TRANSPORTATION ECONOMICS OF COAL RESOURCES OF NORTHERN SLOPE COAL FIELDS, ALASKA

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ABSTRACT

This paper describes the Northern coal fields, the environment in which they are situated, and various routes and systems for transporting metallurgical quality coal from these deposits to a potential market in Japan. Each transportation mode is discussed with respect to northern Alaska conditions. Capital and operating costs were developed for each system.

If the coal must support the entire transportation system cost, the transportation of coal from the North Slope of Alaska to Japan appears to be economically feasible only from easily mined areas which are close to an ocean shipping port. In the case of transportation cost sharing by other users, or by government subsidization, the prospects of northern coal exploitation would be enhanced.

The final feasibility of developing any of this coal deposit cannot be determined until the mining costs and the factors which influence these costs are known.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

Early in the twentieth century, a significant portion of the revenues of the Territory of Alaska came from placer gold mining on the Seward Peninsula and in Interior Alaska, from lode gold mining in the Juneau area and from copper mining near McCarthy in Southern Alaska. Since that time, increasing operational costs without a proportional increase in the price of gold, and closure of the lode gold mines during World War II to increase base metal in production has resulted in the discontinuance of the larger gold mining operations. The largest copper producer suspended its operation when high quality ore became scarce.

It is generally agreed that Alaska has significant mineral potential, but development has been slow because of high capital and operational costs, long distances to a market, lack of internal transportation and recently for political and ecological reasons.

The recent discovery of oil at Prudhoe Bay on the Arctic Ocean and the subsequent planning of the Trans-Alaska pipeline has demonstrated that a number of these problems can be overcome. A copper mine in Northern Alaska, and a fluorite mine on the Seward Peninsula, which has been proposed for operation in the late 1970's, must surmount similar developmental difficulties. Perhaps these activities are the harbingers of a new mining era in Alaska, and will lead the way to a resurgence of other mining developments in the State. One of these developments could be coal mining. Barnes (1967) estimated the coal resources of Alaska to be approximately 130 billion tons, of which 120 billion tons exist in northern Alaska. Recent tests have indicated that part of this deposit is coking coal, a commodity which is in demand on the world markets.

IMPORTANCE OF THE PROBLEM

The economic considerations for the establishment of a commercial coal mining activity on the North Slope fall into two basic elements: mining costs and transportation costs. It is essential that good estimates of both of these elements are known before investment of capital is considered.

It is important that all types of applicable transportation methods are also studied from aspects other than economic considerations; namely, flexibility, ecological effects, and future development.

It is only after the above is accomplished that a reasonable conclusion of North Slope coal development can be reached.

PREVIOUSLY RELATED RESEARCH

Collier (1905) described coal deposits of the Corwin Bluff area which were investigated by a U. S. Geological Survey party in 1904. Coal was discovered near Cape Beaufort in 1826 by A. Collie, who accompanied Captain Beechey to the Arctic Ocean. Whalers used the coal from beds near Corwin Bluff, 28 miles east of Cape Lisburne between 1880 and 1905. In 1900 and 1901, about 1000 tons of this coal was mined and sold at Nome for fuel. (Collier, 1905).

Smith and Mertie (1930) and Chapman and Sable (1960) reported the results of the reconnaissance of northern coal deposits in 1926-1927 and 1944-53 during U.S.G.S. investigations of Petroleum Reserve No. 4. In 1946, the U. S. Bureau of Mines investigated the coal deposits to assess the possibility of their use for heating in local Eskimo villages (Sanford, 1946, Toenges, 1947). A small mine on the Meade River supplied coal to the village of Barrow from 1944 until gas became available as a substitute fuel.

In 1954, representatives of the Morgan Coal Company drove a 70 foot adit and a raise in the coal beds of the Kukpowruk River and extracted a bulk sample from this raise (Warfield, 1969). In the field seasons of 1962, 1963, 1964, and 1966, Bureau of Mines parties gathered samples from surface outcrops, trenches and at depth with the use of a diamond drill from the coal beds of the Kokolik and Kukpowruk Rivers. Extensive carbonization studies were conducted on some of these samples (Warfield, 1966, 1969).

Callahan (1969, 1971) reported the results of U.S.G.S. reconnaissance surveys and surface mapping performed in 1966 and 1967 along the Kukpowruk River and in two adjoining townships, and of surveys done in 1969 in the Cape Beaufort area and near Corwin Bluff in 1970. In the summer of 1970, Kaiser Steel Corporation made a brief study of the coal occurrences along the Kukpowruk River ("Kaiser Steel---", 1970).

The Bureau of Mines continued their drilling program on the coal deposits near Cape Beaufort in the summer of 1972.

Several major studies concerning transportation to northern Alaska have been performed although none of them were directly related to the exploitation of the northern coal fields. Bush (1942) conducted investigations for the U. S. Army Corps of Engineers on the feasibility of a railroad or highway route from Fairbanks to an ocean port on the Seward Peninsula. In 1967, the NORTH Commission was established to foster the development of the northern area of the state of Alaska. Under the direction of this Commission, EBS Management Consultants (1967) performed a study on a proposed extension of the Alaska Railroad to Kobuk, Alaska. In connection with this proposed extension, Heiner and Wolff (1968) performed a study on a proposed extension of the Alaska Railroad to Kobuk, Alaska. In connection with this proposed extension, Heiner and Wolff (1968) prepared a summary of the mineral resources in northern Alaska.

Tudor, Kelly and Shannon (1970-1972) made an extensive study on a proposed railroad from Nenana to Deadhorse and from Alatna to Kobuk, and a highway from Prospect Creek to Kobuk.

As a result of the Prudhoe Bay oil discovery, the Canadian Institute of Guided Ground Transport (1972) prepared a study on a proposed railroad to move arctic oil from Prudhoe Bay, Alaska, to Trout River in the Northwest Territories.

PURPOSE AND SCOPE

The purpose of this study was to investigate alternate routes and transportation systems to move coal from northern Alaska to an export market.

Investigations have been performed on both the North Slope coal fields and northern transportation, but little study has been conducted on a combination of the two. This investigation includes a summary of the information available on the northern coal fields, a description of the area in which the coal is situated, a discussion of coal transportation modes in a northern environment, and system analyses of northern coal transportation.

Since potential mining points in the North Slope coal fields have not been delineated, transportation costs in most systems are computed as a function of annual tonnage transported and distance to a sea terminal. With this procedure, preliminary transportation costs are computed for most areas within the coal deposits.

No ground transportation system presently exists in northwestern Alaska. The establishment of an overland transportation system and ocean harbor, with the specific goal of the movement of coal could benefit additional resource developments such as oil, gas and other minerals, and would benefit State and Federal governments through increased employment and strategic value.

Wolff and others (1972) estimate the sources and magnitude of these benefits in the report Optimum Transportation Systems to Serve the Mineral Industry North of the Yukon Basin in Alaska. The analyses in this study were confined to single use transportation; the benefits derived from a multiple use system were beyond the scope of this investigation.

CHAPTER II

THE NORTH SLOPE COAL DEPOSITS

LOCATION AND EXTENT

The northern coal fields are situated mainly in northwestern Alaska, bounded approximately by the Arctic Ocean and the Chukchi Sea to the west, the Arctic Ocean to the north, the lower Colville and Itkillok Rivers in the east and the Brooks Range in the south. The coal bearing area covers about 30,000 square miles of which 24,000 square miles is included in Naval Petroleum Reserve No. 4.

Barnes (1967) estimated the coal resources of the region to total 120,197 million tons under less than 3000 feet of overburden, of which 19,292 million tons is bituminous coal in beds of more than 14 inch thickness and 100,905 million tons is subbituminous coal in beds of more than 2 1/2 feet thick. The locations of the bituminous and subbituminous coal are shown in Figures 1 and 2, and the reserves of each district of the coal field are listed in Table 1.

ANALYSIS

Warfield (1966) reported that the majority of samples taken from a 20 foot seam in the Kukpowruk River coal beds were found to have significant coking qualities. He also reported that exposure of one of these samples to air for extended periods did not reduce the coking qualities more than noted in similar treatment of an eastern U. S. coking coal.

Several coal deposits sampled in 1964 and 1966 in the Kukpowruk River, Kokolik River and Cape Beaufort areas were established as good quality and of possible use for coke production (Warfield, 1969). In the Cape Beaufort area, none of the surface samples showed coking properties, but a drill sample from a depth of 200 feet had a higher heating value and pronounced coking characteristics.

Warfield (1969) also reported that the coal from these areas has a low moisture, ash and sulfur content.

STRIPPABLE RESOURCES

A recent Bureau of Mines report ("Strippable Reserves---", 1971) listed the strippable coal reserves of the northern coal fields. These estimates are listed in Table 2.

Only coal with a seam thickness of 14 inches or more under 120 feet or less of over-

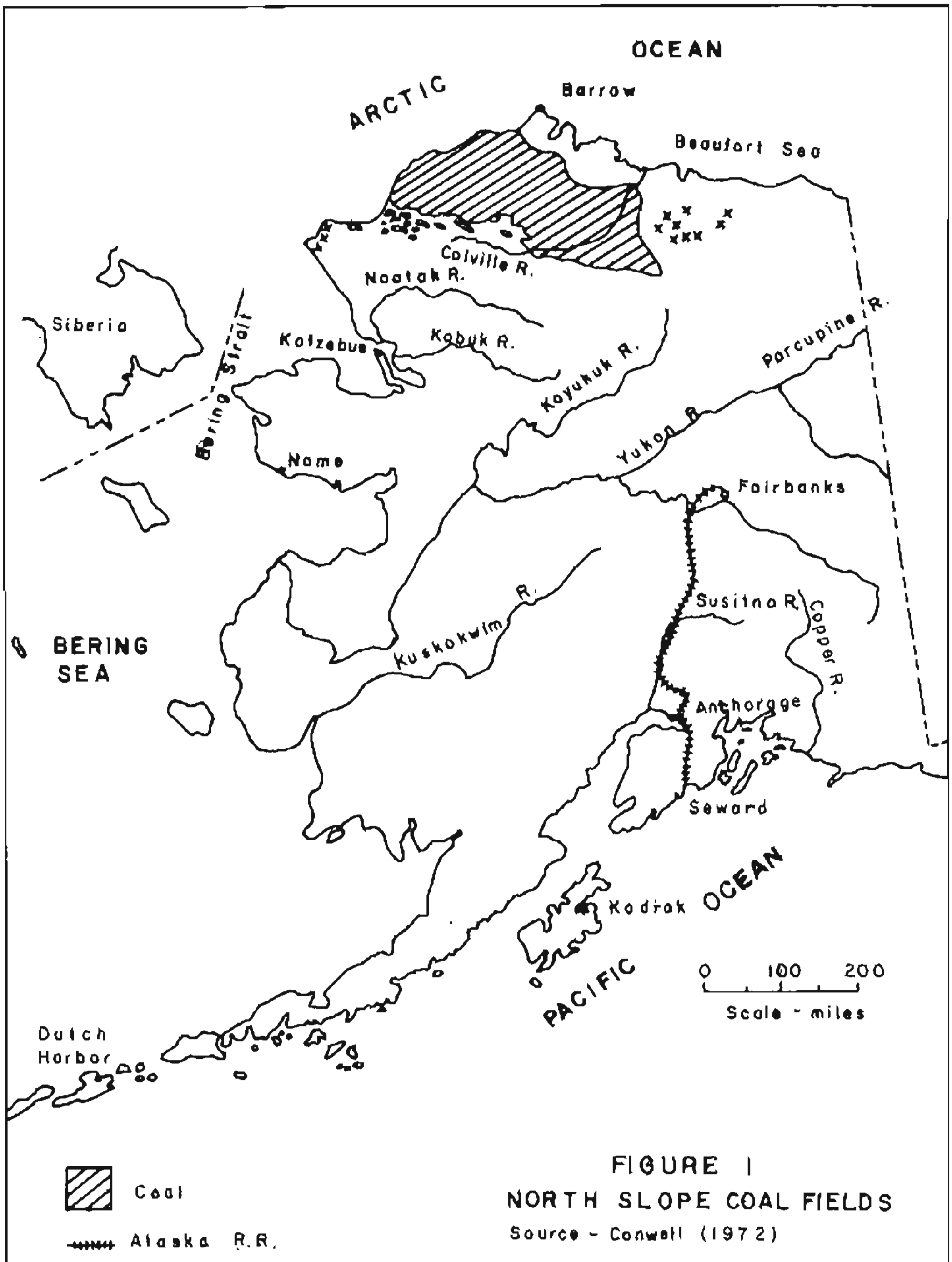


FIGURE 1
NORTH SLOPE COAL FIELDS
Source - Conwell (1972)

Table 1

Coal Reserves of the North Slope

Coal Fields, by District

(millions of short tons)

District	Bituminous	Subbituminous
Corwin Bluff - Cape Beaufort	982.3	
Kukpowruk River	3065.3	
Kokolik River	2336.1	
Utokok River	2737.9	44,738.1
Meade River	2948.3	39,756.3
Colville River	7222.3	11,489.1
Kuk River (Wainwright)		1,457.7
Kugra River (Peard Bay)		840.2
Ikpikpuk River		2,623.9
Total	19,292.2	100,905.3

Source Barnes, (1967)

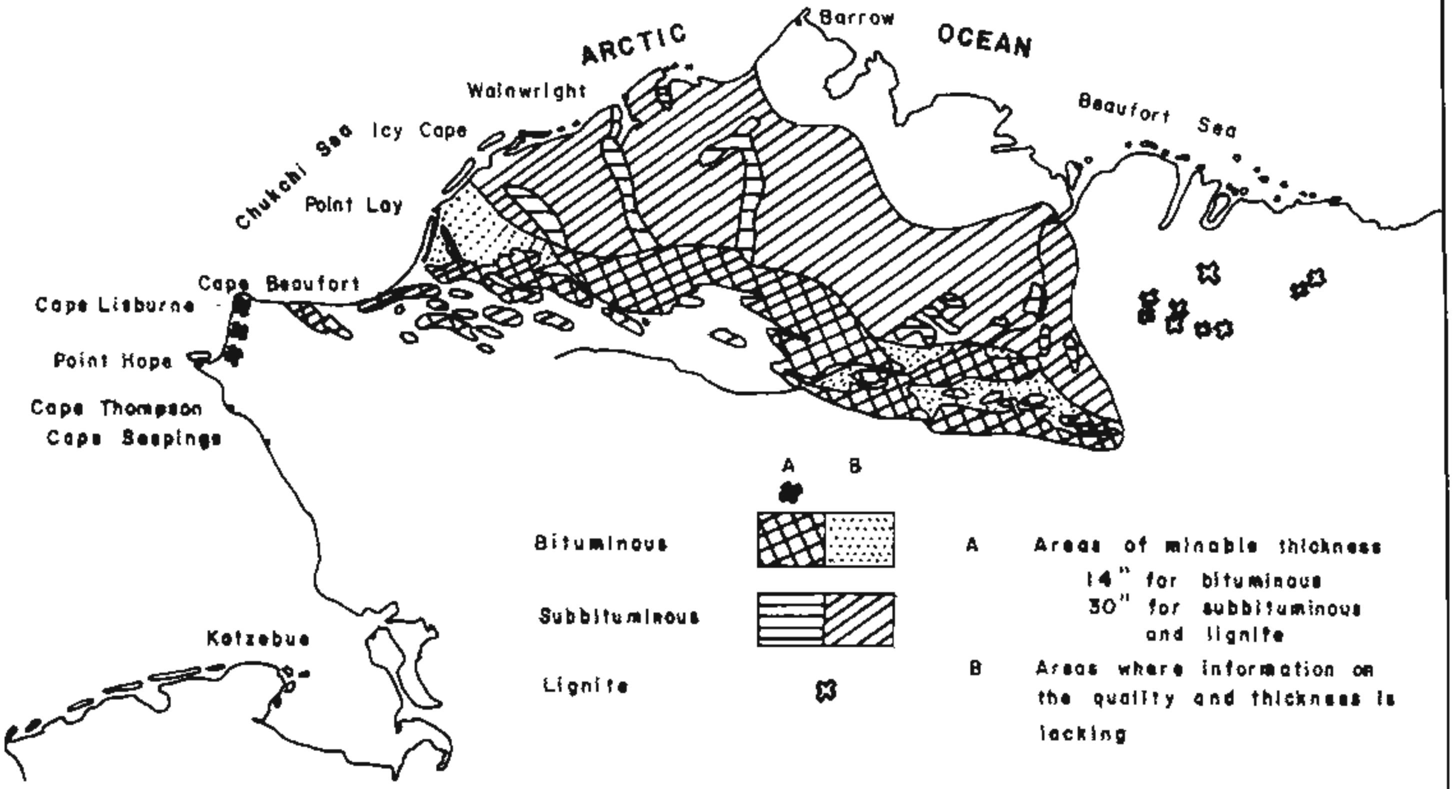


FIGURE 2

CLASSIFICATION OF COAL IN THE NORTH SLOPE COAL FIELDS

Source - Barnes (1961)

burden was counted as reserves.

Table 3 is an estimate of the strippable coal reserves in each of the northern coal field districts. These estimates were computed with the use of the following equation:

$$\frac{\text{Reserves in the District}}{\text{Total Reserves}} \times \text{Total Strippable Reserves}$$

The purpose of this table was only to give an indication of the strippable resources in each district and is not intended to be completely accurate.

LAND STATUS OF THE NORTHERN COAL DEPOSITS

Most of the northern coal fields are contained in Naval Petroleum Reserve No. 4 which at the present time is not open to mineral leasing.

Coal prospecting permits in the Kukpowruk River area have been issued to Morgan Coal Company. Applications for prospecting permits on approximately 140,000 acres in other parts of the coal fields have been submitted by various organizations and are pending approval from the Bureau of Land Management (Bureau of Land Management, 1972). No coal leases have been issued for the northern coal fields.

The most recent (March 17, 1972) Land Classification of Alaska is shown in Figure 3. Only land which is classified as unreserved public lands is open to mineral leasing at the present time (October, 1972).

MARKET

The markets for coal fall into two main categories, coking coal and non-coking coal. Coking coal is a necessary ingredient in the manufacture of steel, whereas non-coking coal is used mainly for fuel in thermal-electric plants.

The market for the non-coking coal of the northern coal fields is very limited. The domestic market for coal in Alaska is presently being filled by a producing mine in the Nenana coal field. Oil and natural gas have replaced coal in the Anchorage and Kenai areas. It is possible that small markets for steam coal could evolve if mining or other developments occur near the northern coal deposit.

In Canada and the lower 48 states, there are adequate supplies of non-coking coal to last several hundred years at the present rate of consumption.

At the present time, Japan is the most favorable market for coking coal from Alaska (Japanese Government regulations restrict the importation of steam coal.) Alaskan coal has

Table 2

Strippable Resources and Reserves of Coal in Northern Alaska

(millions of short tons)

Source – ("Strippable Reserves---," Bureau of Mines, 1971)

Grade	Remaining Strippable Resource	Recoverable Strippable Resource	Strippable Reserves
Bituminous	1,197	957	478
Subbituminous	5,293	4,234	3,387
Total	6,490	5,191	3,865

Table 3

Strippable Reserves by District

(millions of short tons)

District	Bituminous	Subbituminous
Corwin Bluff – Cape Beaufort	24	
Kukpowruk River	76	
Kokolik River	58	
Utukok River	68	1505
Meade River	73	1334
Colville River	179	386
Kuk River		47
Kugrua River		27
Ikpikpuk River		88
Total	478	3387

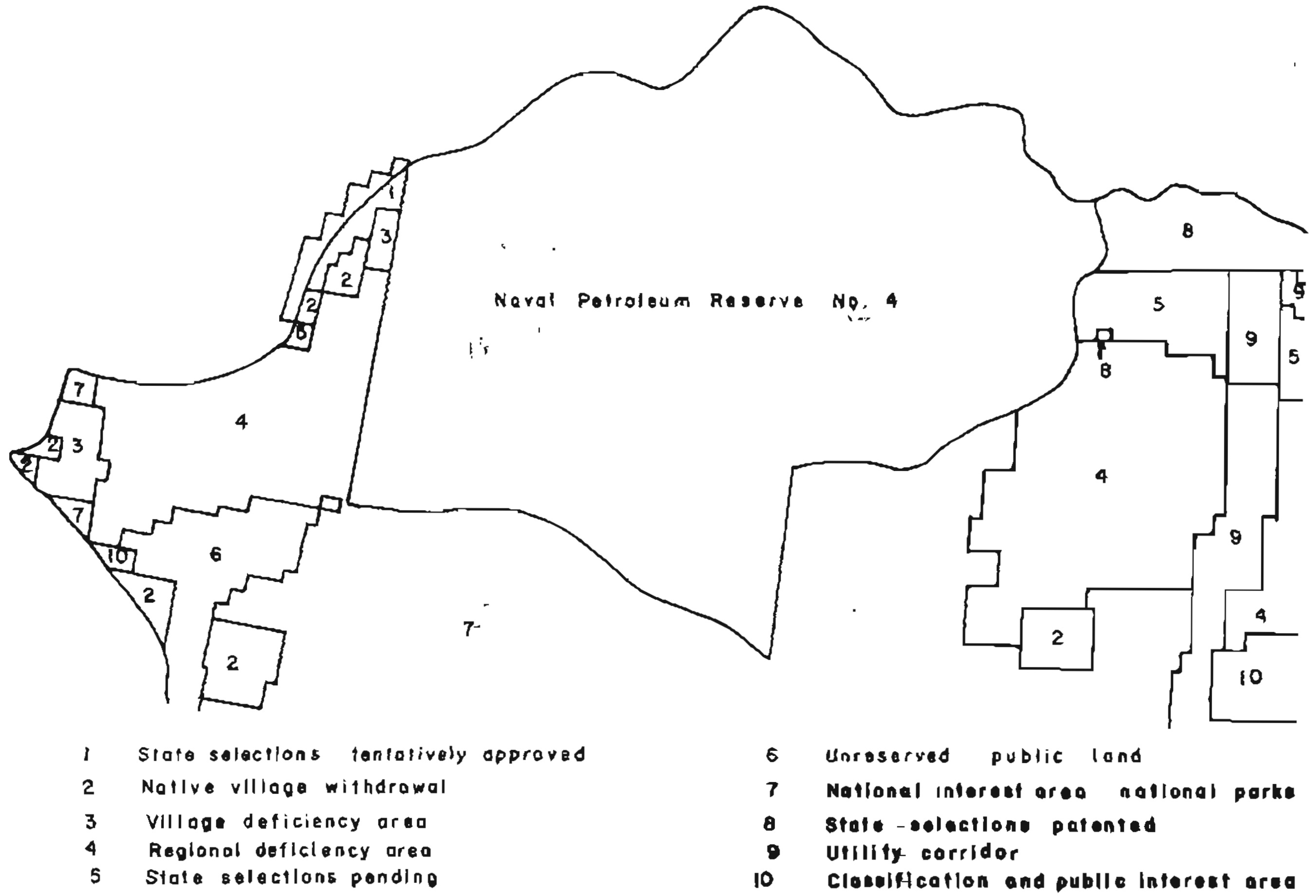


FIGURE 3
LAND STATUS OF NORTHWESTERN ALASKA
Source - Bureau of Land Management (Sept. 1972)

a geographic advantage over many of Japan's coking coal suppliers; this advantage could result in a favorable competitive position through lower shipping costs.

In 1971, 20 million tons or 34.4 per cent (See Fig. 4) of U. S. coal exports were shipped to Japan (International Coal Trade, February, 1972). In recent years, Canada and Australia have captured an increasing portion of the Japanese market. In the first quarter of 1972, Australia displaced the United States as Japan's leading supplier of coking coal.

The U.S. S. R. has proposed to Japan the development of the South Yakutsk, Siberia coal field at a cost of 175-185 million dollars (International Coal Trade, May 1972). Japan conveyed their intention of importing up to 10,000,000 tons per year from this field in the late 1980's provided the quality meets their requirements. Figure 5 shows estimates of Japan's coking coal imports to 1979. ("Iron and Steel---", 1971).

Selling price. The average price per metric ton of coking coal in 1971, C.I.F. Japan was $21.00 (C. Itoh and Company, 1972). This is equivalent to $19.20 per short ton. The premium coking coal from the eastern United States demand a higher price. In the first quarter of 1972, coking coal was purchased C.I.F. Japan at the following prices: (International Coal Trade, May 1972)

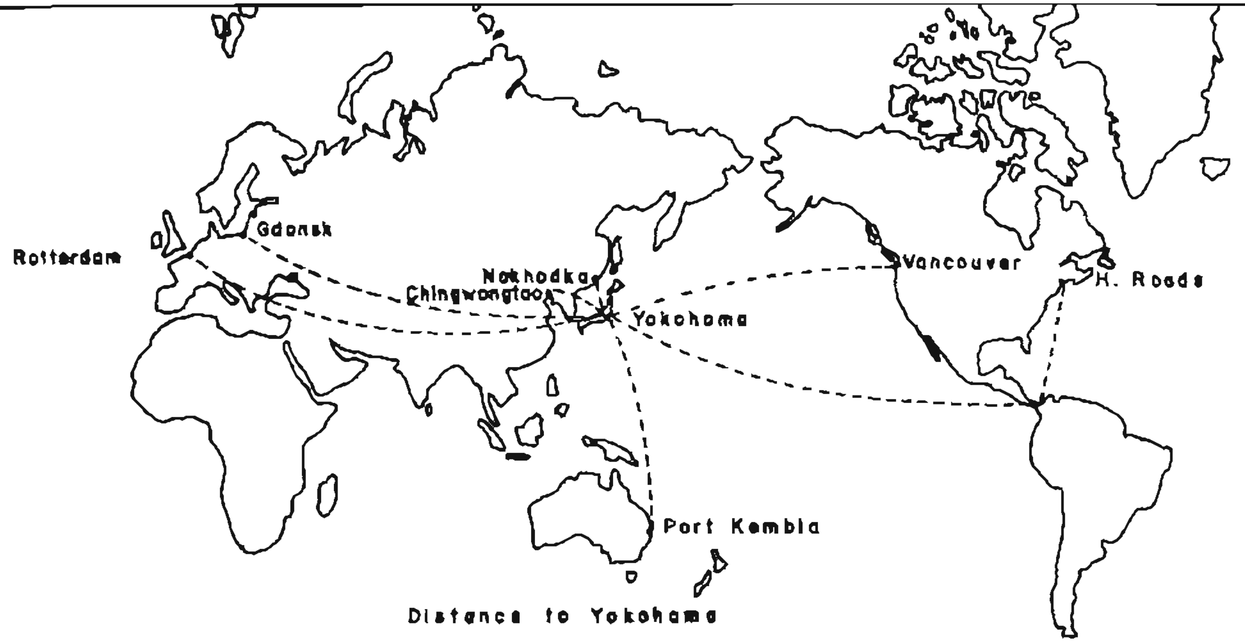
Country	Price per Metric Ton	Price per Short Ton
U.S.A.	$24.46 to $28.20	$22.40 to $25.80
Australia	$16.58	$15.20
Canada	$20.83	$19.15
U.S.S.R.	$19.88	$18.20
Poland	$24.36	$22.30

Since very little of the northern coal has been analyzed, it is difficult to project what sales price it could demand. However, the tests performed to date indicate that the northern coking coal is a blending coal and would therefore sell at the medium to low coking coal prices.

AREA GEOGRAPHY

Physiography

Northern Alaska is composed of four physiographic divisions: namely, moderately high rugged mountains, low mountains, plateaus and highlands and plains and lowlands (See Fig. 6). The major topographic features are the Arctic Coastal Plain, the Arctic Foot-



Distance to Yokohama

Hampton Roads U.S.A.	**9510 miles**
Port Kembla Australia	4370
Nakhodka U.S.S.R.	880
Vancouver Canada	4275
Chingwangtao China	1300
Gdansk Poland	12220
Rotterdam W. Germany	11194

Alaska	(approximate)
Seward	3800 miles
Dutch Harbor	2940
Cape Thompson	3340
Point Lay	3490

FIGURE 4

JAPAN'S SOURCES OF COKING COAL (Alaska excepted)

Source-Barnes (1972)

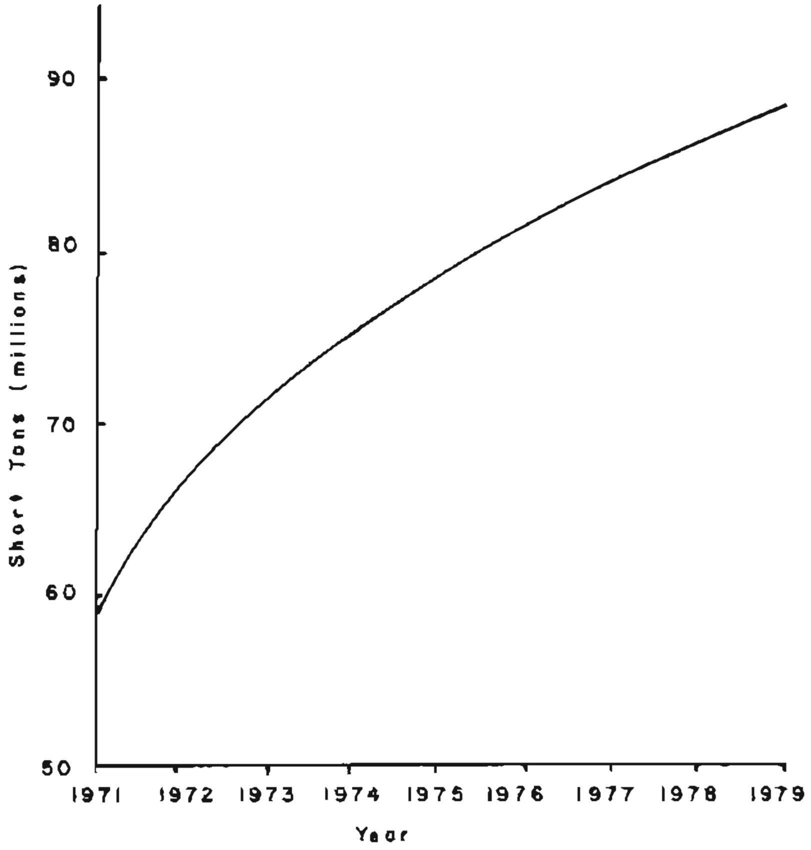


FIGURE 5

Projected Coking Coal Imports to Japan

Source- "Iron and Steel- Japan's Bellwether" (1971)

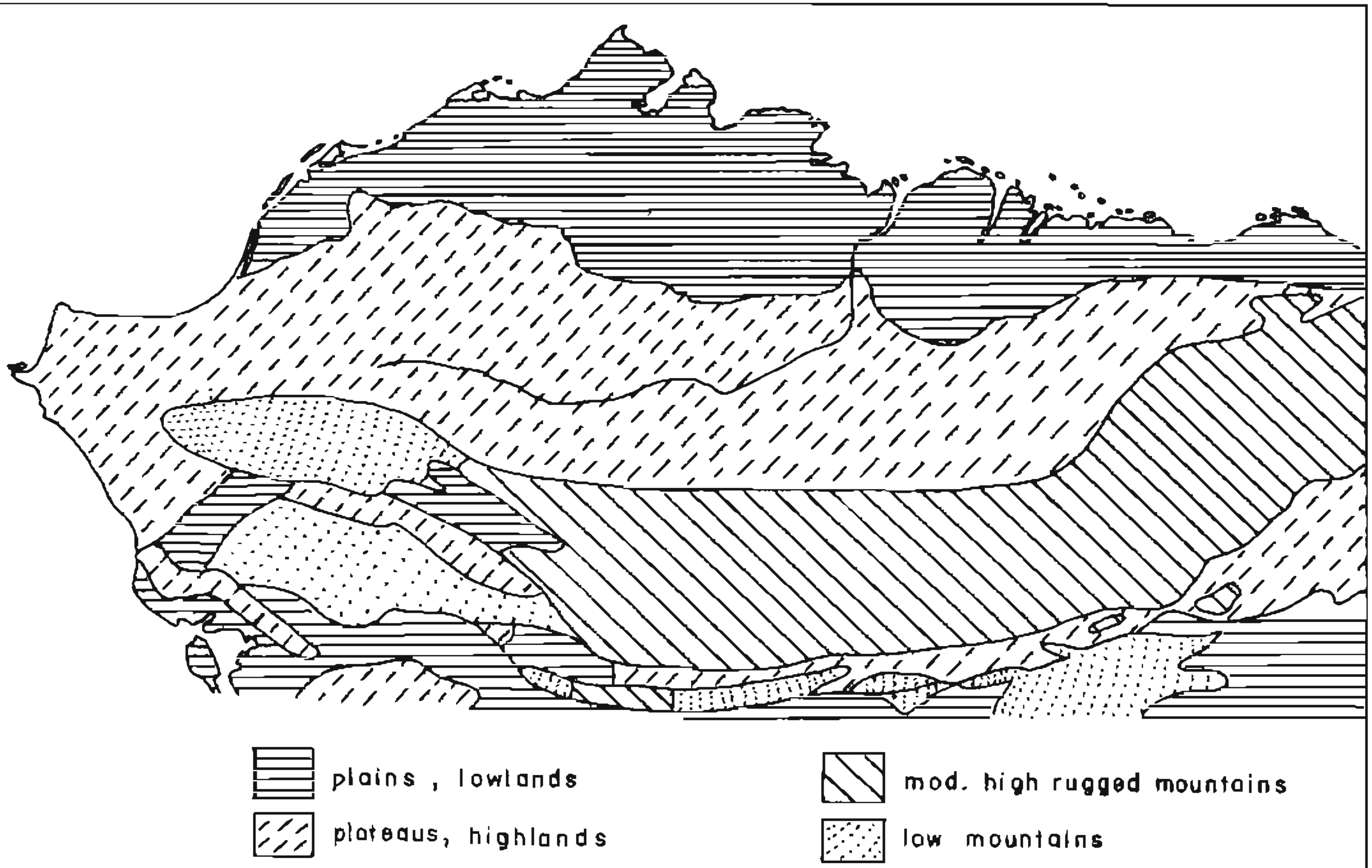


FIGURE 6

PHYSIOGRAPHIC DIVISIONS OF NORTHERN ALASKA

Source - Wahrhaftig (1965)

hills and the Brooks Range.

Arctic Coastal Plain. Wahraftig (1965) described the Arctic Coastal Plain as a smooth plain rising imperceptibly from the Arctic Ocean to a maximum altitude of 600 feet at its southern margin. Thousands of shallow lakes from 2 to 20 feet deep and from a few feet to 9 miles long pockmark the coastal plain. The plain is poorly drained, and as a result, swampy conditions are prevalent during the summer. Pingos and ice-wedge polygons are common features in this area. Permafrost to depths of 1000 or more feet underlie most of this area. The active layer is from three inches to four feet deep.

Arctic Foothills. The arctic foothills are plateaus and low mountains ranging from 600 to 3500 feet in altitude. The northern section of the foothills is dominated by mesalike mountains. The southern section is characterized by irregular buttes, mesas and ridges interrupted by undulating tundra plains. The entire area is underlain by permafrost. (See Fig.7).

Brooks Range. The mountains of the Brooks Range rise to summits of 7000-8000 feet in altitude in the southern part. In the higher areas of the range, small glaciers are common. The main north flowing rivers begin at the head of the wide flat-floored glacier valleys of the Brooks Range.

Drainage and Water Resources

Table 4 is an outline of the major rivers in northern Alaska. Rivers east of the Colville River in the Arctic Coastal Plain have numerous braided channels, whereas rivers west of the Colville meander sluggishly in valleys 50-300 feet deep (Wahraftig, 1965). Most streams in the Arctic Foothills have swift braided courses across broad gravel flats. The major rivers of the Brooks Range flow north to the Arctic Ocean, and south to the Kobuk, Koyukuk and Yukon Rivers.

The many small lakes on the Arctic Coastal Plain are limited to low volume utilization because low annual precipitation results in slow replenishment rates. In most areas, permafrost to depths of over 1000 feet prevents the formation of any subsurface water (Parker, 1972).

In winter, ice cover of approximately 6 feet builds up on all surface water bodies. Many streams are locally covered in winter with extensive sheets of anchor ice. Even in the largest rivers, flow in winter is approximately 5 per cent of the summer flow (See Fig. 8).

Water is available from lakes which do not freeze to the bottom and from unfrozen aquifiers beneath the rivers. Williams (1970) reported that aquifiers in the Colville River

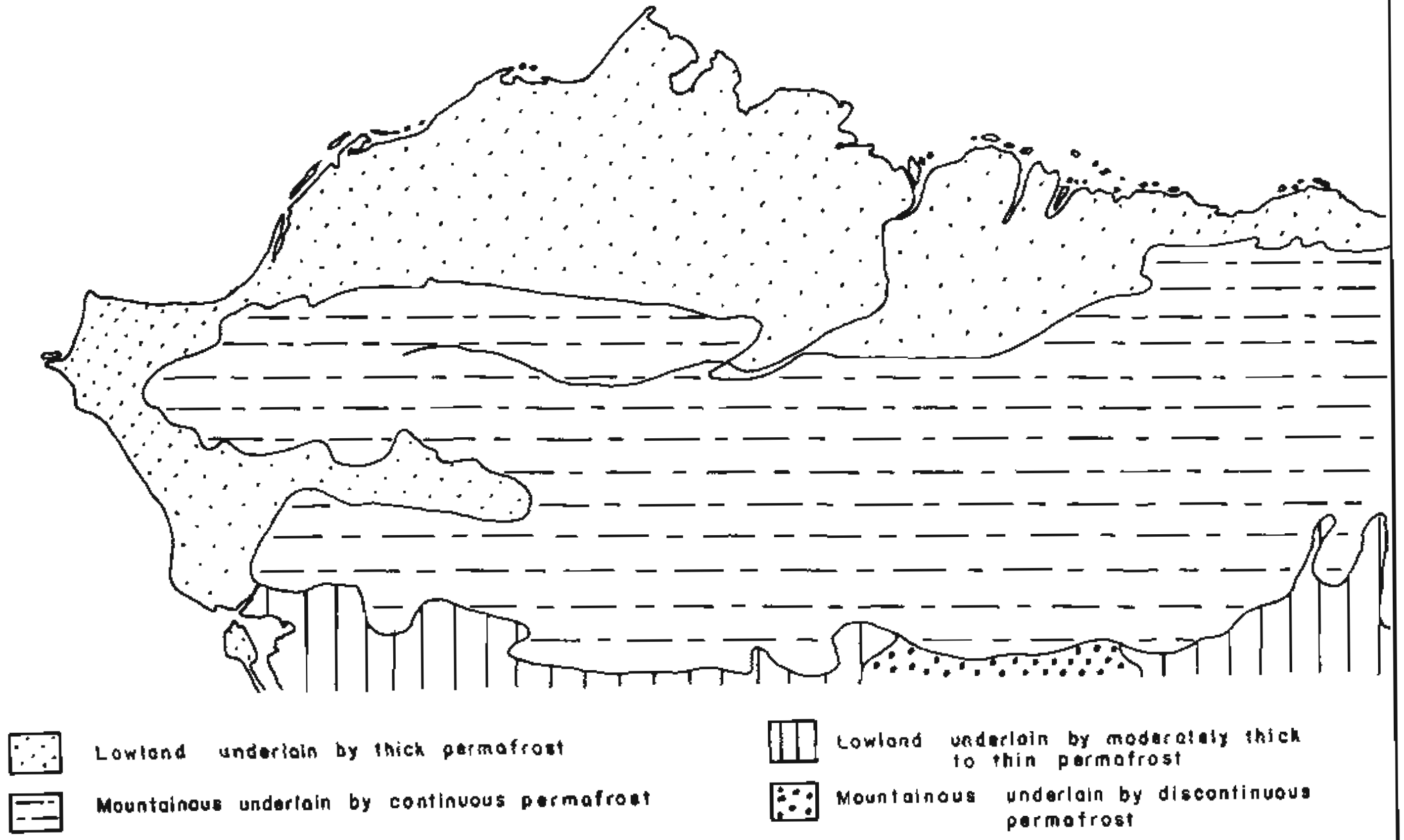


FIGURE 7

DISTRIBUTION OF PERMAFROST IN NORTHERN ALASKA

Source - Ferrians (1969)

Table 4

Major Rivers in Northwestern Alaska

River	Drainage Area (sq. miles)	Length of Main Stream (miles)	Estimated Average Annual Flow (cu.ft./sec.)
Kukpowruk	4,178	42	2,130
Meade	3,850	230	1,925
Ikpikpuk	4,540	169	2,270
Colville	24,000	428	12,000
Kukparuk	3,659	183	1,830
Sagavanirktok	5,546	166	2,770

Source - Parker (1972)

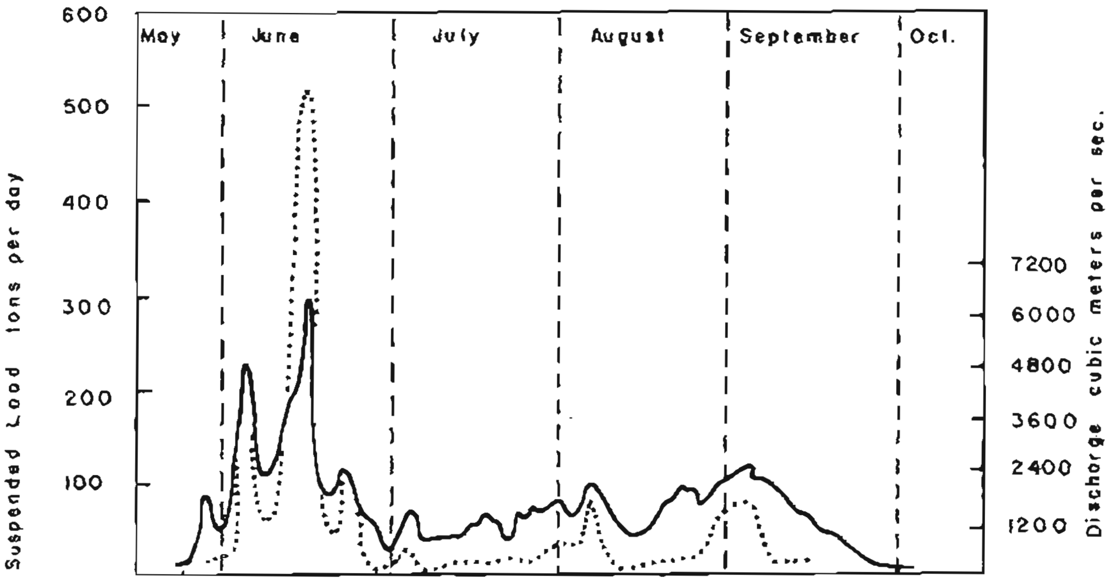


FIGURE 8
Discharge and Suspended
Load in the Colville River, 1962

Source-Greenwood (1972)

yield from several hundred gallons per minute from alluvium to less then ten gallons per minute from bedrock.

Vegetation

Most of the Arctic Coastal Plain consists of tundra which is characteristically treeless. Trees of the willow and poplar variety do exist along the larger valleys in the Arctic Foothills and to a lesser extent in the mountain valleys.

In the Brooks Range, the tree line along the southern slopes usually occurs between the 1000 to 2000 foot elevations. The most prevalent plant life is the cotton grass tussock which is 6 to 10 inches in width and height, and is separated by mossy channels a few inches wide. Other types of vegetation common to northern Alaska are mosses, lichens, sedges, dwarfed berry bushes and many wild flowers.

Climate

All of northwestern Alaska is considered to have an arctic climate (Johnson, 1971). This arctic climate is characterized by light precipitation, strong winds and a 10° to 20° F mean annual temperature. Marine influence affects this climate somewhat in summer, but to a lesser extent in winter.

Temperatures of -40° F. are common in the winter and have been known to drop to -65° F. Strong winds and storms, many approaching gale velocities are common. Table 5 is a summary of climatological data at various points in northwestern Alaska.

Settlement and Accessibility

Settlement in northwestern Alaska consists mainly of isolated Eskimo coastal villages, the largest of which is Barrow with more than 1000 residents. Oil companies engaging in exploration and construction maintain temporary camps at several points in the region.

The area contains no roads, railroads or trails. None of the major rivers are navigatable except the Colville River which is navigatable by barges with a three foot draft.

Travel is principally by air although tractor trains have been used in past exploration programs. Supplies are brought into the coastal villages by ship and barge in the late summer.

Northwestern Coast

Continental shelves of the Bering and Chukchi Seas create fairly shallow waters on

Table 5

Climatological Data at Various Locations in Northwestern Alaska

	Precipitation-In.		Temperature F					
Location	Mean Annual Precip.	Mean Annual Snowfall	Mean Annual	Mean January Minimum	Mean January Maximum	Mean July Minimum	Mean July Maximum	*Heating Degree Days
Barrow	**3.7	20	**9.0	-24	-10	34	46	20,000
Umiat	7	40	10	-18	- 4	40	52	19,000
Pt. Lay	6	25	15	-20	- 6	40	50	19,000
Cape Lisburne	8	30	**19.0	-16	- 4	40	48	18,000
Cape Thompson	8	30	17	-16	- 2	41	50	17,000
Kotzebue	8	40	21	-16	0	46	60	16,000

* Number of degree days below 65 F for one year.

**Source - U. S. Dept. of Commerce, Environmental Science Services Administration

Source - Adapted from Johnson, Hartman 1971 the northwestern coast. (See Fig. 9) Water depths of sixty feet are at least three miles from shore. Port Clarence and Golovnin Bay, both of which are on the Seward Peninsula are the only natural deep harbors north of Norton Sound. The next natural deepwater harbor past Port Clarence is at Herschel Island in the Canadian Arctic.

At Kotzebue, sea going ships must anchor 14 miles offshore, where cargo is transferred to shallow draft lighter barges. At Prudhoe Bay, cargo is transferred from ocean barges to lighter barges 6 miles from shore (Moreau, 1970).

In 1958 a study was undertaken by the U. S. Geological Survey (Pewe, 1958) to determine the most suitable site on the northwestern coast of Alaska for the excavation of an artificial harbor by a nuclear device. The harbor site recommended in this study was at the mouth of Ogotoruk Creek, about seven miles south-east of Cape Thompson. At this point there exists a seavalley which starts one quarter mile from shore and extends seaward for 15 miles to a depth of 135 feet (Sainsbury, 1966).

Seafloor. Reflection studies between Cape Lisburne and Cape Seepings and between Icy Cape and Point Barrow have indicated that bedrock is exposed or nearly exposed on the seafloor in many areas (Craeger, 1967). Sainsbury and Scholl (1966) found outcrops exposed on the surface of the seafloor near the mouth of Ogotoruk Creek.

Coastline topography. Nearly continuous steep sea cliffs characterize the coastal region from Ogotoruk Creek to Cape Beaufort. Breaks in these cliffs occur where stream valleys meet the coast. Beaches are generally steep and narrow except at Point Hope where barrier islands project offshore.

From Cape Beaufort to the Utukok River, about 25 miles south of Icy Cape, the coastline consists of almost continuous sea cliffs from 15 to 45 feet high. In the Cape Beaufort area, the cliffs are directly exposed to the ocean. From approximately 25 miles north of Cape Beaufort to the Utukok River, the coast is fronted with low relief barrier islands which enclose small shallow lagoons.

The shoreline from the Utukok River northeastward to Point Barrow is characterized by moderate to low relief sea cliffs which are either directly exposed to the sea or are fronted by sedimentary barriers (Hartwell, 1972).

Tides. Tides along the northwest coast are weak. Normal maximum tides range from three feet near Kotzebue to 0.6 feet near Point Barrow (Johnson, 1971). Storms can cause changes in the sea level, such as one storm in 1963 when three meter high waves caused flooding and about three million dollars damage to the village of Barrow (Hartwell,

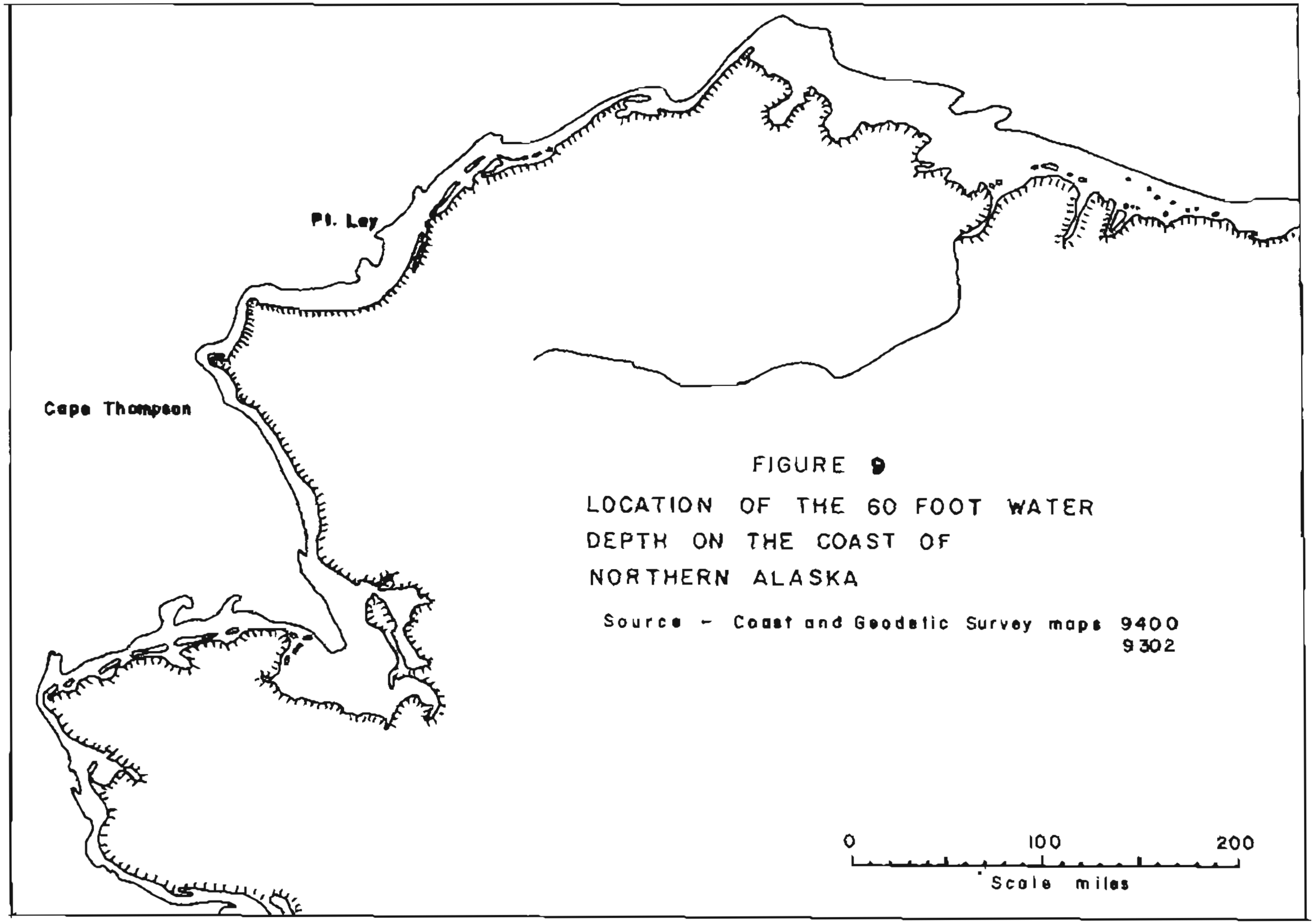


FIGURE 9

LOCATION OF THE 60 FOOT WATER DEPTH ON THE COAST OF NORTHERN ALASKA

Source - Coast and Geodetic Survey maps 9400
9302

1972).

Ice Conditions. In northwestern Alaska, ice begins to form on the beaches in the late fall and remains for approximately 8 months. This ice attains a thickness of about 5 feet (Hartwell, 1972). If shearing occurs between the fast ice (ice frozen fast to the shore) and the floating ice offshore, large pressure ridges and jumbled ice fields usually occur. Pack ice usually forms a major pressure ridge offshore at Barrow and at times grounds on the sea floor to depths of 60 to 100 feet. Even during the normal ice-free season at Barrow, an onshore wind can bring the pack ice into shore. When the protective fast ice thaws, the sea ice may be driven onshore by winds. These major ice shoves can produce ridges up to 6 feet high. Coastal ice scour is prevalent during the winter months. Deep hulls of pressure ridges which extend beneath the floating sea ice rub and gouge the sea floor from shore to depths of 100 feet. Some of this gouging in the Beaufort Sea has produced troughs in the sea floor from 2 to 30 feet deep. ("Ice Gouging---", Whitehorse Star, 1972).

Table 6 is a list of the dates of break-up and freeze-up at locations in northwestern Alaska.

Table 6

Dates of Ice Break-Up and Freeze-Up

	Ice Break-Up			Ice Freeze-Up			Ice-Free Months		
Location	Ave.	Earliest	Latest	Ave.	Earliest	Latest	Ice Free	Light Ice	Heavy Ice
Golovin Bay	May 23	May 13	June 14	Nov 2	Oct 8	Nov 19			
Teller-Port Clarence	June 7	May 12	June 18	Nov 10	Nov 13	Dec 26	*3	*4	*5
Kotzebue	May 31	May 17	June 8	Oct 23	Oct 2	Nov 5			
Point Hope	June 20	May 30	July 8	Nov 11	Oct 6	Dec 19	**3	**3	**6
Point Lay	June 24	June 1	July 10	Nov 4	Oct 12	Nov 27	**2.5	**3	**6.5
Wainwright	June 29	June 7	July 26	Oct 2	Sept 26	Oct 9	*2	*3	*7
Point Barrow	July 22	June 15	Aug 22	Oct 3	Sept 31	Dec 19	*2	**3	**7

* Source - U. S. Coast Guard, Polar Transportation Requirements

Source - U. S. Coast Pilot No. 9, 1964

** Estimated from above sources

CHAPTER III

COAL TRANSPORTATION METHODS

RAILROAD

The most widely used method of transporting coal overland today is the railroad. Railroads have been constructed and successfully operated in many types of environments and climatic conditions.

Early railroads in Alaska were the Seward Peninsula Railroad, the Copper River and Northwestern Railroad near Valdez and the Alaska Railroad which extends from Fairbanks to Seward. Only the Alaska Railroad is still operating. At the present time, approximately one million tons of freight are hauled over the Alaska Railroad annually.

Other railways built in northern areas and still operating are the Labrador Ungava Railway, the Great Slave Railway, the Hudson Bay Railway, all of which are in Canada and the White Pass and Yukon Railway which operates between Whitehorse, Yukon Territory and Skagway, Alaska.

Construction in Permafrost

A railroad built in areas where permafrost is prevalent requires large amounts of fill material. This fill material serves as a railroad bed and as an insulation layer to retard the thawing of the underlying permafrost (See Fig. 10). The general method of construction on permafrost is to preserve the frozen condition by building on it, rather than excavating into it. Side hill railroad construction is a technique which is applied in northern areas. Valley bottoms are often flooded during the spring run-off.

Drainage is also an important consideration for railroad construction in permafrost areas. Water in contact with the permafrost causes thawing, the result being settling of the railroad bed.

Construction Costs

Railroad construction costs in northern areas vary with the location, but in general these costs are substantially higher than for railroads in southern areas. The main reasons for the higher costs are: importation of labor, severe climatic conditions hence lower labor and machine efficiency, the large volumes of fill required, and the transportation costs for supplies and materials from southern areas. Table 7 shows the construction costs of existing and proposed railroads in northern areas.

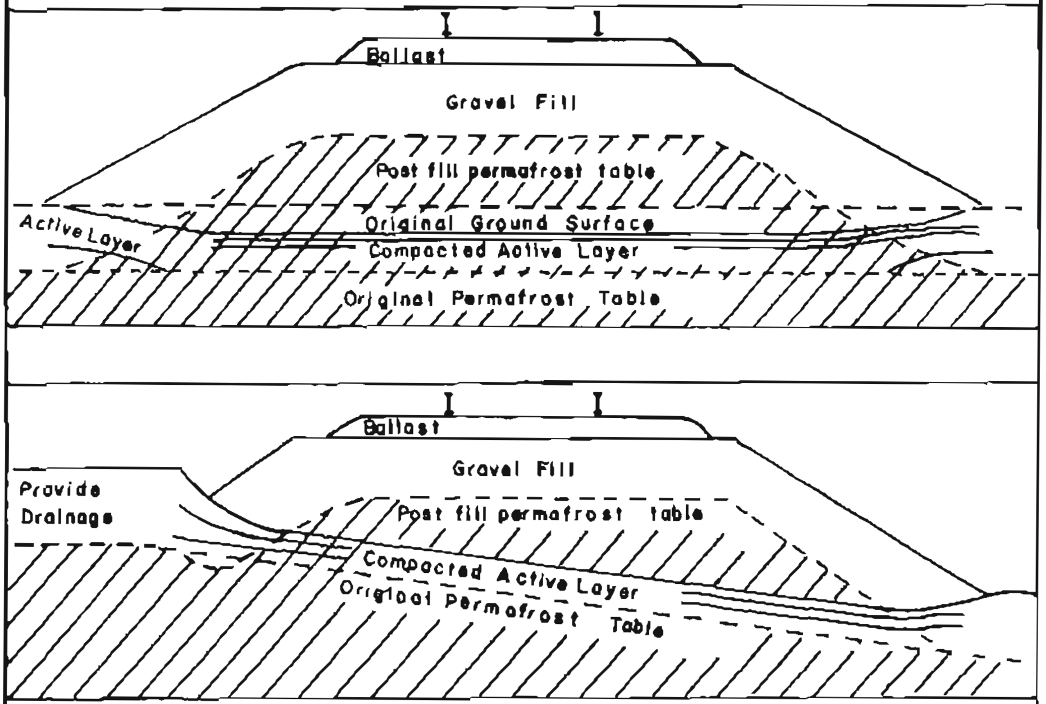


FIGURE 10

PROFILES OF TRACK CONSTRUCTION IN PERMAFROST

Source – Canadian Institute of Guided Ground Transport (1972)

Table 7

Construction Costs of Existing and Proposed Railroads

	Railroad	Location	Length (miles)	Year Constructed or Proposed	Construction Cost per mile (dollars)
1.	Great Slave Railway	Roma, Alberta to Hay River, N.W.T.	377	1964	199,000
2.	Quebec North Shore and Labrador Railway	Sept Iles, Quebec to Shefferville, Labrador	360	1954	325,000
3.	Extension of the Alaska Railroad	Dunbar, Alaska to Kobuk Alaska	405	P-1967	400,000
4.	Railway to the Arctic	Trout River, Alberta to Prudhoe Bay, Alaska	1240	P-1972	1,250,000
5.	Railroad North of Fairbanks	-	-	P-1968	414,000
6.	Railroad to North Slope	Nenana, Alaska to Deadhorse, Alaska	581	P-1972	2,360,000

Sources: 1- Charles (1965)
2- Pryer (1963)
3- EBS Management Consultants (1967)
4 - Canadian Institute of Guided Ground Transport (1972)
5 - Polar Transportation Requirements (1968)
6 - Tudor, Kelly, Shannon (1972)

Unit Trains

The unit train technique is a relatively new concept in railway transportation. The first unit train system started in the United States in 1959. In 1967, 327 coal mines were shipping coal by unit trains (Glover, 1970).

The unit train concept usually involves the following:

a) A train or number of trains dedicated to the haulage of the bulk material.

b) A long term contractoral agreement between the shipper, supplier and receiver.

c) One source and one destination.

d) A predetermined loading, unloading and travel time schedule.

The major advantages of the unit train are: high equipment utilization, low clerical costs, and higher shipper and receiver benefits due to the precision of advanced scheduling.

SLURRY PIPELINE

Slurry transmission by pipeline has been in existence since before the 20th century, but it has been only in recent years that long distance transmission has developed. Two of the most noted pioneer efforts in bulk movement by slurry pipeline were built in 1957. A 71 mile long pipeline used to transport Gilsonite extended from Bonanza, Utah, to Grand Junction, Colorado, and a 108 mile long coal slurry pipeline was constructed between Cadiz and Cleveland, Ohio.

The most recent efforts in the use of slurry pipelines are the 53 mile long Savage River pipeline in Tasmania which transports iron ore slurry, and the 273 mile long Black Mesa pipeline which transports a coal slurry between Arizona and Nevada. A 490 mile long pipeline to transport coking coal from eastern British Columbia to the Pacific coast has been proposed for operation in the late 1970's ("World Wide---", 1972).

A long distance slurry pipeline has only one source and one destination. Each application is a separate case and normally cannot be used interchangeably with other materials. The general requirements for pipeline construction are large ore reserves and a long term market contract. The main advantages of a slurry pipeline are low operating costs and low material losses. In many slurry pipelines, the pumping stations are automated or semi-automated. A pipeline is a closed system, therefore dust losses or contamination of the environment is minimal. Most pipelines are buried, consequently, they do not occupy the land surface or create surface obstructions.

Table 8 is a list of data on some commercial pipeline applications.

Slurry Pipeline Design

Link (1972) stated that slurry transport in many cases is still more of an art than a science. A number of commercial pipeline construction projects have been precluded by extensive laboratory and pilot plant testing.

Particle size, pumping velocity and solids concentration are three of the most important factors in slurry pipeline design.

Pumping velocity. In slurry pipelines it is important that the solid particles remain in a homogeneous suspension. In every case, there exists a critical velocity, the point at which particles begin to settle to the bottom of the pipe. The pumping velocity must be above this critical velocity. If not, solid particles tend to be dragged along the bottom of the pipe causing excessive pipe wear and creating unstable flow conditions. The optimum velocity for commercial coal slurry applications has been determined to be between 3 and 6 feet per second (Wasp, 1971).

Solids concentration. The concentration of solids in a slurry has a direct influence on the particle settling velocity and the pumping velocity. Commercial coal slurry pipelines use solids concentrations of 45 to 60 per cent by weight. Beyond 60 per cent, small increases in concentration mean large increases in the pressure drop, hence a higher pumping horsepower and higher costs with disproportionate gains in the amount of material transported.

Another factor in the design of a pipeline is the carrier fluid. In most cases, water is used as the carrier fluid although it is possible to use oil, gasoline, or other hydrocarbons if readily available. However, it is the rare case where the markets are available for the exact balance of the solids and the carrier fluid.

Major pipeline Components

Pumps. Slurry pipelines have employed centrifugal pumps and piston and plunger reciprocating pumps. Centrifugal pumps are used where the pump discharge pressure is relatively low, below 650 p.s.i. Piston reciprocating pumps are normally used for pressures up to 2000 p.s.i., plunger pumps are used where pressures up to 4000 p.s.i. are required (Thompson, 1972).

The main advantage of the reciprocating pump is the higher operating pressure. This higher pressure allows a greater distance between pumping stations, hence a lower sta-

Table 8

Some Long Distance Slurry Pipelines

Pipeline	Location	Pipe Size (Length)	Annual Tonnage (millions)	Material Transported	% Solids by wt.	Construction Cost (millions)	Year Started or Proposed
American Gilsonite Co.	Utah, Colorado	10" (72)	0.4	Gilsonite	48	N.A.	1957
Consolidated Coal Co.	Ohio	10" (108)	1.3	Coal	50-60	N.A.	*1957
Consolidated Coal Co.	Virginia, New York	18" (350)	10	Coal	N.A.	200	1969-P
Black Mesa Pipeline Co.	Arizona, Nevada	18" (273)	5	Coal	45-50	35	1970
Savage River	Tasmania	9" (53)	2.25	Iron Ore	60	5	1967
Cascade Pipeline Ltd.	British Columbia	N.A. (500)	10	Coal	N.A.	200	1969-P

* Closed due to decreased railroad tariffs

Sources - Job (1969)
*Longest Largest Coal Slurry---" (1971)
Love (1969)
McDermott and others (1968)

tion cost. One of the largest slurry pumps constructed at present is 1750 horsepower, whereas earlier commercial coal pipelines used motors of 450 horsepower.

Another advantage of the reciprocating pump is that they can work effectively under abrasive conditions. In a centrifugal pump, the slurry must be conveyed through the body of the pump, whereas in a reciprocating pump water can be foreced into the face of the piston and plunger so that slurry contact with the components of the pump is minimal.

Pipe. Slurry pipe generally has a higher carbon content than pipe used for oil transmission.

Pipelines conveying a highly abrasive material such as iron ore have to be rotated at intervals. Coal is from one-quarter to one-half as abrasive as iron more, thus pipe wear is not as serious a consideration.

Preparation and dewatering plant. The cost of the slurry preparation and subsequent drying, if required, may be an added cost of slurry transportation if the coal is marketed in the dry state.

Slurry Pipelines in Northern Areas

The cold northern climate poses some unique problems to slurry pipeline construction and operation.

Water. The scarcity of water in northern, particularly arctic areas in the winter may require consideration of seasonal operation, a smaller water supply line from a large water source, or recirculation of water.

Permafrost. Normally pipelines are buried except over river crossings or when traversing a mountainous terrain. Burying a pipeline in permafrost may cause complications. Lachenbruch (1970) studied the effects of a hot oil 48 inch diameter pipeline buried in permafrost and concluded that a cylindrical thaw region 20 to 30 feet in diameter would occur after several years of operation. He also concluded that insulating the pipe would increase the oil temperature rather than decrease the thawing. A similar effect, although much less severe, may result if a slurry pipeline is buried. Heat is generated from the abrasion of the slurry along the pipe and pump walls. Although this heat generation rate may not be high, it will have to be accounted for.

Climate. Slurry pipeline operation could be either seasonal or year round. A seasonal operation would avoid the severe winter temperatures but would have to be proportionately larger than a year-round system.

A year round pipeline system would have to be insulated and/or heated to prevent freezing. No long distance commercial slurry pipelines exist in areas where freezing of the line is a problem. Many short distance pipelines exist in cold areas, but these are either heated or the exposure time to cold temperatures is minimal.

ROADS AND TRUCKS

Compared to other modes of bulk transport, trucking is considered the most flexible. In the development of a system to move large amounts of bulk materials over long distances, the establishment of a road and truck system normally involves a lower capital cost, but a higher operating cost than other systems. Where the belt conveyor and slurry pipeline are designed for a maximum amount of material to be transported, a road-truck system can be expanded simply by the addition of more road and more trucks. Since each truck is self propelled unit requiring one or two operators, the labor costs and maintenance costs are higher than for other systems. Roads are not as limited to grade as are railroads. Railroads generally are restricted to grades close to 2 percent where roads can be constructed with grades of 8 percent or more. To move material from the same source to the same destination in an undulating terrain, a railroad would then normally be longer than a road.

Trucks

There are two major classes of trucks for the movement of bulk materials: on-the-highway trucks and off-the-highway trucks. Off-the-highway trucks with capacities up to 250 tons are presently being used, and trucks with capacities greater than 300 tons are anticipated in the near future. These large trucks are normally used for short hauls in open pit mines or in large construction projects. On-the-highway trucks can be of two types: those operating on public roads and those operating on private roads. Trucks operating on public roads are subject to width, length and weight restrictions. In Alaska, the weight restriction is 18,000 gross pounds per axle for single wheels, and 20,000 gross pounds per axle for dual wheels (Alaska Department of Highways). The maximum allowable truck width is 8 feet and the allowable length is 70 feet. In the Yukon Territory, the maximum allowable gross weight per truck is 95,000 pounds (Baker, 1971). As a result of these restrictions, truck payloads normally range from 25 to 30 tons.

On-the-highway trucks which operate on private roads are not normally subject to restrictions, except those imposed by the condition of the roads on which they operate. A trucking system which has the advantage of greater labor and truck utilization than on public roads operates at a phosphate mine in Idaho. Each truck hauls three 70 ton capacity trailers a round trip distance of 31 miles (Atwood, 1971).

Northern road construction

Road construction over permafrost requires the same special consideration as railroad construction. Damage to the insulating tundra layer will cause rapid degradation of the road bed and adjacent area. Protection of this insulation layer can be accomplished by covering the tundra with large amounts of gravel or sand fill material. (Foam insulation is presently being considered for use in road beds to reduce the amount of fill required.) Stokes (1971) suggested that a 5 foot deep fill layer over high center polygons and a 6 foot deep fill over low areas makes an adequate roadway on the North Slope which requires little maintenance. Drainage is another important factor in road location. Ditching is not always possible because it may result in erosion of the permafrost. An adequate number of drainage culverts are necessary to prevent water from melting the permafrost beneath the road beds. Figure 11 is a cross section of a typical road constructed on permafrost on the North Slope.

Construction Costs

The cost of a road varies with the types of road required. A winter road can be constructed at a very low cost but it can only be utilized for a portion of the year. In most cases, there is a tradeoff between the initial road construction cost and the yearly maintenance cost of the road and trucks. Table 9 is a summary of the construction costs of various types of northern roads.

BELT CONVEYORS

Belt conveyors have been used extensively for the movement of bulk materials since the late 19th century. At the present time, belt conveyors are probably handling more material than any other system. An overland conveyor system is usually composed of a number of single flight conveyors. The length of a conveyor system appears to be unlimited, but the length of a single flight is limited by the maximum tension rating of the belt. Until recently, conveyor belts were composed of rubber with a cotton carcass. New developments such as the nylon belt, the steel cord belt and the cable belt have increased belt tension ratings, which

Table 9

Types of Roads and Construction Costs

Road	Description	Construction Cost (per mile)
1. Minimal Road Class I	Clearing of existing trails	$500-$700
2. Minimal Road Class II	Clearing surface vegetation Natural earth surface	$2000
3. Minimal Road Class III	Minimal cut and fill	$4000-$5000
4. All Weather Track	Filling, drainage systems Ferries at river crossings	$25,000-$50,000
5. Earth Road	Capable of handling heavy truck traffic in good weather	$150,000-$250,000
6. Permanent Earth Road	All traffic - all year all crossings bridged	$300,000-$500,000
7. Tarred or Surfaced Road	All traffic at high speeds all year	$500,000 or greater

Source - Ehrlich (1969)

have permitted increases in the length of single flight belt conveyors.

In nylon and steel cord belts, the nylon or steel cords act as the tension members. The cable belt conveyor consists of a belt held on two parallel wire ropes, and drive power is transmitted down the ropes, instead of through the belt. The cables and belt are supported by cable sheaves instead of the idlers which are used for the support of nylon and steel cord belts.

Before the development of these stronger belts, it was unusual to have a single flight conveyor more than one mile in length. A conveyor manufacturer has reported that within the next year, two conveyors, each of which will be 5 miles between head and tail pulleys, will be installed (B.F. Goodrich, 1972). New drive concepts are being tested to permit longer single flight conveyors - up to 50 miles between centers (B. F. Goodrich, 1972).

The main advantage of longer single flights is in the reduction of transfer points. Transfer points are normally the areas where spillage occurs most frequently. Transfer points cause increased wear on the belt due to the impact of the material, increased chute wear, dust problems, possible sources of plugging, and a greater horsepower requirement due to the added height required.

Conveyors are widely accepted as a transportation vehicle for two main reasons: ease of operation and relatively low maintenance costs. However, long distance conveyor systems are inflexible: that is, they are designed for a specific tonnage, source and destination. Also, conveyors create a surface obstruction which is more apparent than obstructions caused by other transportation modes such as roads and railway. Table 10 is a list of some existing conveyor systems.

Construction and Operation in Cold Weather

The primary consideration in the construction of a belt conveyor system is belt alignment. A misaligned belt will result in excessive belt wear and possibly spillage. Alignment will be a more serious problem in northern areas because of the land shifts caused by frost action. Stability can be attained with the use of sunken pilings to support the structure, but this will be expensive.

Belt conveyors have operated successfully in temperatures below -45° F and belts can be designed to operate in temperatures as low as -67° F. (Goodyear, 1972). Conveyors which are operated in cold climates are normally shut down only for short periods of time. When material is not being transported, the conveyor continues to run, but at a creep speed,

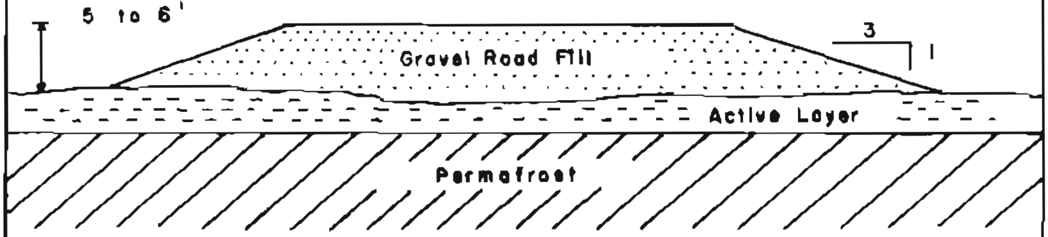


FIGURE 11
Cross Section of a Road
Constructed over Permafrost

Source – Stokes (1971)

Table 10

Some Existing Conveyor Systems

Location	Belt Width (inches)	System Length (miles)	Max. Single Flight Length (miles)	Capacity (millions tons per year)	Speed (feet per minute)	Source
Western Kentucky	42	12.5	9	7	800	Greene (1971)
West Virginia	42	5.1	5.1	4.4	650	Workman (1969)
New Caledonia	32	8.0	8.0	4.6	800	Bocchietti (1972)
Green County, Pa.	36/42	4.5	1.2	N.A.	600	Draper (1966)
Marcona, Peru	36	9.5	3	N.A.	590	Yu (1971)

substantially lower than the normal operating speed.

In areas where snow and wind are common, protective covering of the conveyor is a necessity. Bearings, drives and other mechanical equipment must be designed to withstand extreme temperatures, and must be kept well lubricated with low temperature lubricants. Problems will occur during the freeze-up or thaw times of the year when temperatures are near the freezing point. Ice may build up unevenly on the belt and idlers, which may cause belt run-off and eventual spillage (Oszter, 1965). A conveyor operating in cold weather should be either completely unheated, or completely heated. Problems occur most frequently when freezing takes place on the belt conveyor. Horsepower requirements are normally greater for cold weather operations due to increased friction resistance. A friction multiplier, which accounts for the resistance to idler rotation, used in conveyor belt design at -40° F is three times the multiplier used at 30°F (Conveyor Equipment Manufacturers Assoc., 1966).

Construction Cost

Capital cost estimates of various widths of conveyor belts are shown in Table II. These costs are probably representative of conveyors constructed in southern areas where problems associated with cold temperatures are minimal.

Total capital and operating cost of belt conveyors vary from $.02 to $.07 per ton mile, depending on the amount of material transported and the annual operating time (Maddex, 1971).

SHIPPING

For the movement of large amounts of coal from the North Slope of Alaska, stockpiling and handling at both Japan and the northwest coast of Alaska would be minimal if year round shipping could be achieved. However, the problems of year round shipping to northwestern Alaska may become paramount over the alternative extra stockpiling and handling problems. To date, there has been no successful navigation north of the Bering Strait in winter, even by icebreakers (Lyons, 1972). Alternatives to year round shipping exist, but these may be less satisfactory to the supplier and receiver. Some of the possible alternatives are:

1) Shipment of all the coal to Japan during the ice free season. This alternative may have a negative effect on the marketability of the coal. Large stockpile areas would be re-

Table II

Belt Conveyor Costs
(short distance only)

Belt width (inches)	Idlers 4 & 10 ft. spacing $ per lin.ft.	Belting 1000 ft. $ per lin.ft.	Support Frame and Decking $ per lin.ft.	Installation and Training $ per ft.	Total Installed $ per ft.
36	25-37	25-50	40	10	100-140
48	30-43	35-70	60	15	140-150
60	35-48	45-90	85	20	185-245
72	40-53	55-110	100	25	220-290
84	45-58	65-130	120	30	260-340
96	50-65	75-150	140	35	300-390

Source - Maddex, P. J. and W. F. Haddon (1971) quired in both Alaska and Japan. Assembling enough ships for the short season and arranging haul contracts for the remainder of the year for supplier owned ships may be difficult.

2) Shipment of the coal to a transhipment point during the ice-free season, then from this point to Japan for the remainder of the year. This alternative requires the duplication of harbors and an increase in the ship loading and unloading costs, however, ships could be employed year round and Japan would have a more consistent coal delivery.

3) Same as No. 2 except coal would be delivered simultaneously to Japan and the transhipment point during the ice-free season. Japan would then have a consistent coal delivery throughout the year. A possible problem of alternatives 2 and 3 may be the inequality in the number of ships required between the ice-free season and the remainder of the year. The difficulty of arranging hauling contracts or leasing ships may occur, but to a much lesser extent than in alternative No. 1.

4) Extension of the shipping season: A renewed emphasis has been placed on arctic shipping as a result of the successful voyage of the 108,000 ton dwt. ice-breaking tanker, "Manhattan", through the Northwest Passage in September of 1969. This voyage proved that the technology exists to build ice-breaking carriers and that winter shipping by this method is operationally feasible. It may be a few years before it can be determined if winter shipping through ice is economically feasible.

The first consideration for winter shipping is probably the capital cost of the ships. German (1971) estimates the incremental cost of an icebreaking carrier to be 40 per cent over the cost of a conventional vessel of the same size. This incremental cost is for ice conditions which might be comparable to the first year ice which would be encountered on the northwest coast of Alaska north of the Bering Strait. The next consideration would be additional operating costs. Insurance costs would be very high at least for the first few years of winter shipping. Ice-breaking ships would encounter pressure ridges that can be up to 20 feet in height and five times as deep beneath the water. An aerial reconnaissance of the Bering Strait was made in May of 1968 by the U. S. Coast Guard (Polar Transportation Requirements, 1968) to view the area in terms of sea transport. One of the conclusions made from this study was that, "travel through the Bering Strait in the event of closed leads is impossible without passing through pressure ridges." The ship must be able to pass through these ridges without stopping, or travel time would be excessive. German (1971) gave a hypothetical example where a ship had to stop and ram an ice ridge once every 20 miles, then regain its travelling speed of 8 knots through the ice. The result was an increase in the voyage time of 54 per cent.

Another consideration is the extent of ice-breaker support that would be required for winter shipping. A Coast Guard study (Polar Transportation Requirements) estimated the user cost of such an ice-breaker would be $22,500 per day.

Terminal facilities in the arctic require special innovations. Underwater pipelines would be exposed to ice gouging. Bubbling systems for piers and wharves have been tested in Tuktoyaktuk on the arctic coast of Canada (Inee, 1963) and in Thule, Greenland (Dehn, 1972). These bubblers worked effectively against ice formation; however, Dehn (1972) observed that when a wind blew in the wrong direction, the ice was pushed up against the wharf. This phenomenon can also occur in an open channel broken by an icebreaker. A wind can shift the sea ice together and close the channel completely.

The Soviet policy at present is to use icebreakers to serve locations in northern Siberia for 1 ½ months, thus extending the shipping season from 2 ½ months to 4 months (Armstrong, 1970). Up to the present time, no ship greater than 10,000 tons dwt. appears to have been used for the Northern Sea Route. The shallow waters of the continental shelf in this area would present difficulties to larger ships.

The cost of shipping North Slope coal in ice conditions was not developed in this study. It is the opinion of the author that winter shipping in this area has potential, but that cost estimates of this shipping could only be made properly after more information on the ice conditions becomes available, and a feasible harbor design has been developed.

In the analyses in the following chapter, 100,000 ton dwt. ships were used for the computation of shipping costs. This size of ship was selected as a trade-off between economy of scale (Figure 12) and the draft of the vessel (Figure 13). The draft of the ship is an important consideration due to the shallow waters along the northwestern coast of Alaska.

The ocean freight rates for coal from the east coast of the United States to Japan vary from $3.70 to $4.50 per ton for single trips (International Coal Trade, 1972). Single or spot trips will generally be higher than for long term contracts. Cunningham (1972) estimates the cost of shipping coal from Vancouver to Japan ranges from a low of $2.25 per ton for 100,000 ton dwt. ships to a high of $3.25 per ton for 50,000 ton dwt. ships.

Barging

Tug and barge combinations for the movement of bulk materials have traditionally been confined to inland waterways and coastal areas. It has only been in the last few years that ocean barge developments have become significant. The main reason for the relatively slow progress in tug-barge ocean application was the difficulty in developing a method of

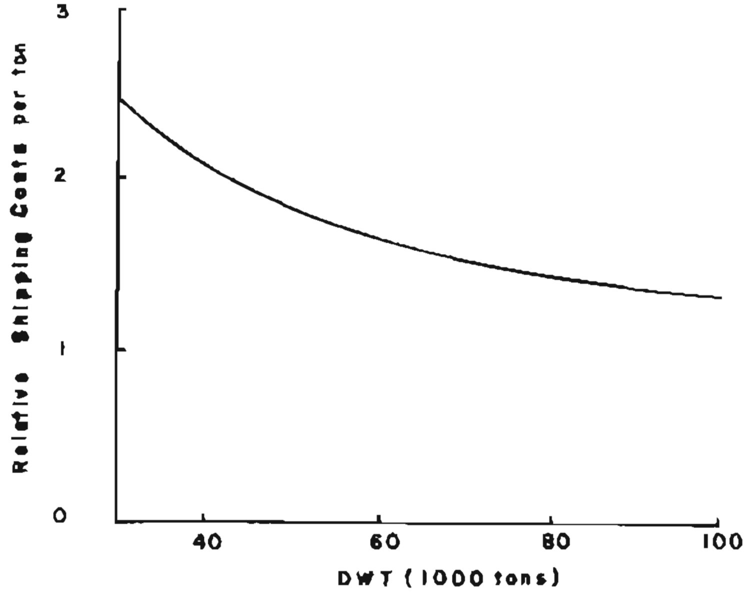


FIGURE 12
Ship Operating Cost vs Ship Size
Source Waugh (1971)
Sasadi (1972)

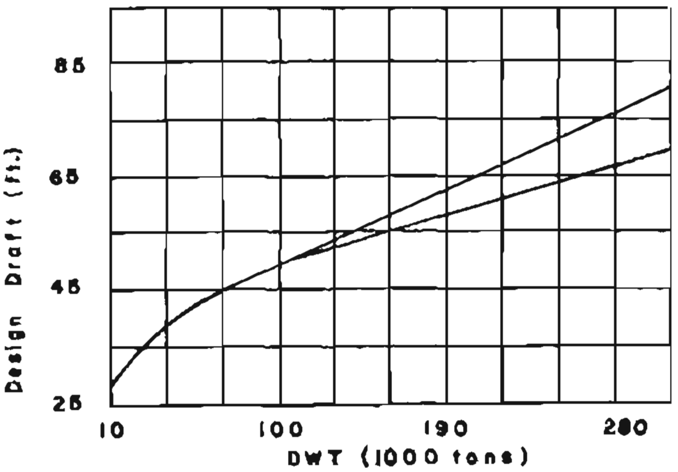


FIGURE 13
Ship Draft vs Ship Size
Source-Kolsch (1971)

coupling the tug and barge together.

Barges up to 30,000 tons dwt. are presently being used in the Gulf of Mexico for the shipment of bulk commodities between ports in Florida and Texas.

The use of a trans-ocean tug barge system for the movement of coal from northern Alaska has a number of advantages over self propelled ships.

1) Crew - Tugs require smaller crew than ships:approximately 10-12 versus 40 or more for ships.
2) Terminals - A tug-barge system can operate in much shallower waters than a ship, consequently, less elaborate harbor facilities are required.
3) Utilization - With the use of extra barges, loading and unloading can be accomplished when the tug is not in port. The only tug port time required would be the time required to change one barge for another.

There are two major disadvantages of tug-barge transport. Tug-barge combinations have a relatively slow cruising speed so the turnaround time is higher than that of a ship. Secondly, tugs are restricted to the ice free season.

The capital costs of tugs and barges are lower than ships mainly because of their relatively simple design. This advantage may be partly offset by the higher insurance costs associated by tug-barge transport. Insurance costs for barges in Alaska are among the highest in the world (Parker, 1972).

In the analyses in the following chapter, 60,000 ton dwt. barges were used to compute the shipping costs. There are no barges of this size presently being utilized, but it is anticipated that technological developments will make construction and operation possible in the near future.

HARBORS

If the North Slope coal is to be transported to Japan, it will be necessary to establish a port site or sites in Alaska and have adequate loading facilities for ocean going ore carriers at these sites.

Natural deep water ice free harbors exist in the southern areas of Alaska, but these harbors are at least 600 miles from the northern coal fields. On the tip of Cape Darby on Golovnin Bay, water depths of 60 feet exist close to shore (C. and G.S. Survey map 9302). This site is approximately 380 miles from the northern coal fields. Also on the Seward Peninsula is the natural harbor of Port Clarence, which is between 40 and 45 feet deep. Port Clarence has a good potential for harbor development, but would require dredging if large ocean vessels were to be used. Its usefulness to the northern coal deposits is again limited by the distance between the coal and the harbor. As previously noted in Chapter II, no natural harbor exists in Alaska north of Port Clarence.

A potential site for the construction of an artificial harbor close to the coal is at the mouth of Ogortoruk Creek, south of Cape Thompson. At this site, the shoreline is fairly flat, and the sixty foot water depth is closer to shore than at most points on the northwest coast. This potential harbor site was used in the analysis of several transportation systems in Chapter IV.

The information available on the seabottom of the Northwest coast indicates that bedrock is at or near the surface of the sea floor. The general cost of removing overburden (sediments) from the seafloor is from $0.40 to $2.50 per cubic yard, while the cost of blasting and removing rock from the sea floor normally ranges from $15.00 to $25.00 per cubic yard (Kolsch, 1971). An excavation close to shore and a channel to this excavation large enough for large ore carriers would require the removal of approximately 10,000,000 cubic yards of material. One estimate of a deepwater Arctic Port was 500 million dollars (Moreau, 1970). A nuclear device was considered for the excavation of an artificial harbor at the mouth of Ogotoruk Creek. However, the ecological consequences of this detonation were determined to be long lasting, and the projected movement of materials through the harbor was not sufficient to warrant the expenditures required for its construction. At the present time, a plan such as this would have considerably more opposition. It would probably have to be a national emergency before such a method could be employed.

It is doubtful that the exploitation of coal deposits alone could carry the economic burden of the construction of an artificial harbor by conventional methods.

The exclusion of an artificial harbor as an alternative does not necessarily rule out shiploading in this area. Other methods presently in use in other areas are:

1) Structural steel, concrete, or earth filled piers to deeper water.
2) An artificial island in deep water to act as base for smaller lighter craft from shore.
3) A slurry pipeline from shore to a moored vessel in deep water.
4) The use of lighter craft to a moored ship and loading to the large vessel in open water.

Piers

The northwest coast of Alaska is an area of extreme ice activity. While it may be possible to design and construct steel and/or concrete piers to withstand the ice pressures, this will be accomplished only after intensive experimentation. Such piers do exist in southern areas, but the ice problem in these areas is either minimal or non-existent.

An earth filled pier three miles long would not be without serious problems, such as wave and ice erosion and perhaps movement by the ice. However, this type of construction would probably be able to cope with the ice pressures more easily than other types. An earth and gravel filled pier about one mile long has been designed for a fluorite mine near Port Clarence, where winter ice conditions are a major design factor. The projected cost of this pier is between 10 and 15 million dollars (Sheardown, 1972). The design and cost of an earth and gravel filled pier in the Cape Thompson area are contained in Appendix C.

Artificial Island

An artificial island in deep water would require large amounts of fill material. This fill material could either be transported from shore or seabottom by pipeline, or by barge from shore. This island would also be vulnerable to wave and ice erosion.

A 50 acre artificial island, connected to shore by a three mile long causeway has been constructed in Vancouver, B.C., for the movement of coal from Japan (Singhal, 1971). Preliminary designs have been made for a 300 acre island three to four miles from shore in the Delaware Bay area for the stockpiling and loading of coal and iron ore ("Zapata Plans---", 1971). In the Beaufort Sea, a two acre island has been constructed for an oil drill site ("Imperial Beaufort---", 1972). Although this island has not yet been subject to ice pressures, it withstood severe storms without a significant loss of material (Imperial's Man---, 1972).

A main objection to an artificial island, other than the high initial cost might be the additional handling and equipment required for the lighter craft required to convey the coal from the shore to the island.

Slurry Loading

Slurry Loading is a system which has evolved over the last few years and has operated successfully for iron ore as well as other mineral ores.

A slurry loading system usually consists of a large slurry pond on shore from which the slurried material is drawn by a floating suction dredge, then pumped to the ship offshore by a moored floating pump. The obvious advantage to this system is that neither a harbor nor a pier is required.

It may be possible that a slurry pipeline loading system could be applied to the transportation of North Slope coal. The design of this system would have to include the following considerations:

1) Coal has a specific gravity of 1.5, iron ore has a specific gravity of approximately 5.2, consequently a much higher settling rate. In order to minimize a shiploading time, the unsettled decanted coal fines would have to be returned to a settling pond on shore by another pipeline, then recovered when shiploading is not in progress. This means the additional expense of another pipeline and another settling pond.
2) Ice gouging of the seafloor may damage the pipelines if they were left submerged on the ocean bottom for winter months, but summer storms would probably preclude a floating pipeline.
3) Slurry ponds would freeze to a depth of six feet in the winter months, hence either continued agitation of the pond or dry storage of the coal would be required if an extension of the shipping season were contemplated.

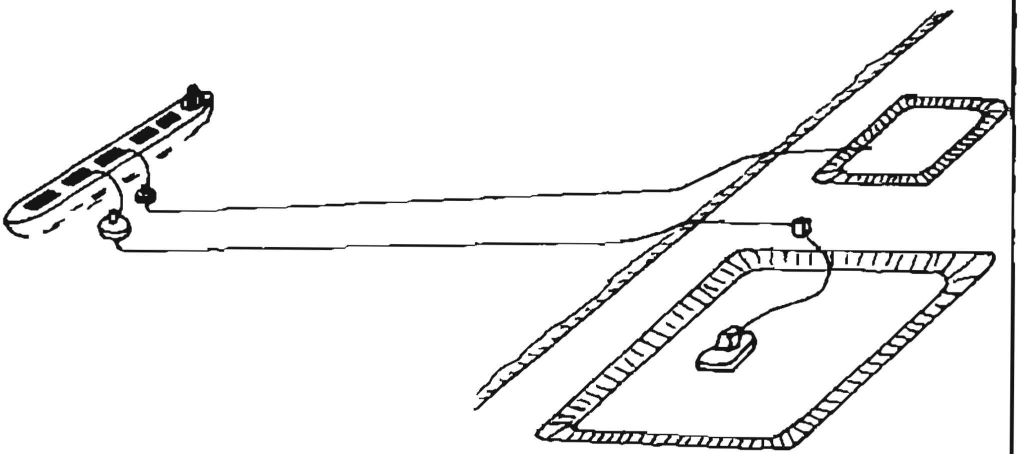
A cost estimate of a proposed coal slurry loading system on the Northwest Coast of Alaska is outlined in Appendix F.

Lighter Craft

Lighter craft are presently used for unloading cargo and yearly supplies at most coastal villages in Northwestern Alaska. For the movement of large amounts of coal, lightering is not practical because of the ship waiting time required, and because of the problems of transferring the coal from the barge to the ship. The waiting problem may be overcome by mooring a number of filled barges in deep water to anticipate the arrival of the ship, however, transfer of the coal would still remain a problem.

In summary,an efficient shiploading system at a harbor close to the coal deposits is a necessity if the north slope coal is to be transported economically.

Several harbor designs have been considered. The two most practical designs appear to be the earth and gravel pier and slurry loading (See Fig. 14). These are the only two designs used in the cost analyses of Chapter IV. Both designs could be applicable to



Slurry Loading - not to scale

Rock and Gravel Filled Pier - not to scale

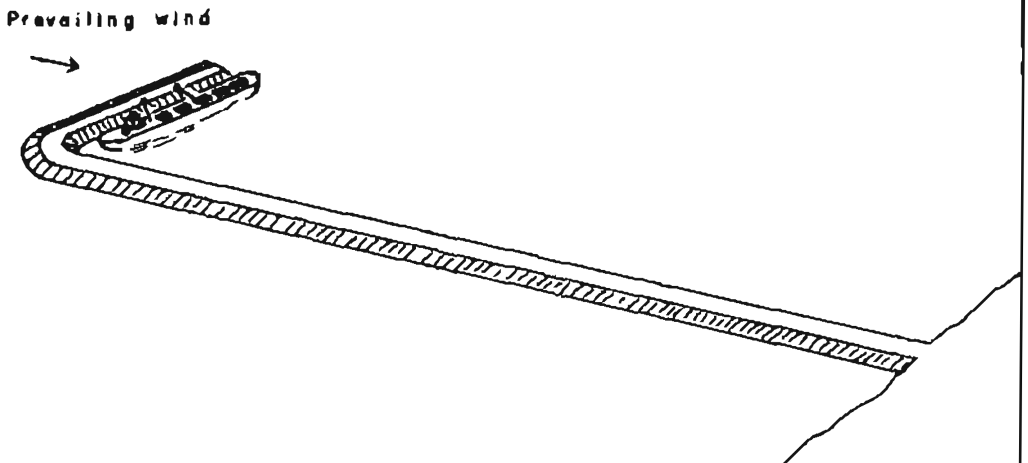


FIGURE 14
POSSIBLE SHIPLOADING METHODS

most areas on the northwestern coast although the earth filled pier would have a length and economic limitation.

COAL GASIFICATION

Introduction

Manufactured gas from coal or coke is not a new concept. Coal gas was used before oil well drilling was developed in Pennsylvania in 1886.

Producer gas and coke oven gas were of considerable importance to industry in the past. Producer gas is made by blowing air or air and steam through an incadescent fuel bed. Producer gas from coke contains several percent methane, some hydrogen, nitrogen, carbon monoxide and carbon dioxide. It has a heating value as high as 180 BTU per cubic foot (Battelle, 1950). Producer gas from coal contains little or no methane and less hydrogen than coke producer gas, consequently, it has a lower heating value. Coke oven gas is the gas released from bituminous coal during the manufacture of coke. This gas has a heating value of approximately 600 B.T.U. per cubic foot.

In 1926, there were 11,000 manufacturers of producer gas, but when natural gas became available at low cost, producer gas manufacture was eliminated.

Renewed interest in the gasification of coal has resulted from projected shortages of natural gas within the next decade. In July 4, 1971, the President's message announced a major new initiative in coal gasification. Under a joint government-industry program, expenditures into coal gasification research would be $30 million per year.

Important considerations which resulted in this expanded program were summarized in a hearing before the Committee on Interior and Insular Affairs on July 27-28, 1971.

1. Natural gas is the least polluting of the fossil fuels.
2. Natural gas can be produced and transported with less environmental degradation than other fuels.
3. For three consecutive years, the amount of gas consumed in the U.S. exceeded new supplies found in the contiguous forty-eight states.
4. Projections of future gas demand are such that every new supply source must be developed, including natural gas by pipeline, importation of liquified natural gas from overseas sources and the gasification of coal.
5. It is important to provide the cleanest fuel to the American consumer using resources that can be produced by American mines and which are secure from the vagaries of foreign suppliers.

Existing Technology

A number of processes can be employed to gasify coal. Most of these processes consist of three stages. The first stage consists of the oxidation of the carbon with steam, producing a hydrogen rich gas.

$$C + H_2O - CO + H_2$$

The second stage consists of the removal of sulfur and other impurities. At the end of the second stage, the resultant gas is a producer gas which has a heating value of about 160 B.T.U. per cubic foot.

The third stage consists of conversion of the low B.T.U. gas to a high methane content, high B.T.U. gas (950-1000 B.T.U. per cubic foot).

$$CO + 3H_2 - CH_4 + H_2O$$

After moisture removal, this gas is considered pipeline quality gas and is very similar in chemical and physical properties to natural gas.

At present, there are no operating commercial plants manufacturing gas from coal. Pilot plants exist in Homer City, Pa., Chicago, Ill., and Rapid City, South Dakota. Each plant employs a different method for converting coal to gas. Plans have been revealed for the construction of two commercial plants in southwestern U.S. for the production of synthetic natural gas from coal (Levene, 1972).

Demand

The U.S. gas supply balance is shown in Figure 15.

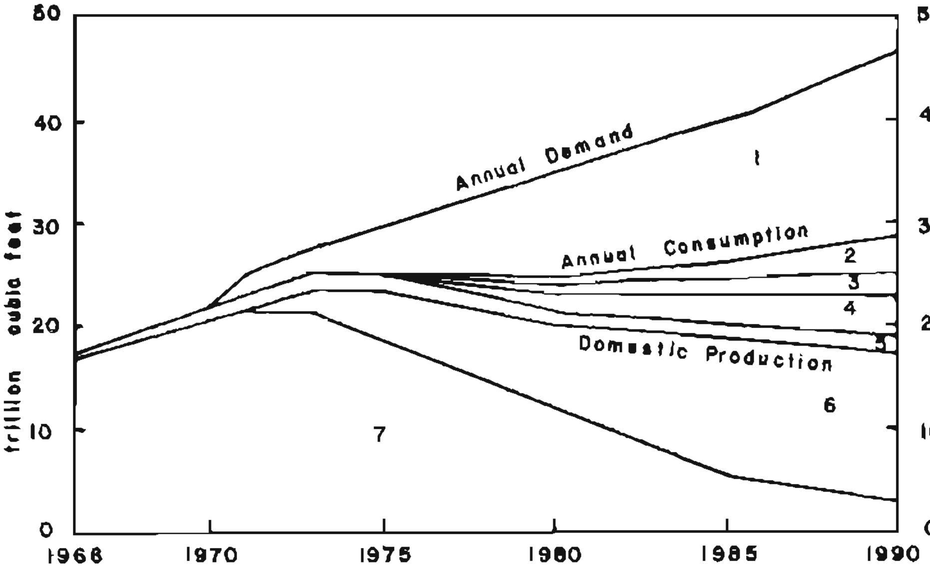
As previously noted, the greatest advantage of natural gas is its clean burning characteristics. Other energy sources listed below have inherent disadvantages or limitations that may restrict their use in the future.

Coal. The greatest disadvantage of burning coal directly is the resultant air pollution from sulfur, fly ash and nitrous oxides.

Nuclear Power. It is anticipated that 10 per cent of the nation's power will be provided by nuclear energy by 1980 and 23 per cent by 1990.

Oil. By 1985, 50 per cent of the nation's oil requirements will be imports from other countries.

Hydropower. Most of the sources of hydropower are being utilized.



1	Unsatisfied demand
2	Gas from coal
3	Gas from Alaska
4	LNG imports
5	Net pipeline imports
6	Production from potential natural gas reserves
7	Production from 1970 reserves

FIGURE 15
U.S. GAS SUPPLY-DEMAND

Source – Levene (1972)

Others. Geothermal sources are not expected to contribute to the nation's energy needs for years to come. Solar energy, tidal energy and other variable sources are limited by the lack of developed technology on the storage of such energy.

Economics

The cost of natural gas at present is approximately 30¢ to 35¢ per thousand cubic feet or 27¢ to 32¢ per million B.T.U. and is increasing with increased demand.

A feasibility study performed in 1967 by Consolidated Coal Company for the Office of Coal Research estimated the cost of a high B.T.U. synthetic gas from coal would cost $.397 per million B.T.U. This study was based on a 250 million cubic foot per day plant production and a coal cost of $1.50 per ton. Costs are broken down as follows:

	¢/million B.T.U.
Lignite cost	16.9
Direct processing	12.6
Capital charges	10.2
Total	39.7

Another study performed by the Institute of Gas Technology for the Office of Coal Research estimated a cost of 46.6¢ per million B.T.U. based on a production of 250 million cubic feet per day and a bituminous coal cost of $3.00 per ton.

Gasification of North Slope Coal

The major part of the North Slope coal is sub-bituminous and non-coking. It is unlikely that much of this low rank coal would be transported for use as steam coal because of its low value and distance to large consumers of power. If this coal were to be used to any large extent, it will probably be converted to another higher value product at or near the mining site.

The recent discovery of oil and natural gas at Prudhoe Bay has resulted in investigations into the design of a natural gas pipeline. This pipeline is reported to be designed for a daily capacity of three billion cubic feet of natural gas ("In the 'Great'---", 1971). The cost of the pipeline will be about five billion dollars. This high construction cost will result in high gas costs to the consumer, high enough to compare with the cost of synthetic gas ("Northwest Project---", 1972).

The construction of the gas pipeline may become an important factor in the economics of developing the North Slope coal reserves. It may be possible that the coal could be gasified at the mine site, then transported to the existing pipeline by a smaller pipeline.

The synthetic gas produced from North Slope coal would have to compete with gas produced from the large coal reserves in the lower western states, which are accessible to existing natural gas pipeline networks. However, it may be possible that gas production could exist in both areas. At the present time, it appears that coal gasification will be the only way that the lower grades of the North Slope coal can become a significant energy source.

CHAPTER IV

TRANSPORTATION SYSTEMS

This chapter contains the results of cost analyses performed on five separate systems used for transporting coal from the North Slope of Alaska to Japan (See Fig. 16).

Each of these systems consists of three stages: each stage is treated as a single entity. In most cases, the cost estimate of each stage was performed in three steps: design of the transportation mode, division of each mode into its basic elements, and summation of the costs of these elements. If it was not feasible to break a transportation mode into basic elements, costs were derived from published information on existing systems and adapted to the situation with the use of cost indexes and cost capacity factors. There are several instances where portions of the systems involved designs or methods which have not been proven technically feasible. In these cases, the author assumed that it is likely they would be proven feasible when such a system is required. Also, since the designs of the transportation modes were used only to facilitate cost estimates, some generalizations were made that otherwise may have to be proven experimentally if the mode were designed for actual use.

The cost of transportation was computed under the assumption that the coal producer would bear the total cost of the system. Government sponsorship or additional revenue from other agencies using the transportation system was calculated in the costs in only one case. All total system transportation costs were F.O.B. Yokohama, Japan.

The capital costs of construction and equipment were converted to annual costs based on a 20 year operating period and a 15 per cent rate of return. Twenty years was selected because large capital expenditures in a transportation system would be made only if a long term agreement was made between the supplier and purchaser, especially if this system is exclusive to coal. A fifteen per cent rate of return was used because this is considered the minimum rate which will attract large investments to these coal deposits.

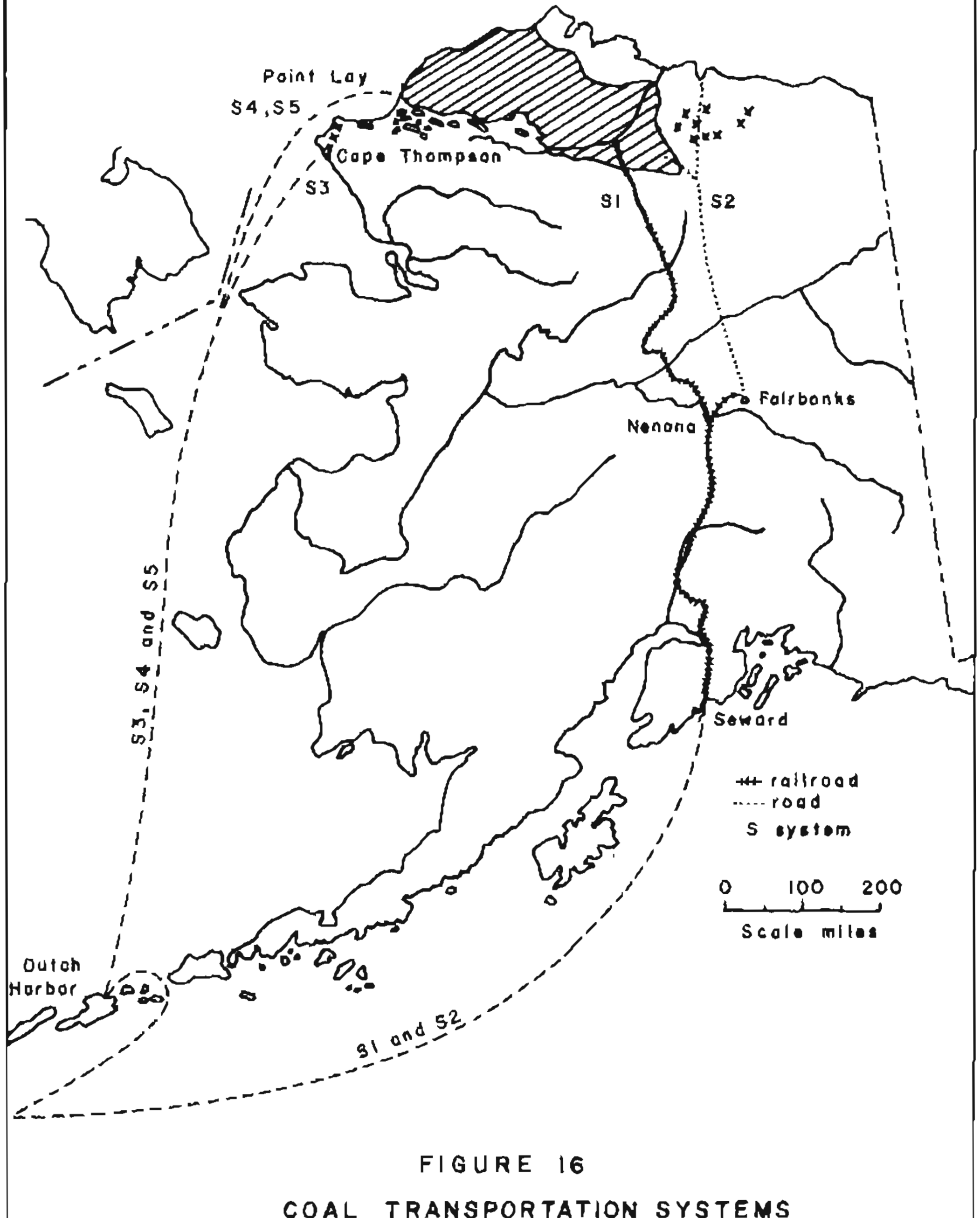


FIGURE 16

COAL TRANSPORTATION SYSTEMS

SYSTEM I

System I consists of a railway which connects a mining area on the eastern portion of the northern coal deposits to the port of Seward on the southern coast of Alaska. This system requires the construction of a 492 mile railroad from the existing Alaska Railroad at Nenana to the coal deposits, and the construction of coal handling facilities at Seward. In this analysis, it is assumed that the Alaska Railroad could bear the additional traffic without significant modification.

Unit trains transport the coal directly from the northern coal fields to Seward without any handling or excess waiting time between the source and destination. Coal is unloaded at Seward, stockpiled, then loaded onto 100,000 ton deadweight ore carriers for year round conveyance to Japan.

Table 12 is a summary of the cost analyses of this system. The analysis and criteria used are contained in Appendix A. Figure 17 is a graphical illustration of the transportation costs of System I.

The total transportation cost to move coal by System I varies from $21.02 per ton for 15,000,000 tons per year to $46.82 per ton for 5,000,000 tons per year. The rail transportation cost is from 80 to 90 percent of the total transportation cost.

If the coal deposit must support the construction of a 492 mile long railroad, then the transportation costs alone are prohibitively high to allow an economically feasible operation. Figure 17 shows that an increase in the number of tons of coal transported over 15 million tons per year does not lower the transportation cost per ton significantly.

Table 12

System I - Annual Costs in Thousands of Dollars
Railway from North Slope Coal Deposits to Seward, Dry Loading,
Shipment to Japan by 100,000 ton dwt. Ore Carriers

Tons Transported Annually (millions)	Rail		Harbor		Shipping		Total System Cost	Total System Cost Per Ton (dollars)
	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	210,763	42.30	4,563	.91	18,069	3.61	233,395	46.82
10	231,104	23.20	6,863	.69	36,139	3.61	274,106	27.41
15	252,505	16.80	9,113	.61	54,208	3.61	315,826	21.02

Tons Transported Annually (millions)	Percent of Transportation Cost		
	Rail	Harbor	Shipping
5	90.5	1.9	7.6
10	84.4	2.5	13.1
15	80.0	2.9	17.1

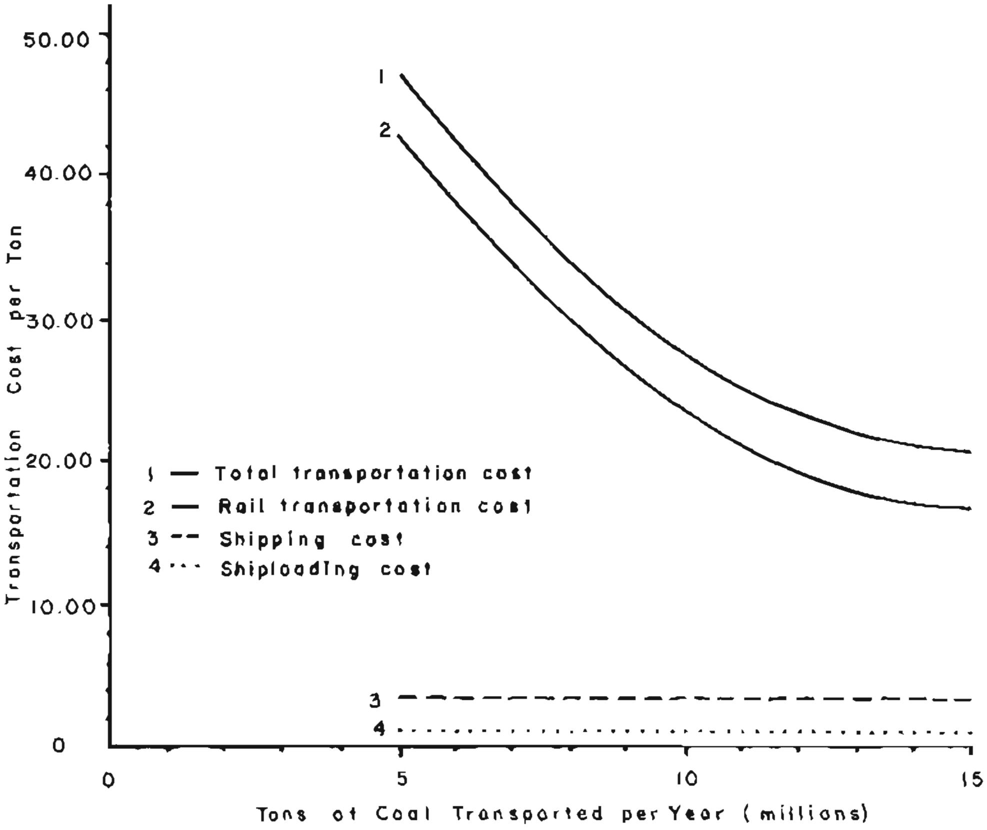


FIGURE 17

COAL TRANSPORTATION COST—**SYSTEM I**

SYSTEM II

This transportation system proposes the use of the road that is to be constructed from Fairbanks to Prudhoe Bay. The coal deposits are reached by travelling 500 miles from Fairbanks on this road, and 100 miles on a secondary road which would be constructed. These two roads supply a linkage to the Alaska Railroad at Fairbanks where the coal is loaded into railway cars and shipped to Seward for futherance to Japan. Since State road weight limitations restricts the use of trucks greater than approximately 25 tons net capacity, 25 ton trucks are used in this analysis.

Annual costs, which are outlined fully in Appendix B were computed only for the transportation costs incurred from the coal fields to Fairbanks.

The cost of ownership and operation of the trucks is a direct function of the tons transported, therefore, if more coal was moved, the annual truck costs would increase accordingly. Consequently, the annual truck cost per ton of coal cannot go below $29.63 On the other hand, if the tonnage transported per year was less than 5,000,000 tons, the road costs would become more significant and the cost per ton of coal transported would increase.

Table 13 is a summary of the coal transportation costs using System II.

To move 5,000,000 tons of coal per year by truck from the North Slope to Fairbanks, it costs $32.69 per ton of coal of which $29.63 per ton is the cost of owning and operating a fleet of trucks. As in System I, this transportation cost is too high to allow an economically feasible operation. The high cost of truck transportation in this System precluded any further investigation into railway costs from Fairbanks to Seward.

Table 13

System II

Truck Transportation from Northern Coal Fields to Fairbanks

5,000,000 tons per year

	Annual Cost
Capital Cost of Trucks	$60,073,020
Operation and Maintenance of Trucks	88,070,400
Road Costs (Capital and Maintenance)	14,770,000
Loading and Unloading (Capital, Operating, and Maintenance)	560,000
Total Annual Costs	$163,473,420

Total Annual Cost per ton = $32.69

Total Annual Truck Cost per ton = 29.63

SYSTEM III

System III involves the movement of coal by an overland system 350 days per year to a harbor near Cape Thompson on the Chukchi Sea. During the ice free season, the stockpiled coal at this port is shipped simultaneously to Japan and to an ice free transhipment port at Dutch Harbor in the Aleution Islands. The purpose of the simultaneous shipment is to maintain a consistent delivery schedule to Japan. The coal shipped to Dutch Harbor is stockpiled until the ice begins to form at the Chukchi Sea port. At this time, the coal stockpiled at Dutch Harbor is shipped to Japan.

Three types of overland systems were considered in this analysis: railroad, slurry pipeline and belt conveyors. Two types of shiploading techniques were also considered: dry loading and slurry loading.

In this system, no definite mining site was established. Instead, costs were computed as a function of the overland distance from the coal source to an ocean port.

In the analysis performed for slurry pipelines, the costs of a secondary smaller pipeline was added to the total cost. Because of the scarcity of an inland winter supply of water in this region, feed water would either have to be recirculated or transported from a large lake or the ocean in order to operate a slurry pipeline year round.

In order to use slurry loading for ship loading, two ponds would have to be constructed on shore, one for the actual loading of the coal to the ship and the second as a settling pond for the fine suspended material decanted from the ship.

Tables 14-19 are the summaries of cost analyses performed for System III. Figure 18 is a graphical illustration of these results. Cost computations and criteria are outlined in Appendices C, D, E, and F.

For the movement of 5,000,000 tons of coal per year, railroad is the most expensive form of overland transportation, belt conveyor is the next most expensive and slurry pipeline, the least expensive. At 15,000,000 tons per year, railroad, belt conveyor, and slurry pipeline transportation costs are very similar.

Overland transportation costs range from a low of $1.35 per ton for 50 miles for 15,000,000 tons to a high of $15.00 per ton for 200 miles for 5,000,000 tons per year,

Slurry loading costs are approximately 50 per cent less expensive than dry loading costs. A significant part of the dry loading cost is the capital cost of a harbor on the shallow coast of the Chukchi Sea.

The cost of ocean shipping, which includes the conveyance of the coal to a transshipment point and furtherance to Japan is $3.57 per ton.

Given the total transportation cost to Japan cannot exceed $10.00 to be economically feasible, then the maximum overland distance in which the coal can be transported can be determined in Figures 18 a, b, and c. For a railroad, this distance ranges from 45 miles to 200 miles depending on the number of tons transported annually. For a slurry pipeline, the distance is from 80 miles to 200 miles and for a conveyor, it is from 70 miles to 200 miles.

The slurry loading costs for System III are the same regardless of the transportation mode from mine to port. This would be true if the coal was stored at the port site in the dry state. Some savings would occur in a slurry loading operation directly connected to an overland slurry pipeline. This savings would be relatively small and probably would not change economic relationship of the different systems.

Table 14

System III - Annual Costs in Thousands of Dollars Railway from Coal Deposits to a Port near Cape Thompson, Dry Loading, Shipment to Japan via a Transhipment Point at Dutch Harbor by 100,000 ton dwt. Ore Ships

Tons Transported Annually (millions)	Rail			Dry Loading		Shipping		Total System Cost	Total System Cost Per Ton (dollars)
	Rail (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	19,917	3.98	15,288	3.06	17,871	3.57	53,076	10.61
	100	38,781	7.76	15,288	3.06	17,871	3.57	71,940	14.39
	200	74,982	15.00	15,288	3.06	17.871	3.57	108,141	21.63
10	50	21,718	2.17	18,940	1.89	35,657	3.57	76,315	7.63
	100	41,858	4.19	18,940	1.89	35,657	3.57	96,455	9.65
	200	82,052	8.20	18,940	1.89	35,657	3.57	136,649	13.66
15	50	23,221	1.54	22,036	1.47	53,613	3.57	98,870	6.58
	100	43,985	2.93	22,036	1.47	53,613	3.57	119,634	7.97
	200	86,982	5.80	22,036	1.47	53,613	3.57	162,631	10.84

Table 15

System III - Annual Costs in Thousands of Dollars
Railway from Coal Deposits to a Port near Cape Thompson, Slurry Loading,
Shipment to Japan via a Transhipment Point at Dutch Harbor by 100,000 ton dwt. Ore Ships

Tons Transported Annually (millions)	Rail			Slurry Loading		Shipping		Total System Cost	Total System Cost Per Ton (dollars)
	Rail (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	19,917	3.98	6,314	1.26	17,871	3.57	44,102	8.81
	100	38,781	7.76	6,314	1.26	17,871	3.57	62,966	12.59
	200	74,982	15.00	6,314	1.26	17,871	3.57	99,167	19.83
10	50	21,718	2.17	10,240	1.02	35,657	3.57	67,615	6.76
	100	41,858	4.19	10,240	1.02	35,657	3.57	87,755	8.78
	200	82,052	8.20	10,240	1.02	35,657	3.57	127,949	12.79
15	50	23,221	1.54	13,674	.91	53,613	3.57	90,508	6.02
	100	43,985	2.93	13,674	.91	53,613	3.57	111,272	7.41
	200	86,982	5.80	13,674	.91	53,613	3.57	154,269	10.28

Table 16

System III – Annual Costs in Thousands of Dollars
Slurry Pipeline from Coal Deposits to a Port near Cape Thompson, Dry Loading
Shipment to Japan via a Transhipment Point at Dutch Harbor by 100,000 ton dwt. Ore Ships

Tons Transported Annually (millions)	Slurry Pipeline			Dry Loading		Shipping		Total System Cost	Total System Cost Per Ton (dollars)
	Pipeline (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	12,064	2.41	15,288	3.06	17,871	3.57	45,223	9.04
	100	19,891	3.98	15,288	3.06	17,871	3.57	53,050	10.61
	200	35,553	7.11	15,288	3.06	17,871	3.57	68,712	13.74
10	50	19,813	1.98	18,940	1.89	35,657	3.57	74,410	7.44
	100	32,750	3.28	18,940	1.89	35,657	3.57	87,347	8.74
	200	58,624	5.86	18,940	1.89	35,657	3.57	113,221	11.32
15	50	28,474	1.90	22,036	1.47	53,613	3.57	104,123	6.94
	100	47,738	3.18	22,036	1.47	53,613	3.57	123,387	8.22
	200	86,265	5.75	22,036	1.47	53,613	3.57	161,914	10.79

Table 17

System III - Annual Costs in Thousands of Dollars
Slurry Pipeline from Coal Deposits to a Port near Cape Thompson, Slurry Loading,
Shipment to Japan via a Transhipment Point at Dutch Harbor by 100,000 ton dwt. Ore Ships

Tons Transported Annually (millions)	Slurry Pipeline			Slurry Loading		Shipping		Total System Cost	Total System Cost Per Ton (dollars)
	Pipeline (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	12,064	2.41	6,314	1.26	17,871	3.57	36,249	7.24
	100	19,891	3.98	6,314	1.26	17,871	3.57	44,076	8.81
	200	35,553	7.11	6,314	1.26	17,871	3.57	59,738	11.94
10	50	19,813	1.98	10,240	1.02	35,657	3.57	65,710	6.57
	100	32,750	3.28	10,240	1.02	35,657	3.57	78,647	7.87
	200	58,624	5.86	10,240	1.02	35,657	3.57	104,521	10.45
15	50	28,474	1.90	13,674	.91	53,613	3.57	95,761	6.38
	100	47,738	3.18	13,674	.91	53,613	3.57	115,025	7.66
	200	86,265	5.75	13,674	.91	53,613	3.57	153,552	10.23

Table 18

System III - Annual Costs in Thousands of Dollars
Conveyor from Coal Deposits to a Port near Cape Thompson, Dry Loading,
Shipment to Japan via a Transhipment Point at Dutch Harbor by 100,000 ton dwt. Ore Ships

Tons Transported Annually (millions)	Conveyor			Dry Loading		Shipping		Total System Cost	Total System Cost Per Ton (dollars)
	Conveyor (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	12,800	2.56	15,288	3.06	17,871	3.57	45,959	9.19
	100	25,600	5.12	15,288	3.06	17,871	3.57	58,759	11.75
	200	51,200	10.24	15,288	3.06	17,871	3.57	84,359	16.87
10	50	16,300	1.63	18,940	1.89	35,657	3.57	70,897	7.09
	100	32,600	3.26	18,940	1.89	35,657	3.57	87,197	8.72
	200	65,200	6.52	18,940	1.89	35,657	3.57	119,797	11.98
15	50	20,200	1.35	22,036	1.46	53,613	3.57	95,849	6.38
	100	40,400	2.70	22,036	1.46	53,613	3.57	116,049	7.73
	200	80,800	5.40	22,036	1.46	53,613	3.57	156,449	10.43

Table 19

System III - Annual Costs in Thousands of Dollars
Conveyor from Coal Deposits to a Port near Cape Thompson, Slurry Loading,
Shipment to Japan via a Transhipment Point at Dutch Harbor by 100,000 ton dwt. Ore Ships

Tons Transported Annually (millions)	Conveyor			Slurry Loading		Shipping		Total System Cost	Total System Cost Per Ton (dollars)
	Conveyor (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	12,800	2.56	6,314	1.26	17,871	3.57	36,985	7.39
	100	25,600	5.12	6,314	1.26	17,871	3.57	49,785	9.95
	200	51,200	10.24	6,314	1.26	17,871	3.57	76,071	15.07
10	50	16,300	1.63	10,240	1.02	35,657	3.57	62,197	6.22
	100	32,600	3.26	10,240	1.02	35,657	3.57	78,497	7.85
	200	65,200	6.52	10,240	1.02	35,657	3.57	111,097	11.11
15	50	20,200	1.35	13,674	.91	53,613	3.57	87,487	5.83
	100	40,400	2.70	13,674	.91	53,613	3.57	107,687	7.16
	200	80,800	5.40	13,674	.91	53,613	3.57	148,087	9.86

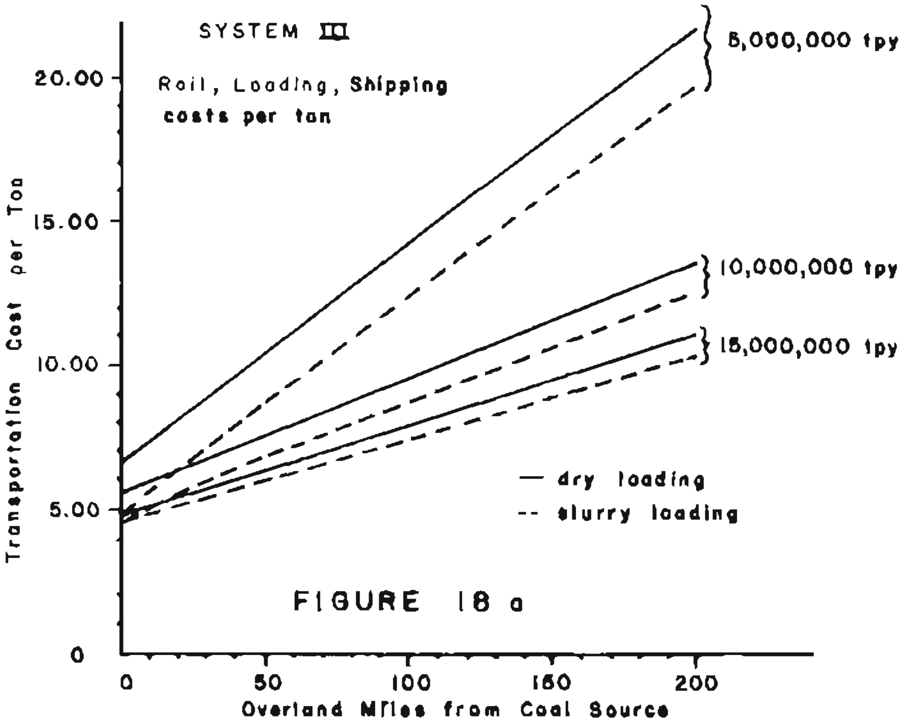


FIGURE 18 a

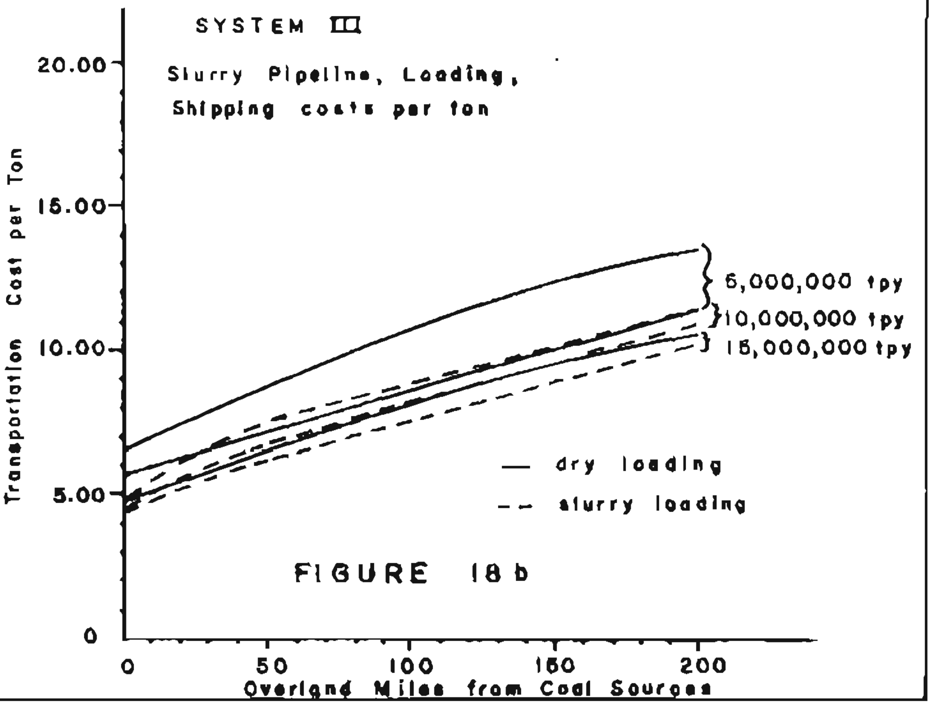


FIGURE 18 b

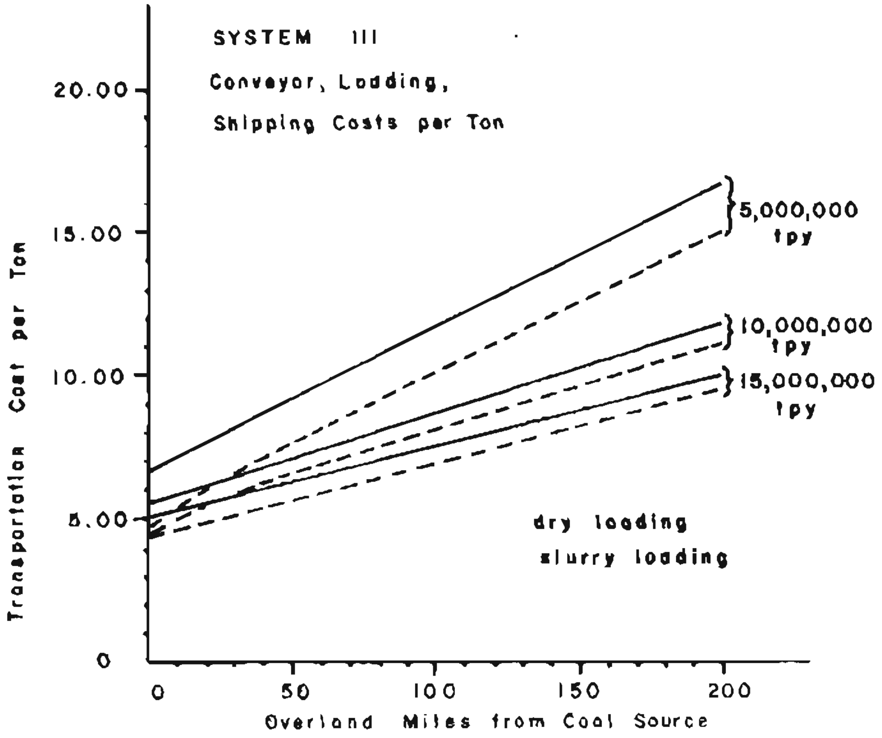

SYSTEM III
Conveyor, Loading,
Shipping Costs per Ton
20.00
15.00
10.00
5.00
0
Transportation Cost per Ton
5,000,000 tpy
10,000,000 tpy
15,000,000 tpy
dry loading
slurry loading
0
50
100
150
200
Overland Miles from Coal Source

FIGURE 18c

SYSTEM IV

In this system, coal is transported overland by either conveyor belt, railroad or a slurry pipeline to a port near Point Lay. At this port, the coal is loaded on 60,000 ton capacity ocean barges by either dry loading or slurry loading.

At Point Lay, forty feet of water depth can be reached approximately two miles from shore. The sixty foot water depth is approximately eight miles from shore. This eight mile distance would preclude dry loading into a 100,000 ton ore ship because of the high cost of a pier facility. In this analysis 60,000 ton dwt. barges are used to move the coal from the Northwestern Coast of Alaska to Japan. The harbor facility for dry loading these barges consists of an earth and gravel pier 1½ miles in length.

The greatest advantage of a port at Point Lay over a port near Cape Thompson is its proximity to the major portion of the coal reserves. A limitation of this port is its shorter ice free season of 75 days compared with a 90 day ice free season at a port near Cape Thompson.

The usefulness of the relatively shallow draft ocean barges in this situation is offset somewhat by their inherent low speed characteristics (average speed of 11 knots versus 16 knots for ships). More tugs and barges are required than ships because of their lower capacity and their slower speed.

During the ice free season, the coal is transported to Japan and simultaneously to a transhipment point at Dutch Harbor. The coal stockpiled at Dutch Harbor would then be transported to Japan by ocean barges when the Point Lay area is non-navigatable due to ice conditions.

The cost of the tug-barge combination depends upon whether or not these quality for the government shipbuilding subsidy of 41 per cent (the U.S. Government allows American shipbuilders in American shipyards a 41 per cent subsidy on merchant ships). Therefore, the tug-barge costs were computed with and without the subsidy.

The transportation costs of the northern coal under System IV are summarized in Tables 20-25. These same costs are shown graphically in Figures 19 a, b, c. The criteria and computation used for System IV are in Appendix G.

The cost of barging from Point Lay to Japan, including a transshipment point is $3.58 per ton if the shipbuilding subsidy is granted or $4.80 per ton without the subsidy. Dry loading costs are lower in System IV than System III because the harbor facilities for 60,000 ton barges are not as expensive as those required for 100,000 ton ships.

Again, if $10.00 is the maximum transportation cost allowed in order to make the operation economic, then the maximum number of overland railway miles varies from 35 miles for 5,000,000 tons per year to 160 miles for 15,000,000 tons per year of coal transported. Similarly, these respective number of miles for slurry pipeline are 65 miles and 155 miles; for conveyor they are 55 miles and 170 miles.

Table 20

System IV - Annual Costs in Thousands of Dollars
Railway from Coal Deposits to a Port near Point Lay, Dry Loading, Shipment to Japan via a Transhipment Point at Dutch Harbor by 60,000 ton dwt. Ocean Barges

Tons Transported Annually (millions)	Rail			Harbor		Barging		Total System Cost	Total System Cost Per Ton (dollars)
	Rail (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	19,917	3.98	12,387	2.48	23,998	4.80	56,302	11.26
						*17,900	*3.58	*50,204	*(10.04)
	100	38,781	7.76	12,387	2.48	23,998	4.80	75,166	15.02
						*17,900	*3.58	*69,068	*(13.82)
	200	74,982	15.00	12,387	2.48	23,998	4.80	111,367	22.27
						*17,900	*3.58	*105,269	*(21,06)
10	50	21,718	2.17	16,004	1.60	47,996	4.80	85,718	8.57
						*35,800	*3.58	*73,522	*(7.35)
	100	41,858	4.19	16,004	1.60	47,996	4.80	105,858	10.58
						*35,800	*3.58	*93,662	*(9.37)
	200	82,052	8.20	16,004	1.60	47,996	4.80	146,052	14.61
						*35,800	*3.58	*133,856	*(13.38)
15	50	23,221	1.54	19,121	1.28	71,994	4.80	114,336	7.62
						*53,700	*3.58	*96,042	*(6.40)
	100	43,985	2.93	19,121	1.28	71,994	4.80	135,100	9,01
						*53,700	*3.58	*116,806	*(7.79)
	200	86,982	5.80	19,121	1.28	71,994	4.80	178,097	11.88
						*53,700	*3.58	*159,803	*(10.66)

* with ship subsidy

Table 21

System IV - Annual Costs in Thousands of Dollars
Railway from Coal Deposits to a Port near Point Lay, Slurry Loading,
Shipment to Japan via a Transhipment Point at Dutch Harbor by 60,000 ton dwt. Ocean Barges

Tons Transported Annually (millions)	Rail			Slurry Loading		Barging		Total System Cost	Total System Cost Per Ton (dollars)
	Rail (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	19,917	3.98	6,314	1.26	23,998	4.80 *(3.58)	50,229	10.04 *(8.82)
	100	38,781	7.76	6,314	1.26	23,998	4.80 *(3.58)	69,093	13.82 *(12.60)
	200	74,982	15.00	6,314	1.26	23,998	4.80 *(3.58)	105,294	21.06 *(19.84)
10	50	21,718	2.17	10,240	1.02	47,996	4.80 *(3.58)	79,954	7.99 *(6.77)
	100	41,858	4.19	10,240	1.02	47,996	4.80 *(3.58)	100,094	10.01 *(8.79)
	200	82,052	8.20	10,240	1.02	47,996	4.80 *(3.58)	140,288	14.02 *(12.80)
15	50	23,221	1.54	13,674	.91	71,994	4.80 *(3.58)	108,889	7.25 *(6.03)
	100	43,985	2.93	13,674	.91	71,994	4.80 *(3.58)	129,653	8.64 *(7.42)
	200	86,982	5.80	13,674	.91	71,994	4.80 *(3.58)	172,650	11.51 *(10.29)

Table 22

System IV - Annual Costs in Thousands of Dollars
Slurry Pipeline from Coal Deposits to a Port near Point Lay, Dry Loading,
Shipment to Japan via a Transhipment Point at Dutch Harbor by 60,000 ton dwt. Ocean Barges

Tons Transported Annually (millions)	Slurry Pipeline			Harbor		Barging		Total System Cost	Total System Cost Per Ton (dollars)
	Pipeline (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	12,064	2.41	12,387	2.48	23,998	4.80 *(3.58)	48,449	9.69 *(8.47)
	100	19,891	3.98	12,387	2.48	23,998	4.80 *(3.58)	56,276	11.26 *(10.04)
	200	35,553	7.11	12,387	2.48	23,998	4.80 *(3.58)	71,938	14.39 *(13.17)
10	50	19,813	1.98	16,004	1.60	47,996	4.80 *(3.58)	83,813	8.38 *(7.16)
	100	32,750	3.28	16,004	1.60	47,996	4.80 *(3.58)	96,750	9.68 *(8.46)
	200	58,624	5.86	16,004	1.60	47,996	4.80 *(3.58)	122,624	12.26 *(11.04)
15	50	28,474	1.90	19,121	1.28	71,994	4.80 *(3.58)	119,589	7.98 *(6.76)
	100	47,738	3.18	19,121	1.28	71,994	4.80 *(3.58)	138,853	9.26 *(8.04)
	200	86,265	5.75	19,121	1.28	71,994	4.80 *(3.58)	177,380	11.83 *(10.61)

*with subsidy

Table 23

System IV - Annual Costs in Thousands of Dollars
Slurry Pipeline from Coal Deposits to a Port near Point Lay, Slurry Loading,
Shipment to Japan via a Transhipment Point at Dutch Harbor by 60,000 ton dwt. Ocean Barges

Tons Transported Annually (millions)	Slurry Pipeline			Slurry Loading		Barging		Total System Cost	Total System Cost Per Ton (dollars)
	Pipeline (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	12,064	2.41	6,314	1.26	23,998	4.80 *(3.58)	42,376	8.47 *(7.25)
	100	19,891	3.98	6,314	1.26	23,998	4.80 *(3.58)	50,203	10.04 *(8.82)
	200	35,553	7.11	6,314	1.26	23,998	4.80 *(3.58)	65,865	13.17 *(11.95)
10	50	19,813	1.98	10,240	1.02	47,996	4.80 *(3.58)	78,049	7.80 *(6.58)
	100	32,750	3.28	10,240	1.02	47,996	4.80 *(3.58)	90,986	9.10 *(7.88)
	200	58,624	5.86	10,240	1.02	47,996	4.80 *(3.58)	116,860	11.68 *(10.46)
15	50	28,474	1.90	13,674	.91	71,994	4.80 *(3.58)	114,142	7.61 *(6.39)
	100	47,738	3.18	13,674	.91	71,994	4.80 *(3.58)	133,406	8.89 *(7.67)
	200	86,265	5.75	13,674	.91	71,994	4.80 *(3.58)	171,933	11.46 *(10.24)

*with subsidy

Table 24

System IV - Annual Costs in Thousands of Dollars
Conveyor from Coal Deposits to a Port near Point Lay, Dry Loading,
Shipment to Japan via a Transhipment Point at Dutch Harbor by 60,000 ton dwt. Ocean Barges

Tons Transported Annually (millions)	Conveyor			Dry Loading		Barging		Total System Cost	Total System Cost Per Ton (dollars)
	Conveyor (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	12,800	2.56	12,387	2.48	23,998	4.80 *(3.58)	49,185	9.84 *(8.62)
	100	25,600	5.12	12,387	2.48	23,998	4.80 *(3.58)	61,985	12.40 *(11.18)
	200	51,200	10.24	12,387	2.48	23,998	4.80 *(3.58)	87,585	17.92 *(16.30)
10	50	16,300	1.63	16,004	1.60	49,997	4.80 *(3.58)	80,300	8.03 *(6.81)
	100	32,600	3.26	16,004	1.60	49,997	4.80 *(3.58)	96,600	9.66 *(8.44)
	200	65,200	6.52	16,004	1.60	49.997	4.80 *(3.58)	129,200	12.92 *(11.70)
15	50	20,200	1.35	19,121	1.28	71,994	4.80 *(3.58)	111,315	7.43 *(6.21)
	100	40,400	2.70	19,121	1.28	71,994	4.80 *(3.58)	131,515	8.78 *(7.56)
	200	80,800	5.40	19,121	1.28	71.994	4.80 *(3.58)	171,915	11.48 *(10.32)

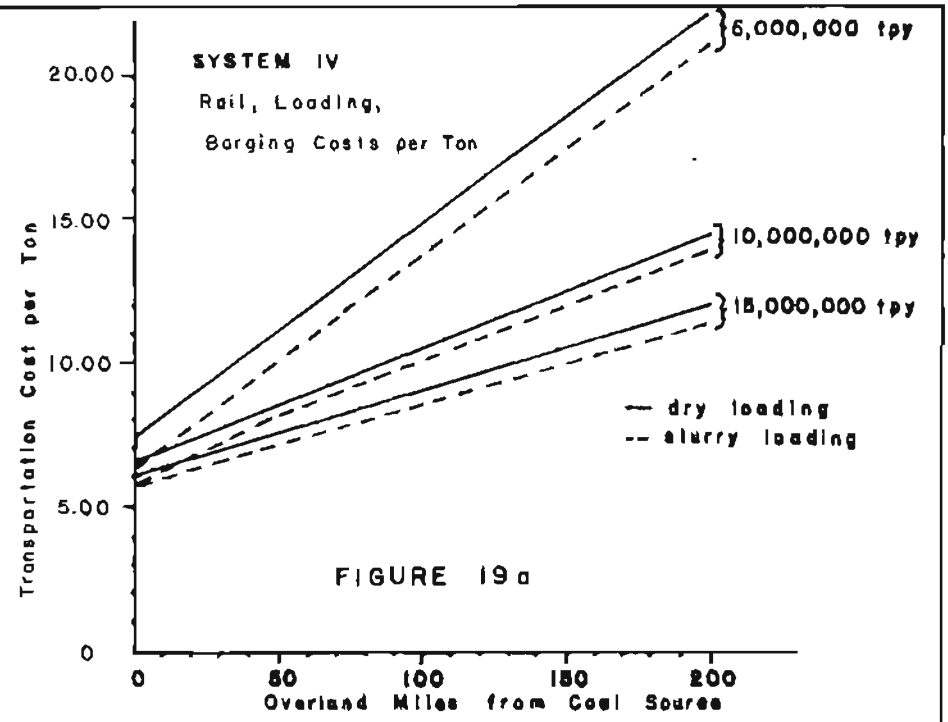
*with subsidy

Table 25

System IV – Annual Costs in Thousands of Dollars
Conveyor from Coal Deposits to a Port near Point Lay, Slurry Loading,
Shipment to Japan via a Transhipment Point at Dutch Harbor by 60,000 ton dwt. Ocean Barges

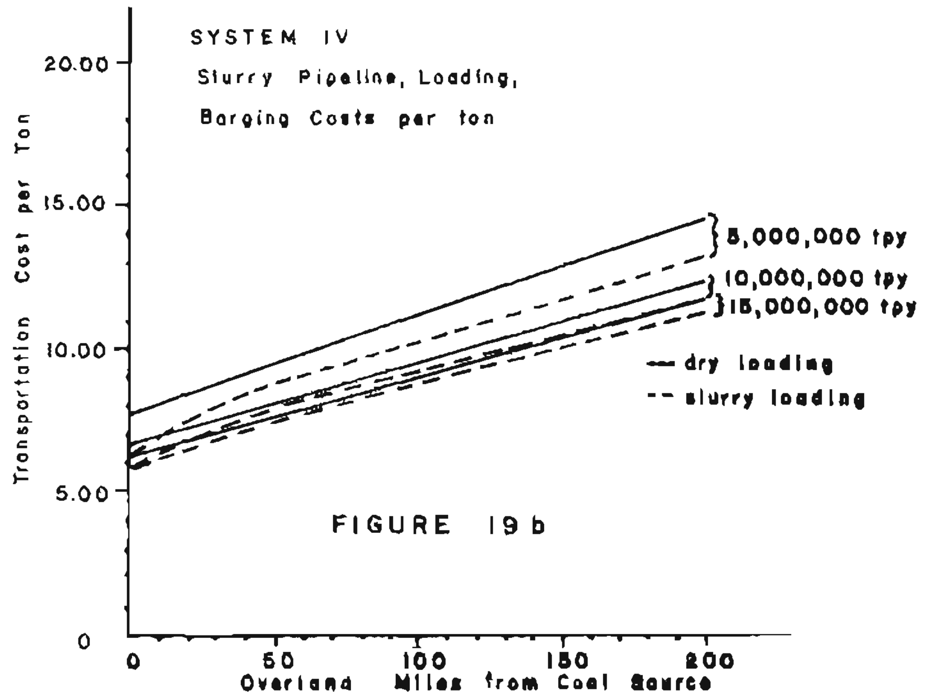
Tons Transported Annually (millions)	Conveyor			Slurry Loading		Barging		Total System Cost	Total System Cost Per Ton (dollars)
	Conveyor (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	12,800	2.56	6,314	1.26	23,998	4.80 *(3.58)	43,112	8.62 *(7.40)
	100	25,600	5.12	6,314	1.26	23,998	4.80 *(3.58)	55,912	11.18 *(9.96)
	200	51,200	10.24	6,314	1.26	23,998	4.80 *(3.58)	81,512	16.30 *(15.08)
10	50	16,300	1.63	10,240	1.02	47,996	4.80 *(3.58)	74,536	7.45 *(6.23)
	100	32,600	3.26	10,240	1.02	47,996	4.80 *(3.58)	90,836	9.08 *(7.86)
	200	65,200	6.52	10,240	1.02	47,996	4.80 *(3.58)	123,436	12.34 *(11.22)
15	50	20,200	1.35	13,674	.91	71,994	4.80 *(3.58)	105,868	7.06 *(5.84)
	100	40,400	2.70	13,674	.91	71,994	4.80 *(3.58)	126,068	8.41 *(7.19)
	200	80,800	5.40	13,674	.91	71,994	4.80 *(3.58)	166,468	11.11 *(9.89)

*with subsidy



SYSTEM IV
Rail, Loading,
Barging Costs per Ton

FIGURE 19a



SYSTEM IV
Slurry Pipeline, Loading,
Barging Costs per ton

FIGURE 19b

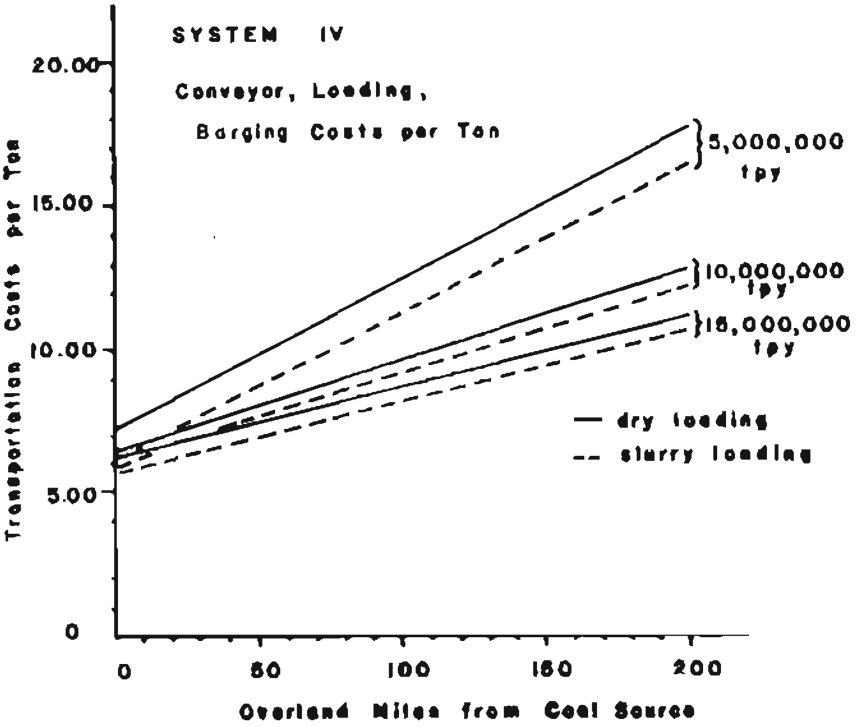

SYSTEM IV
Conveyor, Loading,
Barging Costs per Ton
Transportation Costs per Ton
20.00
15.00
10.00
5.00
0
0
50
100
150
200
Overland Miles from Coal Source
5,000,000 tpy
10,000,000 tpy
15,000,000 tpy
— dry loading
-- slurry loading

FIGURE 19c

SYSTEM V

This system consists of either a railway, pipeline or conveyor system to a coastal point near Point Lay. A slurry pipeline system loads 100,000 ton ore ships anchored 8 to 10 miles offshore.

All loading from this port is accomplished during the 75 day ice free season. The coal is shipped to Japan and to Dutch Harbor simultaneously during the summer months as in Systems III and IV. The analysis of this system is in Appendix H. Tables 26-27 are the results of the analysis, and Figures 20 a, b, c are these results presented graphically.

The total cost of transportation using ships in System V is less than the total cost using barges in System IV when no subsidy on barge cost is considered. When this subsidy is considered, then System V total costs are higher than System IV total transportation costs.

The maximum number of railroad miles the coal can be moved to remain below \$10.00 total transportation cost is 60 miles for 5,000,000 tons per year and 175 miles for 15,000,000 tons per year. For a slurry pipeline, the respective distances are 120 miles and 190 miles, and for a belt conveyor these distances are 85 miles and 200 miles.

Table 26

System V - Annual Costs in Thousands of Dollars
Railway from Coal Deposits to a Port near Point Lay, Slurry Loading, Shipment to Japan via a Transhipment Point at Dutch Harbor by 100,000 ton dwt. Ore Ships

Tons Transported Annually (millions)	Rail			Slurry Loading		Shipping		Total System Cost	Total System Cost Per Ton (dollars)
	Rail (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	19,917	3.98	6,502	1.30	19,576	3.92	45,995	9.20
	100	38,781	7.76	6,502	1.30	19,576	3.92	64,859	12.98
	200	74,982	15.00	6,502	1.30	19,576	3.92	101,060	20.22
10	50	21,718	2.17	10,497	1.04	39,152	3.92	71,367	7.13
	100	41,858	4.19	10,497	1.04	39,152	3.92	91,507	9.15
	200	82,052	8.20	10,497	1.04	39,152	3.92	131,701	13.16
15	50	23,221	1.54	13,975	.93	58,728	3.92	95,924	6.39
	100	43,985	2.93	13,975	.93	58,728	3.92	116,688	7.78
	200	86,982	5.80	13,975	.93	58,728	3.92	159,687	10.65

Table 27

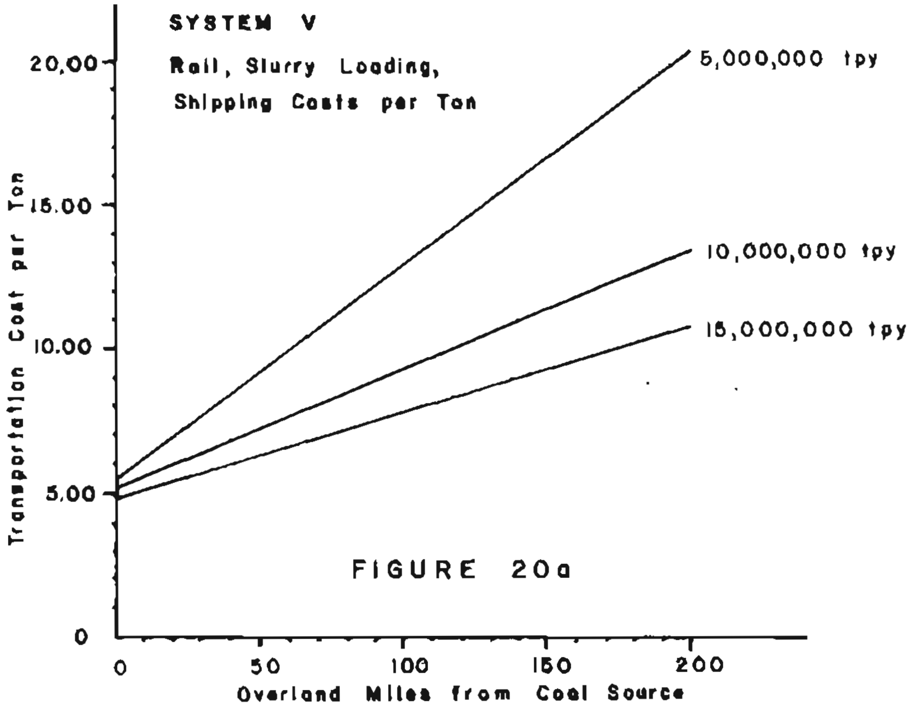
System V - Annual Costs in Thousands of Dollars
Slurry Pipeline from Coal Deposits to a Port near Point Lay, Slurry Loading,
Shipment to Japan via a Transhipment Point at Dutch Harbor by 100,000 ton dwt. Ore Ships

Tons Transported Annually (millions)	Slurry Pipeline			Slurry Loading		Shipping		Total System Cost	Total System Cost Per Ton (dollars)
	Pipeline (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	12,064	2.41	6.502	1.30	19,576	3.92	38,142	7.63
	100	18,981	3.98	6,502	1.30	19,576	3.92	45,059	9.20
	200	35,553	7.11	6,502	1.30	19,576	3.92	61,631	12.33
10	50	19,813	1.98	10,497	1.04	39,152	3.92	69,462	6.94
	100	32,750	3.28	10,497	1.04	39,152	3.92	82,399	8.24
	200	58,624	5.86	10,497	1.04	39,152	3.92	108,273	10.82
15	50	28,474	1.90	13,975	.93	58,728	3.92	101,177	6.75
	100	47,738	3.18	13,975	.93	58,728	3.92	120,441	8.03
	200	86,265	5.75	13,975	.93	58,728	3.92	158,968	10.60

Table 28

System V - Annual Costs in Thousands of Dollars
Conveyor from Coal Deposits to a Port near Point Lay, Slurry Loading, Shipment to Japan via a Transhipment Point at Dutch Harbor by 100,000 ton dwt. Ore Ships

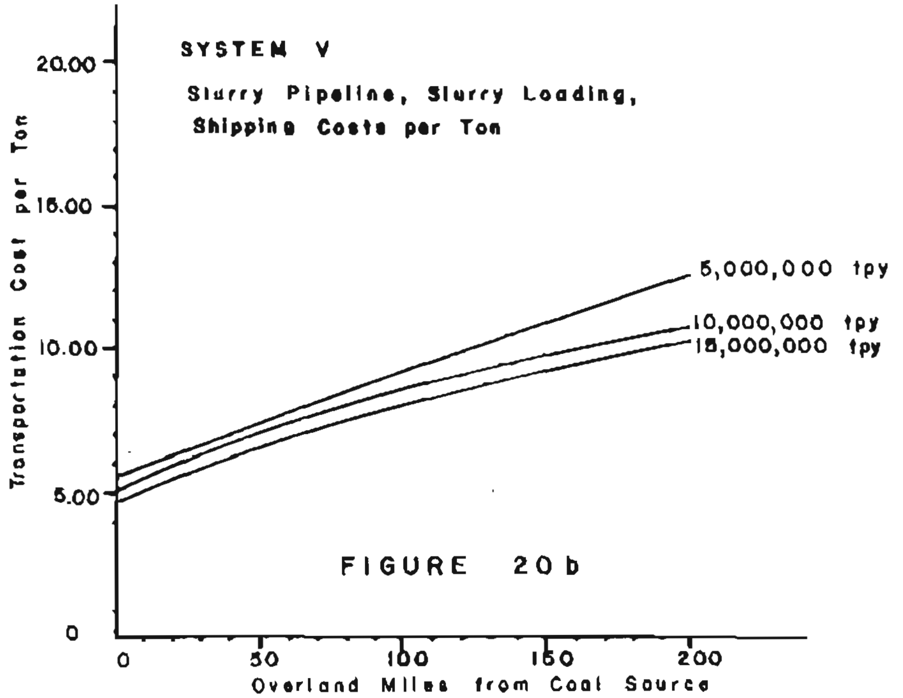
Tons Transported Annually (millions)	Conveyor			Slurry Loading		Shipping		Total System Cost	Total System Cost Per Ton (dollars)
	Conveyor (miles)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)	Total Cost	Cost Per Ton (dollars)		
5	50	12,800	2.56	6,502	1.30	19,576	3.92	38,878	7.78
	100	25,600	5.12	6,502	1.30	19,576	3.92	51,678	10.34
	200	51,200	10.24	6,502	1.30	19,576	3.92	77,278	15.46
10	50	16,300	1.63	10,497	1.04	39,152	3.92	65,849	6.59
	100	32,600	3.26	10,497	1.04	39,152	3.92	82,249	8.22
	200	65,200	6.52	10,497	1.04	39,152	3.92	114,849	11.48
15	50	20,200	1.35	13,975	.93	58,728	3.92	92,903	6.20
	100	40,400	2.70	13,975	.93	58,728	3.92	113,103	7.55
	200	80,800	5.40	13,975	.93	58,728	3.92	153,503	10.25



SYSTEM V

Rail, Slurry Loading, Shipping Costs per Ton

FIGURE 20a



SYSTEM V

Slurry Pipeline, Slurry Loading, Shipping Costs per Ton

FIGURE 20b

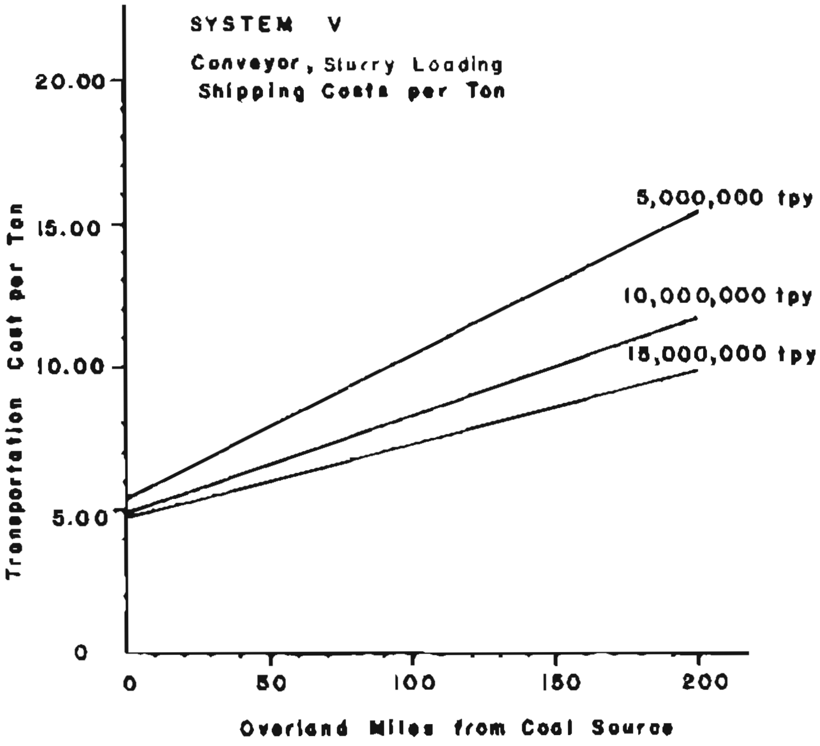

SYSTEM V
Conveyor, Slurry Loading
Shipping Costs per Ton
20.00
15.00
10.00
5.00
0
Transportation Cost per Ton
0
50
100
150
200
Overland Miles from Coal Source
5,000,000 tpy
10,000,000 tpy
15,000,000 tpy

FIGURE 20c

AN ILLUSTRATIVE EXAMPLE FOR SYSTEMS III, IV, AND V

In order to illustrate the transportation costs more clearly, four points in the coal bearing areas were selected and the cost of transporting the coal by various systems were derived from the systems tables and graphs. These costs are only for an annual movement of 5,000,000 tons per year, but the costs for 10,000,000 and 15,000,000 tons per year could be determined readily by using the appropriate tables and graphs.

Costs were also computed for systems without a transhipment point: that is, the movement of all the coal to Japan during the ice free season. This method has been discussed under the section on Shipping. These costs will not indicate marketability or ship lease problems which may occur when all the coal is shipped in such a limited time period.

Figure 21 is a map of the coal area showing the 4 possible coal mining areas. Tables 29 to 32 are summaries of the transportation cost from these mining areas.

Table 29 is a summary of the total transportation cost from point 1 to Japan using System III. The total transportation costs vary from a low of $6.07 per ton of coal using a slurry pipeline, slurry loading and shipping without a transhipment point to a high of $10.10 for a railroad, dry loading, shipping with a transhipment point. All of the total transportation costs are below $10.00 per ton except one, which is $10.10.

The results summarized in Table 30 show that the total transportation costs from point 2 to Japan using System III are very close or above the $10.00 economic limit, but are well below this limit when System IV or V is used. Total transportation costs from point 3 to Japan (Table 31) are above a $10.00 economic limit except in one case using System III, but are below this limit using Systems IV and V. Transportation costs from point 4 (Table 32) using systems IV and V vary from $7.32 per ton to $15.60 per ton. The least expensive method of transportation in this case is pipelining, slurry loading, barging or shipping without a transhipment point.

In summary, this example has shown that if there exists a $10.00 economic limit on total transportation costs, then there is a combination of transportation modes whose total costs are below this limit for each of these possible mining areas for the movement of 5,000,000 tons of coal per year.

Figures 18, 19 and 20 show that transportation costs lower with increased annual movement. The movement of 10,000,000 tons per year or 15,000,000 tons per year means that the total transportation costs from points 1 to 4 to Japan are substantially lower.

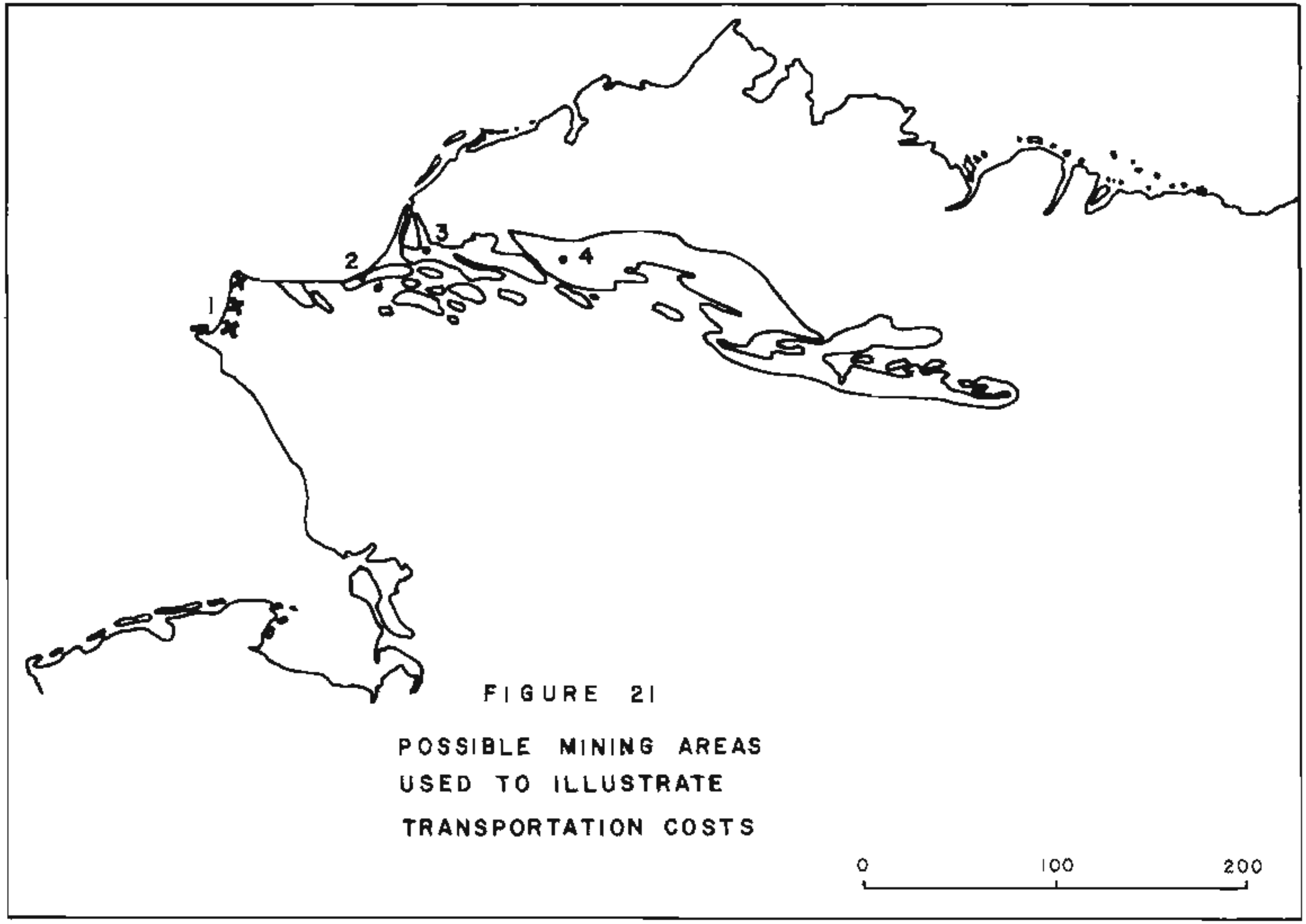


FIGURE 21

POSSIBLE MINING AREAS
USED TO ILLUSTRATE
TRANSPORTATION COSTS

Table 29

Cost Per Ton to Transport 5,000,000 Tons of Coal Per Year from Point 1 to Japan

(see Figure 21)

System Used	Overland Miles (approximate)	Overland	System Elements		Total Transportation Cost	
			Ship Loading	Shipping	Without Transhipment Point	With Transhipment Point
III	45	R	D	Sh	8.21	10.10
		R	S	Sh	7.37	8.50
		P	D	Sh	6.61	8.50
		P	S	Sh	6.07	7.20
		C	D	Sh	7.11	9.00
		C	S	Sh	7.17	8.30

R = Railroad
P = Pipeline
C = Conveyor

D = Dry Loading
S = Slurry Loading

Sh = 100,000 ton Ships
B = 60,000 ton Barges

Table 30

Cost per ton to Transport 5,000,000 Tons of Coal per Year from Point 2 to Japan

(see Figure 21)

System Used	Overland Miles (approximate)	System Elements			Total Transportation Cost	
		Overland	Ship Loading	Shipping	Without Transhipment Point	With Transhipment Point
III	100	R	D	Sh	12.50	14.39
		P	D	Sh	8.55	10.44
		C	D	Sh	9,84	11.73
IV	0	-	S	B	3.52 *(2.88)	6.06 *(4.84)
V	0	-	S	Sh	3.75	5.22

*with subsidy

Table 31

Cost Per Ton To Transport 5,000,000 Tons of Coal Per Year From Point 3 to Japan

System Used	Overland Miles (approximate)	System Elements			Total Transportation Cost	
		Overland	Ship Loading	Shipping	Without Transhipment Point	With Transhipment Point
III	150	R	D	Sh	16.61	18.50
		R	S	Sh	14.97	16.10
		P	D	Sh	10.51	12.40
		P	S	Sh	8.87	10.00
		C	D	Sh	12.41	14.30
		C	S	Sh	11.37	12.50
IV	15	R	D	B	5.52	8.50
					*(4.74)	*(7.28)
		R	S	B	5.10	7.50
					*(4.32)	*(6.28)
		P	D	B	5.32	8.30
					*(4.54)	*(7.08)
		P	S	B	5.80	7.20
					*(4.02)	*(5.98)
		C	D	B	5.02	8.00
					*(4.24)	*(6.78)
		C	S	B	4.60	7.00
					*(3.82)	*(5.78)
V	15	R	S	Sh	5.13	6.60
		P	S	Sh	4.53	6.00
		C	S	Sh	4.73	6.20

*with subsidy

Table 32

Cost Per Ton To Transport 5,000,000 Tons of Coal Per Year from Point 4 to Japan

(see Fig. 21)

System Used	Overland Miles (approximate)	System Elements			Total Transportation Cost	
		Overland	Ship Loading	Shipping	Without Transhipment Point	With Transhipment Point
IV	110	R	D	B	12.62 *(11.84)	15.60 *(14.38)
		R	S	B	12.10 *(11.32)	14.50 *(13.28)
		P	D	B	8.62 *(7.84)	11.60 *(10.38)
		P	S	B	8.10 *(7.32)	10.50 *(9.28)
		C	D	B	10.04 *(9.26)	13.00 *(11.78)
		C	S	B	9.60 *(8.82)	12.00 *(10.78)
V	110	R	S	Sh	11.53	13.80
		P	S	Sh	8.03	9.50
		C	S	Sh	9.53	11.00

CHAPTER V

CONCLUSIONS

Remarks

The results derived from the analysis of System I indicate that it would not be economically feasible to construct and operate a railroad from the North Slope to Fairbanks if the coal deposit must support the entire construction and operation. However, the transportation economics may be entirely different if this railroad was constructed by state and federal governments and the costs were shared by the users of the railroad (eg. coal and oil producers and other developments which may occur along the railroad route).

The transportation of coal by truck from the North Slope to Fairbanks would be prohibitively expensive even if the coal did not have to support any of the main road construction and maintenance costs. The high cost of truck transportation in System II results from the road weight limitations, hence the large number of trucks required. However, even with larger capacity trucks, it is doubtful the transportation cost could be low enough to allow this coal to be competitive with other suppliers to Japan.

The transportation costs of moving the coal from the Northwest coast of Alaska appears to be competitive with the transportation costs of existing coking coal suppliers to Japan particularly if these coal deposits are on or near the coast. As the overland distance to the coal deposits increase, the costs become greater and coal becomes less competitive. If the total transportation costs cannot exceed $10.00 per ton to be economically feasible, and the transportation system was one outlined in Systems III, IV, and V, then the overland distance cannot exceed 120 miles at the 5,000,000 ton per year production level and 200 miles at the 15,000,000 ton per year production level.

In Systems III, IV and V the railway is the most expensive method of overland transportation, whereas conveyor and pipeline have similar transportation costs. As pointed out previously, conveyors and pipeline in most cases can transport material from the same source and destination as a railroad over a shorter route. But, both conveyors and pipelines are inflexible to increased production and new developments, and do not provide backhaul capabilities. A railroad can easily accommodate increased tonnages and backhaul traffic.

The costs of shiploading by slurry pipelines are less than the cost of shiploading by conventional dry methods. One reason is the large capital expenditure required to build a pier facility on any part of the shallow northwestern Alaskan coast.

Ocean transportation costs by 60,000 ton dwt. tug-barge and 100,000 ton dwt. ore ships are almost the same. The fact that ocean going tug-barge combinations are slower than ships means that more of them are required, but each unit costs less to build and less to operate than a large ship. The tug-barge combination has one advantage over a ship in northern Alaska; a barge can operate in much shallower waters.

Summary

On the North Slope of Alaska, there is approximately 120 billion tons of subbituminous and bituminous coal, some of which is coking coal. This coal may be in an advantageous geographical position to one of the world's largest importers of coking coal, Japan.

This study was undertaken to determine the economics of transporting coal from the North Slope of Alaska. Five transportation systems were analyzed. The first two systems linked with the existing Alaska Railroad and a shipping point at Seward on the Pacific Coast. The remaining three systems consisted of an overland transportation mode to a shipping point on the northwestern coast of Alaska.

The costs of transporting North Slope coal to Japan via a port on the Pacific Ocean are too high to be economically feasible if the coal deposit must support the transportation network.

Overland transportation costs from the coal deposit to a harbor on the northwest coast vary from $0.80 per ton mile at a production level of 5,000,000 tons per year to $.025 per ton mile at a production level of 15,000,000 tons per year. Shiploading costs vary from $3.06 per ton for dry loading, at 5,000,000 tons per year to $.91 per ton for slurry loading at 15,000,000 tons per year. (Loading costs are the total of the Dutch Harbor costs and the Chukchi Sea harbor costs). The costs of shipping coal from the northwestern coast to Japan, with a transhipment point between varies between $3.58 per ton and $4.80 per ton.

Given a sales price of $20 per ton in Japan, and allowing $10 per ton for mining costs, profit and unloading costs in Japan, then at a production level of at least 5,000,000 tons per year, part of the North Slope coal reserves is economically competitive with Japan's present coking coal suppliers. As the production rate increases, more of the reserves fall into the economic category. At 15,000,000 tons per year, coal up to 200 miles from a harbor site could be transported to Japan for less than $10.00 per ton.

The overland distance which the coal can be transported economically is sensitive to the market price, mining cost, profit and shipping cost.

Future Research

There are several aspects of coal transportation in northern Alaska which require further research. The foremost of these are marine terminals and shiploading techniques. Before any quantity of coal is moved from the northern coal fields, a suitable harbor and/or shiploading method must be available. Slurry loading of coal onto ore carriers seems to be promising, but this technique has not been fully developed for coal to date.

Extensive design and test work, probably on a pilot plant scale, is necessary to design a slurry pipeline system which can operate year round in the arctic. The marketability of the fine coking coal required by such a pipeline also needs investigation.

Further research and experience into shipping should be undertaken to determine the costs and benefits of extending the shipping season to northwestern Alaska. This research should include a study of the requirements and necessity of transhipment points.

Lastly, and probably most important, the delineation of favorable mining areas, a study of the mining costs and a full marketability study are all necessary before the economic feasibility of development of the North Slope coal reserves can be determined.

APPENDIX A

SYSTEM I

Analysis I - Annual Costs

Railroad.

Operating Basis.

Production	-	5,000,000 tons per year
Schedule	-	350 operating days/year
Round trip time	-	50 hours (30 miles/hr.)
Loading time and Unloading time	-	.05 hours
Size of trains	-	13,000 tons/train (8 locomotives, 125 cars
Number of operating trains	-	3
Performance of each train	-	225,362 miles per year
		126 trips per year
		1,666,000 tons per year

Cost of Equipment.

Gondola cars @ $15,000		$ 5,625,000
Locomotives @ $340,000		$ 8,160,000
Loading Equipment		$ 550,000
Unloading Equipment		$ 1,450,000
	Total	$15,785,000

Train Operating Cost.

Locomotives 24 @ $1.20 per locomotive mile		$ 6,490,426
Gondola Cars 375 @ $0.06 per car mile		$ 5,070,645
Labor 52 @ $30,000 per man		$ 1,560,000
	Total	$13,121,071

Cost of Railroad.

Nenana to North Slope		$1,207,166,673
Communications @ $5000/mile		$ 4,471,500
Buildings & Auxilary Equipment		$ 5,000,000
	Total	$1,216,638,173

Annual Maintenance Cost.

$14,000/mile x 894.3 miles	$12,520,200

Total Annual Costs of Railroad.

Equipment - $15,785,000 (A/P, 15, 20)		$ 2,525,600
Operating Cost		$ 13,121,071
Railroad Capital Cost (1,207,166,673) (A/P, 15, 20)		$182,495,700
Railroad Maintenance Cost		$ 12,520,200
	Total	$210,662,571

Annual Harbor Cost

Capital Costs.

Equipment and Dock (14,150,000) (A/P, 15, 20)		$ 2,162,500

Operating Costs.

Labor, Supervision		$ 200,000
Power, Tugs		$ 2,000,000
Maintenance Costs		$ 200,000
	Total	$ 4,562,500

Shipping

Operating Basis.

Schedule - 335 operating days/year
Round Trip Time - 19 days (16 knots)
Loading Time - 20 hours
Unloading Time - 20 hours
Number of ships required - 3
Ship Size - 100,000 tons deadweight
Performance of each ship - 17.6 trips per year

Annual Cost.

Capital Cost @ 14,750,000/ship		$ 7,080,000
Vessel Expense @ $7500/day/ship		$ 8,212,500
Fuel Costs		$ 2,777,016
	Total	$ 18,069,615

APPENDIX B

SYSTEM 11

APPENDIX B

SYSTEM II

Operating Basis

Production	5,000,000 tons per year
Schedule	300 operating days per year
Round Trip Time	40 hours (30 m.p.h.)
Loading and Unloading Time	.05 hours
Truck Capacity	25 tons
Performance of each truck	198,000 miles per year
Number of trucks operating	1112 trucks

Annual Road Costs

*Capital Cost @ $300,000/mile	$ 4,500,000
Maintenance @ $2700/mile (Rhoads 1972) +.02 per ton mile	$10,270,000
Total	$14,770,000

Annual Truck and Equipment Costs

**Capital Cost @ $49,000/truck	$60,073,020
Operating Cost @ $.40 per truck per mile	$88,070,400
Capital Cost of Loading Equipment	$ 320,000
Labor Cost for Loading & Unloading	$ 240,000
Total	$148,703,420

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*Annual cost based on 15 per cent rate of return and perpetual life.

**Referring to Figure 22, the annual cost of the trucks over a 20 year period truck life of 7200 hours is 110.25% of the original purchase price of the trucks.

Cost of trucks over a 20 year period assuming a 3% per year escalation rate and a 20% salvage value

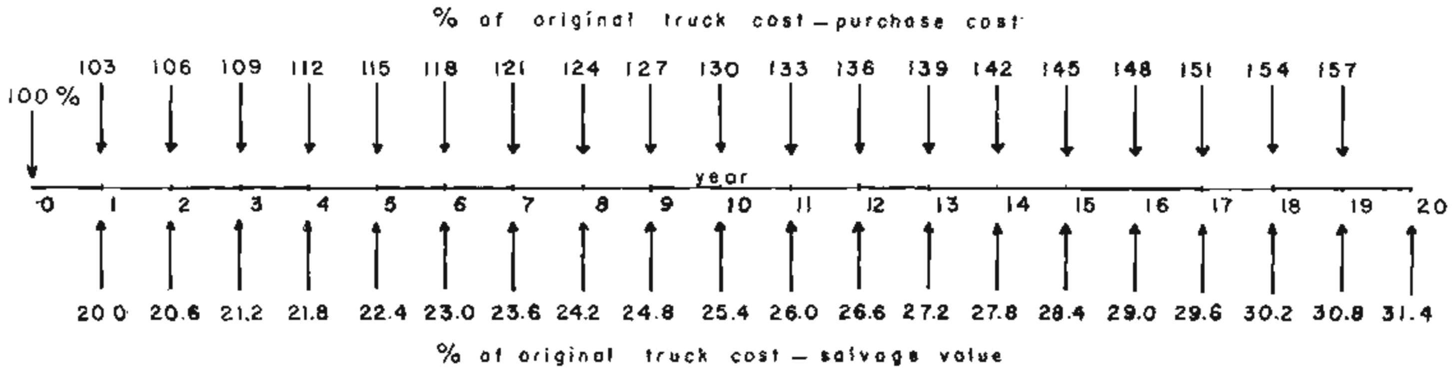

FIGURE 22

TRUCK COST CASH FLOW DIAGRAM

APPENDIX C

SYSTEM III

RAIL, HARBOR, SHIPPING

APPENDIX A

SYSTEM I

Railroad Criteria

Maximum speed - 60 m.p.h.

Maximum speed on curves - 25 m.p.h.

Maximum grade - 1.75 per cent

Construction cost of the 492.2 mile long railroad

(Based on the results of the 3 million dollar, 3 year long study entitled "Alaska Transportation Corridor Study", by Tudor, Kelly, Shannon, Alaskan Transportation Consultants)

Construction	-	$ 922,445,000
Engineering Services		146,354,923
Contingencies		138,366,750
	Total	$1,207,166,673
Cost Per Mile		$2,452,594

Maintenance Costs, variable with tonnage transported

Tonnage Per Year	-	$/mile/year
5,000,000		14,000
10,000,000		22,000
15,000,000		30,000

Other Capital Costs

Communication cost ~ $5000 per mile

Buildings and Auxiliary Equipment - $5,000,000 Total

Train and Loading Equipment.

Loading Time - 80 seconds per car

Unloading Time - 100 seconds per car

Number of Engines - 8 per 125 car train

Average Speed - 30 m.p.h.

Number of days in use per year - 350

Gondola type 105 ton capacity car with rotary coupler	$15,000 each

Six axle, 3000 H.P. Locomotives	$340,000 each
Loading Equipment Feeders and Hoppers	$550,000 total
Unloading Equipment	
Rotary Dumper with foundations	$500,000 total
Train Positioner erected	$400,000 total
Hoppers and Feeders	$550,000 total

Operating and Maintenance Cost of Trains

Locomotives - $1.20 per mile per locomotive

Cars - $0.06 per mile per car

Labor - $30,000 per man per year

Harbor Criteria

Capital Costs.

Stockpile Area	$ 150,000
Dock and Shiploader	$10,000,000
Stacker Reclaimers	$ 4,000,000
Total	$14,150,000

Shipping Criteria

Size - 100,000 tons

Draft - 50 feet

Average Speed - 16 knots

Length - 940 feet

Cost - $25,000,000 Less 41 per cent subsidy ("Six Hundred---", 1972)

$10,250,000

Total $14,750,000

Daily Expense $7500/day (Polar Transportation Requirements, 1967)

Fuel Requirements - 1300 bbl/day at sea

800 bbl/day in port

APPENDIX C

SYSTEM III

Analysis I

Railroad.

Operating Basis.

Production	-	5,000,000 tons per year
Rail Length	-	50 miles

Annual Cost.

Railroad Construction @ 2,452,594/mile	-	$17,406,773
Equipment		$ 493,600
Operation and Maintenance	-	$ 2,017,570
	Total	$19,917,943

Chukchi Sea Harbor - 5,000,000 tons per year.

Capital Cost - Construction.

Stockpile area	-	$ 561,436
Rock, gravel pier	-	$20,373,792
	Total	$20,935,228

Capital Cost - Equipment.

Stacker-Reclaimers	-	$ 4,000,000
Shiploader	-	$ 3,000,000
Conveyor System	-	$ 6,000,000
	Total	$13,000,000

Annual Costs.

Pier and Stockpile Capital Cost - (20,373,792) (P/A, 15,00)		$ 3,125,284
Equipment Capital Costs (13,000,000) (P/A, 15, 20)		$ 2,080,000
Operation & Maintenance		$ 3,400,000
	Total	$ 8,605,284

Dutch Harbor.

Capital Costs.

Dock and Stockpile Area	-	$10,550,000
Equipment	-	$10,000,000
	Total	$20,550,000

Annual Costs.

Dock and Stockpile Area Capital Cost 10,550,000 (P/A, 15,00)	-	$ 1,582,500
Equipment Capital Cost 10,000,000 (P/A, 15, 20)	-	$ 1,600,000
Operation and Maintenance	-	$ 3,500,000
	Total	$ 6,682,500

Shipping.

Operating Basis.

Production	-	5,000,000 tons per year
Ship Size	-	100,000 tons
Round Trip Time	-	17 days to Japan (16 knots)
	-	6.5 days to Dutch Harbor
Ice Free Season	-	90 days
Loading Time	-	20 hours
Unloading Time	-	20 hours
Number of Ships	-	2 for whole year
	-	2 for 3 months
	-	another for 6 months

Annual Costs.

Ship Capital Cost @ 14,750,000/ship	-	$ 7,002,096
Operating Expense	-	$ 8,122,135
Fuel	-	$ 2,746,460
	Total	$17,870,691

APPENDIX D
SYSTEM III
SLURRY PIPELINE

APPENDIX D

SYSTEM III

Slurry Pipeline Design

Design Criteria.

Size of coal - 14 m x O

Average size - 28 mesh = .0232

Specific Gravity of Coal - 1.5

Concentration of coal by weight in the slurry - 60%

Concentration by volume - 49.7%

Flow velocity - 6.0 ft. per second

Analysis II

Operating Basis - Slurry Pipeline.

Production	-	5,000,000 tons per year
	-	634.2 tons per hour
Operating Factor	-	90%
Pipeline Volume	-	3406 gallons per minute
Slurry Velocity	-	6 feet per second
Pipeline Diameter	-	16 inches
[1]Frictional Head Loss	-	119.2 psi per mile (assuming gradient of -20 feet per mile)
[2]Horsepower per mile	-	237
[3]Pumps per mile	-	.201
Distance between pump stations	-	20.0 miles

Capital Costs.		per mile
Pumps @ $225,000 per pump installed	-	$ 45,225

---

1) Frictional Head Loss $JM = Jw + JwCv280\left[\frac{v^2\sqrt{Cd}}{gD\,(s-1)}\right]^{-1.93}$ (Zandi, 1971)

Where JW = Head loss of clear water at same velocity
Cd = Drag Coefficient
g = gravity constant

2) $\text{horsepower} = \frac{QP}{1714}$ Where Q = volume in gallons per minute
P = pressure in p.s.i.

3) 1750 horsepower per pump and 90% pump efficiency, 3 operating and 1 spare pump per station.

Capital Costs. (continued)		per mile
Pipeline	-	$ 52,800
Pump Stations $400,000/station	-	$ 20,000
Piping, Controls per Station $900,000/station	-	$ 45,000
Communications $1000 per mile	-	$ 1,000
Construction Cost $150,000/mile	-	$150,000
Insulation Costs $17,300/mile	-	$ 17,300
Research, Engineering, Contingencies 20% of Capital & Construction Cost	-	$ 66,265
Preparation Facility 2.00/ton = $10,000,000		
Receival Facility $10,000,000		

Total Cost $20,000,000 + $397,590 per mile

Operating and Maintenance Costs.		
Power @ .03 per kw-hr.	-	$ 41,801
Pumps - 0.8 ¢/ton/pump station	-	$ 2,000
Pipeline - 2% of original cost	-	$ 7,040
Inhibitor = $.10 per ton = $500,000		
Labor, Administration, General Overhead - $.10 per ton = $500,000		

Total = $1,000,000 + $50,841 per mile

Total Annual Cost = $4,200,000 + $114,455/mile

Water Pipeline Design and Costs.

Operating Basis - Water Pipeline.

Pipe Diameter	-	12 inches
Water Velocity	-	5 feet per second
Head loss	-	14.6 p.s.i. per mile
Horsepower per mile	-	15.3
Number of pumps per mile @ 800 H.P. per pump	-	.0318
Distance between stations @ 3 pumps per station	-	94.3 miles

Water Pipeline Capital Costs.

		Cost per mile
Pumps @ $30,000 per pump	-	$ 954
Pipeline $43720/mile	-	$ 43,720
Pump Stations $300,000 per station	-	$ 3,181
Piping, Controls $750,000 per station	-	$ 7,953
Construction Costs $100,000 per mile	-	$100,000
Insulation Costs	-	$ 13,000
Research, Engineering, Contingencies	-	$ 33,760

Total = $175,000 + $202,569/mile

Water Pipeline Operating Costs.

Power	-	$ 2,699
Maintenance	-	$ 3,376
Labor, Administration	-	$ 2,000
Pipe Heating	-	$ 1,682
Total		$ 9,758

Total Annual Water Pipeline Cost = $28,000 + $42,169/mile

Slurry and Water Pipeline - 10,000,000 tons per year.

Slurry Pipeline.

Pipe Diameter - 24"

Frictional Head Loss - 115 p.s.i. per mile

Horsepower required per mile = 457 H.P.

Number of pumps per mile = .387 pumps

Distance between stations - 10.6 miles

Capital Cost = $30,300,000 + $618,776 per mile

Operating and Maintenance Cost - $2,000,000 + $100,527/mile
Total Annual Slurry Pipeline Cost = 6,848,000 + $199,531 per mile

Water Pipeline.

Pipe Diameter = 18"

Frictional Head Loss = 9.1 p.s.i. per mile

Horsepower required per mile = 18.6 H.P.

Number of pumps per mile = .0385 pumps

Water Pipeline. (continued)

Distance between stations = 77.8 miles

Capital Cost = $175,000 + $293,929/mile

Operating and Maintenance Cost = $12,179/mile

Total Annual Water Pipeline Cost = $28,000 + $59,208/mile

Slurry and Water Pipeline - 15,000,000 tons per year.

Slurry Pipeline.

Pipe Diameter - 2, 20 inch pipes

Frictional Head Loss - 127 p.s.i. per mile per pipe

Horsepower required per mile - 378.6 H.P. per pipe

Number of pumps per mile = .320 pumps per mile

Distance between stations = 12.5 miles

Capital Costs = $38,640,000 + $925, 715/mile.

Operating and Maintenance = $3,000,000 + $158,360/mile

Total Annual Slurry Pipeline Cost = $9,182,400 + $306,474/mile

Water Pipeline.

Pipe Diameter = 20 inches

Frictional Head Loss = 10.9 psi per mile

Horsepower required per mile = 32.6 H.P.

Number of pumps per mile = .0678

Distance between stations = 44.2 miles

Capital Cost = $175,000 + $381,153/mile

Operating and Maintenance = $17,861/mile

Total Annual Water Pipeline Cost = $28,000 + $78,800/mile

APPENDIX E
SYSTEM III
BELT CONVEYOR

APPENDIX E

SYSTEM III

Belt Conveyors

Design Criteria.

Weight per cubic foot - 50 lb.

Angle of repose - 25°

Surcharge angle - 35°

Analysis III

Operating Basis.

Production - 5,000,000 tons per year

Belt Size - 24 inches

Idler Spacing - 6.5 feet troughing

\- 10.0 feet return

Belt Speed - 1000 feet per second

Idler Configuration - 35°

Single Belt Length Center to Center - 3 miles

Operating Factor - 90%

Horsepower at primary drive - 840

Horsepower at secondary drive - 216

Tension per inch of belt width - 1386 lb.

Belt Conveyor for 10,000,000 tons per year.

Belt Size - 36 inches

Horsepower at primary drive - 1350

Horsepower at secondary drive - 330

Tension per inch of belt width - 1473 lb.

Belt Conveyor for 15,000,000 tons per year.

Belt Size - 42 inches

Horsepower at primary drive - 1880

Horsepower at secondary drive - 480

Tension per inch of belt width - 1668 lb.

Table 33 is a summary of Belt Conveyor Capital Costs; Table 34 is a summary of Belt Conveyor operating and maintenance costs.

Table 33

Belt Conveyors - Capital Costs

Million Tons Transported Per Year	Belt Width	Idlers 1)	Belting 2)	Motors and Pulleys 3)	Structure 4)	Cover 5)	Installation 6)	Total
5	24	$585,115	$395,050	$28,332	$ 620,240	$63,680	$1,289,188	$3,008,105
10	36	681,493	493,812	43,152	810,320	63,680	1,599,343	3,731,800
15	42	726,803	677,968	53,472	1,000,400	63,680	1,934,492	4,513,815

1) Stephans-Adamson Co. (1972) - Replaced every 5 years

2) Adapted from B. F. Goodrich (1972) - Replaced every 10 years

3) Motor cost estimated at $40 per horsepower - pulley costs from 1)

4) Adapted from Maddix (1971) - includes $50,000 for transfer point

5) Cover estimated at $.50 per square foot

6) 75% of equipment cost - Hewitt-Robins Co.

Table 34

Belt Conveyors - Operation & Maintenance Costs

Belt Conveyor 3 miles long center to center

Million Tons Per Year	Belt Width	Power 1)	Annual Labor 2)	Costs Maintenance 3)	Total
5	24	$186,325	$90,000	$ 8,000	$284,325
10	36	286,440	90,000	10,000	386,440
15	42	388,740	90,000	12,000	490,740

1) HP x .746 KW/H.P. x .90 x 24 hrs/day x 365 days/year x $.03/KW-HR

2) 3 men per 3 miles @ $30,000/man

3) Author's estimate

Conveyor Belt - 3 Miles Long

Annual Cost in thousands of dollars

Million Tons Per Year	Belt Width (inches)	Capital Cost 1)	Operating Costs	Total	Total Per Mile
5	24	$ 481	$ 292	$ 733	$ 256
10	36	597	386	982	326
15	42	722	491	1213	404

1) Total Capital Cost (P/A, i, n) where $i = 15\%$
$n = 20$ years

APPENDIX F

SYSTEM III

SLURRY LOADING

APPENDIX F

SYSTEM III

Analysis IV - Slurry Loading

Annual Costs - 5,000,000 tons per year.

Equipment Capital Cost	-	$ 4,923,800
Stockpile Cost - Cape Thompson		$ 79,715
Stockpile Cost - Dutch Harbor	-	$ 82,500
Direct Cost - Cape Thompson @ $.10 per ton	-	$ 500,000
Direct Cost - Dutch Harbor @ $.10 per ton loading and unloading	-	$ 728,000
Total		$ 6,314,015
Cost Per Ton		$1.26

Annual Costs - 10,000,000 tons per year.

Total Cost	-	$10,239,988
Cost Per Ton	-	$1.02

Annual Costs - 15,000,000 tons per year.

Total Cost	-	$13,673,579
Cost Per Ton	-	$.91

APPENDIX G

SYSTEM IV

APPENDIX G

SYSTEM IV

Barging

Design Criteria.

Tug Barge Speed - 11 knots
Barge Size - 60,000 tons
Barge Length - 611 feet
Barge Beam - 135 feet
Barge Draft - 33 feet
Tug Size - 4400 horsepower
Crew Size - 10
Ice Free Season - 75 days

Operating Basis.

Production - 5,000,000 tons per year
Round Trip Time - 23 days (11 knots)
Loading and Unloading Time - 0
Tugs Required - 6 all year
- 6 for 3 months
Barges Required - 8 all year
- 8 for 3 months

*Annual Costs - 5,000,000 tons per year.

Capital Costs @ $8,240,000 per barge	-	$15,114,800
1,609,000 per tug		
Operating Costs - Tugs		
Fuel	-	$ 1,499,460
Lubricants	-	$ 55,868
Maintenance and Repair	-	$ 216,945
Stores and Supplies	-	$ 62,213
Crew	-	$ 1,875,000
Insurance	-	$ 362,025
Operating Costs - Barges		
Maintenance and Repair	-	$ 1,515,400
Insurance	-	$ 3,296,000
Total		$23,997,711

*Computed from formulae by Matson Research Corporation, 1970.

Annual Costs - 5,000,000 tons per year. (continued)

Cost per ton = $4.80

Annual Costs with Shipbuilding Construction Subsidy.

Capital Costs	-	$ 9,017,732
Operating Costs	-	$ 8,882,911
Total	=	$17,900,643
Cost per ton	=	$3.58

APPENDIX H

SYSTEM V

APPENDIX H

SYSTEM V

Shipping

Operating Basis.

Production - 5,000,000 tons per year

Round Trip Time - 18 days (16 knots)

Ships Required - 7 - Ice Free Season
2 - Remainder of the year

Ice Free Season - 75 days

Annual Costs - 5,000,000 tons per year.

2 ships all year - $12,046,344

5 ships for ice free season - $ 7,529,165

Total $19,575,509

Total Shipping Cost per Ton - $3.92

Slurry Loading - Annual Costs

5,000,000 tons per year - $ 6,502,205

10,000,000 tons per year - $10,496,965

15,000,000 tons per year - $13,974,726

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ADDENDA

In systems III, IV and V, a railway capital cost of $2,452,594 per mile was used for determining railway transportation costs per ton of coal. This figure was derived from the Tudor, Kelly, Shannon study on the proposed Nenana to Deadhorse railroad, and included the cost of traversing major rivers and mountain passes. Since a railroad in the foothills and coastal plain of northwestern Alaska would not be required to cross such formdable terrain, a cost of $1,800,000 per mile may be more representative for systems III, IV, and V. This cost was derived from the same report, but from segments which may be more representative of northwestern Alaska terrain. The net effect of this lower per mile cost is to lower the rail costs per ton from 15 to 25 per cent, and the total transportation costs from 5 to 20 per cent.