ASSESSMENT OF GEOTHERMAL ENERGY
AS A POWER SOURCE
FOR U.S. ALUMINUM REDUCTION PLANTS

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SUMMARY

The project described in this report was conducted by the Pacific Northwest Laboratory for the U.S. Department of Energy, Division of Geothermal Energy. This study explored the technical and economic feasibility of using hydrothermal resources as a primary power source for both existing and future aluminum reduction plants in the United States. Applicable hydrothermal resources that should be considered by the aluminum industry for this purpose were identified and evaluated. This work also identified the major institutional parameters to be considered in developing geothermal energy resources for aluminum industry use.

Six tasks were addressed in this study:

- 1) Assess the U.S. aluminum industry's current and future power needs, plant siting requirements, and plant expansion requirements.
- 2) Identify those hydrothermal resources with a potential for providing adequate power to existing and future aluminum plants.
- 3) Determine the relative cost of power from the identified hydrothermal resources.
- 4) Perform a discounted cash flow analysis for two cases--an existing aluminum plant and a new plant located near the geothermal resource.
- 5) Determine the major institutional parameters based upon a comprehensive review of applicable state and federal regulations.
- 6) Determine the viability of geothermal power for aluminum reduction based upon the results of the preceeding tasks.

Based on the findings of this study, it appears technically and economically feasible to power existing aluminum reduction plants in the Pacific Northwest using electricity generated at Roosevelt Hot Springs, Utah. It may also be feasible to power existing plants located on the Gulf Coast from Roosevelt Hot Springs, depending on the cost of transmitting the power.

The economic feasibility of new aluminum plants constructed at or near hydrothermal power sources depends upon the future rate of increase of aluminum prices. Such new plants appear feasible only under an optimistic price scenario.

Currently, institutional barriers that would tend to impede acceptance of geothermal energy by the aluminum industry are regulatory uncertainty, potential for public utility regulation, and difficulty in controlling geothermal resources developed under federal or state leases.

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ASSESSMENT OF GEOTHERMAL ENERGY AS A POWER SOURCE FOR U.S. ALUMINUM REDUCTION PLANTS

1.0 INTRODUCTION^(a)

This report documents a study conducted by the Pacific Northwest Laboratory (PNL) for the Division of Geothermal Energy, U.S. Department of Energy (DOE). The purpose of the project was to determine the technical and economic feasibility of using hydrothermal resources as an alternative source of power for existing and future aluminum reduction plants in the United States. The study also sought to identify the major institutional constraints involved in developing geothermal energy for aluminum industry use.

1.1 SCOPE

This report presents an assessment of the aluminum industry's current and future power needs and plant location requirements, together with plans for plant expansion within the United States, in Section 2.0. Hydrothermal resources with a potential for providing adequate reliable power to existing and/or future aluminum plants are identified in Section 3.0. The extent to which these resources should be considered is determined on the bases of cost and economic analyses presented in Sections 4.0 and 5.0. The major institutional constraints associated with this concept are also identified and discussed in Section 6.0. Section 7.0 presents the conclusions of the study.

1.2 BACKGROUND

The aluminum industry currently faces a power crisis in the Northwest. The ten aluminum smelters located in Washington, Oregon, and Montana have a combined capacity of 1,567,000 tons/year of aluminum ingot, providing 31% of the total U.S. aluminum production capacity. These smelters currently consume about 35% of Bonneville Power Administration (BPA) power, which is primarily low-cost (3 mills/kWh) hydroelectric power. This power consumption amounted

(a) Section author - W. I. Enderlin.

to about 0.2% of the total U.S. energy consumption in 1973, or 2.7% of the energy consumed by the U.S. mineral industry that year. Another 187,000 ton/year reduction plant is planned for Umatilla, Oregon, and ground has been broken for doubling the size of the Goldendale, Washington plant.

Existing aluminum plants currently experience frequent loss of interruptible power, which is about one-fourth of their load. As a result, they reduce production or seek alternative, typically more expensive, sources of power. Of course, as the power supply situation in the Northwest tightens with increasing loads, the frequency and duration of interruptible power loss will increase. Moreover, BPA has notified the aluminum companies that the current low price power contracts due to expire between 1984 and 1988, will not be renewed because of insufficient generation capacity. All acceptable sites for hydroelectric power generation have already been developed. Additional generating capacity must come from expensive thermal power.

As their power contracts expire, the aluminum companies with Northwest plants will likely be forced to choose among several options:

- close the older, more inefficient smelters - This action could involve about half of the smelters in the Northwest, whose ages range from 10 to 37 years, with the average age exceeding 25 years.
- purchase power from the local utilities - However, unless they expand their generating capacity substantially, local utilities would not be able to meet the aluminum companies' requirements.
- obtain roughly half of the required power from BPA's interruptible reserves and the other half from thermal generation sources - This option is currently under serious consideration by both the aluminum industry and BPA. Power from interruptible reserves is expected to cost in excess of 5.6 mills/kWh during the second half of the 1980s. Although a coal-fired plant is currently under construction at Boardman, Oregon, it is not certain that the required thermal generating capacity can be installed by the time the aluminum companies need it. It is expected that fossil fuel and nuclear power may cost in excess of 25 mills/kWh by 1985.

The impending power crisis is not limited to the Pacific Northwest. Energy supplies for the aluminum industry in other regions of the country may also be curtailed. A number of aluminum companies in the southern U.S. currently generate their own electricity using natural gas. Prospects for a continued adequate supply of this commodity are not good, and alternative fuels or new plant locations will have to be identified.

The expansion of U.S. aluminum production capacity during the near future appears to be inevitable. The demand for aluminum in the U.S. is expected to increase at a rate of about 5.8% through 1980, using 1976 as the base year. Furthermore, the demand for imported alumina, the principle feed stock for aluminum reduction plants, is expected to increase at the same rate. However, the domestic aluminum industry is currently operating at over 90% capacity. Because of the recent availability of large quantities of aluminum metal from surplus government stocks, and the sharp drop in demand in the latter part of 1974 and in 1975, industry capacity to produce primary aluminum in the U.S. has not expanded sufficiently to meet expected future demand.

It is reasonable to assume that future aluminum reduction plants will locate in areas where abundant, comparatively low-cost power (other than hydroelectric) and adequate rail or water transportation are available within 375 to 400 miles of a major port facility. The aluminum companies also prefer to locate reduction plants in sparsely populated areas, away from intense agricultural development.

Future plants will employ such processes as the improved Hall or Alcoa, which are considerably more efficient than the Hall process currently used at the older plants. Reduction from alumina to aluminum ingot using the Hall process requires 8 kWh/lb of aluminum; in contrast, the improved Hall process requires 6.5 kWh/lb and the Alcoa process requires approximately 5 kWh/lb. The reduction process accounts for about 90% of the total electric power consumed by the plant. The design size of future plants would probably be between 2.3×10^9 to 5.6×10^9 kWh/year.

There appears to be considerable potential for geothermal power production in the western United States in areas that may also be acceptable as sites for future aluminum reduction plants. According to Muffler (1978),

there are currently approximately 30 known hydrothermal resources with subsurface temperatures from above 150°C and within 375 miles of a major West Coast port. Fifty-seven percent of these resources have subsurface temperatures in excess of 180°C, which is sufficient for commercial power generation using state-of-the-art technology. Many of these hydrothermal resources are in areas of sparse population, close to existing railroads, and away from agricultural development. The potential generating capacity is estimated to range from 8 to 1825 megawatt-Centuries of power per resource.

2.0 ALUMINUM REDUCTION PLANT REQUIREMENTS^(a)

This section describes the power needs and specific location criteria for aluminum reduction plants. Current industry expansion plans are then discussed.

2.1 POWER NEEDS

Aluminum reduction plants, on average, currently require about 8 kWh/lb of aluminum produced. According to the Aluminum Association (1977), existing plants using the improved Hall-Heroult process require about 6.5 kWh/lb aluminum. The Alcoa process under development will require less than 5 kWh/lb aluminum, plus fossil fuel such as #6 fuel oil (exact consumption rate not known), for its aluminum chlorination operation.

In the past 40 years the aluminum industry has steadily reduced its smelting power requirements of over 12 kWh/lb aluminum by about half. The reduction in power consumption has helped to compensate for increasing power costs.

Some of the developments that might reduce future power requirements even further include the Alcoa AlCl_3 electrolytic reduction process, titanium di-boride electrodes (Arthur D. Little 1976), silicon/aluminum blast furnace processes, and other, proprietary developments in progress. Details about the chances of success and projected power savings are lacking for all these developments.

Based upon current technology available to the entire industry, new plants will require about 6 to 6.5 kWh/lb aluminum produced.

2.1.1 Background

Traditionally, aluminum reduction plants have been located close to readily available, low-cost power resources. Aluminum companies have owned and operated their own power generation facilities and still do for some of their requirements.

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By the early 1900s, most of the electricity supplied to the reduction cells was generated by the Aluminum Company of America (Alcoa). Alcoa, the only U.S. aluminum company until about 1941, owned substantial rights to the water power that turned its generators. Enormous undeveloped water power reserves were used as the company expanded.

Through 1955, the primary source (59%) of the industry's electric power was that generated by hydroelectric facilities. By the end of 1957, hydroelectric power supplied 43% of the needs. Natural gas dropped from 33% to 25%, and coal increased from 8 to 32% as sources of electricity.

After 1957 the sites for low-cost hydropower were nearly exhausted so the trend was toward thermal power generation based upon petroleum, natural gas, and coal. Coal became much more attractive because the amount required dropped from 3.2 lb/kWh in 1919 to about 1 lb/kWh in 1955, due to improved coal plant efficiencies. In the 1950s, the aluminum industry constructed coal-fired power plants immediately adjacent to the mine mouths in the Ohio River Valley and the Southwest regions.

The review of past trends suggests that aluminum companies do not construct their own power plants until the technology is well-developed.

2.1.2 Current Power Requirements

In 1974 the U.S. aluminum industry overall electrical power supply comprised about 41% coal, 37% hydro, 21% natural gas and oil, and 1% nuclear. Of this total, nearly one-third (30%) was generated in the producing companies' own power plants.

According to the Aluminum Association (1976b, pp. 4-5), in January 1976 the industry's position with respect to power supplies was summarized as follows:

- 1) The electrical generating plants of the future--solar, fusion, large-scale geothermal, breeder reactor, tidal, coal gasification, wind power--are challenging concepts. But they are still on the drawing board, or have not reached that stage. The industry has to deal with what is here and now.

2) At the present time and for the next 10 to 15 years, there are five principal means of generating new electrical power capacity; only two--nuclear and coal-fired plants--appear practical:

- hydroelectric - There are a few remaining sites, but delays in government approvals are interminable.
- natural gas - Its use as a boiler fuel for new generating capacity is not only impractical but, in most instances, unjustifiable.
- oil - It is not practical to predicate expansion of electric capacity on the use of petroleum products.
- nuclear - It is expected that nuclear plants will provide a major base for future power generation if constraints on new nuclear plant construction are lessened.
- coal - There is enough coal in the U.S. to provide a major base for power generation for several hundred years. Constraints on emission levels and the moratorium on mining of rich government-owned coal must be resolved.

2.1.3 Importance of Reliable Power

When there is a market for the product, a primary aluminum reduction plant operates continuously. Full power is required 24 hours a day, 365 days per year. Restriction of electrical power can result in shutdown of reduction cells.

A modern plant could endure some scheduled, short-term power restrictions without shutting down reduction cells. Table 2.1 indicates the relationships among percentage of power restriction, advance warning time, and duration of restriction that are necessary to avoid an unscheduled production shutdown of one proposed plant.

If power restrictions were no greater in percentage terms and no longer in duration than those shown in Table 2.1, if they were accompanied by sufficient advance warning and were not too frequent, they would not significantly affect the total annual production of the proposed plant.

TABLE 2.1. Power Restriction Limitations
to Avoid Unscheduled Production
Shutdown^(a)

<u>Percentage Power Restriction</u>	<u>Warning Time (Hours)</u>	<u>Restrictions Time (Hours)</u>
10	0	48
20	2	10
50	8	2
100	8	0.5-2

(a) Bonneville Power Administration (1977)

On the other hand, restrictions greater than those shown in Table 2.1, with less advance notice, longer duration, or frequent occurrence would consequently reduce the plant's annual production and significantly increase production costs.

Restriction could result in some or all of the plant's aluminum pots "freezing." This occurs when the pot temperature falls below the temperature necessary to keep the aluminum and bath material molten. Pots start freezing within about 2 hours after power is lost. When pots freeze, they cannot be returned to operation simply by restoring electric current. Instead, the hardened bath material must be manually and mechanically chipped away from the anodes, cathodes, and pot linings. After the lines have been returned to service, a loss of energy and production efficiency is associated with the cells until they can reach steady-state operating conditions. Both the resulting higher energy consumption and loss in production are costly to a plant.

For example, in 1976 the Alcan Aluminum Corporation's Arvida, Quebec, reduction plant power supply was sabotaged, resulting in a sudden shutdown of 14 operating potlines. The pots froze and caused a 5-month plant shutdown. The cost estimate placed losses to the company in the \$50 million to

\$52 million range (\$3.6 million/line), according to Alcan representatives. Alcan is currently constructing a new plant with the technology to restart frozen pots one at a time without significant damage. The cost of restarting potlines with the new technology has not yet been established.

Even a well-scheduled shutdown is costly. The cost of restarting a single pot-line ranges from \$300,000 to \$600,000 (Dullenty 1978) and there are as many as eight potlines in some U.S. plants. Those costs are added to the price of aluminum.

2.2 PLANT LOCATION CRITERIA

The site selection process for an aluminum reduction plant must consider a wide range of location features:

- cost and availability of reliable electric power; large quantities on long-term contracts
- availability and aggregate cost of suitable transportation (seaport, good roads, railroads) to the site for raw materials, finished products, and personnel
- proximity to market
- land availability
- federal, state, and local regulations
- onsite and offsite effluent control requirements
- availability, cost, stability, and productivity of labor
- community acceptance of the plant
- community attractiveness to employees (environment, hospitals, streets, cost of living, fire and police protection, educational, recreational, and civic conditions)
- taxes (state, local, unemployment, etc.)
- labor laws

- fuel oil and natural gas availability
- factory services (water, sewage, and garbage)
- climatic conditions
- other traditional considerations.

If a site looks attractive after thoroughly reviewing the location features, a feasibility study will be made to determine the overall economics and to provide input to a preliminary environmental impact assessment. The feasibility study will include an assessment of such unpredictable factors as

- changing technology and use of bauxite substitutes
- changes in competing materials industries such as steel, copper, magnesium
- policies and prices by bauxite and alumina suppliers
- foreign and domestic politics
- licensing and regulatory uncertainties.

If the feasibility study indicates adequate profits will be made with minimal risk, the steps for obtaining capital and plant licensing will be taken for the selected site.

The most important criterion in evaluating a proposed aluminum reduction plant site is that it be economic, to attract capital for building a new plant. The objective of site selection studies is to find a site that can be developed and from which the operations can be conducted at the lowest long-term overall costs.

Plant locations as of 1977 are shown in Figure 2.1. The primary market for the output of those plants is provided in Figure 2.2. Evansville, Ohio could be considered the centroid for manufacturing of aluminum fabricated products. A comparison of the two figures suggests that a large portion of the current reduction plants is located a considerable distance from the corresponding market centroid. These plants were built where and when low-cost power was available for their electric energy-intensive operations.

FIGURE 2.1. U.S. Aluminum Reduction Plant Locations
(Aluminum Association 1977, p. 10)

FIGURE 2.2. U.S. Aluminum Industry Output Market
(Aluminum Association 1977, p. 9)

As in the past, availability and relative price of electricity and transportation are two of the most important cost factors in evaluating sites for future reduction plants. The other traditional criteria for plant location also apply. In recent years, the importance of federal, state, and local regulations has increased.

A rural area is needed to minimize the offsite impact of potline offgas fumes. It is desirable to locate near attractive communities that would appeal to a stable work force of about 800 employees and 1200 to 2400 support personnel. A seaport location is highly preferred. Good roads and a railroad are required, especially for inland (nonport) sites.

To summarize, an ideal site would offer an ice-free seaport where plentiful, low-cost power is available, and be in a rural area devoid of intensive agriculture, with an attractive city nearby. It is unlikely many such sites exist; if they do, there will be competition from other entities.

2.3 INDUSTRY EXPANSION PLANS

The first aluminum reduction plants were located at sites offering available and inexpensive hydroelectric power. Subsequent plants were located close to the major consumption markets in the Ohio Valley. The next plants were located in Texas due to low-cost natural gas, good ports, and relative proximity to eastern markets. Currently, it is desirable to build plants where energy and transportation can be utilized at economical rates.

Expansion plans for the industry appear vague at this time. Near-term constraints which impact domestic expansion most are:

- power availability uncertainties - Availability must be assured for at least 30 years. Firm long-term contracts are needed so that power rates are not subject to changes by utilities and government. The cost of startup and shutdowns of potlines is quite extensive and plants cannot operate for very long with curtailed power.
- environmental standard uncertainties - The demands of regulatory standards on aluminum reduction plants for the 1980s will have a strong bearing on capital investments. Considerable capital

expenditures have already been made in the 1970s for pollution abatement equipment. The power source plants will also have a cost impact due to environmental standards.

- venture capital uncertainties - Finding investors may be difficult because of the low return on investment experienced in recent years. The uncertainties of future power availability and environmental regulations mentioned previously will also have an effect on the ability to attract capital. New plants will cost over \$3,000/annual ton capacity including the power source.

Domestic expansion is underway by Alumax, which is constructing a new plant in South Carolina. The Alumax plans to build a plant at Umatilla, Oregon are still uncertain. Ground has been broken recently for Martin-Marietta's Goldendale, Washington plant expansion to twice its current capacity. Alcoa has recently announced plans to increase its Anderson, Texas pilot plant by 15,000 tons/year.

The long-term expansion plans are governed primarily by international effects. Over 90% of the alumina resources required for domestic aluminum production is imported. The trend is to consider locating reduction plants closer to the mine; the International Bauxite Association (IBA) has made no secret of their long-range goal to construct reduction plants at the mine and alumina plant sites. Future development of non-bauxite domestic resources of aluminum (e.g., clay, anorthosite, alunite) will also have a bearing on expansion plans. The commercial development of processes using domestic resources will probably not be ready before 1985.

3.0 APPLICABLE GEOTHERMAL RESOURCES^(a)

The location for an aluminum reduction plant must provide a competitive return to the production of aluminum. Thus, the criteria for an acceptable geothermal site must include:

- a resource of sufficient size and temperature to provide continuous power for the basic operation plus a reserve of 50 to 75%.
- a location that is economic with respect to movement of the raw materials, electric power, and finished products.

This section will deal with the fulfillment of the first criterion by selecting potential geothermal sites of sufficient size and temperature. The second criterion will be discussed in conjunction with the overall economics in Section 5.0.

The first cut of possible geothermal resources was made from the list compiled by Renner et al. (1975), and Papadapulos et al. (1975). The intent was to take this list and search out additional, more recent data to provide bases for further limiting the list. Sources of data were to include state agencies and the U.S. Geological Survey (USGS), Lawrence Berkeley Laboratory (LBL), and Lawrence Livermore Laboratory (LLL) data banks. In the literature search, a refined list was found in Williams et al. (1978). This document contains development scenarios for 37 geothermal (both hydrothermal and geo-pressured) resource areas or prospects for electric power generation. Williams' preface states

These scenarios postulate an initial generating capacity of approximately 50 MWe, followed by incremental additions of 50 to 200 MWe at a pace believed to be likely for the prospect. The pace of development at each prospect was based on many factors including anticipated electrical power demand, transmission capabilities and estimated resource characteristics.

(a) Section author - J. J. Jacobson.

The anticipated power demand did not include use for such an electric power-intensive industry as an aluminum reduction plant. However, the document provided a major basis for site evaluation in conjunction with additional data inputs found.

Table 3.1 lists prospective geothermal sites that appear, in the first cut, able to produce sufficient power to support a 200 kT/yr aluminum reduction plant. This list is based predominantly on estimated reservoir size and temperature as outlined by Renner et al. (1975) and Muffler (1978, pp. 46-57). Some of the other parameters and reservoir characteristics considered in the economic evaluation are included in Table 3.1 for comparison. Ten sites were chosen from this list for more detailed analysis to be used in the GEOCOST model. These sites are denoted in Table 3.1 by the asterisk following the site name. Figure 3.1 shows the hydrothermal locations.

The nominal reservoir characteristics including electrical potential were generally taken from Muffler (1978) with exceptions as noted in Table 3.1. Distances to substation/power transmission lines, railroads and ports were taken from Williams et al. (1978) or measured from maps. Ports considered were San Diego, Los Angeles, San Francisco, and Sacramento, California; Portland, Oregon; and Lewiston, Idaho. These ports were used for shortest direct line measurements. Other potential ports include Seattle and Tacoma, Washington.

Williams et al. (1978) give a "postulated site development schedule for the first 50-MWe plant" along with "possible subsequent additions (MWe) and on-line dates." Using these data, charts of power and on-line time (Figure 3.2) were developed to determine areas able to support an aluminum reduction plant. Williams et al. (1978) developed the scenario in Figure 3.2 based on "... many factors including electrical power demand, transmission capabilities and estimated resource characteristics." Development of the resource, then, is the most time-dependent or time-consuming element, as well as the most uncertain, in the scenario. A power-time development chart for the Roosevelt Hot Springs geothermal field is shown in Figure 3.3 along with the annual power requirements needed to support 200 kT/yr by the three reduction processes (Hall, improved Hall, and Alcoa). Also shown in Figure 3.3 is

TABLE 3.1. Prospective Geothermal Sites for Geothermal-Aluminum Feasibility Study

Site	Electrical ^(a) Potential (MWe 30 yrs)	Probability of Development	Distance to Power Line or Substation (mi)	Distance to Port (mi)	Distance to Railroad (mi)	Nominal Reservoir Characteristics						Depth ⁽ⁱ⁾ (m)	Development Problems
						Temp °C	TDS ppm	pH	Noncondensible ^(h) Gases, ppm				
									H ₂ S	Boron			
Alaska													
Geyser Bight	136	Low	--	--	--	210	1400	--	--	--	--	1000	Reservoir unproven, remote location (Umnak Island, Aleutian chain). Absence of port facilities, roads, and power lines.
Hot Springs Point	27	Low	--	--	--	155	2300	--	--	--	--	1000	
Southern California	4860												
*Brawley	640	High	10	100	10	230-300	~100,000					2500	High salinity, scaling, injection
East Mesa	360	High	5	120	2	165-200	~30,000	6.1-7.7				2400	
Heber	650	High	<6	100	16	160-185	~13,000	6.4-7.8				2500	
*Salton Sea	1500 ^(b)	High	<10	100	~6	300-340	>100,000	4.8-6.5				2100	
*Westmoreland	1710	High	~10	100	<10	200-235	~50,000	4.5-5.5	0.2% by wt			2280-2600	High salinities, scaling, injection for deep wells, shallow wells' less briny
East Central Calif.													
COSO	650	Med	8	150	5	190-240	~2,000	8.5				1500	Protection at hot springs
*Long Valley	2100	Med	5-20	120		200-250	~1,400	9.2	100			1000	Environmental & Recreation area
Randsberg	80	Med		110	<10	~150						500-1500	
Northern Calif.	2465												
Surprise Valley	1490	Med	~20	230	25	~175	350-1500	8.9				1200	Temperature may be marginal Hot water usage may affect Geysers steam field
Sulphur Bank-Clear Lake	975	High	~5	100	~5	165-185	~5,500	2.7	30	0.3417		1500	
Hawaii	250	High	<10	20	--	~290	~2,000	<5	~3 ^(j)			1950	
Oregon - Idaho	2250												
*Alvord ^(c)	300	Med	~100	280	~90	200-210	1300-3200	8.1			10-30	500-2000	Reservoir unproven Reservoir unproven Environmentally sensitive Reservoir unproven (remote location)
Vale	970 ^(d)	Med	~12	180	~22	~160	~1,000				9.4	750-2000	
Newberry	740	Low	<15	150	~15	180-280	~1,000						
Crane Creek (ID)	340	Low	<10	160	<5	160-180	~1,000	7.1				500-2000	
Nevada	2245												
Brady	150	High	~16	160	~10	~215	~2,500	7.3				500-1500	Remote location, scaling, injection Remote location, scaling, injection Reservoir unproven, remote location
Beowawe	130	High	~40	300	~5	~240	1100-1300	~9.7	11	2.5		500-1500	
Leach, Kyle, Humboldt House	240	Med	~25	240	~24	~160	~800	8.8		1.2		500-2000	
*Steamboat	350	Med	~10	110	48	~205	~2,500	~6.5-9.3	11	47		~300	
Stillwater	450	Med	~10	170	<20	~157	~5,000	7.6		15		500-1500	Reservoir unproven
*Desert Peak	750	High	~10	160	~10	~220						~1300	
Soda Lake	150	Med	~10	170	<20	~157	~4,000	7.9		5.7		500-1500	
New Mexico													
*Valles Caldera	2700	High	<16	~650	<10	>200	~6,000		290			1500-2700 ^(k)	Brine treatment, scaling, injection
Utah	1750												
*Cove Ft-Sulphurdale	330	Med	<2	~500	<15	~200						~1500	Expensive drilling, H ₂ S
*Roosevelt Hot Springs	970	High	<10	~500	~10	230-260	6000-8000	~6.5				~1000	
Thermo	450 ^(e)	Low	<40	~500	~1	~200						~1500	
Geopressured ^(f)													Reservoir unproven, remote location
Louisiana	1180	Med											All geopressured areas need reservoir characteristics: size, temperature, flow rates, methane content and long-term production capability.
Acadia Parish	350	Med	~15	<25	~15	~165	~65,000						
Calcasieu Parish	350	Med	<8	<25	<8	~160	~20,000 ^(g)						
Cameron Parish	400	Med	<8	<25	<8	~140	~52,000						
Texas	3400												
Brazoria County	2250	Med	~10	<20	~10	~150	~27,000						
Corpus Cristi	450	Med	<10	<20	~10	~170	~33,000						
Kenedy County	300	Med	~10	<20	~10	~170	~168,000						
Matagora County	400	Med	<10	<20		~150	~27,000						

(a) Values from Muffler (1978, Table 5, pp. 46-57).

(b) Williams et al. (1978); Muffler (1978) gave 3400 MWe.

(c) Includes Alvord, Mickey Hot Springs and Borax Lake.

(d) Williams et al. (1978) lists 550 MWe - 30 yrs.

(e) Williams et al. (1978), not listed in Muffler (1978).

(f) Values from Williams et al. (1978).

(g) Estimate only, Williams et al. (1978).

(h) From summary in Wells et al. (1978).

(i) From USGS GEOTHERM file (December 1978). Depths are average for existing wells, or "best estimate" to reservoir.

(j) Chen et al. (1978); Siegal and Siegal (1978).

(k) Dondanville (1978).

* Sites chosen for economic analysis.

FIGURE 3.1. Location of Hydrothermal Convection and Geopressured Systems Considered Possible Sites for Aluminum Plant Power Generation

an accelerated development schedule used by the GEOCOST model. In support of such a postulated development schedule, the Roosevelt Hot Springs geothermal resource area, which includes federal, state and some private lands, has been unitized with Phillips Petroleum designated the operator. Thermal Power, Amax Exploration, and O'Brien Resources, all partners in the unitization, currently have two wells estimated capable of producing 12 to 13 MWe and 6 to 7 MWe, respectively (Petroleum Information 1979). At this time the operators estimate they have developed sufficient potential to operate a 55-MWe plant, but have no contracts for the sale of this energy. The accelerated development schedule postulated for this area is based on the assumption that a demand for

OPERATING ENTITIES	ACTIVITY	RECIPIENTS	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
BLM	ISSUE STG PERMIT	DEVELOPER											
USGS	ISSUE DRILLING PERMITS	DEVELOPER											
BLM	PROCESS EIA/EIS	CEQ											
COUNTY GOVERNMENT	ISSUE LAND USE PERMIT	DEVELOPER											
DEVELOPER	PRELIMINARY GEOPHYSICAL EXPLORATION		ASSUMED COMPLETED										
DEVELOPER	EXPLORATORY DRILLING AND RESERVOIR ASSESSMENT												
DEVELOPER	DEVELOP UTILITY INTEREST												
DEVELOPER UTILITY	FEASIBILITY STUDY												
PRODUCER/DEVELOPER AND UTILITY	FINANCIAL NEGOTIATIONS												
PRODUCER	SITE SELECTION												
PRODUCER/UTILITY	DESIGN												
PRODUCER/UTILITY	PREPARE MASTER DEVELOPMENT PLAN	BLM, USGS											
UTILITY	PREPARE ENVIRONMENTAL DATA STATEMENT	BLM, FPC, STATE, COUNTY											
PRODUCER/UTILITY	COMMITMENT TO DEVELOPMENT												
BLM, FPC, STATE, USGS	CERTIFY PLANT AND SITE, ISSUE PERMITS	PRODUCER AND UTILITY											
USGS	PROCESS EIA/EIS (DRILLING)	CEQ											
FPC	PROCESS EIA/EIS (PLANT)	CEQ											
FPC	PROCESS EIA/EIS (TRANSMISSION LINE)	CEQ											
PRODUCER	DEVELOPMENT DRILLING												
UTILITY	PLANT CONSTRUCTION												
UTILITY	INSTALL TRANSMISSION LINE (96.5 km)												

FIGURE 3.2. Postulated Site Development Schedule for First 50-MWe Plant, Roosevelt Hot Springs, Utah (Williams et al. 1978, p. 26-3)

FIGURE 3.3. Potential Power Development with Reduction Needs for 200 kT Aluminum/Year

the power (200 MWe) exists, and that the user, such as an aluminum company, is willing to obligate himself in advance for the power. Additional charts for the potential sites listed in Table 3.1 are given in Appendix A.

Other sites, such as Westmoreland and Desert Peak, Nevada, have just recently developed into significant potential geothermal resource sites and have not been analyzed in the Metrik model (Williams et al. 1978; Trehan et al. 1978). For this reason, the power-time charts (Appendix Figures A.3 and A.6) show only a maximum estimated level on-line by 2000. However, recently published data (Smith et al. 1978) indicate these two sites may be of high potential somewhat earlier than 2000.

TABLE 3.2. Parameters for GEOCOST Model for the Ten Selected Geothermal Sites^(a)

	Well Flow Rate (lb/hr)	Production Life (years)	Res. Temp. °C	wt. Fraction Steam	wt% Non Cond. Gas	Nominal wt% TDS (PPM)	Nominal Depth (km)	Drilling Hardness	Expected Spacing (acres)	Source
Brawley	500,000 (7 wells)	15	230-300	25-30	0.1	100,000	2.5	soft	20	a,d
Westmoreland	40,000 B/d ^e (3 wells) (560,000)	15	200-235	10-15	2	50,000	2.2-2.6	soft	20	a,b,e
Salton Sea			300-340		0.1	100,000	2.1	soft	20	
Sinclair 4	450,000	15	210°C	15%			1.6			c
Magmamax 1	410,000	15	175°C	13%			0.86			c
Long Valley	233,000	15	200-250	19	100 ppm	1,400	1.0	med	20	a,g
Alvord, Mickey Hot Springs		15	200-210		10.5 ppm	1,300-3,200	5-2.0	med hard	20	
Borax Lake	440,000	15		10-15	30 ppm				20	
Steamboat Springs	440,000	15	205	10-15	0.1	2,500	0.3	med hard	20	a
Desert Peak	440,000 (2 wells)	15	220	10-15	0.1		1.3	med hard	20	
Roosevelt Hot Springs	10 ⁶ (7 wells)	15	230-260	16%	0.1	6,000-8,000	0.3-2.2	med hard	20	a,e,f
Cove Fort-Sulphurdale	440,000	15	200	10-15	0.1		0.5-2.2	hard	20	a
Valles Caldera	440,000	15	273	25-30	290 ppm	6,000	1.5-2.7	med hard	20	a

(a) Muffler (1978) and/or Williams et al. (1978)

(b) D. Michaels - Republic Geothermal, Inc.

(c) Tewhey (1977)

(d) Smith et al. (1978)

(e) Smith et al. (1977)

(f) Smith (1977)

(g) Cosner (1977)

(h) Dondanville (1978).

(a) Italics indicate nominal estimates

that electrical generation from the hot water and hydraulic pressure be viewed as a byproduct of methane production. Without methane revenues to offset high well-drilling costs, estimated electrical generation costs from the thermal energy in the hot water far exceed current generation costs from conventional energy sources. However, if the thermal energy is available "free" as a byproduct of methane production, then the incremental production costs for electricity as a byproduct are estimated to range from competitive to triple the current generating costs from conventional sources (Bloomster and Knutsen 1977). Of course, the methane production itself could be used for electricity generation or sold as pipeline gas, depending on its value for each use.

On the same incremental cost basis, the cost of electricity generated from the geohydraulic energy is potentially competitive with conventional energy sources. This would require development of a small commercial high pressure, hydraulic turbine to extract geohydraulic energy at the wellhead in plants of about 3 MW capacity. Transmission of high pressured fluids from several wells to a central geohydraulic power plant would not be practical. The upper cost target for geohydraulic plants would be about \$800/kW, in 1975 dollars.

Long distances are expected to be required between geopressured wells to prevent excessive subsidence and to prolong well production. This results in significant costs for fluid transmission from the wellhead to a central power plant. In most cases fluid transmission is the largest expense of electricity generation from thermal energy. If electricity generation costs from thermal energy conversion are to become competitive, fluid transmission costs will have to be reduced by developing less expensive piping systems, reducing well spacing, and reducing power plant size.

Bloomster and Knutsen's study (1977) indicated an optimal power plant size in the range of 20 to 60 MWe, based on field-constructed plants, depending on water temperature. However, if standardized thermal conversion power plants could be factory-produced in the 6-MWe range competitively with larger field constructed plants, then the optimal plant size might be reduced to

single wellhead units. Wellhead units would completely eliminate fluid transmission costs, but would probably incur higher costs for heat rejection, power plant operation, and electrical transmission. The upper cost target for competitive wellhead plants would be on the order of \$800/kW in 1975 dollars.

4.0 ANALYSIS OF GEOTHERMAL POWER PRODUCTION COSTS^(a)

The production of electrical power from a geothermal resource for aluminum plant use must be both economical and reliable. The cost of power from a geothermal resource is contingent upon a number of site-specific variables as well as upon the level of reliability desired. The first part of this section describes how the GEOCOST model developed by Bloomster et al. (1975) yields power costs ranging from 12 to 49 mills/kWh for the ten sites shown in Section 3.0. The second part describes a model used to adjust the costs determined using GEOCOST so as to achieve an availability of 98%. This availability model results in increasing the costs for the five best sites to between 18 and 35 mills/kWh.

4.1 UNADJUSTED POWER COSTS

The unadjusted power costs for ten promising sites were calculated using the GEOCOST model. This model is composed of two principal parts: a reservoir model, which simulates the costs associated with the exploration, development, and operation of a geothermal reservoir; and a power plant model, which simulates the costs associated with the design, construction, and operation of the power plant. GEOCOST calculates the capital costs and operating expenses for the power plant using the resource characteristics and assumed financial variables. Using discounted cash flow analysis, GEOCOST calculates the unit cost of energy. Many other factors related to power plant and reservoir design, performance, and operation are also calculated by the model.

The aluminum company was assumed to own the power plant and an oil company was assumed to operate the reservoir that supplies the geothermal fluid to the plant. The financial assumptions used in the GEOCOST model for the aluminum company and for the oil company are shown in Table 4.1. These financial variables, as well as the variables and assumptions shown in Appendix B, were held constant for all cases.^(b)

(a) Section author - S. A. Weakley.

(b) Pollution control costs were not included in this study due to their site-specific nature and to the lack of data on each site.

TABLE 4.1 Financial Assumptions(a)

RESERVOIR DATA -- Oil Company Energy Supply

Capitalization:

Debt = 42%

Equity = 58%

Bond Interest Rate = 8%^(b)

Return on Equity = 15%

PLANT DATA -- Aluminum Company Power Plant

Capitalization:

Debt = 37%

Equity = 63%

Bond Interest Rate = 8.5%^(b)

Return on Equity = 9.1%

-
- (a) Financial data compiled from Moody's Industrial Manual, Moody's Investors Service, New York, N.Y., for 1973 and 1977 from a representative group of oil and aluminum companies.
- (b) Cost of power (mills/kWh) sensitivity to bond interest rates in the GEOCOST model was tested. An increase of one percentage point in both interest rates increased the cost of power by $\approx 1.8\%$.

As documented in Appendix B, a steam cycle power plant was used in all cases. Steam plant technology was used because it is the state-of-the-art technology for geothermal power production. Figure 4.1 shows the steam cycle power plant and its various components.

Table 4.2 shows the parameters input to the GEOCOST model for the ten sites selected for detailed evaluation in Section 3.0. Table 4.2 is similar to Table 3.2 in Section 3.0 except that the values in Table 4.2 are averaged for each site-specific parameter. All ten sites were assumed to have the same well production life (15 years) and well spacing (20 acres).

FIGURE 4.1. Steam Cycle Power Plant and Components

TABLE 4.2. Input Parameters to GEOCOST Model for Ten Selected Geothermal Sites

Site	Reservoir Temperature (°C)	Wellhead Temperature (°C)	Well Flow Rate (lb/hr)	Well Depth (Km)	Drilling Hardness	TDS Wt% (ppm)	Fraction Steam (%)	Non-Cond. Gases (wt%)	Source
Brawley, California	265	135	500,000	2.5	Soft	100,000	27.5	0.1	a,c
Westmoreland, California	217	159	560,000	2.4	Soft	50,000	12.5	2.0	a,d
Salton Sea, California	323	286	430,000	2.1	Soft	250,000	14.0	0.1	b
Long Valley, California	227	134	233,000	1.0	Medium	1,400	19.0	0.1	a,f
Alvord, Mickey Hot Springs, Borax Lake, Oregon	205	144	440,000	3.0	Medium	2,400	12.5	0.1	
Steamboat Springs, Nevada	205	144	440,000	1.0	Medium	2,500	12.5	0.1	a
Desert Peak, Nevada	220	162	440,000	1.3	Medium	30,000	12.5	0.1	
Roosevelt Hot Springs, Utah	245	173	1,000,000	1.25	Medium	7,000	16.0	0.1	a,d,e
Cove Fort - Sulphurdale, Utah	200	139	440,000	1.35	Hard	30,000	12.5	0.1	a
Valles Caldera, New Mexico	273	146	400,000	2.1	Medium	4,800	27.5	0.1	a

(a) Muffler (1978); Williams et al. (1978)

(b) Tewhey (1977)

(c) Smith et al. (1978)

(d) Smith et al. (1977)

(e) Smith (1977)

(f) Cosner (1977)

Also included in Table 4.2 are the wellhead temperatures associated with each site. The wellhead temperatures were calculated from the wellhead steam fractions and the reservoir temperatures, with the assumptions that the liquid at the wellhead is in equilibrium with the steam fraction and that the resource exists in the liquid state before extraction. An iterative enthalpy balance was then done to determine the wellhead temperature using the equation

$$h_{r(1)} = (1-X)h_{w(1)} + h_{w(s)}$$

where

X = weight fraction steam

$h_{r(1)}$ = enthalpy of resource liquid

$h_{w(1)}$ = enthalpy of wellhead liquid

$h_{w(s)}$ = enthalpy of wellhead steam.

The wellhead temperature determines both $h_{w(1)}$ and $h_{w(s)}$, due to the equilibrium assumption, so that an iteration process is needed to satisfy the equation.

In addition to varying the parameters shown in Table 4.2 for each site, the power plant size was also varied. Three plant sizes (25, 50, and 100 MWe) were selected to represent probable plant sizes that an aluminum company would build. These three gross power levels were input to GEOCOST along with the variables in Table 4.2 for all ten sites.

The resulting net power (MWe) and power cost (mills/kWh) for each site, except the Salton Sea, and power level are shown in Table 4.3 (1976 dollars). The Salton Sea costs were unrealistically low because the GEOCOST program does not include the cost of dealing with the high total dissolved solids (TDS) level. As seen in Figure 4.2, the TDS level at the Salton Sea is very high (250,000 ppm) as compared to the other sites (1,000 to 100,000 ppm). At this time, the technology for handling this TDS level is still being developed. The costs associated with solids removal and/or equipment modification to cope with this TDS level are thus currently unknown. Due to the uncertainties as to how much it would cost to clean the fluid and/or modify the equipment, the Salton Sea was eliminated as a potential site for the rest of this study.

TABLE 4.3 Site-Specific Results

Site	Gross Power (MWe)	Net Power (MWe)	Cost (Mills/kWh)
Brawley	25	23.4	26.48
	50	46.8	24.03
	100	93.5	23.03
Westmoreland	25	23.3	26.69
	50	46.6	24.73
	100	93.2	23.47
Long Valley	25	23.1	31.00
	50	46.1	30.67
	100	91.9	32.59
Alvord, Mickey Hot Springs, and Borax Lake	25	23.1	48.95
	50	46.8	46.20
	100	92.3	45.29
Steamboat Springs	25	23.1	26.03
	50	46.2	24.43
	100	92.3	23.94
Desert Peak	25	23.4	23.10
	50	46.8	20.99
	100	93.5	20.19
Roosevelt Hot Springs	25	23.7	16.61
	50	47.4	14.08
	100	94.7	12.73
Cove Fort- Sulphurdale	25	23.0	31.18
	50	45.9	29.02
	100	91.6	28.94
Valles Caldera	25	23.6	25.71
	50	47.2	22.87
	100	94.6	21.42

Table 4.3 suggests that Roosevelt Hot Springs, Utah is the lowest cost site, with power costs ranging from 13 to 17 mills/kWh. The next four sites with the lowest costs are Desert Peak (20 to 23 mills/kWh), Valles Caldera (21 to 26 mills/kWh), Steamboat Springs (24 to 26 mills/kWh), and Brawley (23 to 26 mills/kWh). These four sites all have about the same range of costs, varying from the 100-MWe (gross) plant costing the least per kWh to the 25-MWe (gross) plant costing the most per kWh. These cost figures do not include the cost of providing reliable power to the aluminum plant. The next section discusses this problem and presents a solution to it.

4.2 AVAILABILITY ADJUSTED POWER COSTS

At this point in the study two problems were encountered. The first was how to define and model availability. The second was how to translate the results of the availability model into a cost framework.

An aluminum plant requiring 300 MWe must be supplied with at least 297 MWe if it is not to suffer large financial losses. For this reason, it was assumed that the geothermal power system must be able to provide the 297 MWe needed 98% or more of the time. In the remaining 2% of the time, the short-fall could be made up from an external power source. For the system to provide 297 MWe 98% of the time, excess power capacity will be required. The availability model enables one to calculate how many plants are needed to obtain a 98% level of availability for different power plant sizes. For this discussion, a system will be considered to be available when it is producing more than 297 MWe.

Each power plant in the system is modeled as a continuous time Markov chain (Karlin and Taylor 1975; Barlow and Prochan 1975). The power plants are assumed to function independently of each other; when one fails, the system loses only a portion of its power equal to what the failed plant was generating. Table 4.4 shows failure rates and repair times for the steam plant components. When one component fails, the plant is shut down until the component is repaired. All the plants in the system are assumed to have the same components with the same failure rates and repair times. Appendix C contains a more complete description of the availability model.

TABLE 4.4 Flash Steam System Reliability Data(a)

Plant Component	Estimated Values		Range	
	Mean Failure Rate (FR) (10^{-6} /hr)	Mean Repair Time (RT) (hr)	Failure Rate (10^{-6} /hr)	Repair Time (hr)
Flash Water Reinjection Pump	250	20	78 to 2659	8 to 267
Reject Water Reinjection Pump	34	20	2.5 to 86	6 to 37
Steam Scrubber	0.4	32	0.02 to 10	4 to 50
Generator	70	69	8 to 236	36 to 82
Turbine (Steam)	250	95	39 to 349	44 to 129
Barometric Condenser	12	25	0.3 to 342	13 to 50
Intercondenser	12	25	0.3 to 342	13 to 50
First Stage Ejector	26	4	1 to 63	1 to 8
Second Stage Ejector	26	4	1 to 63	1 to 8
After Condenser	12	25	0.3 to 342	13 to 50
Condensate Pump	70	20	5 to 86	12 to 37
Cooling Water Pump	34	20	2.5 to 86	6 to 37
Cooling Tower	40	25	2 to 52	22 to 28
Production Wells	66	6		

(a) The data in Table 4.4 were compiled by Gordon M. Reistad and Dwight Bushnell, Oregon State University, Corvallis, Oregon.

In addition to the unscheduled downtime patterned by the availability model, 4 weeks of maintenance downtime per plant per year were assumed. Each plant will be down 4 weeks per year on a staggered maintenance schedule to allow the maximum power production from the entire system at any one point in time. For example, if the geothermal power system were composed of ten 50-MWe plants to provide the 297 MWe the aluminum plant needs on a continual basis with an availability of 98%, there would be two levels or modes of system operation. For 40 weeks per year (10 plants x 4 weeks downtime/year) one plant in the system, on a rotating basis, would be undergoing routine, scheduled maintenance. During these 40 weeks only nine plants would be providing power. During the remaining 12 weeks of the year (52-40), all ten plants would be scheduled on line. Thus, the two modes of system operation would be nine plants for 40 weeks per year (40/52 of the time) and ten plants for 12 weeks per year (12/52 of the time). This logic was used to develop the input for the availability model shown in Table 4.5.

As seen in Table 4.5, the total availability of all systems shown is greater than 98%. The number of plants needed at each site and power level is the minimum number needed to provide 98% available power. The figures for the number of plants needed and, consequently, the power plant modes, were attained through a trial and error procedure. The number of plants needed was assumed for the site and the power plant modes were then attained as discussed above. The power plant modes were then input to the availability model, along with the number of wells per plant and the net power level. The availability of each mode was then calculated by the model and the total availability of each site computed by taking the time-weighted average of the two power plant mode availabilities. If the total availability was less than 98%, the above procedure was tried with additional plants until the total availability was greater than 98%.

The unadjusted cost of power values for the five sites must be adjusted to account for the excess capacity needed to ensure a system availability of 98% or greater. The cost of power figures shown include an 85% load factor. The cost of power figures also include a fixed and variable portion. Only the

TABLE 4.5 Availability Model Results

Site	Gross Power Plant Level (MWe)	Number of Plants Needed	Power Plant Modes	Fraction Time in Mode	Availability of Mode (%)	Total Availability (%)
Brawley, California	25	27	15	16/52	98.34	99.323
			16	36/52	99.76	
	50	10	9	40/52	99.65	99.72
			10	12/52	99.97	
	100	6	5	24/52	98.72	99.36
			6	28/52	99.91	
Roosevelt Hot Springs, Utah	25	17	15	16/52	98.34	99.323
			16	36/52	99.76	
	50	10	9	40/52	99.65	99.72
			10	12/52	99.97	
	100	6	5	24/52	98.72	99.36
			6	28/52	99.91	
Desert Peak, Nevada	25	17	15	16/52	98.34	99.323
			16	36/52	99.76	
	50	11	10	44/52	99.50	99.57
			11	8/52	99.95	
	100	6	5	24/52	98.72	99.36
			6	28/52	99.91	
Valles Caldera, New Mexico	25	17	15	16/52	98.34	99.323
			16	36/52	99.76	
	50	10	9	40/52	99.64	99.72
			10	12/52	99.97	
	100	6	5	24/52	98.72	99.36
			6	28/52	99.91	
Steamboat Springs, Nevada	25	17	15	16/52	98.34	99.323
			16	36/52	99.76	
	50	10	9	40/52	99.65	99.72
			10	12/52	99.97	
	100	6	5	24/52	98.72	99.36
			6	28/52	99.91	

fixed portion will be affected by increasing the capacity of the system; the variable costs will remain the same. Thus, the fixed costs must be multiplied by 85% and then increased to take the required excess capacity into account. The excess capacity is defined as the maximum amount of power possible from the system minus the amount needed (297 MWe). The following equation was used to adjust the cost of power figures.

$$PC_{(A)} = PC_{(u)} \times FC \times 0.85 \times \left[\frac{MC}{297} \right] + PC_{(u)} (1-FC)$$

where

$PC_{(A)}$ = adjusted cost of power
 $PC_{(u)}$ = unadjusted cost of power
 FC = fixed cost (%)
 MC = maximum capacity.

Table 4.6 shows the results of the availability model on the total power costs for the best five sites at the three power plant levels.

The Roosevelt Hot Springs, Utah site is still the lowest cost site of the five listed. The 50-MWe (gross) power plant is the most economic size to build at Roosevelt. The optimal plant size at the other four sites is 25 MWe (gross). The cost range for the five sites is 18.3 to 29.3 mills/kWh. Excluding Roosevelt, Utah, the range narrows to 25.6 to 29.3 mills/kWh. The availability study shows that, although the cost of power may be lower for the larger unit size (100 MWe versus 25 MWe), when the entire system is considered as an operating whole, the cost of providing 98% available power may cause the smaller units to be more economical.

TABLE 4.6 Cost of 98% Available Power

Site	Gross Power Plant Level (MWe)	Net Power Plant Level (MWe)	Maximum Capacity (MWe)	Unadjusted Cost of Power (Mills/kWh)	Fixed Cost (%)	Adjusted Cost of Power (Mills/kW)
Roosevelt Hot Springs, Utah	25	23.7	402.9	16.61	83.0	18.72
	50	47.4	474.0	14.08	84.0	18.30
	100	94.7	568.2	12.73	88.0	19.74
Desert Peak, Nevada	25	23.4	397.8	23.10	78.0	25.60
	50	46.8	514.8	20.99	79.0	28.84
	100	93.5	561.0	20.19	80.0	29.97
Valles Caldera, New Mexico	25	23.6	401.2	25.71	77.0	28.65
	50	47.2	472.0	22.87	78.0	29.13
	100	94.6	567.6	21.42	78.0	31.85
Steamboat Springs, Nevada	25	23.1	392.7	26.03	77.0	28.51
	50	46.2	462.0	24.43	77.5	30.53
	100	92.3	553.8	23.94	77.5	34.79
Brawley, California	25	23.4	397.8	26.48	77.0	29.31
	50	46.8	468.0	24.03	77.5	30.35
	100	93.5	561.8	23.03	78.0	33.91

5.0 ECONOMIC FEASIBILITY^(a)

The primary purpose of this section is to evaluate the economic feasibility of using geothermal energy to power an existing or newly constructed aluminum reduction plant in the United States.

5.1 APPROACH AND SCOPE

The general approach to determining economic feasibility employed in this study is that of discounted cash flow analysis.^(b) The method of application differed somewhat, depending upon the case being considered.

In the case of existing aluminum plants, the feasibility of using geothermal power is related primarily to its cost competitiveness with alternative power sources. Consequently, the approach to this phase of the analysis involved using GEOCOST, an engineering and financial simulation model developed by Bloomster et al. (1975), to estimate the cost of power for each candidate geothermal resource. Delivered power costs from the best candidate sites were then compared to delivered costs from conventional sources to determine feasibility.

In the case of newly constructed aluminum plants, the analysis is complicated by the fact that the feasibility of applying geothermal energy to aluminum reduction is contingent upon the feasibility of new reduction plants themselves. Thus, for example, geothermal energy would be infeasible in this application if newly constructed U.S. aluminum plants could not earn a competitive return (given a range of expected power costs) and are, themselves, therefore, infeasible. If, on the other hand, new U.S. plants could earn a competitive return, the situation is further complicated by tradeoffs between transportation costs and energy costs. For example, geothermal must be judged infeasible if an aluminum/geothermal complex provided a lower expected return than a plant utilizing a comparably (or even higher) priced conventional energy

(a) Section author - A. E. Davis.

(b) For a detailed discussion of discounted cash flow techniques see Higgins (1977).

source but which is located close to the market center (the Ohio Valley) and therefore has lower total costs. In other words, geothermal could prove to be infeasible even though (a) an aluminum/geothermal plant would earn a competitive return, and (b) the busbar cost of geothermal power is equal to or lower than that of its competitors.

A comprehensive analysis of the economic feasibility of powering newly constructed aluminum plants with geothermal energy that would take each of these complicating factors into account is beyond the scope of this effort. Such an analysis would require calculating the return on each competing alternative combination of energy source and plant location to identify the most attractive configuration. At a minimum, before the commitment of investment funds could be recommended, the economics of plants located near the market center and powered by coal or nuclear-fired generating capacity, as well as plants located in South America to take advantage of the inexpensive hydroelectric power being developed there, should be evaluated.

The approach selected for this phase of the analysis takes into account the interrelationship between the new aluminum plant itself and the application of geothermal power to the aluminum plant, by jointly analyzing their feasibility. As in the case of existing plants, the cost of power (including a return to capital) at each candidate geothermal resource site was estimated using the GEOCOST model. At that point, current and projected future levels of all other inputs to the production of aluminum, together with the price of aluminum, were used in a second model, OPS (Legan and Engel 1972), which estimated the discounted cash flow of the hypothetical plant. The analysis was thus limited in that the only determination made was whether or not an aluminum/geothermal complex is likely to earn a competitive return on invested capital. Alternative combinations of energy source and aluminum plant locations were not analyzed.

The remainder of this section summarizes the conclusions based on the analysis described above. In Section 5.2, estimated power costs from the best candidate resource sites are reviewed and the feasibility of powering existing

plants with geothermal energy is assessed. Section 5.3 establishes scenarios for future aluminum prices and costs. In Section 5.4, discounted cash flow analyses for aluminum/geothermal complexes are presented.

Based on the estimated busbar cost of power and on a range of transmission cost estimates, it appears economically feasible to power existing aluminum reduction plants in the Pacific Northwest using electricity generated at Roosevelt Hot Springs. This conclusion is relatively insensitive to the level of transmission cost. Existing plants located in the Gulf Coast area could be powered from Roosevelt Hot Springs if transmission cost is near the lower end of the estimated range.

The economic feasibility of new aluminum plants constructed at or near geothermal electric power sources depends upon the future rate of increase of aluminum prices. Based on alternative scenarios for future price increases and on a range of capital and operating costs, new aluminum/geothermal power complexes appear to be economically feasible only under what is judged to be an optimistic price scenario. Under low and moderate price scenarios, such complexes are infeasible, regardless of the assumption made regarding future costs.

5.2 FEASIBILITY OF POWERING EXISTING ALUMINUM PLANTS

To determine the feasibility of powering existing aluminum plants from geothermal resources, three costs were estimated:

- geothermal power costs
- transmission costs
- delivered geothermal electric power costs.

The costs of delivered geothermal power were then compared with conventional power costs to estimate competitiveness.

5.2.1 Geothermal Power Costs

As described in Section 4.0, known hydrothermal convection systems in the U.S. were reviewed and a list of candidate sites prepared based on rough estimates of their levelized costs of power and on their ability to provide sufficient power to support a 200 kT/yr aluminum plant. The GEOCOST model was then

used to make more accurate estimates of power costs for the best candidate sites. These estimates incorporated additional, site-specific information regarding such factors as well flow rates, well depth and drilling hardness, brine chemistry, and taxes. Also incorporated was information on the reliability of the geothermal complex. This information was used to estimate the cost of providing 98% reliable power to the aluminum plant. The results of this analysis are shown in Table 5.1.

TABLE 5.1. Estimated Cost of Power at Best Candidate Sites
(in 1976 dollars)

<u>Candidate Site</u>	<u>Cost of Power (mills/kWh)</u>
Roosevelt Hot Springs, Utah	18
Desert Peak, Nevada	26
Valles Caldera, New Mexico	29
Steamboat Springs, Nevada	29
Brawley, California	29

5.2.2 Transmission Costs

To estimate the delivered cost of geothermal power, transmission costs must be added to the generation costs discussed in Section 5.2.1. The cost of transmitting power from a geothermal resource to an existing aluminum plant will be determined primarily by the distance between the two and by the extent to which new transmission capacity would have to be developed.

It may be that a long-term transmission requirement of the size being considered in this analysis could be accommodated only by adding at least some new capacity, either by expanding the capacity of existing lines or by constructing new lines. On the other hand, it may be possible for portions of the existing transmission system to be used, thus keeping costs lower than if all new capacity were required.^(a) Because of uncertainty as to the required mix

(a) There are potential institutional barriers to the use of existing facilities by a geothermal electric power producer. These barriers are discussed in Section 6.0.

of new and existing transmission facilities, high and low cost estimates were prepared in order to bound the true costs.

To obtain a high estimate it was assumed that all required facilities would have to be newly constructed. Estimates of the levelized annual cost in 1980 of transmitting loads of from 1,600 to 9,000 MW over new lines ranging in length from 500 to 1,500 miles were developed in a study by Banks and Leemans (1976). The smallest load considered, 1,600 MW, was several times larger than that of any existing aluminum plant. It was assumed here, however, that other uses would exist for the portion of capacity not required by the aluminum plant.^(a) Table 5.2 shows the cost in mills/kWh/100 miles of transmitting a 1,600-MW load.

TABLE 5.2. Transmission Costs of New Lines, 1980

<u>Delivered Load (MW)</u>	<u>Type/Size of Power Line</u>	<u>Distance (miles)</u>	<u>Mills/kWh/100 miles^(a)</u>
1,600	400 dc ^(b)	500	2.5
		900	2.2
		1,500	2.1

(a) Based on a 65% capacity factor.

(b) Of the alternative line sizes and types considered, Banks and Leemans found ~400 dc to be optimal for a 1,600-MW load.

Based on these figures, an upper limit on transmission costs in 1976 dollars was assumed to be 1.9 mills/kWh/100 miles. This was calculated by adjusting the 2.5 mills figure of Table 5.2 downward to eliminate the effects of escalation between 1976 and 1980.^(b)

(a) Alternatively, it could be assumed that several aluminum plants would share the capacity of one transmission line. It should be noted here that, if sale of excess power by an aluminum company is required, it is possible for that aluminum company to become subject to regulation as a public utility. See Section 6.0

(b) The escalation rate used by Banks and Leemans was 7.5%. Accordingly, the 1976 cost of 1.9 was calculated as follows:

$$1.9 = 2.5/(1.075)^4$$

To obtain a low estimate it was assumed that existing transmission lines could be utilized and that no new capacity would be required. The 1970 National Power Survey by the U.S. Federal Power Commission (1971) contains transmission cost data for 1968 ranging from 0.3 to 0.9 mills/kWh/100 miles for voltage ranging from 700 kV to 200 kV.^(a)

Assuming that transmission rate increases allowed since 1968 resulted only from changes in the variable portion of total costs, recent year (1976) approximations of transmission costs were obtained by escalating the variable portion of cost and adding this amount to the unescalated fixed portion.

The Power Survey contains data indicating that variable costs represent no more than about 15% of total transmission costs.^(b) Applying an assumed 8.5% escalation rate to 15% of 0.3 and 0.9 yields a range of total costs of from 0.34 to 1.02 mills/kWh/100 miles. Averaging these values yields a low transmission cost estimate of 0.7.

The low and high estimates developed above bound a range of from 0.7 to 1.9 mills/kWh/100 miles. These values will be used below to estimate the cost of geothermal power delivered to existing aluminum smelters.

5.2.3 Delivered Cost of Geothermal Electric Power

Figure 5.1 indicates the locations of aluminum reduction plants in the western United States as well as the geothermal reservoirs identified in Section 5.2.1. To estimate the delivered cost of geothermal electric power, transmission costs per 100 miles were multiplied by the approximate linear distance from the most promising candidate sites to concentrations of aluminum reduction capacity located in either the Pacific Northwest or the Gulf Coast areas. To this amount was added the estimated busbar cost of power at each geothermal site.

The results, shown in Table 5.3, indicate a range of delivered power costs of from 22 to 43 mills/kWh, depending upon generation point and delivery area. The lowest cost is provided by Roosevelt Hot Springs, 22 to 29 mills delivered in the Pacific Northwest, and 26 to 40 mills delivered in the Gulf Coast area.

(a) See Part I, p. I-13-9 and Part III, p. III-3-118.

(b) See Part I, p. I-19-10.

FIGURE 5.1. Locations of Aluminum Plants and Candidate Geothermal Sites

5.2.4 Comparison of Delivered Geothermal Power Costs with Conventional Power Costs

To determine the feasibility of powering existing aluminum plants with geothermal power, the delivered cost of geothermal power estimated in Section 5.2.3 must be compared with the delivered cost of conventional power.

In its 1977 Annual Report to Congress, the Energy Information Agency of the Department of Energy (EIA/DOE) provided forecasts of the cost of conventional power in 1985 and 1990. Based on alternative macroeconomic and energy supply assumptions, a range of projections was developed. For the industrial sector, the range was from 31.2 to 32.5 mills/kWh in 1985 and from 32.1 to 33.6 mills/kWh in 1990.

TABLE 5.3. Cost of Geothermal Power Delivered to Existing Aluminum Plants
(mills/kWh, 1976 dollars)

<u>Concentration of Reduction Capacity</u>	<u>Busbar Power Cost at Best Geothermal Sites</u>	<u>Distance (miles)</u>	<u>Transmission Cost per 100 miles</u>	<u>Delivered Power Costs^(b)</u>
Oregon, Washington	Desert Peak, Nevada ^(a)	500	low: 0.7	30
	26		high: 1.9	36
	Roosevelt Hot Springs, Utah ^(c)	600	low: 0.7	22
	18		high: 1.9	29
Texas, Louisiana, Arkansas	Valles Caldera, New Mexico ^(a)	750	low: 0.7	34
	29		high: 1.9	43
	Roosevelt Hot Springs, Utah ^(c)	1150	low: 0.7	26
	18		high: 1.9	40

(a) Closest site.

(b) Rounded to nearest mill.

(c) Lowest busbar power cost.

Because the EIA/DOE projections are in constant 1978 dollars, it was necessary to deflate them to 1976 dollars before they could be compared to the cost estimates for geothermal power developed in Section 5.2.3. Using an inflation rate of 8.5%, the deflated EIA/DOE projections are 26.5 to 27.6 and 27.3 to 28.5 mills/kWh in 1985 and 1990, respectively.

Comparison of these costs with the geothermal costs of Table 5.3 reveals that, under the low transmission cost assumption, geothermal power from Roosevelt Hot Springs, delivered to either the Pacific Northwest or the Gulf Coast area, would be competitive with conventional electric power costing 27.5 mills/kWh.^(a) Under the high transmission cost assumption, however, none of the candidate geothermal sites would be competitive, with the possible exception of Roosevelt Hot Springs at 29 mills delivered to the Pacific Northwest.

It is concluded on the basis of this analysis that it would be feasible to power an existing aluminum plant with geothermal power generated at Roosevelt Hot Springs unless the levelized busbar cost exceeds 18 mills/kWh and unless the true cost of transmission is near the upper estimate of 1.9 mills/kWh/100 miles.

5.3 ALUMINUM PRICE AND COST SCENARIOS

To evaluate the economic feasibility of powering a newly constructed aluminum plant with geothermal power it was necessary to address the feasibility of the aluminum plant itself as well as the feasibility of the geothermal reservoir and power plant. This feasibility will be determined by the relationship between aluminum prices and costs, both at the present time and in the future. In this section, long-range scenarios for prices and costs will be established.

5.3.1 Consumption, Production, and Price

As reported in the Wall Street Journal (1979a, 1979d) the current (1979) price of aluminum ingot is approximately \$0.60/pound, up sharply over recent

(a) 27.5 is the midpoint between the extreme values of the EIA/DOE projections.

levels. This increased upward trend of price, indicated in Table 5.4, has resulted in the reopening recently of reduction capacity in Texas and Indiana (Wall Street Journal 1979b, 1979e) which had previously been closed because of high operating costs. The upward trend is expected to continue at least through 1985, when a price in the neighborhood of \$1.00/pound has been predicted (Metals Week 1979). To adequately assess the feasibility of a new plant, however, it was necessary to incorporate information about future prices during the entire economic life of the plant, a period of at least 30 years beginning with the onset of plant operations.

A review of published aluminum market forecasts indicated that long-range price projections are not available. Projections of aluminum consumption, however, are shown in Table 5.5 where they are compared with current capacity. These projections indicate a discrepancy between desired consumption at current prices and current production capacity.

If this projected discrepancy is a reliable indicator of future market trends, then it is very likely that the price of aluminum will rise. Because actual, as opposed to desired, consumption cannot exceed supply, either desired consumption must be reduced, supply increased, or some combination of demand reduction and supply growth must occur. Given the economic growth assumptions implicit in the projections of Table 5.5, desired consumption will be reduced only if the price of aluminum rises. The domestic supply of aluminum, on the other hand, can be increased only by expanding production at existing plants, adding new production capacity, or by increasing imports. Only limited increases in production are possible at existing plants.^(a) Expansion of capacity at new or existing plants will involve higher costs and, therefore, higher prices. Expansion of imports is also likely to lead to higher prices given that rest-of-world consumption is projected to grow at a faster rate than is U.S. consumption (Bureau of Mines 1978) and considering that the world price of aluminum is currently well above the U.S. price (Wall Street Journal 1979c).

(a) The primary production rate for U.S. plants during 1978 was 92.5% of capacity (Vais 1979).

TABLE 5.4. Aluminum Prices

<u>Year</u>	<u>Price^(a)</u>
1957	0.28
1958	0.27
1959	0.27
1960	0.26
1961	0.26
1962	0.24
1963	0.23
1964	0.24
1965	0.25
1966	0.25
1967	0.25
1968	0.26
1969	0.27
1970	0.29
1971	0.29
1972	0.26
1973	0.25
1974	0.34
1975	0.40
1976	0.45
1977	0.52
1978 ^(b)	0.53
1979 ^(c)	0.60

Source: Bureau of Mines (1978)

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- (a) In current dollars per pound.
 (b) As of May 1978.
 (c) Wall Street Journal (1979d)

TABLE 5.5. Aluminum Consumption Forecasts Versus Current Capacity

	<u>Consumption (10^6 ST)</u>			
	<u>1980</u>	<u>1985</u>	<u>1990</u>	<u>2000</u>
<u>Data Source</u>				
Bureau of Mines				
Total Consumption (1978)	7.6	10.7	13.2	20.0
Primary Only (1978)	7.0	9.9	12.0	18.0
Apparent Metal (1979)	6.7	9.4	-	-
Federal Preparedness Agency (1978)				
Total Consumption	7.9	10.8	14.2	-
Charles River Associates (1977)				
Most Likely Case	8.1	8.7	11.5	-
<u>Production Capacity (10^6 ST)</u>				
1977 (Bureau of Mines 1979)	5.2			

Table 5.5 thus strongly suggests that the price of aluminum must rise. However, because there is no basis for predicting the extent or timing of that increase, the discounted cash flow analysis presented in Section 5.4 is based on low, moderate, and high price scenarios. The low price scenario makes the conservative assumption that the long-run, compound rate of price growth for aluminum will be no greater than the general rate of inflation. The moderate scenario assumes that aluminum prices will increase 1.5 percentage points faster than the rate of inflation. The high scenario assumes aluminum prices increase 3.0 percentage points faster than inflation.

5.3.2 Costs

The capital cost of new aluminum reduction capacity as of 1976-77 is in the neighborhood of \$2,000 per annual ton (Business Week 1978; Bureau of Mines 1978b).

Input quantities, costs, and annual cash outflows per pound of aluminum production at a new plant as of 1976 are indicated in Table 5.6. The numbers shown there were obtained from a U.S. Department of Commerce study. They are consistent with estimates developed by A. D. Little (1976) and by the Bureau of Mines (1978a).

TABLE 5.6. Annual Cash Outflows Per Pound of Aluminum Production, New Plant (1976 Dollars)

<u>Cash Flow Element</u>	<u>Input/lb of Aluminum</u>	<u>\$/Unit of Input</u>	<u>\$/lb of Aluminum</u>
Electricity	6.5 kWh	0.021/kWh	0.137
Alumina	1.93 lb	0.063/lb	0.122
Cryolite	0.035 lb	0.255/lb	0.009
Aluminum Fluoride	0.02 lb	0.176/lb	0.004
Petroleum Coke	0.52 lb	0.039/lb	0.020
Pitch	0.15 lb	0.041/lb	0.006
Natural Gas	0.0033 x 10 ⁶ Btu	1.65 x 10 ⁶ Btu	0.005
Labor	0.0055/man-hour	11.88/man-hour	0.065
Maintenance Materials	-	-	0.024
Transportation	-	-	0.008
Pollution Control	-	-	0.012
Local Taxes & Insurance	-	-	0.010
Miscellaneous	-	-	0.010
Total Cash Outflow			0.432

Source: U.S. Department of Commerce (1979)

To carry out discounted cash flow analyses for a new plant, long-term projections of cash outflows were required. The Department of Commerce study contains constant dollar projections for the period 1976 through 1991. The

growth rates for each cash flow element are shown in the first three columns of Table 5.7. To generate cash outflows for the remainder of the assumed 30-year economic life of a new plant, rates of increase in costs for the 1986 to 1991 subperiod were assumed to apply to the period 1991 to 2015. Plant operations are assumed to commence in 1985.

TABLE 5.7. Growth Rates for Aluminum Production Cash Outflows

Cash Flow Element	Average Annual Percent Increase ^(a)			
	1976-1981	1981-1986	1986-1991	1991-2015
Alumina	1.4 ^(b)	1.2 ^(b)	1.2 ^(b)	1.2
Cryolite	0	0	0	0
Aluminum Fluoride	0	0	0	0
Petroleum Coke	4.7	4.7	4.8	4.8
Pitch	4.7	4.7	4.8	4.8
Natural Gas	7.1	7.1	3.6	3.6
Labor	2.7	2.8	2.6	2.6
Maintenance Materials	0	0	0	0
Transportation	5.5	5.6	5.6	5.6
Pollution Control	0	0	0	0
Local Taxes & Insurance	0	0	0	0
Miscellaneous	0	0	0	0

(a) Based on constant 1976 dollars.

(b) Source: U.S. Department of Commerce

A very high degree of uncertainty necessarily surrounds these projections. To reflect this uncertainty, the discounted cash flow analyses of Section 5.4 will assume that total cash outflows actually incurred will fall within a high-low range of 25% of the projected outflows. This will result in a range of net cash flows when total cash outflows are subtracted from cash inflows. Associated with this resulting range will be a probability distribution, symmetric with respect to the projected net cash flows. Thus, the most probable net cash flows will be the projected flows, but any amount within the

range will have some probability of occurrence. Probability declines to zero as the discrepancy between projected and actual net cash flow approaches the upper and lower bounds.

The role of this probability distribution in determining the feasibility of powering a new aluminum plant with geothermal power will be discussed in Section 5.4.1.

5.4 DISCOUNTED CASH FLOW ANALYSIS OF NEW ALUMINUM PLANTS

The computer program OPS^(a) was used during this study to assist in evaluating the economic feasibility of investment in new aluminum reduction plants. Specifically, OPS combines discounted cash flow analysis with Monte Carlo simulation techniques to estimate both the net present values of such investments and the probabilities associated with those present values.

5.4.1 Description of OPS Computer Program

The program performs a conventional discounted cash flow calculation by discounting a series of future net cash flows using present worth factors consistent with a user-specified cost of capital. To reflect the difficulty of predicting uncertain cash flows far into the future, the user specifies three values of net cash flow for each year of the project's economic life: a most probable value, a minimum value, and a maximum value. The program uses these values to estimate the net cash flow probability distribution in each year.

Monte Carlo techniques are then employed to estimate a probability distribution for the discounted cash flow of the project, in this case an aluminum/geothermal complex. With the aid of a random number generator, the program selects a set of net cash flow values from the probability distributions for each year and uses these values to calculate a discounted cash flow value. This procedure is repeated many times until a frequency histogram approximating the net cash flow probability distribution is obtained. The procedure is depicted in Figure 5.2.

(a) For a detailed description of the OPS program, see Legan and Engel (1972).

FIGURE 5.2. Flow Chart of Monte Carlo Simulation as Applied in OPS

This approach to evaluating investment projects has two principal advantages. The first is that subjective assessments of the uncertainty of future cash flows can be incorporated in the analysis. The second is that because these subjective assessments are reflected in an estimate of the distribution of returns from the project, information about the risk of the project as well as the expected return is provided. Thus, for example, it is possible to conclude that the expected discounted cash flow of Project X is \$100 million,

i.e., that the odds of making a \$100 million return are 50-50. It is also possible, however, to conclude that the probability of Project X returning at least \$25 million is 90%.

5.4.2 Approach and Assumptions

In light of the power cost estimates of Table 5.1 indicating that Roosevelt Hot Springs is significantly cheaper (8 to 11 mills/kWh lower) than the best competing sites, the discounted cash flow analysis of powering newly constructed aluminum plants with geothermal electric power was limited to the Roosevelt site.

Roosevelt is within 20 miles of two small towns. It also borders a state highway and is within 10 miles of a primary railroad and 20 miles of a 138-kV transmission line (Williams et al. 1978). It would thus appear that no logistical factors exist that would cause Roosevelt to be at a cost disadvantage, relative to the competing sites, sufficient to overcome its power cost advantage. Consequently, limiting the analysis to Roosevelt is not expected to result in the exclusion of some other site that would be less costly after taking all factors into consideration.

To conduct the analysis, three future cash inflow streams were calculated for the period 1985 to 2015 using the aluminum price scenarios identified in Section 5.3.1.^(a) Also calculated were streams of future cash outflows utilizing an assumed capital cost of \$2,000 per annual ton of capacity (spread over a 4-year construction period) and rates of increase in operating costs discussed in Section 5.3.2.

Electric power cost was assumed to be the 18 mills/kWh estimate shown in Table 5.1 for Roosevelt Hot Springs. This figure was assumed to remain constant in real terms over the economic life of the complex. In addition, it was assumed that new aluminum plants will use 6.5 kWh of electric power per pound of output. Thus, a figure of 11.7 cents ($1.8¢/\text{kWh} \times 6.5 \text{ kWh/lb}$) was assumed for the cost per pound for electric power.

(a) The base price for these projections was \$0.47/lb in 1976 dollars. This is equivalent to a \$0.60/lb price in early 1978 dollars.

The transportation cost figure shown in Table 5.6 was modified for this analysis to reflect the western location of the hypothetical aluminum plant by assuming that two-thirds of the plant output would be shipped to the Ohio Valley area at a cost of 2.7¢/lb and that one-third would be shipped to western buyers at a cost of 0.8¢/lb. Thus, a weighted average transportation cost of 2¢/lb was assumed.

Subtracting cash outflows, exclusive of state and federal corporate income taxes, from cash inflows yielded a gross cash flow stream. To arrive at a state tax base, depreciation was calculated (using the sum-of-the-years-digits method) and subtracted from gross cash flow. A state corporate income tax rate of 4% was applied to this base. Subtracting state tax from the state tax base yielded the federal tax base to which was applied a 46% federal corporate income tax rate. Subtracting state and federal income taxes from gross cash flow yielded "probable" net cash flows for all years of operation except the first. In that year a 10% investment tax credit was added in order to arrive at a net cash flow.^(a) These calculations are shown in Table 5.8.

To reflect the uncertainty associated with future levels of both capital and operating cash outflows, an uncertainty band of $\pm 25\%$ was placed around the outflow estimates of Table 5.8. The resulting high and low estimates of total cash outflows are shown in Tables 5.9 and 5.10 for the moderate and high price scenarios, respectively.^(b) (The low price scenario was eliminated from consideration at this point because the net cash flows estimated in Table 5.8 were negative in every year except the first year of operation. Thus, a new aluminum plant would clearly be infeasible under this price scenario.)

Finally, in Tables 5.11 and 5.12, the high and low total cash outflow estimates were subtracted from cash inflows to arrive at high and low net cash flows. The high, low, and probable net cash flow estimates were input to OPS

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- (a) Although the investment tax credit exceeded federal tax for all cases, the entire amount of the credit was treated as a cash inflow on the assumption that the excess amount could be used to reduce tax payments arising from other corporate activity.
- (b) Cash outflows varied with the aluminum price scenario because tax payments change with changes in revenue.

TABLE 5.8. Net Cash Flow Calculations for New Aluminum/Geothermal Complex at Roosevelt Hot Springs

Year	Cash Outflow for Plant Construction	Annual Cash Inflow			Cash Outflow for Materials and Manufacturing	Gross Cash Flow			Depreciation	State Corporate Tax Base			State Corporate Tax			Federal Corporate Tax Base			Federal Corporate Tax			Net Cash Flow		
		Low	Mod	High		Low	Mod	High		Low	Mod	High	Low	Mod	High	Low	Mod	High	Low	Mod	High	Low	Mod	High
1981	(100)																							
1982	(100)																							
1983	(100)																							
1984	(100)																							
1985		188.0	214.8	245.3	194.8	(6.8)	20.0	50.5	25.8	(32.6)	(5.8)	24.7	0.0	0.0	1.0	(32.6)	(5.8)	23.7	0.0	0.0	10.9	33.2 ^(a)	60.0 ^(a)	78.6 ^(a)
1986		188.0	218.4	252.7	198.4	(10.4)	20.0	54.3	25.0	(35.4)	(5.0)	29.3	0.0	0.0	1.2	(35.4)	(5.0)	28.1	0.0	0.0	12.9	(10.4)	20.0	40.2
1987		188.0	221.6	260.2	201.6	(13.6)	20.0	58.6	24.1	(37.7)	(4.1)	34.5	0.0	0.0	1.4	(37.7)	(4.1)	33.1	0.0	0.0	15.2	(13.6)	20.0	42.0
1988		188.0	224.8	268.0	205.2	(17.2)	19.6	62.8	23.2	(40.4)	(3.6)	39.6	0.0	0.0	1.6	(40.4)	(3.6)	38.0	0.0	0.0	17.5	(17.2)	19.6	43.7
1989		188.0	228.0	276.1	208.0	(20.0)	20.0	68.1	22.4	(42.4)	(2.4)	45.7	0.0	0.0	1.9	(42.4)	(2.4)	43.8	0.0	0.0	20.2	(20.0)	20.0	46.0
1990		188.0	231.6	284.4	212.4	(24.4)	19.2	72.0	21.5	(45.9)	(2.3)	50.5	0.0	0.0	2.0	(45.9)	(2.3)	48.5	0.0	0.0	22.3	(24.4)	19.2	47.7
1991		188.0	235.2	292.9	216.0	(28.0)	19.2	76.9	20.7	(48.7)	(1.5)	56.2	0.0	0.0	2.3	(48.7)	(1.5)	53.9	0.0	0.0	24.8	(28.0)	19.2	49.8
1992		188.0	238.4	301.7	219.6	(31.6)	18.8	82.1	19.8	(51.4)	(1.0)	62.3	0.0	0.0	2.5	(51.4)	(1.0)	59.8	0.0	0.0	27.5	(31.6)	18.8	52.1
1993		188.0	242.0	310.7	224.0	(36.0)	18.0	86.7	18.9	(54.9)	(0.9)	67.8	0.0	0.0	2.7	(54.9)	(0.9)	65.1	0.0	0.0	30.0	(36.0)	18.0	54.0
1994		188.0	246.0	320.1	228.4	(40.4)	17.6	91.7	18.1	(58.5)	(0.5)	73.6	0.0	0.0	3.0	(58.5)	(0.5)	70.6	0.0	0.0	32.5	(40.4)	17.6	56.2
1995		188.0	249.6	329.7	232.4	(44.4)	17.2	97.3	17.2	(61.6)	0.0	80.1	0.0	0.0	3.2	(61.6)	0.0	76.9	0.0	0.0	35.4	(44.4)	17.2	58.7
1996		188.0	253.2	339.6	236.4	(48.4)	16.8	103.2	16.3	(64.7)	0.5	86.9	0.0	0.0	3.5	(64.7)	0.5	83.4	0.0	0.2	38.4	(48.4)	16.6	61.3
1997		188.0	257.2	349.8	242.0	(54.0)	15.2	107.8	15.5	(69.5)	(0.3)	92.3	0.0	0.0	3.7	(69.5)	(0.3)	88.6	0.0	0.0	40.8	(54.0)	15.2	63.3
1998		188.0	260.8	360.3	246.4	(58.4)	14.4	113.9	14.6	(73.0)	(0.7)	99.3	0.0	0.0	4.0	(73.0)	(0.2)	95.3	0.0	0.0	43.8	(58.4)	14.4	66.1
1999		188.0	264.3	371.1	251.6	(63.6)	13.2	119.5	13.8	(77.4)	(0.6)	105.7	0.0	0.0	4.3	(77.4)	(0.6)	101.4	0.0	0.0	46.6	(63.6)	13.2	68.6
2000		188.0	268.8	382.2	256.4	(68.4)	12.4	125.8	12.9	(81.3)	(0.5)	112.9	0.0	0.0	4.5	(81.3)	(0.5)	108.4	0.0	0.0	49.9	(68.4)	12.4	71.4
2001		188.0	272.8	393.7	262.0	(74.0)	10.8	131.7	12.0	(86.0)	(1.2)	119.7	0.0	0.0	4.8	(86.0)	(1.2)	114.9	0.0	0.0	52.9	(74.0)	10.8	74.0
2002		188.0	276.8	405.5	268.3	(80.0)	8.8	137.5	11.2	(91.2)	(2.4)	126.3	0.0	0.0	5.1	(91.2)	(2.4)	121.2	0.0	0.0	55.8	(80.0)	8.8	76.6
2003		188.0	281.2	417.7	274.0	(86.0)	7.2	143.7	10.3	(96.3)	(3.1)	133.4	0.0	0.0	5.4	(96.3)	(3.1)	128.0	0.0	0.0	58.9	(86.0)	7.2	79.4
2004		188.0	285.2	430.2	280.0	(92.0)	5.2	150.2	9.5	(101.5)	(4.3)	140.7	0.0	0.0	5.6	(101.5)	(4.3)	135.1	0.0	0.0	62.2	(92.0)	5.2	82.4
2005		188.0	289.6	443.1	286.0	(98.0)	3.6	157.1	8.6	(106.6)	(5.0)	148.5	0.0	0.0	5.9	(106.6)	(5.0)	142.6	0.0	0.0	65.6	(98.0)	3.6	85.6
2006		188.0	294.0	456.4	292.8	(104.8)	1.2	163.6	7.7	(112.5)	(6.5)	155.9	0.0	0.0	6.2	(112.5)	(6.5)	149.7	0.0	0.0	68.9	(104.8)	1.2	88.5
2007		188.0	298.4	470.1	300.0	(112.0)	(1.6)	170.1	6.9	(118.9)	(8.5)	163.2	0.0	0.0	6.5	(118.9)	(8.5)	156.7	0.0	0.0	72.1	(112.0)	(1.6)	91.5
2008		188.0	302.8	484.2	307.6	(119.6)	(4.8)	176.6	6.0	(125.6)	(10.8)	170.6	0.0	0.0	6.8	(125.6)	(10.8)	163.8	0.0	0.0	75.4	(119.6)	(4.8)	94.4
2009		188.0	307.2	498.7	314.4	(126.4)	(7.2)	184.3	5.2	(131.6)	(12.4)	179.1	0.0	0.0	7.2	(131.6)	(12.4)	171.9	0.0	0.0	79.1	(126.4)	(7.2)	98.0
2010		188.0	312.0	513.7	322.8	(134.8)	(10.8)	190.9	4.3	(139.1)	(15.1)	186.6	0.0	0.0	7.5	(139.1)	(15.1)	179.1	0.0	0.0	82.4	(134.8)	(10.8)	101.0
2011		188.0	316.4	529.1	330.4	(142.4)	(14.0)	198.7	3.4	(145.8)	(17.4)	195.3	0.0	0.0	7.8	(145.8)	(17.4)	187.5	0.0	0.0	86.3	(142.4)	(14.0)	104.6
2012		188.0	321.2	545.0	339.2	(151.2)	(18.0)	205.8	2.6	(153.8)	(20.6)	203.2	0.0	0.0	8.1	(153.8)	(20.6)	195.1	0.0	0.0	89.8	(151.2)	(18.0)	107.9
2013		188.0	326.0	561.3	348.4	(160.4)	(22.4)	212.9	1.7	(162.1)	(24.1)	211.2	0.0	0.0	8.5	(162.1)	(24.1)	202.7	0.0	0.0	93.2	(160.4)	(22.4)	111.2
2014		188.0	331.2	578.1	357.6	(169.6)	(26.4)	220.5	0.9	(170.5)	(27.3)	219.6	0.0	0.0	8.8	(170.5)	(27.3)	210.8	0.0	0.0	97.0	(169.6)	(26.4)	114.7

(a) The net cash flow figures for 1985 (only) reflect the addition of a \$40 million investment tax credit.

TABLE 5.9. Total Cash Outflows, Moderate Price Scenario(a)
(millions of 1976 dollars)

Year	-25%	Total Cash Outflow	+25%
1981	75.0	100.0	125.0
1982	75.0	100.0	125.0
1983	75.0	100.0	125.0
1984	75.0	100.0	125.0
1985	146.1	194.8	243.5
1986	148.8	198.4	248.0
1987	151.2	201.6	252.0
1988	153.9	205.2	256.5
1989	156.0	208.0	260.0
1990	159.3	212.4	265.5
1991	162.0	216.0	270.0
1992	164.7	219.6	274.5
1993	168.0	224.0	280.0
1994	171.3	228.4	285.5
1995	174.3	232.4	290.5
1996	177.3	236.4	295.5
1997	181.5	242.0	302.5
1998	184.8	246.4	308.0
1999	188.7	251.6	314.5
2000	192.3	256.4	320.5
2001	196.5	262.0	327.5
2002	201.0	268.0	335.0
2003	205.5	274.0	342.5
2004	210.0	280.0	350.0
2005	214.5	286.0	357.5
2006	219.6	292.8	366.0
2007	225.0	300.0	375.0
2008	230.7	307.6	384.5
2009	235.8	314.4	393.0
2010	242.1	322.8	403.5
2011	247.8	330.4	413.0
2012	254.4	339.2	424.0
2013	261.3	348.4	435.5
2014	268.2	357.6	447.0

(a) 1.5% real increase in price of aluminum.

TABLE 5.10. Total Cash Outflows, High Price Scenario(a)
(millions of 1976 dollars)

<u>Year</u>	<u>-25%</u>	<u>Total Cash Outflow</u>	<u>+25%</u>
1981	75.0	100.0	125.0
1982	75.0	100.0	125.0
1983	75.0	100.0	125.0
1984	75.0	100.0	125.0
1985	155.0	206.7	258.4
1986	159.4	212.5	265.6
1987	163.7	218.2	272.8
1988	168.2	224.3	280.4
1989	172.6	230.1	287.6
1990	177.5	236.7	295.9
1991	182.3	243.1	303.9
1992	187.2	249.6	312.0
1993	192.5	256.7	320.9
1994	197.9	263.9	329.9
1995	203.3	271.0	338.8
1996	208.7	278.3	347.9
1997	214.9	286.5	358.1
1998	220.7	294.2	367.8
1999	226.9	302.5	378.1
2000	233.1	310.8	388.5
2001	239.8	319.7	399.6
2002	246.7	328.9	411.1
2003	253.7	338.3	422.9
2004	260.9	347.8	434.8
2005	268.1	357.5	446.9
2006	275.9	367.9	459.9
2007	284.0	378.6	473.3
2008	292.4	389.8	487.3
2009	300.5	400.7	500.9
2010	309.5	412.7	515.9
2011	318.4	424.5	530.6
2012	327.8	437.1	546.4
2013	337.6	450.1	562.6
2014	347.6	463.4	579.3

(a) 3.0% real increase in price of aluminum.

TABLE 5.11. High and Low Net Cash Flows, Moderate Price Scenario(a)
(millions of 1976 dollars)

Year	Moderate Price Scenario	Low Cash Outflow	High Cash Outflow	High Net Cash Flow	Low Net Cash Flow
1981		(75.0)	(125.0)	(75.0)	(125.0)
1982		(75.0)	(125.0)	(75.0)	(125.0)
1983		(75.0)	(125.0)	(75.0)	(125.0)
1984		(75.0)	(125.0)	(75.0)	(125.0)
1985	214.8	146.1	243.5	108.7(b)	11.3(b)
1986	218.4	148.8	248.0	69.6	(29.6)
1987	221.6	151.2	252.0	70.4	(30.4)
1988	224.8	153.9	256.5	70.9	(31.7)
1989	228.0	156.0	260.0	72.0	(32.0)
1990	231.6	159.3	265.5	72.3	(33.9)
1991	235.2	162.0	270.0	73.2	(34.8)
1992	238.4	164.7	274.5	73.7	(36.1)
1993	242.0	168.0	280.0	74.0	(38.0)
1994	246.0	171.3	285.5	74.7	(39.5)
1995	249.6	174.3	290.5	75.3	(40.9)
1996	253.2	177.3	295.5	75.9	(42.3)
1997	257.2	181.5	302.5	75.7	(45.3)
1998	260.8	184.8	308.0	76.0	(47.2)
1999	264.8	188.7	314.5	76.1	(49.7)
2000	268.8	192.3	320.5	76.5	(51.7)
2001	272.8	196.5	327.5	76.3	(54.7)
2002	276.8	201.0	335.0	75.8	(58.2)
2003	281.2	205.5	342.5	75.7	(61.3)
2004	285.2	210.0	350.0	75.2	(64.8)
2005	289.6	214.5	357.5	75.1	(67.9)
2006	294.0	219.6	366.0	74.4	(72.0)
2007	298.4	225.0	375.0	73.4	(76.6)
2008	302.8	230.7	384.5	72.1	(81.7)
2009	307.2	235.8	393.0	71.4	(85.8)
2010	312.0	242.1	403.5	69.9	(91.5)
2011	316.4	247.8	413.0	68.6	(96.6)
2012	321.2	254.4	424.0	66.8	(102.8)
2013	326.0	261.3	435.5	64.7	(109.5)
2014	331.2	268.2	447.0	63.0	(115.8)

(a) 1.5% real increase in price of aluminum.

(b) Includes \$40 million investment tax credit.

TABLE 5.12. High and Low Net Cash Flows, High Price Scenario(a)
(millions of 1976 dollars)

Year	Moderate Price Scenario	Low Cash Outflow	High Cash Outflow	High Net Cash Flow	Low Net Cash Flow
1981		(75.0)	(125.0)	(75.0)	(125.0)
1982		(75.0)	(125.0)	(75.0)	(125.0)
1983		(75.0)	(125.0)	(75.0)	(125.0)
1984		(75.0)	(125.0)	(75.0)	(125.0)
1985	245.3	155.0	258.4	130.3(b)	26.9(b)
1986	252.7	159.4	265.6	93.3	(12.9)
1987	260.2	163.7	272.8	96.5	(12.6)
1988	268.0	168.2	280.4	99.8	(12.4)
1989	276.1	172.6	287.6	103.5	(11.5)
1990	284.4	177.5	295.9	106.9	(11.5)
1991	292.9	182.3	303.9	110.6	(11.0)
1992	301.7	187.2	312.0	114.5	(10.3)
1993	310.7	192.5	320.9	118.2	(10.2)
1994	320.1	197.9	329.9	122.2	(9.8)
1995	329.7	203.3	338.8	126.4	(9.1)
1996	339.6	208.7	347.9	130.9	(8.3)
1997	349.8	214.9	358.1	134.9	(8.3)
1998	360.3	220.7	367.8	139.6	(7.5)
1999	371.1	226.9	378.1	144.2	(7.0)
2000	382.2	233.1	388.5	149.1	(6.3)
2001	393.7	239.8	399.6	153.9	(5.9)
2002	405.5	246.7	411.1	158.8	(5.6)
2003	417.7	253.7	422.9	164.0	(5.2)
2004	430.2	260.9	434.8	169.3	(4.6)
2005	443.1	268.1	446.9	175.0	(3.8)
2006	456.4	275.9	459.9	180.5	(3.5)
2007	470.1	284.0	473.3	186.1	(3.2)
2008	484.2	292.4	487.3	191.8	(3.1)
2009	498.7	300.5	500.9	198.2	(2.2)
2010	513.7	309.5	515.9	204.2	(2.2)
2011	529.1	318.4	530.6	210.7	(1.5)
2012	545.0	327.8	546.4	217.2	(1.4)
2013	561.3	337.6	562.6	223.7	(1.3)
2014	578.1	347.6	579.3	230.5	(1.2)

(a) 3.0% real increase in price of aluminum.

(b) Includes \$40 million investment tax credit.

to estimate net cash flow probability distributions for each year of the project. These distributions, in turn, were used to estimate discounted cash flow probability distributions for each price scenario. The results are discussed in Section 5.4.3.

5.4.3 Results of Analysis

The average discounted cash flows (DCF) for a new aluminum plant located near Roosevelt Hot Springs were estimated to be -\$166.4 and +\$627.4 million for the moderate and high price scenarios, respectively.

Because the net cash flows to be discounted were in constant dollars, the discount rate used to calculate the above DCFs was also stated in real terms, that is, the effects of anticipated inflation were removed. To accomplish this it was assumed that the long-term rate of inflation currently expected is approximately 7%. Subtracting this from the estimated, current-dollar, weighted average cost of capital for the aluminum industry of 11% (U.S. Department of Commerce 1979) yielded the 4% inflation-adjusted rate used in OPS.

Tables 5.13 and 5.14 and Figures 5.3 and 5.4 indicate the estimated distributions of DCFs around the average values. The variation in these distributions results from the uncertainty bands placed around the estimates of capital and operating cash outflows in Section 5.4.2. Table 5.13 indicates that there is virtually no likelihood of a new plant yielding a nonnegative DCF under the moderate price scenario. Even assuming the most favorable outcomes with respect to uncertain future capital and operating cash flows the DCF would still be -\$75 million.

The interpretation of this result is that if aluminum prices were to increase at no more than 1.5 percentage points faster than the rate of inflation, an investment in a new aluminum plant at Roosevelt would fail to earn a competitive return even if cash outlays turned out to be lower than expected.

Table 5.14, on the other hand, indicates that under the high price scenario there is virtually no probability of a new plant yielding a negative DCF. An unfavorable outcome with respect to future capital and operating cash

TABLE 5.13. Discounted Cash Flows, Moderate Price Scenario
(millions of 1976 dollars)

<u>Upper Limit</u>	<u>Observed Frequency</u>	<u>Percentage of Total</u>	<u>Cumulative Percentage</u>	<u>Cumulative Remainder</u>
-265.00	1	0.50	0.50	99.50
-260.00	1	0.50	1.00	99.00
-255.00	1	0.50	1.50	98.50
-250.00	1	0.50	2.00	98.00
-245.00	1	0.50	2.50	97.50
-240.00	1	0.50	3.00	97.00
-235.00	1	0.50	3.50	96.50
-230.00	2	1.00	4.50	95.50
-225.00	2	1.00	5.50	94.50
-220.00	3	1.50	7.00	93.00
-215.00	7	3.50	10.50	89.50
-210.00	6	3.00	13.50	86.50
-205.00	9	4.50	18.00	82.00
-200.00	7	3.50	21.50	78.50
-195.00	4	2.00	23.50	76.50
-190.00	7	3.50	27.00	73.00
-185.00	6	3.00	30.00	70.00
-180.00	9	4.50	34.50	65.50
-175.00	11	5.50	40.00	60.00
-170.00	14	7.00	47.00	53.00
-165.00	11	5.50	52.50	47.50
-160.00	6	3.00	55.50	44.50
-155.00	12	6.00	61.50	38.50
-150.00	5	2.50	64.00	36.00
-145.00	8	4.00	68.00	32.00
-140.00	8	4.00	72.00	28.00
-135.00	10	5.00	77.00	23.00
-130.00	8	4.00	81.00	19.00
-125.00	8	4.00	85.00	15.00
-120.00	11	5.50	90.50	9.50
-115.00	3	1.50	92.00	8.00
-110.00	3	1.50	93.50	6.50
-105.00	3	1.50	95.00	5.00
-100.00	5	2.50	97.50	2.50
-95.00	1	0.50	98.00	2.00
-90.00	1	0.50	98.50	1.50
-85.00	1	0.50	99.00	1.00
-80.00	1	0.50	99.50	0.50
-75.00	1	0.50	100.00	0.00

TABLE 5.14. Discounted Cash Flows, High Price Scenario
(millions of 1976 dollars)

<u>Upper Limit</u>	<u>Observed Frequency</u>	<u>Percentage of Total</u>	<u>Cumulative Percentage</u>	<u>Cumulative Remainder</u>
518.00	2	1.00	1.00	99.00
522.00	1	0.50	1.50	98.50
528.00	1	0.50	2.00	98.00
534.00	2	1.00	3.00	97.00
540.00	1	0.50	3.50	96.50
546.00	2	1.00	4.50	95.50
552.00	3	1.50	6.00	94.00
558.00	2	1.00	7.00	93.00
564.00	1	0.50	7.50	92.50
570.00	5	2.50	10.00	90.00
576.00	5	2.50	12.50	87.50
582.00	8	4.00	16.50	83.50
588.00	6	3.00	19.50	80.50
594.00	7	3.50	23.00	77.00
600.00	7	3.50	26.50	73.50
606.00	7	3.50	30.00	70.00
612.00	13	6.50	36.50	63.50
618.00	12	6.00	42.50	57.50
624.00	9	4.50	47.00	53.00
630.00	13	6.50	53.50	46.50
636.00	10	5.00	58.50	41.50
642.00	11	5.50	64.00	36.00
648.00	1	0.50	64.50	35.50
654.00	7	3.50	68.00	32.00
660.00	12	6.00	74.00	26.00
666.00	8	4.00	78.00	22.00
672.00	9	4.50	82.50	17.50
678.00	7	3.50	86.00	14.00
684.00	7	3.50	89.50	10.50
690.00	7	3.50	93.00	7.00
696.00	3	1.50	94.50	5.50
702.00	2	1.00	95.50	4.50
708.00	4	2.00	97.50	2.50
714.00	2	1.00	98.50	1.50
720.00	0	0.00	98.50	1.50
726.00	2	1.00	99.50	0.50
732.00	0	0.00	99.50	0.50
738.00	1	0.50	100.00	0.00

-265.000***
 -260.000***
 -255.000***
 -250.000***
 -245.000***
 -240.000***
 -235.000***
 -230.000*****
 -225.000*****
 -220.000*****
 -215.000*****
 -210.000*****
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 -190.000*****
 -185.000*****
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 -170.000*****
 -165.000*AAAAAAAAAAAAAAAAAAAAA
 -160.000*****
 -155.000*****
 -150.000*****
 -145.000*****
 -140.000*****
 -135.000*****
 -130.000*****
 -125.000*****
 -120.000*****
 -115.000*****
 -110.000*****
 -105.000*****
 -100.000*****
 -95.000***
 -90.000***
 -85.000***
 -80.000***
 -75.000***

FIGURE 5.3. Probability Distribution for Discounted Cash
 Flows, Moderate Price Scenario (millions
 of 1976 dollars)

518.000*****
 522.000***
 528.000***
 534.000*****
 540.000***
 546.000*****
 552.000*****
 558.000*****
 564.000***
 570.000*****
 576.000*****
 582.000*****
 588.000*****
 594.000*****
 600.000*****
 606.000*****
 612.000*****
 618.000*****
 624.000*****
 630.000*AAAAAAAAAAAAAAAAAAAAAAAAA
 636.000*****
 642.000*****
 648.000***
 654.000*****
 660.000*****
 666.000*****
 672.000*****
 678.000*****
 684.000*****
 690.000*****
 696.000*****
 702.000*****
 708.000*****
 714.000*****
 720.000*
 726.000*****
 732.000*
 738.000***

FIGURE 5.4. Probability Distribution for Discounted Cash
 Flows, High Price Scenario (millions of
 1976 dollars)

flows would still result in a DCF of +\$516 million. There is a 75% probability of a DCF between \$570 and \$678 million. There is a 90% probability of a DCF greater than \$570 million.

The interpretation of this result is that if aluminum prices were to increase at a rate of 3.0 percentage points faster than the rate of inflation, a new plant would earn a more than competitive return even if cash outlays turned out to be higher than expected.

The analysis to this point indicates that the economic feasibility of newly constructed aluminum plants operated with geothermal electric power depends upon the future rate of increase of aluminum prices. As a result, to reach a conclusion regarding economic feasibility it is necessary to make a judgment as to the likelihood of the high, as opposed to the low and moderate, price scenario.

As indicated in Section 5.3.1, long-range aluminum price projections are not available. However, one recent study by Chase Econometric Associates indicates that the price of aluminum will reach approximately \$1.00/lb (in current dollars) by 1985 (Metals Week 1979). Comparing this with a 1979 price of about \$0.60/lb yields a compound annual rate of increase of 8.9%. This rate was adopted as a reasonable indicator of current expectations about the long-run rate of price increases. Further, an expected long-run average inflation rate of 7.0% was assumed. Given these assumptions, a 3.0% real rate of increase of aluminum prices must be regarded as optimistic.^(a) Accordingly, it is concluded that a new plant at Roosevelt Hot Springs would not earn a competitive return, and would not be economically feasible, except under an optimistic assumption about the future of aluminum prices.

(a) Some would regard 7.0% as a low estimate of the long-run inflation rate. To the extent that this is the case, the argument that 3.0% is an optimistic projection of real aluminum prices is strengthened.

6.0 INSTITUTIONAL CONSIDERATIONS^(a)

This section discusses the institutional considerations in developing geothermal energy for aluminum reduction. As background necessary to identify the considerations, Section 6.1 describes the seven stages of geothermal energy development for aluminum industry use. In Section 6.2, the generic institutional concerns, particularly those arising from federal law or federal land use, are addressed. Potential constraints stemming from laws in the four states being considered for geothermal energy development are discussed. Additional documentation in the form of state overviews is included in Appendix D.

6.1 GEOTHERMAL ENERGY DEVELOPMENT STAGES

In identifying institutional considerations, it is useful to discuss the seven stages of development of geothermal energy for aluminum reduction: leasing, exploration, utilization, construction, power transmission, sale of surplus power, and transportation.

6.1.1 Leasing

The first stage in such development is leasing geothermal development rights for federal, state, or private land.^(b)

Barriers at this stage include delays by both federal and state public agencies in leasing geothermal rights, restrictions on the amount of federal leasehold acreage allowable in any given state, difficulties in federal

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(b) In the case of use of geothermal for aluminum production, of course, it may be the eventual aluminum producer has no involvement at all in this stage but would rather enter the picture after some geothermal developer has developed a reliable resource. Such would most likely be the case with aluminum producers with no experience in geothermal energy development or for early applications of geothermal power for aluminum use. If geothermal were widely accepted as an energy source for aluminum, aluminum companies would be more interested in entering the development process at the beginning. By the same token, companies with expertise in energy development are likely to be more interested in getting involved at the start than those that are not.

procedures concerning competitive and noncompetitive leases of geothermal rights on federal lands, changes in property tax burdens based on leased value of unproven geothermal reserves, similar tax problems for proven but undeveloped geothermal reserves, questions of resource ownership, substantial environmental regulatory problems (e.g., dispute over whether or not environmental reports are required for leases on federal and state lands) and an uncertainty as to whether state and federal leases will be of sufficient duration to justify power plant (and aluminum smelter) investments. Table 6.1 summarizes federal agency lease responsibility.

Federal institutional problems at the leasing stage either have been resolved or are the subject of proposals for their resolution arising from the work of the Institutional Barriers Panel of the Interagency Geothermal Coordinating Council. State-specific leasing problems are described in Appendix D. Private leasing problems, except for tax issues, have been minimal. Even in cases of ownership disputes arising from questions of the nature of the geothermal resource, there has been either litigation to resolve the question or establishment of escrow funds to compensate the ultimate resource owner so development can proceed despite ambiguities.

6.1.2 Exploration

The exploration phase includes a wide range of activities leading up to, and ultimately including, drilling a limited number of geothermal wells, indistinguishable from producing wells that accompany full development. Such activities incur a series of potential environmental impacts and related regulatory attention. On federal lands, there are requirements for approval of drilling plans, controls over drilling activities, and the like. Similar drilling controls are administered by the states over state and private lands as well. Such controls are generally drawn from very extensive experience (at least relative to geothermal) with oil and gas development. Because of this extensive experience, major institutional problems are unlikely at this stage, although intense local political concern, as well as the novelty of geothermal development, may manifest itself in extraordinarily slow or stringent regulation in some places.

TABLE 6.1. Summary of Responsibility in the Federal Geothermal Leasing and Permitting Program^(a)

<u>Responsibility</u>	<u>Agency/Department</u>
Land Management Planning	BLM/FS ^(b)
Pre-Lease BLM Exploration Permit or FS Prospecting Permit	BLM/FS (Primary) GS and FWS (Consulting)
Competitive Lease Sale Scheduling	BLM/FS/GS/Industry/IGCC
Pre-Lease Environmental Analysis	BLM and/or FS (Primary) GS and FWS (Consulting)
Competitive Lease Sales FS/GS/FWS/DOE (Consulting)	BLM (Primary)
Noncompetitive Lease Applications	BLM (Primary) FS/GS/FWS (Consulting)
Scheduling for Non-competitive Leasing	BLM/FS (Primary) GS/FWS (Consulting)
Development of Lease Stipulations	BLM/FS/GS/DOE
Issuance of Lease	BLM/DOE
Post-Lease Environmental Analyses	GS (Primary) BLM/FS/FWS (Consulting)
Post-Lease Exploration Permit	GS (Primary) BLM/FS/FWS (Consulting)

(a) Information presented by the Interagency Geothermal Streamlining Task Force, June 1978.

(b) BLM - Bureau of Land Management
DOE - Department of Energy
FS - Forest Service
FWS - Fish and Wildlife Service
GS - U.S. Geological Survey
IGCC - Interagency Geothermal Coordinating Council

Source: Utah Division of Water Rights

Another, and often more troublesome, source of regulation at the exploration stage can occur where local jurisdictions exert land use control powers. For example, California counties can use their zoning powers to prohibit or otherwise control geothermal exploration activities on state or private land. Generally, this is done by requiring a conditional use permit before exploration can proceed, particularly before sinking geothermal wells. In states with environmental reporting requirements, such permits can in turn carry with them a need for environmental reporting, thereby imposing greater institutional difficulties. Moreover, local land use control powers are apt to be wielded with particular sensitivity to local political concerns. Geothermal development may be prohibited entirely as a land use in a county where there is great local opposition to such development.

6.1.3 Utilization

For electricity applications, utilization involves constructing an electric power plant, drilling geothermal production wells, and developing transmission facilities to connect wells and power plants with geothermal energy. This stage may experience substantial institutional problems. Environmental reporting requirements may arise, particularly where earlier environmental reporting (at leasing or exploration) has been limited to the immediate impacts of such activities. At this stage, regulations concerning development of power plants and utilities regulation of generation and sale of electricity might arise. Utilities regulation questions particularly are likely to be difficult for an aluminum company. However, it is not necessarily the case that public utilities would regulate the mere construction (as opposed to sale or other disposition of the electricity produced by the plant).

The question of public utilities regulation is speculative. Geothermal energy has not been used to reduce aluminum; hence, there are few precedents to serve as bases for estimates.

6.1.4 Construction

Institutional problems may be encountered in acquiring the land for construction, particularly public land. Further, a variety of land use and

environmental problems may arise with smelter operations. Such problems have not proven intractable in the recent past, at least with respect to meeting federal air and water pollution standards. However, local land use controls could be imposed, making development of a new smelter very difficult, if not impossible, depending on local political climates.

6.1.5 Power Transmission

If the geothermal power plant were built to serve an existing smelter, transmission facilities would be required. Substantial institutional problems may be encountered in gaining such transmission capacity. The degree to which private transmission systems would be available for such use is limited. Historically, utilities have been reluctant to carry electricity for others. While a privately-owned (but publicly-regulated) utility might find it profitable to provide transmission services for such electricity, the utility would more likely prefer to sell its own power to an aluminum smelter. This is because profits may be greater and effective systems management enhanced. Transmission rates may reflect such preferences and could change the economic attractiveness of an aluminum company developing its own geothermal capacity.

There are, of course, some solutions to problems in getting wheeling through federal law, and, specifically in the case of geothermal, under the law of some states. For example, California has provisions for the issuance of orders of interconnection to transmit geothermally generated electricity. There are proposals to establish similar powers for the Federal Energy Regulatory Commission.

Publicly-owned utilities, including federal agencies such as the Bonneville Power Administration (BPA), are generally more willing than privately owned ones to provide transmission services. Capacity for such services in a given situation may be limited. More importantly, there may be limits on the reliability of arrangements for such service over the period of time an aluminum company investing in geothermal plant and smelter would require assurance of a firm power supply.

6.1.6 Sale of Surplus Power

There may be difficult issues involving disposal of excess electricity. Technical and economic factors in providing geothermal power for an aluminum smelter may require construction of substantially more power plant capacity than the smelter needs for its operations. For example, one might want to construct extra geothermal power plant units for backup capacity in the event of failure of other units supplying the smelter. This is particularly likely to be the case if the smelter cannot arrange to purchase backup power from a utility and finds it economically prohibitive to develop its own nongeothermal backup capacity (e.g., gas turbines).

While it may be reasonable simply to not use excess generating capacity, it is more likely to be economically and technically desirable to produce the extra power and sell it. Such sales are likely to trigger utilities regulations questions. If such power is sold across state lines to a utility company, for instance, in commerce, the sale would surely be regulated by the Federal Energy Regulatory Commission. Even if the sale is made within a single state, state level public utilities regulation may apply. As noted before, the prospect of utilities regulation is likely to be extremely unpleasant to an aluminum company because of the complexity of meeting regulatory requirements and of the need for financial and other disclosures. Because arrangements for distributing excess electricity produced by industrial users (as opposed to utilities) are unusual, it is difficult to say with certainty how likely regulation would be.

6.1.7 Transportation

Institutional issues may arise over the transportation of alumina to the smelter and aluminum ingots from the smelter to market centers. Such problems are currently resolved by the aluminum industry and should not present any great difficulty in the future.

6.2 INSTITUTIONAL CONCERNS

From the previous discussion and the individual state analyses documented in Appendix D, it is possible to summarize seven principal institutional concerns.

6.2.1 Regulatory Uncertainty

Major complaints in the early 1970s over uncertainties in California's environmental reporting process and the delays in getting reports approved may be explained as products of regulatory uncertainty. It took some time after the passage of the California Environmental Quality Act to decide if geothermal development with its associated permits might require such reporting. Once the reporting was clearly required, it took more time for both state and local, particularly county, agencies concerned with issuing the various permits to develop organizational routines and capability to do the required reporting.

Similarly, novel kinds of development, particularly those which might generate substantial adverse environmental impacts, arouse public concerns and generate political opposition, are apt to experience problems in regulatory uncertainty. On the other hand, some states may be so favorably inclined toward development and exert such relaxed environmental controls that a geothermal developer might proceed with no serious trouble. However, in a time of substantial environmental awareness and associated concern with the effects of rapid development, any geothermal proposal would not likely experience such easy going.

The importance of regulatory uncertainty for aluminum developers of geothermal is apt to be especially great. A public utility may be quite willing to cope with uncertainties over geothermal development for electricity production as a part of development costs of what could potentially be a major source of its generating capacity. Pacific Gas and Electric Company, for example, currently has in excess of 500 MWe capacity at The Geysers, a considerable capacity and one likely to increase substantially. PG&E can expect to build additional geothermal plants for some time and, therefore, to spread the costs it sustained from regulatory uncertainty concerning earlier plants over the

later ones. However, an aluminum company, which presumably would not expect to build plants beyond those needed for its smelter, could not spread the regulatory uncertainty costs.

6.2.2 Public Utilities Regulation

Public Utilities regulation would be encountered in cases where excess geothermal capacity was developed and utilized. Should the aluminum producers decide to sell the electricity produced from such excess capacity, utilities regulation is likely to result in most cases. There are two kinds of regulation that might arise: (1) that under the Federal Energy Regulatory Commission where interstate sales of electricity are involved and (2) regulation under state utility laws. Both kinds can apply simultaneously. For example, the sale of excess electricity to a regulated public utility involved in interstate commerce in a state that chooses to license construction of the facilities for producing the excess electricity would involve both state and federal regulation.

As noted above, the federal regulation would clearly arise for wholesale sales of electricity in interstate commerce. The likelihood of state regulation varies considerably from state to state.

Utility regulation in general involves becoming subject to intense public scrutiny with respect to rates and permission to construct various facilities. The benefit for such regulation for a public utility is monopoly power in a market area and a guaranteed rate of return on capital investment. For an aluminum company or geothermal development for whom electricity generation was an incidental part of its larger affairs, a fixed rate of return on investment and monopoly power would be of little value. Considerable costs would be involved with the high degree of government regulation, loss of flexibility in arranging transactions, and, perhaps most importantly, the need to disclose proprietary information. The likelihood of regulation as a public utility, and even uncertainty on this score, could be a major deterrent to this use of geothermal power.

6.2.3 Regulatory Delay

Regulatory delay is related to regulatory uncertainty. It is in some ways less difficult in its own right. That is, reasonable financial decisions can be made if the length of the delays is known. In the case of regulatory uncertainty, it is impossible to predict the time needed to obtain licenses and clear other regulatory hurdles. Sound investment decisions are therefore very difficult to make. Nonetheless, delay can be a major problem, particularly in periods of high interest rates and rapidly rising costs.

6.2.4 Controlling Geothermal Resources

Resources developed under federal or state leases can experience controlling difficulties. Such leases are usually for a limited term, invariably allow for renewals, but also contain provisions for termination or renegotiation. No initial lease terms are for the 30- to 40-year periods used by most industrial investors to calculate plant lifespan and amortization. Uncertainty over the ability to extend leases for the life of power plants and, in this case aluminum smelters, may be a major difficulty. This problem is compounded, at least at the federal level, by ambiguous language in the Geothermal Steam Act about cancellation or renegotiation of leases apart from their extension.

6.2.5 Insufficient Federal Financial Incentive

The National Energy Act (NEA) of 1978 and the Federal Geothermal Loan Guarantee Program were both conceived to provide incentives for geothermal resource development. However, as discussed below, neither is sufficient to encourage geothermal energy development of the scope required by the aluminum industry.

6.2.5.1 Federal Tax Treatment of Geothermal Resources

The federal tax treatment for geothermal exploration and development expenditures and production was a jungle of unresolved issues and became the single greatest deterrent to geothermal resource assessment on federal, state, and free land. Whether geothermal resources could be accorded the same tax treatment as oil and gas, and thus no longer stand at a competitive disadvantage

when attempting to attract investment capital, was uncertain. The National Energy Act (NEA), passed by Congress in October 1978, resolved this uncertainty. The Act authorizes deduction of intangible drilling costs for geothermal wells on the same basis as for oil and gas. The Act provides that the amount of losses deducted in a year relating to a geothermal deposit cannot exceed the total amount the taxpayer is at risk with regard to the property at the end of the taxable year. And, to the extent the taxpayer has "excess intangible drilling costs" exceeding his net geothermal income, he will have preference income subject to the minimum tax.

Excess intangible drilling costs result when the intangible costs expensed exceed the deduction that would have resulted had the taxpayer capitalized the intangible costs on productive wells and amortized them on a straight-line (120-month) basis from the time of first production (or to the extent the expensed costs exceeded what would have been available under cost depletion).

The Act further provides that a taxpayer disposing of a geothermal property at a gain must recognize ordinary income as opposed to capital gains to the extent that the intangible costs deducted exceed that which would have been allowed had the intangible costs been capitalized and amortized on a straight-line basis (120-month) from the time the property went into production (or what would have been available under cost depletion). These provisions will be effective for all geothermal wells commenced after October 1, 1978, and for taxable years ending after October 1, 1978.

The Act also authorizes a full depletion allowance without the requirement for demonstrating actual depletability of the resource. The rate for geothermal resources is set at 22%, but declines to 15% by 1984 on the same schedule as for oil and gas.

The depletion allowance for geopressured methane is set at 10%, and is allowable only for wells whose drilling begins after September 30, 1978, and before January 1, 1984. Wells drilled after the latter date would be treated as normal gas wells. A well producing both geopressured methane and hot water would be allowed a 10% depletion allowance for income from the methane (until

1984) and a 15 to 22% depletion allowance for income from the hot water. There is no limit on the quantity of geothermal resource production on which percentage depletion can be taken.

For tax purposes, a geothermal deposit is defined as a geothermal reservoir consisting of natural heat, stored in an aqueous liquid or vapor (whether or not under pressure).

The Act provides for an investment tax credit, inter alia, for geothermal equipment which qualify as either "alternative energy property" or "specially defined energy property."

"Alternative energy property" is defined as equipment "used to produce, distribute or use energy derived from a geothermal deposit ... but only in the case of electricity generated by geothermal power up to (but not including) the electrical transmission stage."

"Specially defined energy property" is a list of enumerated items including a heat exchanger, etc., "the principal purpose of which is reducing the amount of energy consumed in any existing industrial or commercial process and which is installed in connection with an existing industrial or commercial facility."

Public utility property, defined in part as "property used in the furnishing or sale of ... electrical energy ... water ... or steam ...," cannot benefit to the extent of "alternative energy property" but can use the credit for "specially defined energy property."

The tax credit is 10% and is nonrefundable but applies only for the period October 1, 1978, through December 31, 1982. The taxpayer must be the original user of the property and the property must have a useful life of 3 years or more.

Natural gas from geothermal brines is a hybrid under the Act and receives varied treatment. For purposes of the intangible drilling deduction, the minimum tax (preference), income recapture and the at-risk provisions, it is deemed a gas and treated as oil and gas under the Internal Revenue Code. It

receives a straight 10% depletion rate which remains constant. This rate applies to wells drilled between October 1, 1978, and January 1984. Wells drilled at other times will be deemed a gas.

6.2.5.2 Federal Geothermal Loan Guarantee Program

The Federal Geothermal Loan Guarantee Program (30 U.S.C. 1141 et seq. P.L. 45-238) was established to help the geothermal developer obtain capital. The applicant is required to put up 25% of the project's capital costs. The guarantee will be provided to qualified borrowers for the purposes of:

1. The determination and evaluation of the resource base,
2. Research and development with respect to extraction and utilization technologies.
3. Acquiring rights in geothermal resources,
4. Development, construction, and operation of facilities for the demonstration or commercial production of energy using geothermal resources,
5. Construction and operation of a new commercial, agricultural, or industrial structure or facility or modification and operation of an existing commercial agricultural or industrial structure or facility, when geothermal hot water or steam is to be used within or by such structure or facility, or modification thereto, for the purposes of space heating or cooling, industrial or agricultural processes, onsite generation of electricity for use other than for sale or resale in commerce, other commercial applications, or combinations of applications separately eligible under this title for loan guarantee assistance (30 U.S.C. 1141(b), as amended P.L. 95-238, sec. 505).

Up to \$100 million can be provided for any loan for a project unless the guarantee is made for the purposes specified under number 5, in which case the limit for any project will be \$50 million (30 U.S.C 1141(e), as amended P.L. 95-238 sec. 508(1)). The amount any single qualified borrower may receive is \$200 million unless the Administrator deems it in the national interest to exceed this amount (ibid. sec. 508(3)).

The Federal Geothermal Loan Guarantee Program appears to have enjoyed limited success as an incentive to geothermal development. Since the program became operational in June 1976, eight guarantee applications have been received. By March 1978, with all processed, only three had been approved.

No geothermal loan guarantees have been made for an industrial facility utilizing geothermal resources for processing and surplus energy sales. The proposed Geothermal Energy Omnibus legislation addresses some of the shortcomings in the loan guarantee program, providing higher guarantees in some cases and even allowing DOE assumption of geothermal loans to prevent defaults.

New ownership and development financing arrangements are being considered in the geothermal industry itself to overcome public and private electric utility reluctance to invest in geothermal-fueled power plants.

6.2.6 Aluminum Company Ownership of Competing Energy Resources

A potential barrier to the development of geothermal energy for aluminum reduction is relatively greater acceptance by the aluminum industry of other resources. Some indication of this acceptance obviously comes from current practice. Aluminum companies obtain the electricity from sources ranging from hydro power in the Pacific Northwest to natural gas on the Gulf Coast. Nowhere in the U.S. are they currently using geothermal energy. However, it is currently planned to use geothermal energy to power an aluminum smelter to be constructed in the Phillipines in the 1980s (Engineering & Mining Journal 1979, p. 15).

Aluminum companies directly, or through other parts of their owner corporations, have substantial ownership of energy resources which might compete with geothermal. Such resources include coal, oil, natural gas, and uranium. There is even direct ownership of hydroelectric resources, although little likelihood of their increase. It is possible that current ownership of substantial energy resources would eliminate any interest an aluminum company might have for pursuing geothermal.

One might speculate that an aluminum company, because of its greater experience with other sources of energy, may choose not to get involved with

such a relatively untested resource as geothermal. For example, a firm with organizational expertise in the use of coal may decide to not take the risks involved in learning about geothermal. On the other hand, emissions, fuel supply, and other problems with coal may make geothermal relatively very attractive in some states. Aluminum company choices about energy supply are likely to be careful economic and technical decisions. Mere ownership of a range of alternative resources will in all likelihood not predetermine the results of such decisions.

6.2.7 The Impact of Federal Environmental Standards

Applicable federal environmental standards were reviewed and it was concluded that there are none that have recently caused great problems for the aluminum industry, and that the industry has been unable to meet. True, the industry has had to modify its procedures to meet air and water permit requirements, but the atmosphere in which this has been done seems to have been largely amicable and void of long delays or litigation.

The one exception to this would be the length of time required for approval of an Alumax EIS. However, the approval of this EIS is now being delayed by an energy-related matter, not an environmental one. Therefore, it seems fair to conclude that, given an industry willing to comply with the federal requirements and procedures established over the past few years, the meeting of federal environmental standards should no longer be cited as one of the principal problems confronting the aluminum industry.

7.0 CONCLUSIONS^(a)

Based on the findings of this study, five primary conclusions are offered:

- Hydrothermal resources of sufficient size and quality to power aluminum reduction plants exist within the United States. However, none of these resources is within the immediate vicinity of an existing reduction plant.
- It is technically feasible to use state-of-the-art geothermal power plants to provide a primary source of power for aluminum reduction.
- Based on the estimated busbar cost of power and on a range of transmission cost estimates, it appears economically feasible to power existing aluminum reduction plants in the Pacific Northwest using electricity generated at Roosevelt Hot Springs, Utah. This conclusion is relatively insensitive to the level of transmission cost. Existing plants located in the Gulf Coast area could be powered from Roosevelt Hot Springs if transmission cost is near the lower end of the estimated range.
- The economic feasibility of new aluminum plants constructed at or near geothermal electric power sources depends upon the future rate of aluminum price increases (cash inflows). Based on alternative scenarios for future price increases and on a range of capital and operating costs (cash outflows), new aluminum/geothermal power complexes appear to be economically feasible only under what is judged to be an optimistic price scenario. Under low and moderate price scenarios, such complexes are infeasible regardless of the assumption made regarding future costs.

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- Currently, the major institutional barriers to aluminum industry acceptance of geothermal energy as a viable alternative source of energy are regulatory uncertainty, potential for public utility regulation, and difficulty in controlling geothermal resources developed under federal or state leases.

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APPENDIX A

ESTIMATED POWER DEVELOPMENT
AT SELECTED GEOTHERMAL SITES

APPENDIX A
ESTIMATED POWER DEVELOPMENT AT
SELECTED GEOTHERMAL SITES

Figures A.1 through A.10 were made from the estimated development time schedules given by Williams et al. (1978). The power levels are cumulative with time. Figure A.1 indicates an initial 50 MWe estimated to come on line in 1984 from Mono-Long Valley and a similar amount from COSO in 1986. COSO then adds 50 MWe in 1987, followed by 150 each year in 1988, 1989 and 1990. Similarly, Mono-Long Valley shows an additional 100 MWe on line in 1987 and 1989 to reach the levels projected by Williams et al (1978). Development is continued on up to the 2000-MWe limit by 1999, as projected by Muffler (1978).

On some charts, e.g., Figure A.3, several sites may have similar initial development schedules and then show a separate individual schedule and maximum level Heber and East Mesa exemplify this. This means that each site plans to have 50 MWe on line by or during 1985.

The power development schedules use the left-hand ordinate, which is in blocks of power, MWe for 30 years. The right-hand ordinate is a power requirement in MWe/yr for aluminum reduction. Power needs for reducing 300 kT/yr and 150 kT/yr with the Hall process, the improved Hall process, and the Alcoa process are shown. Thus, these areas individually could not support a 150-kT/yr Alcoa Process until 1986 at Salton Sea, 1987 at Brawley, 1989 at Heber, or later at East Mesa. These projections are based on the assumption that the developed power is totally committed to an aluminum reduction plant.

FIGURE A.1. East Central California Estimated Power Development

FIGURE A.2. Northern California Estimated Power Development

FIGURE A.3. Southern California Estimated Power Development

FIGURE A.4. Hawaii Estimated Power Development

FIGURE A.5. Idaho-Oregon Estimated Power Development

FIGURE A.6. Nevada Estimated Power Development

FIGURE A.7. New Mexico Estimated Power Development

FIGURE A.8. Utah Estimated Power Development

FIGURE A.9. Texas Geopressured Areas Estimated Power Development

FIGURE A.10. Louisiana Geopressured Areas Estimated Power Development

APPENDIX B

VALUES AND ASSUMPTIONS
CONSTANT FOR ALL GEOCOST RUNS

APPENDIX B
VALUES AND ASSUMPTIONS CONSTANT FOR
ALL GEOCOST RUNS

Cost of drilling production wells: \$400,000
Distance from reservoir to plant: 1,000 meters
Average production life of wells = 15 years
Fraction of excess producing wells = 0.2
Reservoir well spacing = 20 acres
Power plant load factor = 0.85
Number of years to construct plant = 3
Federal income tax rate = 0.48
State income tax rate = 0.07
Property tax rate = 0.025
Property insurance rate = 0.0012
Depletion allowance = 15%
Royalty payments, percentage of reservoir annual power sales = 10%
State gross revenue tax rate on power plant = 0.04
Interim capital replacement rate, fraction of power plant capital
investment = 0.0035
Spent fluid to be reinjected by pumping
Depreciation method = Sum-of-Years-Digits
Steam separated from water at wellhead
Water at wellhead transmitted to plant then flashed in two-stage flasher
No mixing of steam from various sources before turbine
Steam is scrubbed before turbine
Exhaust pressure of steam from turbine = 2 psia.

APPENDIX C

DESCRIPTION OF A GEOTHERMAL
POWER GRID MODEL

APPENDIX C
DESCRIPTION OF A GEOTHERMAL POWER GRID MODEL

The power grid is composed of N plants, possibly of different sizes. An individual plant fails whenever any component within that plant fails. The plant remains down until the failed component is repaired. It is assumed that only one component in a plant can fail at a time; that is, components are not under stress during a repair cycle. Components are also assumed to function independently of each other. Plant K is supplied with steam from a field consisting of M_K wells. These wells are assumed to have an individual capacity of u -megawatt and may also fail. Each well failure will reduce plant production by a u -megawatt increment (if there is no excess capacity in the field). The u -megawatt capacity of a single well describes the basic power unit in the model. To provide a quantitative description of the various parts of the power grid, some definitions are introduced.

Let:

- $Z(t)$ represent the total power flowing out of the grid at time t (in u -megawatt units).
- $Y_K(t)$ represent the capacity of steam field K at time t (in u -MW units).
- $U_{Kj}(t)$ represent the output of the j th well in field K (in u -MW units). U_{Kj} can take on the values 0 or 1.

Let:

- $X_K(t)$ represent the status of plant K . $X_K = 1$ means the plant is operating while $X_K = 0$ means the plant is down.
- c_K represent the minimum number of wells needed to operate Plant K at full capacity.
- $Q_K(t)$ represent the output of plant K at time t .
- $L = \sum_{K=1}^N c_K$ represent the maximum capacity of the power grid.

A mathematical description can now be provided for the power grid:

$$(I) \quad Q_K(t) = X_K(t) \cdot \text{Min}(Y_K(t), c_K)$$

$$(II) \quad Y_K(t) = \sum_{j=1}^{M_K} U_{Kj}(t)$$

$$(III) \quad Z(t) = \sum_{k=1}^N Q_K(t)$$

The structure described in Formulas (I) through (III) is presented schematically on the next page. Formulas (II) and (III) are fairly easy to comprehend; they simply calculate the total power available from field K and all plants in the grid, respectively. Formula (I) describes the relationship between plant power production and steam-field production capability. When plant K is up, its power production is limited by the amount of steam available $Y_K(t)$ and its capacity, c_K . The smaller of these two numbers, $\text{Min}(Y_K(t), c_K)$, will represent the power production. Of course, when the plant is down, ($X_K(t) = 0$), the power production for that plant must be 0. Multiplying $\text{Min}(Y_K(t), c_K)$ by $X_K(t)$ gives an expression for power production that is valid in both circumstances.

The above formulation provides information necessary to calculate the steady-state distribution of $Z(t)$ from those of $X_K(t)$ and $U_{Kj}(t)$. The expression $Z(t)$ must take on one of the integer values:

$$\{1u, 2u, 3u \dots Lu\}.$$

These values are called "states". The steady-state distribution of $Z(t)$ is a vector of probabilities, $(\pi_1, \pi_2, \dots, \pi_L)$, that describes the proportion of time $Z(t)$ spends in each of its states. For example, π_i represents the proportion of time that $Z(t) = i \cdot u$ or, in other words, the proportion of time the grid is producing $i \cdot u$ megawatts. Formally, π_i is defined as:

$$\pi_i = \text{Pr}(Z(t) = i \cdot u)$$

The concept of a steady-state distribution is a generalization of the concept of availability. In fact, the steady-state distributions for $X_K(t)$ and $U_{Kj}(t)$ do nothing more than describe plant and well availability respectively. The steady-state distributions of $X_K(t)$ and $U_{Kj}(t)$ depend only on the mean failure and repair times of the plant components and well.

The distribution for $X_K(t)$ is:

$$\pi_0 = \Pr(X_K(t) = 0) = 1 - \left(1 + \sum_{i=1} \frac{\nu_i}{\mu_i}\right)^{-1}$$

$$\pi_1 = \Pr(X_K(t) = 1) = \left(1 + \sum_{i=1} \frac{\nu_i}{\mu_i}\right)^{-1}$$

where

ν_i is the mean repair time for component i

μ_i is the mean time to failure for component i and the distribution for $U_{Kj}(t)$ is:

$$\pi_0 = \Pr(U_{Kj}(t) = 0) = 1 - \left(1 + \frac{\nu_W}{\mu_W}\right)^{-1} = \frac{\nu_W}{\nu_W + \mu_W}$$

$$\pi_1 = \Pr(U_{Kj}(t) = 1) = \left(1 + \frac{\nu_W}{\mu_W}\right)^{-1} = \frac{\mu_W}{\nu_W + \mu_W}$$

where

ν_W is the mean repair time for an individual well

μ_W is the mean time to failure for an individual well

The π_1 probabilities represent the plant and well availabilities.

A computer program has been written that will numerically evaluate the steady-state probabilities of $Z(t)$ for any specification of the input values:

- (1) # of plants - N
- (2) Steam field sizes - $M_1, M_2, \dots, M_N$

- (3) Minimum number of wells to operate plant -- $c_1, c_2, \dots, c_N$
- (4) Plant component failure times - $\mu_1, \mu_2, \dots, \mu_S$
- (5) Plant component repair times - $\nu_1, \nu_2, \dots, \nu_S$
- (6) Well failure time - μ_W
- (7) Well repair time - ν_W .

APPENDIX D

STATE OVERVIEWS

APPENDIX D

STATE OVERVIEWS

The following summaries focus on both the existing and potential constraints to geothermal development in the four states under consideration. The summaries include discussions of areas where legislation and state agency regulations dealing with geothermal resources are inadequate or nonexistent; the potential for litigation interpreting existing laws and regulations; conflicts between state agencies in the regulation of the resource; potential delays in the permitting process; the presence or absence in the states of mini-NEPAs, land-use plans, county-level zoning authority, and energy facility siting laws; and whether an industry using geothermal resources for its own energy requirements and selling any surplus power to another industry or a public utility would be regulated as a public utility by the state.

CALIFORNIA

California has pioneered the development of the geothermal industry and the geothermal regulatory "industry." Its regulation and legislation of geothermal activities are advanced over all other states. As a result, California has developed a multilevel regulatory scheme that is complex and difficult to navigate. At least a dozen state agencies as well as several regional and local entities may become involved in the geothermal regulatory process in California at any one time. State agencies involved with geothermal exploration and development include: the Energy Resources Conservation and Development Commission (policy, plant siting), the State Lands Commission (leasing of state lands), the Division of Oil and Gas (downhole regulations), the California Department of Fish and Game (Environmental Impact Report and permit review), the Public Utilities Commission (plant siting and rate setting), the Division of Industrial Relations (occupational safety), the Department of Parks and Recreation (permit review), the Division of Forestry (permit review), the Geothermal Resources Board (designation of Known Geothermal Resource Areas (KGRAs)), the State Water Resources Control Board (setting of water quality standards), and the Air Resources Board (setting of air quality standards).

Several governmental actions are usually required for geothermal well development. First is an environmental report. The California Environmental Quality Act (CEQA) was enacted in 1970, one year after NEPA. An EIR prepared under California law must contain all of the information NEPA requires in an EIS plus a description of the growth-inducing effects of the project and any measures that can be taken to mitigate the project's effect on the environment. A geothermal project is almost always associated with environmental impact. Exemptions to environmental reporting requirements are allowed for activities that the Secretary for Resources determines will not have a significant effect, or where legislation has been enacted to create a functional equivalent to the reporting requirement. Case law has made it clear that CEQA applies to private activities on either state or private land so long as discretionary action of a public agency is involved. The delays caused by the EIR process can, to a significant degree, be mitigated by the permittee if environmental monitoring of air and water quality has been an ongoing part of the geothermal exploration program.

Second is a local (city or county) use permit. All of the promising geothermal areas in California lie within counties that have not yet adopted any pervasive planning or zoning guidelines for geothermal development. Therefore, conditional use permits are required. The county officials' knowledge of natural resource operations is quite limited and the final outcome of any geothermal exploration project is not foreseeable at the time of application. These projects, moreover, tend to cluster in traditionally unpopulated areas, where staff and budget support to respond to them are usually lacking.

Third is a Regional Solid Waste Management permit for a drilling sump.

Fourth is a Department of Health permit for drilling a sump.

Fifth is a Division of Oil and Gas permit to drill a well.

And sixth is an Air Pollution Control District authority to construct and a permit to operate.

The permitting process for construction of nonregulated power plants includes (1) an environmental report, (2) a waste discharge requirement from the Regional Water Quality Control Board, and (3) an authority to construct and a permit to operate from the Local Air Pollution Control District.

A notice of intent for an application of site certification from the California Energy Resources Conservation and Development Commission and a certificate of Public Convenience and Necessity from the PUC are not necessary if the power plant is not regulated as a public utility in the state. A company producing power for its own use would not be considered a public utility in California. It would similarly not be regulated if it sold surplus electricity to another industry or to a public utility. The company producing geothermal energy for its own use or for surplus sale would be considered a private energy-producer. The state would thus have the authority to require a public utility to accommodate the company's electricity on its transmission lines. If the capacity of the lines were not sufficient to accommodate the company's needs, then the public utility would have to increase the capacity of its lines at the company's expense. This provision, added to the Public Utility Code in 1976, would certainly encourage the sale of surplus electricity coming from the company's plant.

NEVADA

Although geothermal development in Nevada has been extremely active, no geothermal regulations have been codified. This is probably due to the fact that less than 1% of Nevada is state-owned and 99% of the KGRAs are on federal land. Leasing regulations modeled after the federal system are expected to be issued later in 1979. In addition, a bill (AB 144) to exempt geothermal leases from property taxation is expected to be introduced this year.

The Division of Water Resources is the main agency for regulating of geothermal activities in the state and has the responsibility for issuing of permits for the use of production and injection wells under the "Regulations for Exploration Drilling." Currently, permits are not required to drill geothermal wells but approval is required from the Division of Water Resources to produce a well.

Because geothermal resources are considered water and must be appropriated, a barrier to development could arise due to the fact that many KGRAs coincide with critical groundwater basins. This could become a major deterrent to future development of the resource.

Nevada would regulate a company selling surplus electricity to another industry or a public utility. It would not regulate a power producer that utilizes its own power and does not sell to an outside consumer. If surplus energy were to be sold, a certificate of public convenience and necessity would have to be filed before the plant could be constructed.

There is an energy facility siting law in Nevada (NRS Section 704.820-704.900). It provides that, prior to construction of a power plant by a public utility, a permit must be obtained from the Utility Commission. The State Environmental Commission will review the application and hold hearings on it if any protests against issuing the permit are received. The Utility Commission will grant the permit if it is shown that the facility is needed; the facility represents the minimum adverse environmental impact, considering the state of available technology and the nature and economics of the various alternatives; and that the facility will serve the public interest. In 1973 a section was added granting the Commission the discretion to issue or deny a construction permit if the plant utilizes any of Nevada's natural resources, including geothermal, for the export of electricity outside of the state. The Commission may alternately condition the permit on the public utility's making available for use within Nevada an amount of electricity equal to or less than the amount exported.

NEW MEXICO

New Mexico promotes the utilization of geothermal resources. There is no geothermal electrical generation in the state. Several areas, however, are using low-temperature geothermal resources in direct use applications. Greenhouse heating is the most popular use; examples can be found in the Animas Valley, Silver City area, and Jemez Springs. For further development to occur, certain roadblocks will have to be removed. The resource has not yet been classified as mineral, water, or sui generis. This affects the competitive nature of the lease, because all products of state lands except minerals must be leased competitively. The ownership of geothermal resources on state mineral reservation lands needs to be clarified, also. The requirement of obtaining appropriative rights for geothermal fluid production acts as a further constraint to development.

The Oil Conservation Division of the Department of Energy and Minerals has the authority to regulate and conserve geothermal resources. This division is also in charge of developing drilling regulations. The State Land Office is the agency in charge of leasing state lands.

There is no comprehensive state land-use plan in New Mexico; nor are there any environmental impact requirements. Counties do have the authority to enact zoning ordinances, although none have done so.

An industry utilizing geothermal resources for its own electrical needs would not be considered a public utility in New Mexico. If it sold surplus electricity to another industry or to a public utility, it would also not be regulated. A certificate of public convenience and necessity is required before a regulated power plant can be constructed. Because a company selling surplus electricity would not be regulated as a public utility, the certificate would not be necessary in such a case.

There is no energy facility siting law in New Mexico.

UTAH

The lack of well-defined state policies and regulations concerning geothermal resources is currently impeding development in Utah. The state would be more attractive for geothermal development if 1) private ownership of geothermal resources and state ownership where the state possesses either the mineral or surface estate alone were clarified; 2) constraints on development due to the requirement of obtaining appropriate rights for geothermal fluid production were minimized; and 3) unnecessary delays and burdens in moving from lease application to energy production were minimized.

The state has made an effort to eliminate duplication in the review of environmental impact. To the extent possible, studies, assessments, or statements prepared by other agencies or for other related projects which may be substituted in fulfillment of the requirements of the executive order, in part or in full, are required to be utilized. If the proposed action is federally assisted or in other ways falls under either the NEPA or Office of Management and Budget Circular A-95 or 102 procedures, compliance with these federal

procedures will be adequate and no further review will be required by these guidelines.

A company utilizing geothermal resources for its own electrical needs would not be regulated as a public utility in Utah. Similarly, if the company sold surplus electricity to a public utility it would not be regulated. However, the proposed purchase of the surplus electricity by a public utility would have to be approved by the PUC as a precondition to the sale. Currently, two industrial plants sell surplus electricity to Utah Power and Light. The company would face regulation, though, if it sold surplus electricity to another industry.

There is no energy facility siting law in Utah.

SUMMARY

Table D.1 summarizes the geothermal lease provisions of each state. In Table D.2, other conditions for state geothermal leases are presented. Table D.3 summarizes the conditions under which public utility regulation may be imposed in each state. The numerical water quality standards are listed for each state in Table D.4.

TABLE D.1. Geothermal Lease Provisions

State	Primary term	Renewal	Renegotiation of Rentals and Royalties	Annual Rental	Royalties	Acreage Limits
California	20 years	So long as geothermal resources are produced or capable of being produced in commercial quantities, up to 99 years.	10-year intervals, beginning 20 years after lease date.	\$1/acre	Primary: 10% Byproduct: between 2% and 10% Minimum: \$2/acre/year	Minimum lease: 640 acres Maximum lease: 2,560 acres Maximum state holdings: 25,600 acres (includes acreage under exploration permit)
Nevada	-----	-----	-----	\$1 acre	Primary: 12.5% Byproduct: 5.0%	-----
New Mexico	5 years	So long as geothermal resources are produced in commercial quantities.	10-year intervals, beginning 20 years after lease date.	\$1/acre	Primary: 10% Byproduct: between 2% and 10% Recreation or therapeutic: between 2% and 10% Powerplant: 8% (net revenue) Minimum: \$2/acre/year	Minimum lease: 640 acres Maximum lease: 2,560 acres Maximum state holdings: 25,600 acres
Utah	10 years	For duration of commercial production; 1-year terms in absence of production, upon payment of \$5/acre advance royalty.	3-year intervals.	\$1/acre	Primary: 10% Byproduct: 10% (net proceeds)	Minimum lease: 40 acres Maximum lease: 640 to 2,560 acres at discretion of director of state lands.

TABLE D.2. Other Lease Conditions for State Geothermal Leases

<u>State</u>	<u>Non-KGRA Lands</u>		<u>KGRA Lands (Competitive)</u>	
	<u>Newly Offered</u>	<u>Subsequent Leasing</u>	<u>Bidding Factor</u>	<u>Designating Criteria</u>
California	-----	-----	Cash bonus or other	Producing well
Nevada	(A)	(A)	(A)	(A)
New Mexico	Competitive (3-day filing)	By application	Cash bonus	Determined by Commissioner of Lands
Utah	Cash bonus (B) (15-day filing)	By application	(B)	(B)

(A) Regulations not finalized.

(B) Lands are offered noncompetitively by order of application, except when they are newly offered. Newly offered lands are leased by cash bonus bidding.

Table D.3. Public Utility Regulation

<u>State</u>	<u>Co. Provides Own Electricity</u>	<u>Sale of Surplus to Industry</u>	<u>Sale of Surplus to Public Utility</u>	<u>Power Plant Siting Law</u>
California	No	No	No	Yes
Nevada	No	Yes	Yes	Yes
New Mexico	No	No	No	No
Utah	No	Yes	No	No

Table D.4. Numerical Water Quality Standards

	<u>California</u>	<u>Nevada</u>	<u>New Mexico</u>	<u>Utah</u>
Alkalinity				
Ammonia				
Arsenic	X			(c)
Barium	X			(c)
Boron		*		
Cadmium	X			(c)
Chloride		X	*	(c)
Chromium (hex.)	X			(c)
Conductivity			*	
Copper				(c)
DO		X	X	X
Fluoride		X	X	X
Hardness				
Iron				(c)
Lead	X			(c)
Manganese				(c)
Mercury	X			
Nickel				
Nitrates (+ nitrites)	X	X		(c)
pH (range)		X	X	X
Phosphorus		*	*	
Radioactivity(a)		X		X
Selenium	X			(c)
Silver				(c)
Sulfate			*	(c)
Total Dissolved Gas			X	
Total Dissolved Solids			*	(c)
Toxic Materials		*(b)	X	
Uranyl ion				
Zinc				(c)

X - applies statewide

* - applies only to designated waters

(a) of other than natural origin

(b) free form

(c) The Utah standards for most waters of the state require chemical characteristics conformance with the Public Health Services Drinking Water Standards, 1962.

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