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COST UNCERTAINTY AND SIMPLE MODELING FOR DIRECT USE GEOTHERMAL RESOURCES

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ABSTRACT

Detailed sensitivity analysis of a direct heat application produces an area of cost uncertainty which is significantly large when reasonable values of reservoir characteristics are modeled. Principal cost drivers are identified and their interaction examined through regression analysis. A simple equation with first and second order effects is generated and explains 99% of the variance among cost estimates. A simple nomograph is developed with three cost drivers to aid in reaching minimum cost decisions.

INTRODUCTION

In any definitive plan to resolve the long-term energy problem of the United States, geothermal energy must be given significant attention as a low-cost substitute to increasingly costly fossil fuels for some geographical applications where resource supply, energy demand, and product market come together. The situation must be more than mere coincidence; the economic feasibility for developing and using this resource under a specific set of engineering requirements must be clearly demonstrated. This situation has not occurred in a great number of instances in the past. In truth, the number of successful geothermal projects is sparse. Numerous causes are evident. It is the purpose of this paper to delve into the economic feasibility aspects of direct heat applications and to (1) examine the uncertainty associated with the cost of geothermal energy, (2) discuss the identification and effect of principal cost drivers in direct heat application, and (3) present a nomograph methodology for the economic planner to aid the decision-making process.

COST UNCERTAINTY

The principal uncertainties surround the reservoir itself in terms of difficulty in reaching the resource and its temperature, pressure, and flow. In any particular geologic setting, each of these characters is partially independent of the other. Adjacent wells within the same reservoir often differ in those regards where small differences can make much larger differences in the cost of energy.

The primary thrust of the overall program guiding the research sponsored by the Sandia National Laboratories was the derivation of a set of cost data which would reflect the impact of reduced well drilling costs. The Holly Sugar Company project at Brawley, California, was chosen to insure site-specific inputs. The Holly Sugar project anticipates the substitution of low-grade geothermal resources for natural gas and oil in the refining of beet sugar. Sugar beets are grown in areas of several western states which are near known geothermal resource areas. The Brawley plant is located in the Imperial Valley where six known geothermal areas exist with sufficient data to characterize the resource. The plant produces approximately 1 million pounds of sugar during a 5-month operating period.

A study investigating the economic and technical feasibility of modifying the existing Brawley factory was reported by TRW in 1977. The cost estimates based on a conceptually designed retrofit of the facility providing cascaded boiler and beet dryer operations (with off-season alfalfa drying using the same dryers) were \$1.73 per million Btu compared to 1976 costs of \$2.23 for fossil fuels. The data reported below does not consider any off-season use and includes typical exploration costs to characterize the resource. Simplifying the project to make it more applicable in a general sense does not include any retrofit or heat exchanger costs - it merely provides 400 MBtu/hr of energy in brine at a point (distribution center) 1 mile from the well field.

DERIVATION OF THE PRINCIPAL COST DRIVERS

This study used a modified GEOCITY computer simulation model to derive cost of energy estimates. GEOCITY is composed of two principal submodels. The reservoir submodel calculates the cost of energy by simulating the exploration, development, and operation of a geothermal resource from the identification of potential sites through the economic life of the entire system. The distribution submodel calculates the cost of heat by simulating the piping system which carries the water from the distribution center to the users. Since this study assumes the plant to be adjacent to the distribution center, only the reservoir submodel is used. GEOCITY uses present value techniques to equate expected revenues and costs including the cost of capital.

A model of this complexity requires a large number of input variables to project site-specific cost estimates. All input variables have default values and in many instances these default values were used. By limiting the number and range of site-specific values, the analysis becomes a tool for general cost estimation whenever specific values of interest fall within the range of values used. A set of baseline values was chosen to represent expected characteristics and this provided a cost of energy of $3.04 per MBtu. The area of uncertainty surrounding this cost estimate is quite large, however, when one considers other input values which could occur with reasonable probability. Figure 1 shows the percentage change in costs for appropriate percentage changes in input variables. The data are derived by varying one characteristic at a time while all other variables remain at baseline values.

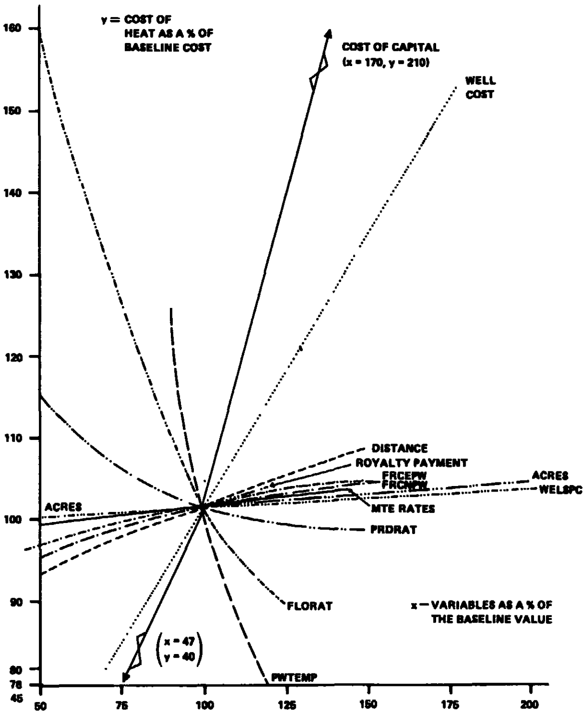

Figure 1. Sensitivity of Cost to Input Changes

Figure 1 clearly shows that some variables have major impacts on costs. Among these are cost of capital, water temperature, flow rate, well cost, injection/production flow, and transmission distance. These first-order effects produce an area of cost uncertainty ranging from $6.57 to $1.43 for changes in the cost of capital.

It is possible to bound an area of uncertainty and to analyze the variability of the cost estimates with statistical techniques. Five factors, each at their low and high values, were incorporated into a 2^5 completely crossed factorial design. With all other factors fixed at baseline values, the GEOCITY model was used to simulate the 32 combinations. Figure 2 is provided to graphically display these data. Since principal project interest involved well completion costs, this factor is displayed in the abscissa. The expected cost of ENERGY value of $3.04 for the baseline case is designated by a star.

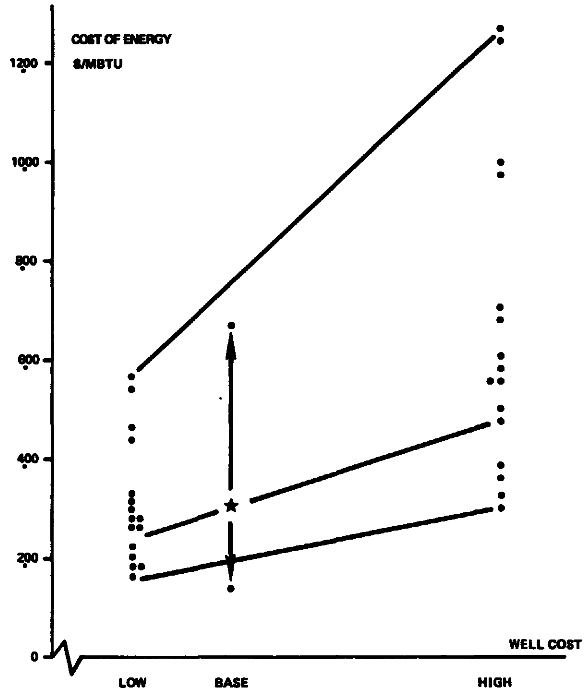

Figure 2. Degree of Cost Uncertainty

The trapezoidal area of cost uncertainty shown in figure 2 is surprisingly large and disproportionately greater in the "higher-than-expected" portion of the figure. It should be noted that the high and low values used to bound each factor were obtained through research of published reports characterizing the specific Holly Sugar Company project. If the high value of the cost of capital were used in lieu of baseline value, the entire cost uncertainty area would shift upward from the baseline value shown. The absolute cost values are biased upward since the data do not take the investment tax credit nor the depletion allowance into effect.

A SIMPLE COST MODEL THROUGH REGRESSION ANALYSIS

Regression analysis was used to statistically assess the influence of the five individual factors and factor interaction effects on the cost of energy. Regression analysis is used to numerically and statistically describe the relationship between a response variable and a set of factors, or independent variables. Because of the absence of any prior information regarding the functional relationship between the cost of energy and other variables, the variables and all second and third-order interactions were included in the model. Variable selection and model search techniques were then employed in the attempt to find the "best" regression equation which could serve as a simple model to estimate the cost of energy for any values of the independent variables within the ranges used in the analysis. The resulting equation is:

$$\begin{aligned}\log (\text{Cost of Energy}) = {} & 3.8855 - 0.3213F \\ & - 0.420P - 0.6544T \\ & + 0.0567W + 0.0150D \\ & + 0.0431F * T \\ & + 0.0236F^2\end{aligned}$$

where $10^{\log (\text{Cost of Energy})}$ = Cost of energy and

F = Flow Rate (100,000 ℓb/hr), range 2-5.
P = Ratio of injection well to producing well flowrate, range 1-3.
T = Brine temperature (in 100°C), range 1.35-1.77.
W = Complete well cost (in $100,000), range 3.50-9.0
D = Distance to plant (in miles), range 0.5-1.5.
C = Cost of capital (fixed at 12.6%).

The model explains 99% of the cost variance (R^2) with a standard error corresponding to cost of energy estimates within 4.4% of the GEOCITY values 67% of the time. This simple equation can be easily programmed into desktop calculators such as the TI-58 to provide almost instant and costless estimates for values of the independent variables within the minimum and maximum bounds from which this equation was computed.

A NOMOGRAPH FOR ECONOMIC PLANNING

With this simple regression model it was possible to put together a nomograph relating temperature, flowrate, and well costs (see figure 3). This construct is uniquely capable of examining additional drilling alternatives at any well depth if temperature and flowrate gradients are known. A given combination of the three characteristics produces an initial estimate by locating the temperature-flowrate combination and moving leftward to the baseline well cost. From this point a diagonal movement parallel to the sloping lines to the exact well cost produces the appropriate cost of energy estimate. The calculation of 500 ft. incremental combinations determined from measured gradient data can be plotted on the temperature flowrate diagram to indicate the potential benefits of deeper drilling. Incremental well costs associated with these points can be calculated by first determining the ratio of actual to average costs of drilling using the well drilling costs diagram, and second, by multiplying the average incremental costs shown for the appropriate depths by the ratio value. These incremental well costs, when added to the actual well costs, are the abscissa coordinates for the incremental temperature-flowrate combinations plotted. The resulting cost of energy versus well drilling cost must eventually turn upward as drilling costs rise at an increasing rate. The lowest point of this generated cost curve represents the estimated minimum cost of energy.

SUMMARY

All geothermal projects represent a real cost risk for the developer, a risk which must be reduced by characterizing the actual resource as much as possible to prevent shocking cost surprises. Simple models can be composed to aid in rapidly examining these risks and to help in making decisions which tend toward minimizing energy costs.

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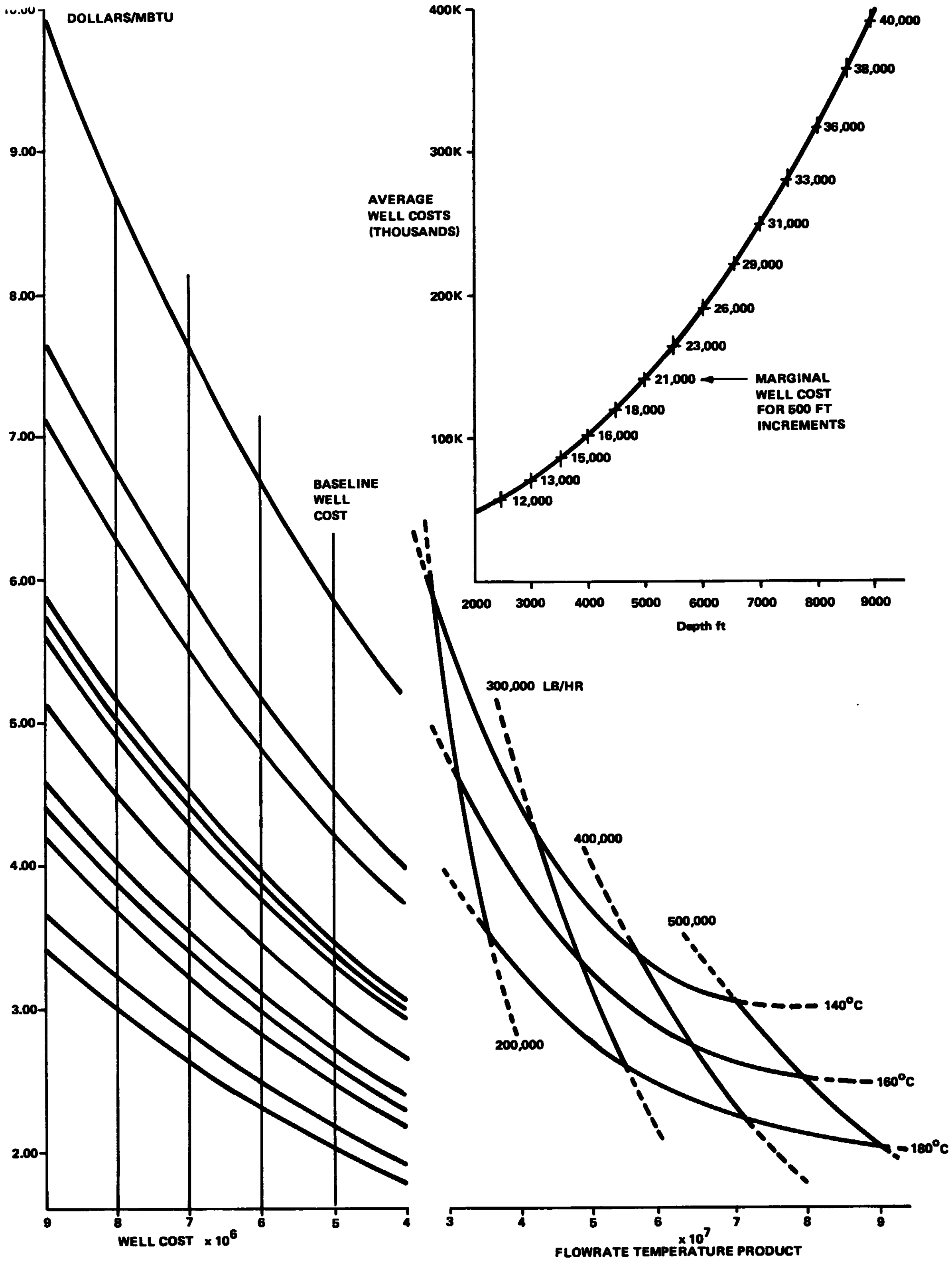

Figure 3. Cost of Energy Nomograph