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BUSBAR ECONOMICS OF LIQUID-DOMINATED GEOTHERMAL POWER

Johan A. Wassenaar

Fugro, Inc.

The state-of-the-art of electrical power generation using hot-water geothermal resources as opposed to geothermal steam, has yet to be developed to where an accurate prognosis of busbar cost can be made. There are many uncertainties that are responsible for this, and until an empirical data base is brought into being through long-term operation of commercial-scale power plants using liquid-dominated hydrothermal resources, no exact economic projections will be possible.

However, the body of knowledge about the use of hot-water resources is expanding rapidly, and through conjectural analyses, it is becoming increasingly possible to draw a fairly tight bead on the prospective busbar costs of power generated from such resources.

It appears fairly certain, for instance, that liquid-dominated geothermal power could generally be cheaper than oil-fired power, but would not be able to compete with nuclear or coal-fired power in areas where the physical and political climates would still permit such power plants to be built.

The main causes of uncertainty about the cost of hot-water geothermal power are variations in the following:

- Plant utility (availability) factor
- Conversion cycle efficiency
- Fuel (heat) price
- Capital cost
- Resource decay characteristics
- Plant cooling provisions
- Operations and Maintenance cost (O&M)
- Power transmission cost

Plant Utility Factor:

A very large portion of the busbar cost of a hot-water geothermal power plant will be fixed. The capital component of busbar cost associated with the power plant is in the order of one-third. However, the fuel (heat) cost which represents more than half of overall busbar cost, also contains a large capital component associated with the drilling and completion costs of production and injection wells. Even the operations and maintenance portion of busbar cost, which is in the order of 10-13%, is mostly fixed as a function of the irreducible staffing and equipment requirements to deal effectively with scale prevention from the saline geothermal brines.

Early indications for a family of 50-100 MWe plants are that a fixed busbar cost component in the order of 80-85% may be expected. This very clearly classifies geothermal power from hot-water resources as base load capacity with very high cost susceptibility to plant utilization. To compete with the cost of conventional or new (combined cycle) oil-fired power, such geothermal power plants would have to be kept on-line at least 75-80% of the time. This could be a serious challenge at reservoirs where the salinity of the geothermal brines is high, such as, for instance, at Niland in Imperial Valley (250,000-300,000 ppm). A substantial amount of redundancy in the brine flow circuits may be justified in such cases to permit off-line cleaning without plant shut-down.

Experience in Mexico at Cerro Prieto, while not involving brine reinjection as yet, nevertheless provides the basis for some optimism that high geothermal power plant availabilities will be achievable.

Conversion Cycle Efficiency:

By definition, the low heat intensity of geothermal power from hot-water resources severely limits the thermal efficiency achievable in the power conversion cycle. This reflects in a high heat flow rate per kilowatt of power which varies substantially as a function of the reservoir down-hole temperature. For example, as shown in figure 1., a flash steam cycle plant at Niland (550°F) would typically use about 16 lb. of steam per kilowatt-hour whereas its counterpart at Heber (360°F) would use as much as 27 lb. per kilowatt-hour. We are, therefore, dealing with conversion cycle efficiencies in the range of 10-15%, which has a great impact on the fuel (heat) component of busbar cost, and which constitutes something in the range of 55-60% of overall busbar cost.

FLASH STEAM GEOTHERMAL POWER PLANT STEAM RATE

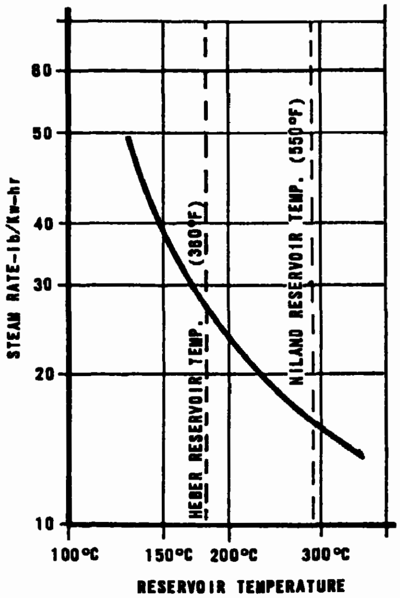


FIGURE 1

Much will be said about the relative merits of different conversion cycles for use at certain reservoirs. For instance, the prospects of using a hydrocarbon binary cycle approach at reservoirs in the 350°F temperature range to attain improved conversion efficiencies over that possible with a flash steam cycle, will hopefully be tested on a commercially comparative scale if the Heber Demonstration Binary Project and other comparable flash steam plants get underway in parallel.

Later prospects for efficiency improvement through use of total flow impulse turbines, or with the introduction of heat augmentation of geothermal steam by fossil-fuel, nuclear or solar energy means will undoubtedly follow. However, the economics of these approaches will be suspect for quite some time.

Fuel (Heat) Price:

During this early evolutionary phase of liquid-dominated geothermal power, it would be unreasonable to expect free market forces to set the price of geothermal heat. There are only so many resource companies involved in the development of the reservoirs, and they are understandably skeptical about the consistency of demand for their geothermal heat product.

Initial heat supply contracts for geothermal power plants will, therefore, tend to contain guarantees for certain minimum heat use rates to ensure reasonable recovery of fixed reservoir development costs. Such guarantees effectively render a large part of the fuel cost of a geothermal power plant invariable, as pointed out before.

The resource operator also still faces many uncertainties that could impact his production costs. Unexpected decay of the resource temperature, deteriorating steam quality, if a flash process is used, and clogging of injection wells and geologic dispersal zones by disassociating mineral salts from the cooled brines, are but a few of the possibilities as yet unproven.

Capital Cost:

No one knows exactly what the capital cost per kilowatt of a series of like geothermal plants, replicated in a region of multiple reservoirs such as Imperial Valley would be. It depends on the choice of optimum power plant designs for the different reservoirs, and could also be seriously impacted by power plant cooling provisions. It appears that initial commercial-scale (50-100 MWe) plants will cost in the range of $750-800 per kilowatt, but the learning curve effect of a construction program involving a series of very similar (or identical) plants should reduce this to something in the $500-700 per kilowatt range (1978 constant dollars).

Resource Longevity:

Until substantial generating capacity is installed and operated for long periods of time at the prime reservoirs, their characteristic behavior in terms of temperature and pressure decay will be left to scientific conjecture. The fingerprint of each reservoir in the sense of convective thermal recharge will not be known with certainty before then. Also, the possible modification of reservoir permeability by the circulation of injected spent brines with high salt contents will not be fully understood without empirical data on a suitably large scale.

The effects of reservoir decay on power plant economics are significant. Heat flow rates of flash steam plants rise rapidly with reducing reservoir temperatures, and binary cycle plants require adjustments in heat transfer surface areas, and in working fluid composition to compensate for temperature drops.

Power Plant Cooling:

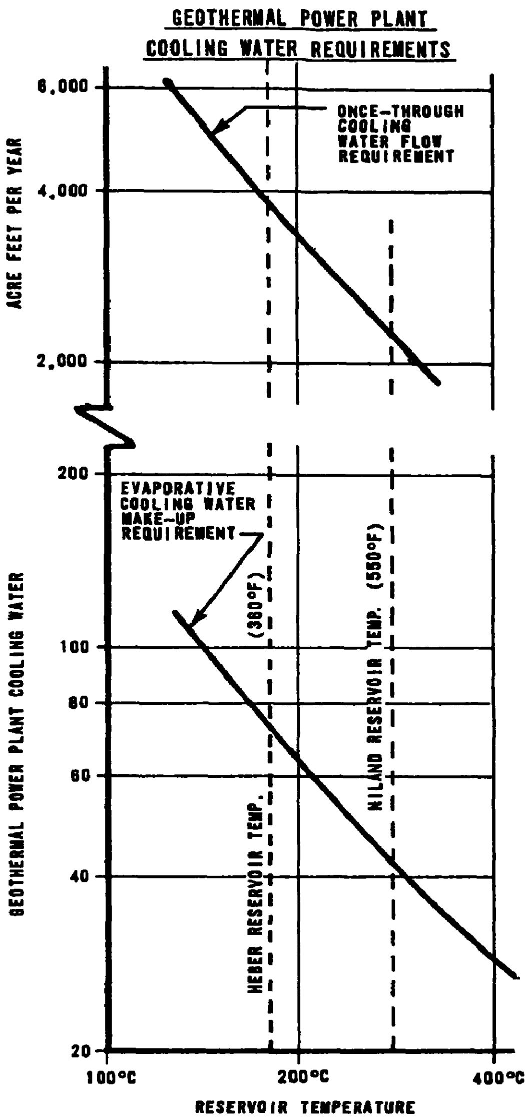


FIGURE 2

Because of their low thermal efficiency, geothermal power plants are gargantuan users of cooling water (see figure 2). In all but a few possible cases, once-through cooling would be economically unfeasible. Evaporative cooling seems to be the best near-term solution, but it requires a substantial supply of cooling tower make-up water (100 acre feet/yr./MWe). While flash steam plants could use their own condensate for this purpose, they still require an equivalent alternative water supply for injection into the reservoir to replace the withdrawn steam, and so avoid the possibility of land subsidence as a result of ultimate fluid depletion.

For instance, Imperial Valley, agricultural drain water would appear to be the best source of plant cooling-related water at upstream locations such as Heber. However, diversion of drain water reduces dilution and replenishment of the Salton Sea, which is already increasing each year in salinity. To obtain water rights, this effect may have to be mitigated by injecting compensating amounts of Salton Sea water into the Niland reservoir in association with power plants at that location. However, the effects on Salton Sea water injection on the reservoir would first have to be investigated.

With large-scale commercial development of geothermal power plants in arid areas such as Imperial Valley and Roosevelt Hot Springs, it seems likely that wet/dry cooling tower methods may ultimately have to be used. This could bring about a 50% reduction in annual make-up water consumption, but would impact busbar cost to the extent of about 10 mills/kw-hr. (in 1977 dollars).

Operations and Maintenance Cost:

Geothermal power plant (liquid-dominated) O&M costs appear to be four to six times more than for equivalent oil or nuclear generation methods. Much of this is occasioned by the small unit sizes of geothermal plants, and by the requirement for flow circuit cleaning and descaling. However, O&M costs still only make up about a tenth of overall geothermal busbar costs, and since the O&M procedures will have a great influence on plant utility factor, compromises to reduce O&M costs will have to be carefully considered. One approach to reduce O&M charges without compromise, may be to improve maintenance efficiency by grouping geothermal plants in clusters.

Power Transmission:

Many geothermal resources are remote from major population centers, and the cost of transmitting power from geothermal power plants could be considerable. This problem is compounded by the fact that economical transmission lines have capacities that would require many geothermal units in the 50-100 MWe size range to fill.

Transmission costs during the initial period of a commercial geothermal plant construction program, when a mismatch between generating and transmission capacities could be expected would, therefore, be high. A potential solution may be the sharing of transmission facilities between different power plant owners, or between different generation plant types within one utility.

While it may be imprudent to risk specific forecasts of liquid-dominated geothermal busbar costs in this uncertain environment, the following preliminary assessment is offered to stimulate thought and discussion. Two hypothetical cases of commercial hot water geothermal power plant development are presented as depicted in figure 3.

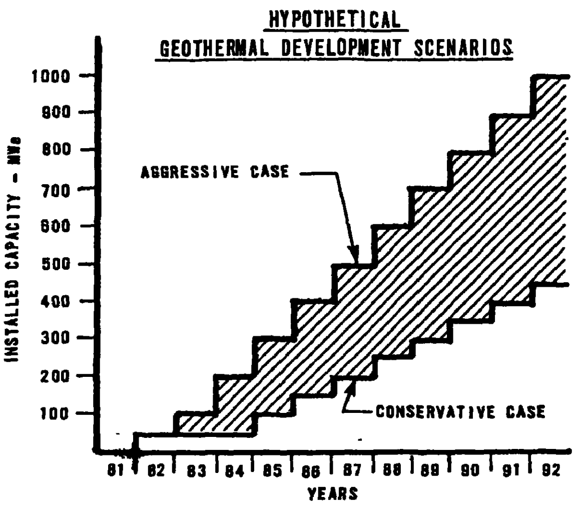


FIGURE 3

The conservative case assumes a cautious construction program resulting in an installed capacity of only 450 MWe by 1991. No government funding aid is postulated, limited tax and rate incentives, and a sharing of transmission facilities with other generation alternatives are assumed.

The aggressive case assumes a bolder construction program yielding 1000 MWe capacity by 1991. A 50% government participation initially in two 50 MWe demonstration plants at different reservoirs, and liberal tax and rate incentives are assumed.

Figure 4 shows the plant utility factors that would result from an 80% learning curve, starting at a 40% utility factor and peaking at 80% with ultimate experience.

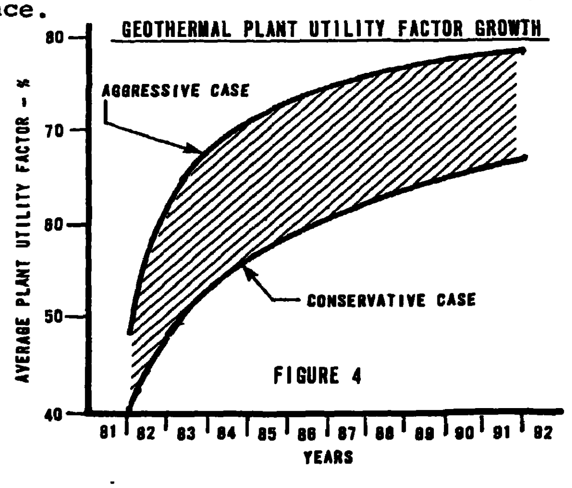


Figure 5 illustrates the fuel cost components of busbar cost for the two cases. The conservative case assumed achievement of 10.8% thermal efficiency for half the plants and 12% for the other half. The aggressive case is premised upon achieving 15% thermal efficiency for the second half. The opposite influences of improving utility factors on the one hand, and labor and materials cost escalation on the other, are apparent from the change in gradient of the two curves.

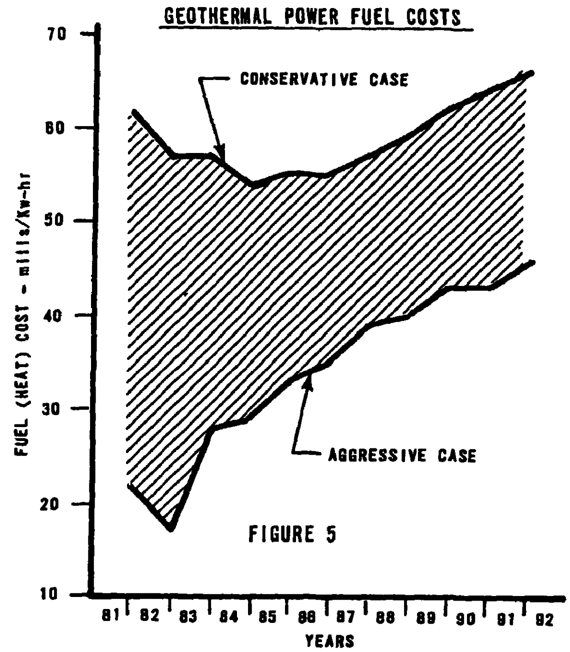
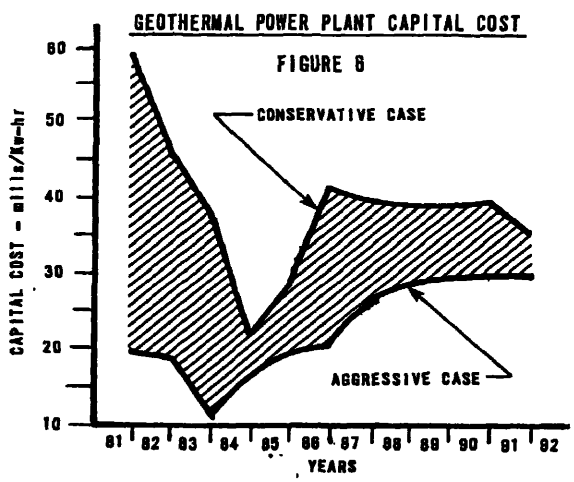


Figure 6 reflects the levelized capital component of busbar cost for each case. The conservative case assumes no demonstration grants from public sources, and assigns a 25-year book life to commercial plants, with a 16-year tax life for Federal purposes, and a 20-year tax life for State purposes. The aggressive case assumes a 30-year book life for commer-



cial units, and provides for 50% public funding in support of two demonstration plants, including government participation in the first five years of operation.

Figure 7 shows the O&M portion of busbar cost for each case. Figure 8 summarizes overall busbar cost for both cases and compares them with the busbar costs of an oil-fired plant in a coastal setting, and a nuclear plant inland in the desert. It will be seen that the optimistic (aggressive) case competes successfully on a cost basis with the oil-fired alternative. However, the range of geothermal busbar costs, as represented by the shaded area between the curves, is still much too wide to feel confident about any conclusions. Nevertheless, it will not escape your notice that geothermal power from hot-water resources will have to be undertaken on a large scale in order to make it competitive with other forms of power generation at the busbar. This mav come as a surprise to those who may have viewed geothermal power as a small incremental electrical growth opportunity consistent with the constrained industrial expansion ethic espoused by some.

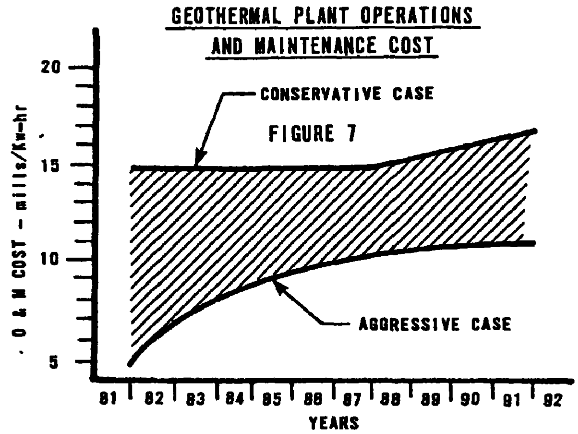


FIGURE 7

More refined economic analyses, using conjectural probabilistic techniques should narrow the range of economic uncertainty about geothermal power substantially in the near future.

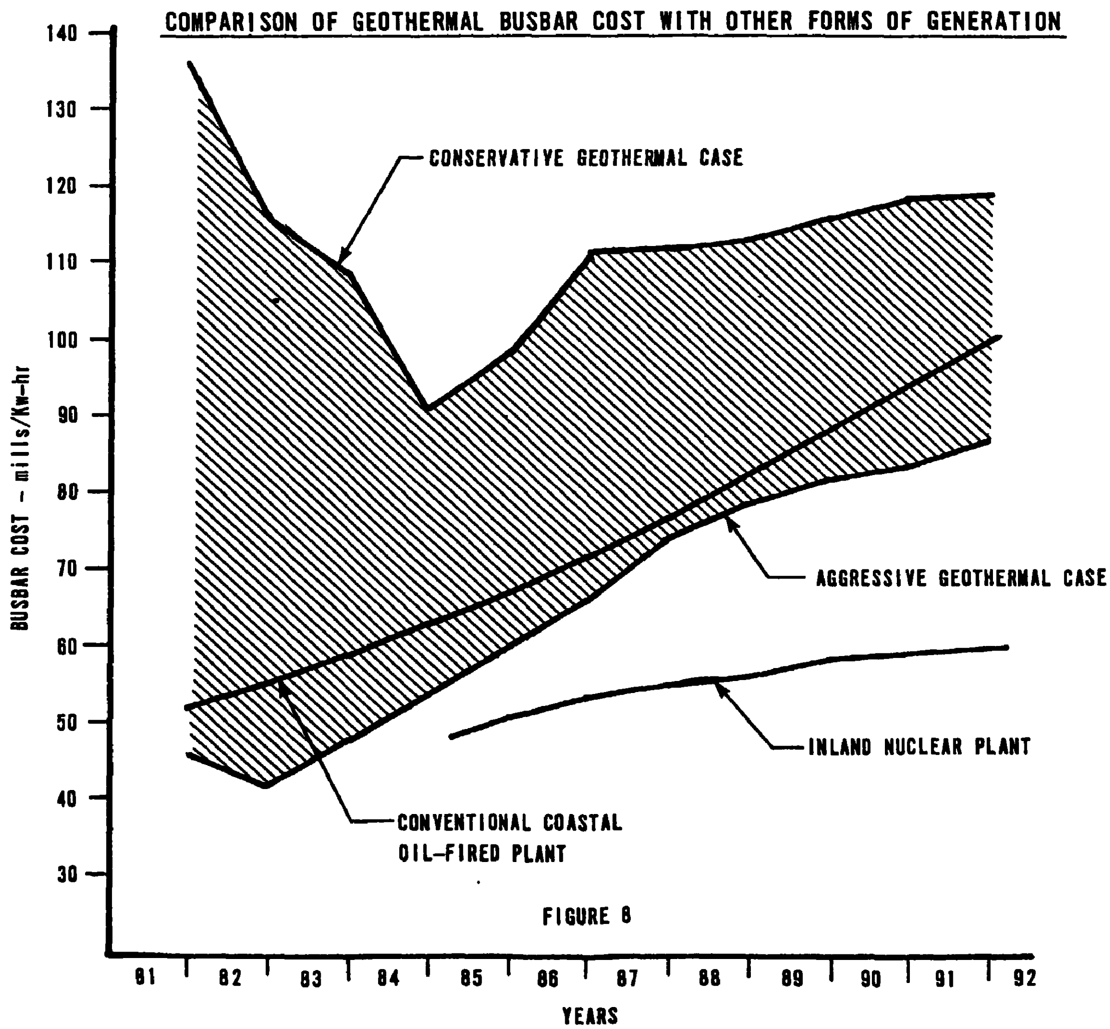


FIGURE 8