SITE-SPECIFIC ANALYSIS OF HYBRID GEOTHERMAL/FOSSIL POWER PLANTS

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INTRODUCTION

Liquid-dominated geothermal resources must be extensively used if geothermal energy is to provide 10,000 to 15,000 MW of electrical power by 1985. The conversion of this resource relies upon the development of new and, for the most part, commercially unproven technology.

Present electric power generation and distribution technology is directed at large plants -- 3000 to 5000 MW -- to ensure the most economical delivery of electric energy to the consumer. The advantages of using this technology for conversion and distribution of geothermal energy are readily apparent. However, the properties of geothermal energy in terms of temperature, pressure, and quantity are far different from the properties of the heat energy produced from fossil fuels.

In 1975, the City of Burbank suggested that fossil fuel and geothermal energy could be combined to mutual advantage in a single power plant. By 1976, the city, Pacific-Sierra Research Corporation (PSR), and other investigators suggested that geothermal energy and fossil fuels could be used to advantage in a hybrid cycle. Geothermal energy could provide low-temperature heat to the boiler feedwater of a Rankine steam cycle, reducing the need for regeneration. The fossil fuel could provide the high-temperature heat at a more efficient level of use. A recent study by Brown University(1) revealed several important advantages of the hybrid cycle.

- Thermodynamically, the hybrid system is superior to a combination of the two state-of-the-art systems, one using only fossil fuel and the other using only geothermal energy. Therefore, to achieve a given generating capacity, the hybrid plant would require less fossil fuel than a conventional steam plant.

- Equivalent geothermal energy conversion efficiencies are substantially higher in feedwater heating than in a state-of-the-art binary fluid or flash plant.

- Geothermal fluids with marginal temperatures (150°C/300°F) can be used in a hybrid cycle to produce electricity. This advantage is especially important because lower temperature geothermal resources are much more abundant than those with high temperatures. In a purely geothermal plant, low-temperature fluids cannot produce power economically under present technology.

Because piping high-temperature geothermal fluid over distances greater than 1.6 km (one mile) is impractical, the hybrid plant must be located within the geothermal resource area. In general, the resource is not optimally located with respect to sources of fuel, fresh water, or transmission networks. Therefore, while the thermodynamic advantage of the hybrid plant had been established, its economic competitiveness remained an open question. Could the economic advantages gained from the geothermal resource overcome the economic penalties owing to the location of the resource?

The Utilization Technology Branch (UTB) of the Energy Research and Development Administration (ERDA) undertook the task of determining the economic viability of a hybrid power plant. ERDA contract E(0-4-1311), "Site-Specific Analysis of Hybrid Geothermal/Fossil Power Plants," was awarded to the city late in 1976 and was completed in the Spring of 1977. Pacific-Sierra, the major subcontractor to the city, was assigned the analytical modeling.

STUDY OBJECTIVES

The objectives of this work are:

- Develop the analytical techniques for rough parametric design of hybrid geothermal/fossil fuel plants for various geothermal resource characteristics
- Develop the analytical techniques for approximate evaluation of hybrid geothermal/fossil fuel plants for given hydrothermal resource characteristics, fossil fuel location, consumer locale, plant size, and environmental restraints
- Evaluate the merits of a hybrid geothermal/fossil fuel plant at four known geothermal resource areas (KGRAs):
  - Roosevelt Hot Springs, Beaver County, Utah
  - Coso Hot Springs, Inyo County, California
  - East Mesa, Imperial County, California
  - Long Valley, Mono County, California
- Prepare a preliminary plan for implementing geothermal energy in hybrid cycle plants

To achieve these objectives, the city assembled a team primarily from the staff of its Public Service Department. The objectives were achieved through the following task sequence:

- Execute the basic hybrid power plant synthesis
- Analyze the geothermal characteristics of each of the four KGRAs
- Conduct a site-specific analysis of power production and delivery
- Prepare preliminary plant designs optimized for each site
- Compare the optimized plant designs against each other and a reference coal-fired plant design

- Compile the report

STUDY CRITERION

Utilities strive to provide electric energy to their customers at the lowest practical cost. Therefore, the selected criterion for this study is to establish minimum cost of delivered electric energy through optimizing the use of coal and geothermal resources within environmental constraints and legal requirements. All regulations presently known, including environmental protection, safety, and water usage, are to be met. Throughout the study, care also is taken to ensure that performance characteristics are readily achievable within the current state of the art.

The site-to-site cost comparisons are made by the general costing method outlined by ERDA (2). The economic assumptions conform to the ERDA method.

FOCUS ON COAL

By focusing on coal as the fossil fuel, this study recognizes the nation's goal to reduce its dependence on oil and natural gas. A hybrid geothermal/coal plant would use two energy sources of great abundance within the United States. Its electrical power would be secure and reliable, immune from any gas shortage or oil embargo.

Another important attribute of coal is its status as the least expensive of the fossil fuels. Because oil and gas are more costly, geothermal energy in a hybrid cycle will show even greater savings than would the use of coal alone.

Because minimum cost of electric power is the study criterion for the design of a hybrid plant, a reference all coal-fired plant is needed in order to provide a standard for measuring the economic viability of the hybrid plant and a guide for the costing of major power plant components.

Ideally, the reference plant should be a state-of-the-art design and optimally sited.

The Intermountain Power Project (IPP) plant was selected as the all coal reference. This plant is to start power production in 1984, which corresponds to the time period a hybrid plant could be ready for operation. Therefore, the IPP and the hybrid plants would face similar requisites relative to federal, state, and local regulations; cost of land, components, and labor; environmental restraints and requirements; and market considerations. The preliminary design of the IPP plant is available to the city because of its participation in the design study. The preliminary design for the IPP plant has not been completed at this time, although the work has been in progress since July 1974, and considerable analyses have been made on the design.

RESULTS AND CONCLUSIONS

<u>Site Evaluation</u>

The energy cost comparisons of a 750-MW hybrid plant at each of the four geothermal sites are presented in Figure ES-1. The principal conclusions drawn from the comparisons are:

- The Roosevelt Hot Springs site has the potential of producing electric energy delivered to Burbank at 10 percent less cost than a well-sited reference all coal-fired plant.
- The Coso Hot Springs site shows slightly greater cost than the all coal-fired plant for delivered electric energy to Burbank.
- The East Mesa and Long Valley sites did not show economic advantage for hybrid plants.

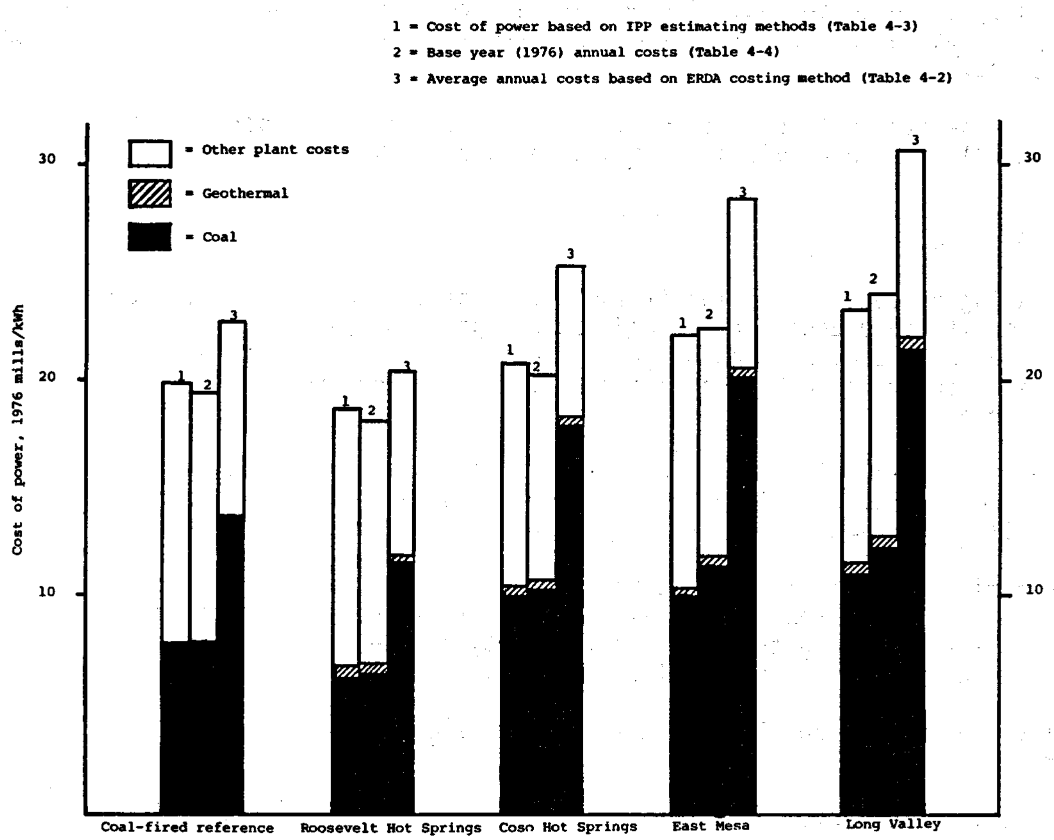

Figure ES-1. Energy Cost Comparisons for a 750-MW Hybrid Plant

Although comparisons were not explicitly made between hybrid and all coal-fired plants located at Coso Hot Springs, East Mesa, or Long Valley, the hybrid plant would be competitive with any all coal-fired plant at the same site.

Figure ES-2 shows why Roosevelt Hot Springs and Coso Hot Springs are more competitive than either East Mesa or Long Valley. With fewer geothermal wells, hybrid plants at Roosevelt Hot Springs and Coso Hot Springs would reduce the coal requirement. For example, the amount of coal could be reduced by at least 46.3 t/h (51.0 tons/h) at Roosevelt Hot Springs. East Mesa and Long Valley have larger cost penalties owing to their greater distance from the coal source.

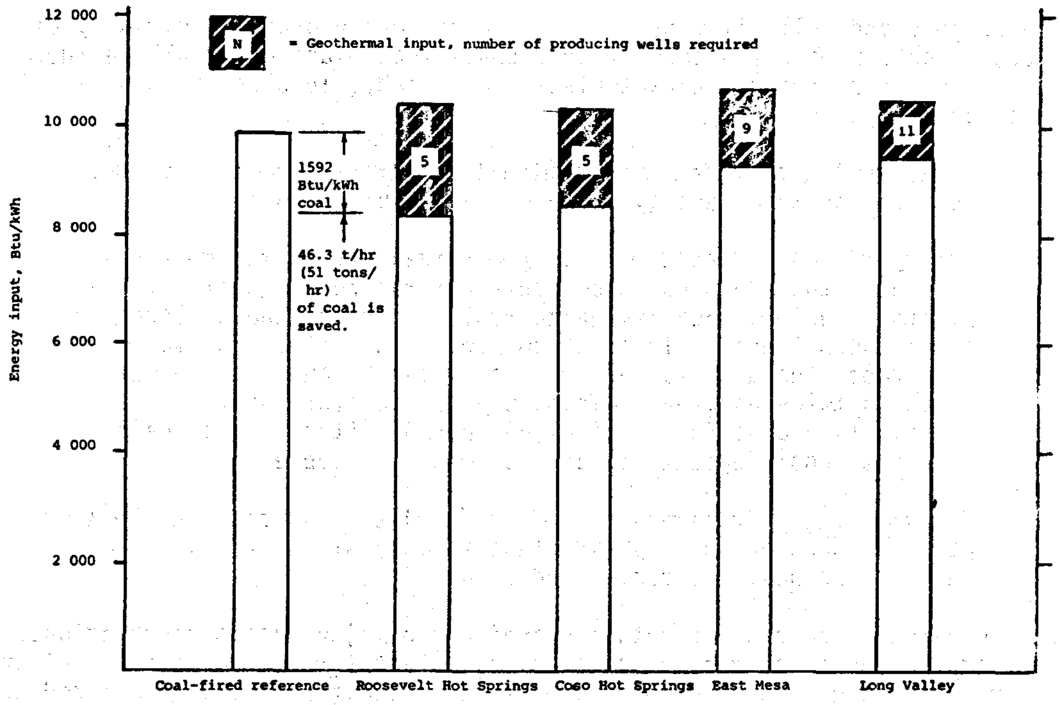

Figure ES-2. Energy Input for a 750-MW Hybrid Plant

<u>Cost Results</u>

Table ES-1 shows the annual costs, based on the ERDA costing method. The cost of coal delivered to the geothermal site is the principal economic factor that impacts upon the cost of delivered electric power from the hybrid plant. In comparison, well cost and well operation and maintenance are less than five percent of the coal costs for each of the four sites; and they are roughly equal to the cost of cooling water. These data indicate that feedwater heating is indeed a most significant application of the geothermal fluid, by its replacement of coal.

Additionally, using the geothermal fluid to dry coal or to supply power to an auxiliary boiler would further increase its ability to replace coal. Further savings would result if the geothermal fluid is used to supply cooling water.

It should be noted that well costs do not include royalties or profits, since they cannot be reliably estimated. If royalties or profits are large enough, they could affect site selection.

The capital cost of geothermal wells, larger condenser, and turbine-generator is more than offset by the reductions in the capital cost of the boiler for an all coal plant. At Roosevelt Hot Springs or Coso Hot Springs, the cost of a hybrid plant would be slightly less than the cost of an equivalent size all coal-fired plant. The development cost of the geothermal resource in East Mesa or Long Valley would more than cancel the reduced cost of the boiler.

Hybrid Plant Design

A well-designed and well-sited hybrid power plant can produce electricity at a lower cost than can either a conventional coal-fired plant or an all geothermal plant. Several performance characteristics of the hybrid plant account for its economic viability:

- Geothermal energy could economically contribute more than 20 percent of the total energy consumed in a hybrid plant.
- The hybrid plant would utilize geothermal energy far more efficiently than do present concepts for future all geothermal plants. For high-quality geothermal resources, the utilization of geothermal energy is about 20 percent greater. For marginal resources, the utilization efficiency can be one-and-one-half times to twice as great. Thus, the hybrid cycle would be especially useful for marginal geothermal sites located near enough to coal deposits to be economically viable.
- The thermodynamic efficiency of the coal contribution to electric power production in a hybrid plant is only slightly less than that of the best all coal-fired plant.

These conclusions were reached notwithstanding two major design restrictions, as well as some lesser ones imposed on the hybrid plant for this analysis. First, the geothermal energy was used only to heat the feedwater before it entered the boiler. Second, the boiler feedwater was heated in a subcritical cycle. Present judgment is that an actual hybrid design would encompass the following features:

- In addition to feedwater heating, the geothermal energy could have other applications, including coal drying and beneficiation, air preheating, flue gas reheating, auxiliary boiler heating, and general heating.
- The water balance in a hybrid plant is such as to allow for complete consumption of the geothermal fluid in evaporative cooling wherever the chemical and local environmental conditions would allow.
- The restriction to a subcritical cycle holds the steam at just below the critical temperature and pressure. It appears that a supercritical cycle could be utilized, with maximum pressures of about 240 bars (3500 psia).
- More than one turbine extraction point probably would be used. This allows flexibility to accommodate variations in the geothermal resource, as well as high-temperature steam for auxiliary station equipment. The hybrid plant is designed to accommodate some well shut-downs.

In view of the above considerations, the hybrid plant shows even greater promise than that revealed in the present study. Moreover, all the components in the hybrid cycle are state-of-the-art. The use of coal ensures a guaranteed plant life, even if the lifetime or quality of the geothermal resource is overestimated.

RECOMMENDATIONS

The results of this present study and the Brown University study show that the hybrid cycle can combine the two abundant national resources, coal and geothermal energy, to advantage. The general recommendation is to design, construct, and operate one or more hybrid power plants at suitable geothermal sites as soon as practicable. An operations target date of 1984 would be a good goal. Supporting recommendations are given below:

ACKNOWLEDGMENTS

This study was supported by the Energy Research and Development Administration Division of Geothermal Energy. Clifton B. McFarland was the Program Manager for ERDA. The work was performed by the City of Burbank's Public Service Department, with the analytical modeling being done by the Pacific-Sierra Research Corporation. Richard E. Roxburgh was the Program Manager for the City of Burbank and was assisted by Acey L. Floyd, Science Advisor to the city.

The study is based on theory developed at Brown University by Professors Ronald DiPippo, Joseph Kestin, and H. Ezzat Khalifa. This theory provided a clear and organized method of analysis of the hybrid geothermal/fossil fuel power plant.

The cost calculations are based upon modification of the computer simulation "A Thermodynamic Process Program for Geothermal Power Plant Cycles" developed by M. A. Green and H. S. Pines of the Lawrence Berkeley Laboratory. This simulation provided the basis for the cost optimization process used for the geothermal portion of the study.

The analysis required an optimally sited coal-fired power plant of the latest state-of-the-art design as a reference in order to provide realistic design and cost considerations for the hybrid plant analysis. The Intermountain Power Project (Joseph C. Fackrell, President) power plant was selected as the reference because of its siting, size, design, and schedule for first operation in the mid-1980s. The use of this ideally sited, cost efficient reference plant greatly enhanced the realism of the analysis.

REFERENCES

1. R. DiPippo, J. Kestin, and H. E. Khalifa. Hybrid Fossil-Geothermal Power Plants. Providence, Rhode Island: Brown University, 1977.

2. Energy Research and Development Administration. Comparing New Technologies for the Electric Utilities. ERDA-76-141 (Discussion Draft). Washington, D.C., December 1976.