5306

Relevance of Geothermal Energy in Today's Energy Situation

MELCHIORRE POLI

ELC-Electroconsult, Via Chiabrera, 8, Milano, Italy

ABSTRACT

Traditional geothermal resources can provide only a small fraction of the world energy demand; nevertheless geothermal generation, where available, has proved very interesting from the economic point of view and for its independence from fuels. Research is under way for possible new forms of geothermal generation from geopressured brines and dry rocks which might produce substantial quantities of energy. While it appears convenient to increase the exploitation of available traditional resources, interest is stressed on the aforesaid research for possible new forms of geothermal generation. Comparative cost estimates are given for geothermal and fossil-fuel generating plants.

TRADITIONAL GEOTHERMAL RESOURCES

The term "traditional geothermal resources," with which considerable experience exists by now, is relevant to "dry steam fields" (such as Larderello in Italy and The Geysers in the USA) and to "wet steam fields" (such as Wairakei in New Zealand and Cerro Prieto in Mexico).

In general, geothermal activities are likely to exist in particular areas which have experienced recent volcanism. These include the circum-Pacific "circle of fire" (parts of the western United States and the Rocky Mountains, the Aleutian Islands, the Kamchatka peninsula, Japan, Taiwan, Indonesia, the Philippines, New Zealand, and many of the South Pacific Islands, the western part of South America, and most of Central America).

Further geothermal activities appear in a great part of the USSR, as well as in other countries of Europe (Italy, Greece, Iceland) and of Africa and Asia (Ethiopia, Kenya, Uganda, Tanzania, Afghanistan, India, Nepal).

So far the geothermal fields have been exploited mainly for electric power generation, and only a minor part has been utilized for heating (houses, nurseries, industrial processes) in the vicinity of the fields.

The exploited resources as per 1974 for geothermal electric generation are listed in Table 1.

The corresponding thermal energy of the total in Table 1 is about 19×10^{12} cal, that is, about 0.03% of the world primary energy demand in 1974 (which is of the order of 60×10^{15} cal). Additional geothermal electric plants are scheduled for installation by 1978, as listed in Table 2. Research projects are under way in Nicaragua, Kenya, Ethiopia, Turkey, and El Salvador with the assistance of the UN.

Further projects for geothermal electric plants are under consideration for construction by 1985 or thereabouts, as listed in Table 3.

The evaluation of the world geothermal resources is still very uncertain. As an indication, the total geothermal power which may be installed in the world is presently evaluated on the order of 60 000 to 100 000 MW, equal to 0.6 to 1% of the primary energy demand in the world in the year 2000 (estimated to be of the order of $170\,000 \times 10^{12}$ cal).

Under average conditions of wet steam, and on the basis of the 1975 U.S. dollar prices, we estimate the cost of energy produced by the typical geothermal plant to be on the order of 16.4 mills/kWh.

For comparison we estimate, on the same basis, the cost of energy produced by a conventional steam plant, as follows:

1. Fuel, Bunker C, with crude oil priced at $9 to $10.5/bbl:
   150-MW unit, 22.1 to 24.4 mills/kWh
   600-MW unit, 18.2 to 20.4 mills/kWh.
2. Fuel, coal priced at $30 to $40/ton:
   150-MW unit, 19.9 to 23.3 mills/kWh
   600-MW unit, 16.3 to 19.6 mills/kWh.

The geothermal power installations are generally uncomplicated in layout and simple to operate; the size of the units is modest, ranging usually between 10 and 50 MW.

As mentioned above, the traditional geothermal power plants can provide only a small fraction of the world energy demand, and they can be located only in some limited areas of the world.

Nevertheless geothermal power plants, wherever feasible, have roused increasing interest because they are independent of foreign supplies of fuel, while their operation is reliable and satisfactory from the viewpoint of economy. Furthermore, while it is true that the contribution of geothermal energy is modest on a world average, on the other hand, it may happen that a geothermal power plant located in a small, developing country would give a remarkable contribution to the local power supply.

With reference to the exploitation of geothermal energy by means of its transformation to electric power, we may in general observe that the dryer the steam, the cheaper is the power produced, as price/kWh. While the major contribution of geothermal energy has been, so far, in the generation of electric power, a further valuable contribution is foreseen in the form of caloric energy (low-pressure steam, hot water) in the vicinity of the geothermal fields, especially through use of the hot water wells.

Table 1. Locations and approximate capacities of geothermal power installations, as of 1974.

Country	Most noted field	Approximate installed capacity (MW)
Italy	Larderello	400
USA	The Geysers	400
New Zealand	Wairakei	200
Mexico	Cerro Prieto	75
Japan	Matsukawa	35
Others	(Iceland, USSR)	10
	1974 world total	1120

Table 2. Geothermal electric capacity to be installed by 1978.

Country	Approximate capacity (MW)
Italy	30
USA	270
New Zealand	120
Mexico	75
Japan	135
El Salvador	90
Philippines	100
Total added by 1978	820

Table 3. Geothermal development under consideration for completion by 1985.

Country	Approximate capacity (MW)
Japan	300
USSR	100
Indonesia	250
Guatemala	90
Projected 1985 total	740

To complete the picture, we would like to mention that new techniques are under development in order to overcome the technical and economical difficulties for a better use of the wet steam fields and hot water wells which represent the major part of the known geothermal resources.

NEW FORMS OF GEOTHERMAL ENERGY

Besides the above-mentioned traditional resources, new forms of geothermal energy, geopressured-brine fields, and hot dry rock systems have attracted great interest. From a theoretical viewpoint, it has been evaluated that the energy stored in these forms might satisfy a great part of the world demand at the beginning of next century, provided that suitable techniques be discovered for their exploitation.

Geopressured-brine fields have been discovered around the Gulf of Mexico, and they consist of highly porous sands, saturated with brines at temperatures on the order of 200°C and pressures on the order of 1000 kg/cm^2.

Hot dry rock systems have been discovered in various places, and they consist of impermeable rocks covering a magma chamber, at temperatures on the order of 170°C, at depths on the order of 2 km; higher temperatures are found at greater depth. As anticipated at the present moment, techniques for exploitation are not available for either of these forms of geothermal energy. Since the great majority of geothermal heat seems to be stored in dry hot rocks, and these are likely to be scattered in many places in the world, priority has been given to research studies relevant to this energy form. As far as we know, researches are under way in the USA and the USSR and possibly in Japan.

One proposed process consists of drilling two bores down to the hot rocks, one for injection of cold water and the other one for extraction of hot water. Cracks in the rocks between the bores could be provided by thermal action of the cold water, or by preliminary use of an explosive. The feasibility of such processes depends upon the results of experiments which appear particularly convenient as they are based on technologies already substantially known (unlike, for example, those relating to hydrogen fusion), with limited expenditures and limited risks to the environment.

In favorable circumstances, it is expected that commercial projects can be in operation by the end of the century.

COMPARATIVE COST

In an indicative way, the costs of geothermal energy at 1975 prices, with reference to typical site conditions, can be estimated and compared with those for conventional steam plants. Cost breakdowns for geothermal power production are given in Tables 4 and 5. Assuming a geothermal plant capacity of 2 × 50 MW, fed from 20 active wells (from

Table 4. Deriving cost per kilowatt of an installed 100-MW geothermal electric plant.

Installation costs (1975 prices)	$ × 10^3
35 wells × 800 m (depth) × $600/m	16 800
Piping from wellhead to powerhouse, and accessories, $400 × 10^3 × 20 wells	8 000
Turbogenerators, transformers, and accessories, $230/kW × 100 × 10^3 kW	23 000
Civil works	9 200
Construction total	57 000
Contingencies (10% allowance)	5 700
Plant total	62 500
Engineering and management	12 500
Interest during construction (2.5 yr)	9 400
Total	84 600 ($846/kW)

Table 5. Geothermal-electric generating costs.

Generating cost	mills/kWh
Capital	
13% of $\frac{\$846/\text{kW}}{8000\ \text{kWh/yr}}$	13.75
Powerhouse operation, maintenance	
1% of $\frac{\$846/\text{kW}}{8000\ \text{kWh/yr}}$	1.05
Field and feeders, annual operation and maintenance	
Drilling 1 well/yr, 800 m × $600/m = $480 000	
Piping and accessories 400 000	
Maintenance on surviving wells 400 000	
Total $1 280 000/yr	
Prorating: $\frac{\$1\ 280\ 000/\text{yr}}{100\ 000\ \text{kW} \times 8000\ \text{hr/yr}}$	1.60
Total	16.40

Table 6. Installation and fuel costs for coal- and oil-fired generating plants.

Cost items	$/kW 150 MW	$/kW 300 MW	mills/kWh 150 MW	mills/kWh 300 MW
Installation (1975 prices)*				
Coal-fired	460	400		
Oil-fired	300	250		
Fuel (1975 prices)				
Coal (7000 kcal/kg)				
@ $40/ton, 57 mills/$10^4$ kcal			13.76	13.16
@ $30/ton, 43 mills/$10^4$ kcal			10.38	9.93
Oil (Bunker C crude, 10150 kcal/kg)				
@ $10.5/bbl, 70 mills/$10^4$ kcal			16.10	15.40
@ $9.0/bbl, 60 mills/$10^4$ kcal			13.80	13.20

*Costs include interest for construction period of 3-1/2 years

Table 7. Coal- and oil-fired generating costs (mills/kWh) based on Table 6.

Cost items	150 MW Coal	150 MW Oil	300 MW Coal	300 MW Oil
Capital share, in mills/kWh				
13% of installation cost; 7000 hr/yr full load	8.54	7.42	5.97	4.64
Operation and maintenance, in mills/kWh				
1% of installation cost as above; 7000 hr/yr full load	0.98	0.86	0.43	.36
Fuel cost range in mills/kWh				
(based on 1975 price ranges)	10.38 to 13.76	13.80 to 16.10	9.93 to 13.16	13.20 to 15.40
Range of total generating costs in mills/kWh	19.90 to 23.28	22.08 to 24.38	16.33 to 19.56	18.20 to 20.40

a total of 35 wells each 800 m deep, of which 15 are unproductive), installation costs come to $846/kW, and final generating costs come to 16.40 mills/kWh.

In a likewise indicative way, costs of installation and generation can be estimated, at 1975 prices, for a conventional steam plant using coal or oil. The particulars are given in Tables 6 and 7; two typical generating capacities (150 and 300 MW) are considered in turn for coal and oil; fuel costs are given in terms of a price range for each fuel. Installation costs are as low as $250/kW (for an oil-fired plant of 300 MW) or as high as $460/kW (for a coal-fired plant of 150 MW). Generating costs range from a low of 16.33 mills/kWh (coal, 300 MW) to a high of 24.38 mills/kWh (oil, 150 MW). For comparison, geothermal installation cost, again, is $846/kWh, and geothermal generating cost is 16.40 mills/kWh.

In all cases, capital costs are reflected in the final generating costs. For geothermal energy, the capital cost is the preponderant part of the generating cost; for conventional energy sources, the fuel cost is obviously the major component of generating cost.

CONCLUSIONS

The exploitation of traditional geothermal fields can make a remarkable contribution to local energy production, and afford relief from the necessity of importing fuels, and at reasonable costs in the particular areas where such resources are available. Therefore development of such plants appears convenient wherever feasible.

Possible new forms of geothermal energy, especially the hot dry rock systems, might make very substantial contributions to satisfy the world power demand by the end of the century.

Great interest is directed at the proposed tests which should ascertain whether or not the exploitation of such new resources is feasible.

REFERENCES CITED

Banwell, C. J., 1967, L'énergie géothermique dans le monde: Impact, v. XVII no. 2.

Barbier, E., and Fanelli, M., 1973, Overview of geothermal exploration and development in the world: Intern. Inst. Geoth. Res., Pisa.

Di Mario, P., and Leardini, T., 1975, Aspetti tecnico-economici della produzione geotermica: L'energia elettrica, no. 1.

Einarsson, S. S., 1970, Utilization of low enthalpy water for space heating, industrial, agricultural and other uses: UN Symposium on the Development and Utilization of Geothermal Resources, Pisa, Proceedings (Geothermics, Spec. Iss. 2), v. 1, p. 112.

OCDE, 1974, Perspectives énergétiques jusqu'en 1985: Paris.

United Nations, 1970: UN Symposium on the Development and Utilization of Geothermal Resources, Pisa, Proceedings (Geothermics, Spec. Iss. 2).