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*Geothermal Energy Development
in the Eastern United States*

**SENSITIVITY ANALYSIS—COST
OF GEOTHERMAL ENERGY**

S. M. KANE, P. KROLL, and B. NILO

The Center for Metropolitan Planning and Research
The Johns Hopkins University
Baltimore, Maryland 21218

This work was supported by the Department of Energy
under Interagency Agreements EX-76-A-36-1008
and DE-Alo1-79ET27025

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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ABSTRACT

The Geothermal Resources Interactive Temporal Simulation (GRITS) model is a computer code designed to estimate the costs of geothermal energy systems. The interactive program allows the user to vary resource, demand, and financial parameters to observe their effects on delivered costs of direct-use geothermal energy. Due to the large number and interdependent nature of the variables that influence these costs, the variables can be handled practically only through computer modeling. This report documents a sensitivity analysis of the cost of direct-use geothermal energy where each major element is varied to measure the responsiveness of cost to changes in that element. It is hoped that this analysis will assist those persons interested in geothermal energy to understand the most significant cost element as well as those individuals interested in using the GRITS program in the future.

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PREFACE

This is the last report prepared by the Johns Hopkins Center for Metropolitan Planning and Research for the Applied Physics Laboratory as part of the program for geothermal energy development in the Eastern United States. Although a portion of this report appeared in summary form in APL's final report (Ref. 1), there has been sufficient interest in the output as well as the mechanics of the Geothermal Resources Interactive Temporal Simulation (GRITS) model to warrant publication of the details of this sensitivity analysis. Persons interested in using the GRITS program can contact the authors at the Johns Hopkins University Department of Geography and Environmental Engineering.

ACKNOWLEDGMENTS

Thanks are due to Julia Cohan, who prepared the original graphs in this report, and to Fletcher C. Paddison (APL), William Barron (formerly of the Johns Hopkins Metro Center), and William Toth (formerly of APL) for their ongoing advice and assistance in developing GRITS for the economic analysis of geothermal energy.

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- Ref. 1. Geothermal Energy Development in the Eastern United States -- Final Report, JHU/APL QM-81-130, Oct. 1981.

1. INTRODUCTION

Exploiting geothermally heated waters has a history going back thousands of years. However, in the United States, the economic feasibility of direct utilization of geothermal energy* has only recently begun to be seriously considered, except for a few localized geothermal resources that have been producing energy since the turn of the century.** The expected continued rise of real prices of fossil fuels over the next few decades and the perceived growing dependence on foreign sources of petroleum are among the many factors contributing to the renewed interest in a relatively well-known energy technology.

Geothermal energy is one of a multitude of energy technologies examined over the last ten years. This report presents an economic analysis based on the discounted unit cost of supplying the end-user with geothermal energy. The tool used is the Geothermal Resources Interactive Temporal Simulation (GRITS) computer model, which is designed to simulate the economic/engineering cost characteristics of a low-temperature geothermal system.

Ideally, a thorough comparison of the relative advantages of developing and utilizing various types of energy requires an evaluation of the total system costs in addition to an evaluation of other selected attributes of each energy technology. The total system costs include both monetary and social costs of developing, generating, transmitting, and distributing the energy to the end-user. Characteristics of the energy systems that are not captured in the total system costs include convenience to the end-user, costs of conversion by end-users, storage capability, and technology innovation costs. However,

*The term "geothermal energy" covers a wide range of technologies and resources. In this report, geothermal energy refers to energy extracted directly from waters heated in the earth's crust. The heating applications include space heating, industrial process heating, and agricultural applications.

**Klamath Falls, Oreg., and Boise, Idaho.

because such a comprehensive analytic procedure encompasses all aspects of the energy technologies, it is difficult to put into practice; copious amounts of detailed data are required, and the tasks of assigning magnitudes to social costs and weighting the attributes to reflect their relative importance are subjective in nature.

Instead, a unit cost approach was chosen for studying the economic feasibility of geothermal energy. Even though this approach is less comprehensive than the one mentioned above, it facilitates preliminary evaluation of the technology through direct cost comparison with currently available heating fuels. It is currently the most appropriate type of analysis considering that available information on geothermal resource conditions is not detailed and energy demand estimates as well as financial conditions are both site and project specific. Unit costs (i.e., the discounted average cost, or DAC) can be viewed as a lower bound* proxy for market price as measured in dollars per millions of Btu's ($\$/10^6\text{Btu}$); as such they can be compared directly with the market price for natural gas or heating oil, the usual source of energy for district heating systems or industrial process heating systems.

This study uses the GRITS model to examine the sensitivity of DAC of geothermal energy to certain parameters critical to its economic performance. By identifying the sensitive range of the parameters, functional relationships between parameters and costs are illustrated. This information can be helpful in project analysis and regional economic planning since it demonstrates which parameters need to be most accurately estimated.

GRITS is an interactive computer program that is designed to evaluate the economic costs of supplying geothermal energy to a community heating system or industrial user; these costs include the purchase of equipment and installation of well and distribution systems, as well as those costs incurred in producing, transmitting, and distributing the energy. Resource study costs and governmental licensing costs can be added. In

*Lower bound since an increment would be added to the DAC to simulate the price that a purchaser would face.

addition to computing annual energy production levels and costs, the model produces several economic accounting measures. The two principal measures are: (a) the DAC, i.e., the price that equates the discounted cost and revenue streams, and (b) the net present value (NPV), the sum of the discounted cost and revenue streams. When the user specifies a selling price for the energy produced that differs from the DAC of producing the energy, the NPV differs from zero. The DAC indicates the value of goods and services required to bring a unit of energy to a customer. The NPV takes into account projected market conditions through the specified selling price or price trend for the energy produced and indicates the potential attractiveness of the investment to developers and financiers. A detailed description of the model is given in Ref. 2.

In Section 2, a basecase simulating a hypothetical geothermal project in Salisbury, Md., is identified and analyzed. The impact of changes in resource and economic conditions on the project economic summary measures are traced in Sections 3, 4, and 5. Lastly, a comparison of geothermal systems highlighting geographical differences in resource and demand conditions is presented in Section 6.

Ref. 2. Peter Kroll and Sally Minch Kane (eds.), GRITS (Version 9): Model Description and User's Guide, JHU/APL QM-81-112 (also MCGER-81-002), Apr 1982.

2. THE SALISBURY BASECASE

A basecase simulating a hypothetical geothermal district heating system in Salisbury, Md., is examined in this section. Discussion of the summary results illustrates the mechanics of specifying a project and provides an interpretation of the economic accounting measures.

Values of the parameters in the basecase are given in Table 2-1. Generally each parameter has been assigned a conservative value selected from the middle range of estimates considered feasible for the Eastern United States, although the values for the maximum flow rate (300 gal/min), market saturation (70%), and wellhead temperature (150°F) represent optimistic estimates.

The set of conditions that determined the basecase values are as follows:

1. Housing stock is comprised of single-family homes (densely spaced), townhouses, and garden apartments in the Salisbury area, and 70% of the households within the service area are hooked up to the district heating system. Two types of commercial buildings, one with 4000 and one with 10,000 ft² of average floor space, are connected to the same district heating system.
2. All space heating demand down to an ambient temperature of 39°F is served exclusively by geothermal energy; additional energy demand for colder temperatures (down to -5°F) is served by a fossil-fuel peaking system that raises the temperature of the circulating water. All domestic hot water heat is provided by geothermal energy.
3. The resource is tapped by a 5000 ft production well that has an average drawdown of 15% (750 ft) at full production as the water is pumped to the surface.
4. The temperature at the wellhead is 150°F and the reinjection temperature is 90°F, resulting in a ΔT of 60°F. Maximum flowrate is 300 gal/min.

5. The water is reinjected into the same aquifer at a depth of 5000 ft.
6. The conditions include a 15% charge for borrowed funds, with the system capital components amortized individually over their expected lives or the evaluation period, whichever is shorter.
7. Electricity to operate the pumps is purchased at 6.2¢/kWh with an annual real increase of 2%. Fossil fuel for the peaking plant is purchased at \$9.00/10⁶ Btu with an annual real price increase of 4%. The selling price is fixed at 70% of the price of fossil fuel (in Btu equivalent terms).
8. The distribution system costs are \$250,000 per mile of installed insulated dual pipe.

The results from running the basecase are shown in Tables 2-2 and 2-3. Note that under these conditions, 90% of all space heating requirements for the 355 households on the single-well system are served by geothermal energy. The production and reinjection well costs represent the single largest capital cost component throughout the evaluation period. The fact that the real value of the debt service declines throughout the project evaluation period and the real cost of purchased fossil fuel and electricity increases steadily leads to an interesting consequence: fossil fuel costs constitute over 30% of the total system costs in the last year of the evaluation period, as compared to less than 20% for well costs. Cost of pumping energy (electricity) nearly equals the well costs in this year. The summary measures for the project that was simulated using the basecase showed a DAC of \$13.69/10⁶ Btu of delivered energy for residential and commercial users and an NPV of revenues less costs of \$691,000. Undiscounted operations costs saved exceed the initial capital cost of \$2,504,000 in year 10.

Table 2-1

Salisbury Basecase Scenario for Residential and Commercial Estimates

Resource Conditions		Value
Area under consideration		Salisbury, Md.
Wellhead water temperature (°F)		150
Depth of upwell (ft)		5000
Number of production wells		1
Reinjection temperature (°F)		90
Depth of reinjection well (ft)		5000
Number of reinjection wells		1
Drawdown of upwell (%)		15
Maximum flow per well (gal/min)		300
Transport distance (miles)		0.25
Demand Conditions		Value
<u>Housing types on system</u>	<u>Percentage</u>	<u>Hookup cost per household (\$)</u>
Single-family, dense	20	1500
Townhouse	40	1500
Garden apartment	40	400
Market saturation (%)		70
Market penetration (%)		
Initial		15
Annual change		8
Domestic hot water (10 ⁶ Btu/yr/h)		20.10
Number of types of commercial buildings		2
Average floor space (ft ²)		
Type 1		4,000
Type 2		10,000
Average heat demand (Btu/ft ² /deg-day)		
Type 1		9
Type 2		9
Number of each type		
Type 1		5
Type 2		2

Table 2-1 (cont'd)

Salisbury Basecase Scenario for Residential and Commercial Estimates

Rate of commercial market penetration (%)		
Initial		50
Annual change		25
Length of commercial distribution system (miles)		
		0.2
System design temperature (°F)		
		39
Minimum ambient temperature (°F)		
		-5
Financial Conditions		Value
System selling price (\$/10 ⁶ Btu) as a multiple of electricity price (%)		
		70
Study period (years)		
		20
Storage tank capacity (hours of flow)		
		2
<u>Capital equipment</u>	<u>Amortization period</u>	<u>Physical life (yr)</u>
Wells	30*	30
Piping system	30*	30
Heat exchanger	10*	10
Pumps	10*	10
Hookup	30*	30
Peaking boiler	30*	30
Storage tank	30*	30
*Reduced as needed to end in study period		
Discount rate (%)		
		4
Interest rate (%)		
		15
Inflation rate (%)		
		8
Real dollar calculations		
Cost of electricity		
Initial price (¢/kWh)		6.2
Annual change (%)		2
Cost of fossil fuel		
Initial price (\$/10 ⁶ Btu)		9
Annual change (%)		4
Operation and maintenance (% of capital)		
		1
Boiler cost (\$/10 ⁵ Btu/h)		
		1500
Distribution system pipe cost (\$ thousands/mile)		
		250

Table 2-2

Basecase Scenario Results for Residential and Commercial Estimates,
Last Year of the Evaluation Period
(annualized values)

Characteristics	Value
Length of distribution system (miles)	1.28
Number of households	355
Total geothermal Btu's (millions)	30,868.07
Total system Btu's (millions)	32,766.14
Geothermal utilization (%)	39.19
Service geothermal (%)	90.06
Pumping energy (million kWh)	0.54
Annualized real cost (\$ thousands)	
Well costs	50
Distribution system costs	13
Heat exchanger costs	4
Original pump costs	4
Hook-up costs	24
Pump overhaul costs	6
Pumping costs	49
Peaking boiler costs	7
Fossil fuel costs	86
Transport costs	5
Storage tank costs	3
Operation and maintenance costs	25
Total annual wellhead costs	123
Total annual system costs	275
Wellhead cost per geothermal million Btu (\$)	3.97
System cost per million Btu (\$)	8.02
Revenue (\$ thousands)	635
Net revenue (\$ thousands)	360

Table 2-3
Summary Measures for Entire Project

Characteristics	Value
Initial capital cost (\$ thousands)	2504
NPV of revenues minus costs (\$ thousands)	691
DAC (\$/10 ⁶ Btu)	13.69
Discounted average wellhead cost (\$/10 ⁶ Btu)	8.26
Break-even point achieved	Year 15
Payback completed	Year 10

3. THE EFFECTS OF RESOURCE CONDITIONS ON GEOTHERMAL ENERGY COST

Following the basecase simulation, parametric runs were made to check the sensitivity of DAC to specific resource, demand, and financial conditions. The values for each parameter tested were varied systematically to capture the effect of the change. In this section, the results from the resource analysis are discussed. Any parameter not specifically listed in the tables or mentioned in the description has the original basecase value.

In preliminary feasibility studies of geothermal energy, knowledge of resource conditions is typically limited. Exploratory wells are expensive to drill; therefore, potential developers often have scant information on resource flow, temperature, aquifer drawdown, required well depth, and reinjection requirements. Analysis of the responsiveness of the economics of geothermal energy development to these resource factors can be a useful supplement to empirical geologic information. GRITS was used to vary certain important resource parameters over a range of possible values in order to examine the cost consequences of various potential resources.

WELL DEPTH

The production well is the single largest initial cost component in geothermal development. Further, pumping the geothermal fluid from the well is a significant operating cost. Both of these factors have a major effect on the DAC and NPV of our basecase project. Figure 3-1* shows that the DAC of the project rises from approximately \$11/10⁶Btu with a production well of 2500 ft to almost \$20/10⁶Btu at 7500 ft, increasing at an increasing rate. The effects on the projected NPV are even more dramatic. Figure 3-2 shows that a 2500 ft well has a \$1.6 million NPV. If that same project required a well only slightly deeper than 6000 ft, NPV would become negative. While a range

*Figures 3-1 through 3-17 follow the text of this section.

of production well depths up to 6000 ft is economically feasible for the basecase, a developer who may require a well deeper than 6000 ft would want to perform more detailed geological studies before deciding on development.

FLOW FROM PRODUCTION WELL

The amount of geothermal energy extractable from a production well is proportional to the flow and the resource temperature. A higher flow at a given temperature means that more demand can be served from the resource with the same well. The residential basecase has positive net returns over the project life once the flow reaches at least 225 gal/min (Fig. 3-3).

Additional pumping costs and infrastructure costs are more than compensated for by economies of sale and higher revenues. Similarly, DAC drops as flow from the well increases (Figs. 3-4 and 3-5). With a resource characterized by 150°F and 25% drawdown, the residential system's DAC drops by one-third, from \$20/10⁶Btu to \$13.5/10⁶Btu, when flow is doubled from 150 to 300 gal/min. The cost effect on industrial process heating is even more impressive; a similar resource improvement more than halves the cost, from \$14.5/10⁶Btu to \$6/10⁶Btu. This is because of the fewer costs attributable to capacity increases in an industrial system, as opposed to, for example, district heating distribution systems.

The strong influence of flow on financial feasibility implies the need for careful analysis of a project's flow projections.

RESOURCE TEMPERATURE

Resource temperature has a relationship to DAC and NPV similar to that of production well flow. Figure 3-6 shows a linear increase in NPV for the residential basecase rise in temperature at the wellhead. Once the temperature is above 137°F, NPV is positive. Temperatures above 150°F can result in geothermal energy delivery costs being competitive with \$1.25/gal for fuel oil.

Analogously, Figs. 3-7 and 3-8 show a continual drop in DAC as a function of wellhead temperature. As with the flow, a better resource allows more demand to be served with roughly the same infrastructure, resulting in economies of scale with higher revenues and lower average cost.

The analysis above assumes that the well temperature remains constant through the life of the project. However, another risk is that a given initial temperature will decrease over time. The GRITS model shows the effect on residential basecase costs of a range of simple linear rates of temperature decrease (Figs. 3-9 and 3-10). Even with a drop of 0.5°F per year, the DAC of the project increases by less than $\$1/10^6\text{Btu}$. Its effect on NPV is more pronounced, as NPV drops by almost two-thirds, from $\$420,000$ to $\$150,000$, with a 0.5°F temperature decline per year. Thus, while initial resource temperature is one primary consideration in analyzing geothermal project feasibility, its degradation over time should also be considered.

DRAWDOWN

With pumping a major operating cost in the geothermal system, the drawdown of the well (that is, the distance to the surface that the geothermal fluid must be pumped) can play a significant role in cost determination. Figures 3-11 and 3-12 show a linear increase in DAC with drawdown for both the residential and the industrial cases. Industrial costs double with a drawdown increase from 0 to 50% of the full depth of the well. The rise in residential costs is not quite as dramatic because other invariant cost factors, such as distribution system and peaking fuel costs, moderate the relative effect of increased pumping energy. NPV (see Fig. 3-13) drops with the increase of drawdown from almost $\$1.2$ million at zero to breakeven at about 37%. The residential project loses more than $\$400,000$ with 50% drawdown.

Drawdown may also increase with time, as the aquifer is depleted. GRITS was used to simulate a range of annual rates of linear decrease (in the residential basecase) with the results given in Figs. 3-14 and 3-15. Only relatively small changes occur in DAC and NPV, at least over the range of rates of increase in drawdown examined. Thus, in this case the danger of drawdown increase over time would appear to be of relatively small significance.

REINJECTION TEMPERATURE

The final resource parameter to be discussed in this section is the reinjection temperature. The amount of heat extracted from the geothermal water is directly related to the discharge reinjection temperature; therefore, from a heat efficiency standpoint, the more heat that can be extracted, the more efficient is the process. However, if the resource is degraded either by depletion (extraction without replenishment) or by reinjecting the used fluid into the aquifer (thereby lowering the aquifer temperature), system heat production will drop. Variations on the choice of the design reinjection temperature for the residential basecase are shown in Figs. 3-16 and 3-17. DAC nearly doubles as heat extraction efficiency decreases from a reinjection temperature of 75°F to one of 120°F. NPV becomes negative once a reinjection temperature of approximately 102°F is reached.

SUMMARY

The analysis of variations of parametric values using the GRITS model demonstrates the relative importance of certain resource characteristics in determining the economic viability of a geothermal project. In particular, flow, temperature, and drawdown play important roles. Their variation over time may be relatively less significant as long as the initial values are justified by strong confidence in operational projections. However, if either geological data are uncertain or economic feasibility is in doubt, a potential developer may wish to perform further geological and economic studies of the feasibility of a particular project.

Fig. 3-1 DAC as a function of production well depth (residential).

Fig. 3-2 NPV as a function of production well depth (residential).

Fig. 3-3 NPV as a function of flow (residential).

Fig. 3-4 DAC as a function of flow (residential).

Fig. 3-5 DAC as a function of flow (industrial).

Fig. 3-6 NPV as a function of wellhead temperature (residential).

Fig. 3-7 DAC as a function of wellhead temperature (residential).

Fig. 3-8 DAC as a function of wellhead temperature (industrial).

Fig. 3-9 DAC as a function of annual temperature drop (residential).

Fig. 3-10 NPV as a function of annual temperature drop (residential).

Fig. 3-11 DAC as a function of drawdown (residential).

Fig. 3-12 DAC as a function of drawdown (industrial).

Fig. 3-13 NPV as a function of drawdown (residential).

Fig. 3-14 DAC as a function of annual increase in drawdown (residential).

Fig. 3-15 NPV as a function of annual increase in drawdown (residential).

Fig. 3-16 DAC as a function of reinjection temperature (residential).

Fig. 3-17 NPV as a function of reInjection temperature (residential).

4. THE EFFECTS OF DEMAND CONDITIONS ON GEOTHERMAL ENERGY COST

The uncertainty of information concerning geothermal energy demand is different from that concerning resource conditions. While resource characteristics are physical and therefore can be determined (albeit expensively) by geologic testing, demand conditions for the life of the project are based on behavioral factors that cannot be independently determined. Depending on the potential market, there may be a relatively small or a relatively high risk in developing a specific resource. For example, for an industrial application with a single process heat user, the heat demand for the project life can probably be projected accurately. However, for a residential-commercial district heating system, a detailed market penetration study will need to be performed (unless the market is guaranteed). In either case, the developer of the resource will need to be sure that sufficient demand exists for the project to be profitable.

INDUSTRIAL PROCESS HEAT

Level of Demand

Figures 4-1 and 4-2* demonstrate the economies of scale of an increased level of demand for industrial process heat. Since the major portion of the system costs is fixed, the effect of additional production and of heat sales reduces the DAC and increases the NPV in a roughly linear fashion. NPV, for example, doubles from \$1.4 to \$2.8 million with an increase in heat supplied from 6.5 to 9×10^6 Btu/hr.

Utilization Factor

When heat is used for a greater portion of the year, DAC and NPV exhibit trends similar to those found for increasing

*Figures 4-1 through 4-8 follow the text of this section.

levels of demand. Figures 4-3 and 4-4 demonstrate an analysis of the effects of a range of utilization factors for several resources. The NPV graph (Fig. 4-3) shows that resources that would be marginally profitable supplying a plant operating under a single 8-hour (33%) shift would be more attractive with greater utilization. At the same time, DAC decreases with greater utilization (Fig. 4-4).

RESIDENTIAL-COMMERCIAL DISTRICT SPACE HEATING

The analysis of residential-commercial market acceptance of a geothermal district heating system is complicated because of the various types of users in the market, the wide geographical area of coverage, and a staggered schedule of market acceptance. Some of the most important factors are discussed below.

Housing Type and Market Saturation

The distribution system is a major cost in a district heating system. A system serving housing that is relatively closely spaced (e.g., apartments as opposed to single-family suburban housing) will need to cover less area, reducing the distribution system size and costs. Similarly, the heating demand of more compact housing is less than that of detached housing -- an apartment costs less to heat than a suburban house. Figures 4-5 and 4-6 show the cost variation for the five housing types modeled in GRITS for a range of market saturation levels.*

As these examples indicate, levels of market saturation below 20% are clearly expensive to maintain. Above this level, the DAC decrease and NPV increase gradually level off. High-rise apartments show a positive NPV through the entire range; garden apartments are feasible through most of the range; town-houses and single-family dense housing service show a profit at

*Market saturation, expressed as a percentage, indicates the ultimate fraction of the market area that will eventually be converted to district heating. For example, a market saturation of 50% would imply that, on the average, every other house would choose not to join the district heating system, so that the system must cover twice as large an area to serve as many customers as it would with a 100% level of market saturation.

80% of market saturation; single-family suburban housing, however, barely breaks even with 100% saturation. Thus, in terms of our basecase, while a district heating system may be installed feasibly in existing communities of denser housing without relying on full market saturation, the need to capture virtually all potential customers in a single-family suburban area would require either a new community development or forced hookups.

Market Penetration

Even when ultimate market saturation can be projected to a satisfactory level, the rate at which customers join the system (market penetration) will affect cost and revenue streams over time. Delays in achieving full market penetration will postpone certain revenues and certain costs. Figure 4-7 shows the GRITS simulation of varying trends at market penetration for several variations on the basecase. A logistic (S-shaped) function was used to indicate slow initial penetration, followed by increasing acceptance, and finally slow adoption by the final stragglers. The NPV is plotted against the year in which all customers are finally on the system. The graph shows clearly the advantage of bringing customers on line as quickly as possible. For example, the middle curve indicates an NPV of about \$600,000 if complete market penetration is achieved in the first year. If everyone is not on line by year 6, the project will show a loss. Plots of DAC (Fig. 4-8) versus the year of 100% market penetration show an analogous straight-line relationship. DAC increases gradually with delayed attainment of complete market penetration; thus, a delay of 10 years only increases DAC on the order of $\$1/10^6$ Btu.

SUMMARY

This section has examined the role of several demand parameters in determining project feasibility. The industrial demand and utilization level and the type of housing, the market situation, and market penetration in the residential case have been shown to be important considerations. Other factors may also be studied using GRITS to determine the sensitivity of planning assumptions to variation in demand parameters. The potential developer of geothermal resources should examine and weigh the risk inherent both in assessing demand conditions and in evaluating them in the context of resource condition assumptions.

Fig. 4-1 NPV as a function of industrial process heat demand.

Fig. 4-2 DAC as a function of industrial process heat demand.

Fig. 4-3 NPV as a function of Industrial utilization factor.

Fig. 4-4 DAC as a function of Industrial utilization factor.

Fig. 4-5 NPV as a function of housing type and density.

Fig. 4-6 DAC as a function of housing type and market saturation.

Fig. 4-7 NPV as a function of market penetration (with logistic function).

Fig. 4-8 DAC as a function of market penetration (with logistic function).

5. THE EFFECTS OF FINANCIAL CONDITIONS AND OTHER GENERAL CONSIDERATIONS ON GEOTHERMAL ENERGY COST

The sensitivity of DAC and NPV to specific financial conditions and other general considerations are reviewed in this section. The parameters that are varied include the number of wells, cost of the assessment period, cost of purchased fuels, cost of installed pipes, and the transport distance. In addition, the effects of changes in the economic parameters, such as the inflation rate and discount and interest rates, will be discussed.

NUMBER OF WELLS

Wells comprise the largest component of geothermal capital costs. Furthermore, in GRITS each well requires a pump and each production well requires a heat exchanger. The DAC rises as the number of wells used to pump a given flow of water increases since the same amount of energy is being produced with higher fixed (capital) and variable (pumping energy) costs. Conversely, the larger the rate of total flow from the wells, all else being equal, the smaller the increase in costs attributed to the additional wells. This is due to certain economies of scale in the larger system. Figure 5-1* illustrates the effect of increasing the number of wells in a geothermal residential or industrial heating system. In each case, DAC rises with the addition of wells, relatively more sharply for those systems with lower flowrates and/or more than two wells.

DISTRIBUTION SYSTEM

For a district heating distribution system of a given length, changes in the cost of installed pipe have a moderate impact on DAC. A 40% (\$100,000) change in pipe cost above the original value of \$250,000 per mile results in an increase of 50¢ per million Btu's of delivered energy (Fig. 5-2). Figure

*Figures 5-1 through 5-20 follow the text of this section.

5-3 indicates that the effect on NPV is a decrease of more than \$150,000 (almost 25%).

TRANSMISSION DISTANCE

Increases in transport distance from the well to the distribution system (district heat system) or to the user (industrial process heating system) have a more significant effect than do increases in distribution system costs. When a transport distance is increased to 1 mile, keeping pipe cost per mile constant, DAC per million Btu's of delivered energy rises by approximately \$1.50 for both the residential and the industrial systems (Fig. 5-4). Moreover, the NPV of the residential project drops to 0 as the transmission distance is increased to 1 mile, as seen in Fig. 5-5. Clearly, transport distance plays a crucial role in determining the economic feasibility of the example projects. This indicates the importance of locating the well as close as possible to the end users.

RESOURCE ASSESSMENT COST

The assessment period is usually designated as the first year or two of a project during which planning and evaluation activities take place prior to utilization of the resource. The costs associated with this period do not substantially affect the DAC or NPV measures, as shown by Figs. 5-6, 5-7, and 5-8. Given a seven-fold increase in the lump sum cost of the assessment period from \$20,000 to \$140,000 per year, DAC increases by less than 10% and NPV drops by only a small amount in both residential and industrial projects.

ENERGY PRICES

Purchase prices for conventional fossil fuels and electricity have soared during the past decade. The sensitivity of DAC and NPV to changes in the initial purchase price of energy and to changes in the real rate of increase in price (above inflation) for electricity were tested. Raising the initial purchase price of fossil fuel (#2 heating oil) from \$9.00 to \$14.00 per million Btu produces a change of 56% over the original base-

case value. Figures 5-9 and 5-10 indicate an increase in DAC of \$1.00 and a decrease in NPV of almost 50%, that is, \$350,000. If the initial electricity price is increased from 6¢/kWh to 9.5¢/kWh, a 50% change over the original price, the DAC only increases by \$0.55 (Fig. 5-11). It is interesting to note that even though electricity is an input into the production of geothermal energy (for pumping), NPV actually rises as a result of the increase in the original price of electricity; this is due to our basecase assumption that ties the selling price of geothermal energy to a multiple of the electricity price (the basecase value for the selling price of geothermal energy is 70% of the price of electricity). Raising the original market price of electricity from 6¢/kWh to 9.5¢/kWh yields an increase in NPV of almost \$3,000,000 a five-fold increase, as shown in Fig. 5-12. Finally, when the real annual increase in electricity price changes from 3% to 4%, and the initial purchase price is held constant at 6.2¢/kWh, DAC increases to \$0.14 and NPV increases by approximately \$450,000 (about 50%), as seen in Figs. 5-13 and 5-14.

INFLATION RATE

Since the fixed nominal annual payments of the debt service are deflated in accordance with a real dollar model, inflation serves to lessen the real cost of the debt service payments toward the later years of a project. A decrease in the inflation rate from 10 to 6% results in an increase in DAC of at least \$0.50 and a decrease in NPV of approximately \$500,000 (Figs. 5-15 and 5-16).

DISCOUNT AND INTEREST RATES

The discount and interest rates work in a direction opposite to that of the inflation rate. Increases in both the discount and interest rates produce increases in the DAC and declines in the NPV. Economic theory suggests that the costs incurred and the revenues generated in the later years of a project are valued less than those faced in the early years.* This is achieved through discounting.

*In simple terms, with all other things being equal, one would prefer that costs be delayed so that the investor has use of the money in the interim. Similarly, revenues delayed are not available for current use and so have less value.

The discount rate can be viewed as including a risk premium. An element of risk is present in the projects since there is no certainty that production of geothermal energy from a reservoir can be maintained throughout the entire project life. Even if resource conditions deteriorate to the point that production becomes economically unviable, the payments for capital cost components must be covered. As indicated by Figs. 5-17 and 5-18, if the discount rate increases from 2 to 4%, DAC increases by less than \$1.00 and NPV declines by approximately \$400,000 for a residential project and \$550,000 for an industrial project.

The interest rate represents the cost of borrowed funds. As the interest rate increases, DAC increases exponentially and NPV declines exponentially. The effect is more pronounced for district heating projects (see Figs. 5-19 and 5-20).

SUMMARY

Analyses of other potential geothermal projects can be performed using similar techniques. Because of the volatility of many of these economic and other general parameters, careful attention should be paid to the effects of these variables over a range of possible values.

Fig. 5-1 DAC as a function of the number of wells.

Fig. 5-2 DAC as a function of distribution system pipe cost.

Fig. 5-3 NPV as a function of distribution system pipe cost.

Fig. 5-4 DAC as a function of transport distance in the residential and industrial sectors.

Fig. 5-5 NPV as a function of transport distance in the residential sector.

Fig. 5-6 DAC as a function of the assessment period cost in the residential and industrial sectors.

Fig. 5-7 NPV as a function of the assessment period cost in the industrial sector.

Fig. 5-8 NPV as a function of the assessment period cost in the residential sector.

Fig. 5-9 DAC as a function of initial fossil fuel purchase price.

Fig. 5-10 NPV as a function of initial fossil fuel purchase price.

Fig. 5-11 DAC as a function of electricity cost.

Fig. 5-12 NPV as a function of electricity cost.

Fig. 5-13 DAC as a function of the percentage in annual change in electricity cost.

Fig. 5-14 NPV as a function of the percentage in annual change in electricity cost.

Fig. 5-15 DAC as a function of inflation rate in the residential and industrial sectors.

Fig. 5-16 NPV as a function of inflation rate in the residential and industrial sectors.

Fig. 5-17 DAC as a function of discount rate in the residential and industrial sectors.

Fig. 5-18 NPV as a function of discount rate in the residential and industrial sectors.

Fig. 5-19 DAC as a function of interest rate in the residential and industrial sectors.

Fig. 5-20 NPV as a function of interest rate in the residential and industrial sectors.

6. A COST COMPARISON OF EASTERN AND WESTERN RESOURCES

The purpose of the analysis in this section is to study how sensitive the discounted average cost of providing one million Btu's of geothermal energy to a user is to incremental changes in several resource and demand parameters. Three sites were selected for comparison on the basis of their heat demands and geothermal resources; they are Salisbury, Maryland, Thermopolis, Wyoming, and Boise, Idaho. By comparing them, the effect of site-related differences in heat demand and resource conditions on supply costs can be highlighted.

The three test scenarios are not intended to represent faithfully any existing geothermal heating system but rather to simulate prototypical geothermal systems for cities with significantly different climates, geology, and geography. The Salisbury (Site 1) scenario is representative of geothermal resources and weather patterns for the eastern United States; the most feasible geothermal sites are located in the Atlantic Coastal Plain. Thermopolis (Site 2) and Boise (Site 3) are representative of areas found in the western United States that are characterized by hotter resources with correspondingly higher flow rates, shallow production wells, and longer transport distances to the nearest user. Table 6-1 lists selected parameters that were allowed to differ from the basecase for the three sites. Note that the values for Salisbury for this scenario differ from those of the original basecase and climate tests.

The results of the simulations are given in Table 6-2. The Salisbury scenario resulted in a DAC of \$17.55. The Thermopolis and Boise scenarios, which simulate hotter resources with correspondingly higher flow rates, shallow production wells, and longer transport distances, gave DAC's of \$9.85 and \$4.37, respectively.

Table 6-1
Variations in Eastern and Western Resource
Conditions from the Basecase

Parameter	East	West	
	Site 1	Site 2	Site 3
Site	Salisbury, MD	Thermopolis, WY	Boise, ID
Production well depth	5000 ft (1524 m)	3000 ft (914.4 m)	1200 ft (365.8 m)
Reinjection well depth	5000 ft (1524 m)	3000 ft (914.4 m)	1200 ft (365.8 m)
Wellhead temperature	140° F (60° C)	170° F (76.7° C)	170° F (76.7° C)
Reinjection temperature	90° F (32° C)	110° F (43.3° C)	110° F (43.3° C)
Flow	225 gal/min (51.1 m ³ /h)	500 gal/min (113.5 m ³ /h)	1000 gal/min (227 m ³ /h)
Drawdown	15% of well depth	10% of well depth	10% of well depth
Transportation distance to users	0.25 mile (0.4 km)	3 miles (4.8 km)	1 mile (1.6 km)
Weather statistics for:	Richmond, VA	Casper, WY	Boise, ID
System design temperature	45° F (7.2° C)	24° F (-4.4° C)	17° F (-8.3° C)
Minimum ambient temperature	-5° F (-21° C)	-28° F (-33° C)	-13° F (-25° C)

Table 6-2
Summary Totals Over Project Life

	Site 1 Salisbury, MD	Site 2 Thermopolis, WY	Site 3 Boise, ID
Initial capital cost	\$2,283,604	\$3,452,585	\$2,699,112
NPV	-\$477,938	\$3,846,158	\$10,726,264
DAC	\$17.551/10 ⁶ Btu	\$9.849/10 ⁶ Btu	\$4.371/10 ⁶ Btu
Discounted average wellhead cost	\$11.551/10 ⁶ Btu	\$1.456/10 ⁶ Btu	\$0.356/10 ⁶ Btu
Break-even point achieved in	-	Year 10	Year 3
Total operation cost saved	\$5,224,416	\$16,243,484	\$26,710,606
Payback completed in	Year 12	Year 9	Year 6

7. SUMMARY AND CONCLUSIONS

Because current knowledge about the economics of geothermal energy utilization of low temperature resources in the United States is still far from complete, the analyst and project evaluator must often rely on preliminary evaluation methods. The GRITS computer program was developed for this purpose, and the discussions in the previous chapters demonstrate the usefulness of the model in assessing important planning and design factors. For resource and economic conditions similar to the basecase discussed in this report, the simulation results may be directly useful in a project assessment. For different resources, the prospective developer is encouraged to perform similar types of analyses to determine the effects of changes in critical factors so that planning resources can be most efficiently allocated.

The GRITS computer program is currently running on The Johns Hopkins University's DEC system-10, the VAX-11/780, and the IBM-4341 computers. Those interested in running the program should contact the authors of this report at The Johns Hopkins University Department of Geography and Environmental Engineering.

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