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Economic Aspects of Geothermal Development

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ABSTRACT

A geothermal scheme can be considered to comprise three parts—production, transmission, and conversion of heat. The equipment needed for heat conversion can be closely specified and costed once the input and output conditions have been identified. Heat production and transmission costs are much more uncertain. As existing geothermal heat sources become depleted, new wells have to be established and the configuration of the transmission network will often change during the lifetime of the scheme. Once the initial investment has been made, there will be recurring capital investment for keeping the converting plants supplied with heat; this expenditure flow may be large enough to put the economic value of the whole geothermal development into question. Heat production also usually involves an important preinvestment phase in which considerable sums may be expended for no foreseeable return; such expenditure is usually written off but this is unsound in economic terms.

The true economic merit of the scheme should be determined at the outset by evaluating all relevant preinvestment and predictable post-commissioning expenditure in present-worth terms. The development strategy should be formulated accordingly. To keep a geothermal scheme economically viable throughout its lifetime, the recurring investment and the economic merit must be reassessed periodically and compared with alternatives presenting themselves at that time. Such reexamination might show that heat production must be curtailed by restricting further capital expenditure to achieve an acceptable economic return, and this would result in a given scheme's becoming relegated progressively to a lower order of merit.

CONCEPT

For purposes of investment analysis, a geothermal power scheme can be broken down into three main parts—(1) the production of steam, (2) its transmission from well to power plant, and (3) its conversion into electricity in the power plant. The power plant can be costed fairly closely once the input and output conditions and the steam quantities available have been specified. The costs of the steam production and transmission system are, however, very uncertain; they can amount to a considerable portion of the total investment costs of the scheme and can greatly affect its economic worth. Further difficulties are that much expenditure on exploration is incurred before a steam supply becomes assured, and that a recurrent investment in additional steam wells and pipelines will be needed to maintain an adequate steam supply throughout the lifetime of the scheme. Unlike the case of a conventional power scheme, the reinvestment needs may distort the economic worth of the geothermal scheme which originally justified them.

The performance of the steam wells is difficult to determine in advance, and generalized treatment of geothermal projects is not possible. All that can be done is to point to the difficulties of establishing a valid comparison with conventional power schemes before practical operating experience with the geothermal scheme has been obtained and the performance of the production wells has been monitored.

A characteristic geothermal field development is illustrated schematically in Figure 1. A power station comprising two 50-MW units is located centrally in the field. Steam conditions are assumed to be 6.6 bar, 184°C (14°C superheat) at the station inlet; the steam consumption at full load is 900 t/hr. Boreholes are arranged symmetrically about the power plant at a density of one well per 16 acres (6.5 ha). With an average steam output of some 56 t/hr at the wellhead (at 7 bar, 200°C), 16 boreholes will be needed to meet the full-load requirements of the plant. The well output is assumed to decay at a rate of about 3% per year so that 16 additional wells will be needed to keep the power plant in full-load operation throughout its asset life of 30 years. In the rather simple example shown in Figure 1, the additional wells are assumed to be symmetrically arranged around the older wells.

The interconnecting pipelines are designed for optimum transmission conditions. But since the pipelines nearest the power station must be large enough to accept the additional throughput from the wells for some of the time, optimum steam flow conditions will only be achieved for relatively brief periods. There will inevitably be an initial over-investment in the steam transmission system which will be related to the additional investment requirements for the new wells and for the pipelines interconnecting these wells with the existing pipeline system.

INVESTMENT

The cash flow for the scheme described above is presented in Figure 2. It comprises a preinvestment phase, five years before commissioning the scheme, for expenditures directly associated with steam exploration for this scheme; but it is assumed that the initial geophysical and geological survey work is written off as research expenditure. The construction phase is taken to span four years, during which the 16 boreholes are drilled and the power station is built. The

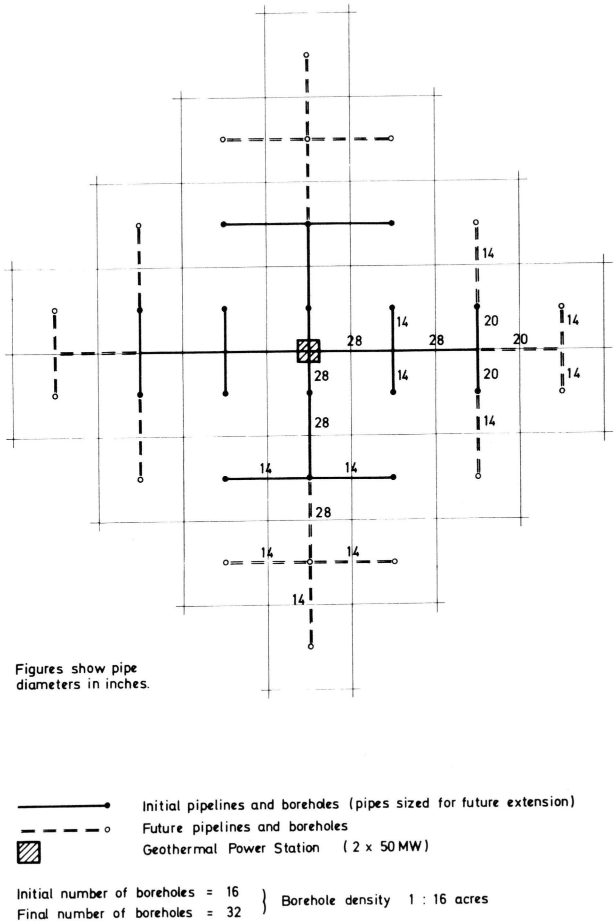

Figure 1. Geothermal field development.

usual retention moneys, amounting to about 5% of the power-plant cost, become payable about one year after commissioning of the plant. The scheme as such is then complete—it incurs operation and maintenance costs throughout its life. However, eight groups of two boreholes each, together with the interconnecting pipework, have to be built after commissioning, and this requires continued capital expenditure up to five years before the ultimate closing down of the power station. This recurring expenditure forms an integral and essential part of the scheme, and thus must be included in the cost flow analysis so that a valid representation of total cost is obtained.

The costs shown refer to price levels in mid-1975. The cost estimates are considered to be typical for a geothermal scheme of 100 MW in a reasonably accessible location. The cost of each borehole, inclusive of wellhead installations, is set at $1.5 million. The power plant is estimated to cost $375/kW inclusive of civil engineering works and electrical services. The initial outlay on the steam pipeline system is assessed at $40/kW, including civil works for a simple above-ground arrangement. Annual expenditure for operation, maintenance, and interim replacement is assumed to be 3% of the total investment in the power plant and the steam supply pipework.

APPRAISAL

On the basis of these figures, the initial leveled cost of the energy produced by the geothermal scheme comes to 14.8 mill/kWh. This cost is computed from the present worth of capital and operating expenditure, discounted at 10% per year, and for an annual energy output of 650 GWh (equivalent to 74.3% annual plant factor) arising throughout the life cycle of the scheme.

The 16 additional boreholes will require an expenditure of $3.0 million every 2 out of 3 years up to the 25th year of commercial service. The associated steam supply pipework will cost a further $0.5 million for every group of two holes. These costs refer to present price levels. If leveled over the life of the scheme, they will raise the production cost by 10% to 16.3 mill/kWh.

The production cost for an oil-fired power station of comparable size will be around 38 mill/kWh on the same pricing basis and with oil costing $10 per barrel. Although such station-by-station comparison is not entirely valid since it ignores the economic disadvantage inherent in a small-scale oil-fired plant, it does show the very considerable margin in favor of geothermal energy; in the face of this margin the recurring investment requirements of the new boreholes become insignificant. However, the extra investment can become a major item. A cost escalation of 10% per year for the additional boreholes, caused by an assumed increasing difficulty of drilling these holes—possibly to greater depths—will raise the leveled production cost to 19.2 mill/kWh. At this point, the production cost will exceed that of a high-efficiency base-load plant, for example, a nuclear plant, and may no longer be economically competitive for operation at this plant factor.

As is well known, the cost per kilowatt-hour generated by a thermal power plant and the energy output allocated to it in a power system (its "order of merit" in the system) are closely interlinked. Where this cost exceeds that of other base load units in the system, the plant output has to be curtailed until the unit (kWh) cost becomes equal with that of the other plant: the output has to be fitted into the system load-duration diagram in its proper order of merit. In the case of a geothermal scheme where the total production costs are practically independent of the amount of electricity produced, curtailment of output will raise the unit (kWh) cost in direct proportion to the extent of curtailment. To achieve an economic balance between actual and economically acceptable unit costs (from the system point of view), the reinvestment, which is to overcome an output curtailment resulting from steam shortage, may itself have to be restricted. The expansion of steam collection must be limited to a pattern which ensures a stable and economically acceptable position of the power plant output in the system load-duration diagram. This means that the economic performance of the scheme must be reexamined periodically during its lifetime, and before a decision on new investments is made, to ensure that it is still satisfactory. Each new well drilled must be economically justified in terms of the value of the total electrical output it makes possible.

The approach here proposed is common to many investment sectors. The difference in the geothermal case is perhaps that while the reinvestment alone may be economically justified by the value of the additional energy output it procures (or the loss of energy it makes good), its effect on the average cost of the energy produced by the scheme may place the total output in an uneconomic position in the order-of-merit table: the electricity may become too

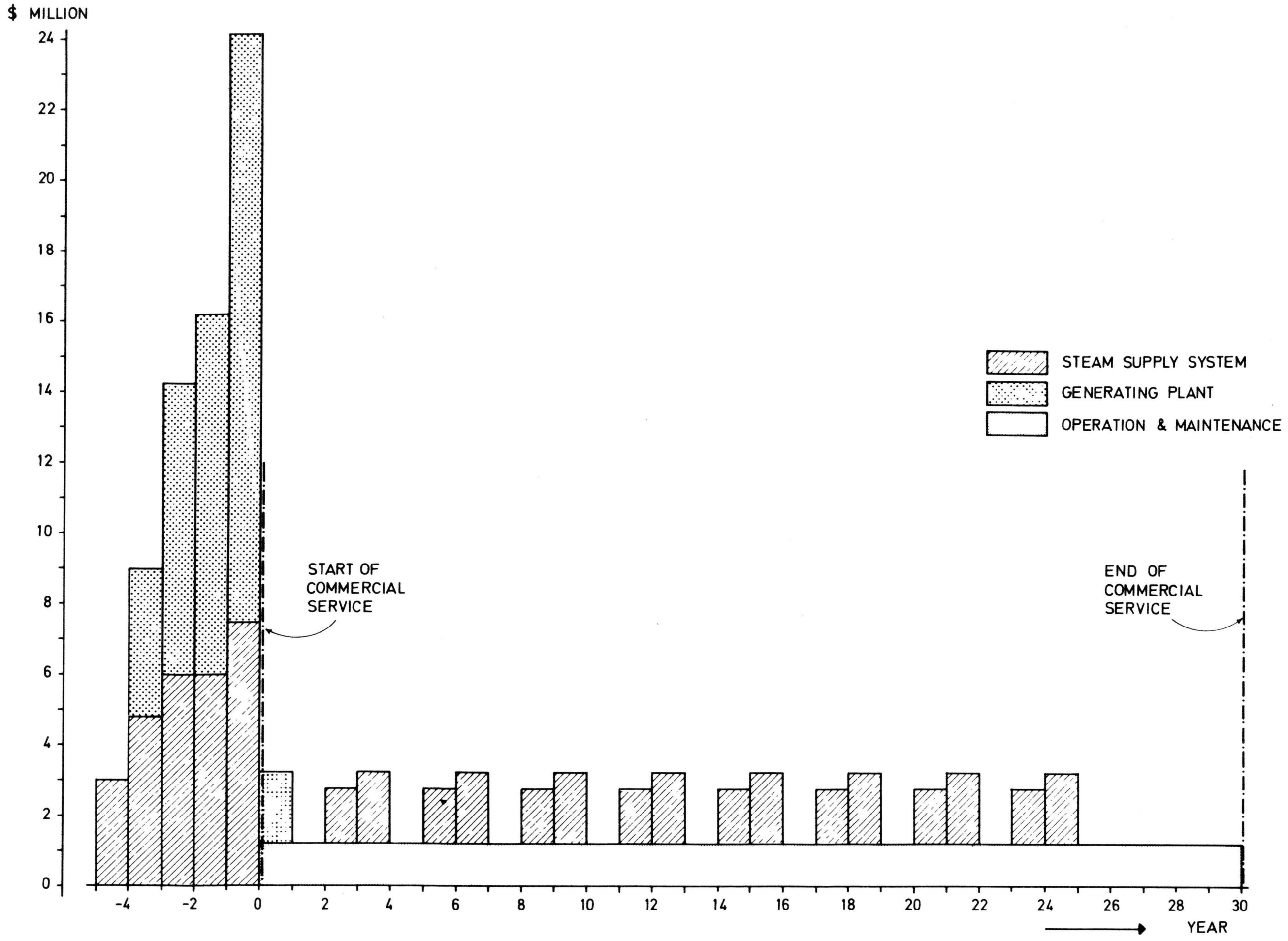

Figure 2. Cash flow for 100-MW geothermal power plant (price level of mid-1975).

expensive in relation to its value at the particular plant factor in question. The appraisal must therefore look at the geothermal scheme as a constituent of the power system, assuming there to be a power system and not an isolated plant. The cost structure will be different in every case and generalization is not possible.