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**AN OVERVIEW OF PROSPECTS AND POTENTIAL
FOR DEVELOPMENT OF GEOTHERMAL ENERGY
FOR DIRECT USE IN CALIFORNIA**

FINAL REPORT

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by

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SUMMARY

As part of the Department of Energy Contract, "Operations Research for Geothermal Energy Resources in California and Hawaii" No. ET-78-C-03-1529, SAI prepared an overview of the direct use of geothermal energy for the State of California. The work performed was under the guidance of the Department of Energy, Geothermal Energy Division, and the State of California Energy Commission Staff. The purpose of the enclosed analysis was to provide a limited time and scope estimate for the prospects in California for the direct use of geothermal energy. The methodology was based on actual experience in direct use projects in the State, however, the individual numbers used within the study should not be taken out of context. The aggregate numbers, representing a prediction of what can be achieved given proper subsidy, is the result of this study. This result is meaningful for planning purposes and should be treated in the same manner as any prediction.

Unlike most other energy sources, geothermal energy must be used close to the areas in which it occurs. To aid in the eventual development of a plan for the commercialization of non-electric geothermal applications, a general overview of the potential for California was prepared. Electric power plants, because their produce is easily transmitted over long distances, can be sited at the source of geothermal energy, but the location of factories, greenhouses, food processing plants, and other potential direct users is often controlled by a variety of competing considerations. The key to the direct use of geothermal energy is finding areas in which resources and users are co-located.

The Direct Use Overview for California was prepared in two parts. The first part concerns the need for a large-

scale program of exploration to define geographically the resources that are located in areas with high potential for direct use. An exploration program to better define the resources available is essential if any large amount of direct use is to be achieved. Areas of high potential that are not actively being explored have been identified in this study.

The second part deals with (1) estimates of the potential energy supply and (2) the associated capital requirements for direct use in the near-term, based on present industrial and demographic patterns in California and on the available resource data. This quantitative estimate covers all of California, using the available data and considering both areas where geothermal resources are known and areas needing exploration.

It was projected that 0.1 quads/year could be utilized in direct heat applications using 456 producing wells. This energy utilization assumes a total capital investment of \$510 million with \$350 to \$400 million from the government and the balance from the private sector.

The methodology to arrive at this estimate was based on applications considered to be a driving force in development and did not include all possible applications. Estimating the effect of those industries omitted, the predicted energy supply for direct use of geothermal energy is between 0.1 and 0.2 quads/year, assuming an aggressive and subsidized development program.

I. INTRODUCTION

1.1 CONSIDERATIONS

Applications of geothermal energy can be separated into two categories — electrical and direct use (non-electrical). Direct use applications include space conditioning, industrial process heat, balneology and agriculture. This paper presents an overview of potential direct use applications and end-users for the State of California.

The overview is based on the following assumption: both the resource and the end-user must be co-located in order to achieve a high level of direct use. Unlike most other energy sources, especially fossil fuels, geothermal energy must be used close to the areas in which it occurs. Electrical power plants can be sited to meet this requirement as necessary, because their product is easily transmitted over long distances. The location of potential direct users of geothermal energy, however, is often controlled by a variety of competing considerations.

California has many indications of geothermal activity, including hot springs, scattered over much of the State. The resources are not well defined for the most part, and it is very possible that in many areas the existing resources have low temperatures and are of limited extent. The volume and temperature of a hydrothermal formation needed for a direct heat application depend on the application (and on the depth and geology of the resource), and may be substantially less than the requirements for power generation. The presence of a resource must be verified and its adequacy determined before it can be exploited for direct use. For a large direct use program to succeed, exploration for appropriate resources will

be needed. Accordingly, areas in California were considered, giving equal weight to the presence of potential users and potential resources, in an effort to define a set of locations in which exploration should be undertaken.

As part of the overview, estimates of the quantity of geothermal energy that could be developed for direct use and of the associated capital costs were prepared. Based on the premise that substantial direct use will only be achieved where resources and potential heat applications co-exist,* the near-term potential for geothermal direct use was estimated using hypothetical resource probabilities and the present distribution of major classes of potential users. This portion of the analysis was governed by the potential users in existing economic and demographic patterns. Given the applications with potential for geothermal direct use, the expected number of wells required was assessed and total energy supply projected. In addition, capital costs for the projected development were estimated.

Only the use of geothermal fluids for heat applications was considered. Direct use of geothermal energy to supply mechanical energy is also possible, but this is dependent on specific characteristics of individual resources and applications and, in the absence of geopressured resources, will probably not be large compared to heat use.

Standard hydrothermal resources alone are considered. The possibility of other classes of geothermal energy in California is too ill-defined to be included (and is inappropriate in a near-term study).

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* To exist within economic transport distance.

Finally, only exploitation of resources for the primary purpose of direct heat use was considered. While direct uses in the form of utilization of effluent brine and steam from geothermal power plants may eventually play a large role in California's energy future, usage of this type was not considered, since it is almost entirely dependent on new development and relocation of industries and population and on the pace of geothermal-electric development.

1.2 BACKGROUND

This overview was performed under the Department of Energy Contract "Operations Research for Geothermal Energy in California and Hawaii", No. ET-78-C-03-1529. The purpose of this contract was to define programmatic needs at the federal, state, and local levels to accelerate the research and development, demonstration, and commercialization of geothermal energy. The contract was cost-shared by the States of California and Hawaii. Initially, the contract's focus was the construction of development scenarios for electrical power production using geothermal energy. In the course of the study, considerable emphasis was placed on direct use applications. The State of California Energy Commission Staff expressed the need for an estimate of the potential of the direct use of geothermal energy for their energy planning efforts. This effort was performed to satisfy that need. It was performed in a limited time period and under a restricted budget. Numerous assumptions were necessary and the results were constrained by the use of available data. The methodology and assumptions were formulated by the SAI geothermal staff working in an interdisciplinary fashion based on the collective experience in both analytical studies and direct heat utilization programs.

2.0 RESOURCE POTENTIAL

Although California has widespread surface indications of geothermal activity, most of the resources are ill-defined. It is possible that in many areas the resources are low temperature and of limited extent. Depending upon the application, the volume and temperature of a hydrothermal resource required for direct use may be substantially less than necessary for power generation.

2.1 EXPLORATION PROGRAM

The major portion of resource location and definition activities have been directed at the isolated electrical quality resources. Most of the defined KGRA's (Known Geothermal Resource Areas) in California are located far from the present concentrations of potential users; however, substantial resource potential does exist in the vicinity of these users which is not now being investigated.

Geothermal resources can be economically recovered from greater depth for direct use than for electrical generation. Since direct use can provide a higher efficiency of energy use than the production of electricity, a resource lying too deep for economical recovery for power plant application may be recoverable for direct use if it can displace large quantities of fossil fuels. For example, a 200°C (400°F) resource can be exploited for generation of electricity at an actual cycle efficiency of only about ten percent. Thus about 34,000 Btu are required to produce one kilowatt-hour of electricity, which can be sold for four or five cents. However, if the heat is used directly to displace natural gas at a value of about \$2.20 per million Btu, 34,00 Btu would be worth six to seven cents. Thus, areas in which the geothermal resource potential has been neglected may deserve consideration for direct use.

However, the economics of exploration for resources for direct use is not the same as the economics of production from a resource once it has been found. If a large number of direct use applications of geothermal energy is to be achieved, an exploration program to better define the resources is essential. The risk involved in exploration and the large investment required for drilling a test well, inhibit individual end-users from proceeding without prior assurance of resource availability and information on resource characteristics.

When exploring for resources capable of electrical generation, the companies involved are structured to withstand high risk ventures. Furthermore, the market for electricity ensures that successful exploration can be followed eventually by rapid, large scale expansion of resource exploration. This provides a high revenue yield and spreads the exploration costs over a large capital investment.

The case is not the same for direct use exploration; rapid expansion of revenues as a reward for successful exploration does not always occur. It is limited by the market for the products of direct use applications, the capital investment structure and often, the condition of land ownership. Exploration companies oriented toward accepting the high risk of exploration (for large gain) will not expand to fulfill the direct-users needs; also, potential direct users themselves are not attuned to investment in long-term energy supplies and high-risk exploration activities. Analysis of some specific potential users indicates that the capital available from private sources for exploration is virtually zero. Thus, a government exploration program is necessary if substantial geothermal direct use is to become a reality in California.

The cost of such a program need not be excessive. The major portion of the investment would finance test well drilling and would be recoverable if such wells were utilized for production or reinjection.

2.2 SCORING POTENTIAL DIRECT USE AREAS

To rank the prospective areas for a direct use resource exploration program, a simple scoring system was used. Areas in California were assigned points on the basis of the presence of surface evidence of resources and potential users. Equal weight was given for resources and users; the maximum point count was 10 (5 for resource indications and 5 for users). Appendices A and B give details of the data used for the ranking.

Since the amount of available subsurface data varied widely from one locale to the next, in order to treat all areas uniformly, only surface indications of geothermal potential were considered, such as location and surface temperatures of thermal springs and wells, surface heat flow, indications of geologically young vulcanism, and the presence of faults. Although, arguments could be made for weighting one indicator more heavily than another, the intent here is to provide a broad first look at where exploration might be valuable by indicating those areas having a spectrum of favorable indications. Hence, each was given equal weight. Obviously, when actual exploration plans are drawn up, more exacting geological analysis should be done.

In order to determine the potential for applications in an area, four aspects of direct use were considered: demand for space conditioning, concentration of industries with major

process heat demands at appropriate temperatures (i.e., high, medium, and low ranges as defined in this study), agricultural activity and population growth in the area. Absolute growth, rather than growth rate, was used to reflect the potential for locating new development near resources. Because of the high levels of concentrated use represented by large industrial establishments, industrial concentration could take on values of 0, 1, or 2. Space conditioning potential was determined on the basis of climate and population and could assume a variety of values between zero and one. Appendix B provides further information on the scoring system.

3.0 UTILIZATION POTENTIAL

This overview assesses the energy use levels that could be achieved in the near-term by exploiting geothermal energy to supply heating demands for both space conditioning and industrial process heating. Major applications for space conditioning and industrial process heating were determined and then co-located in the prospective resource zones. Energy requirements for each application were analyzed and the amount of fossil energy potentially displaced by using geothermal energy was determined.

3.1 SELECTION OF MAJOR USERS

Geothermal utilization in the near-term will be dependent on the present distribution of the demand for heat energy. Once geothermal wells have been developed in an area, additional users may develop if the energy supply is economically advantageous; initial development, however, is assumed to be dependent on the prior existence of a demand. The study's result, therefore, represents a conservative estimate of the level of direct use that could be achieved immediately, given sufficient investment.

Demand for residential space conditioning has not been considered. Although worldwide development has plainly shown that district heating systems provide one of the greatest markets for geothermal energy, experience in California indicates that it is very difficult to initiate geothermal development for the purpose of district heating due to the large number of parties involved, the difficulty of financing the initial capital investment, the low load factors that result from the relatively mild climate in most of the heavily populated areas, and the high costs associated with serving

Californians' decentralized life-style. Very similar problems arise when attempting to initiate geothermal development for multiple use systems involving several disparate industries.

Based on the considerations discussed above, a specific development concept has been adopted for the purposes of this study. It is assumed that the initiation of resource development for direct use is predicated on the co-location of some concentrated heat application with a resource. Then, if the energy yield from the geothermal wells exceeds the energy requirements of the application, the excess brine will be supplied for district heating systems or to other users (e.g., energy cascade systems) at whatever price is necessary to ensure use. For conservatism, no revenue beyond operating costs is assumed to be supplied from this source. A substantial level of government support which has been estimated would be required to help bear the initial investment.

Nine groups of applications were considered as representative of users that would be instrumental in starting large scale direct use applications. These groups are as follows:

- Hospitals
- Colleges and Universities
- Hotels (SIC Code 701)
- Food Processors (SIC 20)
- Lumber Mills (SIC 24)
- Paper and Pulp Manufacture (SIC 26)
- Chemicals and Allied Products (SIC 28)
- Petroleum and Coal Products (SIC 29)
- Rubber and Miscellaneous Plastics (SIC 30)

Obviously, other major applications could be added to the list for space conditioning, major building complexes such as shopping centers, major office complexes, giant apartment complexes, and large prisons and jails, to name a few. But these candidates are not as numerous as hospitals, hotels, and colleges. and sufficient data is not readily available. Similarly, for industrial processes, we have found that these are the major process heat users in the temperature range likely to be available geothermally. Riestad (1975) estimates that these industries account for about two-thirds of the industrial process heat demand in the appropriate temperature ranges. The distribution of the selected applications was found at the county level. Maps of California showing applicable data are presented in Appendix B.

It is not intended to exclude the public sector from a major role in development of geothermal direct use. Government buildings and district heating systems may ultimately use a major portion of the geothermal heat supplied. In addition, public support is essential if the initial capital requirements for the majority of the projected development are to be met. The first phase of development will be to serve some concentrated public or private direct heat demand.

3.2 RESOURCE ZONES

A set of zones in which geothermal resources have been found or in which thermal springs and wells appear were defined (see Figure 3.1). Zone boundaries reflect changes in the density and characteristics of thermal springs and wells. Where appropriate, the boundaries correspond roughly to major geologic features, especially Quaternary fault zones which seem to be related to much of California's geothermal resource. The zones defined generally include areas labeled as "prospective resource areas" by the USGS (EOS, 1977), but additional

FIGURE 3.1 CALIFORNIA RESOURCE ZONES FOR OVERVIEW ANALYSIS

area has been included, since some of the direct uses under consideration can be served with relatively low temperatures. There exist a few isolated thermal springs outside the indicated zones; these were not considered because they would not have significant impact on the total estimate.

The zones were grouped into four classes for each of three temperature ranges (low, medium and high). A value indicating the probability of finding a resource at a given location was assigned to each set of zones. Each temperature range (probability) for each zone and temperature, P_{ZT} , had one of twelve values. The low temperature probability was based roughly on the density of known hot springs and wells in each zone.

Zones were assigned probabilities for the higher temperature classes according to the existence of known high temperatures, high geothermometers, or high thermal gradients and heat flows in the zone. It was assumed that a higher temperature resource could exist only where the next lower temperature resource also existed; thus the total resource probability is the low temperature probability, not the sum of the low, intermediate, and high temperature probabilities.

The resource assumptions used are regarded as conservative in view of the limited exploration and drilling data available in many of the zones. Depths for the various temperature ranges were assigned for each zone based on available subsurface data. Appendix C summarizes the resource assumptions.

3.3 THE COST OF DIRECT USE GEOTHERMAL DEVELOPMENT

Energy demand for the various applications was calculated by the average size of the establishments in each county and known energy consumptions for sample users. Federal and industry publications supplied information on the industrial applications; demand by the three space conditioning users was estimated by sampling actual users. A climatic correction, based on climatic zones defined by the State Energy Commission, was used to extend the space conditioning estimates throughout the State. Appendix D gives details on the energy demand assumptions.

Costs were estimated for the development of geothermal systems in areas in which resources and applications had the potential of being co-located. Cost estimates were made from a formula derived from work by Milora and Tester on power plants:

$$\text{Investment} = 20/9 \text{ CSTE} + 1.75 \text{ CSTW}$$

CSTE is the cost of the equipment for the development, exclusive of the well or wells. The cost of surface transmission of the geothermal fluid to and from the user (over an assumed distance of one mile) was included in this term. The factor, 20/9, represents the non-equipment costs, such as installation, permits, inspection, etc. CSTW is the cost for a well. The conservative assumption that one reinjection well, costing three-fourths as much as a producing well, will be required for each producer resulted in a coefficient of 1.75. No exploration costs were included since (as discussed previously) individual direct users cannot be expected to bear these costs, at least at the present time.

Well costs are a function of the depth of the well and the type of rock in which the well is drilled. Costs for blow-out prevention and casing and cementing may also depend on the type of well and the conditions of the formation drilled into. This is especially noticeable when oil and gas well costs are compared with those for geothermal wells. For this study, however, it was assumed that all wells would be drilled and completed by essentially uniform procedures.

Well costs are commonly divided into two parts: a fixed cost for rig mobilization and a per foot cost. Following Cummings, et al., 1978, a \$96,000 mobilization cost was used (Cummings, et al., use this for wells less than 2,000 meters deep and a higher cost for wells greater than 2,000 meters). Since most of the wells involved in this overview are assumed to be 2,000 meters deep or less, the \$96,000 figure was used for all wells and per foot costs fit by an exponential relationship.

$$D \times 10^{(0.00005 D + 1.7)}$$

Thus, $CSTW = 96,000 + D \times 10^{(0.00005 D + 1.7)}$, where D is depth in feet. Cummings, et al., use this formula for 9 to 12 inch diameter cased geothermal wells in hot crystalline rock; however, it fits reasonably well when applied to several sample estimates made for wells in California in a variety of geologic situations. Usually, wells under 1,000 feet deep are substantially less expensive than would be determined using the formula, so a factor of one-half was applied for D less than 1,000.

Estimates for CSTE were prepared for the necessary equipment and material to transport geothermal fluid from the production well to process heating and cooling equipment located at an application, to an injection well for disposal, and

to modify existing process equipment or add new equipment to utilize geothermal fluids. The total equipment and material cost estimates were made for each application for the low, intermediate, and high temperature ranges, if applicable. It was assumed that the space conditioning applications could be served by any of the three temperature ranges, while the industries were portioned between the intermediate and high temperature ranges. Figure 3.2 summarizes the assumed relationship between application and temperature.

<u>Temperature Range for Application</u>			
Hospitals	Low T ($<80^{\circ}\text{C}$)	Intermediate T ($80-115^{\circ}\text{C}$)	High T ($>115^{\circ}\text{C}$)
Colleges			
Hotels			
Food Processors			
Lumber Mills			
Chemical and Allied Products			
Pulp and Paper			
Petroleum Refining			
Rubber and Miscellaneous Plastics			

Figure 3.2. Temperature Ranges Assumed for Selected Applications

In order to estimate equipment and material costs in a consistent and logical manner, "typical" plant peak heating demands were defined for each direct use application and costs were estimated for these typical plants. For the purposes of this analysis, it was assumed that equipment and material costs for smaller or larger plants would be directly proportional to the magnitude of heat demand (i.e., the cost in \$/MBtu to convert to geothermal direct use for a specific industry is equal for all plants within that industry). It was also assumed that the production wells will require pumping.

Major process equipment and piping were preliminarily specified using standard engineering techniques for each typical plant size within each industry. Equipment and material costs were then estimated with cost estimating references in use throughout the process industries (Richardson, 1978 and Guthrie, 1974). A system capacity factor (annual energy used/peak capacity x 8760 hours per year) was assumed for each application, and costs were converted to dollars per million Btu per year for ease of comparison. Table 3.1 summarizes the equipment and material cost estimates by application and geothermal resource temperature.

Table 3.1 Equipment and Material Cost Estimates, 1978 Price Level, Typical Direct Use Applications (\$/Million Btu/yr)

Application	Geothermal Resource Temperature			Capacity Factor
	<80°C	80-115°C	>115 °C	
Hospital	11.70	8.30	6.90	60%
University/ College	17.30	11.70	8.90	35%
Hotel *	60.00	40.00	31.00	25%
Food Processing	-	1.70	0.86	90%
Lumber	-	2.86	1.70	90%
Pulp and Paper	-	-	0.70	90%
Chemicals	-	2.30	1.20	90%
Petroleum Refining	-	-	1.00	90%
Rubber and Plastics	-	-	2.00	90%

* estimates include costs of well pumps and pipelines; for hotels this has a major impact on unit costs (which would be mitigated if several hotels or other buildings were to be served).

As can be observed, the space conditioning applications have much higher capital requirements than do the industrial applications. Two major factors affect this: the relatively low capacity factors assumed, and the inclusion of space cooling by absorption refrigeration, which has a high equipment cost. In addition, the inclusion of 100% of the cost for pumps and surface pipelines is a major burden for a small, single application, such as a hotel. These equipment cost estimates should not be taken out of context.

3.4

DEVELOPMENT OF THE DIRECT USE MODEL

The direct use model computed energy use based on the resource probability and the number of applications. The key factors are $X_{C,A}$, the number of applications of type A in county C, and the probability $P_{Z,T}$ by zone and temperature. By examining the distribution of population, the applications in each county were partitioned into the resource zones intersecting the county to produce $X_{Z,C,A}$. Then $\sum_Z \sum_C \sum_A P_{Z,T} X_{Z,C,A}$ (with the constraint that T be the minimum for A) is the number of applications that can be served in the State. If $E_{C,A}$ is the expected energy use required for an application of type A in county C, $\sum_Z \sum_C \sum_A P_{Z,T} X_{Z,C,A} E_{C,A}$ is the expected energy used by the application. In addition, if $N_{C,A}$ is the number of wells required to supply $E_{C,A}$, then $\sum_Z \sum_C \sum_A P_{Z,T} X_{Z,C,A} N_{C,A}$ is the expected number of wells (the number of wells was found for each temperature range). After the capital requirements for the geothermal developments were calculated, a check was made to determine the effectiveness in each particular case of seeking higher temperature wells for the lower temperature wells, as appropriate, depending on the resource probabilities and well yields.

In the course of the analytical procedure, it was observed that most applications required less than the energy that could be produced by a single well (wells were assumed to be pumped at the rate of 1,000 gallons per minute). Letting Y_T be the expected well yield in terms of energy supplied (Btu) per year and N_T the number of wells, $\sum_T Y_T N_T$ is the total expected energy supplied by the wells and available for direct use.

In addition, the expected capital investment required for each application was calculated. Using the well costs and

equipment costs, $I_{C,A}$, the total capital requirement is $\sum_Z \sum_C \sum_Z P_{Z,T} X_{Z,C,A} I_{C,A}$, to provide the wells and to equip the applications considered. This investment will supply the total expected energy yield of the wells, but does not include the cost of using the excess yield.

The level of government support required to provide the computed energy supply is the difference between the required investment computed and the portion of that investment that could be borne by the particular applications (private investment, except for some of the hospitals and colleges). To arrive at this portion of the investment, henceforth referred to as the "private investment," it was assumed that fuel worth \$2.20 per million Btu would be displaced, the systems would be operating and maintenance costs would equal 25% of the gross revenue, and financing would be 50% equity and 50% debt with equity recovery in four years allowing 10% investment tax credit and 50% intangible drilling cost writeoff, but no depletion allowance.

Checking against the more sophisticated GEYSER model for geothermal revenues, these assumptions were found to be approximately equivalent to a 17% annual return on investment over 20 years. Fuel costs were assumed to rise no faster than the inflation rate. All these assumptions are regarded as being conservative.

A private investment estimate, $PI_{C,A}$, was calculated for each application type and county. For most applications, $PI_{C,A} \ll I_{C,A}$. The total private investment level would then be $\sum_Z \sum_C \sum_A P_{Z,T} X_{Z,C,A} PI_{C,A}$. The difference between this and

the total required investment gives the necessary initial government support that should be supplied by subsidies, incentives, or interest-free loans. Expanded federal tax incentives, such as those in the energy bills now before Congress, may supply a portion of this requirement.

Total required investment was calculated "generously" using assumptions such as one reinjection well per producing well or participation by only one application in the cost of a well, resulting in a total investment figure that has been maximized. On the other hand, the assumptions used in calculating the private investment portion were conservative, resulting in a minimum value. The figure obtained for the required government support (the difference) is a reasonable estimate of an upper bound, but it should not be taken as a "most probable" estimate. Costs for an exploration program are not included; however, since the major portion of exploration costs are for test wells and most test wells would eventually serve as producer or reinjection wells, the bulk of the cost of an exploration program would ultimately contribute toward the capital requirement.

4.0 RESULTS AND CONCLUSIONS

If any large amount of direct use is to be achieved, an exploration program to better define the resources is essential. During the course of this overview, a scoring system was developed to define promising locations for future investigation. Points were assigned on the basis of the presence of surface indications of resources and potential users. Once these areas were determined, potential applications for direct use -- primarily space conditioning and industrial process heat requirements -- were analyzed. Using a direct use model developed for this study, the energy requirements of these uses were computed, as well as the percentage of these needs that could be supplied by geothermal energy.

4.1 RESOURCE POTENTIAL RESULTS

The scoring system developed to define potential locations for an exploratory program, assigned equal weighting for presence of surface indications of a resource and potential users. The maximum point count was 10 (5 for resource indications and 5 for users).

Only surface indications of geothermal potential were considered. The indicators were each assigned an equal weight and included location and surface temperatures of thermal wells and springs, surface heat flow, indications of geologically young vulcanism and the presence of faults. In addition, to determine the potential for direct use, concentrations of large industrial establishments in an area could assume values of zero, one and two. Space conditioning could take on a variety of values between zero and one.

Scores were rounded to the nearest integer value. Those areas awarded six or more points were identified as having the best potential for a direct use exploration program (5 points was the maximum for either potential resources or uses); these areas must have potential for both. Figure 4-1 presents a map of California showing these areas. A few, such as Imperial Valley, are already the subject of considerable exploratory activity, but most are not. The boundaries of the areas shown include all local geothermal manifestations; an exploration program should first examine the specific geology of each area.

4.2 UTILIZATION POTENTIAL RESULTS

A direct use model was developed to calculate energy use based on resource probability and number of applications. (The model is described in Section 3.3.4.) The number of potential applications in the State was determined, as well as the energy use by application. Then, the number of wells required to supply the application was computed.

The total number of producing wells calculated using the California data and methodology of Section 3 was 456. This consisted of 186 for low temperatures, 210 for intermediate temperatures, and 60 for high temperatures. Assuming a 10% downtime for the system, the total well yield that could be supplied for direct use was then estimated to be about 10^{14} Btu/hr, or 0.1 quads per year. Since the sampled applications did not include all uses, it would be legitimate to project that in the near-term, based on the existing distribution of heating demand and on conservative resource probabilities, an energy supply for direct use between 0.1 and 0.2 quads per year can be projected, assuming an active program to support direct use development is undertaken. The concentrated applications assumed to drive the development

FIGURE 4.1. SUGGESTED AREAS FOR EXPLORATION FOR RESOURCES FOR GEOTHERMAL DIRECT USE BASED ON POTENTIAL FOR APPLICATIONS AND FAVORABLE GEOLOGY.

would consume only about 10% of this energy total. The remainder would be available for district heating or for new or nearby industry or agriculture.

The total capital investment calculated (leading to 0.1 quads) was about \$510 million. The private investment fraction calculated was about 25% of this amount, indicating government support on the order of \$350 to \$400 million. This is total investment in 1978 dollars, not an annual investment level. A ten year program, for example, would need to supply \$30 to \$40 million a year. This support could be provided by government participation in the ownership of the wells, as direct subsidies, as a variety of indirect incentives, or possibly as interest-free loans. It has been assumed that no revenue above operating costs is provided by the sale of the large excess well yield available, because the cost of distribution borne by the hypothesized heating districts or other users may be large. In fact, however, it should be possible for the government supported portion of the investment to be recovered over the long-term operation of the systems.

By limiting the calculation to only those applications that can provide some given percentage of the required investment, it is possible to compute the energy supply that could be achieved for a lower level of government support. This was done for a range of support levels from zero to 100 percent to find energy supply as a function of total (not annual) support. This is displayed in Figure 4.2. Only a very low level of energy use is achievable without support (about 10^{13} Btu/yr). Furthermore, since the risk of exploration has not been allowed for, it must be realized that even this low energy use will not be achieved in the absence of some program to support geothermal

direct use. The risk factor is such that little or no development can be expected unless exploration programs are established to reduce the risks to a level that can be borne by the private sector.

Figure 4.2. Direct Use of Geothermal Energy as a Function of Financial Subsidy

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APPENDIX A

RESOURCE INDICATIONS

This Appendix presents the indicators utilized for ranking the geothermal resource areas within the State of California. As only surface indications were considered during the course of this study, data are presented on presence of thermal wells and springs, temperature gradients, surface heat flow, and Cenozoic vulcanism. These indicators, along with data on potential users, were used to define areas for a direct use exploration program.

As discussed in Section 2 of this overview, areas were ranked in terms of their potential for having geothermal resources co-located with potential direct heat applications to define areas in which an exploration program would be desirable for achievement of a high level of direct use. Since the amount of geological data available is not uniform throughout California, only surface indicators of geothermal potential were considered. Otherwise, areas for which favorable subsurface data were available might receive more attention than areas for which no subsurface data are available; an effect which would rather defeat the purpose, which is to direct attention to areas needing exploration.

Five points were possible for indications of potential resources. Points were assigned as follows:

Resource Indications

One point each was assigned for:

- Presence of thermal wells and springs
- Surface water temperatures above 150°C

- Heat flow greater than 2 hfu
- Evidence of Cenozoic vulcanism
- Presence of two or more faults showing evidence of motion in Quaternary times with a separation less than 10 km.

Figure A.1 shows the locations of hot springs in California and contours of the surface temperatures of the springs in degrees Fahrenheit. Figure A.2 shows contours of surface heat flow, in heat flow units ($1 \text{ hfu} = 1 \mu\text{cal/sec-cm}^2$), based on data from the American Association of Petroleum Geologists (AAPG, 1978) and the USGS (EDS, 1977). It will be noted that there are no data for the extreme northern parts of the State. Since there are numerous water wells in these areas showing substantial temperature gradients (DCMG, 1978), these areas were arbitrarily given a heat flow point (actual heat flows were not calculated due to lack of data on thermal conductivity of the rocks). Figure A.3 shows areas of Cenozoic vulcanism, compiled from geologic maps of the State. Both Quaternary and Tertiary formations were regarded as significant in terms of prospective geothermal resources, since they are intermixed over much of the State. At least one area in California - Imperial Valley - has abundant geothermal resources in which the existing limited volcanics are almost all Tertiary.

Data on the location of faults that have shown movement in Quaternary times were taken from the Fault Map of California (Jennings, 1975). It was found that concentrations of thermal wells and springs were much more strongly associated with faults showing surface displacement in Quaternary (but not historical) times than elsewhere, occurring with three times the density within five kilometers of such faults as elsewhere in the State.

Figure A.1. Hot Springs and Surface Temperature Contours in California

Figure A.2. Heat Flow Contours for California

Figure A.3. Areas of Cenozoic Vulcanism in California

APPENDIX B

POTENTIAL USES

In addition to scoring areas in terms of resource potential, points were also assigned designating the potential for direct use of the geothermal energy discovered. The maximum score attainable was five. Points were assigned on the basis of population density, climate, concentration of agriculture or selected industries, and rate of population growth.

Potential for space conditioning was evaluated as the product of a population density factor and a climate factor. For population, urban areas were given one point; mixed areas, one half; and rural areas, one quarter. Figure B-1 shows contours for heating degree days in California in degrees Celsius. Figure B-2 presents contours of design temperatures (temperature that will be exceeded for the four hottest hours of the day only 2½ percent of the time) for cooling systems. Data more closely related to energy demand for cooling were not readily available. The climate factor was the sum of a heating and a cooling factor assigned, as follows:

<u>Heating</u>		<u>Cooling</u>	
<u>Degree Days</u> <u>(Celsius)</u>	<u>Climate</u> <u>Factor</u>	<u>Degrees</u>	<u>Climate</u> <u>Factor</u>
>4000	0.8	>40	0.8
>2000	0.4	>30	0.4
<2000	0.2	<30	0.2

Although it was theoretically possible to achieve a sum greater than one, no area in California achieved a sum greater than one.

Figures B.3 and B.4 show distribution by county of five types of industrial establishments: food processors, lumber mills, paper and pulp mills, chemical plants, petroleum and

Figure B.1. Heating Degree Days for California

Figure B.2. Cooling System Design Temperatures for California

Figure B.3. Distribution of Five Types of Industrial Establishments by County in California

Figure B.4. Number of Firms with 20 or More Employees in Selected Process Heat Applications by County in California

coal products, and rubber and plastics plants. Figure B.3 presents all establishments, while Figure B.4 shows only those with 20 or more employees, in order to quantify the size and number of industrial locations in each county. These industries embrace the bulk of the industrial process heat demand in appropriate temperature ranges (Riestad, 1975).

Nationally, lumber products are of less significance than several of the other industries, but lumber is a major product in California, especially in some of the most promising resource areas in the State. Kiln drying of lumber has been identified as an excellent candidate for direct use of intermediate temperature geothermal heat (VTN, 1977).

The concentrated high demand for heat represented by industrial establishments, which need both space conditioning and process heat, and the great variation in industrialization over the State necessitated a multiple scoring procedure. A maximum of two points was allowed for heavy concentrations of the selected industries; one point for intermediate concentrations and zero for areas with little industry.

In the scoring, a point was given for areas that contained, or were adjacent to, heavy concentrations of agriculture, especially cattle raising, dairy products, and vegetables. This was done because of the large numbers of applications that have been suggested for agricultural areas, including heating feedlots, pasteurizing milk, pregermination and soil warming, processing and utilization of agricultural waste, and greenhousing. Census Bureau data appearing in Figure B.5 were used in this scoring procedure.

The fifth score was assigned on the basis of population growth. This was intended to reflect the prospects for

CATTLE AND CALVES: 1974

1 DOT = 2,500

74 - 6CA

U.S. Department of Commerce
Bureau of the Census

VALUE OF DAIRY PRODUCTS SOLD: 1974 (FARMS WITH SALES OF \$2,500 AND OVER)

1 DOT = \$500,000

74 - 6CA

U.S. Department of Commerce
Bureau of the Census

VEGETABLES, SWEET CORN, AND MELONS HARVESTED FOR SALE: 1974

1 DOT = 150 ACRES

74 - 19CA

U.S. Department of Commerce
Bureau of the Census

LAND IN ORCHARDS: 1974

1 DOT = 200 ACRES

74 - 17CA

U.S. Department of Commerce
Bureau of the Census

Figure B.5 Distribution of California Agriculture

increased geothermal use represented by the possibility of locating new facilities, such as hospitals, shopping centers, housing developments, industries, etc., near newly discovered resources. It should be easier to shift planned new development to locations where low cost heating can be supplied geothermally, rather than induce existing population or industry to relocate. Since the amount of new energy use will depend on the actual number of new establishments, rather than on the percentage increase (some of the counties in California with the highest percentage growth rates have populations of only a few thousand), absolute growth and not growth rate was used. One point was assigned for an increase in county population of approximately 11,000 or more from 1970 through 1975, thus representing the median growth with half the counties growing faster and half more slowly. Although individual scoring was sometimes greater than one point, no area received more than a five point total for potential use.

APPENDIX C

RESOURCE PROBABILITY AND DEPTH ASSUMPTIONS

Appendix A established the methodology for determining the geothermal resource zones, based on surface indications, within the State of California. In this section, the probability of finding a target geothermal resource for direct use is discussed. The resource probability was assigned on the basis of temperature range and classification. In addition, in an effort to calculate well costs, the depths of the temperature ranges were also assigned using available data on thermal gradients.

Figure C.1 is the basis for Figure 3.1 in the body of the text, with the resource zones given alphabetic designations for identification and probability assignment. These zones include most of the known manifestations of geothermal energy in California. A few isolated hot springs do exist outside the indicated zones, and it would be most unfortunate if future development programs ignored the possibility that resources may be discovered outside the indicated zones. However, for the overview, resources were assumed only in the zones shown.

For direct use, three temperature ranges were assumed: low temperature -- less than 80°C; intermediate -- 80-115°C, and high -- above 115°C. This leaves a rather wide range of temperatures in the high range; however, based on the data available, temperatures exceeding 140-150°C are quite restricted in area. This may be due as much to limited exploration as to the actual distribution of resources. Temperatures of 150 to 200°C can serve some processes that cannot be served with lower temperatures; these were not considered

**FIGURE C.1 CALIFORNIA RESOURCE ZONES FOR OVERVIEW ANALYSIS
(BASED ON THERMAL SPRING AND WELL DATA).**

because in terms of a near-term program based on present industry distribution, their impact on the aggregate use would be small. However, in the longer term, significant development of high temperature geothermal resources for industrial applications is the key to use of geothermal resources having a significant displacement of the use of fossil fuel resources.

A first order estimate of the probability of finding a geothermal resource convenient to a given location was based on four probability classes and an assigned probability associated with each for each temperature range as shown in Table C.1.

Table C.1. Probabilities of Finding Various Temperature Resources by Class

CLASS	ASSIGNED PROBABILITY		
	LOW TEMPERATURE ($<80^{\circ}\text{C}$)	INTERMEDIATE TEMPERATURE ($80^{\circ}\text{C}-115^{\circ}\text{C}$)	HIGH TEMPERATURE ($>115^{\circ}\text{C}$)
1	.33	.22	.11
2	.11	.07	.04
3	.07	.04	.02
4	.03	.02	.01

The zones were grouped into these four classes. A zone could be a different class for each of the three temperature ranges considered. Table C.2 presents the assignment of zones and classes for the prospective regions in California. This table is used to define the estimated probability of finding a geothermal resource in a particular temperature range in an area.

Table C.2 Resource Zone Categorization

CLASS	LOW TEMPERATURE ($<80^{\circ}\text{C}$)	INTERMEDIATE TEMPERATURE ($80-115^{\circ}\text{C}$)	HIGH TEMPERATURE ($>115^{\circ}\text{C}$)
1	U,F,A	U,A,F	U,F,A,Q
2	S,T,N,M,L,E,Q	J,H,E,D,K,R,Q,C	C,H,J,B,K,O,R
3	O,D,B,C,K,R,H	B,M,N,O,P	E,D,P,M
4	G,I,J,P	G,I,S,T,L	G,I,S,T,L,N

Note: Alphabetic characters refer to zones shown on Figure C.1. This table is to be used in conjunction with Table C.1 and Figure C.1 to estimate the probability of finding a geothermal resource in the designated temperature range for any region in the State. Areas without alphabetic characters are assigned a probability of zero.

The low temperature probability was based on the density of hot springs and thermal wells in a zone, given the assumption that resources could be reasonably transported approximately two miles. This is a conservative assumption. For large applications involving large volume flows and high temperatures, transport over much longer distances, perhaps as much as twenty miles, is economically feasible. However, a radius of two miles was used as an appropriate general assumption to obtain a first-order estimate under the study constraints. If increased program financial support or reductions in pipeline costs were to increase the feasible radius, it could have a large impact on the calculated level of geothermal direct use.

The resource zones were grouped into the higher temperature classes depending on the abundance of subsurface data, such as downhole temperatures, high chemical geothermometers, high local thermal gradients, and high heat flows, that would indicate the availability of such temperatures. The amount of available subsurface information is limited; for many of the zones, the resource probabilities assigned should be thought of as

hypotheses rather than conclusions. In addition, a strong degree of conservatism is introduced into the assigned numbers since many of the zones considered are largely unexplored and had few indications of high temperatures (assigned low probabilities).

The assumption was made that higher temperature resources could not exist without the potential for recovering lower temperature deposits as well. Thus, the total resource probability for each zone equalled the low temperature probability. For a few zones, such as zone Q, including the Imperial Valley, the grouping of the zones into the four classes, plus (relatively) abundant subsurface data, resulted in a larger probability for high temperatures than low ones. In these few cases, a constraint was simply applied to set the lower temperature probabilities equal to the higher ones.

In the calculation of well costs, depths at which each temperature range would be found in each zone had to be assumed. Obviously, this may be highly variable in the real case, but for the overview uniform depths were assumed in each zone using available data regarding thermal gradients. Table C.3 summarizes these assigned depths for reaching each temperature range resource by zone.

Table C.3. Assigned Temperature and Depth.
in the Resource Zones (By Zone
in Accordance with Figure C.1)

ZONE	LOW TEMPERATURE (Depth in Feet)	INTERMEDIATE TEMPERATURE (Depth in Feet)	HIGH TEMPERATURE (Depth in Feet)
A	500	1000	3500
B	500	2000	4000
C	500	1500	3500
D	500	1500	3000
E	500	2000	4000
F	1500	2500	4000
G	2000	4000	6000
H	2000	4000	6000
I	2000	3500	5000
J	1500	3000	4500
K	2000	3500	5000
L	2500	4000	6000
M	2000	4000	6000
N	2000	3500	5000
O	2000	4000	6000
P	2500	4000	6000
Q	1500	3000	5000
R	4000	6500	8500
S	2000	4000	6000
T	2500	5000	7000
U	500	1000	2500

APPENDIX D

ENERGY USE ESTIMATES

This Appendix presents energy use estimates for the major industrial users of process heat in the temperature ranges readily supplied from geothermal resources. The energy requirements of individual establishments and manufacturing processes were estimated and the percentage that could be supplied geothermally was developed. Space conditioning requirements were also estimated.

Six industrial process heat applications were considered for California:

- Food Processors
- Lumber Mills
- Paper and Pulp Manufacture
- Chemicals and Allied Products
- Petroleum and Coal Products
- Rubber and Miscellaneous Plastics.

These industries represented the major users of process heat in temperature ranges readily supplied from geothermal resources. Rubber and miscellaneous plastics proved to be less significant than most of the rest. Lumber is included because California is one of the main lumber producing states.

Maps showing the distribution of these industries based on 1975 business patterns data have already been presented in Appendix B (Figures B.3 and B.4). The energy requirements for each industry were analyzed based on industry and federal government publications and a value for energy use per employee was obtained. This was used to estimate the energy requirements of individual establishments.

The manufacturing processes involved were then reviewed and estimates arrived at for the percentage of the energy requirements that could be supplied from geothermal heat for each industry. Assumptions were necessary to the temperature ranges needed. Table D.1 presents the projected purchased energy for selected industries by county. Table D.2 summarizes the State totals for these industries, the value of the energy at \$2.20 per million Btu, the estimated energy use per employee, and the fraction of the energy requirement that was assumed to be supplied geothermally.

The space conditioning applications represented concentrated space conditioning demands that provide conditions conducive to the initiation of geothermal projects. Geothermal space conditioning development in California is hampered by low load factors, decentralized living patterns, and the problems of initiating a program involving numerous parties with potentially conflicting interests. Hospitals, colleges and universities, and hotels and motels were selected as the most widespread opportunities about which reasonably consistent data could be collected. In addition, many were thought to already have centralized circulating water space conditioning systems which could be readily retrofitted. It was assumed that both heating and cooling would be required.

To determine energy demand for the space heating applications, sets of actual establishments were sampled regarding their space conditioning requirements. Many of the responses appeared to contain errors. Energy standards for energy consumption per square foot in new buildings established by the State Energy Commission (CERCDC, 1976) were used to supplement data from the sampled establishments. These standards included

Table D.1 Purchased Fuels and Electric Energy Projected
for California Counties for Six Major Process
Heat Using Industries (Billion BTUs)

	<u>Food</u>	<u>Lumber</u>	<u>Paper</u>	<u>Chemical</u>	<u>Oil</u>	<u>Rubber</u>
Alameda	8,068.5	336.8	3,394.6	6,150.7	1,535.4	371.7
Alpine	-	-	-	-	-	-
Amadore	-	271.2	-	-	-	-
Butte	438.7	495.4	-	-	-	12.7
Calaveras	-	18.1	-	-	-	-
Colusa	39.4	-	-	-	-	-
Contra Costa	1,534.4	70.4	2,280.3	3,937.3	39,725.3	48.8
Del Norte	33.4	554.9	-	-	-	-
El Dorado	-	207.6	-	-	-	37.2
Fresno	3,802.5	374.5	166.7	1,034.8	-	74.3
Glenn	282.4	63.5	-	-	-	-
Humboldt	327.2	2,310.2	395.7	-	-	-
Imperial	362.6	-	-	204.4	-	-
Inyo	33.4	-	-	-	-	-
Kern	779.2	75.5	-	325.9	7,332.5	88.6
Kings	459.4	-	-	113.3	3,079.2	159.3
Lake	-	25.8	-	-	-	-
Lassen	-	151.0	-	-	-	-
Los Angeles	31,644.3	3,882.7	16,514.9	30,226.7	73,743.9	6,753.9
Madera	758.5	152.8	-	-	-	10.6
Marin	85.5	-	-	-	-	78.4
Mariposa	-	-	-	-	-	-
Mendocino	93.5	1,116.3	-	-	-	-
Merced	2,437.1	110.3	52.8	-	-	13.2
Modoc	-	53.3	-	-	-	-
Mono	-	-	-	-	-	-
Monterey	2,228.8	34.5	184.7	58.4	-	371.7
Napa	618.9	63.5	-	204.4	-	-
Orange	4,202.5	855.7	4,397.0	6,387.9	1,650.4	1,663.1

Table D.1. Purchased Fuels and Electric Energy Projected
for California Counties for Six Major Process
Heat Using Industries (Billion BTUs) (Cont'd)

	<u>Food</u>	<u>Lumber</u>	<u>Paper</u>	<u>Chemical</u>	<u>Oil</u>	<u>Rubber</u>
Placer	-	280.5	-	-	-	69.0
Plumas	-	299.0	-	-	-	-
Riverside	885.4	681.0	791.4	735.8	-	104.5
Sacramento	2,434.4	510.2	453.7	661.1	-	29.1
San Benito	116.8	-	52.8	438.0	-	-
San Bernardino	1,583.1	373.8	382.0	1,287.1	-	242.6
San Diego	2,973.3	268.9	317.6	2,047.5	656.9	199.0
San Francisco	3,159.5	136.5	494.9	899.4	-	114.1
San Joaquin	4,350.1	647.4	791.4	869.0	-	99.4
San Luis						
Obispo	101.5	18.1	-	-	410.5	-
San Mateo	2,085.9	103.4	919.1	1,747.3	615.8	631.3
Santa Barbara	1,069.0	39.9	-	-	410.5	37.2
Santa Clara	6,438.6	250.8	1,846.6	2,657.2	410.5	429.6
Santa Cruz	2,185.4	161.1	-	-	-	35.7
Shasta	112.8	974.7	791.4	-	-	10.6
Sierra	-	18.1	-	-	-	-
Siskiyou	46.1	643.8	-	-	-	-
Solano	942.8	54.8	55.9	-	3,079.2	-
Sonoma	1,408.8	516.8	-	-	-	37.2
Stanislaus	6,422.6	179.3	1,086.8	204.4	-	22.5
Sutter	425.3	117.6	-	-	-	-
Tehama	155.6	404.3	395.7	-	-	-
Trinity	-	136.1	-	-	-	-
Tulare	1,149.1	433.7	184.7	-	-	42.3
Tuolumne	-	241.7	-	-	-	-
Ventura	1,197.8	136.5	797.7	210.2	886.8	237.9
Yolo	929.4	321.2	395.7	114.5	-	22.1
Yuba	41.4	221.4	-	-	-	-

Table D.2 Estimated Energy Use By Selected California Industries

INDUSTRY	PROJECTED ENERGY USE IN CALIFORNIA (10^{12} Btu per year)	ANNUAL ENERGY COST AT \$2.20 PER 10^6 Btu	ENERGY USE PER EMPLOYEE (ESTIMATED) (10^9 Btu per year)	FRACTION THAT COULD BE SUP- PLIED GEOTHER- MALLY
Food and Kindred Products	99	218	0.7	0.8
Lumber Mills	33	73	1.1	0.67
Pulp and Paper	20	44	4.1	0.30
Chemicals	61	134	1.2	0.35
Petroleum Refining	438	964	33.1	0.20
Rubber and Plastics	12	26	0.2	0.35

Note: Based on U.S. Department of Commerce data.

a set of climatic zones* for California. These were used to establish a climate correction to extend the energy use data to all parts of California. The climate zone map is shown in Figure D.1. The climate correction used was 1.4 for zones 14 and 15; 1.3 for zones 11, 12 and 13; 1.2 for zones 1, 2, 3, 4; and, 5 and 1.0 for zones 6, 7, 8, 9 and 10. The energy consumption figures used were 3×10^8 Btu/year per bed for hospitals, 1.5×10^7 Btu/year per student for colleges, and 2×10^8 Btu/year per employee for hotels and motels. In addition, it was assumed that the energy consumption for small motels would be twice this figure, to allow for greater heat losses from more spreadout architecture.

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* Different than the zones previously discussed.

Figure D.1 Climate Zone Map for California