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by

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ABSTRACT

Despite the use of a modern transportation system, the movement of more than one-half of the coal mined in Canada an average distance of 1100 km to the west coast remains a major expense. During the next two decades the volume of coal exports is expected to increase fourfold. Inflation and increasing energy costs will likely cause conventional transportation costs to account for an increasingly large proportion of the delivered price of coal and endanger coal sales.

In Canada, with a view to alternate modes of tranportation, slurry pipeline technology has been studied for 20 years and has been considered from time to time for transporting coal to the west coast for export, to energy deficient Ontario for power production and also into the Western Canadian oil fields for use in extraction and upgrading plants. Water is generally assumed to be a vehicle for coal slurry pipelines; there is now an increasing interest in using alternative liquid fuels as the carrier. Water, crude oil and methanol modes of coal pipelining are compared and their implications discussed in terms of their availability, coal-liquid interaction, coal liquid separation, and system economics.

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INTRODUCTION

Many nations have determined that coal is a possible alternative fuel to oil. It can be anticipated that world wide increases in the use of coal, for example, in electric power production, will have a major accelerating effect on the development of the western Canadian coal industry. The international market for thermal coal is now in the early stages of its expansion; increased investment in generation of electricity, coal to liquid conversion technologies, and secondary industry will sustain demands for steel and consolidate international sales of metallurgical coal traditional markets.

Canadian exports of metallurgical coal have expanded significantly in the recent past; this participation in the international market will continue to increase in the immediate future. The transport of many millions of tonnes of coal over distances up to 1600 km is the imminent task of the Canadian transport industry. Traditionally this transportation has been done by unit trains and a fleet of Great Lakes vessels.

This paper describes the relatively new coal transport concept of slurry pipelining as it might be applied in Canadian circumstances when the cross-country pumping of coal in a slurry form could complement existing conventional coal transport systems. SI units are used throughout this paper. All prices and costs are in current dollars.

WESTERN CANADIAN COAL RESOURCES AND COAL MOVEMENTS

The measured and indicated Canadian coal resources of immediate interest total 64 Gt. These resources - as is illustrated in Figure 1 - are predominantly located in the western provinces of British Columbia, Alberta and Saskatchewan. The 1979 coal production was 33 Mt: approximately 21 Mt of this was consumed in Canada generally close to its point of origin; the remainder was exported. Imports of thermal coal into central Canada amounted to 2 Mt. Expansion of Canadian export markets is expected to lead to Canada being a net exporter of coal before 1990. According to a 1980 World Coal Study the current 14 Mt export of Canadian coal may grow as high as 67 Mt by the year 2000 (1). Most of this coal will be transported through the Rocky Mountains over distances up to 1600 km.

The demand for thermal coal in Ontario is forecast to rise annually by 7 Mt and the demand for metallurgical coal by 4 Mt (2). Some of this increase could be met by increased transportation of western Canadian coal above the current level of 2 Mt. Transportation distances could be as great as 3000 km.

Further major demands for multi-mega-tonne coal shipments could arise during the next two decades in conjunction with heavy oil and tar sands extraction and upgrading processes. This transport would be over distances of about 400 km. These possible movements of western Canadian coal by the end of this century are summarized in Figure 2.

Today's movement of western coal is mostly by train. Despite the benefits of a high efficiency integrated unit train system all Canadian railway rates have increased dramatically. For example, between 1970 and 1977 coal freight rates increased between 2 and 3 times. Today's transportation accounts for as much as 30% of the delivered cost of western Canadian metallurgical coal and between 30 and 50% of the delivered cost of thermal coal. If our freight rates grow faster than those of international competitors there is a possibility that they will endanger future exports of western Canadian coal (3).

The alternative long distance coal slurry pipeline may offer cheaper transport at a more stable long term cost (4-6).

COAL SLURRY PIPELINE TECHNOLOGY

Hydraulic transport of solids has been studied since the 1960's particularly in the United States, where the world's longest working coal pipeline, the Black Mesa Pipeline in Arizona, has been in operation since 1970. It delivers 4 Mt/a of coal over a distance of 439 km. Six other pipeline systems are proposed in the United States for transport of thermal coal in water slurry from western states to various markets and export. If completed all systems will transfer 1.3 Tt/a of coal over a total distance of 10,000 km (7). In Europe two coal pipelines have recently been proposed to supply Polish thermal and metallurgical coal to Austria, Italy and later to West Germany (8,9). Similar long distance coal slurry pipelines may also be considered for Canada.

GENERAL CHARACTERISTICS OF LONG DISTANCE COAL SLURRY PIPELINES

A slurry system transporting coal over a long distance should have three components: A preparation plant to crush and pulverize the coal and mix it with liquid to pipeline specifications; a pipeline with pumping stations to maintain adequate velocity and prevent coal particles from settling; and a separation plant to recover coal with an acceptable liquid content and to purify liquid effluents either for further use or, in the case of water, for discharge. A general flow sheet of the system is shown in Figure 3.

Slurry pipelines may operate continuously or batchwise. The coal throughput turndown can be effectively achieved by liquid batching or flushing, combined with pipeline shutdowns. Branching of slurry pipelines is theoretically possible. Unlike railways slurry pipelines provide only one-way point-to-point transport. They can function over rugged terrain.

The estimated economical life of pipelines is 30 years. Initial capital investment is high and fast build-up of the pipeline to full capacity requires a life-long coal contract or a steady coal market. An adequate supply of both coal and liquid must be available for the whole lifetime of pipeline operation. Fixed, capital related costs, could be as high as 70% of total transportation costs but would not increase much during the pipeline lifetime; this leaves a relatively small proportion of the total costs vulnerable to inflation.

Long distance coal slurry pipeline transport requires a considerable quantity of electrical energy for crushing, pumping and separation but does not require diesel fuel like the conventional Canadian train and inland water transport. Once buried, the noiseless slurry lines have virtually no disagreeable effect on the natural and human environment.

The properties of slurries are key factors affecting almost every detail of the pipeline system. A coal slurry suitable for long distance transport comprises a complex suspension of coarse coal particles in a non-Newtonian vehicle of fine coal particles (<40μm) and liquid (10). Such a suspension is known as a mixed or pseudohomogeneous slurry. The concentration of the minus 40 μm particles in the slurry is one of the most important criteria in long distance slurry design. The slurry features a low energy requirement for pumping. Increased content of minus 40 μm particles improves slurry stability, makes resuspension easier after a pipeline shutdown and minimizes plug formation at the pipeline low points. On the other hand a high content of minus 40 μm particles makes the coal separation from slurry more difficult (11-13). Some slurry properties used by the Black Mesa Pipeline are summarized in Table 1.

LONG DISTANCE COAL SLURRY PIPELINES FOR CANADA

Water is generally assumed to be the carrying liquid for potential coal slurry pipelines in Canada. Because of increasing interest in carrying coal in liquid fuels (14-20) two additional modes: coal-oil and coal-methanol should also be considered. In this paper all three modes are viewed with the following criteria in mind:

- coal and liquid availability
- effect of liquid on coal quality and recovery
- effect of Canadian winter conditions on the pipeline facility and operation
- economics

COAL AND LIQUID AVAILABILITY

In selecting potential western Canadian coal deposits suitable for coal-water, coal-oil and coal-methanol pipeline transport the following three factors have to be considered:

1. The output, after preparation, from the deposit or nearby deposits in the same coal field must be at least 30 times the annual pipeline capacity if slurry pipeline is to be the sole coal transport means.

2. Water and methanol slurries both require a river source with an historic Minimum Recorded Discharge that is 10 times the slurry pipeline total water requirement (21). A Specific Water Requirement is the total water requirement per unit of annual coal pipeline capacity. The Specific Water Requirements are tabulated in Table 2.

3. Coal-oil slurries require an adjacent oil source capable of producing oil at a tonnage rate 50% above the coal production throughout the projected lifetime of the pipeline.

The Ultimate Pipeline Throughput, G, for a dedicated pipeline is defined as the recoverable coal, Mt, divided by the Pipeline Lifetime and the mined-to-pipelined coal ratio.

$$G = \frac{\text{Recoverable Coal, (Mt)}}{\text{Pipeline Lifetime, (years)} \times \frac{\text{Mined Tonnage}}{\text{Pipelined Tonnage}}}$$

However, if this produces a water requirement larger than the Minimum Recorded Discharge then the Minimum Recorded Discharge must be used as the decisive factor determining ultimate pipeline throughput.

The coal-water or coal-methanol slurry pipeline transport of potential coal fields of Alberta and British Columbia are listed in Tables 3 and 4 and shown in Figure 4. Information used in these tables was obtained from the Alberta Energy Conservation Board publication (22) for recoverable coal of Alberta mine fields, the 1979 data on coal resources British Columbia (1) and from Environment Canada reports on surface water data in Western Canada (23-25).

Eight of nine selected coal areas of Alberta are situated north of Red Deer River with sufficient water supply from the North Saskatchewan, Athabasca or Smoky Rivers. The ninth area, close to Coleman coal fields in southern Alberta together with southeastern fields of British Columbia could be supplied by water from Kootenay or Elk Rivers. The ultimate coal-water pipeline throughputs vary from 10 to 33 Mt/a and may be as high as 40 Mt/a for Wabamun and Wetaskiwin subbituminous coal fields. Fox Creek-Judy Creek subbituminous coal fields of combined pipeline ultimate throughput of 38 Mt/a with a good infrastructure and lack of main rail transport can be considered the coal areas most suitable for coal-water or coal-methanol pipelining.

Water or methanol pipeline transport from the coal fields of the Alberta Plains drained by the South Saskatchewan River, Battle and Milk River sub-basins, should be ruled out because of the general water shortage and/or plannned industrial development for this area (21).

The possibility of lignite-water or lignite-methanol slurry pipeline transport from southern Saskatchewan coal fields is remote. Water scarcity in the coal field areas means that all water would have to be imported from the Diefenbaker Dam over a distance of 200 to 350 km. There is a general lack of information on behaviour, pipelining and separation of lignite-liquid slurries.

All methanol for coal slurry transport has to be manufactured and may require large quantities of both coal and water. A "worst case" of methanol slurry could require up to four times more coal and 7 times more water than a water-coal slurry. However, about 10% of water is consumed in methanol production, the remainder is utilized in process wet cooling. An advanced coal-to-methanol technology capable of using a high moisture coal, efficient coolant recirculation and dry cooling system might be totally independent on external sources of water (14,16). Production of methanol is a high capital investment venture. For example a methanol-coal pipeline of annual capacity 10 Mt coal would require $\$3.3 \times 10^9$ in capital investment and a pipeline of annual capacity of 20 Mt coal $\$5.5 \times 10^9$ in capital investment (26). Water and coal requirements for the water and methanol pipeline modes are apparent from Table 2.

With permission to produce methanol from abundant western Canadian natural gas the capital investment requirements could be, at least, 2 times lower and dissipated energy within the conversion process more than 2 times lower than coal-based methanol technology (27).

The decision for coal-methanol slurry transport, implying large capital investments, depends on whether there is a market for methanol as a liquid fuel or a feedstock for a high quality gasoline manufacture.

Coal-oil slurry transport assumes availability of large amounts of crude oil ranging from 1.2 to 1.5 m^3 per tonne of transported coal. The National Energy Board (NEB) forecasts for the period 1981-1995 an annual production of suitable light crude oil from established oil wells throughout the province of Alberta that will decrease from 58 to 20 Mm^3 (28). Based on information from the Alberta Energy Conservation Board (AECB) (29) an annual production of synthetic crude oil from tar sands within the same period should increase from 9 to 51 Mm^3. The forecast development of light crude feedstock production in the province of Alberta is summarized in Table 5. Diminishing conventional crude oil production in Alberta suggests that the "near-future" supply will be dominated by tar-sands and heavy oil areas shown in Figure 4.

An economically feasible supply of oil for coal-oil pipeline transport is restricted to oil fields close to coal supply areas. In 1995 some 73% of Alberta oil could come from tar sands and heavy oil fields which are therefore the most probable points of origin for oil slurry pipelines. Current national oil movements to the West coast would restrict slurry transport to 5 Mt of coal per year which is an uneconomically low level. Larger oil movements eastward make the coal fields of Wabamun (A07), Wetaskiwin (A08), Morinville (A09) and Tofield (A10) potential fields for coal-oil pipeline transport.

It will be important to determine whether synthetic crude oil, containing significant proportions of unsaturated hydrocarbons, will adversely affect coal-oil slurry properties, coal end-product and whether compounds extracted from coals would seriously degrade the oil for subsequent refining.

Coal Recovery and Quality of Separated Products

In most end uses, the coal must be separated from the liquid and the liquid effluent must be free of coal or mineral matter. The presence of the minus 40 μm coal fraction in the pipeline slurry, which is desirable for hydraulic behaviour, is likely to be a major problem at a pipeline terminal.

The centrifugal separation of long distance coal-water slurries (30) gives rise to a problematic effluent or "ink" which contains high-ash fine coal. At the Black Mesa pipeline terminal at Mohave Generating Station the "clariflocculation" underflow, a stream containing up to 80% water and "ink" coal, is burned in boilers at the expense of low boiler efficiency (31,32).

For most end-product utilization or handling an agglomeration of fine coal followed by surface moisture reduction to 7 - 10% wt would be required.

Particle size reduction of metallurgical coal to pipeline consist may improve coke strength but presents additional problems of oxidation and dust losses in storage. Furthermore, due to slurrying in water and pumping, coking properties of some metallurgical coals may deteriorate because of adsorption of dispersed fine clays on the coal surface (33-36). Either of these effects can cause serious degradation of coke quality. Therefore, dewatering, restoration of coking properties, and particle size agglomeration to coke-oven charge standards would be expected from the slurry separation plant for a metallurgical coal-water pipeline.

Shell International Ltd. of Great Britain and Australian Broken Hill Proprietary Company Ltd. (BHP) are independently developing two coal end-pipeline processes. In both cases up to 15% of light oil is added as a selective agglomeration agent of fine coal particles (37-41). The BHP separation process has been developed particularly for coking coal pipeline slurries and it is claimed that the latest integrated slurry transportation-separation process either prevents coal deterioration or fully restores coking properties and improves the quality and yield of coke (42). So far, none of these processes have been in commercial operation.

There is no coal slurry ocean transport in the world (43,44). Unless cheaper coal slurry loading/unloading facilities and coal slurry ocean tankers are developed all Canadian pipelined coal for export will have to be agglomerated, separated from the slurry and surface dried for ocean shipment by dry-cargo vessels or bulk carriers.

EFFECT OF CANADIAN WINTER CONDITIONS ON THE PIPELINE SYSTEM AND NON-WATER SLURRIES

Generally, Canadian winter conditions will increase both capital and operating costs. Similarly, non-water coal slurries containing volatile liquid carriers, more expensive than water, will require special measures and equipment.

Water slurry system: Pipe and outdoor tanks will have to be insulated. Semi-active slurry and dead coal storage at the pipeline terminal will not be operative during the winter time. Therefore, the pipeline system coal storage would be located exclusively at the mine mouth.

Non-water slurry system: All lines and storage tanks will require insulation and all equipment would have to be fully enclosed and have explosion-proof electrical installation. Instead of open-air emergency ponds, closed liquid and active slurry storage tanks will have to be installed at pump stations.

THE COST OF COAL SLURRY TRANSPORTATION

A cost estimate of coal-water slurry pipeline transport has been prepared for three possible routes of western Canadian coal shipment:

to Vancouver, 900 km
to Southern Ontario, 3000 km
to oil sands or heavy oil fields, 400 km

The transport cost estimates for each route were prepared for two coal throughput levels postulated as the lower and upper capacities of future Canadian slurry pipelines. As no conceptual design study of either route was available, the approximate transport costs of all three hypothetical pipelines were based on generalized cost estimates for slurry pipelines proposed in a study by the International Energy Agency (IEA) (7) with following major assumptions:

Coal slurry and coal content	Black Mesa type, 48% wt %
Pipeline profile	flat
Average cost of water at the mine mouth	$ 0.60/m^3
Cost of electricity	$ 0.04/kWh
Cost of drying of agglomerated pipelined coal to 10% surface moisture	$ 0.70/tonne coal
Cost of insulation	~3% of capital investment
Annual capital charges (depreciation, return on investment, profits and taxes)	15% of capital investment
Lifetime of pipeline	30 years

Where applicable, charges for particle agglomeration and/or restoration of coking properties should be added to transport costs.

The route to southern Ontario is parallel to the existing Interprovincial Pipe Line (IPL) multiline crude oil pipeline system. Some pipes of the IPL system between Edmonton and Superior, Wisconsin and Sarnia, Ontario and Toronto are technically capable of converting to coal slurry pipelining. In an attempt to estimate transport cost, similar equipment modifications in conversion of existing crude oil pipeline were assumed as those considered by Sandhu and Weston (45).

The estimated coal-water slurry transport costs for the alternative routes are shown in Table 6, Table 7 and Table 8.

Preliminary transport costs for non-water coal slurries were also prepared. (These costs are subject to revision after completion of current research projects on slurry separation). Non-water slurry transport costs and current unit train tariffs are also shown in Table 6 and Table 7.

Coal-water slurry pipeline costs estimated for transport to the Pacific Coast, of about \$12.50 and \$9.50/t coal for respective throughputs of 10 and 20 Mt/a, are close to current tariffs for conventional coal transport by rail, particularly if the annual throughput is higher than 10 Mt. Assuming a \$3.70/m^3 credit for delivered methanol, which compares with a current Trans-Mountain Pipe Line tariff for petroleum (46), the net transport cost of coal by methanol for throughputs 10 and 20 Mt/a could drop from \$16.40 and \$12.50/t coal to \$11.00 and \$7.00/t of coal, respectively.

For transport to Ontario the estimated cost of \$31/t coal by a new coal-water pipeline is approximately equivalent to current rail tariffs if a charge for rolling stock of \$5.00/t coal is assumed in addition to the rail tariff of \$29.15/t coal. If the conversion of a part of existing crude oil pipeline to the coal slurry transport is possible both the water and non-water modes would benefit. Such a conversion to a coal-water mode of operation could give delivered coal costs of \$18.50/t and \$25.00/t at 10 or 5 Mt/a throughput rates. A non-water mode of operation would give delivered costs of \$37.00/t at the lower annual throughput. Assuming a \$4.40/m^3 tariff for delivered liquid fuel, which compares with a current IPL tariff for delivered crude oil (46), the net coal transport cost by non-water mode for throughput 5 Mt/a coal could be as low as \$30/t coal. The coal end-product assumed in these estimates contained 2% oil. The overall transport cost of the coal-oil mode will proportionally increase with increasing petroleum prices.

The coal-water mode was considered for delivery of coal to tar sands and heavy oil fields: both relatively short transport distances. Alternative coal-oil and recycle pipelines were evaluated and found more costly than conventional coal-water pipeline particularly for shorter transport distances (47,48). Rail in some circumstances can deliver coal 50% cheaper than new coal-water pipeline; therefore the state of existing rail network of northern Alberta will be a decisive factor in the selection of transport system for this route.

Capital related charges in all considered cases varied from 50% to 75% of estimated coal slurry pipeline costs. This proportion of costs, once the pipeline becomes operational, will not be affected substantially by inflation.

CONCLUSIONS

Western Canadian coal from selected coal areas of northern Alberta, southeastern and northeastern British Columbia could possibly be transported in pipelines of the Black-Mesa type coal-water or coal-methanol slurry to the west coast ports. The coal-oil slurry is an additional alternative mode for delivery to Eastern Canada. Coal transport to the tar sands or heavy oil fields will depend on the assessment of apparently cheaper transport by existing railway in the area.

Potential western coal pipelines have ultimate annual throughputs between 3 and 15 Mt in methanol and between 9 and 40 Mt in water modes depending on both the recoverable coal resource and the availability of water.

Tentatively, only subbituminous coal from fields around Edmonton and close to the IPL crude oil pipeline seem to be suitable for the coal-synthetic crude oil pipelining to Ontario markets.

Unless coal slurry loading facilities and ocean coal slurry tankers are more established, all western Canadian pipelined coal for export would have to be dried. And unless coal slurry pipeline transport were capable of delivering coke oven size coal (80% minus 3 mm x 0 mm) the coal would have to be agglomerated by an integrated agglomeration/drying process to a form suitable for dry-bulk overseas shipment. A similar process with an additional option for the restoration of coking properties should also be developed and tested for Canadian pipelined metallurgical coal in water.

Because of high capital investment requirements the methanol mode slurry pipeline could only be justified in directions where a stable market for fuel methanol is established.

Estimated coal transport costs, or tariffs after adjustment for coal agglomeration, by newly built coal-water pipelines to the west coast or Ontario should be close to current tariffs of rail transport. Coal pipeline tariffs, because of 75% capital related proportion of costs, could be more stable during the entire pipeline lifetime.

Conversion of a part of existing multiline IPL crude oil pipelines to coal-water slurry pipelines will decrease coal transport costs to 75% of those estimated for newly built coal-water pipelines.

The net transport costs of coal by non-water pipelines will depend on allowable charges for delivered and separated liquid fuel from the slurry.

Transport costs of coal-oil slurry to Ontario will proportionately increase with prices of crude oil and the oil residue on the coal.

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Table 1 - Black Mesa pipeline

Coal:	subbituminous, 28% inherent moisture, 8% ash
Slurry:	coal in water, "pseudohomogeneous" or mixed type
Concentration:	45 to 55% wt solids
Particle size:	1.4 x 0 mm with 18 to 20% wt or minus 40 µm particles
Line velocity:	1.2 to 1.8 m/s
Pipe O.D.:	457 mm
	304 mm (descending part to Colorado River)
Line capacity:	4.5 Mt/a

Table 2 - Coal and water requirements for coal-water and coal-methanol slurry pipelines

a) Water slurry pipeline			
Coal concentration	Water and coal ratio in slurry	Mined and pipelined coal weight ratio	Specific water requirement[1]
wt %	m^3/t coal	t/t	m^3/(s.Mt/a)
45	1.22	1.0	0.39
50	1.00	1.0	0.32
55	0.82	1.0	0.26

b) Methanol slurry pipeline[2]			
Coal concentration	Methanol and coal ratio in slurry	Mined and pipelined coal weight ratio[3]	Specific water requirement[1]
wt %	m^3/t coal	t/t	m^3(s.Mt/a)
45	1.55	3.70	2.6
50	1.27	3.20	2.1
55	1.04	2.80	1.7

1) Specific Water Requirement is a 10 times multiple of the total water requirement or the required water flowrate per unit of annual coal slurry capacity.

2) This table represents a "worst case" of methanol production with wet cooling and delivered coal at 30% moisture. About 90%, of the water requirement is utilized for cooling purposes in methanol production.

3) This ratio varies with moisture content of mined coal.

Table 3 - Potential coal fields of Alberta for coal water or methanol slurry pipeline transport

Coal field code[1]	Coal field or coal deposit[2]	Recoverable coal[3]	ASTM rank	Water supply[4] Name of river, distance and control station	Water supply[4] Minimum recorded discharge	Ultimate coal slurry throughput[5] Water	Ultimate coal slurry throughput[5] Methanol[6]
	-	Mt	-	-	m^3/s	Mt/a	Mt/a
A 01	Blairmore, Coleman Tent Mountain, Beaver Mines, Bellevue and Daisy Creek	390	lm v-b	Kootenay River, 60 km max., Wardner	30.6	13	
A 02	Cadomin - Luscar, Mountain Park and Coalspur	532	m v-b h v-b	Athabasca River, 40 to 60 km., Hinton	17.0	18	
A 03	Hannington and Obed Mountain	278	h v-b	Athabasca River, 10 to 15 km.,	>17.0	9	
A 04	Smoky River	368	l v-b	Smoky River, < 50 km, above Heels Creek	10.2	12	
A 05	Fox Creek (major deposits)	760	sub B/C	Athabasca River, 55 km, Windfall	28.2	25	6 - 8
A 06	Judy Creek and Carson Lake	380	sub C/B	Athabasca River, 40 km, Windfall	28.2	12.7	3 - 4

Table 3 - Cont'd

Coal field code[1]	Coal field or coal deposit[2]	Recoverable coal[3]	ASTM rank	Water supply[4] Name of river, distance and control station	Water supply[4] Minimum recorded discharge	Ultimate coal slurry throughput[5] Water	Ultimate coal slurry throughput[5] Methanol[6]
		Mt			m^3/s	Mt/a	Mt/a
A 07	Wabamun & Mayerthorpe	996	sub A/B	North Saskatchewan River, 20-30 km, Rocky Rapids	24.8	33	8.5 - 11
A 08	Wetaskiwin	1223	sub A/B	ditto	ditto	40	8.6 - 13
A 09	Morinville	563	sub C	North Saskatchewan River, 40 km, Edmonton	16.4	19	5 - 6
A 10	East Edmonton and Toefield (major deposits)	583	sub C	ditto	ditto	19	5 - 6

1) Identical with codes in Fig. 4.

2) Identical with coal field and deposit in Ref. (22).

3) Total surface and underground recoverable coal Ref. (22). Some minor deposits were omitted.

4) Ref. (23)

5) Ultimate coal slurry throughput, G, is defined

$$G = \frac{\text{(Recoverable Coal, (Mt))}}{\text{(Pipeline Lifetime, (years)x(Total Mined and Pipelined Coal Ratio)}}, \text{ Mt/a}$$

If G x (Specific Water Requirement from Table 2) > (Minimum Recorded Discharge from Tables 3 & 4, column 6) then the Minimum Recorded Discharge is a factor determining the ultimate throughput. A 30 year pipeline lifetime was assumed; the ratio of mined and pipelined coal equals one in coal-water mode but in the coal-methanol mode the ratio varies with slurry concentration and moisture content of mined coal.

6) Throughputs were estimated for 45 and 55% wt solid concentrations of methanol slurry at moisture content of mined coal which could vary from field to field between 10 and 30% wt (22).

Table 4 - Potential coal fields of British Columbia for coal water slurry pipeline transport

Coal field code[1]	Coal field or coal deposit[2]	Coal reserve[3]	ASTM rank	Water supply[3] Name of river, distance and control station	Minimum recorded discharge	Ultimate water coal slurry throughput
-	-	Mt	-	-	m^3/s	Mt/a
B 01	Southeastern British Columbia	15 722[2]	lm v-b	Elk River, 50 to 60 km, Elk or	6.6	21[4]
				Kootenay River 55-80 km, Wardner	30.6	29[5]
B 02	Northwestern British Columbia	1 458[2]	lm v-b	Peace River 0 to 75 km, Hudson Hope	173	N/A[6]

1) Identical with codes in Fig. 4

2) Ref. (2)

3) Ref. (24)

4) Based on minimum recorded discharge of Elk River

5) Based on 874 Mt of recoverable coal (2).

6) No data on coal reserves is available.

Table 5 - Variation of Alberta conventional light and synthetic crude oil production until year 1995

Year	Established reserves of light crude oil[2]	Reserves additions of light crude oil[2]	Total light crude oil	Synthetic crude oil	Total crude oil (conventional and synthetic)	Proportion of light crude oil
-	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	%
1981	54.9	3.5	58.4	9.2	67.6	86
1985	32.1	7.1	39.2	11.2	50.4	78
1990	17.5	9.0	26.5	33.7	60.2	44
1995	10.2	9.6	19.8	51.1	70.9	27

1) From National Energy Board (NEB) (28)

2) Alberta's production of light crude oil from reserves additions is estimated as 85% of the total Canadian production from reserves. From NEB (28)

3) Based on Alberta Energy Conservation Board (29)

Table 6 - Estimated coal slurry pipeline transport costs - to Vancouver 900 km

Transport mode	Annual coal throughput	Transport cost or tariff	Comments
	Mt	$/t coal	-
Thermal or metallurgical coal-water slurry	10 20	12.50 9.50	No charges for agglomeration and/or coking properties restoration
Thermal coal - methanol slurry, (45%)	10 20	16.40 12.50	Net coal transport cost can be obtained after cost split between delivered coal and methanol
CPR unit train, (1100 km)	~12	14.90	Published 1980/81 rail tariff; expired in March 1981

Table 7 - Estimated coal slurry pipeline transport costs - to Ontario 3000 km

Transport mode	Annual coal throughput	Transport cost or tariff		Comments
		New pipe	Converted pipe	
	Mt	$/t coal	$/ton coal	-
Thermal coal-water slurry	5	34.00	25.00	
Metallurgical coal-water slurry	10	27.00	18.50	No charges for agglomeration and properties restoration included
Thermal coal-oil or methanol slurry, (45%)	5	47.00	37.00	Net transport cost of coal can be obtained after cost split between delivered coal and liquid fuel
CNR unit train, (2770 km)	1.6	29.15		Published 1981 rail tariff; no charges for rolling stock are included

Table 8 - Estimated coal-water slurry pipeline transport costs, (400 km) and rail transport cost, (450 km) - to tar sands

Transport mode	Annual coal throughput	Estimated transport cost
	Mt	$/t coal
Thermal coal	5	10.50
in water	10	9.00
New rail[1)]	5.4	12.30
Upgraded rail[1),2)]	5.4	4.70

1) Based on IEA data (7)

2) 10% new and 50% upgraded existing rails

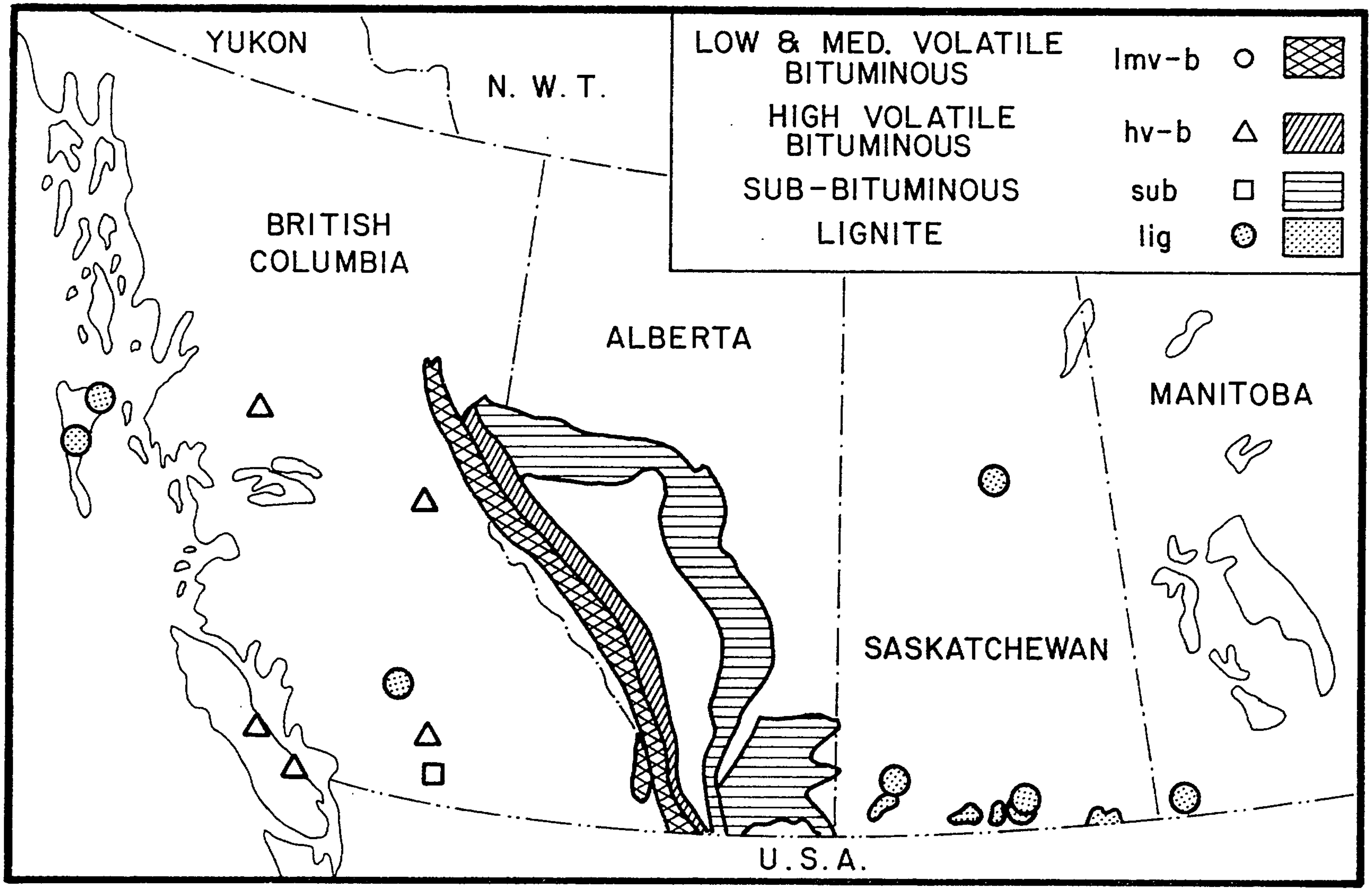

Figure 1. WESTERN CANADA COAL DEPOSITS

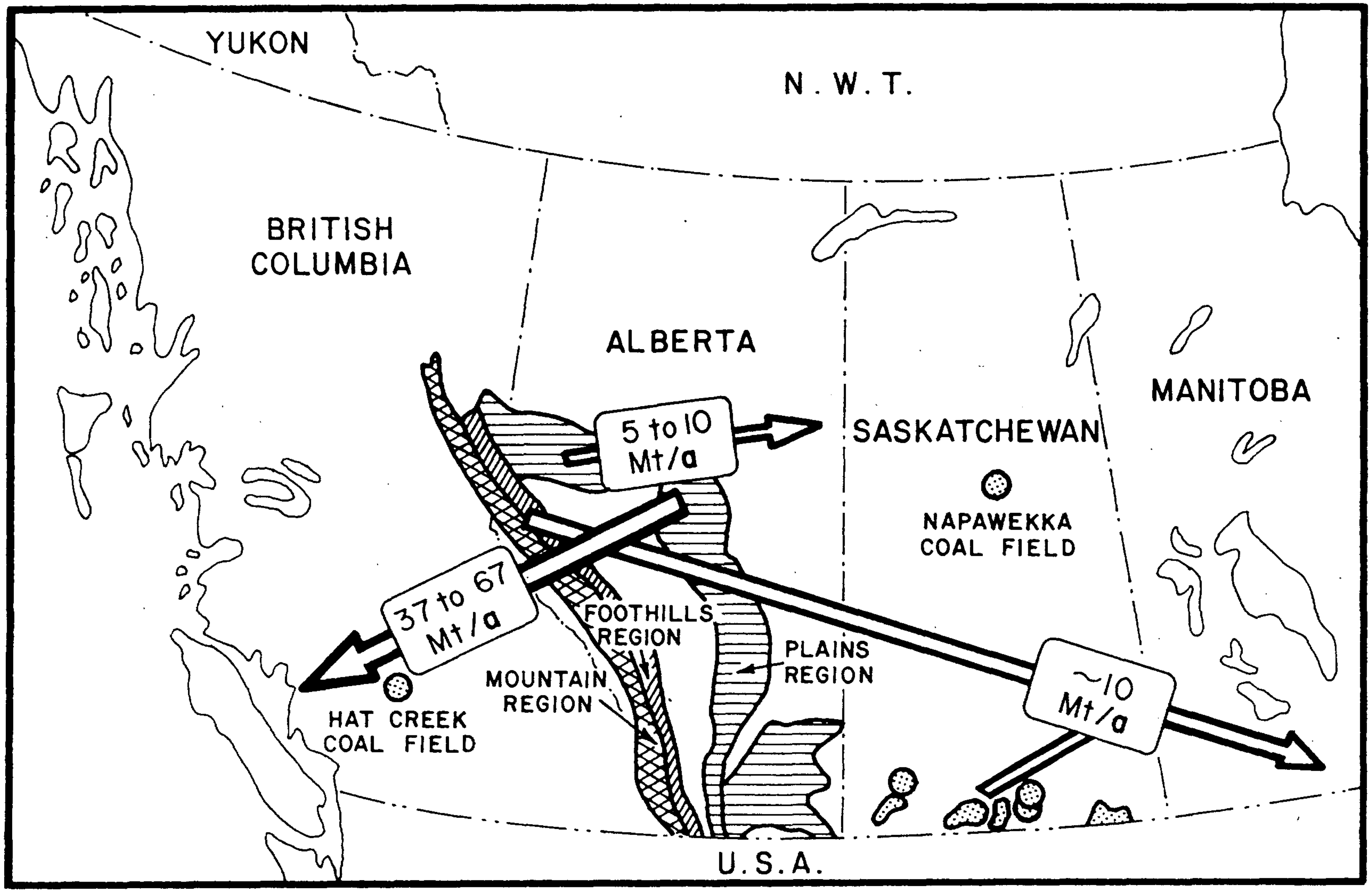

Figure 2. PROJECTED MOVEMENTS OF WESTERN COAL BY YEAR 2000

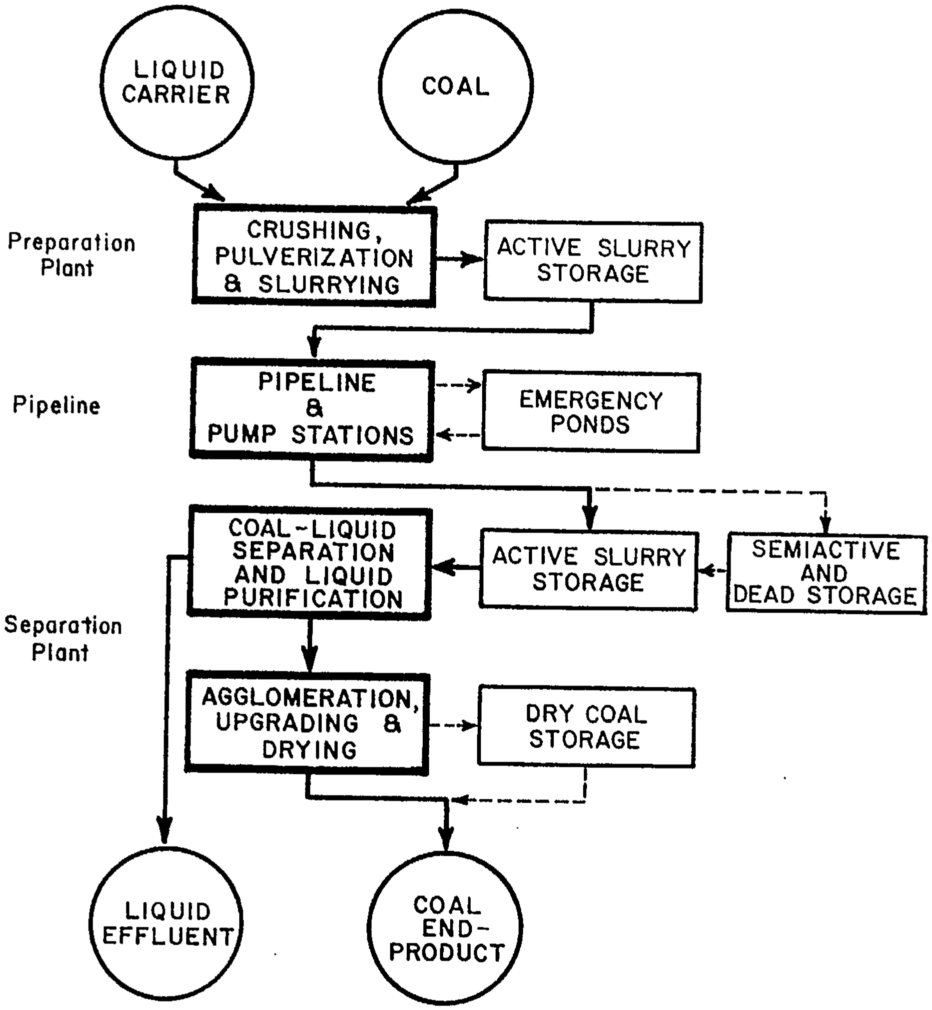

Figure 3. SCHEMATIC FLOW DIAGRAM OF COAL SLURRY PIPELINE TRANSPORT SYSTEM

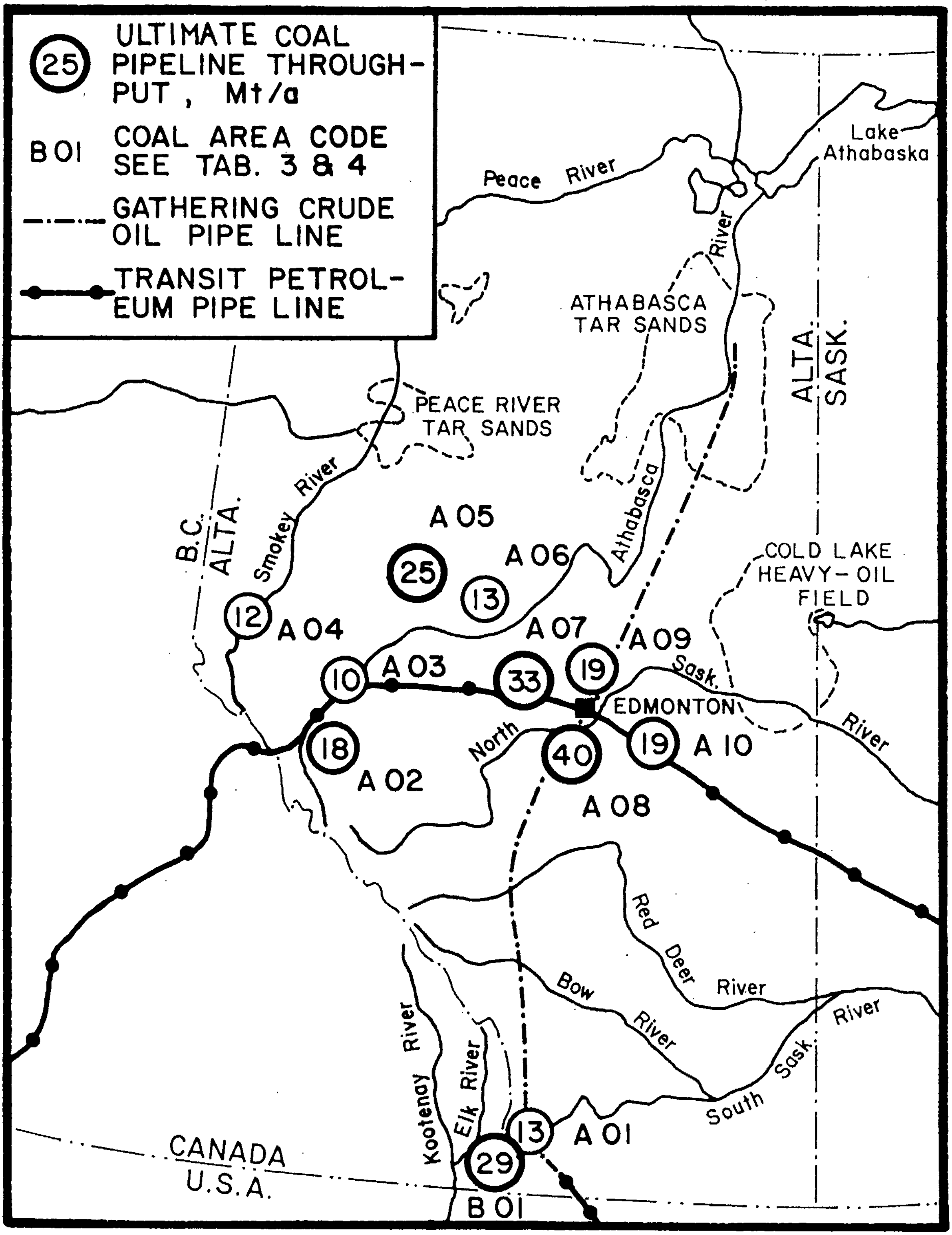

Figure 4. POTENTIAL OF COAL SLURRY PIPE LINE TRANSPORT FOR WESTERN CANADA