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What is the outlook for geothermal power?

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COSTS for the generation of electricity may be categorized as capital, operating, and fuel. This report will describe capital costs and fuel costs in some detail and will touch on operati[ng] costs. Fuel costs will be treated a[s] costs of fuel delivered to the pow[er] generating plant; i.e., inclusive o[f] transportation and pipeline cost[s]. From the point of view of the ener[gy] supplier, the potential profitability o[f] supplying fuel may be calculated b[y] determining the market price for fu[el] less costs of extraction or productio[n] and transportation. (See Fig. 1.)

Operating costs are generally qui[te] small compared with capital cost[s] and fuel costs and generally run fro[m] $0.005, or 0.5 mills, per kw-hr to 1.[0] mills/kw-hr. In other words, for a 100,000-kw plant operating at 70%, the annual operating costs over 1 year of production would amount to $350,000; i.e., 700,000,000 kw-hr multiplied by $0.0005.

A range of present costs for utility construction has been obtained by reviewing announcements over the pas[t] year by the various utilities of their intentions to build new generatin[g] facilities, the type of facility to be constructed, and its cost. As shown in Table 1, the costs for a nuclear plan[t] are now $650 to $700/kw and $350 to

Table 1

Power-plant-construction announcements*

Date	Utility	Nuclear, $	Coal	Oil and gas
1973				
7/17	Commonwealth Edison	545	...	...
7/31	Pennsylvania Power Co.	...	303	...
7/31	Detroit Edison	...	303	...
10/12	Utah Power & Light	...	427	...
11/9	Pennsylvania Power & Light	666	...	...
11/16	Consumers Power Co. (Michigan)	521	...	...
11/27	Columbus & So. Ohio Edison	...	293	...
12/4	Philadelphia Electric	...	...	266
12/4	Dayton Power & Light	...	333	...
1974				
1/25	Alabama Power Co.	604	...	...
1/29	Commonwealth Edison	545	...	...
1/29	American Electric Power	...	323	...
2/15	Iowa Public Service	...	417	...
2/22	Long Island Lighting	568	...	...
3/1	Niagra Mohawk Power		379	...
4/19	Indiana-Michigan Electric Co.	615	...	...
5/17	Toledo Edison	673	...	...
5/20	Rochester Gas & Electric	708	...	...
5/25	New England Electric	695	...	...

*Represents $/kw-hr installed. Data where plant capacity, type of facility, and estimated cost were reported taken from 19 out of 47 announcements as reported by Moody's Utility Service.

Fig. 1

Power-generation capital and fuel-cost comparison

$/kw installed	$100	200	300	400	500	600	700
Capital, mills/kw-hr	4.94	7.41	2.47	9.88	12.35	14.82	17.30
Fuel price, $/bbl	$12.00	10.50	9.00	7.50	6.00	4.50	3.00
Oil, mills/kw-hr	20.00	17.50	15.00	12.50	10.00	7.50	5.00
Total	22.47	22.44	22.41	22.38	22.35	22.32	22.30

The top line of figures ranging from 100 to 700 shows dollar per kilowatt for installed plant capacity.

The second column of figures offset and to the right is the capital cost of 17.3% in mills per kilowatt-hour calculated for an 80% capacity factor.

The third column of figures declining from $12 to $3 is the price of fuel expressed as price per barrel.

The fourth column shows costs in mills per kilowatt-hour for oil.

The fifth column shows total capital and fuel costs in mills per kilowatt-hour, but excludes operating costs. These would normally run from 0.5 mills to 1.0 mills.

The chart provides a method of determining the competitiveness of any fuel when factored with construction costs and when given a fixed power-generation cost such as a 22.0+ mills as shown in the chart.

$400/kw for a coal-fired plant.

The significance of the recent cost escalation is highlighted with the observation that the book-carrying cost for the approximately 360,000-mw generating capacity for the utility industry as a whole ranges from $75 to $125/kw. When the construction of a new facility is announced and the cost is projected at an amount exceeding the book cost for the existing plant, rate increases or external financing must be obtained in an amount proportionate with the cost for new plant as a percentage to that for existing plant and the proportion of new plant capacity to existing capacity.

In reviewing announced construction plans over the last year, it is interesting to note, that of about 47 new installations, only one new oil-fired plant is anticipated. One geothermal unit was announced and the balance is fairly evenly divided between coal and nuclear in terms of numbers of installations.

Recent cancellation and deferrals of new nuclear facilities reflect the increased cost situation perhaps more than environmental and safey considerations. We estimate that current projections showing increasing utilization of nuclear power are greatly exaggerated and will be replaced substantially by coal and, based on the issuance of leases by the federal Government and availability of exploration and development funds, geothermal.

Fossil-fuel power-generation costs—BTU/kw-hr. Fuel costs may be compared directly by determining plant efficiency and by establishing the BTU content of the specific fuel. A review of Part One of the National Power Survey published by the Federal Power Commission in 1970 shows power-generating data for various fossil-fuel and nuclear facilities in the United States. The listing in Table 2 of BTU's required to produce 1 kw-hr of electricity illustrates the typical range of BTU consumption for three types of facilities.

Table 2

BTU's/kw-hr

	Low	High	Weighted
Oil	9,333	17,651	10,500
Gas	9,832	13,279	10,000
Coal	9,836	15,033	10,500

Table 3

BTU content

Fuel	Quantity	High	Low	Common usage
Oil	1 gal	152,000	126,000	*145,000
Gas	1 Mcf	1,200,000	900,000	1,000,000
Coal	1 lb	14,000	9,000	12,500

*Used in this report is 142,857 BTU's × 42 gal = 6,000,000 BTU/bbl of oil.

Nature has given us BTU content in the three physical quantities (Table 3).

There are 42 gal of oil in a barrel, and 2,000 lb of coal in 1 ton, the units commonly used in commodity transactions. Using the average heat exchange rates in Table 3, we can use the standard commodity units (Table 4) to illustrate what comparable quantities may be required for electrical-power generation (assuming 10,000 BTU's are required to produce 1 kw-hr).

Table 4

Conversions

	Quantity of fuel	Comparable BTU's
Oil	4,166-2/3 bbl	25,000,000
Gas	25 Mcf	25,000,000
Coal	1 ton	25,000,000

It may be observed that in a non-regulated market, assuming similar plant-construction costs, the delivered price for oil, gas, and coal would be based solely on BTU content and would be identical for the quantities shown in Table 4. Only nature's variances in quality of the specific fuel by unit would cause price differences.

Geothermal-power-generation costs. The costs of electrical generation using geothermal energy depends on the nature of the resource at the specific site where it is discovered. Geothermal resources in general are:

1. Dry steam.
2. Hot water: (a) Low temperature-low dissolved solids; (b) High temperature-low dissolved solids; (c) High temperature-high dissolved solids; and (d) Low temperature-high dissolved solids.
3. Hot dry rocks.
4. Geopressured zones.

Accurate cost breakdowns for dry steam are available from the Pacific Gas & Electric experience at the Geysers. Generation costs for hot-water systems using "flashed" steam at Cerro Prieto, Mexico, and Otake, Japan, have been obtained from published industry sources (Table 5). The capital cost for each type of plant will vary depending on the amount of BTU's that may successfully be recovered; i.e., the amount of heat that is extracted and its relationship to the pressure and rate of flow, together with the quantity of dissolved solids

Table 5

Geothermal-power capital costs: 110,000-kw plant

(January 1974 base)

Power Plant	Dry steam the Geysers, $	Hot water Otake, Japan, $	Hot water Cerro Prieto, Mexico, $
1.—Condenser-cooling tower	0	4,322	1,600
2.—Structures	1,838	2,651	2,960
3.—Equipment (plant)	648	496	736
4.—Turbogenerator	6,411	7,192	4,240
5.—Electric equipment	1,167	3,366	960
6.—Miscellaneous equipment	234	999	1,585
7.—Engineering—instrumentation	1,012	1,010	960
8.—Overhead	2,130	2,585	2,521
Subtotal	13,440	22,621	15,562
9.—Substation Transformer	441	655	655
10.—Transfission Transformer	153	153	153
Total	14,034	23,429	16,370
Cost/kw Installed	127	212	148
Fixed charges 17.3% ($000)	2,427	4,053	2,832
Operating expenses ($000)	250	375	375
Total fixed ($000)	2,677	4,428	3,207
Cost/mill @ load factor (ex-fuel)			
90% (106 × 7,885 = 835,810 kw-hr)	3.20	5.29	3.83
80% (106 × 7,000 = 742,000 kw-hr)	3.60	5.96	4.32
70% (106 × 6,130 = 649,780 kw-hr)	4.12	6.81	4.93

and noncondensable gases.

The projected costs for binary-cycle electrical generation using geothermal hot water has been described by Ben Holt Co., based on design work completed in California at Niland and Heber in the Imperial Valley and at Mammoth in Long Valley.

They have projected binary-cycle plant-construction costs as a function of hot-water consumption and reservoir temperature. The higher capital costs for a binary-cycle system are principally associated with the heat-exchange system itself. These costs alone appear to increase plant costs about $100/kw capacity over those for a dry or flashed-steam facility.

While the Ben Holt Co. analysis shows the cost-reservoir relationship from 250° to 500° F., only those temperatures in excess of 360° F. are considered commercial herein. The reasons for the 360° F. cutoff are threefold. First, the projected plant cost loses its competitive advantage to a coal-fired facility at temperatures lower than 360° F. Second, the number of wells for production and reinjection accelerate rapidly at lower temperatures. Third, the hot-water consumption at 360° F. is comparable with the minimum temperature of hot water flashed to steam and dry steam considered necessary for commercial development.

These three factors, combined with a knowledge of present drilling costs, lead to the conclusion that the discovery of a reservoir with a minimum temperature of 360° F. should prove to be commercial.

Geothermal energy vs. fossil fuels. The conversion of geothermal energy to electricity has been demonstrated using dry steam and hot water flashed to steam. Development to date indicates that the binary-cycle conversion of hot water to electrical energy will be demonstrated shortly. A method for pricing geothermal energy has been devised based on flow rates for geothermal wells and minimum temperatures.

Dry steam wells at the Geysers produce 100,000 to 200,000 lb of steam an hr, hot-water wells commonly produce 500,000 to 750,000 lb/hr. The minimum temperatures used are those where 20 lb/hr of steam or 100 lb hot water produce 1 kw-hr.

The dry steam at the Geysers enters the steam turbine at 100 psi and 373° F. The steam tables show that the total heat (enthalpy) of the steam is approximately 1,200 BTU's/lb. while the Geysers consumption is 18 lb/kw-hr, the literature often describes the amount as 18-20 lb, leading to the "rule of thumb" that 20 lb/hr are required for 1 kw-hr, or as more commonly expressed, that a 100,000 lb/hr well will supply 5,000 kw-hr. It may be noted that if 20 lb/hr are required to produce 1 kw-hr (3,414 BTU's by definition), then 24,000 BTU's (20 lb multiplied by 1,200 BTU/lb) are required for 1 kw-hr. The thermal conversion efficiency is therefore 14.22% (3,411 ÷ 24,000). Parameters should hold true for dry steam in general.

The amount of steam which can be flashed from hot water is a function of temperature (Table 6) and has been reported.[1]

Table 6

Steam flashed from hot water

Temperature, °C.	Temperature, °F.	Amount flashed, %
150	202	0
175	347	5.5
200	392	11.0
225	437	16.5
240	466	20.0
250	482	22.0
275	527	27.5
300	572	33.0

The temperature of the hot water at Cerro Prieto is in the 550° to 600° F. range. While the amount of hot water flashed is not reported, the Mexican Government has stated that the steam consumption is 16.74 lb/hr. (It is generally felt within the industry that utilization at Cerro Prieto could be improved by 50% without additional wells.)

At Otake, the amount flashed is believed to be 25.6%, thus indicating a temperature around 500° F.

Ben Holt Co. analysis (Table 7) for the binary cycle shows hot-water consumption in pounds relative to temperature required to produce 1 kw-hr

Table 7

Binary-cycle analysis

Hot water (lb/kw-hr)	Temperature, °F.
200	300
150	320
100	360
80	400
75	450
60	500

Note the significantly greater quantities of hot water required at between 300° and 360° F. and the rapid decrease in water consumption at the higher temperatures. While plant costs estimated by Holt within this range appear economically competitive ($400/kw at 300° F., $350/kw at 350 F., $310/kw at 400° F., and $250/kw at 500° F.), the consumption of more than 100 lb/kw-hr generated does not appear to be commercial because of the significantly larger volumes of water and therefore, greater number of wells necessary to supply the plant

Table 8

Fuel prices based on power-generation output

Bbl/oil, $	(4.166 Mcf gas, ¢ bbl) (25 Mcf)	1 Ton coal, $	1 Ton/day geothermal, $*
1	0.16	4.16	4.16
2	0.33	8.33	8.33
3	0.50	12.49	12.49
4	0.66	16.66	16.66
5	0.83	20.83	20.83
6	1.00	25.00	25.00
7	1.16	29.16	29.16
8	1.33	33.32	33.32
9	1.50	37.49	37.49
10	1.66	41.66	41.66
11	1.83	45.82	45.82
12	2.00	50.00	50.00

*The BTU prices are equivalent for oil, gas, and coal but are 41% for geothermal due to less-efficient conversion to electricity.

Table 9

Geothermal-well revenues

Hot water,† lb/hr	Steam, lb/hr	Ton/ day, $	Equivalents @ 80% capacity Revenues oil/ton/day $6/25	$8/33.32	$10/41.66
250,000	50,000	25	$182,500	$243,236	$304,118
500,000	100,000	50	365,000	486,472	608,236
750,000	150,000	75	547,500	729,708	912,354
1,000,000	200,000	100	730,000	972,944	1,216,472

Capacity @ 80% = 292 days. †Assumes 20% flash to steam or 100% utilization with binary cycle.

Table 6 shows that at 466° F. hot water will produce a 20% flash to steam. For a hot-water well flowing at a rate of 500,000 lb/hr, 100,000 lb of steam/hr would be produced. Every 20 lb/hr will produce 1 kw-hr and 100,000 lb/hr will produce 5,000 kw-hr. Similarly, a 500,000-lb/hr well supplying a binary-cycle plant at 360° F. will use 100 lb of hot water an hr for 1 kw-hr and 500,000 lb/hr will provide for the generation of 5,000 kw-hr.

A review of the BTU consumption of fossil fuel (10,000 BTU's are required to generate 1 kw-hr and the useful heat content of dry steam, steam flashed from hot water, or hot water supplying a binary plant, leads to the observation that 2,000 lb of steam or 10,000 lb of hot water produced over 25 hr will have an electrical output in kilowatt-hours which may be compared directly with fossil fuels.

If 20 lb/hr are required for 1 kw-hr given current conversion efficiencies for geothermal-power production, then 2,000 lb of steam produced for 25 hr is equal to 1 ton of coal, 4.166 bbl of oil, or 25 Mcf of gas.

By adjusting the 20 lb/hr downward 4%, the 25-hr component is offset to a 24-hr factor. This produces a unit of measure for the sale of geothermal steam as 2,000 lb/hr/day or simply a ton/day of production.

Table 8 is based on a ton/day for the generation for geothermal and is shown with fossil-fuel prices. Because the natural gas is assumed to have 1,000 BTU/cu ft, the price per Mcf of natural gas with the decimal point moved one place to the right is equivalent to the cost in mills per kilowatt-hour for power generation fuel costs.

Table 9 shows a range of well flows and revenue produced therefrom.

Conclusion. The costs to use geothermal energy for electrical-power generation have been shown for power-plant construction and geothermal-energy purchases. They are competitive with other forms of power generation. This paper, and an awareness of drilling costs, suggests that revenues from the sale of geothermal will lead to a profitable level of operations for the energy supplier sufficient to encourage the commercial exploration and development of geothermal energy—perhaps on a large scale.

Reference

1. D. E. White, Geothermal Energy, p. 81, source (Muffler, in press).