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**HYDROTHERMAL RESEARCH AND
DEVELOPMENT ASSESSMENT
TASK FORCE REPORT:**

**PROJECTIONS FOR
DIRECT-HEAT APPLICATIONS**

SUBMITTED: APRIL 1982

Prepared for

**DIVISION OF GEOTHERMAL AND HYDROPOWER TECHNOLOGY
U.S. DEPARTMENT OF ENERGY**

Prepared by

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THE SECRETARY OF THE
NAVY
WASHINGTON, D. C.
JANUARY 1, 1914

DEAR SIR:
I have the honor to acknowledge
the receipt of your letter of
the 28th inst.

and in reply to inform you that
the same has been forwarded to
the proper authorities for their
consideration.

Very respectfully,
J. D. LONG

JOHN D. LONG, SECRETARY OF THE
NAVY

WASHINGTON, D. C.

Very truly yours,
J. D. LONG
JOHN D. LONG, SECRETARY OF THE
NAVY

RECEIVED BY THE SECRETARY OF THE
NAVY
JANUARY 1, 1914

Foreword*

The analysis documented herein was begun early in 1980 to determine on a realistic basis the extent to which the U.S. Energy market will develop and utilize hydrothermal resources for direct heat (non-electric) applications, and the effect of the present Federal geothermal energy incentives and other programs on market penetration. The analysis was conducted by applying actual investment decision criteria of the relevant market sectors to economic and geologic aspects of hydrothermal resources. It takes into account such controlling factors as innovation lag time, risk aversion and regional differences in market prices, and availability of alternative fuels, which were not adequately considered in previous analyses.

The size and objectives of all Federal programs are being reassessed and realigned in a major way as this report is completed. Much of the Federal program analyzed in this report is being proposed for elimination, so that the results of the analysis are of real value for quantifying the rate at which the private sector will develop these resources on its own.

The analysis demonstrates that a lower but still significant development of hydrothermal direct use applications will continue to occur if government initiatives are reduced to already existing tax incentives.

John W. Salisbury
Acting Director
Division of Geothermal Energy
Department of Energy
February 23, 1981

* The Research and Development Assessment Task Force was established by Department of Energy's Division of Geothermal Energy (DGE). Early working drafts of the Task Force Reports were submitted to DGE Acting Director Dr. J.W. Salisbury. The Task Force Report was finalized subsequent to the reorganization of the Department of Energy, and the final draft was submitted to the newly formed Division of Geothermal and Hydropower Technology.

Acknowledgement

This document represents the efforts of a team of DOE officials and five non-government organizations. We wish to acknowledge the technical guidance and administrative support provided by Dr. J. Salisbury in his role as the Director of the Task Force. Mr. R. Stephens and Dr. F. Abel made significant contributions to the formulation of the technical approach and data base.

The Review Panel members were most helpful in presenting the industry perspective with regard to this analysis. Their objective critique lead to very beneficial changes in the methodology for the analysis. The Review Panel for this study had the following individuals as its members: Dr. C.W. Berge (Phillips Petroleum Company); Mr. Gerald Hutterer (Republic Geothermal Inc.); Mr. Wayne Portanova; Mr. David McClain (Morrison Knudsen); Mr. John Broderick (Department of Energy), and Mr. Robert Murdoch (Bank of Denver).

The contributions made by the five non-government participants--Engineering and Economics Research, Inc.; EG&G, (Idaho) Inc.; Technicon Analytic Research; University of Utah Research Institute; and New Mexico Energy Institute--are recognized throughout this document.

THE END

It was a long and hard journey, but we have reached the end of the road. The journey was not without its challenges, but we have overcome them all. We have seen the world from a new perspective, and we have learned many things about ourselves and the world around us. We have grown as individuals and as a team, and we are proud of what we have accomplished. The journey has been a wonderful one, and we will cherish the memories of it for the rest of our lives. We have reached the end of the road, but the journey continues. We will continue to grow and learn, and we will continue to explore the world around us. We will continue to be a team, and we will continue to support each other. We will continue to be a family, and we will continue to love each other. We will continue to be a part of the world, and we will continue to make a difference. We will continue to be a part of the journey, and we will continue to be a part of the end.

The journey has been a long and hard one, but we have reached the end of the road. We have seen the world from a new perspective, and we have learned many things about ourselves and the world around us. We have grown as individuals and as a team, and we are proud of what we have accomplished. The journey has been a wonderful one, and we will cherish the memories of it for the rest of our lives. We have reached the end of the road, but the journey continues. We will continue to grow and learn, and we will continue to explore the world around us. We will continue to be a team, and we will continue to support each other. We will continue to be a family, and we will continue to love each other. We will continue to be a part of the world, and we will continue to make a difference. We will continue to be a part of the journey, and we will continue to be a part of the end.

Direct-Heat Research and Development Assessment Task Force

The following organizations constituted the Hydrothermal Direct-Heat Research and Development Assessment Task Force: The University of Utah Research Institute (UURI) was responsible for the development of the resource data base and the estimation of the impacts of selected Federal/DOE program elements on the parameters of the Direct-Heat Model. Technecon Analytic Research developed the Direct-Heat Utilization Model, participated in the collection of investment-decision related data, and handled the technical coordination related to model development and data collection.

EG&G, (Idaho) Inc. had the lead role in developing the screening procedures used for determining the industries to be included in the analysis. The New Mexico Energy Institute (NMEI) was responsible for developing the data base of potential direct-heat users.

Engineering and Economics Research, Inc. (EER) undertook the characterization of potential user industries, and participated in the assessment of the impacts of Federal/DOE program elements on the parameters of the Direct-Heat Model. EER was also responsible for overall project management and coordination, and for the preparation of the documents for this analysis.

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Executive Summary

Low and moderate temperature hydrothermal resources suitable for direct-heat applications are widespread in the United States, having been identified in 37 states. The purposes of this analysis were to realistically evaluate the extent to which these resources might be utilized over the next 20 years, and to assess the probable impact of Federal programs on hydrothermal resource utilization.

The resource developer and the hydrothermal energy user are the two primary entities responsible for stimulating the development and utilization of the hydrothermal resource for electric and direct-heat applications. Most of the high temperature resource development (for electric applications) has been initiated by resource developers. To the developer, there is an essential difference between the utilization of hydrothermal resources for direct-heat application and the utilization of high temperature hydrothermal resources for generate electric power. Developers are deterred from direct-heat projects because of their relatively low rate of return on investment and the relatively small present value of profits. Therefore, direct-heat applications in the near-term will be stimulated by user requirements. For this reason, the users' criteria for deciding whether or not to implement direct applications of hydrothermal energy will be important determinants of market penetration.

The first step in the present assessment was to determine the user types that comprise the bulk of the market. These included district heating systems in cities and towns colocated with resources within a 5 mile radius and 24 industries that use a significant amount of low grade (less than 200°C) process heat.

Representative firms and municipalities were interviewed to determine their willingness to use hydrothermal energy, and to determine the investment decision criteria that would influence their actions. Demand growth over time was estimated on a regional and user-specific basis. Additionally, the distribution and characteristics of known and discoverable hydrothermal resources were estimated, predicting the nature of new discoveries in terms of temperature distribution, geographic location, salinity, and other features. The number of users colocated with resources was then estimated. For each user/resource pair, a discounted capital recovery analysis provided the estimated delivered energy price of hydrothermal energy, and the capital investment required for utilization. Using the investment-decision criteria obtained through the interviews, coupled with a probabilistic model, the fraction of all firms and municipalities likely to invest in hydrothermal energy was estimated. The number of firms within the 24 industrial user categories that might choose to relocate to a given resource area was estimated in a similar manner.

Table I presents the Task Force projections of hydrothermal direct-heat utilization through the year 2000, comparing estimates based on the assumption that the current Federal/DOE program will be continued to estimates assuming termination of the program. The relatively small differences between the two scenarios do not indicate that Federal activities to facilitate the development of hydrothermal resources have been ineffective. On the contrary, the indications are that major impacts have already been felt, and that these impacts are stable and will not be reversed, even if Federal activities were terminated. For example, it is assumed that advances made as a result

TABLE I

**TASK FORCE PROJECTIONS OF HYDROTHERMAL
DIRECT-HEAT UTILIZATION
(Quads Per Year)**

SCENARIO	LIKELIHOOD	YEAR			
		1985	1990	1995	2000
NO FEDERAL/DOE PROGRAM	>95%	0.008	0.031	0.061	0.073
	>50%	0.019	0.058	0.110	0.140
	>5%	0.043	0.105	0.186	0.244
CURRENT FEDERAL/DOE PROGRAM	>95%	0.015	0.040	0.074	0.083
	>50%	0.028	0.070	0.127	0.153
	>5%	0.054	0.120	0.206	0.260

of already completed technological development efforts will not be undone, even if the currently planned Federal/DOE hydrothermal program was to be eliminated altogether.

Additionally, it should be noted that the benefits of the Federal/DOE hydrothermal program are multi-dimensional. Regardless of Federal activities, private industry will exploit the most attractive hydrothermal resources, but the Federal/DOE program is intended to permit the profitable development of resources that might previously have been considered marginal in terms of development potential. If a developer is able to profitably utilize a resource that previously would have been unprofitable, society benefits in many ways. In addition providing a profit to the developer, new employment opportunities are created, local tax bases are broadened, and the economy is benefitted. Additionally, national security is enhanced, because hydrothermal energy can reduce the demand for foreign oil importation.

The accuracy of the predictions based on the current model is dependent upon the input data, which are changing even as this report is being written. Nonetheless, because of the conservative nature of the current analysis, the results clearly indicate the existence of a substantial resource that could be available in the near term with a modest Federal program. It should be noted that a basic assumption underlying the Task Force estimates in this report is that a significant ethanol industry will not develop in the United States during the period under study. If ethanol production were to expand rapidly, it is likely that geothermal direct-heat utilization would also expand more rapidly than currently anticipated.

The 0.153 quads/year that appear to be a likely (>50% probability) contribution by the year 2000 would provide for more than 1% of the incremental increase in residential/commercial/industrial direct-heat use projected for the United States as a whole, and approximately 10% of the increase projected for the West, where the resource is most abundant. In addition to being secure and widely dispersed, hydrothermal resources are among the most cost-effective and environmentally safe alternative energy sources available for development.

1.0 RESULTS, METHODOLOGY, AND RECOMMENDATIONS

1.1 Results

Due to the highly dispersed nature of the resources suitable for direct-heat applications, and the large number of potential applications and users, site-specific estimation of resource utilization was not attempted. A macro-economic approach involving aggregation of users into three relatively discrete groups was pursued. The three user groups are:

- (i) District Heat Users
- (ii) Colocated* agricultural/industrial users
- (iii) Relocated agricultural/industrial users

Ethanol plants were excluded from the present analysis. Each of twenty market regions was analyzed separately, and national totals were developed by aggregating the regional estimates. Figure 1.1 shows the utilization estimates for hydrothermal direct-heat applications systems at five-year intervals (1985, 1990, 1995, and 2000) with and without the currently planned Federal/DOE program (as envisioned in early FY 82). The probable estimates correspond to a likelihood of approximately 50%. It can be observed that with a successful Federal/DOE program, it is probable that hydrothermal direct-heat applications will account for nearly 0.153 quads/year by the year 2000**.

The estimates were computed for three levels of likelihood (>5%, >50% and >95%). The projections were based on the geographic loca-

* Users within a distance of 5 miles of a suitable resource are defined as colocated users.

** The currently planned Federal/DOE program is described in Section 5.

FIGURE 1.1

UTILIZATION ESTIMATES AT >50% LIKELIHOOD COMPARING CONDITIONS OF NO FEDERAL PROGRAM TO THE CURRENT FEDERAL PROGRAM FOR HYDROTHERMAL DIRECT-HEAT

tions of potential users. Table 1.1 presents the estimates for a scenario in which there is no Federal/DOE program, and Table 1.2 presents the estimates for a scenario in which the currently planned Federal/DOE program is continued.

The accuracy of the Task Force estimates will be determined by conditions that could change significantly over the next 20 years. Because of the conservative nature of the current analysis, however, the results clearly indicate the existence of a substantial resource that could be available in the near-term with a modest Federal/DOE program.

The detailed results generated by the model are presented in Section 6. The following is a summary of the important indications emerging from these results:

- It is estimated that the current Federal/DOE program will increase the direct-heat utilization of hydrothermal resources by approximately 10%.
- The 0.153 quads/year that appear to be a likely (>50% probability) contribution by the year 2000 would be more than 1% of the incremental increase over the period 1980-2000 in residential/commercial/industrial direct-heat use projected for the United States as a whole, and 10% of the increase projected for the West, where the resource is most abundant.
- Colocated agricultural/industrial users are expected to account for about 8% of the total annual utilization for direct-heat applications by 2000, and relocated agricultural/industrial users are expected to account for 5% of the national utilization. District heating systems are expected to account for the remaining 87%.
- Little utilization of hydrothermal energy by ethanol plants can be expected unless a vigorous Federal/DOE program for matching these ethanol plants with suitable resources is pursued in conjunction with financial incentives for hydrothermal energy users.
- An analysis of the elements of the Federal/DOE program reveals that:

TABLE 1.1

NATIONAL HYDROTHERMAL DIRECT-HEAT UTILIZATION ESTIMATES:

NO FEDERAL/DOE PROGRAM

YEAR	PROJECTED QUADS PER YEAR WITH A LIKELIHOOD		
	>5%	>50%	>95%
1985	0.043	0.019	0.008
1990	0.105	0.058	0.031
1995	0.186	0.110	0.016
2000	0.244	0.140	0.073

TABLE 1.2

NATIONAL HYDROTHERMAL DIRECT-HEAT UTILIZATION ESTIMATES:

CURRENT FEDERAL/DOE PROGRAM

YEAR	PROJECTED QUADS PER YEAR WITH A LIKELIHOOD		
	>5%	>50%	>95%
1985	0.054	0.028	0.015
1990	0.120	0.070	0.040
1995	0.206	0.127	0.074
2000	0.260	0.153	0.083

- The current regulations for investment tax credits and depletion allowance have a perceptible impact on the projected utilization of hydrothermal direct-heat systems.
- While the downhole pump development program appears to be a major contributor to the reduction of field capital costs, other technological R&D programs will have only limited impact on equipment costs. The downhole pump program, if successful, is expected to result in a five-fold increase in pump lifetime by 1986.
- The ongoing technology RD&D program is expected to increase the average well life from a current value of 20 years to nearly 26 years by 1986.

1.2 Methodology

Past attempts to estimate the utilization potential of hydrothermal direct-heat systems have yielded questionable results because of unsound methodology and/or unrealistic assumptions. Variations in estimation methodology and in the data bases for the resource and the potential users have made it difficult to develop valid projections of the rate of growth of hydrothermal direct-heat utilization.

Estimates of hydrothermal electric power generation can be based upon site-specific analyses. However, site-specific analyses are impractical aids to the assessment of direct-heat applications because of the extremely large number of resource sites. The resources are dispersed among 37 states and display wide variations. There is little information available for predicting the location or characteristics of reservoirs expected to be discovered by the year 2000. Additionally, some of the areas currently classified as electric prospects could be reclassified for direct-heat applications if the actual temperatures and/or flow rates of these prospects prove to be lower than current estimates. It is also possible that hydrothermal electric power generation sites will yield additional energy production which can be utilized for direct-heat applications.

A site-specific resource utilization analysis for hydrothermal direct-heat applications requires the development of a reliable data base of suitable resources and potential users. The New Mexico Energy Institute (NMEI) has developed a computerized data base for ten states in the Rocky Mountain Basin and Range region containing information pertaining to confirmed and prospective hydrothermal resources and potential users. Information concerning the resource and potential users in the state of California was subsequently added to this data base. In the eastern United States, the Applied Physics Laboratory (APL) of Johns Hopkins University has undertaken the task of collecting similar data for 38 states.

Although the combined result of these efforts will be a useful collection of resource and user data, the NMEI and APL data bases are limited in that a large segment of the existing resources is yet to be discovered. It is also anticipated that many potential users may move or expand to locations near hydrothermal resources during the next 20 years. For these reasons, the content of the data bases will undergo significant changes during the time period for the study documented in this report.

The potential users of low temperature hydrothermal energy range from individual home owners to large industrial parks. Possible applications have also been identified in agriculture (e.g., crop drying and ethanol production) and in fuel extraction (e.g., enhanced oil recovery).

Estimates of the cost of field development for hydrothermal direct-heat applications may be based upon the experience of the developers of hydrothermal fields for electric power generation. However, there are insufficient data to reliably predict the cost of

designing, building, operating, and maintaining the plants in which the direct-heat energy will be utilized. To make realistic utilization projections, it will be necessary to arrive at credible estimates of plant costs.

Unlike the hydrothermal electric power industry, there is no developed infrastructure for the direct-heat applications industry. The possible organizational interfaces vary from an arrangement in which the resource developer is also the user to a situation in which a "utility" company provides the link between a developer and the users (as in the case of district heating systems). Investment decision behavior, willingness to relocate, acceptance of new technologies, and many other relevant factors are dependent upon organizational arrangements and upon the alternatives available to potential developers.

To the developer, there is an essential difference between the utilization of hydrothermal resources for direct-heat application and the utilization of high temperature hydrothermal resources to generate electric power: Developers are deterred from direct-heat projects because of their relatively low rate of return on investment and because of their relatively small present value of profits. Therefore, hydrothermal direct-heat utilization in the near-term will be stimulated by user requirements. For this reason, the users' criteria for deciding whether or not to implement direct applications of hydrothermal energy will be important determinants of utilization levels.

The Task Force analyzed potential utilization of hydrothermal direct-heat applications in macroeconomic terms. Thus, the analysis emphasized homogeneous geographic regions and industrial groups. Figure 1.2 presents the regional boundaries used by the Task Force.

FIGURE 1.2

HYDROTHERMAL RESEARCH AND DEVELOPMENT
ASSESSMENT TASK FORCE REGIONAL BOUNDARIES

Site-specific analyses of selected potential direct-heat applications provided the basis for the estimates.

The first step of the assessment was to determine the user types that comprise the bulk of the market. These include district heating of cities and towns colocated with resources, and 24 industries that use a significant amount of low grade (less than 200°C) process heat.

Representative firms and municipalities were interviewed to determine their willingness to use hydrothermal energy, and to determine the investment decision criteria that would guide their actions*. Demand growth over time was estimated on a regional and user-specific basis. Additionally, the distribution and characteristics of known and discoverable resources were estimated, predicting the nature of new discoveries in terms of temperature distribution, geographic location, salinity, and other features. The number of users colocated with resources was then estimated. For each user-resource pair, a discounted capital recovery analysis provided the estimated delivered energy price of hydrothermal energy, and the capital investment requirement for utilization. Using the investment-decision criteria obtained in the interviews, coupled with a probabilistic model, the fraction of firms or municipalities that were likely to choose to invest in hydrothermal energy was estimated. The number of firms within the 24 industrial user categories that might choose to relocate to a given resource area was estimated in a similar manner.

* Telephone interviews were conducted with 238 industrial units, 19 communities/municipalities, and 16 real estate developers.

To assess the impact of the Federal/DOE programs on the implementation of hydrothermal direct-heat application systems, the various elements of the program were mapped onto the parameters of the utilization model. These modified parameters formed the basis of the projections with the presence of the currently planned Federal/DOE program.

The direct-heat applications analysis group was composed of senior DGHT officials, DOE laboratories, universities, and private contractors with requisite expertise. A review panel representing many years of geothermal experience and a variety of specialties among its members was convened. The members of this panel provided regular input to the analysis. The critique provided by this panel ensured that the methodology and assumptions associated with the analysis were consistent with decision processes followed in the geothermal industry.

The direct-heat utilization analysis involved seven major segments:

- Resource data base development
- User data base development
- Market characterization and screening of industries
- Industry contacts for collecting investment decision related inputs
- Model development
- Assessment of the impact of the Federal/DOE program and sensitivity analysis
- Documentation

Figure 1.3 shows the responsibilities of Task Force members with regard to this analysis.

FIGURE 1.3

RESPONSIBILITIES OF TASK FORCE MEMBERS

1.3 Recommendations

On the basis of the experience gained during the the direct-heat applications analysis, the following recommendations* are offered:

- In the near-term, a very substantial part of the projected utilization is attributable to district heating systems and colocated agricultural/industrial users. In the context of this observation, it is recommended that a sensitivity analysis of the impact of the definition of colocation on the projections be determined. If the results show that projections are sensitive to the definition, regional or industry specific definition of colocated users may be indicated.
- The cost impact of transporting hydrothermal fluids over long distances to district heating systems on the likelihood of the development of the various candidate district heating systems should be analyzed in detail.
- Because investment decision behavior of developers of district heating systems will not necessarily be similar to that of the industrial sector, it is recommended that a site-specific evaluation of a few top-ranking candidate district heating systems be carried out. In this analysis the system costs should be estimated, and the investment-decision simulation should be based on inputs secured from specific decision makers at the sites.
- In the mid- and long-terms, ethanol plants could represent major proportions of the total direct-heat utilization of hydrothermal resources. A thorough analysis of the potential for development of the ethanol production industry would greatly enhance the validity of attempts to estimate the growth of hydrothermal direct-heat utilization.
- Because the utilization plant capital and O&M cost data were found to be inadequate, it is recommended that an effort be made to develop a comprehensive and accurate data base of utilization plant cost estimates.

1.4 Organization of the Report

The remainder of this report is organized in the following fashion:

* Some of these recommendations were implemented and resulted in the modification of the results which were developed during the first phase of this study.

- Section 2: The Direct-Heat Model

The model developed by Technecon Analytic Research is presented in this section. Additionally, the major assumptions underlying the model are discussed.

- Section 3: Resource Data Base

This section describes the techniques employed and the assumptions made in characterizing hydrothermal resources, in establishing resource confirmation rates, and in evaluating the effects of the Federal/DOE program on hydrothermal direct-heat utilization. A summary of the resources for direct-heat applications is presented and estimates for site-specific collocated and non-collocated direct-heat resources are furnished.

- Section 4: User Screening Data

This section summarizes the screening process and the ultimate selection of potential industries for hydrothermal direct-heat applications, based on four screening criteria. The decision factors that may influence prospective users are also discussed.

- Section 5: Impact of the Federal/DOE Geothermal Program

The Federal/DOE program for direct-heat applications is presented, along with its corresponding impacted parameters. The methodology used in analyzing the program is illustrated. In addition, quantitative estimates of some of the impacted parameters are presented.

- Section 6: Results

Results generated by the model assuming implementation of no Federal program and assuming continuation of the currently planned Federal/DOE program are presented. These results give estimates for five-year intervals from 1985-2000, under three probabilities or likelihoods (>5%; >50%; >95%).

- Appendix A: Technical Discussion of the Hydrothermal Direct-Heat Model

A detailed technical discussion of the Direct-Heat Model is presented.

2.0 MARKET PENETRATION MODEL

2.1 Model Overview

Figure 2.1 illustrates the structure of the computerized hydrothermal direct-heat utilization model. For each potential user/resource pair, a discounted capital recovery (DCR) analysis provided the estimated delivered energy price of hydrothermal energy and the capital investment requirements for utilizing this energy. Project capital costs, recurrent costs, and utilization factors were based upon figures provided by EG&G. The discounted cost flow (DCF) analysis incorporated various component escalation rates derived from the Wharton Annual Model with estimated federal, state, and local tax liabilities and credits. Table 2.1 summarizes the several input parameters which were used in the analysis. Bulleted (•) items were considered to be site-specific, varying from resource to resource and/or user to user. Non-bulleted items were considered to be fixed in the model.

For the purposes of this analysis, district heat distribution systems were assumed to be financed and owned by regulated, tax-exempt municipalities. Hydrothermal fluid suppliers were assumed to be non-regulated and able to take advantage of tax incentives.

2.2 User Decision and Implementation Modeling

Included in the 270 industry interviews conducted by the Task Force were questions pertaining to preferences for (or aversions to) utilizing hydrothermal energy under various combinations of: (a) delivered energy cost relative to that of their alternative fuel, (b) capital investment requirements, (c) energy supply reliability, and

SOURCE: TECHNECON

FIGURE 2.1
HYDROTHERMAL DIRECT-HEAT UTILIZATION ANALYSIS SEQUENCE

TABLE 2.1
DIRECT-HEAT MODEL PARAMETERS

<u>RESOURCE PARAMETERS</u>	<u>ECONOMIC & TAX PARAMETERS</u>
<ul style="list-style-type: none"> • Well-Head Temperature • Contamination Index • Well Flow Unpumped • Well Flow Pumped • Well Cost • Producing Acreage • Fluid Specific Heat 	<ul style="list-style-type: none"> • Inflation Rates: Energy • Energy Prices • Energy Use Efficiencies
<ul style="list-style-type: none"> Spare Well Fraction Producer/Injector Ratio Well Spacing Well Rework Fraction Well Rework Cost Well Redrill Fraction Well Redrill Cost Dry Well Fraction Dry Well Cost 	<ul style="list-style-type: none"> Project Book Life Project Tax Life Depletion Allowance Royalty Fraction Intangible Well Cost Fraction Investment Tax Credit Add'l Investment Tax Credits Equity Fraction Equity Return Long Term Debt Cost Local Tax Rates State Tax Rate Federal Tax Rate User's Discount Rate GNP Deflator Inflation Rate: Maintenance Inflation Rate: Construction
<u>USER PARAMETERS</u>	
<ul style="list-style-type: none"> • Annual Heat Requirement • Temperature Requirement • Annual User Factor • Alternative Fuel Type 	
Temperature Loss and Pinch	

SOURCE: TECHNECON

(d) projected risk. Binary (yes/no) responses were tabulated by user category. Response data were then subjected to a multiple regression analysis of a multivariate logit model. Figure 2.2 presents the steps involved in determining learning curve (N_p , N_c) and N^* , the implementation rate curve.

The logit model estimated the fraction of firms within a given user category that are likely to respond positively to a hydrothermal utilization decision. The decision is characterized by four project attributes, (a) through (d), listed in the preceding paragraph. Statistical tests of confidence indicate that the logit decision models provide acceptable "goodness of fit" to the industry supplied behavioral data. F-statistics (Fisher-Snedecor F test used for standard deviation of samples taken from a normally distributed population) for the multiple regressions indicate good fit at 95% confidence levels and coefficients of determination (corrected for degrees of freedom) fell between 0.5 and 0.6.

The logit model represents one part of the overall user decision model illustrated in Figure 2.3. Also included in the complete model were: (i) an exclusion factor, (ii) a learning curve, and (iii) an implementation rate curve. The exclusion factor was estimated for each user category from industry interviews and represented the fraction of firms that would not consider utilizing hydrothermal energy regardless of incentives. The shape of the learning curve for each user category was determined from an analysis of interview responses combined with published data on industrial innovation characteristics. As shown in the lower left hand corner of Figure 2.2, learning

FIGURE 2.2

HYDROTHERMAL DIRECT-HEAT USER DECISION MODEL
LOGIT FUNCTION, LEARNING CURVE, AND IMPLEMENTATION RATE CURVE

SOURCE: TECHNECON

HYDROTHERMAL DIRECT-HEAT MODEL:

COLOCATED RESOURCES AND USERS

curves provide the fraction of firms that are informed and in a position to make a decision about hydrothermal utilization.

As shown in the center of Figure 2.3, the asymptote of the S-shaped logit model was defined by the combined influences of the exclusion factor and the learning curve. N^* represents the Logit estimate of positive response fraction as a function of the multivariate stimulus S^* . The rate at which N^* firms are expected to put hydrothermal energy into use was estimated by the curve, which considered decision and construction lags and the retirement of existing process heat equipment. The curve was constructed for data compiled from the industry interviews conducted by the Task Force.

The Task Force effort discussed in this section provides a means to estimate hydrothermal direct-heat utilization based upon the individual components of an accepted market diffusion model.

3.0 RESOURCE DATA BASE

3.1 Introduction

This section describes the techniques employed in characterizing hydrothermal resources and in estimating the number of resources in the United States that are available for discovery and confirmation in the 1980-2000 interval. The Earth Sciences Laboratory Division of the University of Utah Research Institute (UURI) provided most of the effort for these tasks. Separate but parallel consideration was given to resources suitable for direct-heat applications and to those suitable for electric power generation, but only the results for non-electric quality resources are reported here.

Figure 3.1 illustrates the work flow. Because resources colocated with a user are treated differently in the investment decision model from those that are not colocated with a user, resources were dichotomized as colocated or non-colocated. Characteristics and mode of occurrence of known hydrothermal resources were used to predict characteristics for undiscovered resources and the number of resources potentially available for confirmation. These results were provided to Technecon as input data for the investment decision model.

3.2 Definitions

In this and other sections of this report the following terminology is used:

- Hydrothermal Resource - An underground source of geothermal fluids.
- Prospect - A site having hydrothermal resource potential.
- Discovery - A prospect where drilling has demonstrated the existence of hydrothermal fluids potentially suitable for application.

FIGURE 3.1

SOURCE: UURI

PROCEDURE FOR ESTIMATING THE SIZE AND
CHARACTERISTICS OF HYDROTHERMAL RESOURCES

- Confirmed Reservoir - A discovery where detailed geological and resource engineering assessment has confirmed the existence of geothermal fluids of sufficient quantity and quality for electric power generation and/or direct-heat application.
- Exploitable Reservoir - A confirmed reservoir for which utilization engineering studies and economic evaluation have shown economic viability for electric power generation and/or direct-heat application.
- Developed Site - An exploitable reservoir that supplies geothermal fluids to an application plant.

Figure 3.2 illustrates that a given site moves through the sequence of classification indicated above with expenditure of money and time, provided, of course, that a usable resource exists at the site in the first place.

3.3 Characterization of the Resource

Data to support characterization of hydrothermal resources came from many sources. USGS Circular 790 (Muffler, 1978) was used extensively. This document contains estimates of the characteristics of individual geothermal systems with temperatures of at least 90°C. The data base was extended to include resources down to 30°C by supplementing the data in Circular 790. UURI staff experience in geoscientific investigation of numerous low- and moderate-temperature geothermal sites, familiarity with geothermal resource data developed by DOE/DGHT through the State Coupled and other programs, and participation with USGS personnel in data compilation and analyses for Circular 790, were all applied to the project. Data from midwestern and eastern resources were obtained from Gruy Federal and from the Applied Physics Laboratory (APL) of Johns Hopkins University.

FIGURE 3.2

DEVELOPMENT SEQUENCE FOR GEOTHERMAL SITES

3.3.1 Summary of Known Resource Base

As a practical matter, hydrothermal electric power generation requires brine temperatures of at least 150°C. By contrast, heat pumps and other augmentation devices allow direct-heat utilization of hydrothermal fluids with temperatures only slightly exceeding normal groundwater temperature. Figure 3.3 shows the distribution of various resource types in the 48 contiguous states. Information for this figure was taken mainly from Muffler (1978), where a more detailed discussion and more detailed maps can be found. It should be emphasized that the present state of knowledge of geothermal resources of all types is poor. Because of the very recent emergence of the geothermal industry, there has been insufficient exploration to permit an authoritative assessment of available resources. Each year brings more resource discovery, so that Figure 3.3 will rapidly become out-dated.

Figure 3.3 shows that most of the known hydrothermal resources and all of the sites that are presently believed to be adequate for hydrothermal electric power generation are located in the western half of the U.S. The preponderance of thermal springs and other surface manifestations of underlying resources is also in the west. Large areas underlain by warm water in sedimentary rock have been identified in Montana, North and South Dakota, and Wyoming (the Madison Group of aquifers), but the extent and potential of these resources is poorly understood. Another important large area, much of which is underlain by low-temperature resources, is the northeast-trending Balcones fault zone in Texas. The geopressured resource areas of the Gulf Coast and surrounding states are also shown but were not included in this study.

Resource areas indicated in the eastern states are speculative because little drilling has been done to confirm their existence.

Regarding the temperature distribution of geothermal resources, low- and intermediate-temperature resources are more plentiful than are high-temperature resources. There are many thermal springs and wells that have water at a temperature only slightly above the mean annual air temperature (which is generally equal to the temperature of non-geothermal shallow ground water). Resources having temperatures above 150°C are infrequent, but represent important occurrences. Muffler (1978) shows a statistical analysis of the temperature distribution of hydrothermal resources and concludes that the cumulative frequency of occurrence increases exponentially as reservoir temperatures decreases (cf. Figure 3.4). This relationship is based only on data for known occurrences that have temperatures equal to or greater than 90°C in the western United States. Nonetheless, this analysis provides a useful means of predicting the number of similar resources of lower temperatures. Based upon this relationship and the wide areal distribution of resource areas shown in Figure 3.3, we can have confidence in the existence of a large and widespread low-temperature resource base.

3.3.2 Generic Resource Categories

An important task to facilitate handling of the large amount of resource data was that of categorizing resource types through use of the physical characteristics that together distinguish each type. Cassel et al. (1979) have determined which resource characteristics are most important in economic decision-making processes. Their list

SOURCE: UURI

FIGURE 3.4

FREQUENCY OF OCCURRENCE VS. TEMPERATURE FOR GEOTHERMAL
RESOURCES

of characteristics is given in Table 3.1, along with the ranges in values used to characterize generic hydrothermal resource types (Earth Science Laboratory Division, 1980).

Resource characteristics other than those shown in Table 3.1 were relegated to a list of constant or dependent characteristics (presented in Table 3.2) or were dropped from further consideration because of lack of significant impact in terms of the present study. For each constant resource characteristic, either the investment decision model was relatively insensitive and an average value can be used, or the model was sensitive to the particular characteristic but the characteristic did not vary significantly. Each dependent resource characteristic could be reliably estimated as a function of other parameters of the model, and so no independent estimate was required.

The generic type was expressed as a number such as 752261, and was derived from the range numbers shown across the top in Table 3.1 by listing in order the range number for the following characteristics: temperature, unpumped flow rate, brine contamination index, well costs, pumped flow rate, and producible acreage. As an example, Table 3.3 illustrates characteristics typical of a resource of generic type 752261.

Because the temperature range of hydrothermal resources was divided into 8 categories (cf. Table 3.1), the unpumped flow rate into 7 categories, etc., Table 3.1 implies that there are a total of $8 \times 7 \times 3 \times 6 \times 7 \times 8 = 56448$ possible generic categories. Actually this study identified about 200 generic resource types that are reasonably representative of all known and undiscovered hydrothermal

TABLE 3.1

VARIABLE GENERIC RESOURCE CHARACTERISTICS AND THEIR RANGES

PARAMETER	RANGES							
Range No.	1 ^a	2	3	4	5	6	7	8
Temperature (°F)	≥100 150	≥150 <200	≥200 <250	≥250 <300	≥300 <350	≥350 <400	≥400 <450	≥450
Unpumped Flow Rate (10 ³ lbs/hr)	<50	≥50 <100	≥100 <200	≥200 <400	≥400 <600	≥600 <800	≥800	
Brine Contamination Index (TDS)	0 (<2,000)	1 (2,000- 100,000)	2 (>100,000)					
Well Costs (\$M)	>2	<2 ≥1	<1 ≥0.5	<0.5 ≥0.3	<0.3 0.1	<0.1		
Pumped Flow Rate (10 ³ lbs/hr)	<50	≥50 <100	≥100 <200	≥200 <400	≥400 <600	≥600 <800	≥800	
Produc. Acreage ^b	5,000 10,000	5,000 7,000	3,000 7,000	1,000 7,000	650 5,000	2,000 5,000	650 3,000	650 1,500

^aThe generic resource characteristics parameter values for a given reservoir can be located in more than 1 column (e.g., a reservoir could have temperature range 1, flow rate 3 and well cost rate 4).

^bThe top figure is the producible acreage at a 99% confidence level, and the bottom figure is the producible acreage at a 50% confidence level.

TABLE 3.2

CONSTANT OR DEPENDENT RESOURCE CHARACTERISTICS

<u>Parameter</u>	<u>Value</u>		<u>Function Of</u>
	<u>Electric</u>	<u>Non-Electric</u>	
Exploration Costs	\$6m	\$1m	-
Well Spacing	40 acres	NA	-
Reservoir Life	30 yrs.	30 yrs.	-
Injection Well Costs	0.9	0.9	Well Costs
Injection Well Fraction	0.5*	0.8*	No. Production Wells
Redrilling (Workover) Costs	0.35	0.35	Well Costs
Redrilling (Workover) Fraction	0.33	0.33	No. Production Wells
Dry Well Costs	0.9	0.9	Well Costs
Dry Well Fraction	0.25	0.25	No. Production Wells
Spare Well Fraction	0.2	0	No. Production Wells

SOURCE: UURI

*At least one injection well needed.

TABLE 3.3

EXAMPLE

GENERIC RESOURCE CHARACTERISTICS

RESOURCE TYPE 752261

<u>Parameter</u>	<u>Value</u>	<u>Range No.</u>
Temperature (°F)	≥ 400 < 450	7
Unpumped Flow Rate (10 ³ lb/hr)	≥ 400 < 600	5
Brine Contamination Index (TDS)	1 (2,000-100,000)	2
Well Cost (\$M)	> 2 ≤ 1	2
Pumped Flow Rate (10 ³ lb/hr)	≥ 600 < 800	6
Maximum Produccible Acreage	7,500	1

SOURCE: UURI

resources suitable for direct-heat application and electric power generation.

One of the problems in placing a particular hydrothermal resource into a generic category was that of some resource characteristics can be estimated with greater confidence than can others, since there are few data available for some of the resource characteristics considered. These aspects are discussed below:

Well-Head Temperature. In general, the confidence level for the temperature data is fairly high. Well-head temperature values were based on measured downhole temperatures or, where this was not available, on geothermometer estimates (Muffler, 1978). Surface temperatures of springs or wells were used if other data were not available. At some sites, particularly in the East, representative thermal gradients were applied to reported surface temperature to postulate temperatures expected at reservoir depth.

Unpumped Well Flow Rate. The confidence level of this parameter is less than that for wellhead temperature. Flow rates are known only in the few reservoirs with production test data. Average flow rates of springs were evaluated and selected as the lower bound in well flow rates. It should be noted that flow rates are variable within a given hydrothermal reservoir, reflecting not only intrinsic characteristics of the resource itself, but also successful selection of a drilling site and use of appropriate drilling and completion techniques. Nevertheless the flow rates postulated here are believed to be representative of what will be found in future geothermal discoveries.

Brine Contamination Index. The values for the brine contamination index are reliable. Many lower-temperature resources contain only small amounts of dissolved substances. Some are actually potable. Typical numbers range from a few hundred parts per million (ppm) for a typical 90°C resource to perhaps 18,000 ppm, for a 200°C resource. At a few sites the amount of dissolved salts is quite high, ranging up to 30% for parts of the Imperial Valley of California and in a few places in the Madison and associated aquifers.

Well Costs. Well costs were determined by accounting for both drilling costs per foot and depth of known and predicted resources. They were expressed in 1978 dollars, and the economic model applied the appropriate correction to 1980 dollars. Drilling costs are fairly well known (Chappell et. al., 1979), and the distribution with depths of known re-

sources is well known. Therefore the distribution of well costs used in this study should be quite reliable.

Pumped Well Flow Rates. Pumped flow rates are highly variable among the few resources that have been tested. We used available data and supplemented them with the somewhat more numerous data on unpumped flow rate by noting that for high unpumped flow rates no pumping would be necessary and that pumping would generally increase flow rate by 1 or 2 range numbers (see Table 3.1).

Producible Acreage. Information on producible acreage is available for only a few reservoirs. Estimates were given for acreage at three levels of confidence, 95%, 50% and 5%. In most cases estimates were made on the basis of geologic models. For example, the conceptual model for the Basin-and-Range type of fault-controlled resource -- which occurs mainly in Regions 1, 2, 3, 5, 6, and 9 -- suggests that the producible area is restricted to specific fault zones. In contrast, the producible area for a resource controlled by an aquifer in a deep sedimentary basin such as the Madison aquifer in Regions 7 and 11 is very large, and a well properly drilled and completed anywhere into the warm aquifer has an excellent chance of production.

3.4 Resources Available for Discovery and Confirmation

A primary task of the resource group was to predict the number, location, and resource characteristics for sites where discovery and reservoir confirmation could take place by the year 2000, provided that a sufficient level of exploration is maintained. The actual level of exploration and of hydrothermal development in the future will be a function of the extent to which positive decisions are made to invest in hydrothermal development. This is estimated by the investment decision model. An analysis of resources that would be candidates for development was provided to the investment decision model by specifying region and predicted generic resource category.

At a few locations, undeveloped confirmed reservoirs exist today. Other, more numerous locations are prospects today and are in need of further exploration work to become confirmed reservoirs. At other

locations that are not even prospects today, future exploration will result in discoveries. Based on experience with exploration for hydrothermal and other types of mineral resources the following guidelines were used in estimating resource discoveries and resource confirmations.

- 1) Current resource data can be extrapolated to unknown, undiscovered resources.
- 2) New reservoir confirmations to the year 2000 will occur in known areas of high geothermal potential, in known geologic environments.
- 3) New, more successful exploration techniques and strategies will be developed within the known geothermal favorable environments.

Development of a given resource depends to a substantial extent on whether or not the resource is located near a user. Although a variety of users can usually be identified for a resource in or near a population center, more remote sites will only be developed if they are desirable enough to cause industry to move to the site. In cases where flows and temperatures from a remote resource are sufficiently high, the fluids may be used to generate electricity, or they might be piped to a user.

There are differences in the geologic mode of resource occurrences that bear on the question of colocation. Most resources in the West are "point" resources, in that the area of geothermal fluid at a given site extends over only a few acres or perhaps as much as a few square miles. Well locations must be very carefully selected on the basis of geology to intersect the producing horizons. There is usually no option to move the well location nearer to the user. By contrast there are resources (e.g., the Balcones Zone in Texas or the Madison aquifer in North and South Dakota, Montana, and Wyoming) that

extend over thousands of square miles. Any consumer of heat energy located over one of these extended resources could be considered a potential user and successful wells can often be drilled for pre-existing plants where energy is needed. For purposes of analysis in the economic decision-making model, resources were divided into two major categories: those colocated with a potential user (within 5 miles) and those not colocated with a potential user. Large aquifers of the Madison type were considered to be colocated resources because users can be found in any city or town over the aquifer.

3.4.1 Colocated Resources

Many cities and towns, especially in the western United States, have hydrothermal occurrences nearby. Several sites have seen development of natural hot springs for district heating purposes: examples are Boise, Idaho; Klamath Falls, Oregon; and Pagosa Springs, Colorado. In other areas, drilling for groundwater development has inadvertently found thermally anomalous waters.

A list of cities and towns that have known colocated hydrothermal occurrences was compiled by New Mexico Energy Institute (NMEI) from computer files. UURI supplemented this initial list in terms of the characteristics of the resources and assigned generic category numbers to the sites. The distribution of postulated resources with temperatures was adjusted to fit the lognormal resource distribution discussed previously.

A resource data base was developed for the Madison Group aquifer, the Balcones fault zone, and the radiogenic and deep basin targets on the East Coast. Individual counties within each state with

potential for these types of resources were identified. One generic resource category matching the known or inferred resource characteristics of the aquifer was assigned by UURI to each county. NMEI then identified cities in each of these counties that would have users sufficient to drill and develop these resources. All of these data were transmitted to Technecon to be input to the investment decision model.

3.4.2 Non-Colocated Resources

There are many more non-colocated resources than colocated resources in the western United States. The non-colocated resources were estimated from the distribution of known resources by considering each area of known or likely geothermal occurrence away from cities and towns, and the potential for discovery in each area. The distribution of resources with temperatures was adjusted to fit the presumed lognormal resource distribution.

3.4.3 Postulated Resource Base

Figure 3.5 shows by region the total resources, postulated to be available for discovery and confirmation by the year 2000. A total of 2568 resource areas have potential for confirmation and development, provided that sufficient incentive exists to explore and develop these resources. Incentives for exploration and development are evaluated by the investment decision model. Particular locations where discovery and resource confirmation are predicted within each region are listed in Table 3.4.

Figure 3.6 shows the distribution of postulated resources by temperature. The distribution is more heavily skewed toward the low-

FIGURE 3.5

POSTULATED RESOURCES BY REGION

SOURCE: UURI

TABLE 3.4

GENERAL AREAS POSTULATED TO HAVE HIGH POTENTIAL FOR THE
DISCOVERY OF GEOTHERMAL RESOURCES

Region	STATES(S)	General Areas with Potential for High-Temperature Discoveries, with Moderate- and Low-Temperature Halos (Wright and others, 1980a, 1980b)	Examples of Areas with Potential for Moderate- and Low-Temperature Discoveries
1	Northern California	The Geysers Mono-Long Valley Cascades	Susanville Area Surprise Valley Area
2	Southern California	Imperial Valley Coso	Los Angeles Basin
3	Oregon Washington	Cascades Alvord Desert Brothers Fault Zone Vale Area	Klamath Falls Area Lakeview Area Le Grande Area Columbia Plateau
4	Nevada	NE-trending Battle Mountain heat flow high (from Steamboat to NE-corner of Nevada)	Las Vegas Area Ely Area Carson-Eagle Valley
5	Utah	SW Utah geothermal district Tintic-Fish springs trend	Wasatch Front
6	Arizona	Safford-Morenci Area San Francisco Volcanic Field	Tucson Area Phoenix Area
7	Idaho Montana Wyoming	Snake River Plain (Margins) Island Park Area Overthrust Belt	Snake River Plain (interior) Madison Formation Aquifer
8	Colorado	Mt. Princeton Area	Northern Extension of Rio Grande Rift
9	New Mexico	Rio Grande Rift	Lordsburg Area Tularosa Basin
10	Texas	Trans-Pecos Trend	Balcones Fault Trend (geopressured resources not considered)
11	North Dakota South Dakota Minnesota	None	Madison Aquifer Deep Sedimentary basins
12	Nebraska Kansas Iowa Missouri	None	Sedimentary basins - deep and selected shallow aquifers
13	Oklahoma Arkansas Louisiana	None	Extension of Balcones Fault Trend Hot Springs, Arkansas (geopressured resources not considered)
14	Tennessee Alabama Mississippi Kentucky	None	None (geopressured resources not considered)
15	Wisconsin Michigan Illinois Indiana Ohio	None	Illinois Basin - deep aquifers
16	New York Pennsylvania New Jersey Maryland Delaware	None	Selected areas of buried radiogenic plutonic rocks Isolated hot springs locations Sedimentary basins
17	Florida Georgia S. Carolina N. Carolina Virginia West Virginia	None	Various hot spring locations Selected areas of buried radiogenic plutonic rock
18	New Hampshire Vermont Massachusetts Rhode Island Maine	None	Isolated hot spring locations
19	Alaska	Aleutian Volcanic Chain	Seward Peninsula Southeastern Alaska Margins of plutons
20	Hawaii	Rift Zones on Big Island	Rift zones on Maui

FIGURE 3.6
POSTULATED RESOURCES BY TEMPERATURE

SOURCE: UURI

temperature end than is Figure 3.4 because inclusion of the extended resources of the mid-continent and the east are predominantly below 200°F in temperature. Postulated resources, including high-temperature resources, are shown in Figure 3.6 to emphasize that high temperature resources that for some reason were unsuited to electric power generation would be considered for direct application.

3.4.4 Timing of Discovery

In order to predict the timing of confirmation for both the co-located and non-co-located direct-heat resources, a preliminary discovery schedule was established by UURI. Estimates of discovery time were based upon the current level of geothermal exploration activity for each region. In regions where there is currently a significant amount of exploration (e.g., Southern California) a high near-term discovery rate was indicated. In contrast, for areas with high resource potential, but relatively little present exploration activity (e.g., the Cascades), it was predicted that most discoveries will not occur until the latter part of the 1980-2000 time frame. For those areas with known geothermal resource potential, it was predicted that there would be no additional discoveries during the next 20 years.

This initial discovery schedule is preliminary in nature. The actual timing of discoveries will depend on future incentive to explore, which in turn depends on future incentive to develop hydrothermal resources. This was evaluated by the investment decision model.

4.0 USER INDUSTRY INTERVIEWS

4.1 Introduction

Hydrothermal electric power projects tend to be on a large scale relative to direct-heat projects. The energy from the electric power generation equipment is wheeled into the electric grid and is consumed by a large number of users, the majority of whom are probably not even aware that they are consuming hydrothermal energy. The decision of whether or not to undertake a hydrothermal electric power project is made jointly by developers and utilities. The energy from hydrothermal direct-heat projects, however, will be consumed by a distinct, and usually relatively small, group of users. Developers and third party investors are deterred from direct-heat projects because of their relatively low rate of return on investment and because of their small present value of profits. For these reasons, hydrothermal direct-heat applications in the near term will be dependent upon the user's criteria for deciding whether or not to implement utilization systems.

This chapter outlines the procedures used to identify the industries most likely to be able to utilize hydrothermal resources for direct-heat applications. Decision criteria were ascertained from responses to an interview questionnaire. Interview procedures and results are discussed in this chapter.

4.2 Industry Identification, Screening, and Selection

Industrial users of process heat were studied to identify potential direct-heat applications of hydrothermal resources. Technical reports and industrial census data prepared by Inter Technology Corporation, the Solar Energy Research Institute, and the U.S. Department

FIGURE 4.1

INDUSTRIAL SCREENING FOR SURVEY SAMPLE

of Commerce were reviewed. Four hundred and fifty-five industries with heat requirements of at least 10^{12} BTU/year were identified as the "Total Industrial Base" of potential hydrothermal direct-heat consumers. As illustrated in Figure 4.1, these 455 industries were subjected to a 4-step screening procedure. Industries requiring process heat with temperatures greater than 400°F were eliminated by the first screen leaving 65 industries. This number was reduced to 57 by eliminating user categories having total national annual process heat demand less than 5×10^{12} BTU/year. The third step was to eliminate user categories with average demand smaller than 0.01×10^{12} BTU/year per establishment, but no additional industries were eliminated by this screen. The final step was to eliminate user groups considered to be unrealistic candidates for practical or logistical reasons (e.g., insignificant total process heat requirements, users not located in potential hydrothermal resource areas). The 25 generic user categories that survived the entire screening process are presented in Table 4.1. For each generic user category, the number of members interviewed was determined as a function of industry size, regional considerations, and the proportion of small, medium, and large companies within the user group.

Following the determination of the sample sizes, state manufacturing directories, trade directories, "Marketing Economics Key Plants," and the Dialog computer system were used to obtain the information necessary for contacting specific companies. The publication "Marketing Economics Key Plants" lists all manufacturing plants in the United States that have over 100 employees. The Dialog computer system covers much of the same information, but is capable of provid-

TABLE 4.1
SURVEYED INDUSTRIES

SIC CODE	INDUSTRY CATEGORY
018	Greenhouses
024	Dairy Farms
025	Poultry & Eggs
0279	Fish Farms
1311	Tertiary Oil Recovery
201	Meat Products
202	Dairy Products
203	Fruits & Vegetables
2046	Wet Corn Milling
206	Sugar Refining
207	Fats & Oils
208	Alcoholic Beverages
2436	Softwood Veneer & Plywood
26	Pulp & Paper Products
281,2	Chemical Products
283	Medicines
2865	Cyclic Crudes & Intermediates
2869	Industrial Organic Chemicals
2873	Nitrogenous Fertilizers
3011	Tires & Inner Tubes
3241	Cement Products
3271	Concrete Block & Brick
3275	Gypsum Products
3295	Minerals, Ground & Treated
----	District Heating Systems

ing information on smaller companies.

4.2.1 Interview Process

Prior to the interviews, a sample script was prepared, interview guidelines were established, and interviewers were trained. The highest ranking available officer within the selected organization was contacted by telephone, and the nature of the survey was described to that person. The interviewer explained that a questionnaire would be forthcoming and attempted to make an appointment for a telephone interview.

The primary purpose of the interview forms was to obtain basic energy decision policy data. The forms solicited information regarding energy systems and choices including: current fuels used, plans for expansion of existing plants; plans for new plants; knowledge of geothermal energy; past involvement in geothermal projects, attitudes toward using geothermal resource energy; attitudes toward moving to a geothermal resource area; the probability of using geothermal energy based on factors such as the cost of energy, capital investment, reliability of the resource, capital loss, and replacement cost; attitudes toward being involved in exploration and field development, and the effects of government programs on decision policies.

4.2.2 Interview Responses

Figure 4.2 shows the proportion of each group of respondents who stated that they had been aware, prior to being contacted by the interviewer, that geothermal resources could be used to supply heat. Respondents were asked if they would take advantage of 100 hours of technical assistance, if the government offered it. The responses to this question are illustrated in Figure 4.3. The proportions of the

FIGURE 4.2
FAMILIARITY WITH HYDROTHERMAL ENERGY

FIGURE 4.3
WOULD USE 100 HOURS OF TECHNICAL ASSISTANCE

four groups of respondents who indicated that they would undertake exploratory drilling if a favorable prospective resource was available are illustrated in Figure 4.4. When asked if they would take advantage of federal loan guaranties for geothermal development, if available, respondents answered as indicated in Figure 4.5. Sample members were asked if they would perform feasibility studies a resource was available. Figure 4.6 illustrates responses to this question.

A review of the completed forms and the analysis of the Figures 4.2 through 4.6 leads to some general observations concerning the industries' attitudes toward Government incentives:

- o About 50% of the respondents knew something about geothermal energy.
- o A sizeable majority of respondents stated they would take advantage of 100 hours of technical assistance.
- o More than 50% would perform a feasibility study on their own if an attractive resource was located near their plant.
- o Interest in being involved in exploration and field development is low unless the government shares the cost. Over 1/3 of the respondents are not interested in getting into exploration and field development regardless of government initiatives.
- o A minority of respondents expressed interest in a Government Loan Guaranty Program. Communities were more interested than industry.

4.3 Decision Factors that May Influence Prospective Users

Industrial facilities that are already colocated with geothermal sites may be retrofitted to use geothermal energy. However, industries will undertake such a change only if they believe that some real benefit will result from the change. Potential motivators include: plant expansion, economy, energy availability, superior energy quality and convenience. Their primary concerns relative to the resource are its location, and ownership. Of secondary concern are legal issues

FIGURE 4.4
EXPLORATION AND FIELD DEVELOPMENT
(With and Without Incentives)

FIGURE 4.5
WOULD USE LOAN GUARANTEE IF AVAILABLE

FIGURE 4.6
FEASIBILITY STUDIES
(With and Without Incentives)

such as water rights, permits, and leases. Finally, economic, demographic, and social/political issues are evaluated. Figure 4.7 presents the essential decision factors for direct thermal use, and Table 4.2 lists the factors affecting existing and prospective colocated geothermal resources.

Plant relocation and plant expansion to new locations are influenced by a large number of criteria including corporate strategy; organizational structure; market and demographic factors; work force wages and productivity; transportation; energy and utilities; materials, supplies, and service; government programs (national, state, and local); and water and waste systems. Among these criteria, energy has been ranked comparatively low. The prime considerations are markets, transportation, raw materials, and seasonal labor.

Table 4.3 describes locational criteria and Table 4.4 presents ranked locational criteria for several industries. Figure 4.8 illustrates the relationship between industry and locational criteria. These data are applicable not only to new plants, but also to plant expansion and relocation. Industries can also be matched, based on their primary criteria, with regions where that element is available. For example, a region would be considered to be a potential location for a soft drink plant if the region were already populous or were growing rapidly. Similarly, if a region had a large labor force with the skills required, a furniture plant might consider locating there.

FIGURE 4.7

ESSENTIAL DECISION FACTORS FOR DIRECT THERMAL USE

TABLE 4.2

FACTORS AFFECTING DIRECT THERMAL
APPLICATIONS FROM EXISTING AND PROSPECTIVE COLOCATED GEOTHERMAL RESOURCE

FACTORS	TOTAL NUMBER OF CITATIONS	HIGHLY FAVORABLE CITATIONS		UNFAVORABLE CITATIONS		RATIO OF HIGH TO UNFAVORABLE
		NUMBER	PERCENT	NUMBER	PERCENT	
Site Suitability	46	38	82.6	8	17.4	4.8
Community Attitude	36	28	77.8	8	22.2	3.5
Price Competitive	41	31	75.6	10	24.4	3.1
Population Change	24	18	75.0	6	25.0	3.0
Available Markets	47	35	74.5	12	25.5	2.9
Environmental Factors	38	28	73.7	10	26.3	2.8
Lease Availability	41	30	72.3	11	26.8	2.7
Certainty of Ownership	48	33	68.8	15	31.3	2.2
Financing Available	25	17	68.0	8	32.0	2.1
Economic Change	23	15	65.2	8	34.8	1.9
Resource Capability	56	36	64.3	20	35.7	1.8
Permits & Regulations	41	26	63.4	15	36.6	1.7
Site Availability	54	33	61.1	21	38.9	1.6
Water Rights	43	25	58.1	18	41.9	1.4

SOURCE: EG&G

TABLE 4.3

INDUSTRY LOCATIONAL CRITERIA

<u>CRITERION</u>	<u>DESCRIPTION</u>
Local Labor	Number of employees available, required skills, level of pay required
Raw Materials	Both basic and associated, such as water for some processes
Associated Services	Including maintenance services, supplies
Taxes	Although tax level is not considered a <u>high</u> priority criterion, tax incentives can be helpful
Energy	Some areas are currently ignored because the natural gas supply is known to be limited
Transportation	Type depends upon the product
Local Market	Not generally considered to be a primary factor for <u>most</u> products
Quality of Life	To attract employees, especially where highly skilled, highly trained and highly educated people are required
Proximity to Headquarters	A primary criteria for some industries - e.g., semi-conductor
Environmental Permits	Industry-specific as well as site-specific
Climate	Important influence apart from quality of life and raw materials, for some facilities such as greenhouses
Water	A critical raw material for some industries
Land	Must be available, but also suitable in terms of such characteristics as topography
Community Attitudes	Cannot only preclude establishment of a particular industry but can be an encouragement by offering incentives

TABLE 4.4

ESSENTIAL CRITERIA FOR LOCATION DECISIONS
FOR NEW PLANTS, PLANT EXPANSIONS, PLANT RELOCATIONS

<u>TYPE OF INDUSTRY</u>	<u>CRITERIA</u>		
	<u>NO. 1</u>	<u>NO. 2</u>	<u>NO. 3</u>
Food Processing	Raw Materials	Adequate Plant	Local Labor
Barley Malting	Transportation	Energy	Raw Material
Mining and Milling	Raw Materials	-	-
Gasohol	Raw Materials	-	-
Timber	Raw Materials	-	-
Apparel	Local Labor	Proximity to Headquarters	-
Electronics	Proximity to Headquarters	Transportation	Quality of Life
Paper	Water	Disposal Permit	Raw Materials
Concrete	Market	Raw Materials	-
Metal Fabrication	Market	Transportation	-
Cabinet Making	Market	-	-
Cement	Raw Materials	-	-

← Criteria →

Industry	Local Labor	Raw Materials	Associated Services	Taxes	Energy	Transportation	Local Market	Quality of Life	Proximity to Headquarters	Environmental Permits	Climate	Water	Land	Community Attitudes
Food Processing	2	1			3									
Gasohol		1		2	3									
Barley Malting		3		2	1									
Paper	3	2									1			
Semi-Conductor	4				2		3	1						
Cabinet Making	2					1								

FIGURE 4.8

THE SCREENING MATRIX

(Identification of Prioritized Essential Industry Locational Criteria)

5.0 IMPACT OF FEDERAL GEOTHERMAL PROGRAMS

5.1 Introduction

The elements of the Federal/DOE program were designed to decrease the time, cost, and/or financial risk associated with hydrothermal development, thus making this energy source more economically attractive to developers and industries. The main emphasis has been placed on accelerating the development of industry infrastructures for direct-heat applications. The R&D necessary to reduce the cost of direct-heat utilization systems has mainly been a by-product of the hydrothermal electric program.

5.2 Federal Activities

Table 5.1 lists the model parameters that are expected to be affected by Federal activities, and Table 5.2 presents the relationship between Federal activities and impacted parameters.

Quantitative estimates of the impact of the Federal/DOE program on selected policy dependent program variables are given in Table 5.3. These estimates are based on engineering judgements made by individuals involved in existing or similar programs, and on consultations with engineers from the private sector. Because technological developments for direct-heat applications will be a spin-off of the hydrothermal electric program technology development, the projections for direct-heat technology development are based on the funding level of the hydrothermal electric technology development program. For the tax credit parameters two cases are given, one for each of the two different tax credit programs. For well capital and field investment risk, separate values are given for successful and for unsuccessful wells.

TABLE 5.1
DIRECT-HEAT MODEL PARAMETERS

<u>NO.</u>	<u>MODEL PARAMETER</u>
1.	Minimum time path of post-discovery resource development
2.	Timing of resource discoveries (UURI Task)
3.	Tax credits (investment tax credits)
4.	Well capital cost
5.	Well field investment at risk
6.	Developer's capital structure (debt/pref./com.)
7.	Developer's cost of debt
8.	Developer's cost of preferred
9.	Developer's cost of common
10.	Developer's investment utility functions
11.	Reservoir risk perception (premature failure w.r.t. time)
12.	Utilization equipment capital cost
13.	Utilization equipment investment at risk
14.	Utilization equipment capacity factor
15.	Utilization equipment life
16.	Utilization equipment O&M cost
17.	Well life
18.	Well field O&M cost
19.	User's capital structure (debt/pref./com.)
20.	User's cost of debt
21.	Geothermal energy price support
22.	Utilization equipment performance (heat transfer efficiency)
23.	Exploratory dry well fraction
24.	Developmental dry well fraction
25.	Perceived variance in stochastic cost and performance parameters

SOURCE: DOE

TABLE 5.2

HYDROTHERMAL DIRECT-HEAT PROGRAM ELEMENTS

ACTIVITIES SPONSORED BY DGE	IMPACTED PARAMETERS
A. Technology Development	1, 4, 11, 12, 14, 15, 16, 17, 18, 22, 23, 24, 25
B. Technology Transfer	
1. Federal Buildings/Facilities	11, 25
2. Regulatory Barrier Mitigation	1, 4, 5, 6, 7, 12, 13, 19, 20
3. Other Technology Transfer Activities	1, 4, 10, 11, 12, 15, 16, 18, 22
ACTIVITIES NOT SPONSORED BY DGE	IMPACTED PARAMETERS
C. USGS Resource Assessment	2, 11
D. Market Definition	1, 11, 25
E. Regulation Mitigation and Barrier Reduction	
1. Utility System Public Works Grants/Loans	4, 5, 6, 7, 12, 13, 19, 20
2. Industrial Users	
- Business Tax Credits	3
- Economic Development Assistance	25
3. Residential Users	
- Residential Tax Credits	3
- Federal Housing Programs	7, 7, 19, 20

SOURCE: EER/EG&G/TECHNECON

TABLE 5.3

IMPACT OF CURRENT FEDERAL PROGRAM ON SELECTED
POLICY-AND PROGRAM-DEPENDENT VARIABLES

VARIABLE NAME	DEFINITION	VALUE ASSUMING CURRENT FEDERAL PROGRAM
MDOT	Flow rate to user	Federal Progress Impact: 2% improvement by 1982 7% " " 1983 12% " " 1984 17% " " 1985 19% " " 1986 21% " " 1987
MOM	Municipal O&M cost of distribution	93% of no-program value
OMF	Well field O&M expense for unpumped wells	93% of no-program value
OMP	Well field O&M expense for pumped wells	93% of no-program value
SPF	Surface Piping Cost (unpumped)	92% of no-program value after 1985
SPP	Surface Piping Cost (pumped)	92% of no-program value after 1985
WC	Well cost	95% of no-program value after 1985 90% of no-program value after 1990
WLF	Well life (yrs)	124% of no-program value

SOURCE: EER/EG&G/TECHNECON

6.0 RESULTS

The Task Force's estimates indicate hydrothermal direct-heat development of 0.153 quads/year (the equivalent of almost 9 million barrels of oil per year) by the year 2000 at a greater than 50% likelihood. This development is dependent upon continued investment by private industry and the support of Federal/DOE programs. Tables 6.1 and 6.2 present the Task Force projections for hydrothermal direct-heat applications through the year 2000; separate sets of projections are given for scenarios with and without the current Federal/DOE program. Figure 6.1 graphically illustrates the anticipated growth of hydrothermal direct-heat utilization if the currently planned Federal/DOE program is continued. Figures 6.2 through 6.4 illustrate the impact of the current program on future development of hydrothermal direct-heat utilization.

Table 6.3 presents a regional breakdown of the hydrothermal direct-heat projections by the year 2000 at a greater than 50% likelihood. Enhanced oil recovery -- estimated to be 0.028 quads by the year 2000 at the >50% likelihood level -- is excluded from these estimates.

TABLE 6.1

NATIONAL HYDROTHERMAL DIRECT-HEAT UTILIZATION ESTIMATES

NO FEDERAL/DOE PROGRAM

YEAR	PROJECTED QUADS PER YEAR WITH A LIKELIHOOD		
	>5%	>50%	>95%
1985	.043	.019	.008
1990	.105	.058	.031
1995	.186	.110	.061
2000	.244	.140	.073

TABLE 6.2

NATIONAL HYDROTHERMAL DIRECT-HEAT UTILIZATION ESTIMATES

CURRENT FEDERAL/DOE PROGRAM

YEAR	PROJECTED QUADS PER YEAR WITH A LIKELIHOOD		
	>5%	>50%	>95%
1985	.054	.028	.015
1990	.120	.070	.040
1995	.206	.127	.074
2000	.260	.153	.083

FIGURE 6.1
NATIONAL HYDROTHERMAL DIRECT HEAT ESTIMATES
ASSUMING EXTENSION OF CURRENTLY PLANNED FEDERAL/DOE PROGRAM

FIGURE 6.2
NATIONAL HYDROTHERMAL DIRECT-HEAT ESTIMATES
ILLUSTRATING IMPACT OF CURRENTLY PLANNED FEDERAL PROGRAM
AT >5% LIKELIHOOD

FIGURE 6.3

NATIONAL HYDROTHERMAL DIRECT-HEAT ESTIMATES
ILLUSTRATING IMPACT OF CURRENTLY PLANNED FEDERAL PROGRAM
AT >50% LIKELIHOOD

FIGURE 6.4

NATIONAL HYDROTHERMAL DIRECT-HEAT ESTIMATES
ILLUSTRATING IMPACT OF CURRENTLY PLANNED FEDERAL PROGRAM
AT >95% LIKELIHOOD

TABLE 6.3
REGIONAL HYDROTHERMAL DIRECT-HEAT UTILIZATION ESTIMATES
(> 50% LIKELIHOOD BY 2000)

NO.	STATES IN REGION	PERCENT OF NATIONAL ESTIMATE	
		NO FEDERAL/DOE PROGRAM	CURRENT FEDERAL/DOE PROGRAM
1	Northern California	14.3%	10.1%
2	Southern California	20.6%	15.9%
3	Oregon, Washington	18.3%	12.7%
4	Nevada	2.3%	1.3%
5	Utah	6.3%	6.3%
6	Arizona	0.6%	2.5%
7	Idaho, Montana, Wyoming	22.3%	27.9%
8	Colorado	1.7%	2.5%
9	New Mexico	0	0.9%
10	Texas	0	0.3%
11	North Dakota, South Dakota	9.1%	13.2%
12	Iowa, Kansas, Missouri, Nebraska	1.7%	1.9%
13	Arkansas, Louisiana, Oklahoma	0	0
14	Alabama, Kentucky, Mississippi, Tennessee	0	0
15	Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin	0	0
16	Delaware, Maryland, New Jersey, New York, Pennsylvania	2.8%	3.2%
17	Florida, Georgia, North Carolina, South Carolina, Virginia, West Virginia	0	1.3%
18	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	0	0
19	Alaska	0	0
20	Hawaii	0	0
		<hr/> 100.0%	<hr/> 100.0%

NOTE: All estimates exclude enhanced oil recovery and assume that intra-regional relocation will occur except for Region 15.

APPENDIX A

TECHNICAL DISCUSSION OF THE HYDROTHERMAL DIRECT-HEAT MODEL

In Section 2 of this report, a summary of the hydrothermal non-electric market penetration model is presented. This appendix expands upon the Section 2 presentation and provides additional explanation and technical detail of Technecon's model.

A.1 Overview

There is a substantial body of literature pertaining to the market diffusion of new technologies and to various analogue forms for modeling diffusion characteristics (see, for example, Linstone and Sahal, 1976). These analogues have been remarkably successful in many cases when used to explain rates and extents of market penetration. Figure A.1, for example, illustrates the close correlation between an S-shape diffusion model used by Fisher and Pry (1971) and aggregate empirical data for the market penetration of seventeen technological advances (e.g., synthetic fibers, plastics, electric arc steel furnaces, etc.). The general form of the S-shape or "logistic" curve used estimating technological substitution may be expressed as:

$$f = \frac{K}{1 + \exp [-(a+bt)]}$$

where f is the fraction of the market penetrated at time t , K is the asymptotic upper bound of f (i.e., the maximum achievable level of market penetration), and a and b are constant parameters which specify the location on a time scale and rate of penetration, respectively. Other forms of the S-shaped diffusion model are specified in the literature -- see, for example, Blackman (1972) and Floyd (1968)

Figure A.1 FIT OF FISHER-PRY MARKET PENETRATION MODEL
TO EMPIRICAL DATA

--though most represent a variation of the fundamental logistic function specified above.

Forecasts of market penetration using a logistic analogue are generally performed by extrapolating the S-shaped curve on the basis of penetration trends derived from regression of empirical data. Satisfactory extrapolations have been achieved from regression analyses based upon data on as little as 3-5% penetration. In the absence of empirical data, or in cases of insufficient data, it is sometimes possible to assume the parameters of the S-shaped curve by using historical data for technological substitution in similar industries or sectors (cf. Sahal, 1976). Whether the functional parameters are estimated by regression analysis or assumed, it is understood that the new technology provides a technological advance or economic benefit to the market.

In the hydrothermal non-electric case, there are unique problems involved with forecasting market penetration. First, there is negligible penetration to date and, therefore, it is not possible to extrapolate an S-shaped curve based upon regression of empirical data. Second, penetration is anticipated in numerous industrial, commercial and residential markets. There is insufficient historical information available on this aggregate and diverse market to support an assumption pertaining to the appropriate quantification of a penetration curve. Third, it cannot be assumed that hydrothermal energy provides either a technological advance or economic benefit to each and every market being studied.

To confront these special hydrothermal problems, Technecon analysts chose to depart from the aforementioned traditional means of market penetration analysis. Instead, after a brief review of the theory behind the S-shaped diffusion analogue, a model was developed by: (a) disaggregating the traditional analogue into several subelements, (b) quantify each subelement separately, and then (c) recoupling the several subelements in an integrated, computerized model. Specifically, the diffusion model comprises the following subelements:

- Exclusion Factor. Industry interviews indicate that, for a variety of reasons usually relating to heat requirements, alternative heat sources, financial or logistical concerns, a fraction of the potential non-electric market will not adopt hydrothermal energy regardless of the level of stimulus to do so. As shown in Figure A.2, this fraction of the total market, N_T , is excluded from consideration and reduces the upper bound market penetration to a level denoted as N_p .
- Learning Curve. Over time, an increasing proportion of the potential market will become aware of hydrothermal energy as "messages" from early innovators and pilots projects diffuse through the market. Within the market, differing levels of resistance exist among the potential users. The time required to inform the market and to overcome varying degrees of resistance are incorporated into the analysis by the learning curve subelement as shown in Figure A.2. At a given point in time, T^* , the fraction of the market which is informed and willing to consider the hydrothermal alternative is specified as N_C .
- Positive Response. The stimulus for a potential user to adopt hydrothermal energy is a function of several variables including technological evolution, relative energy economics, and availability and reliability of energy supply. In a diverse market, these stimuli will be perceived differently by different potential users. As shown in Figure A.2, an S-shaped logistic curve is employed to estimate the fraction of the market that will respond positively, N^* , to a specified multivariate level of the stimulus, S^* . This logistic curve of positive response was quantified by a systematic survey of the market and a multiple regression analysis of survey results.

FIGURE A.2

SUBELEMENTS OF THE HYDROTHERMAL
DIRECT-HEAT MODEL

- o Implementation Rate. From the time, T^* , that a fraction, N^* , of the market is informed and also likely to respond positively to the hydrothermal stimuli, a time lag will be encountered until implementation rate curve shown in Figure A.2. At time T' following T^* , the fraction of the market that will have implemented hydrothermal energy is given by N_1 . Several factors contribute to this lagged response: (i) lead time from the time of decision, T^* , until project financing can be arranged; (ii) lead time requirements for engineering, procurement, permitting, and construction; and (iii) the age and unit operating cost of existing equipment which will be gradually replaced over time with the hydrothermal equipment (ref. Mansfield, 1968).

The hydrothermal non-electric market penetration analogue described above fits into a complete and computerized analytic framework as indicated in Figure A.3. In summary, the analysis is initiated by the specification, by UURI, of a projected hydrothermal resource discovery. Potential colocated and relocatable users are identified at the projected discovery and a discounted cash flow (DCF) analysis is performed for each user/resource pair. Using the market penetration analogue, the likelihood of a positive decision to use this resource is then estimated for each potential user, taking into account alternative energy forms available to each. If a positive user decision is indicated, then the rate of resource development is estimated to accommodate implementation lags. Resource development is constrained by saturation of the available resource as a last step in the analysis.

A.2 Market Analysis

This subsection describes the market sample used in this analysis, the interviewing procedure, and results of the interviews that pertain specifically to the several subelements of the market penetration analogue described above.

FIGURE A.3 HYDROTHERMAL DIRECT-HEAT MARKET ANALYSIS FRAMEWORK

A.2.1 The Market Sample

Early in the project, a committee of representatives from several of the Task Force organizations was assembled to define a market sample of potential hydrothermal non-electric users. This sample would subsequently provide the source of information upon which several sub-elements of the market penetration model would be based, including the exclusion factor, learning curve, positive response model, implementation function and relocation likelihoods.

The committee's objective in defining the market sample was to minimize the number of individual user establishments while preserving, within the sample, as large a fraction as possible of the potential process and space heat market. The total market was first identified by compiling a list of industries, at the 4-digit level of Standard Industrial Classification (cf. O.M.B., 1972), with process heat requirements not greater than 400°F and which conceivably could use hydrothermal energy to meet such requirements. Reports by Brown (1980) and Fraser (1977) were the principal references used in this total market analysis.

The committee then performed a sequence of screening procedures -- as described in Section 4 earlier in this report -- to eliminate insignificant and unlikely users. The resulting market sample comprises the user categories listed in Table A.1. The efficiency of the market sample is realized by considering that there are roughly 10 times as many potential user establishments outside the sample as there are inside the sample, yet the potential hydrothermal energy market outside the sample is only about 0.176 times what within the sample.

TABLE A.1

HYDROTHERMAL DIRECT-HEAT MARKET SAMPLE

SIC CODE	USER CATEGORY	EXCLUSION FACTOR	LIKELIHOOD OF RELOCATION	
			INTRA-REGIONAL	INTER-REGIONAL
018	GREENHOUSES	.04	.75	.30
024	DAIRY FARMS	1.00	0	0
025	POULTRY & EGGS	.10	.60	0
0279	FISH FARMS	.25	.75	.20
1311	ENHANCED OIL RECOVERY	--	0	0
201	MEAT PRODUCTS	.31	.50	0
202	DAIRY PRODUCTS	.08	.60	.10
203	FRUITS & VEGETABLES	.18	.50	.10
2046	WET CORN MILLING	.42	.40	.10
206	SUGAR REFINING	.33	0	0
207	FATS & OILS	.29	.50	.10
208	ALCOHOLIC BEVERAGES	.38	.50	0
2436	SOFTWOOD VENEER & PLYWOOD	.20	.20	0
26	PULP & PAPER PRODUCTS	.26	.20	0
281,2	CHEMICAL PRODUCTS	.28	.60	.40
283	MEDICINES	.16	.60	.30
2865	CYCLIC CRUDES & INTERMEDIATES	.11	.60	0
2869	INDUSTRIAL ORGANIC CHEMICALS	.04	.60	.40
2873	NITROGENOUS FERTILIZERS	.08	.60	.30
3011	TIRES & INNER TUBES	.50	.30	.30
3241	CEMENT PRODUCTS	1.00	0	0
3271	CONCRETE BLOCK & BRICK	.15	.50	0
3275	GYPSUM PRODUCTS	.65	.60	.40
3295	MINERALS, GROUND & TREATED	.10	.30	0
--	DISTRICT HEATING SYSTEMS	.12	0	0

Once the market sample had been selected, the Task Force designed an interview format and identified some 417 establishments within the sample categories as interviewees. Of the 417 establishments contacted, 269 provided useful data for the purposes of quantifying the market penetration model. Section 4 of this report provides further detail of the interview process. Discussed below are the interview results pertaining the specific subelements of the market penetration analogue.

A.2.2 Likelihood of Relocation

As indicated in Figure A.3, for each resource discovery projected by UURI, all potential users at that site are identified from computerized files of colocated establishments maintained by NMEI, and from interview results which provide the likelihood of relocation to the site by each category of user in the market sample. Relocation was examined in terms of both intra-regional and inter-regional migration according to the regional boundaries defined on the map in Figure A.4. From the interview responses, the number of firms willing to relocate within their region and outside of their region was tabulated and converted to the proportions shown in Table A.1 by dividing by the total number of firms interviewed. In cases where the number of firms interviewed was insufficient, or where unrealistic or biased responses were evident, tabulations were corrected in light of the interviewees responses to other pertinent questions.

Inter-regional relocation data were tabulated on a matrix for each user category to indicate the proportion of firms willing to migrate from one specific region to another specific region. Each of

FIGURE A.4
U.S. DEPARTMENT OF ENERGY
HYDROTHERMAL R&D ASSESSMENT TASK FORCE
MAP OF REGIONAL BOUNDARIES

the 24 matrices (i.e., one per user category excluding district heat) contained 20 rows of regional origin and 20 columns of regional destination. Values presented in Table A.1 are representative matrix entries for each respective user category.

A.2.3 Exclusion Factor

Part of the interview format was designed to provide data for estimating the fraction of firms within each user category that would be unwilling to use hydrothermal energy regardless of the stimuli to do so. Interviews were conducted such that unwillingness due to lack of familiarity (i.e., learning curve effects) could be distinguished from unwillingness due to objective and time-dependent considerations which are pertinent to the exclusion factor. Pertinent considerations included, for example, available waste heat from on-site high temperature processes, and the ability to burn waste products for satisfying process heat requirements.

Table A.1 provides the exclusion factors which were derived from the market interviews. These exclusion factors were estimated by tabulating pertinent negative interview responses and dividing these tabulations by the total number of useful interviews. When unrealistically biased responses were evident, data were adjusted in view of other relevant interview questions.

A.2.4 Learning Curve

Learning curve influences on aggregate markets account for the progressive diffusion of information and for the penetration of varying degrees of resistance to change. Works by Blackman (1974), Sahal

(1976) and many others demonstrate the appropriateness of S-shaped learning curve analogues and the quantification of these curves for various industrial market sectors. Blackman (1974) specifies an Innovative Index as a measure of the propensity toward technological change in several industrial sectors. This Innovation Index indicates that chemical, electronic, and aircraft industries are significantly more prone toward change than are paper, textile, and rubber industries. Learning curves for the former group are characterized by steeper gradients than are learning curves for the latter group.

For the hydrothermal market analysis, S-shaped learning curves were quantified by data extracted from the literature and from specific questions in the interview format. The works of Blackman (1974) and Bressler and Hanemann (1980A, 1980B and 1980C) were particularly valuable to this part of the analysis. The functional form of the curve is a variation of the logistic function by:

$$f_L = \frac{1}{1 + [B \times \exp(-At)]}$$

Table A.2 provides a ranking of the user categories within the market sample in descending order of propensity toward change and current degree of education relevant to hydrothermal adaptation. The A and B coefficients of the learning curve for each user category are also provided in this table.

A.2.5 Logit Model of Positive Response

The logit model of positive response estimates the fraction of the potential market (net of exclusion, learning curve, colocation and relocation considerations) which is likely to choose to adopt hydrothermal energy as a function of the stimuli to do so. It is an

TABLE A.2

MARKET SAMPLE LEARNING CURVE CHARACTERISTICS

USER CATEGORY	YEARS UNTIL 50% "LEARNED" ACHIEVED	LEARNING CURVE COEFFICIENTS	
		A	B
GREENHOUSES	0	1	0
FISH FARMS	0	1	0
DAIRY PRODUCTS	2.5	.879	9
SOFTWOOD VEENER & PLYWOOD	2.5	.879	9
POULTRY & EGGS	5	.439	9
ENHANCED OIL RECOVERY	5	.439	9
MEAT PRODUCTS	5	.439	9
FRUITS & VEGETABLES	5	.439	9
SUGAR REFINING	5	.439	9
FATS & OILS	5	.439	9
CHEMICAL PRODUCTS	5	.439	9
MEDICINES	5	.439	9
INDUSTRIAL ORGANIC CHEMICALS	5	.439	9
NITROGENOUS FERTILIZERS	5	.439	9
CONCRETE BLOCK & BRICK	5	.439	9
DISTRICT HEAT SYSTEMS	5	.439	9
WET CORN MILLING	7.5	.293	9
ALCOHOLIC BEVERAGES	7.5	.293	9
PULP & PAPER PRODUCTS	7.5	.293	9
CYCLIC CRUDES & INTERMEDIATE	7.5	.293	9
TIRES & INNER TUBES	7.5	.293	9
GYPSUM PRODUCTS	7.5	.293	9
MINERALS, GROUND & TREATED	7.5	.293	9

S-shaped function and a variation of the logistic function described earlier in this appendix. The logit model accounts for the heterogeneous nature of the non-electric market, and specifically, that hydrothermal energy will provide differing degrees of benefits to differing users.

A decision to implement hydrothermal energy will incorporate trade-offs and weighing of various criteria including investment requirements, investment returns through energy cost savings, and reliability of energy supply among others. Studies by the Earl Warren Legal Institute (cf. Bressler and Hanemann, 1980) were particularly valuable for identifying key decision criteria. In the case of such multi-objective decision behavior, a multivariate logit model may be used to account for the relative weights and interactions of the several criteria in the decision process. Multivariate logit models are described in useful detail by Cassel (1979), Walker and Duncan (1967), Theil (1969), Grizzle (1971), McFadden (1976), and Joskow and Mishkin (1977).

Included in the industry interviews conducted by the Task Force were questions pertaining to a firm's preference for (or aversion to) utilizing hydrothermal energy under various combinations of: (a) delivered energy cost relative to that of their alternative fuel; (b) capital investment requirements; (c) energy supply reliability; and (d) project risk. Binary (yes=1, no=0) responses to each combination of project attributes were tabulated by user category. Step-wise multiple regression analyses were performed on several aggregations of the interview data until efficient and statistically acceptable logit functions were achieved.

The functional form of the logit model used in this analysis is expressed as:

$$f_p = \frac{1}{1 + e^{-X}}$$

where f_p is the fraction of the market which responds positively and X is a multivariate polynomial of stimuli. Results of the above-mentioned multiple regression analysis provided the several forms of the polynomial, X , which are presented in Table A.3.

Subsequent discussions between the Task Force and Industry Review Panel led to modifications in the logit models. It was concluded that back-up, fossil-fueled heat sources would most likely be provided with hydrothermal systems and, therefore, the reliability and capital loss concerns are effectively eliminated. This view is also supported by the successful track record of hydrothermal non-electric projects to date. The logit models were then modified by assuming 100% reliability and no expected loss (i.e., $R=1.00$ and $L=0$) which simplified the functions as shown on the right side of Table A.3.

A.2.6 Implementation Rate

The logit model of positive response, described above, estimates the market fraction that will respond positively to the hydrothermal decision as a function of several time-dependent decision criteria. From the time of a positive decision, studies indicate that, on an average, about 2 years will be required to implement the decision (cf. Linstone and Sahal, 1976). Additional lag may be expected to account for the current age of equipment that will be retired and replaced by the hydrothermal technology. These response lags due to implementation delay and due to the retirement of existing equipment

TABLE A.3

LOGIT MODELS OF POSITIVE RESPONSE
FOR THE HYDROTHERMAL DIRECT-HEAT MARKET SAMPLE

Logit Model: $f = \frac{1}{1 + e^{-X}}$ Variables: <ul style="list-style-type: none"> f = fraction of market sector responding positively C = capital cost differential (Hydroth.-Conv.), \$Millions (1980) E = energy cost ratio (Hydroth./Conv.) L = expected value of capital loss, \$Millions (1980) R = reliability, fraction of year available 		
MARKET SECTOR	UNMODIFIED POLYNOMIAL "X"	SIMPLIFIED FORM OF "X"
Agricultural, Food & Kindred Products (SIC 018, 024, 025, 0279, 201, 202, 203, 2046, 206, 207 and 208)	$X = -4.01 - 0.15C + 5.83R - 3.44ER - 11.7LR + 0.51CER$ (2.86) (2.34) (2.88) (3.25) (3.28) $R^2 = .50$ F=5.98, df=30	$X = 1.82 - 0.15C - 3.44E + 0.51CE$
Stone, Glass, Clay & Concrete Products (SIC 3241, 3271, 3275 and 3295)	$X = 1.41 - 12.6E + 8.84ER - 0.19CER$ (2.99) (1.94) (2.41) $R^2 = .52$ F=9.16, df=25	$X = 1.41 - 3.76E - 0.19CE$
Other Manufacturing Categories (SIC 1311, 2436, 26, 281, 282, 283, 2865, 2869, 2873 and 3011)	$X = -5.39 + 8.59R - 5.35ER - 7.42CR + 9.06CER + 8.63CLR$ (2.79) (3.74) (2.59) (2.30) (2.53) $R^2 = .59$ F=5.11, df=18	$X = 3.20 - 5.35E - 7.42C + 9.06CE$
Municipal District Heat	$X = 4.32 - 10.31 \exp(5.85 - 7.14E^{-1})$ (9.28) (11.7) $R^2 = .64$ F=137, df=76	(no change)

Note: t-statistics given in parentheses
 R^2 = coefficient of determination
 df = degrees of freedom
 F = F-statistic

are incorporated in the market penetration analysis by an implementation rate submodel.

Two approaches to response lag are used in this analysis. One treats positive responses to replace existing heat sources and one treats positive responses to utilize hydrothermal heat to meet industry or district heat growth requirements.

For the purpose of this analysis, existing process heat equipment is assumed to have a 20 year life, and the current age of installed equipment is assumed to be normally distributed across the market (cf. Sahal, 1976). The fraction of today's equipment which will have been replaced at a future point in time is therefore given by a cumulative normal distribution. In functional form, this replacement fraction can be approximated by the expression:

$$f_R = \frac{1}{1 + e^{4.60 - 0.46t}}$$

The market fraction, f_p , for which a positive hydrothermal response is estimated today, will be implemented (including a 2 year minimum lag) according to a distribution over time given by:

$$f_I(t) = f_p(t=0) \times f_R(t-2)$$

As described later in Section A.4, growth in heat demand is included in the analysis by the use of growth rates derived from U.S. Census Forecasts, the Wharton Annual and Industrial Forecasting Model, and DOE/EIA's Regional Shares Model (REGSHARE). Capacity expansions required to meet this growth are assumed to be immediately available for potential hydrothermal heat supply following the above mentioned 2 year response lag. Therefore, the market fraction of new capacity for which a positive response is estimated is assumed to be implemented 2 years after the growth in heat demand is realized.

A.3 Project Analysis

The discussion in Section A.2 focusses on the estimation of market response to specified hydrothermal opportunities. As illustrated in Figure A.3, this market penetration analogue is dependent upon data provided by a hydrothermal project cash flow submodel and upon data pertaining to the costs of competing energy sources (e.g., gas, oil, coal, and electricity). These inputs to the market penetration analogue are discussed below.

A.3.1 Cash Flow Analysis

The purpose of the project cash flow submodel is to provide estimates of the delivered energy cost ratio and capital cost differential (i.e., variables E and C, respectively, in Table A.3) for candidate hydrothermal non-electric projects. A computerized project cash flow model was developed by Technecon for this purpose. For the purposes of this model, district heat distribution systems are assumed to be financed and owned by regulated, tax-exempt municipalities. Hydrothermal fluid suppliers to all users are assumed to be non-regulated and able to take advantage of tax incentives.

Project capital costs, recurrent costs and utilization factors are based upon figures provided by EG&G and NMEI. Table A.4 presents the minimum delivered resource temperatures and utilization factors which were used in the cash flow model for the several user categories in the market sample. The discounted cash flow (DCF) analysis incorporates various component escalation rates derived from the Wharton Annual Model and incorporates estimated, Federal, state and local tax liabilities and credits.

TABLE A.4

HYDROTHERMAL DIRECT-HEAT MARKET SAMPLE
PROCESS HEAT SYSTEM CHARACTERISTICS

SIC CODE	USER CATEGORY	TEMPERATURE REQUIRED (F)	UTILIZATION FACTOR*
018	GREENHOUSES	140	50%
024	DAIRY FARMS	---	---
025	POULTRY & EGGS	140	36%
0279	FISH FARMS	70	100%
1311	ENHANCED OIL RECOVERY	---	95%
201	MEAT PRODUCTS	140	65%
202	DAIRY PRODUCTS	100	48%
203	FRUITS & VEGETABLES	160	65%
2046	WET CORN MILLING	120	96%
206	SUGAR REFINING	110	24%
207	FATS & OILS	160	48%
208	ALCOHOLIC BEVERAGES	170	48%
2436	SOFTWOOD VENEER & PLYWOOD	210	65%
26	PULP & PAPER PRODUCTS	150	100%
281,2	CHEMICAL PRODUCTS	200	96%
283	MEDICINES	150	48%
2865	CYCLIC CRUDES & INTERMEDIATES	250	100%
2869	INDUSTRIAL ORGANIC CHEMICALS	250	93%
2873	NITROGENOUS FERTILIZERS	290	100%
3011	TIRES & INNER TUBES	250	71%
3241	CEMENT PRODUCTS	---	---
3271	CONCRETE BLOCK & BRICK	165	24%
3275	GYP SUM PRODUCTS	300	95%
3295	MINERALS, GROUND & TREATED	160	44%
--	DISTRICT HEATING SYSTEMS	100	25%

*Utilization Factor is the fraction of a year (i.e. fraction of 8760 hours annually) during which the process requires heat. Data from EG&G Idaho, Inc.

A.3.2 Alternative Energy Price Forecasts

Alternative energy price forecasts for the 20 regions were taken from the DOE/EIA's series A - ACR79 base scenarios using the medium price path assumption. Alternative fuel forecasts used in Technecon's model included: industrial oil prices, industrial coal prices, residential oil prices, residential coal prices, residential natural gas prices and residential electricity prices. The share of each type of energy used by a given industrial category was provided by EER, as was the estimated annual energy use per establishment in each category on a regional basis.

A.4 Market Growth Forecasts

To account for industrial and district heat demand growth, the following methodology was incorporated by Technecon:

The baseline distribution of the number of firms in each industrial category per region (with the exception of ethanol facilities and district heat) was compiled by Technecon from Census Bureau documents. Agricultural SIC codes 018, 025, and 0279 were obtained from the 1974 Census of Agriculture. The industry count for the SIC 1311 was provided by the 1972 Mineral Census. The remainder of the manufacturing industry totals were tabulated from the 1972 and 1977 Manufacturers Census. The base line number of ethanol facilities for all regions was zero. District heat population values were provided by NMEI on their data tapes.

Projections of the number of firms per region were needed for each industrial category. This was accomplished in a three step procedure. First, value added forecasts for the 2 digit SIC level were obtained from the Wharton Annual Model, January 1980 control forecast

to the year 2000. Next, the distribution of value added for each industrial category over the 20 regions was determined using REGSHARE, a model used by DOE to derive regional forecasts. For a given SIC category, REGSHARE provides information on the portion of total U.S. value added for the SIC category attributable to a given region. REGSHARE also provides information pertaining to the growth or decline of this share over time. As a last step, the growth or decline in value added per industry for a given region and time period was determined by multiplying the growth rate in the value added for the SIC category over the entire U.S. by the growth rate in the value added of the share for the region in question. Growth in ethanol facilities was provided by EG&G. Growth in district heat demand was modeled using U.S. Department of Census population projections, Series P-25, IIB.

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