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The Economics of Geothermal Power

by

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THE ECONOMICS OF GEOTHERMAL POWER

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Introduction

In 1966, Japan Metals and Chemicals Company completed the construction of the first geothermal power plant in Japan, namely the Matsukawa geothermal power plant, and started operating it. In 1967, Kyushu Electric Power Co. completed the Otake power plant. In 1974, Mitsubishi Metals Co. completed the Onuma power plant, and in 1975 the Electric Power Development Corp. completed the Onikobe power plant. As of this year (1975), three more geothermal plants are being planned, namely Kakkonda, Hatchobaru, and Mori (total output power for these three will be 150 kW). These are supposed to be completed by the end of 1977. Geothermal power is now starting to run in full scale.

Outside of Japan, as of 1975, eight countries, including the United States, Italy and New Zealand, are running geothermal plants of 1,380,000 kW in total output, and additional plants of 2,500,000 kW are under construction or in planning.

After the "oil crisis", geothermal power started to attract many people's attention from the viewpoint of efficient usage of domestic resources, or providing various kinds of energy resources. Now the government is trying to power up the effort of locating geothermal resources, and the development of new technology for the utilization of geothermal energy. The government is using governmental funds to reinforce the capital requirements for the construction of new geothermal power plants. So far geothermal plants have attracted quite a bit of attention. However, it is very important to continue governmental financial support as a national project, from the viewpoint of the efficient use of domestic energy resources, in order to maintain the development and provide a cost competition with alternative resources of energy.

It is also important for geothermal power to maintain cost superiority over other means by striving for technical development. It is also necessary to note that terrestrial heat can be used for various purposes, namely space heating, horticulture, agriculture, and so on, so that it can contribute to the development of the area in many aspects. However, it is very difficult to discuss the economic characteristics of multipurpose usage of terrestrial heat in general terms because of the dependence on various local factors. Therefore, in this paper, I am going to discuss only the economic comparison of geothermal power generation with other means of power generation.

1. Economic Characteristics of Geothermal Power - Comparison of Steam, Nuclear, and Hydraulic Power

Table 1 is a comparison between geothermal, steam, and hydraulic power construction costs, power generating costs, and utilization rate. These data are from new construction plans granted at the 66th meeting of the National Power Development Regulation Board on March 17, 1975.

(a) Construction cost

The geothermal plants presently planned are so small that they cannot take advantage of so-called "economies of scale." Furthermore, the drilling costs for steam wells are relatively large. Therefore, the construction cost per kW for a geothermal plant is larger than that for thermal and nuclear plants, but smaller than for a hydroelectric plant. However, if we assume that geothermal power plant operators will buy steam from geothermal steam suppliers, then the initial cost for the generators will be decreased, and the construction cost for the generators will be comparable to that for conventional steam power plants. In this case, however, the geothermal steam suppliers will have to bear a large amount of initial investment. The reason for the lower costs for thermal and nuclear power is that

they do not have to make any investments for oil wells or uranium minings since they import almost all the oil and uranium they use from foreign suppliers. In other words, as far as initial construction cost is concerned, the rank of power generation systems is as follows: thermal, nuclear, geothermal, and hydraulic (least to most expensive).

It seems to me that the Japanese economy with sparse capital accumulation could only get enough electrical power supply, without incurring any inflationary suffering from high-speed economic developments, by adopting the most inexpensive capital type of power supply systems depending on the present low price of oil. However, if we think about the instability of the supply and the price of oil, and in order not to have any bottle-neck problem in energy supply, it seems to me that we will have to rely on nuclear power. It is the next to the least expensive power supply system, and it is relatively easy to get uranium at the present. Furthermore, the fuel can be stocked in Japan, and can be considered as a semi-domestic supply. However, if we adopt nuclear power, we still have to rely mostly on imported sources for the primary energy source. That is, other countries will have to bear the burdens of developing the primary energy resources with intensive capital needs, and with the high possibility of pollution problems. Then we have to develop our economy by using the energy most efficiently with much anxiety concerning the stability of the supply.

However, if we have to make reasonable anti-pollution investment at the energy development site, and if we need to have efficient use of domestic energies, as well as variety in energy supplies, then the construction cost of geothermal power plants will not be very expensive compared to these alternatives.

(b) Power generating cost

When we compare the electricity generation cost (at the power plant bus bar), the order (from the lowest to the highest) is as follows: geothermal, nuclear, thermal, and hydraulic.

As you will notice from Table 2, the reason why geothermal has the lowest generation cost is that it does not require any fuel. The same can apply for hydraulic power, but the difference comes from the higher construction cost of hydro plants. In both cases, it seems to us that the fuel cost is included in the capital costs, such as the drilling costs of steam wells, or construction costs of dams. In thermal power, the percentage of the fuel cost in the total generation cost is very high, i.e., 61%, and this fact indicates that the cost will be affected greatly by the changes in oil prices. The change in the oil price is shown in Table 3. As you can see from the table, the present price is about four times greater than it was in 1973, and the power generation cost is about three times higher. Moreover, because it is almost impossible to have a very large oil stock, any change in the price of oil will have an immediate effect on the power cost, and increases in the price of oil are very possible in the near future.

As for nuclear power, the fuel price is presently very low and can make up for the relatively high capital cost. However, there is no reason that we can expect uranium to keep the very low price of today forever. If you remember the case of oil which very suddenly shifted from a "cost-based" price to a "market-based" price, and increased rapidly after the "oil crisis", it is also possible that the nuclear fuel price may also be increased. Fortunately, nuclear fuel can be stock-piled in large amounts, and the terms of the supply contracts are usually longer than ten years. Therefore, the generating cost will not be affected very much by the fuel cost, but there still will be some instability in prices in the new supply contracts for the future. As a matter of fact, nuclear fuel cost approximately ¥ 0.7/kW·h of total electricity generation in 1971, but had increased to ¥ 2.0/kW·h in 1975, and if we take the processing cost of the fuel, we may expect some additional increases in the future.

(c) Utilization rate

The utilization rate is the highest in geothermal power plants, and is followed by thermal, nuclear, and hydraulic, in that order. Because geothermal energy is a very stable energy resource, it being possible to run a plant continuously except for some occasions such as regular maintenance work on turbines, power plants of the geothermal type are designed to have a utilization rate of 80% on the average. Actually, the Matsukawa power plant showed 95% in 1974, higher than was planned. Otake and Onikobe power plants showed 75% in 1974. At Onuma power plant, the output power did not reach to the designed output because of a shortage of steam supply. However, the output is very stable and the utilization rates are very high.

On the other hand, thermal power plants have some accidental stoppages caused by explosions of boiler tubes, etc. Other than the regular stops for maintenance of boilers and turbines, the utilization rate for thermal plants is usually planned about 70%. Since thermal power plants have larger number of parts than geothermal power plants, the trouble rate is necessarily higher than that of geothermal plants.

In nuclear power, because the plants have more mechanical apparatus than thermal power plants, and because these parts need to have regular maintenance work (steam generators, fuel containers, turbines, etc.), and because they must be stopped for longer periods than power plants of other types to locate the problem completely for highest safety, the actual utilization rate is usually around 40 to 50%, against a planned rate of about 70%. Though it may be expected that the planned 70% may be achieved in the future by improving the reliability of mechanical components, it seems to be limited to around 40 to 50% for the immediate and foreseeable future.

So far, I have compared the construction costs, power generating costs, and utilization rates in various types of power generation. Geothermal power has the lowest operating cost and the highest utilization rate, though it has a higher

initial investment. Thus geothermal power seems to be quite comparable to, or somewhat advantageous over other means of power generation.

2. The Development Method of Geothermal Power

As I discussed in Section 1, geothermal power is quite comparable to other power systems. However, it is considered that geothermal power is more risky for private corporations. This is because the development of terrestrial heat is a type of exploitation of an underground resource, which is itself very risky.

One example of exploitation of terrestrial heat is shown in Figure 1. A comparison table of the methods of terrestrial heat exploitation and the exploitation of other mineral resources is shown in Table 4. As it is easily understood from Figure 1 and Table 4, the method of terrestrial heat exploitation is quite similar to the method in exploitation of other mineral resources. Thus, the policy and the aid from the government are almost the same in both cases. The developers of terrestrial heat are usually the mining companies in usual mining fields. The most risky stage in an exploitation of geothermal resources is drilling an exploration well to discover if the resource can be commercialized or not. The drilling of exploration wells is very risky because it costs about \$350,000 per well (depth of 1,000 m), and it has a very low percentage of success. It is so risky that it forms a kind of bottleneck for geothermal exploitation. It is necessary to provide some governmental financial help for exploration wells to lower the risks for developers and to encourage geothermal exploitation.

The hot water which comes with the steam can be supplied and used in various purposes, such as horticulture, agriculture (vegetables, fruits, mushrooms, and wild vegetables), poultry farming, and fish breeding. In this way, development of a terrestrial heat resource can contribute the development of the area in various aspects. If we consider the fact that most of these resources are located in sparsely populated districts, terrestrial heat developments seem to prove real

worth in connection with the general development plan of such districts. Examples of multipurpose usage of terrestrial heat are shown in Table 5. All these examples are limited to hot water supplied on a small scale, such as to hot springs resorts. A multipurpose development in a full scale is now being planned at Kakkonda.

Final

Geothermal power recently has been attracting attention as a very precious domestic power resource. However, accommodation of the development to meet stringent environmental standards is a serious problem since most of the prospective sites are located in Natural Parks. For maintenance of the natural environment, we have been taking every necessary precaution, and the cost for these measures have been included already in the power generation cost. Therefore, this is expected to have little additional influence on the economic characteristics of geothermal power.

Of the measures which will probably be needed in the future, one of these would be a system for eliminating H_2S . Since the technique of sulfur elimination has already been established, the power generation cost will be increased by 4 to 5% by providing such apparatus.

The hot water is reinjected underground presently. Therefore this would not add any new expenses in the costs for environmental maintenance, and thus would not affect the power costs.

* * *

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Table 1

Comparison of various methods of power generation
(as of March 17, 1975)

<u>Method of Generation</u>	<u>Output MW</u>	<u>Construction Start-up</u>	<u>Plant Start-up</u>	<u>Const. cost 1000 yen/kW</u>	<u>Electricity cost^(a) yen/kW·h</u>	<u>Capacity Factor</u>
Geothermal A	50	Apr. 1975	June 1977	230.0	6.8	80
Geothermal B(b)	50	July 1975	Dec. 1977	138.4	7.5	80
Hydraulic A - dam	6	July 1975	Aug. 1978	583.3	15.0	60
Hydraulic B - waterway	10	Oct. 1975	Mar. 1978	410.0	11.7	54
Thermal A - coal	350	July 1975	June 1978	157.0	11.6	70
Thermal B - LNG	600	Dec. 1975	Oct. 1978	114.5	11.6	70
Thermal C - crude oil	500	Aug. 1975	Nov. 1977	122.0	9.2	70
Nuclear A	550	Sept. 1977	Mar. 1982	172.7	7.1	70
Nuclear B	890	Feb. 1977	July 1981	185.2	6.8	70

(a) At the busbar; (b) Steam buying.

Table 2

Specifications of generation costs for various systems - basis of cost accounting
(costs in the first year)

	<u>Geothermal A^(a)</u>	<u>Hydraulic B</u>	<u>Thermal C^(b)</u>	<u>Nuclear B</u>
Capital cost, yen/kW·h	5.77	10.36	3.12	4.54
Interest	C.C. x 8%(c)	C.C. x 8%	C.C. x 8%	C.C. x 8%
Depreciation	C.C. x 8.18%	C.C. x 2%	C.C. x 5.63%	C.C. x 5.63%
Fixed property tax	C.C. x 1.4%	C.C. x 1.4%	C.C. x 1.4%	C.C. x 1.4%
Other expenses	-	W.C.(d)	-	-
Direct cost, yen/kW·h	0.86	1.03	0.35	0.78
Salaries	S x 7 persons(e)	-	S x 90 persons	S x 110 persons
Maintenance	C.C. x 1.95%	C.C. x 0.56%	-	C.C. x 1.5%
Other expenses	C.C. x 0.4%	C.C. x 0.59%	C.C. x 0.54%	C.C. x 0.79%
Indirect cost, yen/kW·h	0.17	0.26	0.17	0.17
Business expenses	D.C. x 8%(f)	(D.C. + W.C.)x8%	D.C. x 8%	D.C. x 8%
Enterprise tax	Total x 1.523%	Total x 1.523%	Total x 1.523%	Total x 1.523%
Fuel cost, yen/kW·h	-	-	5.59	1.34
Total busbar cost, yen/kW·h	6.80	11.65	9.23	6.83
Transmission loss	7.9%	-	4.2%	5.0%
Total delivered cost, yen/kW·h	7.39	-	9.63	7.19

(a) Construction cost includes cost of steam wells; (b) Fuel is heavy and crude oil;

(c) C.C. = Construction cost; (d) W.C. = Water concession; (e) S = Salary, 4.6×10^6 yen/year/person;

(f) D.C. = Direct cost.

Table 3

Oil price escalation
(C.I.F. prices from customs statistics)

<u>Year</u>	<u>\$/barrel</u>	<u>Yen/kl</u>
1970 (average)	1.80	4.083
1971 (average)	2.18	4.794
1972 (average)	2.51	4.862
1973 (average)	3.29	5.673
1974 (average)	10.79	19.761
Jan 1974	6.00	10.060
Feb 1974	9.90	18.518
Mar 1974	10.51	18.976
Apr 1974	19.94	19.119
May 1974	11.37	19.888
June 1974	11.26	19.924
July 1974	11.37	20.468
Aug 1974	11.47	21.506
Sept 1974	11.51	21.874
Oct 1974	11.44	21.445
Nov 1974	11.67	22.015
Dec 1974	11.75	22.168
Jan 1975	11.85	22.425

Table 4

Comparison between geothermal exploitation and other mineral resources

Part A: Geothermal exploitation

	<u>Fundamental research</u>		<u>Exploratory phase</u> <u>Exploration well-drilling</u>	<u>Commercialization</u>
	<u>Basic</u>	<u>Precision</u>		
Government funds	S.R.F. (a)	Labor costs	(None)	Loans
Resource developer	Government: AIST, GSJ, Sunshine Project NGES, ⁶ 220x10 ⁶ yen (1975)	Private: GERD, ANRE, MITI 800x10 ⁶ yen (1975)	Private companies; Local governments.	Private companies; Local governments; Japan Development Bank: 1.7x10 ⁹ yen (1975), 40%. Hokkaido and Tohoku Dev. Fund Agency: 1.7x10 ⁹ yen (1975), 70%.

Part B: Exploitation of other mineral resources

	<u>Wide-area research</u>	<u>Precision research</u>	<u>Commercialization</u>
Government funds	Labor costs	Aid	Loans and other aid
Resource developer	Metal mining company: governmental aid = 770x10 ⁶ yen (1975)	Metal mining company: governmental aid = 920x10 ⁶ yen (1975) (gov. aid = 2/3, local gov. aid = 2/15, holders of mining rights = 3/15)	Large private corporations: Japan Development Bank loan: 3.8x10 ⁹ yen (1975), 70%. Medium and small companies: gov. aid for new mineral deposits = 800x10 ⁶ yen (1975), 50%.

(a) Special Research Fund.

Table 5

Status of multipurpose utilization of hot water

<u>Power Plant</u>	<u>Amount of Hot Water</u>	<u>Recipients and Uses</u>	<u>Year of Start-up</u>	<u>Supplier</u>	<u>Remarks</u>
Matsukawa (JMC Co., Ltd.)	(Steam/water heat exchanger)	Hachimantai Hot Springs, Matsuo Village (5.5 km from plant) use 1,000 l/min at 75°C (a)	1971	Hachimantai Hot Springs Development Co., Ltd. (b) capital = 80x10 ⁶ yen	(c)
	20 t/h	Regional Forestry Office (working site) and 3 inns at Matsukawa Hot Springs		JMC Co., Ltd.	
Otake and Hatchobaru (Kyushu Elec. Co.)	370 t/h, Otake 190 t/h, Hatchobaru (d)	110 homes and 30 inns use 209 t/h	1973	Kyushu Elec. Power	
Onuma (Mitsubishi Metals Co., Ltd.)	266 t/h (e)	Nearby inns and hotels use 15 t/h	1972	Tsunodate-city	(f)
Kakkonda (in planning)	2,000 t/h	Morioka-city and Shizukuishi-town use 1,900 t/h for area heating, snow melting for roads, agriculture, tourism, and industry.	1977		(g)

- (a) Includes 200 l/min to "Hachimantai Heights", a recreational center for employees of small companies run by the Employment Promotion Corp. (governmental).
- (b) Comprised of Matsuo-village (Iwate prefecture), JMC Co., Ltd., and Northern Iwate Bus. Co.
- (c) Hot water is supplied free-of-charge to EPC. Other recipient (HHSDC, Ltd.) pays 1/4 of selling price to JMC Co., Ltd.
- (d) River water (200 t/h) is heated to 72°C. Geothermal hot water is totally reinjected.
- (e) River water (15 t/h) is heated to 60-70°C. Geothermal hot water is totally reinjected.
- (f) The cost of the supply facilities is shared equally between MM Co., Ltd. and Tsunodate-city.
- (g) In planning. Expenses incurred in 1974 by Iwate prefecture government amounted to 26,969,000 yen.

Figure 1

Method of geothermal exploitation

First Phase

General Surveys (government)

Mainly along roads:

- Wide-area gravity survey
- Shallow-depth heat survey
- Geological alteration survey

Others:

- Aeronautical magnetic survey
- Photographic geological survey

Detailed Surveys (government)

- Electrical and seismic surveys
- Mid-depth heat survey
- Structural boring

Second Phase

Investigations for Exploitation

Exploration well

- Precision gravity survey
- Electrical survey
- Seismic survey

Third Phase

Investigations for Commercialization

(Private corporations with special loans from governmental financing agencies)

- Additional geophysical surveys
- Additional exploration wells
- Eventually production wells
- Eventually construction of power plant

Note: Some items in each step may be omitted when surface thermal manifestations are sufficiently strong.