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Geothermal Energy Development in the Eastern United States

PAPERS PRESENTED – GEOTHERMAL RESOURCES COUNCIL 1980 ANNUAL MEETING

This work was supported by the Department of Energy
under Interagency Agreements EX–76–A–36–1008
and DE–AI01–79ET27025

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY
Johns Hopkins Road, Laurel, Maryland 20810

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CONTENTS

PREFACE

This report contains preprints of papers pertaining to geothermal energy development in the Eastern United States written by members of the Center for Metropolitan Planning and Research (Metro Center) and by the Applied Physics Laborabory (APL) both of The Johns Hopkins University.

These papers, which were submitted to the Geothermal Resources Council Annual Meeting, 9-11 September 1980, are

1. K. Yu and F. C. Paddison (APL), "Technical Assistance - Hydrothermal Resource Application in the Eastern United States."
2. William J. Toth (APL) and William F. Barron (Metro Center), "GRITS: A Computer Model for Economic Evaluations of Direct-Uses of Geothermal Energy"
3. Allen C. Goodman (Metro Center), "Geothermal Market Penetration in the Residential Sector: Capital Stock Impediments and Compensatory Incentives"
4. William F. Barron, Robin Dubin, and Sally Kane (Metro Center), "An Analysis of Benefits and Costs of Accelerated Market Penetration by a Geothermal Community Heating System"

TECHNICAL ASSISTANCE - HYDROTHERMAL RESOURCE APPLICATION IN THE EASTERN UNITED STATES

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The Johns Hopkins University
Applied Physics Laboratory

ABSTRACT

The APL Technical Assistance Program effort is reviewed through three examples covering space-heating, mariculture, and industrial applications in the Chesapeake Bay area. Where necessary, further needed investigation is identified.

INTRODUCTION

The Applied Physics Laboratory of The Johns Hopkins University is sponsored by the U.S. Department of Energy to provide technical assistance in the application of geothermal energy in the Eastern United States. The Laboratory's efforts are limited to preliminary economic and technical feasibility analyses sufficient to scope the problem and provide direction for further detailed effort.

This paper presents three selected examples of technical assistance in the Delmarva and Chesapeake Bay region to illustrate how the type of resource confirmed at Crisfield, Md., can be utilized. The examples are: space heating, mariculture, and gasification of liquefied natural gas (LNG). In each case, at the recommendation of the Maryland Geologic Survey, the hydrologic conditions similar to those determined by the deep test well at Crisfield, Md. (Ref. 1) were assumed. References 2, 3, and 4 are laboratory reports documenting these programs.

DISCUSSION

To present a broad overview of the work done under the technical assistance program, we have selected three examples.

<u>Space Heating - Crisfield High School</u>. The Crisfield High School is a single story building of 50,000 square feet, located 3.5 miles from the only known resource in the Atlantic

Coastal Plain. The school uses 57,000 gals of fuel oil annually heating circulating hot water (65% efficiency). It thus represents a nontrival, but straightforward application of the geothermal energy.

The annual temperature distribution is shown in Fig. 1. Notice the sharp "low temperature peak." Geothermal system cost can increase substantially over the optimum if an attempt is made to service the entire peak by geothermal energy alone. This is particularly true in the case of a moderate temperature resource because such a stand-alone system will be grossly underutilized during most of the heating season. The inclusion of a peaking system, designed to supplement the geothermal system during the coldest period, would reduce the total system cost while providing the added flexibility to cope with any unexpected low temperature excursions and serve as an emergency backup. In configuring the geothermal (retrofit) system, we have therefore retained the existing oil-fired boilers as the peaking subsystem. A schematic diagram of a geothermal system is shown in Fig. 2. The system design temperature is 30°F which is the temperature at which the peaking system will begin to supplement. The resulting system characteristics are shown in Table 1, together with a summary of the resource data. It is interesting that the geothermal system still supplied 97% of the required annual heat, in spite of the 25°F temperature difference between the average annual-minimum and the system design point.

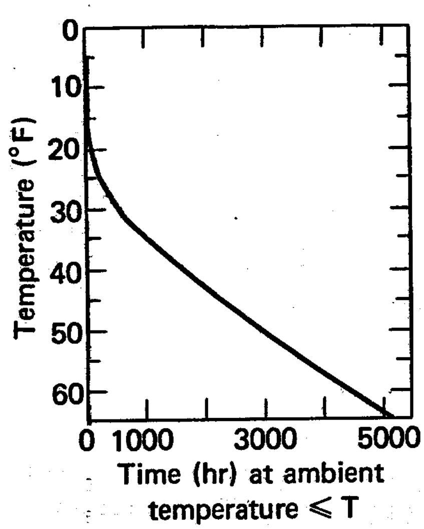


Fig. 1 Annual temperature distribution typical of Crisfield, Md.

Table 1

Application to Crisfield High School

Annual heating need/weather	
Oil (No. 2)	57,000 gal
Heating deg-days	3939 (re 65°F)
Average minimum temp	5°F
Average maximum heating rate	3.6×10^6 Btu/hr
Resource parameters	
Transmissivity	0.50 cm^2/s
Storage coefficient	3.9×10^{-3}
Water temperature	133°F
New heating system	
Geothermal design temperature	30°F
Geothermal system load	97.5%
Peaking system load	2.5% at 1400 gal/yr)
Oil savings	55,600 gal/yr

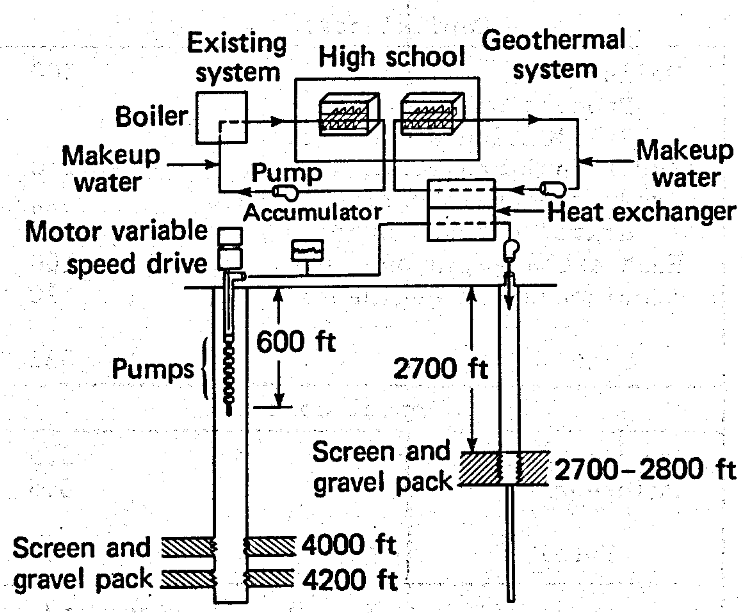


Fig. 2 Schematic of geothermal heating system.

The associated well drawdown for the first year is shown in Fig. 3. At the end of the year, there is a small residual drawdown that accumulates so that the pumping cost increases. The pumping energy was estimated assuming a 100-ft static head for circulation, 70% pump efficiency (production) coupled with a (residual) 200-ft drawdown and an equivalent usage in reinjection. At 5¢/kWh, the annual electric energy cost amounts to about $3,500. In Table 2, we show a rough cost breakdown for the geothermal system. The seemingly high well cost of $500,000 is due to a recent quotation by a driller and does not necessarily reflect the minimum cost. We suggest that the capital investment can be paid off from the net savings (i.e., after subtracting the operational, maintenance, and peaking system oil costs) in oil alone. Since the operational and maintenance work are both energy and labor intensive, they are assumed to track the oil price escalation rate. In Fig. 4, we show the loan payment period as a function of the initial grant fraction (Ref. 5) for the loan interest rate of 7% per year (e.g., school construction bonds). The effect of the oil price escalation rate is shown parametrically. Note that a 30% grant fraction, or equivalently a reduction in the system cost by the same fraction, leads to a very substantial reduction in the capital recovery period.

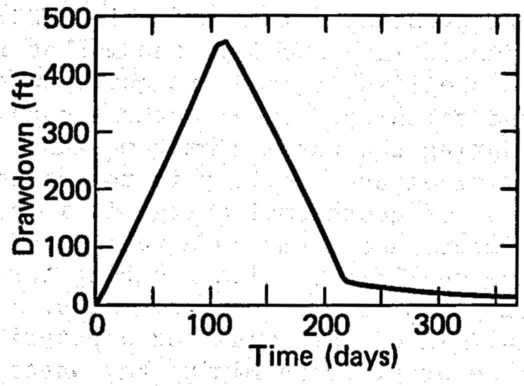
Table 2

Crisfield High School: Geothermal system cost

(000 of $)

Capital costs	
Wells:	500
Production @ 4200 ft.	
Reinjection @ 3000 ft.	
Additional radiators	110
Production pump/variable speed drive/surface motor	52
Heat exchange, pumps, etc.	100
Architects and engineers	70
Total	832
Annual cost	
Pumping (at 5¢/kWh)	3.5
Maintenance	3.5
Total	7.0
Annual oil usage (peaking)	1400 gal/yr

Gravel/screen, R_W = 12 in.
Transmissivity = 0.50 cm^2/s, Storage coefficient = 3.9×10^{-3}
Qm = 98 gal/min
Geothermal system (97.5%)



MISLEADING ?

Fig. 3 Crisfield well drawdown, first year.

?? MUST BE SUBSIDIZED !!

Capital—$832K at 7%
Annual maintenance and operations $7K (1979 $)
Fuel used—1400 gallons Fuel saved —56,000 gallons

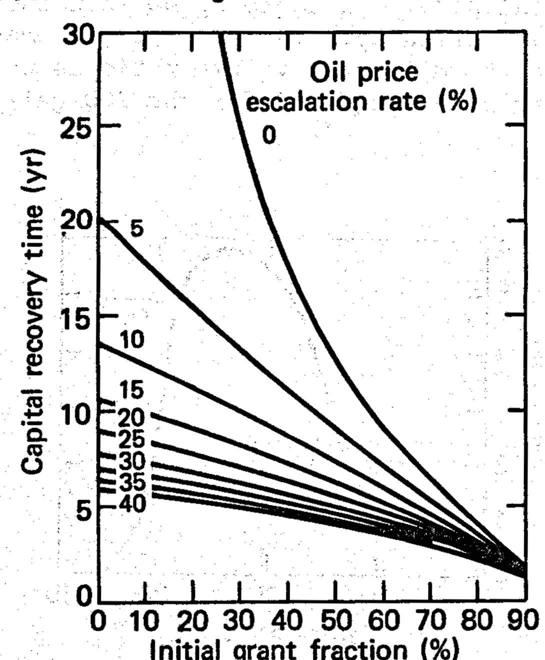


Fig. 4 Crisfield High School capital recovery time.

Mariculture. The application of geothermal energy to shellfish farming in the upper Chesapeake Bay area is our second example. While the harvest of shellfish has steadily declined for nearly a century, due to overharvesting, disease (called MSX), and an increase in the fresh water runoff into the Bay, the market for shellfish has grown. Further, the shellfish larvae are quite sensitive to the ambient temperature and salinity. Under natural conditions, significant growth occurs only during the three summer months. The CEDA Corporation is planning a mariculture facility in the eastern Chesapeake Bay area. Through the use of geothermal energy it is hoped that the facility would grow oysters and clams on a year-round basis, both for seed stock and mature shellfish, while reducing the growing time to 1½ years and improving the larvae survival rates. In the facility, approximately 300 gal/min of warm water of appropriate salinity is needed. This is to be provided by mixing Bay water carrying nutrient with salty hydrothermal water. Further, the geothermal water is to be utilized to provide the space heating of the facility building (25 by 40 ft).

In Fig. 5, we show the temperature dependence of the net (meat) gain for the oysters or clams per unit time during their larval phase, calculated from their linear growth and survival data. The effect of salinity is similar. The geothermal system is then designed to provide 200 gal/min of geothermal and Bay water mixture delivered within 75% of the peak, i.e., at 17 to 29°C temperature with 13 to 35 ppt salinity. In Table 3, we show the Bay water average temperature and salinity. In Table 4, recommended values of the Bay water to geothermal water volume ratio as well as the geothermal well pumping rates required for the 200 gal/min total are

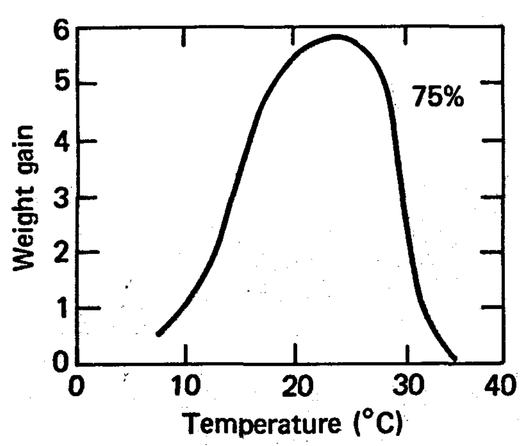


Fig. 5 Temperature effect on the weight gain.

Table 3

Bay water temperature and salinity

	Average temperature (°C)	Average salinity (ppt)
Spring	10	7.0
Summer	26.5	13
Fall	11	13
Winter	1	7.0

Table 4

Recommended parameters

	Pumping* rate (gal/min)	Mixture** ratio	Mixture temperature (°C)	Mixture salinity (ppt)
Spring	66.7	2.0	22	28
Summer	12.5	15	28	17
Fall	57.1	2.5	21	29
Winter	80.0	1.5	19	32

*For the geothermal well
**Volume ratio of Bay water/geothermal water

given for the four seasons. The space heating load, assuming an extractable ΔT (i.e., the difference in the temperature between the production and reinjection points) of 15°F, amounts to 5.3 gal/min. With a ΔT of 10°F, this will increase to 8.0 gal/min. Thus a 100 gal/min pump will take care of both the mariculture (80 gal/min maximum) and the space heating (6 gal/min maximum) needs. Reinjection may not be required if the chemical composition is similar to that found at the Crisfield location. The estimated system costs are shown in Table 5.

For comparison, we considered a hypothetical oil-fired system providing the same 200 gal/min at the same temperature as the geothermal and Bay water mixture. During the winter months, the oil-fired system must furnish 4.9 MBtu/hr in order to heat 200 gal/min of 1°C water to 19°C (70% efficiency). Thus, as a minimum, a 7.5 to

Table 5

Mariculture cost estimates

(000 of $)

Capital layout	
Well (3000 ft)*	100
Pump	22
Miscellaneous	10
Total	132
Annual expenditure	
Maintenance	3.3
Pumping (at 5¢/kWh)	2.9
Total	6.2

*The well cost for this example was estimated according to the oil and gas well costs in the area.

10 MBtu/hr furnace is necessary with an estimated capital expenditure of about $90,000 and annual oil consumption of 19,000 gallons. Due to the large annual cost of the oil-fired system, the net annual expenditure for the geothermal system during the capital recovery period (taken as 15 years at 15% interest rate without any escalation in oil price) is $5500/yr less than the oil-based system expenditure. Once the amortization phase is over, the geothermal system operational cost will be about 1/3 that of the oil-fired system. It should be noted that this comparison is based only upon the mixture temperature and excludes any consideration of the effect of salinity. For this effect, the geothermal system is expected to have a further advantage over the oil-fired system, which would require additional expenditure for the controlled addition of salt.

Industrial application. Hydrothermal energy can be used to vaporize liquefied natural gas (LNG). The LNG, which is imported from Algeria, arrives at -260°F (-127°C) at the receiving station located in Cove Point, Md. At present 1.9×10^9 scf of natural gas is vaporized at this facility. Based upon the estimated water temperature of 110 to 120°F, Columbia LNG Corporation calculated (Ref. 6) its need to be 8000 gal/min. The first question is the extractability and sustainability of the 8000 gal/min figure. At the very best, there will be a very large drawdown in the aquifer. Drawdown and possible subsidence can be reduced by reinjection into the production aquifer (at a suitable distance). This introduces another problem, that of "thermal breakthrough." Figure 6 shows the estimated thermal breakthrough (Ref. 7) for a production-reinjection well pair driven at a constant rate of 100 gal/min. Figure 7 shows the maximum drawdown for the pair as a function of the well separation. The breakthrough time shown in Figure 6 is inversely proportional to the square of pumping rate while the drawdown is directly proportional (in the linear response regime). For the doublet pair, they are 53 years and 1600 ft respectively, at 300 gal/min at 1.5 km separation. This separation appears adequate (with some conservatism). The figure of 300 gal/min is uncertain and is probably an upper bound of producibility under the assumption of a Crisfield type resource. As the step drawdown tests were not conducted at Crisfield, a brief consideration based upon Reynolds numbers is presented. Here, the Reynolds number at the well bore is 10, which is customarily taken as the onset of "turbulent flow" in porous media. So, at 300 gal/min the deviation from a non-Darcyian flow may be noticeable though not severe. Therefore, the 300 gal/min is assumed to be close to a realizable maximum rate.

For the 8000 gal/min, it is estimated that 27 doublet pairs of wells are required. The size of the production field is postulated on an alternating square grid of 1.5 km. Then, by symmetry, each production well draws a quarter (of injected volume) from each of the four nearest neighbor injection wells, and the doublet considerations given are expected to apply. This gives rise to the doublet density of one pair per 4.5 km^2. Thus, for 8000 gal/min, some 120 km^2 (∿47 mi^2), or a 7 x 7 mile production field, are needed. It is not known at this time if the resource is large enough to accommodate the development of a 7 x 7 mile field with allowance for the finite boundary effect. Nor are the (re)injectivity of the aquifer and the reinjectability of the fluid known. A problem of particular concern is the introduction of a very large volume (17 km^3 per year) of very cold water (∿40°F) at depth. It is recommended that resource confirmation and assessment with particular emphasis on size be the next step in analyzing geothermal utilization at Cove Point.

In spite of several uncertainties, the Columbia LNG proposal of utilizing the geothermal energy for the LNG revaporization is most interesting. This is because it is weakly dependent upon hydrothermal water temperature and has the potential for saving substantial quantities of gas. Perhaps the hoped-for 8000 gal/min is not attainable, but with reasonable luck a significant fraction can be realized.

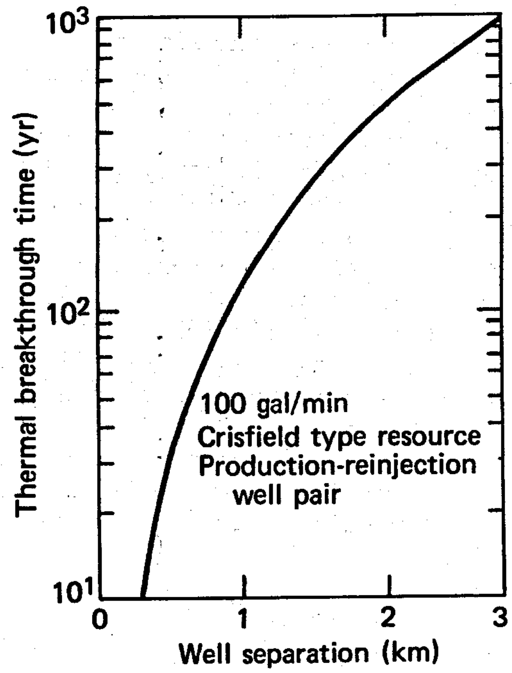


Fig. 6 Thermal breakthrough time.

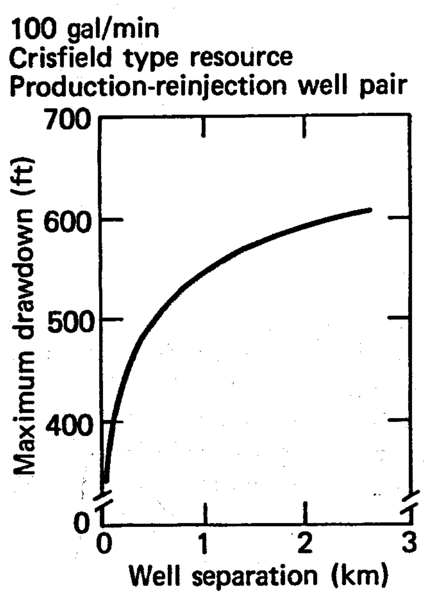


Fig. 7 Maximum drawdown.

CONCLUDING REMARKS

In spite of the modest resource conditions available at Crisfield, we found a considerable interest in the public and commercial sectors in the utilization of the resource. The few cases we have examined, while raising many questions regarding the resource, appear to give rather encouraging results.

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GRITS: A COMPUTER MODEL FOR ECONOMIC EVALUATIONS OF DIRECT-USES OF GEOTHERMAL ENERGY

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ABSTRACT

GRITS is an interactive computer model that was designed to calculate both annual cost and annual revenue streams over the life of direct-use applications of low to moderate temperature geothermal resources. The model is extremely flexible in its ability to evaluate project economics over a wide range of resource characteristics, demand requirements, and financial conditions. Futhermore, many of the input parameters can be expressed as time-dependent functions in order to reflect changes in resource characteristics and demand conditions over the life of the project. Costs and revenues may be computed in either nominal or real dollars. The difference in the cost and revenue streams, i.e., the net present value of the project, is given to allow the preliminary evaluation of the economic viability of the project.

The sensitivity of the economics to various parameters is presented. Although the model can be applied to any low to moderate temperature resource, the emphasis of this paper is on the sensitivity of project economics to resource conditions likely to be encountered in the deep sedimentary basins and coastal plain resources of the Eastern United States.

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INTRODUCTION

The Applied Physics Laboratory of The Johns Hopkins University (APL/JHU) provides assistance to the Department of Energy's Division of Geothermal Energy (DOE/DGE) in the planning and stimulation of the commercialization of geothermal energy in the Eastern United States. As part of its program on the Atlantic Coastal Plain, DOE/DGE has contracted APL/JHU to perform a Geothermal Energy Market Study (GEMS). Among the four objectives of the GEMS efforts was the development of techniques to estimate the costs of geothermal energy delivery systems. Assistance on this task has been provided by the Center for Metropolitan Planning and Research. Results from efforts on this and the associated tasks have been published (Refs. 1 through 5) and are presented here and elsewhere in this Conference.

THE GRITS MODEL

The Geothermal Resource Interactive Temporal Simulation (GRITS) model was developed to calculate both the cost and revenue streams of direct-use applications of geothermal energy resources. GRITS is an interactive computer program that allows the user to vary a wide range of resource, demand, and financial parameters in order to observe their effect on the delivered costs of geothermal energy. This model differs from many other models in that it is a temporal simulation program that produces a series of annual cost and revenue estimates for the entire life of a project. Through this feature, the model is capable of demonstrating the effects of various parameters that may change with time over the course of a project; e.g., resource temperature, flow rate, market penetration rates, etc. GRITS is most useful in the economic evaluations of site-specific direct-use projects where preliminary analyses are desired. In addition, when resources characteristics or other parameters are not known for certain, GRITS provides a powerful tool for sensitivity analyses which can define critical limits for these parameters.

The model consists of two basic subroutines: a residential-commercial subroutine and an industrial subroutine. The residential-commercial subroutine assumes that a district heating system is installed to supply any desired mix of five residential housing types (single family suburban, single family dense, townhouses, garden apartments, or high-rise apartments) and/or commercial buildings. The total system size is determined by the number of wells, the production rate from each well, local weather conditions, and the specified mix of building types. When a commercial system is being considered, the number of each building type and the heat demand of each building may be specified by the user.

The model sizes the system to the maximum number of users feasible by comparing the size of the total heat demand with the heat production from the geothermal well(s). Weather data are built into the program for several areas, and these data are combined with the buiding type data to produce annual and hourly heat demands. Fossil-fuel peaking plants are sized to handle that portion of the peak load indicated by the user-specified design temperature; i.e., the geothermal resource supplies 100% of the heating load until the ambient temperature falls to the specified design temperature, below which the peaking plant supplies the additional heat requirements. This subroutine includes the cost of all equipment necessary to deliver geothermal energy into the residential and commercial buildings, but does not include the costs of retrofitting existing buildings or the heating plants in new buildings.

In the industrial subroutine, the user specifies the well productivity, the plant annual utilization factor (a percentage of 8760 hours per year), transmission distance from the well to the plant, the need and capacity of storage tanks, etc. Again, retrofit costs are not included, since they are so plant-specific. The program computes the costs of delivering geothermal energy to the plant gate. This delivery cost can be combined with the in-plant retrofit costs by the user for a complete cost analysis.

Default Values. To allow use with only partial specification of parameters by the program user, the GRITS model contains typical values for all parameters. Selected "default" values are listed in Table 1 for resource parameters, in Table 2 for demand conditions, and in Table 3 for financial conditions. A complete listing may be found in Ref. 3. Unless specified, these default values are used in the following analyses.

Table 1

Selected default values for resource conditions

Production well depths	5000 ft
Reinjection well depth	5000 ft
Well head temperature	150°F
Annual decline	0°F
Reinjection temperature	85°F
Drawdown (percent of well depth)	15%
Annual change	0%
Transportation distance to users	0.25 mi
Resource assessment period	0 yr
Annual resource assessment costs (thousands)	$0

Table 2

Selected default values for demand conditions

Weather statistics for: Salisbury, MD	
System design temperature	30°F
Minimum ambient temperature	-5°F
Portion of system installed in 1st year	50%
2nd through 5th years	12.5%
Housing mix:	
Single family suburban	0%
Single family dense	20%
Townhouses	40%
Garden apartments	50%
High-rise apartments	0%
Market saturation	70%
Percentage of final system users on line	
In first year	15%
Annual rate of additional users	8%
Industrial utilization rate	25%
Storage tank capacity (hours of well flow)	2

Table 3

Selected default values for financial conditions

Economic Accounting Method: Net Present Value	Discounted Average Cost
Project study period	20 yr
Interest rate	12%
Discount rate	2%
Inflation rate	8%
Electricity costs (per kWh)	5.5¢
Annual change	1.5%
Fossil fuel costs (per 10^6 Btu)	$6.00
Annual change	3.5%
Boiler costs (per 10^5 Btu per hr)	$1500
Distribution system costs ($$10^3$/mile)	250
Capital equipment lifetimes	
Wells, pipelines, boilers, tanks	30 yr
Pumps, heat exchangers	10 yr

SENSITIVITY ANALYSES

Resource Temperature. Average costs drop exponentially as resource temperature increases, assuming a constant reinjection temperature and flow rate. Figure 1 indicates that, at lower resource temperatures, the smaller thermal yields allow the capital costs to dominate the average costs. At higher resource temperatures, these capital costs are spread over larger thermal yields and average costs are dominated by pumping energy costs. The top curve shows production conditions similar to those indicated by the Crisfield, MD, well. At resource temperatures of 130°F or higher, delivery costs of geothermal energy to suitable industrial users can be competitive with fuel oil at $0.90 per gallon.

Production Rates. Resource productivity is usually unknown until a production well is flow tested. Figure 2 shows that, for resources with moderate drawdown, flow rates as low as 100-200 gal/min can be cost competitive for industrial users. When distribution system costs for district heating systems are included, flow rates in excess of 300 gal/min are required.

Drawdown. Drawdown in wells is perhaps the most important resource characteristic since increased drawdown increases pumping energy costs. Figure 3 shows that average costs increase linearly with the drawdown and, therefore, pumping energy for a given production rate. The slope of these lines is independent of flow rate for a given resource temperature; however, the displacement of these lines with flow rate is extremely important. Since drawdown is expected to increase linearly with flow rate, a doubling of the flow rate doubles the drawdown. With twice the flow and twice the drawdown, pumping energy quadruples. Therefore, pumping energy costs increase as the square of the pumping rate; however, the increased thermal production offsets this effect to cause only moderate increases in average cost. For example, by increasing flow from 200 to 500 gal/min and, therefore, drawdown from 1000 to 2500 feet, average costs increase by less than 25% for either resource temperature.

Utilization. Increasing the utilization of a geothermal system dramatically lowers average costs of delivered energy, since fixed costs are apportioned to larger amounts of thermal energy. The upper curve of Fig. 4 shows that average costs for an industrial utilization of 25% (about 40 hours per week) are about 67% higher than those for an industrial utilization of 50% (80 hours per week).

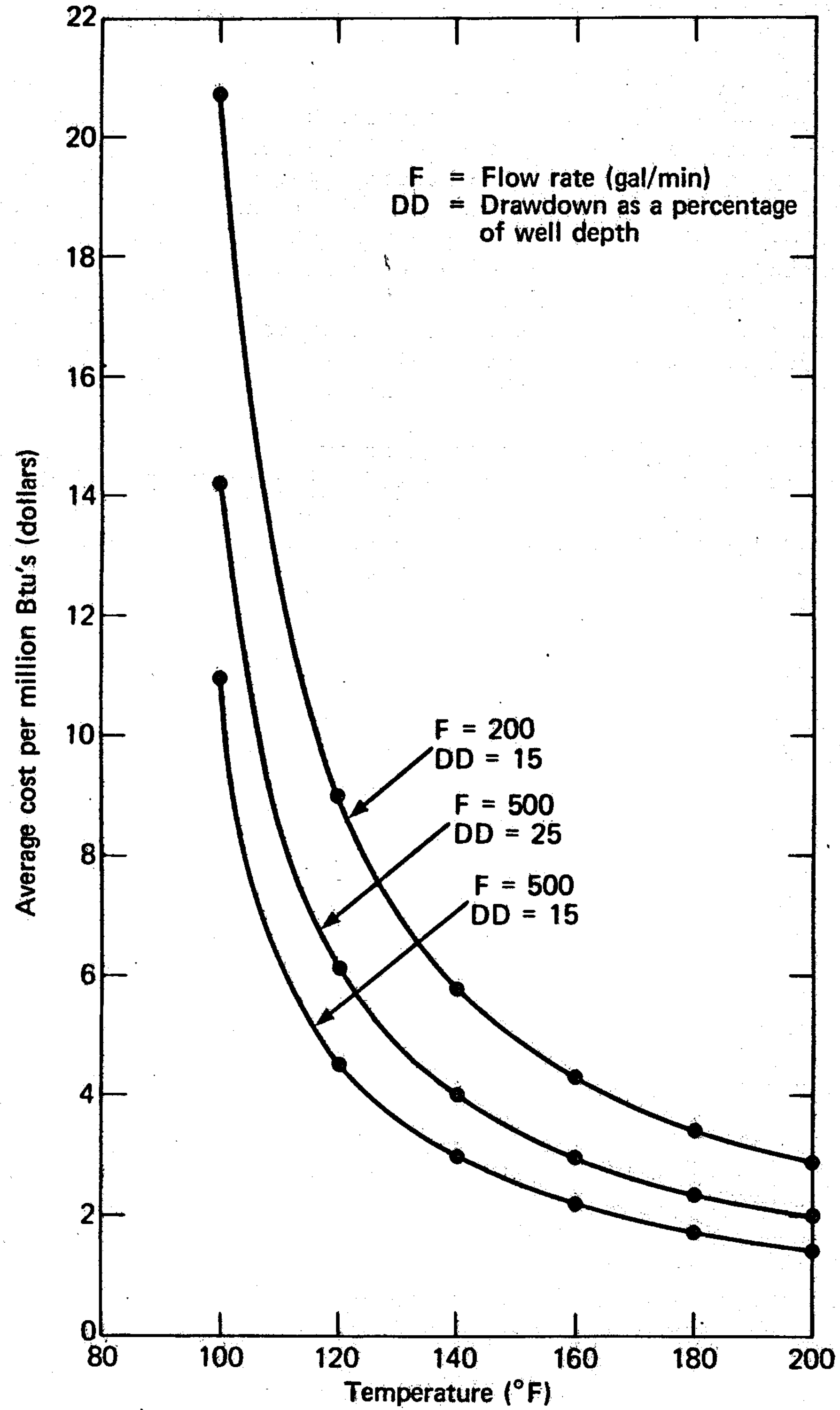

Fig. 1 Average costs of geothermal energy delivered to suitable industrial customers as a function of resource temperature.

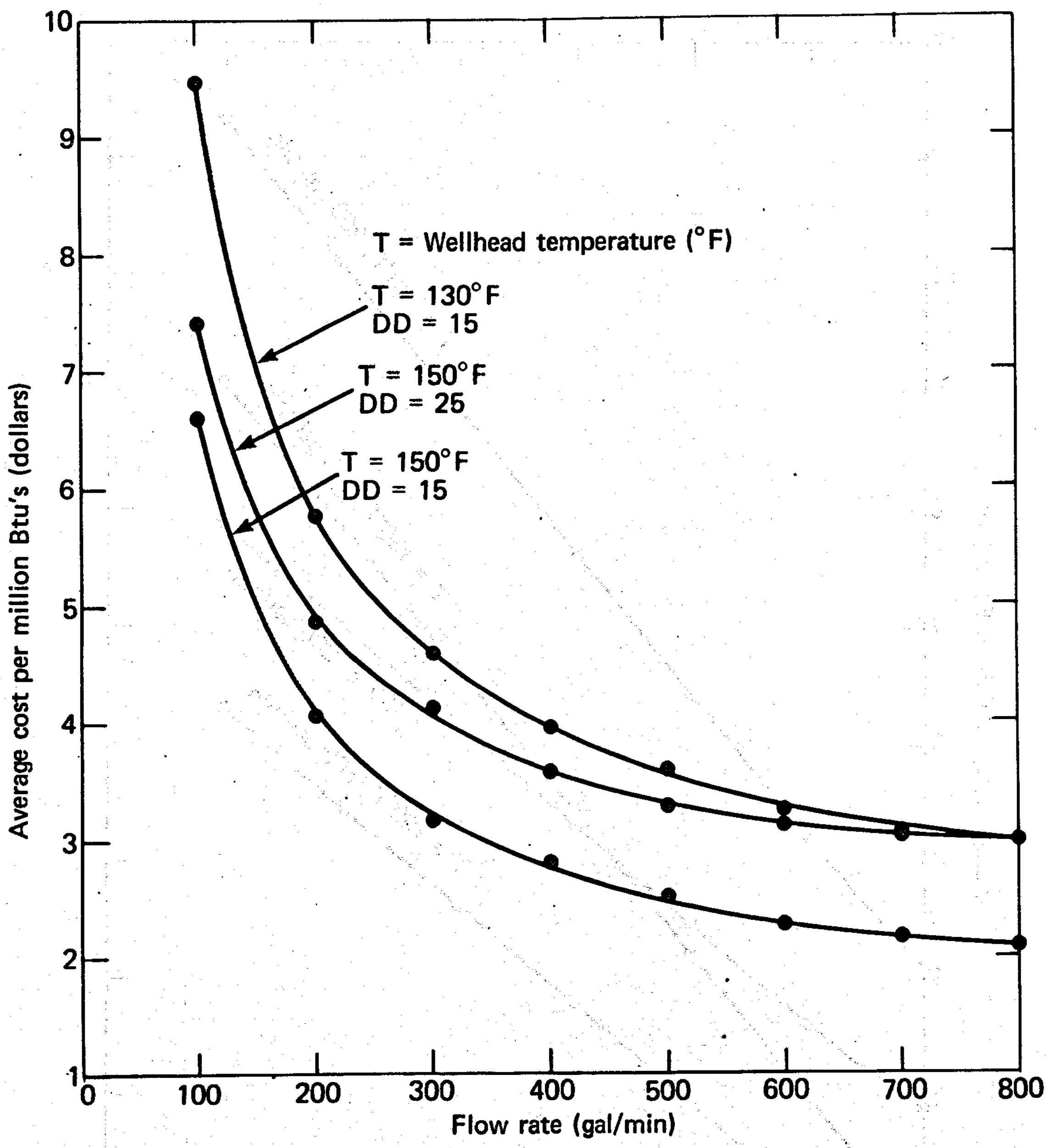

Fig. 2 Average costs of geothermal energy to industrial users as a function of flow rate.

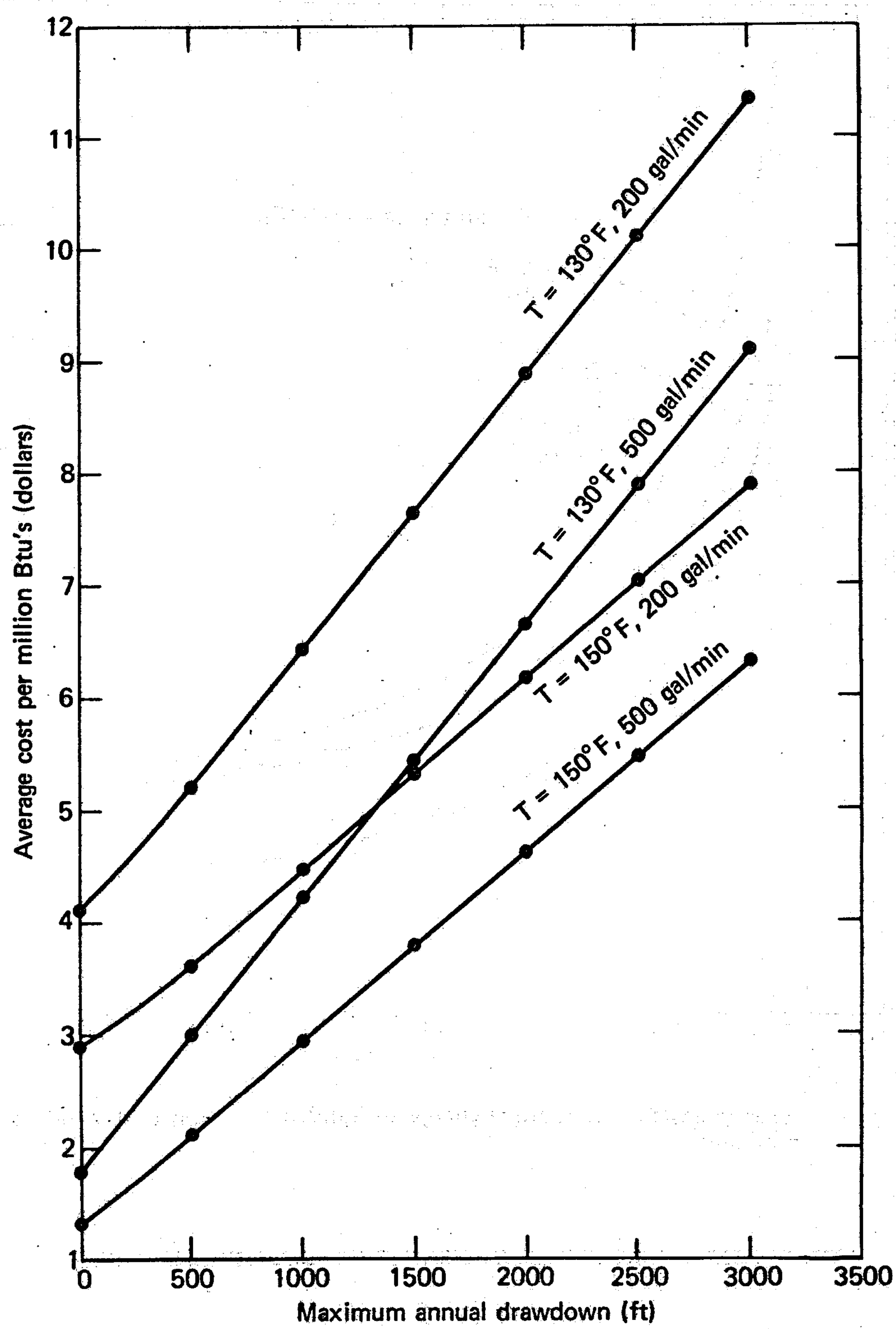

Fig. 3 Average costs of geothermal energy as a function of drawdown.

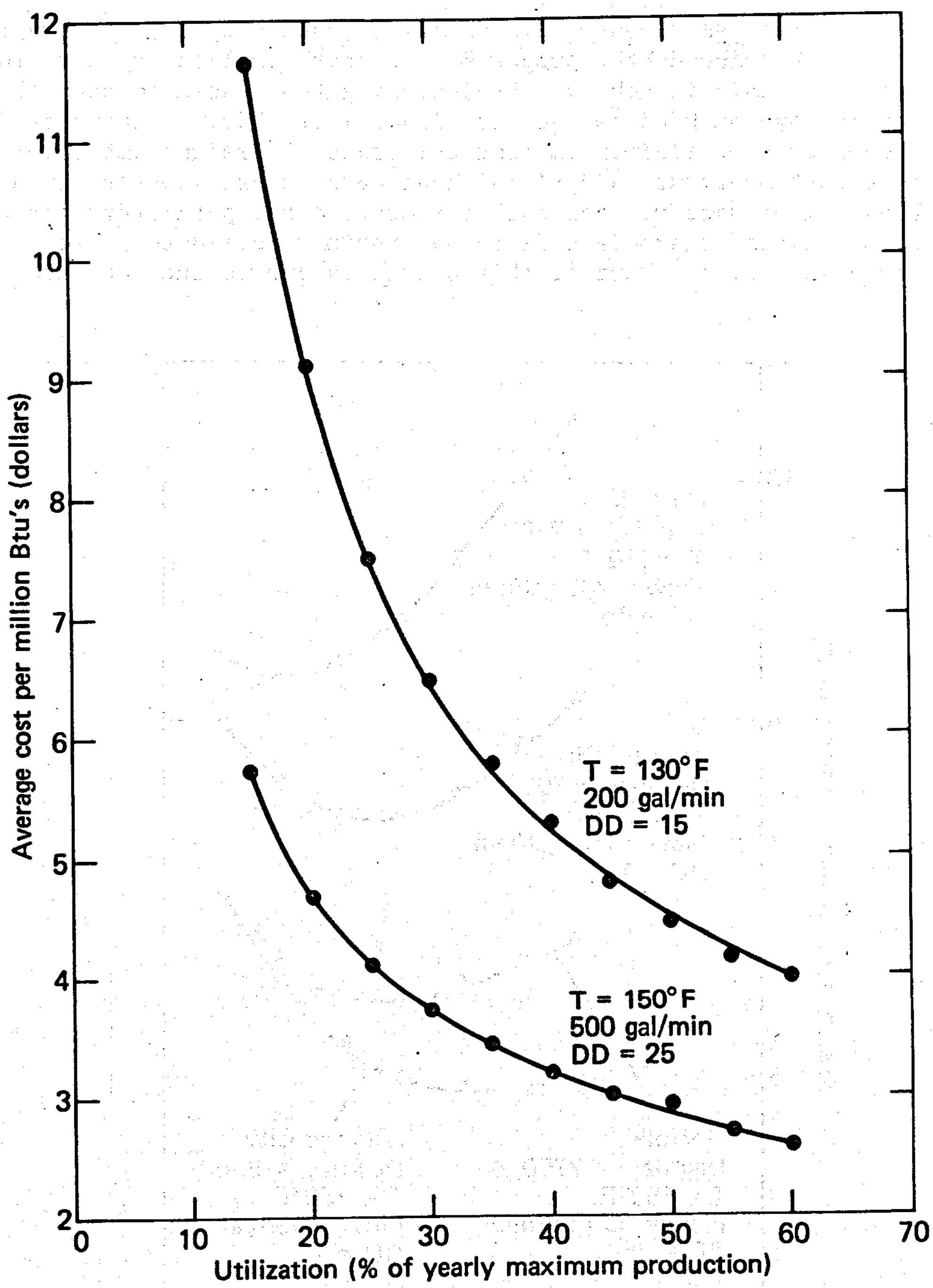

Fig. 4 Average costs of geothermal energy to industrial users as a function of annual utilization.

Design Temperature. In district heating systems, average costs can be reduced by a proper mix of geothermal energy with fossil energy. This is achieved by designing the system so that the geothermal system handles the base load, i.e., 100% of the heat demand down to some minimum ambient temperature (design temperature). Below this temperature additional heat demands are supplied by a peaking boiler system. For each set of resource parameters and demand conditions, there is a different optimum design temperature, as shown in Fig. 5. Part of this effect is due to the increased

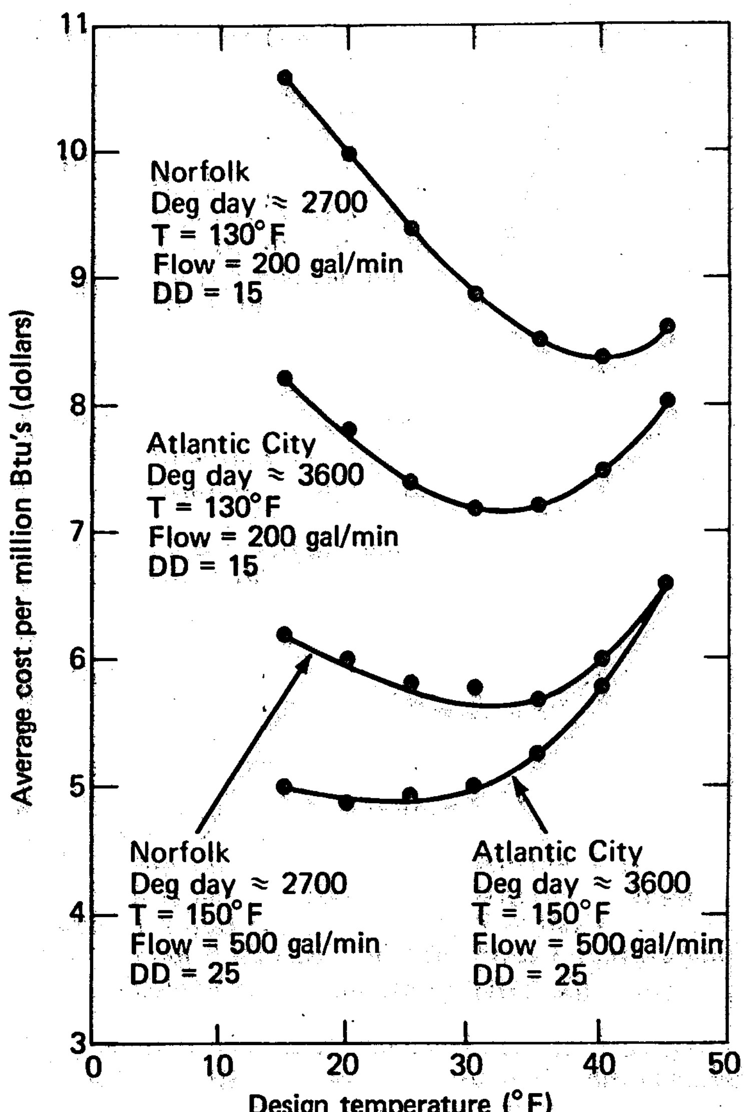

Fig. 5 Average costs of energy to residential customers of a hybrid geothermal district heating system as a function of design temperature.

utilization of the geothermal production system at design temperatures above the minimum expected temperature. Generally, colder climates have lower optimal design temperatures, as will higher temperature resources.

CONCLUSIONS

The economic viability of any direct-use application of low to moderate temperature resources depends on many factors. The GRITS economic model provides a powerful tool for studying the effects of each of these variables. When specific resource, demand, or financial conditions are uncertain, GRITS allows studies of the sensitivity of the average cost on these parameters, and in many cases limiting conditions can be identified.

This work was performed under contract to the Division of Geothermal Energy of the Department of Energy.

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GEOTHERMAL MARKET PENETRATION IN THE RESIDENTIAL SECTOR: CAPITAL STOCK IMPEDIMENTS AND COMPENSATORY INCENTIVES

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INTRODUCTION

There has been substantial interest in and a growing literature on the market penetration of geothermal heating technology (see Refs. 1 through 5). Generally this has occurred at the "macro" level where a resource is located, and the market potential has been calculated based on housing and geographic data (generally formulated as density measures). This type of analysis does not address the household decision process with respect to the conversion of heating systems and ignores, in particular, the capital constraints that face homeowners in the provision of home space heating.

This paper presents a model that discusses the explicit decision made by an individual homeowner who must choose between geothermal and conventional heating systems (see Ref. 6). It addresses the fact that both long-lived capital stock and substantial conversion costs may face anyone who is considering a change in his heating system. From the model, the market penetration is seen to be a function of age of the existing furnace, differential in efficiency of the two systems, and costs of conversion (hookup costs). It is seen that sizable differentials in efficiency (60% or more) may be necessary to cover capital losses and hookup costs attendant on conversion. Furthermore, the model can be used to calculate a set of incentive payments necessary to induce households to convert, even where the efficiency differentials do not so dictate.

THE MODEL

In this section, the model to be used in analysis is discussed, first in fairly intuitive terms, then analytically. The assumptions are that in a given area all homeowners have furnaces of type C, which originally cost $2,000; all furnaces last 20 years; there are equal numbers of furnaces at each age; and the furnace is the only part of the heating system that is ever replaced or converted. Assume now that type G furnaces become available. These furnaces have the same price but produce more heat per dollar of fuel than do the old ones, hence are more efficient. The issue is who will buy the new furnaces, or alternatively, how much more efficient the new furnaces must be to induce homeowners to switch types. For this example, the cost of switching furnace types is taken to be zero.

Not necessarily!

Clearly, homeowners will replace type C furnaces with type G furnaces when the former are ready for replacement. However, if the present type C furnace is less than 20 years old, it still has a useful life. By way of analogy, consider the purchase of a new car. When this occurs, the old one is sold to someone else for its value in use. A furnace cannot generally be resold for this value even though it is still operational (it is probably valuable only for scrap); in this very simple formulation, the type C furnace will sit idle next to the type G furnace, even though the former still has a productive life. In terms of market penetration, it is likely that, if purchasing a new car meant that the old one had to be left in the driveway without being driven, the rate of market penetration for any new car would be substantially lower than is generally seen. The newer the current furnace, then, the more efficient its replacement must be in order to induce a change in types, since conversion implies a capital loss on the current model. This may be a salient problem with market penetration for any alternative heating system.

The model can be formed analytically to generate required efficiency differentials. The conditions necessary for the choice of an infinite stream of geothermal furnaces over an infinite stream of conventional units, given a conventional furnace of age z, can be summarized as

$$G(s,\infty) - M(z) - H > C(s,\infty) ,$$

where

$G(s,\infty)$ = Present value of a stream of net benefits from a geothermal furnace lasting s years and replaced by ∞ similar units,

$C(s,\infty)$ = Present value of a stream of net benefits from a conventional furnace lasting s years and replaced by ∞ similar units,

$M(z)$ = Forgone production from the present (conventional) furnace (or the difference between the discounted value of its net benefits and its scrap value),

H = Cost of converting from a conventional to a geothermal unit, and

ρ = Interest rate which, when compounded continuously, results in an annual growth rate of r, i.e., $e^{\rho t} = (1 + r)^t$.

This condition states that in order to choose a geothermal unit the present value of its net benefits must be large enough to cover the hookup costs plus the capital loss on the current conventional unit, as well as the net benefits of the conventional unit.

Using an analysis developed by Perrin (see Ref. 7), Eq. 1 can be simplified to

$$G(s, 1) - C(s, 1) > (1 - e^{-\rho s}) [M (z) + H] \quad . \qquad (2)$$

Substituting the following expression (for any furnace type X)

$$X(s, 1) = \int_o^s R_x e^{-\rho t} dt - M_x(0) \quad ,$$

where

R_x = Annual net benefits from type X furnace and

$M_x(0)$ = Purchase cost of unit of type X,

yields

$$\int_o^s (R^* - R) e^{-\rho t} - [M^* (0) - M (0)] >$$
$$(1 - e^{-\rho s}) [M (z) + H] \quad , \qquad (3)$$

where

R^*, (R) = Annual net benefits from a geothermal (conventional) unit and

$M^*(0)$, $(M(0))$ = Purchase cost of geothermal (conventional) unit.

For simplicity, assuming that $M^*(0)$ equals $M(0)$, and integrating and reducing,

$$R^* - R > \rho[M (z) + H] \quad . \qquad (4)$$

This equation implies that an existing conventional furnace of age z will be replaced by a geothermal furnace only when the yearly net benefit increase covers the forgone stream of returns of both the asset value of the existing furnace and the hookup fee. Since M (z) has an implicit value equal to the present value of the stream of returns from time 0 to time s - z, it can be rewritten as

$$M(z) = \int_o^s Re^{-\rho t} dt \quad . \qquad (5)$$

When substituted into Eq. 4 and simplified, this yields

$$\frac{R^*}{R} - \frac{\rho H}{R} > 2 - e^{-\rho(s-z)} \quad . \tag{6}$$

The term R*/R gives the increased stream of net benefits (increased efficiency) necessary for conversion, given any age z for the conventional furnace, the useful life s of conventional and geothermal furnaces, and hookup cost H. Since actual benefits of heating might be assumed to be fixed, the increase in net benefits can be interpreted as the lower operating costs (price of fuel) for geothermal heating.

This increased efficiency necessary to induce conversion can be most easily illustrated as a function of current furnace age z, by assuming that hookups are costless (H equals 0). Equation 6 becomes

$$\frac{R^*}{R} > 2 - e^{-\rho(s-z)} \quad . \tag{7}$$

If ρ equals 0.05 and s equals 20, R*/R will be 1.63 with a brand-new conventional furnace. By year 20, R*/R will have fallen to 1.00, as shown in Fig. 1. Any positive hookup costs will force the necessary efficiency ratio even higher. Hookup costs of $1,000 for a new $2,000 geothermal unit will raise the necessary R*/R to 1.95 for a brand-new conventional furnace. (A conventional furnace costing $2,000 has an imputed value for R of $158.20, given ρ = 0.05. This implies a value of ρH/R of 0.32.)

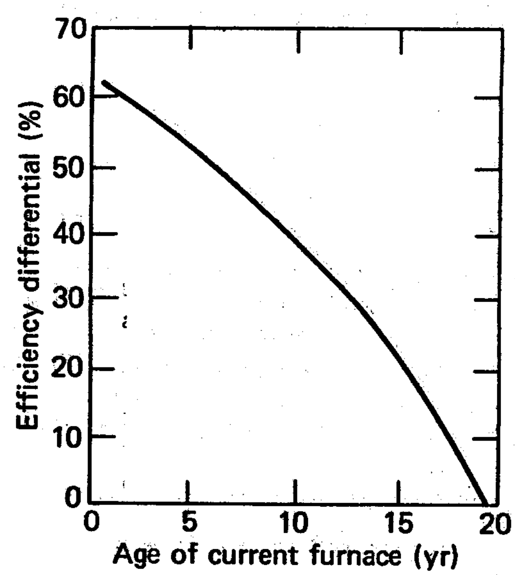

Fig. 1 **Efficiency differential versus age of current furnace.**

The model can also be used to describe a schedule of incentive payments, B, necessary to induce owners of conventional furnaces to convert to geothermal units. Again ignoring hookup costs, select incentive B such that

$$G(s,\infty) - M(z) + B = C(s,\infty) \quad . \tag{8}$$

Simplifying as before,

$$B = \frac{R - R^*}{\rho} + M(z) \quad . \tag{9}$$

$\frac{R - R^*}{\rho}$ refers to the value of a perpetual bond which pays net benefit $R - R^*$. Using Eq. 5,

$$B = \frac{1}{\rho} \left[R \left(2 - e^{-\rho(s-z)}\right) - R^*\right] \quad . \tag{10}$$

With all else equal, as R^* rises B will fall; as z increases B will also fall.

APPLICATIONS

This theoretical model will be employed in the GRITS cost simulation model (see Ref. 8). The expected benefits to a geothermal supplier, namely, from rapid market penetration, are the lower average costs attendant on serving more customers. Ongoing studies with GRITS are examining optimal rates of market penetration and the revenue and cost streams that accompany them. The following example is illustrative only.

Consider a municipality with 2000 houses. Furnaces last 20 years and there are 100 at each age. A geothermal system that is 10% more efficient than the current conventional system becomes available. Hookup costs are zero.

From Fig. 1 it can be seen that owners with furnaces over 18 years of age (actually 17.89) will convert immediately. The incentive payments necessary to induce the rest to convert immediately can be calculated as the integral of Eq. 10 over all z up to the conversion age. This yields a total of just over \$1.7 million. The optimal rate of market penetration will maximize the net present value of the firm with respect to the rate of market penetration, given both cost and revenue projections. Simulation analysis of this type is discussed by Barron et al. (see Ref. 9).

NONSENSE

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AN ANALYSIS OF BENEFITS AND COSTS OF ACCELERATED MARKET PENETRATION BY A GEOTHERMAL COMMUNITY HEATING SYSTEM

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INTRODUCTION

The economic feasibility of geothermal community heating systems depends to a considerable extent on the load factors for system operation. A major determinant of the load carried over the entire economic life of the heating system is the rate at which customers join. Other analyses (Refs. 1 and 2) have assumed that all potential customers within a market service area immediately convert to geothermal heating as soon as it becomes available. While this assumption may be valid in cases of substantial fuel price advantages or compulsory hookups, many valuable geothermal resources may offer more moderate price advantages, and an assumption of compulsory hookups raises questions regarding the political feasibility of such measures.

The approach taken by Cunniff et al. (Ref. 3) assumes that the community heating utility absorbs all capital conversion costs for new customers. The cost of this conversion adds substantially to the size of the initial investment by the utility. The model presented by Goodman (Ref. 4) evaluates the homeowner's fuel choice in terms of investment in capital assets. An important implication of Goodman's approach is that homeowners face capital outlays for heating plants regardless of fuel choice; it is the differential outlays among the fuel types that is the most important factor in the homeowners' decision. In addition to differences in capital outlays, the net present value of expected variable (fuel) costs among types of heating will enter into the homeowners' decision about joining the geothermal community heating system.

Thus, the rate of market penetration within the community heating system's prospective service area will be strongly influenced by the fixed cost (capital) in addition to the variable cost (fuel) differentials between geothermal heat and alternative fuels.

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In many situations fuel cost savings may be insufficient to overcome the capital outlay differential, and the utility will need to offer special incentives to join the system. However, incentives well below the full cost of conversion to the community heating system could be sufficient to encourage rapid market penetration under certain circumstances.

This paper evaluates certain aspects of Goodman's model regarding the appropriate level of incentives, or "bonuses," under several assumed levels of fuel cost savings offered by geothermal energy. The GRITS computer model (the Geothermal Resource Interactive Temporal Simulation model described in Ref. 5) is used to estimate the advantages of accelerated market penetration for two hypothetical utilities. The optimal plan is evaluated with respect to the benefits and costs associated with various levels of market penetration.

It is important to emphasize that the following analysis is a highly stylized representation of the homeowner's fuel choice decision. For example, it is assumed that home heating plants have clearly predictable lives and that all individuals place the same present value on projected fuel cost savings. Clearly, the real world is more complex and less predictable. This type of analysis does, however, provide insights into the nature of the homeowner's and the utility's decision-making processes. The analysis points out factors that are important for the evaluation of geothermal energy's market potential at a macroeconomic level.

ANALYSIS

The benefits to the geothermal utility of accelerated market penetration are calculated through changes in the net revenue stream over the economic life of the project (e.g., 20 years of operation). The costs of accelerated penetration are calculated according to the projected response to a range of cash bonus offers. The level of response is estimated from the assumed capital costs of geothermal and traditional heating plants, as well as from differences in the operating costs of each type of heating. Due to space limitations, certain aspects of the analysis are described only briefly. A more complete description of the approach is presented in a paper by Dubin et al. (Ref. 6).

The homeowner's decision to change from conventional heating involves a comparison of the operating and capital costs of each system. The consumer will choose the system with the lower total costs. However, the utility can influence the decision with cash bonus offers that make geothermal more attractive.

The homeowner with a completely depreciated furnace faces either a capital outlay for geothermal heating, which involves installation of a new heat exchanger, energy meter, and service pipes from the community heating system, or a capital outlay for a traditional heating system, which involves the purchase of a boiler and burner. However, at any ~~point in~~ time most owners of existing housing have a considerable service life remaining in their old heating systems. Thus, in choosing between the two systems, homeowners compare the cost of a new conventional system (K_c), minus the value of services remaining in the existing heating plant (S_t), to the cost of conversion to a geothermal system (K_g).

In Ref. 4, Goodman derives the formula for S_t, which depends on the cost of a new traditional system, the age of the existing one, and the discount rate, as

$$S_t = (\frac{R}{i}) [1 - e^{-i(20 - t)}] \qquad (1)$$

where

R = the value of annual services (net of operating costs) provided by an operating heating system,

i = the discount rate, and

t = the age of the existing heating plant (in this model, 20 years represents the useful life of any heating plant).

The difference in operating costs between geothermal and traditional systems will be entered into the calculations as the net present value of the difference between geothermal and conventional heating fuels. It is denoted here as Δv.

A homeowner will thus convert to a geothermal heating system if the following inequality holds:

$$K_g - (K_c - S_t) - \Delta v < 0 \ . \qquad (2)$$

It will be assumed, in order to simplify the calculations, that the capital outlays for geothermal (K_g) and a new conventional system (K_c) are each \$2,000. Thus, the decision to convert reduces to a comparison of the value of the services remaining in the existing system (S_t) with the value of the savings in geothermal fuel over traditional fuel (Δv). In this case, the consumer will convert if

$$S_t - \Delta v < 0 .$$

Since the decision to convert depends on the age of the current heating system, only a fraction of the market is likely to find geothermal heating an attractive option. The utility, however, can speed up the rate of market penetration by making cash bonus offers in order to overcome the value remaining in the existing heating plant.

The bonus offer considered here takes the form of a tender offer to pay a specified cash amount to any customer who joins the community heating system. The offer remains in effect over the entire project evaluation period.

The size of the bonus required to make the conversion decision attractive to households with heating systems of vintage "t" is

$$b \geq S_t - \Delta v . \quad (3)$$

For a given bonus (b) and fuel cost savings (Δv), those homeowners with heating systems of "t" years of age and older presumably would accept and immediately join the system.

In the analysis, the heating plant stock is assumed for simplicity to have a uniform distribution of ages from 1 to 20. Therefore, based on the decision variables, an additional 5% of the potential customers within the utility's market service area would accept the bonus offer each following year as their heating plants aged and the service values declined.

This analysis used a 5% discount rate. Thus, with a specified value for fuel cost savings (Δv), one may project the market response to a bonus offer of any given size. For example, a bonus of $2,000 (essentially an offer to pay the full conversion costs of geothermal heating as modeled here) would presumably result in 100% immediate market penetration, even where no fuel cost savings are offered, since the maximum value of S_t is $2,000 (which occurs when $t = 0$). If a lower bonus, say $500, is offered and geothermal heat provides a $670 fuel cost savings (one-third of the conversion costs), half of the potential customers (i.e., those with heating systems over 10 years old) would join immediately because, for $t > 10$, S_t is less than the benefits of joining.

The benefits of a specified initial level of market penetration followed by a 5% annual increase until complete penetration is attained have been calculated for a utility exploiting a relatively good geothermal resource and one using a resource of fair quality. The major resource parameters are listed in Table 1.

Table 1

Major resource parameters

	Good resource	Fair resource
Resource temperature (°F)	170	135
Maximum flow (gal/min)	500	200
Average drawdown (ft)	75	575

The higher quality resource is also at a shallower depth than the one of fair quality and does not require the wellhead heat exchanger used by the latter. The heating load is slightly higher for the good resource than for the fair resource. Transport distance for the higher quality resource is 3 miles compared to 0.5 mile for the lower quality resource. Other demand and all financial conditions are the same. Each utility is assumed to sell its energy at a constant 1980 real price of $7 per million Btu's.

The net revenue or gross profit associated with a given initial market penetration followed by the 5% annual increase was calculated, as illustrated in Fig. 1. The GRITS model was used to compute gross profit (π) as a function of market penetration under two extreme conditions: no bonus offer and zero geothermal price advantage ($\Delta v = 0$). The total profit, without accounting for bonuses, continues to rise as initial market is increased, but at a declining rate. Thus, the marginal π is decreasing. Figure 1 shows that the higher quality resource earns a substantial profit even when it pays the maximum estimated bonus (curves a and b).

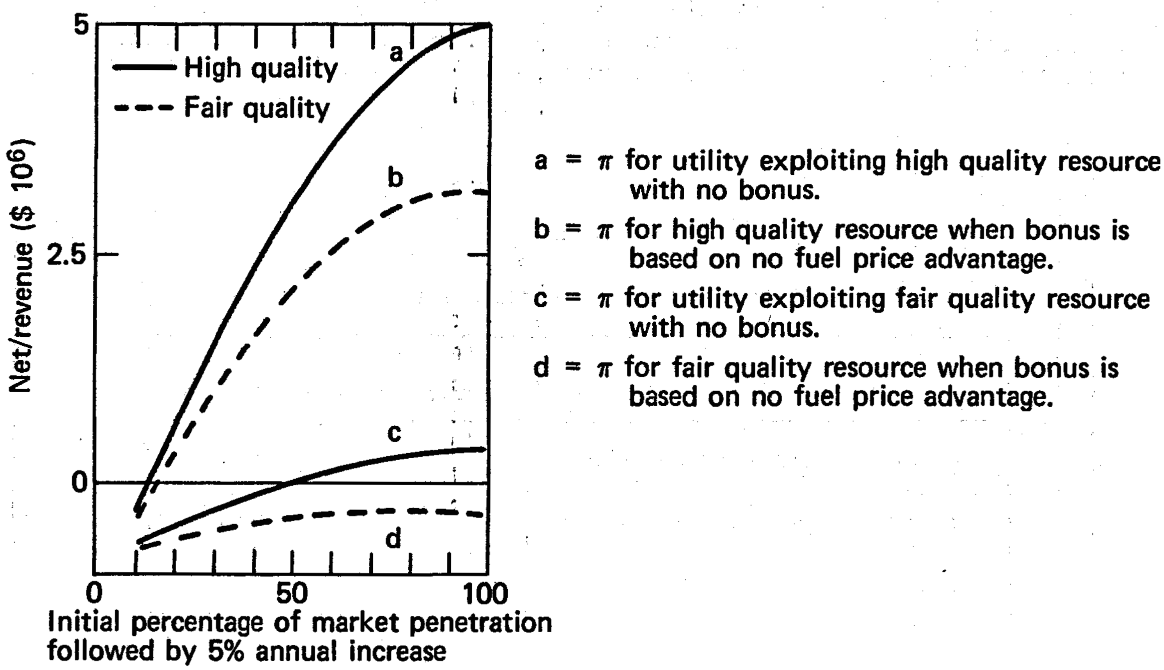
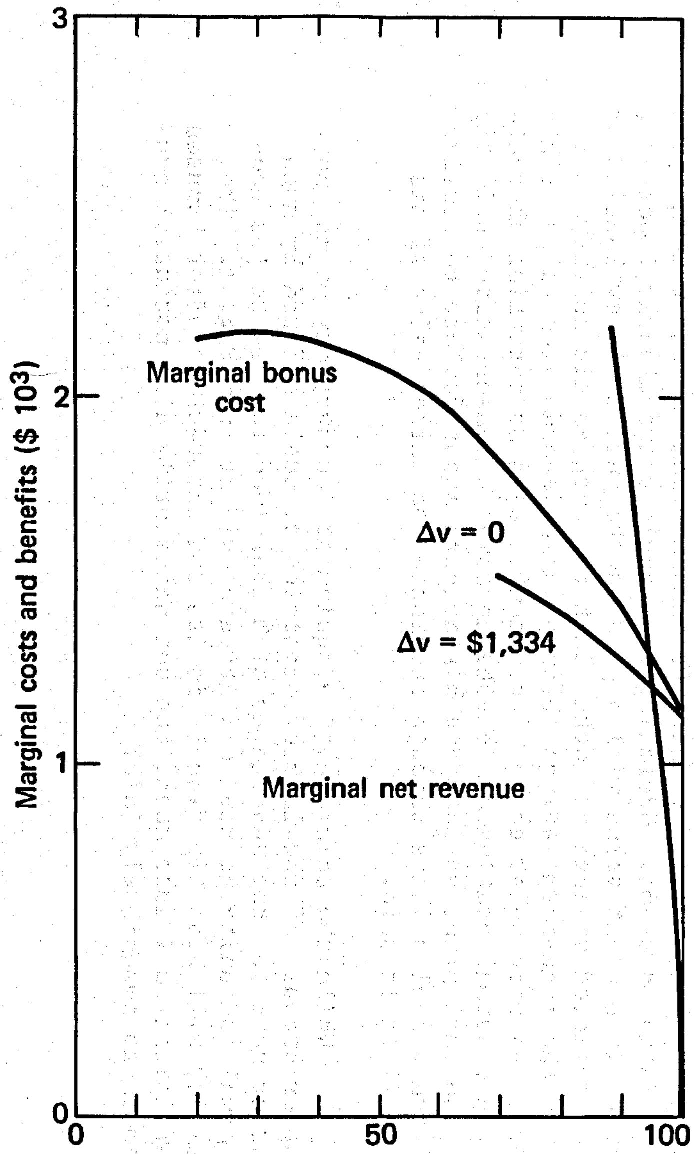
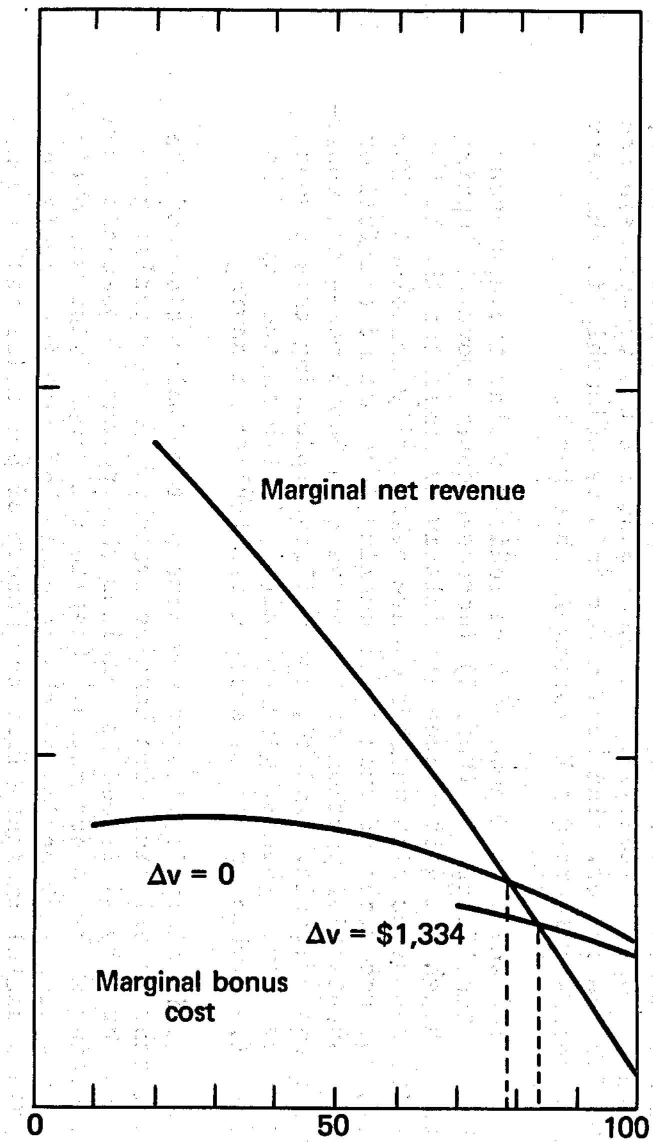


Fig. 1 Effect of bonus on profits and market penetration for high and fair quality geothermal resources.

The utility presumably would compare the gross profit associated with a given initial penetration with the costs required to attain that level. The optimal tender offer is the point at which the marginal costs and profits are equal. Figures 2 and 3 show the marginal curves for the two cases faced by the utilities of high and fair quality resources.

Under conditions of no fuel price advantage, the optimal initial market penetration for the utility with the higher quality resources is 94%. For the other utility, 79% is the appropriate level. These levels correspond to bonus offers of about $1,850 for the good resource and about $1,500 for the fair resource. Interestingly, optimal market penetration changes relatively little even with the substantial drops in the required bonus as Δv increases. At a Δv of $1,334 (two-thirds of the conversion cost),





Initial percentage market penetration followed by 5% annual increase

Fig. 2 Marginal costs versus market penetration for a high quality resource.

Fig. 3 Marginal costs versus market penetration for a fair quality resource.

the optimal initial penetration for the good and fair resources are just over 95% and 84%, respectively. The size of the bonus offer, however, drops substantially to about $550 for the former case and $400 for the latter. The reason for this relationship is the very rapid decrease in marginal profits in this range.

The analysis conducted here indicates that the approach taken by Cunniff et al. (Ref. 3) increases costs above the optimal level, though the differences are relatively small for the higher quality resources with which they are principally concerned. However, for resources of much lower quality, payment of the full or even a substantial portion of the conversion costs makes the undertaking unprofitable. Indeed, the utility exploiting this resource breaks even only when it pays relatively little in the way of bonuses, i.e., when it offers substantial fuel price savings.

This analysis illustrates some of the implications of the investment in existing home heating systems. A prospective geothermal utility will need to consider this potential obstacle when projecting market penetration. Despite the simplifying assumptions, the foregoing examination of the economics of home fuel decisions provides useful insights into the nature of potential market penetration obstacles for geothermal and other unconventional heating systems. Homeowners must receive compensation for their investments in existing systems. Operating cost savings are clearly important, but their present value will depend on the customer's evaluation of the projected savings and other factors, such as his ability to realize the long-term savings through an increased sales value of his home. As with solar energy investments, a major potential obstacle for geothermal heating may be the consumer's conservative estimation of the fuel price savings and his concern about failure to realize adequate fuel savings through the increased market value of his home if it is sold.

While the solar heating equipment industry may or may not suffer because of the lack of economics of scale offered by much larger markets, the advantages of higher load factors to the geothermal community heating utility are evident from Fig. 1. The utility will probably find it in its own interest to offer bonuses sufficient to induce most, but not necessarily all, potential customers to immediately join.

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