APPENDIX: COOK INLET COAL: ECONOMICS OF MINING AND MARINE SLURRY TRANSPORT

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By

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16. Abstract

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CHAPTER I

INTRODUCTION

Declining production of domestic crude oil and recent escalation in cost of foreign oil coupled with increasing domestic energy demands are currently shifting emphasis to coal as the domestic energy source for the United States.

Current federal standards on SO_2 emissions have brought the Western low-sulfur coals into an increasingly larger share of the market, displacing Eastern coal where the high cost of removing sulfur is a significant factor.

The states of Washington and Oregon have almost exhausted feasible hydro-electric sites and are now turning to steam-electric generation to fill future power needs. With the exception of Centralia and other potential fields in Washington, both states are limited with respect to future energy sources and are faced with the prospect of importing energy from states better endowed with fuel resources. Portland General Electric is now planning a coal-fired plant at Boardman, Oregon, on the Columbia River; for this plant coal will be transported by rail from Gillette, Wyoming, a distance of approximately 1200 miles. The cost of rail transport exceeds the mining cost of the coal by more than a factor of 2.

The high cost of rail transport plus increasing federal pressure to shift to coal as an energy source are bringing Alaskan coals into a potentially competitive position in the energy market.

On northern Cook Inlet there exist large deposits of low-grade coal within close proximity to tidewater. These deposits include the Beluga River area and are generally referred to as the Beluga coals.

These deposits are unique in that they are the only large reserves of low-sulfur strippable coal in the United States which are close to tidewater and therefore close to a low-cost form of transport, maritime shipping. It is this possibility of shipping that places the coal in a potentially competitive position for transport to the West Coast.

History

First observations of coal in the Beluga area date back to 1900. Interest increased in the 1950's as a possible mine-mouth power source for Anchorage but was dropped after oil and gas discoveries in the Cook Inlet area.[1]

Maloney summarizes reconnaissance work done in the Beluga coals in 1957 by the Bureau of Mines to determine areas favorable for surface mining.[2] Barnes describes work done by the U.S. Geological Survey in 1961 and 1962 on the Beluga area as part of an effort to appraise the coal resources of Alaska.[3] Warfield evaluates Bureau of Mines investigations from 1959 to 1962 of one of the Beluga fields suitable for surface mining.[4]

In more recent years Placer Amex has started an extensive evaluation of Beluga coals for possible mine-mouth generation and for possible export.[5] Stanford Research Institute, under contract with the Office of Coal Research, has studied the feasibility of an on-site coal conversion plant for solvent refining of Beluga coal for clean export fuels.[6]

Purpose and Scope of This Report

The purpose of this study is to investigate the cost feasibility of extracting Beluga coal by conventional surface mining methods and transporting the coal as a marine slurry to a potential tidewater power plant site in northern Washington. Costs are developed per ton for all phases of the operation from extraction through transport and dewatering at the power plant and per million BTU's as a final figure.

Production rates are evaluated for 1000 and 2000 MW plants at 80% yearly output factor, using the efficiency standard of 10,000 BTU's to produce 1 kilowatt-hour of electrically generated energy. At 8,000 BTU's per pound of clean coal this requires production rates of 4,380,000 short tons of clean coal annually for the 1000 MW plant and 8,760,000 tons for the 2000 MW plant.

Transport systems are evaluated using slurry pipeline diameters of 24 and 30 inches and ship sizes of 70,000; 79,000; and 100,000 deadweight tons.

Costs are developed as selling prices per ton of clean coal for each phase of the operation in 1975 dollars. Capital costs are equity financed based on a 15% discounted cash flow rate-of-return after Federal income taxes of 50%. Capital costs are straight-line depreciated over a 20-year period. Depletion allowance of 10% of the selling price of the coal is applied to all phases from mining through the slurry pipeline and the loading pier, which are considered part of "loading for shipment" in this report.

To account for cost increases for Alaska, capital construction costs are increased by a factor of 1.68 and operating costs are increased by a factor of 1.74.[7]

CHAPTER II

BELUGA COAL DEPOSITS

Location and Extent

The Beluga coal fields lie 50 to 60 miles west of Anchorage, across Cook Inlet. Two areas, Capps and Chuitna, are presently under exploration by Placer Amex, the former lying approximately 20 miles from tidewater and the latter approximately 14 miles from tidewater.[8]

The Chuitna field is chosen for purposes of this study as the location of the mine. This area covers approximately 24 square miles and has at least six coal beds ranging up to 40 feet in thickness.[9]

Strippable Reserves

Accurate figures on total strippable reserves of Chuitna are not presently available, but the reserves are reported to be extensive, and for purposes of this report the supply is considered adequate for the proposed operation to last for at least twenty years.

Average Coal Quality

The Beluga coals are sub-bituminous "C" in rank. Average quality is shown in Table 1.[10] For purposes of this report we will consider average BTU value to be 7500 with upgrading by washing to 8000.[11] Moisture runs very high in this coal, and drying would upgrade the quality greatly, however, for transport as a marine slurry such techniques cannot be used to advantage.

Sulfur is very low, averaging less than 0.2%, low enough to meet Federal regulations for direct burning and minimizing problems of acid mine waters. Current regulations allow 1.2 pounds SO_2 per million BTU's; Beluga coal will average approximately 0.5 pounds SO_2 per million BTU's.

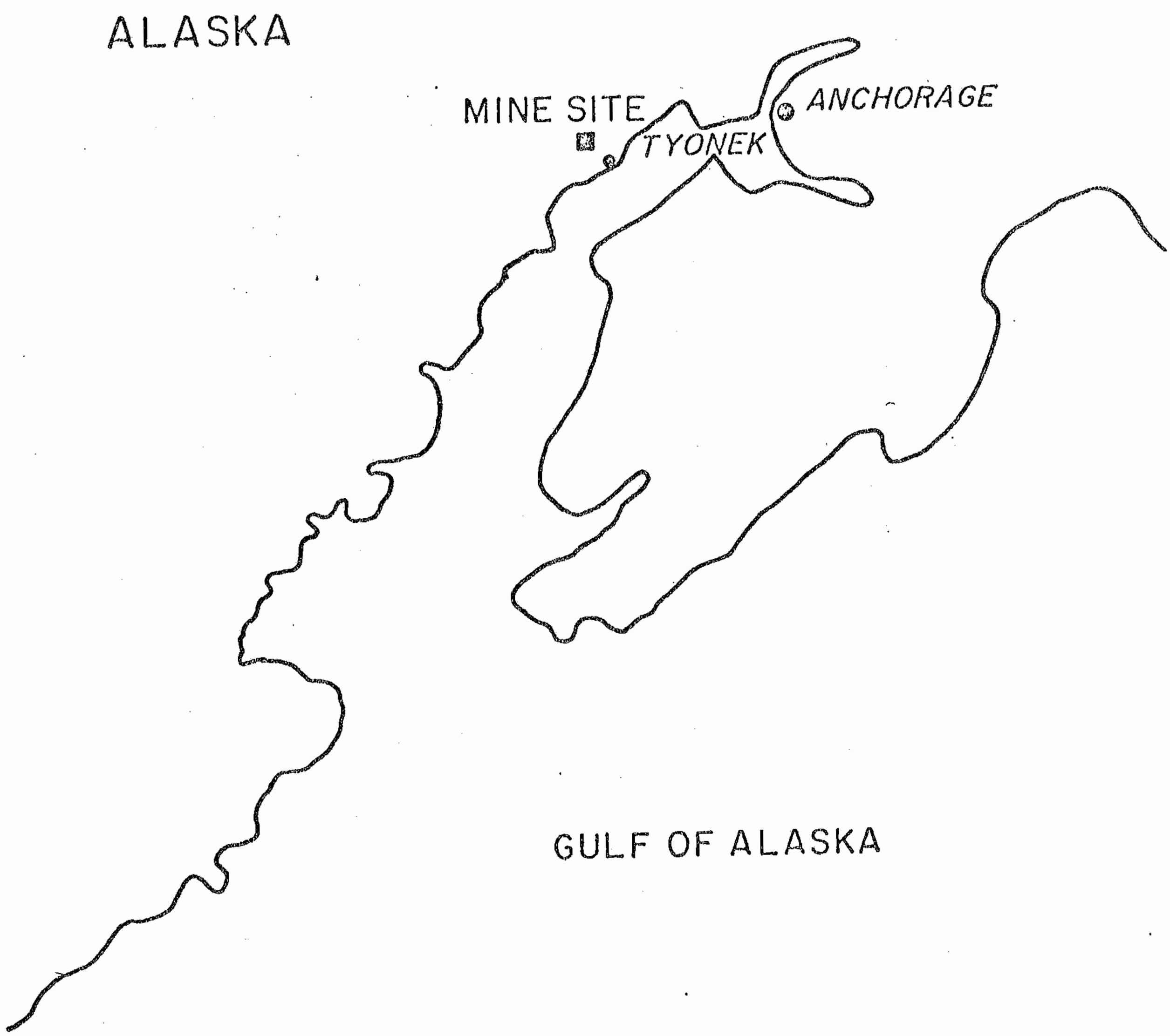


FIGURE I. LOCATION OF MINE SITE ON COOK INLET

Table 1

Average Quality of Beluga Coal

	As Received	Dry
Moisture	28%	-
Ash	10	13
Volatile matter	32	44
Carbon	30	43
Sulfur	0.15	0.2
BTU	7550	10500

Overburden and Interburden

The overburden and interburden are soft siltstones and mudstones with some unconsolidated sands and gravels at a favorable strip ratio.[12] For purposes of this report and in the absence of more complete information, an average ratio of no more than 3 to 1 is assumed with a little blasting and occasional ripping to break overburden.

Topography

The Chuitna area is situated on a plateau approximately 1500 feet in elevation. Relief is generally low, with the exception that the plateau is cut in some areas by deep stream valleys. The plateau slopes in fairly uniform rate to tidewater.[13]

Climate

The climate of the area is similar to Anchorage with the possibility of more average annual precipitation than Anchorage (20 inches) receives. There is no known permafrost in the area. Average January temperature for

Anchorage is 13°F. and average July temperature is 57°F.[14]

Vegetation

There are timber stands in the area of birch, spruce, and alder with thick brush undergrowth.[15] However, much of the coal is above timberline underlying open lands and tundra.

Labor Supply

Though less than 60 air miles from Anchorage, the Beluga coals lie in an undeveloped region of Alaska and will require an entire infrastructure for supporting a labor source. This will include a townsite and access to Anchorage.

The proximity of Anchorage suggests a labor pool to be drawn upon, and it is assumed that qualified personnel are available at standard Alaskan wage rates.

Power Supply

There is no readily available power source in the area. The most apparent economic source of power is steam-electric generation at the mine to supply the mine, preparation plant, pipeline, and town. Use of coal from the mine is probably the most economical method of power generation. For power costs we will use $0.02 per kilowatt-hour, and no other allowance will be made for costs of generation.[16] If coal is used, no allowance will be included in mine production as all costs are included in the cost of power and in operating costs. There is a possibility that fines from the washing plant may be used for generation and dollar savings could be realized.

Accessibility

Harbor facilities at North Foreland and a road to the mine will be required for regular use by light vehicles and occasional access for heavy equipment. The proposed pier will include a trestle which will carry light vehicles. Boat service into Anchorage can be arranged, and a light air strip at the mine will be necessary for easy transportation into Anchorage. Heavy equipment will be barged to North Foreland and moved up the road to the mine site.

The road is to be gravel and will approximately follow the slurry pipeline route. Road length of 16 miles is allowed to the initial mine site.

CHAPTER III

THE MINE

Operation

Detailed aspects of mining the deposit have not yet been carefully studied. Conditions are favorable for conventional open pit extraction methods.[17] The coal occurs in relatively thick beds of 20 to 40 feet, and therefore will require that relatively small amounts of acreage will have to be disturbed on a yearly basis to allow mining. Mining characteristics are assumed to be similar to those of a large strip mine in the Northern Great Plains province.[18]

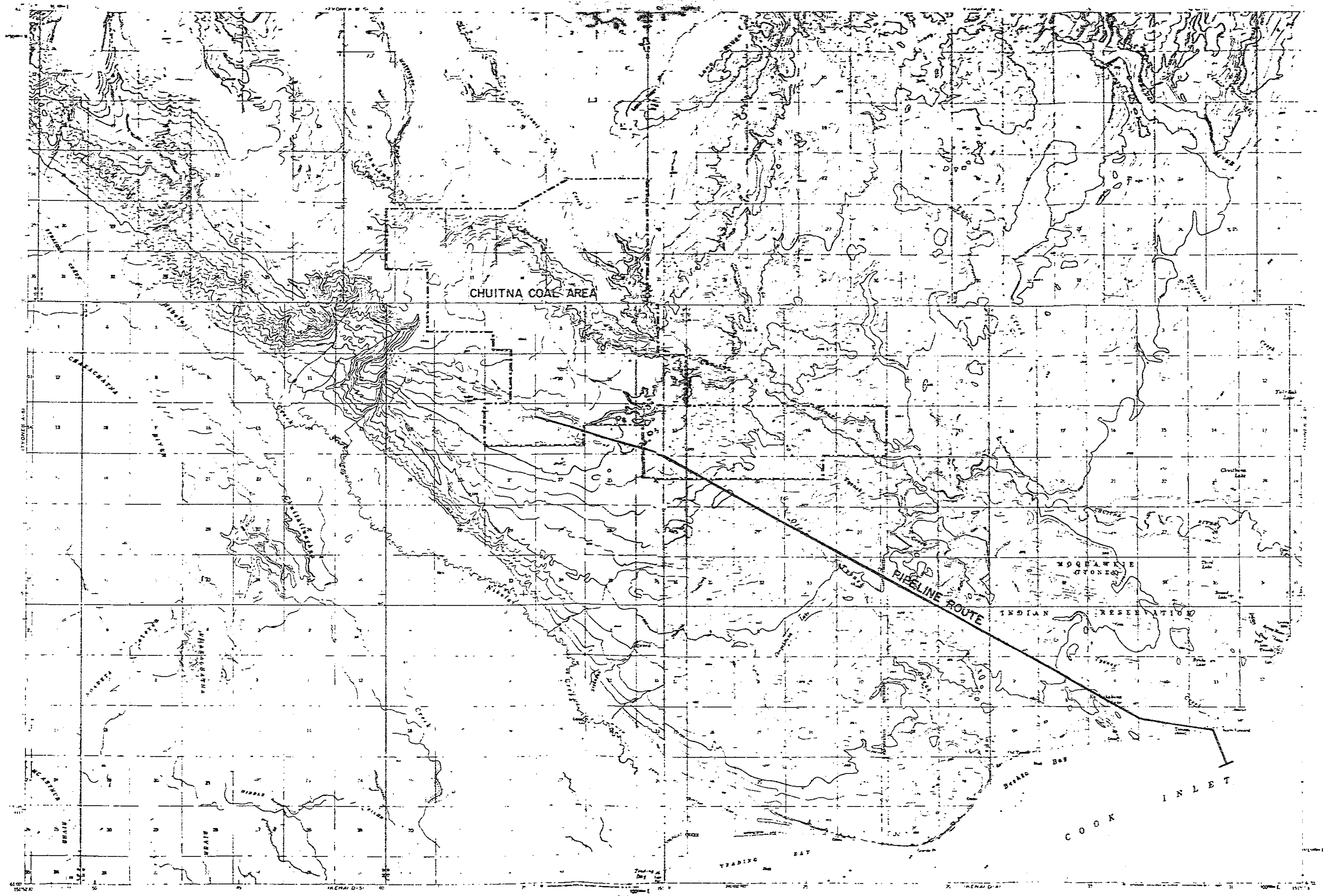
The mine will operate on a year-round basis since it is considered feasible to operate through the winter in this area. Climatic conditions should not interrupt on more than an occasional basis, and conditions are really not more severe than conditions on the Northern Great Plains where surface coal mines operate throughout the year.[19] The Evan Jones Mine operated year-round nearby, and the Usibelli Mine presently operates throughout the year in conditions more severe than the Beluga area experiences.

Coal loading will occur 240 days per year on a 2 shift basis and stripping will occur 345 days per year on a 3 shift basis as in the model after which this mine is fashioned.[20]

Location

Actual location of the mine, townsite, and preparation plant will have to be determined through careful evaluation. For purposes of this report the location is considered to be in close vicinity to the mine end of the slurry pipeline route shown in Figure 2.

FIGURE 2. MAP OF CHUITNA COAL AREA AND PIPELINE ROUTE



CHUITNA COAL AREA
PIPELINE ROUTE
MOQUAWKIE
INDIAN RESERVATION
TRADING BAY
COOK INLET
CHAKACHATNA

Costs

Mining costs are assumed to be similar to those for a Northern Great Plains province strip mine with appropriate increases to modify for Alaska. For the larger production rate (9,636,000 tons raw coal per year) capital costs are taken at $8.54 per ton with 45% of capital costs deferred half of the project life, or 10 years.[21] Mobile equipment is considered to account for 65% of the capital investment which is increased by a factor of 1.1 to allow for delivery to mine site and assembly.[22] Construction is considered 35% of the capital investment and is increased by a factor of 1.68 for the area.

Operating costs are taken at $2.22 per ton for the Northern Great Plains province and increased by a factor of 1.74 for Alaska.

For the smaller operation (4,818,000 tons raw coal per year) costs are taken at six-tenths those of the larger operation.

Capital and operating costs are computed for tons of raw coal actually mined and distributed over tons of clean coal. An increase of 10% of clean coal tonnage is allowed to account for weight losses in washing and preparation.

Cost of the townsite is figured as a simple ratio of employee numbers for a similar townsite proposed nearby.[23] A total of 250 employees is allowed for the mine, plant, and facilities.

Costs for the road and airstrip are taken from the same source as the townsite costs. All costs are updated to 1975.

Mining costs are given in Appendix A.

CHAPTER IV

COAL WASHING AND SLURRY PREPARATION

Washing

Coal will be delivered by truck from the mine to the preparation plant for washing and slurry preparation.

Washing is to be by jig with average upgrading 7500 to 8000 BTU's. An additional 10% of clean coal tonnage is allowed for raw coal tonnage to account for loss in the washing and preparation process.

The general flow will be through crushing, cleaning, grinding, slurry mixing, and into storage to await transport by pipeline to the ship.

Capacity

Due to the remote area and large capital investment required, this plant will operate on a continuous basis allowing time for maintenance only. The plant will operate 3 shifts per day 360 days per year but at 75% availability. A capacity of 1500 tons per hour raw coal will be sufficient to produce 8,760,000 tons clean coal per year and half that (750 tons per hour) for the smaller production rate.

The wash water system will be closed circuit, minimizing pollution problems from wash water discharging into local streams.

Slurry Preparation

Coal cleaning and slurry preparation will occur in the same plant as an integral operation, thereby saving on both capital and operating costs for the entire operation.

Grinding

A combination of cage mills and rod mills is used for the Black Mesa pipeline. A thorough study of the coal, however, will be necessary to determine the proper combination to produce the desired effects.

Storage

The slurry will be mixed and pumped into agitated storage tanks to await transport to the ship. Tanks are agitated to keep the slurry from settling in storage and to allow slurry to be fed into the pipeline at fairly uniform concentration at the high rates desired.

Storage tanks should be enclosed in the plant or heated in some manner to avoid freezing during severely cold weather. If power generation is done through a steam-electric plant, low pressure steam might be used in pipes in the skin of the tanks for heating purposes.

Washing Costs

Capital costs of the washing plant are taken at $12,000 per ton of raw coal per hour capacity for the first 500 TPH capacity and scaled by a six-tenths factor for additional capacity over 500 TPH. This sets capital investment for the larger plant capacity at $14,000,000 and for the smaller capacity at $8,000,000. Capital costs are then increased by the factor of 1.68 for Alaska.

Operating costs are scaled in a similar manner taking $0.85 per ton of clean coal for the first 500 TPH capacity and scaling costs down by a six-tenths factor.[25] The average operating cost for the 1500 TPH capacity is $0.66 per ton of clean coal and for the 750 TPH capacity the average cost is $0.76. Operating costs are then increased by the 1.74 factor for the area.

Slurry Preparation Costs

Slurry preparation costs include all grinding beyond the washing stage, plus mixing, and storage before entering the pipeline to be loaded aboard ship.

Costs of slurry preparation are not published but generally average more than coal cleaning.[26] To allow for savings realized by integrating washing and preparation into one process in one plant, slurry preparation is considered equal to washing, and washing costs are doubled to account for the entire process.

Washing and slurry preparation costs are given in Appendix B.

Water Supply

Water consumption for the washing and slurry preparation plant, pipeline flushing, mine, and town will be approximately 240 gallons per ton of clean coal requiring a system capable of delivering approximately 4500 gallons per minute, 24 hours per day, 365 days per year at 90% availability for a production rate of 8,760,000 tons clean coal per year. A capacity of 2,250 gallons per minute will be required for the smaller production figure.

No information is available on ground water sources, and, though deep wells may be the best source for water, a supply system from the Chakachatna River is proposed. The small lakes and streams in the vicinity of the mine are probably not capable of supplying the necessary water for this operation, though there is a possibility that a number of sources spread over the area may be able to supply the required quantity. Since no accurate information is available, the Chakachatna River will be used.

The water will have to be moved a distance of approximately 6 miles against a static head of about 1100 feet. The proposed water system includes 4 pumps (3 operating, 1 on standby), 6 miles of buried pipeline (18 inch diameter for 4500 GPM and 14 inch diameter for 2250 GPM), power line from the mine to the river, and installation costs.

Water Costs

Cost of water will be about $0.50 per thousand gallons for the 4500 GPM system and about $0.60 per thousand gallons for the 2250 GPM system. Water costs are already allowed in the operating costs of the plant and mine at approximately $0.20 per thousand gallons. At 240 gallons per ton of clean coal this means an additional $0.07 per ton of coal for the larger production figure and $0.10 per ton for the smaller production figure to allow for total water costs of $0.50 and $0.60 per thousand gallons.

Water costs are given in Appendix C.

CHAPTER V

SLURRY PIPELINE

Since the 1950's, use of slurry pipelines has accelerated as an economical method for transporting bulk solid minerals. In times of rapidly climbing costs, slurry pipelines offer an acceptable alternative for companies seeking to stabilize mineral transport costs.

Coal slurry pipelines offer significant advantages:

1) Low operating costs. Low cost escalation follows as a result of low operating costs.

2) Dust control. This includes lack of dust nuisance, no loss of product, and safety from coal dust explosions.

3) No danger of spontaneous combustion.

4) High reliability. Long distance slurry pipelines show availability factors in excess of 95%.[27]

5) Ease of handling of bulk materials.

Some disadvantages of coal slurry pipelines are:

1) Large consumption of water. In arid regions this can be a significant disadvantage and has drawn much opposition to the construction of major slurry pipelines from irrigation interests in the Rocky Mountain States.

2) Transportation of the water. For each ton of coal transported by slurry, close to a ton of water is also transported, thereby reducing the efficiency of the process. This disadvantage can be partially reduced by using the water at the terminal end of the pipeline, thereby saving on consumption of local water at the terminal end.

3) Dewatering costs. If the coal is to be burned in a steam-electric plant the coal must be either dewatered or burned as a slurry with loss of

BTU value. Either manner of use represents an additional cost over dry coal transport.

4) Possible attrition of the solid product during transport. This can be a disadvantage if attrition is undesirable. If a finer product is desired it can possibly be an advantage.

5) Corrosion. With high sulfur content this can be a sufficiently great problem to preclude use of a slurry pipeline.

6) Inflexibility of the system once installed. The capacity of an installed slurry pipeline cannot be varied significantly without complete reconstruction of the pipeline.

7) Possibility of freezing in cold climate.

8) Pipeline wear.

Advantages of Slurry in this Application

1) Lack of dust hazard and nuisance. This is a great advantage in any coal-slurry application.

2) No danger of spontaneous combustion. Spontaneous combustion is considered a problem with the Beluga coals,[28] and, as a coal-water slurry, possibility of spontaneous combustion is eliminated.

3) High reliability. High availability in a remote area such as this with severe weather conditions in winter is considered a strong advantage. Heavy snowfall which could seriously hamper rail or truck operations will have little effect on the operation of a slurry pipeline.

4) Invulnerability to cost escalation. Being a capital-intensive rather than labor-intensive form of transport, the pipeline is relatively immune to increasing labor costs. This advantage is particularly

important in an area such as Alaska where labor costs are high. Pipeline availability is also less likely to be affected by labor disputes.

5) Low shipboard loading and unloading costs. The capital investment for dry shipboard loading and unloading is much greater than that necessary for slurry loading and unloading, given comparable rates of loading.

Disadvantages of Slurry in this Application

1) Water consumption. Though water is plentiful in the area it will add to the cost, and the subsequent shipboard transport of water will add significantly to costs. Use of the water at the power plant may diminish this disadvantage.

2) Possibility of freezing. As discussed later the pipeline can be operated in severely cold conditions without freezing, but precautions will have to be taken.

Corrosion should not be a significant problem here due to the very low sulfur content. Attrition of coal particles has not been significant in coal-water slurries to date and none is anticipated here. Pipeline wear has not been found to be significant in coal slurries in current use, and pipeline wear is not expected to be a problem.[29] Some flexibility in capacity will be available due to over design of the pipeline and the intermittent operation planned. By increasing the number of ships, the pipeline can be operated for a higher percentage of time, allowing increased capacity.

Slurry Characteristics

Slurry technology has not yet reached the stages of an exact science. Extensive testing is required in the design of a slurry system including construction of a test loop of pipeline to determine operating parameters.

Such testing will determine optimum particle-size range, solids concentration, pumping velocity, and pumping head loss. Testing of this sort is far beyond the scope of this report, and such operating parameters must be assumed from examples of operating pipelines, theory, and assumptions based upon the information available.

Solids Concentration

Solids concentration is assumed to be 55% coal by weight. Normal cost concentrations for coal-water slurries is 45-55% by weight.[30] Above 55%, slurry viscosity increases drastically with increasing coal concentrations, and consequently head losses become severe.[31] In this application, due to the comparatively short distance the coal is moved by pipeline and the long distance of transport by ship in a settled state, conditions favor a maximum concentration of coal. Pipeline inefficiency could be favorably traded for increased concentration of coal on board ship and decreased volumes of water. This might make coal concentrations in excess of 55% feasible. Such determinations can only be obtained through careful testing.

Optimum Particle Size Range

Particle size range is an important consideration for slurry characteristics, dewatering, and ultimate use.

Maximum size for coal slurries in long distance pipelines is normally 14 mesh or 20 mesh due mainly to head loss considerations.[32] In this application a coarser slurry will allow better settling characteristics aboard ship, less fines, and better dewatering characteristics. Careful testing may show that a larger particle size is here desirable; product size range is assumed to be -1/8 inch; average size can only be determined by testing.

Pipeline Velocity

Pipeline velocity is largely dependent upon solids concentration, particle size, and pipeline diameter. Optimum velocity will have to be determined through testing. For the 24 inch diameter pipeline 7 feet per second is used as the velocity and for the 30 inch pipeline 8 feet per second is used. At greater velocities head loss and pipeline wear become significant. At lower velocities, critical velocity may be reached causing deposition of coal in the pipeline.

Head Loss

The flow regime will be a combination of homogeneous and heterogeneous flow regimes, finer particles in a homogeneous suspension and larger particles in a heterogeneous suspension. Head loss has been calculated from the following equation for heterogeneous flow:[33]

$$i_m = i_w \left[1 + 81 \cdot C_v \left(\frac{gD\,(s' - 1)}{V^2} \cdot \frac{1}{\sqrt{C_D}}\right)^{1.5}\right]$$

i_m = hydraulic gradient of slurry in feet of water per 100 feet of pipe.

i_w = hydraulic gradient of water in feet of water per 100 feet of pipe.

C_v = concentration of solids by volume, decimal fraction

g = acceleration due to gravity, 32.2 feet per second per second.

D = inside diameter of pipe, in feet.

s = specific gravity of solid.

V = slurry pumping velocity in feet per second.

C_D = drag coefficient, dimensionless.

Head loss for a homogeneous flow regime would be considerably less than for a heterogeneous regime. Since the flow will be a combination of both regimes, actual head loss should be less than the calculated loss, so this figure will be assumed adequate to include any shock losses and all friction loss. Total head loss is not great due largely to the static head developed by the drop in altitude of 1150 feet.

Horsepower Calculations

Horsepower was calculated from this equation:[34]

$$\text{Brake horsepower} = \frac{\text{gpm x head x specific gravity x 8.33}}{\text{33,000 x efficiency of pump}}$$

Pump efficiency is taken at 90% and efficiency of the pump motors is taken at 90%. Brake horsepower is 75% of installed horsepower to allow for 3 pumps on line and one on standby.

Pipeline Description

The pipeline will be approximately 16 miles long from the coal preparation plant to the end of the pier. A route has been proposed as shown in Figure 2 and has been selected due to its relatively even grade (as shown in Figure 3) and lack of obstructions. Present information is inadequate to pick a definite route, and a more thorough study with on-site examination will be required before a specific route is actually selected. However, the

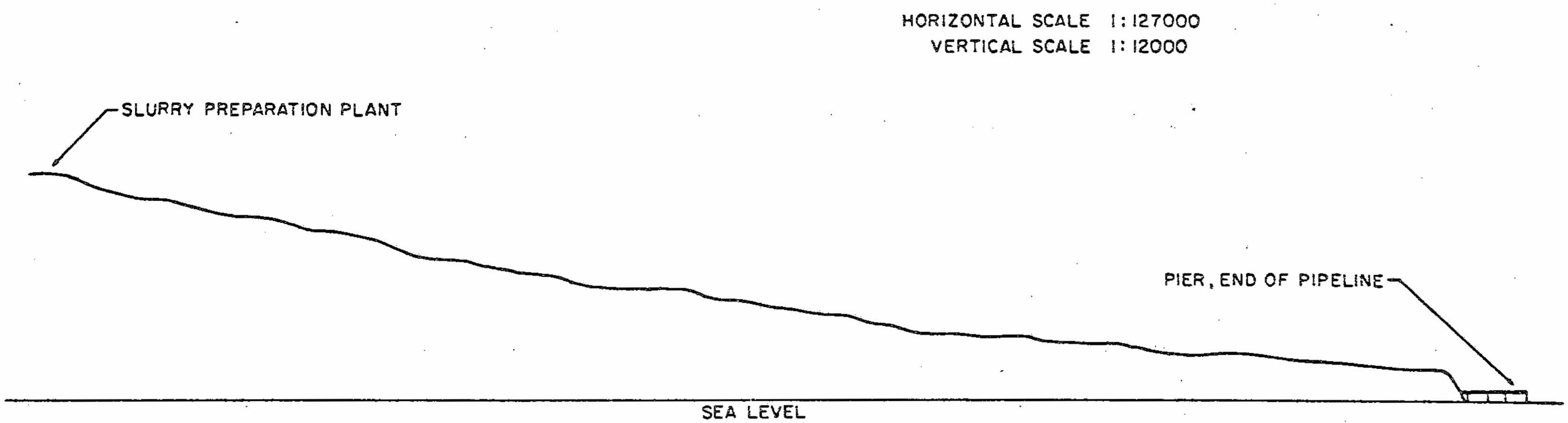


FIGURE 3. TERRAIN PROFILE OF PROPOSED PIPELINE ROUTE

Table 2

Slurry Pipeline Data

Nominal diameter, inches	24	30
Inside diameter, inches	23.25	29
Solids concentration, by weight	55%	55%
Specific gravity of slurry	1.186	1.186
Pumping velocity, feet per second	7	8
Slurry capacity, cubic feet per second	20.64	36.69
Slurry capacity, gallons per minute	9263	16466
Slurry capacity, short tons per hour	2749	4888
Coal capacity, short tons per hour	1512.	2688
Head loss, feet water per 100 feet pipe	1.60	1.59
Head loss for 16 miles of pipe, feet water	1352	1343
Altitude loss, feet	(1150)	(1150)
Net loss for pipeline, feet water	202	193
Slurry horsepower required	560	950
Pump efficiency	90%	90%
Brake horsepower required	622	1055
Efficiency of motor	90%	90%
Installed brake horsepower (3 pumps operating, 1 standby)	830	1400
Energy required per year, kilowatt-hours		
for 4,380,000 tons coal per year	1,493,600	1,424,900
for 8,760,000 tons coal per year	2,987,200	2,849,800

route proposed is sufficiently accurate for cost analysis.

It is assumed that right-of-way can be obtained for this or any alternate route.

Pipeline Operation

Loading of the ships shall occur directly from storage at the preparation plant, through the pipeline, and aboard ship. Once the ship is loaded the pipe will be flushed with water to clear slurry from the line. This will require an allowance for slurry in the pipeline when flushing begins. Since the pipeline will hold a given capacity, it should be easy to accurately predict when to cut off slurry and commence flushing. This will require good communications from pier to plant. When the flushing water reaches the ship, loading will cease and a low-point valve will be opened allowing the water to drain. The border between slurry and flushing water should be very abrupt so that dilution of slurry by flushing water will be negligible. Any particles of coal migrating into the flushing water would be larger particles which would sink easily causing no environmental damage. The amount of coal migrating into the flushing water should be so miniscule as to be of no concern. Water left in the pipeline should precede the slurry with a rather abrupt border and can be drained by low-point valve before loading commences. Dilution should be negligible.

Pipeline Grade

Average grade for the pipeline will be 1.4%. A profile of the proposed pipeline route is shown in Figure 3; the grade will be held as even as possible.

Two options are available on construction. The pipeline can be buried from the preparation plant to the pier. It will have to be buried deep enough so that water trapped in low points will not freeze in severe weather. Since there is no permafrost in the area the pipeline should not require more than a few feet of burial to avoid freezing. Where exposed on the pier it will have to have a constant grade of at least 0.5% to clear water after loading so that the line does not block with ice.

The pipeline could be held to no less than 0.5% grade for the entire length and no low point traps by alternately burying the line in cuts and suspending above ground on pilings. This would allow water to completely drain from the pipe to avoid ice blockage.

Burial of a pipeline is generally preferable if conditions permit, for protection and aesthetic purposes. Burial is desirable where a pipeline might interfere with migrating animal herds, but that is not a concern in this area. Barring unforeseen circumstances, pipeline burial is the more desirable method of installation.

Pipeline Construction

Pipe will be standard weight steel pipe, unlined, of 24 or 30 inch nominal diameter. Joints will be welded and the pipeline will be of relatively simple construction. Some allowance must be made for expansion and contraction of the pipeline, particularly for any pipe exposed above ground.

Installation

Due to a considerable amount of bog in the area, pipeline installation might be best accomplished during winter if freezing makes better ground conditions.

Pipeline Availability

Pipeline availability is assumed to be 100% for purposes of calculations. Due to the non-continuous operation proposed, there will be time available between loadings for equipment maintenance, so that availability during loading periods should be enhanced. Considering this and the high availability of continuously operating pipelines, it is felt that 100% is justified under these conditions.

Pumps

One pump station is sufficient and will be in the slurry preparation plant. Positive displacement reciprocating pumps will be used with three pumps operating and one on standby. An emergency power supply for the pumps should be available to prevent prolonged shutdown of the pipeline with slurry inside. This will avoid possible freezing and plugging of the line during a power failure. The mine and townsite should have an emergency power system available, and the pipeline should receive priority if in operation during power failure.

Freezing

If the pipeline is exposed above ground, the possibility of freezing in severely cold weather becomes an important consideration.

According to calculations done by a taconite company in northeastern Minnesota,[35] the slurry could be pumped in an uninsulated pipe exposed to an air temperature of $-40^{o}F$ and a 20 mile per hour wind for a time period in excess of 10 hours before freezing, due to the latent heat of fusion of the water alone. This does not include an allowance for heat due to friction nor beginning slurry temperatures above $33^{o}F$.

Since the pumping time to reach the ship is less than 3.5 hours and the pipeline would not be exposed for its entire length, insulation of the pipe should not be necessary. The temperature of $-40^{o}F$ is quite severe for this area, and conditions colder than this are not anticipated.

Prolonged shutdown of the pipeline would constitute a danger of freezing in severe temperatures, and precautions must be taken to avoid this situation, including one pump on standby, emergency power supply for the pumping station, and an emergency dump valve in the pipeline. This dump valve should be located on land above the pier so that the pipeline can be cleared without discharing the load of slurry into Cook Inlet. An open discharge pond would be suitable for this without provision for immediate recovery of the slurry.

If possible, the pipeline should still be buried beyond freezing depth, thereby eliminating freezing problems everywhere but on the pier. The exposed pipeline on the pier could be insulated with little problem if desirable.

Costs

Capital costs for the pipeline are taken from the following equation and modified for Alaska:

$$\text{Cost/mile} = 314239. - 67266.41(D) + 5543.78(D^2) - 160.46(D^3) + 1.64065(D^4)$$

D = nominal pipe diameter in inches.

Cost is in dollars per mile.

Capital cost for the pumping station is taken from the following equation:

$$\text{Cost/HP} = 5536.4 - 12.8674\,(\text{HP}) + 0.01411(\text{HP}^2) - 0.722\,3 \times 10^{-5}\,(\text{HP}^3) + 0.1402 \times 10^{-8}(\text{HP}^4)$$

HP = installed horsepower.

Cost is in dollars.

Operating costs are taken to be power costs plus 15% of yearly capital costs.[38]

The depletion allowance is included on the pipeline and the pier which will be considered the point of loading for shipment.

Slurry pipeline costs are given in Appendix D.

CHAPTER VI

LOADING PIER

Location

North Foreland has been chosen as the location for the pier for several reasons:

1) North Foreland is the closest suitable tidewater loading point to the mine.

2) North Foreland is closer to water sufficiently deep for deep-draft vessels than any other points in the area.

3) North Foreland is relatively ice free in the winter due to prevailing winds which clear the ice.[39]

4) There are less navigational hazards in this immediate area than other suitable sites.

A proposed location and orientation for the pier is shown in Figure 2. Actual positioning of the pier will require very careful examination and consideration of local navigational problems, and proper orientation is critical in docking operations. It is to be noted that a shorter pier in the area is oriented in the same approximate manner as suggested for this pier.

Navigational Problems in Cook Inlet

Cook Inlet has several navigational problems of real concern to shipping:

1) Large tidal range. The tidal range is approximately 24 feet.[40]

2) Strong currents due to large tidal range.

3) Ice. Ice largely consists of brash ice with small pans. The ice is generally weak, causing little possibility of ship damage, though high frictional resistance.[41]

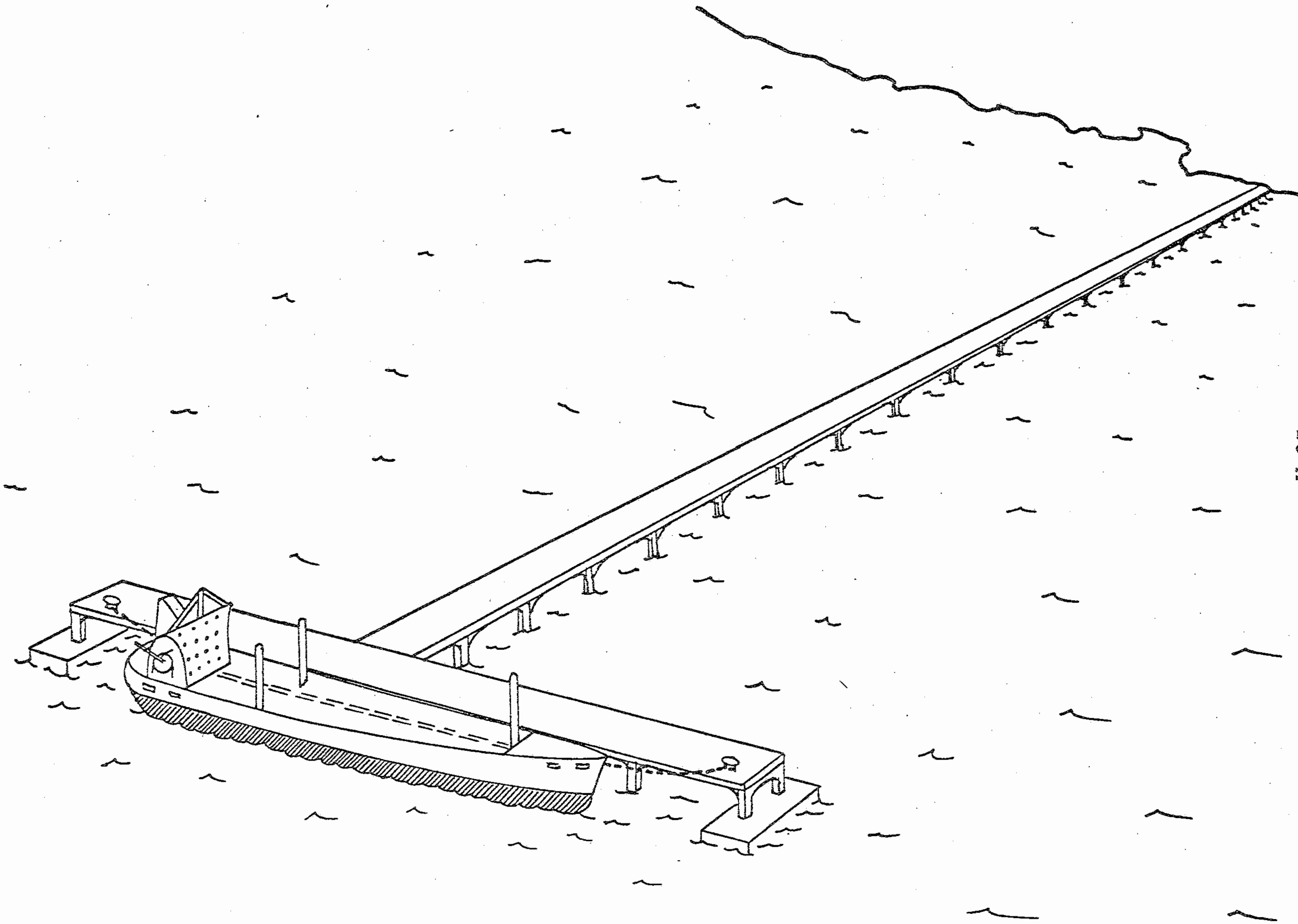


FIGURE 4. PIER FOR SLURRY LOADING.
(FOR ILLUSTRATIVE PURPOSES ONLY)

Water Depth at Berth

Draft of the proposed vessels will be up to 47 feet. Allowing 8 feet clearance, 55 feet of water will be required to accommodate the vessels at mean low low water. Lowest tides are approximately 5 feet below mean low low water, so the 10 fathom curve has been chosen to allow for 100% availability of the pier during all tidal ranges.

Berth

The berth will be approximately 1200 to 1300 feet long depending on the vessel size selected. Only one vessel will be accommodated at the berth at one time. This does not include small support vessels for connections to Anchorage which will use the pier for docking.

The entire pier will sit approximately 40 feet above mean low low water to allow for tidal range. The berth will include all necessary mooring facilities, navigational aids such as lights, and support systems. The pier will be used for supplies and water-borne transportation to Anchorage.

Trestle

There will be a trestle approximately 3500 feet in length connecting the berth to shore. This is of sufficient length to allow the berth to be placed at the 10 fathom line. The trestle will support the slurry pipeline and be large enough to also accommodate light equipment and vehicles.

Pier Availability

As previously mentioned, the berth is set in water sufficiently deep to allow ships alongside at all tidal ranges. The pier is assumed to have 100% availability for purposes of calculations. Docking problems due to severe weather conditions are included in the delay time allowed for ship round-trip schedules.

Costs

Capital costs of the pier include all mooring facilities, support utilities, pipeline manifold, and accessories.[42] The costs are updated to 1975 and increased by the factor of 1.68 for construction in the area. Trestle cost is chosen for an average depth of 40 feet of water in an unprotected area.[43] Operating and maintenance costs for the pier include labor based on 3 shifts per day, 7 days per week.[44] Operating costs are updated for time and increased by a factor of 1.74 for the area.

Depletion is included on pier costs, the pier being considered part of the loading system.

Pier costs are distributed over the coal tonnage to arrive at a cost per ton of clean coal.

Loading pier costs are given in Appendix E.

CHAPTER VII

SHIPS

General Description

The ships chosen for this evaluation are large self-propelled marine-slurry carriers of 70,000; 79,000; or 100,000 deadweight tons. These ships will resemble tankers of similar sizes with the exception that they will be equipped to handle coal slurries rather than crude oil. Ship sizes were selected to allow the number of ships necessary to be close to an integral number. The ships will travel loaded and return in ballast. No combination capabilities are included to allow for transport of other commodities. Table 3 shows characteristics of these vessels.

Marine Slurry Systems

Marine slurry systems are currently in use for transport of iron ore and are under investigation for use with other bulk mineral commodities. Such systems allow solid minerals to be slurried aboard ship, the slurry to settle, excess water to be drained off, and the mineral to be reslurried and pumped off the ship at destination.

The ease of handling, increased loading and unloading rates, and subsequent dollar savings from such systems make marine slurries very attractive.

Though no coal marine slurry systems are currently in use, coal is presently receiving a lot of attention for use in such a system.

In this application the coal is slurried aboard ship at a solids concentration of 55% by weight. Excess water is allowed to drain out through screens in the bottom of the holding tanks. Experiments show that water above the settled coal will contain too much fine coal to decant the water overboard.[45] However, the settled coal filters the fine coal from the water as the water is allowed to drain through the bottom of the tank. An excess of clay in the coal could interfere with this process, and removal of clay in the cleaning plant can be a critical factor. In the experiments, pumping water that had drained through to a sump below the tank showed fine coal for the first few minutes and than a clear liquid after a filter of coal was established in the tank.[46]

It is proposed that the liquid be circulated back to the top of the tanks for a few minutes until clear water has been attained and then the clear water can be discharged or returned to the pier. Results of the experiments are not conclusive, but it is felt that an overall slurry density of 60-65% solids can be achieved through the above method while loading. This must be studied thoroughly as it will be a critical factor in design of the system. The final settled concentration used for calculations is 60%. Additional settling will occur while the ship is underway, but this will not allow additional coal to be taken on board.

At destination the coal will be reslurried by water jets which are located in the bottom of the tanks. The reslurried coal will then be pumped off the ship.

Ship Capacity

The capacities of the ships are shown in Table 3 in short tons. Allowance is made for bunker fuel and fresh water capacity. The ships are filled to capacity.

Round Trip Schedules

Average speeds of the ships are shown in Table 3. Total round trip distance is 2800 nautical miles. Time is allowed for round trip at average speed, time for docking, time for loading, and an additional day is allowed on each trip for delay due to adverse conditions. During good weather this day will probably not be needed, but during adverse conditions more than an extra day may be necessary. One day per trip should be adequate allowance for lost time. To assure that time is not lost for loading bunker fuel and supplies, these will be loaded at the destination pier while the coal is off-loaded.

Ship Availability

Most tanker operators allow a dead time of 15 days each year in drydock and a 350 day work year. Ships will be assumed to have 100% availability for 350 days per year.[47]

Loading Time

The ships will load directly from the pipeline, so loading time is controlled by pipeline capacity. Pipeline size, either 24 or 30 inch diameter, is matched to ship capacity to keep loading time to approximately a 24 hour period. Unloading time is the same as loading time. An additional 1.5 hours is allowed for the slurry to reach the ship at the loading pier. Since the slurry must start from the plant, a distance of 16 miles, it will take 3 to 3.5 hours for the slurry to reach the ship. With practice, it should be possible to predict docking and hook-up time (depending on conditions) so that the slurry can be started in time to reach the ship when ready. An average of 1.5 hours should be adequate to allow for waiting time.

Bow Thrusters

Bow thrusters are rapidly becoming standard equipment on large tankers

Table 3

Ship Data

Ship sizes, DWT	70,000	79,000	100,000
Average speed, knots	16.5	16.5	16.5
Length, feet	810	820	890
Beam, feet	116	121	128
Draft, feet	42	43	47
Horsepower	19,000	19,400	23,000
Capacity, short tons	78,400	88,480	112,000
Allowance for bunker fuel and fresh water, short tons	1,800	1,850	2,000
Slurry capacity, short tons	76,600	86,630	110,000
Dry coal capacity, 60% coal, short tons	45,960	51,980	66,000
Diameter of slurry pipeline, inches	24	30	30
Round-trip time, days:			
sailing	7.07	7.07	7.07
docking, both piers	0.17	0.17	0.17
wait for slurry	0.06	0.06	0.06
load	1.27	0.81	1.02
unload	1.27	0.81	1.02
delay allowance	1	1	1
Total	10.84	9.92	10.34
Round-trips per year per ship	32.29	35.28	33.85
Number ships for:			
4,380,000 tons coal per year	3	–	2
8,760,000 tons coal per year	6	5	4

and bulk carriers due to the increased control at low speeds, turning ability, and the docking ability afforded by such equipment. Bow thrusters are of particular value where docking conditions may be difficult and tug usage would be expensive; they can be considered a necessity under these conditions.

Ships Versus Barges

Self-propelled ships were chosen over barges for several reasons:

1) Marine slurry systems have not yet been reported to have been installed on barges, and no information is presently available concerning feasibility of such systems.

2) Barge sizes for an operation of this magnitude would be excessive, involving sizes for which there is little information available.

3) Barges are particularly attractive where travel time is short and port time is lengthy. The detachable power unit in this case is of economic advantage where it can be used for other hauling purposes while the barge is loading or unloading. Under the proposed system port time is comparatively short and travel time long so that no greatly increased utilization can be achieved.

4) Barge speeds are generally several knots slower than ship speeds and would result in longer travel times.

5) Two hulls are less efficient in the water than a single hull.

6) Coupling systems between barges and tugs are inadequate for the heavy seas that can be expected in the North Pacific. A change from pushing to towing would be required for the open sea and back to pushing for adequate control in Cook Inlet or the Straits of Juan de Fuca. This would

cause extra delay and inconvenience. To use the Inside Passage would require approximately 200 nautical miles additional distance each direction and some open sea through the Gulf of Alaska.

Barges might have an advantage as shallow draft vessels for a destination where deep-water port facilities do not exist and cannot be feasibly developed. However, deep-water port facilities are developed in this application and barging is not considered.

Environmental Considerations

Oil spills have caused increasing concern among environmental interests and consequently tanker traffic in confined waters is drawing heavy criticism due to danger of oil spills. It should be pointed out that coal does not constitute a serious environmental hazard if spilled. Unlike oil, the coal will sink and being non-toxic will minimize environmental problems.

Costs

The ships are U.S. flag as required by the Jones Act for domestic shipping. Capital investment includes installation of marine slurry systems and bow thrusters. The ships are to be new and designed for this one purpose. Capital cost for a 100,000 DWT slurry carrier is quoted.[48] Costs for the other size ships are obtained as a ratio of published costs for tankers of the same sizes.[49]

Operating costs are assumed to be equal to those for tankers of the same size and are updated to 1975.[50]

The ships are depreciated over a 20 year period with no salvage value. Ship costs are given in Appendix F.

CHAPTER VIII

DESTINATION

Location

The exact location of the power plant is not defined in this report. Choosing the actual location of such a plant would be a lengthy and highly controversial task involving many considerations. It should be possible to find a sufficient location on the Straits of Juan de Fuca or the southern end of the Straits of Georgia. A siting study for Washington Public Power Supply System showed these areas as potential sites for coal-fired steam-electric plants, and it is felt that an adequate site can be found in the area.[51]

The main requirement is sufficiently deep water in a protected area to accommodate a deep draft vessel close to a potential site for generation.

Grays Harbor is presently not deep enough for vessels of the proposed size, and would require extensive dredging to be considered a potential site.

The lower Columbia River could be considered a potential area but would not have the navigational advantages that the Straits of Juan de Fuca and the Straits of Georgia afford.

Sufficient transport distance has been allowed to place the site on the southern end of the Straits of Georgia.

It should be pointed out again that the environmental effects of spilling a coal slurry are minimal and that the ship traffic should not generate the concern that oil tanker traffic has caused.

Pier

The berth will be quite similar to that described for the pier at North Foreland. Cost will be the same without the factor of Alaskan prices.

A trestle length of 1500 feet will be allowed to reach the 10 fathom line. Due to the less severe weather conditions this trestle will be designed for a protected area at about 2/3 the cost of a trestle designed for an unprotected area.

Off-loading pier costs are given in Appendix G.

Pipelines

A slurry pipeline of 24 or 30 inch diameter (depending on ship size) will run off the pier and to the dewatering plant. One half mile of pipeline will be allowed from the end of the pier to the dewatering plant at nominal head. If a significant head exists due to altitude or increased distance a pumping station may be required. If it is desired to move the coal several miles inland to a site, the additional costs will not be great.

A return line of 12 inch diameter pipe will return fresh water from the plant to the ship for initial reslurry of the coal.

Dewatering Plant

The slurry will be delivered to storage tanks and fed at a uniform rate into the dewatering facilities.

In the terminal end of the Black Mesa pipeline at Mohave the coal is delivered as a slurry to centrifuges and pulverizer-dryers right at the boiler front.[52] This simplifies handling because the coal can be moved by pipes and pumps right to the boiler front. Such a system is envisioned here, though only careful study and consideration can determine how the case should actually be handled.

Plant capacity will be similar to that of the preparation plant, 24 hours per day, 360 days per year, at 75% availability.

Water removed from the slurry will be stored and recycled to reslurry the coal aboard ship. Excess water will require treatment and can then be used for plant purposes. A closed system will be used to minimize environmental discharge problems.

Costs of dewatering are normally less than slurry preparation costs.[53] For this report costs for dewatering the coal are taken to be equal to slurry preparation costs without the increased factor for the Beluga area.

Dewatering costs are given in Appendix H.

Emergency Storage

A storage pile will be necessary for emergencies and should be sufficient to supply the plant for at least several weeks. It might be advantageous to use a settled slurry storage system similar to that aboard ship. This would have the advantage of easy handling when needed through existing slurry facilities and would alleviate the possibility of spontaneous combustion.

Emergency storage is a generation plant cost necessary to any coal-fired plant, and since generation plant costs are not considered here, no allowance will be made for those costs.

CHAPTER IX

CONCLUSIONS

The systems and appropriate costs are summarized in Table 4. Economy of scale is quite evident in the sharply declining costs from System I through System V.

System V is obviously favored due to the lower cost. Figure 5 shows a percentage breakdown of costs for this system, indicating the areas where significant cost reductions would have to be made, namely mining and shipping costs.

If Beluga coal is to be transported to northern Washington the operation will have to be large, in the neighborhood of 10 million tons per year. Larger ships are preferred for the corresponding reduction in shipping costs.

Calculations show that for System V, the coal can be delivered to northern Washington for $1.32 per million BTU's.

The cost of shipping is high, largely due to the excessive amount of water which must be transported with the coal. At $8.37 per ton of coal, the cost to transport coal is $5.02 per ton of coal, and the cost to transport water is $3.35 per ton of coal. Coupled with the high inherent moisture content of the coal itself, the cost of transporting water becomes a distinct disadvantage.

Dry transport would increase transport costs to tidewater and loading and unloading costs substantially, but these may be offset by cheaper shipping and elimination of slurry preparation and dewatering costs.

The extremely low sulfur content will have to be a major consideration in final determination of feasibility. Since sulfur content is approximately half of that allowed by EPA standards, as the emission standards are tightened, this coal will have considerable leeway, thereby reducing future generation plant costs.

Table 4

Cost Summary

Costs in dollars per short ton of clean coal

and final cost per million BTU's

System	I	II	III	IV	V
Coal tonnage per year, millions of short tons	4.38	4.38	8.76	8.76	8.76
Slurry pipeline diameter, inches	24	30	24	30	30
Ship size, DWT thousands of tons	70	100	70	79	100
Number of ships	3	2	6	5	4
Costs:					
Mining	7.80	7.80	6.40	6.40	6.40
Washing	1.95	1.95	1.70	1.70	1.70
Slurry preparation	1.95	1.95	1.70	1.70	1.70
Water	0.10	0.10	0.07	0.07	0.07
Slurry pipeline	0.46	0.57	0.23	0.29	0.29
Loading pier	1.94	2.04	0.97	0.98	1.02
Shipping	10.37	8.37	10.37	9.40	8.37
Off-loading pier	0.94	1.00	0.47	0.48	0.50
Dewatering	1.27	1.27	1.10	1.10	1.10
Total	26.78	25.05	23.04	22.12	21.15
Per million BTU's	1.67	1.57	1.44	1.38	1.32

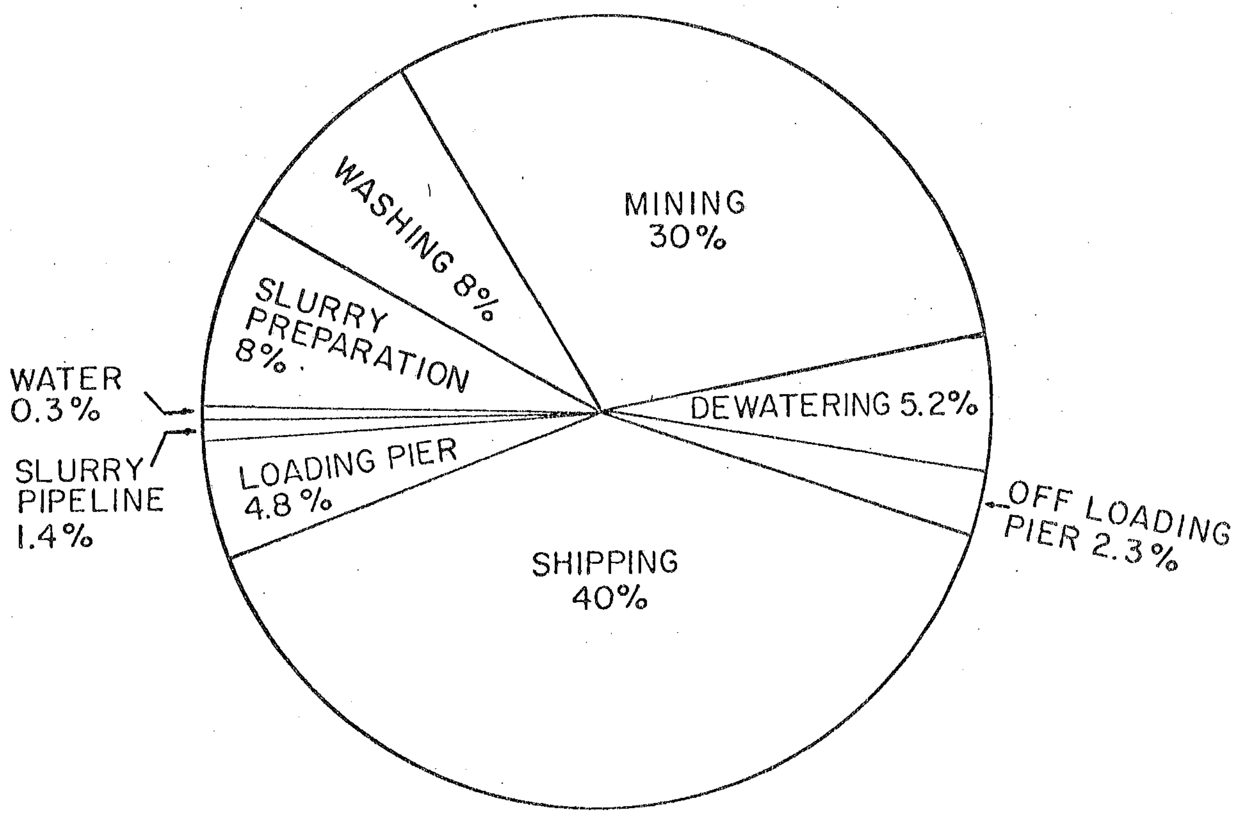


FIGURE 5. COST BREAKDOWN FOR SYSTEM V.

The average cost of all crude oil received in U.S. refineries in July, 1975, was $1.75 per million BTU's.[54] Low sulfur crude oil goes as high as $2.00 per million BTU's. In 1975 the cost of finding and developing natural gas was estimated at $1.19 per million BTU's.[55] Given the price increases expected in the future, Beluga coals may become an economical energy source in the not too distant future.

REFERENCES

1. Patsch, Benno J. G., "Exploration and Development of the Beluga Coal Field," Focus on Alaska's Coal '75. University of Alaska, MIRL Report Number 37, 1975, p. 72.

2. Maloney, R. P., Reconnaissance of the Beluga River Coalfield, Alaska. BuMines RI 5430, 1958.

3. Barnes, Farrell F., Geology and Coal Resources of Beluga-Yentna Region, Alaska. U.S. Geological Survey Bulletin 1202-C, 1966.

4. Warfield, Robert S., Investigation of a Subbituminous Coal Deposit Suitable for Opencut Mining, Beluga River Coalfield, Alaska. BuMines RI 6238, 1963.

5. Patsch, p. 72.

6. Stanford Research Institute, The Potential for Developing Alaskan Coals for Clean Export Fuels. Office of Coal Research, R & D Report No. 108, 1974.

7. Bottge, R. G., "Changing Economics of Alaskan Coals," Focus on Alaska's Coal '75. University of Alaska, MIRL Report Number 37, 1975, p. 142.

8. Patsch, p. 73.

9. Ibid., p. 73.

10. Ibid., p. 76.

11. Personal conversation with former investigator.

12. Patsch, p. 76.

13. Ibid., p. 73.

14. Ibid., p. 76.

15. Ibid., p. 73.

16. Bottge, R. G., Comparative Porphyry Copper Mining and Processing Costs--Alaska and Arizona. BuMines IC 8656, 1974, p. 29.

17. Patsch, p. 76.

18. Katell, S., et al., Basic Estimated Capital Investment and Operating Costs for Coal Strip Mines. BuMines IC 8703, 1976.

19. Patsch, p. 76.

20. Katell, p. 28.

21. *Ibid.*, p. 31.

22. Bottge, 1974, p. 4.

23. *Ibid.*, p. 6.

24. Quinlan, R. M.; Venkateson, S., *Economics of Coal Preparation*, AIME Preprint No. 76-F-108, Energy Sources Division, Kaiser Engineers, Oakland, California, 1976, p. 6.

25. *Ibid.*, p. 6.

26. Wasp, E. J., *et al.*, *Terminal Facilities for Western Coal Slurry Pipelines*, AIME Preprint No. 76-F-115, Bechtel Incorporated, San Francisco, California, 1976, p. 2.

27. Wasp, E. J., *et al.*, "Initial Economic Evaluation of Slurry Pipeline Systems," *Transportation Engineering Journal*, Vol. 97, No. TE2. May 1971, p. 279.

28. Personal conversation with former investigator.

29. Eaton, H., Jacques, R., "Transport of Coal as a Slurry," *Focus on Alaska's Coal '75*. University of Alaska, MIRL Report Number 37, 1975, p. 108.

30. *Ibid.*, p. 106.

31. Wasp, 1971, p. 276.

32. Wasp, 1976, p. 3.

33. Colorado School of Mines Research Foundation, *The Transportation of Solids in Steel Pipelines*. Golden, Colorado, 1963, p. 12.

34. *Ibid.*, p. 11.

35. Personal correspondence with Reserve Mining Company.

36. Chuang, K. C.; Nichols, D. G., *A Cost Model for Coal Slurry Transport*, Department of Chemical Engineering, West Virginia University, Morgantown, West Virginia, 1975, p. 9-4.

37. *Ibid.*, p. 9-4.

38. Wasp, 1971, p. 279.

39. Personal correspondence with Placer Amex.

40. *Ibid.*

41. Private navigational report.

42. U.S. Army Corps of Engineers, West Coast Deep Water Port Facilities Study, 1973, Appendix D, Plate 6.

43. Soros Associates, Inc., Offshore Terminal System Concepts, 1972, Part 2, Appendix B, Figure 2-48.

44. U.S. Army Corps of Engineers, Appendix D, Plate 11.

45. Marcona Corporation, Litton/MARAD Coal Study, Marconaflo Test Center, Development Division Report No. SF 259, 1972, p. B-2.

46. Ibid., p. B-2.

47. U.S. Army Corps of Engineers, Appendix C, p. 14.

48. Personal communication with major carrier.

49. Soros Associates, Inc., Part 1, Appendix B, Figure 1-27.

50. U.S. Army Corps of Engineers, Appendix C, Table 7.

51. Woodward-Clyde Consultants, Siting Study, prepared for Washington Public Power Supply System, 1975, p. A-4.

52. Wasp, 1976, p. 6.

53. Ibid., p. 2.

54. Bottge, 1975, p. 143.

55. Ibid., p. 143.

APPENDIX A

MINING COSTS

Production rate, millions of tons raw coal per year	4.818	9.636
Capital costs:		
Present value of total mine cost	42,540,800	70,901,300
Townsite	8,896,800	14,828,000
Road	2,371,600	2,371,600
Airstrip and facilities	2,807,600	2,807,600
Total	56,616,800	90,908,500
Annual operating cost	22,333,100	37,221,900

Discounted cash flow analysis, mine, 4,818,000 tons raw coal per year

15 percent - 20 years

Annual cash flow = 56,616,800 x 0.15976 =		9,045,000
	less depreciation	2,830,000
	Depletion + net profit =	6,214,200

Depletion = 10 percent of sales

Federal income tax = net profit

Depletion + net profit = cash flow - depreciation

Sales = 1.0/0.55 [1/2 (operating cost + depreciation) + depletion + net profit]

Revenue*	34,174,800
Operating cost	22,333,100
Subtotal	11,841,700
Depreciation	2,830,800
Gross profit	9,010,900
Depletion	3,417,500
Taxable income	5,593,400
Federal income tax	2,796,700
Net profit	2,796,700

Revenue* per ton = 34,174,800 ÷ 4,380,000 = 7.80 per ton

*Costs are developed for each individual phase of the entire operation as revenue required per ton of clean coal.

Discounted cash flow analysis, mine, 9,636,000

tons raw coal per year

Annual cash flow = 90,908,500 x 0.15976 =	14,523,500
less depreciation	4,545,400
Depletion + net profit =	9,978,100

Revenue	56,112,300
Operating cost	37,221,900
Subtotal	18,890,400
Depreciation	4,545,400
Gross profit	14,345,000
Depletion	5,611,200
Taxable income	8,733,800
Federal income tax	4,366,900
Net profit	4,366,900

Revenue per ton = 56,112,300 ÷ 8,760,000 = 6.40 per ton

APPENDIX B

COAL WASHING AND SLURRY PREPARATION COSTS

Coal Washing Costs

Plant capacity, tons per hour	750	1,500
Capital cost	13,440,000	23,520,000
Annual operating cost	5,792,000	10,060,000

Slurry Preparation Costs

Slurry preparation costs taken to be identical to coal washing costs.

Discounted cash flow analysis,

coal washing, 750 TPH plant

Annual cash flow = 13,440,000 x 0.15876 =		2,147,200
	less depreciation	672,000
	Depletion + net profit =	1,475,200

Revenue	8,558,600
Operating cost	5,792,100
Subtotal	2,766,500
Depreciation	672,000
Gross profit	2,094,500
Depletion	855,900
Taxable income	1,238,600
Federal income tax	619,300
Net profit	619,300

Revenue per ton = 8,558,600 ÷ 4,380,000 = 1.95 per ton

Discounted cash flow analysis

coal washing, 1500 TPH plant

Annual cash flow = 23,520,000 x 0.15976 = 3,757,600

less depreciation 1,176,000

Depletion + net profit = 2,581,600

Revenue	14,908,400
Operating cost	10,060,000
Subtotal	4,848,400
Depreciation	1,176,000
Gross profit	3,672,400
Depletion	1,490,800
Taxable income	2,181,600
Federal income tax	1,090,800
Net profit	1,090,800

Revenue per ton = 14,908,400 ÷ 8,760,000 = 1.70 per ton

APPENDIX C

WATER SUPPLY COSTS

System capacity, GPM	2,250	4,500
Capital costs:		
Pumps, installed	955,500	1,114,800
Power line	144,000	144,000
Pipeline, installed	824,700	1,370,900
Total	1,924,200	2,629,700
Annual operating cost	219,000	438,000

Discounted cash flow analysis,

water supply, 2250 GPM

Annual cash flow = 1,924,200 x 0.15976 =		307,400
	less depreciation	96,200
	Depletion + net profit =	211,200

Revenue	670,500
Operating cost	219,000
Subtotal	451,500
Depreciation	96,200
Gross profit	355,300
Depletion	67,100
Taxable income	288,200
Federal income tax	144,100
Net profit	144,100

Revenue per ton = 670,500 ÷ 4,380,000 = 0.15 per ton*

*Including water cost of 0.05 per ton of coal already in operating costs of mine and plant, incremental cost of water per ton of coal is approximately 0.10 per ton.

Discounted cash flow analysis,

water supply, 4500 GPM

Annual cash flow = 2,629,700 x 0.15976 =		420,200
	less depreciation	131,500
	Depletion + net profit =	288,700

Revenue	1,042,600
Operating cost	438,000
Subtotal	604,600
Depreciation	131,500
Gross profit	473,100
Depletion	104,300
Taxable income	368,800
Federal income tax	184,400
Net profit	184,400

Revenue per ton = 1,042,600 ÷ 8,760,000 = 0.12 per ton*

*Including water cost of 0.05 per ton of coal already in operating costs of mine and plant, incremental cost of water per ton of coal is approximately 0.07.

APPENDIX D

SLURRY PIPELINE COSTS

Coal tonnage per year, millions of tons	4.38	4.38	8.76	8.76
Slurry pipeline diameter inches	24	30	24	30
Capital cost of pipeline and pumping station	7,442,700	9,333,400	7,442,700	9,333,400
Annual operating cost	208,200	252,200	238,100	280,700

Discounted cash flow analysis, slurry pipeline,

24 inch diameter, 4,380,000 tons per year

Annual cash flow = 7,442,700 x 0.15976 =		1,189,000
	less depreciation	372,100
	Depletion + net profit =	816,900

Revenue	2,012,800
Operating cost	208,200
Subtotal	1,804,600
Depreciation	372,100
Gross profit	1,432,500
Depletion	201,300
Taxable income	1,231,200
Federal income tax	615,600
Net profit	615,600

Revenue per ton = 2,012,800 ÷ 4,380,000 = 0.46 per ton

Discounted cash flow analysis, slurry pipeline,

30 inch diameter, 4,380,000 tons per year

Annual cash flow = 9,333,400 x 0.15976 = 1,491,100

less depreciation = 466,700

Depletion + net profit = 1,024,400

Revenue	2,516,100
Operating cost	252,200
Subtotal	2,263,900
Depreciation	466,700
Gross profit	1,797,200
Depletion	251,600
Taxable income	1,545,600
Federal income tax	772,800
Net profit	772,800

Revenue per ton = 2,516,100 ÷ 4,380,000 = 0.57 per ton

Discounted cash flow analysis, slurry pipeline,

24 inch diameter, 8,760,000 tons per year

Annual cash flow = 7,442,700 x 0.15976 =		1,189,000
	less depreciation =	372,100
	Depletion + net profit =	816,900

Revenue	2,040,000
Operating cost	238,100
Subtotal	1,801,900
Depreciation	372,100
Gross profit	1,429,800
Depletion	204,000
Taxable income	1,225,800
Federal income tax	612,900
Net profit	612,900

Revenue per ton = 2,040,000 ÷ 8,760,000 = 0.23 per ton

Discounted cash flow analysis, slurry pipeline,

30 inch diameter, 8,760,000 tons per year

Annual cash flow = 9,333,400 x 0.15976 =	1,491,100
less depreciation =	466,700
Depletion + net profit =	1,024,400

Revenue	2,542,000
Operating cost	280,700
Subtotal	2,261,300
Depreciation	466,700
Gross profit	1,794,600
Depletion	254,200
Taxable income	1,540,400
Federal income tax	770,200
Net profit	770,200

Revenue per ton = 2,542,000 ÷ 8,760,000 = 0.29 per ton

APPENDIX E

LOADING PIER COSTS

Ship size, DWT	70,000	79,000	100,000
Capital costs:			
Berth	12,936,000	13,406,400	14,817,600
Trestle	12,348,000	12,348,000	12,348,000
Total	25,284,000	25,754,400	27,165,600
Annual operating cost	2,496,900	2,509,100	2,533,400

Discounted cash flow analysis,

loading pier, 70,000 DWT ship

Annual cash flow = 25,284,000 x 0.15976 =		4,039,400
	less depreciation	1,264,200
	Depletion + net profit =	2,775,200

Revenue	8,465,000
Operating cost	2,496,900
Subtotal	5,968,100
Depreciation	1,264,200
Gross profit	4,703,900
Depletion	846,500
Taxable income	3,857,400
Federal income tax	1,928,700
Net profit	1,928,700

Revenue per ton = 8,465,000 ÷ 8,760,000 = 0.97 per ton for 8,760,000 tons per year

= 1.94 per ton for 4,380,000 tons per year

Discounted cash flow analysis,

loading pier, 79,000 DWT ship

Annual cash flow = 25,754,400 x 0.15976 =		4,114,500
	less depreciation	1,287,700
	Depletion + net profit =	2,826,800

Revenue	8,591,300
Operating cost	2,509,100
Subtotal	6,082,200
Depreciation	1,287,700
Gross profit	4,794,500
Depletion	859,100
Taxable income	3,935,400
Federal income tax	1,967,700
Net profit	1,967,700

Revenue per ton = 8,591,300 ÷ 8,760,000 = 0.98 per ton

Discounted cash flow analysis,

loading pier, 100,000 DWT ship

Annual cash flow = 27,165,600 x 0.15976 = 4,340,000

less depreciation + 1,358,300

Depletion + net profit = 2,981,700

Revenue	8,959,200
Operating cost	2,533,400
Subtotal	6,425,800
Depreciation	1,358,300
Gross profit	5,067,500
Depletion	895,900
Taxable income	4,171,600
Federal income tax	2,085,800
Net profit	2,085,800

Revenue per ton = 8,959,200 ÷ 8,760,000 = 1.02 per ton for 8,760,000 tons per year

= 2.04 per ton for 4,380,000 tons per year

APPENDIX F

SHIP COSTS

Ship size, DWT	70,000	79,000	100,000
Capital cost per ship	36,500,000	40,800,000	45,000,000
Annual operating cost per ship	5,298,150	5,464,500	6,192,850
Number ships used for analysis	6	5	4

Discounted cash flow analysis,

70,000 DWT ships

Annual cash flow = 219,000,000 x 0.15976 =		34,987,400
	less depreciation	10,950,000
	net profit =	24,037,400

Revenue	90,813,700
Operating cost	31,788,900
Subtotal	59,024,800
Depreciation	10,950,000
Taxable income	48,074,800
Federal income tax	24,037,400
Net profit	24,037,400

Revenue per ton = 90,813,700 ÷ 8,760,000 = 10.37 per ton

Discounted cash flow analysis,

79,000 DWT ships

Annual cash flow = 204,000,000 x 0.15976 =		32,591,000
	less depreciation	10,200,000
	net profit =	22,391,000

Revenue	82,304,500
Operating cost	27,322,500
Subtotal	54,982,000
Depreciation	10,200,000
Taxable income	44,782,000
Federal income tax	22,391,000
Net profit	22,391,000

Revenue per ton = 82,304,500 ÷ 8,760,000 = 9.40 per ton

Discounted cash flow analysis,

100,000 DWT ships

Annual cash flow = 180,000,000 x 0.15976 = 28,756,800

less depreciation 9,000,000

net profit = 19,756,800

Revenue	73,285,000
Operating cost	24,771,400
Subtotal	48,513,600
Depreciation	9,000,000
Taxable income	39,513,600
Federal income tax	19,756,800
Net profit	19,756,800

Revenue per ton = 73,285,000 ÷ 8,760,000 = 8.37 per ton

APPENDIX G

OFF-LOADING PIER COSTS

Ship size, DWT	70,000	79,000	100,000
Capital costs:			
Berth	7,700,000	7,980,000	8,820,000
Trestle	2,100,000	2,100,000	2,100,000
Total	9,800,000	10,080,000	10,920,000
Annual operating cost	1,435,000	1,445,000	1,456,000

Discounted cash flow analysis,

off-loading pier, 70,000 DWT ship

Annual cash flow = 9,800,000 x 0.15976 =		1,565,600
	less depreciation	490,000
	net profit	1,075,600

Revenue	4,076,200
Operating cost	1,435,000
Subtotal	2,641,200
Depreciation	490,000
Taxable income	2,151,200
Federal income tax	1,075,600
Net profit	1,075,600

Revenue per ton = 4,076,200 ÷ 8,760,000 = 0.47 per ton for 8,760,000 tons per year

= 0.94 per ton for 4,380,000 tons per year

Discounted cash flow analyis,

off-loading pier, 79,000 DWT ship

Annual cash flow = 10,080,000 x 0.15976 =		1,610,400
	less depreciation	504,000
	net profit =	1,106,400

Revenue	4,161,800
Operating cost	1,445,000
Subtotal	2,716,800
Depreciation	504,000
Taxable income	2,212,800
Federal income tax	1,106,400
Net profit	1,106,400

Revenue per ton = 4,161,800 ÷ 8,760,000 = 0.48 per ton for 8,760,000 tons per year

Discounted cash flow analysis,

off-loading pier, 100,000 DWT ship

Annual cash flow = 10,920,000 x 0.15976 = 1,744,600

less depreciation 546,000

net profit = 1,198,600

Revenue	4,399,200
Operating cost	1,456,000
Subtotal	2,943,200
Depreciation	546,000
Taxable income	2,397,200
Federal income tax	1,198,600
Net profit	1,198,600

Revenue per ton = 4,399,200 ÷ 8,760,000 = 0.50 per ton for 8,760,000 tons per year

= 1.00 per ton for 4,380,000 tons per year

APPENDIX H

DEWATERING COSTS

Coal tonnage per year, millions of tons	4.38	4.38	8.76	8.76
Slurry pipeline diameter, inches	24	30	24	30
Capital costs:				
Pipelines:				
Slurry	175,325	225,725	175,325	225,725
Water return	49,675	49,675	49,675	49,675
Dewatering plant	8,000,000	8,000,000	14,000,000	14,000,000
Total	8,225,000	8,275,400	14,225,000	14,275,400
Annual operating cost	3,328,800	3,328,800	5,781,600	5,781,600

Discounted cash flow analysis, dewatering,

24 inch diameter pipeline, 4,380,000 tons per year

Annual cash flow = 8,225,000 x 0.15976 =	1,314,000
less depreciation	411,300
net profit =	902,700

Revenue	5,545,500
Operating cost	3,328,800
Subtotal	2,216,700
Depreciation	411,300
Taxable income	1,805,400
Federal income tax	902,700
Net profit	902,700

Revenue per ton = 5,545,500 ÷ 4,380,000 = 1.27 per ton

Discounted cash flow analysis, dewatering,

30 inch diameter pipeline, 4,380,000 tons per year

Annual cash flow = 8,275,400 x 0.15976 =		1,322,100
	less depreciation	413,800
	net profit	908,300

Revenue	5,559,200
Operating cost	3,328,800
Subtotal	2,230,400
Depreciation	413,800
Taxable income	1,816,600
Federal income tax	908,300
Net profit	908,300

Revenue per ton = 5,559,200 ÷ 4,380,000 = 1.27 per ton

Discounted cash flow analysis, dewatering,

24 inch diameter pipeline, 8,760,000 tons per year

Annual cash flow = 14,225,000 x 0.15976 =	2,272,600
less depreciation	711,300
net profit =	1,561,300

Revenue	9,615,500
Operating cost	5,781,600
Subtotal	3,833,900
Depreciation	711,300
Taxable income	3,122,600
Federal income tax	1,561,300
Net profit	1,561,300

Revenue per ton = 9,615,500 ÷ 8,760,000 = 1.10 per ton

Discounted cash flow analysis, dewatering,

30 inch diameter pipeline, 8,760,000 tons per year

Annual cash flow = 14,275,400 x 0.15976 =		2,280,600
	less depreciation	713,800
	net profit =	1,566,800

Revenue	9,629,000
Operating cost	5,781,600
Subtotal	3,847,400
Depreciation	713,800
Taxable income	3,133,600
Federal income tax	1,566,800
Net profit	1,566,800

Revenue per ton = 9,629,000 ÷ 8,760,000 = 1.10 per ton

BIBLIOGRAPHY

Armbruster, F. E., Candela, B. J., Research Analysis of Factors Affecting Transportation of Coal by Rail and Slurry Pipeline, Vols. I and II, Hudson Institute, New York, New York, 1976.

Aude, T. C., et al., "Slurry Piping Systems: Trends, Design Methods, Guidelines," Chemical Engineering, June 28, 1971, p. 74.

Bain, A. G., Bonnington, S. T., The Hydraulic Transport of Solids by Pipeline, Pergamon Press, New York, New York, 1970.

Barnes, F. F., Geology and Coal Resources of the Beluga-Yentna Region, Alaska, U.S. Geological Survey Bulletin 1202-C, 1966.

Beebe, R. R., et al., Evaluation of Basic Slurry Properties as Design Criteria for the Marconaflo System, Marcona Corporation, San Francisco, California, 1971.

Black, R. W., Offshore Oil Terminal Design Considerations for United States Waters, U.S. Department of Commerce, Maritime Administration, 1974.

Bottge, R. G., "Changing Economics of Alaskan Coals," Focus on Alaska's Coal '75, University of Alaska, MIRL Report No. 37, 1975.

Bottge, R. G., Comparative Porphyry Copper Mining and Processing Costs--Alaska and Arizona, BuMines IC 8656, 1974.

Branch, A. E., The Elements of Shipping, Chapman and Hall Ltd., London, England, 1970.

Bureau of Mines, International Coal Trade.

Campbell, T. C.: Katell, S., Long-Distance Coal Transport: Unit Trains or Slurry Pipelines, BuMines IC 8690, 1975.

"Can Alaska's Coal Be Competitive on the World Market?" Alaska Construction and Oil, June, 1971.

Chuang, K. C.; Nichols, D. G., A Cost Model for Coal Slurry Transport, Department of Chemical Engineering, West Virginia University, Morgantown, West Virginia, 1975.

Clark, P. R., Transportation Economics of Coal Resources of Northern Slope Coal Fields, Alaska, MIRL Report No. 30, University of Alaska, Fairbanks, Alaska, 1973.

Coles, N. G., Hemmings, S. K., Proceedings of Hydrotransport 3, Third International Conference on the Hydraulic Transport of Solids in Pipes, Golden, Colorado, British Hydromechanics Research Association, London, England, 1974.

Colorado School of Mines Research Foundation. The Transportation of Solids in Steel Pipelines, Golden, Colorado, 1963.

Cowper, N. T., et al., "Processing Steps: Keys to Successful Slurry-Pipeline Systems," Chemical Engineering, Feb. 7, 1972, p. 58.

Davis, J. C., "Long-Distance Slurry Transport--Finally in the pipeline?" Chemical Engineering, April 12, 1976, p. 67.

Eaton, H., Jacques, R., "Transport of Coal as a Slurry," Focus on Alaska's Coal '75, University of Alaska. MIRL Report No. 37, 1975.

Frawley, J. F., "1975-85 Coal Industry's Capital Requirements," Mining Engineering, May, 1975, p. 38.

Geer, M. R., Fennessy, F. D., Washability of Coals from the Matanuska Valley and Beluga River Fields, Alaska, BuMines RI 6017, 1962.

Heaver, D., The Economics of Vessel Size: A Study of Shipping Costs and their Implications for Port Investments, National Harbours Board, Ottawa, Canada, 1968.

Hinman, G., et al., Energy Projections for the Pacific Northwest, Environmental Research Center, Washington State University, Pullman, Washington, 1975.

Katell, S., et al., Basic Estimated Capital Investment and Operating Costs for Coal Strip Mines, BuMines IC 8703, 1976.

Kendall, P. M. H., "A Theory of Optimum Ship Size," Journal of Transport Economics and Policy, Vol. VI, No. 2, May, 1972, p. 128.

King, A. L., et al., Proceedings of Hydrotransport 1, First International Conference on the Hydraulic Transport of Solids in Pipes, Coventry, England, British Hydromechanics Research Association, London, England, 1970.

Kirshenbaum, N. W., Wise, T. R., "Determinants in Selecting Slurry vs. Conventional Shipping Systems," Skilling's Mining Review, Jan. 25, 1975, p. 6.

Kirshenbaum, N. W., Argall, G. O., Proceedings of the First International Symposium on Transport and Handling of Minerals, Vancouver, British Columbia, Canada, Oct. 20-23, 1971, Miller Freeman Publications, 1972.

Kirshenbaum, N. W., The Application of the Marconaflo Slurry System to Mineral Processing and Extraction, Marcona Corporation, San Francisco, California, 1973.

Leonard, J. W., Mitchell, D. R., Coal Preparation, The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, New York, 1968.

Maloney, R. P., Bottge, R. G., Estimated Costs to Produce Copper at Kennicott, Alaska, BuMines IC 8602, 1973.

Maloney, R. P., Reconnaissance of the Beluga River Coalfield, Alaska, BuMines RI 5430, 1958.

Marcona Corporation, Litton/MARAD Coal Study, Marconaflo Test Center, Development Division Report No. SF-259, San Francisco, California, 1972.

Maritime Administration, Relative Cost of Shipbuilding, U.S. Department of Commerce, 1976.

Maritime Administration, The Economics of Deepwater Terminals, U.S. Department of Commerce, 1972.

Matson Research Corporation, Transocean Tug-Barge Systems, U.S. Department of Commerce, Maritime Administration, 1970.

Miller, C. D., "Economics of Superbarge Operation," Marine Technology, Vol. 4, No. 3, 1967, p. 277.

Munro-Smith, R., Merchant Ship Types, Marine Media Management Ltd., London, England, 1975.

Mutschler, P. H., et al., Comparative Transportation Costs of Supplying Low-Sulfur Fuels to Midwestern and Eastern Domestic Energy Markets, BuMines IC 8614, 1973.

Oceanographic Institute of Washington, Offshore Petroleum Transfer Systems for Washington State, A Feasibility Study. Oceanographic Commission of Washington, 1974.

Patsch, B. J. G., "Exploration and Development of the Beluga Coal Field," Focus on Alaska's Coal '75, University of Alaska, MIRL Report No. 37, 1975.

Quinlan, R. M., Venkatesan, S., Economics of Coal Preparation, AIME Preprint No. 76-F-108, Energy Sources Division, Kaiser Engineers, Oakland, California, 1976.

Rao, P. D., Wolff, E. N., Focus on Alaska's Coal '75, Proceedings of the conference held at the University of Alaska, Fairbanks, Oct. 15-17, 1975. University of Alaska, Mirl Report No. 37, 1975.

Schmirler, D. J. Transportation of Alaska Coal, Presented to the PLM/Stanford Coal Conference, San Francisco, California, April, 1976.

"Slurry Handling Techniques Will Lower Ore Transport Cost," Shipbuilding and Shipping Record, Dec. 4, 1970, p. 33.

Soros Associates Incorporated, Offshore Terminal System Concepts, U.S. Department of Commerce, Maritime Administration, 1972.

Stanford Research Institute, The Potential for Developing Alaskan Coals for Clean Export Fuels, Office of Coal Research, R and D Report No. 108, 1974.

Stephens, H. S., Thornton, W. A., Proceedings of Hydrotransport 2. Second International Conference on the Hydraulic Transport of Solids in Pipes, Coventry, England, British Hydromechanics Research Association, London, England, 1972.

Thomas, T. B., Beebe, R. R., Ocean Transportation of Iron Ore Slurries, Marcona Corporation, San Francisco, California.

U.S. Army Corps of Engineers, West Coast Deepwater Port Facilities Study, 1973.

U.S. Department of Commerce, Construction Review, Vol. 22, No. 3, April, 1976.

U.S. Department of Transportation, Federal Energy Administration Project Independence Blueprint Final Task Force Report, Vols. I and II, 1974.

Wasp, E. J., et al., "Initial Economic Evaluation of Slurry Pipeline Systems," Transportation Engineering Journal, Vol. 97, No. TE2, May 1971.

Wasp, E. J., et al., Terminal Facilities for Western Coal Slurry Pipelines, AIME Preprint No. 76-F-115, Bechtel Incorporated, San Francisco, California, 1976.

Woodward-Clyde Consultants, Siting Study, Prepared for Washington Public Power Supply System, 1975.

Zandi, I., Advances in Solid-Liquid Flow in Pipes and Its Application, Pergamon Press, New York, New York, 1971.

OTHER REFERENCES

Personal communications with:

Bechtel Incorporated, San Francisco, California

Max Geer, Seattle, Washington

L. R. Glosten and Associates, Incorporated, Seattle, Washington

Marcona Corporation, San Francisco, California

Placer Amex Incorporated, San Francisco, California

Reserve Mining Company, Silver Bay, Minnesota

Seattle City Light, Seattle, Washington

U.S. Bureau of Mines

Maps:

U.S. Department of Commerce, National Oceanic and Atmospheric Administration:

Nautical Chart 16660, Cook Inlet, Northern Part, 1975.

U.S. Geological Survey Alaska Quadrangles:

Tyonek (A-4), 1958

Tyonek (A-5), 1958