Ann Arbor Oct. '73

PROCEEDINGS —

Fourteenth Annual Meeting

Theme:

"Search For New Transportation Horizons"

October 15-16-17, 1973
Hollenden House
Cleveland, Ohio

Volume XIV • Number 1 1973

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TRANSPORTATION RESEARCH FORUM

The Arctic Petroleum Railway

Some New Developments

by *C. E. Law*, *R. W. Lake*, *E. R. Corneil*, and *G. R. Marsters**

1. INTRODUCTION

It is now some fifteen months since the preliminary feasibility study on a railway to carry Prudhoe Bay oil to market was delivered to the Sponsors,(1)† and nearly ten months since its public release. Since that time there has been a certain amount of publicity on the proposal, including reports on Mr. Barrett's version prepared for his Washington trip.(2) However, there has been little opportunity to have the findings presented to a knowledgable audience, except for one short paper given at NATO Conference.(3) Needless to say, we have continued to develop the concept and have made some interesting calculations. The purpose of this paper is to summarize the concept on which a railway to move large quantities of Arctic oil was designed, and to indicate some of our more recent thinking regarding the movement of liquified natural gas over the same railroad. We feel it necessary to outline the initial study because it has not been fully explained to a large group of transportation people before, and because there are many popular misconceptions about this railway, and indeed any railway, particularly when petroleum movements are involved.

It is widely held, for instance, that railways are much more expensive than pipelines. But this comparison is based on commercial rates for movement of relatively small quantities of petroleum over railways designed for other purposes. It does not consider large movements, unit trains, and particularly the Arctic environment, nor the probably relevant fact that many pipeline companies are substantially owned by oil companies. Besides, British Railways moved 20,000,000 tons of crude oil in 1971, in direct competition with pipelines, and indeed under direct co-operative contracts with oil companies.

It is not our intention here to challenge anyone, certainly not the oil industry. As a research organization, it is our job to bring out facts and make calculations so that these facts can be given proper consideration. In the special case of Arctic oil and gas transportation, we feel that the rail mode has not yet been given proper consideration. Because of the enormous costs, of all sorts, involved here, it is of national and international importance that all the facts be weighed properly. We hope this paper will encourage factual analysis rather than emotional response. We are not recommending the immediate construction of a railway. We are recommending a careful full scale study of the proposal.

**Canadian Institute of Guided Ground Transport, Queen's University, Kingston, Ontario, Canada*

†Numbers in parenthesis refer to References which may be found at the conclusion of this article.

THE RAIL MODE RATIONAL

The presence of permafrost, the significant transmission distances, and not least of all, the presence of an unspoiled environment populated with wildlife, has raised serious engineering, economic, environmental, social and political problems for the movement of oil from the Prudhoe Bay fields.

Crude oil flows from the wellhead at a temperature of about 160°F (70°C). To permit economic transfer of oil by pipelines, it is essential that the temperature be maintained well above the permafrost temperature—i.e., well above 32°F (0°C). Despite extensive insulation, the flow of warm oil through the pipe causes serious construction and environmental problems in zones of frozen ground. Lachenbruch[4] indicates that a 48" pipeline buried six feet deep in permafrost soils and carrying oil at an estimated operating temperature of 175°F (79°C) would thaw the ground to a depth of more than 30 feet (8 metres) in five years. Insulating the pipe increases the temperature of the oil rather than decreases thawing. Of course it is very difficult to predict accurately all of the consequences of rapid, large scale thawing of ice-rich soil without a detailed knowledge of the particular situation.

With the railroad mode, a design approach is possible which minimizes disturbances to surface cover by using fills of well drained materials to blanket and preserve the frozen condition of the frost-susceptible soil material (Fig. 1). Cuts are avoided. Drainage, a most important factor, is given special consideration. Both the Hudson Bay railroad to Fort Churchill, Manitoba and the Great Slave Lake line from Peace River, Alberta to Hay River and Pine Point, N.W.T. were built using this approach.[5,6] No significant disturbance of the permafrost has occurred.

Of particular importance in Alaska is the problem of earthquakes. Coastal Alaska constitutes one of the most earthquake susceptible regions in the entire world.[7] The risk of oil spill damage to Alaskan fisheries is thus high. In the Mackenzie Mountains area, there is also appreciable seismic activity, though low in intensity.[8]

The concept of a railway to deliver Arctic oil to market requires certain assumptions. The Prudhoe Bay oil belongs to the people of Alaska, though leases to develop these oil reserves have been granted to certain oil companies. To oil men, the natural and most attractive method of oil movement is by pipeline. Other modes of transport will only be considered when special circumstances either make pipelines much more expensive than other modes or when specific obstacles, be they physical, environmental, legal or political, are placed in the way of a pipeline. The Arctic permafrost, the Arctic wildlife and fish resources, the earthquake belt, and the rugged Alaskan terrain, plus the lawsuits of environmentalists and others, are just such barriers. The approach we have taken is to examine a combination of railway to better overcome the permafrost and wildlife problems of northern areas together with pipeline to take over distribution when these abnormal conditions give way to more hospitable construction terrain.

ROUTE SELECTION

Three rail routes were considered in some detail. Route I runs from Prudhoe Bay along the North Slope to the Mackenzie Delta and up the Mackenzie

TRACK CONSTRUCTION IN REGIONS OF PERMAFROST

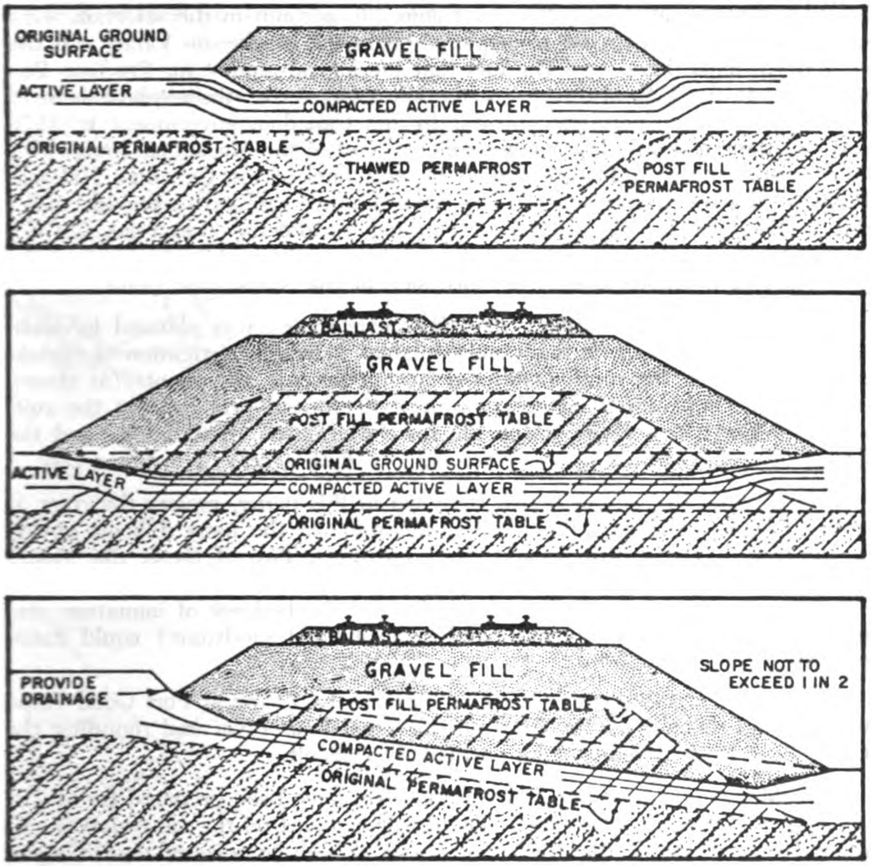

FIGURE 1

Valley ending in the southern Northwest Territories near the extremity of permafrost, in the Trout River area. Route II crosses through the Brooks range into central Alaska, thence into the central Yukon, and crosses the Mackenzie Mountains of the Northwest Territories by one of several passes to reach the Mackenzie Valley near Norman Wells in the Northwest Territories. Route II continues southward along the west bank of the Mackenzie to the Zama Lake area in northern Alberta. Route III penetrates straight through the Brooks range into central Alaska, crosses the Porcupine River, and then climbs up the Yukon River Valley. It then passes through the so called Rocky Mountain Trench to the vicinity of the British Columbia-Yukon Territory border at Watson Lake. It is this route that the Premier of British Columbia proposed in his statement "The Way Out." All three routes would connect to existing rail lines at or near the terminal. Transmission of the oil from the southern terminal would be by pipeline.

After considerable investigation Route I—Prudhoe Bay to Trout River, Northwest Territories—has been chosen as the most feasible from both economic and technical points of view. Taken into account in the selection were such factors as (a) intensive oil explorations in the Mackenzie Valley and the oil and gas finds there. (b) The fact that the logical market for Prudhoe Bay petroleum in the U.S. Midwest; not the West Coast, (c) the establishment of the Mackenzie transportation corridor by the Canadian government in 1970 and (d) the apparently lower environmental cost of the Mackenzie route. This most easterly route had been studied by personnel of the Canadian National Railway. However, their concern was for a resource railroad to provide materials and supplies for construction of the pipelines to carry oil and gas, CIGGT studies have also considered branch lines into the central Alaska area and the possibility of a branch line to the east side of the Mackenzie Delta.

During the 1972 Route I (the Mackenzie route) was planned in detail and layed out on the best mapping available. A field investigation of certain critical points on the routing outlined several feasible alignments (as shown in Fig. 2). The eventual choice of route will depend primarily on the suitability of Fort Good Hope as the site for a Mackenzie River bridge and the desirability of returning to the West Bank to gain access to Prudhoe Bay.

One route, the cost of which is shown in this paper, crosses the river at Police Island, and passes directly through some of the most difficult terrain in the region including five major river crossings. Two of these, the Mountain and Carcajou Rivers will be costly to cross. In addition, the Mackenzie is 5000 feet wide at the Police Island site and the bedrock of immature coal measures (coal, marl, clay and barely consolidated sandstone) could cause problems.

A route continuing along the East Bank to a crossing at Fort Good Hope would avoid these obstacles. Crossing the Great Bear River and rounding the Great Bear Rock should not be particularly difficult.

Profiles at a scale of one inch = 5000 feet have been prepared for all the alternative alignments of Route I. The detailed report on the construction and route layout phase of the 1972[9] program should be released by 15 April with the profiles bound as a separate appendix.

SOME ENVIRONMENTAL EFFECTS

The construction and operation of Arctic railways will interact with the environment in essentially six ways. (a) The construction of the right of way will inevitably destroy a certain amount of habitat. Similarly, the buildings and terminals required must remove some segment of the terrain from availability for other uses. (b) During the construction, the rail right of way will require substantial amounts of granular fill. Fill must be drawn from stream beds or from borrow pits located in old beaches, terminal morraines, eskers or other gravel beds laid down in the distant past. In keeping with railway practice, large volumes of fill materials would be hauled over substantial distances using special ballast cars on the railway itself. (c) During construction, the passage of vehicles and equipment could cause damage to the delicate active layer with consequent melting of the permafrost. This is true in any mode of transport. The only solution is careful planning and strict discipline

ROUTE I POSSIBLE ALIGNMENTS SUPERIMPOSED ON APPROXIMATE LIMITS OF CONTINUOUS, DISCONTINUOUS AND SPORADIC PERMAFROST

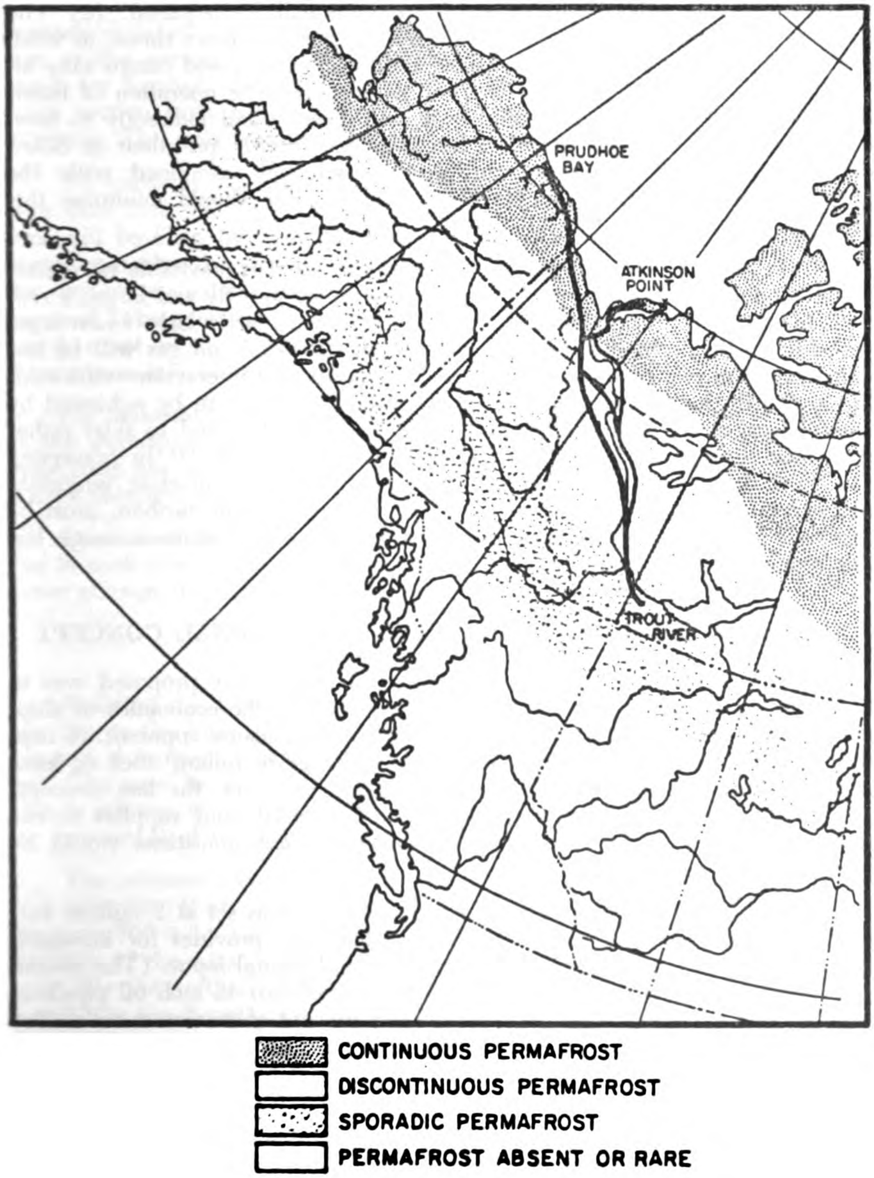

FIGURE 2

CAPITAL AND OPERATING COSTS

Whatever the other considerations, no proposal for a large scale transportation system, particularly into the Arctic, can be seriously entertained without a careful examination of costs, both capital and operating, and employment estimates.

The various pipeline studies have for the most part been costed at their maximum capacity, a volume of two million barrels daily. However, it would not be appropriate to evaluate the rail alternative at its capacity, in excess of six million daily; this mode is limited by supply and demand rather than capacity. The dependent relationships between operating costs, capital costs, and replacement policy on the one hand, and system usage on the other, are complex and necessitate some assumption of volume so that cost and revenue can be calculated. Accordingly, a basic volume of two million barrels of oil daily has been assumed to facilitate comparison between competing modes. At this level, the distinctive capability of the rail mode to absorb much larger volumes of traffic in small increments and at steadily reducing unit cost is not quantified.

In all cases, the figures which follow were compiled by aggregation from fairly detailed elements. In almost every case, these detailed elements were checked with Canadian National Railways experts, or other transportation sources. Where several different estimates were prepared by different groups, the largest figure was always chosen to be "conservative." These assembled "conservative" costs have had overhead and administration costs applied to the consolidated figures rather than to individual items. This may give the impression that the figures are below the "average" costs of similar operations, which of course include overheads. It should also be made clear that such annual costs as maintenance of way materials mean just that; "materials." They do not include personnel costs or equipment costs, which have been segregated for purposes of calculating cash flows including tax allowances.

Capital Costs (thousands of dollars)

The capital costs summarized here include the construction of all terminal facilities including storage tanks at Prudhoe Bay and Trout River. They *do not* include a gathering system on the oilfield or a pipeline southerly from Trout River; nor do they include costs relating to the liquefaction, transportation or regassification of natural gas which are included in a later section.

(1)	Right of Way Construction		$1,538,810
(2)	Signalling		51,850
(3)	Communications Costs		29,922
(4)	Terminals and Stations		
	Prudhoe Bay	$ 63,053	
	Trout River	[illegible]	
	Other	[illegible]	328,280
(5)	Rolling Stock		
	locomotives	[illegible]	
	tank cars	[illegible]	
	crew cars	[illegible]500	

(6)	Track Maintenance and Replacement Machinery	13,000
(7)	Additional Expenses	20,000
	TOTAL	$2,425,000

Operating Costs

As summarized here, operating costs include all operating expenses that would be incurred by a corporation devoted to operation of the system. Responsibility commences with delivery of the oil to a single central location at Prudhoe Bay and terminates as the oil passes (at a uniform rate of 2 million barrels daily) into the pipeline system at Trout River. Operating costs have been calculated at projected 1976 rates, but no allowance has been made for cost escalations beyond that time. Annual Operating costs (applicable to an operation hauling only oil, not LNG) may be summarized as follows:

(1)	Wages, Salaries and Fringe Benefits	$58,315,000
(2)	Maintenance Materials	79,486,000
(3)	Fuel	47,684,000
(4)	Cost of derailments	2,193,000
(5)	Building and Terminal Insurance	1,400,000
(6)	General Contingency Allowance	5,000,000
	TOTAL	$194,078,000

OIL SHIPPING "COSTS" OR TARIFFS

As the economic viability of this project must be evaluated without the benefit of an institutional framework, "satisfactory" net returns to investors are assumed and the discounted cash flow equation is solved for that price per barrel which will generate those returns. No consideration has been given to other uses of the railway or to the benefits particularly resulting from the sharing of facilities with LNG which might accrue.

It was assumed that initial construction cost would be totally financed by equity funds. Debt financing to a maximum level of 75% is used to cover the later construction and early operating costs. The effect of several different debt repayment policies on unit costs has been examined. Replacement policies have been specified for all assets including the renewal of up to 400 miles of road-bed and track annually and the resulting cash flows have been included in the calculations. A computer program was written to assist in computation and 54 different variations of the system were evaluated. Figure 3 shows the oil shi[illegible] "cost" per barrel, or possible tariff, for different interest rates, ra[illegible] on equity and "flow-through" provisions.

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(3)	Communications Costs		29,922
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	Prudhoe Bay	$ 63,053	
	Trout River	228,216	
	Other	47,011	328,280
(5)	Rolling Stock		
	locomotives	$126,000	
	tank cars	303,534	
	crew cars	3,800	433,334

(6)	Track Maintenance and Replacement Machinery	13,000
(7)	Additional Expenses	20,000
	TOTAL	$2,425,000

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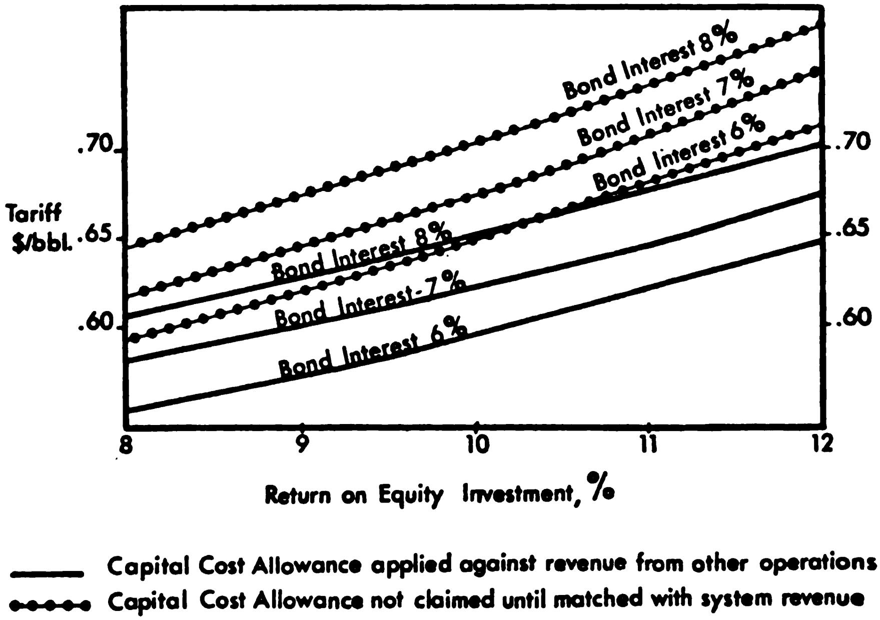
Based on an Interprovincial Pipeline Company's report[12] a rate of $.40 per barrel would seem to adequately cover expenses and provide a reasonable rate of profit for a pipeline link from Trout River to Chicago. Assuming a conservative $0.67 to Trout River, we arrive at a total cost of $1.07 per

THE SENSITIVITY OF OIL SHIPPING "COSTS" TO INTEREST RATES, RETURN ON EQUITY INVESTED, AND THE APPLICATION OF CAPITAL COST ALLOWANCES.



The volume is assumed to be two million barrels of oil daily for a period of 30 years. The system is financed with up to 75% debt after the initial construction stages are financed with $600 million of equity. Debt is reduced to 50% of the $1300 million residual value as a resource railway in equal capital increments after ten years.

The ability to claim Capital Cost Allowance and apply it against revenue from other operations is dependent on the existence of such revenue and accordingly specific to the enterprise that is considering the project. Even in the case of an enterprise with no other income, provisions that permit the carrying forward of losses would enable a strategy approaching the effect indicated by the solid curves.

FIGURE 3

barrel to Chicago and $.93 to Seattle. Using Mackenzie Valley Pipeline Research Ltd. estimates (as per Fig. 4) the tariffs would be $1.22 and $1.08. The recently announced costs of $1.17/bbl. by Alyeska pipeline and West Coast tankers makes these figures highly competitive.

The Technology of Transporting Natural Gas by Rail[1]

The LNG-Rail system is considered in its three main components (a) the liquefaction system, (b) the railway system including terminals, and (c) the regassification and sendout system.

1 This study assumes a 3 billion SCFD throughput.

ESTIMATED OIL SHIPPING "COSTS" USING M.V.P.L. AND ALYESKA ESTIMATED PIPELINE TARIFFS

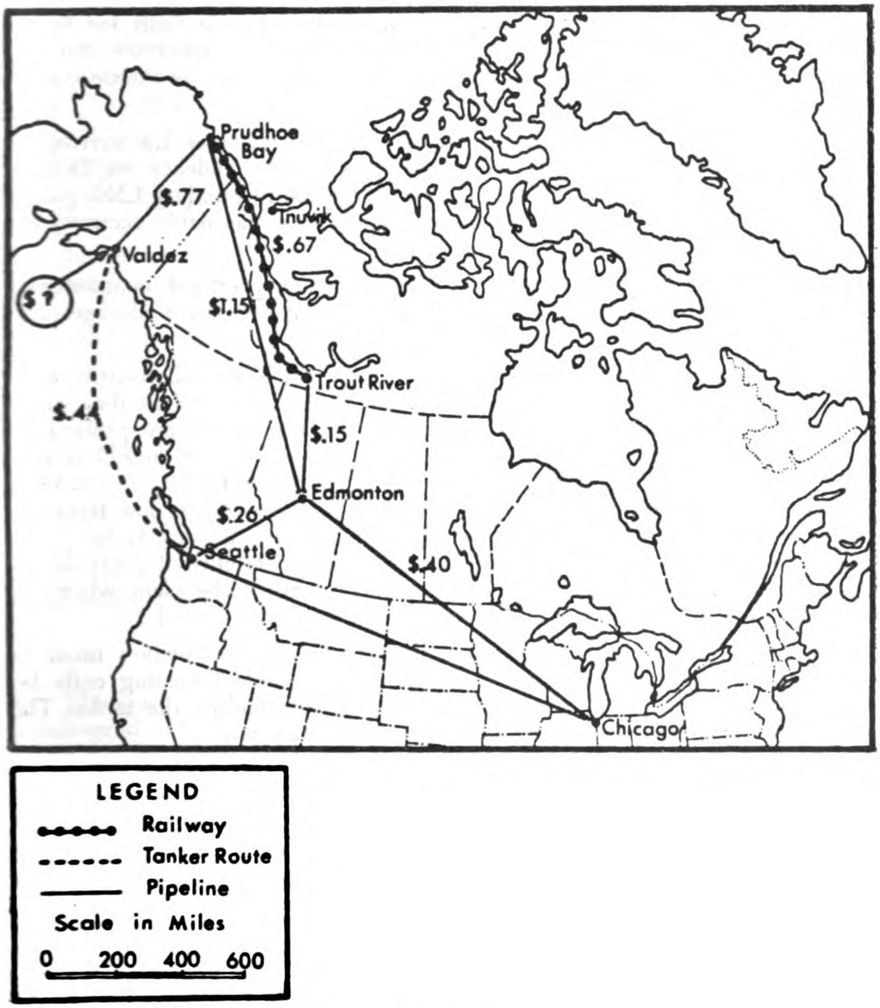


FIGURE 4

The gas, primarily methane, is scrubbed before entering the LNG system so that CO_2, H_2O sulfur compounds and heavy hydrocarbons are removed to provide "pipeline quality" gas. Great care must be taken to contain all impurities, particularly sulfur compounds. The transport of these impurities to southern markets (with the railroad) would be justifiable environmentally if not economically.

Estimates of capital costs for liquefaction plants were obtained from a number of sources, three of which have actually designing and operating facilities: Bechtel Inc.[3]—$300 per thousand cubic feet per day of capacity. (MSCFD), Phillips Petroleum Ltd.[4]—$204 MSCFD and Technip TEAL Inc.—$335/MSCFD. The TEAL estimate was selected as a basis for liquefaction plant cost estimates not only because of TEAL's experience but because the TEAL engineers have considered the ramifications of Arctic conditions.

The TEAL estimate was increased by a further factor of 1.3 arriving at an estimate of $435.5/MSCFD. We place considerable credence on TEAL's figures because of the company's extensive experience in building LNG plants in North Africa. Thus, we believe this cost figure is a reasonably accurate estimate of plant costs.

A liquefaction plant consists of the following principal components: Compressor-turbine train; cold box (heat exchanger tower); storage and sendout station.

The compressor-turbine trains are very large machines and constitute almost half the total investment in the plant. The drive unit may be either steam or gas turbine, however it seems likely that steam turbines[2] are preferable. Current estimates of optimum plant size are about 300×10^6 SCFD requiring just under 150,000 HP. This indicates ten separate plants to process 3 billion cubic feet daily. Since much of the plant operates at very low temperatures, no major problems are expected to arise in operating an Arctic plant. Maintenance out of doors is very difficult, but the availability of portable enclosures will relieve this problem. Only those portions of the plant which require frequent operator attendance need be enclosed and heated.

Storage facilities adequate to handle several days production must be available. In temperate climates it is customary to embed heating coils beneath the tanks to avoid freezing of the ground surrounding the tanks. This would appear to be quite unnecessary in permafrost regions.

An Arctic railway system to handle LNG consists of numerous interacting devices and sub-systems. Some railway cars suitable for the transport of LNG exist, but the problems associated with day-to-day rail operations with LNG are considerable. Cryogenic cars are highly specialized; they have stringent maintenance requirements; the materials of construction are costly; their operating characteristics are determined by American Association of Railroad specifications.

Presently, single car prices in Canada are in excess of $100,000. With mass production, PROCOR Ltd. estimates a price of $80,000 for a 33,000 gallon car meeting A.A.R. specifications. Revere Copper and Brass Inc. is working on considerably larger tanks that are expected to cost $56,000 each, and would be mounted on flat cars.

Assuming a production rate of 3 Billion SCFD, the liquefied product would amount to 35.9 million US gal per day, or about 62,800 tons/day. With present cryogenic rail car equipment (PROCOR) this would require about 1100 cars day, or about ten trains per day. Each train would be powered by three locomotives. It is estimated that some 3317 cryogenic cars

2 TEAL has recently examined the problem further and are tentatively recommending gas turbines for Arctic Slope applications.

would be required in all, along with about 99 locomotives and 30 crew cars. The total cost of rolling stock is estimated to be about $302 million. In view of the optimum LNG plant size of about 300 million SCFD, each of these plants will load only one train per day, probably from twin systems. Thus the loading problem is not severe. Similar conditions will probably exist at the regassification facilities. While conventional methods probably suffice, an automated system is under consideration.

LNG spillage represents an environmental and safety hazard and, one must expect that any serious derailment may cause spillage. However, if no fire occurs, the problem is not serious. Methane is non-toxic and it disperses readily.

In the event that fire occurs, the situation is much more serious. Flame speeds in combustible mixtures are moderately low but intense heating may cause adjacent cars to rupture and burn. Tank car rocketing[15] would tend to make the situation highly spectacular. Fortunately, however, it appears that "LNG has a conspicuously low sensitivity to sources of ignition."[16]

From the southern terminus, gas will probably be sent out in the vapour phase. In order to vapourize the gas, fairly large quantities of heat will be required. If the liquid is first pressurized to pipeline pressures (e.g., 900 psi) and then vapourized to say 20°F, approximately 330 Btu/lb. will be required.

Regassification facilities would be extensive and expensive. At current estimates of $150/MSCFD of capacity, a capital investment of $450 million would be required. Operating expenses (primarily fuel) would amount to about 2½¢/MSCF or $27 million annually.

CAPITAL COSTS

The costs summarized here include all costs after "pipeline quality" gas is delivered to the liquefaction plants up to the point where gas is delivered in the vapour phase at a uniform rate of 3 billion SCFD into a pipeline system at Trout River. They do not include the costs of the field gathering system, scrubbing, or the subsequent pipeline. No allocation of costs shared with the oil carrying function of the system is included.

(1) Liquefaction		
Plant	1,275,000,000	
Storage	33,750,000	
Loading	100,000,000	1,408,750,000
(2) Gassification		
Plant	450,000,000	
Storage	75,000,000	
Unloading	100,000,000	625,000,000
(3) Rolling Stock		
Tank cars (PROCOR)	265,400,000	
Locomotives	35,000,000	
Crew cars	1,700,000	302,100,000
(4) Other		48,534,000
	TOTAL	2,384,384,000

OPERATING COSTS

The operating costs enumerated here do not include an allocation of costs shared with the oil hauling function. In reality these systems costs would be split between the products served. The following are the appropriate costs to consider if one is trying to determine whether to also ship gas on a railroad that has been constructed for the primary purpose of moving oil.

(1)	Liquefaction, Storage, Loading	85,000,000
(2)	Regassification, Storage, Unloading	27,000,000
(3)	Rail System Personnel	19,000,000
(4)	Locomotive Fuel	14,760,000
(5)	Maintenance Materials	29,340,000
(6)	Cost of Derailments	1,000,000
(7)	Insurance	4,000,000
(8)	General Contingency	2,000,000
	TOTAL	182,100,000

GAS SHIPPING "COSTS"

The rate on tariff that would have to be charged to cover all costs, provide for the repayment of debt issues and an adequate return on invested equity capital was calculated on the same basis as the oil shipping "costs." A rate of $.35 to Trout River appears to be a reasonable figure for evaluating the project at the margin. An examination of the cash flow requirements to service outstanding debt and provide a satisfactory return on invested capital shows that the impact of high capital cost completely overshadows operating expenses, even at the level of $182 million annually.

From consideration of current Canadian gas pipeline tariffs it is reasonable to conclude that the Prudhoe Bay gas could be delivered to the U.S. Midwest for about $.60/MCF. Current published estimates for a vapour phase pipeline are of the order of $1.05/MCF.

While $.35 appears to be an attractive rate, the figure is conditional upon the simultaneous transportation of Prudhoe Bay oil. *If the Trans-Alaska pipeline is built and the oil follows that route to markets in Seattle and Japan the gas shipping cost will be much higher.*

REGIONAL ECONOMIC IMPLICATIONS

The railway as examined here has been considered to have the sole purpose of transporting petroleum from North Slope oil fields to "lower 48" markets. Even with this limitation, secondary effects on the northern economy will be great. Primary jobs in operation of the railway for 2 million bbls of oil and 3 billion cu. ft. of gas daily will require over 7,200 people. The distribution of different job classifications is outlined in Table I. Of these jobs some

ESTIMATES OF OPERATING PERSONNEL REQUIREMENTS

	Oil System	Additional for LNG
Train Crew	1248	580
Refuelling	62	20
Inspection	207	80
Oil Terminals	160	—
Emergency	20	4
Power Plants	32	—
Car Repair and Maintenance	631	184
Locomotive Shop	696	253
Wheel Shop	267	78
Maintenance of Way (routine)	530	—
Maintenance of Way (renewal and repair)	130	52
Station and Hostel	107	44
Building and Terminal Maintenance	130	65
Administration	331	110
Liquefaction	—	900
Gassification	—	300
	4533	2670

TOTAL REQUIREMENTS = 7203

TABLE 1

800 positions could be provided almost immediately for local labour. With a minimum of training, some 3,000 of the 7,200 positions could be made available to locally hired personnel.

It is expected that tertiary employment will lead to a town of some 40,000 people in the base area, wherever it may eventually be located.

The estimates covered only those employed in operating the actual railway system and related static installations. The construction employment and its secondary impact on Canadian industry would be substantial, though perhaps a questionable benefit. Even the transportation of materials, rails, locomotives, tank cars, bridging steel and the construction of normal facilities for a city of 40,000 would create tens of thousands of additional jobs.

Without question, the provision of a railroad will lead to substantial secondary effects on other industries. Both the reduced cost of materials backhauled into the north country and the increased prospects for the transportation of mineral wealth at reasonable cost will certainly lead to substantial development. Although non-petroleum mineral deposits are known in the Mackenzie Valley region, development has been minimal. Reduced transportation costs would stimulate this development.

THE COST OF DELAY

It has been stated[17] that a year's delay in the delivery of North Slope oil forfeits the possible resource cost saving of $1.50 to $1.70 per barrel or $1.1-1.25 billion in resource costs. These figures were obtained by the ludicrous assumption that the present value of oil exploited towards the end of the field's approximately twenty year life is zero. While a steadily escalating cost for imported oil is assumed, the calculations fail to consider that by deferring production, later import savings will be a much higher rate and therefore more valuable even if discounted.

The use of discounted cash flow methods in depletable resource exploitation problems is only valid if the discount rate is itself varied to compensate for future supply uncertainties and price changes.[18,19]

The affect of each of the errors above is to inflate the true cost to the United States of a year's delay in the exploitation of Prudhoe Bay oil. Clearly the true cost is substantially less than the $1.1 to $1.25 billions estimated by the Alyeska Group in support of their proposal for a Trans-Alaska Pipeline System. The true cost may in fact be negative and delay actually desirable!

The use of a model that has been constructed for problems of mineral resource development is suggested as a means of estimating the real cost of delay. A complete development of the model is beyond the scope of this paper but in essence the present value is calculated by varying discount rate over time as a means of adjusting for the risk implicit in the futurity and quality of anticipated cash flows. Expected price and cost changes are also considered. A realistic measure of the cost of delay would be:

$$D = V\left[P_f - C - P_f(1+\Delta p)^{20} \prod_{t=1}^{20}(1+ke^{-\alpha t})^{-1} + C(1+\Delta c)^{20} \prod_{t=1}^{20}(1+ke^{-\beta t})^{-1}\right]$$

where: Π from 1 to 0 = 1, and

V = Volume in bbl/yr (780×10^6)

P_f = Delivered price of imported oil (1975) ($2.80)

P_d = Delivered price of domestic oil ($3.50)

C = Estimated Production and Transportation Costs ($1.20)

Δp = Projected annual escalation in the cost of foreign oil (.05)

Δc = Projected annual escalation in Production and Transportation Costs (.03)

k = Short term discount rate (.08)

α = Risk parameter associated with Middle East Supply (.05)

β = Risk parameter associated with Alaska Supply (.01)

When the model was run for a large variety of parameters; rather than the anticipated "cost of delay," an annual benefit to delay of $300 million to $800 million was apparent.

It can only be concluded that the rapid exploitation of remaining United States petroleum reserves is a questionable strategy.

SUMMARY

To overcome environmental problems inherent in pipeline construction in the Arctic, and to take advantage of an unique economic opportunity, a two track railway, using unit trains, is proposed to haul both crude oil and liquefied natural gas from Arctic petroleum fields to pipeline transfer terminals near the N.W.T.-Alberta border. From this point, normal pipelining practice could be followed to distribute the oil and gas to market.

A route crossing the North Slope from Prudhoe Bay to the Mackenzie Delta, thence up the Mackenzie to a point Southwest of Great Slave Lake was chosen. Five years would be required for construction of the 1200 mile double track railway system.

At a volume of two million barrels of crude oil per day, the system would have capital costs of 2.4 billion dollars and annual cost of 194 million dollars. A tariff of about 67 cents per barrel to the Trout River terminal, $1.07 to Chicago would provide a respectable return on investment.

If liquified natural gas were also to be carried, a 3 billion SCFD level of operations would call for an additional 2.4 billion capital investment, 1.4 billion of which would be for liquefaction and an additional 650 million for gassification. Additional operating costs would amount to about 182 million dollars. A tariff of about $.35/MCF to Trout River, $.60 to Chicago seems appropriate. This compares with about $1.05/MCF for vapour phase pipeline to Chicago.

The oil operation would require 20 trains per day of about 168 cars each. The gas movement would require 10 trains of about 110 cars.

Though it has been suggested that delay in completing an oil pipeline from Prudhoe Bay will cost the U.S. more than one billion dollars per year, a more careful calculation suggests that modest delay might *benefit* the U.S. by several hundred million dollars.

At this point it is not recommended that a railroad be constructed immediately. It is recommended that a careful and complete study of a rail alternative for oil and gas movement be completed before any pipeline permit is issued. This should be beneficial on the long term to all concerned.

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