PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Non-Conventional Hydrocarbons and Future Trends in Oil Utilization in North America and their Effect on World Supplies

E. B. Walker

Phil. Trans. R. Soc. Lond. A 1974 **276**, 541-546
doi: 10.1098/rsta.1974.0037

Phil. Trans. R. Soc. Lond. A. **276**, 541–546 (1974)   541
Printed in Great Britain

Non-conventional hydrocarbons and future trends in oil utilization in North America and their effect on world supplies

By E. B. Walker, III
Executive Vice President, Gulf Oil Corporation, Pittsburgh, Pennsylvania, U.S.A.

The world's continuously increasing demand for energy and the decreasing supply of conventional hydrocarbons are on a collision course. While there is a range of non-conventional hydrocarbon sources available to draw upon – including oil shale, tar sands, and liquefied and gasified coal – none of these can become an immediate substitute for conventional hydrocarbons in any significant way. Still, these synthetics do have potential between now and 1985 and development must be pursued. The economic reality of synthetic fuels has reached the point where such fuels cannot be considered uncompetitive and unrealistic. The sooner the United States of America can embark on a vigorous development programme for synthetic fuels, the better off will be the nations of Western Europe and other industrial nations dependent on foreign sources of petroleum. Non-conventional hydrocarbons produced in North America probably will not be exported in large quantities but can help to alleviate the pressure for available world petroleum supplies.

Much of the technology for producing synthetic fuels commercially today was developed in Great Britain and Germany several decades ago. With the discovery in recent years of large oil and gas reserves at its doorstep Europe has moved away from man-made forms to the natural or conventional gaseous and liquid hydrocarbons. Across the Atlantic the situation is shifting in the opposite direction, and North America is now placing great emphasis on the extension and improvement of energy-conversion processes.

One fact is becoming abundantly clear to those associated with the energy industry today. The enormous appetite for energy requires the development of the whole spectrum of energy sources as expeditiously as possible. The competition of the future will be *for* fuels, fuels of all kinds, rather than between or among fuels. Energy should be thought of as continuum rather than as a pendulum, swinging from one fuel to another. A shortage in one fuel usually results in increased demand for another.

Petroleum and natural gas satisfied almost all of the growth in post-World War II energy demand, but in the U.S. the oil and gas industry is now at peak capacity. A rapidly rising import requirement in the U.S. will place a strain on the rest of the Western World's petroleum supply and raises some ominous economic, political and national security issues that are important also to western Europe. By mid-1973 there has been the heightening of international political and monetary pressures as a result of petroleum supply. This in turn has heightened an already obvious need to find attractive alternatives. Synthetic fuels, looking much like an ace in the hole, could be one of those alternatives. The price increases emanating from restraints on petroleum production and higher tax revenues make the economics of synthetic fuels more and more attractive. Fortunately the U.S. has ample resources of coal and oil shale, and its neighbour to the north – Canada – has vast tar-sand resources. These provide the base for a massive synthetic hydrocarbon industry in North America.

There is no major synthetic fuels production today, but the potential for growth by 1985 is substantial and development is being pursued. It is, however, unlikely that any North American synthetic fuels will be exported, because domestic requirements already are so great. It should be emphasized, though, that by reducing North American requirements for imports, pressure on conventional world oil supplies will be lessened. In this sense, the development of a synthetic fuels industry in North America is of great importance to the rest of the world. Furthermore, North American self-sufficiency is of vital strategic importance to all the Western World.

With the volatile Middle East atmosphere posing a continuing threat to O.P.E.C. oil supplies, the production of synthetics in both Europe and North America must be viewed quite differently than a few months ago. Because of the dramatic oil price moves in recent weeks set by unilateral action, Europe's own coal and synthetic-fuel industry also may have to be expanded.

Where do things stand now in synthetics in North America?

The following is a brief look at each resource – tar sands, oil shale, and coal – in terms of technology, timetable and economics.

Tar sands are of first importance because there is some commercial production already in Canada and it is the most likely source of substantial supplies of synthetic hydrocarbons in the *near* future.

Tar sands

The largest known tar-sands deposit and the only one of present commercial importance is in the Athabasca region of Alberta, in western Canada. Substantial volumes of tar sands are close enough to the surface to be strip-mined. Even greater volumes, at depths down to 450 m, will require *in situ* recovery techniques not yet perfected. The Alberta Oil and Gas Conservation Board estimates that there are some 47.5×10^9 m^3 (300×10^9 barrels) of potential reserves. The Canadian Petroleum Association estimates proved, high-grade, easily recoverable reserves at 10^9 m^3 (6.3×10^9 barrels). The technology for tar-sand processing is relatively simple; but there are problems in mining.

There is only one commercial plant in operation – Great Canadian Oil Sands Ltd, started in 1967 – and it is now producing 8000 m^3 (50000 barrels)/day by strip-mining the sand and extracting the oil with a hot-water process. This plant is to be expanded.

Syncrude Canada Ltd, a consortium of companies in which Gulf participates, has announced plans for a second plant in this region. It is designed for a capacity of 17000 m^3 (108000 barrels)/day and is estimated to cost more than $900M. A third project has been proposed to the Alberta Energy Board. So after years of a textbook future, tar sands now are moving toward the energy market.

According to the National Petroleum Council's U.S. Energy Outlook Study, which is perhaps the most comprehensive study ever made of U.S. energy, the Athabasca sand deposit is probably the only significant source of commercial production of tar-sand oil for North American markets through 1985. Roughly speaking, it takes about 2 tons of tar sands to produce one barrel of syncrude. Estimates are that the maximum syncrude production by 1985 may be about 0.2×10^6 m^3 (1.25×10^6 barrels)/day. A higher level of production may be desirable but the pragmatic problems of design and construction of massive facilities, the availability of capital, and political considerations are indeed limiting.

Oil shale

A second major resource for a North American synthetic fuels industry is the oil shales of the western U.S. Incidentally, oil shale is neither a shale nor does it contain oil; it is a marlstone which contains a bituminous material called kerogen.

The magnitude of this resource is estimated to be on the order of 320×10^9 m^3 (2×10^{12} barrels), but only about 8×10^9 m^3 (50×10^9 barrels) are both high grade and easily minable. The N.P.C. study identified areas where the deposits are of adequate quality to have potential commercial value today and the N.P.C. estimates that such recoverable reserves, favourably located are about 5.4×10^9 m^3 (34×10^9 barrels), based on a yield of 146 l/tonne (35 U.S. gallons per ton) or better.

For a number of years there has been adequate technology for mining and retorting the oil shale but full-scale production will require an enormous materials-handling capability and the resolution of ill-defined but massive environmental problems. Present technology requires handling the oil shale twice, both before and after retorting. Large amounts of water are necessary, and oil shale, depending on the process used, expands quite a bit, so disposal of this waste is a problem. It simply cannot all be put back where it came from. And it takes about 9–12 tonnes of oil shale to make 1 m^3 of oil ($1\frac{1}{2}$–2 tons to make 1 barrel).

The oil shale deposits are located in relatively undeveloped and semi-arid areas of the Rocky Mountains. A substantial production capability must be preceded by demonstration plants to determine the best techniques and to minimize environmental problems. The U.S. Department of the Interior is encouraging an industry demonstration programme which should get under way in early 1975, but the requirements for infrastructure, environmental protection, etc., make for very long lead times.

Extensive work on different processes has been done by the U.S. Bureau of Mines and several private companies. The differences are in the design of the retort and the heat transfer mechanism. The Oil Shale Company (Tosco process) has completed operations in a semi-works plant, including several runs of long duration at 900 tonnes a day. In the Tosco process pulverized shale (about 1 cm) is fed continuously into a horizontal kiln. Direct contact with hot ceramic balls heats the shale to retorting conditions. Tosco has worked on the problem of waste disposal and has succeeded in growing grass on this waste.

Gulf is participating with 13 other companies in the Paraho project, which plans to test and demonstrate a vertical-kiln technology that uses more coarsely crushed shale (5–8 cm). The Paraho project, which uses a novel grate that allows continuous operation, has the promise of substantially reducing investment and costs. Both direct and indirect firing methods will be tested. One of the distinct advantages of the Paraho process is that it may reduce the waste problem.

Given the environmental problems of a massive mining operation and the concomitant shale-disposal problem, the development of *in situ* technology is highly desirable for production on a very large scale. A number of companies have been active in *in situ* research, and the U.S. Bureau of Mines is pursuing pilot scale work, but no satisfactory technology is yet indicated.

With the limitation imposed by mining and retorting, the N.P.C. has estimated oil-shale production by 1985 will be in the range of 16000–120000 m^3 (100000–750000 barrels)/day, depending on how great an effort is put into the project. The cost of syncrude at an upgrading plant in Colorado was projected to be from \$4 to \$7/barrel in terms of 1970 dollars. Until the government defines the lease and environmental requirements, the price can only be approximated.

Coal

By volume of reserves, and as a resource base, coal is the most important potential source of fossil energy in the U.S. today. The N.P.C. has estimated a reserve of 140×10^9 tonnes recoverable in formations of thickness and depth comparable to those being mined currently. The total resource is much greater.

Until recently coal fuelled about half of U.S. electric power generation; it has lost some of its market in the heavily populated U.S. East Coast to low-sulphur oils. Oil is not the long-term solution to electric power generation in the U.S., or to the pollution problems of burning high-sulphur coal. In the absence of technology for stack gas desulphurization and the growing desire for clean fuels in all applications, the vast U.S. coal deposits will have to be converted to some form of non-conventional hydrocarbon.

A joint effort by industry and the Federal Government for research and development in coal conversion is gaining speed. At least two commercial-sized coal-gasification plants have been announced, based on Lurgi technology. These plants are designed to supply pipeline-quality gas, i.e. 37 MJ/m^3 (1000 Btu/ft^3), into the natural-gas distribution system. They are the forerunner of many more. The low-energy gas from the Lurgi gasifiers will be upgraded by one or several methanation steps under investigation today.

In Westfield, Scotland, Gulf is participating with a number of companies in cooperation with the British Gas Corporation in a methanation demonstration programme that already has achieved some operating success. Because the U.S. has a very large pipeline system and many natural-gas users, this methanation programme is important to the ongoing development work in synthetic fuels.

Nearly all of the technology is in hand, so coal gasification is likely to be the leader in the development of a U.S. synthetics industry. Using the lower heating value sub-bituminous coals of the West, which incidentally are the least expensive to mine, high-energy gas from coal is estimated to cost about $1.40/$10^9$ J ($1.50/$10^6$ Btu) in the Midwestern or West Coast demand centres.

Several other major demonstration projects are under way; they are construed to be second-generation coal-gasification plants. These are known as the Hygas, Bigas, CO_2 acceptor and Synthane processes, sponsored jointly by the U.S. Government and elements of the energy industry. Some of these processes appear encouraging and attractive but it is doubtful that there will be a full-scale commercial operation much before 1985. The N.P.C. estimates that by 1985 synthetic gas production from coal will range from $14–70 \times 10^9$ m^3 ($500–2500 \times 10^9$ ft^3)/year.

Another coal-conversion project rapidly nearing start-up is the Solvent Refined Coal Pilot Plant at Tacoma, Washington. Early next year Gulf, in cooperation with the Federal Government's Office of Coal Research, will begin a 45 tonne/day operation at this plant to convert coal of low heating value, high ash, high water content coal to an essentially ash-free, low sulphur, high heating value coal product. It also shows great promise for upgrading the vast bituminous coal deposits east of the Mississippi River; these have high levels of sulphur. Work on a larger-scale demonstration plant can begin perhaps as early as late 1974.

Liquefaction

The technology of *liquefying* coal has trailed that of gasification by many years and only recently has received much attention in the U.S. The F.M.C. Corporation has a 33 tonne/day pilot plant in Princeton, New Jersey, that has produced some oil and a significant proportion of char. Other energy companies are devoting considerable research and development effort to liquefaction.

For many years Gulf has done extensive work on the catalytic hydrodesulphurization of

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

crude and residual oils and presently has in operation a number of licensed units in oil refineries around the world. As an extension of this work, there is some very encouraging bench-scale results for catalytic coal liquefaction (c.c.l.). A feature of the Gulf c.c.l. process is its adaptability to a wide range of coals of varying qualities relative to sulphur and ash content. An expanded and integrated pilot plant is being designed now to provide a basis for a semiworks plant just as soon as practical.

The probable price for coal liquids was estimated by the N.P.C. in 1970 dollars to fall in the range of $38–50/m^3$ ($6–8/barrel), depending on the cost of feedstocks at the plant. Our best guess is that liquids produced from Western coal have the potential of being very competitive in Midwestern industrial markets. It also appears that coal liquids can compete favourably with synthetic gas from coal, oil from the North American Arctic, and from North American offshore areas not now explored. The attractiveness of coal liquids versus gas is this: a reduced requirement for hydrogen and a lower transportation cost over long distances. Liquids have the added advantage of flexibility in usage and storage.

Given the most favourable circumstances, a large-scale commercial liquefaction plant will not appear on the scene much before the early 1980s. The N.P.C. has estimated a maximum of 108000 m^3 (680000 barrels)/day by 1985.

Conclusion

By way of summary, it seems clear that from now to 1985 there will be much capital invested in synthetic-fuel development. Although the upper limits of N.P.C. estimates for the synthetic fuels discussed here add up to the equivalent of about 0.6×10^6 m^3 (3.75×10^6 barrels)/day in North America by 1985, it is very probable that recent events will accelerate developments. The importance of synthetics is that they will reduce demand on world petroleum supplies, thus aiding Europe and Japan, and will greatly strengthen the Western World strategically.

For this reason, mankind must be awake to new ideas and new possibilities – in even old ideas such as synthetic fuels. The technology and the capability are partly here and partly in the development stage, and the comparative economics are becoming ever more attractive.

And, most importantly, the *time* has come.

Discussion

Mr F. A. Smith (*Shell Research Limited, Sittingbourne Laboratories, Kent*)

What are the economic objections to gasification of shale?

Mr E. B. Walker

The principal objection to shale mining is the effect on the environment. At the high gas prices expected in the future, gasification would probably be feasible.

Mr H. B. Locke (*National Research Development Corporation*, 66–74 *Victoria Street, London S.W.* 1)

Gasification, and particularly fluidized gasification does indeed seem economically attractive as a means of using the energy in oil shale. Fluidized combustion too, along the lines being developed by Combustion Systems Limited (representing the National Coal Board, British Petroleum Ltd and the National Research Development Corporation), also has some attractions for oil shales and for other low-concentration energy resources as well as fossil fuels as such. The Oil Shale Corporation of Colorado is understood to be considering both approaches. Such technology is also being examined in relation to Athabasca tar sands, high ash graphites in Scandinavia, 70 % ash 'coals' in Czechoslovakia, and other materials elsewhere. In some areas remote from centres of usage it has in the past been assumed that neither gas pipelining nor electric power transmission could be economic: however, modern developments seem likely to enable power and gas transmission to compete in the future with liquid transport in pipes or rail tankers.

The whole family of processes made possible by fluidized combustion, and also the possibilities of oil synthesis already referred to by Sir Kenneth Hutchinson (based upon slagging gasification and slurry synthesis), plus all the various Gas Council developments at present evoking so much interest in the U.S.A. form a considerable body of energy technology. This means that British-based technology should be able to play a most useful part both at home and overseas in energy manipulations in the future. What is now needed is means of connecting the potential users with the development technologists. This is particularly the case with oil synthesis from coal, where plant and staffs still exist at Westfield and elsewhere in the British Gas Corporation, and also at the British Coal Utilisation Research Association at Leatherhead in conjunction with Combustion Systems Limited in London and the National Research Development Corporation.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES