DEVELOPMENT POTENTIAL OF THE MAKUSHIN GEOTHERMAL RESERVOIR OF UNALASKA ISLAND, ALASKA

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ABSTRACT

Flow tests and reservoir analyses have confirmed the existence of a productive geothermal reservoir beneath Makushin Volcano on Unalaska Island in the Aleutian Chain. A preliminary economic analysis has been conducted to determine the potential for developing the resource to meet the electric power demands of the Unalaska/Dutch Harbor community. The analysis was based on characteristics of the resource, deliverability of the reservoir, logistics of development and operation, and power market conditions at Unalaska. The analysis indicates that a geothermal power system may be economically competitive with a diesel power system on the island. A detailed feasibility study of the project should be conducted which concentrates on electric load projections and market conditions at Unalaska.

INTRODUCTION

Unalaska Island is located in the Aleutian Archipelago about 800 miles southwest of Anchorage, Alaska (Figure 1). The City of Unalaska, consisting of the adjacent communities of Unalaska and Dutch Harbor, is situated at the northern end of the island on a well-protected bay. Unalaska was an important crossroads for shipping and trade during Russian occupation (1741-1867) and during the Klondike and Nome gold rushes from 1897 to 1900. Its sheltered, deep-water port made Dutch Harbor a prime location for a major naval base during World War II. Since that time, the fishing and crabbing industries have been the mainstay of Unalaska's economy.

The Alaska Power Authority has recently completed a geothermal exploration program at Makushin Volcano near Unalaska and is involved in studies of both energy needs at Unalaska and alternatives for meeting those needs, including the geothermal alternative. The Alaska Power Authority is a state agency governed under executive and legislative oversight by a seven-member board of directors appointed by the Governor of Alaska. Its goal is the orderly and economic development of energy resources to provide power at the lowest possible cost to the consumer and to encourage the long-term economic growth of the state.

One objective of this paper is to summarize the final results of the Unalaska geothermal exploration program. A second objective is to present a preliminary economic analysis of utilizing geothermal resources, which were discovered in the vicinity of Makushin Volcano, to meet the current and future power needs of Unalaska. The economic analysis has taken into account the characteristics of the resource, the deliverability of the reservoir, the logistics of development and operation, and the demand of the power market.

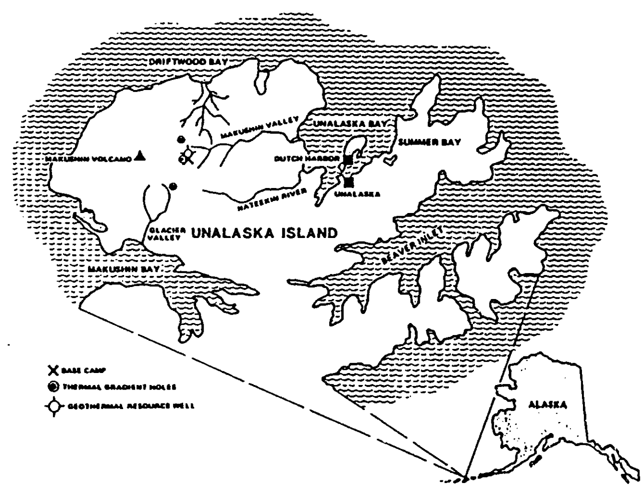

Figure 1. Map showing the location of the Unalaska geothermal project.

THE RESOURCE AND THE RESERVOIR

In 1981, the Alaska Legislature appropriated $5 million to the Alaska Power Authority for geothermal drilling and exploration at Makushin Volcano located 14 miles west of the

City of Unalaska (Figure 1). The appropriation was preceded by a number of geologic investigations that indicated potential for a significant resource at Makushin Volcano.

A competitive request for proposals was issued in 1981 and, after evaluation of the responses, Republic Geothermal, Inc., of Santa Fe Springs, California was selected by the Power Authority to plan and coordinate the exploration and drilling program. The program consisted of three phases. Phase I activities included data review and synthesis; technical planning; land status determination; permitting requirements; acquisition of baseline environmental data; geological, geochemical, and geophysical investigations and mapping; and the drilling of three temperature gradient holes. Phase II activities included the drilling of a deep exploratory well and initial testing of the geothermal resource encountered. Phase III activities included continued and more extensive testing of the geothermal resource, the drilling of a fourth temperature gradient hole, and an electrical resistivity survey to delineate the extent of the reservoir.

Under Phase I, the first three temperature gradient holes were drilled in 1982 to depths of 1500 feet and encountered temperatures of up to 383°F. Two of the holes indicated a close proximity to geothermal resources below, while the third appeared to be on the fringe of the geothermal system. The Phase I findings concluded the strong probability of a water-dominated geothermal system in excess of 480°F on the eastern flank of Makushin Volcano at a depth of less than 4,000 feet (Republic Geothermal, Inc., 1983).

Phase II of the exploration program was initiated in the Spring of 1983. The exploratory well was started in early June. The well encountered a fracture at 1,946 to 1,949 feet that contained a substantial geothermal resource. Initial well tests confirmed a water-dominated geothermal system with a steam cap and with a bottomhole pressure of 478 psi (Republic Geothermal, Inc., 1984a). The bottomhole flowing temperature was measured at 379°F; however, a static temperature of 395°F was measured at that depth. This temperature difference coupled with an observed static temperature gradient reversal from a maximum 399°F at 1500 feet indicates that the geothermal reservoir is located some distance from the well and communicates with the wellbore through a high conductivity fracture system (Economides and others, 1985). The results of gravity and geologic investigations add substantial support to this conclusion (Reeder and others, 1985). The fluid from the producing horizon is approximately 16% vapor and 84% liquid by mass at usable wellhead pressures. It measures 7800 ppm total dissolved solids.

Phase III of the project, conducted in 1984, consisted of further well testing and reservoir analysis, drilling a fourth temperature gradient hole, and conducting an electrical resistivity survey. The temperature gradient hole, drilled in an area that would be more accessible to development than the exploration wellsite, showed no indications of the existence of a similar geothermal resource. The electrical resistivity survey revealed that the site of the current exploration well is actually the most accessible site for encountering the geothermal resource at a reasonable depth (Republic Geothermal, Inc., 1984b).

Flow tests and reservoir analyses conducted in 1984 confirmed a highly productive geothermal reservoir (Economides and others, 1985). Sustained flow of 63,000 lb/hr was achieved through the three-inch diameter wellbore with less than two psi pressure drawdown from the initial 494 psi bottomhole pressure after 34 days. The productivity index derived from the flow test was in excess of 30,000 lb/hr/psi, which indicates a phenomenal permeability-thickness product in the range of 500,000 to 1 million md-ft. Wellbore flow modeling indicated that a commercial-size well at the site should be capable of flow rates of 1.25 to 2 million lb/hr at a wellhead pressure of 60 psia. A material balance calculation by Economides and others (1985) provided an estimate of reserves that could maintain this flow rate (capable of producing 7 to 12 MW of electric power) for over 500 years.

LOGISTICS OF DEVELOPMENT AND OPERATION

The location of Unalaska in the Aleutian Islands creates difficulties for any capital project development. Although there are daily scheduled air freight and passenger flights and regularly scheduled barge service from Anchorage and Seattle, its distance from population centers may increase construction and operation expenses by a factor of 50% or more over continental U.S. costs.

The Makushin geothermal exploration wellsite is located approximately 13 miles west of the City of Unalaska in a remote, rugged, roadless terrain. Access to the site from the city requires crossing a three-mile wide bay, traversing the length of a seven-mile long, wetland valley, and contending with three miles of steep, rocky slopes and canyons. This location would clearly have a significant effect on the costs of both construction and operation of a power plant at the site and a transmission line to the City of Unalaska.

In addition, weather conditions may be a serious impediment to development and operation. Although the average annual temperature (38°F) at Unalaska is higher than many other regions of the state, heavy construction is generally limited to a four-month construction "window" due to wind and snow conditions. Even during summer months, when the average temperature is around 50°F, high winds, heavy rains, and fog could impede construction, operation, and maintenance of a remote power facility.

POWER DEMAND

The power demand of the Unalaska/Dutch Harbor community has been marked by large fluctuations that follow the cyclical trend of the fish-processing industry. In 1978, Dutch Harbor was the nation's leading fishing port based on the value of its landed catch (Morrison-Knudsen Company, Inc., 1981). It has been estimated that the population of Unalaska Island has reached over 5,000 during peak fishing seasons. At such times, the peak power demand has reached 13± MW. However, over the past year, during a serious slump in the fish-processing industry, the population has been estimated at about 1,500 and the peak demand has fallen as low as 4± MW.

Unalaska is pursuing numerous options to diversify its economy, which could both increase and stabilize electrical loads. These options include developing additional marine support facilities, establishing a bottomfish industry, and increasing its tourist trade. In addition, the U.S. Coast Guard is considering the island as the site for a large search-and-rescue facility to respond to calls in the Bering Sea and North Pacific and the petroleum industry may use Dutch Harbor as a staging area for offshore oil development. Any one or combination of these ventures or a rejuvenation of the established fish-processing industry on the island could significantly change the power demand outlook at Unalaska over a very short period of time.

The electric power demand on the island is met entirely with diesel powered generators. The city-owned electric utility primarily serves residential and small commercial users. The city has a current installed capacity of 3.9 MW and plans to increase its diesel generating capacity to 9.5 MW by 1987. Larger commercial establishments and industrial users generate power with their own diesel generators. They have expressed interest in tying into the city system once it has sufficient capacity to economically and dependably meet their demand.

ECONOMIC ANALYSIS

The analysis presented here is meant to provide a preliminary look at the economics of developing a geothermal power facility on Unalaska Island. Prior to design and construction, a more detailed feasibility study would be required.

This analysis used present value calculations to compare numerous energy plans for Unalaska based on three possible load growth scenarios and three types of power systems. Binary and total flow geothermal systems of various sizes were analyzed to determine the optimum size for each of the three growth scenarios. Each geothermal energy plan assumes an on-line date of 1990 and a 35-year useful life. The net present value in 1985 of each geothermal power plan is compared to the net present value of comparable diesel power system plans that would meet the demands of the respective growth scenarios over the same period.

The choice of geothermal systems analyzed and the system cost estimates were based on the actual reservoir characteristics, logistics of development and operation, and market conditions. Since the exploration well is believed to have encountered a high conductivity fracture that communicates with a geothermal reservoir some distance away, there is no guarantee that a well at a second location in the vicinity of the exploration well will encounter an equally productive resource. Consequently, geothermal power conversion systems with high resource use factors were analyzed so that the economics could be based on an assumption of drilling a single commercial-size well at the exploration wellsite. Because the geothermal fluids encountered are of excellent quality with respect to undesirable constituents and total dissolved solids, power system costs were considered both with and without the need for an injection well. Preliminary hydrologic data indicate that geothermal effluent may be disposed of in surface drainage without adversely affecting the environment. Consequently, the results presented here assume that reinjection will not be required. Due to the remote location of the site, conservative cost estimates for a road and transmission line were used, and the total cost of each geothermal power system was subjected to a 20% contingency factor. Finally, because of the relatively low demand at Unalaska, only geothermal power systems that are cost competitive in small unit sizes were considered.

The electric load forecasts used in the analysis were based on three population growth scenarios over a 20-year planning period (1985-2005). Populations and loads were assumed to remain level from year 2005 until 2025--the end of the 40-year period used for the economic analysis. A 2% annual increase in population was considered to be a minimum and somewhat conservative low growth scenario for the planning period. A moderate growth scenario based on a 4% annual population increase was analyzed as a reasonable expectation of growth. A high growth scenario was considered, based on an 11% annual population increase projected by Dames and Moore (1982) assuming a low level of bottomfish harvest and processing on the island. These three growth scenarios are depicted in Figure 2 as they compare to historic population trends.

For each growth scenario, electric load forecasts were developed for residential, commercial, and industrial users and for city services. Figure 3 illustrates the total electric demand forecast for each growth scenario.

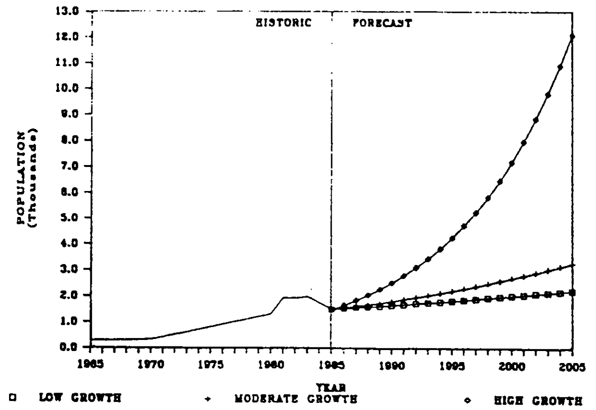

Figure 2. Historic and forecast population trends, 1965 - 2005 (Denig-Chakroff, 1985).

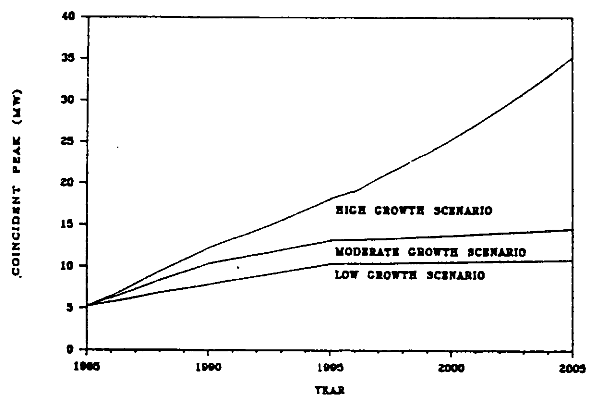

Figure 3. Graph showing the total electric demand forecast for Unalaska/Dutch Harbor from 1985 to 2005 (Denig-Chakroff, 1985).

A diesel power system plan was developed as the "base case" to compare the geothermal power system plans under consideration. A diesel generator capacity addition/replacement schedule was devised such that the needs projected in the electric load forecasts would be met even with the largest power unit down for maintenance. The replacement schedule was based on an assumption that diesel generators have a 20-year useful life. A separate diesel power system plan was developed for each of the three growth scenarios.

The geothermal power system plans were developed by assuming that one or more geothermal units would come on line in 1990. Geothermal units were based on net MW deliverable to the power grid after making deductions necessary to supply station service. Ten geothermal power plans were analyzed for each of the three growth scenarios. These included plans for installing from one to six 2.1 MW net total flow geothermal units and from one to four 3.35 MW net binary geothermal units. It was assumed that the geothermal units would produce 90% of the annual energy demand or 90% of the potential net production of the geothermal system, whichever was less. The remaining energy demand would be met with backup diesel generators.

The net present value of each power system plan was calculated using a 3.5% annual discount rate. Geothermal system construction costs were taken from Republic Geothermal, Inc. (1984c) and modified to reflect a 20% contingency factor. Construction of a 34.5 kv transmission line and a road to the geothermal site were estimated at $15.473 million, including a 30% contingency factor. Diesel fuel prices were assumed to decrease by 4% (real) in 1986, to remain constant between 1986 and 1988, and then to escalate at 2% per year until 2005. Fuel costs were based on a production of 12 kilowatt-hours per gallon of fuel. Diesel generator cost and salvage value were estimated at $700 per kilowatt of installed capacity. Annual operation and maintenance costs were assigned constant values of $1.012 million for the "base case" diesel system and $1.275 million for the geothermal systems.

RESULTS

The net present value was calculated for each power system plan. The optimum diesel, binary geothermal, and total flow geothermal systems (i.e., those with the lowest net present values) are depicted in Figure 4. The optimum geothermal systems for the low and moderate growth scenarios are a single-unit (3.35 MW) binary system and a 2-unit (4.2 MW) total flow system. The optimum systems for the high growth scenario are a 3-unit (10.05 MW) binary system and a 5-unit (10.5 MW) total flow system. Optimum geothermal system plans were compared to the optimum diesel system plan for each growth scenario using a cost-to-cost ratio (Figure 5). The analysis shows that the geothermal systems considered are more economical than diesel generation for each growth scenario. The most economical source of power based on this analysis was the total flow geothermal system which showed a 1.10 cost/cost ratio with a comparable diesel system for the low growth scenario and 1.25 and 1.68 ratios for the moderate and high growth scenarios respectively. Although the construction cost estimates used for the binary geothermal systems were considerably higher than those used for the total flow systems, a binary geo-

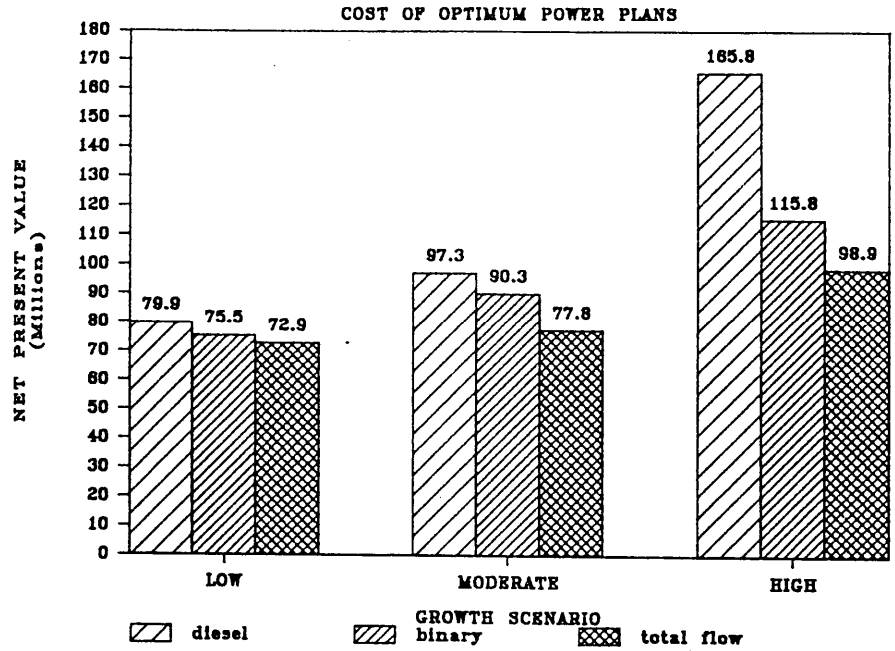

Figure 4. Graph showing the net present value of optimum power system plans for three growth scenarios.

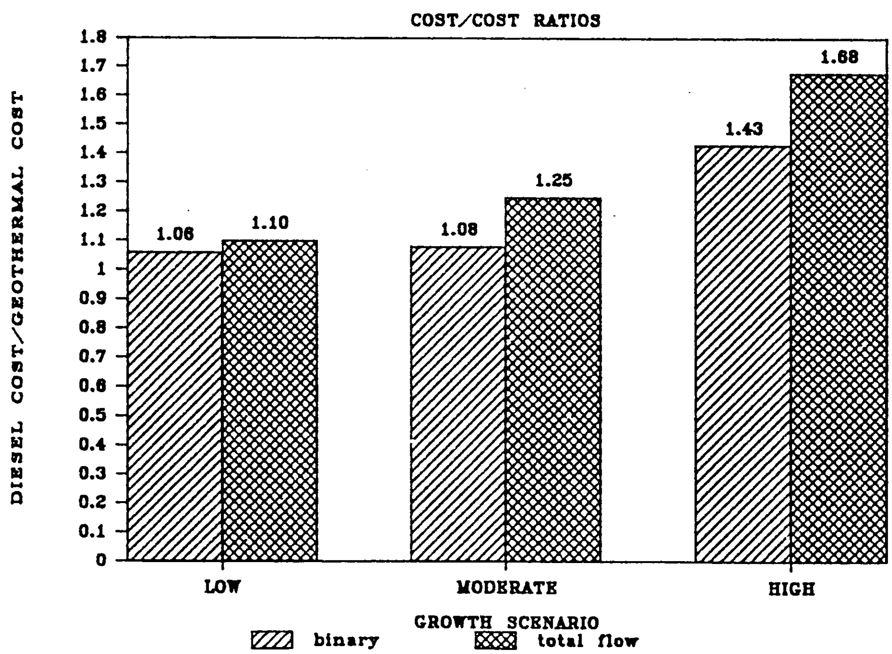

Figure 5. Graph showing the cost/cost ratios of diesel power system plans to geothermal power system plans for three growth scenarios.

thermal system also proved more economical than diesel systems for each growth scenario.

A sensitivity analysis was conducted to determine the effect of a 4.5% discount rate and various diesel fuel escalation rates on the economics of the alternative power systems. The lowest fuel escalation rate analyzed represented a 4% (real) annual decrease in the price of diesel fuel until 1988 and a constant fuel price from 1988 until the end of the period of economic analysis. Even with this low fuel escalation rate and a 4.5% discount rate, the total flow geothermal system was slightly more economical than a diesel system for the moderate growth scenario. For the low growth scenario, geothermal systems were not economical at the low fuel escalation rate but were the most economic source of power with a 4.5% discount rate at medium and high fuel escalation rates.

CONCLUSIONS

Although this is a preliminary economic analysis, some general conclusions can be drawn from the results. It appears that a geothermal power system may be competitive with a diesel power system on Unalaska Island. Major factors contributing to the economic feasibility of a geothermal system are the characteristics of the resource, the logistics of development and operation, and the power market conditions. In the case of Unalaska, construction and operation costs can be developed with a fair amount of certainty because the characteristics of the geothermal fluid and the deliverability of the reservoir have been well defined through flow tests and reservoir analyses (Economides and others, 1985). Major factors affecting the logistics of development have also been ascertained. Factors that are not known with the same degree of certainty are the future load growth of the community, the projected escalation rate of diesel fuel prices, and whether reinjection of geothermal fluids is necessary. Aspects of development that have not been addressed in this analysis, but which may have an effect on the feasibility of a geothermal project, are the potential benefits that may be achieved from utilizing waste heat from the diesel power system for district heating in the community and the potential for cascading uses of the spent geothermal fluid after it leaves the power plant. Based on this preliminary economic analysis, a more detailed study should be conducted to determine the feasibility of developing the Makushin geothermal reservoir for power generation on Unalaska Island, concentrating on load projections and market conditions in the community of Unalaska/Dutch Harbor.

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REFERENCES

Dames and Moore, 1982. Aleutian regional airport,' project documentation. Report for the City of Unalaska, p. 44-45.

Denig-Chakroff, D.N., 1985. Unalaska/Dutch Harbor reconnaissance study findings and recommendations. Report for the Alaska Power Authority.

Economides, M.J., Morris, C.W., and Campbell, D.A., 1985. Evaluation of the Makushin geothermal reservoir, Unalaska Island. Proceedings of the Tenth Workshop on Geothermal Reservoir Engineering, SGP-TR-84, Stanford University, Stanford, Ca., in press.

Morrison-Knudson Company, Inc., 1981. Geothermal potential in the Aleutians: Unalaska. Report for the Alaska Division of Energy and Power Development, p. 2-5.

Reeder, J. W., Denig-Chakroff, D., and Economides, M.J., 1985. The geology and geothermal resource of the Makushin volcano region of Unalaska Island, Alaska, Transactions of the 1985 International Symposium on Geothermal Energy, Kailua-Kona, Hawaii, in press.

Republic Geothermal, Inc., 1983. Unalaska geothermal project, phase IB final report. Report for the Alaska Power Authority contract CC-08-2334, v. 1, p. 2.

Republic Geothermal, Inc., 1984a. The Unalaska geothermal exploration project, phase II final report. Report for the Alaska Power Authority, contract CC-08-2334, p.X19-X25.

Republic Geothermal, Inc., 1984b. The Unalaska geothermal exploration project, executive final report. Report for the Alaska Power Authority, contract CC-08-2334, p. 16-18.

Republic Geothermal, Inc., 1984c. The Unalaska geothermal exploration project: electrical power generation analysis, final report. Report for the Alaska Power Authority, contract CC-08-2334, p. 48-51.