THE VARIATION OF DIRECT-HEAT GEOTHERMAL ECONOMICS WITH PROJECT SIZE

Debra W. Struhsacker
Earth Science Laboratory
Salt Lake City, Utah 84108

June 1981

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Front-end direct-heat geothermal project costs are primarily a function of resource exploration and confirmation costs, and of transmission costs. The cost of resource exploration and confirmation is variable, contingent upon the complexity of the geologic setting and the depth to the reservoir. Resource exploration and confirmation expenses may be of second order importance in projects involving transmission distances of more than several miles. Transmission costs are also variable, depending upon the type of transmission line installation. Pipelines installed in urban zones are quite expensive; those installed in rural settings are much cheaper. Geothermal investment tax credits and depletion allowances may help to reduce geothermal project costs. However, not all types of developers are eligible to take advantage of these tax programs.

The economics of direct-heat geothermal utilization depend primarily upon the size of the application. An analysis of a number of on-line, in progress, planned and attempted direct-heat geothermal projects reveals that many are too small to have any meaningful impact upon the Nation's energy budget. Moreover, the cost of energy from these small projects is significantly more than the cost of conventional energy. Even when future inflation of conventional energy is considered, many small direct-heat geothermal projects remain uneconomic. In contrast, the cost of energy from large-scale projects, specifically those that produce at least $1x10^{-4}$ Quads/year ($1x10^{11}$ BTU/year) of direct-heat energy, is significantly cheaper than that from conventional sources. Large projects involving short transmission distances are the most attractive. The economics of these projects are very sensitive to

transmission distance, and become much less favorable for projects involving long transmission distances. However, under certain conditions, transmission distances of up to 50,000 feet may be economic for large-scale applications. Large-scale direct-heat geothermal projects are the most cost-effective way to develop direct-heat geothermal energy. Private sector and federally subsidized direct-heat geothermal projects should thus emphasize large-scale applications.

Direct-heat geothermal project size is measured by the amount of heat extracted from the resource. This is a function of both engineering and resource parameters. In general, large projects commonly involve either the efficient use of large volumes of intermediate-temperature water or moderate volumes of high-temperature water. Large-scale industrial applications and cascaded systems best meet these criteria. Athough geothermal district heating systems use large volumes of water, the amount of heat extracted from the resource is often less than that for an industrial application or a cascaded system. Moreover, district heating systems generally involve longer transmission distances than other types of applications, and therefore cost more than other projects of comparable magnitude.

INTRODUCTION

The purpose of this study is to compare the economics of large, intermediate, and small direct-heat geothermal projects. This paper attempts to define which types of direct-heat geothermal projects are most cost efficient and produce the most energy for the least amount of money. The potential energy contribution of fourteen different sizes of direct-heat projects is used to determine the number of projects of a given size required to produce 1 Quad ($1x10^{15}$ BTUs) of energy. The cost of developing 1 Quad of direct-heat geothermal energy from large, intermediate, and small projects is compared to the cost of 1 Quad of energy from conventional sources. The engineering and resource parameters controlling project size are defined. The development of large-scale projects is stressed as the way in which direct-heat geothermal energy can make the most significant contribution to the Nation's energy requirements.

ENERGY UTILIZATION OF DIRECT-HEAT GEOTHERMAL PROJECTS

Energy utilization data from 14 direct-heat geothermal projects provide a basis for evaluating both the energy contribution of these projects and the economics of various sizes of direct-heat applications. These projects were chosen in order to provide a representative spectrum of project sizes and types of direct-heat applications. Thirteen of the projects are U.S. Department of Energy funded PON (Program Opportunity Notice) projects. Also included in this study is one project that is not a PON, the Brady, Nevada vegetable dehydration plant.

Figure 1 plots the number of each specific project that would be required to obtain 1 Quad ($1\text{x}10^{15}$ BTUs) per year of energy from identically sized projects. This evaluation assumes that each of the projects is totally successful and produces the amount of energy specified in the original project design. Table 1 lists the projects considered, the designed energy utilization of each project, and the number of correspondingly-sized projects required to produce 1 Quad of direct-heat energy use.

The data from Figure 1 and Table 1 can be grouped into three generic project sizes based upon the designed energy utilization. The largest projects, designated here as "the Brady type," produce the most direct-heat energy, ranging from $1.40\text{x}10^{-4}$ Quads/year/project to $4.59\text{x}10^{-4}$ Quads/year/project. The term "energy utilization" will be used to describe the order of magnitude of energy use per project. For example, a Brady-type project has an energy utilization of $1\text{x}10^{-4}$ Quads/year/project ($1\text{x}10^{11}$ BTUs/year/project) and consumes between $1.00\text{x}10^{-4}$ and $9.99\text{x}10^{-4}$ Quads of direct-heat energy. The second largest generic group, "the Utah Roses type," has an energy utilization of 1×10^{-5} Quads/year/project (1×10^{10} BTUs/year/project), and uses between 1.00×10^{-5} and 9.99×10^{-5} Quads/year/project. The smallest generic group, "the Monroe type," has an energy utilization of only 1×10^{-6} Quads/year/project (1×10^{9} BTUs/year/project).

Figure 1 and Table 1 reveal considerable range in the number of projects needed to produce 1 Quad of direct-heat energy. It would take 4000 projects the size of Brady, each producing 2.50×10^{-4} Quads/year/project, to achieve 1 Quad. Similarly, 58,823 projects matching the size of the Utah Roses effort, or 151,515 projects identical to the Monroe project would be required. Expressed in terms of generic project size, an average of 4086 systems are needed to produce 1 Quad from projects with an energy utilization of 1×10^{-4} Quads/year/project. Similarly, an average of 46,829 projects of the Utah Roses generic size category (1×10^{-5} Quads/year/project) or 164,184 projects in the 1×10^{-6} Quads/year/project generic size range would be needed to realize 1 Quad. It is evident that significantly fewer large-scale projects are required to reach a given direct-heat utilization goal.

DIRECT-HEAT GEOTHERMAL PROJECT COSTS

In order to evaluate the feasibility of obtaining 1 Quad/year of energy from direct-heat geothermal projects, the cost of these projects must be ascertained and compared to the cost of 1 Quad of energy from conventional fuels. Although the development of geothermal energy has long been associated with high front-end costs, there is very little information compiled on direct-heat geothermal project development and operation costs. Even though there is some information available for the PON projects, these data are variable and difficult to evaluate. In addition, some of the PON projects are not yet on-line and represent incomplete data. Since there are very few additional direct-heat projects from which data can be obtained, it is thus necessary to estimate direct-heat project development and operation costs.

Project development costs were determined by picking a range of generic geothermal resource types and assigning exploration and confirmation costs for each resource type. Four generic resource types thought to be representative of most geothermal systems were selected: Resource Type 1 - complex geologic settings with deep reservoir targets, Type 2 - complex geologic settings with shallow target depths, Type 3 - simple geologic settings with deep targets, and Type 4 - simple geologic environments with shallow target depths. Table 2 describes in more detail the characteristics of different resource types. Table 3 outlines the exploration and confirmation costs associated with each type. In general, these costs will be determined by the complexity of the geologic setting, and the depth to the reservoir. Complex geologic terrains will require more detailed geologic data and more exploratory drilling prior to siting a production well. Complex systems require more expensive exploration programs than simple systems. Similarly, deep targets require deeper exploration and production wells and are thus more expensive than shallow reservoirs.

The production well cost formula, Equation 1:

$$\text{Production well cost} = 103(\text{depth}) + 7604 \quad \text{where depth is in feet} \tag{1}$$

is the straight-line regression best fit relationship developed by Eastlake (1980) for well cost data from sixteen geothermal production wells ranging from 410 to 5009 feet in depth, and averaging 2460 feet deep and 11 inches in diameter. This line has a coefficient of determination of 0.891 and has approximately the same slope as the equation derived by Chappell and others (1979) for deep geothermal well costs. Production and completion costs within any generic resource type will be variable since pump selection is site specific, depending upon fluid chemistry, temperature, pressure and the desired flow. The costs listed in Table 3 represent average costs. These project costs assume that sufficient flow can be obtained from one well of the specified average depths. This may be unrealistic for many resources, in which case the production well costs may need to be doubled or tripled.

In addition to exploration and confirmation costs, geothermal project development costs also include the cost of transporting geothermal fluids from the wellhead to the point or points of application. This transmission distance will vary from place to place, independent of the generic resource type. Table 4 lists typical transmission system costs for three methods of pipeline installation: Method 1 - direct burial in rural areas, Method 2 - direct burial in urban settings, and Method 3 - construction of a concrete vault or maintenance tunnel to house pipelines in highly urban zones. As seen from Table 4, transmission line costs are very sensitive to the method of installation. Pipeline installation in urban settings commonly involves street and sidewalk excavation and is thus much more expensive than installation in rural areas. Moreover, in an urban zone it may be desirable to house transmission lines in a concrete tunnel to provide easy and inexpensive access for future repair. Rural installations are the cheapest since excavation of pavement and utilities can often be avoided. The average direct-heat geothermal project will probably require a combination of transmission line installation methods. It must be emphasized that the transmission line costs shown in Table 4 assume installation in level terrains. The effects of topographic relief will greatly increase transmission line installation costs and may involve considerable transmission line pumping costs. In addition, the cost of obtaining right-of-ways for the transmission lines has been excluded.

In summary, direct-heat geothermal project development costs consist of both exploration and confirmation costs, and transmission line costs. These are front-end costs, expenditures necessary prior to start-up and operation of the system. For the purposes of this study, plant equipment costs, including heat exchanger costs, are not considered as part of the geothermal development or front-end costs. These types of expenses are not unique to geothermal systems since facilities using conventional energy would have similar expenses for furnaces, boilers or other utilization equipment.

Once the geothermal project is on-line, the system will incur daily operational expenses. Operational expenses include operation and maintenance of the transmission and wellhead equipment, and the cost of electricity to run any downhole pumps. The additional costs associated with the actual operation and maintenance of the utilization facility _per se_ have not been considered since these are not expenses unique to the geothermal systems and would be similar for systems using conventional fuels (C. Higbee, verbal communication). Operation and maintenance costs for the geothermal facility may increase with either increasing heat load and/or increasing transmission line distance. In this study, operation and maintenance costs are estimated at 5% of pipeline costs based upon data from the Raft River, Idaho project (R. J. Schultz, 1981, written communication). It should be noted, however, that the available data on operation and maintenance costs are variable. Studies at the Oregon Institute of Technology suggest that operation and maintenance costs are a function of heat load rather than transmission distance (C. Higbee, 1981, verbal communication). The OIT analysis includes data from small district heating systems designed for Hawthorne and Fernley, Nevada, and Stanley and Mountain Home, Idaho. Fortunately these different estimates have minimal effect upon this study, since operation and maintenance costs are very small compared to project development costs.

Pumping costs vary with the required flow, static water level, the amount of heat extracted from the fluid (Δt), and the local cost of electricity. As an example, pumping will cost $\$.15/10^6$ BTU of produced geothermal energy, assuming a static water level of 200 feet below the land surface, a required flow of 1000 gpm, a Δt of 72°F and electricity cost of $0.057/kwh (C. Higbee, 1981, verbal communication). This value, $\$.15/10^6$ BTU of geothermal energy, was adopted as the pumping cost factor for all projects with an energy utilization of $1\text{x}10^{-4}$ Quads/year/project, since projects of this size are likely to involve a temperature drop of this magnitude. For purposes of determining the pumping costs the energy utilization in each generic size range was multiplied by 5, the midpoint, to give an average project size. Thus projects with an energy utilization of $1\text{x}10^{-4}$ Quads/year ($1\text{x}10^{11}$ BTU/year) have pumping costs of $75,000/year ($5\text{x}10^{11}$ BTU/year multiplied by $\$.15/10^6$ BTU). Smaller projects, those with an energy utilization of $1\text{x}10^{-5}$ Quads/year/project and $1\text{x}10^{-6}$ Quads/year/project, are likely to be applications involving smaller values of Δt, resulting in higher pumping costs. A pumping cost of \$.30/16^6 BTU will be used for these smaller projects. This corresponds to the conditions described above using a #t of 36°F (C. Higbee, verbal communication).

It must be realized that pumping costs will show considerable variation from resource to resource, depending upon the local hydrologic regime and the flow demands of the specific application. The values used in this study were selected to represent two average conditions. Moreover, these pumping costs are for wellhead pumping only. Transmission line pumping costs have not been considered. Table 5 summarizes the direct-heat geothermal project development and operational costs considered in this study and lists those costs excluded from consideration.

The large amount of capital required to finance the front-end geothermal project development costs will be obtained in most cases by a loan. Rather than payment of the project front-end cost in one lump sum, installments would be paid over the lifetime of the loan. Equation 2 (Higbee and others, 1979) is the standard formula for calculating the annual installment payment on a loan:

$$a = \frac{PV[i(1+i)^n]}{(1+i)^n-1} \tag{2}$$

where
a = annual payment or debt service
PV = present value of the investment (amount of the loan)
i = annual interest rate
n = number of years required to amortize the loan

Examples of this computation are listed in Table 6 for the most expensive type of projects (Resource Type 1/Transmission Method 3) and the least expensive type (Resource Type 4/Transmission Method 1). These computations assume an interest rate of 18% annually and an amortization schedule of 10 years, a common financial arrangement for a taxable corporation in today's economic climate (R. J. Schultz, verbal communication). A non-taxable entity such as a public utility-owned geothermal district heating system would probably finance such an endeavor with tax-free bonds at a 10 to 12% annual interest rate over a period of 20 years (C. Higbee, 1981, verbal communication). Operational costs are not included in Table 6 since these are not amortized costs. They are treated as out-of-pocket expenses paid on a regular basis. As seen from Table 6 there is a considerable spread of direct-heat project development costs, varying chiefly with the transmission line distance. For projects involving transmission distances of more than several miles, project development costs are determined largely by transmission line costs rather than exploration and confirmation costs. This is especially true for urban installations.

In order to obtain the total yearly geothermal project costs, the non-amortized yearly operational expenses must be added to the annual installment payment for the front-end investment. Table 7 lists the total geothermal project development and operational expenses for a Brady-type project with an energy utilization of 1×10^{-4} Quads/year, developed from a Type 1 resource, using transmission installation Method 3, and requiring 10,000 feet of transmission line. Total annual project costs for different sizes of projects are calculated in the same manner.

Geothermal project costs may in some cases be reduced by claiming federal tax credits and deductions such as geothermal depletion allowances, intangible drilling cost deductions and geothermal investment tax credits. Unfortunately, not all types of developers are allowed to take these tax programs. For example, a public utility, a likely developer of a municipal district heating system, cannot benefit from the geothermal tax incentives. In addition, a private developer must have a large tax liability in order to take advantage of the geothermal tax write-offs. Small developers may not have enough up-front revenue to benefit from the geothermal tax incentives (C. Higbee, 1981, verbal communication). Since these tax programs cannot be universally applied, they have not been considered in this economic analysis. They may, however, considerably improve the economics of an eligible project.

THE COST OF 1 QUAD OF DIRECT-HEAT GEOTHERMAL ENERGY

Having determined a spectrum of geothermal project costs, the next step is to calculate the costs of obtaining 1 Quad of direct-heat geothermal energy. Returning to the concept of generic geothermal project size, the cost of 1 Quad of energy from projects with an energy utilization of $1x10^{-4}$ Quads/year/project, $1x10^{-5}$ Quads/year/project, and $1x10^{-6}$ Quads/year/project can be obtained by multiplying total annual geothermal project costs, such as those shown in Table 7, by the average number of projects required in each generic project size range to produce 1 Quad of energy. An average of 4086 developments similar to the Brady-type project listed in Table 7, at $681,661 per project, would be required to develop 1 Quad of energy, resulting in a total cost of $\$2.79x10^{9}$. In order to evaluate the soundness of an investment of $\$2.79x10^{9}$ for 1 Quad of energy, this cost must be compared to the cost of

1 Quad of energy from conventional sources. If geothermal energy costs are less than that for conventional energy, the geothermal investment is attractive.

Figure 2 shows the variation in the cost of 1 Quad per year of direct-heat geothermal energy developed from projects with an energy utilization ranging from 1×10^{-4} Quads/year/project to 1×10^{-6} Quads/year/project, and transmission line distances of 0 to 50,000 feet. These costs are shown for four different types of projects, those involving the most expensive (Resource Type 1) and least expensive (Resource Type 2) exploration and confirmation costs, and those with the most expensive (Transmission Method 3) and least expensive (Transmission Method 1) transmission installation costs. All other types of projects will have costs bracketed by these extremes.

Also shown on Figure 2 are the average current costs of 1 Quad of heating oil, natural gas and electricity. The costs shown for heating oil and natural gas must be adjusted for conversion efficiency by dividing by the conversion factors 0.7 and 0.8 respectively (Higbee, verbal communication). The conventional fuel costs already represent amortized costs since they reflect the price that must be charged in order to recoup the investment in exploration and production of the various resources in question, the cost of financing this investment (debt service), and a profit margin. On a local scale, these costs do not vary with transmission distance since production, transmission and distribution systems are well established. Moreover, the cost of supplying energy from a new conventional source or to a new user is averaged in with production and distribution costs from existing sources (Fassbender and others, 1980). The average costs of conventional energy shown in Figure 2 are representative of costs in the western United States, the area thought to contain the greatest geothermal potential. They are not, however, representative of costs in Alaska or Hawaii.

From Figure 2 it is apparent that only large-scale direct-heat projects, those with an energy utilization of at least $1x10^{-4}$ Quads/year/project, presently compare favorably to the cost of conventional energy. The margin between the cost of geothermal energy from Brady-type resources is very sensitive to transmission distance. The margin is quite large for projects with short transmission distances but decreases markedly with increasing transmission distances. For rural transmission line installations (Method 1), resources as far away as 50,000 feet from the use center may be economic compared to the cost of an equivalent amount of conventional fuels. For urban installations requiring a maintenance tunnel (Method 3), this distance is reduced to 40,000 feet. The cost of most direct-heat geothermal projects will probably lie between the two extremes shown in Figure 2, since transmission lines are apt to be a mixture of both rural and urban installation costs. Again it must be emphasized that the transmission distances assume level terrain, and transmission costs do not include pumping costs. Actual transmission installation and operational costs may be much higher, making some projects with long transmission distances uneconomic.

The cost of 1 Quad of energy from smaller direct-heat projects does not compare favorably with current conventional energy costs. Projects developed from Type 4 resources with an energy utilization of $1x10^{-5}$ Quads/year/project, and using less than 10,000 feet of Method 3 transmission line, cost slightly less or about the same as conventional energy depending upon whether natural gas, electricity or heating oil is being considered. The cost of energy from very small-scale projects, with an energy utilization of 1×10^{-6} Quads/year/project, is significantly more than conventional energy costs for any type of resource, at any transmission distance, for any type of pipeline installation.

PROJECTED FUTURE GEOTHERMAL DIRECT-HEAT ENERGY COSTS

One of the traditional arguments in favor of the development of direct-heat geothermal energy is that once a project is on-line, geothermal energy costs will increase much less rapidly than conventional energy costs. Thus, presently marginal or subeconomic projects may be attractive in the near future if conventional energy costs continue to inflate as predicted. Of the geothermal project costs listed in Tables 6 and 7, only the operational costs are subject to inflation. The annual payment for the project development costs is a fixed cost throughout the life of the loan, and does not inflate with time. An inflation rate of 7%, controlled largely by the cost of labor, is projected for operation and maintenance expenses. Pumping costs will inflate at the same rate as electricity; a rate of 9% is estimated. These inflation rates are similar to those used by Higbee and others (1979). There are numerous different inflation rates projected for conventional energy. For this study it is assumed that conventional energy sources will inflate between 8 and 12% per year for the next ten years.

Figure 3 shows the increase with time in the cost of 1 Quad of geothermal energy for projects with transmission distances of 5000, 25,000 and 50,000 feet. As in Figure 2, geothermal energy costs are grouped into generic project sizes of 1×10^{-4} Quads/year/project, 1×10^{-5} Quads/year/project and 1×10^{-6} Quads/year/project, and four types of geothermal projects encompassing the range of resource and transmission types are shown. Also shown in Figure 3 are the predicted costs of 1 Quad of natural gas and electricity, projected at both an 8% and 12% yearly rate of inflation. The projected costs of heating oil are not plotted in order to avoid diagrammatic clutter; they are slightly less than electricity costs.

It is readily apparent from Figure 3 that, taking inflation into account, energy from large geothermal projects (energy utilization of 1×10^{-4} Quads/year/project) costs less than conventional fuels, even for transmission distances of up to 50,000 feet. This margin between geothermal and conventional energy costs becomes increasingly attractive for projects involving inexpensive, rural transmission line installations. In contrast, energy from smaller-scale geothermal direct-heat projects remains more expensive than conventional energy except for projects involving transmission distances of less than 5000 feet and Method 1 transmission line installation. Even for this type of geothermal project, the margin between geothermal and conventional energy costs is narrow. Any significant increase above the designated geothermal project costs would absorb any competitive edge for geothermal. At 5,000 feet transmission distance, several types of geothermal projects in the 1×10^{-5} Quads/year/project size range do compare favorably with the projected future costs of electricity and heating oil. It must be added, however, that a comparison between the cost of geothermal energy and heating oil may not be valid for the western United States, since heating oil is not the dominant energy source in the west, and this is the area most likely to have significant geothermal resources. A useful economic analysis must compare the cost of geothermal energy with the cost of the type of energy being displaced. Geothermal energy from very small projects (energy utilization of 1×10^{-6} Quads/year/project) is apparently uneconomic at any transmission distance and at any time in the forseeable future. It should be added, however, that small-scale projects may be locally economic in special cases involving significantly lower geothermal project costs than those used in this study. Small-scale applications may be quite attractive in areas of very shallow reservoirs, high-volume flow rates, or exceptionally expensive conventional energy costs.

Figure 3 emphasizes that direct-heat geothermal development should focus projects with an energy utilization of at least 1×10^{-4} Quads/year/project. These projects not only have attractive present-day economics; the positive margin between geothermal energy costs and conventional energy costs is expected to broaden with time and inflation. This large difference between geothermal energy costs from this size category and conventional energy costs indicates that, if necessary, higher project development costs can be justified for geothermal projects of this magnitude. The promise of future price competitiveness for smaller-scale projects may be sufficient to stimulate limited development of small geothermal projects. However, in today's economic climate, many private investors may not consider this type of project an attractive investment. Moreover, the impact of these smaller-scale geothermal projects on the Nation's energy budget is minimal. Large-scale projects are thus the most cost-effective and efficient way to develop geothermal energy.

DETERMINATION OF GEOTHERMAL PROJECT SIZE

Having determined that large-scale direct-heat projects are more economic than smaller-scale projects, it is next necessary to define which parameters influence project size, and control the amount of energy from a specific application. A combination of resource characteristics (temperature and flow) and engineering factors (the amount of heat extracted from the geothermal fluid, and the duration of the process) are the key elements controlling project size. The amount of energy used in a direct-heat geothermal application is expressed as Equation 3 (EG&G, 1978):

$$q = 500(t_1 - t_2)w \text{ (Load Factor)} \qquad (3)$$

where:

q = the amount of energy (BTUs/hr)

500 = a constant

t_1 = temperature (°F) of the incoming geothermal or working fluid

t_2 = temperature (°F) of the discharge fluid

w = volume of geothermal or working fluid (gpm)

$$\text{Annual Load Factor} = \frac{\text{number of hours in operation}}{\text{number of hours in a year}}$$

The quantity ($t_1 - t_2$), the amount of extracted heat, is commonly called #t. To convert q from BTUs/hour to Quads/year, multiply q by 8760 hours (the number of hours in a year), and divide by $1\text{x}10^{15}$ BTUs (the number of BTUs in 1 Quad).

From Equation 3 it is readily apparent that projects involving large values of Δt and large flow rates produce the most energy. It is also obvious from Equation 3 that large values of t_1 and smaller values of t_2 produce the largest Δt. The incoming temperature, t_1, is a resource parameter dependent on the available wellhead temperature; t_2 depends the engineering design of the specific application. Thus the efficient application (small t_2) of high-temperature (large t_1) fluids will result in the largest Δt. Volume, w, is a resource parameter dependent on the flow rate available from the well or wells in question. These relationships are illustrated in Figures 4 and 5. Figure 4 shows the effect of variable Δt for given flow rates; Figure 5 illustrates variable flow rate with constant Δt. For example, assuming a 100% annual load factor and t_2=100°F, a q of 1×10^{11} BTU/yr (1×10^{-4} Quads/year) can be obtained from a project using either 100 gpm of 330°F water (Figure 4) or 450 gpm of 150°F water (Δt=50°F, Figure 5). Thus if sufficient volumes are available, lower-temperature waters can in some cases provide as much energy as higher-temperature fluids.

Up to this point, this analysis of the amount of energy available from a direct-heat project has assumed a full-time operation with a theoretical 100% annual load factor. Although actual operating conditions prevent operation 100% of the time, large-scale industrial applications have annual load factors as high as 90%. However, many direct-heat uses have significantly smaller load factors. For example, the annual load factor common for most geothermal district heating systems averages only 20 to 25% (C. Higbee, 1981, verbal communication). In order for the amount of energy used from a geothermal district heating project to equal that from an industrial application with larger load factors, it must be a large system serving many users. This requires large volumes of fluids, a limiting factor in many low permeability resources. Another potential problem associated with large geothermal district heating systems is the high installation cost of many miles of transmission line in urban areas. Industrial applications of similar energy use magnitude commonly have much cheaper transmission line costs.

Maximizing the amount of heat extracted from a geothermal fluid requires careful engineering. In many cases this can best be accomplished in a cascaded system in which geothermal fluids are used for several different processes. At sequentially lower temperatures, each process extracts heat from the fluid and contributes to the cumulative Δt for the project. District heating systems have a disadvantage in this regard as well; unless included as part of a cascaded system, they are limited to relatively small values of Δt. Geothermal space heating projects are usually designed for a Δt of no more than about 40°F and many operate with as little as 15°F Δt (C. Higbee, verbal communication; EG&G, 1978).

SUMMARY AND CONCLUSIONS

Geothermal direct-heat project costs vary widely depending primarily on the amount of energy produced by the application (the energy utilization), and the distance between the geothermal fluid production center and the use center (the transmission distance). An analysis of the economics and energy contribution of 14 direct-heat projects reveals that many of the types of applications being considered today are too small to be economic when compared to the cost of an equivalent amount of conventional energy. Moreover, these small projects produce too little energy to have any significant impact upon the Nation's energy budget. Of the smallest size category considered (projects with an energy utilization of $1\text{x}10^{-6}$ Quads/year/project), an average of 164,184 projects would have to be developed in order to place 1 Quad of direct-heat geothermal energy on-line. On the other hand, if 1 Quad were developed from projects with an energy utilization of 1×10^{-4} Quads/year/project, an average of only 4086 projects would be required. Clearly it is easier and less expensive to develop 4086 projects than up to 164,184 projects. Large-scale projects involve the efficient use of either large- to moderate-volumes of high-temperature water, or large-volumes of intermediate-temperature water.

A comparison of the cost of direct-heat geothermal energy and conventional energy further emphasizes the attractive economics of large-scale projects, and the marginal to uneconomic nature of most small-scale geothermal direct-heat projects. Energy from most projects with an energy utilization of 1×10^{-6} Quads/year/project to 1×10^{-5} Quads/year/project costs more than the equivalent amount of energy from conventional sources. This is particularly true for projects involving long distance transmission lines and/or expensive transmission line installations in urban settings. Some presently subeconomic small-scale projects may become economic in the future if inflation of conventional energy is considered; however, many small-scale projects remain uneconomic, even in light of projected inflation. In contrast, large projects with an energy utilization of 1×10^{-4} Quads/year/project may compare favorably with the cost of conventional fuels for transmission distances of up to 50,000 feet in rural settings, and 40,000 in urban settings (assuming level terrain and no transmission pumping costs). The popular concept that the resource and user must be colocated may thus be invalid for large-scale projects. In addition, relocation to a resource may be feasible for large-scale applications. For example, the Brady vegetable dehydration project (Table 1) is located in a remote portion of Nevada, removed from both people and raw materials. It should be stressed that the ultimate economic feasibility of both large- and small-scale direct-heat projects must be evaluated on a site-specific basis. There may be local factors such as very shallow well depth, large flow rates or exceptionally high conventional energy costs that can make some small-scale direct-heat geothermal projects economically attractive.

This study suggests that, in order for direct-heat geothermal energy to make the most significant contribution possible to this country's energy needs, development efforts must focus upon large-scale projects producing on the order of magnitude of at least 1×10^{-4} Quads/year/project. Federal programs seeking to stimulate direct-heat geothermal exploration and development should thus encourage large-scale projects. Private sector direct-heat geothermal projects should likewise emphasize large-scale applications.

ACKNOWLEDGEMENTS

This work was performed under U. S. Department of Energy/Division of Geothermal Energy contract number DE-AC07-80ID12079. The author wishes to thank numerous members of the Earth Science Laboratory staff for reviewing this paper. Special thanks go to C. Higbee of the Oregon Institute of Technology and E. G. DiBello of EG&G Idaho, Inc. for their many helpful comments. K. Wallwork typed this manuscript; D. Bolaris drafted the figures.

REFERENCES CITED

Chappell, R. N., Prestwich, S. J., Miller, L. G., and Ross, H. P., 1979, Geothermal well drilling estimates based on past well costs: Geothermal Resources Council Trans., vol. 3, p. 99-102.

EG&G, 1978, Rules of thumb for geothermal direct applications: Department of Energy-Idaho Operations Office.

Eastlake, W. B., 1980, Shallow well cost review: Idaho Geothermal Report, Idaho Office of Energy, 12 p.

Fassbender, L. L., Bloomster, C. H., and Price, B. A., 1980, The economics of geothermal, solar and conventional space heating: Geothermal Resources Council Trans., vol. 4, p. 707-710.

Higbee, C., Huttrer, G. W., Larson, T., and Wagner, S., 1979, Economics of direct-use development, in Anderson, D. N., and Lund, J. W., (eds.), Direct Utilization of Geothermal Energy: A Technical Handbook: Geothermal Resources Council Special Report No. 7.

Little, N. H., 1980, Pipeline sizing and selection: Geothermal Resources Council Trans., vol. 4, p. 641-644.

Table 1. Designed Energy Use of Selected Direct-Heat Geothermal PON Projects.

PROJECT NAME AND LOCATION	TYPE OF APPLICATION	ENERGY USE (QUADS/YR.)	NUMBER OF IDENTICALLY SIZED PROJECTS NEEDED FOR 1 QUAD
Brady Hot Springs, Brady, NV[1,2]	Process Heat	4.59×10^{-4}	2,178
ORE-IDA, Ontario, Oregon	Process Heat	3.32×10^{-4}	3,012
Madison County, Rexburg, Idaho	Process Heat & District Heat	3.14×10^{-4}	3,184
Brady Hot Springs, Brady, Nevada[1,3]	Process Heat	2.50×10^{-4}	4,000
Boise City, Boise, Idaho	District Heat	2.00×10^{-4}	5,000
Holly Sugar, Brawley, California	Process Heat	1.40×10^{-4}	7,143
			Average=4086
Susanville City, Susanville, California	District Heat	4.10×10^{-5}	24,390
Klamath Falls City, Klamath Falls, Oregon	District Heat	3.54×10^{-5}	28,249
Pagosa Springs City, Pagosa Springs, Colorado	District Heat	2.86×10^{-5}	34,965
Utah Roses, Sandy, Utah	Space Heat (Greenhouse)	1.70×10^{-5}	58,823
St. Mary's Hospital, Pierre, South Dakota	Space Heat	1.14×10^{-5}	87,719
			Average=46,829
Haakon Schools, Philip, South Dakota	Space Heat	9.54×10^{-6}	104,822
Monroe City, Monroe, Utah	Space Heat	6.60×10^{-6}	151,515
Klamath Falls YMCA, Klamath Falls, OR	Space Heat	5.00×10^{-6}	200,000
Diamond Ring Ranch, Mid-Central S.D.	Space Heat	4.99×10^{-6}	200,400
			Average=164,184

1. The Brady Hot Springs Project is not a PON project.
2. Assuming a 365 day/year operation (100% annual load factor).
3. Actual campaign of 200 days/yr operation (55% annual load factor).

TABLE 2. GENERIC GEOTHERMAL RESOURCE TYPES

<table>
<tr><th></th><th>RESOURCE TYPE 1
COMPLEX/DEEP</th><th>RESOURCE TYPE 2
COMPLEX/SHALLOW</th><th>RESOURCE TYPE 3
SIMPLE/DEEP</th><th>RESOURCE TYPE 4
SIMPLE/SHALLOW</th></tr>
<tr><td>TARGET DEPTH</td><td>2500-5000 ft (760-1525 m)
Averages 4000 ft (1220 m)</td><td>Less than 2500 ft (760 m)
Averages 1500 ft (450 m)
(less common than complex/deep type)</td><td>2500-5000 ft (760-1525 m)
Averages 4000 ft (1220 m)</td><td>Less than 2500 ft (760 m)
Averages 1500 ft (450 m)</td></tr>
<tr><td>GEOLOGIC SETTING</td><td colspan="2">1) Areas with intricate patterns of folding and faulting due to multiple deformational events
Example: Basin and Range normal faulting superimposed upon Laramide compressional folding and faulting
2) Complex stratovolcanic terrains with or without superimposed caldera volcanism
Examples: The San Juan Mountains/Valles Caldera
The Cascades
3) Blind targets with few surface thermal features due to: burial by an insulating cover of sediments; lack of and/or self-sealing of near-surface faults; or masking of thermal anomalies due to cold, shallow groundwater regime
Examples: Long Valley, California
The Cascades</td><td colspan="2">1) Areas of simple Basin and Range normal faulting
Example: Systems along range-front normal faults
2) Stratabound systems in aquifers of known thickness, depth and hydrologic characteristics
Example: The Madison Aquifer</td></tr>
</table>

TABLE 3. GENERIC GEOTHERMAL EXPLORATION AND CONFIRMATION COSTS (excluding land acquisition costs)

TYPE OF ACTIVITY	COSTS FOR EACH GENERIC RESOURCE TYPE ($K)			
	GENERIC RESOURCE TYPE 1 COMPLEX/DEEP	GENERIC RESOURCE TYPE 2 COMPLEX/SHALLOW	GENERIC RESOURCE TYPE 3 SIMPLE/DEEP	GENERIC RESOURCE TYPE 4 SIMPLE/SHALLOW
EXPLORATION				
Surface Geology & geophysics[a]	100	100	75	50
Shallow, slim diameter thermal gradient drilling @ $20.00/ft. drilling and logging	(6000 ft) cumulative 120	(4000 ft) cumulative 80	(6000 ft) cumulative 120	(1500 ft) cumulative 30
CONFIRMATION - PRODUCTION WELL				
Drilling $=103(depth) + 7604[b]	(4000 ft) 420	(1500 ft) 163	(4000 ft) 420	(1500 ft) 163
Logging[c]	23	23	18	18
Production Testing and Completion	50	50	40	30
Well Head Equipment[d]	90	90	90	90
CONFIRMAION - INJECTION WELL COSTS				
Drilling, Testing & Completion (Same As Production Well)[e]	493	236	488	211
Well Head Equipment[d]	40	40	40	40
	TOTAL 1,336	782	1,291	632

a. Modified after Nielson, Capuano and Wright (in prep.).
b. After Eastlake, 1980.
c. Based on 10/80 Schlumberger price list for Electrical, Sonic, Nuclear, Caliper and Temperature logs.
d. T. Lawford, 1981, Verbal communication (these represented Wellhead equipment costs for fluid temperatures above boiling; Wellhead equipment costs for lower-temperature resources will be less).
e. Injection well costs will be less for injection into horizons shallower than the production zone.

TABLE 4. INSTALLED TRANSMISSION LINE COSTS

TRANSMISSION DISTANCE (ft)	DIRECT BURIAL INSTALLATION[1]($) METHOD 1 RURAL INSTALLATION ($9.00/ft excavation cost[3])	 METHOD 2 URBAN INSTALLATION ($27.00/ft excavation cost[3])	METHOD 3 CONCRETE MAINTENANCE TUNNEL MATERIALS AND INSTALLATION[2]
1,000	43,000	61,000	125,000
5,000	215,000	305,000	625,000
10,000	430,000	610,000	1,250,000
15,000	645,000	915,000	1,875,000
20,000	860,000	1,220,000	2,500,000
25,000	1,075,000	1,525,000	3,125,000
30,000	1,290,000	1,830,000	3,750,000
35,000	1,505,000	2,135,000	4,375,000
40,000	1,720,000	2,440,000	5,000,000
45,000	1,935,000	2,745,000	5,625,000
50,000	2,150,000	3,050,000	6,250,000

1. 8-inch insulated fiberglass-reinforced pipe - ranges in cost from $30.00/ft (Higbee C., 1981, verbal communication) to $38.00/ft (Little, 1980). An average of $34.00/ft is used in Table 3.

2. $125.00/ft for 8-inch steel, schedule 40 pipe (Higbee and others, 1979).

3. Higbee, C., 1981, verbal communication.

TABLE 5. SUMMARY OF DIRECT-HEAT GEOTHERMAL PROJECT COSTS

DEVELOPMENT OR FRONT-END COSTS

1) Resource Exploration
   geology, geophysics, geochemistry, shallow thermal gradient hole drilling & logging

2) Resource Confirmation
   production well: drilling, logging, testing, completion and wellhead equipment
   injection well: drilling, logging, testing, completion and wellhead equipment

3) Transmission Line Installation

   METHOD 1 - rural installation/direct burial ($41.00/ft)
   METHOD 2 - urban installation/direct burial ($63.00/ft)
   METHOD 3 - urban installation/concrete maintenance tunnel ($125.00/ft)

OPERATIONAL COSTS

1) Wellhead and Transmission Line Operation and Maintenance
   5% of transmission line costs

2) Well Pumping Electricity Costs:

   $\$.15/10^6$ BTU for large projects ($1\text{x}10^{-4}$ Quads/year)

   $\$.30/10^6$ BTU for smaller projects ($1\text{x}10^{-5}$ Quads/year - $1\text{x}10^{-6}$ Quads/year)

COSTS EXCLUDED FROM CONSIDERATION

1) Land Acquisition Costs, Royalty Payments And Permitting Expenses

2) Transmission Line Right-Of-Way Costs

3) Transmission Line Pumping Costs

4) Utilization Facility Capital and O&M Costs

LEAST EXPENSIVE PROJECTS RESOURCE 4/TRANSMISSION TYPE 1					MOST EXPENSIVE PROJECTS RESOURCE TYPE 1/TRANSMISSION TYPE 3			
TRANSMISSION DISTANCE (ft)	TRANSMISSION LINE COSTS ($)	EXPLORATION AND DEVELOPMENT COSTS ($)	TOTAL DEVELOPMENT COSTS (PV) ($)	AMORTIZED ANNUAL PAYMENT (a) ($)	TRANSMISSION LINE COSTS ($)	EXPLORATION AND CONFIRMATION COSTS ($)	TOTAL DEVELOPMENT COSTS (PV) ($)	AMORTIZED ANNUAL PAYMENT (a) ($)
1,000	43,000	632,000	675,000	151,943	125,000	1,336,000	1,461,000	325,087
5,000	215,000	632,000	847,000	190,660	625,000	1,336,000	1,961,000	436,342
10,000	430,000	632,000	1,062,000	239,056	1,250,000	1,336,000	2,586,000	575,411
15,000	645,000	632,000	1,277,000	287,453	1,875,000	1,336,000	3,211,000	714,480
20,000	860,000	632,000	1,492,000	335,849	2,500,000	1,336,000	3,836,000	853,548
25,000	1,075,000	632,000	1,707,000	384,246	3,125,000	1,336,000	4,461,000	992,617
30,000	1,290,000	632,000	1,922,000	432,642	3,750,000	1,336,000	5,086,000	1,131,686
35,000	1,505,000	632,000	2,137,000	481,039	4,375,000	1,336,000	5,711,000	1,270,755
40,000	1,720,000	632,000	2,352,000	529,435	5,000,000	1,336,000	6,336,000	1,409,823
45,000	1,935,000	632,000	2,567,000	577,832	5,625,000	1,336,000	6,961,000	1,548,892
50,000	2,150,000	632,000	2,782,000	626,228	6,250,000	1,336,000	7,586,000	1,687,961

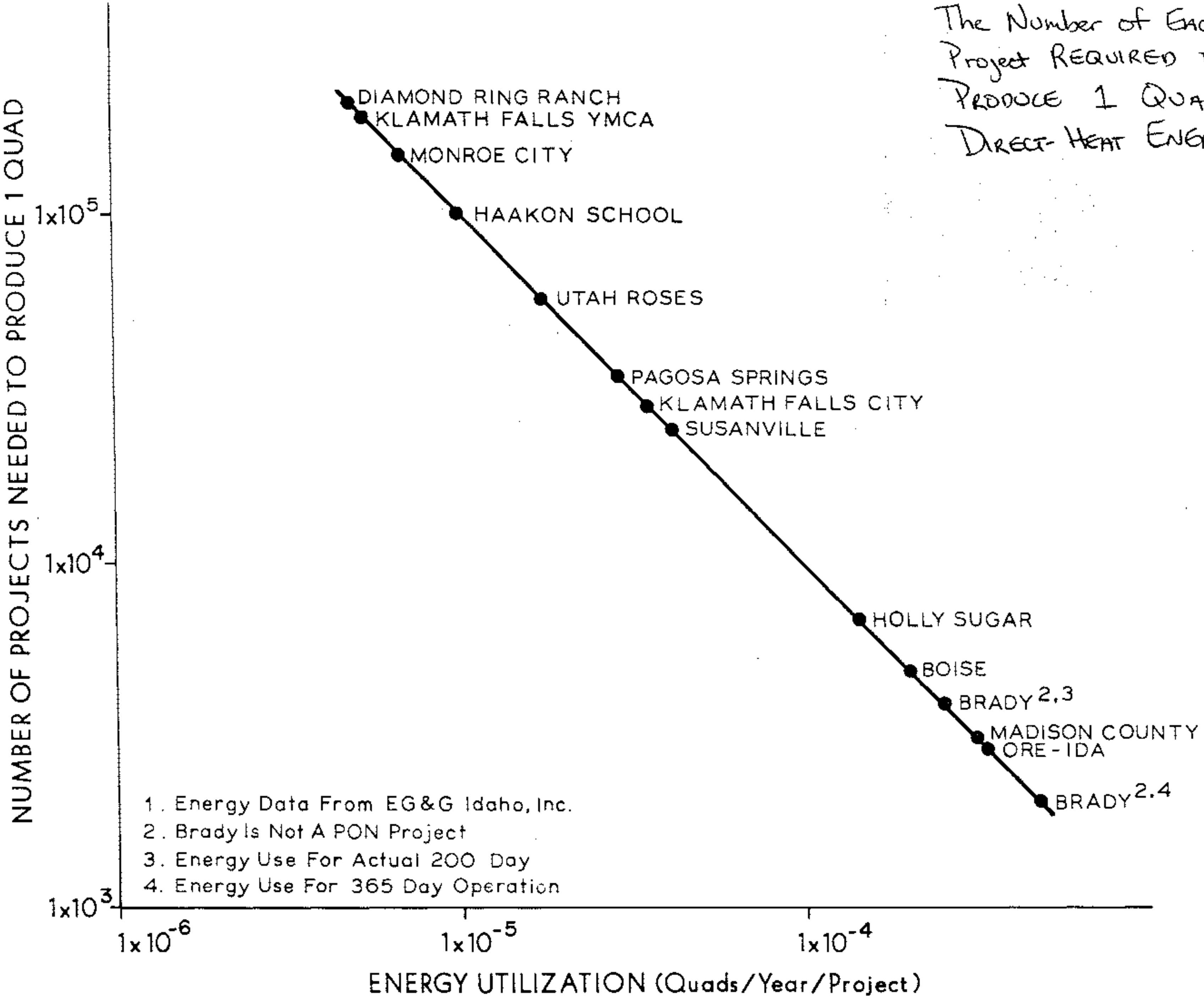
TABLE 6. AMORTIZED GEOTHERMAL DIRECT-HEAT PROJECT DEVELOPMENT COSTS:

$$a = \frac{PV[i(1+i)^n]}{(1+i)^n-1}$$ (assuming i=18% annually, n=10 years)

TABLE 7. TOTAL ANNUAL GEOTHERMAL PROJECT COSTS

PROJECT DEVELOPMENT COSTS	
EXPLORATION & CONFIRMATION (RESOURCE TYPE 1)	1,336,000
TRANSMISSION LINE COSTS - 10,000' (METHOD 3 @$125.00/ft)	1,250,000
TOTAL PROJECT DEVELOPMENT COST	2,586,000
AMORTIZED PROJECT DEVELOPMENT COSTS i=18%, n=10 years	$ 575,411/year
PROJECT OPERATIONAL COSTS	
OPERATION & MAINTENANCE (5% Transmission Line Costs)	$ 31,250/year
WELL PUMPING ELECTRICITY COSTS $(\$.15/10^6 \text{ BTU} \times 5\text{x}10^{11} \text{ BTU})$	$ 75,000/year
TOTAL ANNUAL COST	$ 681,661

FIGURE 1.
The Number of Each PON Project REQUIRED TO PRODUCE 1 QUAD OF DIRECT-HEAT ENERGY[1]



1. Energy Data From EG&G Idaho, Inc.
2. Brady Is Not A PON Project
3. Energy Use For Actual 200 Day
4. Energy Use For 365 Day Operation

FIGURE 2.

Cost of 1 Quad of
Direct-Heat Energy vs.
Transmission Distance
For Projects of Variable
Size

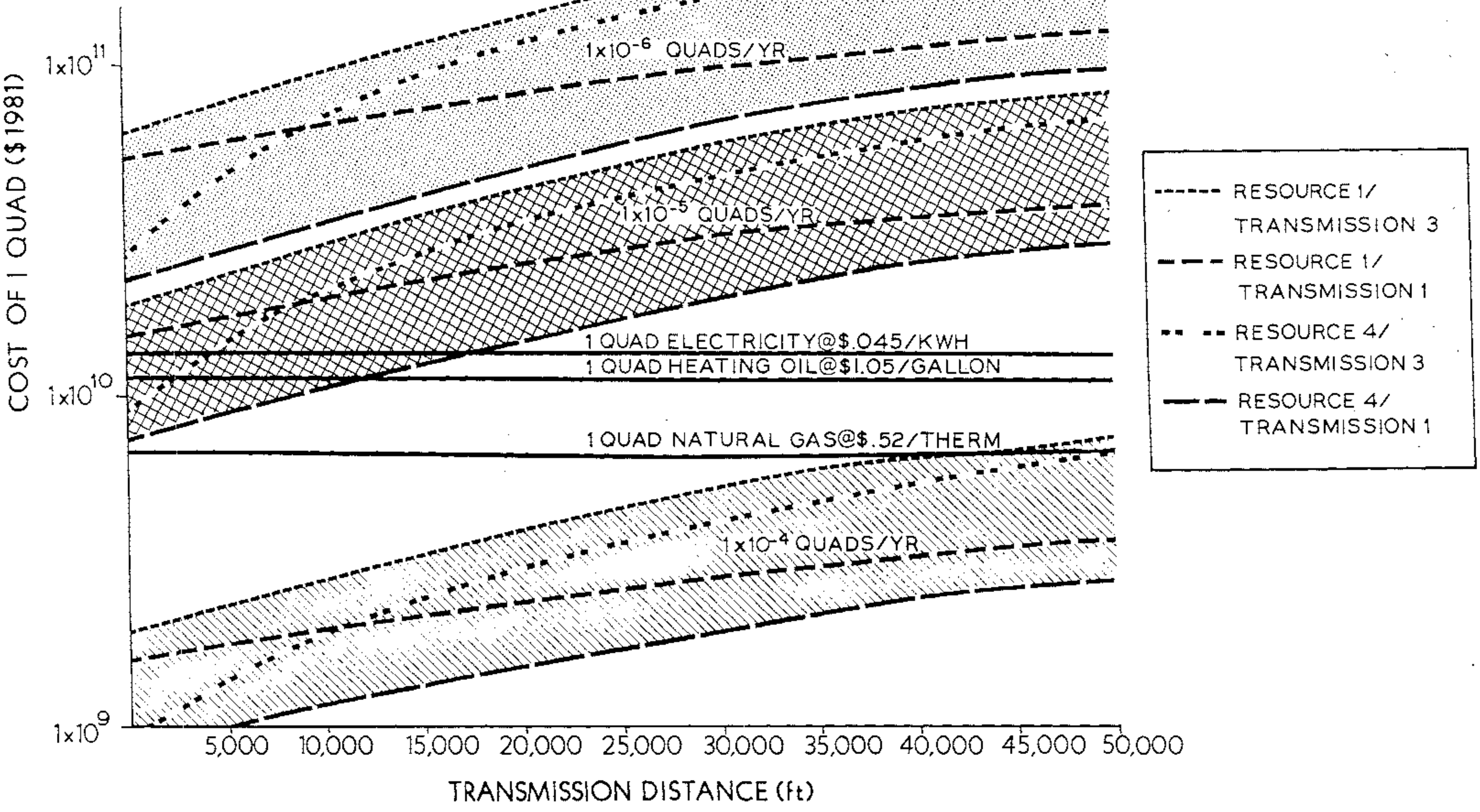


FIGURE 3.
The Effect of Inflation on Geothermal and Conventional Energy Costs

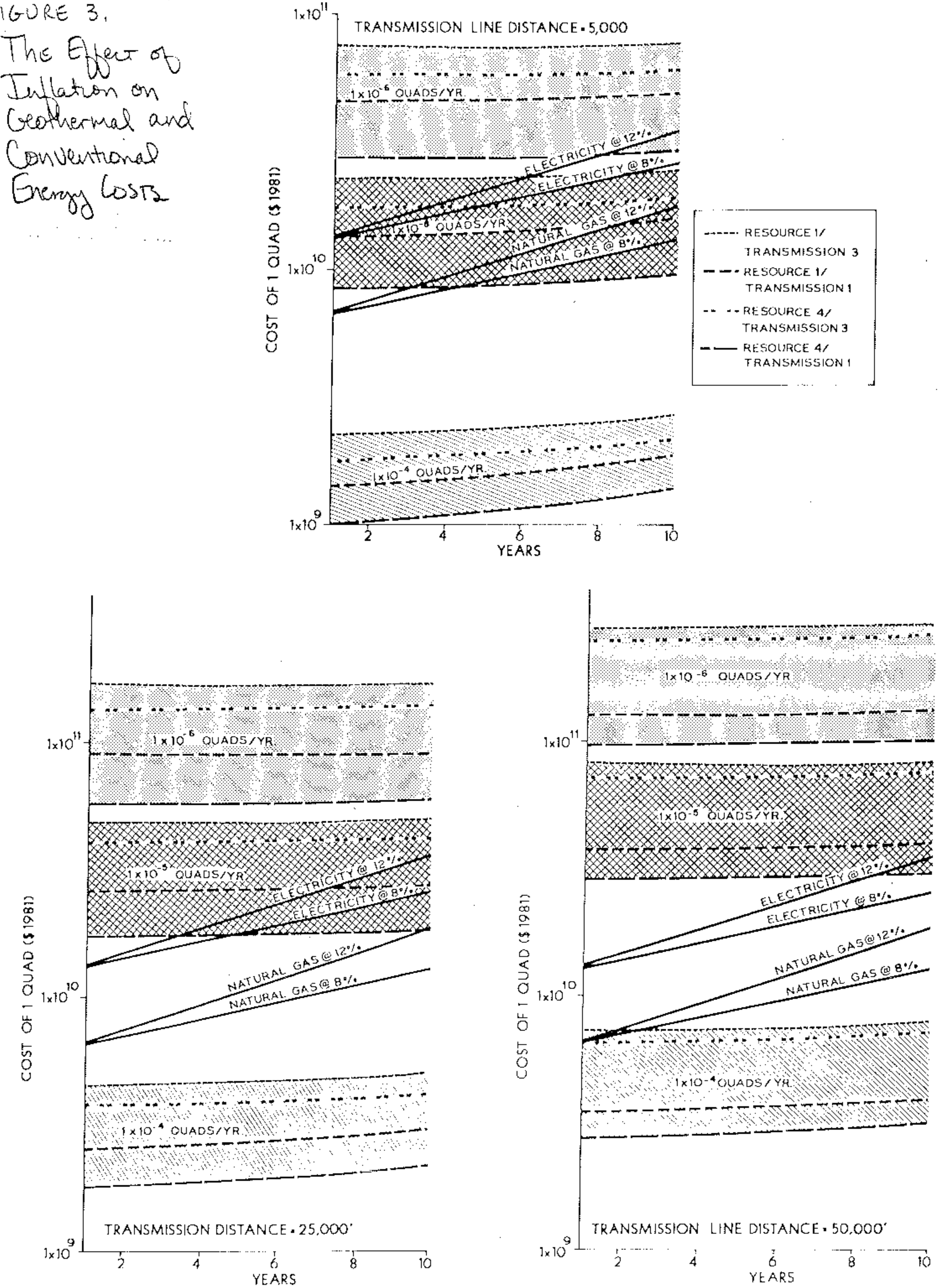
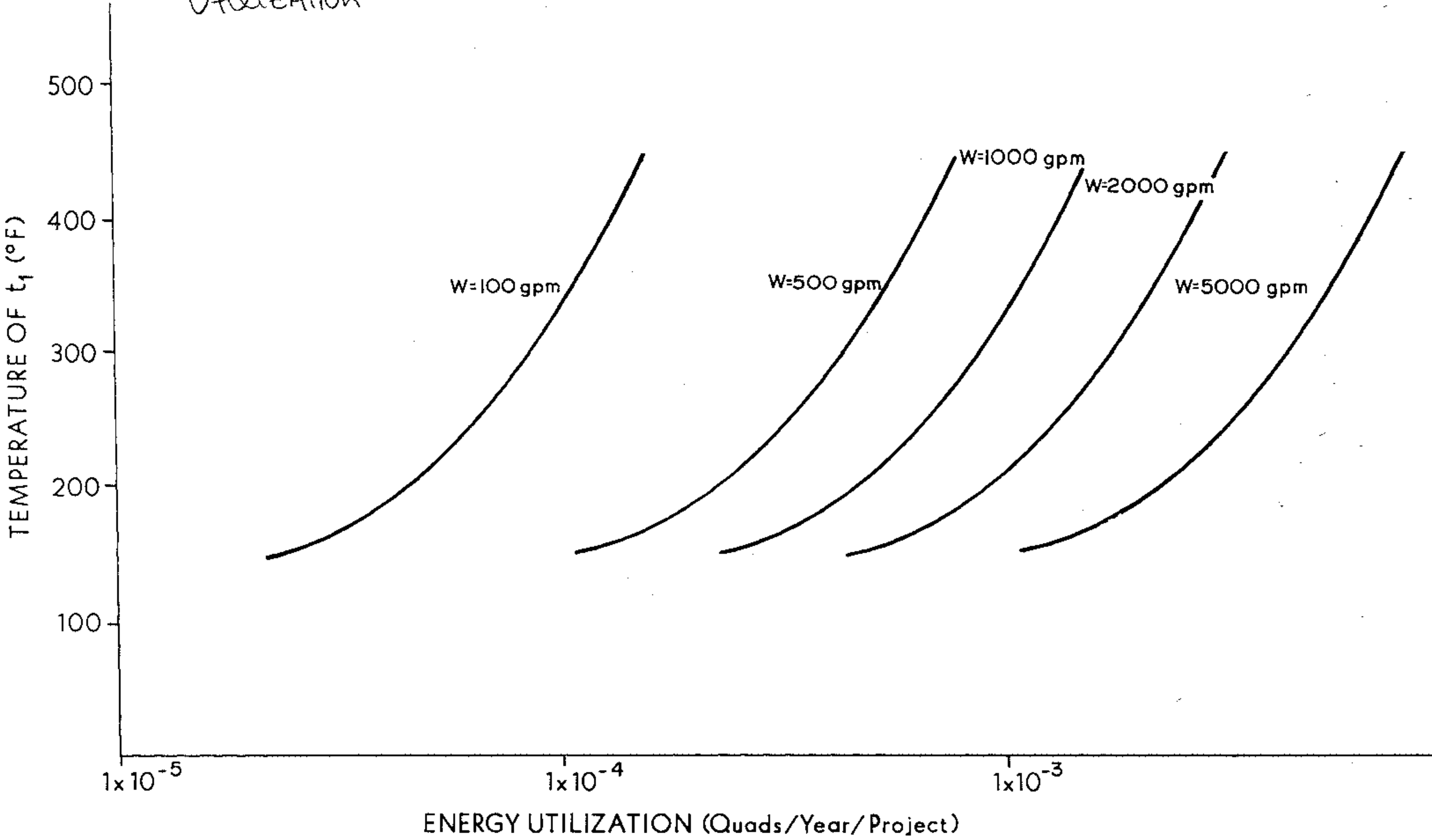


FIGURE 4. The Effect of Variable Fluid Temperature on Direct-Heat Geothermal Energy Utilization



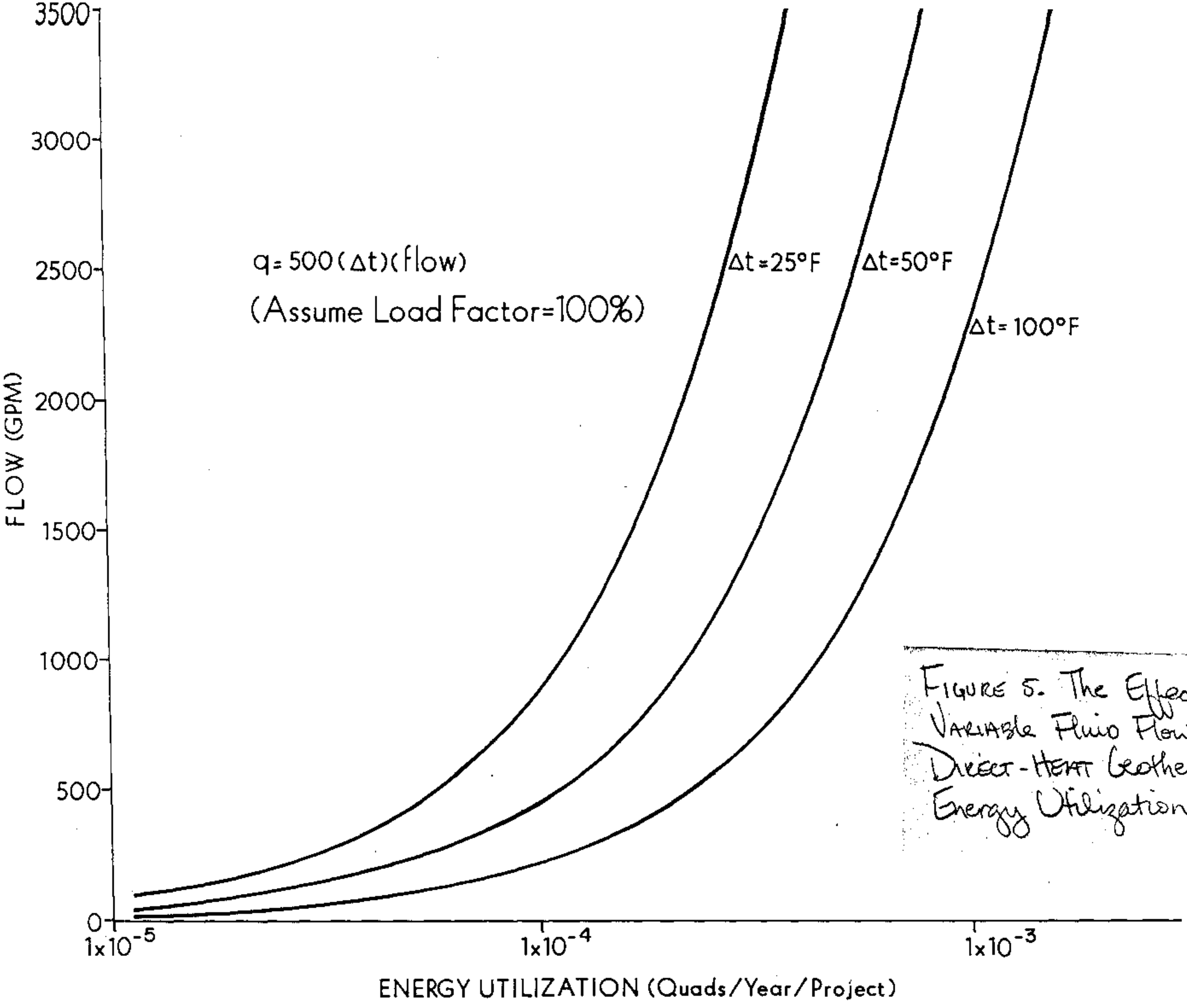


FIGURE 5. The Effect of VARIABLE FLUID Flow on DIRECT-HEAT Geothermal Energy Utilization