumed demand affects all fuels; as demand increases, the amount furnished by geothermal sources is restricted by the assumed level of resources available.

Changing the level of perceived petroleum availability has little direct effect on geothermal capacity; however, it has a very large effect on petroleum generating capacity by the year 2000.

The level of geothermal use is relatively insensitive to changing assumptions about solar central station capacity; a simulated vigorous solar development program leads to the substitution of solar-generated electricity mainly for coal- and nuclear-generated electricity sources, rather than for geothermal-generated electricity.

R U N	W E S T					E A S T					
	COAL	PET.	NUC.	GEO.	SOLAR	COAL	PET.	NUC.	GEO.	SOLAR	IMPORT
BASE	112	29	141	145	2	583	145	708	40	2	56
IMPROVED PETROLEUM AVAILABILITY	93	89	117	123	1	465	423	569	40	1	53

Figure 3.7.12 EFFECT OF INCREASEING PETROLEUM AVAILABILITY
(YEAR 2000--1000 MWe)

R U N	W E S T					E A S T					
	COAL	PET.	NUC.	GEO.	SOLAR	COAL	PET.	NUC.	GEO.	SOLAR	IMPORT
BASE	112	29	141	145	2	583	145	708	40	2	56
THE SOLAR OPTION IS AVAILABLE AFTER 1982.	111	29	141	144	3	581	145	707	40	4	56
THE SOLAR LEARNING PROCESS IS ACCELERATED (SOLAR GAINS WIDE-SPREAD ACCEPTABILITY FOUR YEARS AFTER FIRST INTRODUCTION RATHER THAN TEN YEARS).	112	29	141	144	3	582	145	707	40	4	56
THE SOLAR OPTION IS AVAILABLE AFTER 1982, THE LEARNING PROCESS IS ACCELERATED, AND PERCEIVED RELIABILITY IS INCREASED TO UNITY.	111	29	140	144	5	580	145	706	40	7	56
THE SOLAR OPTION IS AVAILABLE AFTER 1980, THE LEARNING CURVE IS ACCELERATED (TO IMMEDIATE ACCEPTANCE), RELIABILITY IS INCREASED TO UNITY, CAPITAL COSTS ARE HALVED, AND THE COST OF SOLAR ELECTRICITY IS HALVED.	104	29	131	135	23	565	145	688	40	34	56

Figure 3.7.13 EFFECT OF VARYING ASSUMPTIONS ABOUT SOLAR ENERGY (YEAR 2000--1000 MWe)

4. PRIMARY AND HIGHER ORDER IMPACTS OF GEOTHERMAL ENERGY

4.1 Effect on Electric Utility Fuel Mix

"Fuel mix" refers to the distribution of energy sources used in the generation of electricity. Today, the fuel mix includes primarily nuclear (uranium), petroleum, coal, hydroelectric, natural gas, and geothermal energy sources. The introduction of geothermal energy on the scale suggested in earlier sections of this report will have the effect of changing the fuel mix used by utilities and this changing mix will trigger downstream consequences, as well. Figure 4.1.1 presents the top levels of the impact relevance tree; Appendix D presents the relevance tree in detail.

Outlook for Electricity

The consumption of primary fuels for the generation of electricity was about 25 percent of the total national energy input in 1970 and may reach 30-50 percent by the year 2000. [1] This increasing role for electricity has several implications. First, since the generation of electricity involves conversion from primary energy sources and this conversion necessarily involves losses, increasing relative use of electricity will result in rapid growth in the use of primary fuels. In other words, relative growth of electricity generation results in consumption of larger portions of the total energy supply as conversion losses. Of course,

Figure 4.1.1

the magnitude of the conversion losses depends heavily on the absolute levels of electricity generated, the state of generation technology, the fuel mix, and other factors. A recent study can provide an example of the magnitude of energy losses involved. The Ford Foundation Energy Policy Project projected conversion losses of 18.4 percent of total energy input in 1975; by 2000 these losses were projected to be 31 percent of total energy consumption. [2]

The second implication of the increasing relative use of electricity is that otherwise unusable energy sources can be more fully employed. For example, uranium, hydro-resources, solar, geothermal, coal, and residual oil can enter the overall fuel mix in the form of inputs to electricity generation; scarce fuels such as natural gas and petroleum remain available for direct use. Furthermore, the primary energy sources useful in the generation of electricity are, for the most part, indigenous; therefore, the increasing relative use of electricity moves the country towards energy independence from foreign supply with all of its associated political-financial headaches.

The Hudson-Jorgenson energy policy model represents a recent sophisticated attempt to project the rate of growth of consumption of various fuels and electricity. [2] The model is based on an integration of econometric modeling and input/output analysis. The input/output portion of the model included demand for inputs and supply for nine aggregated industrial sectors; the econometric portion of the model involved consideration of business and household sectors, as well as investment, capital, and labor. For electricity, this model projected a growth rate of 5.2 percent per year between 1975 and 2000. (By comparison, the Federal Power Commission has projected that electricity consumption will grow at an average rate of over 7 percent per year between 1970 and 1990, and that by 1990, electricity will have increased its share of total energy consumption to about 41 percent.) [3]

The rate of growth peaks in the 1975-1980 period at 5.5 percent; by 2000, the rate of growth has diminished to 5 percent. Within the electricity sector, personal consumption is projected to grow at the fastest rate: 6.9 percent per year over the period 1975-2000. This rate is somewhat less than that of the recent past due to "different price behavior, the new awareness in energy conservation, the introduction of more energy efficient capital such as heat pumps and thermal insulation, and the approach to saturation of such heavy electricity users as home air conditioning, dishwashers, laundries, ranges, and so on." [2] However, a number of technological and social trends suggest that the role played by electricity may be greater than that expected. These possibilities include: increased home heating by electricity, the advent of electric automobiles, the use of electricity in desalination, increasing mechanization of production, and the introduction and acceptance of new appliances.

Projected Fuel Mix Requirements

Almost all studies dealing with projected electricity supply indicate a diminishing role for fossil fuels and a greatly expanded role for nuclear sources. Figure 4.1.2 presents the results of a recent study illustrating this point.

Interfuel competition has long existed within the fossil fuel sector. Among the factors involved in this competition are:

YEAR	TYPE OF PLANT	INSTALLED CAPACITY*		ELECTRICAL ENERGY	
		(10 ³ MWE)	%	(10 ⁹ KW-HR)	%
1969	HYDROPOWER	53	16.0	246	15.8
	GAS TURBINE AND I-C	14	4.2	15	1.0
	GAS-STEAM	78	23.5	368	23.7
	OIL-STEAM	40	12.0	150	9.7
	COAL-STEAM	143	43.1	761	49.0
	LWR	4	1.2	13	0.8
	TOTAL	332	100.0	1553	100.0
1977	HYDROPOWER	53	10.1	246	10.0
	GAS TURBINE AND I-C	36	6.9	25	1.0
	GAS-STEAM	81	15.5	392	16.0
	OIL-STEAM	61	11.6	293	12.0
	COAL-STEAM	203	38.7	980	4.0
	LWR	90	17.2	514	21.0
	TOTAL	524	100.0	2450	100.0
1985	HYDROPOWER	55	7.1	257	7.0
	GAS TURBINE AND I-C	57	7.3	40	1.0
	GAS-STEAM	79	10.2	367	10.0
	OIL-STEAM	78	10.0	364	9.9
	COAL-STEAM	250	32.2	1175	32.0
	LWR	258	33.2	1469	40.0
	TOTAL	777	100.0	3672	100.0
2000	HYDROPOWER	72	4.4	320	4.0
	GAS TURBINE AND I-C	86	5.3	60	0.8
	GAS-STEAM	90	5.5	400	5.0
	OIL-STEAM	112	6.8	500	6.3
	COAL-STEAM	447	27.3	2000	25.0
	LWR	407	24.9	2320	29.0
	LMFBR	422	25.8	2400	30.0
	TOTAL	1636	100.0	8000	100.0
2020	HYDROPOWER	86	2.4	360	2.0
	GAS TURBINE AND I-C	142	3.9	100	0.5
	GAS-STEAM	86	2.4	360	2.0
	OIL-STEAM	62	1.7	260	1.4
	COAL-STEAM	1070	29.5	4500	25.0
	LWR	443	12.2	2520	14.0
	LMFBR	1739	47.9	9900	55.0
	TOTAL	3628	100.0	18000	100.0

*POST 1969 CAPACITIES ARE DERIVED FROM THE POWER GENERATION FIGURES USING PLANT FACTORS OF 0.08 FOR GAS TURBINE AND I-C PLANTS AND 0.65 FOR NUCLEAR PLANTS. THE PLANT FACTOR OF FOSSIL FUELED STEAM PLANTS IS TAKEN AS 0.55 IN 1977 AND DECREASES THEREAFTER TO APPROXIMATE THE OVERALL SYSTEM LOAD FACTORS FOR 1977 AND 1985.

SOURCE: OFFICE OF SCIENCE AND TECHNOLOGY, ADVISORY PANEL, "AN ASSESSMENT OF NEW OPTIONS IN ENERGY RESEARCH AND DEVELOPMENT," REPORT AET-9 (UPTON, N.Y.: ASSOCIATED UNIVERSITIES, INC., NOVEMBER 1973).

Figure 4.1.2 INSTALLED CAPACITY AND GENERATION FOR CENTRAL STATION POWER PLANTS (INCLUDES INDUSTRIAL SELF-GENERATION)

...the cost of fuel (and) such considerations as plant site and cooling water availability, fuel availability over a period of time, characteristics of the fuel supply market, magnitude and nature of fuel demand, proximity to transportation routes, regional variations in plant construction costs, transmission costs and availability of transmission rights-of-way, local tax structures, import restrictions, and environmental quality considerations...[4]

Many of these considerations, of course, are quite similar to those employed in the decision factors used in the simulation model described in Section 3.4.

Interfuel competition has led to significant changes in fuel mix over the past few years. Figure 4.1.3 illustrates the swing from coal to oil over the last decade; this change was prompted primarily by environmental and economic considerations.

Effect of the Introduction of Geothermal Energy on Fuel Mix

In projecting the effect of geothermal energy on fuel mix, three runs of the simulation model are of interest:

- No Geothermal
- Base case
- Accelerated case

Figure 4.1.4 presents the generation capacity for each of the fuels of interest for both the western portion of the United States and for the United States as a whole. This figure shows that before 1985 geothermal energy has little effect on the total capacity of generating plants using other fuels. By 2000, however, the effect is significant: Geothermal installations substitute primarily for coal and nuclear plants. This substitution is illustrated in Figure 4.1.5. The most important effects of these substitutions are described below.

Effect on Electricity Costs

Even in the simulation of the accelerated program, geothermal energy sources represent only 12 percent of total generation capacity by 2000. If the cost of geothermal electricity were 75 percent of the average cost of electricity from all other sources, the net effect on average electricity costs would only be a reduction of 3 percent. Therefore, the introduction of geothermal energy is not likely to change electricity costs to any great extent.

Number of Power Plants Required

If the average size of new coal or nuclear plants is taken to be 1000 MWe, then the substitutions described in Figure 4.1.5 for the accelerated case would imply, by the year 2000:

- 151 fewer nuclear plants in the United States
- 116 fewer coal-fired plants in the United States
- 62 fewer nuclear plants in the West
- 52 fewer coal plants in the West

Without geothermal energy the simulation model indicates that approximately 181 1000 MWe nuclear plants will be required in the West by the year 2000; with an accelerated geothermal program, this number would be reduced to about 119. This reduction in the number of nuclear plants will probably ease siting problems to some extent because of the limited number of coastline locations available in the West, and the relatively high density of population near available cooling water supplies.

Effect of the Introduction of Geothermal Energy on Water Use

The Federal Power Commission has recently conducted studies of the consumption of fresh water required in

REGION	COAL		GAS		OIL	
	1960	1969	1960	1969	1960	1969
NEW ENGLAND	58	23	5	2	37	75
MID ATLANTIC	78	57	8	9	14	34
E. N. CENTRAL	96	93	4	6	--	1
W. N. CENTRAL	47	55	52	44	1	1
S. ATLANTIC	77	70	15	13	8	17
E. S. CENTRAL	92	89	8	11	0	0
W. S. CENTRAL	0	0	100	100	0	0
MOUNTAIN	26	55	66	42	8	3
PACIFIC	0	0	68	83	32	17
U.S. AVERAGE	66	58	26	29	8	13

SOURCE: FEDERAL POWER COMMISSION, 1970 NATIONAL POWER SURVEY.

Figure 4.1.3 FOSSIL FUEL USE FOR ELECTRIC POWER GENERATION BY REGION (% OF TOTAL Btu)

	FUEL	1985				2000			
		WEST		TOTAL		WEST		TOTAL	
		1000 MWE	%	1000 MWE	%	1000 MWE	%	1000 MWE	%
NO GEOTHERMAL	COAL	47	25.5	307	34.8	147	34.5	787	38.5
	PETROLEUM	36	19.6	202	22.9	33	7.8	183	9.0
	NUCLEAR	41	22.3	258	29.2	181	42.5	959	47.0
	GEOTHERMAL	0	0	0	0	0	0	0	0
	HYDRO	47	25.5	72	8.2	58	13.6	90	4.4
	NAT. GAS	13	7.1	43	4.9	7	1.6	23	1.1
	TOTAL	184	100.0	882	100.0	426	100.0	2042	100.0
BASE CASE	COAL	44	24.0	305	34.6	112	22.7	695	34.4
	PETROLEUM	34	18.6	201	22.8	30	6.1	181	9.0
	NUCLEAR	39	21.3	255	28.9	139	28.2	841	41.7
	GEOTHERMAL	6	3.3	6	.7	147	29.8	188	9.3
	HYDRO	47	25.7	72	8.1	58	11.8	90	4.5
	NAT. GAS	13	7.1	43	4.9	7	1.4	23	1.1
	TOTAL	183	100.0	882	100.0	493	100.0	2018	100.0
ACCELERATED CASE	COAL	43	22.4	303	34.0	95	19.0	671	33.3
	PETROLEUM	32	16.0	200	22.5	28	5.6	177	8.8
	NUCLEAR	38	19.8	254	28.5	119	23.8	808	40.0
	GEOTHERMAL	19	9.9	19	2.1	192	38.5	249	12.3
	HYDRO	47	24.5	72	8.1	58	11.7	90	4.5
	NAT. GAS	13	6.8	43	4.8	7	1.4	23	1.1
	TOTAL	192	100.0	891	100.0	499	100.0	2018	100.0

Figure 4.1.4 FORECAST GENERATION CAPACITY OBTAINED FROM SIMULATION MODEL

Figure 4.1.5 GEOTHERMAL SUBSTITUTION FOR OTHER PLANTS (1000 MWe--YEAR 2000)

the operation of steam-electric power plant cooling systems. If it is assumed that essentially all electric generating plants will require a cooling pond or an evaporative cooling tower (unless they utilize water from the ocean with a long outfall), approximately 14,700 cubic feet per second of fresh water will be consumed in the process of power plant cooling in 1990. [5] This is equivalent to the average annual runoff at the mouth of the Potomac River. The introduction of geothermal energy, to the extent defined by the accelerated case, will reduce surface fresh water demand for the generation of electricity on the order of 10 percent by the end of the century. More important, it will do this in the West where water is already critically short. Therefore, development of the western geothermal resource will significantly help the development of western coal and oil shale for national use.

Effect of the Introduction of Geothermal Energy on Reduction in the Amount of Coal Mined

If coal were to be used as a substitute for geothermal energy in the generation of electric power, it is estimated that an additional 1,000 tons of coal per day would be required to replace each 100 MWe of geothermal generating capacity. [9] A Government estimate of uranium and coal requirements by the year 2000 is given in Figure 4.1.6. [10]

Fuel Resources Committed For Electrical Generation -- Year 2000 (Including Cumulative Usage and For Commitments)		
	Case A LMFBR and LWR	Case B LWR
Uranium (millions of short tons U_3O_8)	1.7	2.0
Coal (billions of short tons)	32.0	32.0
Oil (billions of bbl.)	9.0	9.0

Figure 4.1.6

Therefore comparing the no-geothermal case to the accelerated case leads to an estimate of 4.7 billion tons of coal (cumulative) which would not have to be mined should geothermal energy be developed in accordance with the accelerated program.

"The existing 298 MW Geysers generating capacity would be equivalent to approximately 3,000 tons of coal per

day. An estimated 10,000 to 21,000 tons of coal per day would be required to replace the 1,000 or 2,000 MW power potential of The Geysers. In the West approximately 45 billion short tons of the recoverable resources could be extracted by open pit mining methods. At present, a very large open pit coal mine may produce 5 million short tons of coal per year. Very large underground mines may produce 2 million short tons per year per mine. The replacement impact of coal-fired power plants would thus range from a scale-up of existing facilities to the development of large underground coal mines or very large surface coal mines or a combination of both types of mining. Coal production of this magnitude could have a significant impact on the environment. For example, if such volumes were to be produced by surface mining methods, the estimated areas that would be disturbed annually at alternative geothermal power level could be as shown in Figure 4.1.7." [9]

After World War II, coal lost much of its market to oil and natural gas because of environmental difficulties, transportation costs, and handling complexity. Experts doubt whether coal production can be expanded fast enough now to meet the goals of Project Independence. [7] Recent legislation pertaining to stripmining, declining productivity, stringent safety requirements, and uncertainties in the technology required to remove sulfur, gasify or liquefy coal, make this resource less certain than it would otherwise seem. To the extent that geothermal energy substitutes for coal, these difficulties are ameliorated.

Effect of the Introduction of Geothermal Energy on Reduction in the Amount of Uranium Mined

As for uranium, about 7500 tons per year of U_3O_8 were required in 1970; well over 100,000 tons per year would be required in 1990 assuming no recycle of plutonium. The Government estimates for cumulative uranium requirements in Year 2000 for two cases are given in Figure 4.1.6. In the 1990's the breeder reactor is scheduled to produce significant amounts of plutonium-239 fuel usable in nuclear plants. In its substitution for nuclear plants, geothermal energy lessens demand for uranium by 0.32 million tons (accelerated case) by 2000 and tends to delay the need for added full processing facilities and the breeder reactor. [8,10]

Effect of the Introduction of Geothermal Energy on Atmospheric Pollutants

In 1968 fossil fuel steam electric power plants produced an estimated 16.8 million tons of sulfur oxide, 4 million

LAND REQUIRED FOR SURFACE COAL MINES

Coal Bed Thickness (ft.)	Millions of Tons of Coal Available Per Sq. Mile @ 80% Recovery (1800 ton/acre ft.)	Annual Areas Disturbed (Acres)				
		1,000 MW	2,000 MW	7,000 MW	20,000 MW	100,000 MW
10	9.2	256	525	1,811	5,216	26,080
20	18.4	128	262	902	2,611	13,055
30	27.6	83	173	602	1,741	8,705
40	36.1	64	134	461	1,331	6,655
50	46.1	51	102	358	1,043	5,215

Figure 4.1.7

tons of nitrogen oxide, and 5.6 million tons of particulate matter. [6,11] These amounts represented quite significant levels of pollution: The sulfur oxides emitted by electric power generating plants were 50 percent of all such pollutants released in the United States; the nitrogen oxides, 20 percent; and particulates, 20 percent. [6] The air pollutants which can be released by fossil fuel plants are the result of combustion, and therefore their control requires intervention in the combustion cycle. For example, the fuel can be modified (e.g., the removal of sulfur); boilers can be modified to reduce the temperature of hot spots (and thereby control nitrogen oxides); and the products of combustion can be modified (e.g., through the removal of sulfur compounds and particulate matter). The cost of atmospheric pollution control devices ranges from \$50-125 per kilowatt. [11]

If the accelerated program were realized, geothermal energy would substitute for about 15 percent of the otherwise required coal-fired plants in the United States by 2000. This substitution will result in a commensurate decrease in the amount of atmospheric pollutants released to the atmosphere, and in the costs expended for pollution control devices. This will give the savings shown in Figure 4.1.8.

Reduction in Air Pollutants Resulting From an Accelerated Geothermal Program Substituting For 116,000 MWe Coal-fired Power Plants in Year 2000	
Pollutant	Amount of Reduction Millions of Tons Per Year
Sulfur Oxide	1.76
Nitrogen Oxides	1.01
Particulate Solids	0.29
Capital Cost Savings, Cumulative (1973 dollars)	\$5.8 billion-\$29 billion
Note--Pollutant calculations based on data in Reference [19]. Current EPA emission standards for new coal- fired power plants is assumed--SO ₂ and particulate removal equipment is installed.	

Figure 4.1.8

REFERENCES

- [1] Starr, Chauncey, "Energy and Power," Scientific American (September 1971), p. 44.
- [2] Hudson, Edward A., and Dale W. Jorgenson, U.S. Energy Policy and Economic Growth, 1975-2000 (Cambridge, Mass.: Harvard University and Data Resources, Inc. [part of the Ford Foundation Energy Policy Project], June 1974).
- [3] The 1970 National Power Survey, Part I (Washington, D.C.: The Federal Power Commission, December 1971), p. I-1-13. (Hereafter called The 1970 National Power Survey.)
- [4] The 1970 National Power Survey.
- [5] The 1970 National Power Survey, p. I-10-16.

- [6] The 1970 National Power Survey, p. I-11-2.
- [7] Walsh, John, "Problems of Expanding Coal Production," Science (April 1974), p. 336.
- [8] The 1970 National Power Survey, p. I-6-11.
- [9] Final Environmental Statement for the Geothermal Leasing Program, Vol. 1 (Washington, D.C.: U.S. Department of the Interior, December 1973), p. IV-61.
- [10] Environmental Statement Liquid Metal Fast Breeder Reactor Program, Vol. 1 (Washington, D.C.: U.S. Atomic Energy Commission, March 1974), p. I-11-10.
- [11] Hottel, H. C., and J. B. Howard, New Energy Technology--Some Facts and Assessments (Cambridge, Mass.: The MIT Press, 1971), pp. 70-80.

4.2 Effects on Businesses Relevant to Geothermal Energy

Introduction

Any change in energy source, in an economy as complex as ours, can have ripple effects throughout a broad spectrum of industry. Businesses which utilize the new source of power can be affected, as well as businesses which supply goods and services for its production. Changing requirements in these categories result in secondary and tertiary impacts which are by no means limited to economic or operational areas. There may also be effects on the environment, on institutional arrangements, on research policy, on industry location. Some of these impacts may be expected to be pronounced; others so minor or diffuse as to be unnoticeable. This section will attempt to define the major areas of impact on particular businesses resulting from the development of geothermal energy.

Effects on Businesses that Utilize Geothermal Energy: Businesses That Need Electricity

Most businesses need electricity, although the requirements of individual firms differ drastically. To the extent that geothermal-generated electricity merely substitutes for electricity produced by another energy source, it would have no perceptible general effect on users other than through possible cost variations.[1] But if it alleviates a shortage of electricity which might otherwise occur, the use of geothermal electricity would allow industrial growth to continue rather than to be limited in the future. This overall impact on the economy is discussed in Section 4.3 under macroeconomic effects.

More specifically, it is possible that the use of geothermal energy for electrical generation can have sizeable impacts on industries which have unusually heavy electrical needs and on the areas in which they are located. Figure 4.2.1 shows the fuel consumption of industries with the highest energy needs. The production of aluminum is quite energy-intensive; large plants are located in the Pacific Northwest, drawn there by the availability of hydroelectric power. Until recently power supply seemed assured, but drought conditions in the past few years have made it apparent that alternate or additional energy sources are needed in the area. Some industrial plants were forced to cut power usage by up to one-third during the shortages, and in a few cases, complete shutdowns were necessitated.

INDUSTRY GROUP	COAL	NATURAL GAS	PETROLEUM PRODUCTS	ELECTRICITY	TOTAL ENERGY
PRIMARY METAL INDUSTRIES	2,838	863	306	1,291	5,298
CHEMICALS AND ALLIED PRODUCTS	666	1,219	1,426	1,626	4,937
PETROLEUM REFINING AND RELATED INDUSTRIES		1,012	1,589	225	2,826
FOOD AND KINDRED PRODUCTS	263	593	134	338	1,328
PAPER AND ALLIED PRODUCTS	467	341	211	280	1,299
STONE, CLAY, GLASS, AND CONCRETE PRODUCTS	406	449	87	280	1,222
SUBTOTAL	4,640	4,477	3,753	4,040	16,910
ALL OTHER INDUSTRIES	976	4,781	721	1,572	8,050
TOTAL	5,616	9,258	4,474	5,612	24,960

SOURCE: STANFORD RESEARCH INSTITUTE USING BUREAU OF MINES DATA, AS REPRINTED IN THE POTENTIAL FOR ENERGY CONSERVATION, EXECUTIVE OFFICE OF THE PRESIDENT, OFFICE OF EMERGENCY PREPAREDNESS, WASHINGTON, D.C., OCTOBER 1972.

Figure 4.2.1 INDUSTRIAL FUEL CONSUMPTION BY MAJOR USERS (TRILLION BTU)

Prospects for hydroelectric expansion are limited because major sites have already been exploited, and consequently metals companies are actively seeking other energy sources.[2] The existence in the Northwest of a large power grid acting as a common carrier provides the opportunity to transport and trade power which does not exist in many other parts of the country. Power can be fed into the grid at any point and removed elsewhere on an exchange basis. Aluminum companies located on the coast, for instance, are now looking into coal sources in Wyoming and would be receptive to the use of any available geothermal energy. Amax Corporation has started geothermal exploration on private land in California, Oregon, and other western areas to find energy for its metallurgical operations, and has no doubt that private utilities as well as the public system would utilize any facilities they might develop.[3]

Certain chemical processes also require unusually large amounts of electrical power, and chemical companies are in the forefront of industrial interest in geothermal development. Dow Chemical Company, which needs an assured source of electricity supply for its Washington plant, has bought an interest in Magma Power Company and also is investigating geopressured resources in the Gulf area.[4]

There are other localities of geothermal potential where chemical companies could also be benefitted by additional power sources. The phosphate industry of southeastern Idaho, for instance, needs additional power to produce fertilizer and phosphoric acid from phosphate rock [5], and southern Nevada has a cluster of energy-intensive chemical (chlorine-caustic) and metallurgical plants, [6] based on Hoover Dam.

The availability of geothermal power can be an important factor in keeping existing heavy electrical users in an area and in influencing the location of new capacity. If a particular industry brings with it pollution problems or changes the desired character of an area, these adverse effects might offset to some degree the beneficial local economic effects. On the other hand, the companies themselves and their customers would be benefitted by the assured production levels made possible by adequate and reliable energy supplies. The cost of the products would not necessarily be lower, however, since in some instances production of energy intensive industries has depended on inexpensive, government-subsidized hydro-electric power.

Availability of geothermally-generated electricity could also have an impact on the transportation system of the west. European railroads have long been electrified, but in this country the availability of cheap fossil fuel (diesel oil) did not encourage electrification. In fact, the number of electric locomotives in the United States declined from 827 in 1950 to 255 in 1971. Rapidly rising costs of diesel fuel, which now powers almost all U.S. railroads, may cause a reversal in this trend in the next ten years.

The Southern Pacific Railroad Company is investigating possibilities of using geothermally-generated electricity.[7] Planners envision a line of geothermal plants roughly paralleling the railroad, feeding in power at various points. Institutional and marketing difficulties might stand in the way of implementing such a plan, however. A proprietary transmission system might be required if appropriate arrangements could not be made with local utilities, but this might entail duplicate facilities. In addition, since geothermal power is base-loaded, extra power would, at

times, be available to be sold at either end of the transmission lines, with the local utility the only legal customer. (See Section 4.5, Effects on Institutional Arrangements.)

Depending on the location of geothermal resources suitable for generating power and their distance to population centers, growth of electrified mass transit systems could be influenced by geothermal developments. Greater availability of electricity would reinforce the interest in commuter lines now increasing due to potential auto gasoline shortages. Such a development would in turn affect levels of local air pollution and population mobility patterns.

Businesses that Need Heat

Although interest in U.S. geothermal resources has focused primarily on their use for electrical power production, it is possible that direct use of heat from the earth for space heating and industrial and agricultural processing may emerge as a very sizeable energy factor. The limiting constraint on this type of utilization is its site-dependency. It is likely that moderate temperature water-dominated reservoirs suitable for a large number of direct uses will be identified in many areas of the West, but the hot fluid must be utilized within a few miles of the geothermal field because of the expense of piping and the loss of heat in transmission. Therefore, the extent of development will depend upon the location of the resource with respect to prospective users and the consuming market, as well as upon the particular temperature and chemical composition of the geothermal water at the site.

A most important characteristic of the use of geothermal energy is its potential for a multiplicity of complimentary and auxiliary uses in the same installation. Water remaining after steam has been flashed for electric power production could be utilized for many of the same purposes as direct geothermal fluid, depending on temperatures, composition, and the need for reinjection. Concurrent production of desalinated water and/or chemicals along with electrical power is the subject of current investigations.[8] In the case of utilization of direct geothermal fluid alone, once the resource is made available for a prime user, other secondary uses are likely to follow. Therefore, there is a good possibility that industrial-agricultural complexes could evolve near a geothermal resource, combined possibly with power production and/or residential space heating. Such a development could effect major changes in local economies and draw population to formerly isolated areas.

Lindal [9] has compiled suggestions made by scientists from many different countries for the use of direct geothermal heat. In some few cases practical applications are already in existence; in most the proposals are merely in the conceptual stage. Possible categories of use include process and space heating, drying, distillation, refrigeration, de-icing and tempering in mining operations, production of alumina from bauxite, production of heavy water through the hydrogen sulfide-water isotope exchange process, greenhouse heating, fish farming, and soil-warming. Specific absorption refrigeration processes include those in the production of synthetic rubber, ammonia, protein, vitamins, freeze-dried food, and in metallurgical plants. The feasibility of these various uses, of course, differs in various parts of the world according to prevailing industrial costs, energy, and climatic conditions. Figure 4.2.2 shows the approximate geothermal fluid temperatures re-

quired for various uses. The minimum temperature is the limiting factor, since too high a temperature usually can be easily adjusted.

SOURCE: LINDAL, B., "INDUSTRIAL AND OTHER APPLICATIONS OF GEOTHERMAL ENERGY," *GEOTHERMAL ENERGY*, UNESCO, PARIS 1973.

Figure 4.2.2 THE REQUIRED TEMPERATURE OF GEOTHERMAL FLUIDS (APPROXIMATE)

A range of specific industrial processes which utilize steam and the amount of steam required per dollar of product value are shown in Figure 4.2.3. Although the figures for steam consumption are based on fossil fuel and are not necessarily directly applicable to geothermal steam, they indicate in which processes the cost of steam is a major consideration. Lindal [9] draws an analogy with power-consuming industries, where the cost of electrical power becomes an important factor in plant location when it accounts for more than 10 percent of the value of the product. In the case of steam, if steam cost is \$1.75 per ton of steam consumed, the 10 percent level would be reached by the use of 128 pounds of steam per dollar value. Therefore, industries engaged in the ten processes listed in the figure with over 128 pounds of steam per dollar value might be prime candidates for moving to any cheaper source of steam supply, and those with somewhat lesser though substantial needs would also probably be interested in its utilization. For example, natural sodium sulfate (688,000 tons, 1971) and natural sodium carbonate (2,878,000 tons, 1971) are mined in very large quantities in California and Wyoming.[10] Geothermal fields may be exploited near some of these mining areas.

PRODUCT AND PROCESS	STEAM REQUIREMENTS LB STEAM/LB	PRODUCT VALUE CENTS/LB	STEAM PER UNIT PRODUCT VALUE LB STEAM/ \$ VALUE
HEAVY WATER BY HYDROGEN SULFIDE PROCESS	10,000	3,000	333
ASCORBIC ACID	250	250	100
VISCOSE RAYON	70 ¹	75	93
LACTOSE	40	14	286
ACETIC ACID FROM WOOD VIA SULFIDE PROCESS	35	10	350
ETHYL ALCOHOL FROM SULFITE LIQUOR	22	7	314
ETHYL ALCOHOL FROM WOOD WASTE	19	7	271
ETHYLENE GLYCOL VIA CHLOROHYDRIN	13	13	100
CASEIN	13	56	23
ETHYLENE OXIDE	11	15	73
BASIC MG CARBONATE	9	11	82
35% HYDROGEN PEROXIDE	9	18	50
85% HYDROGEN PEROXIDE FROM 35% H ₂ O ₂	4 3/4	—	—
SOLID CAUSTIC SODA VIA DIAPHRAGM CELLS	8	3	266
ACETIC ACID FROM WOOD VIA SOLVENT EXTRACTION	7 1/2	10	75
ALUMINA VIA BAYERS PROCESS	7 ²	3	234
ETHYL ALCOHOL FROM MOLASSES	7	7	100
BET SUGAR	5 3/4	10	58
SODIUM CHLORIDE	5 1/2	9	61
KRAFT PULP	4 1/5	6	70
DISSOLVING PULP	4 1/5	—	—
SULFITE PULP	3 1/2	6	58
ALUMINUM SULFATE	3 1/2	2	175
SYNTHETIC ETHYL ALCOHOL	3	7	43
CALCIUM HYPOCHLORIDE, HIGH TEST	3 1/3	3	111
ACETIC ACID FROM WOOD VIA OTHER PROCESS	2 3/4	10	28
AMMONIA CHLORIDE	2 3/4	6	46
BORIC ACID	2 1/4	5	45
SODA ASH VIA SOLVAY PROCESS	2	1 1/2	133
COTTON SEED OIL	2	10	20
NATURAL SODIUM SULFATE	1 4/5	1 1/2	120
CANE SUGAR REFINING	1 2/3	10	17
AMMONIA NITRATE	1 1/2	3 1/2	43
AMMONIA SULFATE	1/6	1 1/2	11
FRESH WATER FROM SEA WATER BY DISTILLATION	1/12	1/60	.500

¹SHREVE (1956) QUOTES 150 LB STEAM PER POUND.

²HAS DECLINED IN RECENT YEARS IN MOST CASES.

SOURCE: LINDAL, B., "INDUSTRIAL AND OTHER APPLICATIONS OF GEOTHERMAL ENERGY,"
GEOTHERMAL ENERGY, UNESCO, 1973.

Figure 4.2.3 THE SPECIFIC CONSUMPTION OF STEAM AND THE STEAM USED PER DOLLAR VALUE IN SOME ESTABLISHED PROCESSES

In this country there are a number of industries in promising geothermal areas which can be identified as prospects for use of direct heat. The lumber, paper and pulp, and food processing industries in the Northwest currently use large amounts of low grade heat. This is provided primarily by natural gas, but the gas companies are no longer offering firm supply contracts. [4] Geothermal fluid at a minimum of 230°F could provide this type of heat. The chemicals industry makes extensive use of process heat at from 200° to 450°F, now provided by oil and gas. Greenhouses, fish farming, animal husbandry, and other agricultural applications are also potential utiliziers of geothermal resources.

Most companies in these industries are not exploration-oriented and would not risk drilling for themselves. Development companies and/or government entities would probably have to establish the resource and guarantee the supply for any large-scale utilization. Local impacts of such projects would be pronounced, particularly in rural areas, if they stimulated growth of existing industry or attracted new companies to the area. There would be effects on the economy, the tax base, and the size and character of the population.

Although little research has been done in this country on the use of geothermal process heat, there has been investigation in an allied area, use of thermal effluents from power plants. TVA, in conjunction with the Oak Ridge National Laboratories, has several projects

underway to determine beneficial uses of waste heat. [11] These include use of condenser cooling water for catfish production in power plant water raceways, soil heating to extend the growing season of horticultural and field crops, and environmental control in greenhouses. There are also plans to study the use of hot water in heating and cooling livestock facilities and in recycling nutrients from livestock wastes. A number of utilities are also experimenting with possible uses of warm water discharged from power plants. The effluents from a Long Island Lighting Co. power plant are used by Long Island Oyster Farms to accelerate oyster breeding [12], and Northern States Power Co. in Minnesota recently started a one-year demonstration project to test whether warm water discharge could be used to heat and cool greenhouses. [13] This project is being conducted in conjunction with the University of Minnesota Agricultural Experiment Station, which is also investigating the use of warm water for soil-warming and fish farming. [14] The temperature of water circulated through power plant cooling towers normally ranges from 60° to 115°F, lower than generally expected geothermal fluid temperatures. Since higher temperatures can be adjusted, however, or in many cases, as described below, may prove more effective, the power plant research currently being conducted will be useful in identifying geothermal applications.

The following paragraphs will discuss in greater detail, by industry, the prospects for industrial and agricultural use of geothermal heat. Space heating and cooling will be treated in Section 4.6.

Greenhouses [4,14,15,16,17,18,19,20,21,22,23]

The advent of interest in geothermal energy coincides fortuitously with a trend toward greater use of controlled environments in agriculture. There is increasing demand for off-season, greenhouse-grown products, and some scientists have envisioned the possibility of creating artificial microclimates over large areas using geothermal resources as the heat source. [8] Technology exists to grow super-size vegetables and grains under controlled conditions, although the commercial stage has not yet been reached. In the past, heating costs in conventional greenhouses in Illinois, Ohio, and Southern Ontario have represented 25 to 30 percent of total operating costs [21]. Recent increases in fuel prices have, of course, increased this percentage. Heating costs are high because of the difficulty in insulating transparent panels. Even more important, reduced fuel allocations for horticultural production during the energy crisis heightened the risk of crop loss. Just a few degrees change in temperature for even a few minutes can precipitate disaster under hothouse conditions, and therefore reliability of fuel supply is a paramount consideration. Under today's energy supply conditions, the use of heating water from on-site geothermal wells becomes increasingly attractive for greenhouse use. Although investment costs for equipment and piping would probably be higher than for some conventional systems, the fuel savings and increased reliability of geothermal sources may be of sufficient attractiveness to warrant their use in many applications.

Numerous examples of geothermal usage for greenhouses exist throughout the world. [9] In Hungary, use for both hothouses and animal husbandry has been rapidly increasing in recent years. In Iceland, the greenhouse industry showed tremendous growth from 1940 to 1960 until the market became saturated, and has since remained on a high plateau with 70 percent of the acreage in vegetables and 30 percent in flowers. Japan has some geothermally heated horticultural hothouses and in New Zealand mushroom rooms are grown in propagation houses with the heat also

being used to sterilize the soil. The USSR has experimented with geothermal greenhouses, some surrounded by soil-warming areas. In the United States, there are a few greenhouses heated by geothermal fluids in California, Idaho, and Oregon.

A new trend to accelerate the growth of tree seedlings in greenhouses is currently stimulating geothermal exploration in the Northwest. Most timber companies are interested in greenhouses, and the abundance of geothermal resources in the area make this form of heating a promising alternative to other fuels. Boise Cascade Corporation is building two seedling greenhouses in Oregon adjacent to a hot spring in order to utilize its 85°F hot water for growing half a million seedling conifers a year. The growth rate is expected to be two to three times greater than in conventional ground beds. Weyerhaeuser Company is starting to explore for geothermal resources for space heating and greenhouses.

Forty percent of the country's flower and nursery stock growers are located on the west coast. The horticultural part of the greenhouse industry had particular fuel problems during the energy shortage because they were not classified as agriculture and did not get full fuel allocations. The classification has been recently changed, but uncertainties linger and the industry would probably be quick to take advantage of established geothermal resources. Location is not a particular problem, since more nurseries are specializing today and shipping products greater distances by truck and plane. Ohio has more horticultural and vegetable greenhouses than any other part of the country.

Vegetables grown in greenhouses in remote geothermal areas might have prohibitive transportation costs to population centers. However, as heating costs rise, the lower costs of geothermal energy might offset transportation charges. An interesting sidelight which might contribute to relocation is the fact that many existing greenhouses, originally on the edge of town, are now in the middle of high-valued land. It might therefore be economic for some growers to sell their existing facilities and rebuild in a more remote area. In addition, development of plastic greenhouses has reduced initial investment costs.

Vegetable growing in greenhouses could be a particularly important application of geothermal energy in Alaska. Fresh vegetables are more expensive there because of the very short growing season. Alaskan greenhouses also need a light source for the long Arctic winters. This may be obtained from fluorescent lights utilizing geothermal electricity. Thus, the Alaskan greenhouse could use two attributes of geothermal energy, heat and electricity.[22]

The TVA waste heat research greenhouse at Muscle Shoals, Alabama, is currently testing the use of power plant thermal discharge in growing tomatoes, cucumbers, and lettuce, which account for 93 percent of greenhouse vegetable production in the United States. The preliminary economic evaluation [21] points out that refinements are needed for greater commercial potential. One of the suggested improvements is use of higher temperature water which could be made available if power plants go to closed-loop cooling. This would lower capital and operating costs through, for example, lower waterflow rates or smaller heat exchangers. Warmer water would also maintain lower humidity and thus reduce the cost of disease control. This research would seem to indicate that the higher temperatures generally available in geothermal fields would be more efficient than power plant thermal discharges for greenhouse use. Other disadvantages of power plant waste heat described by TVA which would not exist in

geothermal use are the variation of water temperature with generating load and, of great importance, the problem of temporary plant shutdown causing sudden temperature reductions.

Other power plant research also indicates that low temperature is the major constraint. Russell V. Stansfield, Administrator of Warm Water Utilization for Northern States Power Co., has stated, "The biggest obstacle to using power plant warm water for heating and cooling is that the temperature of the water is so close to that of the desired greenhouse temperature that the equipment needed to transfer that heat from the water to the air must be very large."

Soil-Warming

TVA is currently conducting experiments in the use of warm water for irrigating and heating the soil for vegetable crops in open fields at Muscle Shoals, Alabama.[11] Beds are underlain with electric heating cables to simulate underground warm water pipes, and are subirrigated with porous plastic pipes. Yields of string beans and sweet corn are almost doubled, summer squash yields are increased only during the early production period, and tomatoes show little response. More elaborate experiments are being planned to extend both the early and late growing seasons.

Whether geothermal water can prove economically feasible for this type of soil-warming probably depends on the climate in which it is found and utilized. The University of Minnesota has conducted field studies of heating soil to remove frost in order to extend the growing season. Preliminary conclusions are that it may not be practical because it requires a cold-tolerant crop, and there are no high income cold tolerant crops.[14]

Fish Farming[23,24,25,26,27,28]

It has been predicted that by 1990 about half of all fish consumed will be grown by cultivation methods because of declines in the natural catch. The catfish farming industry, which did not exist ten years ago, grew 25 percent a year from 1968 to 1972 and 10 percent a year for the past two years. Sixty thousand acres are now in production, mostly in the South. Developmental projects are also underway for growing shrimp, oysters, salmon, and crayfish. In 1972, fish farms provided about 90 million pounds of fish, two percent of domestic fish production.[30]

Geothermal fluids may be useful in mariculture. The growth of almost all cold-blooded animals can be accelerated by increased temperatures, and in general, for fish, the warmer the water the greater the growth, up to the limit of tolerance. Optimum temperatures for economic breeding can range from 65° to 90°F. In Iceland, geothermal water is used for tempering pond water in fish breeding stations and at least one salmon breeding station uses the warm water directly. Eels are bred in Japan in ponds where geothermal water is mixed with river water.[9] In the United States several projects are now underway using thermal effluents from nuclear power plants to increase shellfish growth and to breed catfish.

The main problem to be faced in utilizing geothermal fluids for mariculture is water quality. Geothermal water is low in dissolved oxygen, may be too alkaline, and may contain trace elements and high H₂S which would be harmful to fish. Flowing water is needed to remove fecal matter and for aeration, and a flow of 20 cubic

feet per second is needed for raising fish that swim. At the same time, a high concentration of fish is needed to make an operation profitable. At least one pound of fish flesh per cubic foot per year must be produced. To maintain this density, the water must be fairly clean, since disease is a hazard under such crowded conditions. Big fish exhaust oxygen especially quickly.

Each geothermal field would have to be analyzed individually to determine its fish-raising potentialities with respect to temperature, chemical composition, possibility of mixing with other waters, and proximity to markets and transportation. Aeration problems could probably be solved by running the water over a three to four foot waterfall. This could be done up to three times within a mile to maintain sufficient oxygen levels.

The use of geothermal water for fish-raising has one highly desirable advantage over use of power plant effluents--constant temperature. If the plant is temporarily shut off, inlet water temperature can swing wildly, with extremely harmful effects on the fish. Geothermal water would remain at constant temperature. In addition, as artesian water, it is bacteria-free.

Some of many species which might be investigated for cultivation in or with the mixture of geothermal fluids include trout, catfish, crayfish, carp (for fish meal), salmon, fresh water crawfish, and fresh water shrimp. Some experimentation has been done in California on the use of geothermal water to breed talapia and brine shrimp. It is possible that fish which are now confined to southern waters could be grown in warm water further north if the mineral content could be tolerated.

A TVA experiment in using heated water for raising catfish in concrete raceways found that growth rates were significantly enhanced by heated water and that the growing season was lengthened.[11] The project was not able to proceed to commercial operation because of several problems not yet overcome. Feed loss and mortality rates were high and the state imposed requirements for secondary treatment of the used water because of substantial quantities of waste materials. At the University of Minnesota, investigators are using an existing commercial operation to determine if catfish can be kept growing in the winter with the addition of warm water.

Accelerated development of mariculture through use of geothermal water could not only provide additional input to a fish market currently characterized by frequent shortages of particular species and high prices, but would also have a beneficial impact on the balance of trade. The percentage of total fish consumed in the United States which were imported increased from 32.5 percent in 1955 to 65.8 percent in 1972. The total value of edible fish imports in 1972 was \$1,205 million [10], almost 20 percent of all food imports. Any part of this which could be replaced by cultivation methods would contribute to the domestic economy.

Pulp and Paper; Wood Processing

The Tasman Pulp and Paper Co. of New Zealand is the first major industrial user of geothermal steam in the world.[31] It was located specifically for this purpose and uses 400,000 pounds of natural steam per hour for processing cellulose pulp out of wood by the Kraft process. The wells produce wet steam, which is flashed before transmission by pipeline. Some of the steam is used directly and some is fed into steam

generators for producing clean steam. The energy is used for timber-drying, log-handling equipment, pulp digestion, and black liquor evaporation. In addition to this major use, timber is seasoned by natural heat in various parts of the world.

U.S. geothermal applications in the lumber and paper industry appear particularly promising since almost 60 percent of lumber production in this country is in the Mountain and Pacific areas, where geothermal resources are believed to be abundant. Kiln drying of lumber is a standard industry procedure and geothermal hot water would be suitable in many instances.[32]

Food Processing

The food processing industry uses large amounts of heat for freezing and canning fruits and vegetables and for producing sugar from sugar beets. These functions could be implemented by geothermal resources in areas such as the Imperial Valley of California, a major agricultural area, and the Oregon-Idaho border, a food-processing area for potatoes, beets, peas, and other vegetables.[4, 33]

Greater availability of energy resources for processing may increase agricultural production in a particular area, and will very likely supplement a growing greenhouse industry based on the use of geothermal heat if the range of products grown under controlled conditions increases. As in the case of all other applications of process heat, the temperature of discovered resources and their location will play a major part in determining the extent of use.

Crop drying is another application of geothermal heat, and already has small scattered applications. Most wheat, corn, and soybeans must be dried before long term storage to prevent rotting. It has also been suggested that natural heat could be used in the dairy industry for production of dried milk, casein, and sucrose.[9]

Animal Husbandry

In a number of countries, geothermal heat is used in the livestock and poultry industries. In Hungary, it is used for heating cattle stalls, milking rooms, pigsties, and chicken houses; in Japan for hatching eggs and raising poultry; and in New Zealand for biodegradation of wastes from pigsties and for washing and drying of wool.[9, 22] All of these applications are on a small scale at present.

TVA plans to build an experimental feedlot and poultry house heated by hot water as part of its program to develop uses for power plant thermal effluent. Research has shown that feed conversion and efficiency are improved for livestock and poultry within certain ranges of moderate temperatures.[11] In connection with this project, a study of techniques for recycling nutrients from livestock wastes is also planned. It would involve producing algae by utilizing nutrients from manures in a series of heated lagoons and ponds. The algae could then be harvested and processed into a high-protein feed source, although this is a difficult and expensive project. The results of this experiment will probably be applicable for geothermal research, particularly since the Mountain states have both geothermal resources and a sizeable cattle industry.

Mining

Geothermal energy has proven useful in mining operations in some parts of the world. In Northern Iceland, it is being used for recovery and drying of diatomaceous earth which was not able to be economically utilized by other means. Research is being conducted in the USSR on the use of geothermal waters in mining in permafrost regions. Possibilities for usage there are for ore flotation and for heating and humidification of ore air.

Whether any mining applications will be found in the United States is not yet known.

Chemical By-Products and Desalinization

Some high temperature geothermal fluids tend to contain high percentages of minerals, and also contain the energy potential for self-evaporation. Figure 4.2.4 shows the chemical components of high saline brines in the Salton Sea area in California as compared with fluids of much lower salinity at Cerro Prieto and Arizona. Sodium chloride is the most abundant compound, but although extraction of salt has proven feasible in some other parts of the world, it is not currently competitive in this country because of adequate, less costly, deposits and considerable transportation costs that would be involved if geothermal sources were utilized. Potassium and magnesium appear to have the greatest commercial potential, but the costs of production are not yet clearly economic.

ELEMENT	NITLAND (SALTON SEA AREA)			CERRO PRIETO	ARIZONA
	WELL 39	WELL 36	WELL 57	M 3	MUSGROVE 1
SODIUM	50,400	53,000	10,600	5,610	141 ^{xx}
POTASSIUM	17,500	16,500	1,250	1,040	---
CALCIUM	28,000	27,800	1,130	320	148
LITHIUM	215	210	40	14	---
MAGNESIUM	54	10	74	xx	43
STRONTIUM	400	440	85	27	---
BARIUM	235	250	3	57	---
RUBIDIUM	135	70	---	xx	---
CESIUM	14	20	---	xx	---
IRON	2,290	2,000	0.7	xx	---
MANGANESE	1,400	1,370	6.4	xx	---
LEAD	102	80	---	xx	---
ZINC	540	500	---	xx	---
SILVER	xx	xx	---	0.05	---
COPPER	8	xx	---	0.09	---
SILICA	400	400	120	xx	18
CHLORIDE	155,000	155,000	19,700	9,694	188
BORON	390	390	100	12 ^{xxxx}	---
FLUORIDE	15	xx	1	0.88	---
SUM OF SULFUR	xx	30	---	≈10	---
DISSOLVED SOLIDS	258,973	259,000	34,800	≈17,000	1,000

^xINCLUDES POTASSIUM

^{xx}NOT REPORTED

^{xxxx}RECALCULATED FROM H₂SO₄

SOURCE: AUSTIN, A., ET AL., THE TOTAL FLOW CONCEPT FOR RECOVERY OF ENERGY FROM GEOTHERMAL HOT BRINE DEPOSITS, LAURENCE LIVERMORE LABORATORY, UNIVERSITY OF CALIFORNIA, LIVERMORE, 1973, REPRINTED FROM H.C. NELGSON, AMERICAN JOURNAL OF SCIENCE, VOL. 226, NO. 129 (1968).

Figure 4.2.4 ANALYSES OF WATER FROM GEOTHERMAL WELLS AT SALTON SEA GEOTHERMAL AREA (IMPERIAL VALLEY), CERRO PRIETO (MEXICO), AND YUMA, ARIZONA VICINITY (PARTS PER MILLION)

Some efforts have been made in the past in the Imperial Valley to extract minerals from geothermal brine but these proved uneconomic because the minerals carried the full cost of development.[34] If power, minerals,

and possibly desalinated water could be produced concurrently, the costs might be brought down to a commercial level. Demonstration plants will be necessary for this concept to be tested. Geothermal fluid is complex and each field differs just as solid ore deposits differ. Equipment would have to be tailored for each particular location.

If chemical extraction proves feasible using proprietary power, an industrial base could be added to the present agricultural economy of the Imperial Valley and thus reduce the currently high level of unemployment. The crucial element is not necessarily comparative costs for metals today, but those future ones which will prevail at the time a multipurpose geothermal complex could be implemented. Growing scarcities and rising prices of metals may make extraction from geothermal fluid economically viable. U.S. demand for potassium fertilizer in 1985 is projected at 6.85 million short tons (K equivalent), with a value of over \$200 million at current prices, as compared to projected domestic production of 3.66 million. Demand for manganese is estimated at 1.77 million short tons in 1985 with no domestic production.[35] Manganese is almost entirely imported today, at an annual cost of \$34 million.[10] A competitive means of production here could not only contribute to the local economy, but could help improve the balance of trade.

Desalination of geothermal fluid in the Imperial Valley is being investigated by the Bureau of Reclamation, but there is yet little knowledge of the economics involved.[36] Two test wells have been drilled, but desalting is not yet actually underway. Physical data must be obtained before commercial possibilities can be ascertained.

The objective of the Bureau's long-range program is to determine the compatibility of concurrent production of electricity and fresh water, in order to augment the the Colorado River.[34] Within a time-frame of 20 years and depending on the results of research and development steps, 2.5 million acre-feet of desalted water per year could be produced with 10,500 MWe of electricity, of which about 2,000 MWe would be used for processing and pumping.

The major operational and cost problem is the need for substitution of other water for reinjection in order to replace the desalinated fluid. This reinjection is necessary to prevent subsidence in the geothermal field. Several alternatives have been proposed: the use of Salton Sea or other local waters or the importation of water from the Pacific by aqueducts. Only a combination of multi-purpose development plus an urgent need for water is likely to make such an elaborate project economically feasible.

If implemented, however, the impacts would be sizeable. The Colorado River has become increasingly saline, and this condition may threaten the viability of the canal system which now irrigates 5,000,000 acres of land in the Imperial Valley. There are also international implications, since the United States is obligated to furnish Mexico with water from the Colorado River and the deteriorating quality has become an issue of dispute.

Unique Geothermal Applications

The applications of geothermal process heat described above are primarily adaptations and extensions of existing technologies. There are other possibilities for more futuristic uses of the earth's heat which can be envisioned. If geothermal wells were bored into the ocean floor in strategic locations, it is

conceivable that the upwelling of hot water could create accelerated growth areas for ocean nutrients and fish. Other contribution to the food chain would be to breed single cell animals and plants in geothermally heated ponds. When dry hot rock drilling is developed, it is possible that a means will be found to leach out minerals by dissolving them in acidic water circulated in pairs of deep wells bored into deep strata. These speculations serve as illustrations of types of applications which may emerge as new geothermal technology develops.

Effects on Businesses That Supply or Support Geothermal Industries

Summary of Development Requirements

Extensive business activity will be engendered by the heavy capital investment needed to yield the rate of geothermal growth projected by the model described in Section 3.5. Figure 4.2.5 presents a summary of some of the demands which will be placed on the emerging geothermal industry if it is to reach a producing level of about 7,000 MWe in 1985 and 190,000 in 2000. From reported experience at The Geysers, Cerro Prieto, and Wairakei, and from estimates made in the literature, it is possible to project roughly the number of wells, rigs, men, and capital necessary to sustain the postulated development rate. By 2000, some 40 million feet of wells will have to be drilled annually, assuming average depths of 6000 feet, production of 5MWe per well, one disposal well for two producing wells, a wild-cat drilling success rate of 1 well in 10, and a development and production success rate of 9 in 10. (See figure note for hot dry rock modifications.) In the mid-eighties, the model yearly expansion rate of 2000 MWe would require about 150 drilling rigs operating per year, assuming a drilling rate of 24,000 feet a year, including downtime. By 2000, the expansion rate would rise to 20,000 MWe per year, requiring 1,500 rigs. Manpower requirements for rig crews, at the present rate of 17 men for round-the-clock shifts, would total 2,500 in 1985 and rise to 25,000 in 2000. As discussed in Section 3.3, these long-range requirements seem attainable, even in the presence of a vigorous and expanding program of petroleum exploration and development, although special government allocation and incentive programs might be required in periods of rapid expansion.

By 2000, about \$2,800 million per year would be required for drilling, assuming that present estimated costs of \$50 per foot have escalated to \$70 per foot in constant 1973 dollars because of deeper and more difficult drilling attempted. These development and production expenditures will, in general, be net additions to the regional economy and stimulate a wide range of local businesses as well as material supplies. The power plant building stage, in contrast, will substitute for other types of generating plant investments, although it will change the localized impact within the region.

Cumulative geothermal investment, including all drilling and power plant costs, is projected at \$95 billion by 2000. This estimate assumes that present average investment costs of around \$250 per installed kilowatt will gradually rise to about \$500 in constant 1973 dollars by the end of the century as more expensive technologies and labor are employed to utilize high-salinity brines, lower temperature fluids, geopressured resources, and hot dry rock in an environmentally acceptable way. The effects of these factors causing increased costs will more than offset economies affected by exploration, drilling, and equipment design improvements.

This estimate of \$500 per kilowatt in 2000 was derived through Trend Impact Analysis (TIA), a computer program for combining trend extrapolation with human judgment on the probabilities of certain events occurring which would divert the trend. (See Appendix F.) Figure 4.2.6 lists forecasted events which could be expected to impact on the current approximate geothermal cost of \$250 per kilowatt, the probabilities of their occurrence by 1995, the time for the maximum impact to be felt if the event occurs, and the maximum percentage impact on the base trend. (The program also includes probabilities for earlier years.) Figure 4.2.7 shows the range of costs which could occur depending on where the forecasted events come into effect. The most significant result of the analysis is that despite the discrepancy between the possibility of costs as high as almost \$600 and as low as \$250 in the 1990's, depending on the timing of the impacts, all three trend lines are converging on the central estimate of \$500 by the year 2000 as almost all events have exerted their maximum impact on the base trend.

Even at \$500 per kilowatt, geothermal electricity is likely to be less expensive than other energy sources; capital costs of installations utilizing other fuels are expected to rise commensurately because of increased costs of construction materials, equipment, labor, capital, pollution control, and siting, thereby preserving the cost advantage which geothermal resources currently present.

For example, nuclear power plants which cost \$200 per kilowatt in 1966 are projected to cost about \$750 per kilowatt by the mid-eighties, and will continue to rise thereafter about 1.5 percent per year (constant 1973 dollars). About 85 percent of these capital costs represent construction materials, equipment, and labor together with the financial charges of the long construction schedule.[37]

The following sections detail the many enterprises which will participate in and benefit from this heavy spending program. The process starts with the developer, continues through the exploration and drilling stage, and culminates in power production.

Exploration and Drilling Phase

The pioneers in geothermal development, as in the oil and gas industry, have been small entrepreneurial companies which took early leases on private lands. As belief in the potentiality of the resource became more widespread, however, and the oil crisis spurred the search for energy in any form, large oil companies began to show interest in acquiring a stake in the geothermal industry. Several of the developmental efforts now being made on private lands are joint projects of small geothermal developers or land companies, which held the original leases, and major oil companies, which have more extensive financial resources and which may also hold adjacent leases.

Unitization of adjoining lands in a geothermal field is usually necessary for economic viability of the project. Since the energy must be sold on the spot, competing nearby wells are wasteful. Greatest efficiency and profit can be made by planning the least number of wells necessary to develop a whole field and using a single management. The Geothermal Steam Act permits such unitization, and proposed Congressional legislation for geothermal financial incentives encourages it. Therefore, it appears that as commercialization of the resource accelerates, the market may be increasingly dominated by large enterprises or

SUMMARY OF GEOTHERMAL DEVELOPMENT PARAMETERS*

PARAMETERS	1985	2000
NUMBER OF FEET DRILLED/YR. (1000'S)	4,000	40,000
NUMBER OF RIGS/YR.	150	1,500
MANPOWER IN DRILLING (MEN/YR.)	2,500	25,000
DOLLARS NEEDED FOR DRILLING/YR. (MILLIONS)	200	2,800
CUMULATIVE NUMBER OF WELLS DRILLED	2,500	68,000
CUMULATIVE GEOTHERMAL INVESTMENT (BILLIONS)	2.2	95.0
RESOURCE DEVELOPMENT RATE (MWE/YR.)	2,000	20,000
CUMULATIVE RESOURCES DEVELOPED	7,000	190,000
RESOURCES AVAILABLE FOR DEVELOPMENT	10,000	200,000

*RESOURCE DEVELOPMENT FIGURES ARE OUTPUT OF MODEL DESCRIBED IN SECTION 3. DRILLING AND INVESTMENT ESTIMATES ARE DERIVED FROM OPERATING EXPERIENCE IN STEAM AND HOT WATER PLANTS, FROM ECONOMIC ANALYSES IN THE LITERATURE, AND FROM TREND IMPACT ANALYSIS. ONLY CONJECTURES CAN BE MADE AT THIS TIME ON DRILLING PARAMETERS FOR HOT DRY ROCK. IT IS ASSUMED THAT MEGAWATT CAPACITY PER WELL WILL BE HIGHER THAN FOR HOT WATER BUT THAT DRILLING WILL BE DEEPER, SLOWER, AND MORE EXPENSIVE.

Figure 4.2.5

FORECAST	ESTIMATED PROBABILITY BY YEAR SHOWN		YEARS TO FIRST IMPACT	YEARS TO MAXIMUM IMPACT	MAXIMUM IMPACT (PERCENTAGE)
EXPLORATION, DRILLING, AND EQUIPMENT DESIGN IMPROVEMENTS DIMINISH COSTS BY 20%.	.80	1995	0	3	-10
AVERAGE DRILLING DEPTH INCREASES BY A FACTOR OF 1.5.	.50	1995	0	1	15
TIME TO INSTALL GEOTHERMAL PLANTS INCREASES BY 30%.	.60	1995	0	1	15
COST INDEX OF FINISHED EQUIPMENT AND MATERIALS DOUBLES.	.90	1995	0	3	15
INCREASINGLY SEVERE ENVIRONMENTAL REQUIREMENTS ADD 20% TO CAPITAL COSTS.	.50	1995	0	3	20
LABOR COSTS INCREASE TO 1.25 OF CURRENT VALUE.	.80	1995	0	3	25
AVERAGE RESOURCE QUALITY DIMINISHES TO 75% OF CURRENT VALUE.	.40	1995	0	1	25

Figure 4.2.6 EVENTS USED IN TREND IMPACT ANALYSIS OF CAPITAL COSTS OF GEOTHERMAL OPERATIONS

Figure 4.2.7 FORECAST OF CAPITAL COSTS OF GEOTHERMAL OPERATIONS (IN 1974 DOLLARS PER KILOWATT)

consortia. As the prime example of this, The Geysers is unitized with Union Oil Company managing property owned by Union, Magma Power Co., and Thermal Power Co.

The bonus bidding system, by requiring prepayment, also acts in favor of larger, better financed companies. In the recent competitive bidding for KGRA units in California, six out of nine successful bidders were large oil companies. Non-competitive lease applications, however, show a wider range of participants. Included among the first month's (January 1974) applications were oil companies, geothermal companies, a State university, a rural electrical cooperative, and a number of individuals. As in the oil industry, there will probably always be a place for the small wildcatter who is willing to explore in less proven or smaller areas.

As developers enter the exploration and drilling phase, they utilize the resources of a large number of contractors and suppliers. In some cases the activities and materials used in geothermal development and in the oil and gas industry are identical; in others, some modifications are required; but in general, the same support companies service both geothermal and oil and gas operations.[38]

For instance, there are now about a half dozen companies offering geophysical services, all of whom had prior mining or oil experience. Shallow-well drillers engaged in exploratory activities are interchangeable with the oil industry, and laboratories utilized for geothermal chemical analysis are already existing enterprises. The effect, therefore, is not the creation of a large number of new companies, but expanded opportunities for those in allied fields. Regulatory requirements lead to employment of many specialists such as environmental impact consultants and, of course, staffs for government regulatory agencies.

Major drilling contractors hired after the shallow exploratory stage are also interchangeable with the oil industry. For this reason, the supply of rigs and materials available for geothermal drilling will be affected by demand in the oil industry, and vice versa. The recent surge in oil and gas exploration has caused shortages of tubing and casings which are a delaying factor in geothermal drilling. As geothermal development accelerates, it can be expected to contribute to the demand for rigs and materials. This may extend short term material shortages, although in the longer term, the additional requirements of geothermal activities lie within reasonable industry expansion potential if sufficient incentive is perceived.

There are today about 1600 drill rigs operating in the oil and gas industry. About a ten percent expansion over this total level would be required by 1985 to accommodate geothermal demand, and almost 100 percent by 2000. In terms of current production, about a 15 percent annual increase over today's production level of 80 to 100 rigs a year would be necessary to accommodate the additional geothermal demand by 1985, and doubled production would be necessary in ensuing years.

A commensurate increase would be required in materials production. Higher prices may be necessary to encourage this production, but as the market is defined and proven, field supplies can be expected to be forthcoming. Imports of casing and tubing from Europe have recently been stimulated, for instance, by willingness of customers to pay prices higher than those charged by domestic steel mills. Continuation of this trend in the absence of adequate domestic capacity, however, would adversely affect the balance of trade.

The growing utilization of rigs for geothermal drilling will contribute to the growing prosperity of the independent drilling industry. Until revitalized by the sudden surge in oil prices, the industry had been in a downtrend since 1956. Many former workers had left the occupation because of limited opportunities. Drillers are now conducting crew training programs and the geothermal demand will add to employment in the field. Around 2500 persons can be expected to be employed in geothermal drilling in the mid-eighties and up to 25,000 by 2000. These will be transient crews for the most part, except for those permanently employed in drilling replacement wells at established large-scale fields. Therefore their impact on the economy of a particular location will be temporary, although sizeable, particularly in rural areas.

Many auxiliary suppliers and services will also benefit from the drilling phase of development. Manufacturers of bits, valves, drilling muds, control devices, and other drilling equipment and supplies will feel increased demand along with companies making drill pipe and line pipe. Well logging services will be utilized. A number of specialty services will also be needed, such as magnaflux teams to coat casing with powder. In this stage some devices will be required which are unique to geothermal activities, such as new types of wellhead sound mufflers. R&D activities will be engendered for these specific items and for improvements in various aspects of deep drilling at high temperatures.

Local and regional services will be temporarily affected by large-scale drilling. Grading contractors will be heavily involved, as well as vacuum truck companies to haul materials and waste. Craft unions will enter the picture through needs for carpentry and plumbing. A wide range of services will be called upon, such as printers, motel operators, airlines, and rental cars.

Robert Greider of Chevron Oil Company has prepared an economic analysis, shown in Figure 4.2.8, of the costs associated with developing a 250-275 MWe hot water geothermal field.[39] He considers this size the minimum which can support the exploration risk, the field development investment, and the charges for time value of capital invested while waiting for revenue to be generated. In his example, total exploration costs amount to \$8 million. This figure is based on the assumptions that one out of four land areas of interest acquired will be judged worthy of drilling, that only one out of four of the exploratory wells drilled will show enough promise to run pipe and complete for more extensive testing, and that in turn, only one out of four of these completed wells will locate a field of the minimum size to be commercially viable. To develop a producing field with 50 producing wells and 25 injection disposal wells will cost up to \$15 million, bringing the total surface and subsurface capital investment costs to a range of \$21 to \$24 million. Figure 4.2.9 shows Greider's model of how such an investment could generate a rate of return of 13.7 percent with a payment period of 7.3 years if the purchaser of the geothermal energy pays 4.8 mills per kilowatt hour. He emphasizes that a higher rate of return is necessary for geothermal exploration and development than for more conventional fuels because of greater uncertainties and higher risks involved.

EXPLORATION	
GEOLOGY:	
SALARY, OFFICE, AND FIELD EXPENSE	\$3,000 TO \$4,000 PER MONTH
GEOCHEMISTRY:	
GEOLOGIST, ASS'T., VEHICLE, AND ANALYSIS	\$10,000 TO \$14,000 PER MONTH
GEOPHYSICS:	
GRAVITY	\$10,000 PER MONTH
MAGNETICS	\$5.00 TO \$10.00 PER SQUARE MILE
MICRONOISE	\$10,000 TO \$15,000 PER MONTH
RESISTIVITY	\$10,000 TO \$20,000 PER MONTH
TEMPERATURE SURVEYS	\$1.50 PER FOOT TO 500 FEET
LAND ACQUISITION:*	
WILDCAT	\$45,000 TO \$60,000 PER PROSPECT
SEMI-DEVELOPED AREA	\$1.00 PER ACRE BONUS
DEVELOPED AREAS	\$5.00 TO \$10.00 PER ACRE BONUS
PERSONNEL	\$1,000 PER ACRE BONUS
	\$65.00 TO \$130.00 PER DAY
DRILLING	
SEDIMENTARY SECTION	
EXPLORATORY WELL TO 5,000 FEET	\$20.00 TO \$30.00 PER FOOT
COMPLETE WITH CASING	\$10.00 TO \$15.00 PER FOOT
IGNEOUS INTERBEDS AND REMOTE AREAS	
EXPLORATORY WELL TO 6,000 FEET	\$30.00 TO \$60.00 PER FOOT
COMPLETE WITH OPEN HOLE IN FRACTURED RESERVOIR	\$8.00 TO \$15.00 PER FOOT
SUMMARY OF COSTS:	
AREA OF INTEREST	\$75,000 TO \$95,000
FOR ONE DRILLABLE AREA FOUR AREAS WILL BE WORKED	\$300,000 TO \$380,000
ONE AREA OUT OF SIXTEEN DRILLED FINDS 250,000 KW FIELD	
TOTAL EXPLORATION COSTS	\$8,000,000
DEVELOPMENT	
50 PRODUCING WELLS	\$7,500,000 TO \$10,000,000
25 INJECTION WELLS	\$3,500,000 TO \$5,000,000
TOTAL SURFACE AND SUBSURFACE CAPITAL INVESTMENT COSTS	\$21,000,000 TO \$24,000,000
	(INCLUDES EXPLORATION COSTS)
OPERATING	
ESTIMATED OPERATING EXPENSES, TAXES, AND ROYALTY FOR 35-YEAR FIELD LIFE	\$75,000,000 TO \$80,000,000
*THE AVERAGE BONUS AT THE JANUARY 1974 FEDERAL GEOTHERMAL LEASE SALE WAS \$290 PER ACRE.	

SOURCE: GREIDER, ROBERT, "ECONOMIC CONSIDERATIONS FOR GEOTHERMAL EXPLORATION IN THE WESTERN UNITED STATES,"
GEOTHERMAL RESOURCES COUNCIL BULLETIN, VOL. 3, NO. 3 (MAY/JUNE 1974).

Figure 4.2.8 ESTIMATED COSTS FOR EXPLORING AND DEVELOPING A 250,000 kW GEOTHERMAL HOT WATER FIELD

ECONOMIC MODEL	
EXPLORATION PROGRAM THROUGH PRODUCTION 275 MW FUEL SUPPLY	
INCLUDES ALL GEOLOGICAL, GEOPHYSICAL, AND LAND EXPENDITURES REQUIRED FOR DRILLING SIXTEEN PROSPECTS TO DISCOVER ONE FIELD THAT CAN MEET THE REQUIREMENTS FOR THIS SIZE OF PRODUCTION.	
1. PRODUCTION RATE WILL BE THE AVERAGE OF COMPLETED WELLS AT CERRO PRIETO, MEXICO.	
2. PRODUCING WELLS SPACED 10 ACRES APART. INJECTION WELLS ON FIELD PERIPHERY.	
3. TEN PRODUCING WELLS AND FIVE INJECTION WELLS REQUIRED FOR EACH 55 MW TURBINE.	
4. 80% PLANT FACTOR, 90% PRODUCING WELL FACTOR, AND 20% STANDBY CAPACITY.	
5. 10% MAXIMUM ROYALTY EXPENSE.	
6. MINERAL AND PRODUCTION TAXES ARE 6% OF GROSS WORKING INTEREST INCOME.	
7. 22% DEPLETION CREDIT.	
DEVELOPMENT TO 275 MW	
4.8 MIL PER KWH	
INVESTMENT (\$000)	\$20,000 TO \$24,000
OPERATING EXPENSE, TAXES, & ROYALTY (\$000)	\$75,000 TO \$80,000
YEARS TO COMPLETE PAYOUT	7.3 YEARS
RATE OF RETURN	13.7%
NET PROFIT PER YEAR AFTER PAYOUT (\$000)	\$3,820
THE PAYOUT TIME MAY BE DECREASED TO 6.4 YEARS, AND RATE OF RETURN INCREASED TO 17%, IF (1) THE PRICE OF FUEL IS INCREASED TO 5.6 MILS PER KWH GENERATED, (2) THE DRILLING SCHEDULE OF THE FIELD IS ADJUSTED TO ACTUAL MODULE GENERATING PLANT COMPLETION, AND (3) MINERAL AND PRODUCTION TAXES ARE HELD TO 5% OF INCOME.	

SOURCE: GREIDER, ROBERT, "ECONOMIC CONSIDERATIONS FOR GEOTHERMAL
EXPLORATION IN THE WESTERN UNITED STATES," GEOTHERMAL
RESOURCES COUNCIL BULLETIN, VOL. 3, NO. 3 (MAY/JUNE 1974).

Figure 4.2.9

Generating Stage

The drilling phase of development in general brings a increase to the regional economy and to the equipment, contracting, and service firms involved. In contrast, the production and generating stage is probably in large part a substitution for other forms of generation and equipment. It does, however, require more equipment unique to the resource and tailored to the specific requirements of each producing area. It will involve expanded research and development on concepts, materials, and equipment to utilize fluids or steam of varying temperatures and composition.

The pattern which has been set at The Geysers is for the developing and/or producing companies to sell steam energy to the utility company on a royalty basis for units of heat supplied. The utility builds and operates the steam-electrical generating facilities. Unless public utility regulations are changed to allow other types of companies to sell electricity, this pattern will probably be followed in future developments.

The actual construction of the plant and transmission lines will provide temporary business for a variety of contractors and their suppliers. This work can be considered a substitute for construction of other types of power plants to use other fuels, although it will probably be in a different location and built in smaller units of 50 to 150 MW. It is probable that some of the same large regional contractors would be involved, but smaller local businesses, depending on their availability in the area, would probably benefit.

Sales of generating equipment to utilize geothermal heat will, in general, substitute for provision of conventional types of equipment, and will probably transfer business from one division to another of large equipment manufacturers or create new business for specialty manufacturers. To the extent that geothermal heat powers capacity that would not otherwise be built, there would be an increase in equipment sold. The extent of economic gains or losses will depend on comparative costs of the competing equipment.

Until recently, turbines used at The Geysers were of Japanese manufacture, but a new 60 and a 135 MWe turbine will be furnished by General Electric Company. [40] The policy followed by domestic manufacturers appears to be to wait until commercial utilization is assured before developing specific geothermal equipment. Steam equipment is now in that category but hot water, hot dry rock, and geopressure are not. Only after small experimental plants are built to test custom equipment and the process appears economically feasible can U.S. manufacturers be expected to produce geothermal equipment on a commercial scale.

As this commercial development evolves, foreign markets are likely to offer promise along with the domestic one and may eventually turn out to be larger. American manufacturers are not expected to compete heavily in Common Market countries or in Japan, but instead in third world countries which do not have equipment manufacturers of their own. [41] The Philippines, for instance, are now in the process of taking bids for geothermal equipment and Iceland is considering building a geothermal electrical plant. Thus the overall worldwide development of geothermal resources is likely to result in a net increase in business for domestic generating equipment manufacturers.

Summary of Business Impacts

The categories of impact discussed in this section are displayed in Figures 4.2.10, 4.2.11, and 4.2.12. These present the top two levels of the relevance tree section on the impacts of geothermal energy on business. The lower levels of the tree are included in Appendix D.

Figure 4.2.10

Figure 4.2.11

Figure 4.2.12

REFERENCES

- [1] Schurr, Samuel H., et al., Energy in the American Economy (Baltimore, Md.: Johns Hopkins Press, 1960).
- [2] Personal communication, William Pritsky, the Aluminum Association, New York, N.Y., 1974.
- [3] Personal communication, B. Caldwell, Amax Corporation, New York, N.Y., 1974.
- [4] Personal communication, Richard Bowen, Oregon Department of Geology and Mineral Industries, 1974.
- [5] Ross, S. H., "Geothermal Potential of Idaho," Geothermics, Special Issue 2 (1970).
- [6] Personal Communication, Noel Clark, Nevada Public Service Corporation., 1974.
- [7] Personal Communication, Carl McCulloch, Southern Pacific Land Company, San Francisco, California, 1974.
- [8] U.S. Department of the Interior, Geothermal Resource Investigations, Nevada, 1973.
- [9] Lindal, Baldur, "Industrial and Other Applications of Geothermal Energy," Geothermal Energy (Paris: UNESCO, 1973).
- [10] U.S. Department of Commerce, Statistical Abstract of the U.S., 1973.
- [11] Bond, B. J., et al., "TVA Projects--Beneficial Uses of Waste Heat," paper presented at the National Conference on Complete Water Re-use, Washington, D.C., April 23-27, 1973.

- [12] Personal communication, Ralph Pitman, Long Island Oyster Farms, Inmont Corp., New York, N.Y., 1974.
 - [13] Personal communication, L. C. Weber, Research Department, Northern States Power Company, Minneapolis, Minnesota, 1974.
 - [14] Personal communication, Dr. Leonard Boyd, Agricultural Experiment Station, University of Minnesota, St. Paul, Minnesota, 1974.
 - [15] Personal communication, Leonard Bettinger, National Greenhouse Association, 1974.
 - [16] Personal communication, B. J. Bond, Division of Agriculture Development, TVA, Muscle Shoals, Alabama, 1974.
 - [17] Personal communication, A. E. Mercker, Vegetable Growers Assoc. of America, Washington, D.C., 1974.
 - [18] Personal communication, Pat Redding, Horticultural Research Institute, Washington, D.C., 1974.
 - [19] Personal communication, Russell V. Stansfield, Warm Water Utilization, Northern States Power Company, Minneapolis, Minnesota, 1974.
 - [20] Personal communication, Dr. Charles Wilson, Shadetree and Ornamental Plant Lab, ARS, U.S. Department of Agriculture, Delaware, Ohio, 1974.
 - [21] Bond, B. J., et al., "Uses of Power Plant Discharge Water in Greenhouse Production," paper presented at the conference on the Use of Wastewater in the Production of Food and Fiber, Oklahoma City, Oklahoma, March 5-7, 1974.
 - [22] Personal communication, William Ogle, geothermal consultant, Anchorage, Alaska, 1974.
 - [23] Personal communication, Edwin Schlender, Raft River Electric Cooperative, Malta, Idaho, 1974.
 - [24] Personal communication, Porter Briggs, Catfish Farmers of America, Little Rock, Arkansas, 1974.
 - [25] Personal communication, Michael Costagna, Virginia Marine Institute, Newport News, Va., 1974.
 - [26] Personal communication, Paul Kueser, Westinghouse Electric Company, Pittsburgh, Pennsylvania, 1974.
 - [27] Personal communication, Dr. Robert Shlessor, Bodega Marine Labs, University of California, Bodega Bay, California, 1974.
 - [28] Personal communication, Everett A. Tolley, Shellfish Institute of North America, Wash., D.C. 1974.
 - [29] Forecasts from the Japanese Delphi, Report 21-01-04 (Glastonbury, Conn.: The Futures Group, 1971).
 - [30] "Down on the Fish Farm: A Protein Industry Goes Into Production," New York Times (December 9, 1973).
 - [31] Einarsson, Sveinn S., "Geothermal District Heating," Geothermal Energy (Paris: UNESCO, 1973).
 - [32] Personal communication, Eric Shuster, Department of Natural Resources, State of Washington, 1974.
 - [33] Personal communication, Dr. Jay Kunze, Reactor Technology and Geothermal Project Branch, Aerojet Nuclear Company contract under USAEC, Idaho Falls, Idaho, 1974.
 - [34] U.S. Department of the Interior, Geothermal Resource Investigations (Washington, D.C.: Bureau of Reclamation, 1972).
 - [35] Cameron, Eugene (ed.), "The Mineral Position of the United States, 1975-2000" (Madison, Wisc.: University of Wisconsin Press, 1973).
 - [36] Personal communication, M. K. Fulchur, Bureau of Reclamation, Boulder City, Nevada, 1974.
 - [37] Keat, M. F., "Let Us Be Realistic About Our Energy Future," Public Utilities Fortnightly (June 6, 1974).
 - [38] Personal communication, David Anderson, California Division of Oil and Gas, Sacramento, California.
 - [39] Greider, Robert, "Economic Considerations For Geothermal Exploration in the Western United States," Geothermal Resources Council Bulletin, Vol. 3, No. 3 (May/June 1974).
 - [40] Personal communication, John Finney, Pacific Gas and Electric Company, San Francisco, Calif., 1974.
 - [41] Personal communication, R. W. Snyder, Market Development, General Electric Company, Lynn, Massachusetts, 1974.
- The following are other references, not numbered in the text, used as background for this section.
- Robson, Geoffrey R., "Geothermal Electricity Production," Science, Vol. 184 (April 19, 1974).
- "Development and Use of Geothermal Energy," Geothermics, Vol. 2 (March 1973).
- Shcherbakov, A. V., and V. I. Dvorov, "Thermal Waters as a Source for Extraction of Chemicals," Geothermics, Special Issue 2 (1970).
- Patterns of Energy Consumption in the U.S., Office of Science and Technology, Executive Office of the President, Washington, D.C., January 1972.
- Barnea, Joseph, speech, Proceedings of the National Conference on Geothermal Energy (Riverside, Calif.: University of California, 1973).
- Austin, A. L., et al., The Total Flow Concept for Recovery of Energy from Geothermal Hot Brine Deposits, (Livermore, Calif.: University of California, Lawrence Livermore Laboratory, 1973).
- "A Grim Forecast for Steel Users," Business Week (May 11, 1974).
- Geothermal Hot Line, Division of Oil and Gas, State of California, April 1974.
- Personal communication, W. H. Seaman, Southern California Edison Company, Rosemead, California, 1974.

4.3 Macroeconomic and Macrosocietal Impacts

Introduction

This section will deal with net economic and societal effects of geothermal development at the national level and with regional and local effects as well. Figures 4.3.1, 4.3.2, and 4.3.3 show the top two levels of the relevance tree pertaining to this impact category.

The influence of the development of geothermal energy on the national economy and society will be channeled in large part through substitution effects engendered by regional and local impacts. Since capital and materials markets are generally national in scope and American labor is highly mobile, energy-induced changes in one particular region in these factors, along with the attendant social consequences, affect the national picture, albeit with a diluted and often time-lagged impact.

Effect on the National Economy

In order to assess the impact of alternate geothermal development programs on the national economy, it is necessary first to place them within the framework of the overall energy supply-demand situation and then to relate this energy balance to national economic indicators. It has been the usual procedure in making projections which are related to economic factors to assume a basic continuing growth in Gross National Product (GNP), usually at about the 4 percent level. Historical data show a close connection between GNP and energy consumption, however, and it is apparent that recent disruptions and shortages in the energy market have the potential of limiting future GNP growth. Therefore, rather than relying on an exogenous assumption as to GNP growth, this section attempts to estimate the relationship of energy availability to GNP growth and the extent to which different levels of development of geothermal energy could affect any energy-connected limitations on growth.

As the foundation for this procedure, it was necessary to employ some sort of projection model of energy variables to test the effect of differing assumptions or policies pertaining to geothermal development on the overall economy. As this study began, no really comprehensive model existed which could link energy availability to economic variables, although a proliferation

of such studies was underway. Most available models reviewed for possible use[1-13] covered only limited special-purpose domains: some dealt with only one form of energy, such as oil or electricity; others covered only particular geographical areas. Demand is the factor most commonly covered; fewer models include the supply side, with many merely assuming that the amount demanded will be available. Only a few models consider supply-demand interaction, particularly from the point of view of any dynamic relationship or with consideration of the effect of regulatory controls, and only a few include interfuel competition. A most important omission in most existing energy forecasting tools is the role of price.

Modeling approaches used in the various energy studies include input-output, econometric, linear programming, and structural methods, and, in a number of cases, combinations of these. Structural models do not use formal econometric or optimizing techniques but instead develop a set of procedures with which to evaluate the results of alternative sets of initial assumptions over a simulated time interval. This approach is best typified in the widely used energy report of the National Petroleum Council[3].

Figure 4.3.1

Figure 4.3.2

Figure 4.3.3

It was decided, in the absence of any appropriate operational energy mode, to utilize a structural approach in assessing the macroeconomic consequences of various levels of geothermal energy developments, assuming that they constituted net additions to the nation's energy supply. As will be explained in detail below, a level of sustainable growth in GNP was estimated for several hypothetical levels of energy availability through the use of an algorithm. The algorithm was based on historical and projected data pertaining to the ratio of energy consumption to GNP. The results of this analysis are not designed to provide forecasts of absolute levels, but rather to show the macroeconomic consequences of alternative assumptions about geothermal energy availability.

Relationship of Energy Consumed to GNP. Throughout the world, there has been a pronounced positive correlation between GNP growth and energy consumption. The ratio of Btu consumed per dollar of output, however, varies from country to country. The United States is on the high end of the distribution, with a ratio about 17 percent above the mode.

Changes in the energy/GNP ratio have an important bearing on the future of energy consumption. A rising ratio means that energy consumption is increasing at a faster rate than GNP, while a falling ratio indicates that it is increasing at a lesser rate. Since the early 1920's the U.S. energy/GNP ratio has been in a falling trend, as more intensive use of energy was offset by increased technical efficiency.[14] From 1966 through 1970 the trend reversed itself and the ratio moved steadily upwards. This had alarming implications for the future, and there has been much speculation that if the rise continued it would lead to even more drastic energy shortages than have been predicted. In 1971 and 1972, however, the ratio resumed its downward direction. Both the National Petroleum Council and the Bureau of Mines of the U.S. Department of the Interior[4] anticipate that the ratio will continue to fall in the future.

If the energy/GNP ratio could be projected, it would be possible to arrive at an upper level of GNP for any assumed level of energy availability. Trend Impact Analysis (Appendix F) was used to project the energy/GNP ratio based on the historical trend of the energy/GNP ratio from 1947 through 1972 and the set of speculative future events shown in Figure 4.3.4. The judgments shown were provided by the study team. The curves produced are shown in Figure 4.3.5. The median is somewhat below projections made by the Bureau of Mines before the 1973 energy crisis, probably because of the energy-conserving effects of the forecasted events.

If the ratio presented in Figure 4.3.5 is divided into the level of geothermal energy expressed in Btu, the marginal effect of geothermal energy on GNP can be approximated. Figure 4.3.6 presents this estimate. Assume for a moment real GNP grows at just 3 percent per year; in this case GNP in 1985 will be \$1612 billion and GNP in 2000 will be \$2510 billion expressed in constant 1970 dollars. Figure 4.3.6 indicates that the energy available from geothermal sources could "swing" an energy-limited 1985 GNP by \$5 to \$18 billion, or up to about one percent, and an energy-limited 2000 GNP by \$156 to \$231 billion, or 6 to 9 percent.

Relationship of Unemployment to GNP. It is very difficult to derive estimates of components of the economy by working backwards from a given level of GNP. Econometric models of the economy are constructed of interrelated equations involving a number of exogenous variables and there are an almost infinite number of combinations of variables which can result in the same total GNP. In the same way, differing levels of unemployment can exist with the same total GNP, depending on such factors as the size and structure of the labor force, differing growth rates of varying sectors of the economy, and the types of labor required.

Although it is impossible to assign an absolute unemployment rate to a given level of GNP, a relationship can be identified between rates of change of GNP and unemployment. By conducting a simple regression analysis, a fairly high correlation from 1947 to the present was demonstrated between the annual percentage change in GNP and the annual percentage point change in the unemployment rate. This linear trend line is defined by the following equation:

$$\text{Percentage point change in unemployment} = 1.392 - (.344 \times \text{percentage change of GNP})$$

The equation has an r^2 of .73, indicating that about three-quarters of the variations in unemployment are explained by the percentage change in GNP. The standard error of estimate is .62, meaning that two-thirds of the estimated unemployment rates will be within a range of plus or minus .62 percentage point of the actual rate, and 95 percent within a range of 1.24 points. Figure 4.3.7 compares actual unemployment rates, the rates generated by applying the equation to the 1947 rate and proceeding from there, and the rates generated by applying the equation to each actual previous year's unemployment.

EVENT	ESTIMATED PROBABILITY BY YEAR			YEARS TO FIRST IMPACT	YEARS TO MAXIMUM IMPACT	MAXIMUM IMPACT (PERCENTAGE)
	1976	1985	2000			
GENERAL ACCEPTANCE OF A CONSERVATION ETHIC REDUCES DEMAND FOR ENERGY BY 15%.	.10	.20	.30	1	2	-15
COST OF ALL FUELS INCREASES BY 40%.	.30	.50	.85	0	1	-10
WIDESPREAD INTRODUCTION OF HIGHER EFFICIENCY (25%) MANUFACTURING FACILITIES.	.00	.30	.60	0	0	-3
HORSEPOWER AND WEIGHT LIMITS PUT ON ALL NEW AUTOMOBILES.	.10	.30	.50	1	10	-3
10% EFFICIENCY IMPROVEMENTS FOR 25% OF ALL APPLIANCES.	.00	.20	.50	0	0	-1
AVERAGE FAMILY INCOME REACHES \$15,000 PER YEAR (1970 DOLLARS).	.00	.50	.90	0	1	3

Figure 4.3.4 EVENTS USED IN TREND IMPACT ANALYSIS OF ENERGY/GNP RATIO

SOURCE FOR HISTORICAL ENERGY/GNP RATIO: BUREAU OF MINES, REVISED OCTOBER 1973.

Figure 4.3.5 FORECAST OF U.S. ENERGY/GNP RATIO

YEAR	GEOTHERMAL ENERGY (1012 BTU)		THOUSAND BTU/\$ GNP			MARGINAL EFFECT OF GEOTHERMAL ON GNP (BILLIONS OF DOLLARS)					
	BASE PROGRAM	ACCELERATED* PROGRAM	LOW	MEDIAN	HIGH	BASE PROGRAM			ACCELERATED PROGRAM*		
						LOW	MEDIAN	HIGH	LOW	MEDIAN	HIGH
1980	.26	.38	72.9	81.4	88.7	3.6	3.2	2.9	5.2	4.7	4.3
1985	.42	1.25	69.4	79.5	88.2	6.1	5.3	4.8	18.0	15.7	14.2
1990	1.34	3.33	67.8	77.5	86.1	19.8	17.3	15.6	49.1	43.0	38.7
1995	4.47	7.51	68.5	75.7	82.2	65.3	59.0	54.4	109.6	99.2	91.4
2000	12.17	15.97	69.0	74.0	78.1	176.4	164.5	155.8	231.4	215.8	204.5

*ACCELERATED PROGRAM IS ONE IN WHICH VIRTUALLY ALL TECHNOLOGICAL AND NON-TECHNOLOGICAL IMPEDIMENTS ARE REMOVED.

Figure 4.3.6 MARGINAL EFFECT OF GEOTHERMAL AVAILABILITY ON ENERGY-LIMITED GNP

Figure 4.3.7 UNEMPLOYMENT RATE BY YEAR (1947-1972)
(ACTUAL, BY TREND EXTRAPOLATION FROM
1947, BY TREND EXTRAPOLATION FROM
ACTUAL PREVIOUS YEAR)

This equation is presented graphically in Figure 4.3.8. It indicates that a 4 percent increase in GNP produces a 0.2 increase in the unemployment rate. For instance, if we already have a level of 5 percent unemployment, a yearly rise of 4 percent in GNP will increase unemployment to 5.02 percent. This would seem to be compatible with a recent study by the Stanford Research Institute [15] showing that a 4.2 percent yearly increase in GNP is necessary to keep unemployment at or below 5 percent.

Figure 4.3.8 RELATIONSHIP BETWEEN PERCENTAGE CHANGE IN GNP AND PERCENTAGE POINT CHANGE IN UNEMPLOYMENT

The slope of this curve can be obtained by differentiating the regression equation:

$$\frac{(\text{change in unemployment})}{(\text{change in GNP})} = -.344$$

Working with the data of Figure 4.3.6, it is possible to compute the marginal effect of geothermal energy on unemployment through its impact on raising the limits of GNP growth. This is shown in Figure 4.3.9. In utilizing the unemployment equation, the assumption must be made that the labor force will continue to grow at rates similar to those prevailing in recent years. The Bureau of Labor Statistics has recently estimated[16] that the labor force through 1980 will continue to grow at an annual rate of about 1.7 percent, about the same as the average annual rate for the 1960's. After 1980, the rate is expected to drop to 1.0 percent a year, which may make the unemployment estimate derived from the equation slightly high relative to GNP change.

The conclusions from the analysis are as follows:

- The development of geothermal energy is likely to have only a relatively slight impact in raising the limits to GNP growth imposed by energy restrictions and on accompanying unemployment levels until the mid 1990's, when effects could become significant.
- If conservation measures are relatively unsuccessful, as implied by a higher energy/GNP ratio, a base line geothermal program would furnish energy for \$156 billion of a \$2500

billion GNP (1970 dollars) by the year 2000; this increment is equivalent, in an energy-limited economy, to an unemployment level lower by about 2 percentage points than could otherwise be the case. An accelerated program would furnish \$204 billion, equivalent to a lowered unemployment level of about 3 percentage points.

If conservation measures are relatively successful, as implied by a lower energy/GNP ratio, a base line program would furnish energy for \$176 billion of a \$2500 billion GNP by the year 2000. This increment of GNP is equivalent to an unemployment rate lower by about 2 percentage points in an energy-limited economy. An accelerated program would furnish \$231 billion, equivalent to an unemployment level lower by about 3 percentage points.

As this report was being prepared, an energy model designed by Dale Jorgenson and Edward Hudson for Data Resources, Inc., under grants from the Ford Foundation Energy Policy Project and the National Science Foundation, became available[17]. This model takes a new approach in quantitative analysis of U.S. energy policy. It combines econometric modeling and input-output analysis to model the interplay between energy demand and supply and relates it to economic growth. Price, omitted in most other models, plays the dominant role. As energy prices rise, high price elasticities become evident and other production factors are substituted for energy. In order to incorporate the role of price, the traditional fixed input-output coefficients, which represent technological production patterns, are varied according to the prices of the production factors. Price increases are shown to induce energy conservation and substitution measures, and therefore GNP is not affected by energy shortages to the degree implied in the process described above which is based on a more static energy-GNP ratio. The major conclusion of the Hudson-Jorgenson model is that the economy is flexible enough to adapt to changing resource availabilities as defined through the price system and that therefore substantial reductions in energy use can be achieved without major damage to the economic growth rate. The validity of this thesis will hinge in large part upon current data still to be compiled on the actual effect of energy price rises on demand. The effect of price on energy consumption is not yet clear.

Effect on the Federal Budget. Another aspect of the effect of geothermal development on the national economy is the net impact on the federal budget, a major determinant of GNP. The proposed National Geothermal Energy Research Program submitted to the Office of Management and Budget in June 1974 by the Interagency Panel for Geothermal Energy Research[18] proposes spending \$430.2 million in the five years through 1979. The objective is to accelerate commercial geothermal production by the private sector through federally funded programs in resource exploration and assessment, environmental, legal and institutional research, experimental research plants, and advanced research and technology.

Rough estimates can be made to ascertain the monetary return to the Federal Government as the result of commercial geothermal development. Some income has already been generated by the bonus bidding for KGRA tracts in California in January 1974 and in Oregon in June 1974. The California sale brought \$6.8 million at an average of \$290.54 an acre and the Oregon sale (of one small tract) brought in \$13,000 at \$10.26 an acre. Three distinct geographical areas were involved in the California bidding, and brought markedly different

YEAR	CHANGE IN UPPER LIMIT OF GNP, IN PERCENTAGE						UNEMPLOYMENT CHANGES IN PERCENTAGE POINTS					
	BASE PROGRAM			ACCELERATED PROGRAM			BASE PROGRAM			ACCELERATED PROGRAM		
	LOW	MEDIAN	HIGH	LOW	MEDIAN	HIGH	LOW	MEDIAN	HIGH	LOW	MEDIAN	HIGH
1980	.3	.2	.2	.4	.3	.3	-.1	-.1	-.1	-.1	-.1	-.1
1985	.4	.3	.3	1.1	1.0	.9	-.1	-.1	-.1	-.4	-.3	-.3
1990	1.2	.9	.8	2.6	2.3	2.1	-.4	-.3	-.3	-.9	-.8	-.7
1995	3.0	2.7	2.5	5.1	4.6	4.2	-1.0	-.9	-.9	-1.8	-1.6	-1.4
2000	7.0	6.6	6.2	9.2	8.6	8.1	-2.4	-2.3	-2.1	-3.2	-3.0	-2.8

Figure 4.3.9 COMPUTATION OF MACRO IMPACT OF GEOTHERMAL ENERGY ON UNEMPLOYMENT

prices per acre. At The Geysers, land brought \$631 per acre, but tracts in Mono-Long Valley brought \$115 and at East Mesa, \$71. If we assume that future sales attract average bids of \$25 to \$50 an acre (with the Oregon sale indicating that bidders pay considerably less away from proven areas), the approximately 1.8 million acres of land currently identified as KGRA's could generate \$45 to \$90 million in bonus payments. This is equivalent to about one year's spending in the government research and development program.

When the commercial level is reached, however, royalty payments can be expected to exceed considerably the developmental expenditures. Working with the system dynamics model base projection of around 25,000 MWe capacity in the early 1990's, and 190,000 MWe by 2000, a 12-1/2 percent federal royalty on value of energy sold could range from \$130 million a year early in the decade to over \$1 billion annually by 2000. These estimates assume that: (1) about 70 percent of the development will be on federal land; and (2) energy will be sold at 15 mills per kilowatt hour (other energy costs can be expected to rise commensurately). Rent of \$1 per acre per year will also be collected on all leased federal land for the first five years of a lease and an additional \$1 per acre for each of the next five years. (Note that in addition to the 1.8 million acres of KGRA's, there are 58 million acres of Potential Geothermal Resource Areas with leasing potential.) Although not included in the estimates, any by-products, such as chemicals or desalinated water, would also be subject to royalty payments. Furthermore, income tax revenues will be augmented as corporations and individuals are benefited by increased geothermal activity. Thus in the long run, geothermal expenditures will result in a net surplus return to the Federal Government, resulting in an overall deflationary effect. It should be noted, however, that this net return would be reduced by losses to the government resulting from any decreased fossil fuel and uranium production on federal lands and connected income taxes.

National capital markets may also be benefited by substitution of geothermal energy for other sources. Since geothermal capital costs are expected to be lower than for alternate energy sources, demands for investment capital will decrease. For example, if the difference between the capital costs of geothermal and nuclear plants is \$250/KW by the year 2000 and, as indicated in Section 4.1, 117,000-149,000 MWe of nuclear power is displaced, capital savings of 29-37 billion dollars (1973 dollars) will result.

Effects on the Regional Economy

The effect of geothermal development on the economy will be much greater at the regional level than at the national level. Between the present and 2000 most geothermal activity will be concentrated in the eleven western states, the Gulf states if geopressed resources are tapped, and Alaska and Hawaii. If the relationship between GNP and energy postulated in our structural model continues, the availability of geothermal power in a region can help to prevent economic growth from being dampened by energy shortages. Even though in the national model a substitution effect was assumed, with the existence of geothermal energy in the West releasing other fuels for use in the remainder of the country, the region, and particularly its energy-intensive industries, will benefit from the easier accessibility and probably lower cost of a native source of energy. The northwestern states especially have become accustomed to abundant hydropower, but few hydro-expansion sites remain and the recent drought of 1973 pointed up the need for alternate fuels. California has encountered numerous nuclear power plant siting problems, and an indigenous energy source would make it easier to fulfill demand for electricity and maintain economic growth. Some areas in the mountain states are on the fringes of the power network emanating from population centers and experience intermittent outages. Reliability of service could be improved in these areas by a local geothermal generating station.

Although the regional economy would be benefited in this way by more abundant energy, the major discernible impacts will be in the nature of transfer benefits. This will be especially true in the case of power plant construction when geothermal installations substitute for fossil fuel or nuclear plants. The optimum size of a geothermal plant is around 100-200 MWe (although clusters totaling at least 250 MWe may be necessary to justify exploration costs) while the newer fossil fuel and nuclear plants typically have 1100 MWe capacity. Because geothermal plants are smaller and geothermal areas are often isolated, these installations will be widely dispersed.

In contrast to power plant construction, exploration and drilling activity and the support activities they stimulate will bring a net increase to the regional economic product, since regional production of geothermal resources can be expected to exceed any loss in regional production of the fossil fuels and uranium whose use it replaces.

Process heat applications will probably be a plus factor in the regional economy. Although some direct uses of geothermal heat will merely substitute for use of scarcer or more costly fuels, other uses will encourage expansion of existing industries or attract new businesses to the area, as discussed in Section 4.2. Thus new capital investment, plus the additional business generated through the multiplier effect, will contribute to the growth of regional GNP.

The development of geothermal energy will impact on the overall regional employment level most importantly through its salutary influence on energy availability, maintenance of economic growth, and attraction of new or expanded industries. Its specific additions to the working force will be heaviest toward the end of the century with respect to drilling manpower. As estimated in Section 4.2, drilling crew requirements to reach capacity of 190,000 MWe by 2000 should peak at about 25,000 men per year. Production and plant operating manpower requirements are minimal. The generating units at The Geysers are highly automated and currently employ under 40 persons. This number is expected by the utility to increase very little as additional units are added.[19] At any rate, power plant personnel are not net additions to regional employment since comparable numbers would be employed in other power plants in the absence of geothermal energy utilization.

Regional government income can be expected to show a net increase as geothermal development progresses. State government will collect rent and royalties on resources developed on state lands, and possibly royalties on private lands on which they have reserved mineral rights if court cases now pending rule that geothermal resources are mineral. State income taxes will be augmented through geothermal-connected business increases, and excise and sales taxes will be collected on material and equipment. The largest category of tax collection generated by geothermal activity within the region will be local ad valorem taxes on land and possessory interest in land, tangible assets, and steam or heat rights. A substantial part of these will not represent a net increase, but a transfer to geothermal areas of tax income from areas where fossil fuel or nuclear plants would have been built instead.

The impact of these dispersed tax collections will be great at the local level. Local tax bases in rural areas could be increased dramatically by geothermal activity on either private or public land. Since possessory interest on federal and state lands is subject to local property tax, counties or towns in effect can obtain the same income from installations on these lands as from those on private property. Thus areas which previously received no income from government land will be able to add them to their tax base.

The Geysers is now the largest single taxpayer in Sonoma County. In the 1974 fiscal year, taxes totaled approximately \$1 million.[20] This averages out to \$2500 per megawatt of production, and extrapolation would indicate that 190,000 MWe geothermal capacity by 2000 could result in returns in the neighborhood of \$475 million per year to local governments. This would be reduced to the extent that the generating plants are owned by non-taxable, publicly-owned utilities. In addition, areas with process heat applications would receive additional income from taxes on new industries or on increased land values occasioned by the availability of geothermal heat.

Macrosocietal Effects

On the macrolevel, the societal effects of geothermal development parallel the impact on GNP. If the geothermal contribution to energy supply helps to maintain economic growth, then as a corollary it helps to maintain current life styles based on abundant energy. These overall life styles are not discernably affected by whether the electric power on which they are so highly dependent is furnished through fossil fuel, nuclear, solar, or geothermal resources; it is the fact that abundant power is available which permits the existing standard of living to continue. A case can be made, of course, that this current standard is wasteful and that cutting energy usage could actually improve the quality of life. It must be recognized, however, that curtailment of energy either through limitation of use or higher prices could have a serious impact on lower-income groups who have fewer luxuries to eliminate and can least afford increased costs.[21]

There appears to be ample reason to expect that the relative rate of growth of electricity will be higher than the growth of energy as a whole. This is because any effort to reduce dependency on imported fuels will move the United States toward conservation measures and relatively greater usage of indigenous fuels: uranium and coal, primarily. These are most expeditiously utilized in production of electricity. Furthermore, many advanced energy systems are electricity-related: e.g. breeder, solar, fusion, and magnetohydrodynamic (MHD). The development of geothermal resources will promote this shift to electricity since it is also an indigenous resource and it helps to make electricity more abundant and, to a small degree, less costly. The potential macrosocietal impacts of this situation include: maintenance of mobility patterns through growth of electrified railroads and mass transit; improved potential for electric automobiles; growth of electric space heating; and continued growth in electric motor usage for thousands of tasks.

Aside from its general contribution to the standard of living, most of the specific societal impacts of the development of geothermal energy will evolve from the two significant characteristics previously mentioned: the small size of optimum installations and the location of resources in most cases in outlying areas. Figure 4.3.10 superimposes KGRA's upon a population density map of the eleven western states. With only a few exceptions, the geothermal areas are all located in countries with population densities of under 50 persons per square mile.

Development of geothermal sites will mean that a number of formerly isolated areas or small towns will have an increased industrial and tax base accompanied by only a small increase in population, since geothermal power installations and most process heat applications are not labor intensive. This can make smaller towns more viable by improving community services and providing enough opportunities to prevent loss of population. Except in the few cases where unusually large resources are found and major industrial complexes are established, the impact will probably not be substantial enough to attract large numbers of strangers and change prevailing mores.

The transfer of generating facilities from large concentrated fossil fuel or nuclear plants to smaller, scattered units will avoid some of the political and environmental problems encountered in planning and siting

SOURCE: U.S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS; AND U.S. DEPARTMENT OF THE INTERIOR.

Figure 4.3.10 KGRA'S IN RELATION TO POPULATION DENSITY

large installations. It thus could help reduce social conflict and health hazards from pollution in areas where these plants would have been built. Because of lower capital requirements of the smaller plants, small private or publicly-owned utilities could be the purchasers of geothermal steam, rather than larger systems; this would contribute to local control of industrial growth.

There are a number of secondary demographic and cultural effects which may stem from the dispersed nature of the resource. Young people who might previously have moved to the cities may be motivated to remain by the moderate expansion of local community activities. The presence of opportunities for relatively inexpensive geothermal space heating and possibly the revival of interest in therapeutic bathing may provide an attraction for establishment of retirement communities.

It is also likely that health care may improve in geothermal areas as increased local government income makes possible greater contributions to regional hospitals. A similar effect will be felt on local and regional school systems since the school population will increase less, proportionately, than the tax base. Better health and school systems will be an element in retaining and attracting population and improving the quality of life.

In areas utilizing geothermal space heating, personal safety will be enhanced by the absence of conventional

heating system fire hazards. Personal safety may be somewhat diminished, however, by the increased opportunities for crime which accompany any economic expansion. These could range from increases in petty thievery accompanying gains in population to the more remote possibilities of sabotage by blowing up a geothermal well.

As an illustration of the changes which could be wrought in the life of a small town by the nearby discovery of a useful hot water geothermal field of moderate size, a hypothetical example was constructed of such a place. [22-25] This will not be a major geothermal installation or a new town, but a typical small-scale user. Assume that the town, population 2000, is located in an agricultural area producing sugar beets, potatoes, corn, wheat, with some cattle and dairy farms. A small greenhouse on the edge of town utilizes an old geothermal well, once the site of a health spa, to grow flowering plants. About 100 people are employed in several produce-crating companies, and about 300 in retail stores and businesses servicing the surrounding area. Another 50 are employed by the town, county, and school district. The tax rate is one of the highest in the county because of the low tax base of \$10 million. The county collects \$30 per thousand of valuation (at 100 percent assessment) and returns \$9 of this to the town on the basis of its assessed valuation and the size of its budget. The remainder goes for the support of the school district, the county administration, the regional hospital, and the community college.

When, through test wells, the potential of the geothermal field at the edge of town is evaluated to have at least the capability of supporting a 100 MWe power plant, there is some fear voiced by local inhabitants that the character of their rural life will be damaged by an influx of strangers. The prevalent view, however, is that the discovery will immediately benefit the town and provide needed tax revenue. It turns out, however, that neither opinion is entirely accurate. The full impacts of the discovery are not felt at once; it is ten years before they fully evolve.

Although the field is discovered in 1975, it is two years before the extent of the resource is proven by exploration and geological measurements to the satisfaction of the regional privately-owned utility. It then contracts with the geothermal developer to buy enough hot water on a mill per kilowatt hour generated basis to operate a 100 MWe plant. The generating plant is to be built in two 50 MWe stages. Plant construction takes three years and the facility itself is within the town limits although the large producing field is not.

During this time period drilling and construction activities bring anywhere from 20 to several hundred workers at one time into town temporarily. Some commute the fifty miles from the nearest city and others live in transient camps. Local retailers benefit from the business, although residents complain of construction noise, dirt, and traffic, and for the first time begin to lock their doors.

Since the largest part of the producing field is not within the corporate limits, its taxes go directly to the county, but the town reaps the generalized benefits of improved county and school district services. When the power plant is completed, about \$12,000,000 is added to the tax base of the town itself, more than doubling it. At the same time, overall land values in town begin to increase along with improved business activity and anticipation of further geothermal development. This optimism proves justified when a large food-processing company, impressed by the performance of

the power plant and evidence of long-lasting resources, announces that it plans to utilize geothermal heat in a new \$10 million canning plant employing 100 persons. Meanwhile, the existing greenhouse builds an addition and an enterprising local motel owner decides to capitalize on his location near the old spa by refurbishing his accommodations and building therapeutic bathing facilities plus a geothermally-heated swimming pool. Property very close to the producing field has lost some of its value, however, and owners of this property are leaders of the group of townspeople who want further development stopped. They cite the noise and odor of the installation, the changing character of the region, and the environmental consequences of improperly disposed-of geothermal fluids.

If these objections can be answered satisfactorily, the overall effect on the town could be quite beneficial. Trend-Impact Analysis (Appendix F) shows how these events could affect the growth of the town tax base through 2000. Figure 4.3.11 lists these events and assumptions about their probabilities of occurrence; Figure 4.3.12 shows the median forecast and the ranges of the upper and lower quartile. By 1985 it is likely that the tax base will triple, and then continue to rise slowly through 2000, assuming no other improvements are introduced.

In social terms this means that the town, by 1985, could offer more economic opportunities and more community amenities and services to its residents. The rise in town expenditures would be far behind the rise in revenues, since the increase in employment would not have been large enough to bring in sizable numbers of new residents with additional children or new homes requiring municipal services. Rather, local people would probably have been able to find work more easily and not as many young people would have left the area. The total tax rate would drop to \$20 per thousand, with both the town and county rates reduced. The county, profiting from its taxes on the geothermal field, could have moved to improve the local community college and hospital. Electric heating has gradually taken over as residents phased out their natural gas furnaces and there are plans afoot to utilize district geothermal heating and cooling for a new shopping mall. A feeling of optimism is prevalent, and although some of the townspeople are against any further development, the majority have voted to contribute town funds to a County Development Agency to attract new industries using geothermal process heat to the area.

This is an optimistic scenario, but one which is plausible, and given appropriate policies and favorable research results, likely. The experiences of Rotorua, New Zealand, Klamath Falls, Oregon, and Reykjavik, Iceland (see Section 4.6) serve as precursor examples.

FORECAST	ESTIMATED PROBABILITY BY YEAR			YEARS TO FIRST IMPACT	YEARS TO MAXIMUM IMPACT	MAXIMUM IMPACT (PERCENTAGE)
	1980	1985	1990			
100 MWE PLANT BUILT, ASSESSED AT \$12,000,000.	.75	.99	.99	0	1	+120
FOOD PROCESSING PLANT BUILT TO UTILIZE DIRECT HEAT, ASSESSED AT \$10,000,000.	.20	.90	.95	0	2	+100
RESIDENTIAL PROPERTY BASE INCREASES BY 10%.	.50	.95	.99	0	0	+10
EXISTING GREENHOUSE BUILDS \$250,000 ADDITION.	.30	.80	.90	0	0	+2.5
OLD HEALTH SPA REVIVED AT COST OF \$250,000.	.30	.50	.80	0	0	+2.5
RESIDENCES CLOSE TO PRODUCING FIELDS LOSE VALUE TOTALING \$200,000.	.90	.90	.90	0	0	-2

Figure 4.3.11 EVENTS USED IN TREND IMPACT ANALYSIS OF GEOTHERMAL TOWN TAX BASE

Figure 4.3.12 FORECAST OF TAX BASE FOR GEOTHERMAL TOWN

REFERENCES

- [1] Quantitative Energy Studies and Models, A State of the Art Review (Jenkintown, Pa.: Decision Sciences Corporation, 1973).
- [2] Searle, Milton F., Energy Modeling-Art-Science-Practice, Resources for the Future (Washington, 1973).
- [3] U.S. Energy Outlook, National Petroleum Council (Washington, 1972).
- [4] Dupree, W. and R. West, U.S. Energy Through Year 2000 (Washington: U.S. Department of the Interior, December, 1973).
- [5] Total Energy Resource Analysis (TERA) (Jenkintown, Pa.: Decision Sciences Corporation, 1973).
- [6] Herendeen, Robert A., An Energy Input-Output Matrix for the U.S. 1963; User's Guide (Champaign, Ill.: University of Illinois, Center for Advanced Computation, 1972).
- [7] EPA Energy Quality Model (Columbus, Ohio: Battelle Memorial Institute, 1973).
- [8] Reardon, W. A., An Input-Output Analysis of Energy Use Changes from 1947 to 1958 and 1958 to 1963 (Hanford, Washington: Battelle Pacific Northwest Laboratories, 1974).
- [9] Baughman, Martin L., Energy System Dynamics Model for Interfuel Competition (Cambridge Mass.: MIT, February, 1973).
- [10] Reference Energy Systems and Resource Data for Use in the Assessment of Energy Technologies (Associated Universities, Upton, N.Y.: April 1972).
- [11] Debanne, J. G., A Pollution and Technology Sensitive Model for Energy Supply - Distribution Studies (University of Ottawa, 1972).
- [12] Hoffman, K. C., A Linear Programming Model of the Nation's Energy System (Upton, N.Y.: Brookhaven National Laboratory, February, 1973).
- [13] Mooz, W. E., Projecting California's Electrical Energy Demand (Santa Monica, Calif.: Rand Corporation, 1972).
- [14] National Economic Research Associates, Inc., Energy Consumption and Gross National Product in the United States (New York: 1971).
- [15] "Energy Supply and Demand Situation in North America to 1990," visual presentation (Menlo Park, Calif.: Stanford Research Institute, November 1973).
- [16] Johnston, Devis F., "The U.S. Economy in 1985 - Population and Labor Force Projections," Monthly Labor Review (Washington: December 1973).
- [17] Hudson, Edward A., and Dale Jorgenson, U.S. Energy Policy and Economic Growth, 1975-2000 (Cambridge, Mass.: Harvard University and Data Resources, Inc. [part of the Ford Foundation Energy Policy Project], June 1974).
- [18] "A Report to the Office of Management and Budget by the Interagency Panel for Geothermal Energy Research," unpublished report. (Washington, D.C.: National Science Foundation, June 1974).
- [19] Personal communication, David Cohen, Pacific Gas and Electric, San Francisco, California, 1974.
- [20] Personal communication, Earnest Comalli, County Assessor, Sonoma County, California, 1974.

- [21] Berman, M.B., M.J. Haumer, and D.P. Tihausby, The Impact of Electricity Price Increases on Income Groups: Western United States and California (Santa Monica, Calif.: Rand Corporation, November 1972).
- [22] Final Environmental Statement for the Geothermal Leasing Program (U.S. Department of the Interior, Washington, 1973).
- [23] Bratton, Oscar B., Statement of Taxes (Malheur County, Oregon: 1973-1974).
- [24] Personal communication, Howard Ego, Town Manager, Vale, Oregon.
- [25] Personal communication, J. Schneider, Town Manager, Nyssa, Oregon.

4.4. Effects on a National Electrical Grid

The U.S. electric utility industry will continue to be challenged by two demands which are inextricably bound to each other: the need to develop adequate generation facilities and the need to transport electrical energy from points of generation to points of consumption. These two needs must be satisfied under the constraints of system reliability, a rational fuel mix, and environmental impact. It has become apparent to many utilities that because their problems are common, solutions are best found by regional and national planning for the growth of facilities. As the result of such planning, the electrical interconnections between utilities have grown at an accelerated rate during the past few years, and it is expected that this growth will continue for the next several decades. [1]

The development of the transmission grid, by permitting the flow of power among neighboring electric systems, secures several primary benefits: [2]

1. Power may be transferred between systems to meet power shortages on both an emergency and planned basis.
2. Through the planned exchange of power and energy between regions, important reductions in cost of energy production can be achieved.
3. Scheduling of bulk energy transfer over tie lines takes advantage of energy cost differentials between areas.
4. Power exchanges are made possible by differing load characteristics due to seasonal patterns, time zones, and weather.
5. Sharing of operating reserves permits scheduling of different types of generation and through this, improvement in overall system efficiency.
6. Improvement in transient system power stability results from a greater degree of system flexibility.

A further benefit, particularly important in the future, is the ability to transfer power over the grid from sources remote from load centers. In the case of geothermal energy, accelerated development in the West may raise the possibility of sending power eastward. In effect, the West would be "exporting" geothermal energy in the form of electricity; the situation would be analogous to Louisiana exporting an indigenous energy resource, natural gas, to users elsewhere in the United States. If the transcontinental grid is developed first for transmission of electricity from remotely located nuclear plants and coal/mine-mouth generators, the geothermal application would be a marginal addition.

Plans of the Electrical Industry for a National Electricity Grid

Overhead transmission lines in the United States, with voltages of 230 kV and above, totaled approximately 65,000 circuit miles in 1970; by 1990, this total is expected to reach 160,000 circuit miles. Currently, with the exception of a major portion of the electrical systems in Texas, all of the larger utilities in the United States are interconnected. There are places, however, where the interconnecting lines have limited capacity, and therefore cannot ensure continuous and reliable operation. This is

particularly true of the East-West connections in the Rocky Mountain area. It has been strongly recommended by both the National Electrical Reliability Council (NERC) and the Federal Power Commission that inter-regional and transregional transmission lines be strengthened. [1] It is expected that future developments will strengthen the various weak points in the national transmission grid. Continual strengthening of the interconnected networks of the United States is essential if an acceptable level of reliability is to be maintained. The installation of transmission links, not solely as generation outlets but as inter-area and interregional ties with adequate power transfer capability, is required.

An order by the Federal Power Commission (Order 383-3) required the regional electrical councils to submit diagrams showing possible transmission patterns for the year 1992. Generally, these diagrams were developed without detailed engineering or economic studies, but they do represent, on a broad conceptual basis, the current thinking of those engaged in long-range planning for the various power systems within the United States.

A composite of these NERC transmission diagrams submitted in September 1973, is shown in Figure 4.4.1 on the following page [1]. A map of the regional areas of the NERC is shown in Figure 4.4.2. Generally, the transmission system expansion patterns are extensions of the existing Extra High Voltage (EHV) network; it also includes new Ultra High Voltage (above 800,000 volts, UHV). It is significant that in this particular plan, more than 4500 miles of UHV and 2500 miles of EHV DC are envisioned for the year 1992. The diagram does not show any of the special lines required for the proposed coal mine-mouth or geothermal projects discussed in this section.

The Development of Geothermal Electricity West of the Rocky Mountains

The development of large amounts of geothermal electric power in the West by the year 2000 raises the possibility of feeding this electricity into the various consuming centers of the West Coast and the entire region of the United States east of the Rocky Mountains.

Figure 4.4.3 presents forecasts and selected assumptions included in the base case model simulation (Section 3.5); this run suggests that about 147,000 megawatts of geothermal energy will be produced west of the Rocky Mountains by the year 2000. Of this, the model forecasts transmission of 56,000 megawatts east of the Rocky Mountains to the mid-western consuming centers. The national grid, as described above, does not anticipate the transmission of such a large quantity of power over long distances. If geothermal electric power is used at points far from the geothermal resources, not only will the U.S. electrical transmission grid be affected, but several other impacts will be realized as well. These impacts include institutional issues particularly associated with management and operation of the grid, and environmental issues associated with its aesthetics and effects on land use.

As described previously in this study and shown in Figure 4.4.4, geothermal power sources are located primarily west of Rocky Mountains. [3] It is now reasonably clear that geothermal energy will be generated in dispersed plants ranging from 100-1000 megawatts in size. The consuming centers west of the Rocky Mountains are quite a distance from many of the good geothermal locations. Therefore, the power will be probably first gathered locally from one or more

Source: National Electric Reliability Council (Princeton, N.J., April 1973).

Figure 4.4.1

SOURCE: NATIONAL ELECTRIC RELIABILITY COUNCIL (PRINCETON, N.J., APRIL 1973).

Figure 4.4.2

ASSUMPTIONS AND FORECASTS OF BASELINE SCENARIO
RELEVANT TO TRANSCONTINENTAL ELECTRICAL GRID
(1000 MWE)

ASSUMPTIONS AND FORECASTS	YEAR	
	1985	2000
GEOTHERMAL ELECTRICITY CAPACITY IN THE WEST	7	147
GEOTHERMAL ELECTRICITY CAPACITY IN THE EAST	0	41
GEOTHERMAL ELECTRICITY TRANSPORTED WEST TO EAST	0	56
COST OF GEOTHERMAL ELECTRICITY IN THE WEST (CONSTANT 1973 DOLLARS)	10.4 MILLS/KWHR	14.5 MILLS/KWHR
COST OF GEOTHERMAL ELECTRICITY TRANSPORTED TO EAST (2500 MILES) (CONSTANT 1973 DOLLARS)	19.3 MILLS/KWHR	25.7 MILLS/KWHR
NUMBER OF TRANSCONTINENTAL CORRIDORS IN OPERATION (ASSUMING STANDARD FPC RELIABILITY CRITERIA)	0	4

Figure 4.4.3

Figure 4.4.4 MAP OF THE WESTERN UNITED STATES SHOWING LANDS CLASSIFIED FOR GEOTHERMAL RESOURCES EFFECTIVE DECEMBER 24, 1970

fields. Then it will be transmitted the required long distances at high voltages in a few transmission corridors to the consuming centers. It is important to keep in mind that the presently visualized large consuming centers west of the Rocky Mountains are the large cities and their local environs: San Diego, Los Angeles, San Francisco, Portland, Seattle, Phoenix, Albuquerque, El Paso, Salt Lake City, Denver, and Boise-Pocatello. Of course, there is considerable consumption in the other parts of the western territory, but these are the focal point consuming centers. Figure 4.4.1 gives the projected 1992 demand of this region as 211,000 megawatts, and the FPC estimates the year 2000 demand at 480,000 megawatts. It is estimated that in the 1990-2000 time frame, demand by the State of California alone will be 100,000-150,000 megawatts. [14] Therefore, it seems plausible that the amount of geothermal energy postulated in this study for the period 1985-2000 can be accommodated and consumed in the western load centers. For example, the simulation base run indicates that of the 147,000 megawatts generated in the West in 2000, approximately 90,000 megawatts will be consumed in this area; this would constitute about 19 percent of the total western load.

Development of Large Power Complexes at Western Coal Fields

The increasing demand for electricity has led to consolidation of very large coal generating plants near the western coal regions. There are huge coal fields located in Wyoming-Montana and in the New Mexico-Arizona four corners area. More than half of the coal

in the United States is located west of the Mississippi River, and most of that is in these two thinly populated regions. Maps of these areas showing the coal deposits and proposed power plant locations are shown in Figures 4.4.5 (below) and 4.4.6. Both of these projects are at the serious planning phase and have partially started. [5, 6]

The southwest energy system now has about 6000 megawatts of power plants in operation or under construction from the four corners area of New Mexico and Arizona to the Colorado River. The final plans for this complex of generating plants is to achieve a capacity of 30,000 megawatts by 1990. There is sufficient coal at the proposed sites to generate this capacity for well over 200 years. Since these power plants are located in a relatively isolated desert, the electricity which they generate will be transmitted to the consuming centers which are most of the cities named previously in this section. For example, the largest consumer would be the City of Los Angeles, hundreds of miles away.

The north central power system is centered around the tiny city of Gillette, Wyoming. There are vast coal deposits in this area which can be mined easily. In 1970, consuming power companies in the Mid West, and in Wyoming and Montana, began a study of large capacity power plants in this region which would transmit the electricity to mid-western consuming centers: Minneapolis-St. Paul, Omaha, Des Moines, Kansas City, and St. Louis. Also, some of the electricity would be used in the immediate area. Their present plan (1971) is to generate 10,000 megawatts for use in the western

Figure 4.4.5 LOCATION AND POWER GENERATION POTENTIAL OF STRIPPABLE COAL DEPOSITS IN NORTH CENTRAL POWER STUDY AREA

Source: [6]

Figure 4.4.6

area and 40,000 megawatts for transmission to the named mid-western cities. The plan calls for transmitting this electricity along four corridors containing a total of fourteen 765 kV AC lines. Twelve would be in active use and two would provide the required system redundancy.

The important point to be made for this study is that the suggestion for generating very large amounts of geothermal energy for transmission to West Coast and mid-western consuming centers must be taken as a serious future possibility. The electrical industry has already started implementing similar systems based on the Rocky Mountain area coal deposits. The amounts of geothermal energy which might be generated in the West and transmitted to the Mid West and East are of the same order of magnitude as those contemplated for the coal mine-mouth generating plants now being planned. Therefore, the development of the high voltage transmission grids required for the geothermal electricity can and probably will be blended with those for the coal based electricity.

Effect of Export Electricity on Transmission Grids

The huge amounts of geothermal energy likely to be available for export, coupled with projected coal electricity, will have profound effects on the development of the national transmission grid. In this study, these various possible impacts were defined by constructing an impact relevance tree. The first two levels of this impact relevance tree are shown in Figure 4.4.7, and the entire relevance tree is given in Appendix D.

Figure 4.4.7

Effects on the Technology of Electricity Transmission Lines

The demand for efficient transmission of higher power levels will bring an increase in transmission voltage. Increased voltages have, in the past, allowed greater power transmission per line, thus minimizing right-of-way costs and associated environmental impacts. Voltages now used and planned have upper limits of 765 kV AC and 800 kV DC. Such lines can carry a few thousand megawatts at reasonable costs. Transferring larger amounts of power (of the order of 10-15 thousand MW per line) would require an increase in voltage to 1000-2000 kV, a technological development assumed in the next 15-20 years. (See Figure 4.4.8)

There are important developments in transmission technology abroad also. The new Russian five-year plan objectives include development of new equipment for 1500 kV DC and for 1150 kV AC for transporting power from Asian coal fields over 1500 km to Moscow, the lines having a 6000 MWe capacity per circuit. In the future, Siberian hydroelectric power will be brought to Moscow over 4000 km lines. [7]

Increase in transmission voltage is dictated by transmission line economics. In general, transmission line construction costs increase with increasing voltage. The line-carrying capacity, however, also increases with increasing voltage, and there is a minimum cost for transmitting power per unit of distance for the transmission of a given amount of power. Figure 4.4.9 shows this variation of cost with distance for several high voltage lines, both AC and DC.

It may be seen from Figure 4.4.9 that the transporting of larger amounts of power over large distances will probably be done with DC transmission lines. A comparison of the economics of DC transmission with AC transmission may be characterized as follows: [8]

1. Construction of the transmission line overhead or underground is less expensive for DC lines. At present, DC line capital costs are approximately 35 percent lower than for comparable AC lines.
2. DC transmission terminal stations are appreciably more complex and expensive than their AC counterparts, both for initial costs and operating and maintenance expenses.
3. On comparable rated lines, transmission losses for DC lines will be less.
4. DC transmission cable capacities are not limited by reactive charging currents.
5. Modern DC lines do not add appreciably to the short circuit capacity requirements of their receiving buses.
6. The asynchronous nature of DC lines may be an asset in some situations in that there are phasing problems with AC interties. This is now severely limiting long distance AC power transmission.

The rights-of-way have to be wide enough to accommodate transmission towers carrying cables spaced 50-100 feet apart. For 500-765 kV AC lines the total transmission right-of-way width ranges from 250-350 feet, depending on the tower design and the terrain. A future high voltage DC line will require 50-60 percent less width, only 150-200 feet. The AC towers vary from 105-160

Figure 4.4.8 FUTURE DEVELOPMENTS IN TRANSMISSION TECHNOLOGY

SOURCE: FROM INFORMATION SUPPLIED INFORMALLY BY G. BRUER OF GENERAL ELECTRIC CO. AND R. F. LAWRENCE OF WESTINGHOUSE ELECTRIC CORP. (THE FIGURES IN PARENTHESES ARE ESTIMATES OF THE POWER CAPABILITY OF A SINGLE LINE.)

Figure 4.4.9

feet high and the DC towers vary from 100-125 feet. [9]

Since a primary motivation for developing the national grid is improvement of system reliability, the system advantages for DC power transmission indicate that if substantial amounts of electrical power are to be transferred from western coal and geothermal electrical resources, DC transmission will probably be the medium. At present, the longest DC line in the United States is the Northwest-Southwest Pacific Intertie running 846 miles, from The Dalles, Oregon, to Los Angeles. This is a + 400 kV DC line having a capability of approximately 1440 MW. In this case, there are also two 500 kV AC circuits running in parallel with the DC line. Both the AC and DC lines together provide some redundancy so that a necessary level of reliability can be maintained for the system.

The amounts of power which may be transferred from geothermally produced electric generation in the West will be not only a function of the specific costs of delivery (including both generation costs and transmission line costs), but will be quite dependent on total system reliability. To prepare for the contingency of the loss of a line which carries a large amount of power, there will have to be either alternative transmission paths for power or alternate local sources of power which may be used for an emergency. The ability to provide for such an eventuality will be a limiting factor in the amount of power which can be transmitted over any single line.

The caveat on system reliability notwithstanding, delivery of large amounts of power from geothermal electric resources in the West to mid-western and eastern points in the national grid may be economically feasible. As an example, three corridors might be developed by the year 2000 running parallel to transmission links which are likely to have been developed by that period of time. One might run east through Minneapolis to Chicago, the second to Kansas City and St. Louis, and a third to Dallas, Houston, and New Orleans. (If substantial amounts of geopressured geothermal resources are developed along the Gulf regions, such inputs could be fed into the New Orleans terminal.) Each corridor could contain + 1000 kV DC lines running about 2600 miles and capable of carrying 10,000-15,000 megawatts. The scenario of the development of these lines is illustrated in Figures 4.4.10 and 4.4.11. These graphs show the timing for installing the various sized lines and the costs. The transmission costs over such a distance would be about 4 mills per kilowatt hour (see Figure 4.4.9). This cost includes line losses estimated to be about 13 percent of total power transmitted for a line operating at full capacity.

*ASSUMES THAT SUFFICIENT REDUNDANCY IS DEVELOPED IN ENVIRONMENTAL INTERCONNECTED GRID.

Figure 4.4.10 DEVELOPMENT OF GEOTHERMAL POWER TRANSMISSION CORRIDORS TO THE MID WEST

*INCLUDES TERMINALS, EXCLUDES RIGHT-OF-WAY COSTS. RIGHT-OF-WAY COSTS AT \$775/ACRE WOULD ADD ABOUT 5% TO THE CONSTRUCTION COSTS. CONSTRUCTION TIME IS 6 YEARS.

Figure 4.4.11 DEVELOPMENT OF GEOTHERMAL POWER TRANSMISSION TO MIDWEST—LAND AND CAPITAL REQUIREMENTS. ASSUMES 200 FEET RIGHT-OF-WAY AND 2500 MILES LINE LENGTH.

The power transmitted along these three corridors would be equal to about 10 percent of the projected generating capacity for the two FPC regions in which the power would be received (the West Central Region and the South Central Region). Entering the grid at these points, power may be ultimately distributed further east, thus distributing the burden of reliability (related to the percentage of power delivered from geothermal resources to the local generating capacity) throughout large portions of the Midwest and eastern grids.

In planning the U.S. transmission network, changes in voltage level are seldom dictated by short-term growth predictions. When studies are limited to only a few years, the results usually show that the lowest capital requirements are obtained by remaining at existing voltage levels. It is only when studies for the transfer of large blocks of power are projected far enough into the future that new lines at higher voltages may be justified on a present worth basis. If the judgments simulated by the model described in Section 3.5 are correct, the potential Mid West and East Coast markets for western geothermal electricity will be an impetus to increase voltages for the economical transregional transmission of electricity.

Transmission of Hydrogen Produced from Geothermal Power

The nature of the growth of transcontinental transmission of geothermal energy also involves other important fuel technological considerations. It may prove efficient to transmit the energy in the form of hydrogen—that is, geothermally produced electricity would be used to electrolyze water [10]; the hydrogen produced by this process would be pumped over long distances to be used as a fuel at the end of the pipeline.

In considering the synergism of geothermal energy and the hydrogen energy economy, a critical question arises: What is the cost of hydrogen produced from the power? In Figure 4.4.12 the cost of hydrogen produced by the electrolysis of water, using advanced technology now foreseen, is given as a function of power costs in mills per kilowatt hour. These data indicate hydrogen can be produced by electrolysis, using geothermal electricity, for a manufacturing cost of \$2-4 per million Btu. [11, 12]

COST OF HYDROGEN PRODUCED FROM GEOTHERMAL POWER

AUTHOR	POWER COST (MILL./KWH)	HYDROGEN COST (\$/MILLION BTU)
GREGORY [11]	4.0	1.50
	7.0	2.50
	9.1	2.95
LOTKER, FEIN, SALZANO [12]	10.0	4.20
(BOTH REFERENCES ASSUME REASONABLY POSSIBLE FUTURE IMPROVEMENTS ARE MADE IN WATER ELECTROLYSIS TECH- NOLOGY OVER THE PRESENT TECHNOLOGY IN THE NEXT 10 YEARS.)		

Figure 4.4.12

This is higher than the present prices for natural gas in the western United States, but, of course, these supplies are now severely limited. The projected future manufacturing costs for gas from coal gasification are somewhat lower than these figures using 1972 coal prices. However, with the price of coal and oil shale rapidly escalating, gas produced by gasification from both of these sources will probably be in the range of \$1.50-3.00 per million Btu in the near future. [13] Therefore, hydrogen produced from geothermal energy sources in the West may be potentially cost competitive with synthetic fuel gas manufactured from the other available fuels.

Since geothermal energy wells should be operated continuously at full capacity, there will be excess off-peak geothermal energy which can be channeled off to the production of hydrogen. This hydrogen, of course, can be transported either as a gaseous fuel or can be converted into synthetic natural gas, synthetic oil, or methanol. (It has been well established that methanol is a good constituent of automobile fuel.) Since the East will also require a fuel mix of electricity, fuel gas, and liquid fuels, probably it will be desirable to convert some of this export geothermal electricity to hydrogen and methanol for transport to the East. It has been pointed out by Gregory [11] and others [14] that over long distance it is cheaper to transport gaseous hydrogen or liquid fuels than electricity. Therefore, a combined geothermal energy-hydrogen economy, jointly producing electricity, fuel gas, and liquid fuel for export east of the Rocky Mountains, appears to be an interesting alternative.

Effect of Geothermal Energy and Transmission Grid Growth on Electric Service in the West, and East of the Rocky Mountains

Coupling geothermal energy development with a national grid will have beneficial results for electricity consumers in the load centers. The most noticeable effect to them would be to help limit the cost of electricity and enhance its availability. It was previously shown in this study that the cost of geothermal electricity is on the low end of the generation range compared to other fuels available to a power company. The role of the development of the transmission grid, therefore, is to make this large potential supply of geothermal energy available to remote consuming centers. As this development takes place toward the year 2000, this will be noted first in the western consuming centers. After 1985-1990, according to the base simulation, (see Figure 4.4.13), the large transmission lines will be built for transmitting geothermal energy

Figure 4.4.13 GEOTHERMAL ELECTRIC POWER TRANSMITTED TO THE EAST (DATA FROM MODEL, BASE CASE)

east of the Rockies. At that time, the mid-western consuming centers will start to benefit also from the availability of the low-cost geothermal energy. For them, this will probably also be mixed with similarly low-priced electricity from the mountain states' coal generating plants. [5] However, as pointed out in Section 4.1, the cost-diluting effects of geothermal electricity are small: if the accelerated program is realized and geothermal electricity were to cost 75 percent of the national average, the net effect would be a reduction in average cost of only 3 percent.

One of the chief reasons, as mentioned before, for building transmission grids is to assure and, if possible, increase the reliability of the electrical supply to the consumer. [1] This is one of the major responsibilities of a power company. Transmission of 5-20 percent of a consuming center load from geothermal fields will increase the local system reliability in at least two ways. First, it will make the local energy fuel mix more diverse by adding another fuel. Second, a portion of the total energy comes from an outside distant source not subject to the vagaries of local weather or social disturbances. Utility executives contacted during this study indicated the desirability of both of these points in improving the reliability of their local system.

Purchase of 5-20 percent of the local power supply from an outside source will have an important effect on the construction of local power plants. It is obvious that there will be a decreasing need for constructing local power plants. This will alleviate the acute problem of finding local power plant sites. Simultaneously, it will decrease considerably the amount of local pollution which might be caused by the local power plants.

Effects on Institutions

The effects of geothermal electricity transmission and importation on utility administration and institutional arrangements will be to make the management task more complex, because local power companies will now have to deal with an outside power source and transmission controller. The company operating the geothermal power plant probably will be different from the company controlling the transmission lines. Therefore, administration will involve two other groups and, thus, will become more complicated. However, this is not a self-defeating situation, because the equipment (computer controlled) and administrative training of the power industry is being developed and improved so that in the

ture it can deal with these arrangements in a routine manner.

The concomitant development of geothermal generating plants distant from the consuming centers and long distance transmission lines will have a strong effect on the load center power companies. Traditionally, the load center power companies have grown gradually, and their chief mission has been to supply cheap, reliable power to their local customers.

The local power companies get their income from the local customers only; and their return is based, in part, on their invested capital. Furthermore, the power companies are regulated by the several state power commissions as to their business activities. This pattern of development has served the country and industry well. The construction of distant geothermal power plants and high voltage transmission lines are activities which will be new to the regular business of power companies; furthermore, these activities are likely to be outside the local power company service region and probably in other states. This will make the regulation of a power company very complicated.

The present method for determining charges to local consumers takes the entire capital investment of the power company (the rate base) and determines a fair return on this. However, in the future, if the power companies make investments for transmission lines outside of their territory, it is uncertain as to how much of this investment should be borne by the local consumer and how the rate base would be affected.

Nevertheless, the construction of transmission lines for transregional shipments of large amounts of electrical power is occurring and will undoubtedly grow in the future. In the case of the Pacific Intertie which runs from the Dalles, Oregon, to Los Angeles, California, the cost for construction was shared by the several user utilities, principally Los Angeles Water & Power Department and the Bonneville Power Authority, and included several other municipalities and the Southern California Edison Company. Most of this line (800 kV DC) is built on federally owned land. Construction from Los Angeles to the Nevada-Oregon border was done by the Los Angeles Water & Power Division, while the northern remainder was constructed by the Bonneville Power Authority. Acquiring rights-of-way presented no insurmountable problems. While rights-of-way may have been facilitated by federal participants, utilities, particularly in the West, have often built transmission lines to accommodate electricity generated outside of their own territory.

The raising of capital for the building of transregional lines, however, might be difficult to allocate among all of the utilities drawing power from the grid. In the North Central Power study several methods for doing this have been studied but no satisfactory method was decided upon. [5] This is due to the complicated nature of both the consumption and the generation of the electricity. The loads fluctuate daily and seasonally, and are also affected by changing commercial and industrial activities in a particular consuming center. All of this adds up to a variable usage of the transmission line by an individual load center. This being the case, it is clearly difficult to allocate fixed capital charges to a particular load center.

Therefore, the raising of capital for the building of transregional lines might be difficult to allocate among all of the utilities drawing power from the grid. If joint and cooperative efforts among utility companies for the necessary transregional facilities are impractical, it may be necessary to consider forming

an independent transmission company which could provide common carrier service in the same fashion as a gas pipeline company now does. Since power dispatching would have to be under the control of regional consumer utility groups and of generating companies, the responsibility for control of such a line would have to be worked out very carefully. This, of course, is exactly the situation for a common carrier gas pipeline company, which gathers gas from various gas fields owned by other companies and then transmits it to consuming center companies. An interstate electrical transmission company might be private but probably would be regulated by the Federal Government to ensure equitable distribution of costs of the transported power among the user utilities. Since the organizational and institutional methods for this exist in the natural gas and oil pipeline companies, it is reasonable to predict that such private transmission companies may be formed in the future.

This trend will be encouraged by the construction of some of the planned electrical generating complexes in the West, such as the two coal studies previously discussed, and, of course, western geothermal fields. A high voltage electrical transmission line cannot be constructed economically on a small scale. It must be built on a large scale, costing a large amount of money, or not at all. For example, a line going from geothermal fields to the Mid West would cost a minimum of approximately \$1 billion. Therefore, it is not possible for such a system to grow gradually. It is a large enterprise and will have to be handled accordingly. Since much of the required transmission right-of-way land is already government owned, it seems possible that a specially created federal agency for building and operating the transmission lines should be considered.

Placing the financing, construction, and operation of these special interregional high capacity transmission lines in the jurisdiction of a government body or a government-private company can have benefits to the consuming center utilities. It will relieve them of the responsibility for financing, constructing, and operating transmission lines which are out of their territory. (Obtaining the financing of multi-billion dollar transmission lines will be particularly onerous for private companies in the future due to money scarcity and high interest rates.)

The whole question of environment and environmental impacts due to the transmission lines can probably best be handled by a government agency. This agency not only would have the responsibility for reliable economic operation of the lines, but would also be responsible for conserving the environment in the best interest of the citizens.

The development of independent transmission line operating companies would be a strong departure from the present business methods in the electric utilities business. It would enable new companies to go into the electrical generating business. Several non-utility companies have already shown a strong interest in not only operating the geothermal wells but in generating the electricity themselves. However, they have not been able to make suitable business arrangements for delivering and selling their power to a load center. Construction and development of a common carrier transregional electrical transmission grid will enable non-utility companies to generate electricity in geothermal fields and to transmit power through the common carrier to a load center with whom they can arrange a suitable contract. This could bring a great deal more flexibility into the electrical generating capacity of the West, and ensure a more equitable, rational, reliable, and

economic electric service to the consuming centers.

A single transmission-line agency, properly constituted, would also help simplify the problem of overlapping jurisdictions and responsibilities among current organizations. At present many regulatory agencies assert authority over transmission line locations and construction. Federally, the Federal Power Commission has the right to require licensees to construct and locate their lines in accordance with regulations concerning environmental factors. The Environmental Protection Agency does likewise. The U.S. Department of the Interior and the U.S. Department of Agriculture have the authority to impose conditions concerning location, construction, maintenance, and line use practices, of any portion of the transmission lines occupying public lands under their jurisdiction. Some of the conditions which are now, and in the future, imposed by these agencies cover liability for forest fires, construction, clearing, rehabilitation, maintenance practices, access road, and specific line location in relation to surrounding terrain or unusual geologic or historical features. In addition, the Bureau of Public Roads may require transmission line facilities to be located away from interstate and scenic highway systems, and also may reject proposed highway crossings.

Since the full development of geothermal energy transmission lines will cover such a wide part of the country, it is appropriate to review the government agencies and commissions who may have regulatory jurisdiction over the siting and construction of these transmission lines.[16] The list follows:

1. Local (City and County)

- City Council
- Planning Commission
- Board of Supervisors
- Zoning Board
- Flood Control Districts
- County Road Department
- Conservation and Development Commissions

2. State

- Regulatory Commission
- Water Quality Control Agency
- Department of Forestry
- Department of Fish and Game
- Highway Commission
- Lands Commission
- Water Agency
- Department of Conservation
- Department of Beaches and Parks
- River Commission
- Power Plant Siting Committee

3. Federal

- Department of the Interior
 - Bureau of Land Management
 - Bureau of Indian Affairs
 - Bureau of Sports Fisheries and Wildlife
 - U.S. Fish and Wildlife Service
 - National Park Service
- Department of Agriculture
 - United States Forest Service
- Federal Power Commission

- Department of Transportation
 - Federal Aviation Administration
 - Federal Highway Administration
 - Bureau of Public Roads

- Department of Defense
 - Department of the Army

- United States Corps of Engineers

- Environmental Protection Agency

The Effect of Geothermal Energy Transmission Lines on Power Economics

The construction and operation of high voltage transmission lines for conveying geothermal energy from the production field to the consuming centers is clearly going to be a large enterprise. Although it is difficult to talk about transmission lines in general, the projects do have a common method of attack. Each transmission line project involves the following stages:

- Planning and environmental impact analysis
- Route selection
- Rights-of-way acquisition
- Design
- Construction
- Maintenance
- Operation

The cost of a 1-2 million volt DC line in the time period 1985-1995 is estimated to be \$1-1.5 billion (1973 dollars) for 2500 miles. Such a line is projected to have a capacity of 5-15,000 megawatts. The transmission cost of the geothermal energy delivered by such a line is estimated at 7.5 mills per kilowatt hour in 1980 (lower voltage) and 4 mills per kilowatt hour in 1995 (higher voltage) (1973 dollars). This is predicated on the technological improvements occurring from now to 1995, as discussed previously.

This assumes a line cost of \$250,000 per mile, exclusive of rights-of-way costs, and a cost of the inverter-converter terminal of \$25 per kW. Figure 4.4.11 shows the expected cumulative capital costs which are consistent with the scenario of the development of geothermal power for export to the East. This indicates that by the year 2000 about \$4-6 billion (1973 dollars) exclusive of rights-of-way will be required for building the eastward export transmission lines.

The transmission economics presented above check closely with those made for the North Central Power study in 1970. [5] That system (as shown in Figure 4.4.14) involves 14 lines in four corridors carrying 40,000 megawatts from Gillette, Wyoming to the Mid-West consuming centers. A capital cost of \$5 billion (1970 dollars) was estimated for construction finishing in 1975. This was based on the use of 765 kV AC lines; twelve lines would be in use, with two for reliability redundancy. The average transmission length would be 700 miles, with the furthest distance from Gillette, Wyoming, to St. Louis, Missouri, an airline distance of 815 miles, but a 1000 mile line distance. Such a system was designed to carry 40,000 megawatts, with 9000 MWe being delivered to St. Louis. The estimated time of construction was five years. In the present time of high interest rates, this, of course, is a very important consideration. Figure 4.4.15 presents their estimated transmission unit costs based on varying amounts of electricity transmitted. This is important because it shows the advantages to be obtained in transmitting larger amounts of electricity through a few corridors.

Figure 4.4.14 TRANSMISSION SYSTEM-ULTIMATE DEVELOPMENT
DEVELOPMENT LEVEL - 10,000 MW WEST, 43,000 MW EAST

EASTERN SYSTEM
ESTIMATED TRANSMISSION COSTS
1975 PRICE LEVEL

(IN MILLIONS OF DOLLARS)

FACILITIES	GENERATION LEVEL, MW					ANNUAL O & M COST* (%)
	3,000	10,000	20,000	40,000	43,000	
1. TRANSMISSION LINES	582	1,030	1,625	2,920	3,277	0.4
2. SUBSTATIONS, SWITCH-YARDS, ETC.	405	744	1,189	2,115	2,365	1.8
3. CONTROL & COMMUNICATION EQUIPMENT	19	36	56	63	112	5.0
4. SUBTOTAL	1,006	1,810	2,870	5,098	5,734	
5. ALLOWANCE FOR IMPROVED APPEARANCE (3% OF LINE 4)	30	54	86	153	173	
6. TOTAL	1,036	1,864	2,956	5,251	5,927	

*PERCENTAGE OF TOTAL INVESTMENT

Figure 4.4.15

Figure 4.4.16 presents the North Central Power study operating cost estimate. The costs listed at Gillette are for the manufacturing costs at the plant, while the costs listed at the various consuming centers, for example, St. Louis, gives the combination of the plant manufacturing costs plus the transmission costs. Subtraction of one from the other shows that delivery of 9000 megawatts to St. Louis over about 1000 line miles was estimated at 3.5 mills per kilowatt hour for a 14 percent annual fixed charge rate. (This is a normal charge for an investor-owned utility.)

Both the capital costs and operating costs estimates for the North Central Power study are very close to those calculated above for the transmission of geothermal energy in the new high voltage DC lines. Therefore, they act as a good check on the estimates made in this study. The important conclusion to be reached from this discussion is that the long distance transmission of geothermal energy is economically competitive and will be so in the future development of power in the West and Mid West.

Effects on Environment

The environmental consequences of overhead lines fall largely in the domains of visual impact and land use conflicts. In part, transcontinental lines will run through some areas not usually accessed by the public, and obtaining environmentally acceptable rights-of-way for these segments may not be a serious problem. The guidelines prepared by the Working Committee on Utilities, those accompanying FPC Order 414, and a 1970 report of the Departments of the Interior and Agriculture on environmental criteria for transmission systems, show a sensitivity to the esthetic treatment of overhead transmission lines. Criteria particularly relevant to

transcontinental lines include: [15]

1. Scenic recreational, historic areas should be avoided where possible.
2. Heavily timbered areas, steep slopes, and proximity to main highways should be avoided, where possible.
3. Long views of transmission lines perpendicular to highways down canyons and valleys, or up ridges and hills are particularly undesirable. The line should approach and cross these areas diagonally.
4. Transmission facilities should be located with a background topography and natural cover where possible.
5. Where access roads are required they should be curved or run diagonally across the right-of-way to minimize their visual impact.

Compliance with these criteria in certain instances may be easier if existing rights-of-way are expanded or where joint use with another kind of facility is possible. The Federal Power Commission urges such developments where they are feasible.

The effort to lessen the impact on the landscape and open spaces and to minimize urban land requirements for transmission lines, will bring about joint use of air space and multi-purpose rights-of-way in the future. [16] For example, presently there are many miles of transmission lines along railroad rights-of-way; these networks can be used more extensively in the future. This could lead to more railroad electrification which would be a highly desirable economic development.

Figure 4.4.16 TOTAL PARTICIPATION COSTS FOR VARIOUS FIXED CHARGE RATES

A second dual purpose use would involve the use of flood control channels which are particularly important in the West. Many flood control channels are artificial concrete-lined structures that lend themselves to joint usage for utility corridors. Joint use of air space, by building over flood control channels, should be used in the future, if possible.

A third dual usage method involves highways and freeways. Experience has indicated that new freeways often follow existing transmission lines rights-of-way without serious impairment of environmental values. Government agencies and utilities in the future should consider the mutual benefits of joint use of such air space.

These various multi-purpose corridors are receiving serious consideration now and will most probably be developed in the future. For example, the North-Central Power study advocated joint utilization of rights-of-way when desirable, but pointed out that the decision in this regard should be made at state and national levels. [5] One concept which they proposed would be to have corridors one mile apart, and also used for highways, railroads, overhead transmission lines, underground transmission lines, gas lines, oil lines, communication lines, water lines, parks, etc. Minor feeder corridors at shorter intervals could be used as needed.

The new and future designs of transmission lines are such that it is not necessary to fence the right-of-way. This means that the bulk of the right-of-way can remain in the common land-use pattern. For example, some of these secondary use purposes can be cultivation of nursery stock, gardening, general agriculture, pasture, and various recreational purposes such as hiking trails, bicycle paths, snowmobile routes, parks, golf courses, equestrian trails, and so forth. [16]

The question of land requirements for a national transmission grid for geothermal energy can cause some anxiety. However, estimates of the land requirement may be obtained by looking at the two cases of coal mine power plant development. The southwest energy development in New Mexico-Arizona, Utah, Colorado, proposes the generation of 30,000 megawatts electric at several locations in these states and then transportation of the electricity to the major load centers as far away as Los Angeles. This will require a complete network of new transmission lines ranging from 230 kV AC to 765 kV AC lines. The design study for this project indicates that some of these lines can be grouped in common transmission corridors. The total amount of corridor lengths required by 1990 for the completion of this project has been estimated at 3350 miles.

The North Central Power study is a more centralized system than the previous one. It generates 40,000 megawatts electric at Gillette, Wyoming, and then transmits it to mid-western consuming centers ranging from the Twin Cities to Kansas City and St. Louis. The 14 transmission lines are grouped into four corridors which have a total length of 2855 miles.

Averaging the results from these two examples, but giving slightly more weight to the Southwest Energy Study because it would more closely resemble the geothermal situation, approximately 110 miles per 1000 MWe would be required for transmission corridors in a grid transporting geothermal energy east of the Rocky Mountains. This uses technology which either has been developed or will be developed in the next ten years. With the newer type of technology being developed and discussed in the previous section, this amount of land will probably be decreased because each line will carry much heavier load.

Land usage for construction of the inverter-converter terminals will be of minor importance. One of the 1440 megawatt terminals, built in 1970 for the Pacific Intertie, required 21 acres of land. [2] This included space for the service building, all of the electrical gear, service roads, and employee parking areas. Advanced technology is expected to reduce land requirements significantly. The first high voltage DC transmission line to be contracted for since the building of the Pacific Intertie will be constructed by General Electric Company for the Minnesota Power and Light Company. This line, rated at 500 megawatts, will run a distance of 456 miles from a mine-mouth power project to Duluth, Minnesota. Unlike the Pacific Intertie terminals, which use mercury arc conversion equipment, this project will employ thyristor tubes and special solid state terminal circuitry. It is estimated that these terminals will require only one-third of the land needed for a comparable mercury arc installation. [9] For extremely high power densities, future terminals may use gas insulated transformers in conjunction with cooling towers. Such advances in technology may reduce the acreage required by the electrical gear for a terminal to less than 1 acre per thousand megawatts. [9]

The mid-western and eastern terminals of intercontinental transmission lines will probably be located near urban load centers, where the impact of their size on existing land patterns will be important. Attention will have to be given to colors, structural design, and landscape in an attempt to provide minimum visual dissonance.

Trend Analysis

There are, of course, many assumptions and imponderables in the analyses just presented. A more quantitative analytical method, Trend Impact Analysis (TIA), was used in this section to study the multi-effects of several future events on the transmittal of western geothermal electricity to the Midwest and the East. (TIA is described in detail in Appendix F.) Figure 4.4.17 lists nine future events which will have an important influence on electricity transmission. These events were selected by the study team from a longer list derived from the interview sequences and many interviews with experts.

The resulting TIA curves are presented in Figure 4.4.18. Note that the curve marked history is the base case derived from the simulation model. The three curves labeled lower, center, and upper quartile, are the TIA curves predicting the combined effects of the impacts in Figure 4.4.17.

The net effect of these predicted future events will be a substantial increase in geothermal electricity exported to the Mid West. These curves are not meant to be actual forecasts but instead show the trend effects of the major events impacting on the baseline curve. The effect of the events would be a ± 4 to 10 percent change in geothermal electricity transmission starting in 1992.

These results show the powerful effects which may be obtained by government policies which would encourage these future events.

POTENTIALLY IMPORTANT EVENTS	PROBABILITY/YEAR			I M P A C T				
	1980	1990	2000	YEARS TO FIRST IMPACT	YEARS TO MAXIMUM IMPACT	MAXIMUM IMPACT	YEARS TO STEADY STATE IMPACT	STEADY STATE IMPACT
Competition for capital hinders building of energy facilities	.3	.4	.5	0	5	-10	5	-10
Environmental pressures retard development of transregional transmission lines.	.3	.4	.5	0	5	-25	10	-10
Low-loss transmission technology is developed	0	.3	.5	3	6	+5	10	+7
Creation of a new transcontinental transmission utility partially government owned.	.0	.5	.8	1	5	+10	5	+10
First operation of western mine mouth coal plants at 5,000 MWe.	.6	.7	.9	0	5	+15	5	+15
Imported fuels heavily taxed by government and revenue used to stimulate indigenous fuel development.	.4	.8	.8	1	3	+10	5	+15
Public acceptance of an energy conservation ethic.	.4	.8	.8	3	5	-20	5	-20
National effort to develop an electricity economy based on U.S. fuels--uranium, geothermal, solar, coal, shale, etc.	.4	.8	.8	5	10	+15	10	+15
Mid-western agriculture increase for world food supply requires 50% more electricity input.	.7	.9	.9	1	5	+5	10	+5

Figure 4.4.17 IMPACTS ON WESTERN GEOTHERMAL ELECTRICITY TRANSMITTED TO THE MID WEST AND EAST

Figure 4.4.18 CROSS COUNTRY ELECTRIC TRANSMISSION

REFERENCES

- [1] Review of Overall Adequacy and Reliability of the North American Bulk Power Systems (Third Annual Revision) (Princeton, N.J.: National Electric Reliability Council, 1973). See also 1970 National Power Survey, Part I, below.
- [2] 1970 National Power Survey, Part I (Washington, D.C.: Federal Power Commission, 1971), pp. I-13-14.
- [3] U.S. Department of the Interior, Final Environmental Statement for the Geothermal Leasing Program, Vol. I (Washington, D.C.: 1973).
- [4] Mooz, W. E., and C. C. Mow, California's Electric Quandary: I Estimating Future Demands, R-1084-NSF/CSRA (Santa Monica, Calif.: The Rand Corporation, September 1972).
- [5] North Central Power Study: Report of Phase I, Vol. I, II (Billings, Montana: U.S. Bureau of Reclamation, October 1971).
- [6] Southwest Energy Study, draft (Washington, D.C.: U.S. Department of the Interior, April 1972).
- [7] Bureau of Reclamation, Report of United States Delegation Visit to the Soviet Union, July 24-August 6, 1972 (Washington, D.C.: U.S. Department of Interior, Electric Power Transmission and Power Generation Facilities, U.S.-USSR Exchange Agreement).
- [8] 1970 National Power Survey, Part I (Washington, D.C.: Federal Power Commission 1971), pp. I-13-17.
- [9] Brewer, G. D., "HVDC Transmission, An Overview of Solid State Technological Advances," Transmission, Vol. 6 (February 1974), pp. 3-6.
- [10] Maslan, F., and T. J. Gordon, "Geothermal Energy As a Resource in a Hydrogen Energy Economy," the Hydrogen Economy Miami Energy Conference, University of Miami, March 18, 1974.
- [11] Gregory, D. P., "A Hydrogen-Energy Distribution System," summary, Project IU-4-6 for the American Gas Association (June 1972).
- [12] Lotker, M., E. Fein, and F. J. Salzano, "The Hydrogen Economy--A Utility Perspective," IEEE Power Engineering Society Winter Meeting, January 27, 1974.
- [13] Linden, H. R., "SNG in the U.S. Energy Balance," Chilton's GAS Magazine (July 1973).
- [14] Hottel, H. C., and J. B. Howard, New Energy Technology--Some Facts and Assessments (Cambridge, Mass.: The MIT Press, 1971).
- [15] 1970 National Power Survey, Part I (Washington, D.C.: Federal Power Commission, 1971), pp. I-12-17.
- [16] Western Systems Coordinating Council, Environmental Guidelines (December 3, 1971).

4.5 Regulatory and Institutional Impacts

Introduction

A program designed to encourage the development of geothermal resources will require changes in existing regulations and institutions to meet the special requirements of the emerging geothermal industry. The issues which will drive these changes relate to the encouragement of exploration and development, assuring a market for the geothermal steam or hot water, and accomplishing the required research and development in a timely manner. More particularly, the issues include the need for:

1. Establishing an appropriate legal classification of geothermal resources.
2. Resolving uncertainties associated with availability of government-owned lands for development.
3. Refining the regulations associated with land acquisition and tenure.
4. Mitigating environmental concerns and reducing complexity associated with the administration of environmental regulations.
5. Providing incentives which will encourage utility companies to utilize geothermal steam.
6. Diversification of utilities.
7. Transmission of geothermally derived electricity over long distances.
8. Assuring the availability of adequate capital.
9. New legislation.

The impacts flowing from the resolution of these issues are displayed in the top level of the relevance tree in Figure 4.5.1; the detailed relevance tree is included in Appendix D.

Legal Classification of Geothermal Resources

Mineral Reservations. Federal and many state laws fail to specify whether geothermal resources should be classed as water, minerals, or something new in and of themselves (*sui generis*). By failing to define geothermal resources precisely, several significant uncertainties were created which will impede the development of the resource. Various homestead acts reserve mineral rights to the United States. The definition of the resource contained in current laws does not clarify the rights of landowners and the United States in these cases.

Acquisition of Rights. The current broad definition of geothermal resources leaves open the possibility that these resources could be claimed under the provision of state laws which govern the acquisition of water rights on unreserved federal lands. While this approach is unlikely to be successful, ambiguities should not be permitted to persist. The current federal law also excludes oil, hydrocarbon gas, and helium from the definition of geothermal resources by-products; yet, in the case of geopressured resources, it is not uncommon to extract large quantities of dissolved natural gas with the geothermal fluids. The developer of geopressured zones may obtain a mineral lease as well as a geothermal lease. This complicates the development process. Without a clear definition of geothermal fluids vis-a-vis the mineral and water laws, complex regulatory and legal issues seem certain to arise; the time required for the courts to resolve these issues will be long, and the effect will be to delay the development of the resource.

Tax Treatment. The taxation of geothermal resources is a problem which has not yet been resolved. Geothermal developers would like to obtain the favorable tax treatment both under federal and state law which is given to oil and gas developers. The depletion allowance and deductions which permit write-off of intangible costs associated with drilling and developing wells have not yet been applied to geothermal developers. In the single test case in California (*U.S. vs. Reich*) the geothermal resource was held to be depletable and, hence, the tax write-off was allowed; however, the Court of Appeals limited the applicability of the case specifically to the facts of The Geysers area. Developers of geothermal resources in other areas are not certain at this time whether they may claim the depletion allowance and deduct their intangible drilling expenses. There is likely

Figure 4.5.1

to be considerably more litigation with respect to depletion allowance and expense deduction. The problem is not limited to the federal tax laws; there are state, business, income, and franchise taxes which also depend on the characterization of the resource as a gas. Federal legislation is required to define an appropriate method of taxation or subsidy; otherwise, uncertainty will prove inhibiting.

Specifying Use of Lands for Development

Excluded Lands. The federal geothermal statute excludes large parts of the federal domain from geothermal development. While the intent is to protect the public domain from undue exploitation, it is not entirely clear that some of these areas, such as wildlife management areas, and various other kinds of open preserves, could not be made available for geothermal development wholly consistent with the purposes for which those lands are presently reserved or withdrawn. As additional information about the location of geothermal resources develops, attention should be given to the possibility of removing some of the statutory exclusions as to the areas available for geothermal development and determining whether or not the lease of these lands for development could not be put at the discretion of the Secretary of the Interior.

Acreage Limitations. The present acreage limitations may prove an undue restriction to the development of geothermal resources. It is too early to tell whether the limitations of slightly more than 25,000 acres per lessee per state will be a substantial barrier. Careful attention should be paid as the resource is developed to the requirements for economically large developments. While this issue is politically sensitive, it appears that developers acting together cooperatively can control acreage which is substantially in excess of what an individual developer can control. For example, in one recent geothermal non-competitive lease application situation, numerous members of the same family applied for hundreds of thousands of acres of land. Careful study should continue as to whether or not these acreage limitations are realistic.

Administrative Discretion To Withdraw Lands from Geothermal Development. A point made repeatedly by geothermal industry representatives at congressional hearings was that the Secretary of the Interior and other agencies responsible for management of federal lands had virtually unrestricted discretion to withdraw lands from development for any purpose to protect some other function of the department or use of the lands. Depending upon how this discretion is exercised, its effect on geothermal development may be either large or insignificant. However, it would appear as a matter of principle that when lands are classified as KGRA's or noted by the USGS as potentially valuable for geothermal development, there should be some limitation upon the discretion of the Secretary of the Interior to remove these lands from further development. At a minimum some procedure should be available for public notice and hearing so that interested spokesmen can appear and express their support or opposition for the Secretary of the Interior's decision.

Multiple Uses of Public Lands. Present federal land use policy is governed by the multiple-use principle; that is, a series of uses should be permitted upon a single tract of public land if the land is suitable for those uses. While this is a desirable principle generally, in specific instances geothermal development may be curtailed because of the requirement of accommodating other uses of the public domain. While it is not proposed that geothermal development be

given priority over other uses of land, some reconsideration should be made of relative priority in light of the current long-term energy shortage which this country is facing, and that some system of priority for energy development should be considered as an integral part of multiple land use policy.

Land Acquisition and Tenure

Exploration Rights. The federal law, unlike state laws, does not provide for protection of the discovery of geothermal resources by prospectors or explorers. The prospector receives no preferential treatment for his discovery. If he makes a discovery on non-KGRA land, in theory he can apply for a non-competitive lease of the lands. However, if another interested party files a lease application with respect to those lands within the appropriate filing period, the Secretary of the Interior may determine (and, in fact, his regulations and policy statements indicate that he will determine) that a competitive interest is found to exist. Upon a finding of a competitive interest, the land would be reclassified from non-KGRA to KGRA land, thereby depriving the prospector of right to lease the land non-competitively and throwing the lands open for the normal competitive bidding process. This policy of pushing all bidding toward competitive bidding and not protecting exploration rights is likely to have a negative effect on prospecting.

Bonus Bidding. Compounding the problem for the small developer or prospector is the bonus bidding system. This system requires that a lease be given to the highest responsible bonus bidder, that is, the person who bids the largest cash bounty for the right to lease the property. The requirement that this money be put up in advance of development tends to inhibit the participation of small firms because they may not have the cash to compete with large firms in the bonus bidding process. Furthermore, even if small firms attempt to compete actively in the bonus bidding process, they may find their capital depleted by the requirement of paying to the government large sums of money in advance which would otherwise be devoted to the development process. While the intent of the bonus bidding system--to produce the largest cash revenue immediately for the federal government--is laudable, it may in the long run discourage development and perhaps produce less net revenue for the government than a non-bonus bidding system tied to higher royalties. The early bidding on California geothermal leases (January 1974) indicates that the large energy firms have dominated the bonus bidding process.

Public vs. Private Development. The federal government must consider whether there are to be different policies regarding the development of publicly owned resources by private or public organizations. The issue has been enjoined by the American Public Power Association commenting on the Department of the Interior's Geothermal Leasing Program: "APPA is concerned that the Department of the Interior's proposed leasing regulations do not provide safeguards to prevent monopolistic control of publicly owned geothermal resources. Specifically, there are not adequate provisions to assure that publicly owned electric utilities, most of which are small, or other competitors in the energy market are able to get access to geothermal resources on fair non-discriminatory term. [1]"

APPA has requested that the regulations recognize the public interest intent of the Geothermal Act by stating that the federal antitrust policies will apply in weighing bids for geothermal resources. The organization has observed that for decades the Department of the Interior

has been administering power marketing programs which require preference in the sale of energy from federal projects be given to public agencies such as publicly owned electric utilities.

Lease Terms. There was considerable discontent expressed at congressional hearings about the relatively short initial lease terms provided by federal law. The time period specified was considered to be too short to permit development of the properties. On the other hand, the relatively rigorous development requirements were intended to ensure that the land was put into production and not held back for speculation. It is too early to tell whether the primary lease term is too short. However, some states have adopted considerably longer initial lease terms and therefore consideration to revising the term should be given after careful study of the actual performance of the present leasing system.

Renegotiation Rights. The Secretary of the Interior is given certain rights to renegotiate both lease terms and conditions as well as rents and royalties. There is a possibility that the renegotiation process could be used to remove certain geothermal lessees with whom the Secretary of the Interior has various agreements. The statute seems to indicate that failure to arrive at a suitable renegotiated lease will result in termination of the existing lease. While it is not anticipated that the Secretary of the Interior will be permitted by the courts to act in an arbitrary or capricious manner, the fact that there is a possibility of dispute and termination in the negotiation process may inhibit persons from investing substantial amounts of capital in what turns out to be a risky venture largely beyond the control of the private developer.

Administration of Environmental Regulations

Trade-Offs with Development. As noted in Section 4.8, environmental impacts associated with geothermal development can be divided into two categories: those which have important local but temporary significance (e.g., emission of odorous gases, noise, and so on) and those which have potentially lasting significance (e.g., contamination of groundwater supplies, seismicity, and subsidence). Clearly, some of these impacts must be prevented and the regulatory process must identify them a priori; other impacts, while temporarily disturbing, could be permitted if the need to develop this new energy resource is seen as pressing. In the case of temporary impacts, controlling mechanisms could range from indemnification by government for damages caused by geothermal exploration and development (if such activities are viewed as high priority) to self-insurance by the geothermal operators.

The recent congressional action with respect to the Alaska pipeline and strip mining indicates that there has been reassessment of trade-offs between environmental protection and energy requirements. As geothermal development proceeds, environmental protection requirements should be reviewed to forge the most appropriate relationship between geothermal energy development and environmental protection. This relationship must be sensitive to the following factors: the type of geothermal resource; local conditions, needs, and desires; permanence of the impacts; need and method for indemnification; and national energy situation.

Administrative Complexity. There are three distinct areas in which regulation seems to be required: land

use; environmental affairs; and the production and development of the geothermal resource itself. As described in Sections 2.4 and 3.3, the administrative process is extremely complex. One reason for this complexity is that each agency involved views the world from the perspective of its own charter and, despite the fact that the regulatory areas overlap and interact, compromise and accommodation are difficult. One approach to the streamlining of the administrative process would be to initiate "one-stop" geothermal licensing. This may be possible only in the long run. In the shorter run, efforts must be made to coordinate the various regulatory responsibilities both at the state and federal level to ensure that the important values embodied in the regulatory process are preserved and to reduce the burden on the geothermal developer to obtain the approvals necessary to initiate and develop projects.

Incentives for Utility Companies To Buy Steam

Geothermal energy will become an important source of energy in the United States if the utility companies buy it. Therefore, the interface between geothermal development and utility company use is probably the key area for the construction of incentives.

The economic risk involved in exploration and development of geothermal fields will probably limit direct investment by investor owned utilities. They may be expected to purchase steam from geothermal developers for use in generating plants located near the producing fields. To encourage purchase of the resource, the developers will probably be required to guarantee the longevity of the steam supply for a period comparable to the write-off time for the generating plant, normally 30 years. In this way, the utility is protected against the high risk involved in resource development (the early demise of the field), and can maintain its favorable position as an economically conservative industry with a regard to needed capital investment.

Municipally owned utilities, on the other hand, may have greater fiscal flexibility than either investor owned utilities or cooperatives. The municipality may be able to provide capital for geothermal ventures without serious effects on its bond rating.

A particularly powerful incentive will be to provide government "resource insurance," that is, insurance against the risk of early depletion. This would permit the resource developer to offer 30 years worth of steam, or its fiscal equivalent, to his only potential customer, the utilities. Legislation has already been passed by the U.S. Senate to guarantee loans made to geothermal developers (The National Energy Research and Development Policy Act of 1973, S. 1283, would allow the Secretary of the Interior to guarantee loans for projects up to \$25 million). By coupling such a loan program to some kind of private insurance against early depletion of the resource, both exploration and sale would be encouraged. One without the other is vacuous.

Diversification of Utilities

While most geothermal exploration and development will probably be initiated by organizations other than utilities, this will not be true in all instances. Furthermore, the case is certain to arise in which a geothermal developer wishes to utilize the resource for the generation of electricity rather than for selling steam. These situations create important impacts.

Under current SEC regulations, a utility holding company would probably not be permitted to develop geothermal resources for sale to others. Utilities which are not classed as holding companies might not be so constrained. Nevertheless, it is not yet clear how the various state public utility commissions would treat geothermal investments made by utility companies.

The situation would become even more complex if the geothermal resources were used for purposes other than providing energy for the generation of electricity; e.g., water for agriculture, heat for space heating and air conditioning, and the production of chemical and minerals from geothermal brines.

Transmission of Geothermally Derived Electricity

In order to meet its load commitments satisfactorily, a utility system must have a high degree of reliability. System reliability is achieved not only by using components of high reliability but also by providing for interchanges between adjoining systems in the case of an emergency. Because geothermal resources may be located outside a major utility's own area and at a large distance from any existing load center, electricity may be transported by transmission lines jointly owned by several utilities taking advantage of a geothermal site. Thus, an outcome of geothermal development could be the building of transmission lines which increase system interconnections.

Joint ownership of transmission lines may follow the patterns set by the Pacific Intertie. As described in Section 4.4 this DC line is owned by a group of publicly and privately owned utilities, including Southern California Edison Company and the municipality of Los Angeles. Electricity is generated at the federal Bonneville hydroelectric project in Oregon and Washington. Much of this line, over 800 miles long, is on federal land. The line itself was built by the Los Angeles Department of Water and Power up to the California-Nevada-Oregon borders; the rest of the line to the Bonneville power project was built by the federal government. While contractual agreements among the participating utilities are complex, the benefits of joint ownership do result in the economic exploitation of Bonneville power as far as Los Angeles, Calif.

The possibility of moving large amounts of power over dedicated transcontinental lines was discussed in detail in Section 4.4.

Because of the amount of capital required, the land use problems involved, and the complex utility and regulatory interface issues, a new institution will probably be required to do this. There are several alternative designs for this institution:

1. Cooperative arrangements among utilities along the route, extending by a considerable degree regional power distribution pools which currently exist in many parts of the country.
2. A federal agency such as the Bonneville Power Administration.
3. A single private venture, viewing itself as an energy transportation company, in a manner analogous to a gas pipeline company.
4. A quasi public organization modeled after the Communications Satellite Corporation.

This transmission institution will probably grow out

of or merge with the organizations which will transport energy from mine-mouth coal-fired generating plants now starting to be built in the West (Wyoming, Montana, and New Mexico) for power transmission to the Mid-West and the Pacific coast.

By the time dedicated transcontinental lines are in place, it is expected that the interconnected grid between regions of the country will be sufficiently developed to provide necessary system redundancy. The superimposition of transcontinental lines dedicated to "wheeling" large amounts of power from west to east will require careful coordination between the transcontinental lines and the lower voltage interconnected grid. The national transmission agency may have to take on some responsibility for "dispatching." This means closer tying together of all of the utilities in the country and should result in increased benefits in terms of system reliability and load balance.

Assuring Availability of Capital[2]

Figure 4.5.2 is a schematic of the possible monetary flow for geothermal resource development for the production of electricity. The activity of the federal government in terms of R&D and loan guarantees can be regarded as an investment to be returned to the tax-paying consumer in the form of the benefits of geothermal power.

The rate of monetary flow will be modulated by the connections shown by dashed lines in Figure 4.5.2. That is, these activities act as values in controlling the monetary flow. While the confidence level in geothermal resources will increase with government geothermal R&D efforts and thus have impact on the rate of capital flowing into geothermal investments, the primary stimulant to this flow can be expected to be government guarantees for loans. These guarantees may be made to banks or other financial institutions who lend money for development of geothermal resources. Currently proposed legislation (e.g., The National Energy Research & Development Policy Act of 1973) states that such guarantees may be made "against loss of principal or interest on loans made...to qualified borrowers for the purpose of acquiring rights in geothermal resources and performing exploration, development, and construction and operation of facilities for the commercial production of energy from geothermal resources."

Capital inflow will be stimulated by increasing confidence in the viability of developed geothermal resources, and to this end federal government R&D can be expected to contribute heavily, particularly in the areas of resource exploration, assessment of field longevity and productivity, and power demonstration. Two pieces of legislation discussed more fully under New Legislation could accomplish these government contributions.

The competitive position of geothermal energy vis-a-vis fossil fuels and nuclear power could be further influenced by several federal mechanisms if additional legislation were proposed and passed. These influencing mechanisms could include federal subsidies, similar to agriculture subsidies, and federally underwritten resource insurance. This latter will allow developers to guarantee steam production or monetary equivalent over the lifetime of the power plant to utilities who invest in generating and transmitting facilities at geothermal fields, and could provide the needed assurances for capital investments.

Another influencing mechanism could be the application of a salutary income tax depletion allowance and an annual deduction of current drilling costs. These have

NOTE: DASHED LINES INDICATE FACTORS WHICH MODULATE MONETARY FLOW.

Figure 4.5.2 FINANCIAL FLOW

been discussed earlier, especially in Section 2.5 under U.S. vs. Reich; The Geysers test case. It seems that until the geothermal industry enjoys these advantages, capital flow will be unable to become well established.

This is one role which the federal government could play in the early years in the development of geothermal resources which is not indicated in Figure 4.5.2. In order to encourage the substitution of geothermal energy for fossil fuels in the production of electricity, the government could indemnify utilities for certain losses incurred when plans for fossil plants have to be aborted. Because of the long lead-time necessary in the rate of development of geothermal resources, some utilities may not be in a position to switch to geothermal energy without incurring losses in the preconstruction phase of the planning for new fossil fuel generating plants. Where it is in the public interest (in terms of environmental impacts, for example) the federal government could reimburse the utility for such losses. To encourage phasing out of older fossil plants, rapid depreciation write-off may also be allowed. Of course, such reimbursements would require the recipient to reinvest in geothermal development.

Ventures in which utilities join with either oil companies and/or drilling companies can be expected to become a popular vehicle for raising necessary capital. These joint ventures represent the complementary interests of utilities and resource developers. In such arrangements, the participation of a regulated monopoly may provide the confidence needed to encourage investments in resource exploration. The rise of joint ventures on a large scale may require new tax and regulatory procedures, so that advantage can be taken of both utility-type financing and of federal subsidies for exploitation of geothermal resources.

New Legislation[2]

Congress has been working on several pieces of legislation in 1973 and 1974. The major bill is Energy Research and Development Administration (ERDA, formerly S.2744) now labelled HR11510; ERDA is a compromise bill from both Houses in its final stages of preparation. Its purpose is to ensure that all energy technologies receive fair consideration for national priorities and to expedite the United States' program of energy self-sufficiency in ten years. ERDA establishes an inter-agency coordinating committee.

Specific to geothermal energy, ERDA transfers geothermal administration from NSF to the ERDA committee. A related bill, S.1283, mentioned earlier, contains geothermal loan guarantees and provides an incentive for accelerating geothermal exploration. S1283 may either become an amendment to ERDA or be passed as a separate bill.

It seems almost certain in the light of U.S. energy needs that coordination of geothermal R&D must be handled by an objective agency such as the one established by ERDA. Geothermal R&D planning is currently being conducted by a federal interagency panel for geothermal energy research consisting of the National Science Foundation, the Atomic Energy Commission, the Department of the Interior, and the Department of Defense. As the geothermal program develops, these groups may have divergent and conflicting interest. If the legislation mentioned above is passed, this committee will be replaced by the ERDA committee.

An interesting point here is that while some legislation has been introduced by congressmen from states with KGRA's (Washington, Sen. Henry Jackson), other legislation has been introduced by those with no KGRA's

(Connecticut, Ribicoff). The introduction in the last two years of at least four bills that affect geothermal energy is indication of Congress' concern for development of geothermal energy as well as other included novel energy sources.

REFERENCES

- [1] Final Environmental Statement for Geothermal Leasing Program, Vol. 4 (Washington, D.C.: U.S. Department of the Interior, 1973), p. I.134.
- [2] See pp. 25 and 71 for a discussion of the recently enacted Geothermal Energy Research, Development and Demonstration Act of 1974 (P.L. 93-410, Appendix J) which mandates coordination of geothermal R&D and authorizes a loan guarantee and interest assistance program.

The following reference, not numbered in the text, was used as background for this section.

Final Environmental Statement for Geothermal Leasing Program, Vol. 4 (Washington, D.C.: U.S. Department of the Interior, 1973), p. CD-45.

4.6 Effects on Regions, Cities and Buildings

Introduction

When geothermal energy is used to produce electricity, its special effects on regions, cities, and buildings is slight; when it is used directly as a source of heat, it can affect regions, cities and dwellings in several ways. The top two levels of the relevance tree which structures and displays the various primary and secondary impacts are presented in Figures 4.6.1 through 4.6.5 shown on the following page.

In order to set the stage for this review of impacts, it is useful to list some of the characteristics of geothermal energy which will largely determine its effect on urban areas and buildings:

1. The basic resource is not exportable as such; its utility diminishes rapidly as the attempt is made to convey the heat more than 10-20 miles from the point of extraction. This, naturally enough, leads to the construction of heat-utilizing facilities, be they electrical generating plants, hot houses, industrial plants, swimming pools, or district heating services, near the geothermal wells.
2. The geothermal resources are found in widely differing physical circumstances--in relatively close proximity to existing communities and developed regions and, at the other extreme, in utterly wild and desolated land. It occurs in undulating, foothill country, in flat basins and valleys, in proximity to deserts, and in heavily forested areas. The terrain variations in themselves create conditions which will affect the development and utilization of the geothermal resource. In turn, the variations in setting will impact upon the way in which the resource is used, both locally and regionally.
3. In investigating the impacts of geothermal energy on regions and buildings, it would be well to remember that the longevity of each field is not yet well known, nor can it yet be estimated a priori. Compared to the lifespan of human settlements, greater than 100 years, the duration of a field might be short, less than 100 years. If a settlement is designed to rely on geothermal energy, and that source "dries up", then a back-up, perhaps a redundant source of energy, will be required.
4. Geothermal energy is of relatively small scale, at least in electrical generation terms. It appears that electrical generation will be accomplished through the use of a large number of approximately 100-200 megawatt generating stations scattered throughout a geothermal region; compare this to the 1100 megawatt steam and nuclear plants currently in vogue. Each well field and generating station will be, in comparative terms, relatively small in scale, both physically and as to direct spacial impact. This relates to cooling towers, the generating stations and wellheads themselves, collection piping, and all other dependent features.
5. While the scale of physical installations associated with geothermal energy is small, the amount of land used is by no means negligible. If one assumes that 1000 acres is required to support a 100 MWe plant, and that 190,000 MWe are developed by the year 2000, some 1,900,000 acres would be devoted to geothermal purposes.

This is about 2700 square miles, or roughly the area of the State of Delaware. While this number seems large, only about 10 percent of the land is physically disturbed by the installation for geothermal extraction and electrical generation, including rights of way for access roads and transmission lines within the leased site.

6. Some of the physical environmental impacts discussed in Section 4.8 will determine, to a large extent, the impacts of geothermal energy on communities and buildings. For example, patterns of use of geothermal energy will be determined to some extent by the malodorous odor of hydrogen sulfide emitted during the exploratory and operational phases of geothermal energy, the physical hazards associated with exploration, and the sonic effects of geothermal development. Physical hazard will be limited to the immediate environs of the exploratory sites, permanent well points, steam or hot water lines, and generating stations; the noise pollution effects can be considered important within the boundaries of a single well field tract and may be disturbing within one half mile of the periphery of the active wells and generating facilities.
7. The impact of transmission lines upon geothermal regions must be considered. The amount of land visually affected by transmission lines may be greater, perhaps by as much as an order of magnitude, than the total area dedicated to the use of transmission lines. Geothermal phenomena often tend to occur in areas of scenic diversity and even though the use of hot springs as medicinal facilities and health spas is now out of fashion, the continued use of such resources for tourism and recreation clearly must be taken into account. The early spas have tended to establish recreational tourist zones around them in areas of hot springs, as, for example, at Clear Lake, Hot Springs, White Sulphur Springs, etc. Another factor which should be taken into account relative to high lines is that in all likelihood they will not only go from generating station to the nearest point of load, but will tend to develop an interconnected grid from each generating station into its sister installations throughout the geothermal regions. Therefore, each generation station might have emanating from it not one, but perhaps as many as three or four transmission lines for interconnecting to other geothermal stations and to the general regional power grid, thus proliferating the amount of land visually affected by geothermal activity.

It should be noted also that geothermal resources often occur in areas which are water deficient, both with respect to present and future water resource needs. The dividing line between water surplus and water deficiency areas in the United States roughly bisects the Great Plains, with the entire western half of the country, with local exceptions, being in a water-scarce condition. In terms of development of geothermal resources themselves and of competing energy and general water requirements, the water deficiency condition is a very strong factor in determining the energy outcome and general outcome, in public policy terms, of geothermal exploitation.

Before providing more precise impacts on cities and buildings, it will be useful to review the experience of three geothermally active cities: Reykjavik, Iceland; Klamath Falls, Oregon; and Rotorua, New Zealand. All three cities use geothermal energy directly as a source

Figure 4.6.1

Figure 4.6.2

Figure 4.6.3

of heat. These case studies are presented below.

Reykjavik, Iceland

The brochure distributed by Reykjavik to describe its use of geothermal energy begins:

When a visitor approaches Reykjavik on a bright, still winter day, by ship or by airplane, he will first of all notice the absence of smoke rising from its chimneys. The dark cloud he is accustomed to see hanging over cities is nowhere to be seen, the air is fresh and clear...The wholesome air is due to the geothermal resources hidden under the city and its vicinity, and the initiative of its citizens in utilizing it.

Reykjavik has not always been a smokeless city. Those who remember Reykjavik in the 30's and 40's

recall, that sometimes on still days in winter, the cloud of smoke over the city was so black that the town was hardly visible. But under this depressing cloud, people were planning the utilization of the heat they knew to be under the city.

Iceland is indeed an ideal place for this development. The climate requires that houses be heated 90 percent of the time. Except for peat and lignite, no fossil fuel sources are indigenous to the country. The Atlantic rift fortunately runs through Iceland and is manifested by many hot springs and geothermal steam fields.

Exploitation of the geothermal resource near Reykjavik began in the mid-1920's when hot spring water was used to heat hothouses for the growing of vegetables.[1] A hot spring commonly used by Reykjavik inhabitants for washing clothes was tapped in 1928 and soon thereafter

Figure 4.6.4

Figure 4.6.5

190°F water, flowing at a rate of 220 gallons per minute, was piped a distance of two miles to the town's newly built swimming pool, a hospital, two school houses and 70 residential houses near the swimming pool. Satisfactory results with this first experiment led to the search for other natural heat sources near the town.

Today, the Reykjavik District Heating Service derives its energy from three major thermal fields as follows:

Field	Quantity	Temperature
Reykir	3900 GPM	180°F
Reykjahllo	2000 GPM	187°F
Reykjavik	4700 GPM	260°F
	2800 GPM	218°F

The fields at Reykir have now yielded over 300 million cubic meters of water over a period of 35 years without any drop in temperature or decrease in the rate of production. [2] The service in Reykjavik has expanded rapidly. In 1963 only 60 percent of the population of the city enjoyed district heating; by the end of 1971, 96 percent of the population utilized geothermal heat sources. Figure 4.6.6 shows the more than fourfold growth in geothermal energy production in Iceland since 1960.

Source: Einarsson, Sveinn S., "Geothermal District Heating," Geothermal Energy, UNESCO, 1973, p. 125.

Figure 4.6.6 GROSS PRODUCTION OF GEOTHERMAL ENERGY IN ICELAND (ABOVE 40°C)

In Reykjavik, the hot water distribution system is handled by a municipal agency and is considered to be a normal public service roughly paralleling cold water supply and sewerage services. The system is designed around a minimum outside temperature of 14°F. When the temperature drops below this figure, additional energy is supplied from hot water storage tanks and by operating oil-fired peak demand heating plants. After the hot water is circulated in homes for space heating, the users in Reykjavik are permitted to extract the remaining heat for swimming pools or small greenhouses. The delivered heat from geothermal sources is relatively inexpensive compared to other fuels, as the following table shows [2]:

Heat Source	Price (\$ per million Btu)
District geothermal heating	1.04
Night electricity	1.33
Fuel oil	1.73

Hot water from the remote geothermal sites is transmitted to the city through 14 inch diameter steel pipes laid in concrete conduit about ten miles long. Both single and double pipe distribution is used; the double pipe system allowing for the return of expended water. In the double pipe system, the waste water is mixed with

Source: Einarsson, Sveinn S., "Geothermal District Heating," Geothermal Energy, UNESCO, 1973, p. 130.

Figure 4.6.7 SCHEMATIC DIAGRAM OF REYKJAVIK HOT WATER SYSTEM

incoming supply water to capture a measure of the wasted heat. In the main supply lines and street distribution pipes, various forms of insulation are used to decrease the heat loss. These include: turf, lava slag, rock wool, aerated concrete or foamed plastics. The final distribution lines to the homes themselves are insulated with rock wool, felt, polyurethane foam, or high density polyethylene foam. The heat loss in the distribution system is estimated to be approximately 11 percent. Figure 4.6.7 presents a schematic of the Reykjavik hot water distribution system.

The impact of geothermal heat on buildings is demonstrated in the following quotation:

Since about 1930 elementary and secondary boarding schools in the rural areas of Iceland have, whenever possible, been sited at locations where geothermal energy is available. In these centers the school buildings and living quarters for the pupils and staff are geothermally heated. They are also as a rule equipped with a swimming pool, and are self-supplying with vegetables (tomatoes, cucumbers, cauliflower, etc.) grown in their own hothouses. There are now many such schools in various parts of the country and quite often they are used as tourist hotels during the summer holidays. Quite often these centers have formed the nuclei of new service communities in the rural areas.[2]

Klamath Falls, Oregon

Early settlers in Klamath Falls area used the indigenous hot springs and boiling mud pots in the flat rolling hills for cooking fish and game. By 1915 a greenhouse had been built near one of the hot springs and by 1928 a natatorium had been built to exploit the presumably therapeutic capabilities of hot springs in the area. While the original hot springs have disappeared, probably through lowering of the water table, two natural thermal displays still exist near the city: one is a spring which emits water at a temperature of 165°F with a flow rate of at least 100 gallons per minute, and the other is a spring located near Upper Klamath Lake.[3]

By 1967 more than 350 wells had been drilled serving more than 450 houses, several apartments, six schools, a number of businesses and commercial firms, and the Oregon Technical Institute. The depth of the wells ranges from 100 feet to almost 2000 feet; these wells produce water in the temperature range of from 140°F to 235°F.

As contrasted to the Reykjavik case, users of geothermal heat in Klamath Falls tap the resource themselves. In most instances, a well is drilled to a satisfactory depth and is cased to the bottom and perforated. A long single return pipe coil is inserted into the casing. The wellhead is then sealed. The coil within the casing is connected to space heating radiators. The coil is filled with domestic water and, if the system is small, circulated by thermal forces. For large systems, for example involving two or more houses, a pump provides more rapid circulation. This system avoids any problems which might occur due to deposition of solids.

Where Reykjavik provides an example of a centrally controlled large-scale geothermal space heating system, Klamath Falls provides an example of a small-scale, individually exploited geothermal heating system.

Rotorua, New Zealand

In many ways the geothermal activity at Rotorua lies between the extremes of Reykjavik and Klamath Falls: from the standpoint of resource size, effect on the city and its buildings and the institutional arrangements in effect, Rotorua represents a middle ground.

The first use of the geothermal resources in the Rotorua area probably occurred hundreds of years ago when the Maoris utilized the local hot springs and pools for heating of their homes and cooking. The earliest European domestic use of the resource occurred before the turn of the century when coils of steel pipe were inserted into the hot pools; municipal water under pressure was circulated through the coils in order to obtain a hot water supply. The earliest shallow wells were bored just before World War II; scarcity of fossil fuels, lack of reliability of the national electric power grid, and the high cost of electricity led to the initial expansion of the use of geothermal resources.

A fine example of the impact of the use of geothermal resources in building design can be found in the Queen Elizabeth Hospital, built in 1942 as a military hospital, and later converted to the National Hospital for Rheumatic Diseases.[4] In this hospital a physiotherapy pool uses geothermal fluids; the hospital is heated by geothermal sources; sterilizers and kitchen cooking equipment are designed to use geothermal steam; hydrotherapy and alkaline and acid geothermal therapeutic baths are also available.

After the War, geothermal exploitation was accomplished by small groups of property owners who organized into supply districts. By 1970 there were 650 wells drilled to depths of greater than 200 feet; perhaps 300 more exist at lesser depths.

Layout of the city is such that most businesses and residences there can be provided with geothermal heat from within the city's own boundaries; tourist locations also apparently have adequate heat reserves. Industry in Rotorua is not very extensive; it includes a veneer factory, a timber drying kiln, a mushroom farm, and a commercial tomato operation (1970). Geothermal ground is still left in areas ideal for industrial expansion and it is apparently the intent of the city to guard these areas for future use.

The first ten thousand million Btu per year of geothermal heat is free to industrial users in New Zealand; consumption over that amount costs 3¢ per million Btu, payable to the Crown. All private domestic use is completely free.

Rotorua now has placed into effect a series of new regulations which cover private use of geothermal energy. Property owners wishing to drill for geothermal fluid must first obtain a license; licenses will not be issued if the existing wells in the neighborhood may be endangered. Some areas of the city have had wells discharge dangerous gases; permits for drilling in nearby sites are no longer approved. Owners are liable for any damage which their geothermal drilling or operations may cause.

The new regulations also require that wellheads be kept outside of buildings so as to prevent the accumulation of hydrogen sulfide or other leading gases. These regulations have had the effect of encouraging the drilling of community wells in suburban neighborhoods. Expended fluids are disposed of simply by dumping them into

conditioning system employs a 130 ton lithium bromide absorption unit which is capable of absorption of approximately 2.3 million Btu per hour.[6] Individual air conditioning units with separate heat transfer coils and fans are provided in each room. The system functions through the use of a buffer heat exchanger; the 300°F geothermal brine transfers heat to clean water which enters the absorption refrigeration cycle at 250°F.

Cooling water for the absorption comes from a nearby stream. Most of the components are currently commercially available. A review of the system design and the experience to date in Rotorua suggests that the general design principles could be expended perhaps even to the level of providing district cooling. (The lithium bromide absorption air conditioning unit is of American manufacture.)

In the paragraphs which follow impacts on existing regions and cities, new regions and cities, existing buildings, and new buildings are reviewed.

Water Deficiencies. The scenario described in Section 3 calls for the development of at least 190,000 MWe of geothermal electricity in the United States by the year 2000. Most of this energy is produced in the West. Some is exported, but most is used indigenously. As argued elsewhere, low cost energy, particularly low cost electricity, will bring new industry to the area and affect the development of existing and new urban communities. This growth in development, triggered by low cost energy, may be on a collision course with the availability of process and potable water in the West. Not only is low cost energy likely to increase industrial and potable water demands, but the production of energy itself will require water. Given the fact that

GENERAL SCHEMATIC

LEGEND:

- ① PUMP
- ⌘ GATE VALVE
- ⌘ AUTOMATIC CONTROL VALVE
- ⌘ CHECK VALVE
- ⌘ STRAINER

WATER FLOWS:

- 1 CONDENSER COOLING WATER
- 2 CHILLED WATER
- 3 THREE-PIPE RETURN WATER
- 4 HIGH TEMP HOT WATER
- 5 LOW TEMP HOT WATER
- 6 GEOTHERMAL BORE WATER

SHORT SCHEMATIC

TYPICAL RECIRCULATING SYSTEM

SYMBOLS

WATER FLOWS

- 1 CONDENSER COOLING WATER
- 2 CHILLED WATER
- 3 THREE-PIPE RETURN WATER
- 4 HIGH TEMP HOT WATER
- 5 LOW TEMP HOT WATER
- 6 GEOTHERMAL BORE WATER

Figure 4.6.8 PIPING SCHEMATIC - ROTORUA INTERNATIONAL HOTEL

the western states contain not one but at least five possible forms of new energy development, oil, oil, natural gas, coal, and solar, as well as geothermal, the demands upon regional water resources for any of these, much less all of them, will be substantial and probably cannot be met except by importation. On the positive side, however, is the fact that geothermal requires next to the least in the way of water input of any of these five forms; the only one being better would be solar energy, which may be a dry process. Figure 4.6.9 below summarizes the water requirements of water resources regions of the West through the turn of the century as estimated by the Water Resources Council in 1968. [7] Note that by the year 2000 approximately two and a half times as much water will be required for withdrawals as in 1965 and one and a half times as much for consumptive use.

Because of the concern about water, it may be necessary to look to geothermal sources, not only for heat and electricity, but potentially for water as well. As mentioned in Section 2, the Department of the Interior has begun experimentation in this direction in the Salton Sea area of California. Clearly, the production of usable water for agricultural or industrial purposes from geothermal brines would have a most beneficial effect.

Impact on Regional Lifestyle. The effect of geothermal development and indeed of all energy development upon western regional character, regional lifestyle, and regional choices, is considerable and potentially overwhelming. The dichotomy of opinion which seems to have arisen between the States of Montana and Wyoming over the pace of coal resource development is an intraregional argument likely to be repeated and magnified over the next decades. As geothermal resources and other forms of energy production rise in demand nationally, people of the western states fear pressure will be applied on that region to export at any cost to the region. The national will could be imposed on the region, irrespective of the region's attitudes and desires. They fear that the wide open spaces will be full of smokestacks, high lines, and people.

This fear does not seem to be justified in the case of geothermal development. Figure 4.3.8 showed that almost all KGRA's are located in countries with a density

of under 50 persons per square mile. They are widely scattered, however, and except in the few cases where unusually large resources are found, most installations will probably be of moderate size. These are not labor intensive and are not likely to attract any sizeable infusions of population, particularly when limited to power production only. The effect will be more to bolster existing lifestyles than to introduce disruptive elements.

Air Quality Issues. The Colorado Basin states as a whole and many other of the microclimates within the western states are inversion prone. Therefore, it is likely that this air entrapment effect, the water deficiency effect and the perceived threats to future lifestyle may cause setting upper limits on regional development and growth based on air and water quality standards. This would be done irrespective of the abundance of energy resources within these western states. From the standpoint of air quality, geothermal resources ought to be considered for the satisfaction of regional base load power requirements, augmented by solar energy, in priority over other energy forms, in order to preserve the purity of western airsheds. The clean air lessons of Reykjavik should be persuasive here. In short, the impact of geothermal energy on development in the West may be to remove a limit (polluted air) which might have otherwise existed. The effect on air pollution of replacement of 35,000 MWe of coal-fired plants and 41,000 MWe of nuclear plants is displayed in Figure 4.6.10 on the following page.

Thus the development of the base case geothermal electricity would prevent a significant amount of air pollution from coal and nuclear power plants. Further, geothermal space heating could displace even larger amounts of coal, oil, and gas, leading to greater savings from air pollution.

Outdoor Recreation and Tourism. Geothermal locations lie near almost all of the major National Parks, national recreation areas, and national monuments in the West. Therefore, the impact of energy could be to bend the regional character. Without adequate planning, geothermal energy could impact adversely on important outdoor recreation and tourism resources. The most visible element of geothermal development will be the proliferation of high tension transmission lines as well

REGION	WITHDRAWALS			CONSUMPTIVE USE		
	USED 1965	PROJECTED REQUIREMENTS		USED 1965	PROJECTED REQUIREMENTS	
		1980	2000		1980	2000
MISSOURI	19,344	23,264	27,876	10,554	13,160	14,979
RIO GRANDE	7,289	8,330	9,510	4,403	4,676	4,991
UPPER COLORADO	4,017	5,675	6,575	1,982	2,700	3,100
LOWER COLORADO	6,913	8,497	8,428	3,448	4,075	4,645
GREAT BASIN	5,115	7,055	7,550	2,253	3,299	3,562
COLUMBIA - NORTH PACIFIC	29,631	41,407	90,135	10,521	13,581	17,325
CALIFORNIA	37,300	56,290	120,510	20,944	29,205	32,660
TOTAL	109,609	150,518	270,584	54,105	70,696	81,262

SOURCE: WATER RESOURCES COUNCIL, (1968). [7]

Figure 4.6.9 ESTIMATED WATER USE AND PROJECTED REQUIREMENTS, WESTERN WATER RESOURCES REGIONS (MILLION GALLONS DAILY)

POLLUTANT	DISCHARGE/DAY ***** PER 1150 MWE PLANT	DISCHARGE/DAY***** PER 25,000 MWE
COAL-FIRED PLANT		
- SULFUR OR SO ₂ **	150 TONS	4600 TONS
- NITROGEN OXIDES AND OTHER GASEOUS EFFLUENTS	60 TONS	1800 TONS
- PARTICULATES***	9 TONS	270 TONS
NUCLEAR PLANT		
- TRACE AMOUNTS OF RADIOACTIVE SUBSTANCES	A FEW HUNDRED- THOUSANDTHS OF A GRAIN CONTAINING 2 CURIES OF COM- PARATIVELY LONG- LIVED RADIOACTIVITY	ABOUT A THOU- SANDTH OF A GRAIN CONTAIN- ING 75 CURIES OF COMPARATIVE- LY LONG-LIVED RADIOACTIVITY

**ASSUMING USE OF STACK GAS DESULFURIZATION SYSTEM.

***ASSUMING USE OF HIGHLY EFFICIENT PRECIPITATION AND SCRUBBERS.

*****TYPICAL PLANT DATA PER UTILITY INDUSTRY SOURCES.

Figure 4.6.10 POSSIBLE AIR POLLUTANTS ELIMINATED BY
SUBSTITUTION OF GEOTHERMAL POWER PLANTS
FOR 35,000 MWe OF COAL-FIRED PLANTS AND
41,000 MWe OF NUCLEAR PLANTS IN YEAR 2000

the general creep of urbanization and industrial development. It is hard to escape the conclusion that, in common with other forms of energy development, geothermal activity within these scenic preserves or in areas adjacent to them can have an effect which some will view as detrimental. Therefore, a clash of interests between those who feel they guard the appearance of the countryside and those who favor development seems likely. Clearly the developers of geothermal resources will have to be sensitive to their impact on the regional environment and find ways of minimizing or making their effects beneficial. One could imagine that the development of geothermal resources would open new areas to recreational use and that expended geothermal waters could provide a new recreational resource in the form of new health spas or fishing sites.

Ethnic Lifestyles. There is little doubt that the ability of the Indian populations to maintain ethnic integrity, to hold to traditions, and to keep influence over their youth in coming generations; will be impacted by energy-intensive activity throughout the western states. While this can be a positive factor with respect to alleviating poverty and by creating a base of employment in many areas contiguous to Indian lands, this progress will not be without a price in respect to the Indian heritage.

Prime Agricultural Lands. Similarly, highly productive agricultural lands of the Imperial Valley and the Napa-Sonoma vineyard areas, for instance, and the grazing lands of the undeveloped high country, will all be impacted by energy development, thereby reducing the possibility for maintaining the agricultural and, hence, cultural diversity and the distinct regional character of certain parts of the West. It is becoming increasingly evident to students of land use that natural systems and patterns of land use based upon natural process only, that is, farming, ranching, grazing, silviculture, etc., can always be outbid in the free market by any form of land development, industrial process, energy-based development, or mineral extraction. Any and all of these can set a higher mark for the land price than can the economic activity based upon natural process only. This is most certainly true for unmodified existing natural systems, which have no perceived "market" value.

Effect on Existing Close-In Communities

The Exploratory Phase. Aside from the obvious environmental impacts of noise, noxious odors, and the appearance of high tension lines, geothermal energy is likely to bring land speculation to close-in communities. A quote from the Environmental Impact Statement, on the Clear Lake-Geysers area, states that "much of the private land which is under lease would have the value of approximately \$100 per acre if it had no geothermal potential. Sonoma County tax records indicate that one 200-acre parcel (of geothermal potential) adjacent to The Geysers resort had a land value of \$16,400 per acre. The tax on this parcel yields Sonoma County over \$93,000 per year." [8] Taxation for possessory interest in undeveloped leases will be another factor affecting the local close-in communities. That is, the local taxing authority, with regard to geothermal potential, will tend to place assessed value upon lands with geothermal potential in mind. Both the taxing aspect and the speculative aspect will cause land price inflation once geothermal probability has been established.

The increase in land value fueled by geothermal prospecting will be good for those willing to sell or lease their land for those purposes, bad for those seeking to buy land for other purposes, and bad for those keeping their land, particularly if kept for scenic or other low intensity purposes. The market price for geothermal land can outbid the grazing, forestry, and cropland price structure hands down.

The increase in taxation related to anticipation of geothermal development is bad for "keepers," and bad for sellers and buyers, unless the sale or lease is related to geothermal prospecting.

On the other hand, the general population will benefit by an increase in the local tax base. This will lead to increased and higher quality public services such as education, health, police, and welfare. This effect will certainly improve these aspects of the public living environment.

The Operational Phase. Communities close to geothermal resources will attract new industry. This impact is discussed in Section 4.2. Growth of new industries will have concomitant effects on community population and economics. It is difficult to forecast whether such impacts will be considered desirable or undesirable within the communities involved. Some will see this growth as an intrusion into their privacy; others will see it as a dynamic and necessary step into the 21st century and a general improvement of their present life.

The pace of geothermal development will not unduly alter the character and rate of development of any established large close-in city, but its impact will be more strongly felt in smaller communities. The gradual, incremental activities of wellfields and generating plant activity may not provide sufficient impetus in itself to make feasible the regional hospital, the community college, or the group cultural activities which characterize the mature, larger community, without special planning.

The change in regional character likewise will be gradual, except in presently uninhabited or very sparsely inhabited environments, where the new activity will create an immediate and long-term radical change.

Terminal Operations. The individual wellfield will one day go cold; its generating plant will fall idle. The time span is conjectural but is likely to be no less than 20 years and maybe more than 100. In the life of a

community, 100 years is not so very long. Closing of individual geothermal fields will undoubtedly impact negatively upon close-in communities, not as suddenly as Cripple Creek but as inexorably as Appalachia, except to the extent that other wellfields (eventually themselves depleted) or other energy modes take over to hold the line, to provide jobs, taxes, and energy, the acknowledged bloodstream of modern life. These thoughts give rise to questioning whether the leasing program should not make explicit provision for a continuity of energy availability to existing close-in communities, which logic indicates to be the first and last served by the KGRA in or near which it sits.

This could take the form of a cluster of timed-release leasing tracts over which the close-in community had some control as to the date for development. In a loose way, this is analogous to the historical forest preserves controlled in the adjoining hinterland by European capital cities, forests such as Paris' Bois de Boulogne and Oslo's Nordmarken.

The close-in community ought also have protection as to the restoration of the derelict wellfield (which the leasing regulations speak to) and also to settlement growth options for the fallow acreage (which they do not). Now is the time to start planning for all of these eventualities.

Effects on New Cities[9]

Economic Base. The number of jobs provided by the prototypical geothermal installation is, in itself, insufficient to provide a large enough work base to justify development of a new community composed of wage earners dependent upon the geothermal activity and its multiplier effect. Assuming that the geothermal installation employs 150-200 workers and that these workers have an economic multiplier of 2, the communities supported will total between 1000-1300 persons. The 250 households thus created could not justify the application of the Title VII procedures of the National Housing Act, and a proposal so based would fail the job opportunity and economic viability tests of the Department of Housing and Urban Development under the New Communities Review Process. If, however, the geothermal activity supplements another activity, such as outdoor recreation or tourism, which in itself is usually economically marginal, both would be strengthened measurably and the viability threshold might be reached. For example, this is a strong possibility for the Mono Long Valley KGRA in east central California. This is a beautiful mountainous resort area now. Development of the geothermal potential will give all year employment opportunities and economic strength leading to expanded recreational activities. [8]

It is significant to note that all the new towns so far approved under the New Communities Act (Title VII) are located in the central city and the suburbs, and none is beyond the present outer limits of suburbia. One proposal, Brier Hill, was a scant 60 miles from Pittsburgh and yet failed the economic test in the period following pre-application approval, due largely to the work base question.

Longevity. As with the existing close-in community, the new town which depends wholly or partly on a specific geothermal installation will be concerned with the longevity of that wellfield. It will be even more critical for a new community linked to a geothermal source to have assurance as to a relatively long certainty of supply because the new town is in essence an entrepreneurial venture. Neither the government as guarantor, nor a financial institution as mortgagor or

equity partner, would be willing to give their backing on such an uncertain situation based on energy job base of a 30-100 year variable longevity. The National Housing Act Title VII government backed bonds are 50 year obligations. The financial community will require assurances of at least that long a time in the economically viable life of a new geothermal based community. So the unproven longevity of American geothermal sources constitutes a probable block to linking new town development to them, at least directly, attractive as that may be on other grounds. Some special government guarantee might be required to effectuate a marriage of a geothermal new town to a willing financial backer.

Leasing of Federal Lands. Since KGRA's have a high probability of occurring on federal land, another new avenue of governmental sponsorship of new communities could be explored, and that is the leasing of federal lands for a new town. This is unprecedented to date, and would be enormously attractive because of the favorable effect on financial requirements of leasing as against land aggregation by purchase in fee simple. The financial breakeven time for a new town runs from 10 to 30 years. Therefore the financial load of land assemblage and initial development is extremely heavy, especially for private entrepreneurs. (This is one of the chief reasons for the paucity in new town creations in the United States.) If federal land could be based as a complete package for a 99 year minimum, with renewal, the initial financial feasibility for a new geothermal supported town could be greatly enhanced.

At the end of that road there would be another interesting question--what would happen at the ultimate end of the lease term? Would the Federal Government own a new town or would the land have to finally pass into state jurisdiction and become a normal incorporated municipality?

Cultural Maturation. Cultural maturation of communities is a relatively slow process, based primarily on population growth levels but also paced by the sequence of concerns which require community attention and which the community marketplace can afford at various points in its growth cycle. Housing and minimal convenience shopping are succeeded by elementary schools, more shopping, and a church or two. High schools come later, as do clinics and, still later, hospitals. A rule of thumb on medical service indicates that a hospital bed must be supported by from 250-400 people and even a minimal hospital requires a service population of say 12,000-20,000. Public libraries and public gardens are further along in a town's life cycle, as are museums, theaters, and community colleges. These sequences are illustrative only but border on the norm. A community requires quite a number of decades to accumulate the cultural assets which are equated with the full round of communal life and to create the kind of town that will satisfy its citizens' normal requirements for cultural adequacy. Therefore if geothermal energy is to be at the base of a town's being, provision for longevity by reservation of future wellfields would seem to be a requirement of public policymaking. Enough time, greater than 50 years, must be allowed for in order for the new geothermal community to achieve a well balanced social and cultural maturity.

New Locations and Designs; What Would Be the Geographic Considerations Involved in Selecting a Site for a Geothermal City? Proximity to the geothermal resource so that the heat contained in the geothermal fluids could be used directly as well as for the generation of electricity is a prime consideration. In addition, it would be hoped that the geothermal fluids would be of

sufficient purity so that they could furnish potable, industrial, and agricultural water for the community. The community would be served by existing or future transportation systems and would be close enough to existing industrial sites (or could serve as a future location for industry) so as to provide an appropriate and adequate job base.

Idaho, Oregon, and Washington, for instance, might provide such sites since the agricultural and lumber industries located there offer possibilities for immediate use of process heat. Likewise there are valuable mineral resources throughout the West which may be exploited economically with nearby geothermal energy. Some of these are: (a) coal--Wyoming, Montana, Utah, New Mexico, Colorado, Arizona; (b) oil shale--Colorado, Wyoming, Montana; (c) phosphate rock--Idaho, Wyoming, Colorado; (d) copper--Montana, Utah, Arizona; (e) potassium fertilizer--New Mexico; (f) various other metal ores--all western states; (g) aluminum ores (dawsonite)--Colorado, Utah; and (h) magnesium, potassium, lithium, chlorine, bromine--Great Salt Lake, Utah, Imperial Valley, California.

In the design of the new city, important lessons can be learned from Reykjavik, Rotorua, and Klamath Falls. The geothermal fluids would be extracted by a district service organization; it would furnish energy for district heating and cooling as well as for the generation of electricity. In addition, the low grade heat remaining after primary use of the geothermal fluids could be used for greenhouses, aquaculture, swimming pools, health spas, and the like. If the city is located in a semi-arid region, and the geothermal fluids can be processed to form water acceptable for agricultural uses, the surrounding countryside can be made fertile and productive.

Effects on Existing Buildings

Heating. There is likely to be little effect of geothermal energy on existing buildings within communities which are distant from geothermal sources; for buildings in communities close to geothermal sources, the introduction of inexpensive forms of heat could, in some few instances, lead to the conversion of fossil fuel space heating systems to geothermal heating systems. Conversion appears to be quite simple and requires only the substitution of geothermal heat for fossil heat (if the geothermal heat is of high enough quality). It will be easiest for existing hot water heating systems. As for air conditioning, the conversion would be much more complex and probably would not be practical unless district air conditioning were introduced.

The prospects for district heating by recaptured geothermal waste heat are quite attractive. Even there, direct use of the geothermal heat for space heating is many times more thermally efficient in end use than by converting to electricity, the problem being one of bringing the demand to the source.

Prototypical cases for geothermal district heating would include:

1. Taking the hot brines from the steam separator into the district heating loop, which would extract in the order of 50-60°F in temperature drop, returning it to the generating system as condenser water then running to the reinjection wells, or

2. Taking the hot water from the end of the condenser water cycle plus the waste by-pass water, running it through the district heating lines and then to reinjection wells.

The first approach would provide initially higher water temperatures to the district heating system, but would require double piping in the sense that it is assumed that the building complex to be heated is some distance away from the wellfield so as to avoid its hazard, noise, and odor. The second has the logic that the hot waste water must be reinjected to the bearing stratum at some distance from the operating wellfield in any event so that the mains piping for district heating is in large measure already provided as part of the normal generating cycle.

The assumptions underlying a prototypical case might be of these kinds:

Assume: - Hot water of 185°F entering the system

- a 55°F drop within the district heating cycle
- 130°F water into the reinjection wells
- a mild winter climate
- therefore the heating requirement would approximate 30 Btu per square foot per hour, of a typical residence of 1500 square feet.

The equation for hot water gallonage would be:

$$\frac{30 \times 1500}{55^\circ \Delta T \times 8.34 \times 60 \text{ minutes}} = 1.63 \text{ gpm (say 2 gpm)}$$

A rule of thumb therefore would be 2 gpm per residence for residential district heating. Considering the tremendous gallonage of utilizable hot waste water, it can be assumed that any hot water geothermal generating plant could supply district heating for a very sizeable community.

The cost/benefit ratio for such a case would be based upon comparing it to space heating utilizing alternate fuels, residual oil being the obvious measuring stick.

The formula would be:

$$\frac{\text{Annualized full cost of residual oil space heating}}{\text{Annualized full cost of district heating}} = 1$$

- Where: 1. Annualized full cost of residual oil space heating is aggregate of oil-fired heating plus fuel cost
2. Annualized full cost of distinct heating is distribution system plus pumping cost plus price of heat, if any

To test this out, assume a district heating system of 1000 dwelling units. The savings in capital cost for elimination of the oil-fired boiler (or furnace) plus oil tank plus cost of oil would be available for financing the district heating system.

Assume: - Average savings in first cost, \$1000 per dwelling

- Average annual fuel oil cost (1973 prices) per dwelling, \$400
- A constant of .108 write-off of 8 percent for 20 years

The first cost money contribution, assuming a cost/benefit ratio of 1.0, available for the district heating system would therefore be \$12,962 per dwelling, or \$12,962,000 for 1000 dwelling units.

To appreciate the order of magnitude of such a fund, assume for the moment that half of the total would be available for piping, the other half for heat charges, pumping cost, etc. Assume also that the average flow in the primary district heating loops would be half of the connected full demand (i.e., a diversity factor of 2), therefore the mains piping sizes would be in the order of 10-12 inches. Piping of these sizes would cost on the order of \$50 per installed lineal foot. So, for illustrative purposes, if the entire system were of these large sizes (which it would not be), it could finance 24-1/2 miles of piping. In actuality, since the average pipe size would be considerably less counting secondary loops, a figure twice as large is more likely. In that event, if all dwelling units were detached houses, they could be spaced about 500-600 feet apart, ranged on both sides of streets. Considering also that the operating fund might be spread over, say, the 20-year write-off period, the money available for use charges, pumping cost, maintenance, and sinking fund for system replacement, would be \$325 per dwelling unit per annum, a tidy sum, particularly since the waste water should be free of charges. All this approximate arithmetic tends to indicate that the economics of district heating by geothermal waste heat would appear to be very attractive indeed. The savings in oil by the use of geothermal energy depend on the annual load factors. The following figures are reported[2]:

Cherkest (USSR)	680 tons oil/Gcal year
Reykjavik (Iceland)	870 tons oil/Gcal year
Paratounka (USSR)	1090 tons oil/Gcal year
Caspilok (USSR)	1440 tons oil/Gcal year

The Reykjavik district heating system thus saves about 150,000 tons of oil annually that would have had to be imported, and the annual cost of heating for the customers is only 60 percent of the cost of heating with oil. This is for a community of 72,000 people.

District Cooling. If district heating by geothermal waste heat appears attractive, then the economics of geothermal cooling appears even more attractive, particularly as compared to cooling by electric drive evaporative condenser systems.

The heat requirement for absorption system space cooling averages between 14 and 17 pounds of steam per ton hour of refrigeration, or its equivalent in hot water which is 14,000-17,000 Btu. The cooling effect, i.e., 1 ton of refrigeration, equals 12,000 Btu. Thermal efficiency of absorption chillers ranges therefore from 70-85 percent, as compared to the thermal efficiency of 4-1/3 to 8-1/3 percent for space cooling by electric drive systems powered by geothermally-produced power, roughly a tenfold better average benefit in end use and nearly twentyfold in the extreme. (Remember that the geothermal power plant efficiency is only 10-14 percent.)

At the present time, absorption chillers work best, all things considered, at about 500 ton capacity. As these are relatively sophisticated machines, several machines should be grouped together to facilitate professional operation, to provide service through reserve capacity during maintenance shut-downs and breakdown of individual

machines; 100-ton units are about the smallest on the market. Until recently, maximum input temperatures of 220°F plus were required to operate these machines, but now efficient operation can be assured with 170°F plus input temperatures, thus bringing absorption cooling into the realm of possibility for recaptured waste heat from geothermal electric generating plants.

There is also current interest on the part of the equipment manufacturers in producing small unitized absorptive chillers, say 2-10 tons, as a resynthesized version of the old gas-fired household refrigerator. If these become available, then the spectrum of space cooling by geothermal waste heat can be extended to the detached residence or other small detached building. Until then, dwellings and other building uses would have to be clustered, so as to be supplied by the larger absorptive units.

Chilled water travels even less well than hot water due to the narrow usable range of temperatures in which it operates to provide space cooling, normally only 4°F, 44-48°. The minimum temperature safely attainable is 40°, as below this the danger of freeze-up due to operator error or mishap is too high. The maximum temperature to achieve dehumidification of the conditioned air is 55°F. So the distance for transport of chilled water itself must be very short, in the hundreds of feet, to stay within usable range even with the best of modern pipe insulations.

A heat exchanger would have to be interposed between the hot brines or other corrosive geothermal waste waters and the absorption units, but these are of very high efficiency also.

A further interesting facet of geothermal space cooling (and geothermal district space heating also, for that matter) is that the district cooling system can be designed for peak load and operate at any load below the peak without concern for fuel consumption bulk pricing, or other such concerns related to fossil fuel use or fossil-derived electricity. This is because the amount of hot water would be constant, the withdrawal of heat could vary widely according to demand, and the resultant temperature leaving the system would be of no real concern as the water is to be reinjected into the earth in any event; it is simply to be used as a heat resource en passant.

In those geothermal areas in which the climate required no space heating, the district cooling system would need to be designed within the distance limitations imposed by the design criteria for chilled water. However, where space heating and cooling are required in alternation, the district piping system would supply either effect with equal efficiency, thus helping the amortization of the capital cost of the distribution system, if the distance limitations for cooling are respected. The capital cost for the condenser cycle of electric drive central air conditioning equipment would be roughly equal to the cost of a heating plant. Therefore, the economics of district cooling would be roughly analogous to the figures cited for district heating. The operating cost aspect, on a Btu basis, would be even more favorable for geothermal over fossil fuel cooling than for district heating, as compared to electrically powered systems, because of the overall lower efficiencies of the latter. There is a compelling case for further research into the district space heating and cooling aspects of geothermal energy, both with respect to waste heat recapture and direct use.

Effects on New Dwellings

If geothermal electricity has the effect of greatly lowering the cost of electricity, then electric space heating becomes much more practical. However, if new buildings are designed for energy conservation, the price of electricity becomes less critical. As outlined above, the really exciting prospect lies in the use of geothermal energy as a direct source of space heating and as an energy source for absorptive air conditioning.

The availability of large amounts of moderate temperature hot water together with low cost electricity are on excellent circumstances for the increased application of heat pumps. The heat pump has very good efficiency for this type of application and therefore yields good energy economics. Since it is available in single house size units and may heat or cool as desired, the heat pump should find wide new use in new United States geothermally heated dwellings. The western seasonal climate variations usually require both heating and cooling. Einarsson[2] reports such installations in Iceland, USSR, and New Zealand. In regions where geothermal fluids are relatively accessible and ubiquitous, it is not at all impractical to envision small sized systems which can serve single buildings (as in the case of the Queen Elizabeth Hospital and the International Hotel in Rotorua, New Zealand). In such places the evolution of geothermal services might well parallel municipal water and sewer services. At first everybody "digs their own." Then, as the community grows, municipal services are provided to improve convenience, safety, health standards, economics and community regulation.

REFERENCES

- [1] Bodvarsson, G., and S. S. Einarsson, "Geothermal Energy for Domestic and Industrial Heating," Proceedings of the Conference of Icelandic Engineers, Reykjavik, Iceland, 1964.
- [2] Einarsson, S. S., "Geothermal District Heating," Geothermal Energy (Paris: UNESCO, 1973), p. 124.
- [3] Peterson, Norman V., and Edward A. Groh, "Geothermal Potential of the Klamath Falls Area, Oregon, A Preliminary Study," The Ore Bin (November 1967); and J. B. Koenig, "Geothermal Exploration in the Western United States," Geothermics, Special Issue 2, UN Symposium (1970), p. 2.
- [4] Burrows, W., "Geothermal Energy Resources for Heating and Associated Applications in Rotorua and Surrounding Areas," Geothermics, Special Issue 2, UN Symposium (1970), p. 1662.
- [5] Cooke, W. L., "Some Methods of Dealing with Low Enthalpy Water in the Rotorua Area of New Zealand," Geothermics, Special Issue 2, UN Symposium (1970), p. 1670.
- [6] Reynolds, G., "Cooling with Geothermal Heat," Geothermics, Special Issue 2, UN Symposium (1970), p. 1658.
- [7] The Nation's Water Resources (Washington, D.C.: Water Resources Council, 1968).
- [8] U.S. Department of the Interior, Office of the Secretary, Final Environmental Statement for the Geothermal Leasing Program, Vol. II (November 1973), p. V-84.
- [9] Lunde, Frithjof M., and Valentine A. Lehr, Geothermal Energy--Regional, Community, Cultural and Construction Industry Considerations, report to The Futures Group, Inc., Glastonbury, Conn. (New York: Warner, Burns, Toan, Lunde, architects, 1974).

4.7 Impacts on International Relations

Production

Geothermal energy, occurring as it does around the world, will potentially impact on our foreign policy and foreign relations in several ways. First, most directly, it offers opportunities to provide technological assistance to nations endowed with this energy source but unable to develop it. Indirectly, if other nations develop this source of energy, there will be an effect on world fuel demand, and to the degree that geothermal energy can substitute for other forms of energy, fuels which might have otherwise been consumed by these nations will be available on the world market. If geothermal energy is abundant, there could be an effect on world crude oil prices, shipping, storage, refining, and so forth.

It is possible to conjecture about the possible effects of geothermal energy on military operations both on land and under the oceans. Certainly, under some unique circumstances, geothermal sources could provide power for military installations. But beyond this, the knowledge of geology and geophysics derived from commercial deep-drilling development could improve the ability to detect underground explosions. These and other such impacts are discussed in more detail in this section.

Figures 4.7.1-4.7.4 present the top level of the relevance tree of impacts in this area; Appendix D presents the complete tree.

Formation of Geothermal Areas

Where are geothermal resources most likely to be found in the world? Figure 4.7.5 shows the "ring of fire" in which geothermal resources seem to be concentrated.

The study of plate tectonics and the continental drift theory provides some insight into this configuration. New fundamental concepts in earth sciences dealing with the formation and placement of continents were advanced and largely accepted within the last decade. This "continental drift" theory holds that the present continents were part of a single land mass more than 200 million years ago. The outer shell of the earth, the lithosphere, is divided into several "plates," most of which bear one or more continents. Probably driven by thermal convective forces within the earth, the plates spread from deep sea ridges and small ocean basins at rates which are usually in the range of 1-10 centimeters per year on each side of the axis. This is an exceedingly fast rate in geologic terms; taking an average differential rate of 10 centimeters per year, two plates would have separated by 10,000 kilometers in 100,000 years. This simple computation indicates that not only are plates "born" at undersea ridges, they must also flow back into the earth elsewhere. These "subduction" zones are located at deep sea trenches. The continents float with plates; however, because the continents are light, they are not consumed as the plates leave the lithosphere. They can, however, divide at the ridges, and hence oceans can appear across them. This general idea of the motions of the plates and continents has been largely confirmed through analysis of core samples obtained from drilling in the ocean floor by the Joint Oceanographic Institution for Deep Earth Sampling project. The most recent samples were taken from ridge crests; older sediments were identified on either side of the ridges, and age increased with depth.

The relevance of plate tectonics to geothermal energy

and to geothermal energy's impact on international relations is clear: the geography of plate ejection at subduction largely determines which nations are likely to have active geothermal regions. The relationship between plate motion and geothermal activity has been discussed by Sir Edward Bullard as follows:

The areas of downgoing plates contain a large proportion of the geothermal areas of the world. Many of these are around the Pacific, and include Indonesia, the Philippines, Japan, the Aleutians, and the Andes. The New Zealand geothermal area is a southward extension of the Tonga Trench and is probably associated with a sinking plate. Other areas where similar phenomena occur are the Caribbean, the Aegean and the Scotia Arc which runs between the southern tip of South America and Graham Land. There are some important geothermal areas whose positions in this scheme are not clear. The Mediterranean is an area in which very complicated events are in progress. Africa is moving northward and colliding with southern Europe and the Middle East. In the collision the plates have become fragmented and directions of motion have changed. It is probably that the main, north-going African plate is going down and being consumed beneath the Cretan Island Arc, but it is not clear what is happening in Italy; it is possible that there is a small downgoing plate moving in from the west. Another area of doubt is in the mountain states of the U.S.A. The continent has moved westward away from Europe and has probably overrun its own westward boundary trench and also part of a mid-ocean ridge. It is also possible that California is a continental fragment that had its origin somewhere to the west and has collided with the rest of the U.S.A. In view of these complexities, which are typical of continental geology, it is difficult to say what is the origin of the geothermal activity in northeast California and Nevada. It is clear that it is connected with the great outpourings of lava but it is not clear what is the origin and history of these....

In spite of doubts about the meaning of geothermal phenomena in some areas, the suggestion that there are two main environments for igneous activity is a useful unifying concept in considering the phenomena. For any particular example it is useful to ask: Is this a place where the crust is splitting and new material is being added to the plate in the form of basaltic lavas and intrusions, or is it a place where the plate is being destroyed and melted and andesitic lavas are working their way to the surface? [1]

Geothermal Energy and GNP

The countries which lie within the world's geothermal regions are listed in Figure 4.7.6. This figure also includes certain parameters which are germane to foreign policy aspects of geothermal energy: in particular, the amount of energy consumed and the amount of energy produced by these nations in terms of equivalent coal tonnage, as well as the ratio of these two parameters which

Figure 4.7.1

Figure 4.7.2

(To Point (B) in Figure 4.7.1)

Figure 4.7.3

Figure 4.7.4

SOURCE: GEONOMICS, INC. (HEMPSTEAD, NEW YORK, 1974).

Figure 4.7.5 GEOTHERMAL REGIONS OF THE WORLD

REGION AND COUNTRY	POPULATION (THOUSANDS)	GNP (MILLIONS US DOLLARS)	GNP PER CAPITA	ENERGY PRODUCTION (MILL. METRIC TONS - COAL EQUIVALENT) 1969	ENERGY CONSUMPTION (MILL. METRIC TONS - COAL EQUIVALENT) 1969	CONSUMPTION PER CAPITA	GEOTHERMAL DEVELOPMENT	FRACTION INDIGENOUS PRODUCTION OF CONSUMPTION
	1969	1969	1969			1969		
<u>AFRICA</u>				383.4	100.9	291		
ALGERIA	13,349	3,675	275	62.2	6.3	470		.99
BURUNDI REPUBLIC	3,475	188	54	—	.03	9		0
EGYPT (ARAB REPUBLIC OF)	32,501	6,100	188	17.26	7.18	221		2.40
ETHIOPIA	24,769	1,612	65	.03	.57	23	X	.05
KENYA	10,506	1,431	136	.04	1.56	148	X	.03
MALAWI	4,398	272	62	.01	.18	41		.06
MOROCCO	15,050	3,108	207	.71	2.93	195		.24
MOZAMBIQUE	7,376	1,549	210	.31	1.24	169		.25
RHODESIA	5,090	1,303	256	3.74	2.87	564		1.30
RWANDA (REPUBLIC OF)	3,500	262	75	.01	.12	268		.08
SOMALI DEMOCRATIC REPUBLIC	2,730	175	64	0	.07	27		0
SUDAN	15,186	1,725	113	.02	1.52	100		.01
TANZANIA	12,926	1,245	96	.04	.74	58		.05
TUNISIA	5,027	1,162	231	4.84	1.25	248		3.87
UGANDA	8,360	1,122	118	.09	.50	53		.18
ZAIRE (REPUBLIC OF)	915	183	200	.42	1.39	81	X	.31
ZAMBIA	4,170	1,667	400	.44	2.14	509		.20
<u>AMERICA, NORTH</u>				2140.5	2375.2	10,585		
CANADA	21,089	68,710	3260	188.1	185.4	8,794		1.01
UNITED STATES	203,213	947,805	4664	1952.4	2189.4	10,774	X	.89
<u>AMERICA, CENTRAL & CARIBBEAN</u>				342.5	121.5	1,009		
BRITISH HONDURAS	120	49	410	—	.06	483		0
COSTA RICA	1,685	821	487	.10	.56	331		.18
DOMINICAN REPUBLIC	4,174	1,272	305	.01	.97	232		.01
EL SALVADOR	3,390	945	279	.06	.53	156	X	.11
GUADELOUPE	323	174	540	—	.16	483	X	0
GUATEMALA	5,014	1,645	328	.02	1.17	234		.02
HAITI	4,768	405	85	—	.15	31		.02
HONDURAS	2,495	646	259	.02	.57	230		.04
MARTINIQUE	329	229	690	—	.17	518		0
MEXICO	48,933	29,370	600	53.4	51.1	1,044	X	1.05
NICARAGUA	1,915	728	380	.04	.63	328		.06
PANAMA	1,417	917	647	.01	1.91	1,348		.01
PUERTO RICO	2,754	4,468	1622	.02	8.45	3,068		0
<u>AMERICA, SOUTH</u>				67.2	107.6	696		
ARGENTINA	23,983	19,860	828	31.45	37.03	1,544		.85
BOLIVIA	4,804	901	188	2.66	1.05	218		2.53
CHILE	9,566	6,156	644	7.43	11.58	1,210		.64
COLOMBIA	20,463	6,181	302	19.77	12.10	591		1.63
EQUADOR	5,890	1,644	279	.33	1.59	270		.20
PERU	13,172	5,124	389	5.98	8.20	623		.73
VENEZUELA	10,035	9,639	961	256.2	21.6	2,153		11.86
<u>ASIA - MIDDLE EAST</u>				824.1	64.1	636		
IRAN	27,892	9,110	327	219.9	15.7	562		14.00
IRAQ	9,150	2,693	294	98.0	5.83	623		16.81
ISRAEL	2,822	4,729	1676	3.57	6.08	2,154		.59
JORDAN	2,217	575	259	—	.68	308		0
LEBANON	2,700	1,435	531	.11	1.82	689		.06
SAUDI ARABIA	7,520	2,790	388	197.0	5.44	755		36.21
SYRIAN ARAB REPUBLIC	5,866	1,600	273	2.98	2.80	477		1.06
TURKEY	34,375	13,016	380	11.23	15.85	461	X	.71

Figure 4.7.6

REGION AND COUNTRY	POPULATION (THOUSANDS) 1969	GNP (MILLIONS US DOLLARS) 1969	GNP PER CAPITA 1969	ENERGY PRODUCTION (MILL. METRIC TONS - COAL EQUIVALENT) 1969	ENERGY CONSUMPTION (MILL. METRIC TONS - COAL EQUIVALENT) 1969	CONSUMPTION PER CAPITA 1969	GEOTHERMAL DEVELOPMENT	FRACTION INDIGENOUS PRODUCT OF CONSUMPTION
<u>ASIA (EXCEPT MIDDLE EAST)</u>				235.8	486.0	437		
AFGHANISTAN	16,516	1,400	85	2.89	.43	26		6.72
BURMA	26,980	1,990	74	1.04	1.55	58		.67
INDIA	536,984	47,670	89	88.4	103.76	193		.85
INDONESIA	117,610	12,070	104	52.3	11.4	98		4.59
JAPAN	102,321	166,394	1626	59.19	289.4	2,828	X	.20
NEPAL	10,845	868	80	.01	.12	11		.07
PAKISTAN	126,740	16,510	129	5.59	11.80	93		.47
PHILIPPINES	37,158	8,138	219	.28	9.68	261	X	.3
TAIWAN (REPUBLIC OF CHINA)	13,800	4,770	340	6.32	12.06	874		.52
<u>EUROPE</u>				541.9*	1245.5*	3,525*		
BULGARIA	8,434	8,540	1013	16.04	29.45	3,491		.54
CZECHOSLOVAKIA	14,418	26,010	1804	77.43	88.24	6,120		.88
FRANCE	50,320	140,050	2783	61.79	177.17	3,518	X	.35
GREECE	8,835	8,395	950	2.46	10.16	1,150		.24
HUNGARY	10,295	11,280	1096	21.99	29.73	2,888	X	.74
ICELAND	203	383	1870	.11	.70	3,453	X	.16
ITALY	53,170	82,330	1548	25.31	129.24	2,431	X	.20
POLAND	32,555	34,900	1072	150.21	131.92	4,052		1.14
ROMANIA	20,010	16,010	800	56.47	52.58	2,628		1.07
YUGOSLAVIA	20,351	12,296	604	19.89	25.29	1,243		.79
<u>OCEANIA</u>				57.5	69.8	3,901		
NEW GUINEA	1,715	--	--	--	.17	105		0
NEW ZEALAND	2,777	5,326	1918	3.17	7.28	2,623	X	.44
<u>CENTRALLY PLANNED ECONOMIES</u>				1930.0	1832.5	1,634		
CHINA (PEOPLE'S REPUBLIC OF)	746,460	--	--	387.8	392.2	505		.99
U.S.S.R.	240,567	285,710	1188	1138.6	1010.2	4,199	X	1.13

*EXCEPT EASTERN EUROPE.

SOURCES: STATISTICAL YEARBOOK, 1970, 22ND EDN. (NEW YORK: UNITED NATIONS, 1971); HANDBOOK OF INTERNATIONAL TRADE AND DEVELOPMENT STATISTICS, 1972 (NEW YORK: UNITED NATIONS, 1972).

Figure 4.7.6 (Cont.)

is a measure of energy self-sufficiency of the various countries. This ratio is plotted against GNP per capita for each country in Figure 4.7.7. Several inferences can be drawn from this figure:

- All countries within the geothermal zone which have GNP per capita greater than \$1500 per person have indigenous geothermal projects.
- Those countries within the geothermal zone which have a low ratio of energy produced to energy consumed more frequently have geothermal projects.

The locus formed by the points representing the countries of Ethiopia, Zaire, Turkey, Mexico, and the USSR is interesting indeed. All countries with geothermal projects fall below this line; none fall above. One can imagine an explanation for this situation: at a given GNP per capita level the country with the worst energy balance is more likely to pursue the development of its geothermal resources. For convenience the Ethiopia-USSR line on Figure 4.7.7 is called the "self-sufficiency threshold" in the discussion which follows.

All other things being equal, countries likely to pursue important-scale geothermal projects on their own are those lying within the world geothermal region which also have relatively high GNP per capita and fall below the self-sufficiency threshold. These countries are:

Israel
Czechoslovakia
Puerto Rico

Countries likely to pursue important-scale geothermal projects with moderate external assistance are those lying within the world's geothermal region which have mid-range GNP per capita (\$500-1500 per capita) and fall below the self-sufficiency threshold. These countries include:

Panama
Lebanon
Chile
Yugoslavia
Argentina
Romania
Poland
Hungary
Bulgaria
Greece
Martinique
Guadeloupe

Countries which are within the world geothermal region, which have relatively low GNP per capita (less than \$500

Figure 4.7.7 GNP PER CAPITA VS. RATIO OF ENERGY PRODUCED TO ENERGY CONSUMED FOR SELECTED COUNTRIES WITH GEOTHERMAL POTENTIAL (1969 DATA)

YEAR	AMOUNT OF ENERGY			
	MWE		ANNUAL MILLIONS OF BARRELS OF OIL EQUIVALENT	
	BASE	ACCELERATED	BASE	ACCELERATED
1973	.40	.40	4.21	4.21
1976	.73	.73	7.68	7.68
1979	3.59	4.10	37.78	43.15
1982	4.82	9.26	50.73	97.46
1985	6.58	19.50	69.25	205.24
1988	13.39	36.79	140.93	387.21
1991	24.68	59.74	259.76	628.76
1994	54.67	96.94	575.40	1020.29
1997	108.33	158.44	1140.17	1667.58
2000	188.11	249.22	1979.85	2623.04

Figure 4.7.8 OIL EQUIVALENT OF GEOTHERMAL ENERGY

per person) and which fall below the self-sufficiency threshold, are clearly countries which might benefit greatly from technological assistance. These countries include:

Sudan	Tanzania
Dominican Republic	Costa Rica
Guatemala	British Honduras
Honduras	Haiti
Nicaragua	Burundi Republic
Zambia	Somali Democratic Republic
Ecuador	Jordan
Mozambique	El Salvador
Morocco	Ethiopia
Nepal	
Kenya	

Several countries lie on the border of the self-sufficiency frontier and their further development is likely to increase their interest in geothermal projects within the next few years. These countries include:

Malawi	Peru
Rwanda	Pakistan
Uganda	Indonesia

Now some specific impacts in the area of international relations will be reviewed in detail.

Impact of Geothermal Energy on Trade

If instead of developing geothermal energy in the United States, the United States substituted petroleum and petroleum products for the production of electricity and for space heating, all other things being equal, the amount of oil required would be on the order of 2000-2600 million barrels per year. Figure 4.7.8 presents the oil equivalent of geothermal energy used in the production of electricity, both for the base case and for the accelerated program case.

To put these numbers in perspective, the U.S. petroleum supply from domestic sources was about 9.2 million barrels per day in 1973, and total consumption was 17 million barrels per day. Of this, 6.1 million barrels per day were imported and 1.7 million barrels per day came from natural gas liquids. Assuming that the Alaska North Slope brings in from 2 to 2.8 million barrels per day and that offshore petroleum production brings in between 1.6 and 2.7 million barrels per day by 1980, a reasonable expectation of the domestic oil produced ranges from 8.9 to 13.6 million

Figure 4.7.9 IF THE FORECASTED AMOUNT OF GEOTHERMAL ELECTRICITY WERE PRODUCED BY OIL COSTING \$10/BBL, IT WOULD HAVE REQUIRED THE CUMULATIVE EXPENDITURES SHOWN HERE

barrels per day [2]. Assume for the moment that the upper estimate is correct for 1980 and that this figure, through new discoveries and improvements in secondary recovery techniques, remains constant until the end of the century. The barrels of oil equivalent which geothermal energy represents is about 1 percent of domestic production by 1980 and about 40 percent of domestic production by the year 2000. Had that oil been purchased overseas at a cost of \$10/bbl., its cumulative cost by the year 2000 would have been about \$100 billion for the base case and \$160 billion for the accelerated program (assuming \$10/bbl.). (Figure 4.7.9.)

As pointed out in Section 3.6 and illustrated in Figure 3.6.3, it is unlikely that geothermal energy will substitute for petroleum as a fuel for the generation of electricity; geothermal energy is much more likely to substitute for coal and nuclear sources in the world envisioned.

Effect on Coal Exports

Figure 4.7.10 summarizes the effect of various geothermal programs on demand for coal for the production of electricity. By the year 2000 an "accelerated" geothermal program can have the effect of lowering the requirement for coal by 278 million short-tons in that year. This amount of coal would presumably be available for conversion into other forms of fuel or for export.

Our coal exports are extremely important to other countries. For example, the United States normally exports about 10 percent of its total coal production (e.g., 50

COAL FOR ELECTRICITY
(1000 MWE)

PROGRAM	1976	1985	1994	2000
NO GEOTHERMAL	176.3	307.30	569.05	787.18
BASE	176.3	305.05	550.82	695.00
ACCELERATED	176.3	303.13	534.93	671.37

COAL FOR ELECTRICITY
MILLIONS SHORT TONS (240 TONS/MMHR)

PROGRAM	1976	1985	1994	2000
NO GEOTHERMAL	424	739	1368	1893
BASE	424	734	1324	1671
ACCELERATED	424	729	1286	1615

TONS OF COAL "SAVED" OVER NO GEOTHERMAL CASE
(MILLIONS SHORT TONS)

PROGRAM	1976	1985	1994	2000
NO GEOTHERMAL	0	0	0	0
BASE	0	5	44	222
ACCELERATED	0	10	82	278

Figure 4.7.10

million tons out of 545 million in 1968). About half of our exports go to Japan; in 1971 we shipped 25 million tons to that country. Coal accounts for 23 percent of the total energy consumed in Japan and our coal exports provided 6 percent of that total. By the year 2000 Japan's energy demand will probably have increased by a factor of 3 to 4; because of the growing scarcity and increasing costs of petroleum, Japan will undoubtedly put more reliance on other energy sources including indigenous geothermal, nuclear, and imported coal. By developing geothermal energy in the United States our country will be in a better position to meet the demands of other developed countries for coal.

If it is assumed that coal costs will average \$15 per ton between now and the end of the century (this is probably a very conservative estimate), a total of between \$13 and \$20 billion of favorable trade can be realized through the export of coal displaced by geothermal power. The cumulative income from the export of displaced coal is presented in Figure 4.7.11; in the year 2000 the coal exported in the "accelerated" program would bring about \$4 billion into the United States. (For comparison, exports of goods and services in 1972 totaled \$73 billion.)

Geothermal Energy and World Food

It is possible that geothermal energy can, in small measure, help alleviate the world food problem. There are several reasons why the food situation in the near future may be worse than in the recent past.

- World population is currently approaching 4 billion and world population growth rate exceeds 2.2 percent per year.
- Many demographers and sociologists expected that as the affluence of nations grew, their

Figure 4.7.11 CUMULATIVE INCOME REALIZED THROUGH COAL EXPORTATION (IF THE FORECASTED AMOUNT OF GEOTHERMAL ELECTRICITY IS PRODUCED, IT WILL PARTIALLY SUBSTITUTE FOR COAL. IF DISPLACED COAL IS EXPORTED, THE CUMULATIVE INCOME [AT \$15/TON] WOULD BE INCREASED AS SHOWN.)

birth rates would fall. However, in some instances this has not proven to be the case.

- Eighty-five percent of the grain exported in the world comes from North America. Because of this concentration, a climatic disturbance could have extremely deleterious consequences.
- The "green revolution" which significantly increased yields in several countries, including Mexico, the Philippines, and Japan, requires more intensive use of fertilizers and insecticides. With the increasing costs of petroleum-derived raw materials and competition for these raw materials, countries which have come to rely on energy-intensive agriculture may be hard pressed to find or afford sufficient agricultural chemicals.
- As levels of affluence rise in the world, food shifts from more basic cereals to less efficient forms of protein. This will place an additional burden on grain production. For example, a cow raised for beef consumes 7 grams of protein for every gram of protein produced.
- Several technologies have been proposed for increasing yields and for manufacturing synthetic protein; however, these do not promise to be available in sufficient time to alleviate world hunger on a large scale.

- The basic problem is an economic one: The hungry nations are ones that can least afford to pay for needed food or agricultural improvements.

What can geothermal energy do? Some of the potential agricultural applications of geothermal energy have already been described in Section 4.2. For the most part, these were applications which had some measure of attractiveness for entrepreneurs in the United States. However, there are additional applications of geothermal energy which could well be important in increasing the availability of food in developing nations. Some of those applications are described below.

In the most general sense, geothermal energy can be used for heating, drying, distillation, refrigeration, and de-icing; in addition, the geothermal fluids themselves could prove useful. Dragone and Rumi have described their plans to build low-cost modular greenhouses using geothermal waters as the primary heat source [3]. They intend to use polyethylene pipes for the heating of soil and a simple heat exchanger in which natural steam is used to heat the closed loop greenhouse water to the desired temperature. If such systems could be made inexpensively enough, perhaps through the use of vinyl plastic covering over structural plastic frames, developing countries might use geothermally heated hothouses for raising certain fruits and vegetables, and perhaps most importantly, for the initial cultivation of tree seedlings. Lindal estimates that in temperate climates fossil fuel costs represent 15-20 percent of the price of food grown in greenhouses. Where geothermal energy can be substituted, greenhouse farming can be economical [4]. Hungary had 400,000 square meters of greenhouses by the end of 1969 and planned to double this figure in the early 1970's. Iceland by 1970 had 110,000 square meters; the USSR, 20 million square meters [5]. Japan and New Zealand also have hothouses which are warmed by geothermal energy.

Inexpensive hothouse technology would be most important to countries and regions which have geothermal resources and which lie outside of the tropical or temperate zones; for example, Alaska, Canada, Japan, and the Soviet Union.

It is possible that food productivity could be increased in the northern temperate regions of the world through soil warming. Boersma reported that corn silage yields increased by 45 percent, tomatoes by 50 percent, soybean silage by 60 percent, and bush beans by 39 percent compared to yields in untreated soil [6].

Geothermal water can be mixed with cooler surface waters to achieve a desirable temperature for hatching and raising fish. In both Iceland, where salmon are raised to the smolt stage, and Japan, where eels are bred in an inland hatchery, this technique has proven effective. Some other agricultural uses of geothermal energy include:

- Heating animal buildings such as cattle stalls, milking rooms, pig sties, and chicken houses.
- Providing heat to speed biodegradation of animal wastes.
- Washing and drying of wool.
- Producing dried milk, casein, and sucrose.

- Drying of fish meal and timber.
- Canning of food.
- Evaporation in sugar refining.
- Producing fresh water through distillation.
- Drying of organic materials such as fish stock, seaweed, grass, vegetables, etc.
- Refrigerating to reduce spoilage of vegetables and fruit.

Weapons Implications

Section 2.4 discusses the interests of the Department of Defense in geothermal energy for providing sources of rapidly mobile power in appropriate regions of the world. It is doubtful whether drilling and winning of geothermal fluids could ever be routine enough to have tactical importance.

There are other areas, however, in which geothermal resources potentially have strategic implications. Val-fells has pointed out that geothermal steam represents an ideal raw material for producing heavy water [7]. The light water moderated pressurized reactor and the boiling water reactors being used in the United States and elsewhere require enriched uranium as a fuel. Non-nuclear nations can obtain enriched uranium for power production through the IAEA, but unless these nations intend to develop an enrichment industry, which is quite expensive, they must remain dependent on other nations for their supply of fuel. If heavy water is used as a moderator, natural uranium can be used in a power reactor. This may lead some nations in this direction if heavy water can be obtained inexpensively. (Indeed, Canada, India, and Argentina are doing this now.) One of the outputs of a heavy water reactor is plutonium, which can be used in fast-breeder reactors or, given the appropriate technology, in weapons.

Using a H_2S/H_2O isotope exchange process with geothermal steam supplying the process heat, heavy water can be produced at a savings of 10-15 percent over other methods.

There is another possibility which seems extremely improbable, but because of its importance should be mentioned when considering the international implications of the development of geothermal energy, the use of earthquakes as a weapon, which has been described by Gordon J. F. MacDonald, formerly of President Johnson's Science Advisory Committee. He wrote:

The use as a weapons system of the strain energy instability within the solid earth requires an effective triggering mechanism. The scheme for pumping water seems clumsy and easily detectible. On the other hand, if the strain pattern in the crust can be accurately determined, the phased or timed release of energy from smaller faults, designed to trigger a large fault at some distance, could be contemplated. This timed release could be activated through small explosions and thus it might be possible to use this release of energy stored in small faults at some distance from a major fault to trigger the fault....[8]

Knowledge of how to detect, track, and work with underground faults as required by the evolution of geothermal energy, particularly the hot dry rock form of the

resource, leads in this improbable direction. These skills and the new technology which they engender, will probably improve the ability to detect deep underground nuclear explosions.

Relations with Oil Producing Countries

It is an interesting fact that most important oil producing countries are also on the list of countries lying within the geothermal zone. Iran, Iraq, Saudi Arabia, Indonesia, Venezuela: All of these countries have geothermal potential. The development of these resources will probably take place under circumstances different than those in other countries. The central question here is how can geothermal resources be useful in the extraction and processing of petroleum? The literature is poor in this area even though high temperature steam and electricity can be used effectively in the refineries.

The notion of using hot geothermal brines as an energy source for secondary petroleum recovery should not be overlooked. Where both deposits occur in juxtaposition, it might be possible to lower the viscosity of petroleum and increase the pressure on the deposit by introducing heated geothermal brines into the petroleum field.

The development of these special technologies could be the focus of technology transfer programs.

Summary

In summary, then, the most important impacts on international relations brought about by geothermal energy are:

1. The opportunity for forging new alliances on the basis of technology transfer.
2. The decreasing U.S. dependence on imported energy sources.
3. The U.S. ability to export more coal as a result of the domestic substitution of geothermal energy for coal in the generation of electricity.
4. The use of geothermal energy to improve, to a small degree, world agriculture.
5. The possibility, far downstream, of geothermal energy technology providing insight into a new form of strategic weaponry and underground nuclear explosion detection.

REFERENCES

- [1] Bullard, Edward, "Basic Theories," Geothermal Energy: Review of Research and Development (Paris: UNESCO, 1973).
- [2] Adelman, M., et al., "Energy Self-Sufficiency: An Economic Evaluation," Technology Review (May 1974).
- [3] Dragone, G., and O. Rumi, "Pilot Greenhouse for the Utilization of Low-Temperature Waters," Geothermics (Pisa: CNR, 1970), p. 918.
- [4] Lindal, B., "Industrial and Other Applications of Geothermal Energy," Geothermal Energy (UNESCO, 1973), p. 143.
- [5] The USSR figure was quoted by G. Dragone and O. Rumi in "Pilot Greenhouse for Utilization of Low-Temperature Waters," Geothermics (Pisa: CNR, 1970), and was in reference to Anton Juk, AA., "Use of Geothermal Waters in Agriculture (in Russia)" (Moscow: USSR Academy of Sciences, 1963).
- [6] Boersma, L., "Warm Water Utilization," Conference on Beneficial Uses of Geothermal Discharges (New York State Department of Conservation, 1970).
- [7] Valfells, A., "Heavy Water Production with Geothermal Steam," Geothermics (Pisa: CNR, 1970), p. 896.
- [8] MacDonald, Gordon J. F., "How To Wreck the Environment," in Nigel Calder (ed.), Unless Peace Comes (New York: Viking Press, 1968), p. 196.

4.8 Effects on the Environment

Geothermal energy has been hailed as a "clean" energy source by some advocates and has been recommended as an environmentally desirable alternative source of power. Geothermal energy produces no radioactive wastes, generates no products of combustion, and has no requirement for extraction of fuel, with its secondary impacts. Nevertheless, development of geothermal energy resources has the potential for altering the environment in several ways. Some of these may be of the nuisance variety, but others may be more serious and lasting. For example, while geothermal installations can be noisy and potentially unsightly, improper design or operation might result in other more serious impacts such as emission of noxious gases, land surface subsidence, alteration of groundwater characteristics, or seismic instability. The interplay between such environmental considerations and program elements is explored in this section.

Figure 4.8.1 below illustrates the spectrum of primary and higher order environmental impacts which may result from the development of geothermal resources. While only a single branch of the tree is presented, all major geothermal sources were included in this study.

To aid in identifying potentially major environmental impacts, a series of matrices were constructed using a technique based on that of Leopold, et al.[1]. The matrix is constructed using two checklists: (1) major activities involved in geothermal resources development--such as exploration, production drilling and testing with parallel field development operations, plant construction, and operation; and (2) pertinent aspects of the environment.

The first dimension of the matrix, i.e., operations pertinent to field development, plant construction, and operation of a geothermal system, involves the following five "Major Activity Groups."

Exploration. Field development naturally begins with an exploration phase, which consists of geological studies, test drilling, and small-scale access provision. Elements of this group include:

- Mapping and field studies
- Drilling and construction
- Test drilling (shallow and small diameter)
- Temporary roads and traffic
- Equipment operation
- Abandonment (temporary or permanent).

Production Drilling and Testing. Where field development is to proceed beyond the exploration phase, or where existing field capacity is to be expanded, a production well drilling and testing phase is conducted. (Parallel field development activities carried out at the same time comprise a separate phase.) Specific well-related elements include:

- Well drilling and construction (production and reinjection)
- Well stimulation
- Accidental blowouts
- Well testing/venting/ponding/reinjection.

Parallel Field Development Operations. A number of concomitant activities also take place either for new field developments or expansion of existing fields:

- Land clearing and road construction; vehicular traffic
- Gathering systems (pipeline) construction
- Equipment activities
- Service living quarters
- Water, sewage, temporary electricity, and other supporting services development.

Plant Construction. Construction of a power plant is considered a separate phase of activity, involving an integrated set of activities:

- Structures and improvements
- Vehicular traffic/equipment activities
- Special construction activities as required, such as blasting
- Electric transmission systems construction
- Supporting services, such as water lines, labor camp facilities, etc.

Figure 4.8.1

Full-scale Operation. A number of elements characterizing normal operational activities at a geothermal field/power plant complex. These include:

- Cooling tower operation
- Venting (during short-term outages)
- Wellhead bleeding
- Reinjection
- Recharge, stimulation, and redrilling
- Corrosion and scale control
- Gaseous, liquid and solid waste discharge and/or removal
- Work force movement
- Abandonment

The second dimension of the matrix involves "Aspects of the Environment" and includes the following:

Physical and Chemical. Physical impacts upon the land, water, and air resources have been considered, even though the exact nature of the secondary consequences to life systems from these disruptions will vary from site to site. In addition, when disturbances in air quality or regional seismic stability occur, the exact importance or extent of damages to plant and animal life (including man) is rarely definable in a quantitative manner. These disruptions may be regarded as potential environmental impacts to man even though their effects can only be generalized. Particular impact areas include:

- Air quality
- Noise
- Water quality--surface
- Water quality--groundwater
- Soils and erosion
- Land subsidence
- Seismicity.

Biological. Potential impacts upon the aquatic and terrestrial biota have been considered. Special attention has been given to life cycle and habitat disruptions, and potential hazards to rare and unique species and/or ecosystems in the following areas:

- Terrestrial flora and fauna
- Wetlands and marshes
- Aquatic flora and fauna.

Social and Cultural. Potential impacts upon human well-being were considered here as well as elsewhere in this impact analysis (see Sections 4.2, 4.3, and 4.6, particularly). In particular, the environmental impacts were taken to include:

- Land use consistency/water use consistency
- Scenic/aesthetic
- Safety
- Services burden (implying potential for economic and fiscal impacts to less populated regions).

Given such a matrix of geothermal activities versus potential environmental impacts areas, the five types of resources were reviewed in the following sequence: (1) vapor-dominated systems; (2) liquid-dominated systems; (3) hot dry rock; (4) geopressured zones; and (5) magma systems.

Vapor-Dominated Systems

The development of vapor-dominated systems, even in preliminary stages such as exploration, production

drilling and testing, may involve potentially major environmental impacts (see Figure 4.8.2 on the following page). In these and later stages, impacts of potentially major importance are noise, noxious gas emissions (e.g., hydrogen sulfide, sulfur dioxide, ammonia, radio-nuclides), and potential pollution of surface and subsurface waters. The disruption of previously undeveloped areas by activities associated with the development of geothermal energy is also a potentially sensitive issue.

Physical and Chemical Impacts.

Air Quality. The release of toxic substances to the atmosphere is of concern to many scientists, many of whom urge further research in controlling gaseous and particulate emissions. A summary of gaseous products known to be associated with various geothermal systems is presented in Figure 4.8.3 on the following page. Hydrogen sulfide is of special concern because of its offensive odor and extreme toxicity. Other toxic substances such as boron, fluorides, and selenium which can be carried from the cooling towers as "drift-loss" can also contaminate surrounding land areas. Significant amounts of hydrogen sulfide exist in most vapor-dominated systems and control of its emission is needed. Special concern is warranted where hydrogen sulfide is released into areas which experience frequent air stagnation or temperature inversions. In these areas hydrogen sulfide might reach severe nuisance or even toxic levels, especially near the facility itself.

The toxic level for man is .002 percent H_2S in air, by volume. At the Geysers (California) the level of H_2S in undiluted geothermal steam is .033 percent and at Larderello, Italy, .049 percent. The U.S. Department of the Interior calls H_2S "the most prominent environmental hazard" and says, "although removal of noxious gases is chemically possible using various techniques, the economic justification of such systems remains to be established." [2] No deaths of plant personnel from H_2S poisoning are mentioned in any of the literature reviewed for this report.

At the Pacific Gas and Electric Company's Geysers power station, prototype hydrogen sulfide gas scrubbers are under development and are expected to be operational within two to three years. Initial research indicates 70-90 percent of cooling gas H_2S emissions can be economically removed and that the necessary control technology will be developed within the next 12 years (see Section 3.3). Promising techniques include reacting the hydrogen sulfide with appropriate oxidizing agents, or utilizing a closed-loop process in which the energy can be extracted without releasing the contaminants at the surface. However, until such research is sufficiently advanced and the needed equipment is operational, noxious gas emissions at geothermal sites will continue to be a major environmental consideration. In their geothermal environmental impact statement, [2] the USDI reported as follows on other constituents of the geothermal gases:

On the basis of volume percent in undisturbed geothermal steam, ammonia (NH_3) would appear to present the second greatest hazard, being 5 times the toxic level in steam at The Geysers and over 6 times the toxic level in steam at Larderello. Ammonia, however, is lighter than air and is not concentrated locally. Ammonia is readily soluble in water (as in airborne water droplets) forming ammonium hydroxide (NH_4OH). It is therefore rapidly returned to earth as rainfall where it readily is combined with soil materials and plant

	LEGEND	MAJOR ACTIVITY GROUPS				
		EXPLORATION	PRODUCTION DRILLING AND TESTING	PARALLEL FIELD DEVELOPMENT OPERATIONS	PLANT CONSTRUCTION	FULL-SCALE OPERATION
	■ HIGH POTENTIAL IMPACTS LONG TERM AND/OR GREAT INTENSITY ● MODERATE POTENTIAL IMPACTS MAJOR SHORT TERM AND/OR OVERSHADOWED EFFECTS ○ LOW/NEGLIGIBLE POTENTIAL IMPACTS MINOR AND/OR SHORT-TERM	• Mapping/Field Studies • Drilling Pad Construction • Test Drilling (Shallow & Small Diameter) • Temporary Roads/Traffic • Equipment Operation • Abandonment	• Well Drilling & Construction (Production & ReInjection) • Well Stimulation • Accidental Blowouts • Well Testing/Venting/Ponding/ReInjection	• Land Clearing and Roads/Vehicular Traffic • Gathering Systems • Equipment Activities • Service Living Quarters • Water, Sewage, Temp. Elec., & Other Supporting Services	• Structures & Improvements • Vehicular Traffic/Equipment • Activities • Special Construction Activities (e.g., Blasting) • Electric Transmission Systems • Supporting Services (e.g., Water, Elec., etc.)	• Cooling Towers • Venting (During Short Term Outages) • Well-Head Bleeding • ReInjection • Recharge, Stimulation, & Redrilling • Corrosion & Scale Control • Caseous, Liquid, & Solid Wastes • Work Force Movement • Abandonment
ASPECTS OF THE ENVIRONMENT	PHYSICAL/CHEMICAL:					
	AIR QUALITY	■	○/■1	○	○	○/■1
	NOISE	■	●/■1,2	●	●	○/●1
	WATER QUALITY-SURFACE	○	○/■2	○/●2	○	○/■1,2
	WATER QUALITY-GROUNDWATER	○	○/■2	○	○	○/■1,2
	SOILS/EROSION	○	○/●2	○/●2	○/●2	○
	LAND SUBSIDENCE	○	○/●2	○	○	○
	SEISMICITY	○	○	○	○	○
	BIOLOGICAL:					
	TERRESTRIAL FLORA AND FAUNA	○	○/●2	○/●2	○/■2	○
	WETLANDS, MARSHES	○/●2	○/●2	○/●2	○/■2	○
	AQUATIC	○	○/●2	○/●2	○/●2	○/■1,2
	SOCIAL/CULTURAL:					
	LAND & WATER USE (CONSISTENCY)	○	○/■2	○/■2	○/■2	○/■1,2
	SCENIC/AESTHETIC	○	○/●2	○/■2	○/■2	○/■1,2
	SAFETY	○	○/●2	○/●2	○/●2	○
	SERVICES BURDEN	○	○/●2	○/●2	○/●2	○

1 = TECHNOLOGY DEVELOPMENT

2 = SITE DEVELOPMENT

Figure 4.8.2 SUMMARY ENVIRONMENTAL ASSESSMENT MATRIX FOR VAPOR SYSTEM

	GEYSERS* California	LARDERELLO* Italy	MATSUKAWA** Japan	NAMAFJALL*** Iceland
H ₂ O	98.045	98.080	99.87	99.43
CO ₂	1.242	1.786	0.18	0.18
H ₂	0.287	0.037	0.01	0.19
CH ₄	0.299			0.01
N ₂	0.069	0.0105		0.05
A			0.03	
H ₂ S	0.033	0.049		0.14
NH ₃	0.025	0.033		
H ₃ PO ₄	0.0018	0.0075		

*D. White, L. P. J. Muffler, A. Treuesdell, "Vapor-Dominated Hydrothermal Systems Compared with Hot-Water Systems," *Econ. Geology*, Vol. 66, pp. 75-97.

**H. Nakamura, et al., "The Geological Environment of Matsukawa Geothermal Area, Japan, U.S. Symposium on the Development and Utilization of Geothermal Resources, Pisa, Italy, 1970.

***Calculated from B. Lindal, "The Use of Natural Steam in a Diatomite Plant," U.N. Symposium on the Development and Utilization of Geothermal Resources, Pisa, Italy, 1970.

SOURCE: Office of the Secretary, U.S. Department of the Interior, *Final Environmental Statement for the Geothermal Leasing Program*, Vol. 1 (Washington, D.C.: U.S. Government Printing Office, 1973), p. III-13.

Figure 4.8.3 EXAMPLES OF GASES ASSOCIATED WITH VARIOUS GEOTHERMAL SYSTEMS IN VOLUME PERCENT

acids, which are beneficial as natural fertilizer.

Carbon dioxide in undiluted geothermal steam would not present a danger, as the noncondensable gas fraction vented into the atmosphere would act as a single gas and component separation would not take place. Adequate ventilation will prevent any danger from this gas.

Methane (CH₄) is a natural product of organic decay. It is present at about one-fifth the toxic level in The Geysers steam and normally could not collect to toxic concentrations, since it is lighter than air...

Boric acid is present throughout the natural environment and comprises about .026% of the volume of sea water, a slightly higher concentration than boric acid in the geothermal steam at The Geysers, but less than that found in the steam at Larderello, Italy. Boric acid is found in higher concentrations in some hot springs and has been extracted commercially from bedded arid lake deposits, and from saline lake brines in San Bernadino County, California. It is doubtful that this compound as an aerosol would present a health or safety problem at a geothermal area if geothermal brines are disposed of properly.

Mercury is a known constituent of some geothermal fluids and may be present in sufficient

quantities to pose a health hazard at some locations. High concentrations of mercury have been found in areas of hot springs, mud volcanoes, and in brines from a petroleum field in California, although recent work by Barnes and others (1973), has indicated that mercury deposits in northern California could not have originated by deposition of mercury from present thermal waters....

Because of mercury's tendency to vaporize, the atmosphere near ore deposits may contain as much as .02 mg/m³ (2.4 ppb) atmosphere by rain. The mercury content of this rainwater averages 0.2 ppb. The mercury from other sources generally is held tightly in organic and inorganic materials in the upper 2 inches of soils. Mercury apparently is removed from surface waters in large part by absorption on clays and on hydrous oxides of iron and manganese, and also by algae and plankton. Also, the presence of sulfide and reducing conditions will concentrate mercury in the sediments.

Higher concentrations of mercury are likely to occur in underground waters because of longer and more intimate contact of water with mineral grains, and other factors. Limited sampling of oil field brines and petroleum from California showed them to contain from 1000 to 500,000 ppb mercury. Hot springs range generally from undetectable levels of mercury to 3.2 ppb; however, one measurement of 20 ppb has been recorded. Vapors issuing from fumaroles and steam condensates from hot springs have been shown to contain up to 130 ppb mercury. Condensable steam from the McKinley steam field at Castle Rock Spring, Lake County, California, near the Geysers steam field, contains from 1 to 3 ppb mercury. This is below the maximum level of mercury considered safe for drinking water which has been proposed by the U.S. Public Health Service at 5.0 ppb....

Although mercury is not considered as essential food material for organisms, methyl mercury, being soluble in water, is available for incorporation into the body tissues of organisms in the aquatic environment and secondarily into terrestrial predators, such as man. The concentration of mercury by living things may accumulate by way of the food chain, or by direct assimilation from the surrounding medium. In any event, if it accumulates in sufficient concentration in living tissue, it can become extremely toxic. Aquatic organisms, as well as man, will concentrate mercury within their bodies only when the intake rate exceeds the elimination rate. This will result in a buildup with time to the extent that accumulated mercury can become toxic and, eventually, lethal....

As a result of the Japanese and other experiences, a tentative upper limit of 5.0 ppb of mercury in drinking water has been proposed by the U.S. Public Health Service. This maximum is thought to be safe for human health when total probable mercury

intake rates of physiological processes and excretion rates are taken into account. The Food and Drug Administration has declared that fish and other foods that contain more than 500 ppb mercury are unfit for human consumption.

During production testing, considerable monitoring and analytical work will be necessary and required to determine the quantity of mercury vapor and other potentially toxic substances present in geothermal fluids at each field, to evaluate the potential hazard which its presence may create, and to establish the control measures to be imposed to assure meeting environmental and public health and safety requirements.

Radium and radon are known to be associated with certain geothermal manifestations, particularly hot springs....Radium precipitates from solutions under oxidizing conditions with carbonates, iron, and perhaps silicates, and if present in hot-water geothermal systems may accumulate in the scale that builds up in wells and pipelines. Ordinarily, it is very doubtful that a buildup of radium in scale would be greater than that associated with natural tufas and sinters around hot springs and geysers; however, its presence in pipeline scale could conceivably pose a health and safety hazard around steam transmission pipes and power plants after several years of operation.

Radon, a gaseous radioactive decay product of uranium, has a half-life of 3.82 days and, being gaseous, will escape into the atmosphere through any natural or artificial opening. A small amount of radon would be a component of the non-condensable gas fraction of the steam; however, it ordinarily would pose no health and safety hazard as it would be dispersed into the atmosphere with a very short half-life. About 122 tons of radon gas escape to the atmosphere daily on a worldwide basis from natural sources, and buildups of radon gas are quite common where it becomes trapped beneath air inversion layers in the atmosphere. If inversion conditions were prevalent for an extended period of time over a geothermal area, the resultant buildup of radon gas would add only slightly to man's total radiological burden from other natural sources such as rocks and soils. However, monitoring will be required at each lease site to assure public health and safety protection.

Noise. Noise is an unavoidable adjunct in the development of all geothermal systems. Ambient noise levels are increased by truck and other traffic, by steam venting, well drilling, and by other plant activities. Drilling activities and venting of compressed air and steam have been the principal sources of noise in vapor-dominated geothermal fields. Excessive noise levels may adversely affect the health and safety of humans in the area of a geothermal plant and may disrupt wildlife population distributions and breeding patterns. Recent research has produced a considerable improvement in the control of noise associated with the development and operation of geothermal plants. The effectiveness of mufflers, such as those being tested at Cerro Prieto, Mexico, and The Geysers in California, have indicated significant progress toward reducing noise to the levels specified in the current guidelines.[2] It is predicted that adequate solutions to noise problems will be available and installed within 5 years (see Section 2.3). A summary of noise levels at The Geysers is presented in Figure 4.8.4.

SOURCE	LEVEL
<u>The Geysers Area</u>	
Drilling operation (air) (25 ft)	126 dB(A)
Drilling operation (air) 1500 ft)	55 dB(A)
Muffled testing well (25 ft)	100 dB(A)
Muffled testing well (1500 ft)	65 dB(A)
Steam line vent (50 ft)	100 dB(A)
Steam line vent (250 ft)	90 dB(A)
<u>Comparative Levels</u>	
Jet aircraft takeoff (200 ft)	125 dB(A)
Threshold of pain	120 dB(A)
Unmuffled diesel truck (50 ft)	100 dB(A)
Street corner in a large city	75 dB(A)
Residential area at night	40 dB(A)
dB(A) Decibel value measured using the A weighting network of a standardized sound level meter.	

SOURCE: U.S.D.I., 1973, p. III-24.

Figure 4.8.4 COMPARISONS OF NOISE LEVELS BETWEEN THE GEYSERS GEOTHERMAL AREA AND OTHER NOISE SOURCES

Water Quality-Surface and Groundwater, Soils and Erosion, Land Subsidence, and Seismicity. While temporary alterations of surface water, groundwater, and soil quality may occur during the exploration, drilling, testing, and plant construction phases, these impacts are expected to be minor if kept under control. The high boron content of the geothermal fluids at The Geysers has required reinjection of fluid wastes rather than their release into surface streams. Based on past experience at The Geysers, impacts such as land subsidence and seismicity may pose relatively few problems at vapor-dominated fields, although specific site evaluation for these problems will be necessary.

Biological Impacts

Terrestrial Flora and Fauna, Wetlands, Marshes, and Aquatic. Since the fuel cycle for geothermal power is centralized at the field site, and does not require such support activities as mining, fuel processing and transportation, biological impacts should be restricted to the vicinity of the plant and well sites and along transmission line corridors. Some unknown factors, however, do exist regarding the nature of the impacts on local biota. A finite area of habitat will be pre-empted by the facilities, and increased human activities may create additional noise, disturbances, and barriers to animal movement and migration. In addition, some damage to species of plants and animals could occur through the possible release of toxic industrial materials through the destruction of very specialized habitats (such as alpine meadows), and through the release of toxic gases to the atmosphere. [3] These factors clearly need study in selected vapor-dominated geothermal areas, in order to determine the procedures needed for adequate protection of biota in the affected regions.

Social and Cultural Impacts

Use Consistency. Major social and cultural impacts concern problems of land use consistency, aesthetics and safety. Alteration of land use is a potentially serious consideration which requires specific site evaluation. A relatively large land commitment of approximately 0.5-1.0 square miles will be required to support a 100-500 MWe vapor-dominated power plant. The geographical regions with the greatest number of Known Geothermal Resource Areas (KGRA's) are located primarily in undeveloped regions of the western United States. These same wilderness areas, however, are also among the more environmentally sensitive. Land use conflicts are therefore likely to exist within many of the KGRA regions. Challenges to industrial use often develop where such land use is not so designated prior to development. Compatible multiple use, where possible, may be one of the only methods to satisfy both environmental and industrial interests, but adequate planning methods and long term commitments are often necessary, before compatible use can be developed. (See Section 4.6, for example.) As with many large utility projects, safety considerations may limit multiple use, particularly for those activities involving public access.

Scenic and Aesthetic. Aesthetic impacts may be particularly troublesome where unspoiled areas are likely to be developed. With importance often placed on aesthetic quality in these areas for recreational purposes, impacts due to the removal of vegetation and soil cover during road building and plant construction, and the net visual impact of the plant, wells, and collector pipelines will all require consideration. The impacts affect not only the site of the geothermal development but attendant areas as well, such as linear corridors occupied by access roads and power transmission lines. The extent of the visual impact will vary, depending on the size of the plant, topography, vegetative cover, and proximity to populated areas or major travel routes. As the size of the facilities increases, the potential for adverse impact will also increase.

Safety. One of the environmental hazards experienced in test drilling in particular is a well blowout, during which vapor and/or hot water escape uncontrolled from the well. Such occurrences are present in oil and gas drilling as well, but have the additional hazard of fire. Control is difficult but possible and blowouts are expected to be infrequent. A blowout can cause noise, waste of the resource, air contamination, surface and ground water pollution, and the potential for bodily injury to field crew.

The U.S. Department of the Interior in their Final Environmental Statement for the Geothermal Leasing Program provided historical data on the subject of potential blowouts.[2] At Wairakei, New Zealand, approximately 100 wells were drilled during "the pioneer years"; two of these were abandoned because of blowouts during drilling and another blew out after some years of service. There was no loss of life. Safety measures have been introduced at the Wairakei fields and these measures have proven generally effective.[4]

After the production drilling was completed at Wairakei in 1964, extensive exploratory drilling took place elsewhere in New Zealand. Seventy-eight wells were drilled, and although in several cases the bores reached pressure prematurely, there were no notable blowouts. [5] Equipment was not damaged nor were there personnel injuries.

At Lardarello, Italy, blowouts are handled routinely. They are viewed as a "noisy, difficult part of the

regular operations, requiring highly competent drill crews, and are not considered serious mishaps that could cause pollution or have other adverse effects." It is not unusual to experience rapid uncontrolled releases or blowouts of steam and water during drilling when the hydrostatic head inside the well falls below the external pressure of the steam. The crews at Lardarello have developed techniques to cope with these occurrences and to bring such wells under control.[6]

At The Geysers fields, three blowouts had been reported by February 1973. One of these blowouts which was "attributed to a combination of inadequate casing and minor landsliding, has been a continuing noisy nuisance since 1957. A loss of \$125,000 per year is attributed to this wastage. It is estimated that this blowout, during the past 15 year period, has emitted more than 9 million tons of steam and about 4000 tons of hydrogen sulfide, 5000 tons of ammonia, and 6000 tons of methane to the atmosphere." [2]

In January 1970 a well blew out through a nearby fissure after a period of heavy rains. This blowout was controlled within ten days by injecting cement into the casing. In January 1973 a minor landslide occurred after a heavy period of rain; apparently this landslide ruptured the casing of the well and the steam explosion followed which formed a crater 50 feet in diameter. While control measures have not yet been successful, the U.S. Department of the Interior expects that this blowout will be controlled.

At Cerro Prieto in Mexico, two blowouts have occurred, one of which was apparently caused by "mechanical failure due to vibrations in the wellhead equipment." The blowout was controlled by directional drilling and cement injection.

The second blowout was attributed to "improper casing cementation and wellhead construction." It lasted for approximately four months and was first manifested as a large crater emitting water and steam about 300 feet from the well. Within several days there was a violent blowout around the wellhead itself.

In summary, the U.S. Department of the Interior feels that, "although blowouts can be expected to occur, the probability of a significant blowout at any particular location can be greatly reduced as a result of technological refinements, drilling control measures, and increased operating experience." [2]

Liquid-Dominated Systems

Hot water systems are thought to be thermally driven convective systems in which meteoric water percolating down an inclined aquifer is heated by a deep, local heat source and driven upward. Where this upwelling penetrates the surface, hot springs, geysers, and other thermal phenomena occur. These geothermal reservoirs frequently contain high concentrations of salts, trace metals, and a variety of other often undesirable contaminants.

Major problems of both pressurized hot water and steam-flashed systems involve the handling and disposal of the often saline geothermal fluids (see Figure 4.8.5 on the following page). These fluids are often highly corrosive and can seriously pollute surface streams and aquifers if improperly confined, treated, or dispersed. The primary disposal method being considered is reinjection of the spent fluids into the geological formation.

	LEGEND	MAJOR ACTIVITY GROUPS				
		EXPLORATION	PRODUCTION DRILLING AND TESTING	PARALLEL FIELD DEVELOPMENT OPERATIONS	PLANT CONSTRUCTION	FULL-SCALE OPERATION
	<ul style="list-style-type: none"> ■ HIGH POTENTIAL IMPACTS LONG TERM AND/OR GREAT INTENSITY ● MODERATE POTENTIAL IMPACTS MAJOR SHORT TERM AND/OR OVERSHADOWED EFFECTS ○ LOW/NEGLIGIBLE POTENTIAL IMPACTS MINOR AND/OR SHORT-TERM 	<ul style="list-style-type: none"> • Mapping/Field Studies • Drilling Pad Construction • Test Drilling (Shallow & Small Diameter) • Temporary Roads/Traffic • Equipment Operation • Abandonment 	<ul style="list-style-type: none"> • Well Drilling & Construction (Production & ReInjection) • Well Stimulation • Accidental Blowouts • Well Testing/Venting/Fonding/ReInjection 	<ul style="list-style-type: none"> • Land Clearing and Roads/Vehicular Traffic • Gathering Systems • Equipment Activities • Service Living Quarters • Water, Sewage, Temp. Elec., & Other Supporting Services 	<ul style="list-style-type: none"> • Structures & Improvements • Vehicular Traffic/Equipment • Activities • Special Construction Activities (e.g., Blasting) • Electric Transmission Systems • Supporting Services (e.g., Water, Elect., etc.) 	<ul style="list-style-type: none"> • Cooling Towers • Venting (During Short Term Outages) • Well-Head Bleeding • ReInjection • Recharge, Stimulation, & Redrilling • Corrosion & Scale Control • Gaseous, Liquid, & Solid Wastes • Work Force Movement • Abandonment
ASPECTS OF THE ENVIRONMENT	PHYSICAL/CHEMICAL:					
	AIR QUALITY _____	○/●1	○/●1	○	○	○
	NOISE _____	●	●	●	●	○/●1
	WATER QUALITY-SURFACE _____	●	○/■2	○/●2	○	○/■1,2
	WATER QUALITY-GROUNDWATER _____	●	○/■2	○	○	○/■1,2
	SOILS/EROSION _____	○	○/●2	○/●2	○/●2	○
	LAND SUBSIDENCE _____	○	○/■2	○	○	○/■2
	SEISMICITY _____	○	○/●2	○	○	○/■2
	BIOLOGICAL:					
	TERRESTRIAL FLORA AND FAUNA _____	○	○/●2	○/■2	○/■2	○
	WETLANDS, MARSHES _____	○/●2	○/■2	○/■2	○/■2	○
	AQUATIC _____	○	○/■2	○/●2	○/●2	○/■1,2
	SOCIAL/CULTURAL:					
	LAND & WATER USE (CONSISTENCY) _____	○	○/■2	○/■2	○/■2	○/■1,2
	SCENIC/AESTHETIC _____	○	○/●2	○/■2	○/■2	○/■1,2
	SAFETY _____	○	○/●2	○/●2	○/●2	○
	SERVICES BURDEN _____	○	○/●2	○/●2	○/●2	○

1 = TECHNOLOGY DEVELOPMENT

2 = SITE DEVELOPMENT

Figure 4.8.5 SUMMARY ENVIRONMENTAL ASSESSMENT MATRIX FOR LIQUID-DOMINATED SYSTEM

Physical and Chemical Impacts

Quality. Minor well blowouts could lead to air quality problems during exploration and production drilling and testing phases. Potential for dust and related construction problems can exist as well as those problems delineated earlier for vapor-dominated systems.

Noise. Noise levels may be as significant a problem in the operation of liquid-dominated resources as in vapor-dominated systems.

Groundwater Quality. Groundwater contamination from leakage, spillage, or pollution of penetrated freshwater aquifers, are potentially serious problems, particularly during the production drilling and testing phase. Where disposal of spent thermal fluids is to take place through reinjection, it must be demonstrated that usable groundwater will not be contaminated and that precipitation of solids, which would clog passages and restrict flow, will not occur. If percolation of brines from holding ponds is allowed to occur, the potential for groundwater quality alterations is significant and constitutes a potentially major impact.

Land Subsidence. The problem of land surface subsidence, as a result of prolonged geothermal fluid withdrawal from shallow geothermal formations, is a potentially major impact of the development of water-dominated systems in areas such as California's Imperial Valley. Much of the current knowledge on the causes and effects of subsidence has been derived from the exploitation of oil and gas resources and from intensive pumping of groundwater.[7] If large quantities of fluids are removed from an underground reservoir which has an unconsolidated overburden, the land surface may slowly collapse and sink. This may change the surface topography enough to threaten the operation and structural integrity of nearby facilities, such as irrigation systems and earthen dams.[8] Records indicate however, that subsidence is relatively unusual [9], and has only been noted at one geothermal field, Wairakei, New Zealand. There, the subsidence occurs in part of the geothermal field itself.

The best known method of preventing subsidence is by injection of fluids, usually waste water, back into the underground reservoir. Based on experience in the Imperial Valley in southern California, Dutcher, Hardt, and Moyle [10], report that subsidence can be minimized or prevented by either natural or artificial recharge. This requirement for injection fluid is potentially serious in locations where water would have to be imported from outside the area to supplement the spent geothermal fluids [9].

At present there is no reliable technique for predicting the potential for subsidence in advance. Monitoring of fluid pressure and land surface changes must be initiated before actual water extraction takes place. Development of pre-exploratory monitoring programs will be a major requisite for an environmentally sound geothermal development program.

The Bureau of Land Reclamation will monitor possible land subsidence in its East Mesa, Imperial Valley project. For this purpose they are setting up a very elaborate system of benchmarks. These will be used to measure subsidence and lateral movement.[11] On the issue of reinjection, the USDI has said in its environmental impact statement (1973):

Deep well injection is the emplacement of wastes within the earth, usually below the

water table and beneath a confining stratum which serves to isolate the wastes from potable water supplies or other valuable or potentially valuable resources. The feasibility of injecting liquid wastes deep within the earth is suggested by the enormous volume of subsurface fluid storage space. The earth, however, contains little empty space so waste liquids may have to be accommodated by compressing or displacing existing fluids (including injections into depleted reservoirs) or by compressing or deforming the surrounding strata....The possible adverse effects of high pressure waste injection include the displacement of saline waters distant from the injection site, the fracturing of geologic strata that could result in pollution of high quality zones, the migration of wastes and native fluids along existing or created fractures, the upward transfer of pollutants along well casings, and even the gross readjustment of the surrounding strata. The injection of fluids within the earth is concerned not only with hydrostatics but involves also the distribution of the initial pressure increases and their effects on the surrounding rock matrix. Chemically unstable wastes may produce heat and pressure after being injected, and these wastes may react with the fluids and minerals of the injection horizon, changing the permeability or strength of the surrounding strata. Determining the compatibility of the waste solution and the fluids and minerals of the injection horizon requires careful study. The identification of strata where injection may be feasible may be difficult.

Currently there are two distinct types of deep well injection practiced in the United States. The first, and by far the largest in terms of number of wells and volume of fluids injected, is the return of brines and other fluids to the aquifers from which they were extracted. This is a common practice in the oil and gas industry, where 9 million barrels per day[12] of wastes are injected through many thousands of wells in the oil-producing states. Another type of deep well injection is that involving liquid industrial (including geothermal), municipal, or low-level radioactive wastes. Currently a minor practice compared to the reinjection of brines; however, the number of industrial and municipal waste injection wells is increasing rapidly.

Brine reinjection has been practiced by the petroleum industry for over 50 years, both in waterflooding for the secondary recovery of oil and as a means of disposal of the brines associated with the production of oil. Ideally, the brines are reinjected into the strata from which they were produced, not only disposing of great volumes of liquid material but also preventing land subsidence and facilitating greater oil production. In the reinjection of oil-field brines, the most difficult problems are expected to be associated with confining the fluids to the desired strata....

Seismicity. Major and minor faults are common in many of the areas with geothermal potential (e.g., Imperial Valley of California). Exploration of the exact loca-

tion and activity of these faults and related seismic activity is another task which should precede the development of geothermal energy fields. Evaluation must be specific for each site.

Of particular concern is the effect of the injection of fluids on seismic activity. Although experience and research on this problem is limited, available information indicates that seismic activity can be induced by increasing hydrostatic pressure in subterranean fluids near a fault [10]. Since future geothermal developments in this country are expected to dispose of waste water by reinjection into the geothermal reservoir or other strata, consideration of possible seismic effects is required [8]. Seismic occurrences triggered by injection of fluids can be minimized by avoiding the more tectonically active sites. This may severely restrict the development of some promising geothermal resources, since geothermal reservoirs tend to be found in seismically active areas.

Relevant data on the relationship between seismicity and liquid injection were accumulated in a study by Raleigh and others [13] near Denver, Colorado. Routine injection of fluids in a deep disposal well (12,000 feet) was carried out for 18 months (March 1962-September 1963), then halted for a similar duration. The cycle was repeated over a period of years, during which seismic activity was continuously monitored. The frequency of local earthquakes was found to increase during periods of liquid injection, and to decrease to prior levels when injection ceased. [14] Although it was pointed out that the experiment had no control, and that the earthquakes might have occurred even if injection had not occurred, a causal relationship between seismic activity and injection of fluids was strongly indicated.

The science of earthquake prediction is still in the very early states of development, but researchers express hope for progress in the near future. Work in this country and in the Soviet Union indicates that it is likely that the time and place of some earthquakes will be predictable within the next five years (see Section 3.3).

The USDI has suggested that the tapping of geothermal energy may reduce the probability of large earthquakes:

The association of earthquakes with geothermal areas is not surprising, as active tectonism or intrusion would provide the conditions necessary for geothermal phenomena. The role of fluid pressure changes in triggering earthquakes is not as well known, but the possibility of generating earthquakes by large withdrawals or reinjections of geothermal fluids cannot be ruled out as a potential environmental impact. To date, earthquakes associated with fluid pressure changes have been small and not disastrous, and some evidence indicates that seismic activity associated with geothermal areas is a continuous process tending to relieve regional stresses, thus reducing the probability of large earthquakes. [2]

Biological, Social, and Cultural Impacts

Biological impacts and social and cultural impacts of liquid-dominated systems are similar to those already discussed for vapor-dominated systems.

Hot Dry Rock Systems

The most readily accessible hot dry rock systems consist of relatively shallow pockets of impermeable hot dry rock overlying a magma intrusion chamber or other heat source at depths in excess of 50,000 feet. The diffusive flux of heat from the interior of the earth keeps these rock deposits at median temperatures of 580° F or more. It appears that this heat source could be exploited for power production, when deep drilling technologies become available.

To tap this resource, wells will have to be drilled to depths of 15,000-20,000 feet or more and relatively large volumes of fractured rock will have to be created at the bottom of the wells. Water would then be injected into the fractured zone through one well and withdrawn through another. The heated fluid could be utilized in more or less typical generating equipment to produce electricity.

Three methods are potentially available for rock fracturing to produce the underground heat exchange volume: (1) hydraulic fracturing by injection of fluids under pressure, (2) use of chemical or nuclear explosives, and (3) thermal stressing. Nuclear fracturing will require extensive and special feasibility analysis in application to hot dry rock technology and is not considered further in this assessment. Aspects of the environmental impacts of this technique are reviewed in Kruger & Otte. [15] Figure 4.8.5 on the following page summarizes the environmental impacts which appear to be associated with hot dry rock systems.

Physical and Chemical Impacts

Air Quality. Some very small release of natural radioactive elements, as gases and in solution, may result from the fracture of rock masses. The amounts emitted depend on the geologic and hydrologic conditions and cannot be predicted at this time. However, present evidence indicates that such releases will probably be well within the standards presently prescribed for the nuclear power industry.

Potential air emissions problems described for the two previous geothermal technologies do not appear to be as severe for the hot dry rock systems.

Surface Water Quality. Surface water quality will not be affected if the circulating fluids are well contained in a closed cycle. During construction activities, however, care must be taken to avoid contaminating streams and other surface water sources with wind- or water-borne sediment and drilling spoils.

Since, in this technology, fluids are introduced into a subterranean heat exchange chamber and returned to the surface in a closed cycle, problems inherent in storage or disposal of contaminants will be minimal. If fluids become saturated with minerals in the fractured rock chamber, scaling of equipment and clogging of the fractured zone could result. Acceptable control methods will have to be developed to prevent these problems.

The major water-related problem is one of consumptive water loss. An external source of suitably pure water must be found to supply the water to be injected into the subterranean fractured zone and to be used in the cooling system. This water requirement will increase as the volume of the fractured zone increases due to thermal contraction of the rock and cracking of the rock. The commitment of the large volumes of water required to operate a dry hot rock based power plant could conflict with other beneficial uses, such as agricultural or community water supplies, and produce a number of long-term secondary impacts.

	LEGEND	MAJOR ACTIVITY GROUPS				
		EXPLORATION	PRODUCTION DRILLING AND TESTING	PARALLEL FIELD DEVELOPMENT OPERATIONS	PLANT CONSTRUCTION	FULL-SCALE OPERATION
	<ul style="list-style-type: none"> ■ HIGH POTENTIAL IMPACTS LONG TERM AND/OR GREAT INTENSITY ● MODERATE POTENTIAL IMPACTS MAJOR SHORT TERM AND/OR OVERSHADOWED EFFECTS ○ LOW/NEGLIGIBLE POTENTIAL IMPACTS MINOR AND/OR SHORT-TERM 	<ul style="list-style-type: none"> • Mapping/Field Studies • Drilling Pad Construction • Test Drilling (Shallow & Small Diameter) • Temporary Roads/Traffic • Equipment Operation • Abandonment 	<ul style="list-style-type: none"> • Well Drilling & Construction (Production & ReInjection) • Well Stimulation • Accidental Blowouts • Well Testing/Venting/ Flooding/Reinjection 	<ul style="list-style-type: none"> • Land Clearing and Roads/ Vehicular Traffic • Gathering Systems • Equipment Activities • Service Living Quarters • Water, Sewage, Temp. Elec., & Other Supporting Services 	<ul style="list-style-type: none"> • Structures & Improvements • Vehicular Traffic/Equipment • Activities • Special Construction Activities (e.g., Blasting) • Electric Transmission Systems • Supporting Services (e.g., Water, Elec., etc.) 	<ul style="list-style-type: none"> • Cooling Towers • Venting (During Short Term Outages) • Well-Head Bleeding • ReInjection • Recharge, Stimulation, & Redrilling • Corrosion & Scale Control • Gaseous, Liquid, & Solid Wastes • Work Force Movement • Abandonment
ASPECTS OF THE ENVIRONMENT	PHYSICAL/CHEMICAL:					
	AIR QUALITY	○	○	○	○	○/■1
	NOISE	○	●	●	●	○
	WATER QUALITY-SURFACE	○	○/●2	○/●2	○	○/■1
	WATER QUALITY-GROUNDWATER	○/■2	○/■2	○	○	○
	SOILS/EROSION	○	○/●2	○/●2	○/●2	○
	LAND SUBSIDENCE	○	○	○	○	○/●2
	SEISMICITY	○	○/■2	○	○	○/■2
	BIOLOGICAL:					
	TERRESTRIAL FLORA AND FAUNA	○/●2	○/●2	○/●2	○/■2	○
	WETLANDS, MARSHES	○/●2	○/●2	○/●2	○/●2	○/■1,2
	AQUATIC	○/●2	○/●2	○/●2	○/●2	○/■1,2
	SOCIAL/CULTURAL:					
	LAND & WATER USE (CONSISTENCY)	○	○/■2	○/■2	○/■2	○/■2
	SCENIC/AESTHETIC	○	○/●2	○/■2	○/■2	○/■1,2
	SAFETY	○/●2	○/●2	○/●2	○/●2	○
	SERVICES BURDEN	○	○/●2	○/●2	○/●2	○

1 = TECHNOLOGY DEVELOPMENT 2 = SITE DEVELOPMENT

Figure 4.8.6 SUMMARY ENVIRONMENTAL ASSESSMENT MATRIX FOR HOT DRY ROCK SYSTEM

Groundwater Quality. Aquifers will not be adversely affected where exploration and development activities are well planned, regulated, and conducted. If care is not taken, however, the mixing of water from low and high quality aquifers could take place.

Subsidence. Subsidence is unlikely during the development and operation of hot rock geothermal reservoirs, since the majority of the subsurface modification occurs at great depths and in solid rock strata.

Seismicity. As in the case of the liquid-dominated technology, seismicity is of concern. Since the heat exchange process typically takes place at great depths, the chances for passing through a previously undetected minor fault are real, and thus the possibility of triggering seismic activity must be considered. What will be needed is a means for identifying inappropriate deep underground conditions from surface manifestations (in other words, an improvement in geological omniscience) or from instrumentation which, functioning underground, could produce accurate three-dimensional fault maps.

Biological Impacts

Terrestrial Flora and Fauna. The effects of any development of the biota vary greatly with the type of habitat affected. Any reasonably detailed assessment therefore will depend upon the site being considered.

In general terms, an area of habitat will be lost which corresponds to the size of the development. The acceptability of the environmental cost depends on the availability and use of the remaining habitat of the same type. Given the biological diversity of the United States and the potentially large area available for the development of hot dry rock systems, prior planning should minimize the environmental costs to be borne by terrestrial biota. Aside from the direct taking of terrestrial habitat, impacts of a secondary nature, e.g., waste streams, human activity around the site and noise, can be controlled by proper siting and design features. In addition to habitat availability, planning must be adjusted to accommodate breeding grounds, migrating routes, and endangered species or ecosystems.

Social and Cultural Impacts.

Land Use Consistency. With the probability that hot dry rock resources are available under the entire United States, it is likely that power facilities could be developed near urban, industrial, or other high power use areas. It is anticipated that a 100 MWe power plant could occupy only about 1/5 square mile of surface area, reducing the potential for land use conflict to essentially the same level as a conventional thermal power plant. (See Section 4.6.)

Liquid and Solid Wastes

In this technology, extraction and disposal of fluids is avoided; the only wastes are those which emanate from cooling towers.

Safety. Safety primarily concerns the well-being of the work force, as well as others in the area, who can be affected by the increased activity associated with the resource development. General safety could be a problem if blowouts occur, but with proper precautions, unsafe conditions can be minimized or avoided.

Geopressured Zones Systems

The inventory of potential geopressured regions is far from complete. One promising area of the United States

in which geopressured zones have been identified is the Louisiana-Texas Gulf Coast area, a belt of land 35-75 miles wide along the coast from the Rio Grande River to the Mississippi Delta (a distance of approximately 800 miles). Jones[16] reported that the geopressured belt extends far out beneath the Gulf Continental Shelf, and occurs at some depth beneath the main deltaic sand series in Miocene and Pliocene (Neogene) sediments everywhere Gulfward from the innermost zone of growth faults.

Since 1953, when the classic description of geological aspects of abnormal reservoir pressures was published [17], additional data on geopressured reservoirs have been acquired, especially regarding production-engineering characteristics and methods of early detection and pressure estimation.

The technology and environmental impacts involved in developing geopressured reservoirs are similar to those known for the exploration and development of natural gas or petroleum reservoirs (see Figure 4.8.7.) Determination of the hydrodynamic characteristics of the aquifer zones and monitoring of activities are needed to avoid possible major impacts, such as seismicity, land subsidence, surface or groundwater contamination. As in other energy technologies, land use patterns and aesthetic considerations must also be examined.

The withdrawal of geothermal fluids from stacked aquifers would commit approximately 50 square miles of the geopressured strata for each 100 MWe power plant. This precludes the dense clustering of power plants which might occur over a liquid-dominated reservoir. It also places rather severe restrictions on the maximum potential capacity of any one plant. However, only a small surface area would be required for the above-ground installation, minimizing aesthetic and land use conflicts. If it should be necessary to construct extensive holding ponds or percolation fields for spent geothermal fluids, land use conflicts could be considerably greater, however.

Physical and Chemical Impacts

Air Quality. The emission of gases and debris is to be expected only when an accidental blowout occurs. When procedures and precautions known to other technologies are applied at the earliest stages, air emissions from such accidents can be prevented. In normal operation, the methane known to occur in unusually high concentrations in geopressured fluids will be flash separated and burned, or collected for transmission elsewhere.

Noise. Drilling and pumping activities can result in high noise levels. Mufflers and other noise suppression devices similar to those being developed for vapor-dominated systems will probably prove applicable.

Surface Water Quality. An important and related consideration to the exploitation of geopressured thermal waters has been the potential effect of discharging spent fluids to surface waters. The known range of salinities for the Gulf Coast geopressured aquifers is quite broad, from 1000 ppm to 300,000 ppm.[16] Those waters with the lowest concentrations are at the threshold of U.S. Public Health Service limits for total dissolved solids (TDS) in drinking water, while those at the higher end of the range are nearly 9 times the concentration of sea water. The release to surface water of the large volumes of geopressured fluids required to drive a power plant would require careful management to prevent large scale ecological damage to estuarine coastal areas and the commercial and sport

	LEGEND	MAJOR ACTIVITY GROUPS				
		EXPLORATION	PRODUCTION DRILLING AND TESTING	PARALLEL FIELD DEVELOPMENT OPERATIONS	PLANT CONSTRUCTION	FULL-SCALE OPERATION
	<ul style="list-style-type: none"> ■ HIGH POTENTIAL IMPACTS LONG TERM AND/OR GREAT INTENSITY ● MODERATE POTENTIAL IMPACTS MAJOR SHORT TERM AND/OR OVERSHADOWED EFFECTS ○ LOW/NEGLIGIBLE POTENTIAL IMPACTS MINOR AND/OR SHORT-TERM 	<ul style="list-style-type: none"> • Mapping/Field Studies • Drilling Pad Construction • Test Drilling (Shallow & Small Diameter) • Temporary Roads/Traffic • Equipment Operation • Abandonment 	<ul style="list-style-type: none"> • Well Drilling & Construction (Production & ReInjection) • Well Stimulation • Accidental Blowouts • Well Testing/Venting/Ponding/Reinjection 	<ul style="list-style-type: none"> • Land Clearing and Roads/Vehicular Traffic • Gathering Systems • Equipment Activities • Service Living Quarters • Water, Sewage, Temp. Elec., & Other Supporting Services 	<ul style="list-style-type: none"> • Structures & Improvements • Vehicular Traffic/Equipment • Activities • Special Construction Activities (e.g., Blasting) • Electric Transmission Systems • Supporting Services (e.g., Water, Elec., etc.) 	<ul style="list-style-type: none"> • Cooling Towers • Venting (During Short Term Outages) • Well-Head Bleeding • ReInjection • Recharge, Stimulation, & Redrilling • Corrosion & Scale Control • Gaseous, Liquid, & Solid Wastes • Work Force Movement • Abandonment
ASPECTS OF THE ENVIRONMENT	PHYSICAL/CHEMICAL:					
	AIR QUALITY _____	○	○/●1	○	○	○
	NOISE _____	○	○/●1,2	○/●1,2	○/●1,2	○
	WATER QUALITY-SURFACE _____	○/●2	○/■2	○/●2	○	○/○2
	WATER QUALITY-GROUNDWATER _____	○	○/■2	○	○	○/■2
	SOILS/EROSION _____	○/●2	○/●2	○/●2	○/●2	○/■2
	LAND SUBSIDENCE _____	○	○	○	○	●/■2
	SEISMICITY _____	○	○	○	○	○/■2
	BIOLOGICAL:					
	TERRESTRIAL FLORA AND FAUNA _____	○	○/●2	○/●2	○/●2	○
	WETLANDS, MARSHES _____	○/●2	○/■2	○/■2	○/■2	○/■2
	AQUATIC _____	○	○/●2	○/●2	○/●2	○/■2
	SOCIAL/CULTURAL:					
	LAND & WATER USE (CONSISTENCY) _____	○	○/■2	○/■2	○/■2	○/■1,2
	SCENIC/AESTHETIC _____	○	○/●2	○/■2	○/■2	○/■1,2
	SAFETY _____	○/●2	○/●2	○/●2	○/●2	○
	SERVICES BURDEN _____	○	○/●2	○/●2	○/●2	○/●2

1 = TECHNOLOGY DEVELOPMENT 2 = SITE DEVELOPMENT

Figure 4.8.7 SUMMARY ENVIRONMENTAL ASSESSMENT MATRIX FOR GEOPRESSED ZONE SYSTEM

fisheries they support. It is questionable whether water with a salinity much above 35,000 ppm should be discharged even into the open ocean in the volumes being considered or indeed, if the ambient salinity of the receiving water should ever be exceeded.

Groundwater Quality. The hydrology of artesian aquifer systems in the Texas-Louisiana Gulf region has been well documented [16,18,19]. When hydrologic characteristics of geopressed zones are being evaluated, information concerning the salinity of water in the aquifers is often very helpful. Precise information on geotemperature regimes is of critical concern, however. Dickinson notes that abrupt changes in temperature can occur over short ranges, which are hydrologically critical to the geopressure regime [17]. Thus, adequate information concerning geopressed zones may not be available to determine the relationship between the removal of large quantities of geopressed fluids and the impacts already mentioned such as ground or surface water contamination, seismicity, or land subsidence. These effects must be carefully considered as the technology develops.

Subsidence. Subsidence may prove to be a major impact in geopressed systems, since very large volumes of water are extracted from the reservoir. The best known method of retarding subsidence, reinjection, may not be feasible since it would consume a major portion of the energy generated from the fluid. The subsidence of the coastal area could change the high tide contour and result in the inundation of low lying regions. Irreversible property damage and changes in the coastal ecology could result.

Seismicity. Although known geopressed zones are generally not in seismically active areas, data are not yet available to evaluate the probability of induced seismicity. In the geographic areas where utilization of geopressed regions is being considered, reinjection of fluid wastes, if undertaken, is expected to be into aquifers shallower than the thermal formations. Raleigh points out that the Gulf Coast and Mid-Continent areas are relatively inactive tectonically and, except under extreme conditions, appear to hold little potential for artificially induced earthquakes.[13] Nevertheless, injection wells should be located at a safe distance from large faults. Raleigh concludes that if injection into the basement rock near large population centers is planned, even in these tectonically inactive areas, seismic monitoring of the injection wells seems advisable.

Biological Impacts

Baseline biological descriptions of areas suspected to offer potential for exploration must be developed. Disruptions to wildlife habitats, particularly in areas where this technology is under intense investigation, must be given high priority for study. The areas of the United States where geopressed resources regions exist are used extensively by migratory waterfowl. Disturbance of wetlands which serve as rich habitat for native fauna should be avoided as much as possible. The potential for the disruption of salinity regimes is high with this system and could seriously damage coastal habitats. The potential damage to local estuarine ecosystems from the excessive discharge of highly saline geothermal fluids could also have far-reaching effects. Modification of the ambient salinity ranges could eliminate intolerant plant species or modify their distributions. Many of the Gulf's economically important fin fishes and crustaceans are totally dependent on the rich, shallow, highly productive estuaries as nursery grounds for the young. As such, estuarine wetlands are essentially a limited resource requiring continued

preservation from development or extensive changes. Hence activities associated with the exploitation of geopressed regions must be governed by sensitive concern for the biological setting.

Magma Systems

A fifth source of geothermal energy is the magma which forms the molten core of the earth. It may be feasible, when high temperature alloys are developed, to extract heat from near-surface intrusions of magma, generally associated with volcanically active areas. A heat exchange loop could be inserted into the molten material through a well. Fluid circulated through the loop could then be vaporized and used to drive vapor turbines at the surface.

Major technological problems center on developing heat resistant materials for use in constructing the heat exchange loop and on safe drilling into a magma chamber for the insertion of the loop. Blowouts of magma and gases would pose major safety hazards. Exploration and identification of potential magma reservoirs is also required.

Virtually no information has been published on magma resources, technology, or environmental problems and solutions. For this reason, the preparation of an environmental assessment matrix for this resource was not undertaken. The fund of basic knowledge on magma systems must be materially advanced before their impacts can be assessed.

Summary of the Issues

If geothermal technology is developed under existing economic constraints, the evolution of pollution control technology will probably keep pace. Adequate environmental rules and regulations are presently on the books to ensure only nuisance level impacts if all leasing, pollution control, and monitoring procedures are literally applied. Most states have promulgated ambient air quality standards which often exceed federal standards. A summary of air quality standards of states with geothermal potential is presented in Appendix I. Except for accidents, such as blowouts, geothermal sources should not exceed these limitations for more than short periods of time. Hydrogen sulfide emission from steam and hot water sources can be reduced to safe levels by natural dispersion and dilution or, if necessary, by a scrubbing apparatus expected to be available shortly.

Contamination of surface water by geothermal operations is a potential problem, but with careful study it should be possible to avoid unanticipated or irreversible consequences.

Seismicity and subsidence are possible geothermal issues of considerably more concern. As much information as possible should be developed about these issues on a theoretical basis. When deep injection is to take place in areas where faults are likely or possible, or when reinjection is possible, seismicity and subsidence should become primary foci of environmental impact analyses.

The extensive geothermal provinces which have been identified to date are predominantly of the liquid-and-vapor-dominated reservoir type. These resource types are expected to produce a major portion of the geothermal power output in the future. Therefore, under a crash program, it could be assumed that rather large tracts in the arid sections of California, Washington, Oregon, Nevada, Arizona, New Mexico, and others would be thoroughly explored and when suitable reservoirs were discovered, developed

into multiple unit power generating complexes with interconnecting transmission lines. The intermingling of these plants with mineral extraction plants, water reclamation units, and other related industries could result in refinery-type complexes, with interconnecting pipelines, buildings, water holding ponds, and cooling towers which might, in some areas, cover several square miles. Of course, high voltage transmission lines would be installed in these developments also. Based on the forecast energy development assumptions, a maximum of approximately 1500-2500 square miles of surface will ultimately be required to accommodate the development of all of these geothermal and ancillary facilities. Developments of this total magnitude could result in a variety of effects as discussed previously.

Although the indications are that the environmental impacts created out of the development of geothermal energy are not of major significance when compared to other energy forms, it is desirable to evaluate these possible environmental impacts in a summary manner, as presented in Figure 4.8.8, "Evaluation of Important Environmental Impacts." The relative significance of

these impacts was based on the numerical key as shown in the figure. The numbers in the figure represent the consensus opinion of the study team and the panel of consultants.

The two most important environmental impacts were judged to be contamination of surface and subsurface waters and seismicity. It is no coincidence that these two impacts are also judged to be the most important in the Department of the Interior environmental statement for the geothermal leasing program. Many of the points made in this study are derived from those made in the Department of the Interior environmental impact statement.

The impacts listed in the figure summarize the discussion of this section. The weightings given to the columns on lasting qualities and timing indicate the importance of making adequate and timely plans at the beginning of the geothermal energy development. By doing this it appears that environmental disruption can be kept to a minimum while the geothermal resource can be a valuable domestic energy component.

IMPACT AREA	SIGNIFICANCE	NUMBER OF PEOPLE AFFECTED	LASTING QUALITIES	TIMING	SUM OF IMPACT JUDGMENT
BIOTA	0	1	1	2	4
SEISMICITY	3	3	2	2	10
SUBSIDENCE	1	1	3	2	7
CONTAMINATION OF SURFACE AND SUBSURFACE WATERS	2	3	2	3	10
BLOWOUTS	3	1	1	2	7
AESTHETICS	1	1	2	2	6
RELEASE OF H ₂ S	1	1	0	3	5
RELEASE OF NH ₃ AND OTHER ATMOSPHERIC CONTAMINANTS	1	1	0	2	4
NOISE	1	1	1	3	6
LAND USE	2	2	2	1	7

KEY: SIGNIFICANCE	NUMBER OF PEOPLE AFFECTED	LASTING QUALITIES	TIMING
3 = POTENTIALLY KILLING	3 = A GREAT MANY 1,000,000	3 = IRREVERSIBLE	3 = IMMEDIATE CONCERN
2 = VERY DANGEROUS OR IMPORTANT	2 = MANY AFFECTED	2 = REVERSIBLE WITH A GREAT DEAL OF EFFORT	2 = OF CONCERN WITHIN 5 YEARS
1 = SOME DANGER OR IMPORTANCE	1 = LOCALIZED	1 = SOME EFFORT TO REVERSE	1 = OF CONCERN WITHIN 5-10 YEARS
0 = TRIVIAL	0 = NONE	0 = SELF-CORRECTING	0 = OF CONCERN WITHIN 10-20 YEARS

NOTE: THE RELEASE OF RADON GAS (RADIOACTIVE) HAS BEEN IDENTIFIED AT A FEW GEOTHERMAL SITES. HOWEVER, THE CONCENTRATIONS ARE NEGLIGIBLY SMALL OR NOT QUANTIFIED. FURTHER DATA SHOULD BE ACQUIRED.

Figure 4.8.8 EVALUATION OF IMPORTANT ENVIRONMENTAL IMPACTS

REFERENCES

- [1] Leopold, L. B., et al., A Procedure for Evaluating Environmental Impact, U.S.G.C. Circular 645 (Washington, D.C.: 1971).
- [2] U.S. Department of the Interior, Office of the Secretary, Final Environmental Statement for the Geothermal Leasing Program, Vol. I, II, III, and IV (Washington, D.C.: October 1973).
- [3] Hickel, W. J., "Geothermal Energy: A Special Report," Geothermal Resources Research Conference (Seattle, Wash.: Battelle Seattle Research Center, September 1972).
- [4] Bolton, R. S., "Blowout Prevention and Other Aspects of Safety in Geothermal Steam Drilling," Proceedings of the United Nations Conference on New Sources of Energy, Rome, Vol. 3, Geothermal Energy (1968), pp. 78-88.
- [5] Stillwell, W. B., "Drilling Practices and Equipment in Use at Wairakei," United Nations Symposium on the Development and Utilization of Geothermal Resources, Pisa, Italy, Vol. 2, Part 1, Geothermics--Special Issue (1970), pp. 714-724.
- [6] Cigni, V., et al., "Completion of Production Wells," United Nations Symposium on the Development and Utilization of Geothermal Resources, Pisa, Italy, Vol. 2, Part 1, Geothermics--Special Issue 2 (1970), pp. 757-763.
- [7] Poland, J. F., and G. H. Davis, "Land Subsidence Due to Withdrawal of Fluids," Engineering Geology, Vol. 2, pp. 187-269.
- [8] Peck, D. L., Assessment of Geothermal Energy Resources (Washington, D.C.: Committee on Energy [Research and Development Goals], Federal Council for Science and Technology, Panel on Geothermal Energy Resources, September 25, 1972).
- [9] Goldsmith, M., Geothermal Resources in California: Potentials and Problems, E.Q.L. Report 5 (Pasadena, Calif.: California Institute of Technology, Environmental Quality Laboratory, December 1971), pp. 30-31.
- [10] Dutcher, L. C., W. F. Hardt, and W. R. Moyle, Jr., Preliminary Appraisal of Groundwater in Storage with Reference to Geothermal Resources in the Imperial Valley Area, California (Washington, D.C.: U.S. Geologic Survey Circular 649), p. 51.
- [11] Bureau of Reclamation, "Geothermal Resource Investigations, Imperial Valley, California--Development Concepts," 1973.
- [12] "Crack Down on Oil Field Pollution," Petroleum Engineer, Vol. 39, No. 7 (July 1967), pp. 33-36.
- [13] Raleigh, C. B., Earthquakes and Fluid Injection, Memoir 18 (Washington, D.C.: U.S. Geologic Society Publication authorized March 17, 1972 [The Rangely Research Project], Implications, American Association of Petroleum Geologists), pp. 278-279.
- [14] Healy, J. G., et al., "The Denver Earthquakes," Science, Vol. 161 (1968), pp. 1301-1310.
- [15] Kruger, P., and C. Otte (eds.), Geothermal Energy (Stanford University Press, 1973).
- [16] Jones, P. H., "Hydrodynamics of Geopressure in the Northern Gulf of Mexico Basin," Journal of Petroleum Technology, Vol. 21 (1969), pp. 803-810.
- [17] Dickenson, G., "Reservoir Pressures in Gulf Coast Louisiana," AAPG Bulletin, No. 37 (1953), pp. 410-432.
- [18] Jones, P. H., "Geological Hydrodynamics--A Possible Key to the Hydrology of Certain Aquifer Systems in the Northern Part of the Gulf of Mexico Basin," XXII International Geological Congress (1968), pp. 113-125.
- [19] Jones, P. H., "Geothermal Resources of the Northern Gulf of Mexico Basin," Geothermics, Special Issue 2 (1970), pp. 14-26.

5. EVALUATION OF IMPACTS

It is probably appropriate at this point in the report to pause and review the tasks which have been described and those which remain. A plausible path for the evolution of geothermal energy in the United States was developed recognizing technological, political, economic, regulatory, institutional, and environmental impediments. This description was built from a careful review of the state-of-the art and employed judgments derived in interviews and synthesized in a simulation model. The model was used to examine the effects on fuel mix of some potential policies and sensitivity to changes in initial assumptions. Using judgments obtained in the interviews and derived from the literature as a starting point, primary impact areas were defined and relevance tree impacts were constructed. The purpose of the relevance trees was to describe essentially all important higher-order impacts. Estimates of direct consequences flowing from geothermal growth were made using the simulation model and other analysis techniques. The study team then chose secondary and tertiary impacts for elaboration and forecasts of selected indicators associated with these impacts were made using the model where that was possible, trend impact analysis, and other more conventional approaches. These steps have been described in previous sections of this report.

Among the problems which remain are:

1. Who will be affected by the impacts and how deeply?
2. What policies are available to improve these impacts?
3. What level of improvement can be expected?

These questions form the focus of the work reported in this section.

The impact relevance trees provide a source of statements about the consequences of geothermal energy, should it develop. The study team reviewed these statements together with quantitative projections of indicators associated with the impacts (Chapter 4) and the responses of the socio-economic interview panel (Appendix C) in order to form a subset of potentially significant impacts. Figure 5.1.1 on the following page presents this list. To be clear about the nature of the entries on this list, each item should be read with the following preamble:

If geothermal energy develops, in a manner similar to that described by the simulation model, then it is plausible to expect that an important direct or indirect consequence of that development will be....

The technological and impact relevance trees, and the literature (particularly the comments submitted in response to the Environmental Impact Statement issued by the Department of the Interior) were reviewed in order to compile a list of groups likely to affect or be affected by geothermal energy. It was our objective here to be as complete as possible without overstating the obvious (in the end, everyone, to some small measure, will be affected by geothermal energy). The list of interest groups is presented in Figure 5.1.2.

Four matrices were then constructed in which interest groups head the columns and impact statements, the rows. Each cell of the matrix contains a number depicting the study team's judgment about how a particular interest group would be affected should a particular impact be

realized. The coding for these judgments was as follows:

- +8 = pre-emptive positive impact
- +4 = major positive impact
- +2 = important positive impact
- +1 = slight positive impact
- 0 = no impact
- 1 = slight negative impact
- 2 = important negative impact
- 4 = major negative impact
- 8 = pre-emptive negative impact

The criteria used in evaluating the significance of a particular impact for a particular group were:

1. The percentage of the group affected--the most significant impact would be the one which affected the highest percentage of the group being considered.
2. The severity of the effect--the most significant impact would be the one which would have the most deleterious or favorable consequences.
3. The reversibility of the effect--the most serious impact would be one which was on an essentially irreversible path.
4. Responsibility for correcting or obtaining the impact--the most important impact would be one for which no responsible institution exists.

Thus an impact judgment of -8 represented a case in which a large percentage of the group being considered was affected very badly, the effect noted appeared to be essentially irreversible, and the responsibility for correcting the situation was not clearly established. An impact judgment of +8 represented a case in which a large percentage of the group was affected very beneficially, the evolutionary path yielding the benefits appeared to be essentially irreversible, and institutional arrangements seemed to be well enough in place to ensure the achievement of the benefit. Figure 5.1.3 displays a sample value matrix and the complete matrix is presented in Appendix G.

It is worthwhile elaborating on the nature of the entries in the matrix. So that the results of this analysis can be properly interpreted, two cases will be cited as examples:

1. The judgments provided to simulate impacts on the Department of the Interior (Group 2) were as follows:
 - a. Impacts perceived as having a very positive affects (+8 to +4) were:
 32. Increased geothermal R&D for the environment.
 33. Increased geothermal exploration and production of exploration equipment.
 37. Increased geothermal R&D exploration.
 85. Decreasing rate of depletion of oil.
 - b. Impacts perceived as having somewhat positive affects (2 to +3.9) were:
 29. Changes in manpower, funding, and

1. FEWER THAN EXPECTED GAS-FIRED ELECTRIC GENERATION PLANTS.
2. FEWER THAN EXPECTED NUCLEAR PLANTS.
3. FEWER THAN EXPECTED COAL-FIRED PLANTS.
4. FEWER THAN EXPECTED OIL-FIRED PLANTS.
5. LOWER THAN EXPECTED PRICE FOR GASOLINE.
6. LOWER THAN EXPECTED PRICE FOR COAL.
7. LOWER THAN EXPECTED PRICE FOR HEATING AND FUEL OIL.
8. LOWER THAN EXPECTED PRICE FOR JET FUEL.
9. LOWER THAN EXPECTED PRICE FOR ELECTRICITY.
10. LOWER THAN EXPECTED PRICE FOR URANIUM.
11. LOWER THAN EXPECTED PRICE FOR NATURAL GAS.
12. DELAYED DEVELOPMENT OF TAR SANDS AND OIL SHALE.
13. DELAYED DEVELOPMENT OF SOLAR ENERGY.
14. DELAYED DEVELOPMENT OF NUCLEAR FUSION.
15. DELAYED DEVELOPMENT OF BREEDER REACTOR.
16. DELAYED DEVELOPMENT OF SYSTEMS WHICH CONVERT WASTES TO ELECTRICITY.
17. DELAYED DEVELOPMENT OF COAL GASIFICATION AND LIQUEFACTION.
18. IMPROVEMENT IN ENVIRONMENTAL CONSIDERATIONS OF BUSINESSES THAT USE GEOTHERMAL ENERGY FOR ELECTRICITY.
19. FAVORABLE ECONOMIC CONSIDERATIONS FOR BUSINESSES THAT USE GEOTHERMAL ENERGY FOR ELECTRICITY.
20. INCREASED MANPOWER, TECHNOLOGY, AND MATERIAL REQUIREMENTS STEMMING FROM BUSINESSES FORMED AROUND THE USE OF GEOTHERMAL ELECTRICITY.
21. CHANGES IN THE INSTITUTIONAL-SOCIAL SETTING AS A RESULT OF THE CREATION OF NEW BUSINESSES THAT USE GEOTHERMAL ELECTRICITY.
22. CHANGES IN MANPOWER, FUNDING, AND R&D POLICY AS A RESULT OF THE RISE OF BUSINESSES THAT USE GEOTHERMAL ELECTRICITY.
23. MOVEMENT OF BUSINESSES THAT USE GEOTHERMAL ELECTRICITY, HEAT, OR MINERALS INTO GEOTHERMAL REGIONS.
24. MOVEMENT OF BUSINESSES THAT USE GEOTHERMAL ELECTRICITY, HEAT, OR MINERALS OUT OF EXISTING LOCATIONS.
25. CHANGES IN ENVIRONMENTAL CONSIDERATIONS OF BUSINESSES THAT USE GEOTHERMAL SOURCES FOR HEAT OR MINERALS.
26. FAVORABLE ECONOMIC CONSIDERATIONS FOR BUSINESSES THAT USE GEOTHERMAL SOURCES FOR HEAT OR MINERALS.
27. INCREASED MANPOWER, TECHNOLOGY, AND MATERIAL REQUIREMENTS STEMMING FROM BUSINESSES FORMED AROUND THE USE OF GEOTHERMAL HEAT OR MINERALS.
28. CHANGES IN THE INSTITUTIONAL-SOCIAL SETTING AS A RESULT OF THE CREATION OF NEW BUSINESSES THAT USE GEOTHERMAL HEAT OR MINERALS.
29. CHANGES IN MANPOWER, FUNDING, AND R&D POLICY AS A RESULT OF THE RISE OF NEW BUSINESSES THAT USE GEOTHERMAL HEAT.
30. OMIT.
31. OMIT.
32. INCREASED GEOTHERMAL R&D FOR THE ENVIRONMENT.
33. INCREASED GEOTHERMAL EXPLORATION AND PRODUCTION OF EXPLORATION EQUIPMENT.
34. INCREASED PRODUCTION OF GEOTHERMAL HEAT EXTRACTION EQUIPMENT AND SERVICES.
35. INCREASED GEOTHERMAL FIELD OPERATIONS EQUIPMENT AND SERVICES.
36. INCREASED GEOTHERMAL LEGAL AND ADMINISTRATIVE SUPPORT PROFESSIONS AND SERVICES.
37. INCREASED GEOTHERMAL R&D EXPLORATION.
38. IMPROVEMENTS IN GNP OVER A "NON-GEOTHERMAL WORLD."
39. IMPROVEMENTS IN INFLATION OVER A "NON-GEOTHERMAL WORLD."
40. IMPROVEMENTS IN GOVERNMENT INCOME OVER A "NON-GEOTHERMAL WORLD."
41. DIMINISHED GOVERNMENT SPENDING COMPARED TO A "NON-GEOTHERMAL WORLD."
42. USE OF AGRICULTURAL AND FOREST LANDS FOR DEVELOPMENT OF GEOTHERMAL INSTALLATIONS.
43. RELOCATION OF LOCAL POPULATION IN ORDER TO ACCOMMODATE GEOTHERMAL INSTALLATIONS.
44. USE OF LAND FOR NEW INDUSTRIES WHICH MOVE TO AREAS IN WHICH GEOTHERMAL INSTALLATIONS ARE MADE.
45. USE OF RECREATION, PARK, AND WILDERNESS AREAS FOR GEOTHERMAL INSTALLATIONS.

46. CREATION OF NEW OPPORTUNITIES FOR CRIME (E.G., DESTROYING GEOTHERMAL WELLS).
47. CHANGES IN RECREATIONAL PATTERNS.
48. INCREASED FUNDING FOR ELEMENTARY AND SECONDARY EDUCATION AS A RESULT OF CHANGES IN THE TAX BASE NEAR GEOTHERMAL INSTALLATIONS.
49. CREATION OF NEW PROFESSIONS AND, HENCE, NEW DEMANDS ON HIGHER EDUCATION.
50. DIMINISHED COST OF ELECTRICITY AS A RESULT OF THE INTRODUCTION OF A TRANSCONTINENTAL GRID.
51. IMPROVED ELECTRIC RELIABILITY AS A RESULT OF THE INTRODUCTION OF A TRANSCONTINENTAL GRID.
52. NEW RESPONSIBILITIES AND INTERFACES FOR EXISTING UTILITIES AS THE RESULT OF THE INTRODUCTION OF A TRANSCONTINENTAL GRID.
53. NEW RESPONSIBILITIES AND INTERFACES FOR PUBLIC UTILITY COMMISSIONS AS THE RESULT OF THE INTRODUCTION OF A TRANSCONTINENTAL GRID.
54. INCREASED NEED FOR CAPITAL TO FINANCE A TRANSCONTINENTAL GRID.
55. DEDICATION OF SEVERAL TRANSCONTINENTAL CORRIDORS FOR THE CONSTRUCTION OF A TRANSCONTINENTAL GRID.
56. DEVELOPMENT OF LOW-LOSS TRANSMISSION SYSTEMS.
57. INCREASED DEMAND AND COMPETITION FOR MATERIAL USED IN THE CONSTRUCTION OF A TRANSCONTINENTAL GRID.
58. GROWTH OF MANPOWER FOR THE CONSTRUCTION AND OPERATION OF A TRANSCONTINENTAL ELECTRICAL GRID.
59. CREATION OF A NEW FEDERAL INSTITUTION FOR REGULATION OF TRANSCONTINENTAL TRANSMISSION.
60. REVISION OF EXISTING UTILITY COMPANY GENERATION AND TRANSMISSION PLANS.
61. REVISION OF FEDERAL LEASING, TAX, AND LAND-USE REGULATIONS.
62. ESTABLISHMENT OF NEW FEDERAL REGULATORY BODIES FOR GEOTHERMAL ENERGY.
63. REVISION OF STATE LEASING, TAX, AND LAND USE REGULATIONS.
64. ESTABLISHMENT OF NEW STATE REGULATORY BODIES.
65. INCREASING CAPITAL DEMAND FOR GEOTHERMAL DEVELOPMENT.
66. PROVISION OF THE THRUST FOR THE CREATION OF NEW CITIES.
67. ALLOWANCE OF CERTAIN EXISTING CITIES TO DEVELOP INDEPENDENT SOURCES OF ENERGY.
68. DIMINISHMENT OF THE AMOUNT OF IMPORTED ENERGY.
69. PROVISION OF A NEW FOCUS FOR INTERNATIONAL TECHNOLOGY TRANSFER PROGRAMS.
70. EXPORTING OF MINERALS DERIVED FROM GEOTHERMAL SOURCES.
71. DIMINISHED AMOUNT OF STOCKPILED ENERGY MATERIALS.
72. A MAJOR UNITED NATIONS PROGRAM FOR AIDING THE DEVELOPMENT OF CERTAIN COUNTRIES.
73. THE DEVELOPMENT OF NEW KINDS OF WEAPONS.
74. LOWERED DEPENDENCY OF CERTAIN NATIONS (E.G., JAPAN) ON PETROLEUM.
75. DIMINISHED AIR QUALITY NEAR GEOTHERMAL INSTALLATIONS.
76. INCREASED NOISE NEAR GEOTHERMAL INSTALLATIONS.
77. DIMINISHED WATER QUALITY NEAR GEOTHERMAL INSTALLATIONS.
78. INCREASED SOIL EROSION NEAR GEOTHERMAL INSTALLATIONS.
79. INCREASED POSSIBILITY OF LAND SUBSIDENCE NEAR GEOTHERMAL INSTALLATIONS.
80. INCREASED POSSIBILITY OF SEISMICITY NEAR GEOTHERMAL INSTALLATIONS.
81. DELETERIOUS EFFECTS OF FLORA AND FAUNA NEAR GEOTHERMAL INSTALLATIONS.
82. DELETERIOUS EFFECTS ON WETLANDS AND MARSHES NEAR GEOTHERMAL INSTALLATIONS.
83. DELETERIOUS EFFECTS ON AQUATIC FLORA AND FAUNA NEAR GEOTHERMAL INSTALLATIONS.
84. INCREASING RATE OF DEPLETION OF GEOTHERMAL RESOURCES.
85. DECREASING RATE OF DEPLETION OF OIL.
86. DECREASING RATE OF DEPLETION OF COAL.
87. DECREASING RATE OF DEPLETION OF GAS.
88. DECREASING RATE OF DEPLETION OF URANIUM.
89. INCREASING INDEPENDENCE OF THE UNITED STATES ON FOREIGN NATIONS AS A RESULT OF PRODUCING CERTAIN MINERALS INDIGENOUSLY THROUGH THE USE OF GEOTHERMAL MINERALS.

Figure 5.1.1 SIGNIFICANT IMPACTS

1. U.S. GOVERNMENT INTERNATIONAL INTERESTS	27. SOLAR ELECTRICITY
2. DEPARTMENT OF THE INTERIOR	28. GEOTHERMAL EXPLORATION INDUSTRY
3. ATOMIC ENERGY COMMISSION	29. GEOTHERMAL DRILLING INDUSTRY
4. NATIONAL SCIENCE FOUNDATION	30. GEOTHERMAL OPERATING INDUSTRY
5. FEDERAL ENERGY AGENCY	31. MANUFACTURERS OF GAS-FIRED PLANTS
6. DEPARTMENT OF DEFENSE	32. MANUFACTURERS OF COAL-FIRED PLANTS
7. U. S. CONGRESS	33. MANUFACTURERS OF OIL-FIRED PLANTS
8. STATE ENERGY AGENCIES OF STATES WITH GEOTHERMAL ENERGY	34. MANUFACTURERS OF NUCLEAR PLANTS
9. STATE ENERGY AGENCIES OF STATES WITHOUT GEOTHERMAL ENERGY	35. BUSINESSES THAT BENEFIT FROM THE USE OF GEOTHERMAL HEAT
10. UTILITY COMPANIES IN GEOTHERMAL REGIONS	36. BUSINESSES THAT BENEFIT FROM THE USE OF GEOTHERMAL ELECTRICITY
11. UTILITY COMPANIES OUTSIDE OF GEOTHERMAL REGIONS	37. BUSINESSES THAT BENEFIT FROM THE EXTRACTION OR USE OF GEOTHERMAL MINERALS
12. UTILITY COMPANIES AFFECTED BY TRANSCONTINENTAL GRID	38. BUSINESSES THAT SUPPLY THE GEOTHERMAL INDUSTRY
13. NATURAL GAS EXTRACTION INDUSTRY	39. THE FINANCIAL COMMUNITY
14. NATURAL GAS PROCESSING INDUSTRY	40. ANTI-NUCLEAR ORIENTED ENVIRONMENTALISTS
15. NATURAL GAS STORAGE, TRANSPORTATION, AND DISTRIBUTION INDUSTRY	41. ENVIRONMENTALISTS AT LARGE
16. URANIUM EXTRACTION INDUSTRY	42. GROUPS OF HOMEOWNERS NEAR GEOTHERMAL INSTALLATIONS
17. URANIUM PROCESSING INDUSTRY	43. UNITED NATIONS
18. URANIUM STORAGE, TRANSPORTATION, AND DISTRIBUTION INDUSTRY	44. DEVELOPING COUNTRIES WITH GEOTHERMAL ENERGY RESOURCES
19. COAL EXTRACTION INDUSTRY	45. DEVELOPING COUNTRIES WITHOUT GEOTHERMAL ENERGY RESOURCES
20. COAL PROCESSING INDUSTRY	46. FOREIGN COUNTRIES WITH LARGE ENERGY SUPPLIES (E.G., OPEC)
21. COAL STORAGE, TRANSPORTATION, AND DISTRIBUTION INDUSTRY	47. SUPPLIERS OF GOODS AND SERVICES FOR TRANSCONTINENTAL TRANSMISSION LINES
22. PETROLEUM EXTRACTION INDUSTRY	48. MAYORS OF CITIES NEAR GEOTHERMAL ENERGY SOURCES
23. PETROLEUM PROCESSING INDUSTRY	49. EPA
24. PETROLEUM STORAGE, TRANSPORTATION, AND DISTRIBUTION INDUSTRY	50. RESEARCH COMMUNITY INVOLVED IN GEOTHERMAL RESEARCH
26. SOLAR HEATING INDUSTRY	

Figure 5.1.2 INTEREST GROUPS

IMPACTS	INTEREST GROUPS									
	U.S. GOV. INT'L INTERESTS	DEPT. OF THE INTERIOR	AEC	NSF	FED. ENERGY AGENCY	DEPT. OF DEFENSE	U.S. CONGRESS	STATE ENERGY AGENCIES W/ GEO.	STATE ENERGY AGENCIES W/O GEO.	UTILITY COMPANIES IN GEO. REGIONS
FEWER THAN EXPECTED GAS-FIRED ELECTRIC GENERATION PLANTS										
FEWER THAN EXPECTED NUCLEAR PLANTS			-6		-1		1			4
FEWER THAN EXPECTED COAL-FIRED PLANTS										
FEWER THAN EXPECTED OIL-FIRED PLANTS	1									
LOWER THAN EXPECTED PRICE FOR GASOLINE	2	1			4		4	3	3	
LOWER THAN EXPECTED PRICE FOR COAL		-1			4		2	3	3	

Figure 5.1.3 SAMPLE VALUE MATRIX

R&D policy as a result of the rise of new businesses that use geothermal heat.

70. Exporting of minerals derived from geothermal sources.
 71. Diminished amount of stockpiled energy materials.
 74. Lowered dependency of certain nations (e.g., Japan) on petroleum.
 86. Decreasing rate of depletion of coal.
 87. Decreasing rate of depletion of gas.
 88. Decreasing rate of depletion of uranium.
- c. Impacts perceived as having somewhat negative affects (-2 to -3.9) were:
12. Delayed development of tar sands and oil shale.
 42. Use of agricultural and forest lands for development of geothermal installations.
 43. Relocation of local population in order to accommodate geothermal installations.
 55. Dedication of several transcontinental corridors for the construction of a transcontinental grid.
 61. Revision of federal leasing, tax, and land-use regulations.
 62. Establishment of new federal

regulatory bodies for geothermal energy.

75. Diminished air quality near geothermal installations.
 76. Increased noise near geothermal installations.
 77. Diminished water quality near geothermal installations.
 78. Increased soil erosion near geothermal installations.
 81. Deleterious effects on flora and fauna near geothermal installations.
 82. Deleterious effects on wetlands and marshes near geothermal installations.
 83. Deleterious effects on aquatic flora and fauna near geothermal installations.
 84. Increasing rate of depletion of geothermal resources.
- d. Impacts perceived as having very negative affects (-4 to -8) were:
45. Use of recreation, park, and wilderness areas for geothermal installations.
 79. Increased possibility of land subsidence near geothermal installations.
 80. Increased possibility of seismicity near geothermal installations.

2. The judgments provided to simulate impacts on the financial community (group 39) were:

a. Impacts perceived as having a very positive affect (+8 to +4) were:

None

b. Impacts perceived as having somewhat positive affects (+2 to +3.9) were:

5. Lower than expected price for gasoline.

6. Lower than expected price for coal.

7. Lower than expected price for heating and fuel oil.

9. Lower than expected price for electricity.

10. Lower than expected price for uranium.

33. Increased geothermal exploration and production of exploration equipment.

34. Increased production of geothermal heat extraction equipment and services.

35. Increased geothermal field operations equipment and services.

39. Improvements in inflation over a "non-geothermal world."

40. Improvements in government income over a "non-geothermal world."

54. Increased need for capital to finance a transcontinental grid.

65. Increasing capital demand for geothermal development.

68. Diminishes the amount of imported energy.

70. Exporting of minerals derived from geothermal sources.

74. Lowered dependency of certain nations (e.g., Japan) on petroleum.

c. Impacts perceived as having somewhat negative affects (-2 to -3.9) were:

12. Delayed development of tar sand and oil shale.

17. Delayed development of coal gasification and liquefaction.

84. Increasing rate of depletion of geothermal resources.

d. Impacts perceived as having very negative affects (-8 to -4) were:

None.

stances: Case 1, normal; Case 2, crash; Case 3, normal, with heavy emphasis on reducing environmental impacts; and Case 4, identical with Case 3 but with the addition of policies which diminish land-use impacts. In each case the arithmetic manipulation was the same:

1. A weight of unity was assigned to each impact statement for Case 1; where different weights were appropriate for the other cases, these new weights were assigned. The weights are presented in Appendix H.

2. Both positive and negative impacts affected every group. The relative strength of each impact was computed for each group by taking the columnwise sums of the products of impact weights and, first, the positive impact relevance numbers. These sums constituted a "positive figure of merit." Then a "negative figure of merit" was computed for each interest group. These sums indicated, relatively, how the selected impacts seem likely to affect the groups considered, both favorably and unfavorably.

3. The horizontal sum of the products of relevance numbers and the weight of each impact statement constituted a "figure of merit" for each impact statement.

4. A rank ordering of the positive and negative figures of merit for each interest group indicated which groups were likely to be most beneficially or detrimentally affected.

5. A rank ordering of the impacts by their figure of merit indicated which impacts were likely to be seen as most beneficial or detrimental.

Figure 5.1.4 below illustrates the computation, and Figures 5.1.5 and 5.1.6 following both display the net scores for groups most significantly affected and the most important impacts for the four cases considered.

IMPACTS	WEIGHT	INTEREST GROUPS				
		GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
1	1.2	3	0	0	2	8
2	1.3	0	5	3	0	-3
3	1.5	-3	1	2	0	2
4	.7	2	3	5	0	0

TO COMPUTE "POSITIVE FIGURE OF MERIT" FOR THE FIRST INTEREST GROUP:

$$FOM_+ = 1.2 \times 3 + 2 \times 1.7 =$$

TO COMPUTE "NEGATIVE FIGURE OF MERIT" FOR THE FIRST INTEREST GROUP:

$$FOM_- = 1.5 \times 3 =$$

TO COMPUTE FIGURE OF MERIT FOR THE FIRST IMPACT:

$$FOM_{IMPACT 1} = 1.2(3 + 2 + 8) =$$

Figure 5.1.4 SAMPLE COMPUTATION

The four matrices prepared cover the following circum-

GROUPS	CASE 1			CASE 2			CASE 3			CASE 4		
	BASE CASE - 2000			CRASH CASE - 2000			EFFECTIVE ENV. POLICIES			EFFECTIVE ENV. & LAND USE POLICIES		
	NET IMPACTS	POSITIVE SCORE	NEGATIVE SCORE	NET IMPACTS	POSITIVE SCORE	NEGATIVE SCORE	NET IMPACTS	POSITIVE SCORE	NEGATIVE SCORE	NET IMPACTS	POSITIVE SCORE	NEGATIVE SCORE
39. THE FINANCIAL COMMUNITY	460	550	-90	539	652	-113	475	550	-75	475	550	-75
1. U.S. GOVERNMENT INTERNATIONAL INTERESTS	420	590	-170	483	689	-206	420	590	-170	435	590	-155
38. BUSINESSES THAT SUPPLY THE GEOTHERMAL INDUSTRY	410	520	-110	647	788	-141	525	600	-75	535	600	-65
30. GEOTHERMAL OPERATING INDUSTRY	350	750	-400	503	984	-481	550	850	-300	540	840	-300
50. RESEARCH COMMUNITY INVOLVED IN GEOTHERMAL RESEARCH	340	340	0	478	478	0	420	420	0	420	420	0
28. GEOTHERMAL EXPLORATION INDUSTRY	320	730	-410	477	970	-493	515	830	-315	515	820	-305
7. U. S. CONGRESS	310	780	-470	333	897	-564	370	790	-420	417	790	-373
43. UNITED NATIONS	290	450	-160	385	569	-184	330	450	-120	330	450	-120
47. SUPPLIERS OF GOODS AND SERVICES FOR TRANSCONTINENTAL TRANSMISSION LINES	240	280	-40	258	298	-40	240	280	-40	200	240	-40
29. GEOTHERMAL DRILLING INDUSTRY	230	720	-490	361	950	-589	435	820	-385	435	810	-375
44. DEVELOPING COUNTRIES WITH GEOTHERMAL ENERGY RESOURCES	220	280	-60	247	319	-72	250	280	-30	250	280	-30
37. BUSINESSES THAT BENEFIT FROM THE EXTRACTION OR USE OF GEOTHERMAL MINERALS	210	410	-200	262	505	-243	320	470	-150	333	458	-125
5. FEDERAL ENERGY AGENCY	130	620	-490	178	758	-580	290	700	-410	300	700	-400
48. MAYORS OF CITIES NEAR GEOTHERMAL ENERGY SOURCES	60	590	-530	72	694	-622	240	660	-420	336	656	-320

Figure 5.1.5 SCORES FOR GROUPS WHICH PERCEIVE MOST POSITIVE NET BENEFITS FROM GEOTHERMAL ENERGY

GROUPS	CASE 1			CASE 2			CASE 3			CASE 4		
	BASE CASE - 2000			CRASH CASE - 2000			EFFECTIVE ENV. POLICIES			EFFECTIVE ENV. & LAND USE POLICIES		
	NET IMPACTS	POSITIVE SCORE	NEGATIVE SCORE	NET IMPACTS	POSITIVE SCORE	NEGATIVE SCORE	NET IMPACTS	POSITIVE SCORE	NEGATIVE SCORE	NET IMPACTS	POSITIVE SCORE	NEGATIVE SCORE
41. ENVIRONMENTALISTS AT LARGE	-790	710	-1500	-993	841	-1834	-420	810	-1230	-262	810	-1072
49. EPA	-370	380	-750	-455	446	-901	-135	500	-635	-77	500	-577
42. GROUPS OF HOMEOWNERS NEAR GEOTHERMAL INSTALLATIONS	-180	470	-650	-219	561	-780	100	530	-430	180	524	-344
12. UTILITY COMPANIES AFFECTED BY TRANSCONTINENTAL GRID	-80	200	-280	-66	224	-290	-80	200	-280	-60	200	-260
26. SOLAR HEATING INDUSTRY	-40	150	-190	-73	170	-243	-60	150	-210	-64	146	-210
2. DEPARTMENT OF THE INTERIOR	-30	450	-480	29	598	-569	176	530	-354	239	530	-291
27. SOLAR ELECTRICITY	-30	190	-220	-60	218	-278	-70	170	-240	-74	166	-240
46. FOREIGN COUNTRIES WITH LARGE ENERGY SUPPLIES (E.G., OPEC)	0	290	-290	-6	328	-334	0	290	-290	0	290	-290
3. ATOMIC ENERGY COMMISSION	0	260	-260	-28	311	-339	10	270	-260	10	270	-260
34. MANUFACTURERS OF NUCLEAR PLANTS	0	160	-160	-28	184	-212	0	160	-160	0	160	-160

Figure 5.1.6 SCORES FOR GROUPS WHICH PERCEIVE MOST NEGATIVE NET BENEFITS FROM GEOTHERMAL ENERGY

In drawing conclusions from this analysis, it is important to recognize that values of the interest groups were interpreted by the study team and were not furnished directly by the interest groups themselves. Furthermore, the kinds of judgments required by the value matrix are extremely difficult to make and involve subtle guesses about what will be important to people between the present and 25 years from now. Nevertheless, the approach followed provided a systematic way for considering some of the myriad factors involved in public policy formulation in the field of geothermal energy. Some of our conclusions from this analysis (which are demonstrated primarily in Figures 5.1.5 through 5.1.8) are:

1. While many groups would see a "crash" geothermal program (implemented in the absence of concomitant environmental and land use policies) as beneficial, other groups would see such activity as extremely detrimental. Among the groups most threatened by a crash program are: environmentalists at large, the Environmental Protection Agency, and groups of homeowners near geothermal installations.
2. Furthermore, such a "crash" program has the property of promoting turmoil among groups at interest. This can be demonstrated by computing the standard deviations of the net impact in both the Case 1 normal program and the Case 2 crash program. The standard deviation is a measure of the distributions of attitudes toward the impacts; a smaller deviation would mean a greater unanimity of opinion about the desirability or lack of desirability of the impacts. The standard deviation increases by 50 percent between Cases 1 and 2.
3. Case 3 involved consideration of the impact of effective environmental policies on the perceived desirability of the impacts considered. In general, the positive consequences of the impacts were seen to improve and the negative

NO.	IMPACT STATEMENT	SCORE
32	INCREASED GEOTHERMAL R&D FOR THE ENVIRONMENT	61
39	IMPROVEMENTS IN INFLATION OVER A "NON-GEOTHERMAL WORLD"	57
9	LOWER THAN EXPECTED PRICE FOR ELECTRICITY	55
38	IMPROVEMENTS IN GNP OVER A "NON-GEOTHERMAL WORLD"	51
40	IMPROVEMENTS IN GOVERNMENT INCOME OVER A "NON-GEOTHERMAL WORLD"	50
85	DECREASING RATE OF DEPLETION OF OIL	44
87	DECREASING RATE OF DEPLETION OF GAS	42
37	INCREASED GEOTHERMAL R&D EXPLORATION	37
68	DIMINISHMENT OF THE AMOUNT OF IMPORTED ENERGY	36
23	MOVEMENT OF BUSINESSES THAT USE GEOTHERMAL ELECTRICITY, HEAT, OR MINERALS INTO GEOTHERMAL REGIONS	35

Figure 5.1.7 IMPACTS WHICH ARE LIKELY TO BE PERCEIVED AS HAVING GREATEST POSITIVE CONSEQUENCES

consequences were seen to be less detrimental. Among the groups which would perceive environmental policies as most helpful are: environmentalists at large, homeowners near geothermal installations, the Environmental Protection Agency, the Department of the Interior, the geothermal drilling industry, the geothermal operating industry, the geothermal exploration industry, and mayors of cities near geothermal energy sources.

4. Implementation of effective environmental programs also lowers the level of disagreement among groups as measured by the standard deviation of judgments about the severity of the impacts.
5. In Case 4 it was assumed that effective land use policies would be implemented in addition to the environmental policies considered in Case 3. This improved the situation even further, particularly for U.S. Congress, the Department of the Interior, mayors of cities near geothermal sources, environmentalists at large, the Environmental Protection Agency, and groups of homeowners near geothermal installations.
6. Furthermore, the assumptions of Case 4 also have the effect of further reducing disagreement among groups about the desirability of geothermal energy as evidenced by a further decrease in the standard deviation of judgments about the severity of impacts.
7. A review of the events seen as having potentially the greatest negative consequences shows that among the environmental factors considered the potential for seismicity and subsidence should demand the greatest attention.
8. Two of the most negative impacts were not attacked by the policies considered in Cases 3 and 4. These are: the delay in the

NO.	IMPACT STATEMENT	SCORE
80	INCREASED POSSIBILITY OF SEISMICITY NEAR GEOTHERMAL INSTALLATIONS	-70
79	INCREASED POSSIBILITY OF LAND SUBSIDENCE NEAR GEOTHERMAL INSTALLATIONS	-68
13	DELAYED DEVELOPMENT OF SOLAR ENERGY	-41
84	INCREASING RATE OF DEPLETION OF GEOTHERMAL RESOURCES	-37
46	CREATION OF NEW OPPORTUNITIES FOR CRIME (E.G., DESTROYING GEOTHERMAL WELLS)	-34
75	DIMINISHED AIR QUALITY NEAR GEOTHERMAL INSTALLATIONS	-31
43	RELOCATION OF LOCAL POPULATION IN ORDER TO ACCOMMODATE GEOTHERMAL INSTALLATIONS	-29
45	USE OF RECREATION, PARK, AND WILDERNESS AREAS FOR GEOTHERMAL INSTALLATIONS	-29
76	INCREASED NOISE NEAR GEOTHERMAL INSTALLATIONS	-29
77	DIMINISHED WATER QUALITY NEAR GEOTHERMAL INSTALLATIONS	-29
42	USE OF AGRICULTURAL AND FOREST LANDS FOR DEVELOPMENT OF GEOTHERMAL INSTALLATIONS	-27

Figure 5.1.8 IMPACTS WHICH ARE LIKELY TO BE PERCEIVED AS HAVING GREATEST NEGATIVE CONSEQUENCES

development of solar energy, and the creation of new opportunities for crime (e.g., destroying geothermal wells). Both of these impact areas should probably be given attention in any comprehensive geothermal program.

9. Among the most beneficial impacts are, not unexpectedly, impacts associated with economics, particularly inflation, gross national product, and government income. In addition, the ability for geothermal energy to supplant imported energy sources appears high on the list.

Appendix A

THE TECHNICAL INQUIRY

This appendix has three major sections. The first presents a summary of the comments received from the technical respondents during in-person and telephone interviews (and in some cases by written questionnaires) about the nature of technical impediments likely to affect the evolution of geothermal energy. Comments of one interviewee will not necessarily correlate with those of another. The second section presents a copy of the forms used during the inquiry. The third part of this appendix summarizes the method used to synthesize the responses pertinent to the extent of geothermal resources in the United States.

1. Resource Exploration and Appraisal

Impediment No. A1: Need for downhole sampling procedures for the purposes of recovering representative in-situ geological samples of solids, liquids, or gases. At best, thermal I.R. will be 10-50 percent improved over the status in Crash 1985.

Present 1973:

Sampling procedures for the purposes of recovering representative in-situ geological samples of solids, liquids, or gases are divided into two basic groups: those conducted during drilling operations and those conducted after well completion.

Sampling during drilling can be partially characterized as follows:

- a. Solids samples (cores) can most conveniently be retrieved during drilling. These are required to determine physical variations in rock types (such as porosity and permeability).
- b. Bulk chemical composition is often difficult to determine because soluble fractions and clays are usually washed away by the drilling fluid (water or drilling mud).
- c. "Slim holes" (2-3" diameter) yield more useful data because they do not disturb the sample to nearly the same extent as production drilling. Slim holes are practical to an approximate maximum depth of 3000 ft.; their sole purpose is to gain information. Slim hole technology was developed for minerals exploration.

Sampling after well completion can be partially characterized as follows:

- a. Solids sampling is almost impossible to perform after well completion because the well casing prevents it and present samplers are not capable of scooping solid samples from the wall of an unlined hole.
- b. Liquid sampling of ground water at moderate depths is conducted in order to acquire baseline data against which to compare future composition of groundwater in order to monitor possible contamination.
- c. Samplers can be sent to the bottom of a hole to retrieve an in-situ liquid sample under no-flow conditions, or a "grab" sample can be taken at the wellhead while the well is flowing.

- d. One fairly effective in-situ liquid sampler has been developed which is capable of going to approximately 1000 ft.
- e. A small submersible pump has been suggested as an effective sampling device.
- f. There is strong need for better ways to sample fluids and gases.

Normal 1985:

No real change in solids or liquid sampling techniques will occur because of lack of economic impetus for private industry. Good downhole solids and liquid samplers will be developed in 12 years. No real additional progress will be made for drill-stem test equipment beyond the 1973 level.

Normal 2000:

Surface sampling will not change or improve in 12 or 27 years under the "normal" regime for lack of economic incentive to private industry. Good downhole samplers will be readily available off-the-shelf.

Crash 1985:

Surface sampling will not experience appreciable further development, although good downhole solids samplers will be readily available off-the-shelf. A downhole sample pump will be available in less than 12 years. Development of an adequate downhole solids sampler will require two years. In lieu of industry, the government will start solids sampling after production drilling is complete.

Crash 2000:

No forecast made.

Impediment No. A2: Lack of a practical technique for conducting gross exploration; i.e., remote thermal I.R. scanning from Earth Resources Satellite.

Present 1973:

Two individuals felt that the statement of the impediment should not have included reference to thermal I.R. or to any other specific technique.

It was generally agreed that thermal infra-red scanning is ineffective for the purpose of conducting gross geothermal exploration. Minimum heat flow that can be detected is at least 10 times greater than the necessary minimum value for exploration. Instrumentation explicitly for this purpose is not included in the Earth Resources Satellite Program. Microearthquake location techniques may become a gross exploration candidate. One individual regards the lack of an effective gross exploration method as a serious impediment to the fast exploration of U.S. geothermal resources. Another individual thinks such a technique is neither practical nor necessary since the same result can be achieved by conducting a comprehensive mapping program using presently-available uncorrelated information; funds should be spent on this method, not on thermal I.R.

Normal 1985:

Remote thermal I.R. is unlikely to be a practical method. The scientific community will have assessed other promising techniques for reconnaissance-type exploration, but the impediment will still be unresolved.

One authority thinks that the funds and technical expertise should be spent instead on compiling a comprehensive set of geological/heat-flow/surface manifestation maps

of the entire United States, based on existing uncorrelated data; this data should be expanded by further extensive surface and sub-surface physical measurements. This program should employ three to four teams (two people each) working independently and simultaneously for four to five years, supported by funding of \$500,000/year for the first two years.

Normal 2000:

Remote thermal I.R. may be somewhat improved, but is still impractical. Satellite detection probably will remain an order of magnitude behind airplane surveys. Other methods are being developed, but the impediment is still unresolved. Or, problem will have been essentially solved if vigorous mapping program was initiated and carried forward.

Crash 1985:

Will speed up whole program and will achieve same level of understanding five years sooner than under the Normal 1985 regime.

Crash 2000:

At best, thermal I.R. will be 10-50 percent improved over the status in Crash 1985.

Impediment A3: Need for correlation of geophysical data with actual observed data.

Present 1973

With respect to the geopressed zones, geophysical exploration techniques applied in the Northern Gulf of Mexico Basin complement one another very well indeed, and yield definitive information on subsurface conditions to depths of 25,000 ft. or more; therefore, the impediment as stated does not apply here, in the opinion of one respondent.

It was generally agreed that fairly good correlations already exist between sets of data obtained from different geophysical measurement methods. However, one authority characterizes the present situation as confused and unsatisfactory. He stated further that the magnetic, gravimetric, and magneto-telluric methods have not been satisfactory, whereas heatflow, deep electric resistivity and general geological techniques have produced the best results. The real impediments are (1) the lack of correlation between physical data obtained from a given measurement technique and actual fact at depth, and (2) the lack of dissemination of privately-held data (see Impediment A5).

Three respondents declined to make forecasts.

Normal 1985:

There will be considerably improved correlation and interpretation capability, particularly for electric surface resistivity and seismology, but the measurements and the correlative efforts will still be a research tool for preliminary exploration. Geophysical measurements and interpretation will be available as services from oil field service companies and universities. Required inputs will include funding from the government to drill experimental holes at the level of \$4 million/year from now until 1985.

Normal 2000:

Remote temperature sensing methods will not be fruitful.

Porous fluid-filled regions will be well mapped. Geophysical measuring and interpretation services will be available on a routine commercial basis. The geothermal industry will have sorted out and accepted the effective methods, and abandoned the ineffective methods. Required inputs will include governmental support rate of \$2 million/year through 2000 for university-type scientific research.

Crash 1985:

Crash 1985 will be the same as for Normal 2000; however, with less scientific understanding and with some gaps in the basic knowledge. A highly developed, competently operated information exchange center (geothermal data center) is an absolute must. (See Impediment No. A5.)

Crash 2000:

No program required.

Impediment No. A4: Lack of understanding of the inferential significance of a geothermal profile (identity and concentration of constituents).

Present 1973:

Inferential significance of geochemical profile is already fairly well understood; the difficulty lies in the failure of industry to apply the known technology. A chemical profile is needed to predict formation characteristics. It is important in determining the hydrology and porosity, and can be used to determine producibility. It is also the key to assessing the economically recoverable mineral values. The geochemical profile for each field should be determined before the conversion system is designed. In terms of downhole solution chemistry, measuring pressure, as well as temperature, is critical. (See also Impediment No. A1.)

Impediment No. A5: Lack of a geothermal data exchange center to receive, store, process, and disseminate existing and future resource and reservoir data.

Present 1973:

Most data are gathered by private companies and are not available for public release because of the "proprietary" nature of the data. Private companies often thwart the flow and transfer of information internal to their own organizations by isolating the various investigative groups within their organization and maintaining secrecy between them. The industry urgently needs feedback of data from exploration programs (both successes and failures) to a centralized data bank so it will be available for general dissemination and correlation.

Normal 1985 and 2000:

No real change will occur without substantial government action to overcome innate interests of private industry in this regard.

Crash 1985:

Under a crash program, such a publicly-available data bank might be effected through the medium of government-sponsored drilling programs, or the government could buy the information from private companies through a "revolving fund" (high risk money, sometimes called "bottomhole money"), under a "crash" program one required input would be the allocation of approximately

\$10 million/year for 12 years of federal funding for creation of a highly-developed information exchange center (geothermal data center) with two or three very competent people to run it.

Crash 2000:

Three million dollars/year for the next five years would be required to enlarge and maintain the information exchange center.

Impediment No. A6: Lack of coherent, verified, dynamic reservoir models.

Present 1973:

This impediment is not considered to be on the critical path. Not enough drilling done to date; insufficient drilling has failed to yield enough information on which to base a model. A concerted, well-financed program of scientific data recovery must be instituted.

Normal 1985 and 2000:

Private companies will not initiate the necessary programs of scientific data recovery because it is difficult to demonstrate that this kind of investment is recoverable, let alone profitable.

Crash 1985 and 2000:

A crash program heavily supported by government funding is the only way that the required information will be developed.

Impediment No. A7: Need for improvement in procedures, equipment, and data interpretation of the various geophysical exploration and appraisal techniques.

Present 1973:

The presently available techniques for making geophysical measurements are essentially laboratory methods which have been adapted to field use and are often cumbersome, time-consuming, and require the use of trained personnel. Therefore, acquisition of data is an expensive and drawn-out affair. In one individual's opinion, what is needed are greatly improved techniques, procedures, and instruments which will reduce both required time and required costs. Another authority stated that even with research programs to develop improved techniques for data acquisition, such as instruments and procedures, only marginal improvements can be obtained, and funds will be much better spent on information transfer (see Impediment No. A5) and on actual data correlation.

Normal and Crash, 1985 and 2000:

No forecasts were made.

Impediment No. A8: Limited availability of drill rigs for deep to very deep drilling (25,000 ft. and greater).

Present 1973:

Geothermal drilling to date has not exceeded the 10,000 ft. depth. The few existing ultra-deep wells are gas wells. The need, experience, and planning

of deep, hot, igneous, wide-diameter geothermal wells are lacking. There are only eight to twelve rotary drill rigs in the United States today that are capable of drilling to depths greater than 25,000 ft. The geothermal industry can expect strong and increasing competition from the deep oil and gas well drilling industry. Current drill rig production lead time is three to five years. Geothermal drilling requires specially modified petroleum industry equipment. At the present time there is a shortage of trained personnel, an acute shortage of tubular goods (drill steel and well casing), and there is keen competition for drill rigs of all capabilities. The geothermal industry occupies a poor competitive position because of present lack of continuity of the drilling work (The Geysers is an exception), i.e., no long-term drilling contracts of two to three years in the same general location. (See also Impediment No. B13.)

Normal 1985:

A larger number of geothermal wells within the 10,000 ft. and maybe the 15,000 ft. realms (and possibly a few deeper ones) will have been drilled. There are rigs available today to go to 30,000 ft.; but what will be most needed are investors and/or sponsors. A thorough systems analysis and planning of all the components of deep geothermal development appears needed most. Deep capacity drill rigs may not be the answer.

Normal 2000:

It is hoped that we will have found more rewarding ways to penetrate the deep earth than to place blind, deep-point shots from the surface. Deep penetration technology will no doubt be available. Possibly it will cater to multiple users, similar to space stations or computers, on a cost-sharing basis. Required inputs will include systems analysis and planning of deep drilling and other deep penetration methods, as well as total user and requirements analysis. It may be found that the oil and gas drilling requirements are only partially applicable to the inputs required for deep geothermal penetration.

Crash 1985:

By way of performance, we will have just completed or will be about to complete substantial deep geothermal power capability. There will be sufficient availability of equipment to support this performance capability. The required inputs to achieve the above performance and availability will include:

- (a) Administrative priority program and sponsorship of systems and performance-oriented entities.
- (b) National dedication on a "put man on the moon" level.
- (c) Immediate systems engineering conducted on a \$10 million/year level by a dedicated contractor.

Crash 2000:

Specialized drill rigs for many applications, including ultra-deep, non-tapering geothermal drilling, will be available (if this application is still warranted). Several different types of deep penetrators, in addition to drill rigs, will be available. Their integration into the system will probably have occurred. Required inputs will include continued activity as

suggested under Crash 1985 above, centered in industry, and administered in a very benefit-oriented and reward-oriented, multi-agency program. Even present-day drill rigs may be part of this program.

Impediment No. A9: Lack of generalized, coherent regional geological models (static).

Present 1973:

This is not a critical path impediment at this time. It is not considered an impediment at all for the geopressured zones. However, there are many geological cases which have not been verified by the drill bit.

Normal 1985:

Will be able to guide exploration to areas of several hundred square miles of regional geothermal potential. Research and exploration results will be available to the trade through literature, seminars, etc. General geological, geophysical and hydrological studies of the United States will be needed. Large manpower input may be necessary for geologic mapping and geochemical studies, etc. Industry will need more examples of actual geothermal areas which have been located and represented as a model.

Normal 2000:

Will be able to guide exploration to areas of a few tens of square miles, perhaps even directly to reservoir areas.

Crash 1985:

Will be able to guide exploration to areas of a hundred square miles or so, having regional geothermal potential. Required inputs will include training of earth scientists in numbers necessary for the short-term timespan, and greater ability to disseminate information in the short-term timespan. Rapid feedback of information will be required. Drilling, recording, and publishing of many test cases is necessary.

Crash 2000:

Will be able to guide exploration to areas of a few tens of square miles, perhaps even directly to reservoir areas.

2. Reservoir Development

Impediment No. B1: Lack of practical, broadly-applicable technique for very deep drilling (i.e., below 25,000 ft.) and very hot drilling (i.e., greater than 800°F).

Present 1973:

No proven capability exists at present. No broadly-defined need or program to get below 25,000 ft. depth or above 800°F has manifested itself; therefore no associated industrial activity and development has occurred. Most current geothermal energy developments do not consider exploitation of deep, very hot formations because of the lack of drilling technology and energy extraction technology.

The major factor in this impediment is the high temperature. At the present time, the limiting temperature appears to be 600°F (not 800°F) for the following reasons:

- a. Compounded drilling fluids ("mud") begin to break down chemically and physically at about 600°F. Until now, there has been no compelling reason to break through this temperature limit. Baroid, Inc. and Amaco Research (Tulsa, Oklahoma) are currently developing higher temperature drilling fluids.
- b. The water in casing cements boils out of the cement at 600°F. A 700°F setting cement is now being developed.
- c. Data measuring and recording instrument packages (logging tools) generally fail when subjected to temperatures above 500°F.

Divergence of opinion appears here. Two sets of opinion are presented below and they are labelled (1) and (2) respectively.

Normal 1985:

(1) Research will generally be directed toward the temperature and depth goals, proof-of-concepts development, and limited field demonstrations. Very deep drilling will still be extremely expensive. Laboratory data and modest field demonstration may possibly be available. No commercial equipment will be available. Availability of experimental equipment will be limited by what manufacturers are willing to do on special orders. Lead time is therefore a function of funding which comes from the government or private industry. Needed inputs will require that:

- a. R&D efforts be funded at \$3 million/year (which is roughly close to current national level from all sources).
- b. If present interest and levels of effort at Los Alamos Scientific Laboratory and Battelle National Laboratory in hot dry rock geothermal R&D continue, there will be modest interest and support for research into new drilling techniques which can surmount the high temperature and very deep drilling problems.

(2) There will not be any substantial change from the present situation.

Broadly applicable techniques will not come either from the geothermal community itself or from the hydrocarbon industry because both are specialized. Required inputs will include:

- a. A massive R&D program to break through the present temperature barriers.
- b. Substantial government participation, possibly through a government/private industry consortium.
- c. Broadly applicable techniques stimulated by appropriate program definition and incentives. The inputs should be aware of demanding only bigger and better drill rigs. What is needed is bigger and broader thinking, and possibly combinations and stages of ways to get into deep and hot rock, similar to the ways we managed to climb into orbital altitude and beyond.

Normal 2000:

A new commercial source will become available for drill bits and associated heavy-duty drill rigs capable of making holes to depths of 40,000 ft. into formations having temperatures greater than 800°F. Availability will perhaps consist of one big demonstration in the field. Required inputs would include:

- a. Demonstration of the energy extraction technology for hot dry rock to prove this as a practical energy resource at the lower temperature levels (430°F). Then the potential of very hot rock resources for expanded electric power production will generate the impetus for the development of a high-temperature drilling technology to the stage of commercial field equipment.
 - b. Approximately \$25-75 million investment by industry.
- (2) Drilling and rock penetration have a long history. So, unless new stimuli are created, this impediment will not change much in another 15 years. The availability and required inputs will be the same as for Normal 1985. Additional required inputs will include:

- a. Not only combinations of users, but combinations of sponsors; governments that are willing to share space satellites may be willing to co-sponsor new technology development for ultra-deep penetration.

Crash 1985:

- (1) The following forecasts make this basic assumption: The potential of the hot dry rock extraction process has been recognized early to be a major contributor to the nation's electrical energy generating capacity and higher temperature chemical process needs. Therefore, the demand for a drilling technology to tap the heat from high-temperature rocks (approximately 800°F, 700°K) is generated.

In terms of performance, the impediment technology will have achieved the following:

Stage 1: Commercially-available hole-making assembly for 800°F (700°K) service and associated (automatic) rig with 20,000 ft. (6 km) depth capability up to 12 in. (300 mm) diameter at a reliable rate of 3 ft/hr. (1 m/h). (Optimum strategy in upper, cooler formations may dictate use of high penetration rates available with conventional rotary bits and rigs.)

Stage 2: Commercially available hole-making assembly for up to 1260°F (1400°K) service and assorted (automated) ultra-heavy duty rig with 40,000 ft (12 km) depth capability; up to 0.5 m (20 in.) diameter at a reliable rate of 1 m/h (3 ft/h).

Equipment availability will be:

Stage 1: 10 rigs completing 50 pairs of GTE holes in established thermal anomalies.

Stage 2: One rig to provide final demonstration of capability.

The required inputs for the above development will include:

Stage 1:

- (1) Supporting R&D programs to develop four best approaches (including rock melting) to develop the required new hole-making assembly(ies).
- (2) Establishment of commercial sources for fabrication.
- (3) Design and fabrication of special rigs.
- (4) Cost of approximately $\$40 \times 10^6$ to choose hole-making contender(s).
- (5) Establishment of production facilities for new "drill bit" production.

Stage 2:

- (1) Based on selected hole-making technology in Stage 1, scale up in size and extended depth capability.
 - (2) Additional $\$20 \times 10^6$ for R&D.
 - (3) Adaptation of ultra-deep rig to the new hardware.
 - (4) Demonstration of practical field performance.
- (2) In terms of performance, broadly applicable techniques would have contributed to ultra-deep geothermal development, just as Mercury, Gemini, and Apollo contributed toward the moon landing. With respect to availability, there is an abundance of talent and of ideas which are hidden in the many specialized industries and agencies. Required inputs include immediate systems engineering by a dedicated contractor on a \$10 million a year level, backed by administrative priority and sponsorship. The "Rapid Excavation" program of the Department of Defense and the Interior was an attempt in this direction.

Crash 2000:

- (1) In terms of performance, the following would obtain:
 - a. Use of Stage 1 technology and rigs for extensive development of high-temperature (high efficiency) power plants.
 - b. Significant contribution (5 percent) of Stage 2 technology to U.S. electrical power production demands.
 - c. Commercially available hole-making assembly for up to 2060°F (1400°K) service, with associated rig for 60,000 ft. (20 km) depth capability; Stage 3.

Equipment availability will be:

- a. Approximately 1000 of the Stage 2 based units.
- b. Approximately 40 Stage 3 systems.

The required inputs for the above development will include:

- a. Additional $\$100 \times 10^6$ for R&D to perfect

Stage 3 technology.

- b. Extension of rig production, drill steam and casing mill, and machinery manufacturing facilities. Problems foreseen are:
 - (1) Temperature limits on the downhole assembly, drilling fluids, and instrumentation.
 - (2) Handling of high temperature returns at surface complicates surface equipment, e.g., ROP, drill mud cooling, pumps, swivels, hoses, packing sand lubricants.
 - (3) Corrosion damage, accelerated by high temperatures.
 - (4) Drill mud troubles.
 - (5) Cementing and completion.
- (2) In terms of performance, broadly applicable techniques may have added a new dimension to life, by 2000 AD. With respect to availability, there will be no problem; construction, transportation and related industries will be well-developed and capable. The required inputs include:
 - a. Continued activity as required under Crash 1985.
 - b. Awareness of the international and multi-lateral nature of this impediment which may lead to large-scale international cooperation.

It is believed, however, that without drastic action by the U.S. Government in its role as the leader of world technology, very little, if anything, will happen with regard to this item, even by the year 2000.

Impediment No. B2: Present acute shortage of tubular goods (drill steel and well casing) which are essential to drilling and casing operations.

Present 1973:

Geothermal drilling operations must compete with oil and gas drilling operations, both domestic and foreign, for tubular goods, i.e., for drill steel and well casing. Fabrication plants have been able to keep up with the demand until recently. However, the shortage has now become acute, and is due to a rapidly increasing domestic and foreign demand. Foreign buyers prefer U.S. casing and drill pipe because it is cheaper than foreign fabricated tubular goods because of the devaluation of the U.S. dollar. This situation is not being relieved because price control under Phase IV prevents raising the domestic price any higher; therefore, a very substantial fraction of the supply is flowing out of the country.

(At the writing of the Appendix, November 1973, price controls on steel were still in effect.)

In the United States alone, there are 85-100 offshore drill rigs being built at any one time. Each of these requires approximately 40,000 ft. of drill steel (two complete strings).

Prior to development of the shortage, normal delivery time was 30-60 days from date of placement of an order. Now (November 1973), however, delivery is being quoted from 18-24 months from date of placement of order, with a present slippage rate of 2-3 months per calendar month.

Normal and Crash 1985:

The near-term situation is extremely fluid and is strongly influenced by the general worldwide demand for oil and gas, the foreign value of the dollar, and the future course of the federal price control program. In this kind of situation, significant changes can occur very rapidly, and 12 years is much too long a time for which to make predictions. However, it can be said with certainty that geothermal drilling will have a hard time competing for a long time to come. To effectively relieve the shortage domestically will require that we:

- a. Get rid of price control (Phase IV, etc.).
- b. Restrict exportation of drilling-type tubular goods.
- c. Introduce government enforced priority or allocation system for tubular goods.

Impediment No. B3: Lack of demonstrated method for continuous recovery of energy from hot dry rock reservoirs.

Present 1973:

No scheme has yet been demonstrated. Recovery of energy from hot dry rock is just an "idea" at present; it is still in an embryonic state. Approximately six man-months of effort have been expended to date on this concept by the USGS. A paper is presently being written by USGS which includes a numerical solution. Big technological problems remain to be solved. Initial results from the laboratory and field experiments are very encouraging.

A diversity of opinion exists with respect to the future prospects of the hot dry rock concept. Two sets of opinion are given below and they are labelled (1) and (2) respectively.

Normal 1985:

(1) If the present funding is expanded and the research programs are continued until 1980, commercial feasibility will be demonstrated with a 50-150 MWe power plant by 1985. By 1978 the power plant will have demonstrated continuous energy recovery for the western United States with the concept still being developed in the eastern United States. Required inputs to demonstrate this recovery are:

- a. \$5 million/year for energy extraction methods development.
- b. \$5 million/year for heat machines (novel heat engines and processes).
- c. \$10 million/year for small demonstration plants (two required).
- d. \$3 million/year for multiple-use demonstration plant.

(2) Industry will have developed high-temperature drilling technology. The first experimental hot dry rock system will be in operation, possibly a 10 MWe unit, but the entire concept will still be experimental. Massive engineering problems remain to be solved. Required inputs would include the expenditure of \$50 million over 12 years, not including the conversion systems.

Normal 2000:

(1) Hot dry rock will be widely used for generation of electric power and thermal energy. Auxiliaries will be highly developed, including air heat exchangers for low thermal pollution. The concept will be commercially perfected and will be available throughout the world. Decentralized plants will be in common use. Required inputs include continued funding at the \$10 million/year level in order to demonstrate various other types of geological systems such as deep sedimentary basins and shales.

(2) Will be producing a large (?) amount of power.

Crash 1985:

(1) Two million MWe will be on line in the western United States, with a binary cycle in the eastern United States. Multiple-use systems will be demonstrated in Alaska and in the northeastern United States. Commercial systems will be routinely available almost anywhere in the United States. Required inputs will include:

- a. A funding level of \$40 million/year to support four parallel developmental programs for different geological systems and heat flow patterns (or \$50-60 million/year for higher acceleration of the program).
- b. Very strong encouragement by government and positive action by private companies to conserve fuel and reduce pollution.

(2) Hot dry rock systems will have completed an experimental slant-hole with a set of parallel fractures as an initial experiment to prove fracturing methods; this can be completed in three years for \$10 million. In four more years, the system can have a slant-hole with a set of fractures in a real heat-bearing site for possibly \$50 million. Total time required for both above steps is seven to eight years.

Crash 2000:

(1) Many thousands of MWe will be on line, i.e., a significant contribution to electric power generation in the United States. The hot dry rock system will be carrying a substantial heating and air conditioning load in the United States, including nearly all new growth. Availability will be unlimited in terms of technical development. Required inputs will include:

- a. Continued funding of demonstration plants at the \$20-40 million/year level.
- b. Demonstrated feasibility of system for adverse (not most favorable) geological systems.
- c. Considerable advancement in drilling the technology, including increased drilling depths and reduced drilling costs.

(2) Hot dry rock systems will be supplying a major part of the electric power for the Western United States.

Impediment No. B4: Lack of demonstrated method for continuous recovery of energy from magma reservoirs.

Present 1973:

One individual stated that it would be a waste of national effort and funds to consider magma seriously as a practical source of energy.

Normal 1985:

Unwilling to make further forecasts except as follows.

Normal 2000:

Possibly there will be a 10 MWe experimental unit; this will be just a scientific curiosity.

Crash 1985 and 2000:

According to same individual, no public funds should be spent in developing the concept of energy extraction from magma during the time frame under consideration.

Impediment No. B5: Non-existence of a demonstrated, practical down-hole heat exchanger of sufficient capacity to be useful in large-scale energy extraction operations.

Present 1973:

There is no current development in terms of electric power generation.

Normal 1985:

Within two years, a system (Van Huisen concept) will be full-scale tested in the Imperial Valley, California. If this system is proven to be feasible, 2000 MWe will be installed in the Imperial Valley. Required inputs will include:

- a. Sufficient private risk capital to carry out a demonstration installation and test.
- b. Adequate source of cooling water, or other satisfactory heat rejection schemes exist.
- c. Control of deposition of dissolved solids on exterior of heat exchanger can be achieved by judicious management of well production.

Normal 2000:

If demonstrated as being economically attractive, further development will be aggressively pursued by private industry. Ten thousand MWe will be constructed in the Imperial Valley alone, and there may be additional development elsewhere.

Crash 1985:

There will be no appreciable acceleration of demonstration of technical or economic feasibility over what will occur under the "normal" regime. Ten thousand MW will be installed sooner, with possibly 15,000-20,000 MW by 1985.

Crash 2000:

The industry will have established reservoir stimulation techniques which will open up tight or otherwise unproductive formations, permitting widespread application of this system of heat extraction. The downhole heat exchanger will be widely applicable to other geological systems.

Impediment No. B6: Lack of effective method for inhibiting and correcting solids deposition in the producing formation and in the production casing.

A diversity of opinion exists with respect to the

present and future status of this Impediment. Two sets of opinion are given below and are labelled (1) and (2) respectively.

Present 1973:

(1) Presently the hydraulic, chemical, and thermal mechanisms are quite well understood, but are often ignored in the interest of maximizing short-term economic gain.

(2) Calcium carbonate deposition has been a major problem; however, its deposition mechanism is well-known. It may become a greater problem in lower temperature brines. Silica deposition is a problem at temperatures of 240°C and higher, and is a major problem at 280°C and above. The silica deposition mechanism is still not fully understood. No information is available on silica or calcium carbonate deposits in the formation. Field studies and laboratory studies on the kinetics and solubilities are much needed, as well as work on inhibiting scale formation.

Normal 1985:

(1) Close control of well production rates is required to avoid well drawdown, causing flashing and subsequent deposition in the formation which may be irreversible, or at least expensive to correct. The down-hole heat exchanger will be the solution in some cases. The necessary technology for effectively removing this impediment is available today; it's simply a question of putting it into practice by judicious well production management. One required input is that the effects of mechanical pumping must be well understood and carefully applied.

(2) Work will continue to be done by private industry on silica deposition with very little work being done by the universities. A good possibility exists of a breakthrough within 12 years. No work will be done to determine effects on the formation, although this is much needed. A required input for solving the silica deposition problem will be good field studies with strong laboratory support. For the calcium carbonate deposition problem, little or no work will occur in the United States, unless unforeseen need occurs; some foreign work will continue. This respondent considers himself not qualified to discuss correction of existing deposits. For their prevention, artificial stimulation by acidizing, formation fracturing, or other means may be helpful.

Normal 2000:

This would simply be a continuation of developments achieved in the previous 12 years. Additional time would not markedly change the level of development of the technology.

Crash 1985:

More funds should be put into field studies; at least four professionals should be working on solubility and rate studies. Professionals should start looking at the chemical engineering aspects of calcium carbonate deposition. The required funding input would possibly be \$250,000/year to start, with reduced funding after that. Concerning deposition effects in the formation, investigators should get enough thermo-chemical data (collection and evaluation) on an accelerated basis; the technology for doing this already exists.

Crash 2000:

Such a program would not be required.

Impediment No. B7: Non-existence of proven deepwell pumps (for geothermal applications at 500-700°F).

Present 1973:

Electric cable and motor windings presently available for 300°F operation on a routine basis, but at reduced useful life and increased maintenance costs. Electric insulation is temperature-limited. One experimental air-cooled electric motor has been operated continuously at 500-700°F. The present pump manufacturing workload is very heavy.

Normal 1985:

Electric motors and pumps will be capable of continuous operation at 500°F, but with reduced useful life and higher maintenance costs. Availability will be limited only by capacity to manufacture the units. On a relative scale, the demand for pumps will be far less for the geothermal industry than for the oil and gas industry, and this individual is certain that the manufacturers will be able to meet the relatively low demand which will be imposed by the geothermal sector. The ability to predict oil and gas pump business is essential to predicting pump business in general. Required inputs will include:

- a. A strong demonstrated demand (need).
- b. Development of improved lubricants, such as silicones, etc.
- c. Development of high-temperature electric insulation for cables and motor windings.
- d. Development of high-temperature bearings and seals.

Normal 2000:

This would simply be a continuation of developments achieved in the previous 12 years. Additional time would not markedly change the level of development of the technology.

Crash 1985:

There will be no appreciable improvement in the technology for at least 1-1/2 years; the work will be mostly experimental and developmental. A crash development program would be effective but would be much more inefficient (expensive and wasteful) than the "normal" development program. The crash development program would achieve the same results as under "normal," but sooner. The required inputs would include:

- a. A priority system must be established to allocate materials, manufacturing facilities, and personnel.
- b. Sufficient capital must be made available.
- c. Skilled labor must be trained.

Crash 2000:

A crash program beyond 12 years (1985) is not necessary.

Impediment No. B8: Lack of knowledge and experience with
reservoir fluid recharge.

This impediment is inherent in Impediments B6, B10, B12, B15, D1, D3, and D7, and is considered to be redundant to them. Therefore, no interview was conducted directly on it.

Impediment No. B9: Lack of knowledge and experience concerning effectiveness of field stimulation methods on vapor- or liquid-dominated fields.

This impediment is inherent in Impediments B12, B15, and B16, and is considered to be redundant to them. Therefore, no interview was conducted directly on it.

Impediment No. B10: Unknown effects on the producing formation resulting from reinjection of solids-bearing liquid wastes (cooling tower blowdown or flash tank bitters).

Present 1973:

Damage to the producing formation from this cause, if any, has not been investigated and therefore is essentially unknown. Liquid wastes can be cleaned up (pre-treatment) before disposal on the surface or reinjection. It is essential to know the geochemical profile of the liquid wastes, the undisturbed liquids in the formation, and the solids in the reinjection zone, especially with respect to calcium carbonate, silica, clays, and zeolites. There is too little thermo-chemical data presently available to permit prediction of the effects on the formation caused by reinjection. The small amount of available data is not well characterized with reference to temperature and pressure. It will be necessary to collect much new thermo-chemical data, and to develop new computer models with inputs which characterize the various geological systems, i.e., the chemical composition of liquids and solids which are already in place. We must also do modeling of solution/solution reaction dynamics. Experimental drilling should be conducted in which core sampling is done before reinjection and some years after reinjection, to assess the extent of build-up on the formation. It may be necessary to pre-treat before reinjection.

Normal 1985:

Evaluation of thermo-chemical data will occur primarily in the university laboratories. Ten to fifteen percent of the needed data will be collected and evaluated in the next 12 years. Computer modeling will continue, particularly with respect to liquid wastes other than from geothermal sources. Private industry will work on pre-treatment preparatory to reinjection, but little or no work will occur on treatment instead of reinjection, because industry will not pay the price. Very little if any core drilling to investigate possible formation damage will be done in the next 12 years.

Normal 2000:

Approximately 25-30 percent of the data of geothermal interest will be evaluated in 27 years. Possibly some core drilling for damage verification will have been done in 27 years.

Crash 1985:

Seventy-five percent of the required data will be collected in the next 12 years. Types of data required will include phase equilibrium and solubility values. Working computer models would be fully developed well

within 12 years (possibly in two years). Investigators will be able to predict almost all geological/chemical systems with few exceptions. Pre-treatment could be solved in 12 years for all types of geological/chemical systems; silica and calcium carbonate systems must be solved first. Required inputs will include:

- a. Two professionals plus one computer technician full time to evaluate thermo-chemical data, to be supported by \$150,000/year over a 12-year period.
- b. Necessary budget funds for core drilling to assess the effects of reinjection.
- c. \$1.5 million/year, the maximum amount that could be spent well.

Crash 2000:

A crash development program beyond 1985 will not be necessary.

Impediment No. B11: Lack of knowledge of thermal stress-field induced in a hot dry rock formation by massive injection and withdrawal of cold water.

Present 1973:

Occurrence of thermal stress cracking of the formation is not essential to the hot dry rock energy extraction system. Theory is poorly developed for rock; calculations are not convincing. This lack of knowledge is not considered to be an impediment in terms of laboratory experiments. Results of laboratory experiments are encouraging. These experiments include casting concrete blocks, cooling them as a function of time, and observing crack propagation. Later experiments will use granite blocks.

Field experiments have not yet been performed, but successful performance is not considered to be a major impediment.

A diversity of opinion exists with respect to the future prospects of this impediment. Two sets of opinion are given below and they are labeled (1) and (2), respectively.

Normal 1985:

- (1) The problem can be effectively solved in approximately five years.
- (2) Engineering usefulness will be demonstrated convincingly. Thermal stress cracking will be applied as a technique for rock fracturing, and will be as available as the hot dry rock systems themselves. Required inputs will include:

- a. Government-funded support of the development of hot dry rock systems.
- b. Substantial university-type rock mechanics experiments with a research funding level of approximately \$5 million/year.

Normal 2000:

- (1) Theory will be fully confirmed by actual practice.
- (2) Thermal stress cracking will be well understood, and will be available wherever hot dry rock geological systems are being worked. Required inputs include:

- a. Rock mechanics studies continue but on a diminished scale.
- b. Research funding continues at the rate of \$5 million/year for two to three years.

Crash 1985:

- (1) Problems completely soluble in approximately two years. Required inputs will include:
 - a. Two to three people working in the laboratory plus two people doing theoretical work for one year on an in situ field experiment.
 - b. Total program costing approximately \$1 million.
- (2) Engineering usefulness will be demonstrated convincingly, and complete understanding of mechanics and theory will exist. The availability will be the same as for all hot dry rock. Required input will include a funding level of \$10 million/year for support of sophisticated computer studies and large-scale field experiments.

Crash 2000:

The mechanism will be fully understood and economic advantage will be taken of same. This technology will have found other uses, possibly in earthquake control. Required inputs will include:

- a. Some scientific support by university investigation.
- b. Funding of approximately \$1 million/year.

Impediment No. B12: Lack of confirmed understanding of cause/effect relationship between fluid injection into the formation and occurrence of earthquakes.

NOTE: Impediments B12 and D5 are stated identically, but from two different points of view. Impediment No. B12 is concerned with possible damage or destruction of the wells, gathering system, or power plant proper resulting from a severe induced earthquake. On the other hand, Impediment No. D5 is concerned with the untoward environmental effects on the surrounding area and populace resulting from a severe induced earthquake.

Present 1973:

This is incorrectly phrased as an "impediment." The mechanism is better understood than is generally believed. It is presently being studied intensively by the U.S. Geological Survey. Field experiments are very advanced at this time. State-of-the-art of locating earthquakes is also far advanced, i.e., with a network of inexpensive seismic stations. A present impediment is the inability to predict the magnitude of earthquakes. Based on results of recent field experiments by Dr. B. C. Raleigh (USGS) in the oil field near Rangely, Colorado, triggering earthquakes by injection of fluids into the formation can be avoided by not injecting where the pressurized fluid can communicate with active seismic faults.

A diversity of opinion exists with respect to the future prospects of this impediment. Two sets of opinion are given below and they are labeled (1) and (2), respectively.

Normal 1985:

- (1) Seismologists will be able to predict the time and place of earthquakes within the next five years,

based on research work by Russian investigators and by Dr. B. C. Raleigh.

- (2) The mechanism will be well understood. Developers will probably be able to avoid active fault zones and thereby avoid triggering earthquakes. The state of public knowledge and understanding will make the general use of this knowledge routinely available. Required inputs will include:

- a. Continuation of the USGS experiments as well as programs such as the geological probing by the Los Alamos Scientific Laboratory.
- b. Maintenance of a federal funding level of \$2-4 million/year.

Normal 2000:

- (2) The entire subject will be very well understood, and its techniques will be routinely applied. Required inputs will include:

- a. Continued monitoring of seismic signals in developed geothermal systems.
- b. Drilling and hydrofracture experiments conducted in regions of tectonic imbalance (high seismic stress fields) to determine how much release can be achieved (earthquake control).
- c. Research funding of \$5 million/year maintained to the year 2000.

Crash 1985:

- (2) Entire subject will be well understood and seismic occurrences (earthquakes) will be routinely controlled. Required inputs will include:

- a. A large amount of drilling and fracturing conducted in a wide variety of geological formations.
- b. Very heavy funding maintained, possibly \$15-20 million/year.

Crash 2000:

- (2) Seismologists will be using fluid injection to control earthquakes on a fairly routine basis. They anticipate drilling holes along faults and injecting fluids on a scheduled basis to cause continuous release of inter-block shear stresses. Required funding level is unknown.

Impediment No. B13: Limited availability of drill-rigs for deep to very-deep drilling (i.e., below 25,000 ft.) and very hot drilling (i.e., greater than 800°F).

Present 1973:

Geothermal drilling must compete with oil and gas drilling operations for the available drill rigs, skilled personnel, and tubular goods (drill steel and well casing). At present, there is a shortage of trained personnel, an acute shortage of tubular goods, and keen competition for drill rigs of all capabilities. Present geothermal drilling technology depends completely upon the oil and gas industry developed drilling equipment. Deep drilling requirements imply an extended geothermal drilling development beyond present trends which today requires only relatively shallow (approximately 5,000-10,000 ft.) steam and ho

water wells. There are only eight to ten drill rigs in United States capable of drilling to depths greater than 25,000 ft. Current drill rig production lead time is three to five years. The geothermal industry has a poor competitive position because of present lack of continuity of the drill work, i.e., it cannot provide long-term drilling contracts of two to three years in the same general location. (See also Impediment No. A8.) The three largest drill rigs available in the United States today were developed in response to U.S. AEC drilling requirements.

Normal 1985:

The near-term situation is strongly influenced by the general demand for gas and oil in the United States and the foreign value of the U.S. dollar. In terms of performance, drill rig capability will be extended to 40,000 ft., with ability to handle normal geothermal gradient temperature problems (i.e., less than 392-514°F). Present trends in oil and gas exploration and production demands indicate deeper capabilities will evolve in the drilling companies serving the oil and gas industry. Very few drill rigs of this capability will exist. Availability of drill rigs, trained crews, and tubular goods for geothermal will depend on the geothermal industry's ability to attract these essential items with higher prices and long-term contracts. Required inputs will include:

- a. Government-ordered priorities for drilling equipment.
- b. 50 percent depletion allowance for steam (geothermal).
- c. Continuity of work (i.e., two to three year drilling contracts), or the ability to pay premium prices for a one- or two-hole drilling effort.

A diversity of opinion exists with respect to the future status of this impediment. Two sets of opinion are given below and are labelled (1) and (2) respectively.

Normal 2000:

- (1) This is much too long a time period to make a prediction, but it looks like the geothermal industry will have a hard time competing with other drilling interests for a long time to come.
- (2) Drill rig depth performance will not be significantly extended beyond that for normal 1985, but some additional capability in hole size, economy, and slight improvement in high temperature performance equipment can be expected. In terms of availability, perhaps a few (<10) drill rigs will be dedicated to deep geothermal drilling. Required inputs will include a continuing (but modest) expansion of exploration and production activities in deep steam and hot water geothermal reservoirs; this would support the dedication of some drill rigs to these ventures.

Crash 1985:

- (1) This is essentially the same situation as for Normal 1985, except geothermal now has the dollar leverage with which to compete with the oil and gas industry for drilling equipment and crews. Required inputs will include:
 - a. Government-enforced priority or allocations systems for drill rigs, tubular goods, etc.
 - b. Vigorous and sustained crew recruiting and training program.
 - c. Ending of price control (Phase IV, etc.).

- (2) The forecasts for Crash 1985 are premised on the assumption that drilling into hot dry rock formations to exploit the resulting artificial systems is technically feasible. In a 12-year crash program this drilling requirement is implicit. The following goals will be set:

Developing the relatively shallow (<15,000 ft.) low-grade heat (390°F) resources, to satisfy the projected U.S. demands for 1985 for the following:

- (1) Electric power 0.5 percent
- (2) Space heating 0.5 percent
- (3) Industrial process heat 1.0 percent.

With the usual conversion efficiencies, this will require 200,000 MW (thermal) of installed capacity. This in turn requires 1000 pairs of holes at 10-5/8" diameter, each pair delivering 200 MW (thermal). Thus, this plan is essentially limited to 1000 locations in the western United States and areas of high geothermal gradients (thermal anomalies). The downhole assemblies can handle the 390°F environment.

The forecasts are:

Industry will be able to drill 15,000 ft. holes of 10-5/8" diameter into approximately 390°F igneous rock at 20 ft/h. This can be accomplished by using 30 medium-sized (e.g., National Model 110-M or equivalent) oil and gas drilling rigs with suitable modifications for present geothermal drilling.

Required inputs will include:

- a. Initiating production of modified rigs at approximately 10 rigs/year, i.e., \$20 million/year.
- b. Initiating required drill rig specifications and publishing firm drilling contract projections and total market picture.

Crash 2000:

- (1) Declined to make a forecast.
- (2) The forecasts for Crash 2000 are premised on the following assumptions:
 - a. A nationwide exploitation goal. This assumption is necessary in order to forecast the technical feasibility and developed technology of the hot dry rock concept. Particular emphasis should be placed on the eastern states and mid-continent.
 - b. Development of deep, approximately 40,000 ft., resources at 480°F to satisfy the projected U.S. demands for the year 2000 for the following:

- (1) Electric power 0.5 percent.
- (2) Industrial process heat 5.0 percent.
- (3) Space heating 10.0 percent.

This requires approximately 2×10^6 MW of installed capacity. This in turn requires approximately 10,000 pairs of holes at 12"

(300 mm) diameter, each pair producing approximately 200 MW (thermal).

The forecasts are:

Industry will be capable of drilling 40,000 ft. holes, 12" in diameter, into rocks at 4 ft/hr.

In terms of availability, industry will be capable of:

- a. Producing 1000 ultra-heavy-duty rotary drill rigs (approximately 20,000 rig years of drilling!), which are upgraded versions of the present ultra-deep drill rigs.
- b. Producing drill rigs at approximately 100 rigs/year.

The required inputs will include:

- a. \$30 million R&D effort over the next three to five years.
- b. Improved drill pipe strength/weight ratio and drill pipe handling capability, doubled average drilling rate, and reduced friction loss of drilling fluids.
- c. Significant expansion of drilling machinery manufacturing facilities.
- d. Extension of mill capabilities in drill string and casing production.
- e. Cost of rigs estimated at \$5 million each (total is \$5 billion); cost of drilling program at \$10 million per hole (total \$200 billion); or an investment of approximately \$101 per installed kW (thermal).

Impediment No. B14: Lack of an inexpensive, portable two-phase mass flow meter.

No interviews were conducted on this impediment because it was judged to be of very minor importance.

Impediment No. B15: Lack of coherent, verified, dynamic reservoir models.

Present 1973:

This impediment is not considered to be on the critical path. Not enough drilling done to date; insufficient drilling has failed to yield enough information on which to base a model. A concerted, well-financed program of scientific data recovery must be instituted.

Normal 1985 and 2000:

Private companies will not initiate the necessary programs of scientific data recovery because it is difficult to demonstrate that this kind of investment is recoverable, let alone profitable.

Crash 1985 and 2000:

A crash program heavily supported by government funding is the only way that the required information will be developed.

Impediment No. B16: Lack of long-term case history data on which field longevity predictions can be based.

Present 1973:

The situation is very serious. We need to correlate geophysical signatures with reservoir characteristics at depth (see Impediment No. A3), and to develop test methods that allow prediction of reservoir longevity without waiting until the field is exhausted. The only data available at present is on The Geysers, Wairakei, and Larderello for over a few years. Declines in pressure and fluid changes have been noted, but with no real idea of the ultimate significance as yet.

Normal 1985:

Impediments will still be serious because we need at least ten years to get a good idea of field performance. We will be able to predict the behavior of a variety of types of fluid reserves for at least five years in advance. The information will be made available through dissemination of data and models in the literature and throughout the trade. Required inputs will include:

- a. Data placed in the public domain. Information on individual well records from fields developed by private companies are required to be made public.
- b. Better technology developed for measurements of mass flows of geothermal fluids.
- c. Theoretical research conducted on fluid behavior in geothermal systems, including the effects of two-phase fluid flow in the formation.

Normal 2000:

The situation will have improved; it will be a lot better, but it still won't be completely overcome. Industry will be able to predict the behavior of a variety of types of fluid reservoirs 10-20 years in advance. The availability of information and the required inputs are the same as for Normal 1985.

Crash 1985:

This is still a serious impediment for the geothermal industry. Starting right now, it will take an additional ten years to develop field operating experience. We will be able to predict the behavior of a variety of types of fluid reservoirs for at least five years in advance. Money will not help much here, except to enlarge the number of reservoirs being exploited for a short time. The availability of information and required inputs will be the same as for Normal 1985, with additional required inputs as follows:

- a. Specific demonstration facilities on the various geothermal resource types.
- b. A concerted, directed federal program.

Crash 2000:

The impediment will be essentially removed. The industry will be able to predict behavior of a variety of types of fluid reservoirs for 10-20 years in advance. Statistical information will be better, availability of information and the required inputs will be the same as for Normal 1985, with the additional required inputs of continued experimentation and evaluation using pilot

facilities and accumulation, compilation, and publication of data from production facilities.

3. Energy Conversion

Impediment No. C1: Non-existence of a large-scale demonstration electric power plant for liquid-dominated resources of medium to low thermal quality.

Present 1973:

No one has seriously designed a 50-100 MWe unit. No technical impediment exists on the binary process, although no expander of this size has yet been built. (Roto-Flo Corporation has given the Ben Holt Company assurance that they can build single 75-MW hydrocarbon expanders for use in a binary cycle.) All other components are available now. The only real technical impediment is the knowledge of how to control (or live with) the scaling problem. There is no demonstrated technology for this problem yet. Scaling tendency of typical brines is not known. Possibly it can be overcome by multi-stage flash and steam clean-up. Employing multi-stage flash will permit construction of binary plants of any size. Very likely, a substantial number of reservoirs can be produced this way. Control of scaling in the heat exchanger has yet to be proven. Scale formation is likely to be a problem in the majority of cases, with some exceptions. (See also Impediment No. C4.) Plans exist for a small-scale demonstration plant to be built in five years, plus three years of testing, for a total of eight years. Sitting reconnaissance studies for this demonstration plant are underway.

A diversity of opinion exists with respect to the future status of this impediment. Two sets of opinion are given below and are labelled (1) and (2) respectively.

Normal 1985:

(1) There will be ten units of 50 MWe each, plus one unit of 100 MWe, plus 50,000 MW proved reserves for 50 years. In terms of availability, we can produce five units/year of 50-100 MWe each, depending on the marketability of the power. Required inputs will include:

- a. \$50 million in R&D, plus a 50 man-year effort.
- b. \$30 million in federal assistance, plus a 3000 man-year effort.
- c. \$70 million public utility funds, plus a 6000 man-year effort.

(2) A commercially reliable 50 MWe unit will be in operation in six years, and a 100 MWe unit will be in operation in less than 12 years. These installations will be located at the technically and economically most favorable sites, i.e., the "high-grade" sites will be developed first. In terms of availability, there will be no limit except the ability of industry to furnish the hardware. Required inputs will include:

- a. The general solution of the scaling problem, which will require an appropriate R&D program.
- b. Development of a large-scale expander of proven capability.

Normal 2000:

(1) Forty plants having 1000 MWe capacity each will have been built, with proved reserves for 100 years. In terms of availability, industry can build and man five plants/year having 1000 MWe capacity each. Required inputs will include:

- a. \$9 billion invested capital.
- b. Plant manufacturing capability shared by other types of power plants.

(2) The upper limit of unit size is 100 MWe due to limitations of the field. We cannot get the advantage of economy of scale. The distance to transport the fluid in the field is a limitation. Industry will stay with relatively small units, having more sophisticated design, higher efficiencies, and lower capital costs. These plants can be designed for 15 percent plant efficiency. The availability will be the same as for the first 12 years, except the so-called "total flow" expander may have been proved out and with slightly improved efficiency. Required inputs will include:

- a. Improved hardware and thermodynamics.
- b. Competition which will eliminate the less viable candidate systems.

Crash 1985:

(1) Demonstration electric power plant of the following descriptions will have been built:

- a. Four hybrid plants of 200 MWe each.
- b. Fifteen plants of 5 MWe each.
- c. Five plants of 100 MWe each.
- d. Two deep well installations of 50 MWe each.

Availability will be based on industry's capacity to produce five plants of 200 MWe/year. Required inputs will include:

- a. \$6 billion of capital invested in manufacturing facilities and the above power plants.
- b. 50,000 man-years of effort.

(2) Possibly a commercially reliable 50 MWe unit will be in operation within three years. Development time will be compressed due to ready availability of capital. Availability of plant will be the same as for Normal 1985, except sooner.

Crash 2000:

(1) Installed capacity will equal 25 percent of the national needs, or a 300,000 MWt national inventory of geothermal reserves, plus attendant minerals extraction. Industry will have the ability to produce 10,000 MWe/year of plant capacity.

Required inputs will include:

- a. \$80 billion capital investment in utilities.
- b. Necessary personnel to build and operate the plants.
- c. Greatly enlarged manufacturing facilities.

- (2) Crash program is not necessary beyond 1985.

Impediment No. C2: Lack of demonstration electric power plant (of any size) for conversion of energy from heavy-brine reservoirs.

Present 1973:

There has been some previous but mostly negative experience, plus some hopeful plans, plus two trials of plant components which are not yet doing well. San Diego Gas & Electric's 10 MWe binary unit was never built; instead, tests were conducted to identify the scaling problem. If the binary process is to be used, it will be necessary to heat-exchange with the steam. Separation and scrubbing can remove particulates and all silica. Therefore, the use of hypersaline fluid does not pose a serious problem in a direct or binary system after clean-up of the steam. A big problem which is seen is the precipitation of solids out of the residual brines (after flash).

A diversity of opinion exists with respect to the future status of this impediment. Two sets of opinion are given below and are labelled (1) and (2) respectively.

Normal 1985:

- (1) There will be one unit of 20 MWe capacity, plus one unit of 50 MWe capacity. Three to five years of operating experience will demonstrate the excessive cost, unless the sale of recovered minerals will subsidize the operating expenses. One required input will be \$30 million plus a 2000 man-year effort.
- (2) A 50 MWe demonstration plant will be in operation, and will probably use standard state-of-the-art equipment. Availability of generating capacity is just a function of industry's capacity to produce and install the required equipment. Required inputs will include:

- a. The demonstration of a feasible technique for steam clean-up.
- b. The demonstration of a technique for handling and disposing of precipitated solids.

Normal 2000:

- (1) Five units of 200 MWe capacity each will have been built. Availability will be limited only by industry's ability to build; however, there will be little need, except to expand mineral extraction capability. It will be required to invest \$300 million.
- (2) Not applicable because demonstration was achieved by 1985.

Crash 1985:

- (1) Five units of 200 MWe capacity each will have been built, plus a reserve will have been established in the Buttes area of the Imperial Valley. Required inputs will include \$1000 million plus the man-years to match.
- (2) Same as for Normal 1985, except sooner.

Crash 2000:

- (1) Crash program beyond 1985 is not justifiable on any basis.
- (2) Crash program not necessary because goals have been achieved by 1985.

Impediment No. C3: Non-existence of a proven prime mover capable of continuous operation on a predominantly liquid two-phase fluid.

Three different developers of such prime movers were interviewed. Their views concerning their candidate concepts are given below, and are identified as (1), (2), and (3), respectively. ([1], Leonard J. Keller of The Keller Corporation; [2], Roger S. Sprinkle of Hydrothermal Power Company, Ltd.; and [3], Winston H. Bishop of General Ener-Tech, Inc.)

- (1) No demonstrated capability yet. A prototype KROV (Keller Rotating Oscillating Vane) engine is presently being built. Test plans call for a full range of mechanical and performance tests by personnel from M.I.T.
- (2) Several people are proposing such engines but none are yet in commercial operation. Hydrothermal Power Company has accumulated approximately 1000 hours of operation on direct extraction from high-energy brine, employing a helical-screw type expander.
- (3) To date, bladeless turbine generators for operation on geothermal brines have not been built in any size. However, considerable development experience has been accumulated by General Ener-Tech, Inc., in bladeless turbines utilizing superheated steam, and also in various hot gas applications in ranges from 3 hp to 1600 hp. Additionally, General Ener-Tech has developed several two- and three-phase pumps in performance ranges to 1000 gpm which also utilize this principle.

Currently undergoing development testing is a 250 hp, 300 gpm, 500 psig geothermal reinjection pump which is scheduled for testing on one of the Imperial Valley, California, wells.

Normal 1985:

- (1) There should be several 1000 MWe plants operating in the United States and Japan. Units should be shelf items in sizes up to 15 MWe. Units will be available in 200 MWe/unit at the rate of 10 units/year. Required inputs will include:
 - a. \$5 million spent on R&D funding during first three years.
 - b. Selection between the binary and flash cycles made on the most feasible basis.
 - c. \$5 million made available for test, evaluation, and revision.
 - d. Establishment of sufficient manufacturing facilities.
- (2) In five years, the industry will have a 5-10 MWe, two-stage, portable or semi-portable, continuous duty machine, requiring only an annual shutdown for routine maintenance. Availability will be restricted only by the manufacturing industry's ability to produce them. This is estimated at 200 units/year. Required inputs include:
 - a. Upgrading the current capacity of manufacturing facilities.
 - b. A strong demand for this type of prime-mover expressed by the geothermal industry.
- (3) In terms of performance, commercially-reliable

cycles will be made on the most feasible basis.

- c. \$5 million is made available for test, evaluation, and revision.
- d. Establishment of sufficient manufacturing facilities.

(2) In five years, will have a 5-10 MWe, two-stage, portable or semi-portable, continuous duty machine, requiring only an annual shutdown for routine maintenance. Availability will be restricted only by the manufacturing industry's ability to produce them. This is estimated at 200 units/year. Required inputs include:

- a. Upgrading the current capacity of manufacturing facilities.
- b. A strong demand for this type of prime-mover is expressed by the geothermal industry.

(3) In terms of performance, commercially-reliable bladeless turbine generators in sizes of 1-10 MWe will be developed in one to two years. High-speed alternators in the 3600 rpm range are now available. The bladeless turbine already has had significant development, and the short lead time is further supported by the relative simplicity of the device.

By use of the 10 MWe unit in multiples, geothermal power plants of 10-50 MWe size can be available by 1975. Units of larger size do not appear to be practical due to reasons of limited well output and diverse locations of the wells.

In terms of availability, production capability of 10 MWe units at the rate of 20 units per year within three years is feasible.

Required inputs will include:

- a. \$1.5 million R&D over the next year and a half.
- b. Moderate enlargement of facilities and equipment capability.

Normal 2000:

(1) Standardized units will be clearly established in terms of equipment options. Short delivery times after order will be routine on all equipment.

Required inputs will include:

- a. Manufacturing facilities built as required.
 - b. Architectural and engineering firms established to carry out the design and construction.
- (2) The situation is too volatile for a prediction. However, there are certain specific problems which must be overcome, as follows:
- a. Electric utility companies must change their operating philosophies, rate structures, etc.
 - b. The effluent disposal problem must be solved.
 - c. Construction of a demonstration plant by private industry must be accomplished.

(3) This question is probably not realistic, since it implies that the longer time will produce larger-sized plants in 50 MWe and up. While there may be reasons for developing turbine generators of larger than 10 MWe on a selective basis, which is entirely feasible, these applications would probably be limited to isolated installations except possibly in the areas of geopressure systems.

Crash 1985:

(1) Equipment will be proven and standardized with 100,000 MWe capacity in operation. In terms of availability, industry will have the capacity for production and installation of an additional 50,000 MWe/year. Required inputs include:

- a. \$50 million spent on R&D in the first five years.
- b. \$10 million for accelerated testing and standardization.
- c. A concerted program to establish sufficiently large manufacturing facilities.
- d. Adequate training program for engineers and engineering companies.

(2) Same as for Normal 1985, except sooner.

(3) In terms of performance, again, 1-10 MWe units used in multiples to 40-50 MWe seem to have merit as optimum-sized plants. In terms of availability, 100 units/year production capability is reasonable within three years. Required inputs will include:

- a. \$4.5 million R&D program over the next two and a half years.
- b. Substantial enlargement of production equipment and facilities.

Crash 2000:

(1) Completely optimized and standardized designs are available. Availability of plants limited only by the availability of the resource.

(2) Crash program beyond 1985 is not needed.

Impediment No. C4: Lack of effective method for preventing scale deposits on internal surfaces of mechanical equipment, i.e., heat exchangers, pipes, turbines, etc.

Present 1973:

Medium to low-temperature brines with salinity comparable to seawater have given little trouble worldwide. Little or no trouble has been experienced with high-temperature brine except heavy brines at the Buttes (Imperial Valley, California). Little trouble has been encountered at Cerro Prieto with normal brines. Some partially effective methods for preventing scale deposits do exist, and other novel methods, such as low adhesion surfaces and chemical injection control, are currently under development. Corrective steps presently available include use of duplex (100 percent backup) equipment (very expensive), mechanical reaming and chipping, and use of chemical solvents.

Normal and Crash 1985:

Except for probably rare heavy brines, problems will be designed away. Designs and treatments will be available. Required inputs will include \$2 million in R&D plus three years of operation in several plants.

Normal and Crash 2000:

So little work has been done to date, it is difficult to make a prediction.

Impediment No. C5: Lack of sufficient empirical data on which to base the economical selection of plant construction materials.

Present 1973:

Sufficient data are now available to provide useful life at present power costs. Means of protection are also available.

Normal 1985:

Important problems will be solved and costs will be low. There will be widely available designs, for a price. Required inputs include \$2 million in R&D.

Normal 2000:

Not applicable.

Crash 1985:

Same as in Normal 1985, except in much more detail. Necessary information will be widely available in the open files. Required inputs include \$10 million for R&D.

Crash 2000:

Not applicable.

Impediment No. C6: Lack of demonstration electric power plant of any size for conversion of energy from geopressured zones.

Present 1973:

This is a serious impediment to the development of the geopressured resources. However, at the present time, there is no known plan to construct such a plant.

Normal 1985:

Within six months to one year after removal of certain legal impediments, private industry will start to build a demonstration plant in the State of Texas having a minimum of 200 MWe capacity; this would effectively remove the impediment. A required input would be legislative action by the State of Texas to classify geothermal water as natural groundwater, instead of as a mineral, as it is presently classified.

Crash 1985:

It is highly probable that the federal government will undertake construction of a demonstration plant at a geopressured site if a crash program is instituted. For this to occur, however, would require a direct

endorsement by the highest levels of authority within the U.S. Geological Survey.

Impediment No. C7: Lack of demonstration electric power plant of any size for conversion of energy from magma.

While this impediment is of major importance to the development of magma resources, the problem is very remote time-wise, and hence is receiving little or no attention. Therefore, no interviews were conducted on this impediment.

Impediment No. C8: Lack of demonstration electric power plant of any size for conversion of energy from hot dry rock.

Present 1973:

This is a serious impediment to the development of the hot dry rock resources; however, at the present time, there is no known firm plan to construct such a plant.

Normal 1985:

A 10 MWe demonstration plant will be built at the Los Alamos Scientific Laboratory test site, possibly by 1978. This will probably be a joint venture by the federal government and private industry. A required input would be the successful completion of present experiments at LASL with positive demonstration of the feasibility of the heat recovery method.

Crash 1985:

The experimental effort will be extended to a broader base to include possibly two more sites. The demonstration plant will be constructed approximately one year sooner than under the "normal" program.

4. Environmental Technology

Impediment No. D1: Necessity of developing practical techniques for preventing groundwater contamination.

Present 1973:

This has not yet been shown to be an impediment. The severity of the potential impediment is a function of the type of geothermal reservoir, its hydrological setting, and the means employed for fluid recharge or disposal of geothermal fluids.

Normal 1985:

Performance is unlimited. The need is to show that it is possible to recharge at an acceptable rate at the appropriate depth and stratum and still prevent contamination of any groundwater aquifers which are likely to be used as a water supply source. Three million dollars should suffice for field and modeling studies in areas deemed as having potential for contamination.

Normal 2000:

Same as for Normal 1985; not an impediment.

Crash 1985:

Same "need to show..." as for Normal 1985. This can be expedited by continuous observations of on-going or demonstration geothermal fields. The estimate of required funding is increased to \$4 million.

Impediment No. D2: Necessity of developing techniques for effectively controlling harmful or nuisance gaseous emissions (H_2S , CH_4 , ammonia, etc.).

Present 1973:

H_2S emission is the only real problem at present. H_2S is present in substantial amounts in both steam and hot water wells. Research to control H_2S emissions from power generating units with an open cycle, wet cooling tower, and dry steam, as at The Geysers, is essentially complete. Demonstration at the prototype and operational levels is scheduled for 1974. Control of NH_3 and CH_4 emissions is not necessary at The Geysers.

Normal 1985:

H_2S emissions control equipment will be completely operational within two to three years at The Geysers; commercially reliable equipment will be installed on Units No. 11 and 14. The entire problem will be completely solved for both steam and hot water wells in less than 12 years. Two basic approaches to a solution are presently being pursued, as follows:

- Process solution: Chemically reacting the H_2S in the flow stream by introducing an appropriate reagent. This approach permits retrofitting existing plants.
- Engineering solution: Selecting a different power cycle, such as binary, in which the gas is not released to the atmosphere; it is always contained.

Research on methods to control H_2S emissions at the wellhead would be valuable.

All equipment for control of H_2S will be readily available, as required. Each geothermal site is unique, and the local physical and chemical conditions will determine the applicability of the available solutions at any given site. Required inputs will include:

- Continuation of present experimentation and development by private industry.
- Approximately \$1.5 million to be spent in 1974 (already funded by private industry).

Normal 2000:

Not applicable; problem already solved.

Crash 1985 and 2000:

The problem will be completely solved for both steam and hot water wells in five to ten years by private industry. Widespread adoption of the binary process will largely circumvent the problem. A crash program is not required.

Impediment No. D3: Necessity of developing broadly applicable techniques for liquid and solid waste disposal.

Present 1973:

Disposal of liquid condensate by reinjection has already been demonstrated and is commercially reliable at The Geysers. Disposal of solid waste is now being investigated at The Geysers and a solution is expected during 1974.

Normal 1985:

Techniques for disposal of both liquid and solid wastes will be fully developed and commercially reliable. Reinjection wells for disposal of liquid wastes will be in routine use at The Geysers. Disposal of solid wastes may require landfill sites. Research to develop worthwhile uses of elemental sulfur produced by the H_2S emissions abatement processes would be valuable. Required inputs will include less than \$2 million in the next three years for demonstration of landfill site development and monitoring. This will be funded by private industry.

Impediment No. D4: Necessity for developing practical and effective techniques for noise control during initial drilling and testing operations, as well as during operating life of the plant.

Present 1973:

Noise emissions from the power plants proper are already within acceptable limits; this is no problem for the power plant. Techniques and equipment to control noise emissions from the power generating units themselves are already demonstrated, commercially available, and in use at The Geysers plant. The noise problem exists only for high-pressure steam wells during drilling and clean-out blow, which is due to the use of compressed air as a drilling fluid, and the uncontrolled release of the natural steam. At present, drilling mufflers are in an experimental stage of development only. Cleanout blow lasts from 6-48 hours, depending on the characteristics of the well. For hot water systems, noise is not a problem at the well during drilling, because drilling mud is used instead of

compressed air, and there is no uncontrolled release of the geothermal fluid.

Normal 1985:

Adequate mufflers and noise suppression techniques will be designed, built, and in test within three years. The noise problem at the wells will be completely solved within five years. The availability of effective techniques and equipment will be limited only by industry's capacity to manufacture commercially available mufflers and other noise suppression devices. Required inputs will include continuation of the present experimentation and development work by private industry.

Normal 2000:

Not applicable.

Crash 1985:

Noise problem at the wells will be solved in less than five years. Will require \$1-5 million in public funds.

Crash 2000:

Not applicable.

Impediment No. D5: Lack of confirmed understanding of cause/effect relationship between fluid injection into the formation and occurrence of earthquakes.

Present 1973:

This is incorrectly phrased as an "impediment." The mechanism is better understood than is generally believed. It is presently being studied intensively by the U.S. Geological Survey. Field experiments are very advanced at this time. State-of-the-art of locating earthquakes is also far advanced, i.e., with a network of inexpensive seismic stations. A present impediment is the inability to predict the magnitude of earthquakes. Based on results of recent field experiments by Dr. B. C. Raleigh (USGS) in the oil field near Rangely, Colorado, triggering earthquakes by injection of fluids into the formation can be avoided by not injecting where the pressurized fluid can communicate with active seismic faults.

A diversity of opinion exists with respect to the future prospects of this impediment. Two sets of opinion are given below and they are labelled (1) and (2) respectively.

Normal 1985:

- (1) Seismologists will be able to predict the time and place of earthquakes within the next five years, based on research work by Russian investigators and by Dr. B. C. Raleigh.
- (2) The mechanism will be well understood. Developers will probably be able to avoid active fault zones and thereby avoid triggering earthquakes. The state of public knowledge and understanding will make the general use of this knowledge routinely available. Required inputs will include:

- a. Continuation of the USGS experiments as well as programs such as the geological probing by the Los Alamos Scientific Laboratory.
- b. Maintenance by a federal funding level of \$2-4 million/year.

Normal 2000:

- (2) The entire subject will be very well understood and its techniques will be routinely applied. Required inputs will include:

- a. Continued monitoring of seismic signals in developed geothermal systems.
- b. Drilling and hydrofracture experiments are conducted in regions of tectonic imbalance (high seismic stress fields) to determine how much release can be achieved (earthquake control).
- c. Research funding of \$5 million/year is maintained to the year 2000.

Crash 1985:

- (2) Entire subject will be well understood and seismic occurrences (earthquakes) will be routinely controlled. Required inputs will include:

- a. A large amount of drilling and fracturing conducted in a wide variety of geological formations.
- b. Maintenance of very heavy funding, possibly \$15-20 million/year.

Crash 2000:

- (2) Seismologists will be using fluid injection to control earthquakes on a fairly routine basis. They anticipate drilling holes along faults and injecting fluids on a scheduled basis to cause continuous release of inter-block shear stresses. Required funding level is unknown.

Impediment No. D6: Necessity to develop a design safety code dealing with hazards to workers and the public which are specific to the geothermal industry (such as prevention of well blowout).

Present 1973:

The industry's present knowledge is good. Actual practice is fair, considering the general level of safety regulation enforcement.

Normal 1985:

Safer codes will have been adopted. Safe practices will be well known and widely adopted. Required inputs will include:

- a. \$1 million for technique studies to select safe methods.
- b. \$3 million for public and industry information campaign.
- c. \$2 million for legal work (legislation).
- d. \$10 million for enforcement.

Normal 2000:

An excellent safety record will be well-established; this will be at least as good as for chemical plants. Routine regulation and enforcement of the codes will be required.

Crash 1985:

Same as for Normal 1985, except sooner and three times as costly.

Crash 2000:

Not applicable.

Impediment No. D7: Necessity of developing predictive, preventive, and corrective techniques for dealing with land subsidence consequent from geothermal fluid withdrawal.

Present 1973:

This has not yet been shown to be an impediment. The severity of the potential impediment is a function of the type of geothermal resource, as follows:

- a. Deep dry steam (vapor-dominated): Not a likely impediment.
- b. Shallow hot water (liquid-dominated): Greatest potential for impediment.
- c. Geopressured zones: Not a likely impediment.
- d. Hot dry rock: Not a likely impediment.

Normal 1985:

Performance and availability for (a) above are unlimited. The rate of recharge of hot water should be sufficient to reduce the impediment to an acceptable level. If supplementation of the local water supply is part of a system objective (i.e., a net withdrawal of fluids), closer monitoring must be conducted. There may be possible trade-offs between supplementing a water supply and accepting some subsidence. It must also be recognized that land surface subsidence can be a plant operation problem (e.g., well casing failure) as well as an environmental problem. Required inputs would include \$1 million to determine extent of subsidence (if any) during production.

Normal 2000:

Same as for Normal 1985.

Crash 1985:

Performance and availability are unlimited. The only apparent impediment may be the impaired ability to recharge all or a significant fraction of the hydrothermal fluids produced with lower quality substitute water or other waste fluids. Funding should be raised to \$2 million to provide a larger observational network, or observations at additional sites.

Crash 2000:

No need for a crash program in this time period.

Impediment No. D8: Necessity for reconciling design of gathering systems and balance of plant with preservation of local aesthetic values.

Present 1973:

There is an awareness of the desirability of preserving local aesthetic values, but there is little

evidence of intention of official, uniform, and fair enforcement.

Normal 1985:

There will be non-uniform, ambiguous, and indefinite codes, with only nominal enforcement. Required inputs will include \$20 million total in public funds supporting a 1000 man-year effort.

Normal 2000:

There will be good codes and enforcement, with fair enforcement and compliance. Required inputs will include \$50 million in public funds.

Crash 1985:

There will be good but non-uniform codes; they will be understood and enforced. The codes will be widely available but often arbitrarily enforced. Required inputs will include:

- a. \$200 million for fees and wages.
- b. \$500 million for subsidies and inducements.

Crash 2000:

Not applicable.

Forms Used in the Interviews

Bechtel Corporation

Engineers - Constructors

Fifty Beale Street
San Francisco, California 94119

Bechtel Job No. 10571
October 12, 1973

October 12, 1973

Page 2

Dear

As you will recall from our recent phone conversation, Bechtel Corporation is currently involved in the conduct of a study entitled "Technology Assessment of Geothermal Energy Resources Development". This work is being performed in association with The Futures Group, Inc. of Glastonbury, Connecticut, under contract to the National Science Foundation. One of the primary purposes of this study is to search systematically for forecasts of technological developments in geothermal energy and assess the probable significance of such developments. The results of the study may well be used to inform public policy-makers and in the allocation of R&D funds, etc.

Toward that end, we are interviewing experts in various aspects of the geothermal industry. The purpose of the interviews is to solicit candid opinion regarding the present status and the possible future development of certain aspects of geothermal technology under an assumed set of conditions.

The issue of geothermal resources appraisal, in terms of location, magnitude, and quality, stands out as pivotal in determining the potential of geothermal energy. We recognize that the appraisal of geothermal resources requires extensive surveys which have not yet been performed; nevertheless, resource estimates have appeared in the literature. In this series of interviews, we intend to talk with you and other experts in the field to explore current

views of the extent to which the appraisal of geothermal resources can be improved. With this in mind, we would like to solicit your input to the study and we seek your cooperation in the conduct of such an interview. In view of the central nature of the issue of resources appraisal to geothermal development, we sincerely hope that you can address yourself to the questions. Information contributed may be on an anonymous basis, at your option. Participants in the interview will receive a summary of the output of the interviews.

In anticipation of the interview, we have enclosed the following:

- o A Resource Appraisal Forecast form which indicates the data we believe is needed, along with a definition of essential terms.
- o A Geothermal Technology Forecast form, along with its definition of essential terms.

It might be helpful if you would look over the forms and jot down a few notes in anticipation of our next phone call. If, upon reviewing the questionnaires, you feel it necessary to clarify any of the questions, please phone us at any time. Mr. L. O. Beaulaurier (415-764-5914) or Mr. J. W. Hankin (415-764-4081) of our staff will be contacting you during the week of October 22 to discuss the interview and to solicit your replies.

Sincerely,

M. Carasso
Project Manager
Geothermal Technology
Assessment Study

MC:sam
Enclosures

Geothermal Technology Assessment Study

RESOURCE APPRAISAL FORECAST

DEFINITION OF TERMS

In the attached form we have asked for your opinion on the expected developments that you can foresee in relation to specific items that impede development of geothermal energy. We ask that you consider each item in terms of "normal" and "crash" development.

By "Normal Development" is meant that geothermal technology continues to develop on the same basis that it is presently developing, without externally-applied stimuli.

By "Crash Development" is meant that geothermal technology develops under the stimulus of a declared national policy backed by massive governmental support, in which cost is virtually no impediment.

"Reserves" and "Resources": We hope you will use the definitions proposed by Dr. V. E. McKelvey, Director of the United States Geological Survey (attached is a copy of a portion of his paper on this subject). However, please feel free to use any other definitions you feel are needed.

EXCERPTED FROM:

McKelvey, V.E. "Mineral Resource Estimates and Public Policy." Appearing in U. S. Mineral Resources, U. S. Geological Survey Professional Paper 820. GPO, Washington, D.C., 1973.

CONCEPTS OF RESERVES AND RESOURCES

The focus of most of industry's concern over the extent of mineral resources is on the magnitude of the supplies that exist now or that can be developed in the near term, and this is of public interest also. Many other policy decisions, however, relate to the much more difficult question of potential supplies, a question that to be answered properly must take account both of the extent of undiscovered deposits as well as deposits that cannot be produced profitably now but may become workable in the future. Unfortunately, the need to take account of such

deposits is often overlooked, and there is a widespread tendency to think of potential resources as consisting merely of materials in known deposits producible under present economic and technologic conditions.

In connection with my own involvement in resource appraisal, I have been developing over the last several years a system of resource classification and terminology that brings out the classes of resources that need to be taken into account in appraising future supplies, which I believe helps to put the supply problem into a useful perspective. Before describing it, however, I want to emphasize that the problem of estimating potential resources has several built-in uncertainties that make an accurate and complete resource inventory impossible, no matter how comprehensive its scope.

One such uncertainty results from the nature of the occurrence of mineral deposits, for most of them lie hidden beneath the earth's surface and are difficult to locate and to examine in a way that yields accurate knowledge of their extent and quality. Another source of uncertainty is that the specifications of recoverable materials are constantly changing as the advance of technology permits us to mine or process minerals that were once too low in grade, too inaccessible, or too refractory to recovery profitably. Still another results from advances that make it possible to utilize materials not previously visualized as usable at all.

For these reasons the quantity of usable resources is not fixed but changes with progress in science, technology, and exploration and with shifts in economic conditions. We must expect to revise our estimates periodically to take account of new developments. Even incomplete and provisional estimates are better than none at all, and if they differentiate known, undiscovered, and presently uneconomic resources they will help to define the supply problem and provide a basis for policy decisions relating to it.

The need to differentiate the known and the recoverable from the undiscovered and the uneconomic requires that a resource classification system convey two prime elements of information: the degree of certainty about the existence of the materials and the economic feasibility of recovering them. These two elements have been recognized in existing terminology, but only incompletely. Thus as used by both the mining and the petroleum industries, the term reserves generally refers to economically recoverable material in identified deposits, and the term resources includes in addition deposits not yet discovered as well as identified deposits that

cannot be recovered now (for example, Blondel and Lasky, 1956).

The degree of certainty about the existence of the materials is described by terms such as **proved**, **probable**, and **possible**, the terms traditionally used by industry, and **measured**, **indicated**, and **inferred**, the terms devised during World War II by the Geological Survey and the Bureau of Mines to serve better the broader purpose of national resource appraisal. Usage of these degree-of-certainty terms is by no means standard, but all their definitions show that they refer only to deposits or structures known to exist.

Thus, one of the generally accepted definitions of **possible** ore states that it is to apply to deposits whose existence is known from at least one exposure, and another definition refers to an ore body sampled only on one side. The definition of **inferred** reserves agreed to by the Survey and the Bureau of Mines permits inclusion of completely concealed deposits for which there is specific geologic evidence and for which the specific location can be described, but it makes no allowance for ore in unknown structures of undiscovered districts. The previous definitions of both sets of terms also link them to deposits minable at a profit; the classification system comprised of these terms has thus neglected deposits that might become minable as the result of technologic or economic developments.

To remedy these defects, I have suggested that existing terminology be expanded into the broader framework shown in figure 4, in which degree of certainty increases from right to left and feasibility of economic recovery increases from bottom to top. Either of the series of terms already used to describe degree of certainty may be used with reference to identified deposits and applied not only to presently minable deposits but to others that have been identified with the same degree of certainty. Feasibility-of-recovery categories are designated by the terms **recoverable**, **paramarginal**, and **submarginal**.

Paramarginal resources are defined here as those that are recoverable at prices as much as 1.5 times those prevailing now. (I am indebted to S. P. Schweinfurth for suggesting the prefix *para* to indicate that the materials described are not only those just on the margin of economic recoverability, the common economic meaning of the term *marginal*.) At first thought this price factor may seem to be unrealistic. The fact is, however, that prices of many mineral commodities vary within such a range from place to place at any given time, and a price elas-

FIGURE 4.—Classification of mineral reserves and resources. Degree of certainty increases from right to left, and feasibility of economic recovery increases from bottom to top.

ticity of this order of magnitude is not uncommon for many commodities over a space of a few years or even months, as shown by recent variations in prices of copper, mercury, silver, sulfur, and coal. Deposits in this category thus become commercially available at price increases that can be borne without serious economic effects, and chances are that improvements in existing technology will make them available at prices little or no higher than those prevailing now.

Over the longer period, we can expect that technologic advances will make it profitable to mine resources that would be much too costly to produce now, and, of course, that is the reason for trying to take account of submarginal resources. Again, it might seem ridiculous to consider resources that cost two or three times more than those produced now as having any future value at all. But keep in mind, as one of many examples, that the cutoff grade for copper has been reduced progressively not just by a factor of two or three but by a factor of 10 since the turn of the century and by a factor of about 250 over the history of mining. Many of the fuels and minerals being produced today would once have been classed as submarginal under this definition, and it is reasonable to believe that continued technologic progress will create recoverable reserves from this category.

Bechtel Corporation

Engineers-Constructors

Fifty Beale Street

San Francisco, California

Mail Address: P. O. Box 3985, San Francisco, CA 94119

Bechtel Job No. 10571
December 7, 1973

Dear Dr.

As you will recall from the recent phone conversation with Mr. L. O. Beaulaurier, Bechtel Corporation is currently involved in the conduct of a study entitled "Technology Assessment of Geothermal Energy Resources Development". This work is being performed in association with The Futures Group, Inc. of Glastonbury, Connecticut, under contract to the National Science Foundation. One of the primary purposes of this study is to search systematically for forecasts of technological developments in geothermal energy and assess the probable significance of such developments. The results of the study may well be used to inform public policy-makers and in the allocation of R&D funds, etc.

Toward that end, we are interviewing experts in various aspects of the geothermal industry. The purpose of the interviews is to solicit candid opinion regarding the present status and the possible future development of certain aspects of geothermal technology under an assumed set of conditions.

We would like to solicit your input to the study and we seek your cooperation in the conduct of such an interview. Participants in the interview will receive a summary of the output of the interviews.

In anticipation of the interview, we have enclosed a set of questions concerning the present and possible future status of a particular impediment to the development of geothermal technology. Also

December 7, 1973
Page 2

enclosed are definitions of essential terms. It might be helpful if you would look over the questions and jot down a few notes in anticipation of our next phone call. If, upon reviewing the questionnaires, you feel it necessary to clarify any of the questions, please phone us at any time. Mr. L. O. Beaulaurier (415-764-5914) of our staff will be contacting you about December 12 to discuss the interview and solicit your replies.

Sincerely,

M. Carasso
Project Manager
Geothermal Technology
Assessment Study

MC:sam
Enclosures

Geothermal Technology Assessment Study

DEFINITION OF TERMS

In the attached form we ask for your opinion on the expected developments that you can foresee in relation to specific items that impede development of geothermal energy. We are asking what can be accomplished, i. e., what is technically possible, aside from political, competitive, and environmental considerations, etc. We ask that you consider each item in terms of a "normal" and "crash" development.

By "Normal Development" is meant that geothermal technology continues to develop on the same basis that it is presently developing, without externally-applied stimuli.

By "Crash Development" is meant that geothermal technology develops under the stimulus of a declared national policy backed by massive governmental support, in which cost is virtually no impediment.

In order that we may codify your forecasts of the future status of the items which impede development of geothermal energy, it is necessary to specify "performance" and "availability" criteria such as shown in the example below. We ask that the forecasts be given, as much as possible, in quantitative terms of these criteria over future periods of time. Under "required inputs", please give your opinion regarding capital, manpower, research breakthroughs, etc., which will be necessary in order to realize the forecast.

EXAMPLE

Basis: CRASH Development

Item: Lack of a bladeless turbine

What do you think the status of this item can be in 12 years (by 1985)?

Performance: Commercially reliable 200-MW unit

Availability: Production capability of 20 units per year

Required inputs: (1) \$3 million R&D effort over the next three years
(2) Substantial enlargement of manufacturing facilities

Control No. : _____

Imped. Formis: _____

Control No. : _____

R. T. Level: _____

GEOTHERMAL TECHNOLOGY ASSESSMENT STUDY
JOB NO. 10571

TASK 5 INTERVIEW SEQUENCE
(BASIC FORM)

1. Interview

a. Date: _____ b. Time: _____
c. Phone ☐ Mail ☐ In Person ☐ at _____

2. Interviewer: _____

3. Interviewee

a. Name: _____
b. Position: _____
c. Phone No.: () _____

4. Organization

a. Name: _____
b. Type business: _____
c. Address: _____

5. Topic

a. R. T. Level: _____
b. Name: _____

JOB 10571
TASK 5 INTERVIEW SEQUENCE
PAGE 2

Control No. : _____

6. Impediments (R. T. Level & Name)

a. _____
b. _____
c. _____
d. _____
e. _____

7. Interviewer Confidence Level

	Low			High
a. Knowledgeability:	1	2	3	4 5
b. Objectivity:	1	2	3	4 5

Geothermal Technology Assessment Study
Job No. 10571, Task 5

GEOTHERMAL TECHNOLOGY FORECASTS

1. Impediment: _____

2. Present Status of Impediment? _____

3. NORMAL: Assume that the geothermal technology will continue development on an "as is" basis (present trend or normal basis).

a. What do you think the status of this item can be in 12 years (by 1985), in terms of:

Performance? _____

Availability? _____

Required inputs? _____

JOB No. 10571
Geothermal Technology Forecasts
Page 2

Control No. : _____

R. T. Level: _____

b. What do you think the status of this item can be in 27 years (by 2000), in terms of:

Performance? _____

Availability? _____

Required inputs? _____

4. CRASH: Assume that the geothermal technology will be developed on a "crash" basis (expedited basis) in which cost is not an inhibiting factor.

a. What do you think the status of this item can be in 12 years (by 1985), in terms of:

Performance? _____

Availability? _____

Required inputs? _____

- b. What do you think the status of this item can be in 27 years (by 2000), in terms of:

Performance? _____

Availability? _____

Required inputs? _____

Geothermal Technology Assessment Study

RESOURCE APPRAISAL FORECAST

Control No.: _____

R. T. Level: _____

Type of Resource	Classification	NORMAL DEVELOPMENT			CRASH DEVELOPMENT	
		What do you think is the present level of RESERVES and IDENTIFIED RESOURCES in MW years (thermal)? Please specify single values or a range.	What do you think could be the level of RESERVES and IDENTIFIED RESOURCES in MW years (thermal)? Please specify single values or a range.		What do you think could be the level of RESERVES and IDENTIFIED RESOURCES in MW years (thermal)? Please specify single values or a range.	
		1973	1985	2000	1985	2000
Vapor Dominated	a) IDENTIFIED RESOURCES					
	b) RESERVES					
Liquid Dominated	a) IDENTIFIED RESOURCES					
	b) RESERVES					
Hot Dry Rock	IDENTIFIED RESOURCES					
Geo-pressured Zones	IDENTIFIED RESOURCES					
Magma	IDENTIFIED RESOURCES					
						How would you characterize the required inputs to such a program?

RESERVOIR DEVELOPMENT FORECAST

Type of Resource	NORMAL DEVELOPMENT		CRASH DEVELOPMENT	
	* What do you think could be the level of "developed geothermal reservoirs" within the entire United States in MW (thermal)? Please specify single values or a range.		* What do you think could be the level of "developed geothermal reservoirs" within the entire United States in MW (thermal)? Please specify single values or a range.	
	1985	2000	1985	2000
VAPOR DOMINATED				
LIQUID DOMINATED				
HOT DRY ROCK				
GEOPRESSURED ZONES				
MAGMA				
<p>* In this context, "developed geothermal reservoir" means the summation of all developed geothermal power, obtainable from fluids of 272 Btu/lb enthalpy (150°C saturated liquid) and above, as measured at the well-heads, and expressed in MW (thermal) (i.e., before any energy conversion occurs). If the interviewee feels that the above lower limit is not appropriate, please feel free to specify a different value, giving the basis for same.</p> <p>The above limit does not apply to geopressured zones; therefore, please give the well-head pressure and temperature corresponding to the lowest enthalpy considered by the interviewee to be practical for geopressured fluids.</p>			How would you characterize the required inputs to such a program?	

Geothermal Technology Assessment Study

ENERGY CONVERSION FORECAST

Type of Resource	NORMAL DEVELOPMENT		CRASH DEVELOPMENT	
	What do you think could be the installed geothermal electric generating capacity within the entire United States in MW (electric)? Please specify single values or a range.		What do you think could be the installed geothermal electric generating capacity within the entire United States in MW (electric)? Please specify single values or a range.	
	1985	2000	1985	2000
VAPOR DOMINATED				
LIQUID DOMINATED				
HOT DRY ROCK				
GEOPRESSURED ZONES				
MAGMA				
			How would you characterize the required inputs to such a program?	

3. Resource Estimates

Treatment of Uncertainty

Analysis of results from the interview sequence indicates that any attempt to achieve a consensus in describing the potential of geothermal energy by a single deterministic value would have probably failed, with the exception of a few specific cases. A range of forecasts has been obtained both for the technological subsystems and for electric power throughput from geothermal energy systems. In the treatment of results, this range of throughput forecasts will be presented in various forms:

- (1) Full range (all data).
- (2) Midrange, calculated by eliminating forecasts which led to extreme points of full range, and
- (3) Median, calculated by integrating median subsystem forecasts.

The median values are calculated for convenience of results presentation. The two range forecasts reflect better the present state of knowledge. A sample diagram which illustrates this treatment of uncertainty is illustrated in Figure A.4, which depicts the year 2000 results for liquid-dominated resources under normal program emphasis. The estimates of identified liquid-dominated resources range from 16-1200 GWe resource equivalent. The forecasts for technological capability to develop and convert this resource base range from 15-100 GWe. The total range of throughput forecasts of technologically feasible levels of liquid-dominated geothermal energy resources development, after comparing the two sets of forecasts, is 15-100 GWe capacity. The midrange is calculated by dropping the two estimates which led to the extreme points of the range forecast. In both cases, this is the development/conversion forecast rather than a resource forecast. The midrange is found now by integrating a forecast of 16-1200 GWe resource equivalent and a forecast of 100 GWe development/conversion capability to get a midrange forecast of 16-100 GWe. The fact that the midrange is very close to the range indicates that both the lowest and highest forecasts are quite close, or, as in the case of the highest estimate here, identical to other estimates. The median forecast is found by comparing the median resource equivalent forecast of 300 GWe with the median development/conversion capability forecast of 100 GWe and selecting the limiting condition of 100 GWe, as Figure A.4 shows.

Geothermal Technology Forecasts, 1973-2000

Generation of geothermal electric power forecasts involves integration, via the methodology described in Section 3, of the forecasts obtained in the technical interview sequence. This section describes the resulting forecasts of technologically feasible levels of geothermal energy resources development for 1973, 1985, and 2000, for a normal and a crash development program emphasis, by resource type as well as for all resource types combined.

1973 Situation: The current level of installed geothermal electric power capacity in the United States is 0.396 GWe, all of the vapor-dominated resource type, and is located in California. It has been assumed that this value approximately represents the current capability of industry for reservoir development and energy conversion, and no further attempt has been made to solicit estimates from the experts on this question for 1973.

Estimates of the various experts on the current levels of geothermal resources which can be categorized as "identified" are summarized in Figure A.5 following. The uncertainty regarding even the current level of geothermal resources is large, as exemplified by a range of resource equivalent estimates from 9-4100 GWe. However, most of the uncertainty concerns the level of hot dry rock resources. The range of estimates for the remaining four resource types is equivalent to 9-97 GWe, which remains considerably above the amount of existing geothermal-electric capacity of 0.396 GWe.

The technological factors which have restricted geothermal energy resources development to such a negligible amount up to the present time are:

1. The present state of knowledge of the geothermal resources in the United States is skeletal, fragmentary, uncoordinated, and largely undeveloped.
2. Development of vapor-dominated reservoirs and of liquid-dominated reservoirs of moderate salinity has reached the level of technological feasibility, but energy extraction methods have not yet been demonstrated for high-salinity brines nor for hot dry rock, geopressured, or magma resources.
3. Technology for conversion of geothermal energy for vapor-dominated and moderate-salinity liquid-dominated geothermal systems

LIQUID-DOMINATED RESOURCES, YEAR 2000, NORMAL PROGRAM

Figure A.4

SUMMARY OF ESTIMATES FOR IDENTIFIED RESOURCES, YEAR 1973

"RESOURCE EQUIVALENT" IS THE AMOUNT OF ELECTRICAL GENERATING CAPACITY WHICH CAN BE SUPPORTED BY THE ESTIMATED LEVEL OF IDENTIFIED RESOURCES FOR 25 YEARS, ASSUMING 10% OVERALL CONVERSION EFFICIENCY.

Figure A.5

is also far advanced, but conversion processes and equipment for high-salinity and for moderate-to-low temperature liquid-dominated systems, as well as for geopressured and magma systems, are not yet technically feasible.

Geothermal Technology Forecasts--Summary of 1985

Results: Forecasts of technically feasible geothermal development levels for 1985 are derived in Figures A.6 and A.7 for normal and crash program emphasis, respectively. The results are summarized in Figure A.8 which plots the throughput ranges for all resources. Under a normal program the forecasted throughput potential ranges from 5-24 GWe, while the midrange is 9-11 GWe. The median forecast is 10 GWe. These forecasts include comparable contributions from vapor-dominated, liquid-dominated, and geopressured zone resources, with a small amount of hot rock development. Utilization of magma resources is essentially zero. In this short-term time frame, the industry's development/conversion capability appears to be a more limiting factor in nearly all cases than the level of identified resources. However, there exists great uncertainty regarding the level of resources which could be identified by 1985, so that it is unclear whether enhancement of development/conversion capability would significantly increase system throughput.

Figure A.7 on the following page derives the system throughput for 1985 under crash program assumptions. The median forecast for technologically feasible levels of geothermal energy resources development increases from 10 GWe to 35 GWe if spurred by a large influx of research and development efforts. Of this total, the largest potential contributions are to be expected from liquid-dominated and hot-dry rock resources. Forecasted development of magma resources remains negligible. The total range of throughput forecasts is 12-144 GWe, with a midrange of 27-40 GWe. (The high estimate of 144 GWe in the range includes one expert's forecast of 100 GWe of geopressured-zone

resource development, which assumes the existence of a mechanism which can utilize the chemical energy of the methane as well as the thermodynamic energy content of the fluid. If not, his estimate would be reduced by approximately two-thirds to 33 GWe, and the range narrowed to 12-77 GWe.) The limiting factor again appears to be industry's capability to develop and convert resources which are forecasted to be identified, although the uncertainty regarding the resource level remains great.

Resource Type: Vapor-Dominated 1985

Normal development: All three of the interviewees queried on the resource exploration and appraisal question estimate that the level of identified vapor-dominated resources with normal program emphasis will be inadequate to support a substantial level of generating capacity. The highest resource estimate is equivalent to 14.4 GWe capacity. The view of three other experts questioned on the subject of development and conversion of the resource is that the development of vapor-dominated resources will be slightly lower in 1985, with the highest of the three forecasting a capability to install 5 GWe capacity. Combination of the median estimates for resource appraisal and for development/conversion results in a forecast of 3 GWe of electricity from vapor-dominated resources by 1985, with reservoir development/energy conversion capability and the level of identified resources equally limiting constraints.

Crash Development: Under conditions of a crash program, one of the three experts felt that the identified vapor-dominated resource base could be considerably expanded to a level sufficient to support 120 GWe of generating capacity, while the other two experts forecasted no significant increase in identified resources. On the question of development/conversion capability, the three experts agreed that a crash program would not be adequate to significantly increase this capability by 1985, with the most optimistic forecast of 10 GWe capacity.

TYPE OF RESOURCE	RESOURCE EQUIVALENT (GW _e)	RESERVOIR DEVELOPMENT AND ENERGY CONVERSION (GW _e)	(SYSTEM THROUGHPUT) ELECTRIC POWER POTENTIAL		
			RANGE (GW _e)	MIDRANGE * (GW _e)	MEDIAN (GW _e)
VAPOR - DOMINATED	2 - 14.4	→ 1.8 - 5.0	→ 1.5 - 5.0	2.0 - 3.0	3.0
LIQUID - DOMINATED	8 - 1200	→ 2.0 - 7.0	→ 2.6 - 7.0	3.5	3.6
HOT DRY ROCK	2.4 - 60,000	→ 0.0 - 1.5	→ 0.0 - 1.5	1.0	1.0
GEOPRESSURED ZONES	16 - 80	→ 1.5 - 10.0	→ 1.5 - 10.0	3.0	3.0
MAGMA	0 - 12	→ 0.0 - 0.1	→ 0.0 - 0.1	0.0	0.0
TOTALS			5 - 24	9 - 11	10

Figure A.6

GEOTHERMAL TECHNOLOGY FORECASTS, CRASH, 1985

TYPE OF RESOURCE	RESOURCE EQUIVALENT (GWe)		RESERVOIR DEVELOPMENT AND ENERGY CONVERSION (GWe)		(SYSTEM THROUGHPUT) ELECTRIC POWER POTENTIAL		
					RANGE (GWe)	MIDRANGE (GWe)	MEDIAN (GWe)
VAPOR-DOMINATED	2 - 120	→	2.0 - 10.0	→	2.0 - 10.0	2.0 - 4.0	3.5
LIQUID-DOMINATED	16 - 1,200,000	→	7.5 - 28.0	→	7.5 - 28.0	10.0 - 20.0	16.7
HOT DRY ROCK	20 - 60,000	→	0.05 - 5.0	→	0.05 - 5.0	5.0	5.0
GEOPRESSURED ZONES	16 - 200	→	3.0 - 100	→	3.0 - 100	10.0	10.0
MAGMA	0 - 12	→	0 - 0.2	→	0 - 0.2	0 - 0.05	0.05
TOTALS					12 - 142	27 - 40	35

Figure A.7

Figure A.8

The median estimate for maximum electric power contribution of vapor-dominated resources by 1985 with a crash program is 3.5 GWe, with development/conversion only slightly more limiting than the level of identified resources, which could have supported 5 GWe. In the judgment of the experts, a crash program in geothermal energy development would have negligible impact by the year 1985 on the utilization of vapor-dominated resources, due both to resource level limitations and to such technological impediments as shortage of tubular goods essential to drilling operations and to lack of experience with reservoir fluid recharge, among others.

Resource Type: Liquid-Dominated 1985

Normal development: There is a significant difference of opinion among the three resource experts on the level of resources which can be identified by 1985 under normal program emphasis, with estimates ranging from 8-1200 GWe resource equivalent. The middle estimate is closer to the low than the high of this range. However, the significance of this uncertainty pales in light of the fact that none of the three development/conversion experts feels that industrial capability to develop the resource will be even as high as the lowest resource level forecast, with major technological impediments in the form

of a shortage of tubular goods essential to drilling operations and limited availability of drill rigs capable of drilling below 25,000 ft. The range of forecasts is 2.6-7 GWe, with a midrange and median value of 3.5 GWe.

Under conditions of a crash research and development program, forecasts of industry development/conversion capability increase approximately by a factor of 3, and forecasts of identified resource level increase by up to 3 orders of magnitude (factor of a thousand). While considerable uncertainty still exists among the three resource experts (resource equivalent ranges from 16-1, 200,000 GWe), two agreed that the resource base is adequate to support more than 200 GWe of electric generating capacity. Reservoir development and energy conversion capability remain an apparently more limiting constraint to liquid-dominated resource utilization, with estimates ranging from 7.5-26 GWe. While the Task 5 assessment concluded that no major impediments blocked development of the resource, minor impediments to reservoir development and energy conversion include a shortage of tubular goods and lack of experience with fluid recharge, among others. The midrange throughput forecast for this reservoir type is 10-20 GWe, with a median value of 16.7 GWe, which is an increase from 3.5 GWe in the normal program case.

Resource Type: Hot Dry Rock

Normal development: The geothermal experts agreed that hot dry rock will remain a largely undeveloped resource in 1985 under normal program incentives. The highest of these forecasts for development/conversion capability is a mere 1.5 GWe. On the other hand, the quantity of hot rock resources identified by 1985 may prove to be extremely large. One of the experts forecast a virtually limitless resource potential of 15×10^9 MWh-years, adequate to support 2000 GWe of generating capacity for 750 years. A second expert felt that the identified resource base might well be large, but expressed some uncertainty, forecasting a resource equivalent of 40-40,000 GWe. However, the third interviewee was much more pessimistic about the level of resources which would be identified by 1985, with a forecast equivalent to only 2.4 GWe capacity. Even this low estimate is greater than any of the development/conversion capability forecasts, however.

Crash development: A crash program effort in geothermal hot rock is not adequate to significantly increase its electric power potential in the 1985 time frame, according to the consensus of the experts. With this resource, the problem remains one of inadequate technological development/conversion capability to put to use an apparently large resource base. Two of three experts interviewed felt that a crash program would increase the development/conversion industry capability a slight amount to 5 GWe. The third person forecasted no improvement, except perhaps for a small 0.05 GWe experimental facility. The identified resource estimates increased somewhat and remain significantly greater than can be developed in this time frame. The median 1985 electric power from hot rock forecast increased from 1 GWe with normal program emphasis to 5 GWe with crash program emphasis.

A significant conclusion from these forecasts is that any crash program in hot rock development should emphasize the reservoir development/conversion aspects of energy production, including the demonstration of the feasibility of present concepts.

Resource Type: Geopressured Zones 1985

Normal development: Three of the four experts questioned on the quantity of geopressured zone resources which can be identified by 1985 under normal program emphasis agreed that the resource base is less than that necessary to support 80 GWe of electrical generating capacity for 25 years. But the development/conversion capability appears to be a more limiting constraint, with the most optimistic forecast at 10 GWe. (This most optimistic estimate assumes a contribution of approximately 67 percent derived from utilization of the chemical energy of the methane in the geopressured-zone fluid.) The median forecast is for a development/conversion capability of only 1.5 GWe by 1985, although the median resource forecast could support up to 20 GWe.

Crash development: Three of the four experts questioned felt that a crash program would not significantly affect the 1985 level of identified resources, but the remaining person stated that the resource would be adequate to support more than 100 GWe for 50 years. The median resource equivalent estimate increased slightly to 42 GWe. Two of the three development/conversion capability forecasts are less than or equal to 10 GWe, but one forecast increased greatly to 50-100 GWe.

Combining all resource and development/conversion forecasts gives a range for geopressured-zone system throughput of 3-100 GWe for 1985 under crash program conditions. Reservoir development/energy conversion capability forecasts limit both extreme points of the range. After eliminating the two extreme forecasts, a midrange throughput of 10 GWe is gotten, still limited by development/conversion.

Resource Type: Magma 1985

All five experts who discussed resource appraisal and/or development/conversion capability for magma agreed that even under crash program conditions, magma could contribute at most a negligible amount of electric power to the United States' energy system by the year 1985. The most optimistic forecast is for 0.2 GWe capability by 1985, and the median forecast is a mere 0.05 GWe, assuming crash program emphasis. The non-existence of the essential high temperature technology is the critical constraint to magma development.

Conclusions for 1985 Geothermal Electric Power Potential (System Throughput)

Perhaps the major conclusion from the investigation is that most experts agree that 1985 is too soon to expect significant contribution to electric power supply from geothermal resources, even under the conditions of a crash development program. The major subsystem which impedes the timely development of geothermal energy in this time frame appears to be the industry capability to develop the resources and convert them to electricity, rather than the level of identified resources, although there is large uncertainty as to how much expansion geothermal resources could support above and beyond the forecasted system throughputs. The 1985 impact of a crash program is to increase the total potential throughput range from 5-24 GWe to 12-144 GWe, the midrange from 9-11 GWe to 27-40 GWe, and the median from 10 GWe to 35 GWe. The greatest impact of a crash program in the 1985 time frame is forecast to be seen in development of liquid-dominated and to a less degree geopressured-zone resources, with some impact on hot rock resource development, and negligible impact on vapor-dominated and magma resources.

Geothermal Technology Forecast--Summary of 2000 Results

Forecasts of technologically feasible levels of geothermal energy resources development for 2000 are derived in Figures A.9 and A.10 for normal and crash program emphasis, respectively. The results are summarized in Figure A.11 which plots the throughput ranges for all resources. Under a normal program the system throughput forecasts range from 25-600 GWe, with a midrange of 55-200 GWe, and a median of 200 GWe. Half of the median contribution comes from liquid-dominated resources, with approximately 25 percent due to each of hot dry rock and geopressured-zone resources. Negligible potential for development is expected both for vapor-dominated and magma resources. In the case of the most optimistic forecasts, hot dry rock plays the dominant role, contributing two-thirds of the total 600 GWe.

Analysis of the normal program subsystem forecasts indicates uncertainty as to which subsystem most limits geothermal development potential in this time frame. For example, the most pessimistic combination of resource forecasts indicates a level of identified

resources of only 50 GWe for 25 years. On the other hand, two of the three experts interviewed agree that hot dry rock resources are virtually inexhaustible that liquid-dominated resources are quite large (greater than 200 GWe for 25 years). For the other three resource types, the level of identified resource and industry development/conversion capability appear to be approximately equally limiting. A review of the Task 5 report indicates that there are no major technological impediments remaining in the year 2000 which would block development, but several minor impediments remain in the resource exploration and appraisal and the reservoir development subsystems.

Figures A.9 and A.10 illustrate the expected impact by the year 2000 of normal and crash geothermal programs, respectively, on the various resource types. The median forecast for technically feasible levels of geothermal resources development increases from 200 GWe to 770 GWe, which is about 40 percent of projected U.S. demand for installed generating capacity in the year 2000. The major impact of the crash program would be seen as increasing the level of possible development of liquid-dominated resources, according to the median forecasts, and also a significant increase in the potential for hot rock utilization.

GEOHERMAL TECHNOLOGY FORECASTS, NORMAL, 2000

TYPE OF RESOURCE	RESOURCE EQUIVALENT (GWe)	RESERVOIR DEVELOPMENT AND ENERGY CONVERSION (GWe)	(SYSTEM THROUGHPUT) ELECTRIC POWER POTENTIAL		
			RANGE (GWe)	MIDRANGE (GWe)	MEDIAN (GWe)
VAPOR - DOMINATED	2 - 24	5 - 30	2 - 24	4 - 8	6
LIQUID - DOMINATED	16 - 1200	15 - 100	15 - 100	16 - 100	100
HOT DRY ROCK	20 - 120,000	0 - 400	0 - 400	20 - 50	50
GEOPRESSURED ZONES	16 - 80	10 - 70	10 - 70	16 - 40	40
MAGMA	0 - 12	0 - 2.5	0 - 2.5	0 - 1	1
TOTALS			25 - 600	55 - 200	200

Figure A.9

GEOHERMAL TECHNOLOGY FORECASTS, CRASH, 2000

TYPE OF RESOURCE	RESOURCE EQUIVALENT (GWe)	RESERVOIR DEVELOPMENT AND ENERGY CONVERSION (GWe)	(SYSTEM THROUGHPUT) ELECTRIC POWER POTENTIAL		
			RANGE (GWe)	MIDRANGE (GWe)	MEDIAN (GWe)
VAPOR - DOMINATED	2 - 180	6 - 100	2 - 100	6 - 15	10
LIQUID - DOMINATED	40 - 1,200,000	45 - 1000	40 - 1000	45 - 500	500
HOT DRY ROCK	200 - 12,000,000	0 - 2000	0 - 2000	200	200
GEOPRESSURED ZONES	16 - 320	20 - 500	16 - 320	20 - 80	54
MAGMA	4 - 12	0 - 10	0 - 10	2	2
TOTALS			55 - 3430	270 - 800	770

Figure A.10

Figure A.11
SUMMARY OF SYSTEM THROUGHPUT RANGES,
YEAR 2000

Together these two resources account for 90 percent of the 770 GWe.

The range of 2000 crash program forecasts is 55-3430 GWe, which indicates that considerable uncertainty exists among the experts. An investigation of Figure A.10 points out that this uncertainty holds both for the level of identified resources and for industry's development/conversion capability. However, elimination of the extreme points of the forecasted range yields a much narrower midrange of 270-800 GWe.

Resource Type: Vapor-Dominated 2000

Normal development: There is consensus among experts that, under normal program emphasis, the potential of vapor-dominated resources is insignificant in geothermal energy utilization in the year 2000. The most optimistic identified resource forecast is 24 GWe for 25 years, and the median system throughput forecast is only 6 GWe, limited by resource availability rather than industry's technological capabilities to develop the resource.

Crash development: Incentives of a massive R&D program prompted one expert to expect significantly more resources to be identified and a concomitant greater level of electric power capacity installed, for a total throughput of 100 GWe. However, due to resource limitations most experts foresee little potential of vapor-dominated resource utilization, as shown by the midrange throughput value of 6-15 GWe, and a median throughput forecast of 10 GWe.

Resource Type: Liquid Dominated 2000

Normal development. The majority of respondents think that 100 GWe of electric power capacity utilizing liquid-dominated resources can be installed by the year 2000 under normal program conditions. Two of the three resource experts stated that the level of identified resources in the year 2000 could be greater than 100 GWe for 50 years, and two of the three development/conversion experts forecasted a 100 GWe industry capability. However, the third expert in each area was more pessimistic, forecasting a resource equivalent of 16 GWe and a development/conversion capability of 15-30 GWe.

Crash development. All experts agreed that a crash program could significantly increase the potential for liquid-dominated resource utilization by the year 2000. Resource estimates increased by factors of 2-1000 and development/conversion forecasts increased by factors of 2-10. In each of the two subsystems, though, forecasts of the most pessimistic expert remained at least an order of magnitude below those of the other two experts. The most pessimistic system throughput forecast was twice the median, equal to 50 percent of projected U.S. installed capacity in 2000. In both the median and high forecasts, development/conversion capability rather than identified resources limits total throughput, but results do not justify a firm conclusion regarding this question.

Resource Type: Hot Dry Rock 2000

Normal development. There exists a great disparity among experts' forecasts of hot dry rock utilization in the year 2000 as compared with the range of forecasts in other resources, under normal program conditions. The uncertainty stems from the facts that:

1. Hot rock resources have, until recently, received little exploration and appraisal effort.
2. The technology for development/conversion of hot rock resources has not been demonstrated on a large scale.

Two of the three resource experts forecast a virtually inexhaustible supply of identified resources, but a third predicts a very low level of 20 GWe for 25 years. In the reservoir development/energy conversion subsystem, forecasts of technologically feasible levels range from 0-400 GWe. Resulting system throughput forecasts range from 0-400 GWe, with a midrange of 20-50 GWe, and a median of 50 GWe. Each of the three development/conversion forecasts are more limiting than the corresponding resource forecast.

Crash development. Forecasts made under the assumption of crash program emphasis remain widely divergent, for the reasons described in the previous paragraph. The most pessimistic resource expert increased his forecast by an order of magnitude to 200 GWe for 25 years, but a pessimistic development/conversion expert forecasted virtually no impact on his normal case prediction of 0 GWe installed. The other two development/conversion experts increased their forecasts by factors of 4-5. Resulting throughput forecasts for 2000 crash program case are a range of 0 GWe-2000 GWe, with a median value of 200 GWe.

Resource Type: Geopressured Zones 2000

Normal development. The forecasts of three of the four experts indicate that the level of identified resources of geopressured-zone resources limits the potential of this resource type to a lesser role than liquid-dominated and hot rock resources in the U.S. electric power economy of the year 2000 under normal conditions. The development/conversion forecasts are similar to the resource forecasts. The resulting throughput range is 10-70 GWe, with a midrange of 16-40 GWe, and a median of 40 GWe. These throughput forecasts are slightly lower than those for liquid-dominated and hot dry rock resources under normal program assumptions, but the level of identified resources is a much more limiting factor for the geopressured-zone resource case.

Crash development. The dominant view is that the level of identified resources will limit geopressured-zone resource utilization to less than 80 GWe for 25 years, although one expert forecasts identified resources at least four times higher. The median throughput forecasts is a resource-limited 54 GWe, only slightly greater than the normal case median.

Resource Type: Magma 2000

The consensus among the experts is that magma offers no significant potential for electric power production in this century, with the most optimistic throughput forecast only 10 GWe with a crash program.

Conclusions for 2000 Geothermal Electric Power Potential (System Throughput)

While there exists great uncertainty among various geothermal experts, the results tend to suggest that a rather large and perhaps virtually inexhaustible resource base exists and can be identified both for hot dry rock and liquid-dominated resources. Vapor-dominated systems

appear to be resource-limited, and also geopressured-zone systems to a lesser degree. Regarding the capability of industry to develop existing resources and convert them to electric power, there is again considerable uncertainty. A majority of experts interviewed felt that liquid-dominated, hot dry rock, and geopressured-zone resources could be exploited sufficiently to install a total of at least 200 GWe from all geothermal resources under normal conditions and 770 GWe for crash program conditions. In both cases liquid-dominated resources are forecast to contribute 50 percent or more of these totals.

R&D efforts of a crash program emphasis should enhance the development of liquid-dominated and hot dry rock resources, while the impact on the development of other resource types is forecast to be minor.

TECHNOLOGICAL RELEVANCE TREES

One of the major research tools used in this study is the relevance tree. In concept, a relevance tree is a hierarchical structure in which entities at each successive level in the aggregate describe completely the next immediate level above. A relevance tree describes a domain and theoretically, at least, describes it completely. In the technologically-oriented tasks associated with this study, two relevance trees were constructed: the first dealt with geothermal energy and was designed to describe the elements of geothermal energy down to the component level. It was used to provide a framework for impediment evaluation: in essence it was a check list which helped ensure that important system aspects were not overlooked. Figure B.1 shows the levels of the tree, followed by the tree itself.

B.1 shows the levels of the tree and is followed by the tree itself.

In effect the geothermal tree was a detailed elaboration of the one branch of a technological relevance tree describing energy as a whole. The format for this tree is the same as for the geothermal tree, through Level VI, as shown in Figure B.1. The final portion of this Appendix contains the general energy tree itself (pages 330 through 355). The tree provided visibility into technologies other than geothermal for the production of electricity, as well as an orderly framework for impediment evaluation. The level of detail obtained in limiting the energy tree to five levels and the geothermal tree to six levels, was sufficient for purposes of the study. Additional work in further expansion of either tree may be rewarding, however, in defining more detailed technological requirements.

FIGURE B.1 - ENERGY TECHNOLOGY RELEVANCE TREE

OBJECTIVE: Define the availability of technology associated primarily with the production of heat and electrical power from natural resources.

RELEVANCE INTERROGATION:

Level I	What natural resources are available?
Level II	What primary energy forms can be developed from these natural resources?
Level III	What major technologies are associated with the development of these energy forms?
Level IV	What applied technological areas are involved in these major technologies?
Level V (Geothermal)	What systems, processes, or methods are involved in these applied technological areas?
Level VI (Geothermal)	What major components comprise these systems and processes, or what specific techniques are used in these methods?

1. THE GEOTHERMAL RELEVANCE TREE

A1

A2

A3

A4

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A12

A13

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A26

A27

A28

A29

(p. A22)
(p. A41)
(p. A53)
(p. A67)

FOG PLUMES

LEVEL V

Heat Rejection Systems

LEVEL VI

-Wet cooling towers
-Spray ponds and canals

Well Venting

-Testing and clean-out operations
-Uncontrolled blown-out wells
-Intentional venting of standby wells

A30

(p. A22)
(p. A41)
(p. A53)
(p. A67)
(p. A83)

AESTHETICS

LEVEL V

Geothermal Field

LEVEL VI

-Wells
-Gathering systems

Plant

-Buildings
-Heat rejection systems
-Landscaping

Energy Distribution System

-Towers and overhead lines
-Surface piping
-Underground cables and piping

Roads and Improvements

Fog Plumes

-Heat rejection systems
-Well venting

A31

A32

A33

A34

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Sheet 5-48

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Sheet 5-52

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2. THE ENERGY RELEVANCE TREE

SHEET 1

SHEET 2-1

SHEET 2-2

SHEET 2-3

GEOHERMAL ENERGY TECHNOLOGY TREE

(Shown at the beginning of Appendix B.)

SHEET 2-4

SHEET 3-1

SHEET 3-2

SHEET 3-3

SHEET 3-4

SHEET 3-5

SHEET 3-6

SHEET 3-7

SHEET 3-8

SHEET 3-9

SHEET 3-10

SHEET 3-11

SHEET 3-12

Sheet 3-13

SHEET 4-1

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Improved methods are required to determine optimum location for facility. (Insolation; collection, grid-control, and interpretation of solar data.)

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Appendix C

SOCIAL AND POLITICAL INTERVIEWS AND FINDINGS

Introduction

This section of the report provides detailed information about the social and political interviews summarized in Section 3.2. It includes a description of the participants, the interview sequence, interview materials, and a compilation of individual responses to the impact matrix and accompanying comments.

The Social and Political Interview Panel

The members of this panel were selected as knowledgeable representatives of a range of interest groups participating in or affected by the development of geothermal energy. The names and affiliations of the participants are listed in Section 3.2.

In the compilation of opinions on which forms the major part of this appendix, responses are listed by participant numbers which refer to broad interest group connections but do not identify each individual. This preserves the anonymity of specific answers while permitting evaluation of their importance and validity in relation to areas of expertise and points of view.

The Interview Sequence

A. Introduction. The interviewer described the role of The Futures Group in conducting the study and the general objectives of the overall study. He then outlined the specific purposes of the interview:

1. To collect the views of various interest groups regarding the probable future course of geothermal development and the subsequent impact of this development on their specific group, on other interest groups, and on the nation as a whole.
2. To identify and define various policies which might be implemented to mitigate or improve potential impacts of geothermal development.

B. Scenario Discussion.

1. The respondent was asked to review the "normal" and "crash" scenarios, which in most cases had been mailed to him prior to the interview.
2. He was asked to comment on their contents in general and/or in detail.
3. He was asked to present his own appraisal of the course of development and his underlying assumptions.
4. The interviewer directed the discussion to areas of the respondent's expertise or particular interest.

C. Impact Matrix

1. The respondent was given a deck of cards containing 36 possible impacts of the development of geothermal energy.

2. A matrix was laid out in front of the respondent by means of heading cards.
3. The respondent was asked to make two independent judgments regarding each impact in accordance with his own version of the development scenario and to place the card in the corresponding matrix square. The heading cards across the top of the matrix defined a scale of desirability for the nation as a whole:

Very desirable
Desirable
Neutral
Undesirable
Very undesirable
No opinion

The heading cards along the left side of the matrix defined a probability scale:

Almost certain
Very likely
As probable as not
Very unlikely
Almost impossible
No opinion

4. The respondent was encouraged to discuss the nature of the impacts as he proceeded with the card sort, and to explain the assumptions underlying his judgments. Matrix placement and accompanying comments were recorded by the interviewer.
5. If time permitted, the scale of desirability alone was laid out and the respondent was asked to reclassify the impact cards from the point of view of his own self-interest as contrasted to the national interest assumed above. An alternative approach utilized was to ask if there was any area of impact which, if judged from the respondent's own or professional point of view, might be in conflict with any judgments made from a national point of view.

D. Conclusion

1. The respondent was asked to suggest any additional impacts of geothermal developments which he could foresee.
2. He was asked to describe policies which he would like to see implemented in the field of geothermal development.

Interview Material--Scenarios

Normal Development of Geothermal Energy. The energy crisis of 1973 necessitates a changing pattern of input fuels for electricity generation. Shortages of low-sulfur oil and natural gas preclude the continuing substitution of these fuels for coal. Nuclear energy supplies are less than anticipated because of siting problems and long lead times involved in nuclear plant construction. Appropriate environmental accommodations are made allowing coal to fill the generating gap until additional nuclear plants become operative by the mid-1980's. By the early 1980's oil supplies are available from shale, tar sands, and Alaska, but are primarily used for transportation, heating, and petro-chemicals rather than for electricity generation.

By 1974 intensive prospecting for geothermal resources is underway, spurred by the open leasing of federal lands. Supported by venture capital, utility development funds, and governmental pilot projects, exploration for geothermal steam and hot water resources begins in the western regions. This exploration, spurred by new developments for assessing the resource longevity of fields, indicates that most identified geothermal resources are liquid-dominated hot water systems. Potential development of these hot water resources, however, is slowed due to difficulties with high brine content. It is 1978 before any commercially viable plants utilizing hot water are operative.

Legal and institutional impediments are gradually removed during the mid- to late 1970's. By 1980 geothermal resources are treated as unique and statutes are clear regarding what can be developed and in what manner. Specific guidelines are instituted to assure that the physical sites of geothermal systems are developed in a manner compatible with existing land use patterns.

Due to the large risk factor, substantial capital outlay involved, and long lead times which characterize geothermal developments, it becomes evident that private initiative must be supplemented by federal incentive programs (tailored depreciation allowances, investment guarantees, and/or production subsidies). Federal and state policies regarding geothermal resource development are coordinated and most conflicts resolved.

As hot water systems are being developed, work commences on possible utilization of hot dry rock resources. In the 1970's research efforts focus on hydraulic fracturing and also on possible seismic effects of fluid injection into hot dry rock.

By 1985 there is an electrical output capability of about 7500 megawatts from geothermal energy in the West. Of this total, 3000 is from dry steam, 3500 from hot water, and 1000 from hot dry rock. This accounts for 6 percent of the generating capacity of the West. The only other significant geothermal production is on the Gulf coast where geopressured fields produce some 3000 megawatts.

The utilization of geothermal resources proceeds rapidly since it has cost and environmental advantages over coal and in many instances over nuclear powered plants as well. The growth of nuclear development slows somewhat in the West as geothermal power is clearly demonstrated as a practical energy source.

As the year 2000 approaches, geothermal energy is a major factor in the West and a minor, though significant, factor in the Gulf states. Prospecting for geothermal reserves in the East begins, spurred by new advances in drilling and resource locating technology.

By the year 2000 geothermal resources supply over one-third of the generating capacity of the West. Of this total of 140,000 megawatts, 6000 are from dry steam, 100,000 from hot water, and 34,000 from hot dry rock. Plans to export electricity from western regions await the development of additional capacity and adequate transmission technology.

Other uses of geothermal energy being implemented on a relatively large scale include space heating and air conditioning, supplying irrigation water from desalinated wastes, and provision of minerals recovered from fluid wastes. Some geothermal systems are multipurpose, combining electrical generation with one or more of the above-mentioned uses.

Crash Development of Geothermal Development. After the opening of federal lands for leasing in 1974, interest in geothermal energy intensifies. Congress, spurred by an awareness of private industry interest, acts to stimulate geothermal development through a variety of measures. By 1975 and 1976 legislation is passed which coordinates federal research and development activities on geothermal energy and, in addition, funding and guarantees for new programs are passed. Since it has been demonstrated that private industry is unable or unwilling to bear all early risks of geothermal development, the federal government funds entire projects for mapping, exploration, and the development of hot water, hot dry rock, and geopressure technology. To hasten the development of commercially feasible resources (steam and hot water), the federal government utilizes loan guarantees to private industry and actually participates with some utilities and municipalities in joint pilot projects.

The combined actions of federal, state, and local agencies are successful in preventing duplication of effort by establishing standardized procedures regarding the development and definition of geothermal resources. A national data bank for geothermal information is established by 1977 to facilitate orderly research and exploration.

These programs, plus additional federal activity in granting depreciation allowances and instituting manpower training projects, have a significant effect on the pace of development of steam, hot water, and geopressure resources. Exploratory techniques advance rapidly and the scale deposit problem is solved by 1980.

Most major technical impediments to the development of hot water reservoirs have been removed by 1985. In addition, hot rock and geopressure technology is developing rapidly, especially in the area of deep drilling techniques (commercial rigs are available for depths up to 30,000 feet and temperatures of 800°F). Despite the lack of adequate field longevity data some regional utilities have been encouraged through federal incentive programs to base a large part of their new capacity on geothermal energy. This increased utilization is encouraged since geothermal energy has been shown to have cost and environmental advantages over coal and in many instances over nuclear powered plants as well. Production has reached a level of 35,000 megawatts: 3500 in steam, 16,500 in hot water, 5000 in hot dry rock, and 10,000 in geopressure.

While further development of steam and geopressure resources is limited by the extent of these resources, hot water and hot dry rock resources have been identified in very substantial quantities. Whether these resources are to be fully developed depends on the possibility of exporting excess electricity from the West to other regions. In other areas increased demand for electricity is being met through the construction of additional nuclear plants, since fossil and synthetic fuels are largely reserved for other uses. As the use of nuclear power increases so do the perceived environmental problems of siting, safety, and wastes. In dealing with these problems the cost of nuclear power rises and it becomes cost-competitive to transport electricity from geothermal development via high voltage transmission lines from the West to the rest of the country.

After a prolonged national debate which weighs the advantages of more abundant energy versus possible environmental damage, Congress proclaims a national policy to promote this transmission of geothermal electricity. In addition, legislative action

provides funding and incentives to minimize any undesirable environmental and economic effects of this policy.

By the year 2000 the geothermal industry is a major source of income in western regions. Formerly isolated areas are now populated as jobs open at geothermal plants and surrounding industries. Geothermal generating capacity in the West totals 660,000 megawatts: 10,000 in steam, 500,000 in hot water, and 150,000 in hot dry rock. The Gulf Coast states are supplied with 50,000 megawatts from geopressed resources, while hot rock resources utilized for space heating provides the equivalent of 50,000 metawatts in other regions. This crash program, which has eliminated major constraints and accelerated geothermal development, results in geothermal energy supplying about one-third of the electricity produced in the United States.

Interview Material--Impact List

1. Air pollution due to electric generation in western regions reduced.
2. Land subsidence disrupts agricultural production.
3. Noise from geothermal systems disrupts land use patterns (i.e., wildlife withdrawal habitation, residential, agriculture, etc.)
4. Increased seismic activity in western regions due to fractures and fluid withdrawal.
5. Localized climatic modification in areas where vapor-dominated geothermal systems are developed.
6. Development and construction of nuclear power plants slowed markedly in western regions.
7. Contamination of water tables in many localities by geothermal wastes.
8. Previously inaccessible areas opened for recreational use.
9. The development of agriculture in previously unfarmed areas stimulated by the availability of irrigation water from desalinated geothermal wastes.
10. Revitalization of the drilling industry.
11. Other primary energy sources (oil, coal, and natural gas) freed for use other than the generation of electricity.
12. Exclusion of small firms from geothermal development.
13. Large integrated companies dominate the development of geothermal resources.
14. Reduced needs for imported petroleum improve the U.S. balance of trade.
15. The construction of transcontinental transmission lines requiring new rights of way.
16. Tax revenues and royalties from geothermal developments provide the basis for tax reductions in municipalities and states in western regions.
17. Increased industrial development due to the availability of low-cost electricity.
18. Implementation of antipoverty programs based upon municipal development and administration of geothermal resource areas.
19. Alteration or modification of home construction techniques to utilize geothermal potential for space heating.
20. The construction and development of new towns near geothermal resource systems.
21. Commercial market for minerals and mineral salts extracted from geothermal liquids.
22. Eastern electricity demand met in part by electricity exported from western geothermal developments.
23. Living standards improve.
24. Energy intensive industries located in the East migrate to western regions.
25. Real GNP growth higher than it might have been without geothermal power.
26. Population migration from East to West simulated.
27. Shortage of skilled manpower.
28. Slowdown in the growth of the synthetic fuel industry.
29. Increased government regulation of resource development by private enterprise.
30. Despoilation of land by coal strip mining essentially terminated.
31. Recreational space in western states reduced.
32. The state of geological science advanced markedly.
33. Multi-purpose industrial/agricultural complexes developed in West.
34. Natural gas supplies increased.
35. Creation of tax shelters for investment in geothermal developments.
36. Formation of many new federal, state, and municipal agencies to oversee geothermal resource development.

Interview Material--Impact Matrix

IMPACT MATRIX	Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
Almost Certain	1	7	13	19	25	31
Very Likely	2	8	14	20	26	32
As Probable As Not	3	9	15	21	27	33
Very Unlikely	4	10	16	22	28	34
Almost Impossible	5	11	17	23	29	35
No Opinion	6	12	18	24	30	36

Interview Material--Compilation of Individual Responses to Impact Matrix

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
1. Air pollution due to electric generation in western regions reduced.	Almost Certain	1 4					
		3 13					
	Very Likely	6 7	2 12				
			11				
	As Probable As Not	9					
		16					
Very Unlikely			8				
Almost Impossible							
No Opinion							

COMMENTS

8. Very unlikely because level of development not that high.
12. Very likely because geothermal is in isolated areas while other power plants are near load centers.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
3. Noise from geothermal systems disrupts land use patterns (i.e., wildlife habitation, residential, agriculture, etc.).	Almost Certain						
	Very Likely				8 11		
					16	4	
	As Probable As Not				13	6	
Very Unlikely					1 10	3	
					7 12	9	
Almost Impossible						2	
No Opinion							

COMMENTS

4. Inherent problem.
6. Blow out control technology needs developing (at the Geysers took 2 years to bring one well which blew out under control--others no trouble).
2. Geothermal noise problems have been solved.
10. Not important; just a siting problem. Not noisy beyond one-half mile.
11. Problem can be handled.
12. Constantly working on problem--have mufflers. Producing wells are quiet.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
2. Land subsidence disrupts agricultural production.	Almost Certain						
	Very Likely						
	As Probable As Not						
Very Unlikely				2	1 10	7 3	
					9 11	4 6	
Almost Impossible					12		
					8		
No Opinion							

COMMENTS

3. Will be watched for--if evidence of occurrence, work will stop. If due to loss of pressure, reinjection will help.
4. Will be prevented by reinjection--toxic fluids must be reinjected.
9. Unlikely--wouldn't continue development of area if occurred.
10. Of no importance--can be easily taken care of.
12. Depends strictly on the area. There is none at the Geysers. Possible in the Imperial Valley but won't happen because of constant monitoring. Need baseline data because there are constant earthquakes.
16. Likely because of emphasis on Imperial Valley--but not in other areas.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
4. Increased seismic activity in western regions due to fracturing and fluid withdrawal.	Almost Certain						
	Very Likely						
					12	4 8	
	As Probable As Not					9	
Very Unlikely				16	11	1 3	
Almost Impossible						2 13	
No Opinion							6 7 10

COMMENTS

1. Water would re-enter from other underground sources--nature abhors a vacuum--only when resource is depleted might there be danger, but not so long as water is being withdrawn.
3. Monitoring will guide behavior--to either stop or take corrective action.
10. Nobody knows yet.
12. Unknown factor (in Denver, storage of nuclear waste affected earthquake activity).
16. Inappropriate question. Total activity would be the same; only mode in which released would be different--small versus big earthquake.

Participant Code by number: 1. Private industry 5. Public utility 9. Public utility 13. Environment and research
 2. Private industry 6. Government--administrative 10. Government--legislative 14. Private industry
 3. Government--administrative 7. Government--legislative 11. Public utility 15. Private industry
 4. Environment and research 8. Environment and research 12. Private industry 16. Government--administrative

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
Localized climatic modification in areas where vapor-dominated geothermal systems are developed.	Almost Certain						
	Very Likely				4		
	As Probable as Not			16	6 12	1	
	Very Unlikely			11	13	7 9	
	Almost Impossible			10		2	
	No Opinion						3

COMMENTS

- Assumes that systems are not all sealed.
- Fogging from cooling towers, rather than from emerging steam.
- Acknowledged problem--working on it. At Mammoth can see vapor clouds. Have problem at Geysers in cold weather--working it out--cooling towers give problems.

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
7. Contamination of water tables in many localities by geothermal wastes.	Almost Certain						
	Very Likely					8	
	As Probable as Not					4 16	
	Very Unlikely				6 10 9 11 12	13	
	Almost Impossible					1 2 3	
	No Opinion						7

COMMENTS

- In California this is almost impossible. Laws are strict enough to prevent occurrence.
- Very likely to occur.
- Easy to handle--one point source of contamination.
- Can be taken care of.
- Unlikely because of controls by regulatory bodies.

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
6. Development and construction of nuclear power plants slowed markedly in western regions.	Almost Certain						
	Very Likely	1 13	7	6			
	As Probable as Not				2 16		
	Very Unlikely	4	8 9 11	3	12		
	Almost Impossible			10			
	No Opinion						

COMMENTS

- Sites will be found.
- Given political factors and diminishing supplies of cheap uranium.
- No possibility--geothermal just supplemental source.
- Need both geothermal and nuclear to free up fossil fuels.
- Very desirable and highly likely--geothermal will combine with reduction of electricity consumption growth to reduce need for nuclear plants.
- Undesirable--will need all sources of power.

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
8. Previously inaccessible areas opened for recreational use.	Almost Certain						
	Very Likely		12	6			
	As Probable as Not		7 8 9	2	13		
	Very Unlikely		4	1 11			
	Almost Impossible			3 10			
	No Opinion						16

COMMENTS

- Geothermal areas are accessible--but not desirable.
- Roads would be developed to transport equipment, and people could come over them for recreation.
- As probable as not--but odor and noise are deterrents.
- Not impossible, but won't happen.

Participant Code by number:

- Private industry
- Private industry
- Government--administrative
- Environment and research

- Public utility
- Government--administrative
- Government--legislative
- Environment and research

- Public utility
- Government--legislative
- Public utility
- Private industry

- Environment and research
- Private industry
- Private industry
- Government--administrative

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
9. The development of agriculture in previously unfarmed areas stimulated by the availability of irrigation water from desalinated geothermal wastes.	Almost Certain							
	Very Likely		1 9 13					
	As Probable as Not	3	6 11 16					
	Very Unlikely	4	7 10					
	Almost Impossible	2		8				
	No Opinion							13

COMMENTS

2. Water is of too poor quality.
3. Only in Imperial Valley, however, in California.
6. The general need for water is so great for domestic and industrial use that it will prevent agricultural use, in which evaporation losses are high.
10. Economics are against it. Desalinated water wouldn't be cheap enough. Only possibility is hothouses. Might possibly provide water supply for municipal and industrial use.
12. Very possible, but is a project for the government. Industry has a problem with this--not economically feasible. Also, would have to be in area where wouldn't be important if land subsided. Imperial Valley has critical tiling system--cannot be disturbed.
16. Not commercially feasible--except in some cases where water is usable as is.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
11. Other primary energy sources (oil, coal, and natural gas) freed for uses other than the generation of electricity	Almost Certain	1 4 16	6					
	Very Likely	9 12	7 13	2				
	As Probable as Not		8 10			11		
	Very Unlikely							
	Almost Impossible							
	No Opinion							

COMMENTS

3. Electric demand must be met--all fuels will be required.
4. Due to less accelerated electric growth curve. Geothermal is not such a benign source that conservation is not needed.
6. Fairly substantial impact on other fuels in the West.
10. Effect will be felt only after year 2000--then geothermal may be major factor. Must stop using fossil fuels because of cumulative environmental effect.
11. Won't free that much by 2000.
12. Geothermal supplement to free fossil fuel along with nuclear.
16. Almost certain--desperately needed.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
10. Revitalization of the drilling industry.	Almost Certain	2		4				
	Very Likely		7 11	6				
	As Probable as Not			12				
	Very Unlikely	3	8	1 10				
	Almost Impossible							
	No Opinion							9 13 16

COMMENTS

1. Not enough to matter--some effect, though.
2. Drilling business will double or triple.
3. Not that much increased activity due to geothermal.
6. There will be initial shortages in men and material.
10. The industry is not going downhill. There will be material shortages. Offshore drilling and oil problem alone is reviving industry--geothermal will not be much of a factor.
11. Shortage of material could persist for several years.
12. Shortages are not temporary unless there is a government rollback on prices of crude. Now drilling in marginal areas. If prices remain high and the need is there, drilling will expand. Manpower available will now expand--during the slump there was less recruiting.
16. Irrelevant question--doesn't need revitalizing.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
12. Exclusion of small firms from geothermal development.	Almost Certain							
	Very Likely		4		7 16 8	6 9		
	As Probable as Not				1 10	3		
	Very Unlikely				11 12	2		
	Almost Impossible							
	No Opinion							13

COMMENTS

1. Due to their inability to bid on leases and their inability to get proper financing. Can't compete with large companies.
3. Not that expensive an operation. Small companies drilling a few wells can survive.
4. Large companies are beginning to show themselves capable of being responsive to environmental problems, while small companies with less resources are ignoring them.
6. In the beginning, small firms will take the big risks. But the only people who have the financial resources ultimately needed are large companies.
9. Very likely that oil and gas companies will predominate.
10. Yes--if not good government policy. Need financing bills and leasing policy.
12. Unlikely. Smaller companies generate investment. Oil industry has more wells drilled by independents than by big companies.
16. Nature of the game makes this very likely--need potful of money.

Participant Code by number:

1. Private industry	5. Public utility
2. Private industry	6. Government--administrative
3. Government--administrative	7. Government--legislative
4. Environment and research	8. Environment and research

9. Public utility	13. Environment and research
10. Government--legislative	14. Private industry
11. Public utility	15. Private industry
12. Private industry	16. Government--administrative

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
	Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
13. Large integrated companies dominate the development of geothermal resources.	Almost Certain		8	16			
	Very Likely		12	4 7 10	6 9		
	As Probable As Not		3		1		
	Very Unlikely			11	2		
	Almost Impossible						
	No Opinion						13

COMMENTS

- They do not now--but could in future. They would buy their way in, but not swallow small firms.
- Fears large integrated companies.
- Large companies will produce steam, manufacture chemicals, may generate electricity. Some states may make provision for non-utility electrical generation. (Only utilities will continue to transmit, however.)
- Yes, unless conscious policies are undertaken.
- Big companies have more money and manpower. But will not necessarily dominate exploration.

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
	Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
15. The construction of transcontinental transmission lines requiring new rights of way.	Almost Certain		4		3		
	Very Likely	7 13	1 2				
	As Probable As Not	8 9					
	Very Unlikely	11 6	10 12				
	Almost Impossible						
	No Opinion						16

COMMENTS

- Power will be exported, say from Imperial Valley.
- Intercontinental lines will be built regardless of geothermal to take advantage of differences in peak load times.
- Geothermal will develop everywhere--won't move great amounts of electricity around.
- Undesirable from environmental point of view, but desirable from point of view of small companies. Geothermal development not of magnitude to stimulate long distance lines--but other forces will be at work.
- Will happen anyway--without geothermal.
- Unlikely--geothermal will make significant contribution to electric power in the West and will free fossil fuel for East.
- Transmission lines going in anyway--there will be a substitution effect of geothermal in the West--oil will be shipped to East.

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
	Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
14. Reduced needs for imported petroleum improve the U.S. balance of trade.	Almost Certain	3	6				
	Very Likely	1 2	7				
	As Probable As Not		4 9				
	Very Unlikely	10 16	11 12 13				
	Almost Impossible	8					
	No Opinion						

COMMENTS

- Will result from general energy research strategy, not geothermal alone.
- Unlikely in timeframe.
- Not relevant to geothermal--not a dominant factor though may help.
- Geothermal not that significant a factor.

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
	Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
16. Tax revenues and royalties from geothermal developments provide the basis for tax reductions in municipalities and states in west regions.	Almost Certain						
	Very Likely	2 12					
	As Probable As Not	1	11	6			
	Very Unlikely	3 4	7	9		10	
	Almost Impossible					8	
	No Opinion			16			13

COMMENTS

- Most geothermal sites are far from populated areas.
- Geothermal operations will probably cost counties money to monitor and police activities.
- Not likely--purpose of current bills in Congress to think in terms of ultimate tax revenues rather than royalties.
- Highly unlikely--most development on federal lands anyway.
- Won't be that big--not important part of economic sector.
- Very likely--most local governments eager to have companies in their area.

Participant Code by number:
 1. Private industry
 2. Private industry
 3. Government--administrative
 4. Environment and research

5. Public utility
 6. Government--administrative
 7. Government--legislative
 8. Environment and research

9. Public utility
 10. Government--legislative
 11. Public utility
 12. Private industry

13. Environment and research
 14. Private industry
 15. Private industry
 16. Government--administrative

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
17. Increased industrial development due to the availability of low-cost electricity.	Almost Certain						
	Very Likely	16	1 7				
		2	2				
	As Probable As Not		9	6			
			12	8			
	Very Unlikely	3	11	10	13		
Almost Impossible				4			
	No Opinion						

COMMENTS

1. Certain industries which can relocate will; others will get power by transmission exchanges between utilities (e.g., to Bonneville from the Geysers).
3. No real low-cost electricity--since geothermal costs will be tied to total system costs.
4. If geothermal becomes a clean power source, it will have similar cost for the consumer as do other problem power sources.
6. The cost of energy for most industries is a small factor in total cost. For example, development at Massena of hydro didn't bring on great industrial development (beyond aluminum and related industries). There was no great influx (like at TVA) due to poor climate and geography.
7. Private firms interested in establishing greenhouses in Nevada.
10. Electricity will probably never be cheaper--at least not before 2000. Energy producers are trying to keep up with demand and at the same time trying to constrain it. Geysers price based on alternations--therefore won't be cheaper.

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
18. Implementation of anti-poverty programs based upon municipal development and administration of geothermal resource areas.	Almost Certain						
	Very Likely						
	As Probable As Not		9				
			4				
	Very Unlikely	3	7 11	12			
Almost Impossible			8 10	2		1	
	No Opinion						6 13 10

COMMENTS

1. This ties into political/social things which would interest development.
2. Municipalities won't be involved. Nothing special about geothermal--like oil.

COMMENTS (Cont.)	
12. Could possibly take care of an industry.	
13. We will never have low-cost electricity again.	
16. Very likely if include process heat--used for instances by pulp mills, synthetic rubber plants. Ten percent of energy use is process steam.	

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
19. Alteration or modification of home construction techniques to utilize geothermal potential for space heating.	Almost Certain	4					
	Very Likely	2	7 9				
		16					
	As Probable As Not	3	11	6			
	Very Unlikely	1		10			
		8		12 13			
Almost Impossible							
	No Opinion						

COMMENTS

1. Homes will not be built in areas which have resource.
2. By employing advanced concepts to derive heat from the earth in a greater variety of locations, and perhaps near population centers, this impact could be significant.
10. Space heating applications will not be that big--can't move hot water very far. Might use it for industrial complex built at site. No reason to move out to remote areas because of geothermal--only as a result of some deliberate industrial attempt.
11. Locally possible.
12. Very unlikely--heat can't be transported. Could be used for small town. Solar more likely to have this impact.
13. Unlikely--would involve tremendous change--more likely for solar.

Participant Code by number: 1. Private industry 5. Public utility
2. Private industry 6. Government--administrative
3. Government--administrative 7. Government--legislative
4. Environment and research 8. Environment and research

9. Public utility 13. Environment and research
10. Government--legislative 14. Private industry
11. Public utility 15. Private industry
12. Private industry 16. Government--administrative

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
	Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
20. The construction and development of new towns near geothermal resource systems.	Almost Certain						
	Very Likely	3 6	7 8				
		16					
	As Probable As Not	2 1	9 4	3 4			
	Very Unlikely	1 2	10 11	12 13			
	Almost Impossible						
No Opinion							

COMMENTS

1. Towns could spring up around relocated industry.
2. Some population growth, but not a big movement.
4. Only if we can't develop solar and run out of everything else. Accessibility depends on area.
7. Very likely--in Nevada plans for a transportation and warehousing center on an Indian reservation using geothermal energy.
8. Very likely--geothermal could be a regional development tool--small utilities might be able to use it. Geothermal plants are small--perfect for small areas.
12. Very unlikely--doesn't cause that large a workforce.

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
	Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
22. Eastern electricity demand met in part by electricity exported from western geothermal developments.	Almost Certain						
	Very Likely	8 13					
	As Probable As Not	1 4	6				
	Very Unlikely	7 9	2 10	12		16	
	Almost Impossible						
	No Opinion						

COMMENTS

1. Transmission across continent possible.
3. States will not mind exporting power.
4. Much deeper drilling techniques will be needed to develop certain geothermal sources. Exporting will depend on such possible developments.
7. Very unlikely--very few proponents.
8. Will be a transcontinental line by 2000.
10. No export from West--if hot rock successful, will develop in East.

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
	Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
21. Commercial market for minerals and mineral salts extracted from geothermal liquids.	Almost Certain						
	Very Likely	14	3 6 9	7 8			
	As Probable As Not	1 4	11				
	Very Unlikely	16	2	10			
	Almost Impossible						
	No Opinion						13

COMMENTS

1. Long range. But not at all needed to make geothermal economic.
3. Imperial Valley (Morton Salt Co.) was producing potash @ \$30/ton. But Canadian fields underwent development @ \$12/ton.
4. In the short term no, but perhaps for long term outlook.
6. May make a lot of difference to cost of hot water for heating. Electric power, however, will be major area for geothermal heat.
11. Not in timeframe to 2000.
12. There is a likelihood--if market exists.
16. Unlikely to be a big piece of the action.

IMPACT:	INDIVIDUAL RESPONSES, BY PARTICIPANT CODE						
	Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion	
23. Living standards improve.	Almost Certain						
	Very Likely		7 13				
	As Probable As Not	2					
	Very Unlikely	1 3 4	10 9 11	12			
	Almost Impossible			8			
	No Opinion						6 16

COMMENTS

1. Not much impact.
3. Geothermal energy is like any other source of energy--will not affect living standards any more than alternate energy sources.
4. Energy alone does not provide standard of living. There will be a depletion of raw material sources in the future which geothermal will not help.
10. Not significant except on very local basis.
11. Not enough geothermal to affect living standards.
13. Likely--but minor effect. Would reduce nuclear pollution.

Participant Code by number:

1. Private industry
2. Private industry
3. Government--administrative
4. Environment and research

5. Public utility
6. Government--administrative
7. Government--legislative
8. Environment and research

9. Public utility
10. Government--legislative
11. Public utility
12. Private industry

13. Environment and research
14. Private industry
15. Private industry
16. Government--administrative

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Indesirable	Very Undesirable	No Opinion
24. Energy intensive industries located in the East migrate to western regions.	Almost Certain						
	Very Likely	1		8			
	As Probable as Not		4	3 7 16			
	Very Unlikely			11 6 12 9	2 10 13		
	Almost Impossible						
	No Opinion						

COMMENTS

1. Metal processing, metallurgical, chemical, and food processing industries.
3. Problems with over immigration already exist.
4. Most such industries have already located in cheap power areas.
10. Social and economic systems will not let significant differences exist--the days of enticing industry are over.
9. Unlikely--would have done it long ago--relocated to hydro.
13. Economics of transmission system will be worked out so there will be little incentive to move.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Indesirable	Very Undesirable	No Opinion
26. Population migration from East to West stimulated.	Almost Certain						
	Very Likely		7	2			
	As Probable as Not		4	3 16			
	Very Unlikely			6 11 9 12	1	13	
	Almost Impossible			8 10			
	No Opinion						

COMMENTS

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Indesirable	Very Undesirable	No Opinion
25. Real GNP growth higher than it might have been without geothermal power.	Almost Certain						
	Very Likely	3	7 16				
	As Probable as Not	2					
	Very Unlikely	1 4	9	6 11 12			
	Almost Impossible		8 10				
	No Opinion						13

COMMENTS

1. Geothermal will have gradual impact but effect will balance off--long-term effect will be small.
4. Energy is not the entire factor.
6. Energy cost with geothermal may be less than for other energy sources; this may have a negative effect on GNP.
9. Would be same--without geothermal would be other sources--and in addition, demand will be cut. Sees increase in solar power, substantial increase in nuclear (although limited by terrible expenses), major developments in extraction of coal. Would be cheaper to devote costs of developing breeder reactor to coal.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Indesirable	Very Undesirable	No Opinion
27. Shortage of skilled manpower.	Almost Certain					16	
	Very Likely				12	2	
	As Probable as Not				11		
	Very Unlikely			3 4	1 10 7 13 9		
	Almost Impossible					6 8	
	No Opinion						

COMMENTS

1. No problem for development.
2. Shortage in drilling exists now and will get worse. People don't like the rather dirty, difficult work.
3. Geothermal development will be held back by need for skilled labor.
4. Geothermal development will be held back more by shortages of materials--specific supplies needed for energy development.
6. Not peculiar to geothermal needs--school enrollments are down in all mineral fields.
7. Unlikely--will beef up state mining schools--enrollment has been declining.
10. No shortage--don't need many--not enough geothermal drilling.
12. Now great shortage, but word getting around that people are needed.
16. Almost certain shortage of geothermal experts--will be significant lag in training which will make development more confused. Should support colleges with geothermal programs.

Participant Code by number: 1. Private industry 5. Public utility 9. Public utility 13. Environment and research
2. Private industry 6. Government--administrative 10. Government--legislative 14. Private industry
3. Government--administrative 7. Government--legislative 11. Public utility 15. Private industry
4. Environment and research 8. Environment and research 12. Private industry 16. Government--administrative

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
28. Down in the growth of the synthetic fuel industry.	Almost Certain						
	Very Likely						
	As Probable As Not						
	Very Unlikely	4 9	2 3	6 6	12 12	1 20	
	Almost Impossible		10		13		
	No Opinion						7

COMMENTS

1. Geothermal will not compete.
3. Need exists to expand every source of energy.
10. Absolutely no possibility--government stimulus to coal-gas plants--growth will be staggering.
11. Undesirable development if synthetics are to be used for electricity.
12. Undesirable and unlikely--will continue to grow--we need everything.
16. Geothermal won't have any effect on this.

COMMENTS (Cont.)

16. Almost certain--desirability depends on kind of regulations. Need one-stop approval for projects. Leasing system absurd. Government needs knowledge of what activities are underway.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
29. Increased government regulation of resource development by private enterprise.	Almost Certain		7	8 16			
	Very Likely		4 6		1	12	
	As Probable As Not		11 13			2 3	
	Very Unlikely		9	10			
	Almost Impossible						
	No Opinion						

COMMENTS

1. To protect environment, fine; but not to inhibit growth. Regulation, as now seen, will inhibit growth.
3. Too many federal and state bills dealing with regulation--too many county ordinances.
4. Private industry won't regulate itself. Social pressures will bring about controls due to industry's unwillingness to do the job itself.
6. Federal government is hindering geothermal development up to now. Has tried to get maximum return on its land. It has taken too long to prepare impact statements. Government now suing to reclaim mineral rights, and this uncertainty will prevent speculation and development. Favor a central energy group which can look at whole problem to balance government's role as a landlord, and its role as an encourager of energy development. Need to make it possible for small companies to bid through staggered system--not have to pay entire bid amount at delivery of lease.
9. Geothermal only small factor.
10. This is the trend--but not because of geothermal.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
30. Despoilation of land by coal strip mining essentially terminated.	Almost Certain						
	Very Likely						
	As Probable As Not						
	Very Unlikely	1 4	6 3	9 11		7 12	2
	Almost Impossible	8 16		10			
	No Opinion						

COMMENTS

10. No, it is essential to get a lot of coal out.
11. Very likely--but geothermal will have little to do with it.
12. Undesirable and very unlikely--will develop environmentally acceptable practices. Can't see any source of energy neglected--demand so strong that all are needed.
13. Will be terminated regardless of geothermal--will continue to strip mine but will alleviate effects.

Participant Code by number: 1. Private industry 5. Public utility 9. Public utility 13. Environment and research
 2. Private industry 6. Government--administrative 10. Government--legislative 14. Private industry
 3. Government--administrative 7. Government--legislative 11. Public utility 15. Private industry
 4. Environment and research 8. Environment and research 12. Private industry 16. Government--administrative

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
31. Recreational space in western states reduced.	Almost Certain						
	Very Likely					4	
	As Probable As Not			16		13	
	Very Unlikely			6	2 10 7 11 9 12	1	
	Almost Impossible					3 8	
	No Opinion						

COMMENTS

- Geothermal areas are not usually recreational; in some areas recreation can be preserved. Hot fluids need to be handled safely, however, if people are to be allowed into geothermal areas.
- There's enough land for geothermal not to interfere with other recreational lands. Plenty of empty space.
- Certain desirable spaces will be affected. We need recreational space as much as energy.
- Most areas not on recreational land.
- Geothermal does not involve intensive land use.
- Use very little land.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
33. Multi-purpose industrial agricultural complexes developed in West.	Almost Certain						
	Very Likely	16	1 7 4 10	13			
	As Probable As Not		2 11 12	3 6			
	Very Unlikely			8 10			
	Almost Impossible						
	No Opinion						

COMMENTS

- If desalinization problem is solved, Imperial Valley could go this way.
- Geothermal resources not generally in agricultural locations (Imperial Valley an exception).
- Unlikely--not a significant water source.
- Can be compatible with agricultural uses--grazing or crops. Cows graze at Geysers.
- Will develop regardless of geothermal.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
32. The state of geological science advanced markedly.	Almost Certain						
	Very Likely	2 16	2 7 4 10 13 12				
	As Probable As Not		1 8 6 11				
	Very Unlikely						
	Almost Impossible						
	No Opinion						

COMMENTS

- Need for geological research. Where is heat coming from? Where is water coming from?
- Significant things will be learned about the crustal composition of the earth.
- Geothermal only one of pressures to advance knowledge.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
34. Natural gas supplies increased (through utilization of geopressured resource).	Almost Certain	4					
	Very Likely	16	2 9 13				
	As Probable As Not		6				
	Very Unlikely		1 8 10 11				
	Almost Impossible						
	No Opinion						3 12 7

COMMENTS

- Potential effects of geopressure offshore blowouts "horrendous." Geopressure theory attractive. Marine life must be preserved, and hence fears are aroused by private industry turned loose offshore.
- Possibly gas won't be available from geopressured sources--may burn it along with geothermal heat in on-site electrical plant.
- Very unlikely in timeframe.
- Nothing done yet in geopressure.
- Disparity of opinion on prospects for geopressure.

Participant Code by number: 1. Private industry
2. Private industry
3. Government--administrative
4. Environment and research
5. Public utility
6. Government--administrative
7. Government--legislative
8. Environment and research

9. Public utility
10. Government--legislative
11. Public utility
12. Private industry
13. Environment and research
14. Private industry
15. Private industry
16. Government--administrative

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
35. Creation of tax shelters for investment in geothermal development.	Almost Certain				3		
	Very Likely		7 8	16	9	13	
	As Probable As Not		12	10		4	
	Very Unlikely			1 2 11			
	Almost Impossible						6
	No Opinion						

COMMENTS

1. Tax shelter not the way to go.
3. Big companies don't use them much. It means more regulations. It might encourage smaller companies--encourage drilling, not necessarily discovery, since indiscriminate activity might result.
6. Subsidies are generally given to "wrong" people--they are not really productive.
10. In normal times this would be natural development--but now public attitudes are against it.
12. Tax incentives are needed for development.

IMPACT:		INDIVIDUAL RESPONSES, BY PARTICIPANT CODE					
		Very Desirable	Desirable	Neutral	Undesirable	Very Undesirable	No Opinion
36. Formation of many new federal, state, and municipal agencies to oversee geothermal resource development.	Almost Certain					16	
	Very Likely		4 10 7	13		1 11 2 12	
	As Probable As Not			6			
	Very Unlikely		8 9				
	Almost Impossible						
	No Opinion						

COMMENTS

1. Only 50 percent of time is creatively used now because of this.
3. Constant legislation is appearing proposing this. But there are too many against right now.
4. Desirable by necessity. Would like to see reduction of number of agencies involved, but skeptical that one big agency can be in balance with the many diverse forces impinging on geothermal exploitation.
7. Desirable to have new overall agency--but not many.
10. Federal government has plenty of agencies. There will be overall reorganization of federal agencies--will take care of geothermal. (Defining geothermal as a unique resource is the easiest way to go--if follow water and mineral laws in the West will have a mess. Need new body of law.) Federal Government will pre-empt environmental field--local agencies will have little to say--also continued state pre-emption of local federal constraints will operate through grants. air and water regulations. Reduced latitude very pronounced in whole energy field.
12. Very likely but undesirable--already too many agencies. There is more and more desire to regulate industry. Would like to see trend reversed.

Participant Code by number: 1. Private industry 5. Public utility 9. Public utility 13. Environment and research
 2. Private industry 6. Government--administrative 10. Government--legislative 14. Private industry
 3. Government--administrative 7. Government--legislative 11. Public utility 15. Private industry
 4. Environment and research 8. Environment and research 12. Private industry 16. Government--administrative

Appendix D

A RELEVANCE TREE OF PRIMARY AND SECONDARY IMPACTS

As pointed out in Appendix B, the use of relevance trees was important to several tasks in the study. Not only was this approach useful in exploring and describing the content of geothermal technology, it was also used to explore and describe higher order impacts. Eight primary impact areas constituted the top level of the tree; these eight areas are presented below. The remainder of the tree was devoted to a detailed elaboration of the consequences within these prime impact areas.

Figure D.1 summarizes the general framework by which this analysis was conducted, and the tree itself is presented on the following pages.

OBJECTIVE: DEFINE THE "IMPACT SPACE" FLOWING FROM THE EVOLUTION OF GEOTHERMAL ENERGY IN THE UNITED STATES.

RELEVANCE INTERROGATION

LEVEL I WHAT ARE THE PRIMARY IMPACT AREAS?

II WHAT ARE THE PRIMARY IMPACTS WITHIN THESE AREAS?

III WHAT ARE THE SECONDARY IMPACT AREAS?

IV WITHIN THESE AREAS, WHAT ARE THE SECONDARY IMPACTS?

V WHAT TERTIARY IMPACTS FLOW FROM THESE?

Figure D.1 IMPACT RELEVANCE TREE

D.4

D.5

D.6

D.7

D.10

D.11

D.12

D.13

D.14

D.15

D.16

D.17

D.20

D.21

D.22

D.23

1.5
EFFECTS ON
PRIMARY & SECONDARY
FUEL PRICES AND
RELATIVE ABUNDANCE

D. 24

D.25

D.26

D.27

D. 28

D.29

D. 30

D. 33

D. 34

D.35

D.36

D. 37

D. 38

D.41

D.42

D.43

D.44

D.46

D.47

D.48

D.49

D.50

D.51

D.68

D.69

D.70

D.71

D.72

D.76

D.77

THE ELECTRIC UTILITY MODEL

This section presents a full description of the model equations. In the first section they are discussed as they are presented. The second section contains an alphabetical listing of all the variables and constants in the model. Finally, the last section presents the model output for the various runs discussed in earlier sections of the text.

System dynamics equations, written in DYNAMO computer language, are, for the most part, simple mathematical translations of the relationships among model parameters. All variables have a time subscript to indicate what time period is being referenced. System levels and auxiliary variables are subscripted either .J, to indicate the time period just past, or .K, to indicate the present time period. Rates of flow are subscripted either .JK, to indicate the rate during the last time period to the present, or .KL, to indicate the rate from the present to the next time period.

A complete treatment of the theory of system dynamics can be found in Industrial Dynamics by Professor Forrester.[1] The use of the DYNAMO language is described more fully in the DYNAMO II User's Manual.[2]

1. The Model Equations

The model performs separate calculations for the western region of the United States and the rest of the country, called the East. The amount of geothermal resources available at any given time in the East and the West is supplied as an exogenous input to the model.

RAW.K=TABLE(TRAW,TIME.K,1970,2015,15) 1, A
 TRAW=400/7000/160000/306000 1.1, T
 RAW - RESOURCES AVAILABLE - WEST (MW)

RAE.K=TABHL(TRAE,TIME.K,1985,2015,15) 2, A
 TRAE=3000/4000/80000 2.1, T
 RAE - RESOURCES AVAILABLE - EAST (MW)

The amount of resources is supplied to the model through the use of a table function—a function in DYNAMO that permits tabular information to be included in a model. In the case of geothermal resources in the West (RAW) the function specifies that the amount of resources is a function of time—as time increases from 1970 to 2015, in steps of 15 years, the available resources increase from 400 MWe to 7000 MWe to 306,000 MWe. These figures are based on the median estimates, developed in the technical round of interviews (Section 3.1), of the amount of geothermal resource that might be technologically exploitable. These estimates are extrapolated from the last estimate year to the year 2015 by simple straight line extrapolation.

Once the extent of the geothermal resource available to utility planners is known, it is necessary to calculate the amount of that resource that utility companies will actually choose to develop into electrical capacity. To accomplish this requires calculation of the amount of new capacity needed for any given year and the percent of that needed capacity that will be geothermal as opposed to coal, petroleum, nuclear, solar, etc. The process is depicted in Figure 3.4.2, repeated here as Figure E.1.1. Calculations for the East are presented first.

Figure E.1.1 DETERMINATION OF PRESENT CAPACITY AND NEED FOR NEW CAPACITY

The amount of new capacity that will be needed to meet demand ten years into the future (TYCCE) is defined as the projected demand in the East minus the present and planned capacity in the East. The projected demand in the East is supplied to the model as a table function.

PTDE.K=TABLE(TPDE,TPPT.K,1970,2010,5)*1E3 4, A
 TPDE=109/374.5/536/710/1005/1281/1558/2045/2532 4.1, T
 TPPT - TIME PLUS PROJECTION TIME (YRS)

TPPT.K=TIME.K+PT 5, A
 PT=10 5.1, C
 TPPT - TIME PLUS PROJECTION TIME (YRS)
 PT - PROJECTION TIME (YRS)

TPDE (the table of expected demand, shown in Figure E.1.2 for the East and the West) represents the estimates of the Federal Power Commission [3] of future demand until 1990 and a normal extrapolation of those figures to the year 2010. The projected demand for any given year is simply the value that the demand estimate will reach in ten years. Thus, the utilities are supplied with a perfect projection for each year. Planning is based on a ten-year projection period because the longest plant construction time in the model (nuclear) is initially ten years.

YEAR	EAST	WEST
1970	109	44
1975	374	94
1980	536	129
1985	710	181
1990	1005	255
1995	1281	340
2000	1558	406
2005	2045	533
2010	2532	660

Figure E.1.2 PROJECTED DEMAND FOR ELECTRICAL CAPACITY, EAST AND WEST (1000 MWe)

The present and planned capacity used in determining the expected capacity is the sum of planned capacity presently installed capacity that will still be on-line in ten years.

PAPSE.K=(PRCAPE.K+PLCAPE.K) 6, A
 PAPSE - PRESENT AND PLANNED SUPPLY-
 EAST (MW/HR)
 PRCAPE - PRESENT PROJECTED CAPACITY-
 EAST (MW)
 PLCAPE - PLANNED CAPACITY-EAST (MW)

Presently projected capacity (the amount of present capacity that will still be available in ten years) is the sum of projected capacities for each source in the East.

PRCAPE.K=PRCCAPE.K+PRPCAPE.K+NUCCAPE.K+
 GEOCAPE.K+SCAPE.K+PRHCAPE.K+
 PRNGCAPE.K+IMPCAPE.K 7, A
 PRCAPE - PRESENT PROJECTED CAPACITY-
 EAST (MW)
 PRCCAPE - PRESENT PROJECTED COAL CAPACITY-
 EAST (MW)
 PRPCAPE - PRESENT PROJECTED PETROLEUM CAPA-
 CITY- EAST (MW)
 NUCCAPE - NUCLEAR CAPACITY- EAST (MW)
 GEOCAPE - GEOTHERMAL CAPACITY- EAST (MW)
 SCAPE - SOLAR CAPACITY- EAST (MW)
 PRHCAPE - PRESENT PROJECTED HYDRO CAPACITY-
 EAST (MW)
 PRNGCAPE - PRESENT PROJECTED NATURAL GAS
 CAPACITY- EAST (MW)
 IMPCAPE - IMPORT CAPACITY- EAST (MW)

For nuclear plants (with a lifetime of 40 years) and solar and geothermal plants (with lifetimes of at least 30 years) and transcontinental lines (import capacity) there will be virtually no retirement of plants before the year 2000. Thus the entire capacity that is installed in any year can be expected to still be on-line ten years later. For coal, petroleum, and natural gas there will be retiring of old capacity.

PRCCAPE.K=CCAPE.K*(1-(PT*.025)) 8, A
 PRCCAPE - PRESENT PROJECTED COAL
 CAPACITY- EAST (MW)
 CCAPE - COAL CAPACITY- EAST (MW)
 PT - PROJECTION TIME (YRS)

With a lifetime of 40 years, approximately 2-1/2 percent of total coal capacity will be retired each year. Thus, in a ten-year period approximately one-quarter of the present coal capacity can be expected to become obsolete. The same is true for petroleum capacity.

PRPCAPE.K=PETCAPE.K*(1-(PT*.025)) 9, A
 PRPCAPE - PRESENT PROJECTED PETROLEUM
 CAPACITY- EAST (MW)
 PETCAPE - PETROLEUM CAPACITY- EAST (MW)
 PT - PROJECTION TIME (YRS)

The installed capacities of natural gas and hydro-electric power are not calculated in the model but are supplied as table functions. Thus, the capacity for these two sources that is expected to be on-line in ten years is the value those table functions will return in ten years.

PRHCAPE.K=TABLE(THCAPE,TPPT.K,1970,2010,5)*1E3 10, A
 PRHCAPE - PRESENT PROJECTED HYDRO CAPACITY-
 EAST (MW)
 TPPT - TIME PLUS PROJECTION TIME (YRS)

PRNGCAPE.K=TABLE(TNGCAPE,TPPT.K,1970,2010,5)*
 1E3 11, A
 PRNGCAPE - PRESENT PROJECTED NATURAL GAS
 CAPACITY- EAST (MW)
 TPPT - TIME PLUS PROJECTION TIME (YRS)

Total presently installed capacity is the sum of all possible sources of electricity in the East; coal, petroleum, nuclear, geothermal, solar, hydroelectric, natural gas, and imports from the West.

PCAPE.K=CCAPE.K+PETCAPE.K+NUCCAPE.K+GEOCAPE.K+
 IMPCAPE.K+SCAPE.K+HCAPE.K+NGCAPE.K 12, A

PCAPE - PRESENT CAPACITY- EAST (MW)
 CCAPE - COAL CAPACITY- EAST (MW)
 PETCAPE - PETROLEUM CAPACITY- EAST (MW)
 NUCCAPE - NUCLEAR CAPACITY- EAST (MW)
 GEOCAPE - GEOTHERMAL CAPACITY- EAST (MW)
 IMPCAPE - IMPORT CAPACITY- EAST (MW)
 SCAPE - SOLAR CAPACITY- EAST (MW)
 HCAPE - HYDRO CAPACITY- EAST (MW)
 NGCAPE - NATURAL GAS CAPACITY- EAST (MW)

The installed coal capacity in the East is a level that is increased by the addition of new capacity and decreased by the retirement of obsolete plants.

CCAPE.K=CCAPE.J+DT*(CARE.JK-CRRE.JK) 13, L
 CCAPE=137.5E3 13.1, N
 CCAPE - COAL CAPACITY- EAST (MW)
 CARE - COAL ADDITION RATE- EAST (MW/YR)
 CRRE - COAL RETIREMENT RATE- EAST (MW/YR)

The initial value of coal capacity in the East is the 1973 value of 137500 MW. The retirement rate of coal plants is approximated by the total installed capacity divided by the average plant lifetime (assumed to be 40 years for coal plants).

CRRE.KL=CCAPE.K/40 14, R
 CRRE - COAL RETIREMENT RATE- EAST (MW/YR)
 CCAPE - COAL CAPACITY- EAST (MW)

The rate of new capacity addition is defined as a delayed function of planned coal additions.

CARE.KL=BOXC(NPCCE.K,6,4384,11099,8884,11106, 15, R
 9569,14343,0,0,0,0)
 CCT=6 15.1, C
 CARE - COAL ADDITION RATE- EAST (MW/YR)
 BOXC - FUNCTION THAT DELAYS VARIABLE (1)
 FOR A PERIOD OF VARIABLE (2)
 NPCCE - NEW PLANNED COAL CAPACITY- EAST (MW/YR)
 CCT - COAL CONSTRUCTION TIME (YRS)

The new capacity addition rate is a six-year delay of newly planned capacity. BOXC is a special function defined specifically for this model. It delays or saves the first argument, in this case NPCCE.K, for a certain number of years, as defined by the second argument, in this case CCT, or six years. Thus, from the time when a certain amount of new coal capacity is planned there is a delay of six years (the average plant construction time for coal) until that capacity comes on-line. The initial values in the BOXC function represent the sum of announced planned capacities for electric utilities in the West. Figure E.1.3 presents the values used for initial capacities and planned capacities (for as many years into the future as the construction delay time) for each of the generating alternatives, East and West.

YEAR	EAST			WEST			
	COAL	OIL	NUCLEAR	COAL	OIL	NUCLEAR	GEO-THERMAL
PRESENT CAPACITIES	137.5	50.4	12.5	13.2	6.5	1.6	.396
1974	14.343	3.333	14.001	.400	.379	—	110.0
1975	9.569	8.331	13.560	1.100	.060	.916	110.0
1976	11.106	7.435	9.801	2.521	.300	1.066	110.0
1977	8.884	7.375	4.952	1.522	.239	2.183	—
1978	11.099	5.553	11.825	.360	.240	—	—
1979	4.384	—	13.678	—	—	2.199	—
1980	—	—	19.546	—	—	3.322	—
1981	—	—	30.910	—	—	—	—
1982	—	—	6.503	—	—	1.767	—
1983	—	—	8.324	—	—	.765	—

SOURCE: NEW CAPACITY ADDITIONS PLANNED OR IN CONSTRUCTION AS OF JUNE 1, 1973, COMPILED BY ELECTRICAL WORLD (NEW YORK: MCGRAW HILL, 1973).

Figure E.1.3 PRESENT AND PLANNED CAPACITIES USED AS INITIAL MODEL VALUES (1000 MWe)

The same calculations are used to define installed petroleum capacity, petroleum retirement rate, and petroleum addition rate in the East.

PETCAPE.K=PETCAPE.J+DT*(PARE.JK-PRRE.JK) 16, L
 PETCAPE=50.4E3 16.1, N
 PETCAPE - PETROLEUM CAPACITY- EAST (MW)
 PARE - PETROLEUM ADDITION RATE- EAST (MW)
 PRRE - PETROLEUM RETIREMENT RATE- EAST (MW/YR)
 PRRE.KL=PETCAPE.K/40 17, R
 PRRE - PETROLEUM RETIREMENT RATE- EAST (MW/YR)
 PETCAPE - PETROLEUM CAPACITY-EAST (MW)
 PARE.KL=BOXC(NPPCE.K, 5,5553,7375,7435, 8331,3333,0,0,0,0,0) 18, R
 PCT=5 18.1, C
 PARE - PETROLEUM ADDITION RATE- EAST (MW/YR)
 BOXC - FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)
 NPPCE - NEW PLANNED ADDITIONAL PETROLEUM CAPACITY- EAST (MW/YR)
 PCT - PETROLEUM CONSTRUCTION TIME (YRS)

The same calculational procedure is also followed in calculating installed capacities for nuclear power and geothermal power. The only difference here is that the nuclear plant construction times and geothermal plant lifetimes are variable.

NUCCAPE.K=NUCCAPE.J+DT*(NARE.JK) 19, L
 NUCCAPE=12.5E3 19.1, N
 NUCCAPE - NUCLEAR CAPACITY- EAST (MW)
 NARE - NUCLEAR ADDITION RATE- EAST (MW/YR)
 NARE.KL=BOXC(NPNCE.K, (NCT.K), 8324,6503,30910, 19546, 13678,11825,4952,9801,13560, 14001) 20, R
 NARE - NUCLEAR ADDITION RATE- EAST (MW/YR)
 BOXC - FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)
 NPNCE - NEW PLANNED NUCLEAR CAPACITY- EAST (MW/YR)
 NCT - NUCLEAR CONSTRUCTION TIME (YRS)

In the case of nuclear it was estimated that the average time from planning to on-line capacity is currently to years but that with streamlined regulatory procedures and standardized plants this delay would be reduced to six years by 2000.

NCT.K=TABLE(TNCT,TIME.K,1970,2000,30) 21, A
 TNCT=10/6 21.1, T
 NCT - NUCLEAR CONSTRUCTION TIME (YRS)
 GEOCAPE.K=GEOCAPE.J+DT*(GARE.JK-GRRE.JK) 22, L
 GEOCAPE=0 22.1, N
 GEOCAPE - GEOTHERMAL CAPACITY- EAST (MW)
 GARE - GEOTHERMAL ADDITION RATE- EAST (MW/YR)
 GRRE - GEOTHERMAL RETIREMENT RATE- EAST (MW/YR)
 GRRE.KL=FIFGE((GEOCAPE.K/GRT.K),0,TIME.K,2025) 23, R
 GRRE - GEOTHERMAL RETIREMENT RATE- EAST (MW/YR)
 GEOCAPE - GEOTHERMAL CAPACITY- EAST (MW)
 GRT - GEOTHERMAL RETIREMENT TIME (YRS)

The lifetime of a geothermal plant built now is estimated to be about 40 years. It is estimated that this lifetime will increase because of technological advancements to 50 years by 2000.

GRT.K=TABLE(TGRR,TIME.K,1970,2000,15) 24, A
 TGRR=40/50/50 24.1, T
 GRT - GEOTHERMAL RETIREMENT TIME (YRS)
 GARE.KL=BOXC(NPGCE.K,3,0,0,0,0,0,0,0,0,0,0) 25, R
 GCT=3 25.1, C
 GARE - GEOTHERMAL ADDITION RATE- EAST (MW/YR)
 BOXC - FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)
 NPGCE - NEW PLANNED GEOTHERMAL CAPACITY- EAST (MW/YR)
 GCT - GEOTHERMAL CONSTRUCTION TIME (YRS)

The capacity of the transcontinental transmission lines, expressed in megawatts, and the installed capacity in solar power are calculated with the same procedures already described for coal.

IMPCAPE.K=IMPCAPE.J+DT*(IARE.JK) 26, L
 IMPCAPE=0 26.1, N
 IMPCAPE - IMPORT CAPACITY- EAST (MW)
 IARE - IMPORT ADDITION RATE- EAST (MW/YR)
 IARE.KL=BOXC(NPICE.K,6,0,0,0,0,0,0,0,0,0,0) 27, R
 ICT=6 27.1, C
 IARE - IMPORT ADDITION RATE- EAST (MW/YR)
 BOXC - FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)
 NPICE - NEW PLANNED ADDITIONAL IMPORT CAPACITY- EAST (MW/YR)
 ICT - IMPORT CONSTRUCTION TIME
 SCAPE.K=SCAPE.J+DT*(SARE.JK-SRRE.JK) 28, L
 SCAPE=0 28.1, N
 SCAPE - SOLAR CAPACITY- EAST (MW)
 SARE - SOLAR ADDITION RATE-EAST (MW/YR)
 SRRE - SOLAR RETIREMENT RATE- EAST (MW/YR)

SRRE.KL=SCAPE.K/SRT 29, R
 SRT=40 29.1, C
 SRRE - SOLAR RETIREMENT RATE- EAST (MW/YR)
 SCAPE - SOLAR CAPACITY- EAST (MW)
 SRT - SOLAR RETIREMENT TIME (YRS)

SARE.KL=BOXC(NPSCE.K,8,0,0,0,0,0,0,0,0,0) 30, R
 SCT=8 30.1, C
 SARE - SOLAR ADDITION RATE- EAST (MW/YR)
 BOXC - FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)
 NPSCE - NEW PLANNED SOLAR CAPACITY- EAST (MW/YR)
 SCT - SOLAR CONSTRUCTION TIME (YRS)

Hydroelectric and natural gas capacities in the East are supplied to the model as table functions. These projections are based, for gas, on National Electric Reliability Council [4] projections to 1982 and for hydro on FPC [3] projections to 1990 and extrapolated to 2010. These are shown in Figure E.1.4.

YEAR	EAST		WEST	
	NATURAL GAS	HYDRO-ELECTRIC	NATURAL GAS	HYDRO-ELECTRIC
1970	55	22	22	30
1975	43	21	19	35
1980	37	23	16	42
1985	30	25	13	47
1990	24	27	10	52
1995	20	30	9	55
2000	16	32	7	58
2005	14	34	6	61
2010	12	36	5	64

SOURCES: PROGRESS REPORTS OF THE REGIONAL ORGANIZATIONS TO THE EXECUTIVE BOARD OF NATIONAL ELECTRIC RELIABILITY COUNCIL (PRINCETON, N.J.: NERC, APRIL 1973); FEDERAL POWER COMMISSION.

Figure E.1.4 PROJECTED NATURAL GAS AND HYDROELECTRIC CAPACITIES (1000 MWe)

HCAPE.K=TABLE(THCAPE,TIME.K,1970,2010,5)*1E3 31, A
 THCAPE=21.9/20.2/23/25/27/30/32/34/36 31.1, T
 HCAPE - HYDRO CAPACITY- EAST (MW)
 NGCAPE.K=TABLE(TNGCAPE,TIME.K,1970,2010,5)* 32, A
 1E3
 TNGCAPE=55,42.7/37.1/30/24.4/20.4/16.2/14/ 32.1, T
 12
 NGCAPE - NATURAL GAS CAPACITY- EAST (MW)

Since neither natural gas or hydroelectric power expected to play a large role in new capacity additions in the East, estimates prepared by the Federal Power Commission were used to indicate the fraction of demand that is met through either of these sources.

Total planned capacity in the East is the sum of the planned capacities for each of the possible fuels for which the model calculates capacity planning.

PLCAPE.K=PCCE.K+PPCE.K+PNCE.K+PGCE.K+ 33, A
 PICE.K+PSCE.K
 PLCAPE - PLANNED CAPACITY- EAST (MW)

PCCE - PLANNED COAL CAPACITY- EAST (MW)
 PPCE - PLANNED PETROLEUM CAPACITY- EAST (MW)
 PNCE - PLANNED NUCLEAR CAPACITY- EAST (MW)
 PGCE - PLANNED GEOTHERMAL CAPACITY- EAST (MW)
 PICE - PLANNED IMPORT CAPACITY- EAST (MW)
 PSCE - PLANNED SOLAR CAPACITY- EAST (MW)

Total planned coal capacity in the East is a level that is increased by new planned capacity and decreased by capacity that is actually built.

PCCE.K=PCCE.J+DT*(APCCE.JK-CARE.JK+DAPCCE1.JK) 34, L
 PCCE=49.7E3 34.1, N

PCCE - PLANNED COAL CAPACITY- EAST (MW)
 APCCE - ADDITIONAL PLANNED COAL CAPACITY- EAST (MW/YR)
 CARE - COAL ADDITION RATE- EAST (MW/YR)
 DAPCCE1 - DELAYED ADDITIONAL PLANNED COAL CAPACITY- EAST (1) (MW/YR)

The initial value of planned coal capacity is the sum of all reported plans for new coal capacity by utility companies in the East. The total of planned capacity is reduced by the completion of new plants, which removes them from the status of planned plants. The level of planned capacity is increased by two kinds of new capacity planning. New planning is based on projections of the capacity gap ten years into the future. However, contracts for new coal plants need not be made ten years in advance, but since contracts for nuclear plants must be made ten years in advance (because of the initial ten-year delay from planning to on-line capacity for nuclear) a decision not to build a nuclear plant is, in effect, a final decision to sign a contract for new coal (or some other alternative) capacity at some time in the future. Therefore, planned coal capacity in the East is increased by APCCE, planned capacity for which construction is beginning immediately, and DAPCCE1, capacity for which construction will not begin immediately. (In the case of coal, construction of this capacity will begin in four years, so that with a six-year construction time it will be coming on-line in a total of ten years time.)

The coal capacity that will be contracted for immediately depends upon the part of the total capacity gap that will be filled by coal and the time required to build a coal plant.

APCCE.KL=IAPCCE.K*(CCT/PT) 35, R
 APCCE - ADDITIONAL PLANNED COAL CAPACITY- EAST (MW/YR)
 IAPCCE - INDICATED ADDITIONAL PLANNED COAL CAPACITY- EAST (MW/YR)
 CCT - COAL CONSTRUCTION TIME (YRS)
 PT - PROJECTION TIME (YRS)

Coal capacity which will actually be contracted for is equal to the amount of new coal capacity that will be needed in the next ten years (IAPCCE) multiplied by the ratio of the construction time for coal to the projection time (ten years).

The rest of the needed coal capacity is considered to be delayed planning.

DAPCCE1.KL=IAPCCE.K*(1-(CCT/PT)) 38, R
 DAPCCE1=0 38.1, N
 DAPCCE1 - DELAYED ADDITIONAL PLANNED COAL CAPACITY- EAST (1) (MW/YR)
 IAPCCE - INDICATED ADDITIONAL PLANNED COAL CAPACITY- EAST (MW/YR)
 CCT - COAL CONSTRUCTION TIME (YRS)
 PT - PROJECTION TIME (YRS)

This delayed planning is merely the fraction of needed new coal capacity that is not immediately put on contract. This planned capacity is delayed for four years and is then added to the newly planned capacity in that year to produce the total amount of new orders (NPCCE).

DAPCCE.K=BOXC(DAPCCE1.JK,(PT-CCT-2),0,0,0,0, 37, A
0,0,0,0,0,0)

DAPCCE - DELAYED ADDITIONAL PLANNED COAL
CAPACITY- EAST (MW/YR)
BOXC - FUNCTION THAT DELAYS VARIABLE (1)
FOR A PERIOD OF VARIABLE (2)
DAPCCE1 - DELAYED ADDITIONAL PLANNED COAL
CAPACITY- EAST (1) (MW/YR)
PT - PROJECTION TIME (YRS)
CCT - COAL CONSTRUCTION TIME (YRS)

NPCCE.K=IAPCCE.K*(CCT/PT)+DAPCCE.K 36, A

NPCCE - NEW PLANNED COAL CAPACITY-
EAST (MW/YR)
IAPCCE - INDICATED ADDITIONAL PLANNED
COAL CAPACITY- EAST (MW/YR)
CCT - COAL CONSTRUCTION TIME (YRS)
PT - PROJECTION TIME (YRS)
DAPCCE - DELAYED ADDITIONAL PLANNED COAL
CAPACITY- EAST (MW/YR)

The delay time in the BOXC function (PT-CCT-2) is two years for the case of coal (10-6-2), but actually works out to be four years because of the computational sequence involved in adding this planned capacity to installed capacity. (Two rates are involved which, in this case, cause an extra two years delay.)

The fraction of the needed new capacity that is coal capacity is dependent on the coal decision factor.

IAPCCE.K=MAX(0,(((CDF.K/TDFE.K)*TYCGE.K)+ 39, A
(CAFGSFE.K)))

IAPCCE - INDICATED ADDITIONAL PLANNED
COAL CAPACITY- EAST (MW/YR)
CDF - COAL DECISION FACTOR
(DIMENSIONLESS)
TDFE - TOTAL DECISION FACTOR- EAST
(DIMENSIONLESS)
TYCGE - TEN YEAR CAPACITY GAP- EAST
(MW/YR)
CAFGSFE - COAL ADJUSTMENT FOR GEOTHERMAL
SHORT FALL- EAST (MW/YR)

TDFE.K=CDF.K+PDF.K+NDF.K+GDFE.K+IDF.K+ 157, A
SDFE.K

TDFE - TOTAL DECISION FACTOR- EAST
(DIMENSIONLESS)
CDF - COAL DECISION FACTOR (DIMENSIONLESS)
PDF - PETROLEUM DECISION FACTOR (DIMENSION-
LESS)

NDF - NUCLEAR DECISION FACTOR
(DIMENSIONLESS)
GDFE - GEOTHERMAL DECISION FACTOR- EAST
(DIMENSIONLESS)
IDF - IMPORT DECISION FACTOR (DIMENSIONLESS)
SDFE - SOLAR DECISION FACTOR- EAST (DIMENSION-
LESS)

This decision mechanism is present in Figure 3.4.3 which is repeated here as Figure E.1.5. It shows the decision process for nuclear plants.

The coal decision factor (the total desirability of new coal plants) divided by the total decision factor in the East (the sum of the decision factors for all alternatives) yields the fraction of new capacity that the utilities would like to be coal. Multiplying this fraction by the ten-year capacity gap (the total amount of new capacity needed to supply demand in ten years) gives the amount of capacity, in megawatts, that should be coal plants. This number is increased, in some cases, if the amount of that capacity gap that was allocated to geothermal energy cannot be built (because of resource limitations). In that case, the amount of the shortfall that is allocated to coal depends again on the coal decision factor.

CAFGSFE.K=AFGSFE.K*(CDF.K/(CDF.K+PDF.K+ 40, A
NDF.K))

CAFGSFE - COAL ADJUSTMENT FOR GEOTHERMAL
SHORT-FALL- EAST (MW/YR)
AFGSFE - ADJUSTMENT FOR GEOTHERMAL SHORT-
FALL- EAST (MW/YR)
CDF - COAL DECISION FACTOR (DIMENSION-
LESS)
PDF - PETROLEUM DECISION FACTOR (DIMEN-
SIONLESS)
NDF - NUCLEAR DECISION FACTOR (DIMEN-
SIONLESS)

The amount of the shortfall allocated to coal is the total shortfall multiplied by the coal decision factor divided by the sum of the decision factors of the three fuels that are assumed to make up the shortfall: coal, petroleum, and nuclear.

The coal decision factor is based on six decision criteria: reliability, capital investment, environmental considerations, cost of electricity, fuel availability, and construction delay time.

CDF.K=RF*CR.K+CIF*CCI.K+ECF*CEC.K+CEF*CCE.K+ 41, A
FAF*CFA.K

CDF - COAL DECISION FACTOR (DIMENSIONLESS)
RF - RELIABILITY FACTOR (DIMENSIONLESS)
CR - COAL RELIABILITY (DIMENSIONLESS)
CIF - CAPITAL INVESTMENT FACTOR (DIMENSIONLESS)

Figure E.1.5 ALLOCATION OF NEW CAPACITY

CCI - COAL CAPITAL INVESTMENT (DIMENSION-
LESS)
ECF - ENVIRONMENTAL CONSIDERATION FACTOR
(DIMENSIONLESS)
CEC - COAL ENVIRONMENTAL CONSIDERATIONS
(DIMENSIONLESS)
CEF - COST OF ELECTRICITY FACTOR
(DIMENSIONLESS)
CCE - COAL COST OF ELECTRICITY (DIMEN-
SIONLESS)
FAF - FUEL AVAILABILITY FACTOR (DIMEN-
SIONLESS)
CFA - COAL FUEL AVAILABILITY (DIMEN-
SIONLESS)

CCI.K=GCIC.K/CCIC.K 43, A
CCI - COAL CAPITAL INVESTMENT (DIMENSION-
LESS)
GCIC - GEOTHERMAL CAPITAL INVESTMENT COST
(\$/KW)
CCIC - COAL CAPITAL INVESTMENT COST (\$/KW)

The actual capital cost of an average coal plant was estimated over time to the year 2010 and supplied to the model as a table function.

CCIC.K=TABLE(TCCIC,(TIME.K+10),1970,2010,5) 44, A
TCIC=240/359/550/615/662/713/768/828/892 44.1, T
CCIC - COAL CAPITAL INVESTMENT COST (\$/KW)

The decision process in the electric utility is assumed to rely mainly on these six criteria plus a consideration of the technology to develop the resource. Each of these factors is given a weight which corresponds to its importance in the final decision.

RF=.5 41.1, C
CIF=1 41.2, C
ECF=.6 41.3, C
CEF=1 41.4, C
FAF=2 41.5, C
CDLF=.1 41.6, C
RF - RELIABILITY FACTOR (DIMENSIONLESS)
CIF - CAPITAL INVESTMENT FACTOR (DIMEN-
SIONLESS)
ECF - ENVIRONMENTAL CONSIDERATION FACTOR
CEF - COST OF ELECTRICITY FACTOR (DIMEN-
SIONLESS)
FAF - FUEL AVAILABILITY FACTOR (DIMEN-
SIONLESS)
CDLF - CONSTRUCTION DELAY FACTOR (DIMEN-
SIONLESS)

These weights were assigned by the study team and were based on conversations with electric utility planners concerning the factors which they considered in selecting fuel mix, and the importance of those factors to their decisions.

The reliability of coal plants, when rated on a scale from 0 to 1 was assumed to go from .8 in 1970 to .7 in 1985. Figure E.1.6 shows the reliability estimates for all alternatives. (A discussion of this table is included in Section 3.4.)

CR.K=TABLE(TCR,TIME.K,1970,2000,15) 42, A
TCR=.8/.7/.7 42.1, T
CR - COAL RELIABILITY (Dimensionless)

YEAR	COAL	OIL	NUCLEAR	GEO- THERMAL	SOLAR	TRANS- CONTI- NENTAL GRID
1973	.8	.9	.6	.7	--	1
1985	.7	.9	.9	.7	.55	1
2000	.7	.9	.9	.8	.65	1

Figure E.1.6 ESTIMATES OF PERCEIVED PLANT RELIABILITY (THE SCALE IS FROM 0 TO 1, WITH 1 DENOTING THE MOST RELIABLE PLANTS)

The capital investment rating of coal is found by dividing the actual capital investment cost expected to prevail in ten years time, expressed in dollars per kilowatt, into the capital costs associated with the least expensive type of capacity, geothermal.

YEAR	COAL	OIL	NUCLEAR	GEO- THERMAL	SOLAR EAST	SOLAR WEST	TRANS- CONTI- NENTAL GRID
1973	240	220	354	264	--	--	--
1975	359	260	385	272	--	--	--
1980	550	299	615	292	--	--	--
1985	615	332	734	315	3000	1500	467
1990	662	358	791	339	2667	1334	503
1995	713	386	852	365	2334	1167	542
2000	768	416	918	394	2000	1000	583
2005	882	447	989	424	2000	1000	629
2010	892	482	1065	456	2000	1000	677

Figure E.1.7 CAPITAL COST PROJECTIONS (1973 DOLLARS/KW)

The environmental impacts of coal (as perceived by the electric utility) rated on a scale from 0 to 1 (with a value of 1 representing minimal impact) are assumed to vary from .5 in 1973 to .8 in 2000.

CEC.K=TABLE(TCEC,TIME.K,1970,2000,30) 45, A
TCEC=.5/.8 45.1 T
CEC - COAL ENVIRONMENTAL CONSIDERATIONS (DIMENSIONLESS)

The improvement of coal gasification technologies and stack scrubbers will tend to reduce the negative impacts of coal but many other problems will still remain (strip mining, for example). Figure E.1.8 presents the environmental impact estimates for all alternatives.

YEAR	COAL	OIL	NUCLEAR	GEO- THERMAL	SOLAR	TRANS- CONTI- NENTAL GRID
1973	.5	.7	.9	.75	.8	1
2000	.8	.85	.9	.9	.8	1

Figure E.1.8 ENVIRONMENTAL IMPACTS (THE SCALE IS FROM 0 to 1, WITH 1 DENOTING THE LEAST IMPACT ON THE ENVIRONMENT)

The total decision factor for coal is, therefore, found by multiplying the weight for each decision factor by the perceived value of that factor for these alternatives

and summing the products for all six decision factors. For example, for coal in the year 2000 the total decision value is found by summing the following products:

perceived coal reliability (.7) x reliability decision weight (.5) = 0.35
 perceived coal capital cost factor (.51) x capital cost decision weight (1) = 0.51
 perceived coal environmental impacts (.8) x environmental decision weight (.6) = 0.48
 perceived coal electrical cost factor (.46) x electrical cost decision weight (1) = 0.46
 perceived coal fuel availability (.95) x fuel availability decision weight (2) = 1.90
 perceived coal construction delay factor (.5) x construction delay decision weight (.1) = 0.05

The sum of these products, 3.75, is the total decision value for nuclear in 2000. Dividing the value by the total decision value for all possible alternatives in the year 2000, 21.6, for example, yields the amount of new capacity needs that will be met by new coal plants. In this case, one-fifth of the capacity gap will be filled with new coal plants.

The electricity cost of coal was estimated to the year 2010 and supplied to the model as a table function. The costs of electricity from each of the different sources are compared in Figure E.1.9.

CCE.K=ACGE.K/ACCE.K 46, A
 CCE - COAL COST OF ELECTRICITY (DIMENSIONLESS)
 ACGE - ACTUAL GEOTHERMAL COST OF ELECTRICITY (MILLS/KWHR)
 ACCE - ACTUAL COAL COST OF ELECTRICITY (MILLS/KWHR)
 ACCE.K=TABLE(TACCE,(TIME.K+10),1970,2010,5) 47, A
 TACCE=117/18/21/23.3/25.8/28.7/31.8/35.2/39.1 47.1 T
 ACCE - ACTUAL COST OF ELECTRICITY (MILLS/KWHR)

YEAR	COAL	OIL	NUCLEAR	GEO-THERMAL	SOLAR EAST	SOLAR WEST	TRANS-CONTINENTAL GRID
1973	12	21	12	7			14
1975	18	23	18	8			16
1980	21	27	19	9			18
1985	23	30	21	10			19
1990	26	33	23	12	196	98	21
1995	29	37	25	13	180	90	23
2000	32	42	27	14	180	90	26
2005	35	47	29	16	180	90	28
2010	39	53	32	18	180	90	31

Figure E.1.9 COST OF ELECTRICITY (MILLS/KWHR) (CONSTANT DECEMBER 1973 DOLLARS)

Here again the actual cost is divided into the actual cost of the least expensive electricity (geothermal, in this case) to produce an electricity cost factor between 0 and 1.

The fuel availability of coal (defined as the perceived likelihood that a plant built today will have coal available for the entire 40-year lifetime of the plant) was estimated to be .95, again on a scale of 0 to 1. The estimates for all fuels are presented in Figure E.1.10.

YEAR	COAL	OIL	NUCLEAR	GEO-THERMAL	SOLAR	TRANS-CONTINENTAL GRID
1973	.95	.75	1	.75	1	1
1985	.95	.4	.95	.75	1	1
2000	.95	.2	.95	.95	1	1

Figure E.1.10 PROJECTED PERCEIVED FUEL AVAILABILITY

CFA.K=TABLE(TCFA,TIME.K,1970,2000,30) 48, A
 TCFA=.95/.95 48.1, T
 CFA - COAL FUEL AVAILABILITY (DIMENSIONLESS)

The construction delay factor for coal is .5, found by dividing the delay time for coal plant construction (6 years) into the shortest construction delay (3 years for geothermal).

CDT=.5 48.2, C
 CDT - COAL DELAY TIME

The same calculational procedures are followed in determining the planned capacities of nuclear, petroleum, solar, and imports from the West. Therefore, the equations will simply be presented here and only the differences from the coal case will be discussed.

PPCE.K=PPCE.J+(APPCE.JK-PARE.JK+DAPPCE1.JK) 49, L
 PPCE=33.5E3 49.1, N

PPCE - PLANNED PETROLEUM CAPACITY- EAST (MW)
 PPCE - PLANNED PETROLEUM CAPACITY- EAST (MW)
 APPCE - ADDITIONAL PLANNED PETROLEUM CAPACITY- EAST (MW/YR)
 PARE - PETROLEUM ADDITION RATE- EAST (MW/YR)
 DAPPCE1 - DELAYED ADDITIONAL PLANNED PETROLEUM CAPACITY-EAST (1) (MW/YR)

APPCE.KL=(IAPPCE.K*(PCT/PT)) 50, R

APPCE - ADDITIONAL PLANNED PETROLEUM CAPACITY- EAST (MW/YR)
 IAPPCE - INDICATED ADDITIONAL PLANNED PETROLEUM CAPACITY- EAST (MW/YR)
 PCT - PETROLEUM CONSTRUCTION TIME (YRS)
 PT - PROJECTION TIME (YRS)

NPPCE.K=(IAPPCE.K*(PCT/PT))+DAPPCE.K 51, A

NPPCE - NEW PLANNED ADDITIONAL PETROLEUM CAPACITY- EAST (MW/YR)
 IAPPCE - INDICATED ADDITIONAL PLANNED PETROLEUM CAPACITY- EAST (MW/YR)
 PCT - PETROLEUM CONSTRUCTION TIME (YRS)
 PT - PROJECTION TIME (YRS)
 DAPPCE - DELAYED ADDITIONAL PLANNED PETROLEUM CAPACITY- EAST (MW/YR)

DAPPCE.K=BOXC(DAPPCE1.JK,(PT-PCT-2),0,0,0,0, 52, A
 0,0,0,0,0)

DAPPCE - DELAYED ADDITIONAL PLANNED PETROLEUM CAPACITY- EAST (MW/YR)

BOXC - FUNCTION THAT DELAYS VARIABLE (1)
FOR A PERIOD OF VARIABLE (2)
PCE1 - DELAYED ADDITIONAL PLANNED PETROLEUM
CAPACITY- EAST (1) (MW/YR)
PT - PROJECTION TIME (YRS)
PCT - PETROLEUM CONSTRUCTION TIME (YRS)

DAPPC1.KL=IAPPC.K*(1-(PCT/PT)) 53, R
DAPPC1=0 53.1,

DAPPC1 - DELAYED ADDITIONAL PLANNED
PETROLEUM CAPACITY- EAST (1)
(MW/YR)
IAPPC - INDICATED ADDITIONAL PLANNED
PETROLEUM CAPACITY- EAST (MW/YR)
PCT - PETROLEUM CONSTRUCTION TIME (YRS)
PT - PROJECTION TIME (YRS)

IAPPC.K=MAX(0, ((PDF.K/TDFE.K)*TYCGE.K)+
(PAFGSFE.K)) 54, A

IAPPC - INDICATED ADDITIONAL PLANNED
PETROLEUM CAPACITY-EAST (MW/YR)
PDF - PETROLEUM DECISION FACTOR
(DIMENSIONLESS)
TDFE - TOTAL DECISION FACTOR- EAST
(DIMENSIONLESS)
TYCGE - TEN YEAR CAPACITY GAP- EAST (MW/YR)
PAFGSFE - PETROLEUM ADJUSTMENT FOR GEOTHERMAL
SHORT-FALL- EAST (MW/YR)

PAFGSFE.K=AFGSFE.K*(PDF.K/(CDF.K+PDF.K+NDF.K)) 55, A

PAFGSFE - PETROLEUM ADJUSTMENT FOR GEOTHERMAL
SHORT-FALL- EAST (MW/YR)
AFGSFE - ADJUSTMENT FOR GEOTHERMAL SHORT-
FALL- EAST (MW/YR)
PDF - PETROLEUM DECISION FACTOR (DIMEN-
SIONLESS)
CDF - COAL DECISION FACTOR (DIMENSION-
LESS)
NDF - NUCLEAR DECISION FACTOR (DIMEN-
SIONLESS)

PDF.K=(RF*PR.K+CIF*PCI.K+ECF*PEC.K+CEF*PCE.K+
FAF*PFA.K)*PFAM.K 56, A

PDF - PETROLEUM DECISION FACTOR (DIMENSION-
LESS)
RF - RELIABILITY FACTOR (DIMENSIONLESS)
PR - PETROLEUM RELIABILITY (DIMENSIONLESS)
CIF - CAPITAL INVESTMENT FACTOR (DIMENSION-
LESS)
PCI - PETROLEUM CAPITAL INVESTMENT (DIMEN-
SIONLESS)
ECF - ENVIRONMENTAL CONSIDERATION FACTOR
(DIMENSIONLESS)
PEC - PETROLEUM ENVIRONMENTAL CONSIDERATIONS
(DIMENSIONLESS)
CEF - COST OF ELECTRICITY FACTOR (DIMEN-
SIONLESS)
PCE - PETROLEUM ELECTRICITY COST (DIMEN-
SIONLESS)
FAF - FUEL AVAILABILITY FACTOR (DIMENSION-
LESS)
PFA - PETROLEUM FUEL AVAILABILITY (DIMEN-
SIONLESS)
PFAM - PETROLEUM FUEL AVAILABILITY MULTI-
PLIER (DIMENSIONLESS)

In some cases one of the criteria involved in the deci-
sion concerning what type of capacity to build may
become so important that the other criteria have little
influence on the final decision. For example, if the
perceived fuel availability of a particular fuel ap-
proaches zero, no new plants are going to be built
requiring that fuel no matter how attractive it may
appear under the other criteria. Therefore, certain
limitations are set on some of the criteria. If the
value for any particular fuel falls below certain levels

that factor controls the decision. In the case of fuel
availability, for example, we assumed that if the per-
ceived fuel availability of any fuel were to drop below
.50 then no new capacity would be planned for that fuel.
This consideration comes into play in the case of petro-
leum. Thus, the petroleum fuel availability factor multi-
plies the decision factor by some number that varies from
0 to 1 as the perceived availability of petroleum varies
from .50 to .60. The petroleum decision factor may,
therefore, become zero if the perceived availability of
the fuel becomes very low.

PR.K=TABLE(TPR,TIME.K,1970,15) 57, A
TPR=.9/.9/.9 57.1, T
PR - PETROLEUM RELIABILITY (DIMEN-
SIONLESS)

PCIC.K=GCIC.K/PCIC.K 58, A

PCI - PETROLEUM CAPITAL INVESTMENT
(DIMENSIONLESS)
GCIC - GEOTHERMAL CAPITAL INVESTMENT
COST (\$/KW)
PCIC - PETROLEUM CAPITAL INVESTMENT COST
(\$/KW)

PCIC.K=TABLE(TPCIC,(TIME.K+10),1970,2010,5) 59, A
TPCIC=220/260/299/332/386/416/447/482 59.1, T
PCIC - PETROLEUM CAPITAL INVESTMENT
COST (\$/KW)

PEC.K=TABLE(TPEC,TIME.K,1970,2000,30) 60, A
TPEC=.7/.85 60.1, T
PEC - PETROLEUM ENVIRONMENTAL CONSI-
DERATIONS (DIMENSIONLESS)

PCE.K=AGCE.K/APCE.K 61, A

PCE - PETROLEUM ELECTRICITY COST (DIMEN-
SIONLESS)
AGCE - ACTUAL GEOTHERMAL COST OF ELEC-
TRICITY (MILLS/KWHR)
APCE - ACTUAL PETROLEUM ELECTRICITY COST
MILLS (MILLS/KWHR)

APCE.K=TABLE(TAPCE,(TIME.K+10),1970,2010,5) 62, A
TAPCE=21/22.7/26.6/33.4/37.5/42.0/47.1/52.8 62.1, T
APCE - ACTUAL PETROLEUM ELECTRICITY COST
(MILLS/KWHR)

PFA.K=TABLE(TPFA,TIME.K,1970,2000,15) 63, A
TPFA=.75/.4/.2 63.1, T
PFA - PETROLEUM FUEL AVAILABILITY
(DIMENSIONLESS)

PFAM.K=TABHL(TPFAM,PFA.K,.5,.6,.1) 64, A
TPFAM=0/1 64.1, T

PFAM - PETROLEUM FUEL AVAILABILITY
MULTIPLIER (DIMENSIONLESS)
PFA - PETROLEUM FUEL AVAILABILITY
PBT=.6 64.2, C
PDT - PETROLEUM DELAY TIME (DIMEN-
SIONLESS)

PNCE.K=PNCE.J+DT*(APNCE.JK-NARE.JK+
DAPNCE1.JK) 65, L

PNCE=183.6E3 65.1, N

PNCE - PLANNED NUCLEAR CAPACITY-
EAST (MW)
APNCE - ADDITIONAL PLANNED NUCLEAR
CAPACITY- EAST (MW/YR)
NARE - NUCLEAR ADDITION RATE- EAST (MR/YR)
DAPNCE1 - DELAYED ADDITIONAL PLANNED NUCLEAR
CAPACITY- EAST (1) (MW/YR)

APNCE.KL=(IAPNCE.K*(NCT.K/PT)) 66, R

APNCE - ADDITIONAL PLANNED NUCLEAR
CAPACITY- EAST (MW/YR)

IAPNCE - INDICATED ADDITIONAL PLANNED
NUCLEAR CAPACITY- EAST (MW/YR)
NCT - NUCLEAR CONSTRUCTION TIME (YRS)
PT - PROJECTION TIME (YRS)

NPNCE.K=(IAPNCE.K*(NCT.K/PT))+DAPNCE.K 67, A
NPNCE - NEW PLANNED NUCLEAR CAPACITY-
EAST (MW/YR)
IAPNCE - INDICATED ADDITIONAL PLANNED
NUCLEAR CAPACITY- EAST (MW/YR)
NCT - NUCLEAR CONSTRUCTION TIME (YRS)
PT - PROJECTION TIME (YRS)
DAPNCE - DELAYED ADDITIONAL PLANNED NUCLEAR
CAPACITY- EAST (MW/YR)

DAPNCE.K=BOXC(DAPNCE1.JK,(PT-NCT.K-2),0,0, 68, A
0,0,0,0,0,0,0)
DAPNCE - DELAYED ADDITIONAL PLANNED
NUCLEAR CAPACITY- EAST (MW/YR)
BOXC - FUNCTION THAT DELAYS VARIABLE (1)
FOR A PERIOD OF VARIABLE (2)
DAPNCE1 - DELAYED ADDITIONAL PLANNED NUCLEAR
CAPACITY- EAST (1) (MW/YR)
PT - PROJECTION TIME (YRS)
NCT - NUCLEAR CONSTRUCTION TIME (YRS)

DAPNCE1.KL=IAPNCE.K*(1-(NCT.K/PT)) 69, R
DAPNCE1=0 69.1, N
DAPNCE1 - DELAYED ADDITIONAL PLANNED
NUCLEAR CAPACITY- EAST (1) (MW/YR)
IAPNCE - INDICATED ADDITIONAL PLANNED
NUCLEAR CAPACITY- EAST (MW/YR)
NCT - NUCLEAR CONSTRUCTION TIME (YRS)
PT - PROJECTION TIME (YRS)

IAPNCE.K=MAX(0,((NDF.K/TDFE.K)*TYCGE.K)+ 70, A
(NAFGSFE.K))
IAPNCE - INDICATED ADDITIONAL PLANNED
NUCLEAR CAPACITY- EAST (MW/YR)
NDF - NUCLEAR DECISION FACTOR (DIMEN-
SIONLESS)
TDFE - TOTAL DECISION FACTOR- EAST
(DIMENSIONLESS)
TYCGE - TEN YEAR CAPACITY GAP- EAST
(MW/YR)
NAFGSFE - NUCLEAR ADJUSTMENT FOR GEOTHERMAL
SHORT-FALL- EAST (MW/YR)

NAFGSFE.K=AFGSFE.K*(NDF.K/(CDF.K+PDF.K+NDF.K)) 71, A
NAFGSFE - NUCLEAR ADJUSTMENT FOR GEOTHERMAL
SHORT-FALL- EAST (MW/YR)
AFGSFE - ADJUSTMENT FOR GEOTHERMAL SHORT-
FALL- EAST (MW/YR)
NDF - NUCLEAR DECISION FACTOR (DIMEN-
SIONLESS)
CDF - COAL DECISION FACTOR (DIMENSIONLESS)
PDF - PETROLEUM DECISION FACTOR (DIMEN-
SIONLESS)

NDF.K=RF*NR.K+CIF*NCI.K+ECF*NEC.K+CEF*NCE.K+ 72, A
FAF*NFA.K
NDF - NUCLEAR DECISION FACTOR (DIMENSIONLESS)
RF - RELIABILITY FACTOR (DIMENSIONLESS)
NR - NUCLEAR RELIABILITY (DIMENSIONLESS)
CIF - CAPITAL INVESTMENT FACTOR (DIMENSION-
LESS)
NCI - NUCLEAR CAPITAL INVESTMENT (DIMEN-
SIONLESS)
ECF - ENVIRONMENTAL CONSIDERATION FACTOR
(DIMENSIONLESS)
NEC - NUCLEAR ENVIRONMENTAL CONSIDERATIONS
(DIMENSIONLESS)
CEF - COST OF ELECTRICITY (DIMENSIONLESS)
NCE - NUCLEAR COST OF ELECTRICITY (DIMEN-
SIONLESS)
FAF - FUEL AVAILABILITY FACTOR (DIMENSION-
LESS)
NFA - NUCLEAR FUEL AVAILABILITY (DIMENSION-
LESS)

NR.K=TABLE(TNR,TIME.K,1970,2000,15)
TNR=.6/.9/.9
NR - NUCLEAR RELIABILITY (DIMENSIONLESS)

NCI.K=GCIC.K/NCIC.K 74, A
NCI - NUCLEAR CAPITAL INVESTMENT (DIMEN-
SIONLESS)
GCIC - GEOTHERMAL CAPITAL INVESTMENT COST(\$/KW)
NCIC - NUCLEAR CAPITAL INVESTMENT COST (\$/KW)

NCIC.K=TABLE(TNCIC,(TIME.K+10),1970,2010,5) 75, A
TNCIC=354/385/615/784/791/852/918/989/1065 75.1, T
NCIC - NUCLEAR CAPITAL INVESTMENT COST (\$/KW)

NEC.K=TABLE(TNEC,TIME.K,1970,2000,30) 76, A
TNEC=.9/.9 76.1, T
NEC - NUCLEAR ENVIRONMENTAL CONSIDERA-
TIONS (DIMENSIONLESS)

NCE.K=AGCE.K/ANCE.K 77, A
NCE - NUCLEAR COST OF ELECTRICITY
(DIMENSIONLESS)
AGCE - ACTUAL GEOTHERMAL COST OF ELEC-
TRICITY (MILLS/KWHR)
ANCE - ACTUAL NUCLEAR COST OF ELECTRICITY
(MILLS/KWHR)

ANCE.K=TABLE(TANCE,(TIME.K+10),1970,2010,5) 78, A
TANCE=12/18/19/20.9/22.9/24.9/27.0/29.4/32 78.1, T
ANCE - ACTUAL NUCLEAR COST OF ELECTRICITY
(MILLS/KWHR)

NFA.K=TABLE(TNFA,TIME.K,1970,2000,30) 79, A
TNFA=1/.95/.95 79.1, T
NFA - NUCLEAR FUEL AVAILABILITY
(DIMENSIONLESS)

NDT.K=GCT/NCT.K 80, A
NDT - NUCLEAR DELAY TIME (YEARS)
GCT - GEOTHERMAL CONSTRUCTION TIME
(YEARS)
NCT - NUCLEAR CONSTRUCTION TIME (YEARS)

PICE.K=PICE.J+DT*(APICE.JK-IARE.JK+ 114, L
DAPICE1.JK)
PICE=0 114.1, N
PICE - PLANNED IMPORT CAPACITY- EAST
(MW)
APICE - ADDITIONAL PLANNED IMPORT
CAPACITY- EAST (MW/YR)
IARE - IMPORT ADDITION RATE- EAST
(MW/YR)
DAPICE1 - DELAYED ADDITIONAL PLANNED IMPORT
CAPACITY- EAST (1) (MW/YR)

APICE.KL=MAX(0,((IDF.K/TDFE.K)*TYCGE.K/ 115, R
(PT/ICT)))
APICE - ADDITIONAL PLANNED IMPORT
CAPACITY- EAST (MW/YR)
IDF - IMPORT DECISION FACTOR (DIMEN-
SIONLESS)
TDFE - TOTAL DECISION FACTOR- EAST
(DIMENSIONLESS)
TYCGE - TEN YEAR CAPACITY GAP- EAST (MW/YR)
PT - PROJECTION TIME (YRS)
ICT - IMPORT CONSTRUCTION TIME
TDFE - TOTAL DECISION FACTOR- EAST
(DIMENSIONLESS)
TYCGE - TEN YEAR CAPACITY GAP- EAST (MW/YR)
PT - PROJECTION TIME (YRS)
ICT - IMPORT CONSTRUCTION TIME

NPICE.K=(IDF.K/TDFE.K)*TYCGE.K*(ICT/PT)+ 116, A
DAPICE2.K
NPICE - NEW PLANNED ADDITIONAL IMPORT
CAPACITY- EAST (MW/YR)
IDF - IMPORT DECISION FACTOR
(DIMENSIONLESS)

TDFE - TOTAL DECISION FACTOR- EAST
(DIMENSIONLESS)
TYCGE - TEN YEAR CAPACITY GAP- EAST
(MW/YR)
ICT - IMPORT CONSTRUCTION TIME
PT - PROJECTION TIME (YRS)
DAPICE2 - DELAYED ADDITIONAL PLANNED
IMPORT CAPACITY- EAST (2)
(MW/YR)

DAPICE2.K=BOXC(DAPICE1.JK,(PT-ICT-2),0,0,0, 117, A
0,0,0,0,0,0,0)

DAPICE2 - DELAYED ADDITIONAL PLANNED
IMPORT CAPACITY- EAST (2)
(MW/YR)
BOXC - FUNCTION THAT DELAYS VARIABLE
(1) FOR A PERIOD OF VARIABLE (2)
DAPICE1 - DELAYED ADDITIONAL PLANNED
IMPORT CAPACITY- EAST (1)
(MW/YR)
PT - PROJECTION TIME (YRS)
ICT - IMPORT CONSTRUCTION TIME

DAPICE1.KL=(IDF.K/TDFE.K)*TYCGE.K*(1- 118, R
(ICT/PT))

DAPICE1=0 118.1, N

DAPICE1 - DELAYED ADDITIONAL PLANNED
IMPORT CAPACITY- EAST (1)
(MW/YR)
IDF - IMPORT DECISION FACTOR
(DIMENSIONLESS)
TDF - TOTAL DECISION FACTOR- EAST
(DIMENSIONLESS)
TYCGE - TEN YEAR CAPACITY GAP- EAST
(MW/YR)
ICT - IMPORT CONSTRUCTION TIME
PT - PROJECTION TIME (YRS)

Since at the present time there is no transcontinental electric grid, eastern utilities cannot now choose to import power from the West. Therefore the decision factor for imports is initially set equal to zero. It becomes non-zero only when some sort of intercontinental grid is established. It was assumed in this model that planning for such a grid would commence around 1985. Thus, the import decision factor is zero until 1985, after which time it is calculated as are the decision factors for the other alternatives. There is one further limitation on imports of power by the East. Since the East can hardly expect a major portion of its power to be generated in the West and then delivered by a transcontinental grid, imports are limited to 5 percent of total demand. The total decision factor for imports is, then, the indicated decision factor multiplied by a factor that ensures that the total import capacity will not exceed 5 percent of total capacity in the East.

IDF.K=FIFGE(IIDF.K,0,TIME.K,IMPYEAR)* 119, A
POSDFM.K
IMPYEAR=1985 119.1, C
IDF - IMPORT DECISION FACTOR
(DIMENSIONLESS)
POSDFM - POSSIBLE DECISION FACTOR MULTI-
PLIER
IIDF - INDICATED IMPORT DECISION FACTOR
(DIMENSIONLESS)
IMPYEAR- IMPORT START YEAR (YRS)

FIFGE is a DYNAMO function that returns the first argument if the third is greater than or equal to the fourth. Otherwise the second argument is returned.

POSDFM.K=TABHL(TPOSDFM,IMPR.K,0,.05,.005) 120, A
TPOSDFM=1/1/1/1/1/.9/.7/.5/.3/1/0 120.1, T

POSDFM - POSSIBLE DECISION FACTOR
MULTIPLIER (DIMENSIONLESS)
IMPR - IMPORT RATIO (DIMENSIONLESS)

The decision factor multiplier depends on the import ratio. As this ratio approaches 5 percent the multiplier approaches zero.

The import ratio is calculated as the sum of present and planned import capacity divided by total present and planned capacity in the East.

IMPR.K=(IMPCAPE.K+PICE.K)/PAPSE.K 121, A
IMPR - IMPORT RATIO (DIMENSIONLESS)
IMPCAPE - IMPORT CAPACITY -EAST (MW)
PICE - PLANNED IMPORT CAPACITY -EAST (MW)
PAPSE - PRESENT AND PLANNED SUPPLY - EAST
(MW/YR)

Imports are assumed to come from geothermal plants in the West. Therefore, if geothermal resources are not available in the West no new import capacity can be planned. The import decision factor is, then, equal to zero if the geothermal shortfall in the West is positive (indicating an excess of demand over available resources).

IIDF.K=FIFGE(0,IIDF1.K,GEOSFWL.JK,0) 122, A
IIDF - INDICATED IMPORT DECISION FACTOR
(DIMENSIONLESS)
IIDF1 - INDICATED IMPORT DECISION FACTOR 1
(DIMENSIONLESS)
GEOSFWL - GEOTHERMAL SHORT-FALL -WEST LAST
TIME PERIOD (MW/YR)

If geothermal resources are available in the West it is necessary to determine if there is enough resource to satisfy the demand for imported energy by the East.

IIDF1.K=FIFGE((-1*GEOSFWL.JK*TDFEL.JK/TYCGE.K), 123, A
IIDF2.K;(IIDF2.K*TYCGE.K/TDFEL.JK),
(-1*GEOSFWL.JK))
IIDF1 - INDICATED IMPORT DECISION
FACTOR 1 (DIMENSIONLESS)
GEOSFWL - GEOTHERMAL SHORT-FALL- WEST LAST
TIME PERIOD (MW/YR)
TDFEL - TOTAL DECISION FACTOR- EAST LAST
TIME PERIOD (DIMENSIONLESS)
TYCGE - TEN YEAR CAPACITY GAP- EAST
(MW/YR)
IIDF2 - INDICATED IMPORT DECISION FACTOR
2 (DIMENSIONLESS)

The amount of new import capacity desired by the East will be the total capacity gap to be filled (TYCGE) multiplied by the ratio of the indicated import decision factor (IIDF2) and the total decision factor in the East (TDFEL - the total decision factor in the last time period). If this amount (the third argument in the FIFGE function for IIDF1.K) is greater than or equal to the amount of geothermal resources available in the West (-1*GEOSFWL) then sufficient resources are not available and a new decision value must be calculated for imports. This new value is the first argument of the FIFGE function and was determined in the following manner:

If resources are available, the amount of new capacity to be planned (IAPICE) is the total capacity gap (TYCGE) times the ratio of the import decision factor (IIDF2) to the total decision factor (TDFEL), or

IAPICE=TYCGE(IIDF2/TDFEL)

If geothermal resources are limiting, the amount to be planned (IAPICE) is replaced by the amount actually available (GEOSFWL) and the equation is solved for the decision factor IIDF2. Thus,

$$IIDF2 = (GEOSFWL * TDFEL) / TYCGE$$

This expression is the first argument in the FIFGE function for IIDF1.K. If resources are not limiting (the third argument is less than the fourth), the decision factor is simply equal to the indicated decision factor (IIDF2). This variable (IIDF2) is calculated in the same manner that the decision factors are computed for all other generating alternatives.

$$IIDF2.K = (RF * IMR.K + CIT * ICI.K + EFC * IEC.K + CEF * ICE.K + FAF * IFA.K) * ILF.K \quad 124, A$$

IIDF2 - INDICATED IMPORT DECISION FACTOR 2 (DIMENSIONLESS)

RF - RELIABILITY FACTOR (DIMENSIONLESS)

IMR - IMPORT RELIABILITY (DIMENSIONLESS)

CIT - CAPITAL INVESTMENT FACTOR (DIMENSIONLESS)

ICI - IMPORT CAPITAL INVESTMENT (DIMENSIONLESS)

EFC - ENVIRONMENTAL CONSIDERATION FACTOR (DIMENSIONLESS)

IEC - IMPORT ENVIRONMENTAL CONSIDERATIONS (DIMENSIONLESS)

CEF - COST OF ELECTRICITY (DIMENSIONLESS)

ICE - IMPORT COST OF ELECTRICITY (DIMENSIONLESS)

FAF - FUEL AVAILABILITY FACTOR (DIMENSIONLESS)

IFA - IMPORT FUEL AVAILABILITY (DIMENSIONLESS)

ILF - IMPORT LEARNING FACTOR (DIMENSIONLESS)

In order to account for the fact that many companies are slow to accept new technologies, a learning factor has been introduced into the calculations of the import decision factor.

$$ILF.K = TABHL(TLF, TIME.K, 1985, 1995, 1) \quad 125, A$$

$$TLF = 0.04 / .10 / 18 / .30 / .50 / .70 / .82 / .90 / .96 / 1.0$$

ILF - IMPORT LEARNING FACTOR (DIMENSIONLESS)

This learning factor multiplies the import decision factor by a number that is initially zero, in the first year of planning for imports, and increases to one by the tenth year.

$$IMR.K = TABLE(TIMR, TIME.K, 1970, 2000, 30) \quad 126, A$$

$$TIME = 1 / 1 \quad 126.1, T$$

IMR - IMPORT RELIABILITY (DIMENSIONLESS)

GCIC - GEOTHERMAL CAPITAL INVESTMENT COSTS (DIMENSIONLESS)

$$ICI.K = CCIC.K / ICIC.K \quad 127, A$$

ICI - IMPORT CAPITAL INVESTMENT (DIMENSIONLESS)

GCIC - GEOTHERMAL CAPITAL INVESTMENT COSTS (DIMENSIONLESS)

$$ICIC.K = TABLE(TICIC, (TIME.K + 10), 1970, 2010, 5) \quad 128, A$$

$$TICIC = 391 / 403 / 433 / 467 / 503 / 542 / 583 / 629 / 677 \quad 128.1, T$$

ICIC - IMPORT CAPITAL INVESTMENT COST (\$/KW)

$$IEC.K = TABLE(TIEC, TIME.K, 1970, 2000, 15) \quad 129, A$$

$$TIEC = 1 / 1 \quad 129.1, T$$

IFA - IMPORT ENVIRONMENTAL CONSIDERATIONS (DIMENSIONLESS)

$$ICE.K = ACGE.K / AICE.K$$

ICE - IMPORT CAPACITY- EAST (IMW)

ACGE - ACTUAL GEOTHERMAL COST OF ELECTRICITY- EAST (MILLS/KWH)

AICE - ACTUAL IMPORT COST OF ELECTRICITY- EAST (MILLS/KWH)

$$AICE.K = TABLE(TAIC, (TIME.K + 10), 1970, 2010, 5) \quad 131, A$$

$$TAIC = 14.5 / 16.3 / 17.6 / 19.3 / 21.2 / 23.3 / 25.7 / 28.3 / 31.1$$

AICE - ACTUAL IMPORT COST OF ELECTRICITY- EAST (MILLS/KWH)

$$IFA.K = TABLE(TIFA, TIME.K, 1970, 2000, 15) \quad 132, A$$

$$TIFA = 1 / 1 / 1$$

$$IDT = .5$$

IFA - IMPORT FUEL AVAILABILITY (DIMENSIONLESS)

IDT - IMPORT DELAY TIME (DIMENSIONLESS)

$$PSCE.K = PSCE.J + DT * (APSCE.JK - SARE.JK + DAPSCE1.JK) \quad 133, L$$

$$PSCE = 0$$

PSCE - PLANNED SOLAR CAPACITY- EAST (MW)

APSCE - ADDITIONAL PLANNED SOLAR CAPACITY- EAST (MW)

SARE - SOLAR ADDITION RATE- EAST (MW/YR)

DAPSCE1 - DELAYED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (1) (MW/YR)

$$APSCE.KL = (IAPSCE.K * (SCT / PT)) \quad 134, R$$

APSCE - ADDITIONAL PLANNED SOLAR CAPACITY- EAST (MW)

IAPSCE - INDICATED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (MW/YR)

SCT - SOLAR CONSTRUCTION TIME (YRS)

PT - PROJECTION TIME (YRS)

$$NPSCE.K = (IAPSCE.K * (SCT / PT)) + DAPSCE.K \quad 135, A$$

NPSCE - NEW PLANNED SOLAR CAPACITY- EAST (MW/YR)

IAPSCE - INDICATED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (MW/YR)

SCT - SOLAR CONSTRUCTION TIME (YRS)

PT - PROJECTION TIME (YRS)

DAPSCE - DELAYED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (MW/YR)

$$DAPSCE.K = BOXC(DAPSCE1.JK, (PT - SCT - 2), 0, 0, 0, 0, 0, 0, 0, 0, 0) \quad 136, A$$

DAPSCE - DELAYED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (MW/YR)

BOXC - FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)

DAPSCE1 - DELAYED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (1) (MW/YR)

PT - PROJECTION TIME (YRS)

SCT - SOLAR CONSTRUCTION TIME (YRS)

$$DAPSCE1.KL = IAPSCE.K * (1 - (SCT / PT)) \quad 137, R$$

$$DAPSCE1 = 0$$

DAPSCE1 - DELAYED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (1) (MW/YR)

IAPSCE - INDICATED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (MW/YR)

SCT - SOLAR CONSTRUCTION TIME (YRS)

PT - PROJECTION TIME (YRS)

$$IAPSCE.K = MAX(0, ((SDFE.K / TDFE.K) * TYCGE.K)) \quad 138, A$$

IAPSCE - INDICATED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (MW/YR)

SDFE - SOLAR DECISION FACTOR- EAST (DIMENSIONLESS)

TDFE - TOTAL DECISION FACTOR- EAST (DIMENSIONLESS)

TYCGE - TEN YEAR CAPACITY GAP- EAST
(MW/YR)

Central station solar generating plants were estimated to first come on-line around 1995. Thus, the solar decision factor is equal to zero until 1987. In 1987 the first solar plants are planned. They come on-line in 1995 after an eight-year planning and construction delay period.

The decision factor for solar is different for the East and the West. This difference arises from the already mentioned fact that the cost of electricity and the capital costs are different for solar plants in the West and in the East. A separate decision factor is, therefore, calculated for solar for conditions prevailing in the East and for those prevailing in the West. In both cases a cost of electricity multiplier is included in the calculation of the decision factor. This multiplier has the effect of stopping all new planning in solar plants if the cost of electricity generated by those plants becomes extremely high. If the cost of electricity, expressed as a number from 0 to 1 (with 1 representing the least cost) falls below .06, the total solar decision factor goes to zero.

SFDE.K=FIFGE(ISDFE.K, TIME.K, SDT) 139, A
SDFE - SOLAR DIMENSION FACTOR- EAST (DIMENSIONLESS)
ISDFE - INDICATED SOLAR DECISION FACTOR- EAST (DIMENSIONLESS)
SDT - SOLAR DELAY TIME (YRS)

SDFW.K=FIFGE(ISDEW.K, TIME.K, SAT) 140, A
SAT=1987 140.1, C
SDFW - SOLAR DECISION FACTOR- WEST (DIMENSIONLESS)
ISDFW - INDICATED SOLAR DECISION FACTOR (DIMENSIONLESS)
SAT - SOLAR AVAILABILITY TIME (HRS)

ISDFE.K=PF*SR.K+CIF*SCI.K+ECF*SEC.K+CEF*SCEE.K+FAF.K*SFAE.K+CDLF*SDT)*SLF.K*SCEEL.K 141, A
ISDFE - INDICATED SOLAR DECISION FACTOR- EAST (DIMENSIONLESS)
RF - RELIABILITY FACTOR (DIMENSIONLESS)
SR - SOLAR RELIABILITY (DIMENSIONLESS)
CIF - CAPITAL INVESTMENT FACTOR (DIMENSIONLESS)
SCI - SOLAR CAPITAL INVESTMENT (DIMENSIONLESS)
ECF - ENVIRONMENTAL CONSIDERATION FACTOR (DIMENSIONLESS)
SEC - SOLAR ENVIRONMENTAL CONSIDERATION (DIMENSIONLESS)
CEF - COST OF ELECTRICITY FACTOR (DIMENSIONLESS)
SCEE - SOLAR COST OF ELECTRICITY- EAST (DIMENSIONLESS)
FAF - FUEL AVAILABILITY FACTOR (DIMENSIONLESS)
SFAE - SOLAR FUEL AVAILABILITY- EAST (DIMENSIONLESS)
SLF - SOLAR COST OF ELECTRICITY- EAST LIMITATION (DIMENSIONLESS)
SCEEL - SOLAR COST OF ELECTRICITY- EAST LIMITATION (DIMENSIONLESS)
CDLF - CONSTRUCTION DELAY FACTOR (DIMENSIONLESS)
SDT - SOLAR DELAY FACTOR (DIMENSIONLESS)

ISDFW.K=RF*SR.K+CIF*SCI.K+ECF*SEC.K+CEF*SCEE.K+FAF.K*SFAE.K+CDLF*SDT)*SLF.K*SCEWL.K 142, A
ISDFW - INDICATED SOLAR DECISION FACTOR- WEST (DIMENSIONLESS)
RF - RELIABILITY FACTOR (DIMENSIONLESS)
SR - SOLAR RELIABILITY (DIMENSIONLESS)
CIF - CAPITAL INVESTMENT FACTOR (DIMENSIONLESS)
SCI - SOLAR CAPITAL INVESTMENT (DIMENSIONLESS)
ECF - ENVIRONMENTAL CONSIDERATION FACTOR (DIMENSIONLESS)
SEC - SOLAR ENVIRONMENTAL CONSIDERATION (DIMENSIONLESS)
CEF - COST OF ELECTRICITY FACTOR (DIMENSIONLESS)
SCEE - SOLAR COST OF ELECTRICITY- WEST (DIMENSIONLESS)
FAF - FUEL AVAILABILITY FACTOR (DIMENSIONLESS)
SFAE - SOLAR FUEL AVAILABILITY- WEST (DIMENSIONLESS)
SLF - SOLAR LEARNING FACTOR (DIMENSIONLESS)
SCEWL - SOLAR COST OF ELECTRICITY- WEST LIMITATION (DIMENSIONLESS)
CDLF - CONSTRUCTION DELAY FACTOR (DIMENSIONLESS)
SDT - SOLAR DELAY TIME (YRS)

SLF.K=TABHL(TSLF, TIME.K, 1985, 1994, 1) 143, A
TSLF=.1/.2/.3/.4/.5/.6/.7/.8/.9/1.0 143.1, T
SLF - SOLAR LEARNING FACTOR (DIMENSIONLESS)

SR.K=TABLE(TSR, TIME.K, 1985, 2000, 10) 144, A
TSR=.55/.65 144.1, T
SR - SOLAR RELIABILITY (DIMENSIONLESS)

SCIE.K=GCIC.K/SCICE.K 145, A
SCIE - SOLAR CAPITAL INVESTMENT- EAST (DIMENSIONLESS)
GCIC - GEOTHERMAL CAPITAL INVESTMENT COST (\$/KW)
SCICE - SOLAR CAPITAL INVESTMENT COST- EAST (\$/KW)

SCICE.K=TABHL(TSCICE, (TIME.K+10), 1985, 2000, 15) 146, A
TSCICE=3000/2000 146.1, T
SCICE - SOLAR CAPITAL INVESTMENT COST- EAST (\$/KW)

SCIW.K=GCIC.K/SCICW.K 147, A
SCIW - SOLAR CAPITAL INVESTMENT- WEST (DIMENSIONLESS)
GCIC - GEOTHERMAL CAPITAL INVESTMENT COST (\$/KW)
SCICW - SOLAR CAPITAL INVESTMENT COST (\$/KW)

SCICW.K=TABHL(TSCICW, (TIME.K+10), 1985, 2000, 15) 148, A
TSCICW=1500/1000 148.1, T
SCICW - SOLAR CAPITAL INVESTMENT COST- WEST (\$/KW)

SEC.K=TABLE(TSEC, TIME.K, 1970, 2000, 30) 149, A
TSEC=.8/.8 149.1, T
SEC - SOLAR ENVIRONMENTAL CONSIDERATIONS (DIMENSIONLESS)

SCEE.K=ACGE.K/ASCEE.K 150, A
SCEE - SOLAR COST OF ELECTRICITY- EAST (DIMENSIONLESS)
ASCE - ACTUAL GEOTHERMAL COST OF ELECTRICITY (MILLS/KWHR)
ASCEE - ACTUAL SOLAR COST OF ELECTRICITY- EAST (MILLS/KWHR)

ASCEE.K=TABLE(TASCEE, (TIME.K+10), 1970, 2000, 5) 151, A
 TASCEE=400/400/400/400/196/180/180 151.1, T
 ASCEE - ACTUAL SOLAR COST OF ELECTRICITY- EAST (MILLS/KWHR)

SCEEL.K=TABHL(TSCEEL, SCEE.K, 0, .16, .02) 152, A
 TSCEEL=0/0/0/0/.2/.4/.6/.8/1 152.1, T
 SCEEL - SOLAR COST OF ELECTRICITY- EAST LIMITATION (DIMENSIONLESS)
 SCEE - SOLAR COST OF ELECTRICITY- EAST (DIMENSIONLESS)

SCEW.K=AGCE.K/ASCEW.K 153, A
 SCEW - SOLAR COST OF ELECTRICITY- WEST (DIMENSIONLESS)
 AGCE - ACTUAL GEOTHERMAL COST OF ELECTRICITY (MILLS/KWHR)
 ASCEW - ACTUAL SOLAR COST OF ELECTRICITY- WEST (MILLS/KWHR)

ASCEW.K=TABHL(TASCEW, (TIME.K+10), 1990, 2000, 5) 154, A
 TASCEW=98/90/90 154.1, T
 ASCEW - ACTUAL SOLAR COST OF ELECTRICITY- WEST (MILLS/KWHR)

SCEWL.K=TABHL(TSCEEL, SCEW.K, 0, .16, .20) 155, A
 SCEWL - SOLAR COST OF ELECTRICITY- WEST LIMITATION (DIMENSIONLESS)
 SFEW - SOLAR FUEL AVAILABILITY- WEST (DIMENSIONLESS)

SFAW.K=TABLE(TSFAW, TIME.K, 1970, 2000, 30) 156, A
 TSFAW=1/1 156.1, T
 SFAW - SOLAR FUEL AVAILABILITY- WEST (DIMENSIONLESS)

Planned geothermal capacity is a level that is decreased by capacity that is retired and is increased by three types of new planning, additional planned geothermal capacity- East (APGCE) and delayed additional planned geothermal capacity- East (1 and 2) (DAPGCE1 and DAPGCE2).

PGCE.K=PGCE.J+DT*(APGCE.JK-GARE.JK+ DAPGCE1.JK+DAPGCE2.JK) 81, L
 PGCE=0 81.1, N
 PGCE - PLANNED GEOTHERMAL CAPACITY- EAST (MW)
 APGCE - ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (MW/YR)
 GARE - GEOTHERMAL ADDITION RATE- EAST (MW/YR)
 DAPGCE1 - DELAYED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (2) (MW/YR)

Additional planned geothermal capacity- East (APGCE) is normally equal to indicated additional planned geothermal capacity- East (IAPGCE) (which is calculated in the same way that indicated additional planned capacity is calculated for the other fuels). However, in some cases there may not be enough geothermal resources available to fill the demand for new geothermal capacity.

In this case, the amount of new geothermal capacity that is indicated is reduced by the ratio of the available resources (GRAFCAE) to the amount of new capacity that is desired (INPGCE).

APGCE.KL=IAPGCE.K*(MIN(1, (GRAFCAE.K/ INPGCE.K))) 82, R
 APGCE=0 82.1, N

APGCE - ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (MW/YR)
 IAPGCE - INDICATED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (MW/YR)
 GRAFCAE - GEOTHERMAL RESOURCES AVAILABLE FOR CAPACITY ADDITION- EAST (MW/YR)
 INPGCE - INDICATED NEW PLANNED GEOTHERMAL CAPACITY- EAST (MW/YR)

This equation ensures that new capacity additions will not exceed the geothermal resources that are available.

Indicated additional planned geothermal capacity- East (IAPGCE) is equal to IAPGCE1 (the amount of new capacity that will be geothermal as indicated by the ratio of the geothermal decision factor to the total decision factor for all types of generation) multiplied by the time necessary to construct a geothermal plant divided by the projection time.

IAPGCE.K=(IAPGCE1.K*(GCT/PT)) 83, A
 IAPGCE - INDICATED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (MW/YR)
 IAPGCE1 - INDICATED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (1) (MW/YR)
 GCT - GEOTHERMAL CONSTRUCTION TIME (YRS)
 PT - PROJECTION TIME (YRS)

IAPGCE1.K=MAX(0, ((GDFE.K/TDFE.K)*TYCGE.K)) 90, A
 IAPGCE1 - INDICATED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (1) (MW/YR)
 GDFE - GEOTHERMAL DECISION FACTOR- EAST (DIMENSIONLESS)
 TDFE - TOTAL DECISION FACTOR- EAST (DIMENSIONLESS)
 TYCGE - TEN YEAR CAPACITY GAP- EAST (MW/YR)

Thus, the amount of new capacity that is needed to meet expected demand in ten years is multiplied by the ratio of the geothermal decision factor to the total decision factor for all fuels to yield the amount of geothermal capacity that should be built during the next ten years. Since it takes only three years to build a geothermal plant, it is not necessary to begin construction on the entire amount of capacity that will be needed in ten years. Rather, construction should begin immediately on only one-third of the capacity that will be needed. Construction can begin on the second third in three years and on the last third in seven years. In this manner the entire amount will be available in ten years to meet expected demand. The amount of construction that should begin in three years (DAPGCE1) is simply the indicated total amount needed (IAPGCE1) multiplied by GCT/PT, or one-third, again adjusted for the resource availability should desired additions exceed the amount of resources available.

DAPGCE1.KL=IAPGCE1.K*(GCT/PT)*(MIN(1, RAME.K)) 88, R
 DAPGCE1=0 88.1, N
 DAPGCE1 - DELAYED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (1) (MW/YR)
 IAPGCE1 - INDICATED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (1) (MW/YR)
 GCT - GEOTHERMAL CONSTRUCTION TIME (YRS)
 PT - PROJECTION TIME (YRS)
 RAME - RESOURCE AVAILABILITY MULTIPLIER- EAST (DIMENSIONLESS)

INPGCE - INDICATED NEW PLANNED GEOTHERMAL CAPACITY- EAST (MW/YR)

The amount of construction that should begin in seven years (DAPGCE2) is the total amount needed minus what is being built immediately minus what will be built in three years, again adjusted for resource availability.

DAPGCE2.KL=(IAPGCE1.K-(IAPGCE1.K*2*GCT/PT)) 89, R
*(MIN(1,RAME.K))
DAPGCE2=0 89.1, N
DAPGCE2 - DELAYED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- EAST
(MW/YR)
IAPGCE1 - INDICATED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- EAST
(1) (MW/YR)
GCT - GEOTHERMAL CONSTRUCTION TIME
(YRS)
PT - PROJECTION TIME (YRS)
RAME - RESOURCE AVAILABILITY MULTI-
PLIER- EAST (DIMENSIONLESS)

The total amount of new construction that will be beginning at any one particular time is, therefore, the sum of the planning from three different periods. The amount of new capacity to be begun in 1980, for example, will be the sum of new capacity planned in 1980 to begin immediately (one-third the total amount of new capacity needs allocated to geothermal) plus capacity that was planned three years earlier, in 1977, to begin after a three-year delay plus the capacity that was planned in 1973 to begin seven years later (as long as that sum is less than or equal to the total geothermal resources available at that time).

NPGCE.K=IAPGCE.K*(MIN(1,RAME.K))+DAPGCE.K 84, A
NPGCE - NEW PLANNED GEOTHERMAL
CAPACITY- EAST (MW/YR)
IAPGCE - INDICATED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- EAST
(MW/YR)
DAPGCE - DELAYED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- EAST
(MW/YR)
RAME - RESOURCE AVAILABILITY MULTI-
PLIER- EAST (DIMENSIONLESS)

The indicated newly planned geothermal capacity (INPGCE) is the same as NPGCE with the exception that it indicates that amount of new capacity that would be planned if there were no resource restriction, while NPGCE is corrected for resource restrictions, if any exist.

INPGCE.K=MAX(.01,((IAPGCE1.K*(GCT/PT)) 86, A
+DAPGCE.K))
INPGCE - INDICATED NEW PLANNED GEO-
THERMAL CAPACITY-EAST (MW/YR)
IAPGCE1 - INDICATED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- EAST
(1) (MW/YR)
GCT - GEOTHERMAL CONSTRUCTION TIME
(YRS)
PT - PROJECTION TIME (YRS)
DAPGCE - DELAYED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- EAST
(MW/YR)

DAPGCE, the amount of delayed planning from earlier years, is calculated using the BOXC delay function described earlier. The delay time used in this function for the three-year delay is expressed as PT-GCT-2, or one year, because this quantity is used in two successive rate equations in the process of evolving from planned capacity to actual capacity. These two rate equations cause an additional two-year time delay

(when the solution interval of the model is one year) that must be corrected for in this equation. Similarly, the six-year delay is expressed as PT-(2*GCT)-2.

DAPGCE.K=BOXC(DAPGCE2.JK,(PT-GCT-2),0,0,0,0, 87, A
0,0,0,0,0)+BOXC(DAPGCE1.JK,(PT-
(2*GCT)-2),0,0,0,0,0,0,0,0,0,0)
DAPGCE - DELAYED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- EAST
(MW/YR)
BOXC - FUNCTION THAT DELAYS VARIABLE
(1) FOR A PERIOD OF VARIABLE (2)
DAPGCE1 - DELAYED ADDITIONAL PLANNED GEO-
THERMAL CAPACITY- EAST (1) (MW/YR)
PT - PROJECTION TIME (YRS)
GCT - GEOTHERMAL CONSTRUCTION TIME (YRS)
DAPGCE2 - DELAYED ADDITIONAL PLANNED GEO-
THERMAL CAPACITY- EAST (2) (MW/YR)

The resource availability multiplier is a function of available resources and indicated planned capacity.

RAME.K=MIN((GRAFCAE.K/INPGCW.K),(MIN 85, A
((GRACAE6.K/(IAPGCE1.K*2/3)),
(GRACAE9.K/IAPGCW1.K))))
RAME - RESOURCE AVAILABILITY MULTI-
PLIER- EAST (DIMENSIONLESS)
GRAFCAE - GEOTHERMAL RESOURCES AVAILABLE
FOR CAPACITY ADDITION- EAST
(MW/YR)
INPGCW - INDICATED NEW PLANNED GEOTHERMAL
CAPACITY- WEST (MW/YR)
GRACAE6 - GRAFCAE IN SIX YEARS (MW)
IAPGCW1 - INDICATED ADDITIONAL PLANNED GEO-
THERMAL CAPACITY- WEST (1) (MW/YR)
GRACAE9 - GRAFCAE IN NINE YEARS (MW)

RAME is the minimum of three ratios: the ratio of resources available in three years to indicated immediate planning (which would become on-line capacity in three years), the ratio of resources available in six years to two-thirds total indicated new planning (approximately the amount that would be on-line in six years) and the ratio of resources available in nine years to total indicated new planning (the amount that would be on-line in ten years). A value less than one for any of these ratios indicates that sufficient resources are not available for all the new plants desired. RAME is, therefore, set equal to the minimum of the three ratios and restricts new planning to the resources available.

Geothermal resources available for capacity additions in three years (GRAFCAE) is a function of total resources in three years minus resources already allocated.

GRAFCAE.K=MAX(0,((PRAE.K-GEOCAPE.K-(PGCE.K/ 91, A
GCT))/1))
GRAFCAE - GEOTHERMAL RESOURCES AVAILABLE
FOR CAPACITY ADDITION- EAST
(MW/YR)
PRAE - PROJECTED GEOTHERMAL RESOURCES-
EAST (MW)
GEOCAPE - GEOTHERMAL CAPACITY- EAST (MW)
PGCE - PLANNED GEOTHERMAL CAPACITY-
EAST (MW)
GCT - GEOTHERMAL CONSTRUCTION TIME (YRS)

PRAE is a projection of total resources that will be available in three years. Subtracting from PRAE the resources that are already being used (GEOCAPE) and the planned capacity that will come on-line in three years (approximately one-third total planned capacity) yields the amount of resources that are as yet unallocated. These resources are available for new planning.

Projected resources are simply the value that the geothermal resources- East estimate will reach in three years.

PRAE.K=TABHL(TRAЕ,TPGCT.K,1985,2015,15) 94, A
 PRAE - PROJECTED GEOTHERMAL RESOURCES-
 EAST (MW)
 TPGCT - TIME PLUS GEOTHERMAL CON-
 STRUCTION PERIOD (YRS)

TPGCT.K=TIME.K+GCT 95, A
 TPGCT - TIME PLUS GEOTHERMAL CONSTRUC-
 TION PERIOD (YRS)
 GCT - GEOTHERMAL CONSTRUCTION TIME
 (YRS)

Estimates of geothermal resources that are available
 for new planning for capacity additions in six and
 nine years are developed in a similar manner.

GRACAE6.K=MAX(0,((PRAE6.K-GEOCAPE.K-(PGCE.K 92, A
 *2/GCT))/1))
 GRACAE6 - GRAFCAE IN SIX YEARS (MW)
 PRAE6 - PROJECTED (6 YEARS) GEOTHERMAL
 RESOURCES- EAST (MW)
 GEOCAPE - GEOTHERMAL CAPACITY- EAST (MW)
 PGCE - PLANNED GEOTHERMAL CAPACITY-
 EAST (MW)
 GCT - GEOTHERMAL CONSTRUCTION TIME
 (YRS)

GRACAE9.K=MAX(0,((PRAE9.K-GEOCAPE.K-PGCE.K) 93, A
 1))
 GRACAE9 - GRAFCAE IN NINE YEARS (MW)
 PRAE9 - PROJECTED (9 YEARS) GEO-
 THERMAL RESOURCES- EAST (MW)
 GEOCAPE - GEOTHERMAL CAPACITY- EAST
 (MW)
 PGCE - PLANNED GEOTHERMAL CAPACITY-
 EAST (MW)

PRAE6.K=TABHL(TRAЕ,TP2GCT.K,1985,2015,15) 96, A
 PRAE6 - PROJECTED (6 YEARS) GEOTHERMAL
 RESOURCES- EAST (MW)
 TP2GCT - TIME PLUS TWO GEOTHERMAL CON-
 STRUCTION PERIODS (YRS)

TP2GCT.K=TIME.K+(2*GCT) 97, A
 TP2GCT - TIME PLUS TWO GEOTHERMAL
 CONSTRUCTION PERIODS (YRS)
 GCT - GEOTHERMAL CONSTRUCTION
 TIME (YRS)

PRAE9.K=TABHL(TRAЕ,TP3GCT.K,1985,2015,15) 98, A
 PRAE9 - PROJECTED (9 YEARS) GEO-
 THERMAL RESOURCES- EAST (MW)
 TP3GCT - TIME PLUS THREE GEOTHERMAL
 CONSTRUCTION PERIODS (YRS)

TP3GCT.K=TIME.K+(3*GCT) 99, A
 TP3GCT - TIME PLUS THREE GEOTHERMAL
 CONSTRUCTION PERIODS (YRS)
 GCT - GEOTHERMAL CONSTRUCTION TIME
 (YRS)

If indicated new geothermal capacity (INPGCE) exceeds
 available resources the amount of the shortfall is
 calculated and allocated to other power sources. The
 amount of the shortfall is simply equal to indicated
 new capacity planning for geothermal minus the re-
 sources available. Of course, when resources exceed
 the desire for new capacity, the shortfall is zero.

GEOSFE.K=INPGCE.K-GRAFCAE.K 100, A
 GEOSFE - GEOTHERMAL SHORTFALL-
 EAST (MW/YR)
 INPGCE - INDICATED NEW PLANNED GEO-
 THERMAL CAPACITY- EAST
 (MW/YR)
 GRAFCAE - GEOTHERMAL RESOURCES AVAILABLE
 FOR CAPACITY ADDITION- EAST
 (MW/YR)

AFGSFE.K=MAX(GEOSFE.K,0) 101, A
 AFGSFE - ADJUSTMENT FOR GEOTHERMAL
 SHORTFALL- EAST (MW/YR)
 GEOSFE - GEOTHERMAL SHORTFALL- EAST
 (MW/YR)

The technology for geothermal in the East is not yet
 sufficiently developed to make geothermal an alterna-
 tive energy source at the present. It was estimated,
 however, that the technology might become available in
 the mid-1980's. Thus, the geothermal decision factor
 for the East is equal to zero until 1985.

GDFE.K=FIFGE(IGDFE.K,0,TIME.K,1985) 102, A
 GDFE - GEOTHERMAL DECISION FACTOR -EAST
 (DIMENSIONLESS)
 IGDFE - INDICATED GEOTHERMAL DECISION
 FACTOR -EAST (DIMENSIONLESS)

After 1985 the decision factor is a function of the six
 decision variables described earlier.

In order to account for the fact that many companies
 are unwilling to commit themselves to a new technology
 until that technology has been used for some time, a
 learning factor that has been introduced into the equa-
 tion for the geothermal decision factor.

IGDFE.K=(RF*GR.K+CIF*GCI.K+ECF*GEC.K+ 103, A
 CEF*GCE.K+FAF*GFA.K)*LFE.K
 IGDFE - INDICATED GEOTHERMAL DECISION FACTOR-
 EAST (DIMENSIONLESS)
 RF - RELIABILITY FACTOR (DIMENSIONLESS)
 GR - GEOTHERMAL RELIABILITY (DIMENSIONLESS)
 CIF - CAPITAL INVESTMENT FACTOR (DIMENSION-
 LESS)
 GCI - GEOTHERMAL CAPITAL INVESTMENT
 (DIMENSIONLESS)
 ECF - ENVIRONMENTAL CONSIDERATION FACTOR
 (DIMENSIONLESS)
 GEC - GEOTHERMAL ENVIRONMENTAL CONSIDERA-
 TIONS (DIMENSIONLESS)
 CEF - COST OF ELECTRICITY FACTOR (DIMENSION-
 LESS)
 GCE - GEOTHERMAL COST OF ELECTRICITY
 (DIMENSIONLESS)
 FAF - FUEL AVAILABILITY FACTOR (DIMENSION-
 LESS)
 GFA - GEOTHERMAL FUEL AVAILABILITY
 (DIMENSIONLESS)
 LFE - LEARNING FACTOR- EAST (DIMENSIONLESS)

The learning factor reduces the value of the geothermal
 decision factor in the first few years that the tech-
 nology is available in the East. This multiplier
 becomes one ten years later when the technology is well
 understood by all possible users. Thus a type of learn-
 ing process is included with the introduction of new
 geothermal techniques.

LFE.K=TABHL(TIME,TIME.K,1985,1996,1) 104, A
 TLFE=0/.04/.10/.18/.30/.50/.70/.82
 /.90/.96/1.0 104.1, A

The geothermal decision factor for the West is similar
 to that just described for the East with the exception
 that the learning multiplier begins in 1970 and reaches
 1 in 1980.

GDFW.K=(RF*GR.K+CIF*GCI.K+ECF*GEC.K+
 CEF*GCE.K+FAF*GFA.K)*LFW.K
 GDFW - GEOTHERMAL DECISION FACTOR- WEST
 (DIMENSIONLESS)
 RF - RELIABILITY FACTOR (DIMENSIONLESS)
 GR - GEOTHERMAL RELIABILITY (DIMENSIONLESS)
 CIF - CAPITAL INVESTMENT FACTOR (DIMENSION-
 LESS)

GCI - GEOTHERMAL CAPITAL INVESTMENT (DIMENSIONLESS)
 EF - ENVIRONMENTAL CONSIDERATION FACTOR (DIMENSIONLESS)
 GEC - GEOTHERMAL ENVIRONMENTAL CONSIDERATIONS (DIMENSIONLESS)
 CEF - COST OF ELECTRICITY FACTOR (DIMENSIONLESS)
 GCE - GEOTHERMAL COST OF ELECTRICITY (DIMENSIONLESS)
 FAF - FUEL AVAILABILITY FACTOR (DIMENSIONLESS)
 GFA - GEOTHERMAL FUEL AVAILABILITY (DIMENSIONLESS)
 LFW - LEARNING FACTOR- WEST (DIMENSIONLESS)

LFW.K=TABLE(TLF,TIME.K,1970,1981,1) 106, A
 TLF=0/0/0/.2/.3/.4/.5/.6/.7/.8/.9/1 106.1, T
 LFW - LEARNING FACTOR- WEST (DIMENSIONLESS)

The estimates of perceived reliability, capital investment cost, environmental considerations, manufacturing costs of electricity, fuel availability, and construction delay time that are a part of the decision factor calculations have already been discussed. The model equations for these variables are presented below.

GR.K=TABLE(TGR,TIME.K,1970,2000,15) 107, A
 TGR=.7/.7/.8 107.1, T
 GR - GEOTHERMAL RELIABILITY (DIMENSIONLESS)

GCT.K=GCIC.K/GCIC.K 108, A
 GCI - GEOTHERMAL CAPITAL INVESTMENT COST
 GCIC - GEOTHERMAL CAPITAL INVESTMENT COST (\$/KW)

GCIC.K=TABLE(TGCIC,(TIME.K+10),1970,2010,5) 109, A
 TGCIC=264/272/292/315/339/365/394/424/456 109.1, T
 GCIC - GEOTHERMAL CAPITAL INVESTMENT COST (\$/KW)

GEC.K=TABLE(TGEC,TIME.K,1970,2000,30) 110, A
 TGEC=.75/.95 110.1, T
 GEC - GEOTHERMAL ENVIRONMENTAL CONSIDERATIONS (DIMENSIONLESS)

GCE.K=ONE 111, A
 GCE - GEOTHERMAL COST OF ELECTRICITY (DIMENSIONLESS)

AGCE.K=TABLE(TAGCE,(TIME.K+10),1970,2010,5) 112, A
 TAGCE=7/8/9.3/10.4/11.6/13.0/14.5/16.2/18.1 112.1, T
 AGCE - ACTUAL GEOTHERMAL COST OF ELECTRICITY (MILLS/KWHR)

GFA.K=TABLE(TGFA,TIME.K,1970,2000,15) 113, A
 TGFA=.75/.75/.95 113.1, T
 GFA - GEOTHERMAL FUEL AVAILABILITY (DIMENSIONLESS)

GDT=ONE 113.2, C
 GDT - GEOTHERMAL DELAY TIME

The equations for calculating capacities in the West are identical to those already described for the East, with two exceptions. Initial values are, of course, different for installed and planned capacities. Imports of electricity are not included as one of the alternative power sources for the West.

The rest of the calculations for the West are identical to those already described for the East. They are

therefore, presented on the following pages without further comment.

TYCGW.K=PTYDW.K-PAPSW.K 159, A
 TYCGW - TEN YEAR CAPACITY GAP- WEST (MW/YR)
 PTYDW - PROJECTED TEN YEAR DEMAND- WEST (MW/YR)
 PAPSW - PRESENT AND PLANNED SUPPLY- WEST (MW/YR)

PTYDW.K=TABLE(TPDW,TPPT.K,1970,2010,5)*1E3 160, A
 TPDW=44/94/129/181/255/340/406/533/660 160.1, T
 PTYDW - PROJECTED TEN YEAR DEMAND- WEST (MW/YR)
 TPPT - TIME PLUS PROJECTION TIME (YRS)

PAPSW.K=(PRCAPW.K+PLCAPW.K)-IMPCAPE.K 161, A
 PAPSW - PRESENT AND PLANNED SUPPLY- WEST (MW/YR)
 PRCAPW - PRESENT PROJECTED CAPACITY- WEST (MW)
 PLCAPW - PLANNED CAPACITY- WEST (MW)
 IMPCAPE- IMPORT CAPACITY- EAST (MW)

PRCAPW.K=PRCCAPW.K+PRPCAPW.K+NUCCAPW.K 162, A
 +GEOCAPW.K+SCAPW.K+PRHCAPW.K
 +PRNGCPW.K
 PRCAPW - PRESENT PROJECTED CAPACITY- WEST (MW)
 PRCCAPW - PRESENT PROJECTED COAL CAPACITY- WEST (MW)
 PRPCAPW - PRESENT PROJECTED PETROLEUM CAPACITY- WEST (MW)
 NUCCAPW - NUCLEAR CAPACITY- WEST (MW)
 GEOCAPW - GEOTHERMAL CAPACITY- WEST (MW)
 SCAPW - SOLAR CAPACITY- WEST (MW)
 PRHCAPW - PRESENT PROJECTED HYDRO CAPACITY- WEST (MW)

PRCCAPW.K=CCAPW.K*(1-(PT*.025)) 163, A
 PRCCAPW - PRESENT PROJECTED COAL CAPACITY- WEST (MW)
 CCAPW - COAL CAPACITY- WEST (MW)
 PT - PROJECTION TIME (YRS)

PRPCAPW.K=PETCAPW.K*(1-(PT*.025)) 164, A
 PRPCAPW - PRESENT PROJECTED PETROLEUM CAPACITY- WEST (MW)
 PETCAPW - PETROLEUM CAPACITY- WEST (MW)
 PT - PROJECTION TIME (YRS)

PRHCAPW.K=TABLE(THCAPW,TPPT.K,1970,2010,5)* 165, A
 1E3
 PRHCAPW - PRESENT PROJECTED HYDRO CAPACITY- WEST (MW)
 TPPT - TIME PLUS PROJECTION TIME (YRS)

PRNGCPW.K=TABLE(TNGCAPW,TPPT.K,1970,2010,5)* 166, A
 1E3
 TPPT - TIME PLUS PROJECTION TIME (YRS)

PCAPW.K=CCAPW.K+PETCAPW.K+NUCCAPW.K+GEOCAPW.K 167, S
 +SCAPW.K+HCAPW.K+NGCAPW.K
 PCAPW - PRESENT CAPACITY- WEST (MW)
 CCAPW - COAL CAPACITY- WEST (MW)
 PETCAPW - PETROLEUM CAPACITY- WEST (MW)
 NUCCAPW - NUCLEAR CAPACITY- WEST (MW)
 GEOCAPW - GEOTHERMAL CAPACITY- WEST (MW)
 SCAPW - SOLAR CAPACITY- WEST (MW)
 HCAPW - HYDRO CAPACITY- WEST (MW)
 NGCAPW - NATURAL GAS CAPACITY- WEST (MW)

CCAPW.K=CCAPW.J+DT*(CARW.JK-CCRW.JK) 168, L
 CCAPW=13.2E3 168.1, N

CCAPW - COAL CAPACITY- WEST (MW)		GARW.KL=BOXC(NPGCW.K,2,124,106,106,0,0,0,0,0,0)	178, R
DT - LENGTH OF SOLUTION INTERVAL (YRS)		GARW - GEOTHERMAL ADDITION RATE- WEST (MW/YR)	
CARW - COAL ADDITION RATE- WEST (MW/YR)		BOXC - FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)	
CRRW - COAL RETIREMENT RATE- WEST (MW/YR)		NPGCW - NEW PLANNED GEOTHERMAL CAPACITY- WEST (MW/YR)	
CRRW.KL=CCAPW.K/40	169, R	SCAPW.K=SCAPW.J+DT*(SARW.JK-SRRW.JK)	179, L
CRRW - COAL RETIREMENT RATE- WEST (MW/YR)		SCAPW=0	179.1, N
CCAPW - COAL CAPACITY- WEST (MW)		SCAPW - SOLAR CAPACITY- WEST (MW)	
CARW.KL=BOXC(NPCCW.K,6,360,1522,2521,1100,1100,400,0,0,0,0)	170, R	DT - LENGTH OF SOLUTION INTERVAL (YRS)	
CARW - COAL ADDITION RATE- WEST (MW/YR)		SARW - SOLAR ADDITION RATE- WEST (MW)	
BOXC - FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)		SRRW.KL=SCAPW.K/SRT	180, R
NPCCW - NEW PLANNED COAL CAPACITY- WEST (MW/YR)		SCAPW - SOLAR CAPACITY- WEST (MW)	
PETCAPW.K=PETCAPW.J+DT*(PARW.JK-PRRW.JK)	171, L	SRT - SOLAR RETIREMENT TIME (YRS)	
PETCAPW=6.5E3	171.1, N	SARW.KL=BOXC(NPSCW.K,8,0,0,0,0,0,0,0,0,0,0,0)	181, R
PETCAPW - PETROLEUM CAPACITY- WEST (MW)		SARW - SOLAR ADDITION RATE- WEST (MW)	
DT - LENGTH OF SOLUTION INTERVAL (YRS)		BOXC - FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)	
PARW - PETROLEUM ADDITION RATE- WEST (MW/YR)		NPSCW - NEW PLANNED SOLAR CAPACITY- WEST (MW/YR)	
PRRW - PETROLEUM RETIREMENT RATE- WEST (MW/YR)		HCAPW.K=TABLE(THCAPW,TIME.K,1970,2010,5)*1E3	182, A
PRRW.KL=PETCAPW.K/40	172, R	THCAPW=29.7/35/42/47/52/55/58/61/64	182.1, T
PRRW - PETROLEUM RETIREMENT RATE- WEST (MW/YR)		HCAPW - HYDRO CAPACITY- WEST (MW)	
PETCAPW - PETROLEUM CAPACITY- WEST (MW)		NGCAPW.K=TABLE(TNGCAPW,TIME.K,1970,2010,5)*1E3	183, A
PARW.KL=BOXC(NPPCW.K,5,240,239,300,60,379,0,0,0,0,0,0)	173, R	TNGCAPW=22/18.7/16.2/13/10.5/8.7/7/6/5	183.1, T
PARW - PETROLEUM ADDITION RATE- WEST (MW/YR)		NGCAPW - NATURAL GAS CAPACITY- WEST (MW)	
BOXC - FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)		PLCAPW.K=PCCW.K+PPCW.K+PNCW.K+PGCW.K+PSCW.K	184, A
NPPCW - NEW ADDITIONAL PLANNED PETROLEUM CAPACITY- WEST (MW/YR)		PLCAPW - PLANNED CAPACITY- WEST (MW)	
NUCCAPW.K=NUCCAPW.J+DT*(NARW.JK)	174, L	PCCW - PLANNED COAL CAPACITY- WEST (MW)	
NUCCAPW=1.6E3	174.1, N	PPCW - PLANNED PETROLEUM CAPACITY- WEST (MW)	
NUCCAPW - NUCLEAR CAPACITY- WEST (MW)		PNCW - PLANNED NUCLEAR CAPACITY- WEST (MW)	
DT - LENGTH OF SOLUTION INTERVAL (YRS)		PGCW - PLANNED GEOTHERMAL CAPACITY- WEST (MW)	
NARW - NUCLEAR ADDITION RATE- WEST (MW/YR)		PSCW - PLANNED SOLAR CAPACITY- WEST (MW)	
NARW.KL=BOXC(NPNCW.K,(NCT.K),765,1767,0,3332,2199,0,2183,1066,916,0)	175, R	PCCW.K=PCCW.J+DT*(APCCW.JK-CARW.JK+DAPCCW1.JK)	185, L
NARW - NUCLEAR ADDITION RATE- WEST (MW/YR)		PCCW=9.7E3	185.1, N
BOXC - FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)		PCCW - PLANNED COAL CAPACITY- WEST (MW)	
NPNCW - NEW PLANNED NUCLEAR CAPACITY- WEST (MW/YR)		DT - LENGTH OF SOLUTION INTERVAL (YRS)	
NCT - NUCLEAR CONSTRUCTION TIME (YRS)		APCCW - ADDITIONAL PLANNED COAL CAPACITY- WEST (MW/YR)	
GEOCAPW.K=GEOCAPW.J+DT*(GARW.JK-GRRW.JK)	176, L	CARW - COAL ADDITION RATE- WEST (MW/YR)	
GEOCAPW=396	176.1, N	DAPCCW1 - DELAYED ADDITIONAL PLANNED COAL CAPACITY- WEST (1) (MW/YR)	
GEOCAPW - GEOTHERMAL CAPACITY- WEST (MW)		APCCW.KL=IAPCCW.K*(CCT/PT)	186, R
DT - LENGTH OF SOLUTION INTERVAL (YRS)		APCCW - ADDITIONAL PLANNED COAL CAPACITY- WEST (MW/YR)	
GARW - GEOTHERMAL ADDITION RATE- WEST (MW/YR)		IAPCCW - INDICATED ADDITIONAL PLANNED COAL CAPACITY- WEST (MW/YR)	
GRRW - GEOTHERMAL RETIREMENT RATE- WEST (MW/YR)		CCT - COAL CONSTRUCTION TIME (YRS)	
GRRW.KL=FIFGE((GEOCAPW.K/GRT.K),0,TIME.K,2000)	177, R	PT - PROJECTION TIME (YRS)	
GRRW - GEOTHERMAL RETIREMENT RATE- WEST (MW/YR)		NPCCW.K=IAPCCW.K*(CCT/PT)+DAPCCW.K	187, A
GEOCAPW - GEOTHERMAL CAPACITY- WEST (MW)		NPCCW - NEW PLANNED COAL CAPACITY- WEST (MW/YR)	
GRT - GEOTHERMAL RETIREMENT TIME (YRS)		IAPCCW - INDICATED ADDITIONAL PLANNED COAL CAPACITY- WEST (MW/YR)	
		CCT - COAL CONSTRUCTION TIME (YRS)	
		PT - PROJECTION TIME (YRS)	
		DAPCCW - DELAYED ADDITIONAL PLANNED COAL CAPACITY- WEST (MW/YR)	

DAPCCW.K=BOXC(DAPCCW1.JK, (PT-CCT-2), 0,0,0,0, 188, A
0,0,0,0,0,0)
PCCW - DELAYED ADDITIONAL PLANNED
COAL CAPACITY- WEST (MW/YR)
BOXC - FUNCTION THAT DELAYS VARIABLE
(1) FOR A PERIOD OF VARIABLE (2)
DAPCCW1 - DELAYED ADDITIONAL PLANNED COAL
CAPACITY- WEST (1) (MW/YR)
PT - PROJECTION TIME (YRS)
CCT - COAL CONSTRUCTION TIME (YRS)

DAPCCW1.KL=IAPCCW.K*(1-(CCT/PT)) 189, R
DAPCCW1=0 189.1, N
DAPCCW1 - DELAYED ADDITIONAL PLANNED
COAL CAPACITY- WEST (1)
(MW/YR)
IAPCCW - INDICATED ADDITIONAL PLANNED
COAL CAPACITY- WEST (MW/YR)
CCT - COAL CONSTRUCTION TIME (YRS)
PT - PROJECTION TIME (YRS)

IAPCCW.K=MAX(0, (((CDF.K/TDFW.K)*TYCGW.K) 190, A
+CAFGSW.K))
IAPCCW - INDICATED ADDITIONAL PLANNED
COAL CAPACITY- WEST (MW/YR)
CDF - COAL DECISION FACTOR (DIMEN-
SIONLESS)
TDFW - TOTAL DEMAND FACTOR- WEST
(DIMENSIONLESS)
TYCGW - TEN YEAR CAPACITY GAP-
WEST (MW/YR)
CAFGSW - COAL ADJUSTMENT FOR GEOTHERMAL
SHORTFALL- WEST (MW/YR)

CAFGSW.K=AFGSW.K*(CDF.K/(CDF.K+PDF.K 191, A
+NDF.K))
CAFGSW - COAL ADJUSTMENT FOR GEOTHERMAL
SHORTFALL- WEST (MW/YR)
AFGSW - ADJUSTMENT FOR GEOTHERMAL SHORT-
FALL- WEST (MW/YR)
CDF - COAL DECISION FACTOR (DIMEN-
SIONLESS)
PDF - PETROLEUM DECISION FACTOR
(DIMENSIONLESS)
NDF - NUCLEAR DECISION FACTOR
(DIMENSIONLESS)

PPCW.K=PPCW.J+DT*(APPCW.JK-PARW.JK+CAPPCW1.JK) 192, L
PPCW=.4E3 192.1, N
PPCW - PLANNED PETROLEUM CAPACITY-
WEST (MW)
DT - LENGTH OF SOLUTION INTERVAL
(YRS)
APPCW - ADDITIONAL PLANNED PETROLEUM
CAPACITY- WEST (MW/YR)
PARW - PETROLEUM ADDITION RATE- WEST
(MW/YR)
DAPPCW1 - DELAYED ADDITIONAL PLANNED
PETROLEUM CAPACITY- WEST (1)
(MW/YR)

APPCW.KL=(IAPPCW.K*(PCT/PT)) 193, R
APPCW - ADDITIONAL PLANNED PETROLEUM
CAPACITY- WEST (MW/YR)
IAPPCW - INDICATED ADDITIONAL PLANNED
PETROLEUM CAPACITY- WEST (MW/YR)
PCT - PETROLEUM CONSTRUCTION TIME (YRS)
PT - PROJECTION TIME (YRS)

NPPCW.K=(IAPPCW.K*(PCT/PT))+DAPPCW.K 194, A
NPPCW - NEW ADDITIONAL PLANNED PETROLEUM
CAPACITY- WEST (MW/YR)
IAPPCW - INDICATED ADDITIONAL PLANNED
PETROLEUM CAPACITY- WEST (MW/YR)
PCT - PROJECTION TIME (YRS)
DAPPCW - DELAYED ADDITIONAL PLANNED
PETROLEUM CAPACITY- WEST (MW/YR)

DAPPCW.K=BOXC(DAPPCW1.JK, (PT-PCT-2) 195, A
0,0,0,0,0,0,0,0,0,0)
DAPPCW - DELAYED ADDITIONAL PLANNED
PETROLEUM CAPACITY- WEST
(MW/YR)
BOXC - FUNCTION THAT DELAYS VARIABLE
(1) FOR A PERIOD OF VARIABLE (2)
DAPPCW1 - DELAYED ADDITIONAL PLANNED
PETROLEUM CAPACITY- WEST (1)
(MW/YR)
PT - PROJECTION TIME (YRS)
PCT - PETROLEUM CONSTRUCTION TIME (YRS)

DAPPCW1.KL=IAPPCW.K*(1-(PCT/PT)) 196, R
DAPPCW1=0 196.1, N
DAPPCW1 - DELAYED ADDITIONAL PLANNED
PETROLEUM CAPACITY- WEST
(1) (MW/YR)
IAPPCW - INDICATED ADDITIONAL PLANNED
PETROLEUM CAPACITY- WEST
(MW/YR)
PCT - PETROLEUM CONSTRUCTION TIME
(YRS)
PT - PROJECTION TIME (YRS)

IAPPCW.K=MAX(0, (((PDF.K/TDFW.K)*TYCGW.K) 197, A
+PAFGSW.K))
IAPPCW - INDICATED ADDITIONAL PLANNED
PETROLEUM CAPACITY- WEST (MW/YR)
PDF - PETROLEUM DECISION FACTOR
(DIMENSIONLESS)
TDFW - TOTAL DEMAND FACTOR- WEST
(DIMENSIONLESS)
TYCGW - TEN YEAR CAPACITY GAP- WEST
(MW/YR)

PAFGSW.K=AFGSW.K*(PDF.K/(CDF.K+PDF.K 198, A
+NDF.K))
AFGSW - ADJUSTMENT FOR GEOTHERMAL
SHORTFALL- WEST (MW/YR)
PDF - PETROLEUM DECISION FACTOR
(DIMENSIONLESS)
CDF - COAL DECISION FACTOR (DIMEN-
SIONLESS)
NDF - NUCLEAR DECISION FACTOR
(DIMENSIONLESS)

PNCW.K=PNCW.J+DT*(APNCW.JK-NARW.JK+DAPNCW1.JK) 199, L
PNCW=15.7E3 199.1, N
PNCW - PLANNED NUCLEAR CAPACITY-
WEST (MW)
DT - LENGTH OF SOLUTION INTERVAL
(YRS)
APNCW - ADDITIONAL PLANNED NUCLEAR
CAPACITY- WEST (MW/YR)
NARW - NUCLEAR ADDITION RATE- WEST
(MW/YR)
DAPNCW1 - DELAYED ADDITIONAL PLANNED
NUCLEAR CAPACITY- WEST (1)
(MW/YR)

APNCW.KL=IAPNCW.K*(NCT.K/PT) 200, R
APNCW - ADDITIONAL PLANNED NUCLEAR
CAPACITY- WEST (MW/YR)
IAPNCW - INDICATED ADDITIONAL PLANNED
NUCLEAR CAPACITY- WEST (MW/YR)
NCT - NUCLEAR CONSTRUCTION TIME (YRS)
PT - PROJECTION TIME (YRS)

NPNCW.K=IAPNCW.K*(NCT.K/PT)+DAPNCW.K 201, A
NPNCW - NEW PLANNED NUCLEAR CAPACITY-
WEST (MW/YR)
IAPNCW - INDICATED ADDITIONAL PLANNED
NUCLEAR CAPACITY- WEST (MW/YR)
NCT - NUCLEAR CONSTRUCTION TIME (YRS)
PT - PROJECTION TIME (YRS)
DAPNCW - DELAYED ADDITIONAL PLANNED
NUCLEAR CAPACITY- WEST (MW/YR)

CAPNCW.K=BOXC(DAPNCW1.JK,(PT-NCT.K-1),0,0, 202, A
 0,0,0,0,0,0,0,0)
 DAPNCW - DELAYED ADDITIONAL PLANNED
 NUCLEAR CAPACITY- WEST (MW/YR)
 BOXC - FUNCTION THAT DELAYS VARIABLE
 (1) FOR A PERIOD OF VARIABLE (2)
 DAPNCW1 - DELAYED ADDITIONAL PLANNED
 NUCLEAR CAPACITY- WEST (1)
 (MW/YR)
 PT - PROJECTION TIME (YRS)
 NCT - NUCLEAR CONSTRUCTION TIME (YRS)

DAPNCW1.KL=IAPNCW.K*(1-(NCT.K/PT)) 203, R
 DAPNCW1=0 203.1, N
 DAPNCW1 - DELAYED ADDITIONAL PLANNED
 NUCLEAR CAPACITY- WEST (1)
 (MW/YR)
 IAPNCW - INDICATED ADDITIONAL PLANNED
 NUCLEAR CAPACITY- WEST (MW/YR)
 NCT - NUCLEAR CONSTRUCTION TIME
 (YRS)
 PT - PROJECTION TIME (YRS)

IAPNCW.K=MAX(0,(((NDF.K/TDFW.K)*TYCGW.K) 204, A
 +NAFGSW.K))
 IAPNCW - INDICATED ADDITIONAL PLANNED
 NUCLEAR CAPACITY- WEST (MW/YR)
 NDF - NUCLEAR DECISION FACTOR
 (DIMENSIONLESS)
 TDFW - TOTAL DEMAND FACTOR- WEST
 (DIMENSIONLESS)
 TYCGW - TEN YEAR CAPACITY GAP-
 WEST (MW/YR)
 NAFGSFW - NUCLEAR ADJUSTMENT FOR GEO-
 THERMAL SHORTFALL- WEST (MW/YR)

NAFGSFW.K=AFGSFW.K*(NDF.K/(CDF.K+PDF.K 205, A
 +NDF.K))
 NAFGSFW - NUCLEAR ADJUSTMENT FOR GEO-
 THERMAL SHORTFALL- WEST (MW/YR)
 AFGSW - ADJUSTMENT FOR GEOTHERMAL
 SHORTFALL- WEST (MW/YR)
 NDF - NUCLEAR DECISION FACTOR
 (DIMENSIONLESS)
 CDF - COAL DECISION FACTOR
 (DIMENSIONLESS)
 PDF - PETROLEUM DECISION FACTOR
 (DIMENSIONLESS)

PGCW.K=PGCW.J+DT*(APGCW.JK-GARW.JK+DAPGCW1.JK 206, L
 +DAPGCW2.JK)
 PGCW=1831 206.1, N
 PGCW - PLANNED GEOTHERMAL CAPACITY-
 WEST (MW)
 DT - LENGTH OF SOLUTION INTERVAL (YRS)
 APGCW - ADDITIONAL PLANNED GEOTHERMAL
 CAPACITY- WEST (MW/YR)
 GARW - GEOTHERMAL ADDITION RATE- WEST
 (MW/YR)
 DAPGCW1 - DELAYED ADDITIONAL PLANNED
 GEOTHERMAL CAPACITY- WEST (1)
 (MW/YR)
 DAPGCW2 - DELAYED ADDITIONAL PLANNED
 GEOTHERMAL CAPACITY- WEST (2)
 (MW/YR)

APGCW.KL=IAPGCW.K*(MIN(1,(GRAFCW.K/ 207, R
 INPGCW.K)))
 APGCW=110 207.1, N
 APGCW - ADDITIONAL PLANNED GEOTHERMAL
 CAPACITY- WEST (MW/YR)
 IAPGCW - INDICATED ADDITIONAL PLANNED
 GEOTHERMAL CAPACITY- WEST
 (MW/YR)
 GRAFCW - GEOTHERMAL RESOURCES AVAILABLE
 FOR CAPACITY ADDITION- WEST (MW/YR)

INPGCW - INDICATED NEW PLANNED GEOTHERMAL
 CAPACITY- WEST (MW/YR)

IAPGCW.K=(IAPGCW1.K*(GCT/PT)) 208, A
 IAPGCW - INDICATED ADDITIONAL PLANNED
 GEOTHERMAL CAPACITY- WEST
 (MW/YR)
 IAPGCW1 - INDICATED ADDITIONAL PLANNED
 GEOTHERMAL CAPACITY- WEST (1)
 (MW/YR)
 GCT - GEOTHERMAL CONSTRUCTION TIME
 (YRS)
 PT - PROJECTION TIME (YRS)

NPGCW.K=(IAPGCW.K*(MIN(L,RAM.K)))+DAPGCW.K 209, A
 +DAPICE.K
 NPGCW - NEW PLANNED GEOTHERMAL
 CAPACITY- WEST (MW/YR)
 IAPGCW - INDICATED ADDITIONAL PLANNED
 GEOTHERMAL CAPACITY- WEST
 (MW/YR)
 RAM - RESOURCE AVAILABILITY MULTI-
 PLIER (DIMENSIONLESS)
 DAPGCW - DELAYED ADDITIONAL PLANNED
 GEOTHERMAL CAPACITY- WEST
 (MW/YR)
 DAPICE - DELAYED ADDITIONAL PLANNED
 IMPORT CAPACITY- EAST (MW/YR)

RAM.K=MIN((GRAFCW.K/INPGCW.K),(MIN((GRACAW6.K 210, A
 /(IAPGCW1.K*2/3)),(GRACAW9.K/IAPGCW1.K))))
 RAM - RESOURCE AVAILABILITY MULTI-
 PLIER (DIMENSIONLESS)
 GRAFCW - GEOTHERMAL RESOURCES AVAILABLE
 FOR CAPACITY ADDITION- WEST
 (MW/YR)
 INPGCW - INDICATED NEW PLANNED GEOTHERMAL
 CAPACITY- WEST (MW/YR)
 GRACAW6 - GEOTHERMAL RESOURCES AVAILABLE
 FOR CAP ADDITIONS IN 6 YEARS (MW)
 IAPGCW1 - INDICATED ADDITIONAL PLANNED GEO-
 THERMAL CAPACITY- WEST (1) (MW/YR)
 GRACAW9 - GEOTHERMAL RESOURCES AVAILABLE FOR
 CAP ADDITIONS IN 9 YEARS (MW)

INPGCW.K=MAX(.01,((IAPGCW1.K*(GCT/PT)) 211, A
 +DAPICE.K+DAPGCW.K))
 INPGCW - INDICATED NEW PLANNED GEO-
 THERMAL CAPACITY- WEST (MW/YR)
 IAPGCW1 - INDICATED ADDITIONAL PLANNED
 GEOTHERMAL CAPACITY- WEST (1)
 (MW/YR)
 GCT - GEOTHERMAL CONSTRUCTION TIME (YRS)
 PT - PROJECTION TIME (YRS)
 DAPICE - DELAYED ADDITIONAL PLANNED IMPORT
 CAPACITY- EAST (MW/YR)
 DAPGCW - DELAYED ADDITIONAL PLANNED GEO-
 THERMAL CAPACITY- WEST (MW/YR)

DAPGCW.K=BOXC(DAPGCW1.JK,(PT-(GCT*2)-2),307, 212, A
 262,300,0,0,0,0,0,0,0)+BOXC(DAPGCW2.JK,
 (PT-GCT-1),0,322,277,0,0,0,0,0,0,0)
 DAPGCW - DELAYED ADDITIONAL PLANNED
 GEOTHERMAL CAPACITY- WEST (MW/YR)
 BOXC - FUNCTION THAT DELAYS VARIABLE (1)
 FOR A PERIOD OF VARIABLE (2)
 DAPGCW1 - DELAYED ADDITIONAL PLANNED GEO-
 THERMAL CAPACITY- WEST (1) (MW/YR)
 PT - PROJECTION TIME (YRS)
 GCT - GEOTHERMAL CONSTRUCTION TIME (YRS)
 DAPGCW2 - DELAYED ADDITIONAL PLANNED GEO-
 THERMAL CAPACITY- WEST (2) (MW/YR)

DAPGCW1.KL=IAPGCW1.K*(GCT/PT)*(MIN(1,RAM.K)) 213, R
 DAPGCW1=0 213.1, N

DAPGCW1 - DELAYED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- WEST
(1) (MW/YR)

IAPGCW1 - INDICATED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- WEST (1)
(MW/YR)

GCT - GEOTHERMAL CONSTRUCTION TIME
(YRS)

PT - PROJECTION TIME (YRS)

RAM - RESOURCE AVAILABILITY MULTI-
PLIER (DIMENSIONLESS)

DAPGCW2.KL=(IAPGCW1.K-(IAPGCW1.K*(2*GCT/PT))) 214, R
*MIN(1, RAM.K)

DAPGCW2=0 214.1, N

DAPGCW2 - DELAYED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- WEST
(2) (MW/YR)

IAPGCW1 - INDICATED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- WEST
(1) (MW/YR)

GCT - GEOTHERMAL CONSTRUCTION TIME (YRS)

PT - PROJECTION TIME (YRS)

RAM - RESOURCE AVAILABILITY MULTIPLIER
(DIMENSIONLESS)

GRAFCW.K=MAX(0, ((PRAW.K-GEOCAPW.K-(PGCW.K/
GCT)-(PICE.K/GCT))/1)) 215, A

GRAFCW - GEOTHERMAL RESOURCES AVAILABLE
FOR CAPACITY ADDITION- WEST
(MW/YR)

PRAW - PROJECTED RESOURCES AVAILABLE
(MW)

GEOCAPW - GEOTHERMAL CAPACITY- WEST (MW)

PGCW - PLANNED GEOTHERMAL CAPACITY-
WEST (MW)

GCT - GEOTHERMAL CONSTRUCTION TIME (YRS)

PICE - PLANNED IMPORT CAPACITY- EAST (MW)

GRACAW6.K=MAX(0, ((PRAW6.K-GEOCAPW.K-(PGCW.K
*2/GCT)-(PICE.K*2/GCT))/1)) 216, A

GRACAW6 - GEOTHERMAL RESOURCES AVAILABLE
FOR CAP ADDITIONS IN 6 YEARS (MW)

PRAW6 - PROJECTED RESOURCES AVAILABLE
IN 6 YEARS (MW)

GEOCAPW - GEOTHERMAL CAPACITY- WEST (MW)

PGCW - PLANNED GEOTHERMAL CAPACITY-
WEST (MW)

GCT - GEOTHERMAL CONSTRUCTION TIME (YRS)

PICE - PLANNED IMPORT CAPACITY- EAST (MW)

GRACAW9.K=MAX(0, ((PRAW9.K-GEOCAPW.K-PGCW.K-
PICE.K)/1)) 217, A

GRACAW9 - GEOTHERMAL RESOURCES AVAILABLE
FOR CAP ADDITIONS IN 9 YEARS (MW)

PRAW9 - PROJECTED RESOURCES AVAILABLE IN
9 YEARS (YRS)

GEOCAPW - GEOTHERMAL CAPACITY- WEST (MW)

PGCW - PLANNED GEOTHERMAL CAPACITY-
WEST (MW)

PICE - PLANNED IMPORT CAPACITY- EAST (MW)

PRAW.K=TABLE (TRAW, TPGCT.K, 1970, 2015, 15) 218, A

PRAW - PROJECTED RESOURCES AVAILABLE (MW)

TPGCT - TIME PLUS GEOTHERMAL CONSTRUCTION
PERIOD (YRS)

PRAW6.K=TABLE (TRAW, TP2GCT.K, 1970, 2015, 15) 219, A

PRAW6 - PROJECTED RESOURCES AVAILABLE
IN 6 YEARS (MW)

TP2GCT - TIME PLUS TWO GEOTHERMAL CON-
STRUCTION PERIODS (YRS)

PRAW9.K=TABLE (TRAW, TP3GCT.K, 1970, 2015, 15) 220, A

PRAW9 - PROJECTED RESOURCES AVAILABLE IN
9 YEARS (YRS)

TP3GCT - TIME PLUS THREE GEOTHERMAL
CONSTRUCTION PERIODS (YRS)

IAPGCW1.K=MAX(.01, ((GDFW.K/TDFW.K)*TYCGW.K)) 221, A

IAPGCW1 - INDICATED ADDITIONAL PLANNED
GEOTHERMAL CAPACITY- WEST (1)
(MW/YR)

GDFW - GEOTHERMAL DECISION FACTOR-
WEST (DIMENSIONLESS)

TDFW - TOTAL DEMAND FACTOR- WEST
(DIMENSIONLESS)

TYCGW - TEN YEAR CAPACITY GAP- WEST
(MW/YR)

DAPICE.K=BOXC(NPICE.K, (ICT-GCT-1), 0, 0, 0, 0, 222, A
0, 0, 0, 0, 0)

DAPICE - DELAYED ADDITIONAL PLANNED
IMPORT CAPACITY- EAST (MW/YR)

BOXC - FUNCTION THAT DELAYS VARIABLE
(1) FOR A PERIOD OF VARIABLE (2)

NPICE - NEW PLANNED ADDITIONAL IMPORT
CAPACITY- EAST (MW/YR)

ICT - IMPORT CONSTRUCTION TIME

GCT - GEOTHERMAL CONSTRUCTION TIME (YRS)

GEOSFW.K=INPGCW.K-GRAFCW.K 223, A

GEOSFW - GEOTHERMAL SHORTFALL- WEST
(MW/YR)

INPGCW - INDICATED NEW PLANNED GEO-
THERMAL CAPACITY- WEST (MW/YR)

GRAFCW - GEOTHERMAL RESOURCES AVAILABLE
FOR CAPACITY ADDITION- WEST (MW/YR)

GEOSFWL.KL=GEOSFW.K 224, R

GEOSFWL=0 224.1, N

GEOSFWL - GEOTHERMAL SHORTFALL- WEST
LAST TIME PERIOD (MW/YR)

GEOSFW - GEOTHERMAL SHORTFALL- WEST
(MW/YR)

AFGSFW.K=MAX(GEOSFW.K, 0) 225, A

AFGSFW - ADJUSTMENT FOR GEOTHERMAL
SHORTFALL- WEST (MW/YR)

GEOSFW - GEOTHERMAL SHORTFALL- WEST
(MW/YR)

PSCW.K=PSCW.J+DT*(APSCW.JK-SARW.JK+DAPSCW1.JK) 226, L

PSCW=0 226.1, N

PSCW - PLANNED SOLAR CAPACITY- WEST
(MW)

DT - LENGTH OF SOLUTION INTERVAL (YRS)

APSCW - ADDITIONAL PLANNED SOLAR CAPA-
CITY- WEST (MW)

SARW - SOLAR ADDITION RATE- WEST (MW)

DAPSCW1 - DELAYED ADDITIONAL PLANNED SOLAR
CAPACITY- WEST (MW/YR)

APSCW.KL=(IAPSCW.K*(SCT/PT)) 227, R

APSCW - ADDITIONAL PLANNED SOLAR
CAPACITY- WEST (MW)

IAPSCW - INDICATED ADDITIONAL PLANNED
SOLAR CAPACITY- WEST (MW/YR)

SCT - SOLAR CONSTRUCTION TIME (YRS)

PT - PROJECTION TIME (YRS)

NPSCW.K=(IAPSCW.K*(SCT/PT))+DAPSCW.K 228, A

NPSCW - NEW PLANNED SOLAR CAPACITY-
WEST (MW/YR)

IAPSCW - INDICATED ADDITIONAL PLANNED
SOLAR CAPACITY- WEST (MW/YR)

SCT - SOLAR CONSTRUCTION TIME (YRS)

PT - PROJECTION TIME (YRS)

DAPSCW - DELAYED ADDITIONAL PLANNED SOLAR
CAPACITY- WEST (MW/YR)

IAPSCW.K=MAX(0, ((SDFW.K/TDFW.K)*TYCGW.K)) 229, A

IAPSCW - INDICATED ADDITIONAL PLANNED
 SOLAR CAPACITY- WEST (MW/YR)
 SDFW - SOLAR DECISION FACTOR- WEST
 (DIMENSIONLESS)
 TDFW - TOTAL DEMAND FACTOR- WEST
 (DIMENSIONLESS)
 TYCGW - TEN YEAR CAPACITY GAP- WEST
 (MW/YR)

DAPSCW.K=BOXC(DAPSCW1.JK,(PT-SCT-2),0,0,0, 230, A
 0,0,0,0,0,0,0)
 DAPSCW - DELAYED ADDITIONAL PLANNED
 SOLAR CAPACITY- WEST (MW/YR)
 BOXC - FUNCTION THAT DELAYS VARIABLE
 (1) FOR A PERIOD OF VARIABLE (2)
 DAPSCW1 - DELAYED ADDITIONAL PLANNED
 SOLAR CAPACITY- WEST (MW/YR)
 PT - PROJECTION TIME (YRS)
 SCT - SOLAR CONSTRUCTION TIME (YRS)

DAPSCW1.KL=IAPSCW.K*(1-(SCT/PT)) 231, R
 DAPSCW1=0 231.1, N
 DAPSCW1 - DELAYED ADDITIONAL PLANNED
 SOLAR CAPACITY- WEST (MW/YR)
 IAPSCW - INDICATED ADDITIONAL PLANNED
 SOLAR CAPACITY- WEST (MW/YR)
 SCT - SOLAR CONSTRUCTION TIME (YRS)
 PT - PROJECTION TIME (YRS)

TDFW.K=CDF.K+PDF.K+NDF.K+GDFW.K+SDFW.K 232, A
 TDFW - TOTAL DEMAND FACTOR- WEST
 (DIMENSIONLESS)
 CDF - COAL DECISION FACTOR (DIMENSION-
 LESS)
 PDF - PETROLEUM DECISION FACTOR (DIMEN-
 SIONLESS)
 NDF - NUCLEAR DECISION FACTOR (DIMEN-
 SIONLESS)
 GDFW - GEOTHERMAL DECISION FACTOR- WEST
 (DIMENSIONLESS)
 SDFW - SOLAR DECISION FACTOR- WEST
 (DIMENSIONLESS)

DW.K=TABLE(TPDW,TIME.K,1970,2010,5)*1E3 233, A
 DW - DEMAND- WEST (MW/YR)

DE.K=TABLE(TPDE,TIME.K,1970,2010,5)*1E3 234, A
 DE - DEMAND- EAST (MW/YR)

CONTROL CARDS

DT=1 235.1, C
 LENGTH=0 235.2, C
 PRTPER=3 235.3, C
 PLTPER=0 235.4, C
 DT - LENGTH OF SOLUTION INTERVAL
 (YRS)
 LENGTH - LENGTH OF MODEL RUN (YRS)
 PRTPER - PRINT INTERVAL (YRS)
 PLTPER - PLOT INTERVAL (YRS)

2. Model Listing

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* THE FUTURES GROUP- GEOTHERMAL
MACRO BOXC(IN,DEL,N1,N2,N3,N4,N5,N6,N7,N8,N9,N10)
R $V10.KL=$V9.JK
R $V9.KL=$V8.JK
R $V8.KL=$V7.JK
R $V7.KL=$V6.JK
R $V6.KL=$V5.JK
R $V5.KL=$V4.JK
R $V4.KL=$V3.JK
R $V3.KL=$V2.JK
R $V2.KL=$V1.JK
R $V1.KL=IN
N $V10=N10
N $V9=N9
N $V8=N8
N $V7=N7
N $V6=N6
N $V5=N5
N $V4=N4
N $V3=N3
N $V2=N2
N $V1=N1
A $BOXC2.K=FIFGE($V2.JK,$V1.JK,DEL,1)
A $BOXC3.K=FIFGE($V3.JK,$BOXC2.K,DEL,2)
A $BOXC4.K=FIFGE($V4.JK,$BOXC3.K,DEL,3)
A $BOXC5.K=FIFGE($V5.JK,$BOXC4.K,DEL,5)
A $BOXC6.K=FIFGE($V6.JK,$BOXC5.K,DEL,6)
A $BOXC7.K=FIFGE($V7.JK,$BOXC6.K,DEL,7)
A $BOXC8.K=FIFGE($V8.JK,$BOXC7.K,DEL,8)
A $BOXC9.K=FIFGE($V9.JK,$BOXC8.K,DEL,9)
A $BOXC.K=FIFGE($V10.JK,$BOXC9.K,DEL,10)
MEND
N TIME=1973
NOTE
NOTE RESOURCES
NOTE
A RAW.K=TABLE(TRAU,TIME.K,1970,2015,15)
T TRAU=400/7000/160000/306000
A RAE.K=TABLE(TRAU,TIME.K,1985,2015,15)
T TRAE=3000/40000/80000
NOTE
NOTE EAST DEMAND-SUPPLY
NOTE
A TYCDE.K=PTYDE.K-PAPSE.K
A PTYDE.K=TABLE(TPDE,TPPT.K,1970,2010,5)*1E3
T TPDE=109/374.5/536/710/1005/1281/1558/2045/2532
A TPPT.K=TIME.K+PT
C PT=10
A PAPSE.K=(PRCAPE.K+PLCAPE.K)
A PRCAPE.K=PRCCAPE.K+PRPCAPE.K+NUCCAPE.K+GEOCAPE.K+SCAPE.K+PRHCAPE.K+
X PRNGCAPE.K+IMPCAPE.K
A PRCCAPE.K=CCAPE.K*(1-(PT*.025))
A PRPCAPE.K=PETCAPE.K*(1-(PT*.025))
A PRHCAPE.K=TABLE(THCAPE,TPPT.K,1970,2010,5)*1E3
A PRNGCAPE.K=TABLE(TNGCAPE,TPPT.K,1970,2010,5)*1E3
A PCAPE.K=CCAPE.K+PETCAPE.K+NUCCAPE.K+GEOCAPE.K+IMPCAPE.K+SCAPE.K+
X HCAPE.K+NGCAPE.K
L CCAPE.K=CCAPE.K+DT*(CARE.JK-CRRE.JK)
N CCAPE=137.5E3
R CRRE.KL=CCAPE.K/40
R CARE.KL=BOXC(NPCC.E,K,6,4384,11099,8884,11106,9569,14343,0,0,0,0)
C CCT=6
L PETCAPE.K=PETCAPE.J+DT*(PARE.JK-PRRE.JK)
N PETCAPE=50.4E3
R PRRE.KL=PETCAPE.K/40
R PARE.KL=BOXC(NPPCE.K,5,5553,7375,7435,8331,3333,0,0,0,0,0)
C PCT=5
L NUCCAPE.K=NUCCAPE.J+DT*(NARE.JK)
N NUCCAPE=12.5E3
R NARE.KL=BOXC(NPNCE.K,(NCT.K),8324,6503,30910,19546,13678,11825,
X 4952,9801,13560,14001)
A NCT.K=TABLE(TNCT,TIME.K,1970,2000,30)

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10210

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T	TNCT=10/6	10211
L	GEOCAPE.K=GEOCAPE.J+DT*(GARE.JK-GRRE.JK)	10220
N	GEOCAPE=0	10221
R	GRRE.KL=FIFGE((GEOCAPE.K/GRT.K),0,TIME.K,2000)	10230
A	GRT.K=TABLE(TGRR,TIME.K,1970,2000,15)	10240
T	TGRR=40/50/50	10241
R	GARE.KL=BOXC(NPGCE.K,2,0,0,0,0,0,0,0,0,0,0)	10250
C	GCT=3	10251
L	IMPCAPE.K=IMPCAPE.J+DT*(IARE.JK)	10260
N	IMPCAPE=0	10261
R	IARE.KL=BOXC(NPICE.K,6,0,0,0,0,0,0,0,0,0,0)	10270
C	ICT=6	10271
L	SCAPE.K=SCAPE.J+DT*(SARE.JK-SRRE.JK)	10280
N	SCAPE=0	10281
R	SRRE.KL=SCAPE.K/SRT	10290
C	SRT=40	10291
R	SARE.KL=BOXC(NPSCE.K,8,0,0,0,0,0,0,0,0,0,0)	10300
C	SCT=8	10301
A	HCAPE.K=TABLE(THCAPE,TIME.K,1970,2010,5)*1E3	10310
T	THCAPE=21.9/20.2/23/25/27/30/32/34/36	10311
A	NGCAPE.K=TABLE(TNGCAPE,TIME.K,1970,2010,5)*1E3	10320
T	TNGCAPE=55/42.7/37.1/30/24.4/20.4/16.2/14/12	10321
A	PLCAPE.K=PCCE.K+PPCE.K+PNCE.K+PGCE.K+PICE.K+PSCE.K	10330
L	PCCE.K=PCCE.J+DT*(APCCE.JK-CARE.JK+DAPCCE1.JK)	10340
N	PCCE=49.7E3	10341
R	APCCE.KL=IAPCCE.K*(CCT/PT)	10350
A	NPCCF.K=IAPCCE.K*(CCT/PT)+DAPCCE.K	10360
A	DAPCCE.K=BOXC(DAPCCE1.JK,(PT-CCT-2),0,0,0,0,0,0,0,0,0,0)	10370
R	DAPCCE1.KL=IAPCCE.K*(1-(CCT/PT))	10380
N	DAPCCE1=0	10381
A	IAPCCE.K=MAX(0,(((CDF.K/TDFE.K)*TYCGE.K)+(CAFGSFE.K)))	10390
A	CAFGSFE.K=AFGSFE.K*(CDF.K/(CDF.K+PDF.K+NDF.K))	10400
A	CDF.K=RF*CR.K+CIF*CCI.K+ECF*CEC.K+CEF*CCE.K+FAF*CFA.K+CDLF*CDT	10410
C	RF=.5	10411
C	CIF=1	10412
C	ECF=.6	10413
C	CEF=1	10414
C	FAF=2	10415
C	CDLF=.1	10416
A	CR.K=TABLE(TCR,TIME.K,1970,2000,15)	10420
T	TCR=.8/.7/.7	10421
A	CCIC.K=ICIC.K/CCIC.K	10430
A	CCIC.K=TABLE(TCCIC,(TIME.K+10),1970,2010,5)	10440
T	TCCIC=240/359/550/615/662/713/768/828/892	10441
A	CEC.K=TABLE(TCEC,TIME.K,1970,2000,30)	10450
T	TCEC=.5/.8	10451
A	CCE.K=AGCE.K/ACCE.K	10460
A	ACCE.K=TABLE(TACCE,(TIME.K+10),1970,2010,5)	10470
T	TACCE=11.7/18/21/23.3/25.8/28.7/31.8/35.2/39.1	10471
A	CFA.K=TABLE(TCFA,TIME.K,1970,2000,15)	10480
T	TCFA=.95/.95/.95	10481
C	CDT=.5	10482
L	PPCE.K=PPCE.J+DT*(APPCE.JK-PARE.JK+DAPPCE1.JK)	10490
N	PPCE=33.5E3	10491
R	APPCE.KL=(IAPPCE.K*(PCT/PT))	10500
A	NPPCE.K=(IAPPCE.K*(PCT/PT))+DAPPCE.K	10510
A	DAPPCE.K=BOXC(DAPPCE1.JK,(PT-PCT-2),0,0,0,0,0,0,0,0,0,0)	10520
R	DAPPCE1.KL=IAPPCE.K*(1-(PCT/PT))	10530
N	DAPPCE1=0	10531
A	IAPPCE.K=MAX(0,(((PDF.K/TDFE.K)*TYCGE.K)+(PAFGSFE.K)))	10540
A	PAFGSFE.K=AFGSFE.K*(PDF.K/(CDF.K+PDF.K+NDF.K))	10550
A	PDF.K=(RF*PR.K+CIF*PCI.K+ECF*PEC.K+CEF*PCE.K+FAF*PFA.K+CDLF*PDT)*	10560
X	PFAM.K	10561
A	PR.K=TABLE(TPR,TIME.K,1970,2000,15)	10570
T	TPR=.9/.9/.9	10571
A	PCI.K=ICIC.K/PCIC.K	10580
A	PCIC.K=TABLE(TPCIC,(TIME.K+10),1970,2010,5)	10590
T	TPCIC=220/260/299/332/358/386/416/447/482	10591
A	PEC.K=TABLE(TPEC,TIME.K,1970,2000,30)	10600
T	TPEC=.7/.85	10601
A	PCE.K=AGCE.K/APCE.K	10610
A	APCE.K=TABLE(TAPCE,(TIME.K+10),1970,2010,5)	10620
T	TAPCE=21/22.7/26.6/29.8/33.4/37.5/42.0/47.1/52.8	10621
A	PFA.K=TABLE(TPFA,TIME.K,1970,2000,15)	10630
T	TPFA=.75/.4/.2	10631
A	PFAM.K=TABHL(TPFAM,PFA.K,.5,.6,.1)	10640
T	TPFAM=0/1	10641

C	PDT=.6	10642
L	PNCE.K=PNCE.J+DT*(APNCE.JK-NARE.JK+DAPNCE1.JK)	10650
N	PNCE=183.6E3	10651
R	APNCE.KL=(IAPNCE.K*(NCT.K/PT))	10660
A	NPNC.E.K=(IAPNCE.K*(NCT.K/PT))+DAPNCE.K	10670
A	DAPNCE.K=BOXC(DAPNCE1.JK,(PT-NCT.K-2),0,0,0,0,0,0,0,0,0,0)	10680
R	DAPNCE1.KL=IAPNCE.K*(1-(NCT.K/PT))	10690
N	DAPNCE1=0	10691
A	IAPNCE.K=MAX(0,((NDF.K/TDFE.K)*TYCGE.K)+(NAFGSFE.K))	10700
A	NAFGSFE.K=AFGSFE.K*(NDF.K/(CDF.K+PDF.K+NDF.K))	10710
A	NDF.K=RF*NR.K+CIF*NCI.K+ECF*NEC.K+CEF*NCE.K+FAF*NFA.K+CDLF*NDT.K	10720
A	NR.K=TABLE(TNR,TIME.K,1970,2000,15)	10730
T	TNR=.6/.9/.9	10731
A	NCI.K=ICIC.K/NCIC.K	10740
A	NCIC.K=TABLE(TNCIC,(TIME.K+10),1970,2010,5)	10750
T	TNCIC=354/385/615/734/791/852/918/989/1065	10751
A	NEC.K=TABLE(TNEC,TIME.K,1970,2000,30)	10760
T	TNEC=.9/.9	10761
A	NCE.K=AGCE.K/ANCE.K	10770
A	ANCE.K=TABLE(TANCE,(TIME.K+10),1970,2010,5)	10780
T	TANCE=12/18/19/20.9/22.9/24.9/27.0/29.4/32	10781
A	NFA.K=TABLE(TNFA,TIME.K,1970,2000,15)	10790
T	TNFA=1/.95/.95	10791
A	NDT.K=GCT/NCT.K	10800
L	PGCE.K=PGCE.J+DT*(APGCE.JK-GARE.JK+DAPGCE1.JK+DAPGCE2.JK)	10810
N	PGCE=0	10811
R	APGCE.KL=IAPGCE.K*(MIN(1,(GRAFCAE.K/INPGCE.K)))	10820
N	APGCE=0	10821
A	IAPGCE.K=(IAPGCE1.K*(GCT/PT))	10830
A	NPNGCE.K=IAPGCE.K*(MIN(1,RAME.K))+DAPGCE.K	10840
A	RAME.K=MIN((GRAFCAE.K/INPGCE.K),(MIN((GRACAE6.K/(IAPGCE1.K*2/3)),	10850
X	(GRACAE9.K/IAPGCE1.K)))	10851
A	INPGCE.K=MAX(.01,((IAPGCE1.K*(GCT/PT))+DAPGCE.K))	10860
A	DAPGCE.K=BOXC(DAPGCE1.JK,(PT-(2*GCT)-2),0,0,0,0,0,0,0,0,0,0)+	10870
X	BOXC(DAPGCE2.JK,(PT-GCT-2),0,0,0,0,0,0,0,0,0,0)	10871
R	DAPGCE1.KL=IAPGCE1.K*(GCT/PT)*(MIN(1,RAME.K))	10880
N	DAPGCE1=0	10881
R	DAPGCE2.KL=(IAPGCE1.K-(IAPGCE1.K*2*GCT/PT))*(MIN(1,RAME.K))	10890
N	DAPGCE2=0	10891
A	IAPGCE1.K=MAX(.01,((GDFE.K/TDFE.K)*TYCGE.K))	10900
A	GRAFCAE.K=MAX(0,((PRAE.K-GEOCAPE.K-(PGCE.K/GCT))/1))	10910
A	GRACAE6.K=MAX(0,((PRAE6.K-GEOCAPE.K-(PGCE.K*2/GCT))/1))	10920
A	GRACAE9.K=MAX(0,((PRAE9.K-GEOCAPE.K-PGCE.K)/1))	10930
A	PRAE.K=TABHL(TRAE,TPGCT.K,1985,2015,15)	10940
A	TPGCT.K=TIME.K+GCT	10950
A	PRAE6.K=TABHL(TRAE,TP2GCT.K,1985,2015,15)	10960
A	TP2GCT.K=TIME.K+(2*GCT)	10970
A	PRAE9.K=TABHL(TRAE,TP3GCT.K,1985,2015,15)	10980
A	TP3GCT.K=TIME.K+(3*GCT)	10990
A	GEOSFE.K=INPGCE.K-GRAFCAE.K	11000
A	AFGSFE.K=MAX(GEOSFE.K,0)	11010
A	GDFE.K=FIGE(IIGDFE.K,0,TIME.K,1985)	11020
A	IIGDFE.K=(RF*GR.K+CIF*GCI.K+ECF*GEC.K+CEF*GCE.K+FAF*GFA.K+CDLF*GDT)*	11030
X	LFE.K	11031
A	LFE.K=TABHL(TLF,TIME.K,1985,1995,1)	11040
A	GDFW.K=(RF*GR.K+CIF*GCI.K+ECF*GEC.K+CEF*GCE.K+FAF*GFA.K+CDLF*GDT)*	11050
X	LFW.K	11051
A	LFW.K=TABHL(TLF,TIME.K,1970,1980,1)	11060
T	TLF=0/.04/.10/.18/.30/.50/.70/.82/.90/.96/1.0	11061
A	GR.K=TABLE(TGR,TIME.K,1970,2000,15)	11070
T	TGR=.7/.7/.8	11071
A	GCI.K=ICIC.K/GCIC.K	11080
A	GCIC.K=TABLE(TGCIC,(TIME.K+10),1970,2010,5)	11090
T	TGCIC=264/272/292/315/339/365/394/424/456	11091
A	GEC.K=TABLE(TGEC,TIME.K,1970,2000,30)	11100
T	TGEC=.75/.9	11101
A	GCE.K=ONE	11110
A	AGCE.K=TABLE(TAGCE,(TIME.K+10),1970,2010,5)	11120
T	TAGCE=7/8/9.3/10.4/11.6/13.0/14.5/16.2/18.1	11121
A	GFA.K=TABLE(TGFA,TIME.K,1970,2000,15)	11130
T	TGFA=.75/.75/.95	11131
C	GDT=1	11132
L	PICE.K=PICE.J+DT*(APICE.JK-IARE.JK+DAPICE1.JK)	11140
N	PICE=0	11141
R	APICE.KL=MAX(0,((IDF.K/TDFE.K)*TYCGE.K/(PT/ICT)))	11150
A	NPICE.K=(IDF.K/TDFE.K)*TYCGE.K*(ICT/PT)+DAPICE2.K	11160
A	DAPICE2.K=BOXC(DAPICE1.JK,(PT-ICT-2),0,0,0,0,0,0,0,0,0,0)	11170

A	DAPICE1.KL=(IDF.K/TOFE.K)*TYCGE.K*(1-(ICT/PT))	11180
N	DAPICE1=0	11181
A	IDF.K=FIFGE(IIDF.K,0,TIME.K,IMPYEAR)*POSDFM.K	11190
C	IMPYEAR=1985	11191
A	POSDFM.K=TABHL(TPOSDFM,IMPR.K,0,.05,.005)	11200
T	TPOSDFM=1/1/1/1/1/1/9/7/5/3/1/0	11201
A	IMPR.K=(IMPCAPE.K+PICE.K)/PAPSE.K	11210
A	IIDF.K=FIFGE(I0,IIDF1.K,GEOSFWL.JK,0)	11220
A	IIDF1.K=FIFGE((-1*GEOSFWL.JK*TDDEL.JK/TYCGE.K),IIDF2.K,	11230
X	(IIDF2.K*TYCGE.K/TDDEL.JK),(-1*GEOSFWL.JK))	11231
A	IIDF2.K=(RF*IMR.K+CIF*ICI.K+ECF*IEC.K+CEF*ICE.K+FAF*IFA.K+CDLF*IDT)*	11240
X	ILF.K	11241
A	ILF.K=TABHL(TLF,TIME.K,1985,1995,1)	11250
A	IMR.K=TABLE(TIMR,TIME.K,1970,2000,15)	11260
T	TIMR=1/1/1	11261
A	ICI.K=ONE	11270
C	ONE=1	11271
A	ICIC.K=TABLE(TICIC,(TIME.K+10),1970,2010,5)	11280
T	TICIC=391/403/433/467/503/542/583/629/677	11281
A	IEC.K=TABLE(TIEC,TIME.K,1970,2000,30)	11290
T	TIEC=1/1	11291
A	ICE.K=AGCE.K/AICE.K	11300
A	AICE.K=TABLE(TAICE,(TIME.K+10),1970,2010,5)	11310
T	TAICE=14.5/16.3/17.6/19.3/21.2/23.3/25.7/28.3/31.1	11311
A	IFA.K=TABLE(TIFA,TIME.K,1970,2000,15)	11320
T	TIFA=1/1/1	11321
C	IDT=.5	11322
L	PSCE.K=PSCE.J+DT*(APSCE.JK-SARE.JK+DAPSCE1.JK)	11330
N	PSCE=0	11331
R	APSCE.KL=(IAPSCE.K*(SCT/PT))	11340
A	NPSCF.K=(IAPSCE.K*(SCT/PT))+DAPSCE.K	11350
A	DAPSCF.K=BOXC(DAPSCE1.JK,(PT-SCT-2),0,0,0,0,0,0,0,0,0,0)	11360
R	DAPSCE1.KL=IAPSCE.K*(1-(SCT/PT))	11370
N	DAPSCE1=0	11371
A	IAPSCF.K=MAX(0,((ISDFE.K/TOFE.K)*TYCGE.K))	11380
A	ISDFE.K=FIFGE(ISDFE.K,0,TIME.K,SAT)	11390
A	SDFW.K=FIFGE(ISDFW.K,0,TIME.K,SAT)	11400
C	SAT=1987	11401
A	ISDFE.K=(RF*SR.K+CIF*SCIE.K+ECF*SEC.K+CEF*SCEE.K+FAF*SFA.K+CDLF*	11410
X	SDT)*SLF.K*SCEEL.K	11411
A	ISDFW.K=(RF*SR.K+CIF*SCIW.K+ECF*SEC.K+CEF*SCEW.K+FAF*SFA.K+CDLF*	11420
X	SDT)*SLF.K*SCEWL.K	11421
A	SLF.K=TABHL(TSLF,TIME.K,1985,1994,1)	11430
T	TSLF=.1/.2/.3/.4/.5/.6/.7/.8/.9/1.0	11431
A	SR.K=TABHL(TSR,TIME.K,1985,2000,15)	11440
T	TSR=.55/.65	11441
A	SCIE.K=ICIC.K/SCICE.K	11450
A	SCICE.K=TABHL(TSCICE,(TIME.K+10),1985,2000,15)	11460
T	TSCICE=3000/2000	11461
A	SCIW.K=ICIC.K/SCICW.K	11470
A	SCICW.K=TABHL(TSCICW,(TIME.K+10),1985,2000,15)	11480
T	TSCICW=1500/1000	11481
A	SEC.K=TABLE(TSEC,TIME.K,1970,2000,30)	11490
T	TSEC=.8/.8	11491
A	SCEE.K=AGCE.K/ASCEE.K	11500
A	ASCEE.K=TABHL(TASCEE,(TIME.K+10),1990,2000,5)	11510
T	TASCEE=196/180/180	11511
A	SCEEL.K=TABHL(TDFLM,SCEE.K,0,.5,.1)	11520
T	TDFLM=0/.05/.2/.4/.8/1	11521
A	SCEW.K=AGCE.K/ASCEW.K	11530
A	ASCEW.K=TABHL(TASCEW,(TIME.K+10),1990,2000,5)	11540
T	TASCEW=98/90/90	11541
A	SCEWL.K=TABHL(TDFLM,SCEW.K,0,.5,.1)	11550
A	SFA.K=TABLE(TSFA,TIME.K,1970,2000,30)	11560
T	TSFA=1/1	11561
C	SDT=.375	11562
A	TOFE.K=CDF.K+PDF.K+NDF.K+GDFE.K+IDF.K+SDFE.K	11570
R	TDDEL.KL=TOFE.K	11580
N	TDDEL=22	11581
NOTE		11582
NOTE	WEST DEMAND-SUPPLY	11583
NOTE		11584
A	TYCGW.K=PTYDW.K-PAPSW.K	11590
A	PTYDW.K=TABLE(TPDW,TPPT.K,1970,2010,5)*1E3	11600
T	TPDW=44/94/129/181/255/340/406/533/660	11601
A	PAPSW.K=(PRCAPW.K+PLCAPW.K)-IMPCAPE.K	11610
A	PRCAPW.K=PRCCAPW.K+PRPCAPW.K+NUCCAPW.K+GEOCAPW.K+SCAPW.K+	11620

X	PRHCAW.K+PRNGCPW.K	11621
A	PRCCAPW.K=CCAPW.K*(1-(PT*.025))	11630
A	PRPCAPW.K=PETCAPW.K*(1-(PT*.025))	11640
A	PRHCAW.K=TABLE(THCAW,TPPT,K,1970,2010,5)*1E3	11650
A	PRNGCPW.K=TABLE(TNGCAW,TPPT,K,1970,2010,5)*1E3	11660
S	PCAPW.K=CCAPW.K+PETCAPW.K+NUCCAPW.K+GEOCAPW.K+SCAPW.K+HCAW.K+	11670
X	NGCAW.K	11671
L	CCAPW.K=CCAPW.J+DT*(CARW.JK-CRRW.JK)	11680
N	CCAPW=13.2E3	11681
R	CRRW.KL=CCAPW.K/40	11690
R	CARW.KL=BOXC(NPCCW.K,6,360,1522,2521,1100,1100,400,0,0,0,0)	11700
L	PETCAPW.K=PETCAPW.J+DT*(PARW.JK-PRRW.JK)	11710
N	PETCAPW=6.5E3	11711
R	PRRW.KL=PETCAPW.K/40	11720
R	PARW.KL=BOXC(NPPCW.K,5,240,239,300,60,379,0,0,0,0,0)	11730
L	NUCCAPW.K=NUCCAPW.J+DT*(NARW.JK)	11740
N	NUCCAPW=1.6E3	11741
R	NARW.KL=BOXC(NPNCW.K,(NCT.K),765,1767,0,3332,2199,0,2183,1066,916,	11750
X	0)	11751
L	GEOCAPW.K=GEOCAPW.J+DT*(GARW.JK-GRRW.JK)	11760
N	GEOCAPW=396	11761
R	GRRW.KL=FI(FGE((GEOCAPW.K/GRT.K),0,TIME.K,2000)	11770
R	GARW.KL=BOXC(NPGCW.K,2,124,106,106,0,0,0,0,0,0,0)	11780
L	SCAPW.K=SCAPW.J+DT*(SARW.JK-SRRW.JK)	11790
N	SCAPW=0	11791
R	SRRW.KL=SCAPW.K/SRT	11800
R	SARW.KL=BOXC(NPSCW.K,8,0,0,0,0,0,0,0,0,0,0)	11810
A	HCAW.K=TABLE(THCAW,TIME,K,1970,2010,5)*1E3	11820
T	THCAW=29.7/35/42/47/52/55/58/61/64	11821
A	NGCAW.K=TABLE(TNGCAW,TIME,K,1970,2010,5)*1E3	11830
T	TNGCAW=22/18.7/16.2/13/10.5/8.7/7/6/5	11831
A	PLCAW.K=PCCW.K+PPCW.K+PNCW.K+PGCW.K+PSCW.K	11840
L	PCCW.K=PCCW.J+DT*(APCCW.K-CARW.JK+DAPCCW1.K)	11850
N	PCCW=9.7E3	11851
R	APCCW.KL=IAPCCW.K*(CCT/PT)	11860
A	NPCCW.K=IAPCCW.K*(CCT/PT)+DAPCCW.K	11870
A	DAPCCW.K=BOXC(DAPCCW1.K,(PT-CCT-2),0,0,0,0,0,0,0,0,0,0)	11880
R	DAPCCW1.KL=IAPCCW.K*(1-(CCT/PT))	11890
N	DAPCCW1=0	11891
A	IAPCCW.K=MAX(0,(((CDF.K/TDFW.K)*TYCGW.K)+CAFGSFW.K))	11900
A	CAFGSFW.K=AFGSFW.K*(CDF.K/(CDF.K+PDF.K+NDF.K))	11910
L	PPCW.K=PPCW.J+DT*(APPCW.K-PARW.JK+DAPPCW1.K)	11920
N	PPCW=.4E3	11921
R	APPCW.KL=(IAPPCW.K*(PCT/PT))	11930
A	NPPCW.K=(IAPPCW.K*(PCT/PT))+DAPPCW.K	11940
A	DAPPCW.K=BOXC(DAPPCW1.K,(PT-PCT-2),0,0,0,0,0,0,0,0,0,0)	11950
R	DAPPCW1.KL=IAPPCW.K*(1-(PCT/PT))	11960
N	DAPPCW1=0	11961
A	IAPPCW.K=MAX(0,(((PDF.K/TDFW.K)*TYCGW.K)+PAFGSFW.K))	11970
A	PAFGSFW.K=AFGSFW.K*(PDF.K/(CDF.K+PDF.K+NDF.K))	11980
L	PNCW.K=PNCW.J+DT*(APNCW.K-NARW.JK+DAPNCW1.K)	11990
N	PNCW=15.7E3	11991
R	APNCW.KL=IAPNCW.K*(NCT.K/PT)	12000
A	NPNCW.K=IAPNCW.K*(NCT.K/PT)+DAPNCW.K	12010
A	DAPNCW.K=BOXC(DAPNCW1.K,(PT-NCT.K-1),0,0,0,0,0,0,0,0,0,0)	12020
R	DAPNCW1.KL=IAPNCW.K*(1-(NCT.K/PT))	12030
N	DAPNCW1=0	12031
A	IAPNCW.K=MAX(0,(((NDF.K/TDFW.K)*TYCGW.K)+NAFGSFW.K))	12040
A	NAFGSFW.K=AFGSFW.K*(NDF.K/(CDF.K+PDF.K+NDF.K))	12050
L	PGCW.K=PGCW.J+DT*(APGCW.K-GARW.JK+DAPGCW1.K+DAPGCW2.K)	12060
N	PGCW=1831	12061
R	APGCW.KL=IAPGCW.K*(MIN(1,(GRAFCW.K/INPGCW.K)))	12070
N	APGCW=110	12071
A	IAPGCW.K=(IAPGCW1.K*(GCT/PT))	12080
A	NPGCW.K=(IAPGCW.K*(MIN(1,RAM.K)))+DAPGCW.K+DAPICE.K	12090
A	RAM.K=MIN((GRAFCW.K/INPGCW.K),(MIN((GRACAW6.K/(IAPGCW1.K*2/3)),	12100
X	(GRACAW9.K/IAPGCW1.K)))	12101
A	INPGCW.K=MAX(.01,((IAPGCW1.K*(GCT/PT))+DAPICE.K+DAPGCW.K))	12110
A	DAPGCW.K=BOXC(DAPGCW1.K,(PT-(GCT*2)-2),307,262,300,0,0,0,0,0,0,0)	12120
X	BOXC(DAPGCW2.K,(PT-GCT-1),0,322,277,0,0,0,0,0,0,0)	12121
R	DAPGCW1.KL=IAPGCW1.K*(GCT/PT)*(MIN(1,RAM.K))	12130
N	DAPGCW1=0	12131
R	DAPGCW2.KL=(IAPGCW1.K-(IAPGCW1.K*(2*GCT/PT)))*MIN(1,RAM.K)	12140
N	DAPGCW2=0	12141
A	GRAFCW.K=MAX(0,((PRAW.K-GEOCAPW.K-(PGCW.K/GCT)-(PICE.K/GCT))/1))	12150
A	GRACAW6.K=MAX(0,((PRAW6.K-GEOCAPW.K-(PGCW.K*2/GCT)-(PICE.K*2/GCT))/1))	12160

X)	12161
A GRACAW9,K=MAX(0,((PRAW9,K-GEOCAPW,K-PGCW,K-PICE,K)/1))	12170
A PRAW,K=TABLE(TRAU,TPGCT,K,1970,2015,15)	12180
A PRAW6,K=TABLE(TRAU,TP2GCT,K,1970,2015,15)	12190
A PRAW9,K=TABLE(TRAU,TP3GCT,K,1970,2015,15)	12200
A IAPGCW1,K=MAX(.01,((GDFW,K/TDFW,K)*TYCGW,K))	12210
A DAPICE,K=BOXC(NPICE,K,(ICT-GCT-1),0,0,0,0,0,0,0,0,0)	12220
A GEOSFW,K=INPGCW,K-GRAFCW,K	12230
R GEOSFWL,KL=GEOSFW,K	12240
N GEOSFWL=0	12241
A AFGSFW,K=MAX(GEOSFW,K,0)	12250
L PSCW,K=PSCW,J+DT*(APSCW,JK-SARW,JK+DAPSCW1,JK)	12260
N PSCW=0	12261
R APSCW,KL=(IAPSCW,K*(SCT/PT))	12270
A NPSCW,K=(IAPSCW,K*(SCT/PT))+DAPSCW,K	12280
A IAPSCW,K=MAX(0,((SDFW,K/TDFW,K)*TYCGW,K))	12290
A DAPSCW,K=BOXC(DAPSCW1,JK,(PT-SCT-2),0,0,0,0,0,0,0,0,0)	12300
R DAPSCW1,KL=IAPSCW,K*(1-(SCT/PT))	12310
N DAPSCW1=0	12311
A TDFW,K=CDF,K+PDF,K+NDF,K+GDFW,K+SDFW,K	12320
NOTE MACRO	12321
NOTE	12322
A DW,K=TABLE(TPDW,TIME,K,1970,2010,5)*1E3	12330
A DE,K=TABLE(TPDE,TIME,K,1970,2010,5)*1E3	12340
NOTE	12341
NOTE CONTROL CARDS	12342
NOTE	12343
PRINT 1)CCAPE,CCAPW/2)PETCAPE,PETCAPW/3)NUCCAPE,NUCCAPW/	12344
PRINT 4)GEOCAPE,GEOCAPW/5)SCAPE,SCAPW/6)HCAPE,HCAPW/	12345
PRINT 7)NGCAPE,NGCAPW/8)IMPCAPE,*	12346
PLOT CCAPW=C,PETCAPW=P,NUCCAPW=N,GEOCAPW=G,SCAPW=S,HCAPW=H,NGCAPW=M	12347
X (0,200E3)	12348
PLOT CCAPE=C,PETCAPE=P,NUCCAPE=N,GEOCAPE=G,SCAPE=S,HCAPE=H,NGCAPE=M,	12349
X IMPCAPE=I(0,800E3)	12350
C DT=1	12351
C LENGTH=0	12352
C PRTPER=3	12353
C PLTPER=0	12354
RUN BASE RUN	12360

3. Variable Name Definitions

	NO	T	DEFINITION	WHERE USED
ACCE	47	A	ACTUAL COAL COST OF ELECTRICITY (MILLS/KWHR)	CCE,A,46
AFGSFE	101	A	ADJUSTMENT FOR GEOTHERMAL SHORTFALL- EAST (MW/YR)	CAFGSFE,A,40/PAFGSFE,A,55/NAFGSFE,A,71
AFGSFW	225	A	ADJUSTMENT FOR GEOTHERMAL SHORTFALL- WEST (MW/YR)	CAFGSFW,A,191/PAFGSFW,A,198/NAFGSFW,A,205
AGCE	112	A	ACTUAL GEOTHERMAL COST OF ELECTRICITY (MILLS/KWHR)	CCE,A,46/PCE,A,61/NCE,A,77/ICE,A,130/SCEE,A,150/SCEW,A,153
AICE	131	A	ACTUAL IMPORT COST OF ELECTRICITY (MILLS/KWHR)	ICE,A,130
ANCE	78	A	ACTUAL NUCLEAR COST OF ELECTRICITY (MILLS/KWHR)	NCE,A,77
APCCE	35	R	ADDITIONAL PLANNED COAL CAPACITY- EAST (MW/YR)	PCCE,L,34
APCCW	186	R	ADDITIONAL PLANNED COAL CAPACITY- WEST (MW/YR)	PCCW,L,185
APCE	62	A	ACTUAL PETROLEUM ELECTRICITY COST (MILLS/KWHR)	PCE,A,61
APGCE	82	R	ADDITIONAL PLANNED GEOTHERMAL CAPACITY-EAST (MW/YR)	PGCE,L,81
APGCW	207.1	R	ADDITIONAL PLANNED GEOTHERMAL CAPACITY-WEST (MW/YR)	PGCW,L,206
APICE	115	R	ADDITIONAL PLANNED IMPORT CAPACITY- EAST (MW/YR)	PICE,L,114
APNCE	66	R	ADDITIONAL PLANNED NUCLEAR CAPACITY- EAST (MW/YR)	PNCE,L,65
APNCW	200	R	ADDITIONAL PLANNED NUCLEAR CAPACITY- WEST (MW/YR)	PNCW,L,199
APPCE	50	R	ADDITIONAL PLANNED PETROLEUM CAPACITY- EAST (MW/YR)	PPCE,L,49
APPCW	193	R	ADDITIONAL PLANNED PETROLEUM CAPACITY- WEST (MW/YR)	PPCW,L,192
APSCE	134	R	ADDITIONAL PLANNED SOLAR CAPACITY- EAST (MW)	PSCE,L,133
APSCW	227	R	ADDITIONAL PLANNED SOLAR CAPACITY- WEST (MW)	PSCW,L,226
ASCEE	151	A	ACTUAL SOLAR COST OF ELECTRICITY- EAST (MILLS/KWHR)	SCEE,A,150
ASCEW	154	A	ACTUAL SOLAR COST OF ELECTRICITY- WEST (MILLS/KWHR)	SCEW,A,153
BOXC	20	A	FUNCTION THAT DELAYS VARIABLE (1) FOR A PERIOD OF VARIABLE (2)	CARE,R,15/PARE,R,18/NARE,R,20/GARE,R,25/IARE,R,27/SARE,R,30/DAPCCE,A,37/DAPPCW,A,52/DAPNCE,A,68/DAPGCE,A,87/DAPICE,A,117/DAPSCCE,A,136/CARW,R,176/PARW,R,173/NARW,R,175/GARW,R,178/SARW,R,181/DAPCCW,A,188/DAPPCW,A,195/DAPNCW,A,202/DAPGCW,A,212/DAPICE,A,222/DAPSCW,A,230 IAPCCE,A,39
CAFGSFE	40	A	COAL ADJUSTMENT FOR GEOTHERMAL SHORT-FALL- EAST (MW/YR)	IAPCCW,A,190
CAFGSFW	191	A	COAL ADJUSTMENT FOR GEOTHERMAL SHORT-FALL- WEST (MW/YR)	CCAPF,L,13/PCCF,L,34 CCAPW,L,168/PCCW,L,185 PRCCAPE,A,8/PCAPE,A,12/CRRE,R,14 PRCCAPW,A,163/PCAPW,S,167/CRRW,R,169
CARE	15	R	COAL ADDITION RATE- EAST (MW/YR)	CCDF,A,41
CARW	170	R	COAL ADDITION RATE- WEST (MW/YR)	CCDF,A,41
CCAPE	13	L	COAL CAPACITY- EAST (MW)	CCI,A,43
CCAPW	168	L	COAL CAPACITY- WEST (MW)	APCCE,R,35/NPCCE,A,36/DAPCCE,A,37/DAPCCCE1,R,38/APCCW,R,186 NPCCW,A,187/DAPCCW,A,188/DAPCCW1,R,189
CCE	46	A	COAL COST OF ELECTRICITY (DIMENSIONLESS)	IAPCCE,A,39/CAFGSFE,A,40/PAFGSFE,A,55/NAFGSFE,A,71/TDFE,A,157/IAPCCW,A,190/CAFGSFW,A,191/PAFGSFW,A,198/NAFGSFW,A,205/TDFW,A,232
CCI	43	A	COAL CAPITAL INVESTMENT (DIMENSIONLESS)	CCDF,A,41/PDF,A,56/NDF,A,72/IGDFE,A,103/GDFW,A,105/11DF2,A,124/ISDFE,A,141/ISDFW,A,142
CCIC	44	A	COAL CAPITAL INVESTMENT COST (\$/KW)	CCDF,A,41
CCT	15.1	C	COAL CONSTRUCTION TIME (YRS)	CCDF,A,41
CDF	41	A	COAL DECISION FACTOR (DIMENSIONLESS)	CCDF,A,41/PDF,A,56/NDF,A,72/IGDFE,A,103/GDFW,A,105/11DF2,A,124/ISDFE,A,141/ISDFW,A,142
CDLF	41.6	C	CONSTRUCTION DELAY FACTOR (DIMENSIONLESS)	CCDF,A,41
CDT	48.2	C	COAL DELAY TIME (DIMENSIONLESS)	CCDF,A,41
CEC	45	A	COAL ENVIRONMENTAL CONSIDERATIONS (DIMENSIONLESS)	CCDF,A,41
CEF	41.4	C	COST OF ELECTRICITY FACTOR (DIMENSIONLESS)	CCDF,A,41/PDF,A,56/NDF,A,72/IGDFE,A,103/GDFW,A,105/11DF2,A,124/ISDFE,A,141/ISDFW,A,142
CFA	48	A	COAL FUEL AVAILABILITY (DIMENSIONLESS)	CCDF,A,41
CIF	41.2	C	CAPITAL INVESTMENT FACTOR (DIMENSIONLESS)	CCDF,A,41/PDF,A,56/NDF,A,72/IGDFE,A,103/GDFW,A,105/11DF2,A,124/ISDFE,A,141/ISDFW,A,142
CR	42	A	COAL RELIABILITY (DIMENSIONLESS)	CCDF,A,41
CRRF	14	R	COAL RETIREMENT RATE- EAST (MW/YR)	CCAPE,L,13
CRRW	169	R	COAL RETIREMENT RATE- WEST (MW/YR)	CCAPW,L,168
DAPCCE	37	A	DELAYED ADDITIONAL PLANNED COAL CAPACITY- EAST (MW/YR)	NPCCE,A,36
DAPCCE1	38	R	DELAYED ADDITIONAL PLANNED COAL CAPACITY- EAST (1) (MW/YR)	PCCE,L,34/DAPCCE,A,37
DAPCCW	188	A	DELAYED ADDITIONAL PLANNED COAL CAPACITY- WEST (MW/YR)	PCCW,A,187
DAPCCW1	189	R	DELAYED ADDITIONAL PLANNED COAL CAPACITY- WEST (1) (MW/YR)	PCCW,L,185/DAPCCW,A,188
DAPGCE	87	A	DELAYED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (MW/YR)	NPGE,A,84/INPGCE,A,86
DAPGCE1	88	R	DELAYED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (1) (MW/YR)	PGCE,L,81/DAPGCE,A,87
DAPGCE2	89	R	DELAYED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (2) (MW/YR)	PGCE,L,81/DAPGCE,A,87
DAPGCW	212	A	DELAYED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- WEST (MW/YR)	NPGCW,A,209/INPGCW,A,211

DAPGCW1	213	R	DELAYED ADDITIONAL PLANNED GEOTHERMAL	PGCW,L,206/DAPGCW,A,212
	213.1	N	CAPACITY- WEST (1) (MW/YR)	
DAPGCW2	214	R	DELAYED ADDITIONAL PLANNED GEOTHERMAL	PGCW,L,206/DAPGCW,A,212
	214.1	N	CAPACITY- WEST (2) (MW/YR)	
DAPICE	222	A	DELAYED ADDITIONAL PLANNED IMPORT CAPACITY- EAST (MW/YR)	NPGCW,A,209/INPGCW,A,211
DAPICE1	118	R	DELAYED ADDITIONAL PLANNED IMPORT CAPACITY- EAST (1) (MW/YR)	PICE,L,114/DAPICE2,A,117
	118.1	N		
DAPICE2	117	A	DELAYED ADDITIONAL PLANNED IMPORT CAPACITY- EAST (2) (MW/YR)	NPICE,A,116
DAPNCE	68	A	DELAYED ADDITIONAL PLANNED NUCLEAR CAPACITY- EAST (MW/YR)	NPNCE,A,67
DAPNCE1	69	R	DELAYED ADDITIONAL PLANNED NUCLEAR CAPACITY- EAST (1) (MW/YR)	PNCE,L,65/DAPNCE,A,68
	69.1	N		
DAPNCW	202	A	DELAYED ADDITIONAL PLANNED NUCLEAR CAPACITY- WEST (MW/YR)	NPNCW,A,201
DAPNCW1	203	R	DELAYED ADDITIONAL PLANNED NUCLEAR CAPACITY- WEST (1) (MW/YR)	PNCW,L,199/DAPNCW,A,202
	203.1	N		
DAPPCE	52	A	DELAYED ADDITIONAL PLANNED PETROLEUM CAPACITY- EAST (MW/YR)	NPPCE,A,51
DAPPCE1	53	R	DELAYED ADDITIONAL PLANNED PETROLEUM CAPACITY- EAST (1) (MW/YR)	PPCE,L,49/DAPPCE,A,52
	53.1	N		
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DAPPCW	195	A	DELAYED ADDITIONAL PLANNED PETROLEUM CAPACITY- WEST (MW/YR)	NPPCW,A,194
DAPPCW1	196	R	DELAYED ADDITIONAL PLANNED PETROLEUM CAPACITY- WEST (1) (MW/YR)	PPCW,L,192/DAPPCW,A,195
	196.1	N		
DAPSCE	136	A	DELAYED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (MW/YR)	NPSCCE,A,135
DAPSCE1	137	R	DELAYED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (1) (MW/YR)	PSCE,L,133/DAPSCE,A,136
	137.1	N		
DAPSCW	230	A	DELAYED ADDITIONAL PLANNED SOLAR CAPACITY- WEST (MW/YR)	NPSCW,A,228
DAPSCW1	231	R	DELAYED ADDITIONAL PLANNED SOLAR CAPACITY- WEST (1) (MW/YR)	PSCW,L,226/DAPSCW,A,230
	231.1	N		
DE	234	A	DEMAND- EAST (MW/YEAR)	\$BOXC2,A,12/\$BOXC3,A,13/\$BOXC4,A,14/\$BOXC5,A,15/\$BOXC6,A,16/\$BOXC7,A,17/\$BOXC8,A,18/\$BOXC9,A,19/\$BOXC,A,20
DEL				
DFLM			DECISION FACTOR LIMITATION MULTIPLIER (DIMENSIONLESS)	
DT	235.1	C	LENGTH OF SOLUTION INTERVAL (YEARS)	CCAPE,L,13/PETCAPE,L,16/NUCCAPE,L,19/GFOCAPE,L,22/IMPCAPE,L,26/SCAPE,L,28/PCCE,L,34/PPCE,L,49/PNCE,L,65/PGCE,L,81/PICE,L,114/PSCE,L,133/CCAPW,L,168/PE TCAPW,L,171/NUCCAPW,L,174/GEOCAPW,L,176/SCAPW,L,179/PCCW,L,185/PPCW,L,192/PNCW,L,199/PGCW,L,206/PSCW,L,226
DW	233	A	DEMAND- WEST (MW/YEAR)	
ECF	41.3	C	ENVIRONMENTAL CONSIDERATION FACTOR (DIMENSIONLESS)	CDF,A,41/PDF,A,56/NDF,A,72/IGDFE,A,103/GDFW,A,105/11DF2,A,124/ISDFE,A,141/ISDFW,A,142
EF			EFFICIENCY FACTOR (DIMENSIONLESS)	
FAF	41.5	C	FUEL AVAILABILITY FACTOR (DIMENSIONLESS)	CDF,A,41/PDF,A,56/NDF,A,72/IGDFE,A,103/GDFW,A,105/11DF2,A,124/ISDFE,A,141/ISDFW,A,142
GARF	25	R	GEOTHERMAL ADDITION RATE- EAST (MW/YR)	GEOCAPE,L,22/PGCE,L,81
GARW	178	R	GEOTHERMAL ADDITION RATE- WEST (MW/YR)	GEOCAPW,L,176/PGCW,L,206
GCE	111	A	GEOTHERMAL COST OF ELECTRICITY (DIMENSIONLESS)	IGDFE,A,103/GDFW,A,105
GCI	108	A	GEOTHERMAL CAPITAL INVESTMENT (DIMENSIONLESS)	IGDFE,A,103/GDFW,A,105
GCIC	109	A	GEOTHERMAL CAPITAL INVESTMENT COST (\$/KW)	GCI,A,108
GCT	25.1	C	GEOTHERMAL CONSTRUCTION TIME (YRS)	NDT,A,80/IAPGCE,A,83/INPGCE,A,86/DAPGCE,A,87/DAPGCE1,R,88/DAPGCE2,R,89/GRAFCAE,A,91/GRACAE6,A,92/TPGCT,A,95/TP2GCT,A,97/TP3GCT,A,99/IAPGCW,A,208/INPGCW,A,211/DAPGCW,A,212/DAPGCW1,R,213/DAPGCW2,R,214/GRAFCAW,A,215/GRACAW6,A,216/DAPICE,A,222
GDFE	102	A	GEOTHERMAL DECISION FACTOR- EAST (DIMENSIONLESS)	IAPGCE1,A,90/TDFE,A,157
GDFW	105	A	GEOTHERMAL DECISION FACTOR- WEST (DIMENSIONLESS)	IAPGCW1,A,221/TDFW,A,232
GDT	113.2	C	GEOTHERMAL DELAY TIME (DIMENSIONLESS)	IGDFE,A,103/GDFW,A,105
GEC	110	A	GEOTHERMAL ENVIRONMENTAL CONSIDERATIONS (DIMENSIONLESS)	IGDFE,A,103/GDFW,A,105
GEOCAPE	22	L	GEOTHERMAL CAPACITY- EAST (MW)	PRCAPE,A,7/PCAPE,A,12/GRRR,R,23/GRAFCAE,A,91/GRACAE6,A,92/GRACAE9,A,93
	22.1	N		
GEOCAPW	176	L	GEOTHERMAL CAPACITY- WEST (MW)	PRCAPW,A,162/PCAPW,S,167/GRRW,R,177/GRAFCAW,A,215/GRACAW6,A,216/GRACAW9,A,217
	176.1	N		
GEOSFE	100	A	GEOTHERMAL SHORT-FALL- EAST (MW/YR)	AFGSFE,A,101
GEOSFW	223	A	GEOTHERMAL SHORT-FALL- WEST (MW/YR)	GEOSFWL,R,224/AFGSFW,A,225
GEOSFWL	224	R	GEOTHERMAL SHORT-FALL- WEST LAST TIME PERIOD (MW/YR)	11DF,A,122/11DF1,A,123
	224.1	N		
GFA	113	A	GEOTHERMAL FUEL AVAILABILITY (DIMENSIONLESS)	IGDFE,A,103/GDFW,A,105
GR	107	A	GEOTHERMAL RELIABILITY (DIMENSIONLESS)	IGDFE,A,103/GDFW,A,105
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GRACAE6	92	A	GRAFCAE IN SIX YEARS (MW)	RAM,A,85
GRACAE9	93	A	GRAFCAE IN NINE YEARS (MW)	RAM,A,85
GRACAW6	216	A	GEOTHERMAL RESOURCES AVAILABLE FOR CAP ADDITIONS IN 6 YEARS (MW)	RAM,A,210
GRACAW9	217	A	GEOTHERMAL RESOURCES AVAILABLE FOR CAP ADDITIONS IN 9 YEARS (MW)	RAM,A,210
GRAFCAE	91	A	GEOTHERMAL RESOURCES AVAILABLE FOR CAPACITY ADDITION- EAST (MW/..)	APGCE,R,82/NAME,A,85/GEOSFE,A,100
GRAFCAW	215	A	GEOTHERMAL RESOURCES AVAILABLE FOR CAPACITY ADDITION- WEST (MW/..)	APGCW,R,207/NAME,A,210/GEOSFW,A,223
GRRR	23	R	GEOTHERMAL RETIREMENT RATE- EAST (MW/YR)	GEOCAPE,L,22
GRRW	177	R	GEOTHERMAL RETIREMENT RATE- WEST (MW/YR)	GEOCAPW,L,176
GRT	24	A	GEOTHERMAL RETIREMENT TIME (YEARS)	GRRR,R,23/GRRW,R,177
HCAPE	31	A	HYDRO CAPACITY- EAST (MW)	PCAPE,A,12
HCAPW	182	A	HYDRO CAPACITY- WEST (MW)	PCAPW,S,167
IAPGCE	39	A	INDICATED ADDITIONAL PLANNED COAL CAPACITY- EAST (MW/YR)	APGCE,R,35/NPCE,A,36/DAPCE1,R,38

IAPCCW	190	A	INDICATED ADDITIONAL PLANNED COAL CAPACITY- WEST (MW/YR)	APCCW,R,186/NPCCW,A,187/DAPCCW1,R,189
IAPGCE	83	A	INDICATED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (MW/YR)	APGCE,R,82/NPGCE,A,84
IAPGCE1	90	A	INDICATED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- EAST (1) (MW/	IAPGCE,A,83/RAME,A,85/INPGCE,A,86/DAPGCE1,R,88/DAPGCE2,R,89
IAPGCW	208	A	INDICATED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- WEST (MW/YR)	APGCW,R,207/NPGCW,A,209
IAPGCW1	221	A	INDICATED ADDITIONAL PLANNED GEOTHERMAL CAPACITY- WEST (1) (MW/	RAME,A,85/IAPGCW,A,208/RAM,A,210/INPGCW,A,211/DAPGCW1,R,213/DAPGCW2,R,214
IAPNCE	70	A	INDICATED ADDITIONAL PLANNED NUCLEAR CAPACITY- EAST (MW/YR)	APNCE,R,66/NPNCE,A,67/DAPNCE1,R,69
IAPNCW	204	A	INDICATED ADDITIONAL PLANNED NUCLEAR CAPACITY- WEST (MW/YR)	APNCW,R,200/NPNCW,A,201/DAPNCW1,R,203
IAPPCCE	54	A	INDICATED ADDITIONAL PLANNED PETROLEUM CAPACITY- EAST (MW/YR)	APPCCE,R,50/NPPCE,A,51/DAPPCCE1,R,53
IAPPCW	197	A	INDICATED ADDITIONAL PLANNED PETROLEUM CAPACITY- WEST (MW/YR)	APPCW,R,193/NPPCW,A,194/DAPPCW1,R,196
IAPSCE	138	A	INDICATED ADDITIONAL PLANNED SOLAR CAPACITY- EAST (MW/YR)	APSCE,R,134/NPSCE,A,135/DAPSCE1,R,137
IAPSCW	229	A	INDICATED ADDITIONAL PLANNED SOLAR CAPACITY- WEST (MW/YR)	APSCW,R,227/NPSCW,A,228/DAPSCW1,R,231
IARE	27	R	IMPORT ADDITION RATE- EAST (MW/YR)	IMCAPE,L,26/PICE,L,114
ICE	130	A	IMPORT COST OF ELECTRICITY (DIMENSIONLESS)	IIDF2,A,124
ICI	127	A	IMPORT CAPITAL INVESTMENT (DIMENSIONLESS)	IIDF2,A,124
ICIC	128	A	IMPORT CAPITAL INVESTMENT COST (\$/KW)	CC1,A,43/PCI,A,58/NC1,A,74/GC1,A,108/SC1E,A,145/SCIW,A,147
ICT	27.1	C	IMPORT CONSTRUCTION TIME	APICE,R,115/NPICE,A,116/DAPICE2,A,117/DAPICE1,R,118/DAPICE,A,222
IDF	119	A	IMPORT DECISION FACTOR (DIMENSIONLESS)	APICE,R,115/NPICE,A,116/DAPICE1,R,118/TDFE,A,157
IDT	132.2	C	IMPORT DELAY TIME (DIMENSIONLESS)	IIDF2,A,124
IEC	129	A	IMPORT ENVIRONMENTAL CONSIDERATIONS (DIMENSIONLESS)	IIDF2,A,124
IFA	132	A	IMPORT FUEL AVAILABILITY (DIMENSIONLESS)	IIDF2,A,124
IGDFE	103	A	INDICATED GEOTHERMAL DECISION FACTOR- EAST (DIMENSIONLESS)	GDFFE,A,102
IIDF	122	A	INDICATED IMPORT DECISION FACTOR (DIMENSIONLESS)	IDF,A,119
IIDF1	123	A	INDICATED IMPORT DECISION FACTOR 1 (DIMENSIONLESS)	IIDF,A,122
IIDF2	124	A	INDICATED IMPORT DECISION FACTOR 2 (DIMENSIONLESS)	IIDF1,A,123
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ILF	125	A		IIDF2,A,124
IMCAPE	26	L	IMPORT CAPACITY- EAST (MW)	PRCAPE,A,7/PCAPE,A,12/IMPR,A,121/PAPSW,A,161
IMPR	121	A	IMPORT RATIO (DIMENSIONLESS)	POSDFM,A,120
IMPYEAR	119.1	C	IMPORT START YEAR (YEARS)	IDF,A,119
IMR	126	A	IMPORT RELIABILITY (DIMENSIONLESS)	IIDF2,A,124
IN				SV1,R,10
INPGCE	86	A	INDICATED NEW PLANNED GEOTHERMAL CAPACITY- EAST (MW/YR)	APGCE,R,82/GEOSFE,A,100
INPGCW	211	A	INDICATED NEW PLANNED GEOTHERMAL CAPACITY- WEST (MW/YR)	RAME,A,85/APGCW,R,207/RAM,A,210/GEOSFW,A,223
INTRAT			INTEREST RATES (DIMENSIONLESS)	
ISDFE	141	A	INDICATED SOLAR DECISION FACTOR- EAST (DIMENSIONLESS)	SDFE,A,139
ISDFW	142	A	INDICATED SOLAR DECISION FACTOR- WEST (DIMENSIONLESS)	SDFW,A,140
LENGTH	235.2	C	LENGTH OF MODEL RUN (YEARS)	
LFF	104	A	LEARNING FACTOR- EAST (DIMENSIONLESS)	IGDFE,A,103
LFW	106	A	LEARNING FACTOR- WEST (DIMENSIONLESS)	GDFFW,A,105
NAFGSFE	71	A	NUCLEAR ADJUSTMENT FOR GEOTHERMAL SHORT- FALL- EAST (MW/YR)	IAPNCE,A,70
NAFGSFW	205	A	NUCLEAR ADJUSTMENT FOR GEOTHERMAL SHORT- FALL- WEST (MW/YR)	IAPNCW,A,204
NARE	20	R	NUCLEAR ADDITION RATE- EAST (MW/YR)	NUCCAPE,L,19/PNCE,L,65
NARW	175	R	NUCLEAR ADDITION RATE- WEST (MW/YR)	NUCCAPW,L,174/PNCW,L,199
NCE	77	A	NUCLEAR COST OF ELECTRICITY (DIMENSIONLESS)	NDF,A,72
NCI	74	A	NUCLEAR CAPITAL INVESTMENT (DIMENSIONLESS)	NDF,A,72
NCIC	75	A	NUCLEAR CAPITAL INVESTMENT COST (\$/KW)	NCI,A,74
NCT	21	A	NUCLEAR CONSTRUCTION TIME (YRS)	NARE,R,20/APNCE,R,66/NPNCE,A,67/DAPNCE,A,68/DAPNCE1,R,69
NDF	72	A	NUCLEAR DECISION FACTOR (DIMENSIONLESS)	NDT,A,80/NAPW,R,175/APNCW,R,200/NPNCW,A,201/DAPNCW,A,202
NDT	80	A	NUCLEAR DELAY TIME (DIMENSIONLESS)	DAPNCW1,R,203
NEC	76	A	NUCLEAR ENVIRONMENTAL CONSIDERATIONS (DIMENSIONLESS)	CAFGSFE,A,40/PAFGSFE,A,55/IAPNCE,A,70/NAFGSFE,A,71/TDFE,A,157/CAFGSFW,A,191/PAFGSFW,A,198/IAPNCW,A,204/NAFGSFW,A,205/TDFW,A,232
NFA	79	A	NUCLEAR FUEL AVAILABILITY (DIMENSIONLESS)	NDF,A,72
NGCAPE	32	A	NATURAL GAS CAPACITY- EAST (MW)	PCAPE,A,12
NGCAPW	183	A	NATURAL GAS CAPACITY- WEST (MW)	PCAPW,S,167
NPCCCE	36	A	NEW PLANNED COAL CAPACITY- EAST (MW/YR)	CARE,R,15
NPCCW	187	A	NEW PLANNED COAL CAPACITY- WEST (MW/YR)	CARW,R,170
NPGCE	84	A	NEW PLANNED GEOTHERMAL CAPACITY- EAST (MW/YR)	GARE,R,25
NPGCW	209	A	NEW PLANNED GEOTHERMAL CAPACITY- WEST (MW/YR)	GARW,R,178
NPICE	116	A	NEW PLANNED ADDITIONAL IMPORT CAPACITY-EAST (MW/YR)	IARE,R,27/DAPICE,A,222
NPNCE	67	A	NEW PLANNED NUCLEAR CAPACITY- EAST (MW/YR)	NARE,R,20
NPNCW	201	A	NEW PLANNED NUCLEAR CAPACITY- WEST (MW/YR)	NARW,R,175
NPPCE	51	A	NEW PLANNED ADDITIONAL PETROLEUM CAPACITY- EAST (MW/YR)	PARF,R,18
NPPCW	194	A	NEW ADDITIONAL PLANNED PETROLEUM CAPACITY- WEST (MW/YR)	PARW,R,173
NPSCE	135	A	NEW PLANNED SOLAR CAPACITY- EAST (MW/YR)	SARE,R,30
NPSCW	228	A	NEW PLANNED SOLAR CAPACITY- WEST (MW/YR)	SARW,R,181
NR	73	A	NUCLEAR RELIABILITY (DIMENSIONLESS)	NDF,A,72
NTCL			NUMBER OF TRANSCONTINENTAL LINES (LINES)	

NUCCAPE	19	L	NUCLEAR CAPACITY- EAST (MW)	PRCAPE,A,7/PCAPE,A,12
	19.1	N		
NUCCAPW	174	L	NUCLEAR CAPACITY- WEST (MW)	PRCAPW,A,162/PCAPW,S,167
	174.1	N		
N1				SV1,N,11
N10				SV10,N,10.1
N2				SV2,N,10.9
N3				SV3,N,10.8
N4				SV4,N,10.7
N5				SV5,N,10.6
N6				SV6,N,10.5
N7				SV7,N,10.4
N8				SV8,N,10.3
N9				SV9,N,10.2
ONE	127.1	C		GCE,A,111/ICI,A,127
PAFGSFE	55	A	PETROLEUM ADJUSTMENT FOR GEOTHERMAL SHORT-FALL- EAST (MW/YR)	IAPPCPE,A,54
PAFGSW	198	A	PETROLEUM ADJUSTMENT FOR GEOTHERMAL SHORT-FALL- WEST (MW/YR)	IAPPCW,A,197
PAPSE	6	A	PRESENT AND PLANNED SUPPLY- EAST (MW/YR)	TYCGE,A,3/IMPR,A,121
PAPSW	161	A	PRESENT AND PLANNED SUPPLY- WEST (MW/YR)	TYCGW,A,159
PARE	18	R	PETROLEUM ADDITION RATE- EAST (MW/YR)	PETCAPE,L,16/PPCE,L,49
PARW	173	R	PETROLEUM ADDITION RATE- WEST (MW/YR)	PETCAPW,L,171/PPCW,L,192
PCAPE	12	A	PRESENT CAPACITY- EAST (MW)	
PCAPW	167	S	PRESENT CAPACITY- WEST (MW)	
PCCE	34	L	PLANNED COAL CAPACITY EAST (MW)	PLCAPE,A,33
	34.1	N		
PCCW	185	L	PLANNED COAL CAPACITY- WEST (MW)	PLCAPW,A,184
	185.1	N		
PCE	61	A	PETROLEUM ELECTRICITY COST (DIMENSIONLESS)	PDF,A,56
PCI	58	A	PETROLEUM CAPITAL INVESTMENT (DIMENSIONLESS)	PDF,A,56
PCIC	59	A	PETROLEUM CAPITAL INVESTMENT COST (\$/KW)	PCI,A,58
PCT	18.1	C	PETROLEUM CONSTRUCTION TIME (YRS)	APPC,R,50/NPPCE,A,51/DAPPCPE,A,52/DAPPCEL,R,53/APPCW,R,193
PDF	56	A	PETROLEUM DECISION FACTOR (DIMENSIONLESS)	NPPCW,A,194/DAPPCW,A,195/DAPPCW1,R,196
				CAFGSFE,A,40/IAPPCPE,A,54/PAFGSFE,A,55/NAFGSFE,A,71/TDFE,A,157/CAFGSW,A,191/IAPPCW,A,197/PAFGSW,A,198/NAFGSW,A,205/TDFW,A,232
PDT	64.2	C	PETROLEUM DELAY TIME (DIMENSIONLESS)	PDF,A,56
PEC	60	A	PETROLEUM ENVIRONMENTAL CONSIDERATIONS (DIMENSIONLESS)	PDF,A,56
PETCAPE	16	L	PETROLEUM CAPACITY- EAST (MW)	PRPCAPE,A,9/PCAPE,A,12/PRRE,R,17
	16.1	N		
PETCAPW	171	L	PETROLEUM CAPACITY- WEST (MW)	PRPCAPW,A,164/PCAPW,S,167/PRRW,R,172
	171.1	N		
PFA	63	A	PETROLEUM FUEL AVAILABILITY (DIMENSIONLESS)	PDF,A,56/PFAM,A,64
PFAM	64	A	PETROLEUM FUEL AVAILABILITY MULTIPLIER (DIMENSIONLESS)	PDF,A,56
PGCE	81	L	PLANNED GEOTHERMAL CAPACITY- EAST (MW)	PLCAPE,A,33/GRAFCAE,A,91/GRACAE6,A,92/GRACAE9,A,93
	81.1	N		
PGCW	206	L	PLANNED GEOTHERMAL CAPACITY- WEST (MW)	PLCAPW,A,184/GRAFCW,A,215/GRACAW6,A,216/GRACAW9,A,217
	206.1	N		
PICE	114	L	PLANNED IMPORT CAPACITY- EAST (MW)	PLCAPE,A,33/IMPR,A,121/GRAFCW,A,215/GRACAW6,A,216/GRACAW9,A,217
	114.1	N		
PINTRAT			PRESENT INTEREST RATES (DIMENSIONLESS)	
PLCAPE	33	A	PLANNED CAPACITY- EAST (MW)	PAPSE,A,6
PLCAPW	184	A	PLANNED CAPACITY- WEST (MW)	PAPSW,A,161

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PLTPER	235.4	C	PLOT INTERVAL (YEARS)	
PNCB	65	L	PLANNED NUCLEAR CAPACITY- EAST (MW)	PLCAPE,A,33
	65.1	N		
PNCW	199	L	PLANNED NUCLEAR CAPACITY- WEST (MW)	PLCAPW,A,184
	199.1	N		
POSDFM	120	A	POSSIBLE DECISION FACTOR MULTIPLIER (DIMENSIONLESS)	IDF,A,119
PPCE	49	L	PLANNED PETROLEUM CAPACITY- EAST (MW)	PLCAPE,A,33
	49.1	N		
PPCW	192	L	PLANNED PETROLEUM CAPACITY- WEST (MW)	PLCAPW,A,184
	192.1	N		
PR	57	A	PETROLEUM RELIABILITY (DIMENSIONLESS)	PDF,A,56
PRAE	94	A	PROJECTED GEOTHERMAL RESOURCES- EAST (MW)	GRAFCAE,A,91
PRAE6	96	A	PROJECTED (6 YEARS) GEOTHERMAL RESOURCES- EAST (MW)	GRACAE6,A,92
PRAE9	98	A	PROJECTED (9 YEARS) GEOTHERMAL RESOURCES- EAST (MW)	GRACAE9,A,93
PRAW	218	A	PROJECTED RESOURCES AVAILABLE (MW)	GRAFCW,A,215
PRAW6	219	A	PROJECTED RESOURCES AVAILABLE IN 6 YEARS (MW)	GRACAW6,A,216
PRAW9	220	A	PROJECTED RESOURCES AVAILABLE IN 9 YEARS (YEARS)	GRACAW9,A,217
PRCAPE	7	A	PRESENT PROJECTED CAPACITY- EAST (MW)	PAPSE,A,6
PRCAPW	162	A	PRESENT PROJECTED CAPACITY- WEST (MW)	PAPSW,A,161
PRCCAPE	8	A	PRESENT PROJECTED COAL CAPACITY- EAST (MW)	PRCAPE,A,7
PRCCAPW	163	A	PRESENT PROJECTED COAL CAPACITY- WEST (MW)	PRCAPW,A,162
PRHCAPE	10	A	PRESENT PROJECTED HYDRO CAPACITY- EAST (MW)	PRCAPE,A,7
PRHCAPW	165	A	PRESENT PROJECTED HYDRO CAPACITY- WEST (MW)	PRCAPW,A,162
PRNGCAPE	11	A	PRESENT PROJECTED NATURAL GAS CAPACITY- EAST (MW)	PRCAPE,A,7
PRNGCAPW			PRESENT PROJECTED NATURAL GAS CAPACITY- WEST (MW)	
PRNGCPW	166	A		PRCAPW,A,162
PRPCAPE	9	A	PRESENT PROJECTED PETROLEUM CAPACITY- EAST (MW)	PRCAPE,A,7
PRPCAPW	164	A	PRESENT PROJECTED PETROLEUM CAPACITY- WEST (MW)	PRCAPW,A,162
PRRE	17	R	PETROLEUM RETIREMENT RATE- EAST (MW/YR)	PETCAPE,L,16
PRRW	172	R	PETROLEUM RETIREMENT RATE- WEST (MW/YR)	PETCAPW,L,171

PRTPER 235.3 C PRINT INTERVAL (YEARS)
 PSCE 133 L PLANNED SOLAR CAPACITY- EAST (MW)
 133.1 N
 PSW 226 L PLANNED SOLAR CAPACITY- WEST (MW)
 226.1 N
 PT 5.1 C PROJECTION TIME (YRS)

PLCAPE, A, 33
 PLCAPW, A, 184

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 DAPCCE, A, 37/DAPCCE1, R, 38/APPCCE, R, 50/NPPCE, A, 51/DAPPCCE, A,
 52/DAPPCCE1, R, 53/APNCE, R, 66/NPNCE, A, 67/DAPNCE, A, 68
 DAPNCE1, R, 69/IAPGCE, A, 83/INPGCE, A, 86/DAPGCE, A, 87/DAPGCE1,
 R, 88/DAPGCE2, R, 89/APICE, R, 115/NPICE, A, 116/DAPICE2, A, 117
 DAPICE1, R, 118/APSCCE, R, 134/NPSCE, A, 135/DAPSCCE, A, 136
 DAPSCCE1, R, 137/PRCCAPW, A, 163/PRPCAPW, A, 164/APCCW, R, 186
 NPCCW, A, 187/DAPCCW, A, 188/DAPCCW1, R, 189/APPCW, R, 193/NPPCW,
 A, 194/DAPPCW, A, 195/DAPPCW1, R, 196/APNCW, R, 200/NPNCW, A,
 201/DAPNCW, A, 202/DAPNCW1, R, 203/IAPGCW, A, 208/INPGCW, A, 211
 DAPGCW, A, 212/DAPGCW1, R, 213/DAPGCW2, R, 214/APSCW, R, 227
 NPSCW, A, 228/DAPSCW, A, 230/DAPSCW1, R, 231

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PTYDE 4 A PROJECTED TEN YEAR DEMAND- EAST (MW/YR)
 PTYOW 160 A PROJECTED TEN YEAR DEMAND- WEST (MW/YR)
 IPAGE 8 FILE G2 THE FUTURES GROUP- GEOTHERMAL 8/01/74

RAF 2 A RESOURCES AVAILABLE EAST (MW)
 RAM 210 A RESOURCE AVAILABILITY MULTIPLIER
 (DIMENSIONLESS)
 RAME 85 A RESURCE AVAILABILITY MULTIPLIER- EAST
 (DIMENSIONLESS)
 RAW 1 A RESOURCES AVAILABLE WEST (MW)
 RF 41.1 C RELIABILITY FACTOR (DIMENSIONLESS)
 RIR RELATIVE INTEREST RATES (DIMENSIONLESS)
 SARE 30 R SOLAR ADDITION RATE- EAST (MW/YR)
 SARW 181 R SOLAR ADDITION RATE- WEST (MW)
 SAT 140.1 C SOLAR AVAILABILITY TIME (YEAR)
 SCAPE 28 L SOLAR CAPACITY- EAST (MW)
 28.1 N
 SCAPW 179 L SOLAR CAPACITY- WEST (MW)
 179.1 N
 SCEE 150 A SOLAR COST OF ELECTRICITY- EAST
 (DIMENSIONLESS)
 SCEEL 152 A SOLAR COST OF ELECTRICITY- EAST LIMITATION
 (DIMENSIONLESS)
 SCEW 153 A SOLAR COST OF ELECTRICITY- WEST
 (DIMENSIONLESS)
 SCEWL 155 A SOLAR COST OF ELECTRICITY- WEST LIMITATION
 (DIMENSIONLESS)
 SCI SOLAR CAPITAL INVESTMENT (DIMENSIONLESS)
 SCIC SOLAR CAPITAL INVESTMENT COST (\$/KW)
 SCICE 146 A
 SCICW 148 A
 SCIE 145 A
 SCIW 147 A
 SCT 30.1 C SOLAR CONSTRUCTION TIME (YEARS)
 SDFE 139 A SOLAR DECISION FACTOR- EAST (DIMENSIONLESS)
 SDFW 140 A SOLAR DECISION FACTOR- WEST (DIMENSIONLESS)
 SDT 156.2 C SOLAR DELAY TIME (DIMENSIONLESS)
 SEC 149 A SOLAR ENVIRONMENTAL CONSIDERATIONS
 (DIMENSIONLESS)
 SFA 156 A
 SFAE SOLAR FUEL AVAILABILITY- EAST
 (DIMENSIONLESS)
 SFAW SOLAR FUEL AVAILABILITY- WEST
 (DIMENSIONLESS)
 SLF 143 A SOLAR LEARNING FACTOR (DIMENSIONLESS)
 SR 144 A SOLAR RELIABILITY (DIMENSIONLESS)
 SRRE 29 R SOLAR RETIREMENT RATE- EAST (MW/YR)
 SRRW 180 R
 SRT 29.1 C SOLAR RETIREMENT TIME (YEARS)
 TACCE 47.1 T
 TAGCE 112.1 T
 TAICE 131.1 T
 TANCE 78.1 T
 TAPCE 62.1 T
 TASCEE 151.1 T
 TASCEW 154.1 T
 TCAP TOTAL CAPACITY (MW)
 TCCIC 44.1 T
 TCEC 45.1 T
 TCFA 48.1 T
 IPAGE 9 FILE G2 THE FUTURES GROUP- GEOTHERMAL 8/01/74
 TCR 42.1 T
 TDFE 157 A TOTAL DECISION FACTOR- EAST (DIMENSIONLESS)
 TDFEL 158 R TOTAL DECISION FACTOR- EAST LAST TIME
 PERIOD (DIMENSIONLESS)
 TDFLM 152.1 T TABLE OF DECISION FACTOR LIMITATION
 MULTIPLIER (DIMENSIONLESS)
 TDFW 232 A TOTAL DEMAND FACTOR- WEST (DIMENSIONLESS)
 TGCIC 109.1 T
 TGEC 110.1 T
 TGFA 113.1 T
 TGR 107.1 T
 TGRR 24.1 T
 THCAPE 31.1 T
 THCAPW 182.1 T
 TICIC 128.1 T
 TIEC 129.1 T

NPGCW, A, 209/DAPGCW1, R, 213/DAPGCW2, R, 214

NPGCE, A, 84/DAPGCE1, R, 88/DAPGCE2, R, 89

CDF, A, 41/PDF, A, 56/NDF, A, 72/IGDFE, A, 103/GDFW, A, 105/IIDF2, A,
 124/ISDFE, A, 141/ISDFW, A, 142

SCAPE, L, 28/PSCE, L, 133
 SCAPW, L, 179/PSCW, L, 226
 SDFE, A, 139/SDFW, A, 140
 PRCAPE, A, 7/PCAPE, A, 12/SRRE, R, 29

PRCAPW, A, 162/PCAPW, S, 167/SRRW, R, 180

ISDFE, A, 141/SCEEL, A, 152

ISDFE, A, 141

ISDFW, A, 142/SCEWL, A, 155

ISDFW, A, 142

SCIE, A, 145

SCIW, A, 147

ISDFE, A, 141

ISDFW, A, 142

APSCCE, R, 134/NPSCE, A, 135/DAPSCCE, A, 136/DAPSCCE1, R, 137/APSCW, R,

227/NPSCW, A, 228/DAPSCW, A, 230/DAPSCW1, R, 231

IAPSCCE, A, 138/TDFE, A, 157

IAPSCW, A, 229/TDFW, A, 232

ISDFE, A, 141/ISDFW, A, 142

ISDFE, A, 141/ISDFW, A, 142

ISDFE, A, 141/ISDFW, A, 142

ISDFE, A, 141/ISDFW, A, 142

SCAPE, L, 28

SCAPW, L, 179

SRRE, R, 29/SRRW, R, 180

ACCE, A, 47

AGCE, A, 112

AIICE, A, 131

ANCE, A, 78

APCE, A, 62

ASCEE, A, 151

ASCEW, A, 154

CCIC, A, 44

CEC, A, 45

CFA, A, 48

CR, A, 42

IAPCCE, A, 39/IAPPCCE, A, 54/IAPNCE, A, 70/IAPGCE1, A, 90/APICE, R,

115/NPICE, A, 116/DAPICE1, R, 118/IAPSCCE, A, 138/TDFEL, R, 158

IIDF1, A, 123

SCEEL, A, 152/SCEWL, A, 155

IAPCCW, A, 190/IAPPCW, A, 197/IAPNCW, A, 204/IAPGCW1, A, 221

IAPSCW, A, 229

GCIC, A, 109

GFC, A, 110

GFA, A, 113

GR, A, 107

GRT, A, 24

PRHCAPE, A, 10/HCAPE, A, 31

PRHCAPW, A, 165/HCAPW, A, 182

ICIC, A, 128

IEC, A, 129

TIFA 132.1 T
TIME .1 N

TIME 126.1 T
TLF 106.1 T
TNCIC 75.1 T
TNCT 21.1 T
TNEC 76.1 T
TNFA 79.1 T
TNGCAPE 32.1 T
TNGCAPW 183.1 T
TNR 73.1 T
TPCIC 59.1 T
TPDE 4.1 T
TPDW 160.1 T
TPEC 60.1 T
TPFA 63.1 T
TPFAM 64.1 T
TPGCT 95 A

TIME PLUS GEOTHERMAL CONSTRUCTION PERIOD
(YEARS)

TPOSDFM 120.1 T
TPPT 5 A

TIME PLUS PROJECTION TIME (YRS)

TPR 57.1 T
TP2GCT 97 A

TIME PLUS TWO GEOTHERMAL CONSTRUCTION
PERIODS (YEARS)

TP3GCT 99 A

TIME PLUS THREE GEOTHERMAL CONSTRUCTION
PERIODS (YEARS)

TRA 2.1 T
TRAH 1.1 T
TSCICE 146.1 T

IPAGE 10 FILE G2 THE FUTURES GROUP- GEOTHERMAL 8/01/74

TSCICW 148.1 T
TSEC 149.1 T
TSFA 156.1 T
TSLF 143.1 T
TSR 144.1 T
TYCGE 3 A

TEN YEAR CAPACITY GAP- EAST (MW/YR)

TYCGW 159 A

TEN YEAR CAPACITY GAP- WEST (MW/YR)

\$B0XC2 12 A
\$B0XC3 13 A
\$B0XC4 14 A
\$B0XC5 15 A
\$B0XC6 16 A
\$B0XC7 17 A
\$B0XC8 18 A
\$B0XC9 19 A
\$V1 10 R
11 N
\$V10 1 R
10.1 N
\$V2 9 R
10.9 N
\$V3 8 R
10.8 N
\$V4 7 R
10.7 N
\$V5 6 R
10.6 N
\$V6 5 R
10.5 N
\$V7 4 R
10.4 N
\$V8 3 R
10.3 N
\$V9 2 R
10.2 N

IFA, A, 132
RAW, A, 1/RAE, A, 2/TPPT, A, 5/NCT, A, 21/GRRE, R, 23/GRT, A, 24/HCAPE
A, 31/NGCAPE, A, 32/CR, A, 42/CCIC, A, 44/CEC, A, 45/ACCE, A, 47
CFA, A, 48/PR, A, 57/PCIC, A, 59/PEC, A, 60/APCE, A, 62/PFA, A, 63
NR, A, 73/NCIC, A, 75/NEC, A, 76/ANCE, A, 78/NFA, A, 79/TPGCT, A, 95
TP2GCT, A, 97/TP3GCT, A, 99/GDFE, A, 102/LFE, A, 104/LFW, A, 106
GR, A, 107/GCIC, A, 109/GEC, A, 110/AGCE, A, 112/GFA, A, 113/IDF, A
119/ILF, A, 125/IMR, A, 126/ICIC, A, 128/IEC, A, 129/AICE, A, 131
IFA, A, 132/SDFE, A, 139/SDFW, A, 140/SLF, A, 143/SR, A, 144/SCICE
A, 146/SCICW, A, 148/SEC, A, 149/ASCEE, A, 151/ASCEW, A, 154/SFA
A, 156/GRRW, R, 177/HCAPW, A, 182/NGCAPW, A, 183/DW, A, 233/DE, A
234

IMR, A, 126
LFE, A, 104/LFW, A, 106/ILF, A, 125

NCIC, A, 75

NCT, A, 21

NEC, A, 76

NFA, A, 79

PRNGCAPE, A, 11/NGCAPE, A, 32

PRNGCPW, A, 166/NGCAPW, A, 183

NR, A, 73

PCIC, A, 59

PTYDF, A, 4/DE, A, 234

PTYDW, A, 160/DW, A, 233

PEC, A, 60

PFA, A, 63

PFAM, A, 64

PRAE, A, 94/PRAW, A, 218

POSDFM, A, 120

PTYDE, A, 4/PRHCAPE, A, 10/PRNGCAPE, A, 11/PTYDW, A, 160/PRHCPW, A
165/PRNGCPW, A, 166

PR, A, 57

PRAE6, A, 96/PRAW6, A, 219

PRAE9, A, 98/PRAW9, A, 220

RAE, A, 2/PRAE, A, 94/PRAE6, A, 96/PRAE9, A, 98

RAW, A, 1/PRAW, A, 218/PRAW6, A, 219/PRAW9, A, 220

SCICE, A, 146

SCICW, A, 148

SEC, A, 149

SFA, A, 156

SLF, A, 143

SR, A, 144

IAPCCE, A, 39/IAPPCCE, A, 54/IAPNCE, A, 70/IAPGCE1, A, 90/APICE, R,
115/NPICE, A, 116/DAPICE1, R, 118/IDF1, A, 123/IAPSCE, A, 138

IAPCCW, A, 190/IAPPCW, A, 197/IAPNCW, A, 204/IAPGCW1, A, 221

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\$B0XC4, A, 14

\$B0XC5, A, 15

\$B0XC6, A, 16

\$B0XC7, A, 17

\$B0XC8, A, 18

\$B0XC9, A, 19

\$B0XC, A, 20

\$V2, R, 9/\$B0XC2, A, 12

\$B0XC, A, 20

\$V3, R, 8/\$B0XC2, A, 12

\$V4, R, 7/\$B0XC3, A, 13

\$V5, R, 6/\$B0XC4, A, 14

\$V6, R, 5/\$B0XC5, A, 15

\$V7, R, 4/\$B0XC6, A, 16

\$V8, R, 3/\$B0XC7, A, 17

\$V9, R, 2/\$B0XC8, A, 18

\$V10, R, 1/\$B0XC9, A, 19

4. Model Output

A. Policy Runs

TIME	CCAPW	PETCAPW	NUCCAPW	GEOCAPW	SCAPW	HCAPW	NGCAPW	IMPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+00 E+00	E+03 E+03	E+03 E+03	E+00
1973.	137.50	50.40	12.50	.00000	.0	20.880	47.620	0.
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.00000 732.0	.0 .0	20.760 36.400	41.580 18.200	0.
1979.	173.35 17.95	100.79 16.313	97.23 7.96	.00900 1601.0	.0 .0	22.440 40.600	38.220 16.700	0.
1982.	207.69 31.17	118.96 21.060	164.82 28.78	.02400 2200.0	.0 .0	23.800 44.000	34.260 14.920	0.
1985.	260.59 46.71	167.94 35.974	217.19 41.23	.05400 2200.0	.0 .0	25.000 47.000	30.000 13.000	0.
1988.	321.00 62.98	186.45 40.401	303.27 61.55	.08400 2200.1	.0 .0	26.200 50.000	26.640 11.500	0.
1991.	393.53 84.13	188.82 41.151	401.87 89.20	.11400 2200.1	.0 .0	27.600 52.600	23.600 10.140	0.
1994.	465.06 103.99	175.01 38.142	512.21 119.03	.14400 2200.1	.0 .0	29.400 54.400	21.200 9.060	0.
1997.	537.38 122.23	162.21 35.352	622.70 144.05	.17400 2200.2	614.9 521.8	30.800 56.200	18.720 8.020	0.
2000.	640.04 147.14	150.35 32.766	777.71 180.96	.20400 2200.2	2895.0 2632.8	32.000 58.000	16.200 7.000	0.

Figure E.4.1 GEOTHERMAL RESOURCES NOT DEVELOPED

TIME	COOP COAPW	PECAPE PEYCAPW	NUCCAPW NUCCAPW	GECCAPW GECCAPW	SCAPW SCAPW	HCAPW HCAPW	HCAPW HCAPW	HCAPW HCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+00
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .396	.0 .0	20.880 32.880	47.620 20.020	0.
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .732	.0 .0	20.760 36.400	41.580 18.200	0.
1979.	173.35 17.95	100.79 15.656	97.23 7.96	.000 3.589	.0 .0	22.440 40.600	38.220 16.700	0.
1982.	207.69 30.33	118.96 19.802	164.82 27.53	.000 4.821	.0 .0	23.800 44.000	34.260 14.920	0.
1985.	260.59 44.46	167.94 33.942	217.19 38.72	.000 6.583	.0 .0	25.000 47.000	30.000 13.000	0.
1988.	321.00 58.97	186.45 37.392	303.27 57.21	.000 13.393	.0 .0	26.200 50.000	26.640 11.500	0.
1991.	393.53 75.68	188.82 38.094	401.87 82.11	1.831 22.930	.0 .0	27.600 52.600	23.600 10.140	0.
1994.	463.28 89.06	175.01 35.308	510.50 101.33	13.539 39.542	.0 .0	29.400 54.400	21.200 9.060	0.
1997.	524.73 98.27	162.21 32.725	605.35 116.55	23.082 64.148	563.8 316.5	30.800 56.200	18.720 8.020	0.
2000.	609.02 111.58	150.35 30.332	734.99 138.90	43.378 90.040	2289.1 1592.9	32.000 58.000	16.200 7.000	0.

Figure E.4.2 GEOTHERMAL RESOURCES NOT
EXPORTED FROM WEST TO EAST

TIME	COARPE COARPI	FELOARPE FELOARPI	FOOARPE FOOARPI	HEOARPE HEOARPI	SOARPE SOARPI	FOARPE FOARPI	FOOARPE FOOARPI	HEOARPE HEOARPI
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03 E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	99.71 15.318	97.23 7.96	.000 2.80	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	208.35 30.22	116.88 19.160	166.21 28.00	.000 4.57	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	262.05 44.53	163.45 32.360	220.01 39.22	.000 6.61	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	322.50 59.20	180.89 36.131	307.56 58.71	.000 12.59	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	394.43 75.94	182.77 36.597	406.73 83.36	1.677 21.98	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.83 89.15	169.40 33.920	514.43 102.91	11.385 41.23	.0 .0	29.400 54.400	21.200 9.060	3.267
1997.	515.68 98.42	157.01 31.439	599.69 118.40	22.613 83.51	540.6 324.6	30.800 56.200	18.720 8.020	21.553
2000.	582.55 112.04	145.52 29.140	708.42 141.40	42.020 144.67	2018.8 1623.0	32.000 58.000	16.200 7.000	56.402

Figure E.4.3 BASE RUN

TIME	SCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPE HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	100.79 15.594	97.23 7.96	.000 3.56	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	207.69 30.25	118.96 19.728	164.82 27.41	.000 4.76	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	260.59 44.38	167.94 33.835	217.19 38.57	.000 6.48	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	321.00 58.78	186.45 37.269	303.27 56.96	.000 13.51	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	393.53 75.21	188.82 37.972	401.87 81.65	1.903 23.69	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.62 88.22	175.01 35.195	508.93 100.25	12.634 44.58	.0 .0	29.400 54.400	21.200 9.060	3.295
1997.	515.45 96.97	162.21 32.621	592.60 114.99	22.020 88.38	519.9 306.2	30.800 56.200	18.720 8.020	21.527
2000.	583.90 110.00	150.35 30.235	701.72 136.98	40.243 148.19	1927.3 1547.3	32.000 58.000	16.200 7.000	56.018

Figure E.4.4 INCENTIVES CREATED TO REDUCE PERCEIVED
RISK ASSOCIATED WITH FIELD DEPLETION RATE

TIME	CCAPW	PETCAPW	NUCCAPW	GEOCAPW	SCAPW	HCAPW	NGCAPW	IMPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	100.79 15.656	97.23 7.96	.000 3.75	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	207.69 30.33	118.96 19.791	164.82 27.53	.000 6.91	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	260.59 43.26	167.94 33.120	217.19 38.70	.000 10.62	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	321.00 57.36	186.45 36.270	303.27 55.85	.000 20.23	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	393.53 73.24	188.82 36.621	401.87 80.28	1.751 30.15	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.76 86.55	175.01 33.942	509.06 99.27	11.823 49.81	.0 .0	29.400 54.400	21.200 9.060	3.309
1997.	516.09 95.75	162.21 31.460	593.48 114.29	22.340 92.79	523.3 314.1	30.800 56.200	18.720 8.020	21.746
2000.	583.71 109.31	150.35 29.159	701.59 136.73	41.293 155.61	1950.2 1580.1	32.000 58.000	16.200 7.000	57.476

Figure E.4.5 GOVERNMENT FUNDED HOT ROCK
DEVELOPMENT PROGRAM

TIME	CCAPW	FECCAPW	NUCCAPW	GEUCCAPW	SCAPW	HCAPW	NUCCAPW	FECCAPW
E+00	E+03	E+03	E+03	E+03	E+00	E+03	E+03	E+03
1973.	137.50	50.40	12.50	.000	.0	20.880	47.620	.000
	13.200	6.500	1.60	.40	.0	32.880	20.020	
1976.	161.51	65.44	40.81	.000	.0	20.760	41.580	.000
	14.787	6.743	5.76	.73	.0	36.400	18.200	
1979.	173.35	100.79	97.23	.000	.0	22.440	38.220	.000
	17.946	15.656	7.96	3.75	.0	40.600	16.700	
1982.	207.69	118.96	164.82	.000	.0	23.800	34.260	.000
	30.330	19.791	27.53	8.38	.0	44.000	14.920	
1985.	260.59	167.94	217.19	.000	.0	25.000	30.000	.000
	43.144	32.804	38.70	17.54	.0	47.000	13.000	
1988.	321.00	186.45	303.27	.000	.0	26.200	26.640	.000
	53.211	35.788	52.39	33.14	.0	50.000	11.500	
1991.	393.53	188.82	401.87	1.751	.0	27.600	23.600	.000
	65.342	35.667	69.35	52.18	.0	52.600	10.140	
1994.	461.76	175.01	509.06	11.823	.0	29.400	21.200	3.309
	76.228	33.058	87.25	76.22	.0	54.400	9.060	
1997.	516.09	162.21	593.48	29.081	523.3	30.800	18.720	21.746
	85.868	30.640	101.86	118.81	305.2	56.200	8.020	
2000.	576.76	150.35	692.99	54.775	1950.2	32.000	16.200	57.469
	99.743	28.399	123.88	181.15	1541.2	58.000	7.000	

Figure E.4.6 TECHNICAL "CRASH" PROGRAM

TIME	CCCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GECCAPE GEOCAPW	SCCAPE SCAPW	HCCAPE HCAPW	NGCCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.200	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.787	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.946	100.87 15.573	97.23 7.96	.000 4.10	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	207.65 30.181	119.10 19.638	164.72 27.29	.000 9.26	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	260.50 42.633	168.23 32.441	216.99 38.27	.000 19.50	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	320.93 52.033	186.80 35.254	302.97 51.21	.000 36.79	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	393.52 63.266	189.20 35.044	401.51 67.09	2.015 57.73	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.61 73.329	175.36 32.481	508.43 83.83	13.279 83.66	.0 .0	29.400 54.400	21.200 9.060	3.288
1997.	515.15 82.297	162.54 30.106	591.48 97.61	30.532 127.91	457.6 224.9	30.800 56.200	18.720 8.020	21.376
2000.	575.85 95.523	150.65 27.904	690.77 118.63	56.987 192.24	1690.7 1158.9	32.000 58.000	16.200 7.000	57.200

Figure E.4.7 ACCELERATED PROGRAM

B. Sensitivity Tests

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPW	NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	100.16 15.479	97.23 7.96	.000 2.81	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	208.38 30.24	117.75 19.403	165.25 27.72	.000 4.61	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	261.92 44.54	165.33 32.873	218.27 38.77	.000 6.67	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	322.14 59.18	183.22 36.738	305.41 58.20	.000 12.58	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	393.66 75.90	185.31 37.242	405.04 83.02	1.639 21.81	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	460.50 89.10	171.75 34.518	513.77 102.90	11.146 40.84	.0 .0	29.400 54.400	21.200 9.060	3.296
1997.	513.83 98.39	159.19 31.993	600.03 118.69	22.763 82.99	535.4 322.1	30.800 56.200	18.720 8.020	21.777
2000.	579.83 112.01	147.55 29.653	709.71 142.12	42.404 143.94	2004.7 1611.3	32.000 58.000	16.200 7.000	56.555

Figure E.4.8 RELIABILITY DECISION WEIGHT
DOUBLED (RF=1)

TIME	CCAPE CCAPW	PETCAPE PETCAPW	HUCCAPE HUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HUCAPE HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	99.44 15.224	97.23 7.96	.000 2.79	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	208.33 30.21	116.38 19.018	166.76 28.16	.000 4.55	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	262.13 44.52	162.36 32.061	221.04 39.47	.000 6.59	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	322.72 59.21	179.53 35.776	308.81 59.01	.000 12.61	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	394.88 75.97	181.28 36.220	407.72 83.57	1.699 22.08	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	462.61 89.18	168.02 33.571	514.82 102.92	11.524 41.45	.0 .0	29.400 54.400	21.200 9.060	3.249
1997.	516.75 98.44	155.73 31.115	599.50 118.24	22.523 83.82	543.6 326.1	30.800 56.200	18.720 8.020	21.423
2000.	584.14 112.05	144.34 28.839	707.67 140.99	41.791 144.84	2026.9 1629.7	32.000 58.000	16.200 7.000	56.312

Figure E.4.9 RELIABILITY DECISION WEIGHT
HALVED (RF=.25)

TIME	COCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPW HCAPW	NGCAPE NGCAPW	IMPCAPE IMPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	101.79 15.963	97.23 7.96	.000 2.77	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	207.09 29.84	120.86 20.169	163.55 27.09	.000 4.51	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	259.25 43.74	172.04 34.531	214.61 37.73	.000 6.54	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	319.63 58.35	191.54 38.690	299.33 56.55	.000 12.87	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	392.72 75.11	194.38 39.320	397.38 80.71	1.821 22.81	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.73 88.30	180.16 36.444	504.08 99.56	12.238 43.14	.0 .0	29.400 54.400	21.200 9.060	3.349
1997.	516.52 97.42	166.99 33.779	587.70 114.45	22.058 86.96	506.8 310.9	30.800 56.200	18.720 8.020	21.929
2000.	585.62 110.82	154.77 31.308	696.13 136.55	40.556 146.74	1885.0 1565.8	32.000 58.000	16.200 7.000	56.362

Figure E.4.10 CAPITAL INVESTMENT DECISION
WEIGHT DOUBLED (CIF=2)

TIME	CCAPW	PETCAPW	NUCCAPW	GECCAPW	SCAPW	HCAPW	NGCAPW	TCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	98.37 14.901	97.23 7.96	.000 2.81	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	209.16 30.46	114.33 18.510	167.91 28.59	.000 4.61	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	263.85 45.03	157.96 30.966	223.49 40.18	.000 6.68	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	324.36 59.75	174.10 34.488	312.79 60.10	.000 12.44	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	395.57 76.48	175.38 34.855	412.63 85.05	1.590 21.47	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.99 89.70	162.55 32.305	520.90 105.03	10.867 40.05	.0 .0	29.400 54.400	21.200 9.060	3.216
1997.	515.24 99.06	150.66 29.943	607.15 120.89	22.865 81.33	560.9 333.2	30.800 56.200	18.720 8.020	21.323
2000.	580.79 112.81	139.64 27.753	716.05 144.45	42.732 142.10	2100.3 1658.7	32.000 58.000	16.200 7.000	56.444

Figure E.4.11 CAPITAL INVESTMENT DECISION
WEIGHT HALVED (CIF=.5)

TIME	CCAPW	PETCAPW	NUCCAPW	GEUCAPW	SCAPW	HUCAPW	NGCAPW	IMPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	99.76 15.343	97.23 7.96	.000 2.80	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	207.13 29.88	117.05 19.207	167.41 28.40	.000 4.59	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	259.23 43.81	163.87 32.472	222.29 39.85	.000 6.64	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	318.12 58.15	181.46 36.276	311.25 59.67	.000 12.57	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	388.48 74.59	183.44 36.763	411.96 84.72	1.652 21.87	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	454.66 87.61	170.02 34.074	520.93 104.58	11.209 40.98	.0 .0	29.400 54.400	21.200 9.060	3.294
1997.	507.65 96.81	157.59 31.582	606.99 120.28	22.737 83.14	554.6 331.0	30.800 56.200	18.720 8.020	21.713
2000.	573.63 110.39	146.06 29.272	716.36 143.58	42.309 144.16	2069.0 1651.4	32.000 58.000	16.200 7.000	56.520

Figure E.4.12 ENVIRONMENTAL DECISION WEIGHT
DOUBLED (ECF=1.2)

TIME	COCAPE CCAPW	PECAPE PECAPW	INDCAPE HUCAPW	CCCAPE GECAPW	SCAPE SCAPW	HCCAPE HCAPW	INDCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	99.67 15.303	97.23 7.96	.000 2.79	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	209.07 30.42	116.79 19.132	165.49 27.76	.000 4.56	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	263.73 44.95	163.20 32.294	218.67 38.84	.000 6.60	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	325.11 59.83	180.56 36.044	305.35 58.15	.000 12.61	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	397.98 76.75	182.36 36.497	403.61 82.55	1.692 22.04	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	466.12 90.07	169.02 33.828	510.55 101.92	11.492 41.38	.0 .0	29.400 54.400	21.200 9.060	3.250
1997.	520.47 99.38	156.66 31.354	595.32 117.28	22.537 83.73	532.2 320.8	30.800 56.200	18.720 8.020	21.456
2000.	587.90 113.02	145.20 29.060	703.67 140.10	41.843 144.79	1988.5 1606.0	32.000 58.000	16.200 7.000	56.330

Figure E.4.13 ENVIRONMENTAL DECISION WEIGHT
HALVED (ECF=.3)

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPW	NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	99.23 15.110	97.23 7.96	.000 2.74	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	208.60 30.25	116.04 18.879	166.83 28.08	.000 4.45	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	262.55 44.55	161.71 31.799	221.23 39.41	.000 6.45	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	322.89 59.14	178.79 35.486	309.34 58.99	.000 12.73	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	394.41 75.55	180.54 35.932	408.87 83.54	1.806 22.61	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.17 88.33	167.34 33.304	516.85 102.63	12.150 42.73	.0 .0	29.400 54.400	21.200 9.060	3.246
1997.	514.02 97.09	155.10 30.868	601.81 117.75	22.115 85.90	487.2 291.6	30.800 56.200	18.720 8.020	21.288
2000.	580.53 110.11	143.76 28.611	711.56 140.28	40.712 145.91	1809.1 1461.4	32.000 58.000	16.200 7.000	56.108

Figure E.4.14 COST OF ELECTRICITY DECISION
WEIGHT DOUBLED (CEF=2)

TIME	COCAPE CCAPW	FETCAPE PETCAPW	NUCCAPE NUCCAPW	GECCAPE GEOCAPW	SCCAPE SCCAPW	HCCAPE HCCAPW	NUCCAPE NGCAPW	INPCAPE INPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	99.99 15.443	97.23 7.96	.000 2.83	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	208.20 30.20	117.38 19.329	165.84 27.95	.000 4.65	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	261.76 44.50	164.49 32.694	219.30 39.10	.000 6.75	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	322.28 59.25	182.14 36.516	306.49 58.56	.000 12.56	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	394.44 76.19	184.09 36.993	405.46 83.28	1.598 21.60	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	462.24 89.67	170.62 34.287	512.98 103.11	10.915 40.30	.0 .0	29.400 54.400	21.200 9.060	3.279
1997.	516.69 99.26	158.14 31.779	598.42 118.84	22.904 82.02	573.2 345.6	30.800 56.200	18.720 8.020	21.717
2000.	583.78 113.26	146.58 29.455	706.54 142.13	42.790 142.66	2148.1 1725.3	32.000 58.000	16.200 7.000	56.584

Figure E.4.15 COST OF ELECTRICITY DECISION
WEIGHT HALVED (CEF=.5)

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HUCAPE HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	97.95 14.800	97.23 7.96	.000 2.84	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	210.03 30.74	113.44 18.317	167.82 28.63	.000 4.70	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	266.08 45.65	155.95 30.514	223.33 40.21	.000 6.82	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	327.95 60.73	171.51 33.931	312.05 60.05	.000 12.38	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	400.61	172.46	410.44	1.505	.0	27.600	23.600	.000
1994.	468.48 91.67	159.84 31.731	517.05 104.83	10.384 38.91	.0 .0	29.400 54.400	21.200 9.060	3.178
1997.	523.31 101.52	148.15 29.410	602.57 120.75	22.464 79.30	600.0 360.1	30.800 56.200	18.720 8.020	21.198
2000.	590.14 115.84	137.32 27.259	709.79 144.35	42.149 139.50	2257.5 1789.7	32.000 58.000	16.200 7.000	56.534

Figure E.4.16 FUEL AVAILABILITY DECISION
WEIGHT DOUBLED (FAF=4)

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GECCAPE GEOCAPW	SCAPE SCAPW	HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03	E+03	E+03	E+00	E+00	E+03	E+03	E+03
	E+03	E+03	E+03	E+03	E+00	E+03	E+03	E+03
1973.	2.00	6.500	1.60	.000	.0	20.000	40.000	.000
	13.20	6.500	1.60	.40	.0	32.880	20.020	
1976.	161.51	65.44	40.81	.000	.0	20.760	41.580	.000
	14.79	6.743	5.76	.73	.0	36.400	18.200	
1979.	173.35	101.40	97.23	.000	.0	22.440	38.220	.000
	17.95	15.813	7.96	2.75	.0	40.600	16.700	
1982.	206.73	120.19	164.65	.000	.0	23.800	34.260	.000
	29.72	19.967	27.40	4.46	.0	44.000	14.920	
1985.	258.17	170.70	216.82	.000	.0	25.000	30.000	.000
	43.44	34.129	38.27	6.47	.0	47.000	13.000	
1988.	317.24	189.95	303.22	.000	.0	26.200	26.640	.000
	57.74	38.238	57.45	12.88	.0	50.000	11.500	
1991.	388.41	192.73	403.18	1.848	.0	27.600	23.600	.000
	74.02	38.862	82.02	22.93	.0	52.600	10.140	
1994.	455.32	178.64	511.97	12.362	.0	29.400	21.200	3.355
	86.75	36.020	101.10	43.46	.0	54.400	9.060	
1997.	508.19	165.57	596.98	21.991	481.9	30.800	18.720	21.901
	95.48	33.385	116.19	87.24	291.6	56.200	8.020	
2000.	575.28	153.46	707.47	40.339	1787.7	32.000	16.200	56.291
	108.44	30.943	138.63	146.91	1467.4	58.000	7.000	

Figure E.4.17 FUEL AVAILABILITY DECISION
WEIGHT HALVED (FAF=1)

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPE HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	97.47 14.687	97.23 7.96	.000 2.88	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	211.10 31.10	112.47 18.117	167.56 28.65	.000 4.79	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	268.41 46.38	153.82 30.068	223.05 40.25	.000 7.01	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	330.88 61.66	168.83 33.344	311.89 60.09	.000 12.27	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	403.59 79.14	169.50 33.613	410.29 85.08	1.364 20.27	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	471.14 93.18	157.10 31.155	517.41 105.82	9.527 37.08	.0 .0	29.400 54.400	21.200 9.060	3.159
1997.	526.00 103.42	145.61 28.876	604.20 122.36	21.778 76.14	629.5 379.2	30.800 56.200	18.720 8.020	21.243
2000.	592.01 118.20	134.96 26.764	711.87 146.84	41.106 135.14	2386.6 1879.8	32.000 58.000	16.200 7.000	56.812

Figure E.4.18 DECISION WEIGHT SET PESSIMISTIC
FOR GEOTHERMAL DEVELOPMENT

TIME	COCAPE CCAPW	PETCAPE PETCAPW	HUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPPE HCAPW	HGCCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	103.38 16.336	97.23 7.96	.000 2.66	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	203.93 28.85	124.09 20.882	163.87 26.95	.000 4.31	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	251.79 41.61	179.30 36.124	214.89 37.61	.000 6.23	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	308.76 55.32	200.72 40.640	300.32 56.41	.000 13.44	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	379.09 70.88	204.68 41.449	401.07 80.73	2.191 24.74	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	445.90 82.91	189.71 38.417	510.14 98.67	14.112 47.51	.0 .0	29.400 54.400	21.200 9.060	3.458
1997.	497.89 90.80	175.83 35.607	593.27 112.73	24.827 91.53	390.0 245.3	30.800 56.200	18.720 8.020	22.141
2000.	566.17 102.76	162.97 33.003	704.71 133.72	44.875 150.02	1430.2 1248.3	32.000 58.000	16.200 7.000	55.333

Figure E.4.19 DECISION WEIGHT SET OPTIMISTIC
FOR GEOTHERMAL DEVELOPMENT

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPE HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	99.71 15.318	97.23 7.96	.000 3.62	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	208.35 30.08	116.88 18.906	166.21 28.00	.000 8.49	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	262.05 42.85	163.45 31.111	220.01 38.69	.000 14.20	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	322.50 56.29	180.89 34.186	307.56 55.49	.000 24.67	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	394.43 71.85	182.77 34.337	406.73 79.34	1.677 35.34	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.83 84.94	169.40 31.826	514.43 98.61	11.385 54.25	.0 .0	29.400 54.400	21.200 9.060	3.267
1997.	515.68 94.26	157.01 29.498	599.69 113.83	38.246 96.28	540.6 319.6	30.800 56.200	18.720 8.020	21.553
2000.	569.87 108.02	145.52 27.341	692.77 136.66	73.285 158.10	2018.8 1602.2	32.000 58.000	16.200 7.000	57.082

Figure E.4.20 GEOTHERMAL RESOURCES DOUBLED

TIME	CCCAPE CCAPW	EECAPE PETCHPW	NUCCAPE NUCCAPW	GECCAPE GECCAPW	SCCAPE SCCAPW	ECCAPE ECCAPW	NUCCAPE NUCCAPW	EECAPE EECAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .396	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .732	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	99.71 15.449	97.23 7.96	.000 1.797	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	208.35 30.85	116.88 19.798	166.21 28.27	.000 2.592	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	262.05 45.71	163.45 33.453	220.01 40.61	.000 2.963	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	322.50 60.85	180.89 37.289	307.56 60.10	.000 8.499	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	394.43 77.87	182.77 37.804	406.73 85.70	1.677 17.431	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.83 91.38	169.40 35.039	514.43 105.43	6.716 35.012	.0 .0	29.400 54.400	21.200 9.060	3.267
1997.	518.54 100.60	157.01 32.476	603.42 121.04	14.686 62.045	540.6 326.5	30.800 56.200	18.720 8.020	15.720
2000.	606.36 118.91	145.52 30.101	741.41 150.20	20.750 81.515	2310.4 1723.0	32.000 58.000	16.200 7.000	23.468

Figure E.4.21 GEOTHERMAL RESOURCES HALVED

TIME	COCAPE CCAPW	FECAPE PETCAPW	NUCAPE NUCCAPW	GECAPE GEOCAPW	SCAPE SCAPW	HCAPL HCAPW	NGCAPL NGCAPW	IMPCAPL IMPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	125.79 21.412	97.23 7.96	.000 2.64	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	241.59 38.49	146.07 25.423	219.25 40.39	.000 4.27	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	323.60 55.45	222.55 43.692	285.82 53.53	.000 6.11	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	400.43 70.30	242.14 46.094	397.55 69.98	.000 15.45	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	493.65 93.50	243.47 45.191	521.18 107.78	2.102 28.79	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	577.64 114.40	225.66 41.886	659.21 137.84	14.083 56.11	.0 .0	29.400 54.400	21.200 9.060	4.094
1997.	646.45 127.55	209.16 38.822	765.82 157.50	24.557 103.12	676.3 396.1	30.800 56.200	18.720 8.020	26.965
2000.	739.90 145.97	193.86 35.983	914.55 188.50	44.893 155.39	2594.6 2019.6	32.000 58.000	16.200 7.000	59.576

Figure E.4.22 DEMAND INCREASED BY 25 PERCENT

TIME	CCAPF CCAPW	PETCAPF PETCAPW	NUCCAPF NUCCAPW	GECCAPF GEOCAPW	SCAPF SCAPW	HCAPF HCAPW	NGCAPF NGCAPW	IMPCAPF IMPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.5 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.8 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	143.22 25.612	97.2 7.96	.000 2.64	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	275.48 46.76	175.59 32.496	254.7 48.94	.000 4.27	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	382.41 69.12	277.65 56.619	351.4 69.28	.000 6.10	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	478.73 88.12	303.68 60.252	486.2 89.57	.000 17.25	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	591.68 116.32	304.19 58.894	635.6 135.89	2.540 33.29	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	693.95 141.80	281.94 54.586	803.4 172.58	13.730 66.43	.0 .0	29.400 54.400	21.200 9.060	4.948
1997.	778.57 157.72	261.32 50.594	932.8 196.59	26.344 117.16	813.6 483.2	30.800 56.200	18.720 8.020	30.404
2000.	902.75 181.86	242.21 46.893	1127.6 236.70	43.262 160.43	3285.9 2450.1	32.000 58.000	16.200 7.000	51.487

Figure E.4.23 DEMAND INCREASED BY 50 PERCENT

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPE HCAPW	NGCAPE NGCAPW	IMCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.5 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.8 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	143.22 25.491	97.2 7.96	.000 5.92	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	275.48 45.65	175.59 31.237	254.7 48.69	.000 12.86	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	382.41 65.87	277.65 53.811	351.4 66.57	.000 25.88	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	478.73 80.36	303.68 56.208	486.2 81.29	.000 45.51	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	591.68 105.15	304.19 54.457	635.6 122.10	2.540 69.18	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	693.95	281.94	803.4	17.155	.0	29.400		
1997.	777.80 145.42	261.32 46.782	931.8 181.21	29.769 170.56	813.6 468.8	30.800 56.200	18.720 8.020	32.470
2000.	880.54 165.82	242.21 43.361	1098.3 215.71	54.680 263.73	3043.3 2396.1	32.000 58.000	16.200 7.000	86.105

Figure E.4.24 DEMAND INCREASED BY 50 PERCENT AND
GEOHERMAL RESOURCES INCREASED TO LIMIT
OF TECHNICAL DEVELOPMENT POLICY

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GECCAPE GEOCAPW	SCAPE SCAPW	HUCAPE HUCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.200	50.40 6.500	12.50 1.600	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51	65.44	40.81	.000	.0	20.760	41.580	.000
1979.	173.35 17.946	73.52 9.166	97.23 7.964	.000 2.57	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	174.92 22.093	87.54 11.441	112.96 15.488	.000 4.75	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	200.23 26.572	104.08 15.867	153.86 21.971	.000 7.13	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	244.28 34.711	119.37 17.533	217.19 29.737	.000 14.14	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	294.89 47.681	121.79 17.499	291.89 51.910	1.252 22.00	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	345.71 60.390	112.88 16.219	369.21 68.642	8.524 37.56	.0 .0	29.400 54.400	21.200 9.060	2.438
1997.	384.58 68.104	104.63 15.033	433.10 79.918	20.940 69.70	404.9 225.7	30.800 56.200	18.720 8.020	16.137
2000.	430.00 78.339	96.98 13.933	508.52 96.878	39.474 115.91	1507.8 1163.9	32.000 58.000	16.200 7.000	43.025

Figure E.4.25 DEMAND DECREASED BY 25 PERCENT

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HUCAPE HCAPW	NGCAPE NGCAPW	IMPCAPE IMPCAPW
E+00	E+03 E-03	E+03 E-03	E+03 E-03	E+03 E-03	E+00 E-00	E+03 E-03	E+03 E+03	E+00
1973.	13.200	6.500	1.600	.396	.0	20.000	47.620	.0
						32.880	20.020	
1976.	161.51	65.44	40.81	.000	.00	20.760	41.580	.0
	14.787	6.743	5.765	.732	.0	36.400	18.200	
1979.	173.35	82.27	97.23	.000	.00	22.440	38.220	.0
	17.946	9.166	7.964	2.574	.0	40.600	16.700	
1982.	181.50	91.78	130.75	.000	.00	23.800	34.260	.0
	22.093	11.441	15.488	4.749	.0	44.000	14.920	
1985.	207.55	112.98	164.16	.000	.00	25.000	30.000	.0
	26.572	15.867	21.971	7.134	.0	47.000	13.000	
1988.	233.37	123.98	220.43	.000	.00	26.200	26.640	.0
	34.711	17.533	29.737	14.144	.0	50.000	11.500	
1991.	247.57	124.77	237.20	.290	.00	27.600	23.600	.0
	47.681	17.499	51.910	21.998	.0	52.600	10.140	
1994.	243.97	115.65	254.83	1.695	.00	29.400	21.200	564.9
	60.390	16.219	68.642	35.686	.0	54.400	9.060	
1997.	239.54	107.19	267.53	5.008	86.29	30.800	18.720	3205.5
	68.104	15.033	79.918	56.707	225.7	56.200	8.020	
2000.	231.29	99.35	275.35	10.752	265.97	32.000	16.200	8154.7
	78.241	13.933	96.758	80.198	1163.9	58.000	7.000	

Figure E.4.26 NO GROWTH IN DEMAND AFTER 1990

TIME	CCAPW	PETCAPW	NUCCAPW	GEOCAPW	SCAPW	HCAPW	NGCAPW	LMPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	100.07 15.427	97.23 7.96	.000 2.79	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	207.02 29.83	117.56 19.329	166.94 28.22	.000 4.55	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	258.93 43.70	164.88 32.719	221.50 39.59	.000 6.59	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	317.63 57.97	182.64 36.547	310.48 59.40	.000 12.64	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	387.66 74.26	184.64 37.033	411.59 84.47	1.704 22.13	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	453.27 87.07	171.13 34.324	521.22 104.26	11.526 41.62	.0 .0	29.400 54.400	21.200 9.060	3.319
1997.	505.39 95.99	158.62 31.814	607.60 119.90	22.531 84.37	548.6 327.8	30.800 56.200	18.720 8.020	21.819
2000.	570.46 109.12	147.01 29.487	718.23 143.12	41.779 145.23	2042.7 1638.3	32.000 58.000	16.200 7.000	56.500

Figure E.4.27 COAL ELECTRICITY GENERATION
COSTS INCREASED BY 50 PERCENT

TIME	CCCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCCAPE SCAPW	HCCAPE HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 5.500	12.50 1.00	.000 .00	.0 .0	20.880 20.880	47.620 20.020	.000
1976.	161.51 14.727	65.44 6.753	16.0 1.00	.000 .00	.0 .0	20.760 36.500	41.580 18.200	.000
1979.	73.33 17.95	30.60 15.005	57.00 7.96	.000 2.82	.0 .0	22.000 40.600	38.220 16.700	.000
1982.	212.15 31.32	114.96 18.677	164.10 27.36	.000 4.63	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	270.95 46.87	159.38 31.335	215.79 38.14	.000 6.70	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	336.34 62.69	175.93 34.941	299.26 56.78	.000 12.49	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	413.58 80.75	177.44 35.352	393.05 80.22	1.600 21.55	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	486.02 95.09	164.46 32.767	495.29 99.09	10.981 40.10	.0 .0	29.400 54.400	21.200 9.060	3.118
1997.	544.77 105.37	152.43 30.370	577.34 114.15	22.850 81.06	517.9 315.6	30.800 56.200	18.720 8.020	20.790
2000.	616.69 120.39	141.29 28.149	680.75 136.49	42.712 142.16	1950.1 1578.3	32.000 58.000	16.200 7.000	56.151

Figure E.4.28 COAL ELECTRICITY GENERATION
COSTS DECREASED BY 50 PERCENT

TIME	CCCAPE CCAPW	EECAPE PETCAPW	NUCCAPE NUCCAPW	GECCAPE GEOCAPW	SCCAPE SCAPW	HCCAPE HCCAPW	NGCCAPE NGCAPW	EMPCAPE EMPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	100.50 15.558	97.23 7.96	.000 2.78	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	205.43 29.37	118.36 19.530	167.83 28.49	.000 4.53	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	255.22 42.73	166.58 33.146	223.26 40.04	.000 6.56	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	311.84 56.52	184.71 37.041	313.95 60.21	.000 12.69	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	379.64 72.26	186.86 37.550	417.34 85.79	1.735 22.31	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	443.14 84.61	173.19 34.803	529.25 105.84	11.688 42.09	.0 .0	29.400 54.400	21.200 9.060	3.380
1997.	493.27 93.14	160.52 32.258	616.93 121.65	22.438 85.35	557.9 331.3	30.800 56.200	18.720 8.020	22.125
2000.	556.22 105.72	148.78 29.898	729.75 145.13	41.501 145.84	2070.1 1655.8	32.000 58.000	16.200 7.000	56.618

Figure E.4.29 COAL ELECTRICITY GENERATION COSTS AND
CAPITAL INVESTMENT COSTS INCREASED
BY 50 PERCENT

TIME	CCAPE CCAPW	FFCAPE FFCAPW	NUCCAPE NUCCAPW	GECCAPE GECCAPW	SCCAPE SCCAPW	HCCAPE HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.7 14.79	51.50 6.787	14.00 1.77	.000 .00	.0 .0	20.760 32.800	41.580 18.000	.000
1979.	221.34 17.95	60.50 14.668	17.23 2.96	.000 2.84	.0 .0	22.590 40.600	38.000 16.700	.000
1982.	216.20 32.50	112.91 18.162	161.85 26.68	.000 4.69	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	280.35 49.36	155.08 30.244	211.30 37.00	.000 6.80	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	350.82 66.37	170.69 33.681	290.58 54.74	.000 12.40	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	433.44 85.78	171.85 34.037	378.94 76.95	1.523 21.10	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	510.97 101.30	159.28 31.548	475.68 95.12	10.558 38.92	.0 .0	29.400 54.400	21.200 9.060	2.966
1997.	574.76 112.64	147.63 29.240	554.39 109.72	22.571 78.49	494.5 305.9	30.800 56.200	18.720 8.020	19.993
2000.	651.88 129.15	136.83 27.102	652.55 131.37	42.371 139.36	1878.3 1530.6	32.000 58.000	16.200 7.000	55.949

Figure E.4.30 COAL ELECTRICITY GENERATION COSTS
AND CAPITAL INVESTMENT COSTS
DECREASED BY 50 PERCENT

TIME	CONFE CCAPW	FEUCAPE PETCAPW	NUCCAPE NUCCAPW	GEUCAPE GEOCAPW	SCAPE SCAPW	HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	100.11 15.439	97.23 7.96	.000 2.79	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	209.07 30.42	117.63 19.347	164.66 27.48	.000 4.55	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	263.83 44.96	165.04 32.759	216.92 38.37	.000 6.59	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	325.81 59.96	182.85 36.596	302.34 57.39	.000 12.67	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	399.79 77.09	184.87 37.088	399.47 81.47	1.719 22.21	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	469.25 90.58	171.35 34.375	505.04 100.49	11.633 41.85	.0 .0	29.400 54.400	21.200 9.060	3.349
1997.	524.64 100.03	158.82 31.861	588.24 115.55	22.454 84.94	553.6 330.6	30.800 56.200	18.720 8.020	22.021
2000.	593.99 113.90	147.20 29.530	695.10 137.86	41.598 145.59	2061.3 1652.0	32.000 58.000	16.200 7.000	56.548

Figure E.4.31 NUCLEAR ELECTRICITY GENERATION
COSTS INCREASED BY 50 PERCENT

TIME	COGEP CCAPW	PETGEP PETCAPW	NUCCEP NUCCAPW	GEOGEP GEOCAPW	SCGEP SCAPW	HGEP HCAPW	NGGEP NGCAPW	IMPGEP IMPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	98.57 14.975	97.23 7.96	.000 2.82	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	206.31 29.66	114.78 18.632	170.57 29.47	.000 4.63	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	257.07 43.30	158.99 31.236	228.71 41.59	.000 6.71	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	313.32 57.08	175.42 34.819	322.11 62.43	.000 12.42	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	379.64 72.77	176.86 35.216	426.85 88.63	1.562 21.33	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	441.49 85.18	163.92 32.640	540.26 109.64	10.703 39.51	.0 .0	29.400 54.400	21.200 9.060	3.043
1997.	491.08 93.94	151.93 30.253	631.17 126.34	22.729 79.55	505.0 308.1	30.800 56.200	18.720 8.020	20.263
2000.	551.40 106.87	140.82 28.040	744.93 151.26	42.533 140.54	1901.5 1541.9	32.000 58.000	16.200 7.000	56.084

Figure E.4.32 NUCLEAR ELECTRICITY GENERATION
COSTS DECREASED BY 50 PERCENT

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEUCAPE GEUCAPW	SCAPE SCAPW	HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	100.48 15.552	97.23 7.96	.000 2.78	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	209.74 30.60	118.31 19.519	163.22 27.00	.000 4.53	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	265.43 45.35	166.49 33.123	214.11 37.60	.000 6.56	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	328.77 60.65	184.61 37.019	297.65 56.19	.000 12.73	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	404.56 78.10	186.78 37.532	392.97 79.78	1.755 22.42	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	475.78 91.85	173.11 34.786	496.73 98.36	11.842 42.38	.0 .0	29.400 54.400	21.200 9.060	3.419
1997.	532.49 101.45	160.45 32.242	578.24 113.06	22.321 86.16	564.7 335.6	30.800 56.200	18.720 8.020	22.415
2000.	603.89 115.51	148.72 29.884	683.59 134.83	41.241 146.33	2097.1 1676.1	32.000 58.000	16.200 7.000	56.679

Figure E.4.33 NUCLEAR ELECTRICITY GENERATION
COSTS AND CAPITAL INVESTMENT
COST INCREASED BY 50 PERCENT

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPPE HCCAPW	NGCAPE NGCAPW	LMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	97.62 14.687	97.23 7.96	.000 2.84	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	204.63 29.19	113.05 18.194	174.22 30.70	.000 4.68	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	253.01 42.29	155.35 30.311	235.86 43.56	.000 6.79	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	306.04 55.38	170.97 33.746	333.78 65.44	.000 12.30	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	368.16 70.28	172.10 34.092	442.64 92.80	1.478 20.85	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	425.96 82.08	159.51 31.599	560.11 114.89	10.204 38.23	.0 .0	29.400 54.400	21.200 9.060	2.880
1997.	472.49 90.47	147.85 29.288	655.05 132.48	22.324 76.60	479.1 295.6	30.800 56.200	18.720 8.020	19.320
2000.	528.38 102.90	137.03 27.146	772.24 158.79	41.926 137.37	1816.1 1481.8	32.000 58.000	16.200 7.000	55.910

Figure E.4.34 NUCLEAR ELECTRICITY GENERATION
COSTS AND CAPITAL INVESTMENT COST
DECREASED BY 50 PERCENT

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPE HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	99.46 15.269	97.23 7.96	.000 2.83	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	208.48 30.28	116.44 19.076	166.53 28.17	.000 4.65	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	262.31 44.66	162.53 32.173	220.65 39.46	.000 6.74	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	322.71 59.37	179.79 35.919	308.50 59.07	.000 12.50	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	394.42 76.24	181.09 36.378	507.66 83.91	1.025 21.47	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.57 89.62	168.31 33.717	515.77 103.85	10.723 39.93	.0 .0	29.400 54.400	21.200 9.060	3.263
1997.	515.30 99.02	156.00 31.251	601.46 119.53	22.768 80.97	966.4 629.4	30.800 56.200	18.720 8.020	21.594
2000.	580.65 112.47	144.59 28.965	709.14 142.51	42.549 140.73	3806.3 3120.5	32.000 58.000	16.200 7.000	56.600

Figure E.4.35 GEOTHERMAL ELECTRICITY GENERATION
COSTS INCREASED BY 50 PERCENT

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPF HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .00	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .00	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	99.99 15.373	97.23 7.96	.000 2.76	.0 .00	22.440 40.600	38.220 16.700	.000
1982.	208.20 30.15	117.39 19.255	165.84 27.81	.000 4.49	.0 .00	23.800 44.000	34.260 14.920	.000
1985.	261.76 44.37	164.49 32.570	219.29 38.94	.000 6.51	.0 .00	25.000 47.000	30.000 13.000	.000
1988.	322.28 59.02	182.15 36.368	306.49 58.33	.000 12.74	.0 .00	26.200 50.000	26.640 11.500	.000
1991.	394.44 75.62	184.09 36.842	405.45 82.76	1.792 22.55	.0 .00	27.600 52.600	23.600 10.140	.000
1994.	462.10 88.63	170.62 34.147	512.87 101.86	12.111 42.64	.0 .00	29.400 54.400	21.200 9.060	3.266
1997.	515.95 97.70	158.14 31.649	597.42 117.06	22.101 86.14	283.8 98.13	30.800 56.200	18.720 8.020	21.449
2000.	583.99 111.31	146.58 29.335	706.64 139.85	40.741 145.98	1052.5 476.77	32.000 58.000	16.200 7.000	56.176

Figure E.4.36 GEOTHERMAL ELECTRICITY GENERATION
COSTS DECREASED BY 50 PERCENT

TIME	COCAPE CCAPW	PETCAPE PETCAPW	HUCCAPE HUCCAPW	GECCAPE GECCAPW	SCCAPE SCCAPW	HCCAPE HCCAPW	NGCAPE NGCAPW	IMPCAPE IMPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	100.83 15.729	97.23 7.96	.000 2.84	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	207.67 30.06	119.03 19.770	164.78 27.63	.000 4.69	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	260.54 44.21	168.07 33.641	217.10 38.55	.000 6.80	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	320.95 58.95	186.62 37.642	303.14 57.75	.000 12.60	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	393.50 76.00	189.00 38.197	401.72 82.39	1.586 21.60	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.91 89.64	175.18 35.404	509.05 102.25	10.813 40.27	.0 .0	29.400 54.400	21.200 9.060	3.326
1997.	516.92 99.40	162.37 32.814	594.40 118.03	22.833 82.15	526.7 330.1	30.800 56.200	18.720 8.020	22.044
2000.	584.68 113.61	150.49 30.414	702.67 141.44	42.663 142.48	1979.6 1656.4	32.000 58.000	16.200 7.000	56.742

Figure E.4.37 GEOTHERMAL CAPITAL INVESTMENT
COSTS INCREASED BY 50 PERCENT

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GECCAPE GEOCAPW	SCAPE SCAPW	HCCAPE HCCAPW	NUCCAPE NGCAPW	THPCAPE THPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	98.36 14.832	97.23 7.96	.000 2.75	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	209.16 30.40	114.32 18.437	167.92 28.44	.000 4.45	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	263.86 44.89	157.95 30.841	223.50 40.01	.000 6.45	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	324.36 59.52	174.08 34.341	312.80 59.87	.000 12.65	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	395.57 75.91	175.36 34.704	412.64 84.54	1.781 22.42	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.81 88.64	162.53 32.166	520.75 103.74	12.035 42.30	.0 .0	29.400 54.400	21.200 9.060	3.199
1997.	514.32 97.37	150.64 29.813	605.89 118.91	22.177 84.99	556.4 318.6	30.800 56.200	18.720 8.020	20.993
2000.	580.23 110.34	139.63 27.632	715.23 141.45	40.916 145.33	2063.0 1586.0	32.000 58.000	16.200 7.000	56.006

Figure E.4.38 GEOTHERMAL CAPITAL INVESTMENT
COSTS DECREASED BY 50 PERCENT

TIME	OCAPW	PEOCAPE PETCAPW	NUOCAPE NUCCAPW	GEUCAPE GEOCAPW	SCAPW	HCAPW	NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50	50.40	12.50	.000	.0	20.880	47.620	.000
1976.	161.51 14.787	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.946	100.39 15.548	97.23 7.96	.000 2.80	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	207.64 30.035	118.64 19.606	165.53 27.80	.000 4.60	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	257.52 43.621	177.96 35.643	218.21 38.80	.000 6.61	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	301.70 54.747	228.00 47.801	288.81 54.81	.000 11.19	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	347.44 66.364	282.30 59.698	355.71 71.89	1.179 18.46	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	387.79	327.88	429.26	8.601	.0	29.400	21.200	2
1997.	422.62 82.160	372.07 78.855	492.65 98.97	20.928 65.90	388.4 255.9	30.800 56.200	18.720 8.020	16.295
2000.	464.80 92.656	423.04 89.279	569.18 127.22	40.000 123.08	1543.8 287.7	32.000 58.000	16.200 7.000	52.589

Figure E.4.39 PETROLEUM FUEL AVAILABILITY
INCREASED TO CONSTANT VALUE OF .75

YEAR	CCAPW	PETCAPW	NUCCAPW	GEOCAPW	SCAPW	HCAPW	NGCAPW	IMPCAPW
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.200	50.40 6.500	12.50 1.60	.000 .00	.0 .0	20.880 20.880	47.620 29.020	.000
1976.	161.51 14.79	15.54 6.743	50.41 5.76	.000 .73	.0 .0	20.200 36.400	11.090 18.200	.000
1979.	173.35 17.95	99.71 15.318	97.23 7.96	.000 2.80	.0 .0	22.440 40.600	38.220 16.700	.000
1982.	208.35 30.22	116.88 19.160	166.21 28.00	.000 4.57	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	262.05 44.53	163.45 32.360	220.01 39.22	.000 6.61	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	322.50 59.20	180.89 36.131	307.56 58.71	.000 12.54	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	394.19 75.83	182.77 36.597	406.51 83.24	1.671 21.84	202.5 142.4	27.600 52.600	23.600 10.140	.000
1994.	461.26 88.90	169.40 33.920	513.79 102.63	11.354 40.93	998.5 661.4	29.400 54.400	21.200 9.060	3.255
1997.	514.83 98.05	157.01 31.439	598.81 117.99	22.649 82.98	2287.3 1395.5	30.800 56.200	18.720 8.020	21.495
2000.	581.42 111.54	145.52 29.150	707.17 140.82	42.107 144.09	4169.3 2649.9	32.000 58.000	16.200 7.000	56.413

Figure E.4.40 SOLAR AVAILABILITY TIME
SET AT 1982

TIME	COCAPE CCAPW	PECAPE PETCAPW	NUCAPE NUCCAPW	GECAPE GEOCAPW	SCAPE SCAPW	HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 19.79	65.44 8.753	40.81 5.33	.000 .03	.0 .0	20.760 30.500	41.580 18.300	.000
1979.	173.35 17.95	70.11 15.318	47.13 7.96	.000 2.80	.0 .0	20.600 40.600	38.220 16.700	.000
1982.	208.35 30.22	116.88 19.160	166.21 28.00	.000 4.57	.0 .0	23.800 44.000	34.260 14.920	.000
P 1985.	262.05 44.53	163.45 32.360	220.01 39.22	.000 6.61	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	322.50 59.20	180.89 36.131	307.56 58.71	.000 12.59	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	394.43 75.94	182.77 36.597	406.73 83.36	1.669 21.94	.0 .0	27.600 52.600	23.600 10.140	.000
1994.	461.70 89.10	169.40 33.920	514.25 102.84	11.327 41.08	.0 .0	29.400 54.400	21.200 9.060	3.251
1997.	515.28 98.21	157.01 31.439	599.03 118.10	22.679 83.09	1380.8 817.8	30.800 56.200	18.720 8.020	21.442
2000.	581.62 111.62	145.52 29.140	707.24 140.86	42.176 144.30	3911.8 2946.6	32.000 50.000	16.200 7.000	56.379

Figure E.4.41 SOLAR LEARNING PROCESS ACCELERATED

TIME	CCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPPE HCCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+00 E+00	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.0 .0	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.0 .0	20.760 36.400	41.580 18.200	.000
1979.	277.30 17.95	99.7 15.318	97.33 7.96	.000 2.80	.0 .0	22.140 40.600	43.220 16.700	.000
1982.	208.35 30.22	116.88 19.160	166.21 28.00	.000 4.57	.0 .0	23.800 44.000	34.260 14.920	.000
1985.	262.05 44.53	163.45 32.360	220.01 39.22	.000 6.61	.0 .0	25.000 47.000	30.000 13.000	.000
1988.	322.50 59.20	180.89 36.131	307.56 58.71	.000 12.50	.0 .0	26.200 50.000	26.640 11.500	.000
1991.	394.00 75.74	182.77 36.597	406.33 83.14	1.659 21.71	361.8 252.5	27.600 52.600	23.600 10.140	.000
1994.	460.67 88.65	169.40 33.920	513.15 102.35	11.301 40.61	1782.9 1171.3	29.400 54.400	21.200 9.060	3.231
1997.	513.89 97.64	157.01 31.439	597.73 117.51	22.688 82.37	4348.0 2602.4	30.800 56.200	18.720 8.020	21.395
2000.	580.10 111.01	145.52 29.140	705.71 140.21	42.226 143.57	6877.7 4751.2	32.000 58.000	16.200 7.000	56.404

Figure E.4.42 SOLAR AVAILABILITY TIME SET AT 1982,
LEARNING PROCESS ACCELERATED, AND
RELIABILITY INCREASED TO 1.0

TIME	SCAPE CCAPW	PETCAPE PETCAPW	NUCCAPE NUCCAPW	GEOCAPE GEOCAPW	SCAPE SCAPW	HCAPPE HCAPW	NGCAPE NGCAPW	IMPCAPE
E+00	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+03 E+03	E+03
1973.	137.50 13.20	50.40 6.500	12.50 1.60	.000 .40	.000 .000	20.880 32.880	47.620 20.020	.000
1976.	161.51 14.79	65.44 6.743	40.81 5.76	.000 .73	.000 .000	20.760 36.400	41.580 18.200	.000
1979.	173.35 17.95	99.71 15.318	97.23 7.96	.000 2.80	.000 .000	22.440 40.600	38.220 16.700	.000
1982.	208.35 30.22	116.88 19.160	166.21 28.00	.000 4.57	.000 .000	23.800 44.000	34.260 14.920	.000
1985.	262.05 44.53	163.45 32.360	220.01 39.22	.000 6.60	.000 .000	25.000 47.000	30.000 13.000	.000
1988.	321.17 58.38	180.82 36.089	306.57 58.18	.000 11.97	.000 .000	26.200 50.000	26.640 11.500	.000
1991.	390.09 73.40	182.61 36.514	401.95 80.20	1.594 20.34	6.298 4.798	27.600 52.600	23.600 10.140	.000
1994.	453.34 84.68	169.26 33.843	504.44 97.61	10.904 37.57	15.501 11.061	29.400 54.400	21.200 9.060	3.106
1997.	503.80 92.40	156.88 31.368	585.96 111.20	22.888 76.20	25.082 16.140	30.800 56.200	18.720 8.020	20.643
2000.	565.49 103.77	145.40 29.074	688.28 131.19	42.779 135.06	33.669 23.219	32.000 58.000	16.200 7.000	56.524

Figure E.4.43 SOLAR AVAILABILITY TIME SET AT 1980,
RELIABILITY INCREASED TO 1.0, LEARNING
PROCESS ACCELERATED, ELECTRICITY GENERATION
COSTS HALVED, AND CAPITAL INVESTMENT COSTS
HALVED

REFERENCES

- [1] Forrester, Jay W., Industrial Dynamics (Cambridge, Mass.: M.I.T. Press, 1961).
- [2] Pugh, Alexander L., III, Dynamo II User's Manual, 4th Edition (Cambridge, Mass.: M.I.T. Press, 1973).
- [3] Estimated Fossil Fuel Requirements for the Electric Utility Industry of the United States 1973-1982, National Electric Reliability Council, February 12, 1974.
- [4] The 1970 National Power Survey (Washington, D.C.: Federal Power Commission, December 1971).

Appendix F
Trend Impact Analysis

Trend Extrapolation

The ability to quantify various parameters and project them into the future is an important factor in accomplishing the various steps in the planning process. Many techniques are and have been used to obtain such time series data. These range from highly judgmental, intuitive methods to highly complex mathematical treatments. In the former case, individual estimates (genius, expert, or non-expert) or group consensus (obtained by polling, face-to-face conferences, Delphi conferences, or situation gaming) may be employed.

Unfortunately, both human judgment and mathematical extrapolation have their own fallibilities. Past combinations of the two have not been notably successful in combining the best features of each, while avoiding their weaknesses. A principal strength of judgment in trend extrapolation is that humans can take into account the possible impacts of unprecedented future events that may cause unique perturbations in the trends. For example, if a pharmaceutical industrialist or food manufacturer might be interested in how the discovery of a link between pancreatic cancer and the consumption of sugar would influence the trend in sales of artificial sweeteners. This influence, however, could manifest itself in quite novel ways, since, by its very nature, it has never been felt before. Common mathematical methods of extrapolation are unable to take into account potential future events since the past history of a trend cannot reveal how it would be influenced by such events.

On the other hand, subjective or unaided human judgment is usually inferior to mathematical formulas when it comes to fitting a set of points with a best-fit curve. Moreover, mathematical curve-fitting techniques are well established in theory and application. They can be readily communicated and used by others, thereby overcoming the stigma of arbitrariness or mere idiosyncrasy that attends subjective projections. At best, however, a mathematical approach simply produces a good estimate of how a trend would appear if it were not modified by unprecedented future events.

Three examples illustrate how the occurrence of unprecedented events can influence a previously stable trend.

1. Until about 1955 the birth rate in the United States rose regularly and smoothly. The trend reversed dramatically in the 1960's when cheap and effective contraceptives permitted the expression of new values and attitudes about ideal family size (see Figure F.1). Extrapolations based on the historical trend from 1950 through 1960 consistently over-estimated the present birth rate in the United States.
2. Figure F.2 illustrates the long-term drop in the cost of electricity in the United States. The trend towards diminishing costs began almost with the advent of the first electricity generating system and reflected the generally unstated goal of producing cheap power. Cost was reduced through economies of scale, improved technology and operating efficiency, more readily available fuels, etc. Recently, however, the cost of electricity has stabilized and begun to rise because of

increasing costs of fuel, new requirements for costly anti-pollution devices, and restrictions on the size of generating plants that end or lower savings through economies of scale. An extrapolation based on all but the latest data would have missed the recent "turn-around."

Source: U.S. Public Health Service, Vital Statistics of the United States, annual.

Figure F.1 BIRTH RATE IN THE UNITED STATES

Source: Edison Electric Institute, Questions and Answers About the Electric Utility Industry, annual.

Figure F.2 ELECTRICITY USED IN THE HOME AVERAGE REVENUE PER KILOWATT-HOUR

3. The long-term trend in the United States toward the sale of automobiles of increasingly greater weight and horsepower has begun to change appreciably in recent months. This change may be the result of concern about increasing costs of gasoline, new public attitudes about conservation of the environment, or both.

Many other examples can, of course, be cited. The point is that deviations from historically-based extrapolations usually seem to reflect the impact of unprecedented events.

Trend Impact Analysis (TIA), an analytic procedure newly developed by The Futures Group, divides the task of extrapolation in such a way that humans and computers are assigned precisely the task that each does best. First, the computer extrapolates the past history of a trend. Second, the human specifies a set of unique future events and how the extrapolation would be changed by the occurrence of each of these events. The computer then uses these judgments to modify the trend extrapolation. Finally, the human evaluates the resultant adjusted extrapolation and modifies the input data to the computer in those cases where the output appears unreasonable. Figure F.3 schematically shows this procedure.

Mathematical Trend Extrapolation

The development of a surprise-free extrapolation is the first step in the TIA process. A computer program selects the "best-fitting" curve from a set of alternative equations. This curve is then used to provide the surprise-free future extrapolation. At the option of the program user, in order to avoid unreasonable extrapolations, the program can either truncate extrapolations that fall outside upper or lower bounds, or select the "best-fitting" curve only from among those that do not give rise to extrapolations falling outside the specified bounds. Alternatively, the user can reject the mathematical extrapolation generated by the TIA program and supply an extrapolation developed by some other curve fitting program or one based entirely on human judgment.

Several refinements in the programming of this aspect of TIA enhance the effectiveness of the best-fit test and extrapolation procedure.

1. Although the extrapolation is usually in terms of annual estimates (at least for the work done to date by The Futures Group), the input data may be quarterly, monthly, or any other more meaningful interval.
2. It is not necessary that the data cover a continuous span of time. Data in which there are gaps are fully acceptable--the program makes use of whatever data are available, taking into account any gaps, but without being stymied by them.
3. The program does not give equal weight to all data. Rather, a year may be specified (normally the present year) for which data are to be given maximum weight. As the times to which the data refer are further removed from the year which has maximum weight, the data are given less weight.* This procedure thus takes into account the possibly lower reliability of data that are more distant in the past or, more important perhaps, the lower influence on the future of developments that have occurred progressively farther in the past. The formula chosen also makes the sum of an infinite number of weights infinite, rather than convergent, so that every very distant years continue to have a finite contribution.
4. Since there is no guarantee that a mathematical extrapolation will give a good fit to the given data, the TIA program reports to the human user just how good the fit was,

*The weighting formula is $\frac{1}{1+|y-y_0|}$, where y is a given year and y₀ is the year given maximum weight.

Figure F.3 TREND IMPACT ANALYSIS (TIA)

using the same squared correlation coefficient that determines which mathematical formula should be used. As noted earlier, where judgment or analysis indicates a more realistic set of data should be used, they can be input directly as part of the specified data used for subsequent steps.

Human Judgments of Events Impacts

Human judgment and imagination are central to the second step of TIA. Here, the program modifies the surprise-free extrapolation to take into account important unprecedented future events. First, a list of such events is prepared. These events should be unprecedented, plausible, potentially powerful in impact, and verifiable in retrospect. The source of this list of events might be, typically, a literature search, a Delphi study, or a consensus among consultants. Whatever the source, the events selected comprise an inventory of potential forces which could lead to a departure from a surprise-free future.

Several judgments are made about each selected event. First, estimates are made of the probability of occurrence of each event as a function of time. Second, the impact of each event on the trend under study is estimated. Impacts can be specified in several ways; our procedure (Figure F.4) involves specification of:

1. The time from the occurrence of the impacting event until the trend begins to respond.
2. The time from the occurrence of the impacting event until the impact on the trend is largest.
3. The magnitude of that largest impact.
4. The time from the occurrence of the impacting event until the impact reaches a final or steady-state level.
5. The magnitude of that steady-state impact.

Each of the three specified times and the impact magnitudes associated with them are taken to be completely independent. For example, the maximum impact might be positive, and the steady-state impact negative, or the steady-state impact might be zero, meaning that the impact is only temporary. Finally, the maximum impact might be the same as the steady-state impact.

In addition, impacts can be specified in either relative or absolute units--i.e., they can be specified as percentages of the values of the trends at the time of impact, as a percentage change of that number, or they can be specified in absolute units of magnitude of the trend. For example, the impact of a particular event on the number of dentists could be specified either as 90 percent of that number, as a 10 percent decline of that number, or as a downward shift of 12,000. The form used to record these estimates is shown in Figure F.5.

Computer Processing of Impact on Extrapolated Trends

The heart of TIA is the computer program for using these judgments to calculate the expected impact of the selected events on the extrapolated trend. A closed-form procedure is used to solve this problem. The expected value, or mean, of the impact and upper and lower quartiles of the distribution of possible impacts are computed for each indicator. The expected value of the impact is computed by summing the products of the probabilities of the impacting events for each possible year times the magnitude of their impact, taking into account their specified lags. Probabilities of events for years not specified are estimated by linear interpolation, assuming that an event has 0.00 probability at the present time. Similarly, impacts are linearly interpolated between the three specified impact magnitudes.

This approach treats the coupling among the impacts of the various events as negligible. Thus, the impact estimate is produced as the sum of independent random variables. The net result is that the variance of the impact-adjusted forecast is the sum of the variance of the trend extrapolation (as measured by the square of the standard error of estimate) and the variances of the impacts of the associated events.

Figure F.4 EVENT IMPACT ESTIMATES

INDEX NO.		ESTIMATED PROBABILITY BY YEAR SHOWN PROB. YEAR	YEARS TO FIRST IMPACT	YEARS TO MAXIMUM IMPACT	MAXIMUM IMPACT (PERCENT)	YEARS TO STEADY STATE IMPACT	STEADY STATE IMPACT (PERCENT)
021277	SINGLE UNIT DRUG PACKAGING ACCOUNTS FOR AT LEAST 50% OF DRUG PRODUCTS SALES.	.99 1975	1	10	-5	10	-5

ESTIMATES PROVIDED BY EXPERTS

Figure F.5 FORMAT FOR EVENT IMPACTS

Thus, where P_{ye} is the likelihood that event e will occur in year y , and $a_{y_k-y,e}$ is the impact that event e would give rise to (y_k-y) years after its occurrence, the expected value of the impact in year y_k would be

$$\sum_e \sum_{y=y_0}^{y_k} P_{ye} a_{y_k-y,e} \quad \text{where } y_0 \text{ is the present year}$$

(e.g., 1974). (See Figure F.6.)

1979	-	-	-	-	$P_{79}^X I_0$
1978	-	-	-	$P_{78}^X I_0$	$P_{78}^X I_1$
1977	-	-	$P_{77}^X I_0$	$P_{77}^X I_1$	$P_{77}^X I_2$
1976	-	$P_{76}^X I_0$	$P_{76}^X I_1$	$P_{76}^X I_2$	$P_{76}^X I_3$
1975	$P_{75}^X I_0$	$P_{75}^X I_1$	$P_{75}^X I_2$	$P_{75}^X I_3$	$P_{75}^X I_4$
	1975	1976	1977	1978	1979

YEAR OF EVENT OCCURRENCE

- P_X = PROBABILITY OF OCCURRENCE IN YEAR X
- I_Y = IMPACT OF EVENT Y YEARS FROM OCCURRENCE OF THE EVENT
- $I_{TOTAL Y} = \sum I_{E_{1Y}} + I_{E_{2Y}} + \dots + I_{E_{1Y}}$
- ASSUMES COUPLING AMONG EVENTS AND EVENT IMPACTS IS NEGLIGIBLE

Figure F.6 EXPECTED VALUE OF AN EVENT IMPACT

Appendix G

THE VALUE MATRIX

The charts which follow present the value matrix discussed in Section 5 of the report. Potential impacts of geothermal energy form the rows of the matrix, and interest groups, the columns. The relevance numbers shown within the cells of the matrix display the study team's judgments as to the significance of each impact for each interest group.

Please refer to Section 5 for the scaling used, the impact statements, and the names of the interest groups.

* BASE 2000 NORMAL.
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IMPACTS	INTEREST GROUPS																																																		WEIGHTS: VALUE IN CASE CONSIDERED VALUE IN BASE CASE						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	CASE 1 I	CASE 2 II	CASE 3 III	CASE 4 IV			
32		6	1	4	4		-1	1	-1																		-2	-2	6	6	6				2	2	2	8		6						3	6	8	1	1.3	2	2					
33	-2	8			-1			1					-1			-1						-2	-1						8	2	2	-1		-2	-1	1	1	1	8	2	-2				2	-2		1	1.5	1	1						
34	-1		2		-1			1					-1			-1						-2	-1						2	8	2	-1		-2	-1	1	1	1	8	2	-2				-2		1	1.5	1	1							
35					-1			1					-1			-1						-2	-1						2	2	8	-1		-2	-1	1	1	1	8	2	-2	-2			-2		1	1.5	1	1							
36	-1				-1			1														-1	-1						2	2	4			-1		1	1	1	8						4		1	1.5	1	1							
37		4	-2	4	4		-1	1					-1			-1						1					-2	-2	8	7	6	-1		1	-1			8		-6		4				6		1	2	1	1						
38	4	1	1	1	1	2	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
39	4	1	1	1	1	1	4	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
40	4	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
41	-1	-1	-1	-1	-1	-1	4	-2	-2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
42	-1	-2					-2	-2		-1	-1	-1																	-1	-1						-1	-1	-1	-1		-6				-2	-3		1	1.2	1	.5						
43	-2	-2					-2	-2		-1																			-1	-1						-1	-1	-1	-1		-4	-4			-4	-2		1	1.2	1	.5						
44							-1	-2		-1																										-1	-1	-1		-6	-2			-4	-2		1	1.2	1	.5							
45		-5					-2	-2		-1																										-1	-1	-1		-6	-4			-4	-2		1	1.2	1	.5							
46	-2					-4	-4	-2		-3												-1	-1													-2	-2	-2	-2		1			-4			1	1.2	1	1							
47		-2						-1	-1																														-2	-2			-2	-1		1	1.1	1	.5								
48								1																																				6			6	1	1	1.2	1	1					
49																																															6		1	1.3	1	1					
50			2		2		1	1	1	4	2	2	-1	-1	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	-1	1	1	1	1	2		1	-1	1			1		1	1.2	1	1							
51					2		1	1	4	2	2	-1	-1	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	-1	1	1	1	1	2		1	-1	1			1		1	1.2	1	1							
52							-1	-1	-2	-3	-4																																				1		1	1	1	1					
53					-2		-1		-1	-1	-2																																				1		1	1	1	1					
54	-1						-1	-1		-2	-2	-2				-1	-1	-1											-1	-1	-1					-1										3			2	-2		1	1	1	1		
55		-2			-2		-2	-2	-2	-1	-1	-3																																				-6	-2		8		1	1	1	.5	
56				1								4																																				2		6	2	3	1	1	1	1	
57	-1				-2		-1		-1	-1	-4																																						1	-2		-2		1	1	1	1
58					-1				-1	-1	1																																							2		2		1	1	1	1
59							2	-2		-2	-2	-4																																					2		1	1	1	1	1		
60										-2	-2	-2																																						-1	4		1	1.2	1	1	
61		-2					-2	-1		1	1	1																		6	6	6																1	-2		-1		1	1.2	1	1	
62		-2					2	-2		-1	-1	-1																		-3	-3	-3																1	-2		-2		1	1	1	1	

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[illegible]

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 **** "LAND USE" POLICIES INTRODUCED (IN ADDITION TO ENVIRONMENTAL POLICIES) WHICH DIMINISH "DISLOCATIONS."

Appendix H

STATE AIR QUALITY STANDARDS
FOR STATES WITH GEOTHERMAL POTENTIAL

STATE	PARTICULATES	CARBON MONOXIDE	DUST	H ₂ S
Nevada	60 micrograms/M ³ annual geometric mean 150 micrograms/M ³ maximum 24-hour concentration	10,000 micrograms/M ³ (9.0 ppm) maximum 8-hour concentration 40,000 micrograms/M ³ (35.0 ppm) 1-hour concentration		
Oregon	60 micrograms/M ³ annual geometric mean 100 micrograms/M ³ 24-hour concentration for more than 15% of the samples collected in any calendar month 150 micrograms/M ³ 24-hour concentration not to be exceeded more than once per year	10 milligrams/M ³ (8.7 ppm) maximum 8-hour average not to be exceeded more than once per year 40 milligrams/M ³ (35 ppm) maximum 1-hour average not to be exceeded more than once per year	10 grams/square meter per month in an industrial area if visual observa- tion show a presence of wood waste or soot and the vola- tile fraction of the sample exceeds 70% 5.0 grams per square meter per month in residential and com- mercial areas 3.5 grams per square meter per month in residential and com- mercial areas if visual observations show presence of wood waste or soot and the volatile fraction of the sample exceeds 70%	
Utah	90 micrograms/M ³ annual geometric mean not more than 1% of the samples collected between April 1 and October 31; not more than 5% of the samples collected between November 1 and March 31 shall exceed a concentra- tion of 200 micrograms/M ³	9 ppm maximum 8-hour concentration not to be exceeded more than once per year 35 ppm maximum 1-hour concentration not to be exceeded more than once per year		
Washington	60 micrograms/M ³ annual geometric mean 150 micrograms/M ³ maximum 24-hour concen- tration not to be exceeded more than once per year	10 milligrams/M ³ (9 ppm) 8-hour average concentration not to be exceeded more than once per year 40 milligrams/M ³ (35 ppm) 1-hour average concentration not to be exceeded more than once per year	10 grams per square meter per month in industrial areas 5 grams per square meter per month in an industrial area if visual observa- tions show a presence of wood waste or soot and the volatile fraction of the sample exceeds 70% 5 grams per square meter per month in residential or com- mercial areas 3.5 grams per square meter per month in residential or com- mercial areas if visual observations show a presence of wood waste or soot and the volatile fraction of the sample exceeds 70%	
Wyoming	60 micrograms/M ³ annual geometric mean 150 micrograms/M ³ maximum 24-hour concen- tration not to be exceeded more than once per year	10 milligrams/M ³ (9 ppm) maximum 8-hour concentration not to be exceeded more than once per year 40 milligrams/M ³ (35 ppm) maximum 1-hour concentration not to be exceeded more than once per year	5 grams per square meter per month for any 30-day period in residential areas. Includes 1.7 grams per square meter background. 10 grams per square meter for any 30-day period in industrial areas. Includes 1.7 grams per square meter background.	70 micrograms/M ³ 1/2-hour average not to be exceeded more than two times per year 40 micrograms/M ³ 1/2-hour average not to be exceeded more than two times in any 5 consecu- tive days

STATE	PARTICULATES	CARBON MONOXIDE	DUST	H ₂ S
Alaska	60 micrograms/M ³ annual geometric mean 150 micrograms/M ³ 24-hour maximum not to be exceeded more than once per year	10 milligrams/M ³ 8-hour maximum not to be exceeded more than once per year 40 milligrams/M ³ 1-hour maximum not to be exceeded more than once per year		
Arizona	70 micrograms/M ³ annual annual geometric mean 100 micrograms/M ³ 24-hour maximum	7,000 micrograms/M ³ (8 ppm) 8-hour maximum 38,000 micrograms/M ³ (43.5 ppm) 90 minute maximum 6,000 micrograms/M ³ (6.9 ppm) maximum 7-day average		
California	60 micrograms/M ³ annual geometric mean 100 micrograms/M ³ 24-hour maximum	20 ppm 8-hour maximum		0.03 ppm 1-hour average
Colorado	45 micrograms/M ³ annual arithmetic mean of all 24-hour concentrations 150 micrograms/M ³ 24-hour maximum not to be exceeded more than once in a 12-month period	"Not to exceed National Standards"		
Hawaii	100 micrograms/M ³ average value during any 24-hour period 55 micrograms/M ³ annual arithmetic mean value during any 12-month period	10 milligrams/M ³ average value during any 1-hour period 5 milligrams/M ³ average value during any 8-hour period		
Idaho	<u>Primary</u> 75 micrograms/M ³ annual geometric mean 260 micrograms/M ³ maximum 24-hour concentration not to be exceeded more than once per year <u>Secondary</u> 60 micrograms/M ³ annual geometric mean 150 micrograms/M ³ maximum 24-hour concentration not to be exceeded more than once per year	10 milligrams/M ³ (9 ppm) maximum 8-hour concentration not to be exceeded more than once per year 40 milligrams/M ³ (ppm) maximum 1-hour concentration not to be exceeded more than once per year	0.8 milligrams per square centimeter per month not to be exceeded more than 25% of the time	
Montana	75 micrograms/M ³ annual geometric mean 200 micrograms/M ³ not to be exceeded more than 1% of days a year	"Not to exceed National Standards"	15 tons per square mile per month, 3-month average in residential areas 30 tons per square mile per month, 3-month average in heavy industrial areas	0.03 ppm 1/2-hour average not to be exceeded more than twice in any 5 consecutive days 0.05 ppm 1/2-hour average not to be exceeded over twice a year
New Mexico	150 micrograms/M ³ 24-hour average 110 micrograms/M ³ 7-day average 90 micrograms/M ³ 30-day average 60 micrograms/M ³ annual geometric mean Asbestos presenting particulate maximum concentration 0.01 micrograms/M ³ based on a 30-day average	8.7 ppm 8-hour average 13.1 ppm 1-hour average		

UNITED STATES GEOTHERMAL STEAM ACT 1970

Public Law 91-581
91st Congress, S. 368
December 24, 1970

An Act

To authorize the Secretary of the Interior to make disposition of geothermal steam and associated geothermal resources, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Geothermal Steam Act of 1970".

SEC. 2. As used in this Act, the term—

(a) "Secretary" means the Secretary of the Interior;

(b) "geothermal lease" means a lease issued under authority of this Act;

(c) "geothermal steam and associated geothermal resources" means (i) all products of geothermal processes, embracing indigenous steam, hot water and hot brines; (ii) steam and other gases, hot water and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; (iii) heat or other associated energy found in geothermal formations; and (iv) any byproduct derived from them;

(d) "byproduct" means any mineral or minerals (exclusive of oil, hydrocarbon gas, and helium) which are found in solution or in association with geothermal steam and which have a value of less than 75 per centum of the value of the geothermal steam or are not, because of quantity, quality, or technical difficulties in extraction and production, of sufficient value to warrant extraction and production by themselves;

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

SEC. 3. Subject to the provisions of section 15 of this Act, the Secretary of the Interior may issue leases for the development and utilization of geothermal steam and associated geothermal resources (1) in lands administered by him, including public, withdrawn, and acquired lands, (2) in any national forest or other lands administered by the Department of Agriculture through the Forest Service, including public, withdrawn, and acquired lands, 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.

SEC. 4. If lands to be leased under this Act are within any known geothermal resources area, they shall be leased to the highest responsible qualified bidder by competitive bidding under regulations formulated by the Secretary. If the lands to be leased are not within any known geothermal resources area, the qualified person first making application for the lease shall be entitled to a lease of such lands without competitive bidding. Notwithstanding the foregoing, at any time within one hundred and eighty days following the effective date of this Act:

(a) with respect to all lands which were on September 7, 1965, subject to valid leases or permits issued under the Mineral Leasing Act of February 25, 1920, as amended (30 U.S.C. 181 et seq.), or under the Mineral Leasing Act of Acquired Lands, as amended (30 U.S.C. 351, 358), or to existing mining claims located on or prior to September 7, 1965, the lessees or permittees or claimants or their successors in interest who are qualified to hold geothermal

84 STAT., 1566

Geothermal Steam
Act of 1970.
Definitions.

Acreage
Limitation.

Leases.

Lease
provisions.
Royalties.

Bids.

41 Stat., 437.

Conversion.

Rent.

41 Stat., 437.

61 Stat., 913.

84 STAT., 1567

leases shall have the right to convert such leases or permits or claims to geothermal leases covering the same lands;

(b) where there are conflicting claims, leases, or permits therefor embracing the same land, the person who first was issued a lease or permit, or who first recorded the mining claim shall be entitled to first consideration;

(c) with respect to all lands which were on September 7, 1965, the subject of applications for leases or permits under the above Acts, the applicants may convert their applications to applications for geothermal leases having priorities dating from the time of filing of such applications under such Acts;

(d) no person shall be permitted to convert mineral leases, permits, applications therefor, or mining claims for more than 10,240 acres; and

(e) the conversion of leases, permits, and mining claims and applications for leases and permits shall be accomplished in accordance with regulations prescribed by the Secretary. No right to conversion to a geothermal lease shall accrue to any person under this section unless such person shows to the reasonable satisfaction of the Secretary that substantial expenditures for the exploration, development, or production of geothermal steam have been made by the applicant who is seeking conversion, on the lands for which a lease is sought or on adjoining, adjacent, or nearby Federal or non-Federal lands.

(f) with respect to lands within any known geothermal resources area and which are subject to a right to conversion to a geothermal lease, such lands shall be leased by competitive bidding: *Provided*, That, the competitive geothermal lease shall be issued to the person owning the right to conversion to a geothermal lease if he makes payment of an amount equal to the highest bona fide bid for the competitive geothermal lease, plus the rental for the first year, within thirty days after he receives written notice from the Secretary of the amount of the highest bid.

SEC. 5. Geothermal leases shall provide for—

(a) a royalty of not less than 10 per centum or more than 15 per centum of the amount or value of steam, or any other form of heat or energy derived from production under the lease and sold or utilized by the lessee or reasonably susceptible to sale or utilization by the lessee;

(b) a royalty of not more than 5 per centum of the value of any byproduct derived from production under the lease and sold or utilized or reasonably susceptible of sale or utilization by the lessee, except that as to any byproduct which is a mineral named in section 1 of the Mineral Leasing Act of February 25, 1920, as amended (30 U.S.C. 181), the rate of royalty for such mineral shall be the same as that provided in that Act and the maximum rate of royalty for such mineral shall not exceed the maximum royalty applicable under that Act;

(c) payment in advance of an annual rental of not less than \$1 per acre or fraction thereof for each year of the lease. If there is no well on the leased lands capable of producing geothermal resources in commercial quantities, the failure to pay rental on or before the anniversary date shall terminate the lease by operation of law: *Provided, however*, That whenever the Secretary discovers that the rental payment due under a lease is paid timely but the amount of the payment is deficient because of an error or other reason and the deficiency is nominal, as determined by the Secretary pursuant to regulations prescribed by him, he shall notify the lessee of the deficiency and such lease shall not automatically terminate unless

the lessee fails to pay the deficiency within the period prescribed in the notice: *Provided further*, That, where any lease has been terminated automatically by operation of law under this section for failure to pay rental timely and it is shown to the satisfaction of the Secretary of the Interior that the failure to pay timely the lease rental was justifiable or not due to a lack of reasonable diligence, he in his judgment may reinstate the lease if—

(1) a petition for reinstatement, together with the required rental, is filed with the Secretary of the Interior; and

(2) no valid lease has been issued affecting any of the lands in the terminated lease prior to the filing of the petition for reinstatement; and

(d) a minimum royalty of \$2 per acre or fraction thereof in lieu of rental payable at the expiration of each lease year for each producing lease, commencing with the lease year beginning on or after the commencement of production in commercial quantities. For the purpose of determining royalties hereunder the value of any geothermal steam and byproduct used by the lessee and not sold and reasonably susceptible of sale shall be determined by the Secretary, who shall take into consideration the cost of exploration and production and the economic value of the resource in terms of its ultimate utilization.

Sec. 6. (a) Geothermal leases shall be for a primary term of ten years. If geothermal steam is produced or utilized in commercial quantities within this term, such lease shall continue for so long thereafter as geothermal steam is produced or utilized in commercial quantities, but such continuation shall not exceed an additional forty years.

(b) If, at the end of such forty years, steam is produced or utilized in commercial quantities and the lands are not needed for other purposes, the lessee shall have a preferential right to a renewal of such lease for a second forty-year term in accordance with such terms and conditions as the Secretary deems appropriate.

(c) Any lease for land on which, or for which under an approved cooperative or unit plan of development or operation, actual drilling operations were commenced prior to the end of its primary term and are being diligently prosecuted at that time shall be extended for five years and so long thereafter, but not more than thirty-five years, as geothermal steam is produced or utilized in commercial quantities. If, at the end of such extended term, steam is being produced or utilized in commercial quantities and the lands are not needed for other purposes, the lessee shall have a preferential right to a renewal of such lease for a second term in accordance with such terms and conditions as the Secretary deems appropriate.

(d) For purposes of subsection (a) of this section, production or utilization of geothermal steam in commercial quantities shall be deemed to include the completion of one or more wells producing or capable of producing geothermal steam in commercial quantities and a bona fide sale of such geothermal steam for delivery to or utilization by a facility or facilities not yet installed but scheduled for installation not later than fifteen years from the date of commencement of the primary term of the lease.

(e) Leases which have extended by reasons of production, or which have produced geothermal steam, and have been determined by the Secretary to be incapable of further commercial production and utilization of geothermal steam may be further extended for a period of not more than five years from the date of such determination but only for so long as one or more valuable byproducts are produced in commercial quantities. If such byproducts are leaseable under the Mineral Leasing Act of February 25, 1920, as amended (30 U.S.C. 181, et seq.), or under the Mineral Leasing Act for Acquired Lands (30 U.S.C.

61 Stat. 913.

351-358), and the leasehold is primarily valuable for the production thereof, the lessee shall be entitled to convert his geothermal lease to a mineral lease under, and subject to all the terms and conditions of, such appropriate Act upon application at any time before expiration of the lease extension by reason of byproduct production. The lessee shall be entitled to locate under the mining laws all minerals which are not leaseable and which would constitute a byproduct if commercial production or utilization of geothermal steam continued. The lessee in order to acquire the rights herein granted him shall complete the location of mineral claims within ninety days after the termination of the lease for geothermal steam. Any such converted lease or the surface of any mining claim located for geothermal byproducts mineral affecting lands withdrawn or acquired in aid of a function of a Federal department or agency, including the Department of the Interior, shall be subject to such additional terms and conditions as may be prescribed by such department or agency with respect to the additional operations or effects resulting from such conversion upon adequate utilization of the lands for the purpose for which they are administered.

(f) Minerals locatable under the mining laws of the United States in lands subject to a geothermal lease issued under the provisions of this Act which are not associated with the geothermal steam and associated geothermal resources of such lands as defined in section 2(c) herein shall be locatable under said mining laws in accordance with the principles of the Multiple Mineral Development Act (68 Stat. 708; found in 30 U.S.C. 521 et seq.).

Sec. 7. A geothermal lease shall embrace a reasonably compact area of not more than two thousand five hundred and sixty acres, except where a departure therefrom is occasioned by an irregular subdivision or subdivisions. No person, association, or corporation, except as otherwise provided in this Act, shall take, hold, own, or control at one time, whether acquired directly from the Secretary under this Act or otherwise, any direct or indirect interest in Federal geothermal leases in any one State exceeding twenty thousand four hundred and eighty acres, including leases acquired under the provisions of section 4 of this Act.

At any time after fifteen years from the effective date of this Act the Secretary, after public hearings, may increase this maximum holding in any one State by regulation, not to exceed fifty-one thousand two hundred acres.

Sec. 8. (a) The Secretary may readjust the terms and conditions, except as otherwise provided herein, of any geothermal lease issued under this Act at not less than ten-year intervals beginning ten years after the date the geothermal steam is produced, as determined by the Secretary. Each geothermal lease issued under this Act shall provide for such readjustment. The Secretary shall give notice of any proposed readjustment of terms and conditions, and, unless the lessee files with the Secretary objection to the proposed terms or relinquishes the lease within thirty days after receipt of such notice, the lessee shall conclusively be deemed to have agreed with such terms and conditions. If the lessee files objections, and no agreement can be reached between the Secretary and the lessee within a period of not less than sixty days, the lease may be terminated by either party.

(b) The Secretary may readjust the rentals and royalties of any geothermal lease issued under this Act at not less than twenty-year intervals beginning thirty-five years after the date geothermal steam is produced, as determined by the Secretary. In the event of any such readjustment neither the rental nor royalty may be increased by more than 50 per centum over the rental or royalty paid during the preceding period, and in no event shall the royalty payable exceed 22½ per centum. Each geothermal lease issue under this Act shall provide

Term.

Limitation.
Renewal.

Extension.

Leases,
coverage.

Limitation.

Increase.

Readjustment.

Notice.

41 Stat. 437.

for such readjustment. The Secretary shall give notice of any proposed readjustment of rentals and royalties, and, unless the lessee files with the Secretary objection to the proposed rentals and royalties or relinquishes the lease within thirty days after receipt of such notice, the lessee shall conclusively be deemed to have agreed with such terms and conditions. If the lessee files objections, and no agreement can be reached between the Secretary and the lessee within a period of not less than sixty days, the lease may be terminated by either party.

(c) Any readjustment of the terms and conditions as to use, protection, or restoration of the surface of any lease of lands withdrawn or acquired in aid of a function of a Federal department or agency other than the Department of the Interior may be made only upon notice to, and with the approval of, such department or agency.

Sec. 9. If the production, use, or conversion of geothermal steam is susceptible of producing a valuable byproduct or byproducts, including commercially demineralized water for beneficial uses in accordance with applicable State water laws, the Secretary shall require substantial beneficial production or use thereof unless, in individual circumstances he modifies or waives this requirement in the interest of conservation of natural resources or for other reasons satisfactory to him. However, the production or use of such byproducts shall be subject to the rights of the holders of preexisting leases, claims, or permits covering the same land or the same minerals, if any.

Sec. 10. The holder of any geothermal lease at any time may make and file in the appropriate land office a written relinquishment of all rights under such lease or of any legal subdivision of the area covered by such lease. Such relinquishment shall be effective as of the date of its filing. Thereupon the lessee shall be released of all obligations thereafter accruing under said lease with respect to the lands relinquished, but no such relinquishment shall release such lessee, or his surety or bond, from any liability for breach of any obligation of the lease, other than an obligation to drill, accrued at the date of the relinquishment, or from the continued obligation, in accordance with the applicable lease terms and regulations, (1) to make payment of all accrued rentals and royalties, (2) to place all wells on the relinquished lands in condition for suspension or abandonment, and (3) to protect or restore substantially the surface and surface resources.

Sec. 11. The Secretary, upon application by the lessee, may authorize the lessee to suspend operations and production on a producing lease and he may, on his own motion, in the interest of conservation suspend operations on any lease but in either case he may extend the lease term for the period of any suspension, and he may waive, suspend, or reduce the rental or royalty required in such lease.

Sec. 12. Leases may be terminated by the Secretary for any violation of the regulations or lease terms after thirty days notice provided that such violation is not corrected within the notice period, or in the event the violation is such that it cannot be corrected within the notice period then provided that lessee has not commenced in good faith within said notice period to correct such violation and thereafter to proceed diligently to correct such violation. Lessee shall be entitled to a hearing on the matter of such claimed violation or proposed termination of lease if request for a hearing is made to the Secretary within the thirty-day period after notice. The period for correction of violation or commencement to correct such violation of regulations or of lease terms, as aforesaid, shall be extended to thirty days after the Secretary's decision after such hearing if the Secretary shall find that a violation exists.

Sec. 13. The Secretary may waive, suspend, or reduce the rental or royalty for any lease or portion thereof in the interests of conservation and to encourage the greatest ultimate recovery of geothermal

Notice.

Surface
land, use.

Byproducts.

41 Stat. 1075;
62 Stat. 275.

Relinquishment.

16 USC 1.

Lessee,
citizenship
requirement.

Suspension.

Lessee,
termination.
Notice.

Cooperative
or unit
plan.

resources, if he determines that this is necessary to promote development or that the lease cannot be successfully operated under the lease terms.

Sec. 14. Subject to the other provisions of this Act, a lessee shall be entitled to use so much of the surface of the land covered by his geothermal lease as may be found by the Secretary to be necessary for the production, utilization, and conservation of geothermal resources.

Sec. 15. (a) Geothermal leases for lands withdrawn or acquired in aid of functions of the Department of the Interior may be issued only under such terms and conditions as the Secretary may prescribe to insure adequate utilization of the lands for the purposes for which they were withdrawn or acquired.

(b) Geothermal leases for lands withdrawn or acquired in aid of functions of the Department of Agriculture may be issued only with the consent of, and subject to such terms and conditions as may be prescribed by, the head of that Department to insure adequate utilization of the lands for the purposes for which they were withdrawn or acquired. Geothermal leases for lands to which section 24 of the Federal Power Act, as amended (16 U.S.C. 818), is applicable, may be issued only with the consent of, and subject to, such terms and conditions as the Federal Power Commission may prescribe to insure adequate utilization of such lands for power and related purposes.

(c) Geothermal leases under this Act shall not be issued for lands administered in accordance with (1) the Act of August 25, 1916 (39 Stat. 535), as amended or supplemented, (2) for lands within a national recreation area, (3) for lands in a fish hatchery administered by the Secretary, wildlife refuge, wildlife range, game range, wildlife management area, waterfowl production area, or for lands acquired or reserved for the protection and conservation of fish and wildlife that are threatened with extinction, (4) for tribally or individually owned Indian trust or restricted lands, within or without the boundaries of Indian reservations.

Sec. 16. Leases under this Act may be issued only to citizens of the United States, associations of such citizens, corporations organized under the laws of the United States or of any State or the District of Columbia, or governmental units, including, without limitation, municipalities.

Sec. 17. Administration of this Act shall be under the principles of multiple use of lands and resources, and geothermal leases shall, insofar as feasible, allow for coexistence of other leases of the same lands for deposits of minerals under the laws applicable to them, for the location and production of claims under the mining laws, and for other uses of the areas covered by them. Operations under such other leases or for such other uses, however, shall not unreasonably interfere with or endanger operations under any lease issued pursuant to this Act, nor shall operations under leases so issued unreasonably interfere with or endanger operations under any lease, license, claim, or permit issued pursuant to the provisions of any other Act.

Sec. 18. For the purpose of properly conserving the natural resources of any geothermal pool, field, or like area, or any part thereof, lessees thereof and their representatives may unite with each other, or jointly or separately with others, in collectively adopting and operating under a cooperative or unit plan of development or operation of such pool, field, or like area, or any part thereof, whenever this is determined and certified by the Secretary to be necessary or advisable in the public interest. The Secretary may in his discretion and with the consent of the holders of leases involved, establish, alter, change, revoke, and make such regulations with reference to such leases in connection with the institution and operation of any such cooperative or unit plan as he may deem necessary or proper to secure reasonable protection of the

public interest. He may include in geothermal leases a provision requiring the lessee to operate under such a reasonable cooperative or unit plan, and he may prescribe such a plan under which such lessee shall operate, which shall adequately protect the rights of all parties in interest, including the United States. Any such plan may, in the discretion of the Secretary, provide for vesting in the Secretary or any other person, committee, or Federal or State agency designated therein, authority to alter or modify from time to time the rate of prospecting and development and the quantity and rate of production under such plan. All leases operated under any such plan approved or prescribed by the Secretary shall be excepted in determining holdings or control for the purposes of section 7 of this Act.

When separate tracts cannot be independently developed and operated in conformity with an established well-spacing or development program, any lease, or a portion thereof, may be pooled with other lands, whether or not owned by the United States, under a communitization or drilling agreement providing for an apportionment of production or royalties among the separate tracts of land comprising the drilling or spacing unit when determined by the Secretary to be in the public interest, and operations or production pursuant to such an agreement shall be deemed to be operations or production as to each lease committed thereto.

The Secretary is hereby authorized, on such conditions as he may prescribe, to approve operating, drilling, or development contracts made by one or more lessees of geothermal leases, with one or more persons, associations, or corporations whenever, in his discretion, the conservation of natural products or the public convenience or necessity may require or the interests of the United States may be best served thereby. All leases operated under such approved operating, drilling, or development contracts, and interests thereunder, shall be excepted in determining holdings or control under section 7 of this Act.

Sec. 19. Upon request of the Secretary, other Federal departments and agencies shall furnish him with any relevant data then in their possession or knowledge concerning or having bearing upon fair and adequate charges to be made for geothermal steam produced or to be produced for conversion to electric power or other purposes. Data given to any department or agency as confidential under law shall not be furnished in any fashion which identifies or tends to identify the business entity whose activities are the subject of such data or the person or persons who furnished such information.

Sec. 20. All moneys received under this Act from public lands under the jurisdiction of the Secretary shall be disposed of in the same manner as moneys received from the sale of public lands. Moneys received under this Act from other lands shall be disposed of in the same manner as other receipts from such lands.

Sec. 21. (a) Within one hundred and twenty days after the effective date of this Act, the Secretary shall cause to be published in the Federal Register a determination of all lands which were included within any known geothermal resources area on the effective date of the Act. He shall likewise publish in the Federal Register from time to time his determination of other known geothermal resources areas specifying in each case the date the lands were included in such area; and

(b) Geothermal resources in lands the surface of which has passed from Federal ownership but in which the minerals have been reserved to the United States shall not be developed or produced except under geothermal leases made pursuant to this Act. If the Secretary of the Interior finds that such development is imminent, or that production from a well heretofore drilled on such lands is imminent, he shall so report to the Attorney General, and the Attorney General is authorized

and directed to institute an appropriate proceeding in the United States district court of the district in which such lands are located, to quiet the title of the United States in such resources, and if the court determines that the reservation of minerals to the United States in the lands involved included the geothermal resources, to enjoin their production otherwise than under the terms of this Act: *Provided*, That upon an authoritative judicial determination that Federal mineral reservation does not include geothermal steam and associated geothermal resources the duties of the Secretary of the Interior to report and of the Attorney General to institute proceedings, as hereinbefore set forth, shall cease.

Sec. 22. Nothing in this Act shall constitute an express or implied claim or denial on the part of the Federal Government as to its exemption from State water laws.

Waste,
prevention.

Sec. 23. (a) All leases under this Act shall be subject to the condition that the lessee will, in conducting his exploration, development, and producing operations, use all reasonable precautions to prevent waste of geothermal steam and associated geothermal resources developed in the lands leased.

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

Rules and
regulations.

Sec. 24. The Secretary shall prescribe such rules and regulations as he may deem appropriate to carry out the provisions of this Act. Such regulations may include, without limitation, provisions for (a) the prevention of waste, (b) development and conservation of geothermal and other natural resources, (c) the protection of the public interest, (d) assignment, segregation, extension of terms, relinquishment of leases, development contracts, unitization, pooling, and drilling agreements, (e) compensatory royalty agreements, suspension of operations or production, and suspension or reduction of rentals or royalties, (f) the filing of surety bonds to assure compliance with the terms of the lease and to protect surface use and resources, (g) use of the surface by a lessee of the lands embraced in his lease, (h) the maintenance by the lessee of an active development program, and (i) protection of water quality and other environmental qualities.

Sec. 25. As to any land subject to geothermal leasing under section 3 of this Act, all laws which either (a) provide for the disposal of land by patent or other form of conveyance or by grant or by operation of law subject to a reservation of any mineral or (b) prevent or restrict the disposal of such land because of the mineral character of the land, shall hereafter be deemed to embrace geothermal steam and associated geothermal resources as a substance which either must be reserved or must prevent or restrict the disposal of such land, as the case may be. This section shall not be construed to affect grants, patents, or other forms of conveyances made prior to the date of enactment of this Act.

Sec. 26. The first two clauses in section 11 of the Act of August 13, 1954 (68 Stat. 708, 716), are amended to read as follows:

"As used in this Act, 'mineral leasing laws' shall mean the Act of February 25, 1920 (41 Stat. 437); the Act of April 17, 1926 (44 Stat. 301); the Act of February 7, 1927 (44 Stat. 1057); Geothermal Steam Act of 1970, and all Acts heretofore or hereafter enacted which are amendatory of or supplementary to any of the foregoing Acts; 'Leasing Act minerals' shall mean all minerals which, upon the effective date of this Act, are provided in the mineral leasing laws to be disposed of thereunder and all geothermal steam and associated geothermal resources which, upon the effective date of the Geothermal Steam Act of 1970, are provided in that Act to be disposed of thereunder;"

Moneys.

Publication in
Federal Register.

30 USC 530.

30 USC 281.

30 USC 281.

Sec. 27. The United States reserves the ownership of and the right to extract under such rules and regulations as the Secretary may prescribe oil, hydrocarbon gas, and helium from all geothermal steam and associated geothermal resources produced from lands leased under this Act in accordance with presently applicable laws: *Provided*, That whenever the right to extract oil, hydrocarbon gas, and helium from geothermal steam and associated geothermal resources produced from such lands is exercised pursuant to this section, it shall be exercised so as to cause no substantial interference with the production of geothermal steam and associated geothermal resources from such lands.

Certain mineral rights, retention by U. S.

Approved December 24, 1970.

LEGISLATIVE HISTORY:

HOUSE REPORT No. 91-1544 (Comm. on Interior and Insular Affairs).
SENATE REPORT No. 91-1150 (Comm. on Interior and Insular Affairs).
CONGRESSIONAL RECORD, Vol. 116 (1970):
Sept. 16, Oct. 14, Dec. 4, 10, considered and passed Senate.
Oct. 5, Dec. 9, considered and passed House.

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GEOHERMAL ENERGY RESEARCH, DEVELOPMENT,
AND DEMONSTRATION ACT OF 1974,
Public Law 93-410
93rd Congress, H.R. 14950,
September 3, 1974

An Act

To further the conduct of research, development, and demonstrations in geothermal energy technologies, to establish a Geothermal Energy Coordination and Management Project, to provide for the carrying out of research and development in geothermal energy technology, to carry out a program of demonstrations in technologies for the utilization of geothermal resources, to establish a loan guaranty program for the financing of geothermal energy development, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SHORT TITLE

SECTION 1. This Act may be cited as the "Geothermal Energy Research, Development, and Demonstration Act of 1974".

FINDINGS

SEC. 2. The Congress hereby finds that—

(1) the Nation is currently suffering a critical shortage of environmentally acceptable forms of energy;

(2) the inadequate organizational structures and levels of funding for energy research have limited the Nation's current and future options for meeting energy needs;

(3) electric energy is a clean and convenient form of energy at the location of its use and is the only practicable form of energy in some modern applications, but the demand for electric energy in every region of the United States is taxing all of the alternative energy sources presently available and is projected to increase; some of the sources available for electric power generation are already in short supply, and the development and use of other sources presently involve undesirable environmental impacts;

(4) the Nation's critical energy problems can be solved only if a national commitment is made to dedicate the necessary financial resources, and enlist the cooperation of the private and public sectors, in developing geothermal resources and other nonconventional sources of energy;

(5) the conventional geothermal resources which are presently being used have limited total potential; but geothermal resources which are different from those presently being used, and which have extremely large energy content, are known to exist;

(6) some geothermal resources contain energy in forms other than heat; examples are methane and extremely high pressures available upon release as kinetic energy;

(7) some geothermal resources contain valuable byproducts such as potable water and mineral compounds which should be processed and recovered as national resources;

(8) technologies are not presently available for the development of most of these geothermal resources, but technologies for the generation of electric energy from geothermal resources are potentially economical and environmentally desirable, and the development of geothermal resources offers possibilities of process energy and other nonelectric applications;

(9) much of the known geothermal resources exist on the public lands;

Geothermal
Energy Research,
Development,
and Demonstra-
tion Act of
1974.
30 USC 1101
note.

30 USC 1101.

88 STAT. 1079
88 STAT. 1080

(10) Federal financial assistance is necessary to encourage the extensive exploration, research, and development in geothermal resources which will bring these technologies to the point of commercial application;

(11) the advancement of technology with the cooperation of private industry for the production of useful forms of energy from geothermal resources is important with respect to the Federal responsibility for the general welfare, to facilitate commerce, to encourage productive harmony between man and his environment, and to protect the public interest; and

(12) the Federal Government should encourage and assist private industry through Federal assistance for the development and demonstration of practicable means to produce useful energy from geothermal resources with environmentally acceptable processes.

DEFINITIONS

30 USC 1102.

SEC. 3. For the purposes of this Act—

(1) the term "geothermal resources" means (A) all products of geothermal processes, embracing indigenous steam, hot water, and brines, (B) steam and other gases, hot water and hot brines, resulting from water, gas, or other fluids artificially introduced into geothermal formations, and (C) any byproduct derived from them;

(2) the term "byproduct" means any mineral or minerals which are found in solution or in association with geothermal resources and which have a value of less than 75 percent of the value of the geothermal steam and associated geothermal resources or are not, because of quantity, quality, or technical difficulties in extraction and production, of sufficient value to warrant extraction and production by themselves;

(3) "pilot plant" means an experimental unit of small size used for early evaluation and development of new or improved processes and to obtain technical, engineering, and cost data;

(4) "demonstration plant" means a complete facility which produces electricity, heat energy, or useful byproducts for commercial disposal from geothermal resources and which will make a significant contribution to the knowledge of full-size technology, plant operation, and process economics;

(5) the term "Project" means the Geothermal Energy Coordination and Management Project established by section 101(a);

(6) the term "fund" means the Geothermal Resources Development Fund established by section 204(a); and

(7) the term "Chairman" means the Chairman of the Project.

TITLE I—GEOTHERMAL ENERGY COORDINATION AND MANAGEMENT PROJECT

ESTABLISHMENT

30 USC 1121.

SEC. 101. (a) There is hereby established the Geothermal Energy Coordination and Management Project.

Membership.

89 STAT. 1080

90 STAT. 1081

(b) (1) The Project shall be composed of six members as follows:

(A) one appointed by the President;

(B) an Assistant Director of the National Science Foundation;

(C) an Assistant Secretary of the Department of the Interior;

(D) an Associate Administrator of the National Aeronautics and Space Administration;

(E) the General Manager of the Atomic Energy Commission;
and

(F) an Assistant Administrator of the Federal Energy Administration.

(2) The President shall designate one member of the Project to serve as Chairman of the Project.

(3) If the individual appointed under paragraph (1)(A) is an officer or employee of the Federal Government, he shall receive no additional pay on account of his service as a member of the Project. If such individual is not an officer or employee of the Federal Government, he shall be entitled to receive the daily equivalent of the annual rate of basic pay in effect for level IV of the Executive Schedule (5 U.S.C. 5315) for each day (including traveltime) during which he is engaged in the actual performance of duties vested in the Project.

Compensation.

20 Stat. 461;
83 Stat. 863.

(c) The Project shall have overall responsibility for the provision of effective management and coordination with respect to a national geothermal energy research, development, and demonstration program. Such program shall include—

- (1) the determination and evaluation of the resource base;
- (2) research and development with respect to exploration, extraction, and utilization technologies;
- (3) the demonstration of appropriate technologies; and
- (4) the loan guaranty program under title II.

(d) (1) The Project shall carry out its responsibilities under this section acting through the following Federal agencies:

(A) the Department of the Interior, the responsibilities of which shall include evaluation and assessment of the resource base, including development of exploration technologies;

(B) the National Aeronautics and Space Administration, the responsibilities of which shall include the provision of contract management capability, evaluation and assessment of the resource base, and the development of technologies pursuant to section 102(b);

(C) the Atomic Energy Commission, the responsibilities of which shall include the development of technologies; and

(D) the National Science Foundation, the responsibilities of which shall include basic and applied research.

(2) Upon request of the Project, the head of any such agency is authorized to detail or assign, on a reimbursable basis or otherwise, any of the personnel of such agency to the Project to assist it in carrying out its responsibilities under this Act.

(e) The Project shall have exclusive authority with respect to the establishment or approval of programs or projects initiated under this Act, except that the agency involved in any particular program or project shall be responsible for the operation and administration of such program or project.

PROGRAM DEFINITION

SEC. 102. (a) (1) The Chairman, acting through the Administrator of the National Aeronautics and Space Administration, is authorized and directed to prepare a comprehensive program definition of an integrated effort and commitment for effectively developing geothermal energy resources. Such Administrator, in preparing such comprehensive program definition, is authorized to consult with other Federal agencies and non-Federal entities.

30 USC 1122.

Transmittal to
President and
Congress.
Interim re-
ports.

Inventory
schedule and
objectives,
transmittal to
President and
Congress.

(2) The Chairman shall transmit such comprehensive program definition to the President and to each House of the Congress. Interim reports shall be transmitted not later than November 30, 1974, and not later than January 31, 1975. Such comprehensive program definition shall be transmitted as soon as possible thereafter, but in any case not later than August 31, 1975.

(3) As part of the comprehensive program definition required by paragraph (1), the Chairman, acting through the Geological Survey, shall transmit to the President and to each House of the Congress a schedule and objectives for the inventorying of geothermal resources.

(b) The National Aeronautics and Space Administration is authorized to undertake and carry out those programs assigned to it by the Project.

RESOURCE INVENTORY AND ASSESSMENT PROGRAM

30 USC 1123.

SEC. 103. (a) The Chairman shall initiate a resource inventory and assessment program with the objective of making regional and national appraisals of all types of geothermal resources, including identification of promising target areas for industrial exploration and development. The specific goals shall include—

(1) the improvement of geophysical, geochemical, geological, and hydrological techniques necessary for locating and evaluating geothermal resources;

(2) the development of better methods for predicting the power potential and longevity of geothermal reservoirs;

(3) the determination and assessment of the nature and power potential of the deeper unexplored parts of high temperature geothermal convection systems; and

(4) the survey and assessment of regional and national geothermal resources of all types.

(b) The Chairman, acting through the Geological Survey and other appropriate agencies, shall—

(1) develop and carry out a general plan for the orderly inventorying of all forms of geothermal resources of the Federal lands and, where consistent with property rights and determined by the Chairman to be in the national interest, of non-Federal lands;

(2) conduct regional surveys, based upon such a general plan, using innovative geological, geophysical, geochemical, and stratigraphic drilling techniques, which will lead to a national inventory of geothermal resources in the United States;

(3) publish and make available maps, reports, and other documents developed from such surveys to encourage and facilitate the commercial development of geothermal resources for beneficial use and consistent with the national interest;

(4) make such recommendations for legislation as may from time to time appear to be necessary to make Federal leasing policy for geothermal resources consistent with known inventories of various resource types, with the current state of technologies for geothermal energy development, and with current evaluations of the environmental impacts of such development; and

(5) participate with appropriate Federal agencies and non-Federal entities in research to develop, improve, and test technologies for the discovery and evaluation of all forms of geothermal resources, and conduct research into the principles controlling the location, occurrence, size, temperature, energy content, producibility, and economic lifetimes of geothermal reservoirs.

RESEARCH AND DEVELOPMENT

30 USC 1124.

SEC. 104. (a) The Chairman, acting through the appropriate Federal agencies and in cooperation with non-Federal entities, shall initiate a research and development program for the purpose of resolving all major technical problems inhibiting the fullest possible commercial utilization of geothermal resources in the United States. The specific goals of such programs shall include—

(1) the development of effective and efficient drilling methods to operate at high temperatures in formations of geothermal interest;

(2) the development of reliable predictive methods and control techniques for the production of geothermal resources from reservoirs;

(3) the exploitation of new concepts for fracturing rock to permit recovery of contained heat reserves;

(4) the improvement of equipment and technology for the extraction of geothermal resources from reservoirs;

(5) the development of improved methods for converting geothermal resources and byproducts to useful forms;

(6) the development of improved methods for controlling emissions and wastes from geothermal utilization facilities, including new monitoring methods to any extent necessary;

(7) the development and evaluation of waste disposal control technologies and the evaluation of surface and subsurface environmental effects of geothermal development;

(8) the improvement of the technical capability to predict environmental impacts resulting from the development of geothermal resources, the preparation of environmental impact statements, and the assuring of compliance with applicable standards and criteria;

(9) the identification of social, legal, and economic problems associated with geothermal development (both locally and regionally) for the purpose of developing policy and providing a framework of policy alternatives for the commercial utilization of geothermal resources;

(10) the provision for an adequate supply of scientists to perform required geothermal research and development activities; and

(11) the establishment of a program to encourage States to establish and maintain geothermal resources clearinghouses, which shall serve to (A) provide geothermal resources developers with information with respect to applicable local, State, and Federal laws, rules, and regulations, (B) coordinate the processing of permit applications, impact statements, and other information which geothermal resources developers are required to provide, (C) encourage uniformity with respect to local and State laws, rules, and regulations with respect to geothermal resources development, and (D) encourage establishment of land use plans, which would include zoning for geothermal resources development and which would assure that geothermal resources developers will be able to carry out development programs to the production stage.

(b) The Chairman, acting through the appropriate Federal agencies and in cooperation with non-Federal entities, shall implement a coordinated program of research and development in order to demonstrate the technical means for the extraction and utilization of the resource base, including any byproducts of such base, and in order to

accomplish the goals established by subsection (a). Research authorized by this Act having potential applications in matters other than geothermal energy may be pursued to the extent that the findings of such research can be published in a form for utilization by others.

DEMONSTRATION

30 USC 1125.

SEC. 105. (a) The Chairman, acting through the appropriate Federal agencies and in cooperation with non-Federal entities, shall initiate a program to design and construct geothermal demonstration plants. The specific goals of such program shall include—

(1) the development of economical geothermal resources production systems and components which meet environmental standards;

(2) the design of plants to produce electric power and, where appropriate, the large-scale production and utilization of any useful byproducts;

(3) the involvement of engineers, analysts, technicians, and managers from industry field and powerplant development, which shall lead to the early industrial exploitation of advanced geothermal resources;

(4) the provision for an adequate supply of trained geothermal engineers and technicians;

(5) the provision of experimental test beds for component testing an evaluation by laboratories operated by the Federal Government, industry, or institutions of higher education;

(6) the construction and operation of pilot plants; and

(7) the construction and operation of demonstration plants.

(b) In carrying out his responsibilities under this section, the Chairman, acting through the appropriate Federal agencies, and in cooperation with non-Federal entities, may provide for the establishment of one or more demonstration projects utilizing each geothermal resource base involved, which shall include, as appropriate, all of the exploration, siting, drilling, pilot plant construction and operation, demonstration plant construction and operation, and other facilities and activities which may be necessary for the generation of electric energy and the utilization of geothermal resource byproducts.

Cooperative
agreements.

(c) The Chairman, acting through the appropriate Federal agencies, is authorized to investigate and enter into agreements for the cooperative development of facilities to demonstrate the production of energy from geothermal resources. The responsible Federal agency may consider—

(1) cooperative agreements with utilities and non-Federal governmental entities for construction of facilities to produce energy for commercial disposition; and

(2) cooperative agreements with other Federal agencies for the construction and operation of facilities to produce energy for direct Federal consumption.

(d) The responsible Federal agency is authorized to investigate the feasibility of, construct, and operate, demonstration projects without entering into cooperative agreements with respect to such projects, if the Chairman finds that—

(1) the nature of the resource, the geographical location, the scale and engineering design of the facilities, the techniques of production, or any other significant factor of the proposal offers opportunities to make important contributions to the general

knowledge of geothermal resources, the techniques of its development, or public confidence in the technology; and

(2) there is no opportunity for cooperative agreements with any utility or non-Federal governmental entity willing and able to cooperate in the demonstration project under subsection (c) (1), and there is no opportunity for cooperative agreements with other Federal agencies under subsection (c) (2).

(e) Before favorably considering proposals under subsection (c), the responsible Federal agency must find that—

(1) the nature of the resource, the geographical location, the scale and engineering design of the facilities, the techniques of production, or any other significant factor of the proposal offers opportunities to make important contributions to the general knowledge of geothermal resources, the techniques of its development, or public confidence in the technology;

(2) the development of the practical benefits as set forth in paragraph (1) are unlikely to be accomplished without such cooperative development; and

(3) where non-Federal participants are involved, the proposal is not eligible for adequate Federal assistance under the loan guaranty provisions of title II of this Act.

(f) If the estimate of the Federal investment with respect to construction and operation costs of any demonstration project proposed to be established under this section exceeds \$10,000,000, no amount may be appropriated for such project except as specifically authorized by legislation hereafter enacted by the Congress.

(g) (1) At the conclusion of the program under this section or as soon thereafter as may be practicable, the responsible Federal agencies shall, by sale, lease, or otherwise, dispose of all Federal property interests which they have acquired pursuant to this section (including mineral rights) in accordance with existing law and the terms of the cooperative agreements involved.

Federal property interests, disposal.

(2) The agency involved shall, under appropriate agreements or other arrangements, provide for the disposition of geothermal resource byproducts of the project administered by such agency.

Project by-products, disposal.

SCIENTIFIC AND TECHNICAL EDUCATION

SEC. 106. (a) It is the policy of the Congress to encourage the development and maintenance of programs through which there may be provided the necessary trained personnel to perform required geothermal research, development, and demonstration activities under sections 103, 104, and 105.

30 USC 1126.

(b) The National Science Foundation is authorized to support programs of education in the sciences and engineering to carry out the policy of subsection (a). Such support may include fellowships, traineeships, technical training programs, technologist training programs, and summer institute programs.

(c) The National Science Foundation is authorized and directed to coordinate its actions, to the maximum extent practicable, with the Project or any permanent Federal organization or agency having jurisdiction over the energy research and development functions of the United States, in determining the optimal selection of programs of education to carry out the policy of subsection (a).

(d) The National Science Foundation is authorized to encourage, to the maximum extent practicable international participation and cooperation in the development and maintenance of programs of education to carrying out the policy of subsection (a).

TITLE II—LOAN GUARANTIES

ESTABLISHMENT OF LOAN GUARANTY PROGRAM

30 USC 1141.

SEC. 201. (a) It is the policy of the Congress to encourage and assist in the commercial development of practicable means to produce useful energy from geothermal resources with environmentally acceptable processes. Accordingly, it is the policy of the Congress to facilitate such commercial development by authorizing the Chairman of the Project to designate an appropriate Federal agency to guarantee loans for such purposes.

(b) In order to encourage the commercial production of energy from geothermal resources, the head of the designated agency is authorized to, in consultation with the Secretary of the Treasury, guarantee, and to enter into commitments to guarantee, lenders against loss of principal or interest on loans made by such lenders to qualified borrowers for the purposes of—

- (1) the determination and evaluation of the resource base;
- (2) research and development with respect to extraction and utilization technologies;
- (3) acquiring rights in geothermal resources; or
- (4) development, construction, and operation of facilities for the demonstration or commercial production of energy from geothermal resources.

(c) Any guaranty under this title shall apply only to so much of the principal amount of any loan as does not exceed 75 percent of the aggregate cost of the project with respect to which the loan is made.

Terms and conditions.

(d) Loan guaranties under this title shall be on such terms and conditions as the head of the designated agency determines, except that a guaranty shall be made under this title only if—

- (1) the loan bears interest at a rate not to exceed such annual per centum on the principal obligation outstanding as the head of the designated agency determines to be reasonable, taking into account the range of interest rates prevailing in the private sector for similar loans and risks by the United States;
- (2) the terms of such loan require full repayment over a period not to exceed thirty years, or the useful life of any physical asset to be financed by such loan, whichever is less (as determined by the head of the designated agency);
- (3) in the judgment of the head of the designated agency, the amount of the loan (when combined with amounts available to the qualified borrower from other sources) will be sufficient to carry out the project; and
- (4) in the judgment of the head of the designated agency, there is reasonable assurance of repayment of the loan by the qualified borrower of the guaranteed indebtedness.

Limitation.

(e) The amount of the guaranty for any loan for a project shall not exceed \$25,000,000, and the amount of the guaranty for any combination of loans for any single qualified borrower shall not exceed \$50,000,000.

"Qualified borrower."

(f) As used in this title, the term "qualified borrower" means any public or private agency, institution, association, partnership,

corporation, political subdivision, or other legal entity which (as determined by the head of the designated agency) has presented satisfactory evidence of an interest in geothermal resources and is capable of performing research or completing the development and production of energy in an acceptable manner.

PAYMENT OF INTEREST

SEC. 202. (a) With respect to any loan guaranteed pursuant to this title, the head of the designated agency is authorized to enter into a contract to pay, and to pay, the lender for and on behalf of the borrower the interest charges which become due and payable on the unpaid balance of any such loan if the head of the designated agency finds—

Contract
authority.
30 USC 1142.

(1) that the borrower is unable to meet interest charges, and that it is in the public interest to permit the borrower to continue to pursue the purposes of his project, and that the probable net cost to the Federal Government in paying such interest will be less than that which would result in the event of a default; and

(2) the amount of such interest charges which the head of the designated agency is authorized to pay shall be no greater than the amount of interest which the borrower is obligated to pay under the loan agreement.

(b) In the event of any default by a qualified borrower on a guaranteed loan, the head of the designated agency is authorized to make payment in accordance with the guaranty, and the Attorney General shall take such action as may be appropriate to recover the amounts of such payments (including any payment of interest under subsection (a)) from such assets of the defaulting borrower as are associated with the project, or from any other surety included in the terms of the guaranty.

PERIOD OF GUARANTIES AND INTEREST ASSISTANCE

SEC. 203. No loan guaranties shall be made, or interest assistance contract entered into, pursuant to this title, after the expiration of the ten-calendar-year period following the date of enactment of this Act.

30 USC 1143.

GEOTHERMAL RESOURCES DEVELOPMENT FUND

SEC. 204. (a) There is established in the Treasury of the United States a Geothermal Resources Development Fund, which shall be available to the head of the designated agency for carrying out the loan guaranty and interest assistance program authorized by this title, including the payment of administrative expenses incurred in connection therewith. Moneys in the fund not needed for current operations may, with the approval of the Secretary of the Treasury, be invested in bonds or other obligations of, or guaranteed by, the United States.

Establishment.
30 USC 1144.

(b) There shall be paid into the fund the amounts appropriated pursuant to section 304(c) and such amounts as may be returned to the United States pursuant to section 202(b), and the amounts in the fund shall remain available until expended, except that after the expiration of the ten-year period established by section 203, such amounts in the fund which are not required to secure outstanding

Financial re-
ports, sub-
mittal to
Congress.

guaranty obligations shall be paid into the general fund of the Treasury.

(c) Business-type financial reports covering the operations of the fund shall be submitted to the Congress by the head of the designated agency annually upon the completion of an appropriate accounting period.

TITLE III—GENERAL PROVISIONS

PROTECTION OF ENVIRONMENT

30 USC 1161.

SEC. 301. In the conduct of its activities, the Project and any participating public or private persons or agencies shall place particular emphasis upon the objective of assuring that the environment and the safety of persons or property are effectively protected; and the program under title I shall include such special research and development as may be necessary for the achievement of that objective.

REPORTING REQUIREMENTS

Reports to
President and
Congress.
30 USC 1162.

SEC. 302. (a) The Chairman of the Project shall submit to the President and the Congress full and complete annual reports of the activities of the Project, including such projections and estimates as may be necessary to evaluate the progress of the national geothermal energy research, development, and demonstration program and to provide the basis for as accurate a judgment as is possible concerning the extent to which the objectives of this Act will have been achieved by June 30, 1980.

(b) No later than one year after the termination of each demonstration project under section 105, the Chairman of the Project shall submit to the President and the Congress a final report on the activities of the Project related to each project, including his recommendations with respect to any further legislative, administrative, and other actions which should be taken in support of the objectives of this Act.

TRANSFER OF FUNCTIONS

30 USC 1163.

SEC. 303. (a) Within sixty days after the effective date of the law creating a permanent Federal organization or agency having jurisdiction over the energy research and development functions of the United States (or within sixty days after the date of the enactment of this Act if the effective date of such law occurs prior to the date of the enactment of this Act), all of the research, development, and demonstration functions (including the loan guaranty program) vested in the Project under this Act, along with related records, documents, personnel, obligations, and other items to the extent necessary or appropriate, shall, in accordance with regulations prescribed by the Office of Management and Budget, be transferred to and vested in such organization or agency.

(b) Upon the establishment of a permanent Federal organization or agency having jurisdiction over the energy research and development functions of the United States, and when all research and development (and other) functions of the Project are transferred, the members of the Project may provide advice and counsel to the head of such organization or agency, in accordance with arrangements made at that time.

AUTHORIZATIONS OF APPROPRIATIONS

Sec. 304. (a) For the fiscal years ending June 30, 1976, and September 30, 1977, 1978, 1979, and 1980, only such sums may be appropriated as the Congress may hereafter authorize by law. 30 USC 1164

(b) There are authorized to be appropriated to the National Aeronautics and Space Administration not to exceed \$2,500,000 for the fiscal year ending June 30, 1975, for the purpose of preparing the program definition under section 102(a).

(c) In addition to sums authorized to be appropriated by subsection (b), there are authorized to be appropriated to the fund not to exceed \$50,000,000 annually, such sums to carry out the provisions of the loan guaranty program by the Project under title II.

Approved September 3, 1974.

LEGISLATIVE HISTORY:

HOUSE REPORTS: No. 93-1112 (Comm. on Science and Astronautics) and No. 93-1301 (Comm. of Conference).

SENATE REPORT No. 93-849 accompanying S. 2465 (Comm. on Interior and Insular Affairs).

CONGRESSIONAL RECORD, Vol. 120 (1974):

July 10, considered and passed House.

July 11, considered and passed Senate, amended, in lieu of S. 2465.

Aug. 20, Senate agreed to conference report.

Aug. 21, House agreed to conference report.