IDENTIFICATION OF GEOTHERMAL RESERVES AND ESTIMATION OF THEIR VALUE

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ABSTRACT

This paper discusses a procedure for estimating the value of a hot water geothermal property from a resource owner's point of view. Two methods make up the procedure: a "conservative" method of estimation and an "optimistic" one. Value of a property by both methods is estimated to equal the present value of future income less the cost of resource extraction. The two methods share a common set of assumptions (e.g., that the price of hot water at the start of cash flow from a project will be the same). However, the methods differ in important ways. The optimistic method, for example, allows for future increase in price that in turn offsets discounting of future income. Together the methods define a range of values that might reasonably be assigned to a property.

INTRODUCTION

This paper describes and illustrates a procedure for estimating the wellhead value of a hot water geothermal resource. The procedure also provides a basis for estimating what part of a geothermal resource is a reserve. The procedure may be applied to property for which no specific development plans have been formulated or announced. It may be termed "property appraisal." The procedure should not be confused with the procedure one would follow in deciding upon the financial merit of a specific, complete development plan for a resource. Such a procedure is usually called a "project evaluation."

ASSUMPTIONS ABOUT PRICE, COST, AND GEOLOGY

To carry out this analysis, we begin with a series of assumptions regarding: 1) price that one would expect to receive for sale of geothermal fluid (Howard, 1980 a,c), 2) cost to establish the capability to produce the resource (Howard, 1980 b,c), and 3) the plan and schedule to bring the resource into service (Howard, 1980 d). We assume complete knowledge of the resource, that heat contained in the fluid only is recovered, and that fluid is completely recovered. We assume that any well drilled into the resource will yield an ultimate recovery of approximately 10^{10} lbm (Howard, 1980 b). We assume that enough wells are available to service demand at all times during production.

Consideration of possible plans for bringing a resource on stream is particularly complex. This problem is reviewed in some detail in Howard (1980 d) and is discussed briefly below. It has been necessary to make assumptions regarding: a) the use to which the hot water property will be put (low temperature direct use, industrial heating at medium temperatures, or to produce electricty), b) to assign annual and lifetime loads accordingly and c) to define a time for start of cash flow.

ARGUMENT FOR THE PRESENCE OF A RESERVE

According to the definition of a reserve, a reserve exists if the geothermal energy can be extracted and used at costs competitive with other energy sources at the present time (Muffler and Guffanti, 1979). The price of hydrothermal geothermal fluid, p, at the wellhead is proposed to depend on its energy content as shown in Figure 1 and is a function of relative specific enthalpy (see Howard, 1980 a,c). On the other hand, the cost, c, of bringing hydrothermal fluid to the wellhead is proposed to depend on its depth of occurrence and ultimate recoveries per well (Howard, 1980 b,c). Figure 2 shows the cost function. Both functions are given on a mills per pound mass basis. To a first approximation that volume of fluid for which

$$p > c$$

can be considered a reserve.

Table 1 lists information regarding a specific resource. This information can be used to make price and cost estimates in order to determine the part, if any, of the resource that is a reserve. The volume under consideration in this example is actually only a part of a still larger resource. The example is bounded by the 310°F isothermal surface, the 7500 foot depth plane, and the vertical sides of the property.

Study of Table 1 shows that, according to definition, volumes between 2500 and 6500 feet are reserves. No reserve exists below 6500 feet because cost exceeds price.

ASSUMPTIONS REGARDING DEVELOPMENT

The value of a reserve depends not only on its size, average price, and cost per unit mass, but also on the plan and schedule for its development. Income to be received at some future time is generally discounted in order to compare cumulative income over the life of a project with costs borne at the start of the project. In order to discount future income, however, we need to make some assumptions regarding the way in which a resource is to be developed. Assumptions regarding plan and schedule for development are discussed in Howard (1980 d) and are summarized in Table 2. If the representative temperature is greater than 350°F, for instance, we assume that the resource will be used for electrical power generation. The annual load is assumed to be in the range of 20 to 100 x 10^9 lbm depending on temperature (cf. Austin, 1975) and the 30 year lifetime load is assumed to be in the range of 650 to 3000 x 10^9 lbm.

We also assume, for example, that an application in the less than 250°F temperature range will start its cash flow one year after purchase and will produce a constant cash flow equal to the product of annual load and price per pound mass (dependent on temperature) for 30 years. For an application in the 250–350°F range, we assume that a constant cash flow will start three years after purchase and will continue for 30 years. For electric power production we assume the start of cash flow to begin six years after purchase. We assume that all costs to establish a 30 year capability to produce are borne at the start of development of the project.

CONSERVATIVE ESTIMATES OF VALUE

A reasonable estimate of the monetary fair market value of a property can be determined by calculating the present worth of the initial project one might logically expect the property to support. Such a determination can be made if one accepts the assumptions that: 1) the size and representative temperature and depth to the resource are known, 2) estimates for the average price and cost of the fluid in the resource are valid, and 3) the plan and schedule for development of the first project on the property are those sketched in the previous section and summarized in Table 2. If one accepts these assumptions, it is a straightforward procedure to calculate a present worth as a function of discount rate. One may then use these quantities as a measure of the value of the property.

We calculate the present worth of the anticipated initial project on the property as follows.

The annual mass use of the resource, Q_A, expressed in pounds-mass, varies with the type of project and more fundamentally, with the representative temperature of the resource (see Table 2). The price that one might expect to realize from sale of a pound-mass of the resource, p, is a function of relative specific enthalpy given in mills per pound mass (see Figure 1). Annual cash income, I_A, is the product:

(1) $$I_A = Q_A p$$

We assume a 30 year lifetime for a project and a constant annual income. Thus the value of all income from the 30 year life of the project is, at the start of cash flow, given by:

(2) $$I' = I_A D';$$

where D' is the discount factor given by

$$(3) \qquad D' = \frac{(1+i)^{30} - 1}{i(1+i)^{30}} .$$

The quantity i is the annual discount rate.

Inasmuch as income from the 30 year life of the project will start at various future times depending on the type of project, anticipated 30 year income at the start of cash flow must itself be discounted to zero time. This discount factor is given by

$$(4) \qquad D'' = \frac{i}{(1+i)^m}$$

where, as before, i is interest rate and m is years until start of cash flow.

The present value of future incomes, I", is equal to all income discounted to the start of cash flow, I', and then disounted again to zero time.

Algebraically:

$$(5) \qquad I'' = I'D''$$

$$(6) \qquad = I_A D'D''$$

$$(7) \qquad = I_A \frac{(1+i)^{30} - 1}{i(1+i)^{30}} \cdot \frac{1}{(1+i)^m} .$$

Present worth, PVP, is the difference between present value, I", and present cost, C. We estimate present cost by determining the lifetime mass requirements of the project and multiplying by a cost per unit mass, c. The lifetime requirements are listed in Table 2 and Figure 2 shows costs on a pound-mass basis as a function of representative depth to the reservoir (see Howard, 1980b). Thus:

$$(8) \qquad PVP = I'' - C.$$

OPTIMISTIC ESTIMATES OF VALUE

Although an estimate of present worth, discounted appropriately as explained above, provides a basis for estimating value of a property, still other considerations should be addressed in order to fully appreciate its value: 1) escalation of prices (and costs) over the lifetime of the project; 2) the assignment of value to that part of the property in excess of the requirements of the initial project; 3) factoring in the likelihood that development will actually occur in view of geographic and demographic considerations.

DISCUSSION

We propose to treat the question of escalation of costs and prices in a simple way. In making an appraisal we propose to treat all costs as incurred at the start of the project. In brief, our reasoning is that deferred escalated costs (discounted at about 12%) and present costs are more or less equivalent (Howard, 1980d).

Escalation of prices for energy had been dramatic in the 1970's and recently has been on the order of 20-25% (Howard, 1980a,c). Increases in price on the order of 12% or more per year are in the range of rates of return on investment that appear to be acceptable to resource developers. Comparison of escalation of prices and rates of return suggests that increases in prices and the process of discounting future incomes may cancel each other. The consequence of this cancellation is that the present value of a project is equal to annual income times duration of the project.*

The question of mass of the resource much greater than 30 year load, or in other words, assignment of value to that part of the property in excess of that required for the initial project, can be handled in several ways. First is to define the property areally (or volumetrically) so that it is insignificantly bigger than that required for the initial project. The second is to expect no present value of the excess but to ask a royalty on production from it, should production of the excess ever occur.

The possibility that development will ever occur on a property is impossible to generalize about because it is dependent upon the specific property and on individual judgment. This subjective uncertainty and the uncertainty associated with escalation of

*A more rigorous analysis could have been carried out wherein future prices (and income) are increased according to an equation involving an escalation factor. Among the solutions derivable from such an approach is the solution wherein escalation just offsets discounting (i.e., the so-called optimistic case, likelihood of 1, of this paper). Other solutions would also be available, in principle, however, whereby one could estimate the value of the property as a function of escalation as well as other parameters discussed in the paper. The importance of such escalation was emphasized to me by my colleague, A.N. Graf, however, its investigation is beyond the scope of this paper.

prices offsetting discounting of future income may be combined in a single factor, f ($0 < f < 1$), that we have called a "likelihood" factor. We recognize it as a subjective factor and feel that the best way to handle is is to display it clearly.

Treatment of the considerations introduced in this section of the paper may be summarized as follows:

1) the value of an anticipated initial project on an undeveloped geothermal property is equal to annual income from the project times a 30 year expected project lifetime:

(9) $$V = I_A x30;$$

2) the value of the project should be discounted by the factor f

(10) $$0 \leq f \leq 1$$

to reflect the likelihood that development will occur and that discounting of future income is unnecessary:

(11) $$V' = Vf = f\ I_A x30;$$

3) the cost of the project, C, is calculated as in the conservative case;

4) the value of the property is its present value profit, V":

(12) $$V'' = V' - C = f\ I_A x30. - C$$

COMPARISON AND GENERAL COMMENT

It can be shown that the estimated value of the property is the same according to either method for certain conditions. For $i = 0$ and $f = 1$, $V'' = PVP$.

Furthermore, the two estimates are equal, $V'' = PVP$, when

(13) $$f = \frac{D'D''}{30}$$

The quantity D'D" depends on the discounting rate, i. For discount rates in the range of 10-20%, namely the range most commonly mentioned as reasonable for discounting, D'D" has value of about 5. Thus, roughly, $V''>PVP$ if $f>1/6$. Based on this argument, feeling that most of the time f will be a bit greater than 1/6 and will therefore lead to higher values, we have termed the method involving the likelihood factor, f, as the optimistic method.

It should be fairly clear from the previous discussion that only a range of values can be reasonably defined by the procedure. Subjectivity cannot be avoided, and perhaps it is unreasonable to expect that it could be avoided. The procedure does, however, define a finite range of values and helps to elucidate the consequences of certain subjectively set prejudices, particularly acceptable discount rates and "hunches" regarding energy prices in the future. We anticipate that sellers will favor the optimistic method; buyers, the conservative method--for obvious reasons. We also propose that the range of values will be practically limited by the conservative methods using discount rates close to the prime rate (a low estimate) and by the optimistic method using a likelihood factor of about 0.5. It would be surprising to us if any property were appraised for more than its optimistic value with a likelihood factor of 1.0.

EXAMPLE CALCULATION

In this section, we illustrate the procedures explained previously by application to a specific example. Information about the illustrative example is listed in Table 3.

We wish to calculate and display information about the property using both conservative and optimistic methods.

Figure 3 shows present value profit for the property as a function of discount rate and of likelihood factor. Inspection of the figure shows the following. For interest rates greater than 8%, value of the property is negative. For an interest rate of 12% value is -\$125 K. In contrast, value of the property is estimated to be almost \$200 K for a likelihood factor of 0.5.

Study of a report on this property suggests that ultimate recoveries of more than 10×10^9 lbm per well may be attainable and thus that our general cost estimating should be modified in view of specific information. Initial flow rates per well (pumped) are on the order of 400,000 lbm/hr. The calculations shown in Figure 3 are based on a representative well having an ultimate recovery of 10×10^9 lbm, an hourly mass flow of 240,000 lbm, and a lifetime of at least 5 years. Thus we have recalculated the example using only 60% of costs (i.e., 240,000/400,000). (If even greater ultimate recoveries could be shown costs would decline still more and property value increase even more.) Recalculation leads to the conclusions shown in Figure 4. For interest rates greater than about 14%, value of the property is negative. For an interest rate of 12%, value is \$40,000. In contrast, value of the property is approximately \$372,000 for a likelihood factor of 0.5.

Clearly a fairly wide range of values results from the two methods and two appraisals. Some subjectivity and arbitrariness are necessary if the range is to be cut down. As a seller we would argue for a value of at least \$372 K. As a buyer we would propose a nominal price of 0 (current price rate being more than 14%). Thus a reasonable compromise value, which obviously must be negotiated, would be $186 K, namely half the difference.

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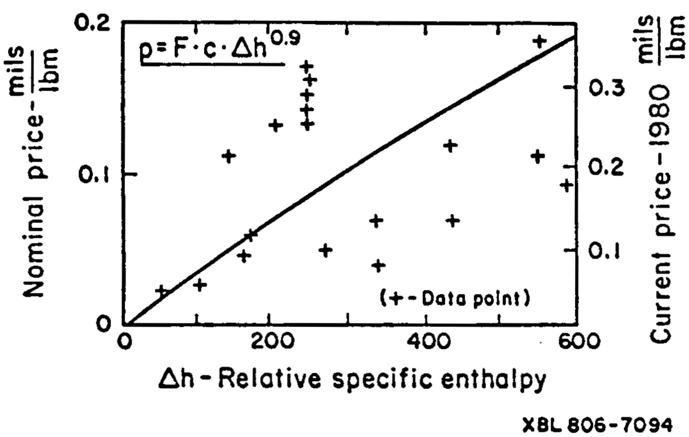

Figure 1. Proposed equation for estimating price of geothermal hot water based on its energy content.

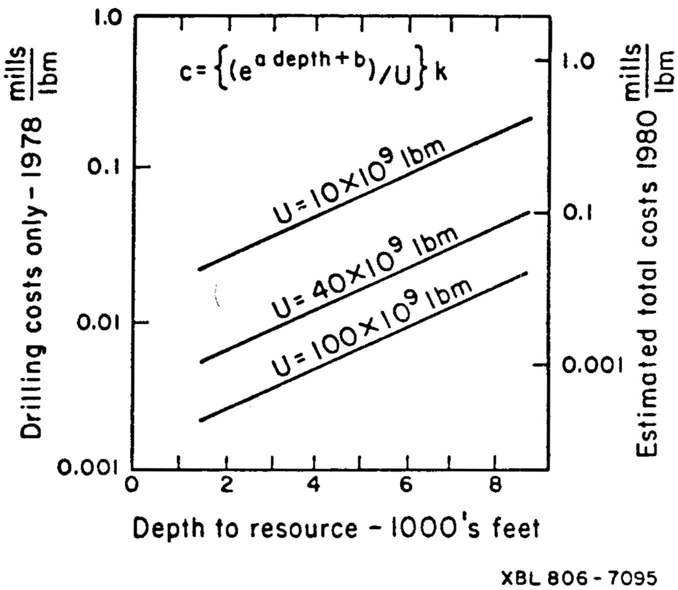

Figure 2. Proposed equation for estimating cost of geothermal hot water based primarily on its representative depth of occurrence.

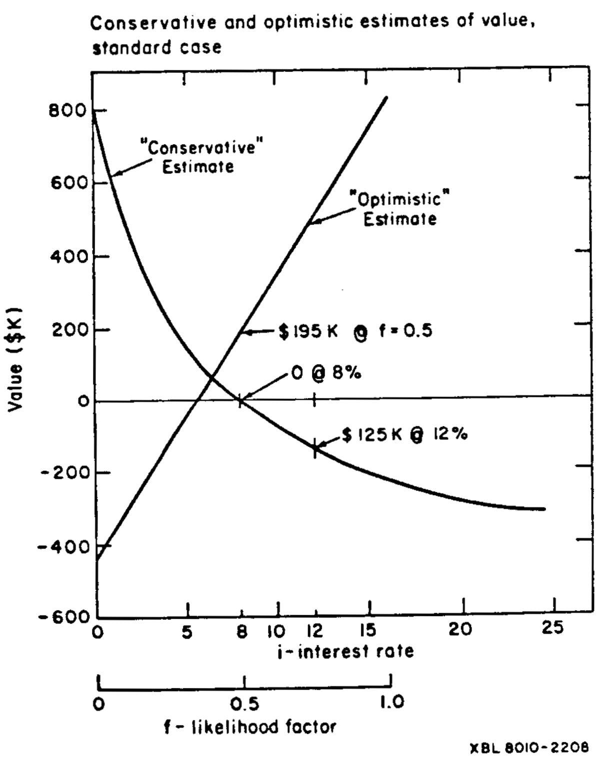

Figure 3. Conservative and optimistic estimates of value for the illustrative example, standard case.

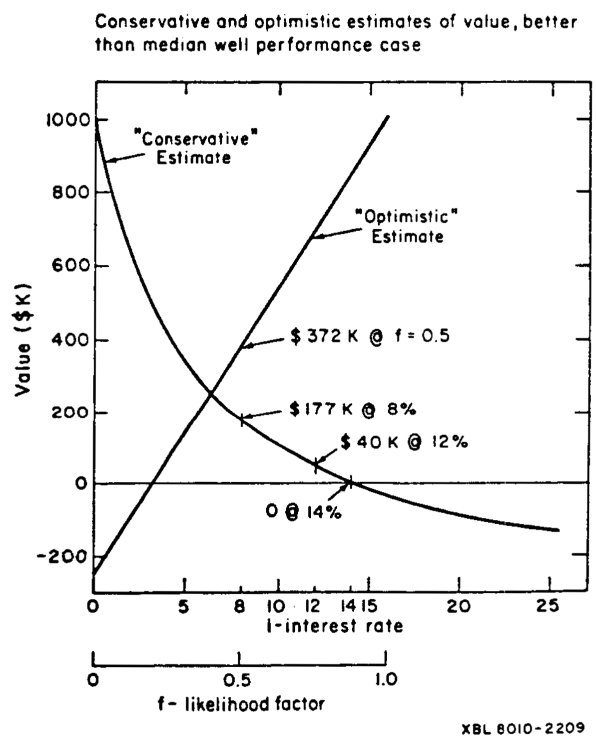

Figure 4. Conservative and optimistic estimates of value for the illustrative example, for better than median well performance.

TABLE 1. DATA ON PROPERTY A*

DEPTH INTERVAL (Feet)	MASS OF FLUID (lbm) X10"	AVERAGE TEMPERA-TURE °F	AVERAGE ENTHALPY PER POUND MASS (Btu/lbm)	AVERAGE RELATIVE SPECIFIC ENTHALPY (Btu/lbm)**	ESTIMATED PRICE PER POUND MASS (Mills/lbm)	**REPRESEN-TATIVE DEPTH (Feet)	ESTIMATED COST PER POUND MASS (Mills/lbm)	DIFFERENCE (Mills/lbm)	COMMENT
2500-3500	7.81	320	264	237	0.171	3000	0.051	0.120	Reserve
3500-4500	7.56	326	270	243	0.174	4000	0.070	0.104	Reserve
4500-5500	11.7	329	273	246	0.176	5000	0.097	0.079	Reserve
5500-6500	17.1	334	278	251	0.180	6000	0.134	0.046	Reserve
6500-7500	16.4	338	282	255	0.182	7000	0.185	- 0.003	Not a Reserve

*Reservoir originally defined by 310°F surface, 7500 foot depth plane, and lateral boundaries of the property.
**Relative to 27 Btu/lbm reference point.

TABLE 2. ASSUMPTIONS FOR DEVELOPMENT OF A HOT WATER GEOTHERMAL RESOURCE

CLASS	TEMPERATURE RANGE °F	USE	ANNUAL LOAD x 10^9 lbm	LIFETIME LOAD (30 YEARS) x 10^9 lbm	INSTANTANEOUS WELL REQUIREMENTS NO.	LIFETIME (30-YEAR) WELL REQUIREMENTS NO.	DELAY TO START OF CASH FLOW-YEARS
LOW	250°F	residential heating	0.5	15	1	2	1
MEDIUM	250-350°F	commercial heating	5.0	150	3	15	3
HIGH	350°F	produce electricity	20-100	600-3000	10-50	60-300	6

TABLE 3. INFORMATION ABOUT THE ILLUSTRATIVE EXAMPLE

ITEM			COMMENT
$\tilde{T}$,	representative temperature	180°F	
$\tilde{d}$,	representative depth	1300 ft.	
R,	total mass of fluid in the reservoir	2.79×10^{11} lbm	
I_A,	anticipated annual income from initial project	\$42,470	0.5×10^9 lbm $\times$ $0.0849 \frac{\text{mills}}{\text{lbm}}$
I_{30}	30 year income from initial project, no "discounting"	\$1,274,100	
C_{30},	anticipated total cost to service initial project	\$442,564	15×10^9 lbm $\times$ $0.029504 \frac{\text{mills}}{\text{lbm}}$
$\dot{q}$,	reported flow rates	800 gpm (∿400,000 lbm/hr)	