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FINAL REPORT

A BENEFIT-COST ANALYSIS OF DOE's "CURRENT FEDERAL PROGRAM" TO INCREASE HYDROTHERMAL RESOURCE UTILIZATION

MASTER

Contract Number DE-AC02-79ET27248

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PREFACE

CONSAD Research Corporation prepared this report during the period July 1, 1981 - December 10, 1981, under Contract Number DE-AC02-79ET-27248, for the Division of Geothermal and Hydropower Technologies, Office of Renewable Technology, within the Office of the Assistant Secretary for Conservation and Renewable Energy, Department of Energy (DOE). Dr. Fred Abel was the DOE Technical Project Officer.

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1.0 INTRODUCTION

Geothermal energy is the natural heat of the earth which can be used for the production of electricity, residential and commercial space heating and cooling, industrial process heat, and agricultural process applications. In 1980, geothermal energy sources produced 5,073 million kilowatthours of electricity and supplied 0.003 quads* of energy for direct heat use,** saving the equivalent of 25 thousand barrels of crude oil per day.

The three principal types of geothermal resources -- in order of technology readiness -- are hydrothermal, geopressured (including dissolved natural gas), and hot dry rock.

Hydrothermal resources include hot water and steam trapped in fractured or porous rock relatively near the surface. Electricity is currently generated at The Geysers steam field in California, and the economic production of power from hot water reservoirs is expected in the near future in several western states.*** Hydrothermal resources are also currently being used in 14 western states for direct heat applications, and feasibility studies are underway in several eastern states as well.

Geopressured resources are hot water aquifers containing dissolved methane trapped under high pressure in deep sedimentary formations. Commercial production of energy (primarily methane) from these large resources

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*One quad of energy equals one quadrillion (10^{15}) Btu's of energy.

**Does not include enhanced oil recovery applications or ethanol plants.

***For example, two small plants -- each having a capacity of 10 megawatts (MWe) -- recently began operation (in June 1980) in California's Imperial Valley using liquid dominated resources.

may begin in the late 1980's along the United States Gulf of Mexico coast. The economic feasibility of this resource will depend upon the amount of methane that a given well can produce; a factor that is highly uncertain at the present time.

Hot dry rock resources are geologic formations at accessible depths that have abnormally high heat content but contain little or no water. Energy from this resource is extracted by circulating a heat transfer fluid, such as water, through deep wells that are connected by manmade fractures in the rocks. Hot dry rock is currently seen as a longer term possibility; commercial production is not expected to occur until the early 1990's.

Therefore, of the three types of geothermal resources, hydrothermal is most ready for further commercialization since much of this resource can now be used economically with current technology. Moreover, with new technology almost ready to be used commercially, additional hydrothermal resources will become economically recoverable. The technological development of hydrothermal resources will also contribute to the industrialization of geopressured and hot dry rock resources, since much of the hydrothermal technology can also be utilized with other geothermal resources.

Through the Federal Geothermal Energy Program, various agencies* support the development of geothermal resources as a clean, safe,

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*These include the Departments of Energy, the Interior, Agriculture, Treasury, Commerce, Defense, Housing and Urban Development, and the Environmental Protection Agency.

economical alternative source of energy to coal, oil, natural gas and nuclear energy. The overall objective of the program is to enable private industry to undertake commercial development of geothermal resources by providing an appropriate level of federal assistance and, at the same time, removing disincentives to exploration and development.

In this report, the impact of the Department of Energy's "Current Federal Program" on the commercialization of hydrothermal resources between 1980 and 2000 is analyzed. Geopressured and hot dry rock resources are not included in this analysis since their commercialization will largely occur after 2000. Because the development of hydrothermal resource sites is dependent upon both the cost-competitiveness of those sites (in relation to alternative energy sources) and market demand (relative to the existing capacity of area utilities and other energy supplying facilities), some hydrothermal sites will be developed regardless of whether any federal program exists to promote hydrothermal resource development. Therefore, the impact of DOE's "Current Federal Program" on hydrothermal resource development is analyzed in relationship to the hydrothermal resource development likely to occur in the absence of continued DOE involvement (that is, assuming a "No Federal Program"). The expected change in hydrothermal resource development under the "Current Federal Program" versus the "No Federal Program" serves as the basis for evaluating the benefits and costs of DOE's "Current Federal Program."

The analysis begins with a brief description of the hydrothermal resources in the United States and the types of DOE activities used to stimulate the development of these resources for both electric power and direct heat use applications (Chapter 2.0). The "No Federal Program" and the "Current Federal Program" are then described in terms of funding levels and the resultant market penetration estimates through 2000 (Chapter 3.0). These market penetration estimates are also compared to other geothermal utilization forecasts. The direct benefits of the "Current Federal Program" are next presented for electric power and direct heat use applications (Chapter 4.0). An analysis of the external impacts associated with the additional hydrothermal resource development resulting from the "Current Federal Program" is also provided (Chapter 5.0). Included are environmental effects, national security/balance-of-payments improvements, socioeconomic impacts and materials requirements. A summary of the analysis integrating the direct benefits, external impacts and DOE program costs concludes the report (Chapter 6.0).

2.0 OVERVIEW OF HYDROTHERMAL RESOURCES AND THE DOE HYDROTHERMAL PROGRAM

2.1 Hydrothermal Resources in the United States*

The United States Geological Survey (USGS) is responsible for assessing the extent of hydrothermal resources within the United States. The most recent USGS assessment was completed -- with DOE support -- in July 1978 and published in 1979.**

The electrical generating capactiy associated with 52 identified high temperature (>150°C) systems is estimated to be 23,000 ± 3400 megawatts for 30 years. This represents about 25 times the current (1980) installed electric utility generating capacity using hydrothermal resources. About half of these 52 identified high temperature resource sites are located in California and almost all the others are located in six other western states: Hawaii; Idaho; Nevada; New Mexico; Oregon; and Utah. In particular, six of the known locations*** appear able to support more than 1,000 megawatts each for 30 years and together represent 13,000 megawatts for 30 years (or 57 percent of the total estimated electric energy potential). Including the undiscovered high temperature resources, it is estimated that hydrothermal resources could contribute 95,000-150,000 megawatts of generating capacity for 30 years.

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*This discussion excludes an estimated 1,290 quads of hydrothermal energy in the National Parks (mainly in Yellowstone) where energy development is prohibited.

**Muffler, L.J.P. (editor), Assessment of Geothermal Resources of the United States - 1978, Geological Survey Circular 790, 1979.

***These include: The Geysers, California; Long Valley, California; Salton Sea, California; Surprise Valley, California; Westmoreland; California; and Valles Caldera, New Mexico.

For direct heat use applications, the beneficial heat producible from identified intermediate temperature (90° - 150°C) systems is estimated to be approximately 42 ± 13 quads (or over 3000 times the amount of beneficial heat utilized in all direct heat applications in 1980). These identified resources are located at over 200 sites in 12 western states. Total beneficial heat (identified and undiscovered) from intermediate temperature systems is estimated to be approximately 230 - 350 quads.

In addition to intermediate and high temperature hydrothermal resources, the discovery and development of low temperature ($< 90°C$) geothermal waters from depths of less than one kilometer is favorable in areas of the U.S. covering 37 states. The development of an accurate estimate of the thermal energy associated with these resources is now being undertaken.*

2.2 The DOE Hydrothermal Program

Hydrothermal resources within the U.S. are vast relative to the extent that they are currently utilized. The commercialization of hydrothermal (and other geothermal) energy has been hindered by several major barriers; for example:**

- The initial risk associated with the expensive drilling needed to confirm geothermal reservoirs of all types deters many potential users from starting projects;
- The vast majority of higher temperature hydrothermal reservoirs suitable for electric power production are only marginally economic with present technology;

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*Muffler, L.J.P. (editor), Assessment of Geothermal Resources of the United States - 1978, op. cit., p. 2.

**Interagency Geothermal Coordinating Council (IGCC), Fifth Annual Report, Final Draft, July 1981, pp. 25-26.

- The overall rate of leasing of federal lands appears to be too slow to sustain rapid development of hydrothermal resources in the 1990 - 2000 time period;
- The present state laws need further development to promote a clear legal climate for industrial geothermal activities;
- There is a lack of an industrial infrastructure to support direct heat applications;
- There exists a general lack of knowledge about geothermal energy on the part of potential users and developers; and
- The technology and economics have not been proven for geopressured and hot dry rock resources.

To assist in resolving these problems, the Federal Geothermal Energy Program -- authorized by several federal statutes,* involving many federal agencies,** with DOE designated as the lead agency -- supports the industrial development of geothermal resources based on the overall premise that U.S. industry will rapidly develop all types of geothermal resources if the government provides initial assistance to resolve technical problems, economic uncertainties and institutional barriers that are unique to geothermal energy systems and the U.S. geothermal industry. The principal components of the federal government's strategy to promote the use of hydrothermal (and other geothermal) resources have included the following:***

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*These include: The Geothermal Research, Development and Demonstration Act of 1974 (P.L. 93-410); The Energy Reorganization Act of 1974 (P.L. 93-438); The Federal Non-Nuclear Energy Research, Development and Demonstration Act of 1974 (P.L. 93-577); The Department of Energy Organization Act (P.L. 95-91); The Department of Energy Act of 1978-Title V (P.L. 95-238); and The Energy Security Act-Title VI, The Geothermal Energy Act of 1979 (P.L. 96-294).

**See Chapter 1.0.

***IGCC, _Fifth Annual Report_, _op. cit_., pp. 26-27.

- Accelerate the identification and quantification of the various types of geothermal resources (approximately 80 percent of the estimated U.S. geothermal resource is still undiscovered);
- Continue an aggressive research and development effort to improve technology which is likely to reduce geothermal energy costs, expand the economically competitive resource base and lead to more rapid commercialization;
- Propose ways to which federal leasing and permitting processes can be simplified to speed the implementation of new development projects;
- Support states in site-specific planning and outreach activities; and
- Establish appropriate environmental regulations, continue monitoring of environmental effects at each resource area, and develop control technology and procedures for mitigating potential problems.

Specifically related to hydrothermal resources, the federal government's strategy has also included the following components:*

- Encourage widespread acceptance of the hydrothermal energy resource by developing a program to increase technology transfer;
- Improve estimates of the nature and size of identified hydrothermal resources through improvement of geothermometers and geophysical techniques. Refine estimates of undiscovered resources through characterization studies;
- Provide technical assistance to support use of conventional technologies for electric or direct heat applications; and
- Support research to develop adequate environmental controls.

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*IGCC, Fifth Annual Report, op. cit., pp. 27-28.

Implementation of these strategies within DOE primarily rests with the Division of Geothermal and Hydropower Technologies (DGHT) within the Office of the Assistant Secretary for Conservation and Renewable Energy (CRE).* While the basic program structure of DOE/CRE's activities has not changed over the last several years, the focus of the current program -- as now conceived -- has shifted from emphasizing both commercialization and research and development (R and D) activities, to emphasizing R and D activities that have high risk but potentially high payoff. Specifically, R and D activities are being concentrated on improving hydrothermal resource technology in order to reduce the costs of hydrothermal commercialization (in the near term) and stimulate the development of hot dry rock and geopressured resources (in the longer term). This shift in program focus reflects a policy decision of continuing to work with industry to identify technical problems that significantly affect the technical and economic feasibility of hydrothermal applications, to assess the need for federal involvement in seeking solutions, to perform the high risk/high payoff research and development needed, and to rely more heavily on the private sector for the shorter term industrialization activities, such as the construction and operation of pilot demonstration plants.

The specific program elements that have supported DOE/CRE's hydrothermal development activities over the last several years include:

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*The major exception is some basic research conducted by DOE's Office of Energy Research.

hydrothermal industrialization; the Geothermal Resource Development Fund; hydrothermal technology development; planning and analysis and technology transfer; and program direction.*

Hydrothermal industrialization activities are designed to encourage private industry to use hydrothermal resources for electric power production and direct heat use applications at the earliest possible date. The activities have included the following: **

- Resource definition in cooperation with the U.S. Geological Survey, state agencies, and industry;
- Non-electric technical and economic feasibility studies (42 in all) and demonstration projects (24 in all) to determine the engineering and economic aspects of using hydrothermal resources for direct heat. The participants have been selected through competitive solicitation; and
- Geothermal facilities designed, constructed, and operated to perfect new geothermal equipment and process techniques, particularly for electric power production. These facilities include two 50 MWe demonstration power plants -- one flash steam and one binary -- to produce electric power from high temperature hydrothermal reservoirs, and a five MWe binary pilot power plant using a moderate temperature hydrothermal reservoir.

DOE/CRE support for resource definition ended after FY 1981 with responsibility shifted to the private sector (as well as remaining with the USGS through its Geothermal Research Program). Likewise, support for new non-electric feasibility studies and demonstration projects was also terminated

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*Hot dry rock technology development and geopressured resources are the remaining two program elements of DOE/CRE's geothermal program.

**DOE, Assistant Secretary for Conservation and Renewable Energy, "Geothermal Energy: Program Summary Document - FY 1982," Draft, April 1981.

after FY 1981. Additional DOE/CRE support for geothermal power plant demonstrations is scheduled to end after FY 1982.

The Geothermal Resource Development Fund was established in 1974 to support the Geothermal Loan Guaranty Program (GLGP), which was designed to assist the private sector in facilitating the commercial development and use of geothermal energy by minimizing the financial risks associated with new technology and reservoir uncertainties. By providing loan guarantees for the construction and operation of geothermal facilities, R and D projects, and field exploration, the GLGP helped borrowers secure necessary loans by reducing a lender's financial risk. The GLGP presently has guaranteed parts of six loans (including one refinancing) totalling $136 million for projects totalling $203 million in cost. No additional guarantees will likely be issued however, since the GLGP is scheduled to be phased out with responsibility shifted to the private sector in accordance with the federal government's policy to rely more heavily on the marketplace for the short term industrialization activities. Administration of the outstanding loans will continue until the five projects are successfully completed.

DOE/CRE's hydrothermal technology development activities are R and D oriented and designed to develop new technologies to solve the currently existing problems of operating in a hydrothermal environment. Efforts are focused on: developing techniques, materials and equipment specifically designed for hydrothermal conditions; reducing technology costs; and encouraging the establishment of industry-wide standards for hydrothermal materials and equipment. These activities are also designed to eventually benefit technology development for hot dry rock and geopressured resources, still in the preliminary stages of development. Over the last several years, several tasks have been pursued to fulfill these requirements, including:*

- Drilling and completion technology -- designed to develop conventional rotary drilling equipment such as drill bits and downhole motors, and completion equipment for use in geothermal environments, as a means for reducing the costs of geothermal field development.

- Energy conversion technology -- designed to reduce geothermal electric generating costs by increasing well productivity (pumping), increasing plant efficiency at moderate temperatures, and improving overall system reliability. Emphasis is placed on technology for moderate temperature geothermal reservoirs, which constitute a much larger resource base than do high temperature resources. Downhole pumps, heat exchangers, and binary conversion systems for electricity production are being developed under this task.

- Reservoir stimulation -- designed to increase well flow rates, through stimulation of the geothermal reservoir, in order to improve the economics of geothermal systems. To develop new reservoir stimulation technology, field experiments are conducted first at lower temperature reservoirs as appropriate technology is developed. Techniques under development include chemical treatment and hydraulic and explosive fracturing.

- Geochemical engineering and materials -- designed to improve the containment and handling of geothermal fluids (i.e., fluid handling technology development). Fluid disposal and maintenance procedures for injection wells are being developed to control wastes and to optimize the use of geothermal waste by-products. DGHT's program seeks to advance

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*DOE, Assistant Secretary for Conservation and Renewable Energy, "Geothermal Energy: Program Summary Document - FY 1982," op. cit., Section 6.4.

economic construction materials and to develop elastomers, metals, and non-metallic materials for use in geothermal environments. Materials under development include polymer concrete for pipes and pressure vessels, and corrosion resistant steels for well casing, drill pipes, and energy conversion equipment. Over the next five years, the geochemical engineering and materials effort will complete laboratory development of new corrosion and temperature resistant materials and will apply this knowledge to construction and field testing of equipment for new components and systems.

- Geoscience (or reservoir evaluation) technology -- designed to improve the technology and assessment of reservoirs. Such technology development is essential to maintain the current rate of discovery and development. Four components of this task include: exploration technology; reservoir engineering; logging instrumentation; and log interpretation.
- Environmental control technology -- designed to improve the state-of-the-art of geothermal environmental control technology to comply with federal, state, and local environmental regulations. DOE and the U. S. Environmental Protection Agency (EPA) are pursuing a research program to control hydrogen sulfide and other air emissions, injection of geothermal fluids as they may affect underground sources of drinking water, solid waste resulting from geothermal operations, induced subsidence, and induced seismicity.

The planning and analysis activities undertaken by DOE/CRE have helped support and coordinate the other hydrothermal program activities described above (as well as the hot dry rock and geopressured program activities). More specifically, these activities have been designed to obtain information necessary to formulate geothermal development plans, maintain a national geothermal progress monitoring system, assess the market penetration potential for hydrothermal resources, and identify direct heat markets suitable for early market penetration. Other activities encompass interagency coordination through the Interagency Geothermal Coordinating Council (IGCC), policy development, and streamlining the federal regulatory process. Also included are studies that identify critical high/risk payoff R and D needs, assess the probability that the private sector will conduct the required R and D, and quantify the costs and benefits for federal support of the needed R and D.

The transfer of technological information and innovation provides a means to disseminate the results from research and development efforts to the geothermal community. Technology transfer has been facilitated by DOE/CRE by the publication of articles in scientific journals, the presentation of papers at scientific meetings, the publication of technical reports, the dissemination of scientific information developed by the private sector, and the sponsoring of technical symposia to insure the rapid dissemination of technical information. Such outside activities increase the level of public and private understanding for using geothermal energy as an alternative to imported or depletable domestic energy sources, and inform potential users of geothermal energy about the costs, benefits, reliability and environmental effects of alternative geothermal systems.

Outreach activities to disseminate information about geothermal energy technologies have also included DOE/CRE support of technical assistance centers and state commercialization teams. Six technical assistance centers are now operating to provide free consultation on a limited scale to potential industry, community and utility end-users in areas such as: definition, characterization, and assessment of geothermal reservoirs; technical or economic feasibility of a proposed project; and review of a proposed system design.* DOE has also supported state commercialization teams in 16 states to provide -- at no cost -- a variety of activities for potential developers and users of hydrothermal resources. Typically, each commercialization team would first prepare a report (or series of reports) detailing the location and potential of the geothermal resources, the types of energy demand they might meet, and the laws, regulations, and procedures for developing geothermal resources. These teams would also: respond to inquiries about geothermal development; provide limited geologic and engineering assistance necessary to perform preliminary project analyses for would-be geothermal developers and users; refer users to sources of financial assistance; and, in general, provide other information, consulting, and referral services to assist geothermal developers with any legal or institutional problem that confronts them. The commercialization teams have also served as a communication link between DOE program officials (in Washington and the field offices) and the community of developers, users, financiers, technical specialists, and regulators.**

Program direction is the last major component of DOE/CRE's hydrothermal development activities (and also supports DOE/CRE's hot dry rock

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*Consistent with DOE's shift in emphasis to high risk/high payoff R and D endeavors, all six technical assistance centers are scheduled to close by the end of 1981, leaving such activities to the private sector.

**Federal support for these state commercialization teams is scheduled to end at the end of 1981, for similar reasons as stated above.

and geopressured program activities). As indicated earlier, DOE has been designated by Congress as the lead agency for federal geothermal energy programs and, as such, not only coordinates and monitors the several hundred active DOE/CRE's contracts involving projects throughout the U.S. and abroad, but also coordinates -- through the IGCC -- the activities of the other federal agencies that contribute to the Federal Geothermal Energy Program. DOE concentrates all policy, planning, overall budget definition and program defense activities at its Washington, D.C. headquarters. DOE field organizations (i.e., operations offices, national laboratories, and regional representatives) are responsible for project definition, day-to-day management in the field, and coordination with state and local authorities.

3.0 DESCRIPTION OF SCENARIOS

The purpose of this report is to evaluate the potential impact that DOE's "most likely" (i.e., current) hydrothermal program initiatives over the 1981-1990 time frame may have on the rate of hydrothermal power plant commercialization and non-electric direct heat utilization. This requires the development of a realistic view of hydrothermal energy market prospects and technology potentials likely to result from both DOE's "Current Federal Program" and a program where DOE support of hydrothermal energy development is terminated (i.e., DOE's "No Federal Program"). The expected change in hydrothermal resource development under the "Current Federal Program," as compared to the "No Federal Program," then provides the basis for examining the impacts of DOE's "Current Federal Program."

Two market penetration estimation models (one for electric power applications and one for direct heat use applications) were employed for estimating the hydrothermal energy market prospects under alternative DOE hydrothermal initiatives.* Those policy and program dependent variables (in each of the market penetration estimation models) significantly impacted

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*For a description of these models, see: Engineering and Economics Research, Inc., et al., Market Shares Estimation Task Force Report: Projections for Hydrothermal Electric Systems Market Shares, prepared for Division of Geothermal Energy, U.S. Department of Energy, November 1980; and Engineering and Economics Research, Inc., et al., Market Shares Estimation Task Force Report: Projections for Hydrothermal Direct-Heat Systems Market Shares, prepared for Division of Geothermal Energy, U.S. Department of Energy, December 1980.

by government programs were appropriately quantified -- and incorporated into each model -- to reflect the impact of DOE's "No Federal Program" and "Current Federal Program."*

The market penetration estimates, as well as DOE's "No Federal Program" and "Current Federal Program" (including funding levels), are described in this chapter.

3.1 "No Federal Program" Case

DOE's "No Federal Program" represents a baseline case which assumes that future hydrothermal development will be left entirely to the non-federal sector after a one year phaseout. Therefore, new budget authorities are provided for FY 1982 and are zero for FY 1983-FY 1990 (see Exhibit 3.1). In constant 1982 dollars, funding for FY 1981 and FY 1982 is estimated to be about $145 million for hydrothermal energy development. The discounted or present value of these costs (in 1982) is approximately $157 million (in 1982 dollars).**

The market penetration levels expected to result if DOE involvement in hydrothermal development is terminated after FY 1982 are shown in Exhibit 3.2.

For electric power applications, generating capacity is projected -- with a high (90 percent) degree of confidence -- to be about eight times

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*Significant policy and program dependent variables include parameters affecting the: per unit cost of electric power or direct heat use; rate-of-return; project size; capital-at-risk; and discovery of new hydrothermal resources. For further details, contact: Dr. Thomas A.V. Cassel, Technecon Analytic Research, Inc., Philadelphia, Pennsylvania; and Mr. John Redman, The Futures Group, Washington, D.C.

**Assumes a real discount rate of 10 percent in accordance with DOE's planning, programming and budgeting guidelines for FY 1983-FY 1987.

Exhibit 3.1: DOE/CRE Funding Levels for the "No Federal Program" Case

	Budget Authorities ($1,000's)			
Program Component	Actual FY 1980	FY 1981	FY 1982	FY 1983-FY 1990
Hydrothermal Industrialization	58,795	44,776	13,000	0
Resource Definition	12,634	13,124	0	0
Non-Electric Demonstration	9,778	11,500	0	0
Geothermal Facilities	35,363	20,152	13,000	0
Capital Equipment	1,020	0	0	0
Geothermal Resource Development Fund	181	21,200	200	0
Reserve Fund	0	21,000	0	0
Administrative Expenses	181	200	200	0
Hydrothermal Technology Development	28,375	36,249	10,439	0
Drilling and Completion Technology	6,630	-	2,539	0
Energy Conversion Technology	8,781	-	2,500	0
Reservoir Stimulation	1,656	-	1,900	0
Geochemical Engineering and Materials	4,196	-	700	0
Geoscience Technology	4,915	-	2,300	0
Environmental Control Technology	2,197	2,600	500	0
Planning and Analysis and Technology Transfer	9,420	8,185	0	0
Hot Dry Rock Technology Development	15,000	14,000	10,000	0
Geopressured Resources	34,692	31,935	20,336	0
Program Direction	1,802	2,376	1,600	0
Total	148,265	158,721	55,575	0
Hydrothermal*	98,573	112,786	25,239	0
Hot Dry Rock	15,000	14,000	10,000	0
Geopressured	34,692	31,935	20,336	0

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*All funds for "Planning and Analysis and Technology Transfer" and "Program Direction" are included here.

\- = Data Not Available.

Source: DOE, Assistant Secretary for Conservation and Renewable Energy, Division of Geothermal and Hydropower Technologies, September 1981.

Exhibit 3.2: Market Penetration Estimates for Electric Power and Direct Heat Applications from Hydrothermal Energy Under the "No Federal Program" Case

	Electric Power Applications* (net megawatt capacity)			Direct Heat Applications** (quads per year)		
	Likelihood			Likelihood		
Year	>5%	>50%	>90%	>5%	>50%	>95%
1980	922	922	922	0.003	0.003	0.003
1985	1,699	1,699	1,599	0.043	0.019	0.008
1990	3,889	3,889	3,399	0.105	0.058	0.031
1995	6,509	6,309	6,109	0.186	0.110	0.061
2000	8,319	7,809	7,369	0.244	0.140	0.073

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*A 50 megawatt geothermal power plant with a capacity factor of 85% consumes an amount of energy equivalent to 0.008 quads per year (and produces an amount of electricity equal to 0.0013 quads per year).

**Includes collocated industry direct heat use, relocated industry direct heat use, and district heat (does not include ethanol plants or enhanced oil recovery applications).

Source: 1980: DOE, Assistant Secretary for Conservation and Renewable Energy, Geothermal Progress Monitor Report Number 5, June 1981, DOE/CE-0009/5, pp. 3, 23. 1985-2000: Technecon Analytic Research, Inc., "Results from Market Penetration Estimation Models," prepared for Division of Geothermal and Hydropower Technologies, DOE, July 1981.

its current (1980) level by 2000, and has a good chance (50 percent likelihood) of reaching a level 8.5 times its 1980 generating capacity, or 7,800 megawatts. Although unlikely, there is a five percent chance that the generating capacity might reach 8,300 megawatts by 2000 or nine times its current level. An increase in the hydrothermal generating capacity of approximately 6,900 megawatts between 1980 and 2000 (as indicated by the 50 percent likelihood market penetration estimates) would be capable of providing about three percent of the approximate 1,670 billion kilowatt-hour increase in electricity generation nationwide over this 20 year period, as projected by both the Third National Energy Policy Plan (midrange estimate)* and the 1980 Annual Report to Congress (mid oil price case).** However, based upon the industry's construction schedule for proposed hydrothermal power plants,*** most of the increase in generating capacity -- at least through 1990 -- can be expected to take place in California (and largely in The Geysers area). Smaller amounts (under 50 megawatts in each state through 1990) can be expected in Hawaii, Idaho, New Mexico, Nevada, and Utah. Therefore, because the increased electricity generation provided by hydrothermal power plants will actually contribute to satisfying increased generation requirements in only a small part of the U.S., its contribution will be more significant than indicated above.

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*DOE, Office of Policy, Planning and Analysis, Energy Projections to the Year 2000, A Supplement to the National Energy Policy Plan, July 1981, DOE/PE-0029, Chapter 10.

**DOE, Energy Information Administration, 1980 Annual Report to Congress, Volume Three: Forecasts, March 1981, DOE/EIA-0173(80)/3, p. 159.

***DOE, Assistant Secretary for Conservation and Renewable Energy, Geothermal Progress Monitor Report Number 5, June 1981, DOE/CE-0009/5, pp. 3-7.

Direct heat use applications under the "No Federal Program" are expected to increase from 0.003 quads in 1980 to between 0.073 quads (with a 95 percent likelihood) and 0.244 quads (with a five percent likelihood) by 2000 (see Exhibit 3.2). Such increases -- ranging from 24 to 80 times current levels -- will likely result in a more geographically dispersed use of these resources; for example, from the present 14 western states to at least 22 states, including several eastern states.* Such increases will not, however, contribute more than one to three percent of the expected increase in residential, commercial and industrial energy consumption nationwide between 1980 and 2000, which is projected to increase from almost 42 quads in 1980 to between 50 quads (under the midrange estimate of the National Energy Policy Plan)** and 54 quads (under the mid oil price case in the <u>1980 Annual Report to Congress</u>)*** by 2000. However, because the increase in hydrothermal direct heat uses will actually contribute to satisfying the increased energy consumption requirements in less than half of the U.S., its contribution will be more important than indicated above.

3.2 "Current Federal Program" Case

DOE's "Current Federal Program" represents a group of initiatives reflecting the federal government's current policy of providing the required

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*DOE, Assistant Secretary for Conservation and Renewable Energy, Geothermal Progress Monitor Report Number 5, op. cit., p. 23.

**DOE, Office of Policy, Planning and Analysis, Energy Projections to the Year 2000, op. cit., p. 1-7.

***DOE, Energy Information Administration, 1980 Annual Report to Congress, Volume Three: Forecasts, op. cit., p. 142.

longer term high risk/high payoff research and development to expand hydrothermal energy development, while shifting the responsibility for shorter term industrialization activities to the private sector. Overall, it also represents a smaller commitment, consistent with the current federal policy of reducing federal expenditures and eventually balancing the federal budget.

Hydrothermal technology development would be the key component of the DOE hydrothermal program (see Exhibit 3.3) and would provide the necessary R and D activities too expensive and risky for the private sector to undertake alone; representative projects have already been described in Section 2.2. Funding for hydrothermal industrialization activities would also continue, but only through FY 1982 and only for those facilities -- notably the Heber, California, Raft River, Idaho and Baca Ranch, New Mexico projects -- that demonstrate and perfect new hydrothermal equipment and process techniques, particularly for electric power applications. Support for resource definition would be shifted to the private sector (and also would remain with the USGS). The loan guaranty program, supported by the Geothermal Resource Development Fund, would also be phased out, with funds only provided to monitor the existing loans until the projects are completed. Other hydrothermal program support activities -- planning and analysis, technology transfer, and technical assistance (for example, state commercialization teams and technical assistance centers) -- would also be phased out beginning in FY 1982. Sufficient funds would, however, be provided to insure an adequate level of program direction.

Exhibit 3.3: DOE/CRE Funding Levels for the "Current Federal Program" Case

Program Component	Actual FY 1980	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985	FY 1986	FY 1987	FY 1988	FY 1989	FY 1990
	Budget Authorities (thousands of constant 1982 dollars)**										
Hydrothermal Industrialization	58,795	44,776	13,000	0	0	0	0	0	0	0	
Resource Definition	12.634	13,124	0	0	0	0	0	0	0	0	0
Non-Electric Demonstration	9,778	11,500	0	0	0	0	0	0	0	0	0
Geothermal Facilities	35,363	20,152	13,000	0	0	0	0	0	0	0	0
Capital Equipment	1.020	0	0	0	0	0	0	0	0	0	0
Geothermal Resource Development Fund	181	21,200	200	200	200	200	200	200	200	200	200
Reserve Fund	0	21,000	0	0	0	0	0	0	0	0	0
Administrative Expenses	181	200	200	200	200	200	200	200	200	200	200
Hydrothermal Technology Development	28,375	36,249	10,439	15,000	15,000	15,000	15,000	15,000	15,000	15.000	15.000
Drilling and Completion Technology	6,630	-	2,539	-	-	-	-	-	-	-	-
Energy Conversion Technology	8,781	-	2.500	-	-	-	-	-	-	-	-
Reservoir Stimulation	1,656	-	1,900	-	-	-	-	-	-	-	-
Geochemical Engineering and Materials	4,196	-	700	-	-	-	-	-	-	-	-
Geoscience Technology	4,915	-	2.300	-	-	-	-	-	-	-	-
Environmental Control Technology	2,197	2,600	500	-	-	-	-	-	-	-	-
Planning and Analysis and Technology Transfer	9,420	8,185	0	0	0	0	0	0	0	0	0
Hot Dry Rock Technology Development	15,000	14,000	10,000	0	0	0	0	0	0	0	0
Geopressured Resources	34,692	31,935	20.336	5,000	5,000	0	0	0	0	0	0
Program Direction	1,802	2,276	1,600	800	800	800	800	800	800	800	800
Total	148,265	158,721	55,575	21,000	21,000	16,000	16,000	16,000	16,000	16,000	16,000
Hydrothermal*	98.573	112,786	25,239	16,000	16,000	16,000	16.000	16,000	16,000	16.000	16,000
Hot Dry Rock	15,000	14,000	10,000	0	0	0	0	0	0	0	0
Geopressured	34,692	31,935	20,236	5.000	5,000	0	0	0	0	0	0

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*All funds for "Planning and Analysis and Technology Transfer" and "Program Direction" are included here.

**Data for FY 1980 and FY 1981 are in current dollars.

- = Data Not Available.

Source: DOE, Assistant Secretary for Conservation and Renewable Energy, Division of Geothermal and Hydropower Technologies, September 1981.

Overall, DOE/CRE funding for hydrothermal energy development under the "Current Federal Program" would be about $25 million in FY 1982 and $16 million each year from FY 1983 through FY 1990 (in constant 1982 dollars). Total funding over the 10 years FY 1981-FY 1990 would be approximately $273 million (in constant 1982 dollars), with almost 45 percent of the total funding budgeted in the first year, FY 1981. The discounted or present value of this future stream of program costs (in 1982) is estimated to be $242 million (in 1982 dollars).*

The market penetration levels expected to result if current DOE policies are pursued are shown in Exhibit 3.4. Electric generating capacity by 2000 is projected to range from about 7,700 megawatts (with 90 percent likelihood) to about 9,800 megawatts (with five percent likelihood); or 8.3 to 10.7 times the current (1980) capacity. Such increases could supply between three and four percent of the expected increase in electricity generation nationwide (see Section 3.1). Similar to the results expected under the "No Federal Program" case, all of the increased development will no doubt occur in California and other western states. But, it can also be expected that the distribution of generating capacity among states will be greater under the "Current Federal Program" case than under the "No Federal Program" case. Direct heat use applications from 1980 to 2000 are projected to increase by a factor ranging somewhere between 28 and 87. Such

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*Assumes a real discount rate of 10 percent in accordance with DOE's planning, programming and budgeting guidelines for FY 1983-FY 1987.

Exhibit 3.4: Market Penetration Estimates for Electric Power and Direct Heat Applications from Hydrothermal Energy Under the "Current Federal Program" Case

	Electric Power Applications* (net megawatt capacity)			Direct Heat Applications** (quads per year)		
	Likelihood			Likelihood		
Year	>5%	>50%	>90%	>5%	>50%	>95%
1980	922	922	922	0.003	0.003	0.003
1985	1,754	1,754	1,754	0.054	0.028	0.015
1990	4,024	4,024	3,554	0.120	0.070	0.040
1995	6,924	6,414	6,244	0.206	0.127	0.074
2000	9,834	9,254	7,684	0.260	0.153	0.083

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*A 50 megawatt geothermal power plant with a capacity factor of 85% consumes an amount of energy equivalent to 0.008 quads per year (and produces an amount of electricity equal to 0.0013 quads per year).

**Includes collocated industry direct heat use, relocated industry heat use, and district heating (does not include ethanol or enhanced oil recovery applications).

Source: 1980: DOE, Assistant Secretary for Conservation and Renewable Energy, Geothermal Progress Monitor Report Number 5, June 1981, DOE/CE-0009/5, pp. 3, 23. 1985-2000: Technecon Analytic Research, Inc., "Results from Market Penetration Estimation Model," prepared for Division of Geothermal and Hydropower Technologies, DOE, July 1981.

an increase would provide from one to three percent of the expected increase in nationwide residential, commercial and industrial energy consumption between 1980 and 2000 (see Section 3.1).

3.3 Comparison of Hydrothermal Utilization Forecasts

Further insights about DOE's "No Federal Program" and "Current Federal Program" are provided here by comparing other hydrothermal forecasts with the market penetration estimates expected to result from implementation of these two programs. While explicit comparison of such forecasts can be difficult since differing assumptions are often used, the use of a variety of projections can provide insights into the potential extent of electric power and direct heat use applications using hydrothermal energy.

Several recent estimates of hydrothermal electric power generation in the U.S. are shown in Exhibit 3.5 for the "likely" or midrange scenarios. For the near term (through 1985), there is a general consensus that somewhere between 1,600 and 2,100 MWe could be installed; this is not surprising since commitments have already been made for most facilities likely to be operating by 1985. Projecting the development of hydrothermal electric power generation beyond 1990 is more difficult due to the lack of knowledge about economic conditions and uncertainty about the discovery of currently unknown hydrothermal resources. Thus, it can be expected that a greater amount of variation will be found in projections for 2000.

For example, the capacity forecasts by 2000 under DOE's "No Federal Program" and "Current Federal Program" are 30 to 55 percent above the

Exhibit 3.5: Comparison of Hydrothermal Electric Forecasts

Forecast Scenario	Year Forecast Made	Megawatt Capacity					Billion Kilowatt-Hours Per Year					Quads (output) Per Year *				
		1980	1985	1990	1995	2000	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
DOE's "No Federal Program" Case[1] 50% likelihood	1981	922	1,699	3,889	6,309	7,809	5.1	12.7	29.0	47.0	58.1	0.017	0.043	0.099	0.160	0.198
DOE's "Current Federal Program" Case[1] 50% likelihood	1981	922	1,754	4,024	6,414	9,254	5.1	13.1	30.7	48.9	70.5	0.017	0.045	0.105	0.167	0.241
DOE's "Establish Capacity" Case[1] 50% likelihood	1981	922	2,019	5,899	12,609	24,607	5.1	15.0	45.0	96.1	187.5	0.017	0.051	0.154	0.328	0.640
Third National Energy Policy Plan[2] Midrange Estimate	1981	-	1,800	3,500	-	6,000	-	11.0	21.5	-	36.8	-	0.038	0.073	-	0.126
1980 Annual Report to Congress[3] Mid Oil Price Case	1981	1,005	-	-	-	16,240	5.1	-	-	-	99.6	0.017	-	-	-	0.034
Interagency Geothermal Coordinating Council (IGCC)[4] Production Potential	1981	663	3,000	7,000	14,000	25,000	-	-	-	-	-	-	-	-	-	-
Electric Power Research Institute (EPRI) Survey of Industry Estimates[5]	1980															
Announced		-	1,574	2,294	2,599	3,299	-	-	-	-	-	-	-	-	-	-
Probable		-	1,912	4,216	5,631	7,416	-	-	-	-	-	-	-	-	-	-
Possible		-	2,117	5,203	8,106	10,761	-	-	-	-	-	-	-	-	-	-

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* Assumes 3,412 Btu's per kilowatt-hour of electricity produced.

\- = Data Not Available.

Sources:

[1] Technecon Analytic Research, Inc., "Results from Market Penetration Estimation Model," prepared for Division of Geothermal and Hydropower Technologies, DOE, July 1981. Kilowatt-hours calculated assuming a capacity factor of 0.85 (or 0.87 for "Current Federal Program" and "Establish Capacity" after 1985). Data for 1980 megawatt capacity from DOE, Assistant Secretary for Conservation and Renewable Energy, Geothermal Progress Monitor Report Number 5, July 1981, DOE/CE-0009/5, p. 3. Data for 1980 kilowatt-hours from reference 3 below.

[2] DOE, Office of Policy, Planning and Analysis, Energy Projections to the Year 2000, A Supplement to the National Energy Policy Plan, July 1981, DOE/PE-0029, p. 9.7. Data provided for megawatt capacity. Kilowatt-hours calculated using OPPA's assumed capacity factor of 0.70.

[3] DOE, Energy Information Administration, 1980 Annual Report to Congress, Volume Two: Data, April 1981, DOE/EIA-0173(80)/2, p. 191; and Volume Three: Forecasts, March 1981, DOE/EIA-0173(80)/3, p. 128. Data for 2000 provided in quads of electricity produced. Converted to kilowatt-hours assuming 3,412 Btu's per kilowatt-hour. Megawatt capacity calculated using EIA's assumed capacity factor of 0.70.

[4] Interagency Geothermal Coordinating Council (IGCC), Fifth Annual Report, Final Draft, July 1981, p. 8.

[5] Roberts, V. and Kruger, P., Geothermal Resources Transactions, September 1980. Reprinted in reference 4 above, p. 13.

mid-range estimate found in the Third National Energy Policy Plan (NEPP), but well below the projection found in the 1980 Annual Report to Congress. The NEPP forecasts are based on a recent National Academy of Sciences (NAS)* assessment of the potential for geothermal energy and reflect a combination of both the "business-as-usual" case and the "moderately accelerated development" case. The 1980 Annual Report to Congress forecasts reflect middle world oil prices ($60 per barrel by 2000 in 1979 dollars) and midrange assumptions about economic growth, energy conservation, and alternative energy supplies.**

The market penetration estimates generated under DOE's "No Federal Program" and "Current Federal Program" are most similar to the forecasts compiled by the Electric Power Research Institute (EPRI), based upon a survey of utility industry estimates. EPRI's "probable" estimate for 2000 is about five percent lower than DOE's "No Federal Program" forecast for 2000, while EPRI's "possible" estimate for 2000 is about 15 percent higher than DOE's "Current Federal Program" forecast for 2000.

All of these projections, however, are below the IGCC's production potential estimate of 25,000 MWe by 2000. The production potential estimates generated by the IGCC are used to provide a basis for framing the Federal Geothermal Energy Program; the IGCC believes that they are well within the

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*National Academy of Sciences, "Geothermal Resources and Technology in the United States," 1979.

**DOE, Energy Information Administration, 1980 Annual Report to Congress, Volume Three: Forecasts, op. cit., pp. 7-8.

private sector's capability considering the amount of capital, materials, labor and hydrothermal resources required.* Reaching the IGCC production potential estimates would require aggressive exploration, identification of new hydrothermal resources, technology to produce electric power from resources with temperatures as low as 150°C, and a financial commitment that insures that currently known hydrothermal sites are fully developed to their estimated production capacities through the successive installation of power plants at each hydrotheraml site.** In other words, the comparative economics of hydrothermal electric power versus alternative power sources, and the degree of risk accepted by the geothermal industry, will together determine if these production potentials are achieved.

Results produced by the market penetration estimation model have shown that under certain conditions, the IGCC's production potential estimates may be possible. If DOE pursued a strategy of establishing capacity, almost 25,000 MWe are expected to be on-line by 2000 (see Exhibit 3.5). Such a strategy includes active DOE support to remove technological and legal barriers to resource development. Economic incentives would also be strongly stressed to insure that financial considerations do not deter new private investment. Technical assistance and industry support would be strongly pursued as well. In sum, an aggressive federal role at all stages of resource development would be undertaken (in sharp contrast to DOE's "No Federal Program" case).***

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*Interagency Geothermal Coordinating Council (IGCC), Fifth Annual Report, op. cit., p. xii.

**Ibid., p. 7.

***"A Strategy Analysis of Hydrothermal Development," prepared by The Futures Group for the Division of Geothermal and Hydropower Technologies, DOE, December 10, 1980.

A comparison of several hydrothermal direct heat use forecasts (see Exhibit 3.6) is hindered somewhat since the market penetration estimation model projections for DOE's "No Federal Program" and "Current Federal Program" exclude direct heat use applications by ethanol plants and enhanced oil recovery operations. If such applications are assumed to be approximately equal to or greater than other direct heat use applications by 2000,* estimates projected by 2000 under DOE's "No Federal Program" and "Current Federal Program" would exceed the 2000 NEPP estimate and be similar to the 2000 1980 Annual Report to Congress projection. Achievement of the IGCC production potential estimates would require a greatly accelerated pace of development, continued exploration and assessment of the lower-temperature resources, reservoir confirmation, substantial user education and technical assistance, and removal of institutional and legal barriers to development.** DOE's "establish capacity" case, providing extensive federal support to the geothermal industry, would apppear able to meet the IGCC production potential estimates.

In conclusion, DOE's "Current Federal Program" can be expected to sufficiently stimulate the use of hydrothermal resources -- for both electric power and direct heat use applications -- so that the role of hydrothermal

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*This appears plausible since enhanced oil recovery operations used 0.01 quads of hydrothermal energy in 1980, and ethanol plants now operating, or currently under consideration (under development, proposed or under study) and expected to be operational by 1984, are expected to use 0.016 quads of hydrothermal energy per year. This combined total of 0.026 quads by 1984 equals or exceeds direct heat use applications projected under the "No Federal Program" and "Current Federal Program" by 1985. See DOE, Assistant Secretary for Conservation and Renewable Energy, Geothermal Progress Monitor Report Number 5, op. cit., p. 8.

**Interagency Geothermal Coodinating Council, Fifth Annual Report, op. cit., pp. 8-9.

Exhibit 3.6: Comparison of Hydrothermal Direct Heat Forecasts

Forecast Scenario	Year Forecast Made	Quads Per Year				
		1980	1985	1990	1995	2000
DOE's "No Federal Program" Case[1] 50% Likelihood	1981	0.003	0.019	0.058	0.110	0.140
DOE's "Current Federal Program" Case[1] 50% Likelihood	1981	0.003	0.028	0.070	0.127	0.153
DOE's "Establish Capacity" Case[1] 50% Likelihood	1981	0.003	0.092	0.204	0.343	0.407
Third National Energy Policy[2] Midrange Estimate	1981	-	-	0.07	-	0.20
1980 Annual Report to Congress[3] Mid Oil Price Case	1981	-	-	-	-	0.28
Interagency Geothermal Coordinating Council (IGCC)[4] Production Potential	1981	0.01	0.1	0.2	0.4	1.0

- = Data Not Available.

Sources:
1) Technecon Analytic Research, Inc., "Results from Market Penetration Estimation Model," prepared for Division of Geothermal and Hydropower Technologies, DOE, July 1981. Data do not include direct heat use from ethanol plants or enhanced oil recovery applications (which amounted to 0.01 quads in 1980). Data for 1980 from DOE, Assistant Secretary for Conservation and Renewable Energy, Geothermal Progress Monitor Report Number 5, June 1981, DOE/CE-0009/5, p. 23.
2) DOE, Office of Policy, Planning and Analysis, Energy Projections to the Year 2000, A Supplement to the National Energy Policy Plan, July 1981, DOE/PE-0029, p. 9.3.
3) DOE, Energy Information Administration, 1980 Annual Report to Congress, Volume Three: Forecasts, March 1981, DOE/EIA-0173(80)/3, p. 128.
4) Interagency Geothermal Coordinating Council (IGCC), Fifth Annual Report, Final Draft, July 1981, p. 8.

energy sources in meeting the Third National Energy Policy Plan's projected national energy needs is achieved. The "Current Federal Program" will not, however, be intensive enough to achieve the IGCC's production potential estimates. A much larger federal effort would be required in conjunction with favorable economic conditions and a sustantial commitment on the part of the private sector.

4.0 ANALYSIS OF DIRECT BENEFITS

The market penetration estimates presented in Chapter 3.0 suggest that federal expenditures associated with DOE's "Current Federal Program" will result in direct benefits that can be expressed as the expected hydrothermal power plant generating capacity (and electricity production) and direct heat use applications <u>in excess of</u> (or in addition to) what is expected to be realized without any continued federal involvement. These direct benefits are discussed in detail in this chapter; first, for the additional electric power applications, followed by the additional direct heat applications.

To facilitate the analysis, the market penetration probability distributions (see Exhibits 3.2 and 3.4) are represented here as single "expected value" estimates for the most likely generating capacity (and electricity production) and direct heat energy use resulting from the "No Federal Program" and the "Current Federal Program." In calculating the "expected value" estimates for generating capacity and direct heat energy use, it was assumed -- for 1985, 1990, 1995, and 2000 -- that a suitable lower bound estimate was the comparable figure presented for five years earlier. Furthermore, it was conservatively assumed that without market penetration study estimates of fully assured upper limits, five or ten percent likelihood figures represented sensible upper bounds.

A number of additional assumptions are also used in the analysis that follows. Because they have a direct bearing on interpretation of the analysis, they are summarized below:

- The FY 1981-FY 1990 program outlays were assumed to have an effect on new generating capacity and direct heat use through 2000 to account for the time between an initial decision to build a hydrothermal facility and full-scale operation. It was also assumed that the FY 1981-FY 1990 program outlays would have relatively little influence on hydrothermal development beyond 2000.

- In calculating electricity production from generating capacity, an average 85 percent capacity factor was used under DOE's "No Federal Program" and through 1985 under DOE's "Current Federal Program." For all generating capacity on-line after 1985 under DOE's "Current Federal Program," an average 87 percent capacity factor was used reflecting technology gains obtained from the program for both existing and newly installed generating capacity.

- All increases in generating capacity and direct heat use were assumed to be linear within five-year intervals between 1980 and 2000.

- The facility life of power plants was assumed to be 30 years, implying that plants started up in 2000 would produce effects through 2029.

- The facility life for direct heat systems was assumed to be 20 years in the "No Federal Program" case. It was assumed to be 25 years for the "Current Federal Program" as a reflection of program-generated technology gains. As a result, some direct heat energy gains would stretch out through 2024.

All of these assumptions contain no unusual elements and are consistent with assumptions utilized in developing the market penetration estimates presented in the previous chapter. They, nevertheless, provide for the appropriate interpretation of the analysis which follows.

4.1 Electric Power Applications

DOE's "Current Federal Program" is expected to increase hydrothermal electric power applications, above and beyond what can be expected without continued federal involvement, in two ways: by stimulating the construction of power plants that, otherwise, are not expected to be brought on-line by 2000; and by improving the average operating performance (or capacity factor) of all other power plants. The "expected value" estimates for electric power applications are shown in Exhibit 4.1 and include projections of generating capacity (megawatts) and production of electricity (thousand megawatt-hours per year).

Prior to 1996, the additional hydrothermal generating capacity attributable to DOE's "Current Federal Program" is expected to be small (less than 200 megawatts). However, from 1996 to 2000, it is projected that an additional 925 megawatts will come on-line. By 2000, then, DOE's "Current Federal Program" is expected to increase hydrothermal generating capacity by about 1,120 megawatts or to approximately 115 percent of the capacity expected under DOE's "No Federal Program." Stated another way, DOE's "Current Federal Program" is expected to result in the construction of about 22 additional 50 megawatt hydrothermal power plants from 1981 to 2000. The projected start-up dates can be assumed to be as follows: one power plant in 1983, 1985 and 1991; four power plants in 1996 and 1997; three power plants in 1998; and four power plants in 1999 and 2000.

The additional generating capacity coupled with the improved operating performance of all other power plants -- both a result of DOE's "Current

Exhibit 4.1: Expected Value Estimates for Electric Power Applications From Hydrothermal Energy

	No Federal Program Case				Current Federal Program Case				Additional Hydrothermal Electric Power Applications Attributable to DOE's Current Federal Program			
	Megawatts		Thousand Megawatt-Hours Per Year*		Megawatts		Thousand Megawatt-Hours Per Year**		Megawatts		Thousand Megawatt-Hours Per Year	
Year	Total	Yearly Addition	Total	Yearly Addition	Total	Yearly Addition	Total	Yearly Addition	Total	Yearly Addition	Total	Yearly Addition
1980	922	NA	5,073	NA	922	NA	5,073	NA	0	NA	0	NA
1981	1,065	143	7,930	2,857	1,088	166	8,101	3,028	23	23	171	171
1982	1,207	142	8,987	1,057	1,255	167	9,345	1,244	48	25	358	187
1983	1,350	143	10,052	1,065	1,421	166	10,581	1,236	71	23	529	171
1984	1,492	142	11,109	1,057	1,588	167	11,824	1,243	96	25	715	186
1985	1,635	143	12,174	1,065	1,754	166	13,060	1,236	119	23	886	171
1986	2,039	404	15,182	3,008	2,162	408	16,477	3,417	123	4	1,295	409
1987	2,443	404	18,191	3,009	2,570	408	19,586	3,109	127	4	1,395	100
1988	2,846	403	21,191	3,000	2,977	407	22,688	3,102	131	4	1,497	102
1989	3,250	404	24,200	3,009	3,385	408	25,798	3,110	135	4	1,598	101
1990	3,654	405	27,208	3,008	3,793	408	28,907	3,109	139	4	1,699	101
1991	4,158	504	30,960	3,752	4,308	515	32,832	3,925	150	11	1,872	173
1992	4,663	505	34,721	3,761	4,823	515	36,757	3,925	160	10	2,036	164
1993	5,167	504	38,473	3,752	5,338	515	40,682	3,925	171	11	2,209	173
1994	5,672	505	42,234	3,761	5,853	515	44,607	3,925	161	10	2,373	164
1995	6,176	504	45,986	3,752	6,368	515	48,532	3,925	192	11	2.546	173
1996	6,490	314	48,325	2,339	6,867	499	52,335	3,803	377	185	4,010	1,464
1997	6,804	314	50,663	2,338	7,366	499	56,138	3,803	562	185	5,475	1,465
1998	7,117	313	52,993	2,330	7,864	498	59,933	3,795	747	185	6,940	1,465
1999	7,431	314	55,331	2,338	8,363	499	63,736	3,803	932	185	8,405	1,465
2000	7,745	314	57,669	2,338	8,862	499	67,539	3,803	1,117	185	9,870	1,465

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*Assumes an average 85% capacity factor for all generating capacity on-line from 1981-2000.

**Assumes an average 85% capacity factor for all generating capacity on-line from 1981-1985 and an average 87% capacity factor for all generating capacity on-line after 1985.

NA = Not Applicable.
Source: Exhibits 3.2 and 3.4.

Federal Program" -- are projected to produce an added 10 million megawatt-hours of electricity by 2000 (see Exhibit 4.1). Over the 30 year lifetime of each of the 22 additional hydrothermal power plants, an added 255 million megawatt-hours of electricity are expected to be produced (see Exhibit 4.2). The largest amounts of this additional electricity are projected to be generated between 2000 and 2010 when all 22 additional power plants are in operation. As each of the 22 power plants are retired between 2011 and 2030, the additional generating capacity and electricity production will decline, and will ultimately become zero when the last of the 22 power plants is retired.

Almost 41 million more megawatt-hours of electricity are also expected to be produced as a result of improved operating performance in all other power plants over their 30 year lifetimes (see Exhibit 4.2). The largest amounts of this additional electricity are projected to be generated between 2000 (when all power plants will first be in operation) and 2015 (reflecting the assumption that power plants are not expected to operate at improved performance levels until 1986). These 41 million megawatt-hours of electricity are equivalent to almost four 50 megawatt hydrothermal power plants operating over a 30 year lifetime.

In total, then, DOE's "Current Federal Program" is expected to produce an additional 296 million megawatt-hours of electricity over a 50 year period spanning the lifetime of all facilities impacted by the program. This is the equivalent of twenty-six 50 megawatt power plants with a useful life of 30 years. Because a consumer's demand for electricity is not usually directly dictated by the energy source providing that

Exhibit 4.2: Additional Hydrothermal Electric Power Applications Attributable to DOE's "Current Federal Program", by Year, Over Lifetime of Facilities

		Production of Electricity (thousand megawatt-hours per year)		
Year	Generating Capacity (megawatts)	Associated With Additional Generating Capacity	Associated With Improved Operating Performance in All Other Facilities	Total
1980	0	0	0	0
1981	23	171	0	171
1982	48	358	0	358
1983	71	529	0	529
1984	96	715	0	715
1985	119	886	0	886
1986	123	937	358	1,295
1987	127	968	427	1,395
1988	131	998	499	1,497
1989	135	1,029	569	1,598
1990	139	1,059	640	1,699
1991	150	1,143	729	1,872
1992	160	1,219	817	2,036
1993	171	1,303	906	2,209
1994	181	1,379	994	2,373
1995	192	1,463	1,083	2,546
1996	377	2,873	1,137	4,010
1997	562	4,283	1,192	5,475
1998	747	5,693	1,247	6,940
1999	932	7,103	1,302	8,405
2000	1,117	8,513	1,357	9,870
2001	1,117	8,513	1,357	9,870
2002	1,117	8,513	1,357	9,870
2003	1,117	8,513	1,357	9,870
2004	1,117	8,513	1,357	9,870
2005	1,117	8,513	1,357	9,870
2006	1,117	8,513	1,357	9,870
2007	1,117	8,513	1,357	9,870
2008	1,117	8,513	1,357	9,870
2009	1,117	8,513	1,357	9,870
2010	1,117	8,513	1,357	9,870
2011	1,094	8,342	1,357	9,699
2012	1,069	8,155	1,357	9,512
2013	1,046	7,984	1,357	9,341
2014	1,021	7,798	1,357	9,155
2015	998	7,627	1,357	8,984
2016	994	7,576	999	8,575
2017	990	7,545	930	8,475
2018	986	7,515	858	8,373
2019	982	7,484	788	8,272
2020	978	7,454	717	8,171
2021	967	7,370	628	7,998
2022	957	7,294	540	7,834
2023	946	7,210	451	7,661
2024	936	7,134	363	7,497
2025	925	7,050	274	7,324
2026	740	5,640	220	5,860
2027	555	4,230	165	4,395
2028	370	2,820	110	2,930
2029	185	1,410	55	1,465
2030	0	0	0	0
Total (1981-2030)	NA	255,390	40,710	296,100

NA = Not Applicable.
Source: Exhibit 4.1.

electricity, it can be expected that the additional hydrothermal electricity, projected to be produced as a result of DOE's "Current Federal Program," will displace electricity otherwise generated by a competitive alternative energy source (most likely western coal if in the Mountain Region or nuclear power if in the Pacific Region).

It is reasonable, therefore, to compare the power production costs of these alternative energy sources. The levelized busbar cost of power (in mills per kilowatt-hour)* represents a constant charge over the life of a power plant which will result in a present value of revenues precisely equal to the present value of costs (including initial capital costs and yearly operating and maintenance costs). While levelized busbar costs will not represent the actual year by year kilowatt-hour charges, they provide a way to determine the relative attractiveness of alternative sources of electricity. Exhibit 4.3 provides levelized constant dollar busbar cost information (mills per kilowatt-hour in constant 1982 dollars) for hydrothermal, western coal and nuclear plants starting up in 1982, 1985 and 1990. These data indicate that hydrothermal energy is competitive in cost with western coal and nuclear power for high temperature resources (as at Baca), but is considerably more expensive at moderate temperature resources (as at Heber). The Public Service Company of New Mexico estimates that a 30 year hydrothermal plant will produce power at essentially the same cost as a 40 year coal plant and assumes the second plant at the Valles Caldera (Baca) site will have lower operating and maintenance and fuel

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*One mill equals $0.001.

Exhibit 4.3: Representative Levelized Busbar Cost of Power For Hydrothermal, Western Coal and Nuclear Power Plants

Plant Type and Name	Start-Up Date	Levelized Busbar Cost of Power (mills per kilowatt-hour in constant 1982 dollars)
Hydrothermal		
Public Service Company of New Mexico (PNM) Baca Flash Demonstration Plant*	1982	36
PNM Baca Subsequent Unit**	1982	36
San Diego Gas and Electric Company (SDG&E) Heber Binary Demonstration Plant***	1985	61
Western Coal		
PNM Estimate (San Juan Unit 4)	1982	36
SDG&E Estimate (Blythe)	1985	29
Nuclear Regulatory Commission (NRC) Estimate	1990	30
Nuclear		
SDG&E Estimate (Sundesert)	1985	24
NRC Estimate	1990	37

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*50 percent DOE funded plant.

**Assumes no DOE funds.

***Ignores 50 percent DOE funding.

Source: DOE, Division of Geothermal and Hydropower Technologies, "Working Paper: Hydrothermal Cost of Power," April 1981.

costs which essentially compensate for the 50 percent DOE subsidy of the demonstration unit.* San Diego Gas and Electric Company (SDG&E) estimates that their moderate temperature generation costs will be twice as high for geothermal as coal, and 2.5 times as high for geothermal as nuclear, for plants starting up in 1985. The reasons for the high costs on the proposed SDG&E binary plant are straightforward:**

> At 365°F, the binary plant requires approximately 2.5 times the brine flow rate as the 550°F flash plant. The higher brine flow dictates larger piping, valves and reinjection pumps. The lower temperature necessarily means a 20 percent lower thermal efficiency, which requires approximately 20 percent larger condensers, cooling towers, water circulating pumps and 20 percent more make-up water. In addition, the lower vapor pressure of the 365° brine causes wells to be low in productivity unless they are pumped. The binary plant will use approximately 5 MWe of parasitic power for downhole pumps which is not required for the 550°F resource, plus an additional 2 MWe of parasitic power for injection pumps. Capital costs for downhole pumps add 2.5 million dollars in initial cost and will require frequent maintenance and replacement.

Although moderate temperature resource utilization with current technology is not competitive with coal and nuclear power, market penetration might still proceed under certain circumstances because this resource is relatively benign environmentally (see Section 5.1), and coal and nuclear may be discouraged by state policy (as is currently being done in California).

The dominant cost in hydrothermal energy (50-75 percent of the kilowatt-hour charges) is fuel, and high hydrothermal fuel costs can be attributed primarily to high drilling costs, low reservoir temperature

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*DOE, Division of Geothermal and Hydropower Technologies, "Working Paper: Hydrothermal Cost of Power," April 1981, p. 4.

***Ibid.*, p. 4.

(requiring more wells) or low well productivity. The prospect for improving economics through technological progress is excellent, especially for the moderate temperature resources. Drilling technology development, reservoir stimulation for the purpose of increasing well flow, improved downhole pumps, and more efficient conversion systems, together, have a realistic potential for cutting moderate temperature costs in half, which is why the development of hydrothermal technology is such an important part of DOE's "Current Federal Program."*

4.2 Direct Heat Applications

As was found for electric power applications, the impact of DOE's "Current Federal Program" on the use of hydrothermal resources for direct heat energy use is also expected to take two forms. First, it is projected that there will be direct heat use applications that, otherwise, will not be realized if DOE's "No Federal Program" is undertaken. Second, it is expected that the useful life of those facilities that will become operational even in the absence of DOE's "Current Federal Program", will be extended from 20 to 25 years (due to technology gains resulting from DOE's "Current Federal Program"), thereby also producing added direct heat applications.

The additional hydrothermal direct heat applications attributable to DOE's "Current Federal Program" between 1980 and 2000 are shown in Exhibit 4.4. This additional use is solely related to facilities that would not have become operational under DOE's "No Federal Program."

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*DOE, Division of Geothermal and Hydropower Technologies, "Working Paper: Hydrothermal Cost of Power," April 1981, p. 5.

Exhibit 4.4: Expected Value Estimates for Direct Heat Applications*
From Hydrothermal Energy

Direct Heat Energy Use (quads per year)

Year	No Federal Program Case		Current Federal Program Case		Additional Hydrothermal Direct Heat Applications Attributable to DOE's Current Federal Program	
	Total	Yearly Addition	Total	Yearly Addition	Total	Yearly Addition
1980	0.003	NA	0.003	NA	0.000	NA
1981	0.007	0.004	0.009	0.006	0.002	0.002
1982	0.011	0.004	0.014	0.005	0.003	0.001
1983	0.014	0.003	0.020	0.006	0.006	0.003
1984	0.018	0.004	0.025	0.005	0.007	0.001
1985	0.022	0.004	0.031	0.006	0.009	0.002
1986	0.030	0.008	0.040	0.009	0.010	0.001
1987	0.038	0.008	0.048	0.008	0.010	0.000
1988	0.046	0.008	0.057	0.009	0.011	0.001
1989	0.054	0.008	0.065	0.008	0.011	0.000
1990	0.062	0.008	0.074	0.009	0.012	0.001
1991	0.073	0.011	0.086	0.012	0.013	0.001
1992	0.084	0.011	0.097	0.011	0.013	0.000
1993	0.094	0.010	0.109	0.012	0.015	0.002
1994	0.105	0.011	0.120	0.011	0.015	0.000
1995	0.116	0.011	0.132	0.012	0.016	0.001
1996	0.125	0.009	0.140	0.008	0.015	- 0.001
1997	0.133	0.008	0.149	0.009	0.016	0.001
1998	0.142	0.009	0.157	0.008	0.015	- 0.001
1999	0.150	0.008	0.166	0.009	0.016	0.001
2000	0.159	0.009	0.174	0.008	0.015	- 0.001

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*Includes collocated industry direct heat use, relocated industry heat use, and district heating (does not include ethanol or enhanced oil recovery applications).

NA = Not Applicable.

Source: Exhibits 3.2 and 3.4.

By 1985, an additional 0.009 quads are expected to be consumed. This represents an amount 40 percent higher than the level expected under DOE's "No Federal Program." Between 1993 and 2000, the additional hydrothermal direct heat applications attributable to DOE's "Current Federal Program" are projected to remain fairly constant at 0.015-0.016 quads per year; therefore, by 2000, direct heat applications are expected to be about 10 percent greater under DOE's "Current Federal Program" compared to a cessation of DOE involvement after FY 1982.

The majority (80-85 percent) of the 0.015-0.016 quads of additional direct heat use by 2000 is expected to be consumed in the residential and commercial sectors for district heating requirements (see Exhibit 4.5). Industrial use of hydrothermal resources -- in absolute amounts -- is projected to be about the same under both DOE's "No Federal Program" and "Current Federal Program." Assuming that each residential or commercial project will provide, on average, 25 billion Btu's per year, and each industrial project about 150 billion Btu's per year,* it can be expected that about 480-560 additional residential and commercial projects, and about 10-20 additional industrial projects, will become operational from 1981 to 2000 solely as a result of DOE's "Current Federal Program." Over the 25 year lifetime of each of these facilities, a total of 0.375 quads of additional hydrothermal energy are expected to be consumed,

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*Residential and commercial direct heat use projects now under development, undergoing feasibility studies or proposed, will provide, on average, about 25 billion Btu's per year; for industrial projects, the average consumption is expected to be about 150 billion Btu's per year. See DOE, Assistant Secretary for Conservation and Renewable Energy, Geothermal Progress Monitor Report Number 5, *op. cit.*, pp. 19-22.

Exhibit 4.5: Expected Value Estimates for Direct Heat Applications* From Hydrothermal Energy, by Type of Application

	Direct Heat Energy Use (quads per year)								
	No Federal Program Case			Current Federal Program Case			Additional Hydrothermal Direct Heat Applications Attributable to DOE's Current Federal Program		
Year	District Heating	Industrial	Total	District Heating	Industrial	Total	District Heating	Industrial	Total
1980	**	0.002	0.003	**	0.002	0.003	0.000	0.000	0.000
1985	0.017	0.005	0.022	0.026	0.005	0.031	0.009	0.000	0.009
1990	0.052	0.010	0.062	0.062	0.012	0.074	0.010	0.002	0.012
1995	0.099	0.017	0.116	0.113	0.019	0.132	0.014	0.002	0.016
2000	0.135	0.024	0.159	0.147	0.027	0.174	0.012	0.003	0.015

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*Includes collocated industry direct heat use, relocated industry direct heat use, and district heat (does not include ethanol plants or enhanced oil recovery applications).

**Less than 0.0005 quads.

Source: 1980: DOE, Assistant Secretary for Conservation and Renewable Energy, Geothermal Progress Monitor Report Number 5, June 1981, DOE/CE-0009/5, pp. 12,19-22. 1985-2000: Technecon Analytic Research, Inc., "Results from Market Penetration Estimation Model," prepared for Division of Geothermal and Hydropower Technologies, DOE, July 1981.

with the largest amounts consumed between 2000 and 2005 before any of these additional projects are retired (see Exhibit 4.6).

Additional direct heat applications are also expected to be realized from DOE's "Current Federal Program" by extending the useful life of those facilities that are expected to come on-line anyway between 1980 and 2000 (i.e., under DOE's "No Federal Program"). In fact, it is projected that an added 0.780 quads of hydrothermal energy can be consumed over the lifetime of those facilities, if each facility's useful life is extended by five years due to technological gains obtained through the research and development efforts of DOE's "Current Federal Program" (see Exhibit 4.6). All of this additional energy would be consumed after 2000 when the benefits of extending the useful life of those facilities first begin to appear. Consumption is actually expected to increase through 2015 since fewer hydrothermal facilities would be retired each year through 2015 than otherwise expected. Most of those facilities are, again, projected to serve residential and commercial energy needs since the bulk (about 85 percent) of the direct heat applications are for district heating purposes (see Exhibit 4.5).

To summarize, then, DOE's "Current Federal Program" is expected to result in the consumption of an additional 1.155 quads of hydrothermal energy over a 45 year period spanning the lifetime of all facilities impacted by the program. Much of this additional consumption (about 85 percent) is projected to be for district heating purposes in the residential and commercial sectors. Such uses can be assumed to displace the use of

Exhibit 4.6: Additional Hydrothermal Direct Heat Applications* Attributable to DOE's Current Federal Program, by Year, Over Lifetime of Facilities

	Direct Heat Energy Use (quads per year)		
Year	Associated With Facilities That, Otherwise, Would Go Undeveloped	Associated With Extending Useful Life of Facilities	Total
1980	0.000	0.000	0.000
1981	0.002	0.000	0.002
1982	0.003	0.000	0.003
1983	0.006	0.000	0.006
1984	0.007	0.000	0.007
1985	0.009	0.000	0.009
1986	0.010	0.000	0.010
1987	0.010	0.000	0.010
1988	0.011	0.000	0.011
1989	0.011	0.000	0.011
1990	0.012	0.000	0.012
1991	0.013	0.000	0.013
1992	0.013	0.000	0.013
1993	0.015	0.000	0.015
1994	0.015	0.000	0.015
1995	0.016	0.000	0.016
1996	0.015	0.000	0.015
1997	0.016	0.000	0.016
1998	0.015	0.000	0.015
1999	0.016	0.000	0.016
2000	0.015	0.000	0.015
2001	0.015	0.004	0.019
2002	0.015	0.008	0.023
2003	0.015	0.011	0.026
2004	0.015	0.015	0.030
2005	0.015	0.019	0.034
2006	0.013	0.023	0.036
2007	0.012	0.027	0.039
2008	0.009	0.032	0.041
2009	0.008	0.036	0.044
2010	0.006	0.040	0.046
2011	0.005	0.043	0.048
2012	0.005	0.046	0.051
2013	0.004	0.048	0.052
2014	0.004	0.051	0.055
2015	0.003	0.054	0.057
2016	0.002	0.052	0.054
2017	0.002	0.049	0.051
2018	0.000	0.048	0.048
2019	0.000	0.045	0.045
2020	- 0.001	0.043	0.042
2021	0.000	0.034	0.034
2022	- 0.001	0.026	0.025
2023	0.000	0.017	0.017
2024	- 0.001	0.009	0.008
2025	0.000	0.000	0.000
Total (1981-2025)	0.375	0.780	1.155

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*Includes collocated industry direct heat use, relocated industry direct heat use, and district heat (does not include ethanol plants or enhanced oil recovery applications).

Source: Exhibit 4.3.

conventional fuels (electricity, oil and natural gas) that, otherwise, would have provided these energy requirements.

Without specifying the locations of where these resources would be developed, the direct heat production cost savings associated with utilizing these additional hydrothermal resources are difficult to calculate, since heating costs are so site-specific. Nevertheless, there are clear indications that hydrothermal district heating is competitive in cost in many parts of the U.S. In early 1980, for example, the median levelized heating costs* in the residential sector using conventional fuels was estimated to be about $15 million Btu's of heat delivered (in 1979 dollars), based on costs in a large representative sample of U.S. cities.** The economics of hydrothermal district heating is very dependent on the density of heat demand per unit area (which, in turn, is related to both population density and climatic conditions), and the production and transmission costs (which are related to the temperature, depth, and production rate of the resource and the transmission distance).*** Given these considerations, and a median levelized cost of conventional heating of $15 per million Btu's, residential district heating from identified high temperature hydrothermal resources was found to be lowest in cost in nearly every urban center throughout the West. Moreover, residential district heating

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*The levelized heating cost represents a uniform stream of annual payments over the life of the system which will result in a present value of payments equal to the present value of life-cycle costs.

**Bloomster, C.H., Garrett-Price, B.A. and Fassbender, L.L., Residential Heating Costs-A Comparison of Geothermal, Solar and Conventional Resources, prepared by the Pacific Northwest Laboratory for the U.S. Department of Energy, PNL-3200-UC-66i, August 1980, p. 45.

***Ibid., p. 57.

using normal gradient resources that underly the rest of the U.S. (including areas in the West where high and intermediate temperature resources are not found), was found to be lowest in cost in nearly every urban center in the northern half of the U.S.* The hydrothermal heating cost for commercial applications was also estimated to be about the same or lower than residential heating costs; thus commercial applications, too, appear to be very cost-competitive. While these results indicate that hydrothermal resources are cost-competitive, detailed feasibility studies at individual sites would be required to exactly determine the commercialization potential, based upon the specific conditions at each location.

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*Bloomster, C.H., Garrett-Price, B.A. and Fassbender, L.L., Residential Heating Costs-A Comparison of Geothermal, Solar and Conventional Resources, op. cit., pp. 89-90.

5.0 ANALYSIS OF EXTERNAL IMPACTS

DOE's "Current Federal Program" is expected to result in additional hydrothermal resource development (as described in the previous chapter). Associated with these direct benefits are a series of external impacts imposed by the development of the additional hydrothermal resource sites. Balanced against these impacts, however, are a similar set of foregone impacts associated with the effects that would have resulted had alternative energy sources (for example, coal or nuclear) been utilized in place of these additional hydrothermal resource sites. The change in these external impacts, then, provides a measure of the effects associated with DOE's "Current Federal Program." Several broad categories of external impacts can be identified. These include:

- Environmental effects;
- National security/balance-of-payments improvements;
- Socioeconomic impacts; and
- Materials requirements.

This chapter addresses each of these areas.

5.1 Environmental Effects

The development of hydrothermal resource sites -- either for the production of electricity or for direct heat energy use -- can involve adverse environmental effects associated with the production, processing, distribution, use, and disposal of the resources. These effects conceivably might include land subsidence, induced seismic activity, degradation of air and water quality, generation of solid wastes, noise, damage to the local ecosphere, and various health and safety impacts. For example, the potential environmental impacts of geothermal power production and the likely incidence of those impacts is illustrated in Exhibit 5.1.

Any adverse environmental effects associated with the development of additional hydrothermal resource sites (as a result of DOE's "Current Federal Program") will be offset, however, by the avoidance of similar undesirable impacts that would have resulted from the use of the alternative energy sources displaced by hydrothermal energy. For example, the displacement of coal and nuclear energy could reduce the harmful impacts of their extraction and conversion on environmental quality, mitigate the health and safety hazards linked to the radioactive by-products of nuclear energy, and diminish the adverse health effects associated with air pollution arising from the use of coal.

An overview of the key environmental issues surrounding hydrothermal development is first provided; where the impacts of electric power and direct heat applications are significantly different, such variations are noted. The environmental impact of DOE's "Current Federal Program" is, then, specifically addressed.

Exhibit 5.1: Potential Environmental Impacts of Geothermal Power Production

Impact	Estimate of Probability	Technology/ Resource Type	Severity of Consequences
Land subsidence	moderate	hot-water	variable-can be high
Induced seismic activity (earthquakes)	low	all	high
Air pollution resulting from discharge of noncondensable gases (e.g., hydrogen sulfide, carbon dioxide)	high	all except hot-water binary fluid and other "closed-cycle" use of geothermal fluids	variable-depends on emission controls
High noise levels of drilling and plant operation	high	all; worst for vapor-dominated	moderate
Chemical or thermal pollution of surface and groundwaters	moderate	all; greatest probability with hot-water	high
Well blowouts	low	hot-water; vapor-dominated	moderate
Increased erosion and sedimentation resulting from site disturbance	high	all	moderate
Consumption of water for cooling purposes	high	hot-water binary fluid; hot dry rock	high
Consumption of land for wells, power plants, transmission lines	high	all	moderate
Short-term climatic changes resulting from release of heated steam and carbon dioxide	high	hot-water; vapor-dominated	low
Disturbance of habitat; alteration of ecosystems	moderate to high	all	moderate to low

Source: Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, prepared for the Environmental Protection Agency, Office of Research and Development, Office of Energy, Minerals and Industry, 1977, p. 42.

5.1.1 Overview

5.1.1.1 Air Quality

Air pollution generated by the use of hydrothermal resources can occur over all phases of development: exploration and well drilling; well testing; and site operations. While there are known health hazards associated with a number of typical hydrothermal air emissions, no significant health problems have been documented at existing hydrothermal facilities.

The most active source of air pollution is power plants. The potential for impairing air quality from direct heat applications is much smaller than in the case of electricity generation because no continuous release of geothermal gases occurs. Nevertheless, the potential for temporary air pollution is present during the well drilling and construction phases of direct heat projects.

Air pollution from electric power applications is most likely to occur when geothermal steam is emitted during exploration, well drilling and well testing, and when noncondensable gases (for example, hydrogen sulfide and carbon dioxide) are emitted during power plant operations. Air pollution resulting from power plant construction, where heavy equipment generates fugitive dust, is temporary and usually insignificant.* Exhibit 5.2 indicates the relative importance of these emissions as pollution sources based on current, but limited, evidence. No significant difference exists between

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*Woodward-Clyde Consultants, Impact Prediction Manual for Geothermal Development, prepared for Western Energy and Land Use Team, Office of Biological Services, Fish and Wildlife Service, U.S. Department of Interior, June 1978, p. 82; and Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, prepared for the Environmental Protection Agency, Office of Research and Development, Office of Energy, Minerals and Industry, 1977, p. 71.

Exhibit 5.2: Sources of Geothermal Steam and Noncondensable Gas Emissions During Geothermal Power Plant Development

Development Phase	Relative Importance as Pollution Source
Steam discharge during well drilling and clean-out	Moderate
Production testing of wells	Moderate
Well blow-outs	Low
Venting or "bleeding" of test wells prior to power generation	Low
Steam line vents during power plant operation	Moderate
Accidental steam line breaks	Low
Venting of wells during plant shutdown	Low-Moderate
Power plant operation	High

Source: Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, prepared for the Environmental Protection Agency, Office of Research and Development, Office of Energy, Minerals and Industry, 1977, p. 71.

air pollution potentials of vapor dominated systems and flash hot water systems; both may vent potentially hazardous emissions from the production well and the power plant cooling tower. While accidental well blowouts are not a relatively important source of air pollution, they can produce significant amounts of pollution; for example, an uncontrolled blowout at The Geysers resulted in a total release of four thousand tons of hydrogen sulfide, five thousand tons of ammonia, and six thousand tons of methane.*

A complete and accurate assessment of the severity of air pollution from hydrothermal resources rests on a number of considerations, including:

- Concentration of gases in the geothermal fluid;
- Regional meteorology;**
- Types of conversion technology employed; and
- Fluid requirements of the plant.

The concentration and type of gases in the geothermal fluid, for example, varies among sites (see Exhibit 5.3) and may even vary among contiguous underground reservoirs and over the lifetime of an individual well.*** Thus, there will be variation in the type and quantity of pollutants

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*Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, op. cit., p. 72.

**Layton, David (editor), An Assessment of Geothermal Development in the Imperial Valley of California, Volume 1 -- Environment, Health and Socioeconomics, prepared by the Lawrence Livermore National Laboratory for the U.S. Department of Energy, Technology Assessments Division, 1980, DOE/EV-0092, p. 5-1.

***Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, op. cit., p. 68.

Exhibit 5.3: Concentration of Selected Noncondensable Gases in Geothermal Fluids From Wells at Selected Sites

	Range and Average Values (milligrams per kilogram of fluid-ppmw)								
	Geysers[1] (steam)		Salton Sea[2] (brine)		East Mesa[2] (brine)		Brawley[3] (brine)	Heber[4] (brine)	Baca[5] (brine)
	Range	Average	Range	Average	Range	Average	Average[6]	Average[6]	Average[6]
Hydrogen Sulfide (H_2S)	5-1600	222	1.6-6.0	3.2	0.12-1.6	0.54	55.1	0.18	60.7
Carbon Dioxide (CO_2)	290-30600	3260	1100-3800	1700	270-2300	1100	23500	34.6	8410.0
Methane (CH_4)	13-13447	194	3.0-10	6.0	4.0-56	33	319	1.7	0.6
Ammonia (NH_3)	9.4-1060	194	20-41	35	1.3-8.1	4.5	51	-	-

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[1] Average value measurements from 61 producing wells, 1972-1974.

[2] Measurements from 2 or 3 wells.

[3] Average from 2 wells: Veysey 2 and TOW 1. Data subject to sampling errors. Values are probably closer to those found in Salton Sea brine.

[4] Average of 2 wells.

[5] Baca Ranch, Sandoval County, New Mexico.

[6] Meaningful range data not available.

Source: Morris, William and Hill, John (editors), An Assessment of Geothermal Development in the Imperial Valley of California, Volume 2 -- Environmental Control Technology, prepared by the Lawrence Livermore National Laboratory for the U.S. Department of Energy, Environmental and Safety Engineering Division, 1980, DOE/EV-0092, p. 7.

released into the atmosphere at well sites. Once the pollutants reach the atmosphere, regional meteorological factors must be considered, including:*

- Wind velocity;
- Persistence of wind direction;
- Atmospheric turbulance;
- Mixing height; and
- Properties of the ambient atmosphere (e.g., temperature, humidity, presence of other pollutants, sunlight).

Even though the broad variation of geothermal fluid composition and meteorological conditions among geothermal zones limits the generalizability of air pollution findings, the pollutants likely to be present at a typical hydrothermal site are well known and include: particulate matter; carbon dioxide; ammonia; methane; hydrogen sulfide; nitrogen; and, in trace amounts, radon, mercury vapor and argon. Each poses its own special concern and potential hazards.

Hydrogen sulfide is the most potentially hazardous noncondensable gas emitted from geothermal sites. In high concentrations it can cause respiratory problems or even death; however, in the context of most geothermal development, hydrogen sulfide constitutes an aesthetic irritant

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*Woodward-Clyde Consultants, Impact Prediction Manual for Geothermal Development, op. cit., p. 84.

resulting from its "rotten egg" odor which can be detected by some people at levels ten times more diluted than the level set by California's ambient air quality standard (0.030 ppm).*

Normal meteorological activity usually dilutes hydrogen sulfide emissions sufficiently to prevent harmful accumulation; however, development site personnel and people in low lying areas near geothermal developments may be physically affected by hydrogen sulfide. The probability of physically harmful incidents is increased by the fact that hydrogen sulfide in high concentrations is less easily detected by the sense of smell.**

Hydrogen sulfide is also chemically reactive; in the atmosphere it converts to other compounds of sulfide (for example, sulfur dioxide) which resemble emissions released in the burning of fossil fuels. This is important since sulfur dioxide is a criteria air pollutant and subject to national ambient air quality standards stipulated by the Clean Air Act.***

Most geothermal reservoir steam contains ammonia, but the quantities appear too small to represent health hazards. Atmospheric dilution reduces the effect of ammonia even more and ensures that it is present in acceptable levels. However, ammonia in the presence of hydrogen sulfide can combine to form ammonia sulfate, a potentially hazardous gas. No health

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*Scott, M.J., et al., An Exploratory Benefit-Cost Analysis of Environmental Controls on Hydrothermal Energy, prepared by the Pacific Northwest Laboratory for the U.S. Department of Energy, February 1981, PNL-3527-UC-66e, p. 31.

**Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, op. cit., p. 68.

***Ibid., p. 68.

problems related to the geothermal release of ammonia have been noted to date. Relative to the hazard posed by hydrogen sulfide, the effects of the release of ammonia are inconsequential.*

Radon is a radioactive gas, trace amounts of which have been detected in geothermal releases. The health hazard posed by radon results from its breakdown into "daughter products" which attach themselves to atmospheric particles. These particles can lodge on and in the human body where they can cause cancer. To date, no specific health hazards from radon have been recorded as a result of hydrothermal resource development.**

Like radon, mercury has been detected in geothermal fluids in trace amounts; however, mercury is sufficiently hazardous to human health that its introduction into the environment is always a reason for concern. Mercury, which has a tendency to vaporize, is present in geothermal vapor releases. It precipitates and falls in normal rains to the earth where, in sufficient concentrations, it can be hazardous to living organisms. In spite of its danger, mercury is not expected to present a serious environmental impediment to the development of geothermal energy because its presence in releases is insignificant.***

Carbon dioxide has been detected at toxic levels in undiluted geothermal releases; however, because carbon dioxide is a significant component of the atmosphere, releases from geothermal facilities dilute rapidly and pose only minor problems.**** Nevertheless, there is a general concern that increased

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*Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, op. cit., p. 69.

**Ibid., p. 71.

***Ibid., p. 71.

****Ibid., p. 69.

levels of atmospheric carbon dioxide trap additional infrared radiation, which, in turn, results in the warming of the earth's atmosphere. The past and future development of hydrothermal resources, however, has not produced such concerns.* In fact, the presence of carbon dioxide may promote growth of specific crops adjacent to geothermal emission points.**

To summarize, of all the air pollutants associated with geothermal developments, hydrogen sulfide is expected to represent the only serious health hazard. The other gases have been detected in amounts too small to cause concern. Even in the case of hydrogen sulfide, the principal objection arises not from health concerns, but rather from aesthetic-odor considerations, especially in situations where several wells in close proximity are releasing hydrogen sulfide.*** Because hydrogen sulfide is also released from numerous manufacturing and drilling procedures other than geothermal development, the issues related to abatement of the gas have received considerable study. However, abatement procedures

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*Recent analyses suggest that essentially all of the increase in atmospheric carbon dioxide over the last 20 years has resulted from the burning of fossil fuels (See Council on Environmental Quality, Globol Energy Futures and the Carbon Dioxide Problem, 1981). In particular, carbon dioxide releases from a coal-fired power plant are from five to 50 times as great as those from a hydrothermal flash steam plant, per trillion Btu's of energy produced (see Exhibit 5.8).

**Layton, David (editor), An Assessment of Geothermal Development in the Imperial Valley, Volume 1, op. cit., p. 5-15.

***Hinman, George W. and Robertson, Jeremy, Comparison of Geothermal Energy with Coal, Oil, and Natural Gas for Selected Uses, Environmental Research Center, Washington State University, 1979, p. 5.

developed for other polluting sources are not suitable for restricting hydrogen sulfide emissions from geothermal releases due to high cost, slow kinetics, or the form of the chemical residue.*

Considerable research has been applied to hydrogen sulfide abatement at The Geysers, resulting in procedures which can be applied at other geothermal sites, either vapor dominated systems or flash hot water systems.** Exhibit 5.4 is a schematic representation of a flash hot water power plant, demonstrating the emission points for air pollutants. The Stretford process, developed for removal of hydrogen sulfide from synthetic fuel gases, is currently being utilized at The Geysers to remove up to 99 percent of the hydrogen sulfide entering the abatement unit. A number of other promising procedures are also under development (see Exhibit 5.5). The waste sludge that is produced from these abatement processes will require the same type of disposal techniques as now used by other industries producing similar types of sludge.

The development of liquid dominated resources in the Imperial Valley, California provides the opportunity to observe, first-hand, the effect of geothermal development on a region's air quality. Studies have shown that

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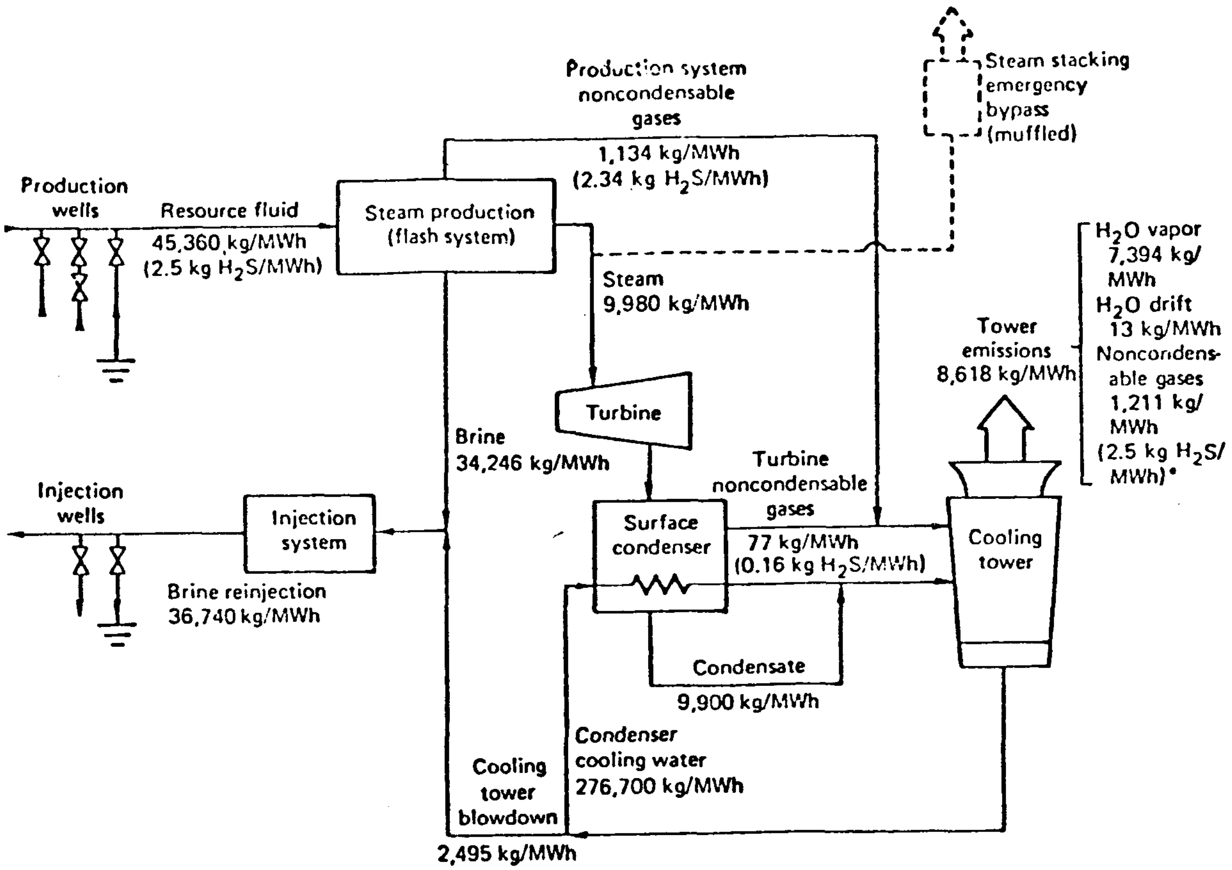
*Morris, William and Hill, John (editors), An Assessment of Geothermal Development in the Imperial Valley of California, Volume 2 -- Environmental Control Technology, prepared by the Lawrence Livermore National Laboratory for the U.S. Department of Energy, Environmental and Safety Engineering Division, 1980, DOE/EV-0092, p. 14.

**Most, if not all, of the additional hydrothermal generating capacity resulting from DOE's "Current Federal Program" will come from flash hot water or binary systems (See Section 5.1.2.1). Since binary systems release insignificant amounts of air pollutants, control of hydrogen sulfide emissions is most important for flash hot water systems.

Exhibit 5.4: Schematic Representation of Air Pollution Emission Points for a Flash Hot Water Hydrotermal Power Plant



Source: Morris, William and Hill, John (editors), An Assessment of Geothermal Development in the Imperial Valley of California, Volume 2 -- Environmental Control Technology, prepared by the Lawrence Livermore National Laboratory for the U.S. Department of Energy, Environmental and Safety Engineering Division, 1980, DOE/EV-0092, p. 16.

Exhibit 5.5: Comparison of Various Hydrogen Sulfide Control Systems for Various Process Streams Related to Geothermal Electric Power Development in the Imperial Valley

PROCESS STREAM H_2S control system	Potential H_2S removal (percent)	Geothermal status[1]
NONCONDENSABLE GAS STREAMS		
Stretford	99+[2]	U
Brine Scrubbing	80 to 90	L
EIC Copper Sulfate	98 to 99	P
UOP Catalytic Oxidation	Unknown	L
SINGLE-FLASH STEAM STREAMS		
EIC Copper Sulfate	98 to 99	P
Steam Convertors[3]	90+	P
LIQUID RESOURCE STREAMS		
Dow Oxygenation	90 to 100	L
SRI Electrolytic Oxidation	95	L

[1] U - Used currently for geothermal H_2S abatement.
L - Laboratory or very small-scale field evaluation.
P - Pilot plant studies being conducted.

[2] Better than 99% applies to Stretford unit only. Overall abatement efficiency depends on partitioning.

[3] Technology to apply this process to a full scale unit has been demonstrated by Resources, Conservation Company (RCC). Steam convertors separate noncondensable gases from the steam. They require H_2S abatement equipment for the noncondensable gas stream.

Source: Morris, William and Hill, John (editors), An Assessment of Geothermal Development in the Imperial Valley of California, Volume 2 -- Environmental Control Technology, prepared by the Lawrence Livermore National Laboratory for the U.S. Department of Energy, Environmental and Safety Engineering Division, 1980, DOE/EV-0092, p. 28.

the only gases posing health hazards are hydrogen sulfide and its related compound sulfur dioxide, both of which are controllable by abatement of hydrogen sulfide emissions.* However, a study of the benefits and costs of controlling hydrogen sulfide emissions at two selected sites in the Imperial Valley (Heber and Niland) concluded that the minimum cost of preventing the nuisance exceeded by several times the maximum estimated value of prevention (as measured by the willingness of individuals to pay to avoid the odor) for full development of the Valley's resources.** The presence of trace amounts of mercury, radon, and ammonia were also determined to be insignificant health hazards and the release of considerable amounts of carbon dioxide was postulated to aid adjacent crops.***

A comparison of the air emissions resulting from the mining, cleaning and burning of coal with the release of noncondensable gases from using hydrothermal resources, reveals a number of similarities between the types of emissions; for example:****

Hydrothermal	Coal
Particulates	Particulates
Hydrogen Sulfide	Sulfur Oxides
Ammonia	Nitrogen Oxides
Carbon Dioxide	Carbon Dioxide

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*Morris, William and Hill, John (editors), An Assessment of Geothermal Development in the Imperial Valley of California, Volume 2, op. cit., p. 12.

**Scott, M.J., et al., An Exploratory Benefit-Cost Analysis of Environmental Controls on Hydrothermal Energy, op. cit., p. 6.

***Layton, David (editor), An Assessment of Geothermal Development in the Imperial Valley, Volume 1, op. cit., p. 5-15.

****Hinman, George W. and Robertson, Jeremy, Comparison of Geothermal Energy with Coal, Oil, and Natural Gas for Selected Uses, op. cit., p. 4.

As indicated earlier, the hydrogen sulfide released from geothermal development is chemically reactive. Once in the atmosphere it converts to sulfur dioxide, thereby increasing the similarity between emissions from coal combustion and geothermal activity. The principal differences between these emissions are the process by which they are emitted and the quantities emitted. For example, emissions from coal-fired power plants occur as a consequence of the oxidation of coal elements during combustion. Noncondensable geothermal gases are not combusted, but rather are reduced compounds of the geothermal fluid.

Unlike the coal fuel cycle, the nuclear fuel cycle also produces a group of air pollutants different than those from the hydrothermal fuel cycle. For example, while the uranium mining and fuel conversion processes release similar types of air pollutants as hydrothermal and coal facilities, they also release some radioactive gases not typical of either type of facility. In particular, nuclear power plants release a series of radioactive gases (such as krypton, xenon, radioiodine, carbon-14 and tritium) that are of concern since some are believed to pose potentially long-term public health risks.*

5.1.1.2 Water Quality and Use

The most likely areas for hydrothermal development are located predominently in semi-arid regions of the West. Although many potential hydrothermal sites are rural and isolated, others are situated in developed

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*DOE, Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness, Energy Technology and the Environment: Environmental Information Handbook, 1981, DOE/EP-0026, p. 231.

areas such as the Imperial Valley, California where numerous activities (for example, agricultural production) compete for the limited amount of available water resources. The introduction of hydrothermal projects will affect not only the quantity of available water, but also the quality of surface and underground waters. The exact impact that hydrothermal development will have depends upon a number of factors, including:

- The configuration of subsurface and surface topography;
- The chemical content of geothermal liquids;
- The type of hydrothermal facility constructed; and
- The type of pollution abatement systems used.

The above considerations suggest that the impact of a hydrothermal project on local water systems will vary widely. As in the case of atmospheric emissions resulting from hydrothermal development, water related impacts tend to be site-specific due to the wide expected variations among geothermal sites with respect to surface and subsurface topography and geochemical liquid. For example, while some geothermal liquids are sufficiently pure to be used for agricultural irrigation, most contain dissolved solids and heavy metals.*

Nevertheless, all electric power applications utilizing hydrothermal resources produce a similar variety of water related impacts. The most

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*DOE, Assistant Secretaries for Energy Technology and Environment, <u>Environmental Development Plan for Geothermal Energy Systems</u>, 1979, DOE/EDP-0036, p. 27.

potentially severe impacts can be divided into three categories: those related to the use of hydrothermal liquids for power production; those related to the use of water for heat rejection systems; and those related to the disposal of spent hydrothermal liquids and cooling water blowdown once they have been used to drive generators or cool hydrothermal liquids.* Power plant construction activities may also result in watershed hydrology shifts.**

The removal of hydrothermal liquids from the earth to fuel generating plants can result in a number of potential impacts on subsurface water bodies, including:***

- Changes in ground water levels as liquids are withdrawn;
- Contamination of relatively pure aquifers through an interchange between underground aquifers;
- Changes in ground water recharge rates in closed systems; and
- Contamination of ground water from accidental leaks of drilling mud and additives.

Because all of the additional hydrothermal power plants coming on-line as a result of DOE's "Current Federal Program" will likely use liquid dominated resources (see Section 5.1.2.1), these concerns are of particular interest.

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*Direct heat applications would produce similar concerns about water quality, particularly with respect to liquid waste disposal.

**Woodward-Clyde Consultants, Impact Prediction Manual for Geothermal Development, op. cit., p. 47.

***Ibid., p. 63.

Hydrothermal power plants, particularly flash hot water systems, also require relatively large amounts of exogenous sources of water to cool geothermal liquids once they have passed through the turbines (see Exhibit 5.4). A considerable amount of make-up water is also required to replace losses due to evaporation, drift and blowdown from the cooling tower. The use of these large amounts of cooling water may deplete surface water bodies,* and affect aquatic habitats as well as other local users. For example, agricultural producers may be impacted if the quantities of water available for irrigation are reduced forcing the removal of land from agricultural production. Such conflicts have been noted both in the Imperial Valley, California and in the Valles Caldera, New Mexico.**

The most serious water quality concern relates to the proper disposal of spent hydrothermal fluids and cooling water blowdown so that neither near-by lands or water bodies are polluted. For example, a series of hydrothermal power plants totalling 1,000 MWe of capacity must dispose of 50 billion gallons of waste water per year containing 50 million tons of solids.*** In particular, most spent hydrothermal fluids contain large amounts of dissolved solids such as sodium, calcium and potassium chloride. Cooling water blowdown may be brackish

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*Woodward-Clyde Consultants, Impact Prediction Manual for Geothermal Development, op. cit., p. 63.

**DOE, Assistant Secretary for Environment, Final Environmental Impact Statement - Geothermal Demonstration Program, 50 MW Power Plant, Baca Location, Sandoval and Rio Arriba Counties, New Mexico, 1980, DOE/EIS-0049, pp. 2-27, 4-29.

***Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, op. cit., p. 59.

and may contain additives and geothermal compounds. Thus, the discharge of these two liquid effluents into local surface waters could easily contaminate them and impact upon the aquatic ecosystems. Ground water, too, could be contaminated by percolation of effluents either stored in sumps or directly discharged.* Thus, considerable efforts must be undertaken to insure that local water resources are not contaminated.

A number of potential solutions to the disposal of liquid wastes have been suggested. These include:**

- Direct release of spent water;
- Evaporation of spent water;
- Surface spreading of spent water to shallow aquifers;
- Desalination and reuse; and
- Reinjection.

In most instances, the brackish quality of the spent fluids prevents solutions such as direct release or surface spreading. For example, discharge of geothermal liquids from the Imperial Valley, California into the Salton Sea will increase the rate of salinization of the Sea and threaten sports fishery. Even though the Salton Sea is increasing in salinity due to other factors, the acceleration associated with the discharge of geothermal brine would be significant. Moreover, the direct

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*Woodward-Clyde Consultants, Impact Prediction Manual for Geothermal Development, op. cit., p. 53, 69.

**Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, op. cit., p. 59.

release of spent water can also result in the inundation of valuable agricultural land; for example in the Imperial Valley, the discharge of geothermal liquids into the Salton Sea would accelerate the rate of inundation of coastal lands which has already begun to occur because the level of the Salton Sea is rising. Fortunately, however, in this situation, the withdrawal of water for cooling purposes would decelerate the rise of the water level thereby preserving coastal lands.*

Therefore, the most often mentioned solution to waste water involves reinjection of the water back into the underground reservoir from which it was drawn. However, a number of possible complications to reinjection exist, including:**

- The high amount of compounds in geothermal brine causes clogging in reinjection lines due to precipitation of solids; if cooling water blowdown is also reinjected with the spent hydrothermal fluids, this problem may worsen.
- Once geothermal liquids are drawn from underground formations, these spaces may collapse, thus preventing reinjection.
- The cost of reinjection can be high; indeed, a recent study at two Imperial Valley sites found that the environmental benefits of reinjecting the spent fluids did <u>not</u> exceed the costs when 100 percent of the fluid was reinjected.***

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*Scott, M.J., <u>et al.</u>, <u>An Exploratory Benefit-Cost Analysis, of Environmental Controls on Hydrothermal Energy</u>, <u>op. cit.</u>, pp. 32, 35.

**Resource Planning Associates, <u>Western Energy Resources and the Environment: Geothermal Energy</u>, <u>op. cit.</u>, p. 59.

***Scott, M.J., <u>et al.</u>, <u>An Exploratory Benefit-Cost Analysis of Environmental Controls on Hydrothermal Energy</u>, <u>op. cit.</u>, p. 6.

The long term effects of reinjection on surrounding land and water bodies are also unknown; thus careful monitoring of underground water will have to accompany reinjection activities.

For very saline waters, such as those in the Imperial Valley, California, reinjection without any waste water treatment is not possible due to scaling (i.e., clogging of reinjection pipelines). Therefore, the spent liquids will have to be treated prior to reinjection.* This will produce a sludge which will have to be disposed of in approved solid waste landfills. This, however, does not represent a large problem because disposal of similar residuals has been carried out in other industries.

While it is certain that hydrothermal resource development will require large quantities of water and produce large quantities of liquid wastes, such concerns are no different when coal and nuclear energy are used. In fact, the 50 MWe flash steam hydrothermal power plant being constructed in the Valles Caldera, New Mexico -- with DOE support -- will use cooled geothermal fluid for cooling. This recirculation of the geothermal fluid will free the plant from the requirement for large quantities of water as is common with closed-cycle steam systems in fossil-fueled and nuclear power plants.** Moreover, the water use requirements associated with coal and uranium mining

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*DOE, Assistant Secretaries for Energy Technology and Environment, Environmental Development Plan for Geothermal Energy Systems, op. cit., p. 27.

**DOE, Assistant Secretary for Environment, Final Environmental Impact Statement - Geothermal Demonstration Program, 50 MW Power Plant, op. cit., p. 2-23.

activities will not be present with hydrothermal power plants. Likewise, the substantial changes in watershed hydrology associated with coal and uranium mining are far more severe than those associated with geothermal site development.

Furthermore, although the treatment of most spent geothermal liquids will produce moderate amounts of solid wastes which will have to be disposed of using environmentally sound methods, the solid wastes produced by the nuclear and coal fuel cycles are far greater for the equivalent production of electricity.* Thus, even though nuclear and fossil power plants may, by themselves, produce less solid wastes than geothermal plants, geothermal plants, on the whole, produce less when the required mining activities are taken into account.

5.1.1.3 Soils and Geology

Activities associated with hydrothermal facility development may affect local soils and geological conditions. The significance of these impacts will depend largely on the value of affected properties. Because hydrothermal development sites are unique, generalized impacts on soils and geology are difficult to derive. Nevertheless, as in the cases of air and water impacts, typical potential environmental problems are apparent and include erosion, subsidence and induced seismicity.

As in all major construction projects, the development of geothermal plants and well sites involve the disturbance of land, an action which

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*Resource Planning Associates, <u>Western Energy Resources and the Environment: Geothermal Energy</u>, <u>op. cit</u>., p. 55.

can lead to erosion depending on site characteristics. Erosion can occur during several phases of geothermal field development when soil is exposed to rain and wind. Vehicle use, route preparation, clearing of vegetation, grading and cutting, and other site preparation activities expose soil to rain and wind. Without proper preventive treatment, serious erosion can result. The environmental effects of erosion include:*

- Destruction of vegetation;
- Reduction of quality and quantity of breeding cover for animals and birds;
- Reduction of availability and quality of food and water for wildlife;
- Clogging of streams with silt;
- Alteration of stream channels; and
- Changes in basin hydrology.

A chain of cause and effect resulting from these changes would affect aquatic life. Temperatures of water bodies could change, and loss of food and habitat could occur.** The above results of land disturbances underline the importance of careful erosion control activities including revegetation, proper drainage preparation, and use of mulch and matting to protect exposed soils.***

To date, geothermal resource development has not produced any significant problems related to soil erosion. The Geysers vapor dominated

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*Woodward-Clyde Consultants, Impact Prediction Manual for Geothermal Development, op. cit., pp. 30, 42.

**Ibid., p. 43.

***Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, op. cit., p. 50.

field, for example, located on mountainous terrain in an area of high rainfall, is quite susceptible to soil erosion on the steep slopes. In spite of this propensity for erosion, strict enforcement of California erosion prevention procedures has resulted in successful control of the problem, demonstrating the availability of methods for impeding erosion.* The fact that most potential hydrothermal development sites are located in flatter, more arid, zones than The Geysers, indicates that environmental problems associated with erosion will be controllable.

A more important geological concern associated with hydrothermal resource development is subsidence. Subsidence occurs when withdrawal of subsurface liquids from below underground structures sufficiently weaken them and cause collapse of subsurface rock and soil formations. This underground shift can result in vertical movement of surface areas. The geothermal field at Wairakei, New Zealand, for example, has experienced a vertical drop of twelve feet since 1956 over a 25 square mile area. Much of this subsidence has occured outside the production field, indicating the complex nature of subsidence.**

Hot water resources, which will provide most of the additional hydrothermal energy in the U.S. over the next two decades, display a greater

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*Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, op. cit., p. 50.

**Ibid., p. 50.

likelihood of causing subsidence than do vapor systems.* In particular, subsidence is of major concern in the Imperial Valley, California. The Valley is flat and has a highly developed agricultural irrigation system which depends on gravity to function. Subsidence of portions of the Valley could seriously disrupt this system and cause substantial economic losses.** While no problems have been noted to date, careful monitoring of the Valley's subsidence will have to be carried out throughout the future.***

Controlling subsidence can be accomplished by the reinjection of spent geothermal liquids (as described in Section 5.1.1.2). Although there are a number of uncertainties associated with reinjection, it nevertheless, greatly reduces (but does not exclude) the possibility of harmful subsidence.

The effectiveness of using reinjection techniques can be improved in a number of ways. For example, if lower production and reinjection rates, which reduce pressure losses and gains, are used, the likelihood of subsidence is lowered; such measures, however, might require the drilling of more wells to maintain the desired power production. Production and reinjection wells can also be drilled closer together to reduce pressure losses and gains, but these measures could deplete the hydrothermal resource faster and be more costly. Induced subsidence might also be mitigated by locating production and reinjection wells in deeper rock foundations.

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*Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, op. cit., p. 50.

**Ibid., p. 51.

***Morris, William and Hill, John (editors), An Assessment of Geothermal Development in the Imperial Valley of California, Volume 2, op. cit., p. 96.

Deeper sediments tend to be better consolidated and cemented which reduces the likelihood of subsidence.*

Closely related to the extraction and injection of geothermal liquids is the problem of induced seismicity. While it is well known that geothermal resources and seismicity occur naturally in the same locations because both are produced by unstable conditions in the earth's crust,** high pressure reinjection of fluids into known seismic formations can induce seismic disturbances. Evidence, however, suggests that geothermal reinjection pressures will be low enough to avoid seismic disturbances.*** Nevertheless, there is also some theoretical indication (although no direct proof exists) that geothermal fluids lubricate major faults, thus triggering earthquakes in specific locations. Therefore, although it does not appear that seismicity will be a major impediment to development, geothermal development will require constant monitoring of seismic activity over the period of each individual project.

5.1.1.4 Land Use

The development of hydrothermal energy resources requires the disturbance of a considerable amount of land area. Moreover, the exact land areas to be developed are restricted by the need to locate hydrothermal facilities at well sites. The combined effect of heavy land requirements

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*DOE, Assistant Secretary for Resource Applications, <u>Environmental Assessment, Geothermal Energy, Heber Geothermal Binary-Cycle Demonstration Project</u>, October 1980, DOE/EA-0119, p. 109.

**Resource Planning Associates, <u>Western Energy Resources and the Environment: Geothermal Energy</u>, <u>op. cit.</u>, p. 52.

***DOE, Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness, <u>Energy Technologies and the Environment: Environmental Information Handbook</u>, <u>op. cit.</u>, p. 376.

and restricted location possibilities for hydrothermal facilities, substantially increases the probability of conflict where competing land uses exist.*

Hydrothermal power plants require more land than direct heat applications. A 110 MWe plant requires, on average, one square mile of land area** to accommodate hydrothermal infrastructures including:***

- Drilling pads;
- Sumps;
- By-product processing facilities;
- Access roads;
- Pipe lines;
- Generating plants;
- Cooling towers; and
- Transmission lines.

Exhibit 5.6 provides additional detail concerning the surface areas affected during exploration and development of a typical hydrothermal development site.

The nature of hydrothermal resources results in a dispersed infrastructural development rather than a concentrated or contiguous one. It has been estimated that within the boundaries of a typical hydrothermal development, only 20 percent of the surface land is actually disturbed

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*Ellickson, Phyllis, Brewer, Saundra, and Knight, Kathleen, _The Resolution of Environmental Issues in Geothermal Development, A Working Note_, prepared for the Energy Research and Development Administration by the RAND Corporation, 1977, p. 27.

**_Ibid._, p. 27.

***Resource Planning Associates, _Western Energy Resources and the Environment: Geothermal Energy_, _op. cit._, p. 52.

Exhibit 5.6: Land Use Requirements for a Typical Hydrothermal Power Plant

Development Phase	Surface Area Required
Exploration and Testing Phase	
Road construction	3 to 4 miles, graded and compacted.
Drill pads	1 acre each, cleared and compacted.
Mud sump	Each one requires an area 100' x 125' x 10' deep to temporarily store up to 1,000,000 gallons of effluent and cuttings.
Full Field Development	
Road construction	Acreage varies. Access roads may be built to drilling pads, mud sumps, buildings for housing equipment and storage. Estimate: 30 acres of land cleared for every 15 wells.
Pipelines	Each pipeline is 10" to 30" in diameter, raised on supports rising no more than 12 feet. The area cleared for the pipeline is from 10' to 300' wide, depending on whether access roads are constructed.
Power generation facilities	Roughly 5 acres are required; most of the land must be paved or otherwise made impervious.
-turbine generators and condensers	Each is 150' x 65' x 60' high.
-cooling towers	Each is 360' x 65' x 60' high.
-transformer	Each is 100' x 100' x 55' high.
Transmission lines	Lines consist of towers or poles at a height of 80 to 120 feet, with concrete bases 40 feet apart.

Source: Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, prepared for the Environmental Protection Agency, Office of Research and Development, Office of Energy, Minerals and Industry, 1977, p. 45.

physically by such activities as paving, grading and clearance of vegetation.* Nevertheless, the extended hydrothermal power plant may indirectly affect the remaining undisturbed land area, impeding alternate uses of the entire acreage (for example, recreation areas, wildlife preserves, or scenic areas). This loss of the land for alternate uses would last, on average, for 30 years. This trade-off between alternate land uses can result in serious conflicts, as has been demonstrated in Lake County, California where alternate competing uses (recreation and scenic areas) for potential hydrothermal zones are sufficiently valued by local residents to produce political opposition.**

In the Imperial Valley, California, hydrothermal development may conflict with agricultural activities; however, estimates indicate that less than 0.2 percent of the Valley's 475,000 cultivated areas would be removed from agricultural production by the introduction of hydrothermal power plants totalling 2,700 MWe of capacity. Again, the unavailability of this land for cultivation would last approximately 30 years.***

While the development of direct heat facilities would physically disturb much less surface land than would power plant development, the disruption would not be insignificant. Land would be required for several functions, including:

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*Resource Planning Associates, <u>Western Energy Resources and the Environment: Geothermal Energy</u>, <u>op. cit.</u>, p. 45.

**Ellickson, Phyllis, Brewer, Saundra, and Knight, Kathleen, <u>The Resolution of Environmental Issues in Geothermal Development, A Working Note</u>, <u>op. cit.</u>, p. 27.

***Layton, David (editor), <u>An Assessment of Geothermal Development in the Imperial Valley of California, Volume 1</u>, <u>op. cit.</u>, p. 9-16.

- Drilling pads;
- By-product processing facilities;
- Access roads; and
- Pipelines (more than in the case of power plants).

The disruption would be greatest during field development when construction and drilling machinery are present.

In comparison with the surface mining of coal or uranium at one location, and the generation of electricity by coal-fired or nuclear power plants at another location, land disturbances and land use conflicts caused by hydrothermal site development are generally far less severe. The hydrothermal fuel cycle is also confined to one location. Moreover, restoration of the land to previous functions is simpler, less expensive, and more likely to be successful with hydrothermal resource development.*

While land use conflicts associated with hydrothermal energy development cannot be "abated" as other environmental impacts may be, the social cost of land use conflicts may be minimized by careful comprehensive planning. Prospects for such planning are good since hydrothermal resource development will probably be built in small incremental units. Such planning would allow optimal utilization of the land for competing uses.**

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*Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, op. cit., p. 44.

**Ellickson, Phyllis, Brewer, Saundra and Knight, Kathleen, The Resolution of Environmental Issues in Geothermal Development, A Working Note, op. cit., p. 48.

5.1.1.5 Noise

Noise levels associated with the development of geothermal energy resources are high enough to be considered environmental disturbances. It has been suggested, however, that noise levels alone are not irritating enough to cause public opposition; but in conjunction with other irritants, such as the odor from hydrogen sulfide, noise levels may be criticized by local residents, particularly if facilities are located close to populated areas, as in Lake County, California.*

High noise levels may not only irritate humans, but may also disturb wildlife habitats. The American Peregrin Falcon, for example, is so rare that only 10 nesting pairs were counted in the early 1970's. Noise levels emanating from geothermal plants could disturb the Falcon, and other wildlife, potentially affecting reproduction.**

For electric power applications, noise is produced -- at varying levels -- during all stages of site development: exploration; drilling; construction; and power plant operation. Even though the noise may be continuous and loud, it will not constitute a serious environmental disturbance at most hydrothermal power plant sites because the noise emissions are local and usually occur in rural settings.*** Noise emissions are greater during drilling and testing than during other stages of development, especially for vapor dominated systems. Hot water systems produce

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*Ellickson, Phyllis, Brewer, Saundra, and Knight, Kathleen, The Resolution of Environmental Issues in Geothermal Development, A Working Note, op. cit., pp. 25, 31.

**Ibid., p. 30.

***Resource Planning Associates, Western Energy Resources and The Environment: Geothermal Energy, op. cit., p. 62.

less noise but enough to affect local residents and wildlife. Testing of wells is particularly loud; however, following testing, hot water wells are capped, thus eliminating this source of noise. Plant construction, which may coincide with well drilling, is also a temporary source of noise resulting from road and plant construction machinery.*

During power plant operations, noise is generated by cooling tower fans, venting of wells, and accidental blowouts. Liquid dominated power plants produce less noise than vapor dominated power plants. Because the additional hydrothermal power plants attributable to DOE's "Current Federal Program" will likely use hot water resources (see Section 5.1.2.1), the effective noise levels should be less than those at The Geysers (a vapor dominated system) where all complaints, to date, have taken place.

Direct heat applications from hydrothermal development will also produce noise, but only during the well drilling and pipeline construction stages of development. Actual operation of direct heat facilities will generate no significant noise except during accidents or repair periods.**

Noise abatement technology can reduce noise levels considerably at both hydrothermal power plants and direct heat facilities. Mufflers can be installed on vents, reducing noise levels of steam releases. In populated areas, drilling and construction activities can be restricted to day-time (working) hours, thus eliminating noise irritation during quiet evening and morning hours.

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*Resource Planning Associates, Western Energy Resources and the Environment: Geothermal Energy, op. cit., p. 62.

**Ellickson, Phyllis, Brewer, Saundra, and Knight, Kathleen, The Resolution of Environmental Issues in Geothermal Development, A Working Note, op. cit., p. 30.

5.1.1.6 Concluding Remarks

There is no doubt that environmental concerns exist with the development of hydrothermal resources. Air pollution, water use, liquid waste disposal, and subsidence are all issues that must be dealt with in a responsible manner. To promote such actions, DOE's "Current Federal Program" is committed to funding research and development activities on environmental strategies. While it is difficult to generalize since environmental impacts are so dependent upon local conditions, it is believed that most of these impacts can be adequately addressed to produce a beneficial resolution at all hydrothermal resource sites.

Moreover, compared to alternative energy sources (i.e., coal and nuclear) hydrothermal resource development is relatively benign environmentally. Indeed, it may well offset more environmentally adverse effects which could otherwise accompany fossil fuel or nuclear powered facilities in the absence of hydrothermal power plants and direct heat use facilities.

5.1.2 Impact of DOE's "Current Federal Program"

The variety of environmental impacts that can be expected from the additional hydrothermal electric power and direct heat use applications associated with DOE's "Current Federal Program", were described qualitatively in the previous section, and were also compared to the types of impacts resulting from the use of competing alternative energy sources. In this section, where possible, a more quantitative assessment and comparison is made. Specifically, attention is focused on comparing the type and magnitude of environmental pollutants released during the operation of hydrothermal power plants with those released during the operation of coal-fired and nuclear power plants. A similar assessment is provided for hydrothermal direct heat use facilities and the use of alternative coal, oil and natural gas resources for space and process heating purposes.

While such comparisons are useful, their limitations are also important to recognize. For example, developing (and comparing) estimates of pollutant releases resulting from DOE's "Current Federal Program" required certain generalizations about the types of facilities that will be constructed and the quality of the hydrothermal resources (or alternative energy sources) used.* While it is recognized that the same type of power plant or direct heat use facility will not be built everywhere, and that the quality of the hydrothermal resource (or alternative energy source) varies from site to site, such simplifying assumptions were, nevertheless, made by using pollutant coefficients for "typical" power plants or direct heat use facilities in order to compare pollutant releases for competing technologies. Because these pollutant releases are representative of "typical" operating conditions, such comparisons are not unreasonable.

Equally important, the release of pollutants into the environment do not, per se, constitute damage. Rather, it is the interaction of these releases with the prevailing environmental conditions of a given location (for example, the ambient air and water quality) that dictates the impact that a certain level of pollution will have. Therefore, equal quantities of pollutants released at two different locations will not

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*These assumptions are described later in this section.

necessarily have the same environmental impact. Generally, however, the larger the pollutant releases are at a particular location, the greater the detrimental impact on the environment will be at that location compared to other locations. Thus, such comparisons can provide meaningful insights even when pollutant releases from different energy sources -- for example, a hydrothermal power plant versus a coal-fired power plant -- will not likely occur in similar localities.

The pollutant releases associated with the additional electric power applications are first described, followed by those associated with the additional direct heat use applications.

5.1.2.1 Electric Power Applications

While some of the increased use of hydrothermal resources for electric power applications between 1980 and 2000 will utilize currently unused vapor dominated resources located in The Geysers area, the additional hydrothermal electric power, resulting from DOE's "Current Federal Program", can be assumed to mostly come from liquid dominated resources. That it, it is reasonable to assume that the remaining available vapor dominated resources will be exploited under DOE's "No Federal Program", and that DOE's "Current Federal Program" will stimulate the additional use of liquid dominated resources. Therefore, it can be assumed that the electricity produced from the additional 22 hydrothermal power plants will solely utilize liquid dominated resources, while the electricity produced as a result of improved operating performance at all other power plants will, to a small extent, utilize vapor dominated resources, but, largely, also utilize liquid dominated resources.

For purposes of the environmental assessment, it is assumed that all of the additional production of hydrothermal based electricity (i.e., the 296 million megawatt-hours between 1980 and 2030) will come from power plants built in 50 MWe increments utilizing hydrothermal flash steam designs.* This system requires 12 production wells to provide an adequate flow of geothermal fluid and six reinjection wells to minimize land subsidence and to control the disposal of spent brine and cooling tower blowdown. Hydrogen sulfide emissions are controlled by using either the Stretford or EIC process.** Given these assumptions, the environmental impacts associated with DOE's "Current Federal Program" are summarized in Exhibit 5.7, both for a typical 50 MWe power plant producing 381 thousand megawatt-hours of electricity each year, and for the additional 296 million megwatt-hours of electricity produced between 1980 and 2030.

The key resources consumed by hydrothermal power plants include geothermal fluid, cooling tower make-up water and land. While carbon dioxide is expected to represent the largest amount of air pollution, releases of hydrogen sulfide will be more significant due to the concerns associated with its odor and the transformation of hydrogen sulfide into sulfur dioxide.*** Because all liquid wastes are reinjected into subsurface aquifers, no water pollutants are projected to be released to

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*Because vapor dominated systems tend to utilize less resources and produce more environmental residuals per unit of electricity produced, the environmental impact presented here can be viewed as an upper bound estimate. See DOE, Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness, Technology Characterizations: Environmental Information Handbook, 1981, DOE/EP-0028, pp. 178-183.

**For additional detail, see *Ibid*., pp. 180-182.

***One ton of hydrogen sulfide, when oxidated, produces 1.88 tons of sulfur dioxide.

Exhibit 5.7: Summary of Environmental Impacts for Additional Hydrothermal Electric Power Applications Attributable to DOE's "Current Federal Program"

Resources Used and Environmental Residuals Released	Quantity Per Year For A 50 MWe Power Plant*	Quantity For All Additional Hydrothermal Electric Power Applications Over Lifetime of Facilities**
Resources Used		
Geothermal Fluid - 230°C (tons)	28.9×10^6	2.2×10^{10}
Cooling Tower Make-Up Water (acre-feet)	4.9×10^3	3.8×10^6
Land (acres)	110.4 - 127.8	$8.6 \times 10^4 - 9.9 \times 10^4$
Environmental Residuals Released (tons, unless otherwise specified)		
Air Pollutants		
Hydrogen Sulfide	5.1 - 51.2	$4.0 \times 10^3 - 39.8 \times 10^3$
Ammonia	192.4 - 19,760	$1.5 \times 10^5 - 153.6 \times 10^5$
Methane	525.2 - 5,252	$4.1 \times 10^5 - 40.8 \times 10^5$
Carbon Dioxide	7,865 - 78,650	$6.1 \times 10^6 - 61.1 \times 10^6$
Arsenic	0.5 - 5.3	$4.1 \times 10^2 - 40.8 \times 10^2$
Boron	13.3 - 132.6	$1.0 \times 10^4 - 10.3 \times 10^4$
Mercury	0 - 2.6	$0 - 2.0 \times 10^3$
Benzene	126.5 - 1,391	$9.8 \times 10^4 - 108.1 \times 10^4$
Radon (curies)	12.2 - 18.7	$9.5 \times 10^3 - 14.5 \times 10^3$
Water Pollutants	None Released***	None Released***
Solid Wastes		
Drilling Mud (cubic feet)	$2.1 \times 10^3 - 4.6 \times 10^3$	$1.6 \times 10^6 - 3.5 \times 10^6$
Solids	$11.4 \times 10^3 - 114.1 \times 10^3$	$8.9 \times 10^6 - 88.7 \times 10^6$
Thermal Discharge (Btu's)		
To Air	20.0×10^{12}	15.6×10^{15}
Noise Pollution (dB(A) at 50 feet)		
Well Drilling	75 - 85	75 - 85
Construction Machinery	70 - 95	70 - 95
Plant Operation	70 - 100	70 - 100

*Assuming a capacity factor 0.87, a 50 MWe plant produces 381.1×10^3 megawatt-hours of electricity per year or 1.3×10^{12} Btu's of energy per year.

**Assumes all additional power will be generated by flash steam systems.

***All liquid wastes are reinjected into a subsurface aquifer; therefore, these pollutants are not released to surface water (except by accidental occurrence).

Source: Exhibit 4.2 and pollutant coefficients from DOE, Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness, Technology Characterizations: Environmental Information Handbook, 1981, DOE/EP-0028, pp. 180-182.

surface waters (unless accidental releases occur). Solid wastes, however, will be produced since the spent brines will need to be treated prior to reinjection.

To provide a better perspective of the environmental impacts associated with DOE's "Current Federal Program", Exhibit 5.8 compares the resources used and the environmental residuals released (per trillion Btu's of energy produced) for hydrothermal flash steam systems and its two competing alternative energy sources -- coal and nuclear. The coal fuel cycle utilized here consists of a western coal-fired power plant with 500 MWe generating capacity, supported by an adjacent coal beneficiation/preparation plant, a western coal unit train operation and a western coal surface mining operation extracting low sulfur (0.63 percent) coal. Pollution control devices are assumed to be in use to minimize air, water and solid waste pollution in compliance with current regulations.* The nuclear fuel cycle utilized here consists of an underground uranium mining operation, a uranium mill, a uranium hexafluoride conversion plant, a gaseous diffusion enrichment plant, and a fuel fabrication plant providing 3.0 percent enriched uranium-235 fuel to a pressurized water reactor (PWR) power plant with 1,000 MWe capacity. Compliance with current environmental regulations is also assumed.**

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*For additional detail, see DOE, Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness, Technology Characterizations: Environmental Information Handbook, op. cit., pp. 60-79.

**This nuclear fuel cycle configuration is assumed for the following reasons: 60 percent of all uranium comes from underground mining operations; the gaseous diffusion enrichment process is a well known and more proven technology than the gas centrifuge enrichment process; more pressurized water reactors (PWR) are now in operation or planned for the future than boiling water reactors (BWR); and PWR power plants consume 38 percent less water (per kilowatt-hour of electricity produced) than BWR plants, an important factor in the arid western states. For additional detail, see Ibid., pp. 2-21.

Exhibit 5.8: Comparison of Environmental Impacts for Hydrothermal, Western Coal and Nuclear Power Generation Systems

Resources Used and Environmental Residuals Released	Quantity Per Trillion Btu's Of Energy Produced[1]		
	Hydrothermal Flash Steam System[2]	Western Coal Fuel Cycle[3]	Nuclear Fuel Cycle[4]
Resources Used			
Feed Materials (tons)[5]	22.6×10^6	1.8×10^5	1.27
Water Consumed (acre-feet)	3.8×10^3	4.3×10^2	2.2×10^3
Land (acres)[6]	84.9 x 98.3	35.1	99.2
Environmental Residuals Released (tons, unless otherwise specified)			
Air Pollutants			
Particulates	-	949.4	57.2
Sulfur Compounds[7]	3.94 - 39.4	617.7	194.4
Nitrogen Compounds[8]	148 - 15,200	873.7	53.3
Hydrocarbons[9]	404 - 4,040	43.6	0.6
Carbon Monoxide	NA	110.3	1.5
Carbon Dioxide	6,050 - 60,500	3.1×10^5	19.0
Arsenic	0.4 - 4.0	5.4×10^{-3}	NA
Boron	10.2 - 102	NA	NA
Mercury	0 - 2.0	NA	NA
Benzene	97.3 - 1,070	NA	NA
Zinc	NA	0.012	NA
Fluoride	NA	NA	0.021
Aldehydes	NA	2.7	0.003
Other Non-Radioactive	NA	0.002	0.353
Radon (curies)	9.38 - 14.4	NA	311
Uranium (curies)	NA	0.085 tons	2.4×10^{-3}
Noble Gases-Krypton and Xenon (curies)	NA	NA	85.7
Carbon-14 (curies)	NA	NA	0.3
Tritium (curies)	NA	NA	38.1
Other Radioactive (curies)	NA	1.2×10^{-4}	2.1×10^{-3}
Water Pollutants[10]			
Total Dissolved Solids	None	192.9	-
Total Suspended Solids	None	9.7	-
Ammonia and Other Nitrogen Compounds	None	0.8	1.6
Sulfate	None	170.2	190.5
Fluoride	None	NA	1.4
Other Non-Radioactive	None	NA	8.4
Tritium (curies)	NA	NA	14.4
Other Radioactive (curies)	NA	NA	0.56
Solid Wastes[11]			
Drilling Mud (cubic feet)	$1.62 \times 10^3 - 3.50 \times 10^3$	NA	NA
Solids	$8.8 \times 10^3 - 37.8 \times 10^3$	68.4×10^3	9,003 tons plus 1.2×10^5 cubic feet
Radioactive Wastes (curies)	NA	NA	282.9
Thermal Discharge (Btu's)			
To Air	15.4×10^{12}	-	2.04×10^{12}
To Water	NA	-	0.103×10^{12}
Noise Pollution (dB(A))	70 - 100 at 50 feet	95 at 100 feet	-

NA = Not Applicable.
- = Data Not Available.
Source: DOE, Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness, Technology Characterizations: Environmental Information Handbook 1981, DOE/EP-0028, Chapters on geothermal, coal and nuclear technologies.

Note: Footnotes are contained on back of this page.

Footnotes to Exhibit 5.8

[1] This is equivalent to 293 x 10^6 kilowatt-hours of electricity.

[2] Includes hydrothermal production and reinjection wells, and flash steam power plant.

[3] Includes western coal surface mining, western coal unit train, coal beneficiation plant, and western coal-fired power plant.

[4] Includes underground uranium mining, uranium milling, uranium hexafluoride (UF_6) conversion, gaseous diffusion enrichment plant, fuel fabrication plant, and pressurized water reactor (PWR) power plant.

[5] For hydrothermal flash steam system - geothermal fluid at 230°C; for western coal fuel cycle - low sulfur (0.63%) coal; for nuclear fuel cycle - uranium dioxide (UO_2) with 3.3% uranium -235.

[6] For western coal, does not include land displaced by unit train operation; for nuclear, does not include land required for gaseous diffusion enrichment plant.

[7] Hydrogen sulfide (H_2S) for hydrothermal flash steam system and sulfur dioxide (SO_2) for coal and nuclear fuel cycles.

[8] Ammonia (NH_3) for hydrothermal flash steam system and oxides of nitrogen for coal and nuclear fuel cycles.

[9] Methane (CH_4) for hydrothermal flash steam system.

[10] For nuclear, does not include water pollutants from underground uranium mining.

[11] For western coal, does not include solid wastes from surface mining; for nuclear, does not include solid wastes from gaseous diffusion enrichment plant.

While the water and land use requirements (per trillion Btu's of energy produced) are less with the coal or nuclear fuel cycles than with the hydrothermal flash steam system, such results are somewhat misleading since each energy system typically requires a different minimum sized power plant (as described above) in order to be constructed and operated economically. Indeed, since coal-fired and nuclear power plants must, generally, be much larger than hydrothermal power plants, the water and land use requirements at a given power plant location will actually be the same or larger with coal-fired or nuclear power plants. For example, a 50 MWe hydrothermal power plant and a 500 MWe coal-fired power plant (with an adjacent coal benefication plant) will both require about 5,000 acre-feet of water per year; a 1,000 MWe nuclear power plant will require about 15,500 acre-feet of water per year. The land use requirements would be as follows: about 110-128 acres for a 50 MWe hydrothermal power plant; about 335 acres for a 500 MWe coal-fired power plant (and adjacent coal beneficiation plant); and about 1,850 acres for a 1,000 MWe nuclear power plant.

A comparison of the environmental residuals released for hydrothermal western coal and nuclear power generation systems is somewhat more difficult since the types of pollutants released are different in many respects. Some important observations include the following:

- All three power generation systems release similar air pollutants (for example, sulfur compounds, nitrogen compounds, hydrocarbons, and carbon dioxide) but in varying quantities. For the nuclear fuel cycle, most of these pollutants come from the diffusion enrichment plant. For the coal fuel cycle, most come from power plant operations; in particular the release of those pollutants believed to be precursors to acid rain (i.e., sulfur and nitrogen

- compounds and particulates) and a warming of the earth's atmosphere (i.e., carbon dioxide), are much greater for coal-fired power plants than for hydrothermal power plants.

- The nuclear fuel cycle releases a series of radioactive air pollutants not produced by either the hydrothermal or western coal fuel cycles. Radon is primarily emitted during uranium mining and milling* while the noble gases (krypton and xenon), carbon-14 and tritium are emitted during power plant operations.

- While no water pollutants are expected with hydrothermal flash steam systems since all liquid wastes are reinjected, western coal-fired power plants and beneficiation plants, and uranium milling operations, are expected to produce a series of non-radioactive water pollutants. Radioactive water pollutants are also expected from nuclear power plants.

- All three power generation systems produce sizable quanities of solid wastes as a by-product of pollution control activities, but nuclear power plants also produce radioactive solid wastes.

- Thermal discharges and noise pollution are produced by all three power generation systems in varying quantities.

Once again, however, these results must also consider that a hydrothermal power plant can be economically constructed and operated on a much smaller scale than either a coal-fired or nuclear power plant. If the environmental residuals released are adjusted to reflect these different plant sizes, hydrothermal flash steam systems would produce much less pollution at any single location.** Moreover, hydrothermal flash steam systems are self contained in one location, whereas the coal and

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*Hydrothermal flash steam systems also emit radon but at levels less than five percent of the levels found for the nuclear fuel cycle.

**The environmental residuals released by a 50 MWe hydrothermal flash steam power plant system would be 1.3 times the levels shown in Exhibit 5.8; for a 500 MWe coal-fired power plant system, they would be about 12 times the levels shown; and for a 1,000 MWe nuclear power plant system, they would be about 21 times the levels shown.

nuclear fuel cycles require several locations to accommodate the mining, fuel conversion, fuel transport and power generation facilities.

Therefore, the additional hydrothermal electric power applications (resulting from DOE's "Current Federal Program") will consume geothermal fluids, water and land, and release a series of environmental residuals at about 22 locations.* However, these occurrances -- at any one location -- will be relatively small compared to the much larger amounts of resources consumed and residuals released at the coal-fired or nuclear power plants (2-3 if coal and 1-2 if nuclear), and companying support facilities, necessary to supply the same amount of electricity. Furthermore, with the nuclear fuel cycle, in particular, a series of radioactive air, water and solid waste residuals would be produced which pose long-term environmental and public health concerns not found with hydrothermal flash steam systems.

5.1.2.2 Direct Heat Applications

The additional direct heat use applications resulting from DOE's "Current Federal Program" will provide both district heat (i.e., residential and commercial space heat) and industrial process heat. Of the total additional 1.155 quads of hydrothermal energy supplied between 1980 and 2025, approximately 0.975 quads are expected to be consumed by residential and commercial customers for space heating, and approximately 0.180 quads are expected to be consumed by industrial users for process heating.**

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*The additional resources used and residuals released associated with the improved operating performance at all other power plants is expected to be very minimal at any one location (less than 2.5 percent over what would occur without improved operating performance).

**These estimates are based on data contained in Exhibits 4.5 and 4.6.

For purposes of the environmental assessment, residuals data are used for a hydrothermal space heating system designed to heat garden apartments, and for a hydrothermal industrial process heating system used in an existing potato processing plant. Both systems are assumed to be closed with the spent geothermal fluid reinjected into subsurface aquifers. Therefore, air emissions are primarily associated with drilling, testing and cleaning operations, while waterborne residuals are released when spills occur.*

To compare environmental residuals from these hydrothermal direct heat use systems with those from competing alternative energy sources, three competing systems -- using western coal, oil and natural gas -- are utilized. With the western coal system, space heat is provided using electricity generated by a coal-fired utility; process heat is generated by transporting the coal to the industrial user and burning it directly in an industrial boiler. For the oil and gas systems, the energy source is transported to the residential/commercial (or industrial) customer where it is burned directly in an oil or gas furnace (or industrial boiler) to produce space heat (or industrial process heat).**

The levels of environmental residuals associated with these hydrothermal, western coal, oil and natural gas systems are shown in Exhibit 5.9 for five selected pollutants: particulates; sulfur compounds; nitrogen

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*Hinman, George W. and Robertson, Jeremy, Comparison of Geothermal Energy with Coal, Oil and Natural Gas for Selected Uses, op. cit., pp. 3-5 and Appendix A.

**Ibid., p. 15, Addendum.

Exhibit 5.9: Comparison of Environmental Impacts for Space and Process Heating Using Hydrothermal, Western Coal, Oil and Natural Gas Energy Resources

	Tons Per Quad of Heat Delivered to End Users								Tons For All Additional Direct Heat Use Applications Over Lifetime Of Facilities[6]		Tons of Excess Residuals If Alternative Source to Hydrothermal Used					
	Hydrothermal[3]		Western Coal		Oil[5]		Natural Gas[5]				Western Coal		Oil[5]		Natural Gas[5]	
Residuals	Space Heat	Process Heat	Space Heat[4]	Process Heat[5]	Space Heat	Process Heat	Space Heat	Process Heat	Space Heat	Process Heat	Space Heat[4]	Process Heat[5]	Space Heat	Process Heat	Space Heat	Process Heat
Air Emissions																
Particulates	1.1E3	2.8E2	1.7E6	1.5E7	1.1E6	5.1E5	2.4E5	1.2E5	1.1E3	5.0E1	1.7E6	2.7E6	1.1E6	9.2E4	2.3E5	2.2E4
Sulfur Compounds[1]	3.6E4	9.1E3	2.9E6	7.7E6	3.9E6	1.7E6	2.4E5	4.0E3	3.5E4	1.6E3	2.8E6	1.4E6	3.8E6	3.0E5	2.0E5	-9.2E2
Nitrogen Compounds[2]	2.4E4	6.1E3	1.5E7	3.6E6	2.1E6	9.6E5	3.8E6	1.9E6	2.3E4	1.1E3	1.5E7	6.5E5	2.0E6	1.7E5	3.7E6	3.4E5
Carbon Dioxide	6.9E5	1.8E5	6.9E9	2.1E9	2.9E9	1.3E9	1.8E9	8.8E8	6.7E5	3.2E4	6.7E9	3.8E8	2.8E9	2.3E8	1.8E9	1.6E8
Water Effluents																
Salt	1.1E5	7.5E4	7.6E5	2.3E5	1.8E6	8.0E5	0	0	1.1E5	1.4E4	6.3E5	1.5E5	1.6E6	1.3E5	-1.1E5	-1.4E4

Note: Ex means multiply number by 10^x.

[1] Hydrogen sulfide (H_2S) for hydrothermal; sulfur dioxide (SO_2) for other energy sources.

[2] Ammonia (NH_3) for hydrothermal; nitrogen oxide (measured as NO_2) for other energy sources.

[3] Based on most typical hydrothermal reservoir concentrations.

[4] Based on supplying residential heat through coal-fired utilities.

[5] Based on supplying the energy source directly to the end-user.

[6] Assumes an additional 0.975 quads for space heat and an additional 0.180 quads for process heat (see Exhibits 4.5 and 4.6).

Source: Exhibits 4.5 and 4.6 and pollutant coefficients from Hinman, George W. and Robertson, Jeremy, Comparison of Geothermal Energy With Coal, Oil, and Natural Gas For Selected Uses, Environmental Research Center, Washington State University, 1979, pp. 16, 17 and Addendum.

compounds; carbon dioxide; and salts. For all residuals, for both space and process heat applications, hydrothermal systems are expected to produce less residuals (per quad of heat delivered to end-users) than either western coal or oil systems. Compared to natural gas systems, hydrothermal systems are also expected to produce less residuals, except for sulfur compounds released by process heat applications and salts released by both space and process heat applications.

A typically sized hydrothermal facility supplying 25 billion Btu's of space heat to residential and commercial customers per year, would produce the following quantities of residuals per year:

- Particulates - 0.0275 tons;
- Hydrogen sulfide - 0.9 tons;
- Ammonia - 0.6 tons;
- Carbon dioxide - 17.25 tons; and
- Salts - 2.75 tons.

Similarly, a typically sized hydrothermal industrial process heat facility supplying 150 billion Btu's of energy per year, would produce the following quantities of residuals per year:

- Particulates - 0.042 tons;
- Hydrogen sulfide - 1.365 tons;
- Ammonia - 0.915 tons;
- Carbon dioxide - 27.0 tons; and
- Salts - 11.25 tons.

For all of the additional hydrothermal direct heat applications attributable to DOE's "Current Federal Program," pollutant releases are expected to range from 50 tons of particulates for process heat applications, to 670,000 tons of carbon dioxide for space heat applications, over the 45 years covering the lifetime of all facilities impacted by the program (see Exhibit 5.9).

More important, however, is the reduction in pollutant releases expected to be realized by the use of hydrothermal resources, rather than western coal, oil or natural gas resources. The largest reductions are expected to occur for carbon dioxide; for example, an additional 6.7 billion tons would be released from space heat applications if western coal resources are used to supply the additional 0.975 quads of hydrothermal energy expected as a result of DOE's "Current Federal Program" (see Exhibit 5.9). Clearly, then, although the additional hydrothermal direct heat use applications are expected to release environmental residuals, environmental benefits will actually be realized since many more tons of residuals would be released if the competing alternative energy sources are used instead.

5.2 National Security/Balance-of-Payments Improvements

The additional hydrothermal electric power and direct heat facilities projected to become operational if DOE's "Current Federal Program" is pursued, will directly benefit the consumers of this energy. However, the substitution of this additional hydrothermal energy for alternative energy sources will also provide indirect benefits to society as a whole by increasing the security of the U.S. and its energy supplies with the creation of this energy option. While it is likely that the additional electric power generated by hydrothermal resources will directly substitute for coal or nuclear power plants, such a substitution can also be viewed as indirectly replacing oil or natural gas fired power plants if such a replacement would have been accomplished by the construction of a coal or nuclear facility. For direct heat applications, the additional use of hydrothermal resources will directly (and indirectly, through the use of electricity) substitute for oil and natural gas.

The substitution of hydrothermal resources for oil is particularly important since other end-use energy sectors, such as transportation, currently have no practical alternatives to oil. Moreover, reducing the consumption of oil in the U.S. reduces the nation's dependence on imported oil. This, in turn, lessens the potential for disruptions in the U.S. economy by actions of other governments, and decreases the national trade deficit thereby improving the balance-of-payments situation.

The remainder of this section explores these issues in more depth.

5.2.1 Crude Oil Barrel Equivalent Effects

The additional production of electricity (296 million megawatt-hours) and direct heat energy use (1.155 quads) from hydrothermal resources over the lifetime of the facilities impacted by DOE's "Current Federal Program" can be expected to save the equivalent of over 700 million barrels of crude oil between 1980 and 2030 (see Exhibit 5.10). Approximately 10 percent (500 million barrels) of the crude oil saved can be attributed to the additional electric power applications, with the remainder attributable to the additional direct heat uses.

Exhibit 5.10: Additional Hydrothermal Electric Power and Direct Heat Applications Attributable to DOE's "Current Federal Program", by Year, Over Lifetime of Facilities: Crude Oil Barrel Equivalent

	Million Barrels of Crude Oil Per Year		
Year	Electric*	Direct Heat**	Total
1980	0.00	0.00	0.00
1981	0.29	0.35	0.64
1982	0.61	0.52	1.13
1983	0.90	1.03	1.93
1984	1.21	1.20	2.41
1985	1.50	1.55	3.05
1986	2.20	1.72	3.92
1987	2.38	1.72	4.10
1988	2.55	1.89	4.44
1989	2.72	1.89	4.61
1990	2.89	2.07	4.96
1991	3.18	2.23	5.41
1992	3.45	2.23	5.68
1993	3.76	2.58	6.34
1994	4.03	2.58	6.61
1995	4.32	2.75	7.07
1996	6.82	2.58	9.40
1997	9.30	2.75	12.05
1998	11.78	2.58	14.36
1999	14.29	2.75	17.04
2000	16.78	2.58	19.36
2001	16.78	3.27	20.05
2002	16.78	3.96	20.74
2003	16.78	4.47	21.25
2004	16.78	5.16	21.94
2005	16.78	5.85	22.63
2006	16.78	6.20	22.98
2007	16.78	6.71	23.49
2008	16.78	7.05	23.83
2009	16.78	7.56	24.34
2010	16.78	7.91	24.69
2011	16.49	8.25	24.74
2012	16.17	8.77	24.94
2013	15.88	8.94	24.82
2014	15.56	9.46	25.02
2015	15.27	9.81	25.08
2016	14.58	9.29	23.87
2017	14.40	8.77	23.17
2018	14.23	8.26	22.49
2019	14.06	7.74	21.80
2020	13.89	7.22	21.11
2021	13.60	5.84	19.44
2022	13.31	4.30	17.61
2023	13.02	2.92	15.94
2024	12.75	1.37	14.12
2025	12.45	0.00	12.45
2026	9.96	NA	9.96
2027	7.48	NA	7.48
2028	4.98	NA	4.98
2029	2.49	NA	2.49
2030	0.00	NA	0.00
Total (1981-2030)	503.33	198.63	701.96

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*Assumes 1.7 barrels of crude oil per 1000 kilowatt-hours of of electricity produced.

**Assumes 172 million barrels of crude oil per quad of energy consumed.

NA = Not Applicable.

Source: Exhibits 4.2 and 4.6.

Maximum yearly savings are projected to occur after 2000 when all impacted facilities will be operating. As these facilities begin to reach their useful lives and are retired, yearly crude oil barrel equivalent savings will decline. By 2030, when all impacted facilities are finally retired, the savings will be zero.

On a daily basis, the average crude oil barrel equivalent savings are projected to range from about 5,000 barrels per day between 1981 and 1985 to over 68,000 barrels per day between 2011 and 2015 (see Exhibit 5.11). While these amounts may be small compared to the nation's average consumption of 17 million barrels of oil per day in 1980,* they still represent from about 210,000 to 2.9 million gallons of gasoline per day,** which equals the daily gasoline consumption of between 175,000 and 2.4 million individuals.***

If DOE's "Current Federal Program" is not pursued, and if the most competitive alternative energy source (i.e., coal or nuclear) is utilized to supply the added electricity that would have been supplied by the additional hydrothermal power plants, then the same crude oil barrel equivalent savings could result. However, if less oil-fired power plants are retired because DOE's "Current Federal Program" is not pursued (for example, not enough new coal fired or nuclear power plants can be constructed to both supply the additional electricity that would have been supplied by hydrothermal resources, as well retire existing oil-fired plants), then

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*DOE, Energy Information Administration, 1980 Annual Report to Congress, Volume Two: Data, op. cit., p. 49.

**Assumes one barrel of crude oil approximately equals 42 gallons of gasoline.

***Assumes a daily per capita consumption of gasoline in 1980 of 1.2 gallons. See, DOE, Energy Information Administration, 1980 Annual Report to Congress, Volume Two: Data, op. cit., p. 233.

Exhibit 5.11: Additional Hydrothermal Electric Power and Direct Heat Applications Attributable to DOE's "Current Federal Program", By Five-Year Intervals, Over Lifetime of Facilities: Crude Oil Barrel Equivalent

Five-Year Interval	Barrels of Crude Oil Per Day Electric	 Direct Heat	 Total
1981-1985	2,470	2,550	5,020
1986-1990	6,980	5,090	12,070
1991-1995	10,270	6,780	17,050
1996-2000	32,320	7,260	39,580
2001-2005	45,980	12,440	58,420
2006-2010	45,980	19,420	65,400
2011-2015	43,490	24,780	68,270
2016-2020	38,990	22,620	61,610
2021-2025	35,690	7,910	43,600
2026-2030	13,650	NA	13,650
Fifty-Year Average (1981-2030)	27,580	12,090*	38,460

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*This figure represents a 45 year average.

NA = Not Applicable.

Source: Exhibit 5.10.

crude oil barrel equivalent savings will be less. Regardless, the operation of coal fired and nuclear power plants, instead of hydrothermal power plants, will deplete domestic energy supplies of coal and uranium, but in relatively small amounts compared to current levels of consumption for electricity generation. For example, assuming that half the additional electricity produced by hydrothermal resources will, instead, be generated by each of the two alternative sources, about 75 million tons of coal and over 800 tons of uranium dioxide would be consumed between 1980 and 2030;* in comparison, electric utilities consumed almost 570 million tons of coal and almost 1,400 tons of uranium dioxide in 1980 alone.**

For direct heat use applications, the crude oil barrel equivalent savings using the most competitive alternative energy sources (i.e., electricity, oil or natural gas)*** will likely be less than the savings generated by the additional hydrothermal direct heat use applications resulting from DOE's "Current Federal Program." To be equal in crude oil barrel equivalent savings, all the additional hydrothermal direct heat use would, instead, have to be provided using natural gas and/or electricity generated by coal, natural gas or nuclear power plants; in other words, the use of oil -- directly or in oil-fired power plants -- would have to be prohibited. The depletion of domestic

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*Assumes 0.5 tons of coal and 5.5×10^{-6} tons of uranium dioxide are needed to produce one thousand kilowatt-hours of electricity. See DOE, Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness, Technology Characterizations: Environmental Information Handbook, op. cit., pp. 14-17, 74-75.

**DOE, Energy Information Administration, 1980 Annual Report to Congress, Volume Two: Data, op. cit., pp. 129, 177.

***While some direct use of coal may also be possible for the additional hydrothermal direct heat consumed by the industrial sector, this would be small since only 15 percent of the additional direct heat use is expected to be consumed by the industrial sector (see Section 4.2).

energy supplies (to equal the energy provided by the additional hydrothermal direct heat from 1980 to 2025), would amount to : 170 million tons of coal (if only coal-fired power plants were utilized); 1,850 tons of uranium (if only nuclear power plants were utilized); and between 1.2 and 3.4 trillion cubic feet of natural gas (if only natural gas was utilized either directly or in gas-fired power plants).*

5.2.2 Impact on Balance-of-Payments

In 1980, the U.S. imported 5.2 million barrels of crude oil per day and 1.6 million barrels of refined petroleum products per day,** at a combined cost of almost $74 billion.*** Furthermore, the value of all goods imported into the U.S. exceeded the value of all goods exported out of the U.S. by $20 billion in 1980.**** If the 700 million barrels of crude oil equivalent saved between 1980 and 2030 (as a result of DOE's "Current Federal Program") are totally, or even partially, used to reduce the nation's dependence on imported oil, a tremendous benefit will accrue to the U.S. in terms of reducing the outflow of U.S. dollars to foreign countries for petroleum products thereby improving the balance-of-payments.

Using the Energy Information Administration's middle world oil price assumptions,***** the value of the 700 million barrels of crude oil

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*For conversion factors used, see DOE, Energy Information Administration, <u>1980 Annual Report to Congress</u>, Volume Two: Data, <u>op. cit.</u>, p. 233.

**<u>Ibid</u>., p 49.

***Department of Commerce, Bureau of Economic Analysis, <u>Survey of Current Business</u>, Volume 61, Number 6, June 1981, p. S-20.

****<u>Ibid</u>., pp. S-18, S-19.

*****DOE, Energy Information Administration, <u>1980 Annual Report to Congress</u>, Volume Three: Forecasts, <u>op. cit.</u>, pp. ix, 6, 126, and 137. Adjusted from 1979 dollars to 1982 dollars assuming 9 percent general inflation in 1980, 10 percent general inflation in 1981, and 6 percent general inflation in 1982.

equivalent is estimated to total almost $64 billion (in constant 1982 dollars) over the 50 year period (see Exhibit 5.12). The discounted or present value of this future stream of benefits (in 1982) is estimated to be approximately $6 billion (in 1982 dollars).** In other words, if all these barrels of crude oil equivalent do, indeed, reduce oil imports, it is estimated that the nation's oil import bill can be reduced by $50 million next year (1982), rising to $2.5 billion in 2015 (its highest level). Even if only 1.5 percent of these barrels of crude oil equivalent are used to reduce oil imports, the present value of this balance-of-payments benefit ($90 million 1982 dollars in 1982) will approximately equal the present value of DOE's additional budgetary costs for the "Current Federal Program" during FY 1981 to FY 1990 (above and beyond those for the "No Federal Program").

5.2.3 Planning Flexibility

DOE's "Current Federal Program" is expected to speed the commercial development of hydrothermal resources. By creating this energy option to conventional fuels, increased flexibility is afforded to energy suppliers, particularly the electric utility industry.

Economically feasible hydrothermal power plants are smaller and require less time for field development and construction than nuclear or coal-fired plants. For example, hydrothermal power plants with generating capacities of only 50 megawatts can typically be operating in one-half to two-thirds the amount of time it takes a much larger economically viable nuclear or coal-fired power plant to be constructed.** These smaller

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*Assumes a real discount rate of 10 percent in accordance with DOE's planning, programming and budgeting guidelines for FY 1983-FY 1987.

**El-Sawy, A.H., Leigh, J.G. and Trehan, R.K., A Comparative Analysis of Energy Costing Methodologies, prepared by The MITRE Corporation for the Division of Geothermal Energy, DOE, February 1979, pp. 75-76.

Exhibit 5.12: Value of Crude Oil Barrel Equivalent Savings Attributable to DOE's "Current Federal Program," By Year, Over Lifetime of Facilities

Year	Millions of Constant 1982 Dollars	Year	Millions of Constant 1982 Dollars
1980	0.00	2006	1,962.75
1981	26.20	2007	2,042.14
1982	47.97	2008	2,108.04
1983	84.88	2009	2,190.28
1984	109.66	2010	2,259.43
1985	143.43	2011	2,308.03
1986	188.34	2012	2,371.06
1987	201.15	2013	2,403.82
1988	222.35	2014	2,467.71
1989	235.54	2015	2,518.26
1990	258.47	2016	2,439.24
1991	294.30	2017	2,408.94
1992	321.98	2018	2,378.26
1993	373.90	2019	2,344.08
1994	404.94	2020	2,307.45
1995	449.30	2021	2,166.92
1996	621.26	2022	2,000.98
1997	827.04	2023	1,845.66
1998	1,022.09	2024	1,665.44
1999	1,256.15	2025	1,495.37
2000	1,476.39	2026	1,217.81
2001	1,559.59	2027	930.74
2002	1,644.90	2028	630.43
2003	1,717.76	2029	320.60
2004	1,806.99	2030	0.00
2005	1,898.34	Total (1981-2030)	63,976.36

Source: Exhibit 5.10 and DOE, Energy Information Administration, 1980 Annual Report to Congress, Volume Three: Forecasts, March 1981, DOE/EIA-0173(80)/3, pp. ix, 126 and 137 (mid oil price case).

plant sizes and shorter construction times increase the ability of utility planners to respond to unanticipated changes in demand. In addition, they reduce the length and mitigate the consequences of periods of excessive or insufficient generating capacity. Smaller plant sizes also tend to increase the reliability of a utility's overall generating system by reducing the impacts resulting from the temporary or permanent loss of a single plant.

5.3 Socioeconomic Impacts

The construction and operation of the additional hydrothermal power plants and direct heat use facilities, resulting from DOE's "Current Federal Program", can provide many positive impacts in the social and economic areas including: increased employment/reduced unemployment; an increased and more diversified tax base; increased tax revenues; and accelerated economic development. Moreover, hydrothermal projects will probably occur as a phased development with exploration and well drilling leading to the construction of power plants or non-electric uses, in modest size increments. Such an approach should not overburden existing community services and facilities (for example, police, health, fire, and eduction) or create an unmanageable housing situation. While recreational cultural and religious conflicts may arise, early planning with the affected communities can be effective in resolving most issues.*

Most of the additional hydrothermal power plants constructed over the next 20 years will likely be located in rural portions of western states, while most of the additional direct heat use facilities will likely be

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*DOE, Assistant Secretary for Energy Technology and Environment, <u>Environmental Development Plan for Geothermal Energy Systems</u>, <u>op. cit.</u>, p. 31.

located near urban centers in the West and and in northern half of the U.S. Socioeconomic conditions will vary from site to site, suggesting that the type and magnitude of the socioeconomic impacts described above will be highly site-specific. Nevertheless, useful insights can be obtained from information collected about existing hydrothermal power plant developments.*

5.3.1 Manpower Requirements

The construction and operation of a "typical" 50 MWe hydrothermal power plant will require a labor force with a variety of skills, as indicated in Exhibit 5.13. Over the two year construction period for the 50 MWe Baca flash steam power plant, maximum employment will consist of about 225-235 workers over a six month period. Approximately 70 workers will be required annually to operate and maintain the power plant.

Assuming that the approximately 22 additional hydrothermal power plants expected to come on-line by 2000, as a result of DOE's "Current Federal Program", will be flash steam systems as at Baca,** the following manpower requirements are projected to result:***

- An average of about 150 construction workers for two years (300 person-years) at any one 50 MWe location, with maximum employment of 260-270 workers for a six month period;****

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*Little socioeconomic data exist for direct heat use projects; however, because these projects are generally small relative to hydrothermal power plant development, their negative (and positive) socioeconomic impacts will be much smaller than those expected for hydrothermal electric power applications.

**See Section 5.1.2.1 for a discussion of this assumption.

***Based on manpower requirements contained in DOE, Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness, Technology Characterizations: Environmental Information Handbook, op. cit., p. 180.

****These numbers are slightly higher than at Baca since the assumed capacity factor at this plant (0.87) is higher than at Baca (0.75) and, therefore, requires more construction personnel.

Exhibit 5.13: Employment Schedule for 50 MWe Baca Flash Steam Power Plant

O C No.*	Craft Employment Category	Quarterly Requirements									
		1980				1981				1982 and Future	
		1	2	3	4	1	2	3	4	1	2
801-805, 809	Iron Workers (PNM)	0	1	2	12	7	18	6	4	1	1
810	Welders and welders' helpers (Union)						7	7			7
828-829	Electricians (PNM)				1	1	17	30	22	7	
859	Operating engineers (PNM)			2	2	2	4	5	4	2	
859	Operating engineers (Union)						4	4			
860	Carpenters (PNM)		1	8	15	16	40	15	9	3	3
862	Pipe fitters (PNM)			1	1	1	14	32	26	8	8
862	Pipe fitters (Union)						4	4			
900-909	Teamsters (Union)	5	5	5	5	5	8	8	5	5	3
[illegible]	Drill crewman (Union)	20	20	20	20	20	20	20	20	20	20
[illegible]	Derrickmen and roughnecks (Union)	5	5	5	5	5	5	5	5	5	5
930	Laborers (PNM)		2	6	17	9	17	6	4	2	2
930	Laborers (Union)						6	6			
	Other crafts (PNM)		1	3	1	3	16	24	16	4	6
	Other crafts (Union)						1	1			
Total craft		30	35	52	79	69	181	173	115	57	55
Supervisory (Union Geothermal offices located at Rio Rancho)		12	12	12	12	12	12	12	12	12	12
Transmission-line contractor**											
Operating engineers							5	5			
Linemen							5	5			
Laborers							25	25			
Foremen							5	5			
Total Baca employment		42	47	64	91	81	233	225	127	69	67

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*Department of Labor occupation category number.

**Preliminary estimates.

Source: DOE, Assistant Secretary for Environment, Final Environmental Impact Statement - Geothermal Demonstration Program, 50 MW Power Plant, Baca Location, Sandoval and Rio Arriba Counties, New Mexico, 1980, DOE/EIS-0049, p. 4-17.

- Total employment of 3,300 construction workers for two years (6,600 person-years), with about 85 percent of this employment occurring between 1994 and 2000 when 19 of the 22 additional power plants will be constructed;

- An average of about 78 operating and maintenance personnel for 30 years (2,340 person-years) at any one 50 MWe location;* and

- Total employment of about 1,740 operating and maintenance personnel for 30 years (52,285 person-years), with maximum employment of 1,740 workers between 2000 and 2010 when all 22 additional plants are in operation.

At all the other power plants on-line by 2000, the improved operating performance resulting from DOE's "Current Federal Program" will also require additional operation and maintenance personnel than, otherwise, necessary. Specifically, the following additional requirements can be expected at all the other power plants on-line by 2000:**

- An average of almost 2 additional operating and maintenance personnel for 30 years (54 person-years) at any one 50 MWe location; and

- Total employment of about 278 additional operating and maintenance personnel for 30 years (8,335 person-years), with maximum employment of 278 additional workers between 2000 and 2015 when all power plants are operating and reflecting the fact that improved operating performance is not expected until 1986.

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*These numbers are slightly higher than at Baca since the assumed capacity at this plant (0.87) is higher than at Baca (0.75) and, therefore, requires more operating and maintenance personnel.

**While some of these power plants (perhaps 30 percent) will be vapor dominated systems, the manpower requirements are calculated assuming all are flash steam in design. Because vapor dominated systems require <u>less</u> personnel than flash steam systems per megawatt of generating capacity or megawatt-hour of electricity produced, these personnel estimates can be viewed as upper bound estimates. See DOE, Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness, *Technology Characterizations: Environmental Information Handbook*, *op. cit.*, pp. 178, 180.

Therefore, DOE's "Current Federal Program," in total, is expected to require 6,600 person-years of construction labor between 1980 and 2000, and 60,620 person-years of operating and maintenance labor between 1980 and 2030. However, because hydrothermal power plants will likely be constructed in small incremental units (for example, 50 MWe), these manpower requirements will not likely cause difficulties at any single location. In fact, this has been the case for both the 50 MWe Baca flash-steam power plant* and the 50 MWe Heber binary-cycle power plant, where much of the manpower requirements have been (or will be) found locally.** The use of local labor, however, may not always be possible. For example, in the Imperial Valley, if large scale geothermal power development occurs (i.e., 4,500 MWe of electric power by 2020), in-migration is likely to increase to meet manpower demands for skilled labor.***

5.3.2 Housing Needs

While finding temporary local housing (for example, rental units or facilities for a worker's own mobile home) for non-local construction personnel may prove to be somewhat of a problem, such occurrances can be

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*DOE, Assistant Secretary for Environment, Final Environmental Impact Statement - Geothermal Demonstration Program, 50 MW Power Plant, op. cit., p. 4-16.

**DOE, Assistant Secretary for Resource Applications, Environmental Assessment, Geothermal Energy, Heber Geothermal Binary-Cycle Demonstration Project, op. cit., p. 143.

***Layton, David (editor), An Assessment of Geothermal Development in the Imperial Valley, Volume 1, op. cit., p. 12-10.

mitigated by planning in advance for the additional housing needs during the two year construction period. Moreover, the relatively small number of permanent operating and maintenance personnel will, generally, not have difficulty finding local housing. In the Imperial Valley, for example, it is projected that housing supplies will grow faster than the anticipated increase in population assuming large scale hydrothermal resource development occurs.*

5.3.3 Economic Development

One of the most significant benefits expected to result from DOE's "Current Federal Program" will be the improvement in the local economies where hydrothermal power plants are located. With increased employment opportunities, the level of unemployment can be reduced, particularly if appropriate steps are taken to train the locally unskilled or semi-skilled unemployed individuals. If such steps are not taken, however, hydrothermal resource development may have little effect in reducing unemployment rates unless the unskilled workers find employment opportunities in secondary industries and service establishments induced by the hydrothermal resource development.**

The additional hydrothermal power plant development resulting from DOE's "Current Federal Program" will also contribute to the creation of more diversified local economies. For example, the development of 4,500 MWe of hydrothermal electric power by 2020 in the Imperial Valley would

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*Layton, David (editor), An Assessment of Geothermal Development in the Imperial Valley, Volume 1, op. cit., p. 12-10.

**Ibid., p. 12-12.

make hydrothermal and related industries a greater contributor to the economy of Imperial County than agriculture; in contrast, the agricultural sector and related industries comprised 70 percent of the gross county product in 1975.* The economy of Imperial Valley is also expected to grow faster with hydrothermal resource development, adding $1.5-2.0 billion to the annual gross county output by 2000, far surpassing the estimated losses of one million dollars in agriculture due to the withdrawal of agricultural lands by hydrothermal facilities.**

5.3.4 Tax Revenues and Expenditures and Impact on Community Services and Facilities

The increased, more diversified tax base, and the increased employment created by additional hydrothermal power plant development, will also increase the tax revenues received by local governments. The Baca flash steam power plant, for example, is expected to increase Sandoval County's tax base by 24 percent (and, therefore, tax revenues in a corresponding fashion) to more than compensate for any additional costs incurred with the small increases in population or increased demand for services.*** Likewise, in the Imperial Valley, it is projected that increased tax revenues received by local governments will exceed any increased expenditures associated with additional services associated with hydrothermal power

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*Layton, David (editor), An Assessment of Geothermal Development in the Imperial Valley, Volume 1, op. cit., p. 12-14.

**Ibid., p. 12-18.

***DOE, Assistant Secretary for Environment, Final Environmental Impact Statement - Geothermal Demonstration Program, 50 MW Power Plant, op. cit., p. 4-50.

plant development. The distribution of these additional tax revenues and expenditures may be problematic in that the increased tax base (and revenues) accompanying hydrothermal resource development is excluded from any city boundaries in the Imperial Valley where much of the associated residential, commercial and industrial growth will occur. Thus, while Imperial County's increased tax revenues will exceed increased expenditures, such may not be the case in the surrounding cities; some form of income redistribution may, therefore, be necessary.*

In general, then, hydrothermal resource development is expected to have a beneficial effect on local public agencies. Indeed, hydrothermal power plant development, in the incremental fashion expected under DOE's "Current Federal Program", has not been found in the past to exert any excessive strain or increased demand on local community facilities and services, including health, fire and police services, and educational facilities.** In prior situations, where communities have received large tax base increases without similar increases in population or demand for government services (as has been found to be the case with hydrothermal resource development), local governments have been able to reduce or stabilize tax rates and also improve and increase the services available to their residents.***

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*Layton, David (editor), An Assessment of Geothermal Development in the Imperial Valley, Volume 1, op. cit., pp. 12-14, 12-15, 12-19.

**DOE, Assistant Secretary for Resource Applications, Environmental Assessment, Geothermal Energy, Heber Geothermal Binary-Cycle Demonstration Project, op. cit., p. 145; and DOE, Assistant Secretary for Environment, Final Environmental Impact Statement - Geothermal Demonstration Program, 50 MW Power Plant, op. cit., pp. 4-15, 4-16.

***Ibid., p. 4-50.

5.3.5 Comparison of Hydrothermal Development With Competing Energy Sources

The social and economic benefits of the additional hydrothermal power development, resulting from DOE's "Current Federal Program", can be further seen by briefly examining the socioeconomic impacts associated with the competing alternative sources for producing electricity. Exhibit 5.14 compares the construction and operating and maintenance personnel requirements for hydrothermal, western coal and nuclear power generation systems.*

While a hydrothermal flash steam system is expected to require about 230 person-years of construction labor (per trillion Btu's of energy produced annually), nuclear power plants are expected to require from 205 to 990 person-years of construction labor. An additional 34-46 person-years of construction labor is also expected to be required for the uranium mining and conversion processes necessary to support each trillion Btu's of energy produced by nuclear power plants. Equally important is the fact that economical nuclear power plants must usually be about 20 times larger than a typical 50 MWe hydrothermal power plant. Thus, at a given location, from 480 to 2,300 construction workers for nine years would be required to construct a 1,000 MWe nuclear power plant, compared to an average of 150 construction workers for two years to construct a 50 MWe hydrothermal power plant.

The permanent (i.e., operating and maintenance) personnel requirements for hydrothermal flash steam systems (expressed per trillion Btu's

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*See Section 5.1.2.1 for a brief description of each of these systems.

Exhibit 5.14: Comparison of Personnel Requirements for Hydrothermal, Western Coal and Nuclear Power Generation Systems

Energy System	Construction Time (years)	Personnel Per Trillion Btu's of Energy Produced Annually*		Personnel Per Year To Support A Typically Sized Power Plant**		Personnel to Support Total Additional Hydrothermal Electric Power Applications Attributable to DOE's Current Federal Program (person-years)	
		Construction	Operation and Maintenance***	Construction	Operation and Maintenance***	Construction	Operation and Maintenance***
Hydrothermal Flash Steam System	2	208 (maximum) 114 (average)	60	270 (maximum) 150 (average)	78	6,624	60,624
Western Coal Fuel Cycle							
Surface Mining	-	11.6	11.6	139	139	-	11,721
Unit Train	-	-	23.9	-	287	-	24,149
Coal Beneficiation/Preparation	1	28.0	5.2	336	62	943	5,254
Coal-Fired Power Plant	-	-	13.0	-	155	-	13,135
Total	-	-	53.7	-	643	-	54,255
Nuclear Fuel Cycle							
Uranium Mining							
Undergound	3	1.1	12.3	23	258	111	12,428
Open Pit	4	1.0	3.5	21	74	135	3,536
Uranium Milling	5	1.76	2.34	37	49	296	2,364
Uranium Hexafluoride Conversion	3	0.3	0.4	6	8	30	404
Uranium Enrichment							
Gaseous Diffusion	8	2.8	1.0	59	21	754	1,010
Gas Centrifuge	7	2.8	1.0	59	21	660	1,010
Fuel Fabrication Plant	2-3	0.7-3.4	15-71	15-71	34-71	47-344	1,617-3,435
Nuclear Power Plant							
Pressurized Water Reactor	9	110	11	2,310	230	33,343	11,114
Boiling Water Reactor	9	22.8	-	479	-	6,911	-
Total	9	29.36-119.36	19.84-30.44	617-2,506	416-637	9,055-34,902	20,046-30,757

*This is equivalent to 293 x 10^6 kilowatt-hours of electricity per year.

**50 MWe for hydrothermal producing 1.3 x 10^{12} Btu's of energy per year; 500 MWe for coal producing 12 x 10^{12} Btu's of energy per year; 1,000 MWe for nuclear producing 21 x 10^{12} Btu's of energy per year.

***Operation and maintenance personnel will be required for 30 years.

- = Data Not Available.

Source: DOE, Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness, Technology Characterizations: Environmental Handbook, 1981, DOE/EP-0028, Chapters on nuclear technologies, coal technologies and geothermal technologies.

of energy produced annually) are approximately the same when compared to the western coal fuel cycle, and about two to three times higher when compared to the nuclear fuel cycle. However, the permanent manpower impacts at a given location will actually be more severe for both coal-fired and nuclear power plants due to the larger plant sizes required. As an example, while a 50 MWe hydrothermal power plant would require about 78 operating and maintenance personnel for 30 years, a 500 MWe coal-fired power plant (including the coal beneficiation plant) would require about 220 operating and maintenance personnel for 30 years and a 1,000 MWe nuclear power plant would require about 230 operating and maintenance personnel for 30 years. In addition, the mining, conversion and transport activities associated with the coal and nuclear fuel cycles would also produce substantial operating and personnel requirements, but, generally, at locations separate from the site of the coal-fired or nuclear power plant.

Therefore, while the additional hydrothermal electric power production (resulting from DOE's "Current Federal Program") is likely to produce relatively small construction opportunities for two years at 22 locations, the alternative use of coal or nuclear energy to supply the same amount of electricity would produce substantially larger construction requirements for up to nine years at far fewer locations (for example, at 2-3 coal-fired power plants or at 1-2 nuclear power plants).*

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*The actual construction of new surface coal mines or new uranium mining and conversion facilities is probably unlikely. The coal or nuclear power plant requirements for coal or uranium would be very small relative to the already existing production capabilities (see Section 5.2.1), and can, therefore, be handled by existing facilities.

Overall, more operating and maintenance personnel are expected to be required with hydrothermal power generation, than with the alternative coal or nuclear power generation, but at any one location, the number will be far less. These findings suggest that the manpower impacts of using hydrothermal resources (rather than coal or nuclear) will be smaller in magnitude and more widespread, but sufficient enough to provide the opportunity for economic development in many rural localities without overburdening the existing social and government systems. Conversely, the large scale nuclear or coal development at a relatively few locations, can overwhelm the existing community services and facilities and create undesirable "boomtown" effects.

5.4 Materials Requirements

The additional use of hydrothermal resources for the production of electricity and direct heat energy use, expected to be realized as a result of DOE's "Current Federal Program", will in all likelihood utilize moderate to high temperature liquid dominated resources. The chemical composition of these resources is highly variable, with salinity ranging from under 300 ppm to over 300,000 ppm, pH ranging from 2 to 10, and temperatures ranging from 80°C to 340°C.* The common feature of using any of these hydrothermal resources is that they all present a unique and challenging experience for the developers of hydrothermal energy. Corrosive constituents are present in varying amounts in the hydrothermal fluid

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*Committee on Materials Needs for the Utilization of Geothermal Energy, Materials Needs for the Utilization of Geothermal Energy, prepared by the National Academy of Sciences for the Brookhaven National Laboratory, March 1981, pp. 8-9.

and abrasion and wear often result from the high fluid flow rates and the presence of large quantities of insoluble matter.

Hydrothermal technology development has produced existing materials capable of withstanding the environments of dry steam systems as well as liquid dominated systems with temperatures under 225°C and salinities under 1,800 ppm. Moreover, with only modest extensions to existing technology, materials can be developed to withstand hydrothermal reservoirs containing fluids below 250°C and salinities below 10,000 ppm, which represents about half of the U.S. geothermal resources.*

For direct heat use applications, the materials requirements would appear not to be a significant problem since the resources utilized are usually of high quality with temperatures under 150°C. Conversely, there may be materials requirements problems for electric power applications, particularly for some areas in the Imperial Valley with high temperature resources and high amounts of salinity; for example, some of the Salton Sea brines contain 300,000 ppm of total dissolved solids at temperatures of 340°C and other areas (for example, East Mesa, Brawley, and Heber) contain high amounts of total dissolved solids while temperatures are below 250°C. Fortunately, hydrothermal resources with such severe characteristics represent less than 10 percent of the potential U.S. resources.**

In the most hostile liquid dominated systems, expensive materials (or the frequent replacement of less expensive and less durable materials)

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*Committee on Materials Needs for the Utilization of Geothermal Energy, Materials Needs for the Utilization of Geothermal Energy, op. cit., pp. 8-9.

**Ibid., pp. 7-10.

will be required. While much progress has been made towards the development of suitable materials for such resources, additional research and development is still needed as illustrated in Exhibit 5.15. Equipment and materials must be developed that are resistant to corrosion and scaling, and effective under a wide range of temperatures and salinity.

To a large extent, the geothermal industry has borrowed the drilling hardware and technology developed by the oil and gas industry. Many of the difficulties present in drilling and extracting hydrothermal resources are also found in oil and gas drilling and extraction. However, because of the unique characteristics of hydrothermal resources, much of the equipment and materials are not fully adequate; for example:*

- The wide variability of geothermal fluid compositions and formation characteristics often requires highly site-specific materials requirements.
- Geothermal fluids may be corrosive to materials normally used for oil and gas drilling and completion. Many of the basic parts of the equipment used in drilling (bits, casing, piping) are subject to breakdown, corrosion and scaling caused by the high temperatures, high pressures, and varying salinities found in geothermal resources. The high rate of precipitation of solids in drill pipes interferes with drilling and requires that the pipes be cleaned and replaced frequently.
- Oil field rock bits and drilling tools have been modified for geothermal drilling, but the short life of bits, tools and drill pipe are major contributors to the high cost per foot of drilling geothermal wells. Some of the materials used to resist the very severe abrasive/erosive/corrosive wear are tungsten, cobalt, and chromium, strategic

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*Committee on Materials Needs for the Utilization of Geothermal Energy, <u>Materials Needs for the Utilization of Geothermal Energy</u>, <u>op. cit.</u>, Chapter V; and Resource Planning Associates, <u>Western Energy Resources and the Environment: Geothermal Energy</u>, <u>op. cit.</u>, pp. 31-32.

Exhibit 5.15: Geothermal Energy Systems and Components: Significant Materials Problems/Needs Limiting Progress

Geothermal Energy System Component	Status of Problem or Need: Problems Partially Solved	Work in Progress	Additional/ New Work Needed
Drilling Hardware/Technology			
Rotary Drilling Rigs	*		
Drilling Fluid Handling, Flow Control			
Solids/Gas Separation Equipment	*		
Cooling Hardware		*	*
Blowout Preventers, Associated Valves, Rotating Heads	*	*	*
Drill Pipe, Collars, Tool Joints	*	*	*
Drill Pipe Inspection Systems		*	*
Drilling Fluids			
"Muds"		*	*
Air/Nitrogen	*	*	*
Foams		*	*
Lost Circulation Technology		*	*
Materials			
Rock Bits	*	*	*
Drilling Tools (shock absorbers, reamers, stabilizars, jars, etc.)		*	*
Downhole Motors (for drilling)		*	*
Directional Drilling Systems	*	*	*
Alternative Drilling Systems/Components		*	
Measurement While Drilling Systems		*	
Logging Hardware/Technology		*	*
Completion Hardware/Technology			
Casing		*	*
Cement-Materials/Placement Systems		*	*
Packers		*	*
Stimulation Systems			
Perforation Systems	*		*
Hydraulic Fracturing Systems	*		*
Production Hardware/Technology			
Pumps (Systems)			
Downhole		*	*
Brine Transport		*	*
Hot Brine Feed		*	*
Brine Reinjection	*	*	
Hydrocarbon Feed (Binary)	*		
Cooling Tower	*		
Turbines			
Steam	*	*	
Binary Working Fluid		*	*
Scale Control Systems/Technology	*	*	*

Source: Committee on Materials Needs for the Utilization of Geothermal Energy, Materials Needs for the Utilization of Geothermal Energy, prepared by the National Academy of Sciences for the Brookhaven National Laboratory, March 1981, p. 20.

materials for which major resources lie outside the United States. Any interruption of supply of these materials would greatly reduce drilling productivity. This problem, however, is equally acute for oil and gas drilling.

- Vital to the drilling process, drilling mud lubricates and cools the drill string and bits, and is also used to remove cuttings as the well is drilled. However, drilling mud deteriorates rapidly at temperatures above 177°C, slowing the circulation rate of the cuttings being removed. The useful lives of the bearings and seals now being used -- and largely adapted from oilfield hardware and technology -- are also reduced by the high temperatures and other adverse downhole operating conditions.

- The environment of the geothermal well also causes a number of serious problems when using normal portland cement systems. If the cement comes in contact with brine, chemical attack will occur, particularly with acidic ($<$pH 7) fluids. High temperature causes difficulties in controlling setting time and deteriorates strength and pressure differential. Pressure may cause deterioration of the bond strength and compressive strength. Such deterioration will reduce the cement's ability to provide the required support, prevent fluid migration, and prevent corrosion. Also important in controlling fluid migration is the stability of cement properties such as porosity and permeability. The cementing method must also be compatible with the cement used, well conditions, well depth, temperature, pressure, and mud system. In general, cement failures usually result from occurrences such as construction deficiencies, frozen casings, corrosion, collapse and loss of cement into fractures.

- While metallic materials are available for casing, drill pipe, and other tubulars required for geothermal systems, the service life is not always satisfactory. In particular, the serious problem involving well-aging of high alloy tubulars for oil and gas applications will be of major concern when these materials are used in hotter geothermal environments.

- Logging instruments are used to record the temperature, flow rate, pressure, and physical characteristics of the geothermal resource during drilling. Currently available devices and instruments, however, are accurate only to temperatures near 180°C. Logging and sampling in higher temperatures can cause great problems.

- Downhole pumps for producing brine wells represent the largest single pump problem associated with geothermal energy development. The standard designs of such pumps are limited to liquid temperatures of 121°C and thus are not suitable with the more severe geothermal brine fluids. Likewise, the use of hot brine feed pumps (or brine transport pumps) require additional field testing to identify the materials of construction that will provide the lowest cost of service for each brine chemistry. Brine reinjection pumps used in demonstration plants have also experienced trouble from the release of entrained gases (mostly carbon dioxide), which, at reduced temperatures, results in precipitation of solids (carbonates and silicates). However, because of the reduced temperatures, the material requirements will be less severe than for the downhole pump. For hydrocarbon (isobutane, freon) feed pumps used in binary systems, pumps of standard construction, design and material are acceptable for the working fluid used in a binary cycle. Radially split pumps, required for the low gravity fluid with materials suitable for the hydrocarbons used, have been fully tested by the petroleum refining industry.

- While turbines for use with geothermal steam use the same materials that would be used in turbines for steam from fossil-fired boilers, stand-by corrosion (which occurs when steam leaks into a machine that is not in service) is a more acute problem with turbines in geothermal service because of contaminants that make the condensate more aggressive. Either materials resistent to hydrogen sulfide or hydrogen sulfide/oxygen are needed, or these gases should be removed or excluded from the stream. Sand and particles can also erode the turbine blades.

Highly durable materials and equipment, therefore, must be utilized in geothermal wells and facilities to prevent breakdowns created by material/equipment failures. Such failures cannot be tolerated because the costs related to such occurrences (for example, loss of electricity or heat, and adverse environmental effects such as blowouts) can be extremely high.* DOE has recognized that private industry, by itself,

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*Committee on Materials Needs for the Utilization of Geothermal Energy, Materials Needs for the Utilization of Geothermal Energy, op. cit., p. 4.

cannot adequately meet this challenge due to the large, and often very risky, expenditures that are involved. DOE's "Current Federal Program" is designed to assist industry in solving these difficulties by focusing on hydrothermal technology development which specifically includes research and development activities to develop improved materials for hydrothermal resource development (see Sections 2.1.2 and 3.2).

For example, the rapid advance of polymer technology should prove very useful in perfecting the use of nonmetallic materials. Such materials are needed when higher geothermal well temperatures are utilized, and would be used for all hydrothermal system components, as well as linings. The major advantages include: light weight; abrasion resistance; chemical resistance; high strength-to-weight ratio; resistance to contamination by corrosion products in process streams; and lower cost. There are, however, some disadvantages, including: low thermal conductivity; low impact strength; decreased stiffness and structural strength at high temperatures; and high coefficients of thermal expansion.*

Polymer concrete seems to show the most promise, both technically and economically, for high temperature applications. Other materials being investigated include asbestos cement, polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS), reinforced plastic mortar, and glass-fiber reinforced epoxy.** In addition, much as been accomplished in developing and testing materials to satisfy well cement needs, and

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*Committee on Materials Needs for the Utilization of Geothermal Energy, <u>Materials Needs for the Utilization of Geothermal Energy</u>, <u>op. cit</u>., pp. 41-42.

**<u>Ibid</u>., p. 42.

work is continuing on developing ways to evaluate and predict material and cementing method compatibility.*

Research and development activities are also being undertaken to improve the performance of elastomeric materials for seals at temperatures above 225°C.** Improved downhole pumping systems, consisting of hydraulic turbine-driven multistage pumps and steam turbine-driven multistage pumps, have also been or are being tested in geothermal testing simulators, as well as at operating geothermal facilities.***

With continued research on developing longer lasting, lower cost materials for use in hydrothermal resource development as illustrated above, the successful use of the higher temperature and more corrosive hydrothermal resources can be achieved. Moreover, such gains in drilling and extraction technology can provide additional benefits if properly transferred to the oil and gas industry.

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*Committee on Materials Needs for the Utilization of Geothermal Energy, Materials Needs for the Utilization of Geothermal Energy, op. cit., p. 37.

**Ibid., p. 40.

***Ibid., p. 37.

6.0 SUMMARY AND CONCLUSIONS

With a relatively modest expenditure by the Department of Energy during the 1980's, noticeable improvements in the use of hydrothermal resources for electric power and direct heat use applications are expected to be achieved by 2000. In fact, the Third National Energy Policy Plan's expectations for hydrothermal based energy (towards contributing to the nation's energy needs) can likely be achieved with DOE's currently planned activities.

Implementation of DOE's "Current Federal Program" will require funding of about $25 million in FY 1982 and $16 million each year from FY 1983 through FY 1990 (in constant 1982 dollars). This amounts to $128 million (in constant 1982 dollars) above and beyond what would be spent under DOE's "No Federal Program." The discounted or present value of this future stream of additional program costs (in 1982) is estimated to be about $85 million (in 1982 dollars).* The majority of these expenditures will focus on improving the various components of hydrothermal technology (i.e., drilling and completion, energy conversion, reservoir stimulation, geochemical engineering and materials, geosciences, and environmental controls), and will provide the necessary R and D activities too expensive or risky for the private sector to undertake alone.

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*Assumes a real discount rate of 10 percent in accordance with DOE's planning, programming and budgeting guidelines for FY 1983-FY 1987.

The direct benefits associated with DOE's "Current Federal Program" will include additional electric power applications, most likely resulting in 8,862 megawatts (rather than 7,745 megawatts) of hydrothermal generating capacity by 2000 and improved operating performance in all hydrothermal power plants. More specifically, DOE's "Current Federal Program" is expected to induce, by 2000, the construction of about 22 additional 50 MWe hydrothermal power plants (i.e., power plants beyond those that are projected to be built anyway), each producing about 381 thousand megawatt-hours of electricity per year for 30 years. It is also expected that improved operating performance in all other hydrothermal power plants will result from DOE's "Current Federal Program," producing almost 41 million more megawatt-hours of electricity over the lifetime of these facilities. In total, then, DOE's "Current Federal Program" is expected to produce an additional 296 million megawatt-hours of electricity (or approximately one quad of energy) over a 50 year period (1980-2030) spanning the lifetime of all facilities impacted by the program. This additional energy is assumed to displace electricity otherwise generated by western coal-fired and nuclear power plants.

Direct benefits from DOE's "Current Federal Program" will also include additional direct heat applications, most likely resulting in 0.174 quads (rather than 0.159 quads) of hydrothermal direct heat use by 2000. The full impact of the program, however, is expected to take two forms: direct heat use applications that, otherwise, are not expected to be realized if DOE's "Current Federal Program" is not undertaken (i.e., the additional 0.015 quads by 2000 as described); and added direct heat use applications associated with a longer facility life (25 years rather than 20 years) for all projects that are expected to become operational anyway between 1980 and 2000. Specifically, the additional direct heat use applications are most likely to appear in the form of 480-560 residential and commercial projects (each consuming 25 billion Btu's per year for 25 years) and 10-20 industrial projects (each consuming 150 billion Btu's per year for 25 years), by 2000, that, otherwise, are not likely to be constructed. Moreover, for those projects that are projected to be built anyway, an additional 0.675 quads associated with residential and commercial uses, and an additional 0.105 quads associated with industrial uses, will likely be provided by extending each project's useful life by five years. In total, then, DOE's "Current Federal Program" is expected to result in the consumption of an additional 1.155 quads of hydrothermal energy -- 0.975 quads residential and commercial and 0.180 quads industrial -- over a 45 year period (1980-2025) spanning the lifetime of all facilities impacted by the program. This additional energy is assumed to displace the use of conventional fuels (electricity, oil and natural gas) otherwise providing these energy requirements.

Combined, the additional electric power and direct heat use applications are expected to provide direct benefits totalling almost 2.2 quads of energy between 1980 and 2030 for an expenditure by DOE of $85 million (discounted present value in 1982) during the 1980's. These DOE program costs and direct benefits associated with DOE's "Current Federal Program" are summarized in Exhibit 6.1; also included in Exhibit 6.1 is a summary of the external impacts associated with DOE's "Current Federal Program."

The development of hydrothermal resource sites -- either for electric power or direct heat applications -- will consume resources (geothermal fluids, water and land), and release environmental residuals, notably hydrogen sulfide, that can create objections primarily because of aesthetic-odor considerations. However, the size of any individual site is expected to be relatively small (compared to competing energy technologies) and self contained, producing environmental impacts that can likely be adequately addressed, thereby avoiding any serious environmental threat.

Hydrothermal flash steam power plants, for example, can be economically constructed and operated on a much smaller scale (50 MWe) than either a typical coal-fired (500 MWe) or nuclear (1,000 MWe) power plant. Therefore, the amount of resources used or environmental residuals released -- at any one of the additional 22 hydrothermal power plant locations -- will be relatively small compared to the generally <u>larger</u> amounts of resources consumed and residuals released at the 2-3 coal-fired power plants or 1-2 nuclear power plants (and accompanying support facilities at other locations) necessary to supply the same amount of electricity (see Exhibit 6.1). In particular, coal-fired power plants release much larger quantities of air pollutants that are believed to be the precursors to acid rain and a warming of the earth's atmosphere. Moreover, nuclear facilities are expected to produce a series of radioactive air, water and solid waste residuals which pose long-term environmental and public health concerns not found with hydrothermal flash steam systems.

Exhibit 6.1: Summary of Costs and Benefits Associated with DOE's "Current Federal Program"

Cost/Benefit Category	Summary of Expected Impacts
DOE Program Costs	"No Federal Program" • $145 million (constant 1982 dollars) for FY 1981 and FY 1982 and zero for FY 1983 through FY 1990. • Present value in 1982 is approximately $157 million (in 1982 dollars). "Current Federal Program" • $273 million (constant 1982 dollars) for FY 1981 through FY 1990. • Present value in 1982 is approximately $242 million (in 1982 dollars); or $85 million above the program costs for DOE's "No Federal Program".
Direct Benefits	Electric Power Applications • 8,862 MWe of generating capacity on-line by 2000, instead of only 7,745 MWe. • Construction of about 22 additional 50 MWe hydrothermal power plants that, otherwise, would not be brought on-line by 2000, producing 255.4 million megawatt-hours of electricity between 1980 and 2030. • Improved operating performance at all other hydrothermal power plants, producing an additional 40.7 million megawatt-hours of electricity between 1980 and 2030. • Total additional electric power applications equal to 296.1 million megawatt-hours (or about 1.01 quads of energy). Direct Heat Applications • 0.174 quads of direct heat use by 2000, instead of only 0.159 quads. • Construction of about 480-560 additional residential and commercial projects, providing 0.300 quads of hydrothermal energy between 1980 and 2025. • Construction of about 10-20 additional industrial projects, providing 0.075 quads of hydrothermal energy between 1980 and 2025. • Extension of the useful life of residential and commercial projects that would be built anyway, from 20 to 25 years, providing an additional 0.675 quads of hydrothermal energy between 2000 and 2025. • Extension of the useful life of industrial projects that would be built anyway, from 20 to 25 years, providing an additional 0.105 quads of hydrothermal energy between 2000 and 2025. • Total additional direct heat use applications equal to 1.155 quads of energy.

Exhibit 6.1: Summary of Costs and Benefits Associated with DOE's "Current Federal Program" (continued)

Cost/Benefit Category	Summary of Expected Impacts
External Impacts Environmental Effects	Electric Power Applications • Impacts at about 22 locations for 30 years including: - use of geothermal fluids (29 million tons/site/year); - consumption of water (4,900 acre-feet/site/year); - use of land (110-128 acres/site/year); - release of air pollutants (8,740-105,000 tons/site/year; mostly carbon dioxide); - no release of water pollutants under normal operating conditions; and - creation of solid wastes (2,100-4,600 cubic feet of drilling mud/site/year and 11,400-114,000 tons of solids/site/year). • Compared to the western coal and nuclear fuel cycles, water and land use requirements and environmental releases of certain air pollutants -- e.g., hydrocarbons -- are greater (per kilowatt-hour of electricity produced); but because western coal-fired and nuclear power plants are usually built in minimum sizes 10 to 20 times larger than hydrothermal power plants, particular resource requirements and environmental releases can actually be from several times as large to several hundred times as large for a coal-fired or nuclear power plant (and accompanying support facilities), compared to a hydrothermal power plant. • Releases of pollutants that are believed to be precursors to acid rain (i.e., sulfur and nitrogen compounds and particulates) and a warming of earth's atmosphere (i.e., carbon dioxide) can be at least 5-10 times as large for coal-fired power plants than for hydrothermal power plants (per kilowatt-hour of electricity produced). • Some environmental residuals from the western coal and nuclear fuel cycles are notably different than those released from hydrothermal flash steam systems, for example: liquid waste effluents; and radioactive air, water and solid waste pollutants from the nuclear fuel cycle. • Environmental impacts from hydrothermal flash steam systems are self-contained in one location, whereas coal and nuclear fuel cycles require several locations to accommodate the mining, fuel conversion, fuel transport and power generation facilities. Direct Heat Applications • Hydrothermal space and process heat systems are closed so air emissions result primarily from drilling, testing and cleaning operations, while waterborne residuals result when spills occur. • For those residuals analyzed (particulates, sulfur compounds, nitrogen compounds, carbon dioxide, and salts), hydrothermal space heat (process heat) systems release -- for 25 years -- about 21.5 tons (40.6 tons) of pollutants/site/year; in both cases, mostly carbon dioxide. • Per quad of heat delivered to end-users, hydrothermal space and process heat systems release residuals several orders of magnitude less than either western coal or oil systems; releases are also several orders of magnitude less than those from natural gas systems, except for sulfur compounds released by process heat applications (which are 128 percent greater), and salts released by both space and process heat applications (which are zero with natural gas systems).

Exhibit 6.1: Summary of Costs and Benefits Associated with DOE's "Current Federal Program" (continued)

Cost/Benefit Category	Summary of Expected Impacts
External Impacts (cont.)	
National Security/ Balance-of-Payments Improvements	• Substitution of hydrothermal resources for coal, oil or natural gas. • Creation of an energy option increasing the security of the U.S. and its energy supplies. • Savings of over 700 million barrels of crude oil equivalent between 1980 and 2030 from the additional electricity and direct heat energy use; average daily savings of 38.5 thousand barrels for 50 years. • While use of competitive alternative energy sources may also be able to reduce oil imports, reductions would likely be less, and domestic energy supplies would also be consumed (although in small amounts compared to current levels of consumption). • Improvement in balance-of-payments equal to $64 billion (in constant 1982 dollars) if all crude oil savings do, indeed, reduce imports; present value in 1982 is approximately $6 billion (in 1982 dollars). • Increased planning flexibility for utilities since minimum sized hydrothermal power plants can be 10 to 20 times smaller than minimum sized coal-fired or nuclear power plants, and can be constructed in one-half to two-thirds the amount of time.
Socioeconomic Impacts	• In general terms, increased employment/reduced unemployment, an increased and more diversified tax base, increased tax resources exceeding increased government expenditures, and accelerated economic development, without overburdening existing community services and facilities or housing. • For additional electric power applications, total employment of 3,300 construction workers for two years (6,600 person-years) between 1980 and 2000, and 60,620 person-years of operating and maintenance labor between 1980 and 2030; any single 50 MWe power plant would have no more than 150 construction workers for two years or 78 operating and maintenance personnel for 30 years. • Compared to western coal-fired and nuclear power plants, hydrothermal power plant construction requirements are less, but operating and maintenance requirements are greater (per kilowatt-hour of electricity produced); however, larger minimum sized coal-fired and nuclear power plants will produce significantly larger manpower requirements at any single location, possibly overwhelming existing community services and facilities and creating undesirable "boomtown" effects.
Materials Requirements	• Highly durable materials and equipment must be utilized in hydrothermal resource development in order to withstand the corrosive and abrasive nature of liquid dominated resources. • While the oil and gas industry face similar problems, the wide variation of geothermal fluid temperatures and salinity create a unique set of problems. • Much progress has been made in developing suitable materials and equipment, and DOE's "Current Federal Program" is designed to assist industry in solving these difficulties. • Development of longer lasting, lower cost materials for extracting hydrothermal resources will provide additional benefits if properly transferred to the oil and gas industry.

For the additional direct heat use applications, environmental releases will result from drilling, testing and cleaning operations and from accidential spills (see Exhibit 6.1). However, compared to the competing alternative energy sources (i.e., western coal, oil and natural gas), environmental residuals, several orders of magnitude less, are expected to be released; this reduction in pollutant releases will produce a substantial net environmental benefit.

In sum, the additional hydrothermal electric power and direct heat resource development, when compared to the competing alternative energy sources, is relatively benign environmentally, and may well offset more environmentally adverse effects which could otherwise accompany fossil fuel or nuclear powered facilities.

Indirect benefits from this additional hydrothermal resource development will also result by increasing the security of the U.S. and its energy supplies with the creation of this energy option (see Exhibit 6.1). Hydrothermal facilities can generally be brought on-line much more quickly than facilities utilizing either coal or nuclear resources. Moreover, hydrothermal resources can directly and indirectly substitute for oil, thereby: reducing the nation's consumption and dependence on imported oil; lessening disruptions in the U.S. economy caused by actions of other governments (i.e., oil embargoes); and improving the balance-of-payments situation. Over 700 million barrels of crude oil equivalent -- with a discounted present value (in 1982) of $6 billion (in 1982 dollars) -- are expected to be saved between 1980 and 2030 from the additional electricity and direct heat energy use made available by hydrothermal resources. Compared to the $85 million dollars (discounted present value in 1982) in expenditures for DOE's "Current Federal Program," these equivalent crude oil savings represent a substantial benefit.

Turning to the socioeconomic impacts associated with the additional hydrothermal resource development, most of the additional hydrothermal power plants are likely to be developed in rural portions of western states, while most of the additional direct heat use facilities are likely to be developed near urban centers in the West and in the northern half of the U.S. Because the scale of both the construction activities and facility operations is expected to be relatively small at any single location (see Exhibit 6.1), the overall socioeconomic impacts are expected to be beneficial in nature, unlike the severe impacts often associated with larger, more intensive, and disruptive energy developments based on alternatives that utilize coal, oil or uranium. In essense, then, the relatively small increases in public service requirements, and the modest, but helpful, employment opportunities associated with well planned and phased hydrothermal resource development, are expected to provide a positive stimulus for the expansion and diversification of many local economies.

In concluding this chapter, the need for durable materials and equipment, capable of withstanding the hostile liquid dominated hydrothermal resource environments, cannot be overlooked if the additional hydrothermal electric power and, to a smaller extent, direct heat use applications are, indeed, to become a reality (see Exhibit 6.1). DOE's "Current Federal Program" is structured to stimulate public and private R and D activities necessary to develop economical materials and equipment for hydrothermal resource environments. Much progress has already been made and continued research will not only benefit hydrothermal resource development, but will also aid technology development in the oil and gas industry.