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Centre canadien de la technologie des minéraux et de l'énergie

REPORT 79–13

LIQUID FUELS FROM CANADIAN COALS

G.W. TAYLOR

ENERGY RESEARCH PROGRAM
TECHNOLOGY INFORMATION DIVISION

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PREFACE

This paper represents a consolidation of the knowledge and considered opinions of CANMET scientists on the subject of producing liquid fuels from coals in the Canadian context. It is an information document, intended to provide background needed for policy decisions and research and development planning.

J.F. Kelly was the principal technical consultant to the author. He helped identify the main issues to be addressed, and made major contributions to the substantive content of the report, particularly on liquefaction technologies and their applicability in Canada. His assistance was fundamental to the report's accuracy and completeness.

D.S. Montgomery, former CANMET Energy Adviser, provided advice and guidance at the conceptual stage of the report, pinpointing the main questions of concern to Canada. M. Ternan, K. Belinko and B.B. Pruden also provided information, comments and suggestions.

AVANT-PROPOS

Le présent rapport est une compilation des connaissances et opinions des chercheurs scientifiques du CANMET sur la production de carburants liquides à partir des charbons du Canada. Ce document est publié à titre d'information et tente d'exprimer la formule de base employée pour l'élaboration de politiques et la planification de la recherche et du développement.

J.F. Kelly a été le principal consultant technique de l'auteur. Il a aidé à identifier les principales idées et a grandement contribué à la matière du rapport particulièrement en ce qui a trait aux technologies sur la liquéfaction de les applications au Canada. Sa contribution a été indispensable à la précision et à l'état complet du rapport.

D.S. Montgomery, ancien conseiller sur l'énergie de CANMET, a offert ses conseils et son aide au stade de conception du rapport et a identifié les principaux points d'interêt pour le Canada. Messieurs M. Ternan, K. Belinko et B.B. Pruden ont fourni des renseignements, des commentaires et des suggestions.

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LIQUID FUELS FROM CANADIAN COALS

by

G.W. Taylor*

ABSTRACT

In Canadian energy planning, the central issue of security of supply must be addressed by developing flexible energy systems that make the best possible use of available resources. For liquid fuel production, oil sands and heavy oils currently appear more attractive than coal or biomass as alternatives to conventional crude oil, but the magnitude of their economic advantage is uncertain. The existence of large resources of oil sands, heavy oils, natural gas and low-sulphur coals in Western Canada creates a unique opportunity for Canadians to optimize the yield from these resources and develop new technology. Maritime coals deserve special consideration to meet regional needs arising from total reliance on imported crude.

Many variations on the three basic liquefaction routes -- hydroliquefaction, pyrolysis and synthesis -- are under investigation around the world, and the technology is advancing rapidly. In the Canadian context, each process has merit under certain circumstances.

Based on our limited current understanding of the available coals, surface-mineable subbituminous and lignite coals of Alberta and Saskatchewan appear to offer the best combination of favourable properties, deposit size and mining cost, but other deposits in Alberta, Nova Scotia and British Columbia should not be ruled out.

The research effort in Canada is small by world standards, but it is unlikely that technology could be imported that is ideally suited to Canadian conditions. Importing technology is undesirable, and innovation or process modification to suit Canadian coals and markets is preferred. Coprocessing of coals with bitumen or heavy oils would be a uniquely Canadian, exportable technology.

The cost of synthetic crude from coal in Canada is uncertain, estimates ranging from \$113 to \$220/m^3 (\$18 to \$35/bbl). Existing economic evaluations vary widely depending on assumptions, and can be misleading. Product quality is an important consideration.

Several priority areas for research and development are identified in this paper. Of particular importance are basic engineering, hydrogen supply, coal quality and environmental impact. The main considerations bearing on research and pilot plant strategies are discussed. Such strategies should improve our understanding of Canadian coals, develop Canadian technology, and above all, build the infrastructure and expertise that will be needed if coal liquefaction reaches the commercial stage.

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COMBUSTIBLES LIQUIDES A PARTIR DE CHARBONS CANADIENS

par

G.W. Taylor*

RESUME

Afin d'assurer l'approvisionnement des sources d'énergie il faut mettre au point des systèmes d'énergie flexibles qui utiliseront le plus efficacement possible les sources énergétiques dans le cadre de la planification de l'énergie au Canada. Pour le moment, la production de carburants liquides à partir des sables bitumineux et des huiles lourdes, est plus attrayante qu'avec le charbon ou la biomasse comme substituts au pétrole brut classique, mais on ne peut estimer leur importance au point de vue économique. L'existance de ressources abondantes de sables bitumineux, d'huiles lourdes, de gaz naturel et de charbons à basse teneur de soufre dans l'Ouest du Canada permet aux Canadiens d'optimiser le rendement de ces ressources et de mettre au point une nouvelle technologie. Les charbons provenant des Maritimes méritent d'être considérés car ils peuvent alléger une trop grande dépendance sur le pétrole importé.

Plusieurs variations des trois techniques de liquéfaction de base -- hydroliquéfaction, pyrolyse, et synthèse -- sont maintenant étudiées à travers le monde et la technologie se perfectionne rapidement. Au Canada, chacun des procédés a des mérites selon la circonstance.

Compte tenu des connaissances actuelles des charbons disponibles, les charbons subbitumineux de surface et la lignite provenant de l'Alberta et de la Saskatchewan semblent offrir la meilleure combinaison des propriétés favorables, de l'envergure des dépôts et des coûts d'exploitation. Par contre, il ne faudrait pas ignorer ceux de l'Alberta, de la Nouvelle-Ecosse et de la Colombie-Britannique.

L'effort de recherche que déploie le Canada est minime lorsque comparé à celui du monde entier; mais il est peu probable qu'une technologie importée puisse être adaptée aux conditions canadiennes. Il est plus favorable de perfectionner et de modifier les procédés actuels pour convenir aux charbons et marchés canadiens que d'importer la technologie. Le traitement des charbons avec le bitume ou l'huile lourde peut devenir une technologie canadienne unique et exportable.

Le coût de la transformation du charbon canadien en pétrole brut est incertain mais peut varier de \$113 à \$220/m^3 (\$18 à \$35/baril). Ces chiffres peuvent varier selon les hypothèses et donc peuvent être trompeurs. La qualité du produit est un important facteur.

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Le présent rapport décrit certains domaines importants de recherche et de développement notamment les techniques de base, l'approvisionnement en hydrogène, la qualité du charbon et l'impact sur le milieu. Les points importants traitant de la recherche et de la stratégie de l'installation pilote y sont décrits. De telles stratégies devraient améliorer notre connaissance des charbons canadiens et surtout mettre sur pied l'infrastructure et l'expertise dont on aura besoin si la liquéfaction du charbon atteint les marchés commerciaux.

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THE CANADIAN CONTEXT

Liquid fuels enjoy a special place in the total energy system because they are the form in which energy can be transported most cheaply over long distances, and their high energy density makes them uniquely suitable as fuels for transport and agriculture. It is hard to envision modern society without them. A decrease of more than a few per cent in their use in this century would require radical technological or social change.

Canada relies almost exclusively on conventional crude oil for its liquid fuel supply, the only other current source being synthetic oil from oil sands. There is serious concern about the ability of this conventional crude to meet future demands, and synthetic oil is only now beginning to have an impact. Not until the mid-1980's will more than 10% of total domestic oil demands be met by oil sands plants.

Proven Canadian reserves of conventional petroleum peaked in 1969 and production peaked in 1973. Both are now well below those levels. Recent National Energy Board projections indicate that producibility from Western wells will decrease by 1985 to about 65% of the present level and will then increase again only slightly by 1995, whereas demand will continue to increase. Potential discoveries in frontier areas are unlikely to add significantly to short and medium-term supply because of high production costs, logistical problems and environmental risks.

Projected shortages of domestically produced crude constitute one of the most significant economic challenges facing Canada. The inevitable conclusion is that unless substitutes are developed quickly, imports will have to be increased to assume a larger role in meeting demands.

A major goal of the national energy strategy is to eliminate oil imports, which now account for about 34% of domestic needs. The task is formidable: replacing today's imports by oil sands production would require five Syncrude-sized plants. Furthermore, eastern provinces have come to rely almost exclusively on imports for petroleum supply, resulting in an acute problem which is being addressed by federal and provincial governments.

The central issue in national liquid fuel strategies is, then, security of supply. Oil sands, heavy oils, coal and biomass are possible alternative sources. With the possible exception of biomass, each can, like crude petroleum, be used to produce the full range of fuels and chemicals, depending on the nature and extent of processing.

On the other hand, with similar processing the chemistry of these feedstocks leads each to selectively yield products of particular characteristics. Coal, for example, lends itself well to high-octane gasoline production, whereas bitumen, the raw "oil" in oil sands, may be better suited for diesel or fuel oil production. Coprocessing of the two feedstocks might yield a versatile product slate. Product yields and characteristics must be considered carefully in determining how each resource will help meet the security of supply problem.

Although oil sands and heavy oils currently are more attractive than coal as liquid fuel sources, mainly for economic reasons, the extent and quality of Canada's coal resource base suggest that coal also deserves serious attention. As the 1973 oil crisis taught us, it is difficult to predict energy prices. Coal could conceivably become a cheaper source of liquid fuels than oil sands in the medium term.

With the lead time available, Canada can and should develop strategies that will make the best possible use of the coal resource. From the liquid fuels standpoint, this will involve learning more about the resource and developing or acquiring the most suitable technology. To be prepared for the possible eventual need for coal liquids, infrastructure and technical competence must be built. Close cooperation among scientists, engineers, economists and policy-makers is essential. Regional energy needs must be given special attention.

Expanded understanding of the Canadian coal resource base would be useful in all coal-related decisions, not just those involving liquid fuels. Ideally it would be possible to identify the most appropriate use for each deposit, and reserve it for that use, provided it is compatible with projected social and environmental goals.

Liquid fuel supply and demand

Canada's principal liquid fuel sales are summarized in Fig. 1. Figure 2 indicates where refining capacity is located, and what percentage of the crude petroleum feedstock is met by imports.

	$10^6 m^3/a$	%
MOTOR GASOLINE	37.1	38
LIGHT FUEL OIL, KEROSENE & STOVE OIL	16.9	17
HEAVY FUEL OIL	15.6	16
DIESEL FUEL	13.1	13
AVIATION FUELS	4.2	4
OTHER PRODUCTS	11.8	12
TOTALS	98.7	100

Fig. 1 - Sales of refined petroleum products in Canada in 1978. (1 x $10^6 m^3/a$ equals about six million barrels a year.)

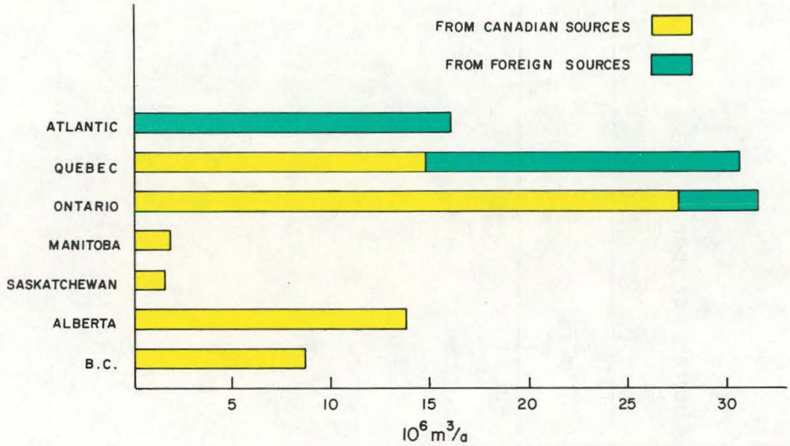

Fig. 2 - Refinery capacity and source of feedstock, by province or region, 1978. Note the heavy dependence on foreign sources in Eastern Canada.

Distribution of refinery products is such that regions east of Ottawa rely primarily on foreign crude for their liquid fuel supply. The total reliance on expensive foreign sources in the Atlantic Provinces is a subject of serious concern. Provincial governments, particularly Nova Scotia, are taking action with federal assistance to increase the role played by non-liquid domestic energy resources such as coal and gas. Although Western Canada is more generously endowed with petroleum resources, declining reserves and production mean that other energy resources will grow in importance for liquid fuel supply there as well.

Demand for the liquid fuels shown in Fig. 1 has been examined and forecasted by the National Energy Board. Although other scenarios are possible, the NEB projections are shown in Fig. 3 for purposes of illustration.

Total demand is expected to be about 15% higher in 1995 than in 1978. Energy conservation measures, improved efficiencies and high energy prices are expected to cause a reduction in gasoline and light fuel oil requirements, and an increase in diesel and heavy fuel oil. Diesel oil, in fact, accounts for most of the projected increase - suggesting that the suitability of the resources at hand to meet diesel demand might be a subject for detailed study.

Declining conventional crude oil production, coupled with growing liquid fuel demand, emphasizes the urgency of conservation, inter-fuel substitution, and measures to increase crude oil supply and develop other liquid fuel feedstocks. It should also be noted that because the quality of crude oil from Western oilfields is steadily declining, its refining will become increasingly difficult and expensive.

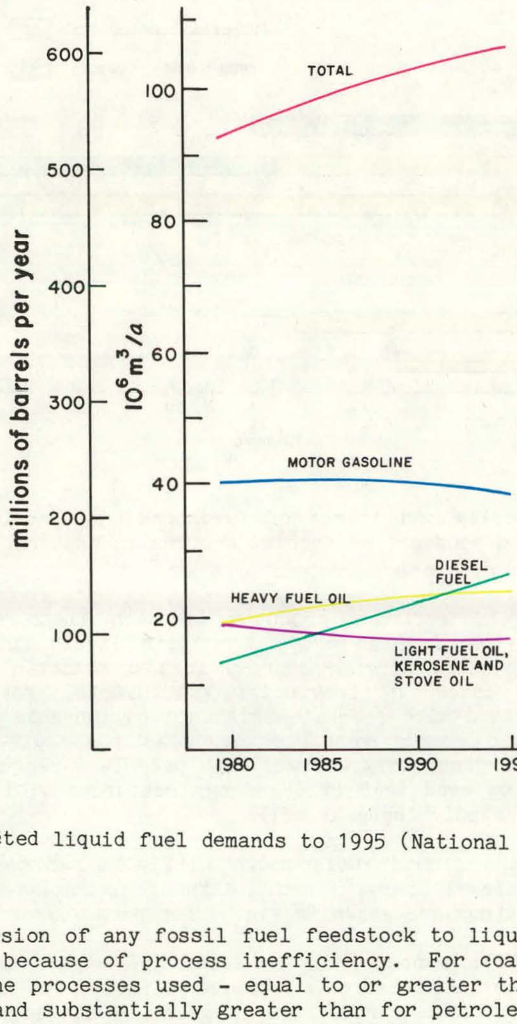

Fig. 3 - Projected liquid fuel demands to 1995 (National Energy Board, 1978).

Conversion of any fossil fuel feedstock to liquid fuels entails some loss of energy because of process inefficiency. For coal the loss is 30-65%, depending on the processes used - equal to or greater than for oil-sand bitumen refining, and substantially greater than for petroleum refining. Because one objective of the national energy strategy is to conserve energy by making better use of the resource, priority in energy projects must be based to some degree on the efficiency with which each option can contribute to liquid fuel supply. Thus exploration and development, technology to improve production from conventional wells, and recovery of oil from oil sands and heavy oils, might be expected to receive more attention than coal liquefaction.

The problem is not that simple, however, as a variety of other technological, economic, environmental and social factors come into play. Full evaluations of each option will be needed to assess the influence of these factors and verify the energy efficiency data.

Coal resources

Table 1 shows the extent of Canadian coal resources and reserves in comparison with other fossil fuels. Not all coals are suitable for liquefaction, and some should be reserved for other uses. Also, it can not be assumed that coal resources can be developed at will. There are many constraints on coal mining, not the least of which are environmental considerations, labour availability, and provincial government policies. A more detailed view of the resource base is given later in this report.

Canada's special advantages

Several other industrialized nations besides Canada are paying close attention to coal as a way of reducing dependence on imported oil. Circumstances in Canada, however, differ in some very important respects from those in other countries.

First, Canada has abundant reserves of low-sulphur coal in the West, which are suitable for electricity production by direct combustion.

Second, the vast resources of oil sands and heavy oils in Alberta and Saskatchewan have excellent potential to replace crude oil. In the medium to long term they are certainly more significant than, say, Britain's North Sea oilfields. Canada is the acknowledged world leader in technology to develop these resources, and is continuing to build experience.

Third, Canada's natural gas supplies in relation to domestic demand are more substantial than those of either the United States or Europe. Moreover, they are situated close to coal and low-grade petroleum deposits - an important consideration because the gas is a prime source of hydrogen needed to convert these resources to liquid fuels.

Consequently, Canada may have more lead time to develop a liquids-from-coal capability than do most other industrialized nations - time that should allow us to ensure that the technology is well suited to Canadian needs and has maximum Canadian content. In the West, the concentration of several types of fossil fuel resources in one geographic region affords excellent opportunities to develop the resources jointly in such a way that they can complement one another to maximize overall energy yield.

In the Maritimes the coals are high in sulphur but are otherwise of excellent quality. Climatic and geographic conditions create a different environment for coal utilization than in, say, the United States. Furthermore, as in Western Canada, coal development must be evaluated as part of the entire energy system that includes other resources as well. In Nova Scotia and New Brunswick, opportunities exist to blend coal projects with nuclear, tidal, biomass and perhaps other less conventional sources to create an energy "package" that is uniquely suited to the region.

In the United States, where national energy policy objectives are similar to Canada's, there has been an acceleration of coal liquefaction research and development in recent years, and the current thrust is to bring the most promising technologies to commercial scale as quickly as possible.

Utilities in the U.S.A. are attempting to reduce the use of oil in power plants, but stringent environmental regulations rule out the most ac-

Table 1 - Estimated resources and reserves of fossil fuels in Canada, and recoverable oil content or equivalent. Recoverable reserve data for coal were made in 1976 and are considered conservative, particularly as data for Alberta were incomplete. Furthermore, the coal reserve data were based on technical and economic criteria for thermal end use; no such assessment has been done for liquefaction end use. Reserve estimates for different fuels are based on different criteria. This table therefore gives, at best, only an approximate indication of relative reserve amounts.

Fossil fuel	Resources in place (1)		Recoverable reserves	
	Quantity	Energy content, MJ	Energy content, MJ	Recoverable oil content or equivalent, 10^9 m^3 (billion bbl)
Conventional crude oil	16×10^9 m^3 (98 billion bbl)	600	35(2)	0.92 (5.78)(2)
Oil-sand bitumen and heavy oils	158×10^9 m^3 (3) (995 billion bbl)	6700(3)	255(1,4)	4.21 (26.50)(1,5)
High-volatile bituminous, sub-bituminous and lignite coals	146×10^9 t (161 billion short tons)	2800(6)	89(1,7)	1.97 (12.40)(1,8)
Natural gas	25×10^{12} m^3 (84 trillion cu ft)	900	70(9)	1.84 (11.56)(10)

(1) Based on EMR estimates, 1976
(2) Based on National Energy Board estimate, 1978
(3) Bitumen and heavy oil in place
(4) Recoverable crude bitumen
(5) Recoverable synthetic crude oil after upgrading
(6) Estimated from average calorific value of each rank
(7) Reserves of thermal coal
(8) Based on assumed oil yields of 0.53 m^3/t (3.0 bbl/short ton) for high-volatile bituminous, 0.44 m^3/t (2.5 bbl/ton) for subbituminous, and 0.35 m^3/t (2.0 bbl/ton short ton) for lignite
(9) Based on National Energy Board estimate, 1979
(10) Crude oil equivalent on calorific bases

cessible coals which are high in sulphur, and the cost of converting power plants from oil to coal is very high. Hence, there is great interest in converting the coal to cleaner-burning liquids. Note, however, there is a substantial penalty involved because the liquefaction step results in a substantial energy loss which is not recovered in the combustion step.

West Germany is another nation with a heavy investment in liquefaction technology. The Germans produced much of their liquid fuel supply from coal during World War II. They have retained their expertise from that era, and are building on that foundation, apparently with the principal intention of exporting the technology in the near term. Early German technology still forms the basis for many of the most highly developed liquefaction processes. Because of high coal cost, liquids from coal are not expected to be economically competitive in Germany for a long time.

Currently, the only commercial coal liquefaction operation in the world is the SASOL complex of the South African Coal, Oil and Gas Co. (Fig. 4). A plant has been in operation for about 20 years, producing a wide range of fuels and chemicals using German technology. A second plant, now under construction, will be four to five times the size of the first, and will supply up to 40% of the country's motor gasoline.

Why does South Africa produce liquids from coal at apparently marginal profit when the technology has been considered uneconomic in other nations?

South Africa has very limited indigenous petroleum reserves, and for political reasons must avoid any risk of an embargo imposed by petroleum exporters. On the other hand, the country does have very large deposits of easily-accessible low-rank coals and has chosen to tap them in the national interest. The mine provides suitable employment for a large population of unskilled workers, and the local steel and chemical industries make good use of byproduct gases.

The SASOL technology is inefficient and expensive, although well-suited for the available coal. The consensus in North America is that, in its present form, it is so uneconomic for North American conditions that it does not warrant serious immediate consideration. In the long run, process modifications and improvements, and the ability to selectively produce certain types of chemicals and use high-ash coals, may make SASOL-type technology particularly suitable in certain parts of Canada.

A Canadian synthetic fuels industry - What shape will it take?

At the present time coal conversion is not the top priority for synthetic liquid fuel production in Canada. Oil sands and heavy oils currently enjoy an apparent cost advantage over coal, although its magnitude is uncertain. Also, the technology for their development is better established. With two plants in operation, one of which is planning expansion, and two more proposed, oil sands and heavy oils will form the basis of a synthetic fuels industry in Canada for the rest of this century. The projected capacity of these four plants amounts to about 25% of domestic refinery demand for crude oil.

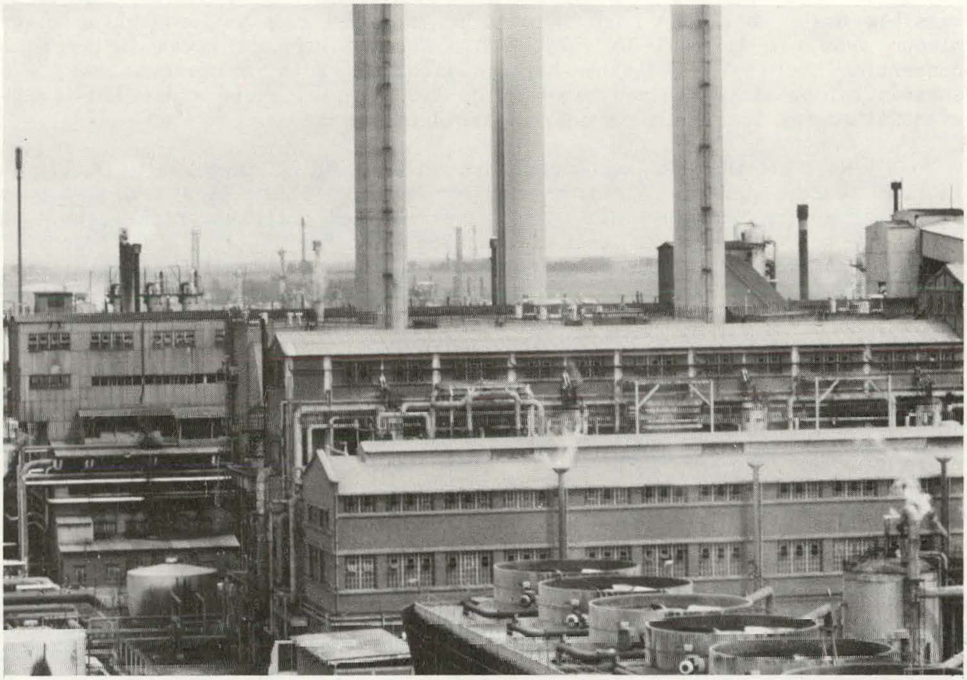

Fig. 4 - A portion of the SASOL complex in South Africa -- the only commercial-scale coal liquefaction facility in the world. A second, larger plant is under construction.

It should be noted, however, that the world-wide coal liquefaction effort makes Canada's oil sands and heavy oils R & D seem small by comparison. As a result the development "inertia", which involves a large commitment of manpower and resources by the private and public sectors, could eventually change in coal's favour, depending on economic conditions.

Coal may also have an immediate and important role to play in improving the yield of liquids from oil sands and heavy oils. It can be used to generate steam for well stimulation, or to provide process heat and electricity. For these applications it is cheaper than the oil product, and by the year 2000, millions of tonnes of Western coal might be used in this way each year.

There is a further possibility that is still in the exploratory stages but shows good promise. If coal is mixed with bitumen or with heavy oil, it adds to liquid product yield. This might be particularly useful in the CANMET hydrocracking process for bitumen and heavy oil upgrading.

Canada is in an excellent position to be the world leader in the technology of coprocessing coal with heavy petroleum feedstocks. If the CANMET process were used, the technology would be uniquely Canadian.

What about biomass? There is much talk about the potential of methanol from biomass to meet part of our liquid fuel demands. Canada has a very large biomass resource base, particularly in the forests, but they are not infinite. Indeed they could only supply a small portion of the present liquid fuel requirements. Under current conditions a 16 000-m^3/d (100 000-bbl/d) biomass-to-liquids facility would require a short rotation plantation covering 2-5% of the total forest area of Canada. The thermal efficiency of converting wood to liquids is below 40% and the environmental impact of the large harvesting operations would be extensive.

Reports prepared to date on the biomass option have presented conflicting evidence. A detailed assessment of the resource base and its potential productivity would help resolve the differences.

Although it currently appears unlikely that biomass will play a major role in supplying national liquid fuel needs, it may be important to supply liquids or replace oil in certain regions, especially in central Canada where forests are plentiful and fossil fuels scarce. The potential depends in large part on progress in short rotation forestry.

The large amount of residues associated with forestry operations may be very significant. About 30% of the harvest is rejected as waste and the energy content of this waste equals about 3.5% of Canadian primary energy demand. There are about 20 sites in Canada that could each support a facility producing 1000 t/d of methanol, equivalent to 560 m^3/d (3500 bbl/d) of crude oil, from residues. The residues can also be gasified to produce fuel gas to replace fuel oil.

In regions such as the Maritimes, the potential of forest biomass to play a part in an integrated energy system that includes other energy sources should be evaluated - whether the biomass is burned, gasified, or liquefied.

In Quebec, there is some research interest in producing liquid fuels from peat. In the geological sense, peat is essentially very young, very low grade coal, containing up to 90% water. Its efficiency and cost of conversion to liquids would not compare favourably with those for coal, but it too might be of regional importance. There are extensive peat resources throughout Eastern Canada.

Constraints - It must be recognized there are some major constraints on the development of a synthetic liquid fuels industry. These must be addressed in research and development programs and in policy-making.

Such facilities require large amounts of capital and would have to compete for this capital with other energy projects such as pipelines, nuclear and hydro-electric developments, and thermal power plants. Large construction projects also have long lead times and face international competition for equipment and trained manpower. It takes about seven years to develop a new coal mine and certain large pieces of equipment have to be ordered as long as five years in advance.

Environmental impact would be of serious concern, particularly in connection with mining operation and water requirements. As a large portion of the resources is concentrated in Alberta, this would be a major consideration for the provincial government, which has already put restrictions on mining of some of the larger coal deposits.

Such projects require large quantities of hydrogen, and their viability is thus tied in with utilization strategy for natural gas, which is a main source. There are other ways to produce hydrogen but they are more expensive. Gasification of the coal itself or of coal liquefaction residues are possibilities. Because of its importance in fossil fuel upgrading, the generation of low-cost hydrogen will become an important issue in Canadian energy strategy. Hydrogen production also requires large quantities of water.

Uncertainties about coal liquids - In speculating on the contribution of coal to liquid fuel supply, it must be remembered that liquids derived from coal are different from those produced from petroleum. The chemistry is complex and the differences often subtle. Our knowledge of these matters needs to be expanded.

Planning a role for coal will therefore involve careful consideration of what products will be made and how they will be used. Canada's climate requires that liquid fuels be usable in very cold temperatures. This is not always possible with products obtained from technology developed elsewhere, which may require further processing to meet Canadian specifications. Product quality improvement may result from current research and development.

Clearly, converting coal to high quality liquid fuels presents many challenges and uncertainties. The role of research and development is paramount. There is a need to gain knowledge and experience both through following developments in other countries and conducting research here in Canada. The objective, as in all energy programs, should be to make the best possible use of the resource.

LIQUEFACTION TECHNOLOGY

Coal is a complex mixture of carbon, hydrogen, oxygen, nitrogen, sulphur and a host of different minerals. Being of botanical origin, it is a geological and chemical cousin to other fossil fuels such as petroleum, oil sands and oil shale.

Technologically, however, it is very different. First, because it is a solid, it presents markedly different handling and transportation problems from petroleum. Second, to be converted to liquid fuels, it must be upgraded - as bitumen and heavy crude oil must - to liquid hydrocarbons that can be refined to the desired products. Thus coal, bitumen and heavy oil can be converted to liquid fuels just as conventional crude oil can, but at least one extra processing step is necessary.

To convert coal to liquids, the ratio of hydrogen to carbon must be increased. As Fig. 5 shows, lighter products such as natural gas and gasoline have higher hydrogen-to-carbon (H/C) ratios than do heavy liquids and solids.

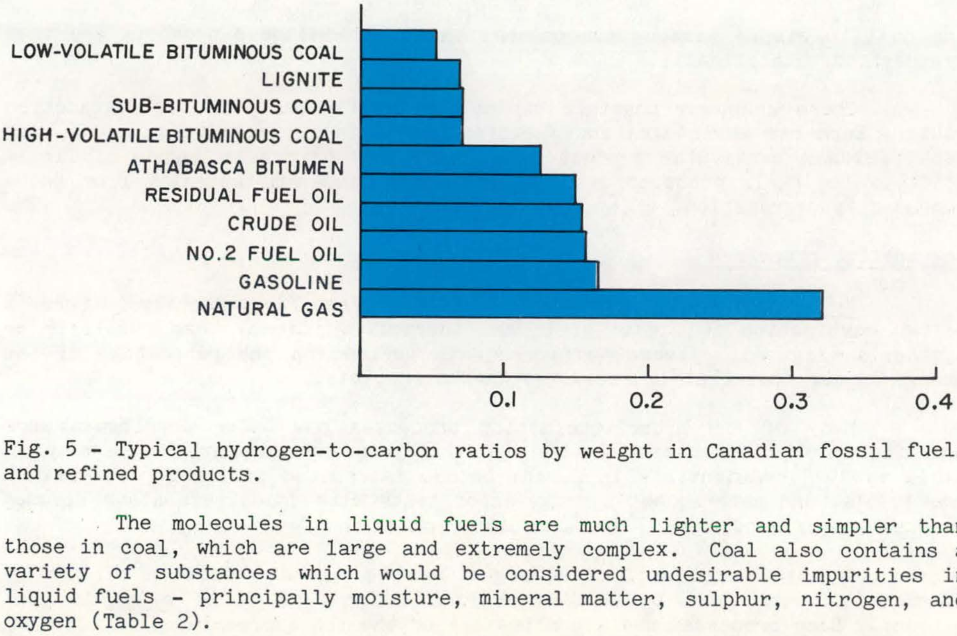

Fig. 5 - Typical hydrogen-to-carbon ratios by weight in Canadian fossil fuels and refined products.

The molecules in liquid fuels are much lighter and simpler than those in coal, which are large and extremely complex. Coal also contains a variety of substances which would be considered undesirable impurities in liquid fuels - principally moisture, mineral matter, sulphur, nitrogen, and oxygen (Table 2).

Changes in the H/C ratio, molecular structure, and concentration of impurities can be brought about by either a degradation or synthesis route (Fig. 6). Degradation involves decomposing the coal while increasing the ratio by adding hydrogen, a process known as hydroliquefaction, or by removing carbon, known as pyrolysis. In the synthesis route, the chemical structure of the coal is altered more drastically. First, gasification converts

Table 2 - Typical levels of impurities in Canadian fossil fuels (averages based on CANMET data). Premium liquid fuels such as gasoline, No. 2 fuel oil, and diesel fuel are virtually free of such impurities. The table indicates the upgrading needed to convert coal or bitumen to synthetic crude oil.

	Impurities (Per cent by weight)				
	Moisture	Oxygen	Nitrogen	Sulphur	Mineral matter
Lignite	28.0	16.8	1.1	0.7	6.5-34.0
Subbituminous coal	20.0	16.0	1.4	0.6	7.5
High-volatile bituminous coal	3.9-8.5	4.1	1.2	0.5-7.0	8.5-20.0
Athabasca bitumen	<3.0	1.6	0.4	4.5	0.6
Crude oil	<0.1	<0.5	0.2	0.1-2.0	<0.1

the coal to simple gaseous components; the desired liquid products are then synthesized catalytically.

There are many possible variations, particularly in the degradation route. Each has advantages and disadvantages under given circumstances, and each yields a particular product slate which may have some degree of flexibility. The fuels produced by synthesis can differ substantially from those produced by degradation.

Degradation processes

Hydroliquefaction - Hydroliquefaction (Fig. 7) presently offers a better combination of liquid yield and thermal efficiency than pyrolysis or synthesis (Fig. 8). Thermal efficiency is defined as the percentage of the energy in the coal that is recovered in the products.

Many of the hydroliquefaction processes now under development are essentially improvements on technology that was investigated in Germany as early as 1913. Scientists in Canada became interested in the German work in the 1930's, and carried out hydrogenation tests with domestic coals. Bitumen eventually replaced coal in the Canadian studies.

In hydroliquefaction, hydrogen can be either added as a gas or "donated" to the coal by a hydrogen-rich solvent to yield a liquid coal extract. Some processes use a combination of the two approaches.

Hydroliquefaction was the basis for the Bergius process which was used to produce much of Germany's liquid fuel supply during World War II. The coal-hydrogen reaction takes place in a slurry under high pressure and temperature in the presence of a catalyst. The liquid product is distilled, and the needed hydrogen can be produced from the solid residue by modern gasification technology.

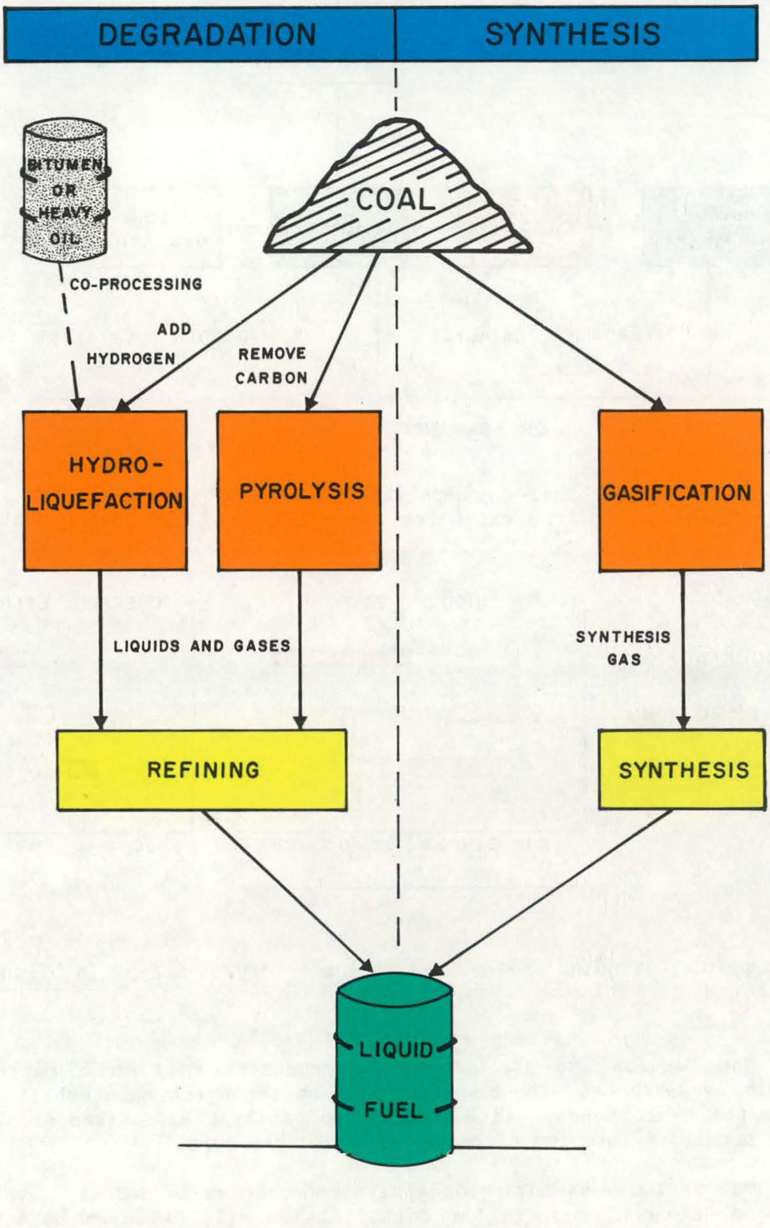

Fig. 6 - Principal routes to liquid fuels from coal.

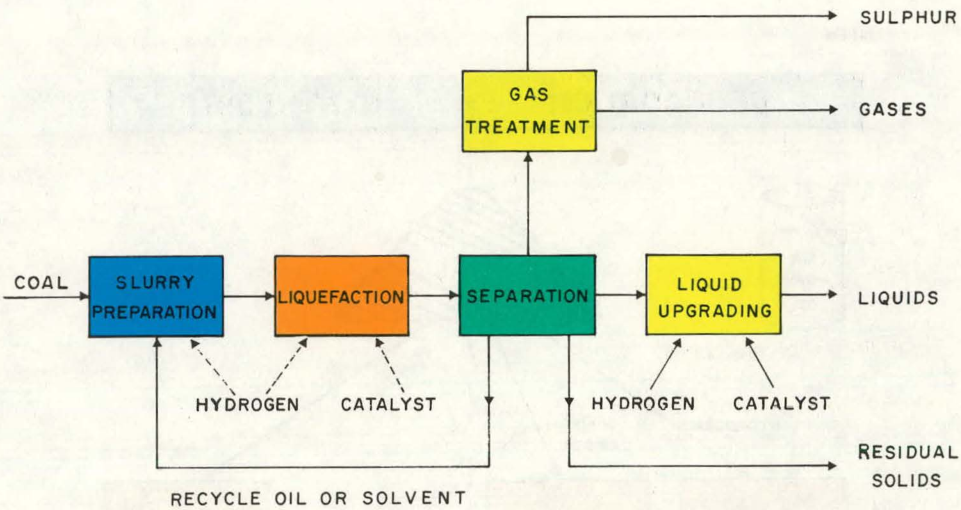

Fig. 7 - Hydroliquefaction -- generalized flow diagram. The broken lines indicate that several options exist for the addition of hydrogen or catalyst in the primary stage.

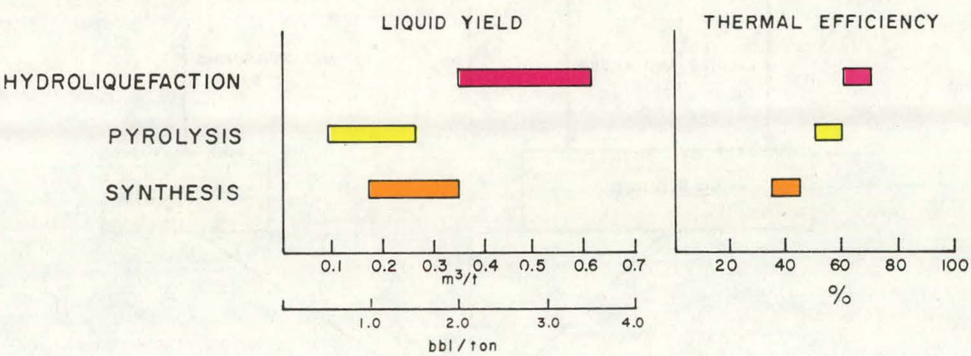

Fig. 8 - Typical liquid yields and thermal efficiencies in liquefaction routes.

The Bergius and its descendant processes rely on a catalyst for acceptable performance. The modern processes represent substantial improvements on the basic concept with respect to catalyst effectiveness; a better catalyst permits a lowering of temperature and pressure.

One of the most advanced catalytic processes is H-Coal, developed by Hydrocarbon Research, Inc. in the United States. It has high potential for early commercialization and is flexible with respect to feed characteristics and product slate.

Other hydroliquefaction processes using catalysts in the primary liquefaction stage include Synthoil, developed at the Pittsburgh Energy Technology Center, C-E Lummus's Clean Fuels from Coal (CFFC) and Gulf's Catalytic Coal Liquefaction (CCL). The West Germans are also further developing the Bergius process, blending their previous experience with new concepts.

Other organizations, principally in the United States, have studied coal hydrocracking as a way of producing lighter products. Hydrocracking is an established petroleum refinery process used mainly to upgrade residuals. If a powerful zinc chloride catalyst is used, high gasoline yields from coal are possible, although corrosion caused by the zinc chloride may be a problem.

Catalytic processes suffer from a major drawback: some of the impurities and large heavy molecules in the coal quickly contaminate the catalysts, which are both difficult to regenerate and expensive to replace. A new Dow Chemical Company process may alleviate these problems by using a novel system to recover and recycle the catalyst. The process is in an early development stage, but shows good promise. There is also increasing interest in catalyst development and in processes that either use no catalyst, avoid direct contact between the coal and the catalyst, or are pseudocatalytic, that is, they take advantage of the inherent catalytic properties of coal mineral matter.

One approach is to eliminate the catalyst from the primary liquefaction step but still produce an extract that can be hydrogenated to a synthetic crude or low-sulphur fuel oil. This process is very flexible with respect to feed and products, and uses a catalyst indirectly in that the recovered solvent is catalytically hydrogenated before it is recycled to the primary reactor. The principal developers are Exxon and Consolidation Coal Co. The Exxon process, along with H-Coal and SRC-II, has been identified as one of the most promising liquefaction technologies in the United States, and is being scaled up to a large pilot plant.

The non-catalytic Solvent Refined Coal (SRC) process uses a coal-derived oil to dissolve the coal under moderate hydrogen pressure. The original version of this process (SRC-I) produces a low-ash, low-sulphur solid fuel that is environmentally cleaner than coal and has a higher heating value. It is also useful as a source of carbon; the Germans have used it in the past to make electrode coke - a possibility being pursued by the Canadian aluminum industry. A variation of the process (SRC-II) carries some of the mineral matter in the recycle stream to the primary conversion step; the catalytic action of the mineral matter promotes further hydrogenation, resulting in a synthetic crude oil rather than a solid product. Both SRC-I and SRC-II products have shown satisfactory performance in utility boiler tests in the United States.

One hydroliquefaction technique that may be particularly promising for Canada is the use of synthesis gas - hydrogen plus carbon monoxide - instead of pure hydrogen to hydrogenate coal. Known as COSTEAM, it improves liquid yields when used with low-rank coals, and, like SRC-II, takes advantage of the pseudocatalytic effect of the mineral matter. This type of process is being studied with Canadian lignites in a CANMET-funded project.

At CANMET, bitumen upgrading studies have led to development of a hydrocracking process that improves the liquid yield from oil sands and heavy oils in comparison with coking methods now in use. The thrust of the work has been to develop either a non-catalytic process or an effective throw-away catalyst. The process may be adaptable to coal as well.

Researchers in the United Kingdom are studying a novel technology called supercritical gas extraction in which the solvent is present in a dense gaseous phase. It has several advantages over liquid phase operation. Solids separation, which is a problem area in most liquefaction schemes, can be achieved by simple temperature or pressure reduction to recover the solvent. Also, the liquid extract has a lower molecular weight and is therefore easier to refine than that obtained from liquid solvent extraction.

The supercritical gas process needs further development because even with optimum coals, extract yields tend to be low and large amounts of residual char are generated. The char might be suitable as a gasification feedstock or as a fuel for fluidized bed combustion.

<u>Pyrolysis</u>, or carbonization, is simply the heating of coal in the absence of air. The decomposition that occurs results primarily in a carbon-rich coke or char, with hydrogen-rich tars, oils and gases as byproducts suitable for upgrading to liquid fuels (Fig. 9). Hence from the point of view of liquid fuel production, pyrolysis is essentially a carbon removal operation.

Metallurgical coke for the iron blast furnace is made by pyrolysis. The tars and oils are used principally as petrochemical feedstocks, and the gas is burned to heat the coke ovens. Normally no hydrogen is used in the primary step and liquid yields are low, making the process unsuitable as a primary liquefaction process. Liquid yields can be improved if temperatures are lower, heating rates are faster, or hydrogen is added. Hydrogen also helps remove sulphur.

Coking coals, because of their chemistry, produce a coke that is strong enough for blast furnace use. The non-coking coals yield a char which does not show adequate strength properties. In pyrolysis, at least half the feed coal goes to char or coke.

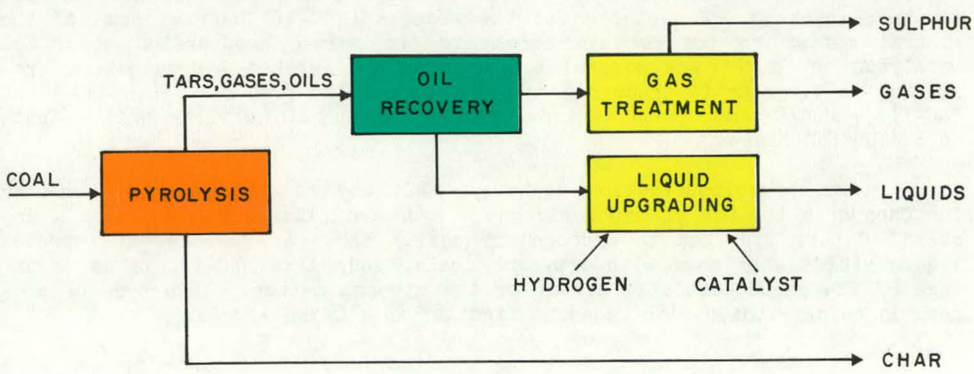

Fig. 9 - Pyrolysis -- generalized flow diagram.

Pyrolysis is also common in the petroleum refining industry, where it is more commonly called coking. It is used to recover light liquid products from heavy residual oils. It is, in fact, the process used to upgrade bitumen in the two commercial oil sands plants in Canada.

Coal pyrolysis schemes for liquid fuel production yield oils that can be hydrogenated to liquid fuels, and byproduct gases. The principal problem appears to be marketing the large volumes of char produced, as it does not burn well. It may be possible to gasify the char to useful fuel gases.

In Germany, the Lurgi-Ruhrgas pyrolysis process has reached the commercial scale on low-rank coals, but gives low liquid yields of about 20%. Several other processes are under development in the United States. The highest reported liquid yield attained to date is about 35%.

Another method is to heat the coal much more rapidly in the presence of hydrogen. This technique, known as flash hydropyrolysis, gives a char with improved burning properties, in addition to relatively high liquid and gas yields. Because hydrogen is added, the process is a combination of hydroliquefaction and pyrolysis, and could be used to produce both liquids and a solid boiler fuel.

Synthesis processes

Gasification, the reaction of coal with steam and oxygen at high temperature and pressure, yields a mixture of gases, principally carbon monoxide and hydrogen. If liquids are desired rather than gases, the mixture can be used to synthesize a variety of liquid hydrocarbons (Fig. 10). The synthesis involves Fischer-Tropsch chemistry, another development pioneered in Germany before World War II.

Synthesis, used at the SASOL plant in South Africa, is inherently inefficient because the molecular bonds in the coal are first broken and then new ones created. It can, however, use a wide range of coals, including those high in ash, and produces high-quality liquids. The synthesis step can be modified to vary the product slate within defined limits.

A different synthesis step based on the reaction of carbon monoxide with steam to produce hydrocarbons is under study on a laboratory scale, in Canada and elsewhere.

Another well-established route to liquid fuels is to convert the coal to methanol by a synthesis route (Fig. 10) and use the methanol as a fuel or petrochemical feedstock. Most methanol is now made from natural gas.

There is currently much interest in methanol as an automotive fuel, partly because it can be produced from biomass as well as from coal. With minor engine modifications, conventional automobiles could use up to 15% methanol in gasoline. Use of 100% methanol would require more substantial engineering changes. Methanol has a higher anti-knock rating than gasoline, but only about half the energy content.

The Mobil Oil Co. has recently developed a new one-step catalytic process to produce gasoline from methanol. The process is similar to Fischer-Tropsch synthesis, but produces high-octane gasoline selectively.

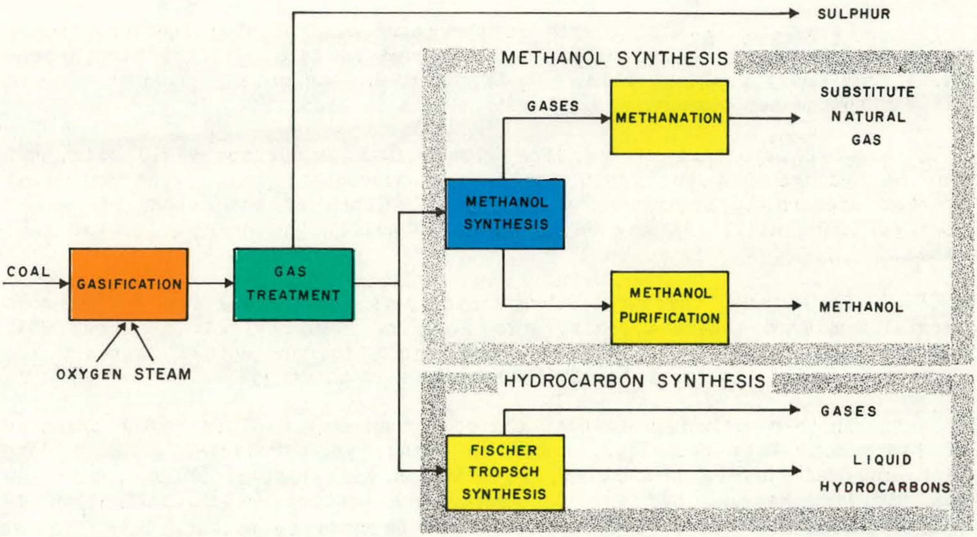

Fig. 10 - Synthesis -- generalized flow diagram.

Coal refinery concept

All the processes described above yield more than one product, but most rely on a single primary step, and would probably be engineered to produce one or two principal products. It may be that coal liquefaction technology will ultimately be more promising as part of a "coal refinery" which integrates several primary processes to produce a wide range of products. Such a complex may offer economic advantages over separate production facilities.

This is the concept used in South Africa's SASOL complex, which produces gasoline, diesel fuel, fuel oil, ammonia, sulphur, and a range of chemicals and coal-tar derivatives. It is also the basis for U.S. Steel Co's Clean Coke process, which produces metallurgical coke and a range of liquids through both pyrolysis and hydroliquefaction.

Many processes produce a flexible product slate and could form the basis for such a complex. The coal refinery concept has been explored in several countries. The success of such a scheme would appear to depend on the marketability of all the products, although incorporating flexibility would allow the operators to adjust to fluctuating demand. Also, the integration of several processes would afford better opportunities for internal use of byproducts and waste heat, thus improving economics.

State of the art in Canada

Coal liquefaction research and development is under way in several countries, with the United States, West Germany and the United Kingdom leading the way in the non-Communist world. The only commercial facility is in South Africa. In Canada, the current research effort is just getting started, although hydrogenation studies were conducted as early as 1933. Canadian interest has naturally focussed on oil sands, which require similar technology. The Canadian research program, the relative merits of the various routes in the Canadian context, and an assessment of research and development needs, are presented later in this report.

If Canada is to opt for liquefaction in the future it will first be necessary to improve our understanding of Canadian coals.

CANADIAN COALS

Selection of a processing route for coals, whether for liquefaction or for any other utilization option, depends on a knowledge of the composition and properties of the available coal and how those properties bear on the technology being considered.

One of the most common pitfalls in dealing with coal is to think of it in the singular. It is not a single substance, but a complex, often poorly-understood conglomerate containing a variety of organic and inorganic compounds.

The complex nature of coal suggests that no two samples are identical - and this is in fact the case. Coal varies in composition and properties from deposit to deposit, from seam to seam, and often within the same seam. Often the differences are subtle, but they can be surprisingly significant in technological processes.

This variability means that not all coals, even if they are of the same apparent grade, can be processed similarly. To use coals most efficiently, it is important to have as full an understanding as possible of their chemical and physical properties in a particular utilization mode.

Knowledge of Canadian coal resources, other than deposits currently being mined, is still limited, although much information has been gathered in recent years through federal, provincial and industrial exploration and sampling programs. More seriously lacking is a full assessment of the suitability of various coal deposits for particular uses. Such knowledge is essential if we are to develop our energy resources in a way that will yield the greatest benefit over the longest period of time.

The information in this chapter notwithstanding, it must be remembered that coal quality is not the most important factor in liquefaction economics. Coal cost - although not unrelated to properties - is usually a much more significant determinant of viability. Thus, surface-mined low-rank coals, although they may not be the best coals for a particular technology, may be the most desirable because of their low production cost.

Coal properties bearing on liquefaction

Coals may be analyzed or characterized in a variety of ways. Proximate analysis determines the content of moisture, ash, volatile matter, fixed carbon and sulphur. Ultimate analysis measures the amounts of the main chemical elements present. Along with heating value, these analyses help determine the rank of the coal, discussed below.

Other properties of the coal may be assessed to determine its suitability for a given use. Examples are petrographic composition, ash characteristics, physical behaviour of the coal upon heating, and grindability. The major uses of coal require fine grinding, an energy-intensive process.

It must be emphasized that these measurements give only an indication of the coal's usefulness. Laboratory tests are needed for verification.

The limited available knowledge of the influence of properties on liquefaction suggests that several parameters can be identified as most significant.

Rank is the most commonly-used parameter for classifying coals. It is, simply put, a measure of the geological maturity of a coal, which in turn is influenced primarily by the various temperatures and pressures to which the coal was exposed over geologic time. The classification established by the American Society for Testing and Materials and used in Canada, is shown in Fig. 11. Coal composition and properties vary with rank.

Tests on Canadian coals conducted by CANMET in the 1930's indicated that in hydroliquefaction the highest liquid yields are obtained with high-volatile bituminous coals (Table 3). Above or below that rank, yields decrease. Studies by other researchers over the years have confirmed this observation.

Subbituminous and lignitic coals liquefy most quickly and thus require less severe conditions of temperature and pressure. The advanced maturation of coal tends to produce complex, highly-compacted, inert molecules

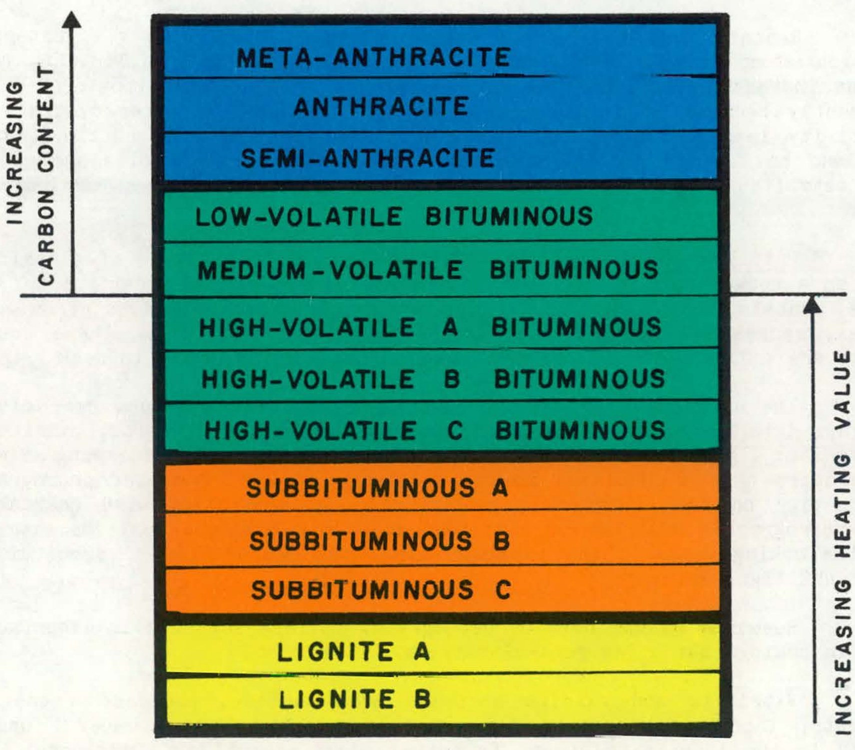

Fig. 11 - Classification of coals by rank. (American Society for Testing and Materials method).

Table 3 - Typical yields of primary oils by hydroliquefaction of Canadian coals (CANMET Data, 1939)

Coal rank	m^3/t	bbl/ton(short)
Medium-volatile bituminous	0.59	3.37
High-volatile bituminous	0.45 - 0.72	2.57 - 4.11
Subbituminous	0.40 - 0.48	2.26 - 2.71
Lignite	0.35	1.97

which are less amenable to decomposition than simpler molecules in a less compacted structure.

The higher the rank of coal, the greater is its carbon content. Because advanced maturation drives out hydrogen-rich volatile hydrocarbons such as methane, high-rank coals tend to have lower hydrogen-to-carbon ratios (Fig. 5). Because one objective of liquefaction is to increase this ratio, it follows that high-rank coals should be more difficult to liquefy.

Recent research has also indicated that if synthesis gas instead of hydrogen alone is used for hydrogenation, liquid yields from low-rank coals can be increased to compare more closely with yields from bituminous coals, apparently because of the action of carbon monoxide. Greater yields, high reactivity leading to greater throughput, and less severe conditions, would all lead to lower liquefaction costs. Some of these principles are not yet well established for low-rank coals, however, and much research remains to be done.

Petrographic composition - Petrography is the science of classifying coal as a rock, that is, by its organic and mineralogical constituents. All coals contain a variety of microscopic constituents derived from wood, leaves, spores, resins and other plant materials (Fig. 12). These constituents are called macerals, and are analogous to the minerals in rock.

The standard petrographic classification of bituminous coal divides macerals into three groups based on botanical origin: vitrinite, exinite and inertinite. Although coal petrography is a relatively inexact science, researchers have accumulated useful knowledge of the effect of petrographic composition on coal behaviour, particularly in connection with cokemaking. Most petrographic work has in fact been done on bituminous coals because they are the coking coals. Less is known about the composition of subbituminous coals and lignites.

Research on the role of petrography is less advanced in liquefaction than in coking, but a few generalizations can be made.

Vitrinite and exinite macerals are reactive, whereas as the name suggests, inertinite is generally inert. Semi-fusinite, a maceral usually placed in the inertinite group, is actually semi-reactive. In general, coal high in vitrinite and exinite and low in inertinite makes a desirable feed-

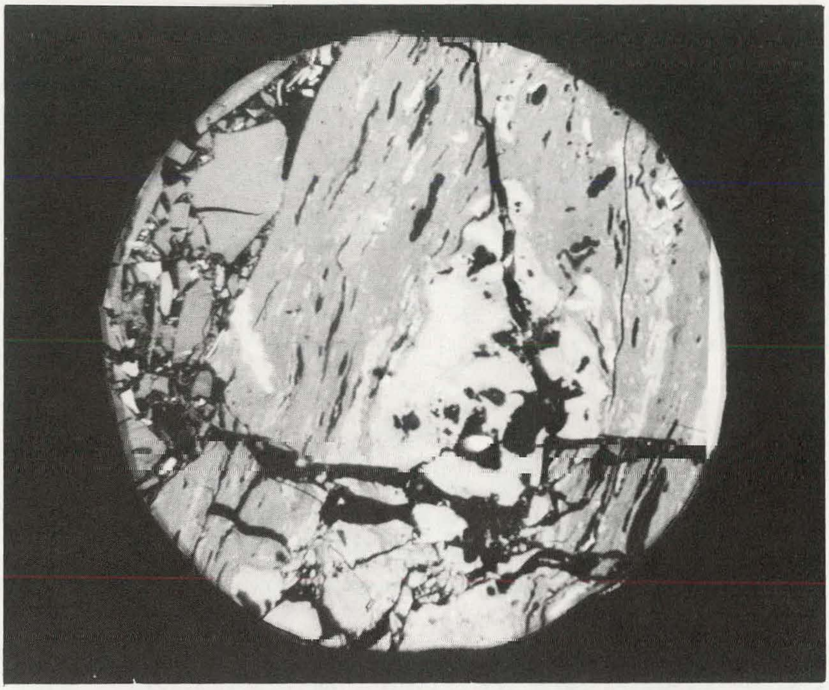

Fig. 12 - A look at a typical coal through a microscope, showing its complex nature. The medium gray material is vitrinite, and the dark matter interspersed in it is exinite. Together these constitute the reactive macerals. The remainder of the material is composed of various minerals and other inert or semi-inert matter.

stock for chemical processing. The presence of large amounts of semifusinite makes assessment of reactivity difficult.

Petrographic investigations can provide useful information on the changes in maceral composition occurring during coal processing. In conjunction with other types of analysis and experimental studies, they can give a more complete understanding of the processes. For example, they have played an important role in establishing that certain constituents of the mineral matter may exhibit catalytic effects during liquefaction.

Another important property influenced by maceral composition is coal solubility. In hydroliquefaction, dissolution of the reactive macerals can help bring about effective hydrogen transfer.

Reactivity - Coal reactivity, although dependent on other factors noted above, is often treated as a separate parameter. A more reactive coal liquefies faster and to a greater extent. Reactivity is important in all utilization routes, and is a function of the process.

Exposure of the coal to air can decrease its reactivity because of oxidation. For this reason, prolonged transportation and storage is undesirable. There is evidence, however, that reactivity can be restored to some extent through high-pressure hydroliquefaction.

Mineral matter in coal, although undesirable because it does not convert to liquids, and because it creates a solid residue that leads to separation and disposal problems, appears to exhibit a catalytic effect during liquefaction. This effect is exploited in some processes. It is not known precisely which minerals are important, although sulphur-containing iron pyrite apparently plays an important role.

Mineral matter is also of interest as it may be a cause of abrasion in processing equipment.

Sulphur in coal is an undesirable constituent from an environmental point of view. Its removal is an important step in most coal conversion schemes, which thus permit the use of higher-sulphur coals that otherwise might be unacceptable.

Removal of large amounts of sulphur requires severe operating conditions and extra hydrogen. If sulphur shows up in the product, as it often does, it must be removed, adding to processing costs. On the other hand, its possible role as a catalyst when present in mineral matter may mean that a certain amount is desirable in the primary liquefaction step.

Coal requirements for a liquefaction plant

Before a commercial liquefaction plant can be established, sufficient coal to feed the plant over its expected life must be assured.

The optimum capacity to make a coal liquefaction plant economic is usually considered to be 16 000 m^3/d (100 000 bbl/d) of liquid product, four-fifths the size of the Syncrude oil sands refinery. Assuming an optimistic liquid yield of 0.5 m^3/t (3 bbl/ton) of coal, such a plant would use about 30 000 t/d. This would amount to 11 x 10^6 t/a, about 35% of the total Canadian production in 1978, and almost four times the Nova Scotia total. If the product were a synthetic crude, it would supply less than 5% of today's national needs.

If the recovery factor in surface mining and preparation were assumed to be 60%, the total required coal in place over the minimum 20-year life of the plant would be about 360 x 10^6 t. Recent studies which have also taken water supply into account indicate there are between 6 and 10 sites that could support such a facility, all in Western Canada. This assumes a mine-mouth plant to reduce costly haulage requirements.

Unit production costs would probably be higher for a smaller plant of, say, 8000 m^3 (50 000 bbl) or 5000 m^3 (30 000 bbl) daily capacity because economies of scale would be lost Nonetheless, such smaller plants may prove desirable in the long term if the local or regional benefits could justify the government subsidies required, or if coal liquefaction economics improved substantially. This possibility merits further study.

Canadian coal resources

Canada's coal resources are indeed vast in relation to current depletion rates. The exact extent and quality of the resources is not well known, although much information has been gathered since rebuilding of the coal industry began a few years ago.

High-volatile bituminous, subbituminous and lignitic coals are favoured for liquefaction. Medium and low-volatile coals, which occur only in the inner foothills of the Rocky Mountains, should be reserved for their prime use, which is cokemaking. Coking coals are expected to be in short supply in the world for the next two or three decades and are an important Canadian export.

Coals suitable for liquid fuel production lie in Nova Scotia, New Brunswick, Ontario, Saskatchewan, Alberta and British Columbia. The New Brunswick and Ontario deposits can be ruled out because they are small and are either committed to, or intended for electric power production. The deposits in Alberta and Saskatchewan are particularly large.

Nova Scotia - In Nova Scotia the only deposit large enough to consider is the Sydney coalfield, a high-volatile A bituminous bed extending out under the ocean. Other Nova Scotia deposits are small, scattered and generally difficult to mine.

Resources in the Sydney coalfield total more than 1×10^9t (1×10^9 = 1 billion). The coal is relatively low in ash and contains a high proportion of reactive macerals, making it an excellent coal for conversion processes (Fig. 13). The sulphur level is moderately high, and liquefaction might prove to be a good way to reduce it.

The Sydney coalfield is expensive to mine, and will become even more so as the workings are forced to extend further out to sea. Furthermore, much of the deposit - probably at least half - makes an excellent component of a coking blend and should be reserved for that purpose. Coking coals fetch a high price, and if exported would bring important economic benefits to Nova Scotia. They are also needed for the local steel industry.

Decisions on the Sydney coals must take into account a variety of factors. They have a potentially important role to play in Ontario's steel mills; shipments to Ontario have already begun.

Nova Scotia currently relies heavily on imported petroleum for its liquid fuel supplies and is striving to reduce this dependence, principally by substituting coal for oil in thermal power plants. In the future it might be more environmentally desirable to convert the coal to low-sulphur liquid fuels first. Nova Scotia, in fact, might be a suitable site for a coal refinery which could produce coke, liquid fuels, and other products currently derived from imported oil or domestic coal. The viability of such a project could significantly improve if natural gas were available in the Maritimes, as the gas could be a source of hydrogen.

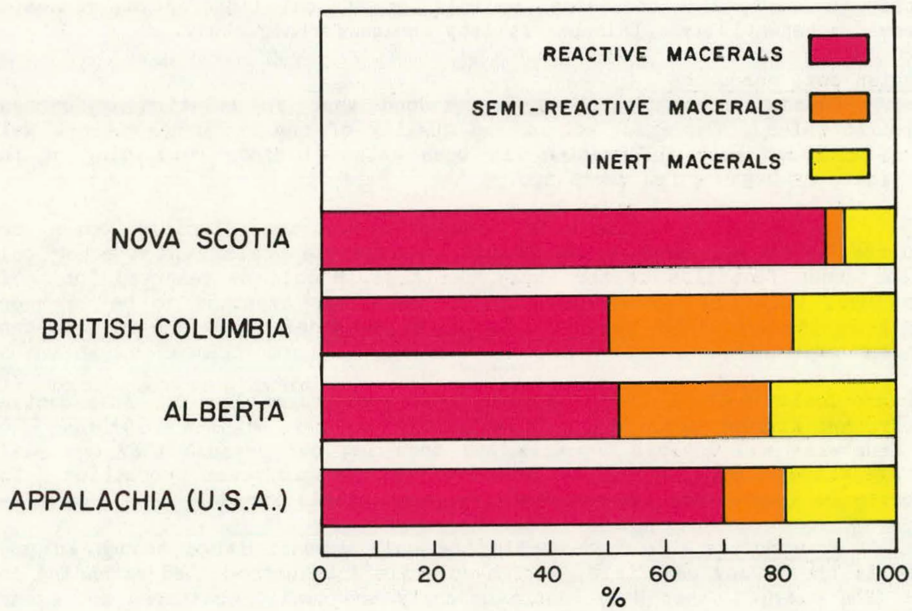

Fig. 13 - Relative proportions of reactive, semi-reactive and inert macerals in typical Canadian and American coals.

Saskatchewan has very large lignite deposits - a total of more than 35 x 10^9 t. There are four major deposits, each sufficient to support a commercial liquefaction facility. They are generally inexpensive to mine because they usually occur in near-surface deposits in flat terrain. They are currently being developed as fuel for mine-mouth thermal power plants.

Low liquid yields and high moisture and ash levels have traditionally made lignites undesirable for liquid fuel production by most processes. The possibility that using synthesis gas rather than hydrogen alone might improve yields is being pursued in a CANMET-sponsored study. Related research, particularly on the chemistry and structure of lignites, about which little is known, would provide further insight into their potential for all liquefaction processes. Problems associated with high ash levels would have to be overcome.

Alberta - In Alberta, high-volatile bituminous coals occur in the outer foothills of the Rocky Mountains, whereas the extensive plains coals are predominantly subbituminous. Resources in these two regions total about 100 x 10^9 t. Large deposits of coals suitable for cokemaking are located in the inner foothills belt along the British Columbia border.

On the whole, the Alberta coals show greater potential than those in other provinces as a liquefaction feedstock because of their extent, quality and mineability. They are moderately high in ash and moisture, but very low in sulphur.

Western Canadian bituminous coals tend to be relatively low in reactive macerals, and have a high semi-reactive component (Fig. 13). It is difficult to predict the role of the semi-reactive portion, and thus the behaviour of the coal as a whole, without laboratory liquefaction studies. They also oxidize readily, further decreasing reactivity.

Alberta is currently turning from gas to coal to meet its future electricity requirements, as the province has a low hydro-electric potential. A process such as flash hydropyrolysis or supercritical gas extraction that could remove some of the valuable hydrocarbons from the coal, perhaps for petrochemical production, while still producing a good power plant fuel, might be particularly useful.

British Columbia - Coal deposits are scattered throughout British Columbia. Substantial deposits of bituminous coals occur in the mountainous regions of the southeastern and northeastern parts of the province, but these coals are of excellent coking quality and should be reserved for that use.

Several other deposits of lower-grade coals occur in the central and south-central parts of the province, but most are too small or difficult to mine to be considered for liquid fuel production.

The one deposit that may be of interest is the Hat Creek deposit. This is a very thick, near-surface lignitic to subbituminous bed. It is very low in quality but because of its size and mineability, it is of interest, particularly as a power plant fuel. B.C. Hydro and EMR are collaborating on studies of ways to use this deposit in modern, high-performance, coal-to-electricity processes.

High ash, moisture and oxygen contents and low liquid yields make hydroliquefaction or pyrolysis of the Hat Creek coals technically impractical. A synthesis route to make liquid fuels or petrochemical feedstocks may be more feasible.

Northern Territories - The limited geological information available on coals in Canada's northern regions suggests that the resources may be extensive, but it is premature to speculate on their potential.

Outlook - Canada has large resources of coals suitable for liquefaction, but caution must be exercised in estimating their potential. One cannot assume, for example, that they can all be developed at will. Environmental factors, provincial government policies and regulations, and a variety of economic factors come into play.

It must be remembered also that liquefaction experience with Canadian coals has been very limited, and current assessments of their potential are generalizations based largely on theoretical considerations and on experience with similar coals elsewhere. Actual experimental trials will be necessary to properly evaluate their behaviour in liquefaction processes.

Current economics dictate that the coal feed for a liquefaction facility be mineable by inexpensive surface means. This consideration would indicate that the subbituminous and lignite deposits of Alberta and Saskatchewan are most attractive (Fig. 14). Regional needs and security of supply considerations may however, override economic considerations under certain circumstances, which would make other Canadian coal deposits of interest as liquid fuel sources. This possibility deserves particular attention in Nova Scotia.

Fig. 14 - Mining subbituminous coal in Alberta; near-surface deposits such as this may be preferred over higher-grade coals because of low mining cost.

In the short and medium term, Canadian coals will continue to be used predominantly for thermal power generation and cokemaking. Oil sands and heavy oils offer competition for coal in liquid fuel production. On the other hand, important immediate potential exists for coal to play a role in improving liquid yields from these low-grade petroleum feedstocks.

The relative advantages of the various utilization routes for coal can be expected to change with time, and it is expected that coal will become more attractive as a liquid fuel source. A better understanding of the economics of such routes, and strategies to keep our technological options open, are needed. These subjects are discussed in the final part of this report.

RESEARCH AND DEVELOPMENT NEEDS AND STRATEGIES

As with all of Canada's energy resources, it is prudent to assess as accurately as possible the options that exist for coal in the context of a self-reliance strategy. Based on information in the first three parts of this report, the following discussion will attempt to tie together the many factors bearing on the liquids-from-coal options, and to identify the technological needs and opportunities facing Canada.

Canadian research efforts

The federal government, through CANMET, initiated an on-going coal conversion contracting-out program in 1976 to study various ways to process coals into other energy forms. The liquefaction studies have included assessment of the applicability of various processes in Western Canada, bench-scale studies with Nova Scotia coals and Saskatchewan lignites, investigation of electrode coke production for the aluminum industry by the solvent refined coal process, and other more fundamental studies at various universities and research establishments. The work has served to expand Canada's technical knowledge base and to build Canadian expertise. Experimental facilities are also under construction for bench-scale research at CANMET (Fig. 15).

Notwithstanding this effort, Canada's coal liquefaction research has been very limited in manpower and dollar value in comparison with such countries as the United States, Germany, and Britain. Since the 1930's, synthetic fuels research has focussed on the oil sands and heavy oils, with only brief incursions into coal liquefaction.

To some extent, the current large research effort on coal liquefaction in other countries has tended to discourage Canadian research, partly because it is easy to assume that Canadian coals are similar to those elsewhere, and that we can simply adapt foreign-developed technology to them, and partly because of a feeling that any research effort Canada could muster would be dwarfed and therefore outpaced by the American effort.

Such assumptions are erroneous as energy resource quality and distribution, geography, climate and a host of economic factors create unique conditions in this country. Technology cannot be assessed independently of these factors. It is unlikely that foreign technology could be acquired in a form best suited to Canadian coals, environmental conditions, and markets.

Furthermore, imported technology is usually accompanied by a wide range of imported subsidiary goods and services. Sellers and developers of technology understandably have their preferred suppliers who, in turn, have their own preferred suppliers. Such chains, built up over the years, are difficult to break. Process licensors can also impose additional bonds, such as requiring that future improvements in the technology be repatriated to the licensor for an indefinite period.

At the same time, the nature of the research infrastructure in Canada, particularly in the private sector, suggests that special incentives may be required to develop technology that is uniquely Canadian. Given a continuation of current economic circumstances, coupled with heavy foreign

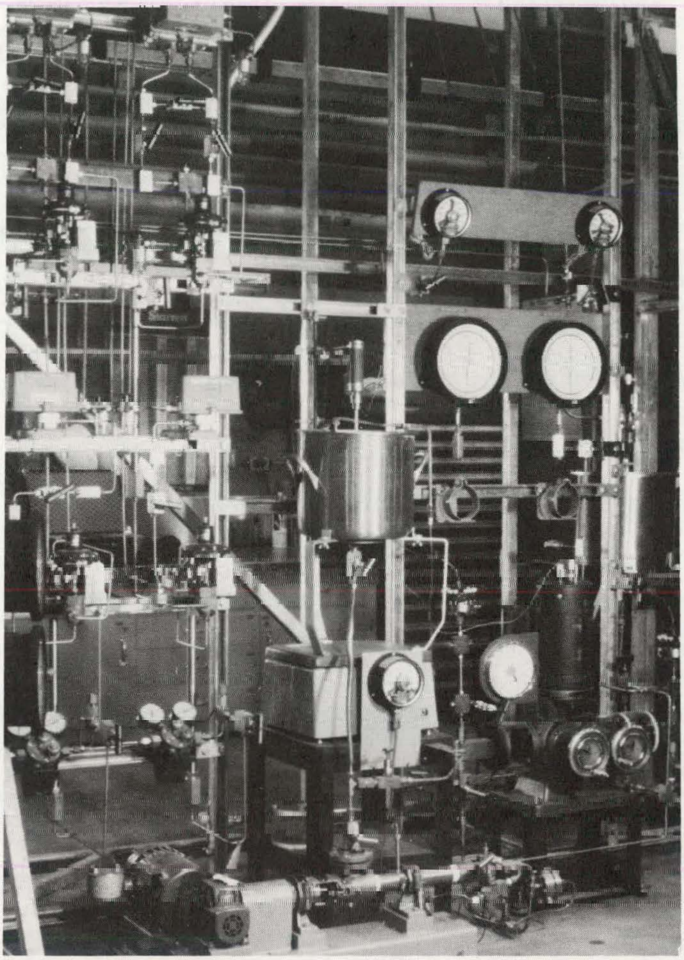

Fig. 15 - A portion of the bench-scale coal liquefaction facilities under construction at CANMET's Bells Corners complex near Ottawa. Equipment of this scale is particulary useful for studying process fundamentals, evaluating coals, and identifying potential operating problems in larger-scale installations.

ownership of the energy industries, governments will have to assume the lead. At the large pilot plant or demonstration plant scale, however, the energy industries must become involved because only they have the resources and expertise to carry out the work.

On the surface it might appear that the most prudent route for Canada to follow would be to adapt or modify technology developed elsewhere. Apart from considerations related to Canadian coals and Canadian demands, this simplistic approach ignores the need for personnel and infrastructure to commercialize the technology. If the necessary effort were made to improve our understanding of Canadian coals and of future liquid fuel requirements, and the need for expertise and infrastructure were addressed immediately, the emergence of uniquely Canadian technology would be more likely.

The other main option available to Canada is to pursue the use of coals to maximize liquid product yield from oil sands and heavy oils. This prospect deserves immediate attention, because it represents an opportunity for Canada to take the lead in a technology that may be of interest to other nations as they turn to lower-grade petroleum resources. If Canada is to participate fully in international research and information exchange, it must have something to offer, and this technology could be it.

Preferred liquefaction options

If Canada does eventually turn to coals for liquid fuels, it is far from clear what technology would be most appropriate, although some processes are now in a more advanced stage of development. Each option has its own merits in particular circumstances. The choice will ultimately be based on desired products, coal characteristics, and of course, cost.

The world research effort in coal liquefaction is vigorous, and progress is rapid. The observations made in this report may be out of date in a matter of a year or two. Close monitoring of research developments is therefore essential.

Hydroliquefaction - The three most promising American processes, H-Coal, Solvent Refined Coal, and Exxon Donor Solvent, represent variations on the hydroliquefaction principle. The American experience suggests that these processes deserve careful consideration in Canada, especially as they may be commercially available before too long. Process conditions in all three can be varied depending on the products desired.

Currently there is more interest around the world in hydroliquefaction than in either pyrolysis or synthesis, principally because its higher thermal efficiency and liquid yield leads to more favourable economics and greater promise of commercialization if production of liquid fuels is the goal.

There are, however, some disadvantages to all hydroliquefaction processes. All require large quantities of hydrogen which is currently expensive. Also, handling of large quantities of slurries at high pressure has proven difficult in pilot plant studies. Separation of residual solids from the product stream is a serious problem which is further complicated if the feed coal is high in ash. Finally, processes such as H-Coal which require a catalyst, face the problem of rapid catalyst deactivation by impurities and heavy molecules in the coal. Good catalysts are expensive. These problems are avoided to some extent in processes such as supercritical gas extraction.

Hydroliquefaction processes are particularly well suited to the high-volatile bituminous coals of Nova Scotia. Recent research has also indicated that low-rank coals such as those in Saskatchewan and Alberta might be excellent feedstocks in a process that uses synthesis gas. On the other hand, high ash content in some Western Canadian coals might preclude their use in a hydroliquefaction scheme.

Solvent refined coal is of interest to the Canadian aluminum industry as a source of electrode coke. The industry has traditionally relied on petroleum coke, a refinery byproduct, but concern about possible future shortages, increasing prices, and declining quality have turned industry attention to coal as a possible long-term source. The coke would be produced by pyrolysis of solvent refined coal, giving useful oils as by-products.

Pyrolysis avoids some of the principal problems associated with hydroliquefaction because hydrogen and catalysts are not necessary - although they can be added - and there is no requirement to separate solids from product slurries.

Current pyrolysis processes give low liquid yields, and have therefore not been considered leading contenders for liquid fuel production. Large quantities of solid fuel of questionable combustion quality are produced. It is possible to gasify the solid to fuel gas. In fact, char gasification has been applied to FMC Corp's COED process, thus improving substantially the economics of the process.

Process improvements are making pyrolysis more attractive. Flash hydropyrolysis might be particularly applicable in Alberta and Saskatchewan, which are turning to low-rank coals for thermal electric power generation. The process may allow production of tars and oils, while still producing a coal-derived solid fuel. Thus power plant needs would still be met, but other valuable constituents in the coal would be produced as well. From the standpoint of products, the process might also be of interest in Eastern Canada, but the agglomerating tendencies of Nova Scotia coals would create reactor problems, and the coals' high sulphur content would be largely carried over to the char.

Synthesis processes have some serious deficiencies, but do have some advantages that can be significant in particular circumstances. It is appropriate to consider first whether the technology used at SASOL in South Africa is applicable in Canada, as it is already commercially available.

The SASOL plant uses gasification followed by Fischer-Tropsch synthesis to produce a range of products. The process is flexible with respect to the products, which are very pure relative to those from other coal-to-liquids schemes, but products may still not meet Canadian specifications. The plant produces an acceptable gasoline, but the diesel oil tends to be waxy and has poor low-temperature characteristics. Product quality can, of course, be improved by modified or extended processing, but this would only add to product cost, which would already be very high if such a plant were located in Canada.

Thermal efficiency of synthesis processes is low, which means both that coal throughput per unit liquid product is high, and that much of the energy value of the resource is lost. Synthesis plants are very complex and expensive to construct, particularly at the large scale favoured in Canada.

In the South African context, which differs from the Canadian in many important respects, the SASOL complex is reported to be marginally profitable. One important factor is the sale to local steel works of byproduct methane, which constitutes 13% of the gas stream from the gasifier. Such a market could not be counted on in Canada.

These disadvantages have tended to discourage research on Fischer-Tropsch synthesis in Canada and the United States. Offsetting these are several advantages that could be significant in certain regions of Canada.

Because the primary conversion stage is a gasifier, the synthesis route can tolerate a wide range of coals. Of particular importance is acceptability of coals with up to 45% ash. Coals fed to SASOL typically contain 25-35% ash. Some Western Canadian coals, such as those of the Hat Creek Valley in B.C., have comparable ash contents.

Fischer-Tropsch processes offer full potential for chemical development because a wide range of products is possible. The synthesis step can be modified to give a high yield of selected petrochemical feedstocks, including methanol or low-molecular-weight olefins.

Typically, it is possible to obtain a higher yield of methanol than of gasoline using established synthesis technology. A recent study done for EMR indicated that methanol is currently the most economically attractive route to liquid fuels from coal. Methanol's applicability in Canada depends on markets, whether it is used as a petrochemical feedstock or as a fuel.

A large effort would be required to convert the automotive fuel distribution and utilization system to methanol or to a methanol-gasoline mix. If current trends continue, it is much more likely that gasoline engines will be partly or fully replaced by diesels, which offer improved fuel economy and reduced emissions over the range of Canadian temperatures. There is interest in using methanol as a fuel for gas turbines, electric power plants or fuel cells, but there are many problems to overcome. Methanol also can be substituted for premium fuels for domestic heating, but presents safety problems in homes.

Perhaps the greatest promise for synthesis processes, at least from the technical point of view, lies in Mobil's methanol-to-gasoline process. The economics need further study. Developments in this process should be followed closely.

Production of methanol from coal would free some natural gas for other uses, such as for the critically-important production of hydrogen. Currently about 3 or 4% of domestic natural gas production is used to make methanol.

Costs

Most economic studies have shown that liquid fuels from coal are currently not economically competitive with those derived from conventional crude oil or oil sands. The estimated selling price for synthetic crude varies widely, generally between \$113 and \$220/m^3 (\$18 and \$35/bbl) - above the crude oil price, but not necessarily by a margin that would exclude possible development.

Economic analyses of coal liquefaction schemes must be read carefully, as they differ widely and can be misleading. The assessments vary depending on the assumptions made, particularly on coal cost, on the economic ground rules used, and on the degree of conservatism exhibited by the author.

Even more important, because it is so often overlooked, is the question of product value, as opposed to price. Synthetic crude oil from coal is not the same as conventional crude oil. It generally has more impurities (although it may contain less sulphur), different chemical composition and different properties, and under similar processing conditions would yield a different product slate. Currently it would be virtually worthless in Canada, because no refinery would accept it. Synthetic crude oil from oil sands is somewhere between the two in terms of quality.

A realistic economic analysis should therefore be based on the value of the refined products, i.e., of liquid fuels, or must at least take into consideration the extra processing needed to bring coal syncrude up to refinery specifications. It must also take into account coal quality, plant location, necessary infrastructure, and a variety of other economic factors.

For these reasons, no attempt wil be made in this report to estimate the cost of producing liquid fuels from coal. However, generalized cost breakdowns are given for the hydroliquefaction case in Tables 4 and 5, simply to indicate the economic features of a typical liquefaction facility.

Economic information related to Canadian conditions is lacking, and there is a need for detailed studies on the many aspects of synthetic fuels based on coal. Forecasts of product prices relative to those from conventional oil and oil sands would be particularly useful.

Problem areas

The basic approach in current liquids-from-coal R & D is to maximize the yield of premium products without resorting to extreme temperatures and pressures which lead to high costs. In most experimental plants there have been several recurring problems common to most processes.

Table 4 - Average capital cost breakdown for an 8000-m^3/d (50 000-bbl/d) hydroliquefaction facility

Total capital cost $850-950 x 10^6 (1978)	% of Total
*Coal storage & preparation	10
Primary hydrogenation step	30
Hydrogen production	25
Utilities and facilities	25
Product and byproduct handling and treatment	10

*does not include mine

Table 5 - Annual operating cost breakdown for an $8000-m^3/d$ (50 000-bbl/d) hydroliquefaction facility - Range of estimates

Item	%
Coal	30-60
Catalysts and chemicals	2-15
Labour	2-10
Utilities	3- 6
Fixed costs (overhead, taxes, etc.)	4-12
Capital charges	30-45
Other	5-10

In the more advanced processes, these are related less to the process itself than to basic mechanical engineering and auxiliary operations. As the processes approach commercialization, these problems begin to be measured in dollars, particularly as scale-up can aggravate them.

The problems are many, but some do currently stand out as being most significant. Some examples are given below.

Basic engineering - Hydroliquefaction processes use hot, high-pressure slurries. The handling and pumping of large quantities of such slurries is difficult. The are abrasive, and tend to plug equipment. Canada has extensive experience with mineral slurries, but not at coal liquefaction temperatures and pressures.

All hydroliquefaction processes produce residual solids consisting of ash and unreacted coal. Separation of these solids from liquid products can be very difficult by conventional methods which have not been designed for the type of streams coming from a coal liquefaction process. The problem arises from the presence of very finely-divided solids in heavy, viscous liquids. Several separation techniques have been tried, the most promising of which are distillation and solvent extraction.

High temperatures and pressures, and the nature of the liquids handled in coal liquefaction processes, create harsh environments that lead to corrosion and erosion of vessels and piping materials. Processes that use hydrogen face the problem of the hydrogen reacting with certain steels, leading to cracking. Other chemicals, such as carbon monoxide, may present similar problems, but knowledge of these is limited. Because such environments are also encountered in processes like bitumen hydrocracking, development of improved materials of construction will be an improtant area of research for Canada.

Hydrogen supply - Hydrogenation, whether for coal liquefaction, bitumen upgrading, or petroleum refining, requires large quantities of hydrogen. Development of Canada's coal and petroleum resources will require increasing amounts of hydrogen, and costs and methods for its production are receiving serious attention.

Currently almost all the hydrogen used in Canada is made by steam reforming of natural gas, probably consuming about 5% of domestic gas production. There are several other ways to make hydrogen: steam reforming of naphtha and refinery off-gases, gasification of coal or liquefaction residues, and nuclear-assisted electrolysis. Currently, natural gas is in most circumstances the cheapest source, but further analysis may reveal that use of liquefaction residues could substantially improve plant economics, particularly as it would also reduce waste disposal requirements.

Fossil fuel development plans are thus linked to natural gas strategy descisions. This is certainly the case in Western Canada, and may also hold true in the Atlantic Provinces depending on offshore natural gas discoveries, delivery of liquefied natural gas from the Arctic, or extension of the natural gas pipeline to the Atlantic Provinces, and on possibilities for deriving hydrogen from such sources as coal washery rejects.

Feedstock quality and basic coal science - Experimental results at the bench and pilot scales often outpace fundamental process research in engineering fields. Fundamental studies usually help improve the process later. As the technology advances toward commercialization, seemingly minor improvements can make major financial differences.

This is the case in coal liquefaction, in which better knowledge of the effects of feedstock characteristics on product quality and process operability might improve yields and thermal efficiencies, reduce capital costs, and help avoid costly shut-downs. Such knowledge is necessary for a full evaluation of the suitability of Canadian coals for liquefaction. Of particular interest are the petrographic and chemical characterizations of the coals, of which knowledge is superficial.

This knowledge would find application in all coal utilization routes, and could be obtained in conjunction with process development studies at the laboratory bench scale.

Environmental impact - Commercial coal liquefaction facilities would be expected to undergo environmental impact assessment before approval. The subject has to date received little attention. The impact of the mining operation itself is common to all utilization routes and will not be discussed here.

The principal emissions of concern are large quantities of gaseous, liquid and solid effluents, as well as waste heat, although undesirable noise and odours are also produced. Gaseous and liquid emissions could probably be dealt with by conventional means employed in petroleum refineries.

As all coal liquefaction processes produce residual solids - consisting primarily of mineral matter, unreacted coal, washery rejects and miscellaneous sludges - solids disposal could be a serious problem. A 16 000 m^3/d (100 000-bbl/d) liquefaction plant would produce up to three times the waste solids of a 1000-MW power plant. Such a facility would use about 30 000 t of coal a day, and with a typical feed coal with 15% mineral matter, 4500 t of waste mineral matter alone would be rejected each day. These and the waste liquids would be expected to contain hazardous organic, organometallic and radioactive compounds, which would present a risk to the environment. Use of the residue as a construction material or to produce hydrogen or fuel gas would of course reduce the solids disposal problem.

Even more important in the Canadian context is the large water requirement, which might prove insurmountable in certain areas in Western Canada where water is not plentiful. Based on energy output, and depending on the processes used, a coal liquefaction plant might be expected to use two to four times as much water as an oil refinery, but less than 25% as much as a coal-fired or nuclear power station. An oil sands plant based on surface mining would consume about 50% more water than a coal hydroliquefaction facility of equivalent size.

These estimates do not take into account water consumption for hydrogen production. Water is needed to make hydrogen through the reaction of steam with hydrocarbons or through electrolysis. It should be noted that in Alberta, oil sand deposits are located closer to water supplies, i.e., on the Peace and Athabasca river systems, but further from populated regions than are coal deposits. Environmental considerations thus tend in general to mitigate in favour of oil sands developments. Site-by-site assessments are necessary to obtain a full evaluation of the comparative impacts of each type of development.

Working conditions in and adjacent to coal liquefaction facilities are adversely influenced by the presence of polynuclear aromatic compounds in coal-derived liquids and plant effluents. These compounds are known to be carcinogens. Recently there has also been growing concern over the radioactivity of coal ash.

<u>Principal technological uncertainties</u>

The lead time available to Canada should permit development of a research capability and infrastructure that could evaluate the many aspects of the liquids-from-coal option to ensure that decisions are made with as sound an information base as possible.

Identifying technological uncertainties amounts to asking "What don't we know?" and therefore leads to an endless list. However, a number of recurring subjects have surfaced in research efforts in Canada and elsewhere. Thus it is possible to identify the following as the principal concerns that are ripe for immediate study, but these are not necessarily given in the order of importance:

1. assessment of the suitability of Canadian coals for liquefaction, deposit by deposit, particularly where other utilization routes are also being considered; this would include consideration of deposit size and environmental factors;
2. process studies to develop technology especially well-suited to domestic coals;
3. chemical, physical and petrographic characterization of Canadian coals, and ways in which these affect behaviour in liquefaction processes;
4. technical and economic assessment of ways in which coals can be used to improve liquid yields from oil sands and heavy oils;
5. relative economic evaluation of hydrogen production processes in the context of natural gas strategy;

6. fundamental studies of the chemistry of coal-derived liquids, to determine properties and identify problems associated with specific end uses;
7. development of improved catalysts for catalytic processes;
8. mechanical and design engineering on such problems as the handling of coal and coal-in-oil slurries, and solid-liquid separation;
9. research on improved materials for the harsh environments to be expected in coal, bitumen and heavy oil processing;
10. investigation of the environmental impacts of coal liquefaction facilities, preferably site-specific, including health hazards presented by the products and compatibility with existing and projected government regulations;
11. economic projections to determine need for the full range of coal-derived fuels in the Canadian market.

The success of research, development and demonstration efforts on these topics would depend in large part on the level of co-operation that can be achieved between scientific and engineering personnel. Furthermore, the development of a synthetic fuels industry in Canada requires a co-ordinated multi-disciplinary program that draws on the talent existing in many sectors of the Canadian work force. A fragmented effort is wasteful of time, manpower and money.

The question of manpower is critical if only from the point of view of preparedness for possible future needs for coal liquids. Involvement of industry in R & D helps to build industrial expertise; encouragement of studies in universities helps ensure that young professionals with relevant knowledge will be available; and involvement by government will build a team that can provide national leadership in technology and assist in the formulation of sound energy policies.

Should EMR fund a coal-to-liquid-fuels pilot plant?

Speculation on the future prospects for coal liquefaction raises many questions, the main one probably being whether EMR should fund a pilot plant. Although a definite answer is beyond the scope of this report, the ensuing discussion will pinpoint some of the main considerations.

Although there is currently no urgency about the need for coal to liquid fuel conversion in Canada, it is clear that we will turn to coal for more and more of our fossil energy supplies as we move into the next century. Coal liquefaction could become important as the quality and quantity of other liquid fuel sources decline.

To be prepared to meet the challenge if and when the time for coal liquefaction comes, it is imperative that we begin now to build a solid base of knowledge and expertise across Canada. The studies that are required would provide an excellent opportunity for Canadian firms, research organizations and universities, both large and small, to gain experience in coal processing and to participate in Canadian energy planning.

There would be two basic elements to the effort: keeping abreast with developments in other countries, and conducting studies here in Canada. An efficient information system would be required to monitor foreign work, and our own research would give us a base from which to negotiate in exchanging information internationally. The objective would be to ensure that the most appropriate technology is applied to Canadian coals, whether it be developed in Canada, or purchased from elsewhere, perhaps in a modified form to suit Canadian needs.

Even if the technology is purchased, the infrastructure and competence required to implement it on our own terms cannot be. The building of these two elements would be the initial objectives of a demonstration effort in coal liquefaction.

Pilot plant objectives and scale - Understanding the full range of Canadian coals with respect to liquefaction would require a series of experimental runs at both bench and pilot scales. The pilot scale would also provide the opportunity to gain valuable operating experience with Canadian coals, particularly with handling of coals and coal-in-oil slurries. Together with the experience that is rapidly being accumulated with bitumen and heavy oil processing, this should help prepare Canadian engineers and scientists for the eventual introduction of coal liquefaction at the commercial level. This experience may even be exportable, particularly if the experiments include the concept of coprocessing coals with heavy petroleum feedstocks.

Experimental plants can range in size from the laboratory bench scale, measured in kilograms of coal input a day, to a demonstration or pioneer commercial plant using several thousand tonnes of coal a day.

Because of the long lead times of at least ten years needed to fully develop major new energy technologies, process development plants on the scale of tonnes of coal input a day are required at some point. The main objectives of plants of this size would be to study process operability, to verify data obtained at smaller scales, to gather further data, and to gain more insight into requirements for materials of construction and maintenance. Perhaps even more important is the need to build a process engineering team that can move to the larger scale if required. It should be noted also that research results, particularly if they involve patentable concepts, are more readily accepted if generated on a larger scale.

The urgency of the need for liquid fuels in the United States has led to discussion of the most appropriate size for pilot and demonstation-scale plants. The most promising processes are now being developed at capacities of at least 200 t/d. The next logical step would be a demonstration plant using several thousand tonnes a day. Some experts suggest that a full-scale pioneer commercial plant would expedite development and provide more realistic operating experience.

An example of a pioneer commercial plant in Canada is the Great Canadian Oil Sands facility near Fort McMurray, Alberta, which has been operating for about ten years (Fig. 16). Operating experience in that plant has been valuable in research, development and engineering leading to the larger, more modern facilities such as Syncrude (Fig. 17).

Large plants tend to fix design concepts because of the heavy investment. A small scale pilot plant is more flexible, an important criterion when a preferred process route has not yet been clearly identified. Further-

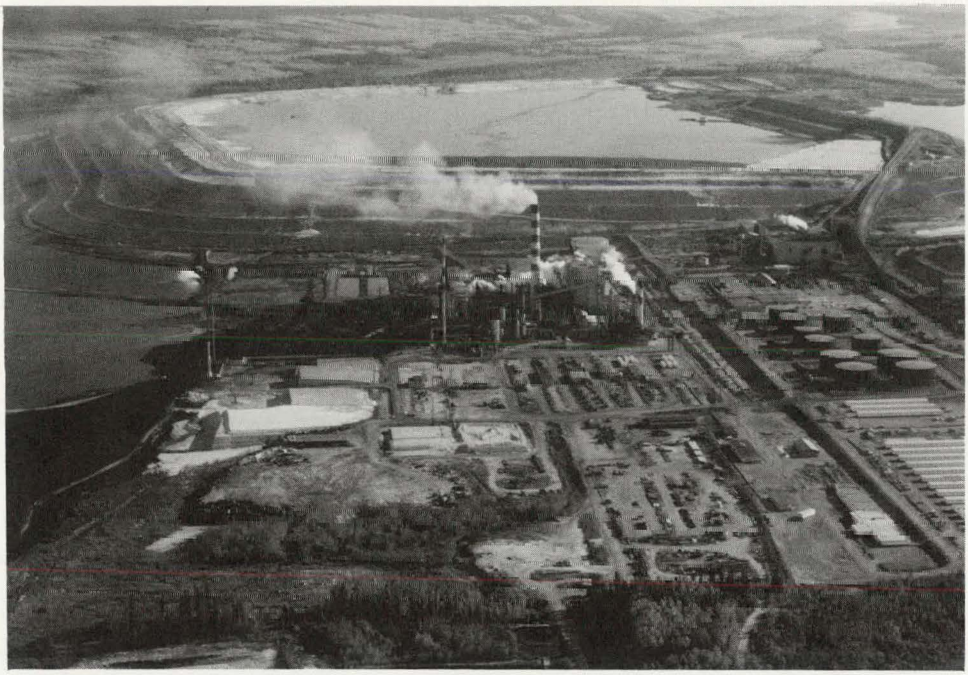

Fig. 16 - The Great Canadian Oil Sands Limited facility near Fort McMurray, Alberta -- an example of a pioneer commercial plant. Operating experience in this plant, the first commercial-scale oil sands installation in the world, has helped engineer larger plants such as Syncrude (Fig. 17).

more, it would be difficult to justify a large scale facility until a better indication is obtained of the probable date of introducing coal liquefaction. This implies in turn there is a need to match time-demand curves for liquid fuels to the estimated time required to develop the technology to the demonstration and commercial scales.

Current economics indicate that private industry would probably be unwilling to make the commitment required for an experimental facility. However, only industry currently has the financial and engineering capability to undertake a large pilotor demonstration-scale project. Government leadership and some degree of government funding of industrial ventures will be needed - especially if the national interest overrides economics.

Attention to pilot-scale plants should not overshadow the need for bench-scale facilities such as those now under construction at CANMET, which would be useful to study Canadian coals, to develop process technology, and to build experience. Coal liquefaction research strategy would also involve maintaining a capability in fundamental studies, particularly at the univer-

Fig. 17 - The Syncrude Canada Limited oil sands plant during construction near Fort McMurray, Alberta, a full-scale commercial installation. In developing technology from the bench scale (Fig. 15) to this scale, several intermediate steps may be involved: small pilot, large pilot, demonstration, and pioneer commercial (Fig. 16). Decisions on when or whether to proceed to the next stage are crucial as large investments in time and money are involved.

sities, where such activity would also have educational benefits. Catalysis is a prime area for such research, since catalysts will assume greater importance as fossil fuel feedstocks become more difficult to refine.

Plant location - The decision on pilot plant location is not a minor one, as it relates to regional needs, and to the ability to draw on expertise in the energy industries. It would also take into account the proximity of coal resources and product processing facilities.

The Americans and Germans, for example, have found that integration of a pilot plant with an existing refinery provides benefits to both the commercial operation and the experimental facility. On the other hand, it is likely that a commercial liquefaction facility would have to be near the mine, because of the high cost of transporting coal.

If the pilot plant is intended to meet a regional need, it is logical that it be located in that region. In such a case it might be integrated with other energy projects in the region, perhaps even in an energy complex, with the objective of developing the best mix of energy sources to meet projected regional requirements.

Preparing for the future

A well-developed research infrastructure will help ensure that we keep our energy options open and are well prepared to meet the challenges as they come. Coal liquefaction research is advancing rapidly and it is difficult to predict what concepts will be in the limelight in a few years. Canada must have the capacity to keep abreast of these developments.

Although it is difficult to predict when liquid fuels from coals will be required in Canada, it is clear there is an immediate need to build knowledge and experience, and to learn as much as we can about the coal resource base.

It must be remembered that the coal-to-liquids option is only one possible element in the energy systems that we must build for the future - flexible systems that will take into account what forms of energy we will need and where, as well as how we can make the best possible use of the resources we have.

In the case of liquid fuels, the critical issue is security of supply. Decisions on coal liquefaction programs, then, are based essentially on how much we are willing to expend to ensure that we can meet the demand in the years ahead.

OPINION POLL

The opinion of concerned readers may influence the direction of future CANMET research.

We invite your assessment of this report — No. ____________

Is it useful? Yes______ No______

Is it pertinent to an industry problem? Yes______ No______

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