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PRICE ESTIMATES OF HOT WATER GEOTHERMAL ENERGY

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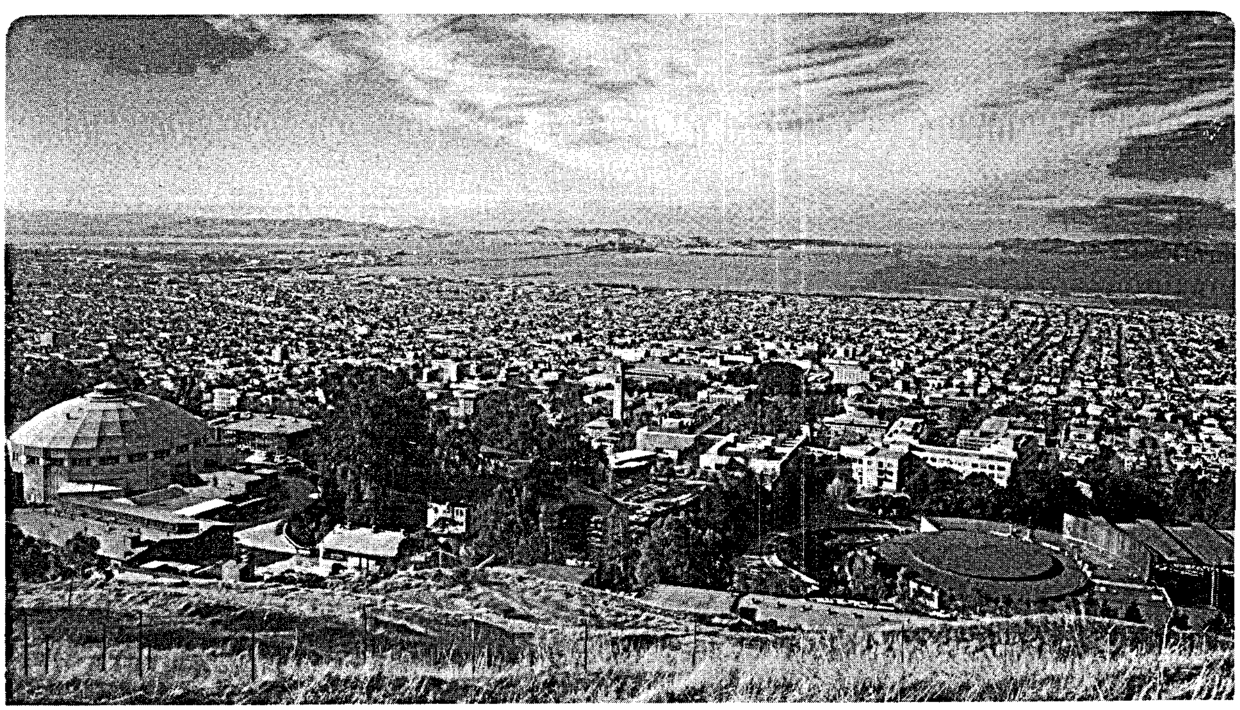
J.H. Howard

February 1981



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ABSTRACT

A generalized price equation for hot water geothermal energy has been developed. The equation is based on analysis of proposed plans for use of geothermal energy to displace specific quantities of fossil fuels. The equation is useful in starting negotiations for sale of heat from a hot water resource and is necessary in any reserve valuation in the absence of a firm sales contract. The proposed equation is:

$$p = F \cdot c \Delta h^{0.9}$$

where p is the price in mills per pound mass of fluid containing energy with specific enthalpy, Δh (in Btu's per pound mass, lbm) relative to $59^{\circ}F$ ($15^{\circ}C$) saturated compressed liquid. The factor F is the dimensionless ratio of current national average fossil fuel price to major users to the nominal price of $\$1/10^{6}$ Btu; the factor varies with time. The factor c is a constant equal to 6×10^{-4} mills/Btu.

The sales price of the only known hot water geothermal energy sales contract is presently 0.082 mills/lbm and compares with 0.079 mills/lbm according to the proposed equation. Good agreement---although perhaps somewhat fortuitous---supports the contention that the equation is a useful frame of reference for negotiation and for reserve valuation.

INTRODUCTION

Purpose of the Paper

This paper discusses estimates for the price of hot water geothermal energy. The price of naturally occurring steam from vapor dominated systems is fairly well set by the history of contracts at The Geysers, California, (see Finn, 1975; Jenkins, 1978) and its consideration is outside the scope of this paper.

The discussion is presented from the point of view of a resource owner who is interested in estimating a value for his property or in entering into negotiations for the sale of geothermal energy over the lifetime of the resource.

The term "hot water fuel prices" is used interchangeably with the term "prices of hot water geothermal energy" and compares with the term "alternate fuel prices." "Price" should be distinguished from "cost." Price refers to the "amount at which transactions take place in the market." "Cost" emphasizes "whatever is requisite to secure benefit." The price at which a geothermal resource owner sells a unit of his geothermal energy should exceed his cost to recover it from the earth.

Price and specific enthalpy are presented with respect to pound mass because in dealing either with resource in the ground or with sales of production, a resource owner must carry out his calculations on the basis of mass of geothermal fluid he can produce from his property.

METHOD OF ANALYSIS

Possible Methods of Determining Prices

Three possible methods for determining prices for hot water fuel are:

1. reference to a marketplace,
2. negotiation in view of a specific application, of appreciation of the total economics of the proposed use, and of the bargaining positions of interested parties; and
3. review of a suite of possible uses of the resource and consideration of the price of displaced alternate fuels.

Although contracts exist (e.g., Finn, 1975; Eastlake, 1979) which influence the new contract price for geothermal energy---at least locally---there is no geothermal marketplace in the sense of a commodities market. Consequently reference to a marketplace is really not a viable method.

Negotiation in view of a specific application of a specific resource is the method that will undoubtedly be followed for the foreseeable future when a sale approaches final stages. Negotiated prices will rest in part on arguments involving the price of displaced alternate fuel. However, they will also very likely include provision to assure optimum and efficient energy use (and payment for it), provisions for penalties in the event of non-performance by either party, and so on.

The third method, a review of a suite of possible uses of hot water geothermal resources and consideration of the price of displaced alternate fuels, leads to a generalized price equation. This paper addresses the third method and presents a correlation of price per pound of hot water geothermal fluid with relative specific enthalpy. A generalized price equation relating price and enthalpy is proposed, but the argument recognizes variation of price from the proposed equation in view of the information used in the analysis. The equation should be a useful reference in starting negotiations for the sale of geothermal energy. This information should also be useful as a guide to setting prices for bonuses at lease sales, in the outright sale of a geothermal property, and in national resource assessments analysis wherein an effort is made to determine the part of the resource that could be labeled "reserve." The author's interest in a generalized price equation grew out of concern over geothermal property valuation. It is impossible to carry out a valuation without knowledge of the value of the commodity. In view of the lack of a marketplace for geothermal energy and of only one known contract for sale of hot water geothermal energy, it became necessary to envision what the price of hydrothermal fuel might be in view of its potential capacity to displace alternate fuels, the prices of which are known.

Procedure Based on Suite of Possible Uses and Consideration of Displacements of Alternate Fuels

The procedure in this paper involves the following steps:

1. selection of suite of proposed uses for hot water geothermal energy over the temperature range 110°F to 600°F,
2. for each potential direct use, determination of:
   a. entrance temperature requirements for use,

b. specific enthalpy content of the geothermal fluid called for in the use, referred to a reference specific enthalpy of 27 Btu/lbm (i.e., enthalpy of saturated compressed liquid at $59^{o}F$ or $15^{o}C$) and assuming that the geothermal fluid is saturated compressed liquid,

c. the energy content of the fuel to be displaced annually through the proposed use of geothermal energy, 100% energy conversion is assumed for the alternate fuel (cf. Bloomster et al. 1977),*

d. the number of pounds of geothermal fluid at required temperature needed to displace the alternate fuel annually. The mass required depends on the specific enthalpy content of the geothermal fluid, the enthalpy of the fluid discarded after use in the process, and the total amount of energy called for in the substitution.

e. the total price of the alternate energy displace in one year at a nominal price of $\$1.00/10^{6}$Btu and

f. the ratio of the total price of the alternate energy to the number of pounds of geothermal energy used in a year,

3. for use in generation of electricity, determination of:

a. kilowatt-hours of electricity that can be generated per pound of hot water geothermal fluid at a specified temperature,

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*This assumption is slightly prejudiced against geothermal, and thus equation (6) (below) for the price of hot water geothermal energy is somewhat on the low side in the direct use temperature range (say 15^{o} - $150^{o}C$). Conversion efficiencies to raise steam or hot water from fossil fuels is perhaps 95% (cf. Bloomster et al., 1977, p. A-1).

b. determination of the number of Btu's required to generate, by alternate fuel, one kilowatt-hour of electricity at representative conversion efficiency. The efficiency chosen is 36.5% and is the average of the best rate and the systemwide rate reported by PG&E in 1974 (see Finn, 1975). This quantity is 9350 Btu; i.e., 9350 Btu's of fossil fuel will, on average, produce 1 kwhr of electricity.

c. the price of 1 kwhr of electricity when the price of 10^6 Btu of alternate fuel is 1000 mills. In view of the conversion efficiency (in b, above) this price is 9.35 mills and

d. the price of 1 pound of hydrothermal fluid in view of the number of kilowatt hours that can be generated by that pound of hydrothermal fluid at specified temperature and of the fact that hot water geothermal energy can displace alternate fossil fuels that produce electricity at a nominal price of about 9.35 mills/kwhr (c, above).

Algebraically the procedure can be summarized by the following formulas for direct use applications:

(1) D_{alt} = displaceable alternate fuel per year (Btu/yr)

(2) $\Delta h\big|_T$ = specific enthalpy content of saturated compressed geothermal liquid at temperature T (Btu/lbm) relative to a reference enthalpy, 27 Btu/lbm

(3) R_g = geothermal energy required to displace alternate fuel per year,

$$\frac{\text{lbm}}{\text{yr}} = \frac{D_{alt}}{\Delta h\big|_u}$$ where $\Delta h\big|_u$ is the enthalpy of the geothermal fluid that will, in fact, be utilized in the process

(4) Σp_{1yr} = total price of the alternate energy displaced in one year ($/yr) $= D_{alt} \times \frac{\$1}{10^6 Btu}$

(5) r = ratio of the total price of the displaced energy to the geothermal energy required to displace it,

$$(\$/lbm) = \frac{\Sigma P_{1yr}}{R_g}$$

For conversion to electricity similar reasoning follows if one assumes that geothermal replaces a unit quantity of alternate fuels per year.

The suite of potential uses is listed in Table 1. Direct use applications are from information supplied by Bakewell and Herron (1979) who reviewed engineering studies of applications prepared for the Energy Research and Development Administration under a 1976 Program Research and Development Announcement (see Bakewell and Herron, 1979, Table 1). Information on use of geothermal energy to displace fossil fuels is based on studies of the efficiency of conversion of geothermal energy to electric energy by Austin (1975) and Meal and Guillamon-Duch (1979).

The reference point $p = 0, \Delta h = 0$, represents the contention that 59^oF (15^oC) geothermal fluid has no value.

GENERALIZED PRICE EQUATION

Expected General Features of the Equation

Three features one would expect between the price of hot water geothermal energy and its relative specific enthalpy, as based on a displaced fuels argument, are:

1. it should have essentially no value at zero specific relative enthalpy,
2. it should have a higher price at higher values of specific relative enthalpy, and
3. price should increase as an increasing power function of enthalpy, inasmuch as maximum energy availability from hydrothermal fuel is an increasing power function of enthalpy (Milora and Tester, 1976, p. 17).

Proposed Generalized Price Equation for Nominal Price of Alternate Fuel

We sought a simple function between price and relative specific enthalpy that could represent the data. The proposed function is based on a curve fitting routine by Hewlett-Packard that is summarized in the Appendix of this paper. The generalized nominal price equation is:

$$(6) \qquad P = c\Delta h^{0.9}$$

where c is a constant equal to 6×10^{-4} mills/Btu and Δh is relative specific enthalpy given in Btu's/lbm. The function, along with plots of the data points on which it is based, is shown in Figure 1.*

The function itself ($y = (a)x^b$) was chosen in order to satisfy the first relationship, namely that price be zero at zero relative specific enthalpy.

The equation calls for higher prices at higher values of relative specific enthalpy.

The equation, which is a best fit of a power function to the data set, is, however, a decreasing power function. This feature results from the anticipated capacity of geothermal energy to displace alternate fuels more efficiently in the 200-300 Btu/lbm relative specific enthalpy range (see Figure 1) than might be expected on the basis of available work.

The underlying basis and thus the limitations of the proposed generalized price equation should be kept in mind. The equation is based on consideration of a suite of potential uses of hot water geothermal energy wherein geothermal energy replaces a specific amount of alternate fuel.

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*In using the Hewlett-Packard curve fitting routine, the point (0,0) was approximated by 0.001 (Btu's/lbm), and 0.000001 mills/lbm. Unfortunately, this approximation strongly affects the constants of the proposed equation. Although the equation presented appears to be a reasonable one in view of the arguments given in the text, one can generate his own specific equation by a different choice of samples and a different approximation to the point (0,0). Nevertheless, any new proposed equation should have the general features described in the text and should lead to price estimates in the same range as those proposed in equation (6).

The replaceable quantity and the price of alternate fuels is considered to be known. The pattern of displacement including:

- the quantities of geothermal fluid required for a kind of application (e.g., beet sugar refining)
- the temperature requirement for use
- the efficiency of use and, therefore, the efficiency of displacement of alternate fuels*

is presumably represented in general by the suite of potential uses employed in determining the generalized price equation. The uncertainty estimated for the equation itself can be evaluated by noting other information computed from the data set. The mean price of hydrothermal fuel is 0.100 mills/lbm and its standard deviation is 0.056 mills/lbm. The scatter of price about the proposed generalized price equation is .057 mills/lbm. If this value is taken as the standard error of the estimate of price, it follows that the estimate of nominal price is valid two-thirds of the time if the nominal price range is given by:

$$P = 0.6\,\Delta h^{0.9} \pm 0.058 \text{ mills/lbm.} \qquad (7)$$

---

*There appears to be some question that the direct use processes referenced in the study make most efficient use of hydrothermal fuel (see Bakewell and Herron, 1979, p. 25). If efficiency of use could reasonably be argued to be higher than represented in the Bakewell-Herron study, the substitutability per pound mass of geothermal hot water would increase and price would increase. Presumably efficient process designs would be assured in a negotiated sale.

Generalized Price Equation for Current Prices of Displaced Alternate Fuels

The price of alternate fuels has increased very much in recent years. Also, the prices of fuels that hydrothermal geothermal fluid could conceivably displace (e.g., coal, natural gas) varies. For these reasons a pricing formula based on a nominal price of alternate fuels of $\$1/10^6$Btu was set up. In order to translate the pricing equation into current prices it is necessary to multiply by the factor:

$$\text{(8)} \qquad \frac{\text{Current price of alternate fuels } (\$/10^6\text{Btu})}{\text{Nominal price } (\$1/10^6\text{Btu})} = F.$$

These factors can be obtained from Monthly Energy Review, and Figure 2 of this paper displays price of fossil fuels delivered to steam-electric utility plants as a function of time. The national average of all fossil fuels that one might consider to be displaceable by hydrothermal geothermal energy indicates that a value for F (which changes monthly and with fuel type) of 1.89 is reasonable (May, 1980, national average projected price). Figure 1 shows a scale that includes this factor.

COMPARISON OF GENERALIZED PRICE EQUATION WITH SELLING PRICE AT BOISE WARM SPRINGS WATER DISTRICT (IDAHO)

The contract for sale of hydrothermal fuel to customers of the Boise Warm Springs Water District ("BWSWD"), Idaho, provides the only known opportunity to determine if the generalized price equation is "in the right ball park." According to Eastlake (1979; see also

Higbee, 1978, and Isherwood et al., 1980) 170°F geothermal fluid is sold by BWSWD for $0.50/100ft^3$. Assuming that the fluid is saturated compressed liquid, its relative specific enthalpy is 110 Btu/lbm and its sales price then is 0.082 mils/lbm. According to the generalized price equation, sales price in May, 1980, should be 0.079 mils/lbm. The agreement is quite close. Agreement appears, in fact, to be better than one might logically expect (cf. Eastlake, 1979, p. 174). However, if the price were seriously out of step with alternate fuel prices, use of the hydrothermal fuel would presumably be discontinued by the buyer. On the other hand, the seller is also endeavoring to maximize his income and presumably is selling at maximum price while also being competitive with alternate fuels. The close agreement supports the conclusion that the generalized price equation---along with its estimate of variation---is a reasonable reference in assigning price to hydrothermal fuel and value to a geothermal property.

ACKNOWLEDGMENT

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APPENDIX

The routine for a power curve fit (Hewlett-Packard, 1976)

$$y = ax^b$$

is based on the following choices for a and b:

$$a = \exp\left[\frac{\Sigma \ln y_i}{n} - b\frac{\Sigma \ln x_i}{n}\right]$$

$$b = \frac{\Sigma(\ln x_i)(\ln y_i) - \frac{(\Sigma \ln x_i)(\Sigma \ln y_i)}{n}}{\Sigma(\ln x_i)^2 - \frac{(\Sigma \ln x_i)^2}{n}}$$

The total number of data sets (x_i, y_i) is n , and $x_i > 0$ and $y_i > 0$.

A coefficient of determination r^2 is calculated from

$$r^2 = \frac{\left[\Sigma(\ln x_i)(\ln y_i) - \frac{(\Sigma \ln x_i \Sigma \ln y_i)}{n}\right]^2}{\left[\Sigma(\ln x_i)^2 - \frac{(\Sigma \ln x_i)^2}{n}\right]\left[\Sigma(\ln y_i)^2 - \frac{(\Sigma \ln y_i)^2}{n}\right]}$$

A value of r^2 close to one indicates better fit than values close to zero.

Note: values of $x = 0$, $y = 0$, are not permissible.

REFERENCES

Austin, Arthur L., 1975, Prospects for advances in energy conversion technologies for geothermal energy development: Proc. Second United Nations Symposium in Geothermal Resources, Lawrence Berkeley Laboratory, Berkeley, CA pp. 1925-1935 (LCN-75-32682)

Bakewell, Charles A. and Herron, E. Hunter, 1979, Low temperature, direct use geothermal energy costs: Geothermal Resources Council, Transactions, vol. 3, pp. 23-26.

Bloomster, C.H., Fassbender, L.L., and McDonald, C.L., 1977, Geothermal energy potential for district and process heating applications in the U.S. - an economic analysis: Batelle Pacific Northwest Laboratories, Richland, Washington 99352, 45 p. and Appendices (BNWL-2311).

Eastlake, William B., 1979, Geothermal alternatives for the Idaho Capital Mall: Trans. Geothermal Resources Council, vol. 3, pp. 173-176.

Finn, Donald F.X., 1975, Price of steam at the Geysers: Proc. Second United Nations Symposium in Geothermal Resources, Lawrence Berkeley Laboratory, Berkeley, CA pp. 2295-2300 (LCN-75-32682).

Hewlett-Packard, 1976, HP-67 Standard Pac: Hewlett-Packard Do., Corvallis, Oregon 97330, (Publication 00 067-90021) approximately 100 p.

Higbee, Charles V., 1978, The economics of direct use geothermal energy for process and space heating: In "Commercialization of Geothermal Resources," Geothermal Resources Council, PO Box 98, Davis, California, pp. 31-34.

Isherwood, W.F., Brook, C.A., and MacGillray, T.J., 1980, Valuation of federal geothermal resources in the Boise Barracks Military Reservation, Boise, Idaho: U.S. Geol. Survey, Menlo Park, CA 37 pp, in press.

Jenkins, C.B., 1978, New Concept in geothermal steam pricing: Trans. Geothermal Resources Council, vol. 2, pp. 327-329.

Meal, Harlan C., and Guillamon-Duch, Higinio, 1979, Substitution value of geothermal energy as process heat and electric power: Geothermal Resources Council, Transactions, vol. 3, pp. 437-440.

Milora, Stanley L. and Tester, Jefferson W., 1976, Geothermal energy as a source of electric power: the MIT Press, Cambridge, Massachusetts, 186 p. (ISBN: 0-262-13123-4)

U.S. Dept. of Energy, Energy Information Administration, 1979, Monthly Energy Review for December, 1979: U.S. Gov't Printing Office, Superintendent of Documents, Washington, D.C. 20402.

TABLE 1

STATISTICS USED IN ESTIMATING PRICE OF GEOTHERMAL ENERGY

EXAMPLE NO.	T(°F)	Δh(Btu/lbm)	P(mils/lbm)*	COMMENT
1	59°F(15°C)	0	0	Included to represent geothermal fuel with essentially no use.
2	392	339	0.038	Binary cycle calculation (Austin, 1975, Fig. 2, pp. 1927-1929) 120°F sink, 10% parasitic load minimization example
3	392	339	0.068	Austin (1975); 120°F sink, 10% parasitic load; double flash system (pp. 1926-1927).
4	482	439	0.072	Austin (1975); binary cycle; minimization example
5	482	439	0.119	Austin (1975); as in Ex. 4, double flash
6	572	551	0.106	Austin (1975); binary cycle; minimization example
7	572	551	0.187	Austin (1975); double flash.
8	302	245	0.134	Bakewell and Herron (1979), process no. 2-refine beet sugar.
9	327	270	0.048	" " " " , process no. 8 - refine beet sugar
10	300	243	0.162	" " " " process no. 20- refine beet sugar
11	300	243	0.082	" " " " processes no. 13&14- refine beet sugar (retro & new)
12	220	161	0.045	" " " " process no. 9 - alfalfa drying
13	340	284	0.183	" " " " alfalfa drying

* Given in terms of nominal prices; i.e., 10^6Btu costs $1.

TABLE 1

STATISTICS USED IN ESTIMATING PRICE OF GEOTHERMAL ENERGY

(Continued)

EXAMPLE NO.	T(^{o}F)	Δh(Btu/ lbm)	P(mils/ lbm)	COMMENT
14	230	171	0.059	Bakewell and Herron (1979), process no. 11 - onion drying
15	340	284	0.153	" " " " process no. 4 - district heating
16	160	101	0.025	" " " " process no. 5 - district heating
17	110	51	0.020	" " " " process no. 6 - greenhouse
18	200	141	0.110	" " " " process no. 10- greenhouse
19	300	243	0.172	" " " " process no. 7 - potato processing
20	260	202	0.132	" " " " process no. 3 - barley malting
21	300	243	0.154	" " " " process no. 15&16- salt evap. (retro & new)
22	300	243	0.142	" " " " process no. 17&18- tomato paste (retro & new)
23	600	590	0.0958	Binary cycle electric production (see Meal & Guillamon-Duch, 1979)

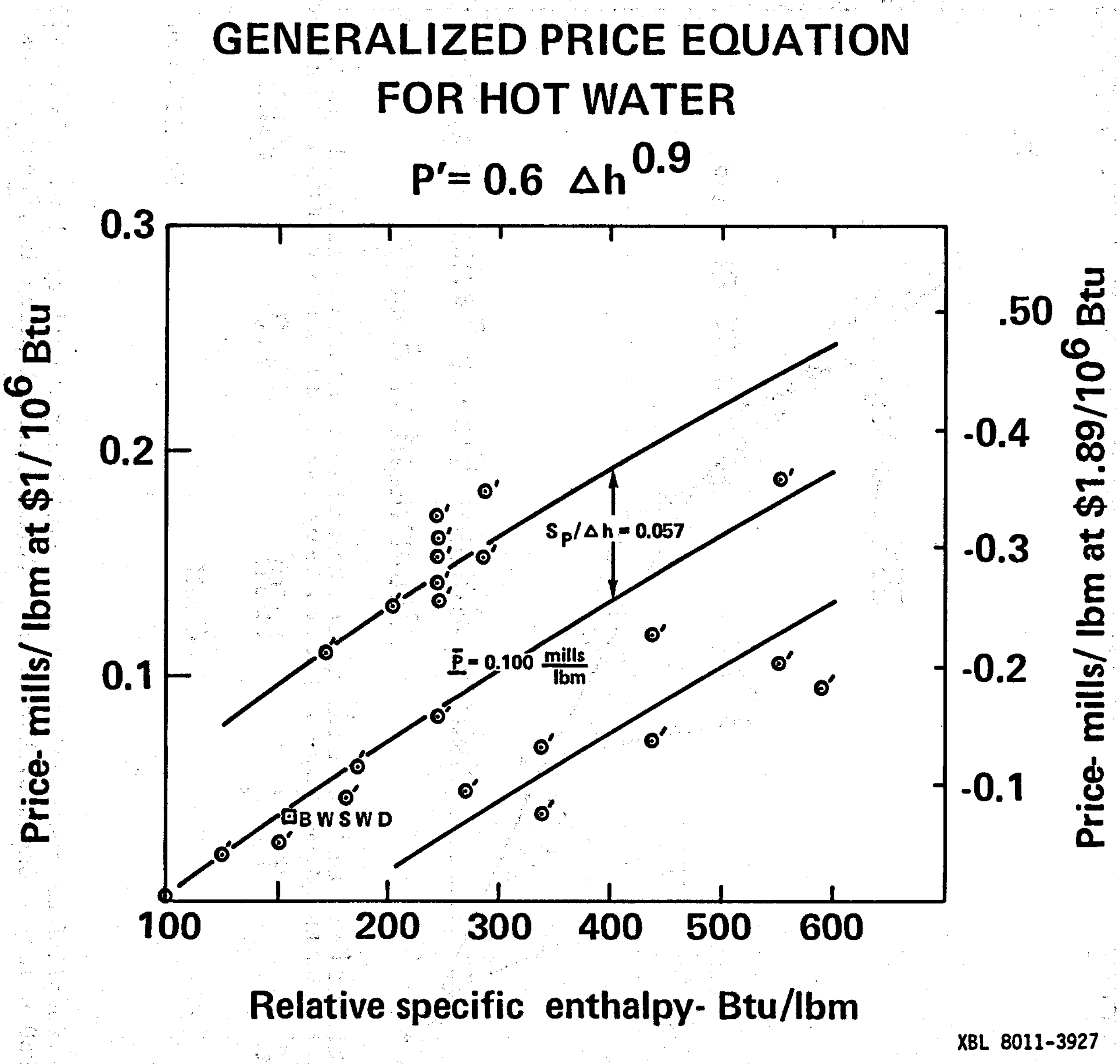

Figure 1. Price equation for hot water geothermal energy. Scale at left shows price on the basis of a nominal value of $\$1/10^6$Btu of displace fossil fuel. Scale on right applies to current (May, 1980) fossil fuel prices.

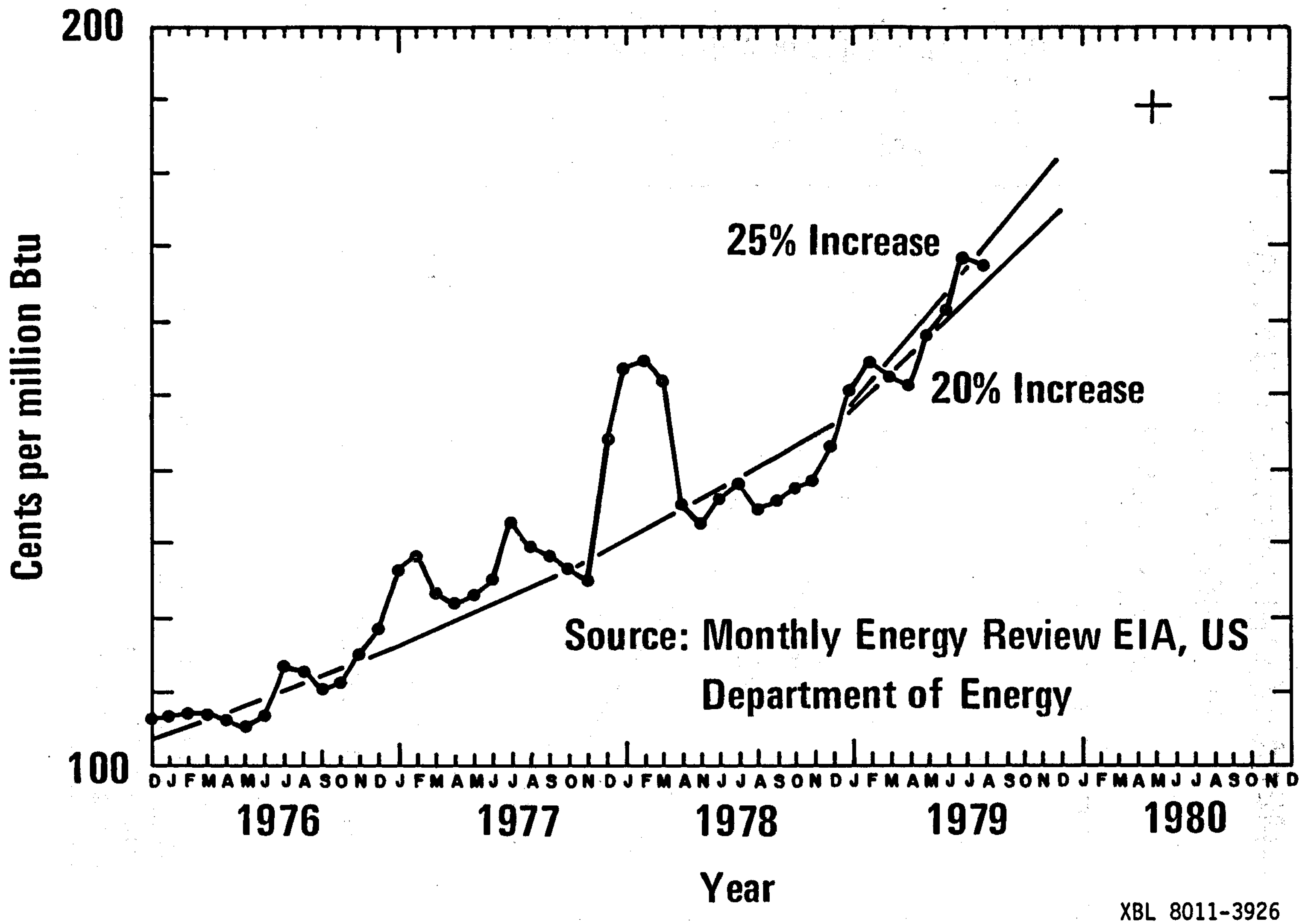

Figure 2. National average fossil fuel costs delivered to steam electric utility plants, 1976-1977. Estimated May 1980 price is shown with a cross. Percent annual price increases are as indicated.