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ENVIRONMENTAL READINESS DOCUMENT

HYDROTHERMAL ELECTRIC AND DIRECT HEAT

Commercialization Phase III Planning

September 1978

U.S. Department of Energy
Assistant Secretary for Environment

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FOREWORD

Environmental Readiness Documents are prepared periodically to review and evaluate the environmental status of an energy technology during the several phases of development of that technology. Through these documents, the Office of Environment within the Department of Energy provides an independent and objective assessment of the environmental risks and potential impacts associated with the extensive use of the technology.

This Environmental Readiness Document was prepared to assist the DOE Commercialization Task Force on Hydrothermal Electric and Direct Heat to evaluate the commercial readiness of this technology with respect to environmental issues. An effort has been made to identify potential environmental problems that may be encountered based upon current knowledge, proposed and possible new environmental regulations, and the uncertainties inherent in planned environmental research.

This document is one of several assessments of energy technologies prepared for DOE management and public review. It is being distributed so that persons having interests and responsibilities in this area can provide DOE with additional information and comments.

Ruth C. Clusen
Assistant Secretary for Environment

ACKNOWLEDGMENT

This document was prepared under the direction and guidance of the Division of Technology Assessment (DTA), Office of Technology Impacts (OTI), Office of the Assistant Secretary for Environment, with support from the Divisions of Policy Analysis and Environmental Impacts.

Others who contributed significantly to the preparation of this document were personnel from the Division of Biomedical and Environmental Research, the Division of Environmental Control Technology, Lawrence Livermore Laboratory, DOE Geothermal Commercialization Task Force, and The Aerospace Corporation.

For further information concerning this document, contact Robert Blaunstein, Division of Technology Assessment (202-566-7907).

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SECTION 1. SUMMARY STATEMENT ON ENVIRONMENTAL ACCEPTABILITY OF HYDROTHERMAL ELECTRIC AND DIRECT HEAT

The stated near-term goal of the Department of Energy (DOE) Geothermal Energy Program is to encourage and assist industry or municipal utilities to discover and exploit hydrothermal resources. This action could result in electric and thermal power equivalents that could replace 1,000,000 barrels of oil per day by the year 2020.

Attainment of these goals is critically dependent on: (1) demonstration of long-term resource availability, (2) development of near-term technologies (i.e., binary and tertiary systems), and (3) early resolution of environmental concerns.

Nine environmental concerns have been identified: (1) airborne effluents, (2) waterborne effluents, (3) noise, (4) subsidence, (5) enhanced seismicity, (6) water use conflicts, (7) land use, (8) socioeconomic impacts, and (9) system safety and occupational health. Resolution of these issues is expected to occur at staggered intervals over the next 8 to 10 years.

Of these concerns, airborne emissions and water use conflicts are judged to have a medium likelihood of having research findings adverse to commercialization. Waterborne effluents and subsidence are also judged to have a medium likelihood. The other concerns — noise, enhanced seismicity, land use, socioeconomic impacts, and system safety and occupational health — are judged to have a low likelihood of adverse findings.

The overall environmental research and development plan related to hydrothermal electric and direct heat includes funds to assess the adequacy of candidate control technology options. However, it does not include the resource requirements to fully develop and demonstrate commercial control hardware, process modifications, and for strategies.

The conclusions, stated as probabilities, are given in Table 1-1. It should be emphasized that these probabilities are the synthesis of the collective judgments of Office of Environment scientists which are rendered in greater detail in the technology and governmental milestones shown in Section III and in the discussion of significant concerns in Section IV. Three factors are evaluated in terms of probability of occurrence. These are that (1) there will be an adverse finding as a result of future environmental R&D, (2) that given this finding the commercialization program will encounter delays, and (3) that the consequence of an adverse finding will result in increased costs of control. The term "adverse finding" is used to reflect an R&D outcome identifying an environmental impact which must be dealt with. The later in the commercialization schedule that this determination is made, the greater the likelihood that the full commercialization program will be delayed somewhat while appropriate mitigation measures are chosen. No judgments are made concerning the length of the delay. The last judgment, regarding the increase in abatement costs takes into consideration the extent and difficulty of control, as well as the possibility that additional measures may be required to deal with each of several environmental problems.

Table 1-1. Conclusions for Hydrothermal Electric and Direct Heat

	Probability				
	0.1-----	0.5-----	0.9		
	Low	Low-Med	Med	Med-High	High
The probability of determining an adverse finding in the conduct of environmental R&D			X		
*The probability of technology program delays in event of an adverse finding			X		
The probability of increased energy costs in event of adverse finding				X	

* Probability of technology program delays:

Low-----Assessment of environmental factors will be substantially complete prior to commercialization,
 Medium--Assessment of environmental factors will be concurrent with DOE commercialization development, or
 High----Assessment of environmental factors will not be complete until after commercialization.

Note: These conclusions are based on an assessment of the information contained in Table 4-1.

SECTION II. INTRODUCTION

This Environmental Readiness Document (ERD), prepared by the Office of Environment (EV), is one of 16 independent reviews of the environmental uncertainties associated with the candidate commercialization technologies.

An Environmental Readiness Document is prepared from time to time in the development cycle of a technology program to inform decisionmakers of the present environmental status of an energy technology. The purpose of an ERD is to bring to bear the collective judgments of EV scientists on the potential environmental concerns for which current information is incomplete. As later research results are forthcoming, and when appropriate to the timing of the decision process, the ERD will be updated.

The document addresses the uncertainties that remain to be resolved through research and development. These uncertainties constitute a limitation on the confidence which can be placed on the conclusions from the assessment. The conclusions are presented as a probabilities table showing that commercialization of the technology may encounter adverse findings from research, increased mitigation costs, or delays.

The impacts and concerns presented in the document are treated generically without reference to specific predetermined sites. Identification of specific facility sites that comprise the commercialization strategy was not available from the Commercialization Task Force. Hence, site-specific implications are not included in the assessment.

The report contains two main sections, III and IV, as well as Appendixes. Section III highlights the characteristics of the technology, provides status information on the technical and environmental R&D programs, presents a milestone chart representing a relationship between a considered commercialization schedule and relevant environmental R&D, and reviews the environmental concerns significant to the technology. Information pertinent to the technology R&D program was drawn from Phase II Task Force reports.

Section IV examines the likelihood and consequences of adverse findings, the problems and uncertainties stemming from current or anticipated environmental regulation, and potential costs of environmental controls. On this basis, an assessment is offered of the existing or potential barriers to commercialization.

Appendix A presents a tabulation of outstanding environmental concerns. These concerns are an updated version of those appearing in the 1977 Geothermal Environmental Development Plan. Research required to resolve these concerns is also listed with estimated costs. The research requirements represent the best judgment of EV scientists and engineers at this time of what is needed and are presented herein as a reference for all interested research participants. As such, this listing does not describe a proposed Federal R&D plan or program. In Appendix B, the relative contribution of environment control costs to total energy costs is presented for current standards and possible new standards.

The lack of appropriate National Environmental Policy Act (NEPA) documentation can cause a significant delay in the development and commercialization cycle. However, no attempt has been made in this presentation to identify formal NEPA requirements (the type of NEPA document required and its schedule). There is a prescription, however, that Programmatic Environmental Reviews, as appropriate, will be prepared pursuant to 10 CFR 1021, "Compliance with the National Environmental Policy Act" (Federal Register Vol. 43, No. 35, February 21, 1978), prior to the DOE taking action to commercialize any technology or process.

SECTION III. TECHNOLOGY PROGRAM AND MAJOR ENVIRONMENTAL CONCERNS

A. TECHNOLOGY

Hydrothermal resources are convective systems of water and steam trapped in fractured rocks or sediments by impermeable earth surface layers. A specific resource is classified as being "vapor" or "liquid" dominated according to the physical state of the fluid produced and released when such systems are tapped by drilling.

The applications of geothermal energy are divided into two categories: electric and nonelectric. In electric applications, vapor or water at temperatures above 150°C are extracted and used to drive a turbine generator. Nonelectric applications utilize geothermal fluids at temperatures above 50°C for space heating and cooling, biodegradation fermentation, and various processes in the food, chemical, and petroleum industries.

Moderate temperature resources are more numerous and widespread and therefore offer a larger potential number of sites for development than geothermal electric complexes.

Figure 3-1 is a schematic of the principal elements in the three types of electric power systems anticipated for commercialization. Environmentally related resource requirements and associated energy production residuals are identified in Table 3-1. The quantity of geothermal fluid processed, the fluid characteristics, and the amount of residual materials are highly site- and technology-specific. The range of values given in Table 3-1 represents those encountered in present hydrothermal development activities.

Brief descriptions of the conversion cycles are as follows:*

- Dry Steam - Scrubbed steam drives a turbine generator, with condensate water used for cooling. Noncondensable gases, (particularly hydrogen sulfide (H_2S)), high noise levels, and odor (mainly from H_2S) are typical problem areas for this type of cycle.
- Direct Flash - High temperature steam is produced by flashing the brines from the well. Precipitation of solids, corrosion, and erosion are problems. Subterranean injection of spent brine is anticipated. Noise levels may be high, and noncondensable gases may be a problem.

*"An Overview of Hydrothermal Resource Development Activities and Associated Potential Environmental Problems," Working Paper 11997, Contract No. E(49-18)-2268 EX76-C-01-2268, Lawrence Livermore Laboratory, 1977.

Figure 3-1. Geothermal Hydrothermal Description

Table 3-1. Hydrothermal Power-Plant Resource Requirements and Production Residuals *

1. Power plant size	
a) Capacity	110 MW
b) Operation Factor	90%
c) Average power level	100 MW
2. Land area per power plant for geothermal facilities	20 acres (0.03 sq. mi.)
3. Well field area per power plant	1.25 - 2.50 sq. mi.
4. Average down-hole resource temperature	285°C - 190°C
5. Geothermal fluid required	30 - 60 kg/kW-hr
6. Geothermal fluid residual	
a) Flashed Steam System	21 - 45 kg/kW-hr
b) Binary Flow System	30 - 60 kg/kW-hr
7. Steam condensate	
a) Flashed Steam System	9 - 15 kg/kW-hr
b) Binary Flow System	0 kg/kW-hr
8. Cooling water requirements	60 - 90 $\frac{\text{acre-ft}}{\text{MW-yr}}$
9. Hydrogen sulfide emissions to the atmosphere	
a) Flashed Steam System	1.2 - 2.4 g/kW-hr
b) Binary Flow System	0 g/kW-hr
10. Thermal efficiency	10 - 12%

* D. L. Ermak, "A Scenario for Geothermal Electric Power Development in Imperial Valley," Energy Volume 3, 203 (1978).

- **Binary Cycle** - Generally employed to utilize reservoirs with lower temperature brines, this system uses a second fluid (binary) in a closed system. The binary fluid (e.g., isobutane, propane, freon, ammonia) is vaporized via a heat exchanger. The geothermal brine side of the heat exchanger may also operate as a closed system by having the "spent brine" injected into a disposal well. Primary environmental problems may be associated with cooling towers, waste management, and containment of binary fluids.

The total geothermal fluid processes and net residuals are shown in Table 3-2. The potential market penetration due to commercialization (electric) is: 800 MWe by 1985, 4,800 by 1990, and 13,050 by the year 2000, excluding the Geysers and the Gulf Coast geopressed resources. Example uses of direct heat are shown in Table 3-3.

The near-term dominant known geothermal resource areas (KGRAs) are confined to 11 western States (California, Oregon, Washington, Nevada, Utah, Colorado, Arizona, New Mexico, Wyoming, Idaho, Montana), Hawaii, and perhaps Alaska. Limited areas within these States will bear the principal burden of resource development and environmental impact. Considerable attention must be directed toward preservation of the desirable features of the environment, as well as the social and economic structures of these localities.

Table 3-2. Annual Geothermal Production* and Residuals (Western U.S., Hawaii, and Alaska)
Electric (Flash System)

ITEM	1985	2000	2020
Production (MW _e)	3,000 - 4,000	20,000 - 40,000	70,000 - 140,000
Geothermal Fluid Required (10 ⁹ Tonne)	1.2 - 1.6	8 - 16	28 - 56
Geothermal Fluid Residual (10 ⁹ Tonne)	1.1 - 1.4	7 - 14	25 - 50
Steam Condensate (10 ⁹ Tonne)	0.3 - 0.4	2 - 4	7 - 14
Cooling Water Requirements (10 ⁶ Acre-Feet)	0.2 - 0.3	1.5 - 3	5.3 - 10.6
H ₂ S Emissions (Tonne)	26,000 - 35,000	175,000 - 350,000	610,000 - 1,220,000
Nonelectric			
Production (quads)	0.1 - 0.2	0.5 - 2	6 - 8
Geothermal Fluid Required (10 ⁹ Tonne)	0.5 - 1	2.5 - 10	30 - 40
Geothermal Fluid Residual		(amounts are unknown)	

* DOE Commercialization Task Force Report, June 15, 1978.

¹These figures are from the August 31, 1978 Commercialization Strategy Document of the DOE Commercialization Task Force.

Table 3-3. Direct Geothermal Energy Used by Integrated Industrial Complex *

Process	Capital Cost ** (\$ in millions)	Land Requirements (in acres) +	Annual Energy Usage (exclude onsite electricity) (in 10 ¹⁰ Btus)	Capital Cost Energy Output (\$/10 ⁶ Btu)
Potato Dehydration	7	100	58.0	12.0
Manure Processing	1.5	5	7.0	21.43
Cattle Feedlot	2	7	8.8	25.00
Green Housing	1.5	12	150.0	10.0
Fish Farming	0.6	2	160.0	3.75
Refrigeration - Slaughter House	1	1	280.0	3.75
Tree Breeding	0.1	10	0.55	18.18

Average Capital Cost

 $\frac{\$13.42}{10^6 \text{ Btu}}$

* Derived from INEL Progress Report #1, ERDA 1976.

** Excludes exploration and drilling costs.

+ Land requirements here are for industrial facilities alone. Land usage due solely to geothermal development must be based upon the number of wells required to service the given consuming facility(ies). In this case, a total of seven wells, and thus, seven acres, are required to provide sufficient hydrothermal energy for the eight industrial applications. Estimates on well spacing range from 10 to 50 acres between wells. However, livestock grazing, potato growing, and other activities are expected to occur between wells with minimal inconvenience.

B. SIGNIFICANT ENVIRONMENTAL CONCERNS

The major environmental concerns associated with geothermal development are presented in Appendix A. The areas of concern are: airborne and waterborne effluents, noise, subsidence, enhanced seismicity, land and water use, socio-economics, and safety and occupational health. The EV research requirements, research time, project status, and research costs for each identified concern are presented. Pertinent comments and caveats are included in the column titled "Uncertainties."

Of the concerns, airborne emissions and water use are judged to have a high or medium-to-high likelihood of having research findings adverse to unrestricted commercialization, thus defining the problems requiring engineering, scientific, or economic solutions. Waterborne effluents and subsidence are judged to have a medium likelihood of adverse findings, and the other concerns are judged to have a low likelihood.

C. PROGRAM STATUS

Technology Program

The technical readiness for electric power generation from hydrothermal reservoirs has been established for the better quality geothermal resources such as those currently in production. The resources, however, span a broad range of conditions (such as temperature, fluid chemistry, reservoir permeability, and depth), which influence the economic and technical feasibility.

A number of liquid-dominated geothermal reservoirs in the United States can be developed, and cost-competitive electric power can be produced. A much larger resource base exists, however, which cannot be considered ready for commercialization at present from a technical/economic standpoint. Economic incentives pending under the National Energy Act, and success of technological developments presently under way, may facilitate rapid development of these additional geothermal resources.

Although the technical feasibility of using geothermal energy for direct thermal application has been demonstrated worldwide, use within the United States has been small. Commercial uses in the United States are shown in Table 3-4. These applications have frequently utilized shallow, relatively inexpensive wells.

Environmental Program

Concurrent with the technology development effort, environmental R&D is being performed. Appendix A contains a listing of ongoing and needed future research to resolve environmental concerns. Figure 3-2 shows the major milestones associated with the ongoing work.

Figure 3-2. Hydrothermal Electric and Direct Heat

TECHNOLOGY AND ENVIRONMENTAL MILESTONES

TECHNOLOGY *

Demo Plant #1 (50MWe)
(Valles Caldera, NM)

Imperial Valley
(Niland, CA)

Raft River Pilot Plant
(ID)

ENVIRONMENTAL

Demo Plant #1 (50MWe)
(Valles Caldera, NM)

Raft River Pilot Plant
(ID)

The Geysers
(Sonoma County, CA)

Symbols:

DOE Controlled Milestone

Decision Point

Program Milestone

Activity Bar

MILESTONES:

1. Begin construction
2. Operation
3. Establishment of flora and fauna baseline conditions; identification of endangered species
4. Description of the characterization, transport, and fate of H₂S atmospheric emissions
5. Determination of the effects of H₂S and boron on crops
6. Modeling of H₂S transport and field verification of the models
7. Determination of the fate of inorganic pollutants from cooling tower drift
8. Evaluation of the effects of excessive noise on local fauna
9. Determination of the fate of soluble inorganic elements in surface water and aquifers
10. Establishment of preoperational and operational rates of subsidence
11. Evaluation of the nature and frequency of microseismic activity
12. Appraisal of impact on ecosystems after startup

DECISIONS:

- A. Recommendations for contract award
- B. Decision whether to proceed with construction
- C. Environmental Readiness Document - assesses environmental acceptability

* The Geysers intentionally omitted as it is considered commercial.

An extensive environmental measurements, analysis, and assessment program has been carried out in the Imperial Valley, California, area during the past 3 years. A full range of problems related to air quality, water quality, ecology, subsidence, seismicity, control technologies, and socioeconomic factors was addressed. Integrated assessments of the results are in preparation. In addition to providing a sound foundation for evaluating the environmental consequences of potential geothermal development in the Valley, the program has developed the methodologies and techniques and provided experienced scientists for environmental studies in other regions. Limited environmental studies programs are underway in other geothermal resource areas.

A series of well-attended workshops on the environmental problems at The Geysers was held in late 1977 and early 1978. From these, a unified research program addressing the more consequential problems is being formulated.

The integrated cooperative program will include county, State, industrial, and Federal participation. It is expected that the portion of the program concerned with air quality, and the transport and diffusion of air pollutants in complex terrain, will be initiated soon. A parallel program oriented around a liquid-dominated resource (Valles Caldera, New Mexico and/or Niland, California) is in the early stages of formulation.

SECTION IV. ENVIRONMENTAL ANALYSIS AND ASSESSMENT

Large-scale utilization of vapor-dominated reservoirs has been demonstrated at The Geysers area of California. However, further expansion and even continued operation of the present power plants is contingent upon the successful demonstration of an operational abatement system to limit H_2S emissions to acceptable levels.

For liquid-dominated reservoirs, large-scale utilization has not been demonstrated in the United States, but has been successful in New Zealand, Mexico, and Japan. Both flashed-steam and binary systems appear feasible, but long-term problems of spent fluid injection, corrosion control, and the reliability of down-hole pumps must be solved.

A. CONCERNS

There are a number of environmental concerns that require resolution. Table 4-1 presents each of the concerns in terms of the likelihood of a finding adverse to technology development, the degree of program delay resulting from that adverse finding, and the associated mitigation cost. As can be seen from Table 4-1, there are wide variations in the probabilities and mitigation costs for the various issues. The overall probability of an adverse finding is judged to be low to medium, the overall probability of program delays in the event of an adverse finding is judged to be medium, and the overall probability of increased energy costs in the event of an adverse finding is judged to be medium to high (see Table 1-1).

The problem of H_2S emission has already been discussed. Studies to date indicate that it is unlikely that H_2S emission will cause significant ecological or health effects, but its odor does present a major nuisance that is unacceptable to the public. Noise associated with many geothermal operations, particularly the venting of wells tapping vapor-dominated reservoirs, is a significant problem and better noise abatement techniques are needed.

For liquid-dominated reservoirs, other environmental impacts are of serious concern. These include the related problems of spent fluid disposal, land subsidence, and enhanced seismicity. It is expected that the disposal of spent geothermal fluids can be achieved by injection into the reservoir, and that this will also eliminate the potential problem of land subsidence that has been observed at many sites after fluid withdrawal. Unfortunately, the injection process is a significant consumer of energy and has not been adequately demonstrated over long time periods.

Mineral scaling and precipitation problems associated with injection may prove to be so severe that chemical treatment and/or settling ponds may be required. Even if injection is successful, the process itself might produce an enhanced level of seismic activity, or the thermal strain from use of the reservoir might cause seismic events. If the injection process is successful only because of the removal of compounds such as silica, a large-scale solid waste disposal problem may result.

Table 4-1. Significance of Concern of Hydrothermal Electric and Direct Heat

Environmental Concern	Status (State of Knowledge)	Research Time	Likelihood of a Finding Adverse to Technology Development*	Additional Mitigation Cost (\$) **	Program Delay	Environmental Risk of Proceeding with Technology Development
<u>Column Content</u> Concern statement as provided in Appendix A	Present Knowledge of: - severity of hazard - adequacy of control	Years of required research (as in Appendix A)	Estimate of probability of adverse finding (high, medium, or low) and character of likely adverse finding	The total cost (direct and indirect) of controls that may be required in the event of adverse finding	Period of program delay that may result from adverse finding	Assessment of risk of proceeding with technical development schedule in light of state-of-environmental knowledge, research schedule, and uncertainty of research outcome
<u>1. Release of Airborne Effluents</u> Hydrothermal fluids typically contain a number of compounds such as CO ₂ , NH ₃ , As, H ₂ S, CH ₄ , Rn, Hg, and B. These and other chemicals such as salts in cooling tower drift may be released to the atmosphere; impacts may occur on local ecosystems and on human health.	a) H ₂ S is of particular concern because of unacceptable odor (above 5ppb) and toxic effects (above 20 ppm). Abatement systems now used at The Geysers cannot comply with California H ₂ S standards; new systems with improved capability and reliability are just approaching demonstration phase. Long-term accumulation and effects of Hg, G, As, and H ₂ S on ecosystems are unknown. Methodology does not exist for predicting atmospheric transport of H ₂ S in rough terrain. This is needed for siting power plants. b) Data concerning long-term accumulation and effects from Hg, B, As, and H ₂ S on ecosystems are limited. Currently, there are no controls being deployed for these pollutants.	3	a) Medium - Optimum utilization of geothermal regions is limited by H ₂ S abatement constraints. Systems in commercial operation now are not satisfactory. Future well head abatement systems, use of dry cooling towers, and injection with a binary system will require unproven technology with a significant cost penalty. Also, it is unlikely in the future to have adequate abatement during well drilling, well bleeding, or bypassing for vapor dominated resources or during flashing of hot water resources. Development of predictive atmospheric modeling capability for rough terrain will maximize dispersion of H ₂ S by selective power plant siting. b) Medium - Current characterization of effluents indicate a build-up of Hg, B, and As. While these pollutants are not regulated and have not hindered siting to date, innovative techniques may be needed for clean-up if they are regulated.	a) For H ₂ S cleanup, the following increases in levelized busbar energy cost will be incurred above those for surface condensers and Stretford process: • Well-head abatement, 1-5% (1) • Dry Cooling, 10-15% (2) • Injection with binary system, 20-25% (3) b) For Hg, B, and As cleanup 5-10% increase in levelized busbar cost. (4)	Delay in the Geysers area will be significant. Delay in hot water resources will depend if flash steam design is used.	Medium if H ₂ S abatement systems are proven in field applications. Impact of Hg, B, and As cleanup will depend upon regulations and proven technologies.

- LOW = 0.1-0.3 probability of occurrence
- MEDIUM = 0.4-0.6 probability of occurrence
- HIGH = 0.7-0.9 probability of occurrence

** These are order of magnitude cost estimates

References

1. MRI Report, C00/4255-07.
2. PNL Report, BNWL-2120.
3. Private communication, D. Boehm, DOE, with Ron Walter, PNL, 7/5/78.
4. Imputed using subjective evaluation.

Table 4-1. Significance of Concern of Hydrothermal Electric and Direct Heat

Environmental Concern	Status (State of Knowledge)	Research Time	Likelihood of a Finding Adverse to Technology Development*	Additional Mitigation Cost (\$)***	Program Delay	Environmental Risk of Proceeding with Technology Development
<u>Column Content</u> Concern statement as provided in Appendix A	Present Knowledge of: - severity of hazard - adequacy of control	Years of required research (as in Appendix A)	Estimate of probability of adverse finding (high, medium, or low) and character of likely adverse finding	The total cost (direct and indirect) of controls that may be required in the event of adverse finding	Period of program delay that may result from adverse finding	Assessment of risk of proceeding with technical development schedule in light of state-of-environmental knowledge, research schedule, and uncertainty of research outcome
2. <u>Release of Waterborne Effluents</u> Large volumes of spent geothermal fluids and cooling tower blowdown will be generated. They may contain dissolved volatile compounds and large quantities of dissolved solids. The concern is for long-term disposal of such fluids so that beneficial sources of water are protected.	Most high temperature resource fluids contain moderate to high levels of salts and trace heavy metals (Hg, B, As). Experience in Imperial Valley dictates that salts will have to be filtered out before reinjection to avoid plugging of reservoir matrix. Pre-treatment before injection will leave residuals requiring surface disposal. Safe disposal of high saline fluids under pressure has not been demonstrated. Moderate to low temperature fluids (non-electric applications) probably will present minimal hazard.	Because of the large volume of waste and uncertainties surrounding plugging R&D will be substantial (5 years).	Medium - Safe disposal of brine in Imperial Valley will be required to protect agricultural developments. In most cases geothermal fluids cannot be dispensed into surface or groundwater systems if total dissolved solids (TDS) exceed 1000 ppm. Plugging from injection may be resolved by pretreatment, usually for silicates. Another option is evaporative ponding of the waste. Innovative treatment, such as reverse osmosis, could result in a secondary use of the water. All of these advanced systems will have an accompanying solid waste disposal problem.	The leveled busbar costs will increase above injection by: <ul style="list-style-type: none">• Injection with treatment about 9% (1)• Ponding about 1% (1)• Reverse osmosis about 22% (1) Note: Above costs do not include solid waste disposal.	Delay in Geysers would be minor because low TDS fluids present little, if any, problems for disposal. Delay in Imperial Valley could be significant if high salt content fluids cannot be injected.	Moderate for most non-electric and low saline applications. Significant for high saline applications because there is a need to establish that fluid can be injected at high rates over long periods of time. Also, EPA standards for safe drinking water may preclude injection into potential water aquifers, and Resource Conservation and Recovery Act may limit ponding.

** LOW = 0.1-0.3 probability of occurrence
 MEDIUM = 0.4-0.6 probability of occurrence
 HIGH = 0.7-0.9 probability of occurrence

*** These are order of magnitude cost estimates

Reference

1. Private communication, D. Boehm, DOE, with Ron Walter, PNL, 7/5/78.

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<u>Column Content</u> Concern statement as provided in Appendix A	Present Knowledge of: - severity of hazard - adequacy of control	Years of required research (as in Appendix A)	Estimate of probability of adverse finding (high, medium, or low) and character of likely adverse finding	The total cost (direct and indirect) of controls that may be required in the event of adverse finding	Period of program delay that may result from adverse finding	Assessment of risk of proceeding with technical development schedule in light of state-of-environmental knowledge, research schedule, and uncertainty of research outcome
<p>3. Noise</p> <p>Uncontrolled noise levels associated with exploration and drilling, well venting, and operational processes can reach levels as high as 120dBA near the plant and may have deleterious effects on human health, animal husbandry and perhaps rare and endangered species' breeding habits.</p>	<p>Most noise pollution will be associated with vapor dominated resources and well venting and bleeding operations during air drilling phases. Adequate noise abatement techniques for drilling and well flow testing need to be developed. Moderate impact on wildlife habitat can be expected. Auxiliary drilling equipment will need to be acoustically shielded. Present muffling systems are moderately successful but are costly.</p>	1-2	<p>Low - Adequate controls can be developed for well drilling and well venting tests in vapor dominated resources. Need further R&D on long-term effects on wildlife habitats and drilling operations within nearby community boundaries. Noise from development of hot-water resources will be less and controllable.</p>	<p>Noise abatement systems will have an additional leveled busbar cost of less than 1%.</p> <p>(1)</p>	<p>Major delays could be associated with expansion of the Geysers to 2000 MWe.</p> <p>Delay is moderate for Imperial Valley.</p>	<p>Low risks if economical and reliable systems, using present day technology, can be demonstrated for air drilling and plant venting/bleeding.</p>

* LOW = 0.1-0.3 probability of occurrence
MEDIUM = 0.4-0.6 probability of occurrence
HIGH = 0.7-0.9 probability of occurrence

** These are order of magnitude cost estimates

Reference

1. Private communication, D. Boehm, DOE, with P. Leitner, St. Mary's College, 7/5/78.

Table 4-1. Significance of Concern of Hydrothermal Electric and Direct Heat

Environmental Concern	Status (State of Knowledge)	Research Time	Likelihood of a Finding Adverse to Technology Development*	Additional Mitigation Cost (\$)**	Program Delay	Environmental Risk of Proceeding with Technology Development
<u>Column Content</u> Concern statement as provided in Appendix A	Present Knowledge of: - severity of hazard - adequacy of control	Years of required research (as in Appendix A)	Estimate of probability of adverse finding (high, medium, or low) and character of likely adverse finding	The total cost (direct and indirect) of controls that may be required in the event of adverse finding	Period of program delay that may result from adverse finding	Assessment of risk of proceeding with technical development schedule in light of state-of-environmental knowledge, research schedule, and uncertainty of research outcome
4. <u>Subsidence</u> The removal of large quantities of hydrothermal fluid may result in subsidence. The importance of subsidence will be site-specific; at locations such as The Imperial Valley where the geothermal reservoirs are overlain with agricultural land, subsidence impact could be significant.	Current mitigation strategies are based upon oil field and ground water extraction experiences. Little actual experience exists in management of subsidence in geothermal fluid withdrawal-injection. Most plans call for injecting into strata different from where fluid is initially extracted. The prevention of subsidence under these conditions is not clearly understood, nor are the factors that control subsidence in general. Once subsidence occurs, the effects may be reversed, but at significant cost.	3	Medium - The efficacy of subsidence prevention by injection of spent fluids has not been demonstrated.	If injection is used for liquid waste, no incremental costs. If ponding is used and some form of injection is needed to control subsidence, then an additional levelized busbar cost of up to 20% could be incurred.(1)	Delays in Imperial Valley could be significant if process is proven infeasible or unsuccessful. Delays are not foreseen for Geysers area.	Significant for Imperial Valley due to sensitive agriculture and uncertainties surrounding plugging of injected fluids. The Geysers would be unaffected.

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1. Private communication, D. Boehm, DOE, with Ron Walter, PNL, 7/5/78.

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5. <u>Enhanced Seismicity</u> The withdrawal and/or injection of hydrothermal fluids may enhance the frequency or magnitude of seismic events.	Evidence for inducing seismic events exists from high pressure injection at Rocky Mountain Arsenal, Colorado. It is unlikely that low pressure injection associated with geothermal fluid disposal will induce seismic events. Observations in Imperial Valley where limited injection has taken place, indicate no observable correlation between seismic phenomenon and injection. Need more data for various geological formations and long-term high flow rates of injection. It is postulated that reservoir cool-down resulting from fluid withdrawal may induce microseismic events. (This, however, could be beneficial by precluding a large acute event.)	3	Low - Minor impact expected, however, sufficient baseline observations should be made in early phases of development to establish data base necessary for distinguishing between natural seismic events and possible induced activity.	It is expected that monitoring program will indicate no need for controls or that procedural control will impose minor cost penalties.	None expected, but early baseline data on seismic activity should be developed and monitoring program established for early (1-2 yr) fluid withdrawal and injection.	Low - However, essential to establish pre-startup background data and monitoring program during early resource utilization -- both electrical and non-electrical applications.

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Table 4-1. Significance of Concern of Hydrothermal Electric and Direct Heat

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<p>6. <u>Water Use</u></p> <p>Many proposed methods of utilizing geothermal energy will require outside sources of water for cooling systems. As many geothermal resource areas are in semi-arid regions, conflicts concerning the most beneficial uses of water may arise.</p>	<p>In most cases, powerplant condensate will not be available for cooling purposes since it may be needed for reinjection into the ground for control of possible subsidence. Alternate sources of water should be recognized and developed. It may be possible to use agricultural waste water in the Imperial Valley. Alternatives for cooling water resources in most KGRAs have yet to be identified.</p>	1	<p>Medium - Depending upon the development of sources for cooling water and extent of reinjection. Local regulations in Imperial Valley mandate injection of volumes of water equivalent to quantities extracted. Other KGRAs (both electric and non-electric) face similar problems, except vapor dominated resource areas of the Geysers. Hot water resources in the Geysers will present reinjection and water resource problems.</p>	Indeterminate	<p>Delay could be substantial if alternative water resources use becomes an issue.</p>	<p>Significant environmental effects from utilizing water resources, i.e., agricultural waste water, Salton Sea, etc. could stop further development.</p>

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7. <u>Land Use</u> Some geothermal developments may cause land use conflicts. They may threaten pristine wilderness areas; impact upon habitat of endangered, threatened, or recreationally important species; or conflict with other beneficial uses such as agriculture or recreation.	Full scale development in Imperial Valley is predicted not to result in major conflict with agriculture or game refuge areas. Baseline data insufficient in most KGRA's and impact on endangered species is hard to predict at this time. Disturbance of raptor nesting areas may be threatened in The Geysers and Raft River, Idaho, KGRA's. Insufficient data exists between relationship of hot springs and nearby drilling of geothermal wells when common reservoir is involved.	2	Low - Relationship between well drilling and impact on hot springs may prove to be benign. Will affect development of wells within 1-2 miles of protected hot springs. Effects on raptor nesting areas and wild population and nearby human population need to be confirmed.	Indeterminate	Permanent - If drilling near protected hot springs (especially California) cannot be shown to have minimal effects on hot spring productivity, nearby areas could be withdrawn from geothermal development.	Land will be removed from alternative uses. Well sites and associated resource technologies will include agriculture, wild game hunting, recreation, placement of lodges and other human recreation resources in the area.

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8. <u>Social Services, Community Structure</u> All hydrothermal developments will have an impact through the demand for workers and the influx of money. This impact may be considered positive or negative depending upon the existing community structure and life-style, and may range from negligible to major depending upon the size of the development and the size and diversity of the local economy.	Present knowledge indicates economic impacts will be positive, especially in Imperial Valley. Impacts on life-styles in the Geysers KGRA cannot be assessed fully due to lack of data. Social and life-style modifications relative to religious and other cultural beliefs need further analysis and assessments.	3	Low - In Imperial Valley. Possible significant problems in Hawaii, the Geysers, Coso Hot Spring, Long Valley due to established religious-social mores associated with hot springs and energy extraction. Environmental organizations may object to development in some KGRAs in Oregon and Long Valley, California.	Indeterminate	Could be significant within specific areas of several KGRAs (e.g., Lake Country and Long Valley, Coso).	Failure to resolve issues where there is local opposition to siting could result in generalized public reaction to hydrothermal development.

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<p>9. <u>System Safety and Occupational Health</u></p> <p>The safety of hydrothermal energy extraction and utilization systems could become a major issue if early significant failures occur. Problems may arise related to proper handling of high pressure, corrosive hydrothermal fluids and explosive fluids, such as isobutane and propane which may be used in secondary or tertiary heat exchange loops.</p>	<p>Data from field experience in hydrothermal binary systems using isobutane and/or propane does not exist. Although much data is available for handling volatile gases in other industries, hazards could be considerable with heat exchangers utilizing corrosive high temperature geothermal fluids. Possible effects to workers exposed to low levels of H₂S have not been fully evaluated.</p>	3	Low-- Since most systems will flash hot water to steam. H ₂ S will be controlled by abatement strategies.	Incremental cost, above H ₂ S and noise abatement, for safety controls will be 0-1% of levelized busbar cost.(1)	Low--Unless major emphasis is placed upon development of binary systems, especially in Niland, Calif. where geothermal fluids are the most corrosive and constitute a worst case situation.	Low

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Reference

1. Imputed using subjective evaluation.

Socioeconomic problems may also be significant at some sites. These include issues of compatible land use and general problems of resistance to large-scale developments that threaten to alter community lifestyles or leadership structures. The seriousness of these problems will be highly site-specific and will range from negligible to severe depending upon the size, diversity, and attitudes of the affected local communities. Some developments are already being opposed because they threaten pristine wilderness areas, impact upon habitats of endangered or recreationally important species, or conflict with other beneficial uses, such as agriculture or recreation. Conflicts are also occurring over the threat of the loss of the hot water resource of hot springs used for medicinal or cultural purposes.

Well blowouts have occurred at several locations; the results have not caused major damage because of the isolated locations, but such events could be much more serious in other locations. Many proposed power plant designs are of the binary type with working fluids such as isobutane and propane. Technology to ensure containment of such explosive fluids under geothermal working conditions is essential.

One of the more serious barriers to the large-scale expansion of the use of geothermal energy is competition for available resources, such as water for heat rejection systems. If injection of most of the withdrawn water is required, then a supplementary source of cooling water will be required. As many hydrothermal reservoirs are in regions of limited water availability, this lack of water resources could result in a delay or could halt further development. If hot springs productivity is affected or if there is impact on pristine environments, recreation areas, and cultural artifacts, land needed for development may be made unavailable, thereby halting effective commercialization. The likelihood of water use conflicts is very site-specific and ranges from high to low.

The research necessary to resolve environmental concerns is being conducted concurrent with the development and demonstration of the technology itself (see Figure 3-2). Therefore, the impact of environmental concerns can be considered whenever decisions must be made regarding the course the technology should take (whether to alter the size of plants, whether to accelerate their development, etc.).

B. IMPACT OF REGULATORY STANDARDS

As shown in Table 4-2, the predominate impacts of existing or possible new regulatory standards are in the areas of airborne and waterborne effluents, land use, subsidence, and induced seismic activity. The technology for economically removing sufficient H_2S to prevent the odor problem for production-scale operations has not been developed. Waterborne effluents can be managed by injecting them into the ground, but regulations require proof that public health will not be endangered (e.g., contamination of drinking water). If complete injection is ruled out, there is a considerable cost penalty for required alternatives such as desalination and storage in lined holding ponds. In the event that brine is defined as a hazardous waste, there could be requirements for expensive processing, recordkeeping, and financial bonding.

Table 4-2. Regulatory Impacts of Hydrothermal Electric and Direct Heat

LEGISLATION	POLLUTANT/CONCERN	CURRENT/PROPOSED STANDARDS	POSSIBLE NEW STANDARDS
Clean Air Act and Amendments	Airborne emissions, see Concern 1 in Table 4-1.	There are currently no Federal standards which apply to geothermal, per se, i.e., NSPS does not apply to geothermal California standards limit H ₂ S ambient concentrations to 30 ppb	The presence of numerous criteria pollutants suggests future NSPS for geothermal H ₂ S standard is under review and may be lowered in California.
Federal Water Pollution Control Act	Waterborne effluents, see Concern 2 in Table 4-1.	Resource Conservation and Recovery Act - the process of desalination involves RCRA control Safe Drinking Water Act establishes minimum standards to protect drinking water from contamination by sub-surface injection of fluids	Solid waste disposal criteria will require considerable attention to siting and residual management. Protection of ground water and environmentally sensitive areas will be emphasized New state regulations may arise as geothermal technology is adopted
Geothermal Steam Act	Land use, see Concern 7 in Table 4-1.	Geothermal Steam Act of 1970 restricts land leasing. A large percentage of geothermal resources are on federal land. Provisions of Endangered Species Act apply.	
	Subsidence, see Concern 4 in Table 4-1.	None	Regulations to limit or preclude subsidence may be proposed.
	Enhanced seismicity, see Concern 5 in Table 4-1.	None	Regulations to control injection of fluids may be proposed as a means of minimizing inducement of seismic activity.
Occupational Safety and Health Act	H ₂ S	Current standards limit exposure to H ₂ S and other effluents to protect workers.	Improved OSHA standards.

NOTE: This chart displays regulatory impacts on this technology in relationship to the other commercialization candidates for reference.

CONSTRAINTS IMPOSED BY ENVIRONMENTAL LEGISLATION ON EMERGING TECHNOLOGIES

○ potential low impact ● potential high impact ★ Implemented by States and enforced	Toxic Substances Control Act		CLEAN WATER ACT										CLEAN AIR ACT				
	Testing of Chemicals S4,5	Reporting S8	NSPS/BAT S306/301	WQS S304	NPDES	Dredge & Fill 404	Safe Drinking Water Act Part C:UIC	Resource Conservation and Recovery Act	Energy Facility Siting (Land, Air, and Water Availability	Surface Mining Control and Reclamation Act	Fish & Wildlife Coordination Act F&WCA	Endangered Species Act	New Source Performance Standards	PSD/BACT	NA/Lowest Achievable Emission Rate Technology	Visibility/BART	Occupational Safety & Health Act
Coal Liquefaction	●	○	●	○★	●★	○		●★	○★	●★	○		●	●★	●★	●★	●
Coal Gasification	●	○	●	○★	●★	○	●★ (In Situ)	●★	○★	●★	○		●	●★	●★	●★	●
Advanced Electric-Gen.								○★		○★			○	○★	○★	○★	○
Enhanced Gas Recovery			●	○★	●★		○★	○★	○★				○	○★	○★	○★	○
Enhanced Oil Recovery			●	○★	●★		○★	○★	○★				○	○★	○★	○★	○
Oil Shale	●	○	●	○★	●★		●★ (In Situ)	●★	●★	●★			●	●★	●★	●★	●
Coproduction								○	○★				●	○★	●★	○★	○
Urban Wastes	○	○	●	○★	●★			●★	○★				●	○★	●★	○★	○
Air Fuel Ratio																	
Oil Burners & Heat Pump																	
Electric Motors																	
Electric & Hybrid Vehicles								○★									
Hydrothermal					○		●★	○★	○★			○					○
Large Wind Energy									●★		○						
Small Wind Energy									○★		○						○
Small (Low Head) ¹ Hydropower						○			○★		○	○					○
Photovoltaics	●	○						○★									○
Solar Water Heating	○	○						○★	○★								
Passive Solar Space Heating	○	○							○★								

Land use is restricted by the Geothermal Steam Act of 1970, which does not allow interference with multiple land uses. Accordingly, further expansion of geothermal technology may be restricted. Although there are no current regulations on subsidence or induced seismic activity, any significant occurrences would be strong motivation for restrictive legislation and would serve as barriers to public acceptance of the technology.

C. ACTION NEEDED

From an industry viewpoint, the economic viability of vapor-dominated resources was successfully demonstrated before H₂S abatement systems were required. As no H₂S abatement system has yet been demonstrated successfully at the production level, future economic considerations will be modified. In addition, the required (site-specific) levels of abatement have not been determined, nor have the methods for reasonably setting requirements been developed.

The economic viability of utilizing liquid-dominated reservoirs has not been demonstrated in the United States. Parasitic losses, such as power for injection pumps, may approach 25 percent of production. The plants will be more expensive than those for vapor-dominated reservoir use. Several pilot and demonstration units are under construction or in advanced stages of planning to resolve these engineering and economic questions.

Significant, rapid expansion of the Nation's use of geothermal energy requires an active program of environmental research and control-technology research, development, and demonstration. An immediate, compelling need is for the successful demonstration of an abatement system for H₂S suitable for full-production conditions. Industry and DOE are aggressively investigating several potential systems for solution of this problem. One promising system involves removal of H₂S from steam before it reaches the turbine. If successful, this system also could be used when it is necessary to vent steam to the atmosphere.

Because abatement systems cannot remove all detectable H₂S, efforts are needed to allow optimum power plant siting for maximum dispersion of emitted H₂S. In particular, research on models for the prediction of atmospheric dispersion and transport of pollutants over rough terrain is needed. More complete data are also needed on other airborne effluents such as Hg, As, and B from cooling towers. Their rates of accumulation and effects of the environment must be delineated. Baseline and monitoring data for concentrations of these and other parameters are also required. The effects on surface and groundwaters (and resultant ecosystem effects) of disposing of spent geothermal fluids must be investigated fully. This includes the possible effect of reservoir utilization on the flow rates and temperatures of adjacent, existing hot springs with cultural or commercial value.

Management strategies for the optimum use of available water resources on a regional basis are needed so that future confrontations may be avoided. Subsidence will remain an important issue, and detection networks at all utilization locations are required. Until the necessary research is completed, the factors that control

subsidence will not be known, and its occurrence and significance will not be predictable. Networks to monitor seismic activity will also be required until the relationship between reservoir management and seismic activity is understood. It would also be appropriate to provide Federal assistance to local regulatory agencies so that adequate long-range strategies can be developed for ultimate land use and to mitigate socioeconomic effects.

Power plants using liquid-dominated resources, such as those at Wairakei, New Zealand, and Cerro Prieto, Mexico, have been successful. They do present environmental impacts, however, that would not be acceptable in the United States. These include discharge of spent fluids to surface waters and the uncontrolled release of H_2S to the atmosphere. Operating experience at these and other utilization sites has provided a great deal of data concerning the effluents and environmental impacts that might be expected. Some impacts are quite serious and will require extensive R&D efforts to resolve, but the prospect of solution is good, provided that effective coordination and cooperation is maintained to achieve needed control technologies and public acceptance through confidence in local planning and regulatory processes.

D. MITIGATION COSTS

The pollution control costs associated with the hydrothermal technology were estimated under two regulatory conditions (Appendix B). The initial case assumed that only existing standards were operable. In that scenario, the annualized control costs of meeting extant standards were estimated to be \$0.20/10⁶ Btu (steam) and 3.5 mills/kWh (electric). In the second case, costs were determined assuming that standards likely to be proposed were in effect. The latter is then a more stringent case, including costs of meeting existing standards and those costs that can be reasonably estimated for foreseeable standards. Those annualized costs are estimated to be \$0.62/10⁶ Btu and 9.8 mills/kWh, respectively.

It should be noted that significant uncertainties are associated with these estimates, for the following reasons:

- Several independent sources were consulted for each scenario.
- The cost estimates were first order approximations involving the use of standard factors and extrapolation.
- Costs associated with site-specific requirements and the uncertainties of regulatory process were not considered.

Appendix B further discusses the uncertainties associated with these control cost estimates.

HYDROTHERMAL ELECTRIC AND DIRECT HEAT

APPENDIX A - MAJOR ENVIRONMENTAL REQUIREMENTS AND R&D

Concerns	Requirements and R&D	Estimated Research Completion Time (yr)	Resources (\$)		Environmental R&D "Uncertainties"
			Project Status	Additional	
<p>A. <u>Release of Airborne Effluents</u></p> <p>Hydrothermal fluids typically contain a number of compounds such as CO₂, NH₃, As, H₂S, CH₄, Rn, Hg, and B. These and other chemicals such as salts in cooling tower drift may be released to the atmosphere; impacts may occur on local ecosystems and on human health.</p>	A.1 Analyze atmosphere emissions, transport, and fate of H ₂ S (required for completion of demo plant #1.	1 year after plant completion	\$500K Planned	\$500K	If analysis shows that H ₂ S could not be sufficiently abated and thereby exceeded California standards, further permitting would not be allowed.
	A.2 Conduct a computational modeling study of the fate of H ₂ S and complete verification tests.	2 years	\$750K Planned	\$750K	If modeling identified H ₂ S "sink" then well would need to be closed and additional studies would be needed to establish siting criteria
	A.3 Analyze atmospheric emissions and fate of H ₂ S at Raft River	1 year after Plant completion	\$500K Planned	\$500K	Unlikely to demonstrate effect.
	A.4 Determine the effects of H ₂ S and boron on crops	3 years	\$100K Ongoing	\$200K	Studies will likely indicate no significant negative effect of boron on crops.
	A.5 Determine the state-of-the-art of air pollution controls for geothermal in terms of removal effectiveness for H ₂ S and other pollutants, cost, reliability, and inadequacies.	3 years	\$56K Ongoing	\$30K	Actual performance and cost of airborne effluent abatement may render advanced control hardware prohibitive. The efficacy of the state-of-the-art process has not been proven; even if successful the system is not economically practical for backfitting to older units and cannot be used when steam must be vented to release pressure.
	A.6 Develop R&D for control options for existing and anticipated regulations to support commercialization.	3 years			

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<p><u>B. Release of Waterborne Effluents</u></p> <p>Large volumes of spent geothermal fluids and cooling tower blowdown will be generated. They may contain dissolved volatile compounds and large quantities of dissolved solids. The concern is for long-term disposal of such fluids so that beneficial sources of water are protected.</p>	<p>B.1 Establish the fate of inorganic pollutants from cooling tower drift after demo plant #1 and Raft River plant are completed.</p>	1 year after plant completion	\$500K Required	\$500K	If inorganic pollutants drift onto or into human food or water, resource studies will be needed to determine health and safety.
	<p>B.2 Establish the fate of soluble inorganic elements in surface water and aquifers after demo plant #1 and Raft River plant are completed.</p>	2 years after plant completion	\$300K Required	\$300K	If studies show significant addition of inorganics to surface or aquifer waters studies will be needed to determine their definitive distribution and fate.
	<p>B.3 Determine the state-of-the-art of water pollution control options (surface and subsurface) for treating and disposing of waste; analyze cost effectiveness, reliability, and inadequacies.</p>	2 years	\$249K Ongoing	\$300K	Use of injection back into the reservoir is the planned method of disposal, but has not been successfully demonstrated over long periods of time. To prevent operational problems, settling and/or treatment ponds for this water may be required prior to injection.
<p><u>C. Noise</u></p> <p>Uncontrolled noise levels associated with exploration and drilling, well venting, and operational processes can reach level as high as 120dBA and may have deleterious effects on human populations and local fauna.</p>	<p>C.1 Evaluate the effects of noise on behavior and reproductive capacity of local animal species.</p>	1 year after plant completion	\$100K	\$100K	Studies are likely to demonstrate no significant effect. However, the Perigrine Falcon (endangered specie) nesting habits may be affected in which case, pressure may be brought to bear -- precluding further development in some parts of the Geyser area.
	<p>C.2 Define the state-of-the-art of noise abatement systems in terms of effectiveness, cost, reliability, and inadequacies.</p>	1 year	\$125K Planned	\$125K	Actual performance and cost effectiveness may render advanced noise abatement systems economically prohibitive.

HYDROTHERMAL ELECTRIC AND DIRECT HEAT
APPENDIX A - MAJOR ENVIRONMENTAL REQUIREMENTS AND R&D

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			Project Status	Additional	
<p><u>D. Subsidence</u></p> <p>The removal of large quantities of hydrothermal fluid may result in subsidence. The importance of subsidence will be site-specific; at locations such as The Imperial Valley where the geothermal reservoirs are overlain with agricultural land, subsidence could be significant impact.</p>	<p>D.1 Conduct pre-operational and operational measurements in the Imperial Valley to establish rates of subsidence.</p>	<p>3 years after demo plant completion</p>	<p>\$100K Ongoing</p>	<p>\$50K</p>	<p>If subsidence at Imperial Valley significantly affects agricultural ventures or practices, either further geothermal development will not be permitted or economic trade offs will be demanded which may preclude further development. The extensive study of subsidence at the Raft River plant Idaho cannot be evaluated at this date for lack of information. However, findings of subsidence effects will delay commercialization until new methods of prevention can be developed.</p>
	<p>D.2 Verify practices in subsidence control as done in the field.</p>	<p>2 years</p>	<p>\$200K Planned</p>	<p>\$200K</p>	<p>Because of site-specific problems, control practices will need to be developed that would be suitable for each site.</p>
<p><u>E. Enhanced Seismicity</u></p> <p>The withdrawal and/or injection of hydrothermal fluids may enhance the frequency or magnitude of seismic events.</p>	<p>E.1 Conduct pre-operational and operational microseismic studies at demo plant #1.</p>	<p>3 years after plant completion</p>	<p>\$100K Ongoing</p>	<p>\$300K</p>	<p>Studies are likely to demonstrate that seismicity will not be significantly enhanced.</p>
	<p>E.2 Conduct pre-operational and operational microseismic studies at the Raft River plant.</p>	<p>3 years after plant completion</p>	<p>\$150K Required</p>	<p>\$150K</p>	<p>Studies are likely to demonstrate that seismicity will not be significantly enhanced.</p>
	<p>E.3 Verify seismic control practices as done in the field.</p>	<p>2 years</p>	<p>\$140K Planned</p>	<p>\$140K</p>	<p>The actual conditions under which micro-seismic events are caused are not known with certainty. In particular, it is not known whether anticipated injection pressures will initiate micro-seismic events. If, however, findings indicate a correlation, it is likely that local "groups" will develop institutional barrier to preclude further development.</p>

HYDROTHERMAL ELECTRIC AND DIRECT HEAT

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Concerns	Requirements and R&D	Estimated Research Completion Time (yr)	Resources (\$)		Environmental R&D "Uncertainties"
			Project Status	Additional	
<p><u>F. Water Use</u></p> <p>Many proposed methods of utilizing geothermal energy will require outside sources of water for cooling systems. As many geothermal resource areas are in semi-arid regions, conflicts concerning the most beneficial uses of water may arise.</p>	F.1 Assess water resource availability and uses.	1 year	Required	\$250K for each KGRA	Findings may indicate that water use conflicts can not be settled amicably and therefore further development would be delayed by court cases.
<p><u>G. Land Use</u></p> <p>Some geothermal developments may cause land use conflicts. They may threaten pristine wilderness areas; impact upon habitat of endangered, threatened, or recreationally important species; or conflict with other beneficial uses such as agriculture or recreation.</p>	G.1 Identify flora and fauna baseline conditions within the impact area of the demo plants and the Raft River plant.	1 year	\$75K IVEP Ongoing \$50K Raft River	\$75K \$50K	Studies will likely not develop information that will preclude demo plant development.
	G.2 Determine the impact on ecosystems as a result of operation at demo plants and Raft River plant.	3 years after plant completion	\$75K IVEP Required \$75K Raft River	\$75K \$75K	No significant negative impact is likely to be found; nevertheless, public perception of potential effect may continue to delay
<p><u>H. Social Services, Community Structure, and Impacts</u></p> <p>All hydrothermal development will have an impact through the demand for workers and the influx of money. This impact may be considered positive or negative depending upon the existing community structure and life-style, and may range from negligible to major depending upon the size of the development and the size and diversity of the local economy.</p>	H.1 Analysis of impact of hydrothermal development on the social and economic structure of communities.	3 years	Required	\$300K	Findings will likely not identify factors that would preclude development. Nevertheless, data is necessary for NEPA process.
	H.2 Evaluation of socioeconomic impact of hydrothermal development (4 counties area) Geysers, CA.	3 years	\$100K Ongoing	\$200K	Findings will likely show that large scale development will have significant impact on social structure and life-style.
<p><u>I. System Safety and Occupational Health</u></p> <p>The safety of hydrothermal energy extraction and utilization systems could become a major issue if early significant failures occur. Work place problems are related to noise, H₂S and handling of high pressure, corrosive hydrothermal fluids and explosive fluids such as isobutane and propane which may be used in secondary or tertiary heat exchanges loops.</p>	I.1 Review of OSHA standards and practices related to hydrothermal development.	1 year	Required	\$100K	

APPENDIX B

Environmental Control Cost Estimates

The environmental control costs presented represent first-order estimates for process configurations that have been arbitrarily selected to represent each energy conversion technology. The intent of these costs is to give the reader an appreciation for the relative contribution the imposition of environmental controls may make to total energy costs for a particular technology.

Two environmental control scenarios have been chosen to further indicate the potential, and perhaps significant impact, the more stringent emerging Federal environmental standards may have on energy cost and ultimate marketplace competitiveness. The first scenario is based on meeting near-term-compliance environmental standards similar to those in effect for new utility plants. The second scenario assumes that very stringent environmental standards are promulgated (i.e., for emissions: tighter H_2S , NH_3 , and other effluent control; refractory organics and trace metal control; for solids: long-term organics and trace element control).

There are a number of caveats that must be stressed to emphasize the uncertainty of the numbers presented in Table B-1:

- The variability of the reference technology. Most cost data are highly sensitive to site specific criteria, e.g., feedstock, process configuration, end product mix, and environmental and boundary conditions. Thus, there is a high natural variability of baseline energy costs.
- The lack of actual confirmatory costs. The costs presented, especially for the scenario dealing with future regulations, are based on paper studies, not actual experience. These costs may be subject to drastic change as scale-up and commercial cost data become available.
- The uncertainty of the environmental targets. For most technologies, a complex matrix of overlapping Federal, State, and local environmental standards is evolving. It is extremely difficult to extrapolate to the controlling standards for emerging technologies that represent a moving target in their own right. This situation is further complicated by the potential advent of more stringent future standards.
- The uncertainty of secondary effects associated with controls. Environmental controls should not be isolated from the total energy system; they are an integral part of it; thus process efficiency loss, secondary waste production, additional resource consumption, etc., must be accounted for in assessing the efficacy of the control option. Only cursory consideration was given to these factors in this study. Additionally, the identification of environmental control systems apart from the energy system itself is largely subjective.

Table B-1. Estimated Contribution of Pollution Control Costs to Energy Costs for Hydrothermal

	Current Standards			Future Stringent (Worst Case) Standards		
	Energy* Cost \$/10 ⁶ Btu	Environmental Cost ¹ \$/10 ⁶ Btu	%	Energy* Cost ³ \$/10 ⁶ Btu	Environmental Cost ^{2,4} \$/10 ⁶ Btu	%
Direct Heat	5.2	0.20	4	5.8	0.82	11
	Mills/kwhr	Mills/kwhr	%	Mills/kwhr	Mills/kwhr	%
Electricity	30	3.5	11	36	9.8	27

*Includes environmental cost.

1. Based on MOPP's data (DOE/ET 0010/6) for geothermal steam extrapolated to current cost basis.
2. Based upon expected incremental cost for "worst case" controls of well head abatement (3%) and trace metal cleanup (7%); injection-with-treatment (9%); noise abatement (1%); and safety systems (1%)--total increase of 21% or 6.3 mills/kwhr for electricity. For direct heat, the incremental cost is the same as above but without injection-with-treatment, for an increment of 12% or \$0.62/10⁶Btu.
3. Estimated from "current standard costs" by adding incremental "worst case" control costs.
4. This cost estimate was generated from the column labeled Mitigating Costs in Table 4-1. In several cases a range reflecting uncertainty is represented by the single number appearing above. The assumptions and caveats appropriate for the estimate are in the introduction to this appendix.

GLOSSARY

CFR	Code of Federal Regulations
EV	DOE Office of Environment
KGRA	known geothermal resource area
NEPA	National Environmental Policy Act
R&D	research and development
USGS	U.S. Geological Survey