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A Market Survey of Geothermal Wellhead Power Generation Systems

Final Report

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Prepared for
Department of Energy
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by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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FOREWORD

The Jet Propulsion Laboratory, California Institute of Technology, has performed this study for the Geothermal Energy Division (GED) of the Department of Energy (DOE) under Interagency Agreement No. EG-77-A-36-1021. The purpose of the study was to assess the market potential for a portable geothermal wellhead power conversion device. Major objectives of the study were to identify the most promising applications of these systems, the potential impediments confronting their industrialization, and the various government actions needed to overcome these impediments. While the primary emphasis of the study was a marketing survey, through structured interviews of key decision-making individuals in the various disciplines of the geothermal community, some technical and economical analysis of a candidate system was performed to support the feasibility of the whole concept.

This paper is the final report for the project; it documents the work performed and presents the project's conclusions and recommendations.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to all those who contributed to this study and report. We would like to acknowledge Rogers Engineering Company, Inc. for their contribution to the detailed economic analysis section of the report. Also, our special thanks go to the many members of the geothermal community and industry (listed in Appendix A) who graciously gave up their time, usually on very short notice, to submit to the structured interviews. Finally, we would like to thank Dr. David Elliott for his support on the technical and incremental-cost analysis sections of the report, and Donna Pivrotto for her support in formulating the structured interview and assistance in the final report.

ABSTRACT

The purpose of this study was to assess the market potential for a portable geothermal wellhead power conversion device (1-10 MW generating capacity). Major study objectives included identifying the most promising applications for such a system, the potential impediments confronting their industrialization, and the various government actions needed to overcome these impediments. The heart of the study was a series of structured interviews with key decision-making individuals in the various disciplines of the geothermal community. In addition, some technical and economic analyses of a candidate system were performed to support the feasibility of the basic concept.

SUMMARY

Summarizing the myriad of ideas, thoughts, concerns and suggestions gathered during the course of personal interviews with many leading individuals in the geothermal community was not an easy task. In terms of a broad overview, no one saw the wellhead generator concept as the panacea for all geothermal industry problems; however, most saw a definite place for them as resource development tools, for many special applications, and as an important near-to-medium-term psychological factor in moving the industry forward.

The biggest question marks about wellhead generators were in the areas of economics, portability, and permitting. Although there are some notable exceptions, which will be mentioned, most applications are very sensitive to (and in fact dependent upon) a favorable economic analysis. In other words, if a wellhead generator could not compete favorably (economically) in these applications, it would not be considered. The area of portability was questioned from the standpoint of transportability (particularly related to the maximum size unit that would still be portable), but more often from the standpoint of resource compatibility. That is, given the wide variations in resource characteristics and properties that exist from one field to the next, would it really be possible to build a wellhead generator that would be flexible enough to adapt to these changes? In the area of permitting, the problem is more a matter of unknowns rather than any particular negative biases. Most felt that permitting could be resolved to the advantage of wellhead generators with a concerted effort of government and industry.

The many applications for wellhead generators that were identified during the interviews seemed to divide fairly well (with a modest amount of overlapping) into two main categories: those applications in which the unit would have to compete, on its own merit, with a conventional energy plant (possibly a large central geothermal installation); and those special applications where a wellhead unit could perform a unique function. The first category was further broken down into the large user and the small user.

The outlook for the large user was the bleakest. The only applications felt to be applicable here were as resource test and development tools, and then later to serve as cold-start generators, auxiliary, and peak-power units. With the small user the picture was much brighter. Promising applications were seen for dedicated service to private industry (spurred by the desire for energy independence and future energy cost projections), small utility companies (especially those strongly motivated by environmental factors), and the development of small geothermal resources that might not otherwise be feasible to develop.

In the special applications area, one of the most often mentioned uses was for the foreign market, especially the underdeveloped countries. This was viewed as perhaps the first step required before wellhead generators could be introduced into the domestic market. The units could be mass produced to meet foreign needs, which would then benefit the domestic market by lowered cost and increased confidence. A second use was to

serve in remote areas, such as military bases, isolated towns and villages, and various industrial applications (mining, lumber, etc.). Since in many of these proposed applications there is no available power grid, the only competitive power source is a diesel generator. The economic operation could be favorably affected in some of these applications by also utilizing the steam and/or hot water from the geothermal resource.

The final application is as a general resource test and development tool. Here, one or more wellhead units could be used to identify site-specific chemistry problems of a resource that could affect the subsequent development of the field or central power plant. In addition, these initial units could provide the power needs during this development. This could be very important in areas without access to the existing power grid. With the current trends toward ever-increasing environmental constraints and requirements, electric drilling rigs could become a required item in the future.

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SECTION I

INTRODUCTION

Current Geothermal Development Strategy

Current state-of-the-art technology for the development of geothermal resources is focused on large, central power stations in the range of 50-100 MW_e. The impetus for this approach arises primarily from two separate, but related factors. First, the utility companies have traditionally favored large over small power plants (<50 MW_e) in order to take advantage of economies of scale and lower operating and maintenance costs. In fact, with the advent of nuclear plants, a trend toward even larger units (up to 1000 MW_e) has developed. Second, the building blocks necessary to assemble a 50 MW_e geothermal power plant (e.g., steam or gas turbines, generator sets, switch gears, etc.) are readily adaptable from conventional power plant technology. It should be added, however, that there are many small power plants (mostly conventional rather than geothermal) in operation today. For example, a 1970 study of the transmission facilities in Nevada (Ref. 1) showed that 15 of the 24 power generating stations in the state had a generating capacity less than or equal to 8 MW. The smallest generating station was only 0.5 MW.

The development of a geothermal resource using large central power plants is not without disadvantages. One major disadvantage is that the long lead-time necessary to prove the viability of the field and construct the power plant is costly to the explorer/developer in terms of capital commitments. Depending upon the particular field development strategy, permitting requirements, environmental impact reporting, utility/developer negotiations, and actual plant construction, it can be a matter of 6-10 years after inception of the project before actual revenues are produced. Another disadvantage inherent in the large geothermal power plant concept is the risk associated with the uncertainty of the resource life. If the resource were depleted sooner than expected, the power plant would be reduced to its salvage value, with a resulting major impact on the economics of the project.

Proposed Development With Wellhead Generators

The above problems could be mitigated - perhaps even eliminated - through the utilization of small (1 to 10 MW_e) portable geothermal power conversion devices located at the wellhead. Such an approach to geothermal development offers a number of potentially significant advantages:

- (1) It offers a rapid return on investment since the production of electricity could begin shortly after the completion of wells.
- (2) Since the wellhead conversion device is portable, it can be removed and transported to another site if the field ceases to be economically viable or is depleted sooner than projected.

- (3) Data on the resource would be obtained concurrently with the production of electricity.
- (4) Because the devices are small, a single device or series of devices could be used to develop fields that are too small to justify the cost of development with a large central plant.
- (5) Because small increments of power could be made available quickly, the wellhead devices could be used to expand existing power production capacity or provide direct power to larger industrial users.

These advantages, and others to be discussed later in the report, lead to the belief that the utilization of geothermal wellhead power conversion devices (wellhead generators) could not only advance the timetable for the development of geothermal energy, but could also provide a source of capital for further development; i.e., capital originally committed to front-end investment would be freed for other exploration and development.

Supporting Research for Wellhead Generator Concept

The basic concept of the small geothermal power plant was endorsed in September 1975 at the NATO-sponsored Workshop on Small Power Plants. It was the conclusion of this workshop that the concept should be carried forward by the development of actual design guidelines for such a device. Subsequent to the workshop, guidelines were prepared and published (under ERDA sponsorship) which defined the general requirements for a nominal 5 MW, modularized, road-transportable geothermal power plant (Ref. 2). This study supported the technical feasibility of the concept, namely that a modular 5 MW could be constructed that would have the portable characteristics assumed by the aforementioned discussion. The study assumed the conversion unit was a steam turbine generator with steam provided by flashing, and that the cooling tower (for a condensing unit) would be erected in the field.

Other research is currently under way that supports the wellhead generator concept. Two such programs are the Helical Rotary Screw Expander Project (Ref. 3) at the Jet Propulsion Laboratory and the Total Flow Impulse Turbine Concept Project (Ref. 4) at the Lawrence Livermore Laboratory. Both of these projects are investigating conversion devices which would allow the total hot, untreated, wellhead brine-system mixture to pass directly through the prime mover. Power generation systems designed around the total flow system are potentially more efficient than flash steam systems, and could therefore offer a more complete exploitation of the geothermal resource. As of the writing of this report, a 1-MW Helical Screw Assembly has been built and checked out with compressed air, and is now being set up on location in Utah for a field test with geothermal brine.

Study Guidelines and Ground Rules

As mentioned previously, the main purpose of this study was to survey the needs of the geothermal power industry and to assess the market potential of wellhead generator systems that might meet these identified needs. Data were gathered from a wide variety of potential power users, exploration and field developer organizations, architectural and engineering firms, and equipment manufacturers. In addition, regulatory agencies were queried as to what possible unique problems might be encountered or avoided with the use of wellhead generators.

The following ground rules and assumptions formed the basis for the study:

- (1) The wellhead generator unit was defined as being a road-transportable power conversion system in the 1-10 MW range, designed for operation at the geothermal wellhead.
- (2) The entire unit will be modularized and skid mounted, with the single exception of the cooling tower, which will be erected in the field.
- (3) The study will not be limited to a particular power conversion cycle (e.g., flash steam, binary or total flow), but all configurations will be required to be condensing systems.
- (4) Noncondensable, nontoxic gases will be exhausted to the atmosphere.
- (5) The release of toxic gases will be limited in accordance with required emission standards.
- (6) Waste disposal and disposal of brine will be accomplished by reinjection.
- (7) The study will be limited to the domestic market, and specifically to the western states which have known geothermal resources and are likely to use such resources.

SECTION II

CHARACTERIZATION OF WELLHEAD GENERATOR SYSTEMS

To establish a firm basis for the formulation and conduct of the structured interviews and for the subsequent analysis of the data acquired, two analyses--one technical and one economic--were conducted for a generic wellhead generator system. These analyses also served to demonstrate the general feasibility of the wellhead generator concept. This task was performed in three separate steps: technical analysis, simplified incremental-cost analysis, and detailed economic analysis. The first two steps were accomplished before the formulation and conduct of the structured interviews, and the last step was done by Rogers Engineering Co. in parallel with the interviews and data analysis.

A. TECHNICAL ANALYSIS

The technical analysis was made using an existing computer model, and characterized the performance of a typical wellhead generator as a function of the resource temperature. The results of the analysis are displayed in Table 2-1. For the example shown, the flash steam conversion cycle was used, with utilization efficiencies ranging from 40% to 47%. The highest efficiencies (~70%) would be achieved with the total flow conversion cycle, with the output power some 60% higher than the respective values in the table.

Although a ground rule of the study was to consider only condensing systems the corresponding data for a noncondensing system are also included in Table 2-1 as a point of reference. Other assumptions made in performing this analysis are listed at the bottom of the table. A key point to be noted from these data is that the flow rates necessary to support the range of 1-10 MW are consistent with the flow from 1-3 individual wells.

B. SIMPLIFIED INCREMENTAL-COST ANALYSIS

The original plan at the outset of the wellhead generator study was to perform all of the economic analysis prior to formulating the structured interviews. A computer program was available that had been used in the past for detailed geothermal economic analysis. However, after looking more closely at this program, it was found that the model was heavily oriented toward large central power plants with elaborate distribution networks, and would require substantial modification to accommodate the small wellhead generator concept. Upon reviewing these required modifications in light of the demanding schedule for the study, it became obvious that nothing useful could be accomplished in time to support the interviews, and it was doubtful that the task could even be finished within the timeframe of the overall study. Thus, a simplified incremental-cost analysis was performed to support the structured interviews, and the task of performing the more detailed economic analysis was subcontracted to Rogers Engineering.

Table 2-1. Peak-Power Well Flow Conditions for a Single-Stage Flash System*

Reservoir Temp., °C (°F)	Wellhead Temp., °C (°F)	Wellhead Quality, %	Well Flow Rate, kg/s (gpm)	Available Enthalpy J/g (Btu/lb)	Utilization Efficiency, %	Power Output, MW
CONDENSING						
150 (302)	126 (259)	4.6	56 (888)	53 (23)	39.9	1.2
200 (392)	160 (320)	8.5	90 (1427)	112 (48)	42.1	4.2
250 (482)	188 (370)	14.2	120 (1903)	187 (80)	44.6	10.0
300 (572)	218 (424)	21.4	138 (2188)	284 (122)	47.2	18.5
NONCONDENSING						
150 (302)	133 (271)	3.4	53 (840)	12 (5)	40.4	0.3
200 (392)	167 (333)	7.1	87 (1380)	46 (20)	41.7	1.7
250 (482)	199 (390)	12.1	116 (1839)	100 (43)	43.7	5.1
300 (572)	226 (439)	19.8	135 (2141)	171 (74)	46.8	10.8

* Assumptions: Well depth = 1500 m (4920 ft); well diameter = 0.25 m (10-5/8 in.); reservoir pressure = 14.7 MP_a (2130 psi); draw-down pressure = 25 kPa/kg/s (3.6 psi).

The incremental-cost analysis concentrated on only one issue-- the value of early power. What cost penalty (\$/kW) would be justified for a wellhead generator by the economic benefits derived from the early power produced? Two field development scenarios were compared here: a 48 MW central power plant that requires six years to produce the first power, and a six-year incremental buildup using 8 MW wellhead generators, with each new installation requiring a year before power is produced. Other assumptions made in the analysis were that the wellhead generators would have a capacity factor of 82% and that the breakeven cost of electricity was 20 mills/kW-h.

Table 2-2 shows the results of this analysis. For the assumptions listed above and a 12% cost of capital assumed, the value of the early power would justify a cost penalty for a wellhead unit of \$312/kW. Thus, a 48 MW central power plant at a cost of \$250/kW and six 8 MW wellhead generators at a cost of \$562/kW are economically equivalent. Based upon discussion at the ERDA-sponsored forum in San Francisco on geothermal wellhead generators (Ref. 5), and comments from a large number of those interviewed on this study, \$500-600/kW was felt to be a reasonable target cost for a unit. This simplified analysis does not take into account any operating and maintenance cost penalties that might be associated with wellhead units; these will be addressed in the detailed economic analysis.

Table 2-2. Economic Benefit of Early Power for Incremental Development With Wellhead Generators (Cost of Capital = 12%)

Year No.	Total Power Installed, Year End, MW	Cost of Added Units, Year End, \$	Present Value of Added Units, \$	Added Income, Year End, \$	Present Value of Added Income, \$
1	8	A*	0.893A	0	0
2	16	A	0.797A	8,000B**	6,378B
3	24	A	0.712A	16,000B	11,388B
4	32	A	0.636A	24,000B	15,252B
5	40	A	0.567A	32,000B	18,158B
6	48	A	0.507A	40,000B	20,265B
			4.112A		71,441B

Therefore; $4.112 \times 8,000 \times \Delta C_g = 71,441 \times 0.82 \times 8,760 \times 0.02$
or, $\Delta C_g = \$312/\text{kW}$

* A = $8000 \times \Delta C_g$; where ΔC_g is the cost penalty/kW for wellhead generators.

**B = Capacity factor (0.82) $\times 8760 \times C_e$; where C_e is the breakeven cost of electricity.

The analysis was repeated, this time assuming the cost of capital to be 18% rather than 12%. These results are shown in Table 2-3. The cost of early power was found to be relatively insensitive to the cost of capital (\$291/kW versus \$312/kW), since both the future capital outlays and the future income were similarly affected. On the other hand, the allowable cost penalty is directly proportional to the breakeven cost of electricity. Thus, for Table 2-3, an increase from 20 mills/kW-h to 25 mills/kW-h would raise the allowable cost penalty from \$291/kW to \$364/kW.

C. DETAILED ECONOMIC ANALYSIS

The purpose of the detailed economic analysis was to parametrically formulate both capital costs and operating and maintenance costs for wellhead generators over the size range of 1-10 MW. Because of the problems mentioned earlier, the decision was made to have Rogers Engineering Co., Inc. perform the analysis. Rogers Engineering's previous experience with the design of a 5 MW geothermal wellhead power plant (Ref. 2) and their general expertise in the geothermal industry made them a logical choice.

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Table 2-3. Economic Benefit of Early Power for Incremental Development With Wellhead Generators (Cost of Capital = 18%)

Year No.	Total Power Installed, Year End, MW	Cost of Added Units, Year End, \$	Present Value of Added Units, \$	Added Income Year End, \$	Present Value of Added Income, \$
1	8	A*	0.847A	0	0
2	16	A	0.718A	8,000B**	5,744B
3	24	A	0.609A	16,000B	9,744B
4	32	A	0.516A	24,000B	12,384B
5	40	A	0.437A	32,000B	13,984B
6	48	A	0.370A	40,000B	14,800B
			3.498A		56,656B

Therefore: $3.498 \times 8,000 \times \Delta C_g = 56,656 \times 0.82 \times 8,760 \times 0.02$
or, $\Delta C_g = \$291/\text{kW}$

* $A = 8000 \times \Delta C_g$; where ΔC_g is the cost penalty/kW for wellhead generators

** $B = \text{Capacity factor } (0.82) \times 8760 \times C_e$; where C_e is the breakeven cost of electricity.

The basic ground rules and assumptions made for the analysis are spelled out in Table 2-4. The first group is technical in nature, applying to the conversion cycle or the resource properties, and the second group is economic in nature. Note that a resource temperature of 250°C (400°F) was assumed for all cases.

The results of the detailed economic analysis are displayed in Figure 2-1, plotted parametrically as a function of power plant output (1-10 MW_e). Curve 1 shows the capital cost (expressed in mills/kW-h), curve 2 shows the operation and maintenance cost, and curve 3 is the sum of curves 1 and 2. All curves show a perceptible slope change, or knee in the curve, at around 2-3 MW_e. Above 5 MW_e the curves are relatively flat. Thus, from the standpoint of purely economic considerations, a minimum practical size for a wellhead generator would be 3-5 MW_e. Over the size range of 3-10 MW_e, the total cost of a wellhead generator (curve 3) drops by a factor of two when the plant capacity triples.

Obviously, the final criterion as to what size of wellhead generator is required for economic viability is a function of the prevailing rates for alternate and available sources of power. Thus, the minimum size would vary depending upon the type of use for the wellhead generator, the particular part of the country and even the timetable for use of the unit (e.g., the projected escalation of petroleum costs

Table 2-4. Ground Rules and Assumptions for the Detailed Wellhead Generator Economic Analysis

PLANT SPECIFICATIONS

All cases considered were condensing units, with barometric condenser.

Noncondensable gas content of 2 percent by weight of flashed steam, and with low salinity.

Bottom-hole temperature of 205°C (400°F), with a single-stage flash unit at a pressure of 45 kg/cm² (640 psia).

Turbine inlet pressure of 3.8 kg/cm² (54 psia) and exhaust pressure of 104 mm Hg (2 psia).

COST STRUCTURE

Cost of capital of 18 percent, which is approximately equivalent to the following capital structure:

Debt to equity ratio	0.5
Bond interest rate (%)	8.0
Return on equity (%)	12.0
Federal income tax rate (%)	48.0
State income tax rate (%)	7.0
Property tax rate (%)	2.5
Revenue tax rate (%)	4.0

Plant service life of 30 years and capacity factor of 0.82.

Costs are for power plant only, excluding gathering and reinjection systems.

Since it was assumed that the energy would be consumed locally, capital costs do not include a step-up transformer.

Power plants in the range of 1 to 5 MW_e were not considered to be the main local sources of electricity. Therefore, they do not require as high dependability as the plants in the range of 5 to 10 MW_e. A single shift was therefore assumed for the operators of a 1 to 5 MW_e plant, and three shifts for the operators of a 5 to 10 MW_e plant. The increased operating cost for the latter would be reduced by sharing the operators with an additional unit.

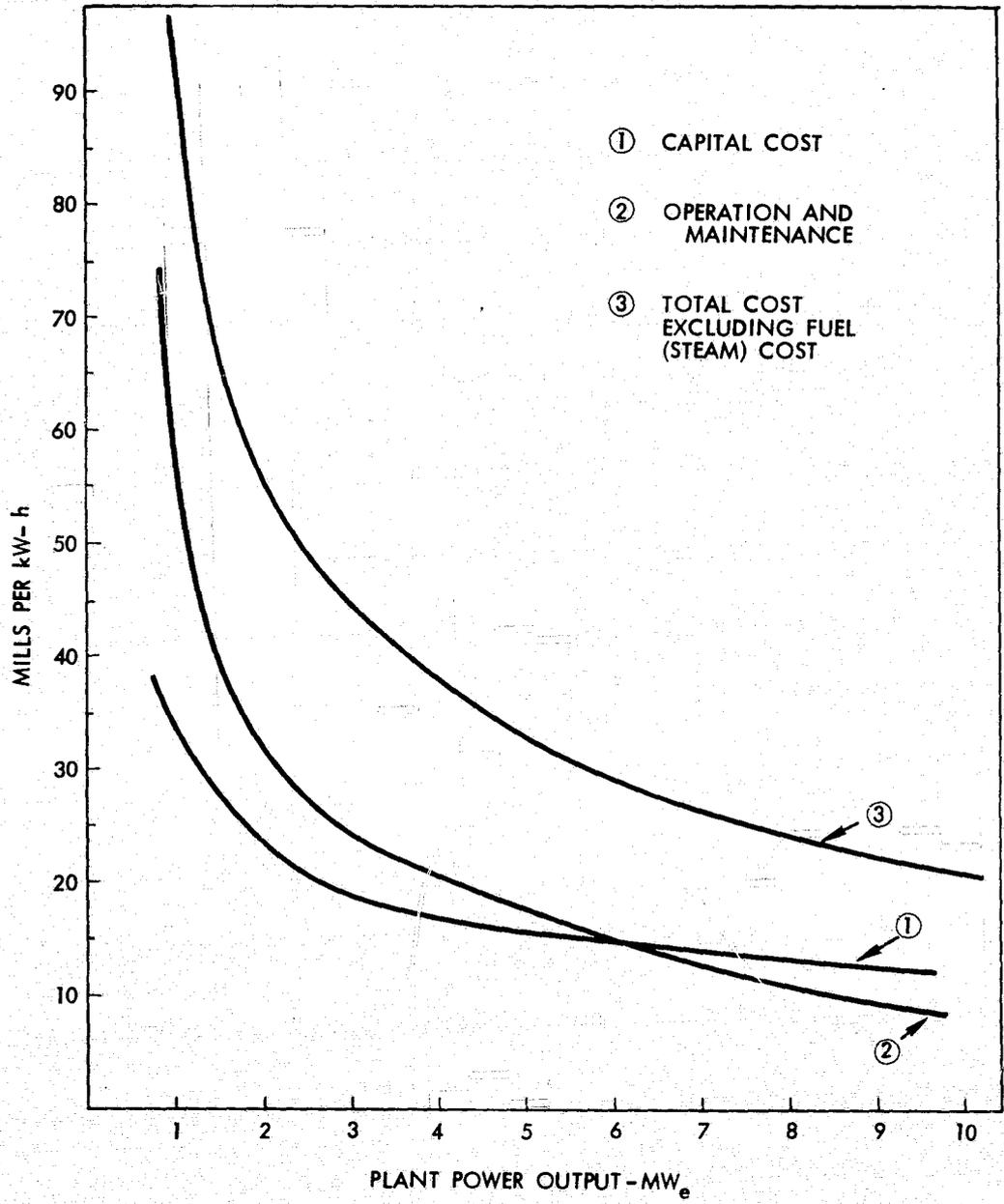


Figure 2-1. Wellhead Generator Capital and Operating and Maintenance Costs as a Function of Plant Capacity

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would affect the sizing). In a recently negotiated contract between San Diego Gas and Electric and Magma Energy Company, the output power from Magma's East Mesa Geothermal Plant will be sold for 25 mills/kW-h. Curve 3 in Figure 2-1 indicates that this would correspond to a breakeven situation for a wellhead generator of the size of 7-8 MW.

SECTION III

POTENTIAL APPLICATIONS, USERS, AND SUPPLIERS

To develop a list of potential companies to be considered for the structured interview phase of the study, the overall geothermal community was first divided into broad disciplines, and then various target companies were identified within each discipline. The disciplines initially selected were as follows: users (subdivided into large and small utilities and private industry), equipment manufacturers, explorer/developers, architectural and engineering firms, regulatory agencies and financial organizations.

After further examination, the financial organizations group was eliminated. It was found that the financial institutions had been surveyed in 1975 in detail (Ref. 6) to determine their attitude toward and influence upon the expansion of geothermal energy. The information collected in this survey is directly applicable to geothermal wellhead generators. Conventional financial institutions, such as banks, do not usually provide risk capital unless the borrowing institution has sufficient equity to cover the loan. Thus, loans made by banks and other conservative institutions to utility companies or other energy companies are usually corporate rather than project loans. In other words, the assets of the company rather than the assets of only a specific project provide backing for the loan.

In the case of wellhead generators, the specific technology used in producing geothermal energy is of little concern to the lending institution, provided a corporate loan can be made. In the case of a project loan, if the assets of the project (i.e., the geothermal well and associated equipment) can be shown to sufficiently exceed the value of the loan, the type of technology used is unimportant. However, the lending institution might make an independent assessment of the project value. If a wellhead generator were used and was not a proven technology, it could adversely affect the loan.

Funds to develop or build wellhead generators would have to be obtained on a risk basis, i.e., through investments in the building or developing corporation. Investments could be made through stock purchases or through high return risk loans arranged by investment brokers. Energy companies (such as oil companies), which might purchase wellhead generators for geothermal field development, would probably finance the ventures internally or through their standard borrowing procedures.

In conclusion, the characteristics of a wellhead generator, per se, would have little impact on the ability of a corporation to finance a project, provided it was technically and economically competitive with alternate types of generators.

After identifying the various disciplines in the geothermal industry, the second step of this task was to select the target companies

within each discipline. The proposal for this study (Ref. 7) contained a first cut at a comprehensive list of companies that might have an interest in wellhead generators. This list served as the starting point for subsequent review and revision. Some additions were made and numerous deletions were necessitated by time and financial limitations. This revised list then served as the checklist for setting up formal interviews by telephone. Further limitations were imposed by time, scheduling, and negative responses, and the list was finally pared to that shown in Appendix A.

In cases where an interview could not be arranged, the chief reasons were usually either the inability to meet with the desired people in a timely manner (which was aggravated by two major holidays within the interview period) or the feeling by the person contacted that wellhead generators would not be of interest to his company.

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SECTION IV

FORMULATION AND CONDUCT OF STRUCTURED INTERVIEWS

Based upon the list of candidate applications, users and suppliers mentioned in Section III, and on the information developed during the characterization of wellhead generator systems (Section II), the task of formulating the structured interviews was begun. The final interview format was organized into five separate areas: defining the wellhead generator, reviewing potential applications, reviewing the various field development scenarios, ranking the perceived advantages of a wellhead generator, and concluding the interview (final thoughts and any areas missed during the interview).

The interviews were all arranged in advance by telephone with one or more persons felt to be decision-makers in the particular company. A brief description of a wellhead generator was given, along with the purpose and scope of the program. Then, assuming the response was positive, an interview appointment was set up for between one and two hours in duration. The general response to this initial contact was very good and in almost all cases it was possible to arrange for an interview with the individual selected in advance or an equivalent alternate.

The actual interview began with the interviewee reading a definition of a wellhead generator. This was an essential starting point to insure that a clear understanding of the concept existed from the outset of the interview. The definition (see Appendix B) was generic in nature and attempted to outline the scope, limitations, and ground rules for a wellhead generator. In addition it included some rough estimates of size, weight, and cost for a unit. Any questions or comments on the definition were discussed and noted.

The second phase of the interview involved having the interviewee read a list of potential applications for wellhead generators. The list (shown in Appendix B) was oriented toward the general end user (i.e., utilities, developers, and private industries) rather than specific applications (e.g., resource development tool or power for remote mining operation). The interviewee was asked which of the applications would be of most interest to his company and if there were any additional applications that were not included in the list. Many special applications were suggested here, including several that were not considered during the formulation of the interview.

In the next phase of the interview, the interviewee was shown a flow chart (see Appendix B) illustrating various ways in which wellhead generators could be utilized to develop a geothermal resource, in contrast to the conventional development of a resource with a large central power plant. Where the flow chart was found to be confusing, a straight itemized listing of the development scenarios was also available. Each person was asked to discuss the relevance of the different scenarios and which of them would be of prime interest (if any) to their company.

The fourth section of the interview was the most lengthy and also most highly structured. The interviewee was presented, one by one, with approximately 18 index cards, each containing a perceived advantage offered by wellhead generators. The interviewee then placed the cards into one of five categories, which ranked the relative importance (or unimportance) of the advantage. The five categories were noted by index cards laid out on the table with the following labels: very important, somewhat important, neutral, somewhat unimportant, and very unimportant. If the interviewee disagreed with the validity a given advantage or that it was even an advantage, the card was removed.

In some cases the ranking of an advantage was found to be a function of which type of development scenario was assumed. For these cases the card could be separately ranked for each scenario. The rankings for each advantage were recorded using an alphanumeric code to designate the level of importance as well as any specific development scenario. In addition, all pertinent comments dealing with the reasons behind the rankings were recorded. These comments were often more important, in the end, than the ranking.

The final phase of the interview was the wrap-up. This was planned as a time to discuss any final thoughts the interviewee might have on wellhead generators, and also to cover any items that might have been overlooked during the interview. General questions were asked here, such as, for example: What do you see as the major impediments to the future development of wellhead generators? Also, depending upon the course the interview took, a general set of follow-up questions was formulated in advance to probe any important areas that might not have been thoroughly covered.

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SECTION V

INTERVIEW RESULTS AND DISCUSSION

The results of the interviews, when reviewed, were found to present an almost bewildering array of diverse opinions and thoughts. This was expected to be the case from the outset of the program for the unstructured portion of the interview; however, it had been hoped that the structured portion would yield results that could be reduced to a matrix presentation format and perhaps even subsequent statistical analysis. For several reasons this did not prove to be true. First, although answers to the structured questions were reduced to quantized values, in many cases qualifying statements were linked to the answer that were essential to the proper understanding of the answer. Thus, to merely record the numerical answer into a matrix and ignore these statements would distort the intent of the answer. In fact, as a general rule, the real value of the structured interview was derived from the discussion that accompanied the answers rather than the final answers themselves.

A second problem hindering the statistical analysis of the results was the fact that there appeared to be definite biases between different industry groups on various questions. These biases produced significant scattering of the answers. Any attempt to average the individual results would have produced a distorted final conclusion. Also, because of the limited number of interviews within any given industry group, it would not have been statistically relevant to analyze the data on a group-by-group basis.

As mentioned, there were definite biases within specific industry groups. On the other hand, there was a certain degree of continuity among those industries in the private sector (i.e., developers, private industry, manufacturers, and architectural and engineering firms) that differentiated them from the highly regulated utility sector. For this reason the interviews were divided so that one interviewer contacted all of the utility companies and regulatory agencies while a second interviewer contacted all of the private sector. The results are presented in the following sections by the same groupings.

A. PRIVATE SECTOR

1. Wellhead Generator Definition

As previously mentioned, the interviews began by reading a "black box" definition of a wellhead generator, in order to insure that the concept was clearly understood from the outset. In general, the definition caused no major problems. The two areas of cost and size received the most comment. An estimated cost range was stated of \$300-600 per kW, exclusive of any external plumbing, cooling tower, and well costs. Many felt that the upper range (\$500-600/kW) was a reasonable target but that the lower end was unrealistic. The incremental-cost analysis in Section II-B showed that, for such a price range, the value of the early power

produced would make the wellhead generator competitive with a central geothermal plant at a cost of \$250/kW. Several individuals felt that even the upper limit was too low, considering the requirement for a condensing system. One respondent suggested that the upper range might be applicable for a flash steam system, but that \$600-800 was more appropriate for a binary cycle. Another individual felt that by the time all the emission requirements were imposed, the costs for a small condensing unit could run as high as \$1500 per kW.

The manufacturers questioned the weight estimate of 20 tons and had some reservations about the overall size of 30 feet long by 8 feet wide by 9 feet high, especially for the upper end of the power output range (7-10 MW_e). The stated numbers were felt to be satisfactory for the 1-5 MW_e range. One manufacturer noted that the weight of a 10 MW generator alone was approximately 40 tons. A couple of individuals challenged the basic feasibility of a portable 10 MW_e unit, and felt that 5 MW was the practical limit.

2. Potential Applications for a Wellhead Generator

The second phase of the interview dealt with the potential applications for a wellhead generator. The architectural and engineering firms usually saw all listed applications as valid candidates for potential business and added the following specific areas: cold-start generators for large utility units, remote industries such as mining and lumber mills, pumping stations for irrigation or coal slurry, foreign use in underdeveloped countries, and as a general resource development test tool. The suggestion was made that several units be utilized during the construction of a central plant and then left in place to serve as peak or auxiliary power as required.

The remainder of the private sector tended to be more specific toward a particular end user as their most likely application. Some favored the small utilities, due to past biases of large utilities against small power units; others saw the private industrial user as the key to the whole concept. One manufacturer felt his best potential application was the small developer, another the private utility since they move faster than municipal utilities. Some of the additional applications suggested were as follows: remote military installations, remote towns and villages (such as those in Alaska), distillation of fresh water from brackish, and the addition of offsite power to the industries group (i.e., wheeling power from an area where the geothermal power is available to another area more suitable to the industry location).

3. Field Development Scenarios

This phase of the interview dealt with the various ways in which a wellhead generator could be utilized to develop a geothermal resource. Although some individuals viewed all of the various scenarios as reasonable, most had reservations or definite negative reactions toward some of the scenarios. The developers, as a whole, were the most pessimistic

group, which was somewhat of a surprise. Many of the advantages perceived for a wellhead generator during the original formulation of the interviews seemed to benefit developers particularly.

One of the most persistent negative reactions that surfaced here was a doubt expressed as to how portable a wellhead unit would really be--not from a standpoint of transportability but from a standpoint of compatibility from one field to the next. Some felt it was possible with minor adjustments or modifications while others questioned the basic concept. Several people felt that the implication of "instant" power from the wellhead generator as contrasted to 6-10 years for power from the conventional plant was misleading. They argued that for most of the scenarios the wellhead generator and the central plant differed only by the approximately 2 1/2 years involved in the actual construction of the central plant; otherwise, they both shared the same problems and delays with securing permits, negotiating contracts and leases, and well drilling.

The scenario that a majority felt was not realistic was the incremental development of a field with wellhead generators, followed by the construction of a central plant to replace them. Most felt that, if a major development were warranted in the first place, it would proceed directly with a central plant. Another option would be to use one or two wellhead generators only, to prove, test, and develop the field and central plant. One factor that negatively affected this scenario was the ERDA Loan Guarantee Program. Prior to the inception of the program it was necessary to drill all of the wells for a central plant before committing to final construction and development. This type of development would tend to favor the use of wellhead generators. However, it might be noted here that the loan guarantee application period presently expires as of 1984.

The scenario to develop a field with numerous permanent wellhead units also encountered considerable resistance on similar grounds--if you intend to install more than 3 units from the beginning, it is more economical to install one larger unit. Reasons will be suggested in the next section of the report that might offset this latter argument.

The most positive development scenarios were viewed as the onsite industrial use, initial installation to develop the remainder of a field, limited numbers used to develop small fields, or provide remote power requirements. One individual expressed the opinion that all of the scenarios were possibly applicable for the next few years, owing to the infancy stage of geothermal development; however, timing would make all the difference. He felt that when the industry was more mature they would no longer be expedient.

4. Perceived Advantages of Wellhead Generators

In this section of the interview, each person was asked to rank and discuss the importance of a number of proposed advantages to using wellhead generators. The advantages themselves could be grouped into four general categories: those advantages related to economic issues;

those related to environmental, legal, or institutional issues; those in which the advantage was a direct benefit from the inherent small size of a unit; and several miscellaneous advantages not fitting into the above breakdown. Although the advantages were not grouped in this manner during the interview, the results will be presented in this section under these four groupings. Some of the advantages pertained to more than one of the groupings; however, each will be discussed only in the area in which it is most directly impacted.

a. Economic Issues. Four of the advantages pertained most directly to economic issues. These four could be stated as follows:

- (1) A wellhead generator minimizes investment risk since the cost of the unit is amortized over the life of the unit rather than the project.
- (2) A wellhead generator offers rapid power production (return on investment) after the completion of the wells.
- (3) Data on the resource can be collected concurrently with the generation of revenues.
- (4) The smaller investment required with a wellhead generator and the closeness of the investment to generation of revenues could favorably impact "capital crunch" problems, long lead-time decisions, and early capital disbursements.

A basic fact that was obvious before this study was undertaken, and was underscored in Section II of this report, is that there is an economic penalty associated with wellhead generators when they are compared to a larger central plant. This results not only from economies of scale inherent with the respective capital costs, but also from the higher annual operating and maintenance costs for several small units versus an equivalent larger unit. Thus, the four wellhead generator advantages listed above present some perceived benefits that might offset or outweigh this penalty.

In general, the responses to the economic advantages were quite mixed and lacked any real consensus of agreement, even within a particular industry segment. The first statement was perceived as an advantage by all parties, but its importance was ranked over the entire range from very important to very unimportant. Part of this scatter was attributed to the loan guarantee program. Several individuals noted that they ranked this advantage less important than they would have otherwise since the program removed the normal risk associated with the resource life. Another respondent ranked it very unimportant because the wellhead generator cost was only a small portion of the entire development cost. Thus, the amount saved by the portability of the unit was unimportant compared to the sum lost on the project in the event the resource proved to be a loss. The end use of the unit was also noted as affecting the importance of this advantage. On one hand, if the wellhead unit were to function as a field development tool, portability would be of the

utmost importance. On the other hand, in the case of dedicated service to an onsite industrial application, the unit life is essentially the project life and the portability of the unit is unimportant.

The response to the importance of early power generation was also somewhat mixed, although more positive than the previous advantage. The developers, for the most part, were neutral (although one challenged the basic concept of rapid power); the remaining industries ranked it from neutral to very important. One developer, whose chief customers were seen as utility companies, noted that rapid power was not important because utilities have to plan their electric needs at least five years in advance anyway. Thus, even if they did buy this "rapid power", they would be willing only to pay for the energy (fuel displaced) rather than capacity value. Without capacity charges, this would mean a very uneconomical operation for the wellhead generator. This same developer did concede that there would, however, be some special cases where early power would be beneficial. One such use cited by him and several others was the use of the early power to develop the remaining resource.

Another respondent ranked early power generation very important for onsite industrial use but neutral for the end use where energy was collected and distributed elsewhere. Because of the loan guarantee program, the funds no longer have to be committed for the majority of the production wells until much closer to the electric generation. The challenge to the concept of "rapid power" from a wellhead generator was discussed earlier; basically, it was argued that the time delays involved with regulatory agencies, permitting, contract negotiations, etc. are common to both large central plants and wellhead generators.

With two exceptions, the third advantage (collection of resource data concurrently with power generation) was ranked as important. The exceptions both ranked it unimportant because they felt that they would have all the data they needed (from initial well flow and chemistry tests) before installing the unit. The opposite view was expressed by several of those ranking it as important. They felt that no matter how many well tests were performed, the real proof of operation comes only when the actual hardware is matched to the resource.

The fourth economic advantage attempted to address the whole general idea of improved cash flow with wellhead generators. This comes about not only from the early revenues generated, but also by the smaller initial capital investments required and the late commitment of funds. Since this advantage did overlap some of the earlier areas covered, those redundant comments will be either omitted or only briefly mentioned. The ranking of this advantage was quite mixed, ranging from unimportant to very important. Those ranking it high did so because they saw improved cash flow as an extremely important step in geothermal development. Improved cash flow could mean the difference between developing two or more projects concurrently versus only one project. The chief negative responses again focused on the philosophy change brought about by the inception of the loan guarantee program, and that the major investment is in the field development rather than the wellhead generator itself.

b. Environmental, Legal, and Institutional Issues. Five of the advantages dealt primarily with environmental, legal, and institutional issues. They were as follows:

- (1) A wellhead generator or series of units could develop a resource with less site preparation and restoration than a central plant.
- (2) It is cheaper and more environmentally attractive to collect energy (from a series of wellhead generators) than steam (from a series of wells to support a central plant).
- (3) A wellhead generator provides private companies with an opportunity for energy independence.
- (4) A wellhead generator could provide small utilities with an opportunity to utilize geothermal energy.
- (5) Permitting problems should be simpler for a wellhead generator than for a large central plant.

This group of advantages proved to be the most controversial, and resulted in the highest number of low rankings as well as disputed statements. The first two statements dealt with the favorable environmental impact of a wellhead generator compared to a central plant, and were rejected almost unanimously. As was pointed out by numerous respondents, these two advantages were not applicable to the scenario in which the central plant is eventually installed anyway.

In addressing the site preparation issue, several people argued that, although the disturbance to a particular spot would naturally be less for a wellhead unit as opposed to a large central plant, the overall disturbance of the total number of wellhead units (equivalent to the central plant) could well be worse. It was also mentioned that when the impact of reinjection was included, the site preparation could be more involved for the wellhead generator. For the central plant, slant drilling techniques would probably be utilized, facilitating the connection of multiple source wells into a common reinjection system. The handling of reinjection for a series of wellhead generators in different locations would not be accomplished as easily. Another questionable environmental impact of the wellhead generators was whether multiple cooling towers would disturb the environment more or less than a single large unit.

In spite of the preponderance of negative reactions to this first statement, several persons did view the wellhead generator as being able to make an important impact for cases where only one or two units were involved. Specific cases cited were for resource testing applications, and onsite service to industry or to remote villages.

The second environmental issue was rejected by almost everyone for reasons very similar to the first issue. Although the question specifically mentioned only the collection system (steam lines versus wires), it was obvious to all that the real environmental intrusion was again

the issue of multiple wellhead generators versus a single large plant. After all, if environmental forces dictated, either the collection lines or wires could be buried. One individual summed up the general comments to both issues by noting that he saw nothing environmentally pleasing about either development scenario.

The next two advantages addressed institutional issues. For both of these, some distinct industry biases surfaced. The developers ranked both issues an unimportant or very unimportant, whereas the remaining groups viewed them unanimously as important or very important. In structuring these two advantages, no particular common link was intended or noted. However, after studying the responses, a common thread was apparent. Both probed the role of the government in advancing the geothermal industry by stimulating private industry. The typical stance of the developer was that, although it would be a good idea for more companies to work toward energy independence, and although it would be a good idea if small utilities were able to utilize geothermal energy, these are not adequate reasons to justify developing a wellhead generator. Other responses cited by the developers were that small utilities can now participate in geothermal utilization by buying a portion of a larger power plant, and that reliability and economic questions about small wellhead units might be a deterrent to small utilities anyway.

The remainder of the private sector saw the desires of industry to achieve energy independence and the desire of small utilities to develop new alternate energy sources, as basic free enterprise forces that will in time create a solution (i.e., wellhead generators). Thus, they saw the government role of stimulating the development of a wellhead generator as merely speeding up the timetable.

The last issue in this category was a legal one, that of permitting problems. The assertion was made that permitting problems should be simpler for a wellhead generator than for a large central plant. This assertion was unsupported at the time it was formulated, since the regulatory agencies were not interviewed until last, hence the weak form of the assertion ("should be simpler"). However, as with any of the perceived advantages, the individual was free to disagree that it was really an advantage.

Although no one flatly disagreed with the assertion, many openly questioned its validity. A couple of others had no comment. Those who accepted the statement at face value ranked it as neutral or unimportant. One respondent noted that, even if the costs associated with permitting were less for a wellhead generator, the costs per kW were still higher. Several others felt that while permitting might well be simple for the first unit (which would be an advantage for cases where only one wellhead generator was needed), if separate permits were required for each successive unit the overall permitting problem probably would be worse than for a central plant.

c. Issues Related to the Size of a Wellhead Generator. Six of the advantages were attributed to benefits derived directly from the inherent small size of a wellhead generator:

- (1) A wellhead generator provides an opportunity to develop small geothermal fields.
- (2) Additional increments of power can be easily and quickly added to an existing system.
- (3) A wellhead generator could develop confidence in a field with a modest capital investment.
- (4) Wellhead generators, because of their portable nature, are reusable from one field to the next.
- (5) The wellhead generator concept offers the possibility for a user to lease a unit and become his own developer.
- (6) Since a wellhead generator requires brine from only one or two wells, it eliminates potential problems from mixing the brines from different wells.

The first advantage was motivated by a theoretical relationship believed to exist between the number of geothermal fields available and the size of the respective fields. This qualitative relationship is expressed in Figure 5-1. Although the developers were generally negative toward this advantage, the remainder of the private sector ranked it as very important. In fact, several individuals rated this as the single most important advantage to a wellhead generator -- the ability to develop a large number of small fields that might not otherwise be feasible to develop with large central plants. One A&E representative felt that, while this was a very important advantage for onsite use (remote mining, etc.), it was less important for situations of power collection and distribution where there was no existing grid. If no grid currently existed, the power generated from a small field could not justify the expense of installing new transmission lines.

The negative responses of the developers were motivated in each case by a different reason. One did not believe that there were a large number of small fields to be found. Another felt the relationship was true but stated that his company was not interested in developing small fields. Still a third felt that this was an important advantage but that the government should not place a high priority on the development of small fields -- the government-sponsored work should concentrate on areas that will have the greatest impact on the national energy picture.

The response by industry groups to the second advantage was somewhat similar to the response the first. In this case the developers ranked it neutral to unimportant whereas the rest of the groups ranked it important to very important. All respondents agreed with the basic premise that additional increments of power could be added to an existing facility. The difference of opinion arose over just how easily and quickly, and the degree of importance attached to this flexibility. A relationship between the importance of the advantage and the size of existing facility was noted by one interviewer. For example, the ability to expand an existing onsite application utilizing only one or two units would be much more important than expanding a utility currently rated at 100 MW_e.

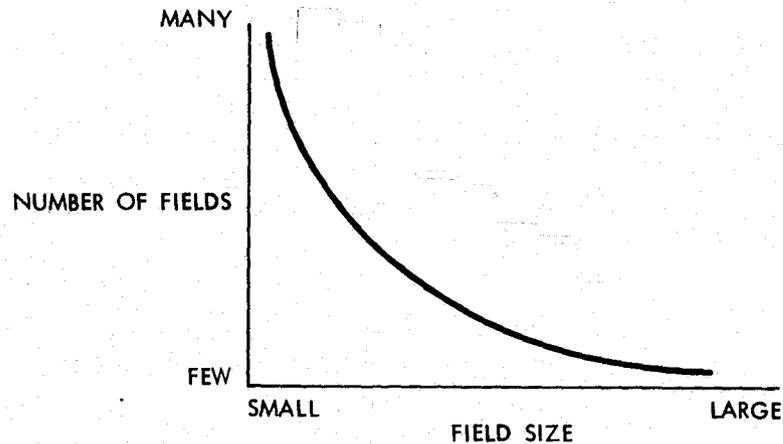


Figure 5-1. Relationship of Number and Size of Geothermal Fields

Several of those who rated this advantage as very important were quick to point out some assumptions tacitly made that, if untrue, could change its ranking. First, the assumption was made that existing transformers and transmission lines were adequately sized to handle the increased load. Second, it was assumed that additional reservoir engineering and permitting would not be required.

The third advantage in this grouping received mixed rankings from the developers, but was almost unanimously ranked as very important by the remainder of the private sector. This latter majority felt that a wellhead generator could provide some very important psychological advantages, especially in the area of the investor confidence in the financial community. The only low ranking by this group was by an individual who felt that he could gain sufficient confidence in a field with well flow data alone. Another person noted that, although the first unit was very important for building confidence in the field, no further advantage would be gained from successive units.

One developer maintained that the wellhead generator did not develop confidence in the field at all but in the generator hardware itself. Along these lines, another developer argued that the real concerns today over geothermal resources are related to the production lifetime and long-term effects from reinjection. Both of these are long-term effects as opposed to immediate interactions between the hardware and the resource. He felt that a minimum power plant size of 50 MW_e was required to sufficiently evaluate key field parameters such as porosity and transmissivity.

The next advantage dealt with the basic assertion that a wellhead generator was reusable from one field to the next. As mentioned earlier, several people questioned whether this was true since resource quality and chemistry can differ so widely from one field to the next. The

total flow conversion cycle was seen by several respondents as having the most promise. Given that the statement was true, most agreed that it represented an important advantage.

Another aspect to this advantage was the dependency of the degree of importance on the selected end use. That is, if it is planned to ultimately replace the wellhead generators with a central power plant, it is imperative that they be reusable. On the other hand, if a unit is being used in an onsite dedicated service role to a large industrial user, reusability here would be less important.

The next advantage--that a user could become his own developer by leasing a wellhead generator--was not meaningful to such a large number of those first interviewed that the card was deleted for the remaining half of the interviews. Most of those that were given the statement could not conceive of a user actually doing his own developing. Interestingly enough, however, the only industrial user interviewed stated that his company did all of their own developing as well as virtually all other phases of the project.

The final advantage in this grouping dealt with potential problems from mixing together brines from multiple wells. The responses here were very scattered. Several had never heard of a problem associated with mixing brines and had no comment. Others cited cases at Cerro Prieto where two different well brines were mixed together and resulted in a troublesome precipitate formation. They felt it was somewhat important that a wellhead generator did not require mixing of brines. Another respondent stated that the problem at Cerro Prieto developed when one well with a brine chemistry problem was mixed with other good wells. Hence, it was not really a brine mixing problem but a case of a problem well.

One final comment was made on the Cerro Prieto facility. A manufacturer stated that the gathering system there involved manifolding together wells that differed greatly in pressure. Thus the high pressure wells were orificed down, which represents a waste of energy. Wellhead generators would capitalize on the full pressure available at each different well.

d. Miscellaneous Advantages. The final grouping consisted of three miscellaneous advantages that did not seem to fit squarely into any of the previous categories. They were as follows:

- (1) A wellhead generator would allow for early determination of site-specific chemistry problems.
- (2) With wellhead generators, the wells could be sited in locations that were geologically optimum, without regard to the location of a central plant.
- (3) Wellhead generators could offer an interim power production period while the central plant was under construction.

Responses to the first advantage varied over the entire range from very unimportant to very important. As previously mentioned, the geothermal community seems to be split into two groups: those who believe that well flow tests and sample analysis provide all the data they need, and those who believe that the real proof of a field comes when the hardware is matched to the resource. One developer took a somewhat intermediate stance by stating that although he did not believe it was a necessary step to have the hardware in place, it was a nice idea. Several responses were tied to a particular conversion cycle. That is, although this advantage might be important for a flash or total flow cycle, it would be unimportant (or not even an advantage) for a binary cycle.

The next advantage was formulated to determine the importance of the siting flexibility that is possible with wellhead generators. In the case of a central plant, economic considerations (e.g., minimizing piping distances) might cause wells to be sited in locations that are not geologically optimum. As with the previous advantage, the responses again were very scattered and covered the entire range.

A definite dependence between the particular end use and the degree of importance associated with this advantage was noted. Siting flexibility was seen to be more important for dedicated onsite use, less important for the central collection and distribution scenario, and obviously unimportant (or not applicable) to the scenario where the central plant was to be installed later. Several persons felt that wellhead generators would offer an advantage in this area but that it was unimportant. Another felt that it could be very important in hilly areas. A final negative aspect was mentioned by several individuals, that of the need for reinjection. The plumbing involved with collecting the spent brine from several individual wellhead units for reinjection into a common well would offset any advantage in selecting optimum sites.

The final advantage presented was a basic restatement of the development scenario in which the initial field development was done with wellhead generators, which operated until the central plant was completed. Most of the responses to this advantage were presented in the discussion on field development scenarios and will not be repeated here; however, a few new thoughts will be included. A couple of respondents did not see the concept as being practical as it was stated, but suggested a modified version. A limited number of wellhead units could be installed for field development and interim power needs, and then left in place after the central plant was operational to serve as backup units, peak-power sources, etc.

One individual viewed the "advantage" as a disadvantage because it involved planning the field development two separate times. Also mentioned was the fact that the cooling towers for the wellhead generators were not portable and would have to be scrapped upon removal of the wellhead units. One developer saw this scenario as a possibility only in the case where the government had a quantity of wellhead generators built and made them available to industry for the purpose of spurring geothermal development.

5. Final Follow-up Questions

This final portion of the interview was planned as a time to take care of any loose ends that might remain. Questions of a general nature were asked here, such as: Do you have any final thoughts on wellhead generators? and, what do you see as the major impediments to the future development of wellhead generators? Also, depending upon the course the interview took, a general set of questions was formulated to probe any important areas that might not have been discussed.

Many new thoughts and ideas did surface here as well as some reinforcements of previously mentioned issues that warrant repeating. Many echoed the feeling that when all was said and done, the key issue was still economics--can a wellhead generator compete economically with the alternate energy source? In the case where the competing source was a central plant, most felt that it could not. In the case where the competing source was a diesel generator (e.g., remote Alaskan villages) or even aviation fuel (e.g., remote military bases), many believed the wellhead unit could compare favorably. For cases in between these extremes, the general feeling was "not today, but maybe in the near future," especially considering conventional energy cost projections. One person felt that the potential efficiency improvements possible with the total flow concept might be sufficient to make the economics of a wellhead generator compare favorably with a large flash steam plant.

Since all of those interviewed recognized the economic problems inherent in small power units, many suggested approaches to mitigate or circumvent the problem. Several of those interviewed saw the development and use of wellhead generators as an important building block in the future of geothermal development, and suggested that government intervention and incentives should be used to make the economic picture better. Tax incentives were the most frequently mentioned vehicle.

One form of government intervention suggested was that the Department of Energy purchase a quantity of wellhead units and make them available to the geothermal community. The cost could be in the form of a leasing arrangement, with the charge set somewhere between the operating and maintenance costs and the cost necessary to recover the capital investment. Most likely, the cost would be set equal to the cost of conventional energy. This would accomplish two things: it would spur the development of geothermal energy and it would stimulate free enterprise. On this latter item, it was noted by one individual that the potential currently exists for a wellhead generator industry (especially in the foreign market), but nobody is willing to take the first step (the manufacturers won't build a unit until someone orders it, and no one will order a unit that hasn't been built!). A final suggestion in the area of economics was that a wellhead generator application should consider utilizing both water and steam in addition to power in order to improve economic viability. It was also added, however, that the current split in the Geothermal Energy Division between electric and nonelectric applications does not encourage this scheme.

Several thoughts were expressed as to what the next most significant deterrents (other than economic issues) were to wellhead generator development. One item mentioned numerous times, that is also common to the general state of the geothermal industry, was that the DOE Loan Guarantee Program needs to be improved. The main suggestion mentioned was eliminating some of the red tape and thereby cutting down on the time and cost involved in securing a loan guarantee. Another issue seen by many as a major impediment is the whole area of permitting. As one individual stated, if you need to get a separate permit for each wellhead generator in a field, then forget it! Another item mentioned as an unknown at the present time (but a potential deterrent) was the reliability of wellhead generators. The units would have to be very reliable, especially those in a dedicated service role, in order to be seriously considered.

Finally, several respondents felt that biases by the utility companies could pose a major obstacle for wellhead generators. This can work in two ways. First, utility companies have generally expressed a preference for large blocks of power and avoided small units. Second, utility companies have historically discouraged independent attempts to generate power within their territory. Getting the people with the geothermal resources together with the users of the energy has proved to be a real headache in the past, and the introduction of a smaller unit of power would not help the matter.

B. UTILITY SECTOR

The electrical utilities interviewed expressed a moderate amount of interest in the concept of geothermal wellhead generators, tempered by a certain amount of skepticism. The primary dissatisfaction with the concept as it currently stands is that power generated by wellhead generators is not economically competitive with geothermal power generated by large central plants. If the economics of wellhead generators can be improved, their use would be warranted under many and diverse circumstances, although the central station concept will probably remain the standard.

The fact that wellhead generators can minimize investment risk was seen as their most important advantage, although some of the attributes responsible for this (reusability, and use as a test tool) were not thought to be particularly advantageous.

Of almost equal importance was the potential for using wellhead generators on fields of marginal quality or small capacity where central station technology could not be employed (or where it was not economical to do so). If wellhead generators were able to economically exploit these marginal resources, a demand for them appears guaranteed; however, there is the possibility that marginal resources are not worth utilizing (is the lifetime of a small-capacity field sufficiently long that its exploitation is worthwhile?).

Wellhead generators may benefit from simpler permitting procedures, and if this is so then it is an attractive advantage. However, most of those interviewed were uncertain on this matter.

Although the installation time for wellhead generators is short (about 30 days), the time required for the permitting and licensing procedures makes the time gained due to this rapid installation and power producing ability much less significant. The time necessary for construction of transmission lines is also a factor which remains unchanged for wellhead generators. Utilities plan facilities years in advance and do not need immediate power to meet loads, and although immediate power is good for cash flow, large utilities and some smaller ones do not appear to be troubled by tight money. However, in spite of the above-mentioned delays and the low priority for immediate power, rapid installation was still ranked as a significant advantage.

As one would expect, the higher costs of operation and maintenance, and initial hardware (per kW) compared to a large central plant are important disadvantages which will have to be mitigated or overcome. Only in special cases will a wellhead generator be used if the cost of the power produced cannot compete with the price of power from alternate (and available) sources. However, if the cost of power from wellhead generators can be substantially reduced, there appear to be numerous areas where their other advantages would make them a strong contender.

The use of wellhead generators for various types of testing drew a mixed response. In general, the larger utilities were interested in the possible use of wellhead generators for testing, whereas the smaller utilities (which, perhaps, do not have budgets large enough to afford testing of this type) had little or no interest in this use. In spite of the interest shown, some uncertainties did exist about the usefulness of wellhead generators for testing. Although it is possible that wellhead generators could help in the discovery of site-specific chemistry problems, it was felt that other methods of chemical testing exist, and such tests would be made prior to the installation of a wellhead generator. It was suggested that without some chemical tests, one would not know how to optimize the design for a given well (or assuming that wellhead generators were "off the shelf", which particular model would be best suited). Little interest was shown in the capability to produce power during the testing phase.

The remaining advantages offered by wellhead generators were not viewed with particular interest. Reusability was important only in the replacement scenario (no one believed that a unit would outlive the well and still be fit to use), but this scenario did not generate much interest. The productive interim phase offered by the replacement scenario and the more rapid return of investment thus possible also generated little enthusiasm. As would be expected, large utilities were not interested in the idea that wellhead generators could supply a small working unit at a fraction of the cost of a traditional plant. Smaller utilities viewed this as a moderately important benefit.

Assuming that the decision was made in favor of using wellhead generators, most utilities would prefer to own the generators in order to have control over the system for reliability. This was particularly true for large utilities. Leasing would be considered if it would reduce the risk or if only a temporary use of the units was seen, but in general, leasing was considered as more expensive than ownership and thus less desirable.

In general, no definite answer can be given on whether the generators would be assigned to wells permanently and hooked together with transmission lines, or whether they would be removed and replaced with a central generator when the field was sufficiently developed. One large utility preferred a central plant, but the rest of the utilities interviewed agreed that the decision would depend upon economics and the circumstances of a given situation. Almost all of those interviewed could envision a potential use in which it would not be possible to employ central station technology. The size at which a central station would replace the wellhead generators would vary between companies. Fifty and 100 MW were both quoted, as well the feeling that such a decision would be site-specific and require a thorough economic analysis. After replacement, the used units would be reused, sold or salvaged, depending upon their condition.

The amount of capital which could be invested in wellhead generators would depend upon the economics and the use. For straight power production, wellhead generators would have to be economical compared to other power sources. In other uses, however, they could be more valuable than just selling power. It was suggested that wellhead generators could be useful in the validation of geothermal leases, and if so, this would increase their value. Their use as a testing instrument might also increase their worth. No quantitative information on the amount of capital available for such an investment could be obtained.

As long as the price (or compensation) is right, most utilities have no lower bound on the amount of power they are willing to buy, generate, or wheel, assuming that the transmission equipment exists. One utility indicated that it might not want to operate a small remote station, but instead might turn it over to someone else for operation. However, if needed and if economic, the power station would get built, regardless of size. On the basis of equipment cost, another utility felt that it was not interested in buying less than 5 MW or generating amounts less than 10 MW. The same general answers held true for the question of what increments of power over the minimum would be of interest. These answers were encouraging with respect to wellhead generators because they demonstrated that the amounts of power which would be generated by wellhead generators are not too small to be of interest; even large utilities expressed interest in obtaining small amounts of energy.

The rate at which increments of power supplied by wellhead generators would have to come on line could not be uniquely determined. Supply, demand, the costs of power production, and the costs of alternate means of power production are constantly changing, which alters the situation. The increments would have to be able to meet the load, and although some uncertainty can be tolerated, the rate of installation cannot be completely uncertain. Some of the utilities stated that a generating capacity of 5 MW is necessary in order to be counted on as capacity. They need security for their customers, and currently cannot depend upon geothermal energy, so they do not count on it as capacity.

Finally, every utility interviewed was interested in wellhead generators to some extent, but their reasons differed. One large utility felt that unless some unique situation drove them away from it, they would opt for the central station concept. They noted, however, that the possible use of wellhead generators on marginal resources or the possibility of using them to validate leases were two such situations. The use of wellhead generators as a testing and development tool was of primary interest to one utility. Another saw them as an opportunity to introduce geothermal power production into the state with a minimum of adverse environmental effects. In that case, favorable reviews by environmentalists were more important than the full utilization of the resources. Wellhead generators would also allow geothermal development to start small. Wells could be more widely spaced than slant drilling allows. Servicing remote areas which do not have access to the power grid was most attractive to one small utility. They had investigated the possibility of utilizing geothermal resources for remote on-site use, but didn't find it economically attractive. They hoped that wellhead generators can be made to be more economical for such an application.

It was difficult to summarize the varied responses of the electric utilities. The only item on which they all agreed was that the use of wellhead generators was not presently economical and that it must be made so before they will be considered seriously. Each utility had many unanswered questions on the use of wellhead generators (How portable are they? What is their realistic lifetime? How will pollutants be handled?). Only time and more study, or the actual construction and use of some units can answer these questions.

C. REGULATORY AGENCIES

The general response of the regulatory agencies to the wellhead generator concept was positive, although there was no consensus of opinion regarding the effects of current regulations on such devices (or the impact of such devices on future regulations). In addition, since wellhead generators are not yet in commercial use, no data exist upon which to base such opinions; thus, much of what was said was speculative.

The primary interest of some of the agencies was in the wells and the drilling of the wells, as opposed to the development or production of power. Of the agencies which were concerned with the power production technology, either no finalized regulations or guidelines for power plants yet exist, or the stipulations and restrictions put into permits and leases are site-dependent, making generalizations difficult. If a generalization must be made at this time, it would be that no differences are foreseen in the way regulations, permits, and licenses would treat wellhead generators and central station developments.

In gaining permits for the drilling of wells, wellhead generators would be neither at an advantage nor a disadvantage. In most cases a permit must be secured for each well, and so 10 wellhead generators would require the same number of drilling permits as a central station being fed from 10 wells.

Site-dependent criteria such as slope, ground cover, and land use are utilized in deciding the type of development to be permitted in any given location. Such factors are studied and weighed in order to reach a decision as to which restrictions should be placed upon a geothermal development. The nature of this decision-making process makes it difficult to generalize about the changes wellhead generators may introduce into it, although it is possible to visualize situations that would favor development with wellhead generators. If wellhead generator technology is further developed, it may be possible that one of the restrictions put upon geothermal development at a given site would be that the development be made utilizing wellhead generators. For instance, if the adverse environmental impacts of central station development were too serious to allow its implementation and those of wellhead generators were found acceptable, then permission to develop the geothermal resource at that site could dictate the use of wellhead devices. One respondent noted, however, that if the environmental situation were so critical as to restrict development to wellhead generators, then it is possible that no geothermal development at all would be allowed at that site. At this point in time it is not possible to predict which, if any, of the above actions would be taken.

Since most regulatory agencies contacted have not seriously considered the use of wellhead generators, the differences between wellhead generators and central stations are not yet well understood; and those differences which are understood were not considered significant enough to warrant any different treatment by most regulations. Although it is possible that mass production and utilization of wellhead generators could encourage simplified and standardized permitting procedures, it must be recognized there is more to a geothermal development than hardware. The interaction of environment and hardware depends equally on both. Thus, even though wellhead generators may become standardized, each site is unique, making standardization of regulations and procedures difficult.

In the state of California, power plants with a generating capacity of less than 50 MW do not come under the jurisdiction of the state regulatory agency, the California Energy Resources Conservation and Development Commission (CERCDC). Thus, a field development involving a single wellhead generator or multiple units with a total capacity less than 50 MW would not currently be regulated by CERCDC. However, if the total field development scenario involved a capacity greater than 50 MW, it is not clear how the current regulations would impact the development. In addition, there was no indication that there would be any special treatment for wellhead generators with respect to environmental reporting or permitting requirements.

CERCDC, as with most other agencies, viewed wellhead generators as a research and development item, and therefore have no regulations applying specifically to them. One thought was expressed that future regulations might be framed to consider wellhead generators at one of two levels -- either as a temporary or as a permanent installation. For temporary situations, such as a field test tool, the regulations, permitting and environmental reporting could be much less stringent than for a permanent installation.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

Based upon a majority of the opinions expressed during the market survey interviews, the wellhead generator concept warrants further consideration by the Department of Energy (DOE). Wellhead generators were not seen as an overall answer to all geothermal problems, by any means, but they were viewed as an important near-term psychological factor in furthering geothermal development.

The recommended approach for the DOE would be a modest but short-term effort to develop a number of wellhead units, which would then be made available to the geothermal industry, perhaps on a lease arrangement. This approach would not only stimulate the geothermal industry, but also could provide the important first step in starting a self-sustaining wellhead generator industry through free enterprise.

The biggest single impediment to the development of wellhead generators is questionable economic viability. On a straight one-on-one comparison of wellhead generators to large central plants, it is doubtful that wellhead generators can be expected to compete favorably based only on economic considerations.

Wellhead generators possess some unique characteristics that could potentially offset or outweigh the inherent economic disadvantages for certain applications. These characteristics include portability, reusability, modest capital investment, and relatively rapid power production capability.

The most promising applications identified for wellhead units are for foreign countries (especially underdeveloped), onsite industrial use, small resource field development tool, and as cold-start generators, auxiliary and peaking units for larger utilities.

Three different conversion cycles were considered in the study-- flash steam, binary, and total flow. It is recommended that future wellhead generator efforts concentrate on the binary or the total flow cycles rather than flash steam. The binary cycle offers a high degree of versatility from a field-to-field compatibility standpoint; the total flow cycle has the highest potential efficiency, and hence the best economic potential.

A second major area of uncertainty surrounding wellhead generators was the whole area of permitting. Many unanswered questions remain as to the receptivity of the regulatory agencies to wellhead generators. These questions must be answered, and in a positive sense with respect to wellhead units, before any progress can be made.

It is recommended that joint efforts between the electric and nonelectric sections within the Geothermal Energy Division of DOE be encouraged. This could enhance the economic viability of wellhead generators for applications such as onsite service to a pulp mill, by utilizing electricity, steam, and hot water.

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APPENDIX A

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APPENDIX B

SAMPLE STRUCTURED INTERVIEW

INTERVIEW FORMAT

1. General introduction.
2. Read and discuss the wellhead generator definition.
3. Discuss applications list and what their best possible applications might be.
4. Discuss the flow chart (or list) on the field development scenarios.
5. Discuss and rank the perceived advantages and disadvantages.
6. Miscellaneous wrap-up questions.

GEOHERMAL WELLHEAD GENERATOR DEFINITION

A geothermal wellhead generator device is defined for the purpose of this survey as a portable, self-contained, power conversion system, in the 1-10 MW range, made for operation at the geothermal wellhead. The unit would be completely self-sufficient, requiring only cooling water and hot geothermal fluid to produce electricity. The wellhead generator will be modular in nature. For the case of a flash steam wellhead generator, the major modules would consist of the turbine generator, condensor and noncondensable gas removal module, controls and switch gear assembly, steam-water separator and the cooling water circulation pump module. Other alternate wellhead generator systems that might be employed are the total flow concept or the binary system, in which case the modules would differ. Regardless of which conversion process is selected, only a condensing system will be considered.

All of the modules of a given configuration would be mounted on a common bed frame to facilitate road transportation by trailer trucks from one site to another. The wellhead generator would be approximately 30 feet long by 8 feet wide by 9 feet high and would weigh 20 tons. The time from delivery of the unit to the completed well to the first production of electricity would be approximately 30 days. Estimated costs for a wellhead generator are expected to be in the range of \$300-600 per kW, exclusive of any external plumbing, cooling tower, source well or reinjection well costs.

GEOHERMAL APPLICATIONS

Utilities

Private Utilities

Power into grid

Municipal Utilities

Power into grid

Onsite power (pumping etc.)

Rural Electric Associations

Power into grid

Onsite power (pumping etc.)

Developers

Power sales to utilities

Steam sales to utilities

Power sales to industries

Steam sales to industries

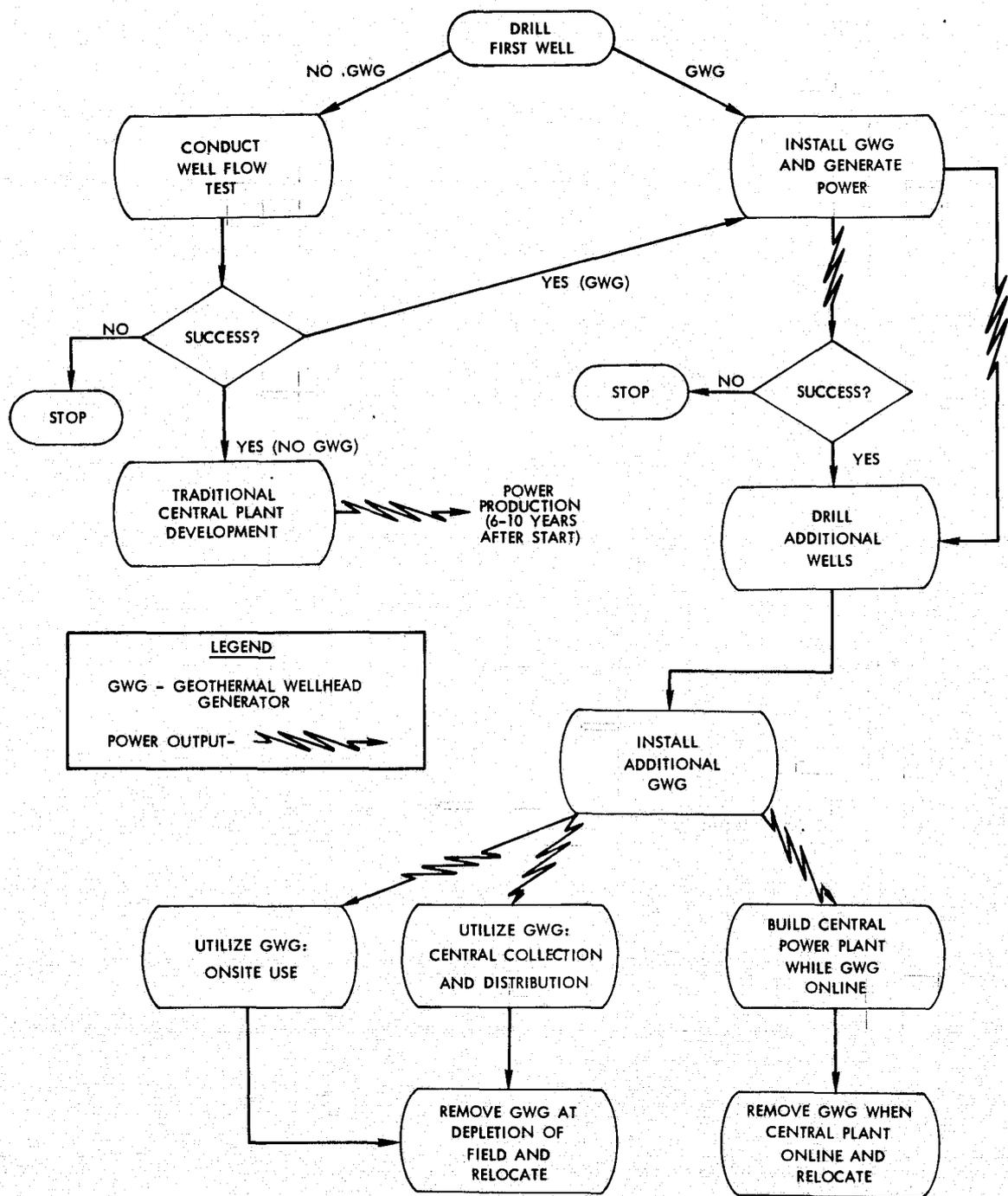
Industries

Onsite power

Onsite power and steam

GEOHERMAL RESOURCE
FIELD DEVELOPMENT SCENARIOS

- (1) Traditional field development would begin by flow testing an initial well or wells for a period of time sufficient to determine the field characteristics and build confidence in the size and quality of the field. If the flow tests were successful, a permanent central plant would be constructed.
- (2) The wellhead generator could serve the remote user (either without access to the grid or at the "end of the line") as a single unit or several multiple units.
- (3) The wellhead generator could be installed in incremental units to develop a large field at a pace dictated by the success of the preceding wells.
- (4) The wellhead generator could be installed as above and operate until a full-sized plant could be completed and on-line. The wellhead generator would then be moved to a new site.
- (5) The successful operation of several wellhead generators could influence the decision to proceed with the construction of a large central plant. The wellhead generator would obtain data relative to the resource quality and capacity that could affect the design of the central plant.
- (6) The power from the initial wellhead generator could be used to further develop the field (drilling rigs, pumps, etc.). This would enhance development of fields without initial access to the power grid.



Flow Chart - Field Development Scenarios

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ADVANTAGES

- (1) A wellhead generator is reusable.
- (2) A wellhead generator offers almost immediate power production.
- (3) A wellhead generator allows for early determination of site-specific chemistry problems.
- (4) The initial data collection can be concurrent with energy production.
- (5) Data on productive aspects of the well and field can be obtained earlier.
- (6) A wellhead generator offers a more rapid return on investment.
- (7) Wellhead generators can be used to develop fields of marginal quality or small capacity, not otherwise economically feasible with a large plant.
- (8) Wellhead generators provide the opportunity for small utilities to use geothermal resources.
- (9) One can obtain a working unit (albeit small) at a fraction of the cost of a traditional geothermal power plant.
- (10) It is cheaper and more environmentally attractive to collect electricity than steam.
- (11) Wellhead generators offer a productive interim phase until central generator is completed.
- (12) A wellhead generator can help to develop maximum confidence in a field with a modest capital investment.
- (13) Dispersive systems are generally more reliable than central systems.
- (14) Small increments of power can be made available quickly.
- (15) Wellhead generators may require simpler permitting procedures, at least initially.
- (16) Wellhead generators minimize investment risk.
- (17) The wellhead generator concept allows the possibility of leasing equipment.

DISADVANTAGES

- (1) The increments of power may be too small to interest large users.
- (2) Wellhead generators have a higher initial hardware cost per kW.
- (3) Wellhead generators have higher operation and maintenance costs per kW.

MISCELLANEOUS WRAP-UP
QUESTIONS FOR UTILITIES

1. Would you prefer to own or lease the generators or buy power?
2. If ownership or leasing is chosen, would you assign the generators permanently to the wells and hook them together with transmission lines, or would you remove them and create a central generator when the field was sufficiently developed?
3. If the latter, at what size would this occur?
4. What would you do with the wellhead generator?
5. How much capital could you invest in geothermal wellhead power generators?
6. What is the minimum amount of power (energy) you would consider buying (generating, wheeling)?
7. What increments of power over the minimum would you buy (generate, wheel)?
8. In order to be an attractive investment, at what rate would the increments have to come on line?
9. Are you interested in the use of wellhead generators, and do you have any final thoughts?