SUMMARY OF NATO SYNTHETIC FUEL ALTERNATIVES

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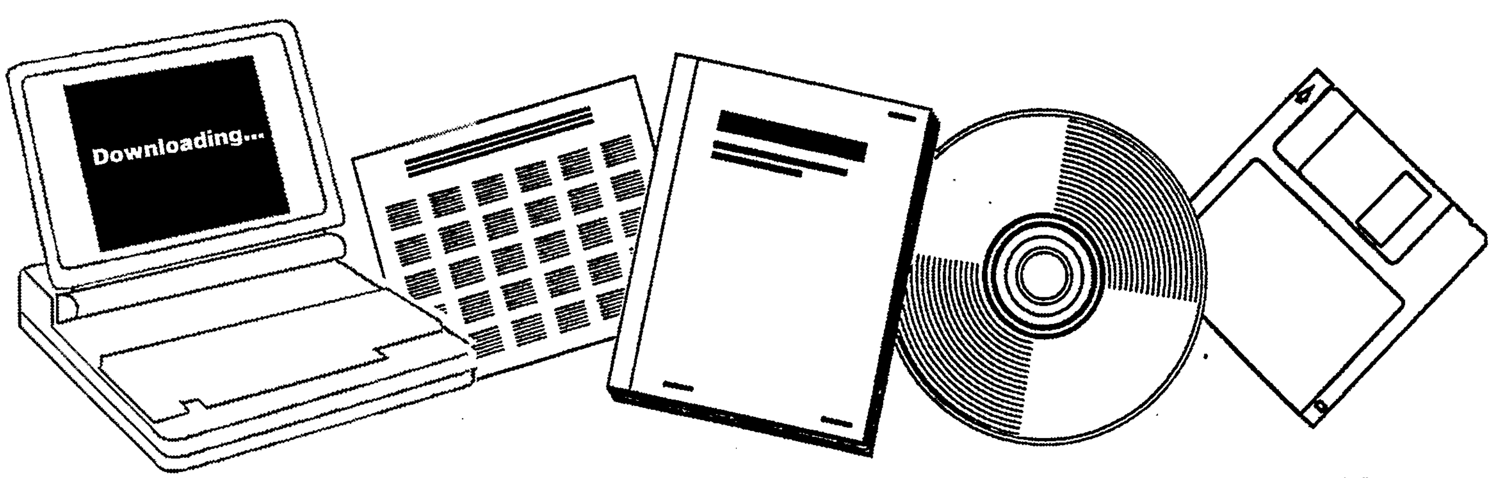
27 JAN 1975



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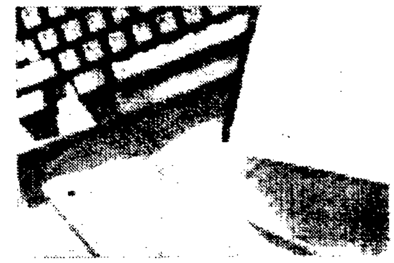

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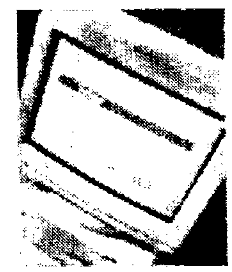

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U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Technical Information Service
Springfield, VA 22161

TT-A-642-75-158

27 January 1975

SUMMARY OF NATO SYNTHETIC FUEL ALTERNATIVES

POINT PAPER

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
TT-A-642-75-158

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
Summary of NATO
Synthetic Fuel
Alternatives

5. TYPE OF REPORT & PERIOD COVERED
Point Paper

6. PERFORMING ORG. REPORT NUMBER
TT-A-642-75-158

7. AUTHOR(s)
Glen Tomlinson et. al.

8. CONTRACT OR GRANT NUMBER(s)
N00014-74-C-0348

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Tetra Tech, Inc.
1911 Ft. Myer Drive
Arlington, VA 22209

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
N/A

11. CONTROLLING OFFICE NAME AND ADDRESS
Commander
Defense Contract Administration
Region P.O. Box 7730
Philadelphia, PA 19101

12. REPORT DATE
27 January 1975

13. NUMBER OF PAGES
28

14. MONITORING AGENCY NAME & ADDRESS (If different from Controlling Office)
Scientific Officer
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release;
distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

N/A

18. SUPPLEMENTARY NOTES

N/A

PRICES SUBJECT TO CHANGE

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

N/A

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

N/A

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SUMMARY OF NATO SYNTHETIC FUEL ALTERNATIVES

SUMMARY

In the past year, the problem of natural crude supply (and its cost) has reached critical proportions for the United States and Western Europe. In view of this crisis the NATO countries have been forced to consider such alternative fossil fuel sources as coal, oil shale, and tar sands for their military forces. The use of these fuels does not present a problem of supply, for the NATO nations have deposits of these fossil fuels that far exceed the proven world reserves of crude oil. It does, however, present a problem of technology — how to realize and use effectively the synthetic product of these deposits. Coal, for example, is particularly plentiful, exceeding the NATO oil reserves and oil shale and tar sands resources by almost a factor of ten.

NATO naval forces are affected by the fuel shortage and cost since most NATO naval ships and all its aircraft use liquid hydrocarbon fuels; the requirement for large quantities of liquid fossil fuels will continue for at least the next 25 years. Consequently, the military forces of NATO are particularly interested in the development of other sources and production methods for liquid fossil fuels.

Conversion technologies for producing liquid fuel products from oil shale and coal have been demonstrated, a commercial tar sands plant is currently in operation in Canada, and several research and development programs are being conducted to improve the conversion process and to reduce the cost of synthetic fuels. The improved oil shale and coal conversion processes are now entering the pilot plant stage; commercial oil shale plants are expected to begin operation by 1980 and commercial coal liquefaction plants should begin operation by 1985. The tar sands industry, which was expected to reach a significant level of operation by 1982, is being impeded by capital requirements for construction, legal restrictions, environmental constraints, inadequate national policies in energy matters, and other factors.

Preliminary data indicate that the new synthetic fuels may not meet current military specifications for existing engines. This problem might be resolved through additional chemical processing of the fuel, modification of the specifications or engines, or combinations of these. Consequently, procedures for refining synthetic fuels need to be evaluated and physical property and qualification tests need to be performed with existing engines.

Recent projections of the cost of synthetic fuels indicate that oil shale will be competitive with Middle East crude oil and that the cost of synthetic fuel from coal depends upon the cost of coal and the value of the co-product fuel gases. [All synthetic fuel cost projections, however, are tentative at this time and should be used with extreme care.] The more efficient that coal processes become, the more competitive the products will be with Middle East crude oil. A commercial-scale tar sands plant in Canada, which had been operating at a loss since 1967, has recently shown a profit. However, it is not known whether new plants constructed today would be profitable. Currently, Canada is exporting tar sands products at the government-regulated price for crude oil.

FINDINGS AND RECOMMENDATIONS

Findings

The study upon which this analysis is based made the following determinations:

- Coal, oil shale, and tar sands resources in the NATO countries are much greater than the entire world reserve of crude oil.
- The conversion technology exists for producing synthetic liquid fuels from coal, oil shale, and tar sands; however, improved technologies will be available in 5-10 years.
- Commercial quantities of synthetic fuels can be derived from tar sands now, from oil shale by 1978-80; and from coal probably by about 1985.
- The development of synthetic fuels on a commercial level is being delayed by economic, legal, and environmental factors as well as a lack of decisive action by the United States and other NATO governments.
- Before synthetic liquid fuels can be used on naval ships, it may be necessary to provide additional chemical processing, to modify the specifications, and/or to modify the engines.

Recommendations

To accelerate and ensure the development of synthetic fuel, for the NATO naval forces, it may be necessary to:

- Stimulate the energy industry to develop synthetic liquid fuels by
  - providing a committed market,
  - supporting industry R&D,
  - subsidizing construction of process plants, and government agencies to support energy R&D.

- Persuade the U.S. Congress to form a positive policy on synthetic fuel development.
- Evaluate potential synthetic fuels as they become available by
  - supporting necessary refining procedures,
  - performing physical property evaluations, and
  - performing qualification tests on existing hardware using the new fuels.
- Recommend any necessary changes in fuel physical properties, military fuel specifications, and power plant specifications that would permit synthetic fuels to be used effectively.

I. INTRODUCTION

The convenience of liquid hydrocarbon fuels has led to their widespread use by the navies and industries of the world. The recent world energy situation, however, has made it apparent that the supply of crude oil is limited and that other sources of energy must be developed. The world supply of hydrocarbon fuel is still extensive; it must, however, be developed from other, less convenient but less politically affected forms as coal, oil shale, and tar sands. These alternative sources have been used for naval fuel in the past but were replaced because of the ready availability of the then less-expensive crude oil. In light of recent world events, alternative liquid fuels derived from coal, oil shale, and tar sands are once again becoming competitive with the fuels from natural crude.

The following sections of this paper contain a review of the past use of the synthetic fuels, the fossil resource base that exists within the NATO countries, the existing technology and estimated costs of the synthetic fuels, and the U.S. Navy's evaluation of the suitability of these alternative fuels.

II. BACKGROUND

Coal, one of the first fossil fuels used by man, has been burned directly for centuries. (A fuel gas was made from coal almost 200 years ago, and coal liquids were derived by pyrolysis or hydroliquefaction approximately 50 years ago. The most notable use of liquid fuel derived from coal was that of the German armed forces during World War II. Germany had built several synthetic fuel plants, with a combined output of approximately 5 million metric tons/year (about 100,000 bbl/day). Approximately 20 percent of the production came from the distillation (pyrolysis) of brown and bituminous coal; 12 percent, from the Fischer-Tropsch synthesis process; and 68 percent, from the direct hydrogenation of coal.

Germany's supply of petroleum was limited prior to World War II. Consequently, a part of its World War II armament program was to build synthetic fuel plants. Although the costs at the time were entirely uneconomical compared with natural crude oil, Germany, in an effort to be self-sufficient, demonstrated that adequate synthetic fuels could be derived from coal.

Since World War II, the synthetic fuel industry has dwindled. Although in 1956 a new plant, based on the Fischer-Tropsch synthesis technology, began production (5000 bbl/day) in the Union of South Africa, and three of the World War II plants located in East Germany were reported to have a combined annual output of about 11 million bbl (30,000 bbl/day). In general, the manufacture of synthetic fuels from coal has been uneconomical in recent years and has not contributed significantly to the overall supply of liquid fuels. Nevertheless, a substantial effort has been expended since the early 1960s by the U.S. Office of Coal Research (OCR) and various energy companies to perfect the synthetic fuel technology. Many of these new processes (discussed in the technology section) are now in the pilot plant stage and could be operating on a commercial level within a few years.

The use of oil shale for liquid fuels also predates the use of natural crude oil. The earliest patent relating to oil shale processing was issued in 1694. Commercial-scale oil shale industries existed in such countries as Australia, France, Sweden, and Scotland until 10-20 years ago, and oil shale is currently being processed on a commercial level in Manchuria (China) and Estonia (USSR). One of the most significant applications of shale-derived products was the use of a shale oil by the Japanese Navy during World War II.

Again, the availability of low-cost natural crude products made the recovery of shale oil uneconomical and commercial-scale industry has virtually disappeared. However, several research and development efforts (discussed in the technology section) have been conducted since World War II and some of these projects have been developed to the point at which the results can be used in commercial-scale processing.

The recovery efforts on tar sands, primarily performed in Canada, began as early as 1897. Although virtually all of the early development projects failed, recently the Sun Oil Company formed Great Canadian Oil Sands, Ltd., and constructed a 45,000-bbl/day plant. This plant, which became operational in 1967, produces a synthetic crude comparable to natural crude.

Again, the processing of tar sands into fuel products has previously been uneconomical. However, with the changing world energy situation, several new tar sands plants have been designed and could be in operation by 1982 (discussed in the technology section) depending upon economic factors.

III. FOSSIL FUEL AVAILABILITY IN NATO COUNTRIES

In discussing the availability of fossil fuels in NATO countries, two designations are made: fossil fuel reserves and fossil fuel resources. In this discussion, reserves refer to the amount of fossil fuel that is recoverable with current technology and in the current economic environment; resources are the total quantities available in the earth that may be successfully extracted within the foreseeable future.

Considerable quantities of fossil fuels other than oil exist within the NATO countries. Extensive deposits of oil shale and tar sands are in the United States and Canada and vast deposits of coal exist both in North America and Europe. A summary of the energy sources available in the NATO countries is presented in Table 1. Also included in Table 1 are the current reserve estimates for oil, natural gas, and uranium. Inclusion of these reserve estimates permits a comparison of the magnitude of the alternative fossil fuel reserves (or resources) and the more convenient crude oil fuels. The dimensions used in Table 1 are the standard international units of measure. For a better energy content comparison, each of the reserve and resource estimates from Table 1 has been converted into equivalent barrels of oil, as shown in Table 2.

Only data on tar sands and oil shale resources are available. However, data on both coal reserves and coal resources are available. As seen in these tables, large quantities of fossil fuels are available within NATO, and the coal resource exceeds the combined supply of petroleum reserves and oil shale and tar sands resources by nearly an order of magnitude.

Table 1. SUMMARY OF NATO ENERGY SOURCES

NATO Countries	Reserves: Crude Oil, megatonnes	Reserves: Natural Gas, billion m^3	Reserves: Coal, megatonnes	Reserves: Uranium, tonnes	Resources: Coal, megatonnes	Resources: Oil Shale, megatonnes	Resources: Tar Sands, megatonnes	Resources: Uranium, tonnes	Resources: Thorium, tonnes
Belgium	—		253	—	253	—	—	—	—
Canada	1,075	2,576	9,034	185,799	108,777	24,860	50,250	716,984	159,664
Denmark (Greenland)	34.75	51	561	—	583	—	—	8,500	26,400
France	9.21	136	1,407	34,850	1,407	237	—	85,000	
Germany (F.R.)	53	350	99,520	—	286,150	311	—	816	
Greece	—	0.08	908	—	1,575	—	—	—	
Iceland	—	—	2,000	—	2,000	—	—	—	
Ireland	—	—	422	—	448	—	—	—	
Italy	6.6	166	110	1,148	110	1,087	—	24,098	
The Netherlands	37	1,967.5	3,705	—	3,705	—	—	—	
Norway	228.3	432.8	2	—	152	—	—	—	264,000
Portugal	—	—	42	7,395	42	—	—	23,545	
Turkey	19.5	4.24	2,893	753	7,282	2	—	2,702	
United Kingdom	503.6	870	98,877	—	162,814	298	—	—	
United States	5,569	7,556.5	363,562	329,267	2,924,503	145,000	2,175	2,041,156	319,016
Total	7,535.96	14,110.12	583,296	559,212	3,499,801	171,795	52,425	2,902,801	769,080

*tonnes = metric tonnes = 1000 kg = 2204.6 lb

SOURCE: Survey of Energy Resources, World Energy Conference—1974

Table 2. SUMMARY OF NATO ENERGY SOURCES

NATO Countries	Reserves*				Resources*				
	Crude Oil	Natural Gas	Coal	Uranium	Coal	Oil Shale	Tar Sands	Uranium	U+Th+Breeder
Belgium	—	—	0.91	—	0.91	—	—	—	—
Canada	7.88	16.68	36.14	27.07	445.11	182.22	368.33	104.46	7,654.08
Denmark (Greenland)	0.25	0.03	2.24	—	2.32	—	—	1.24	303.73
France	0.07	0.88	5.63	5.08	5.63	1.74	—	12.38	742.90
Germany (F.R.)	0.39	2.27	398.08	—	114.60	—	—	0.12	7.13
Greece	—	—	3.63	—	6.30	—	—	—	
Iceland	—	—	8.00	—	8.00	—	—	—	
Ireland	—	—	1.69	—	1.99	—	—	—	
Italy	0.05	1.07	0.44	0.17	0.44	7.97	—	3.51	210.62
The Netherlands	0.27	12.74	14.82	—	14.82	—	—	—	
Norway	1.67	2.80	0.01	—	0.61	—	—	—	2,294.42
Portugal	—	—	0.17	1.08	0.17	—	—	3.43	205.78
Turkey	0.14	0.03	11.57	0.11	28.97	0.01	—	0.39	23.62
United Kingdom	3.69	5.63	395.51	—	651.26	2.18	—	—	—
United States	40.82	48.92	1,454.25	47.97	11,698.01	1,062.95	15.94	297.40	20,612.26
Total	55.23	91.05	2,333.09	81.48	13,999.14	1,259.35	384.27	422.94	32,054.55

*Billion barrels of oil equivalent.
SOURCE: Survey of Energy Resources, World Energy Conference—1974

IV. FUEL SYNTHESIS TECHNOLOGIES

Conversion technologies required to use coal, oil shale, or tar sands as sources of liquid fuels have existed for many years, but most have been uneconomical because of low-priced natural crude. However, over the last two decades, considerable research and development efforts have improved the efficiency of conversion processes, lowered the cost of the facilities required, and together with increasing crude prices, made these alternate fuel sources more competitive. These research efforts have had considerable success and many new and/or refined process technologies now exist. The most recent development efforts have been directed toward building pilot plants based on these improved technologies as a first step toward a full-scale commercial plants. Brief descriptions of the most promising of these conversion technologies are contained in the following subsections.

Coal Liquefaction

Synthesis Gas

The production of synthetic fuels using the synthesis gas process is relatively simple but is generally a more expensive process than other processes. The advantage of this process is the increased control over the types of product manufactured. Consequently, this process would be preferred if part of the product mix would be used to supply a petrochemical industry.

The synthesis gas technology could also be applied to any hydrocarbon starting material. Basically, the process partially oxidizes the coal (or any other organic materials) to produce the synthesis gases CO and H_2. These synthesis gases passed over an appropriate catalyst under particular pressure and temperature conditions will form a synthetic liquid product, which is then refined into the useful fuel fractions. The ratio of CO to H_2, the particular catalyst used, and the operating conditions of pressure and temperature all influence the type of product distribution obtained by the processes. Modifications of the synthesis gas process have also been used to manufacture methyl and higher alcohols from combustible waste.

The use of the synthesis gas process during World War II was discussed in the preceding section. Currently, Sasol in the Union of South Africa has a commercial-scale synthesis gas plant that produces approximately 5000 bbl/day of liquid products. Some of these products are used as fuel; some, for feed stock to a chemical plant.

Pyrolysis

Coal has been thermally distilled into coke, fuel gases, and liquid fuels on a commercial level for many years. The adaptation of these pyrolysis techniques to produce primarily liquid and gas products from a wide range of coal types has been pursued by several organizations. Some of the more noteworthy research efforts in the United States have been Project Seacoke, sponsored by OCR and conducted by the Atlantic Richfield Company; Project COED (Char Oil Energy Development), sponsored by OCR and conducted by the FMC Corporation; TOSCOAL, conducted by The Oil Shale Corporation (TOSCO); and the independent work conducted by Garrett, a subsidiary of Occidental Petroleum Company.

The COED process, under development by the FMC Corporation for OCR, is typical of the pyrolysis conversion technology available and represents the most advanced state of the art. The COED process begins by crushing and drying the coal feed stock, which is then fed into a series of four fluidized-bed reactors that operate at successively higher temperatures. The process requires a source of steam and oxygen in addition to the feed stock. Approximately one-third of the feed stock is distilled into a liquid product; the rest remains as char. The economics of the process are dominated by the char – whether it is burned directly in a boiler or subsequently converted into a fuel gas.

Based on current prices for coal and co-product fuel gas, the COED process is not economical. However, if the co-product fuel gas is priced nearer to its true energy value, then the COED process can be used to produce fuels economically. (The coal pyrolysis, catalytic hydrogenation, and solvent refining processes produce highly aromatic fuels which tend to be more suitable as boiler or spark ignition engine fuels rather than diesel or gas turbine fuels.)

Catalytic Hydrogenation

The direct catalytic hydrogenation of coal appears to be one of the most promising of the evolving synthetic fuel technologies. Catalytic hydrogenation seems to offer higher overall thermal efficiencies and probably lower costs. During World War II, the Germans used direct hydrogenation much more extensively than either the pyrolysis or synthesis processes. In the early German processing, Bergius used a process in which pulverized coal and hydrogen were allowed to react in the presence of a catalyst and at a particular pressure and temperature condition. By varying the choice of catalyst, the coal-hydrogen ratio, and the operating pressure and temperatures, liquid products can be obtained that approximate a very heavy fuel oil or that contain mostly high-volatile aviation fuel and hydrocarbon gases.

Recent research efforts have all tried to improve the conversion yield of the hydrogenation process, tailor the catalyst and operating conditions to obtain particular products, and improve the cost effectiveness. Different approaches using the chemical reactor have also been tried. In its H-Coal process, Hydrocarbon Research, Inc., has used improved catalysts in a fluidized-bed reactor, while in its Synthoil process, the U.S. Bureau of Mines has been using improved catalysts in a fixed-bed reactor. In general, a direct hydrogenation process will yield approximately 3-4 bbl of products and should be operational at 70-80 percent thermodynamic efficiency.

Both private industry and the U.S. government are sponsoring major direct hydrogenation projects, but most projects are just moving into the pilot plant stages. Based on the present rate of progress, commercial-scale production will probably not be achieved for several years.

Solvent Refining

A recent development in synthetic fuel technology has been solvent refining of coal (SRC). The SRC process is a special-purpose technology development conducted by the Gulf Energy and Minerals Co. for OCR to provide a uniform, low-sulfur fuel for use by utilities.

Basically, the process mixes pulverized coal, hydrogen, an organic solvent (derived from coal) under specific pressure and temperature conditions in a reactor. No catalyst is used. The coal is dissolved and mildly hydrogenated. The inorganic sulfur and other inorganic compounds are filtered and the hydrocarbon product is distilled to recover the solvent, a small amount of liquid product, and a hydrocarbon fuel with a 350°F melting point. This hydrocarbon can be treated by further hydrogenation, used directly as a hot liquid boiler fuel, or solidified for use in a solid-fuel boiler. For naval purposes, in using the SRC process, the hydrocarbon would probably require further hydrogenation.

Oil Shale

The conventional technology for converting the hydrocarbons in oil shale into synthetic fuel requires that the shale be mined in either an open-pit or underground mine. The shale is transported, crushed, and fed into a retort in which the organic material (kerogen) is converted from a solid waxy material into a liquid. The hydrocarbon liquid is collected, frequently hydrotreated to remove excessive nitrogen and sulfur compounds, and piped to a refinery for further processing. The spent shale is disposed of in a landfill.

Several oil shale development projects have been conducted in the United States since World War II. These projects include the work by the Bureau of Mines at Anvil Points, Colorado; by the Union Oil Company at Parachute Creek, Colorado; by the Colony Development Group at Parachute Creek, Colorado; by the Paraho Development Corporation at Anvil Points, Colorado; and a new process by the Union Oil Company at Parachute Creek, Colorado. The differences between these projects are primarily in the different retort techniques being used. All of these various development projects are trying to demonstrate the feasibility of the recovery technology using a pilot plant and to improve the efficiency and cost effectiveness of the recovery process. Several commercial-scale projects are also being planned, with the first significant production scheduled for 1978-80.

The in situ recovery of shale oil has received considerable attention recently. In situ technology is still limited, however, and is not expected to have any significant impact for many years.

Tar Sands

The Great Canadian Oil Sands (GCOS) Co. has a commercial-scale tar sands processing plant in Canada that has been in operation since 1967. This particular plant produces about 50,000 bbl/day of tars and syncrude. In this process, the mined tar sands are mixed with water and heated in rotating drums. The bitumen and sand are separated by gravity, and final clarification and dehydration of the bitumen are performed in a centrifuge. The bitumen is then coked, yielding a distillate, which is further hydrotreated by unifining. This syncrude can then be processed into conventional products by normal refinery procedures.

Other processes have been proposed to separate the bitumen from the tar sands. One such process is the Syncrude Canada, Ltd., process, which uses a dense phase technique, followed by a froth-flotation step; and the chemical-addition separation process proposed by the Guardian Chemical Corporation.

In the United States, efforts to recover oil from tar sands have been limited to an in situ project of the Bureau of Mines and two small development projects being undertaken on SOHIO property in Utah.

Development Plans

The statuses of the synthetic fuel process plants vary considerably; new projects are frequently being announced, while some previously announced projects are being delayed or withdrawn. The development of these industries is being hampered by many environmental, legislative, zoning, legal, and regulatory restrictions as well as emotional, technological, and economic factors. The current project for tar sands, oil shale, and coal liquefaction projects are summarized in the following subsections.

Tar Sands

At the present time, the only commercial-scale synthetic fuel operation is the GCOS tar sands plant in Alberta, Canada. This plant, operational since 1967, produces approximately 50,000 bbl/day of syncrude, and has demonstrated the technical feasibility of tar sands as a source of fuel. The project was uneconomical, however, until the recent increases in crude oil prices.

Additional tar sands projects have been or are being planned; however, recent changes in project costs due to inflation and Canadian government tax and export policies have caused several corporations to reconsider sponsoring of the projects. Several corporations have announced that they are going to withdraw from cooperative ventures or suspend plans indefinately. A summary of the current statuses of the Canadian projects is contained in Table 3.

In addition to the commercial-scale projects mentioned, several small development projects are underway. Three projects are known to be underway in the United States. Two small companies are testing different recovery methods on SOHIO land in Utah and the Bureau of Mines is testing an in situ method on federal land in Utah. The Canadian government has pledged $100 million for a 5-year research plan to assist in developing

Table 3. STATUS OF CANADIAN TAR SANDS SYNCRUDE COMMERCIAL-SCALE PROJECTS

Project	Principal Participants	Capacity (bbl/day)	Date Operational	Status
GCOS	Sun Oil Co. (100%)	50,000	1967	Expansion of capacity deferred.
Syncrude	ARCO (30%), Imp. Oil (30%), City Service (30%), Gulf Oil (10%)	125,000	1978	ARCO withdrawn; Canadian government studying participation
Shell	Shell Explorer (50%), Shell Canadian (50%)	100,000	1982	Shell Explorer withdrawn, seeking buyer for 50% share
Petrofina	CanDel Oil Ltd. (6.9%), Petrofina Canada, Ltd.	122,500	1982	CanDel considering withdrawal.
Home	Home Oil (80.5%), Alminex Ltd. (12.5%)	103,000	1982	Construction plans shelved.

technology by which to tap deep tar sands reserves. A Canadian firm, New Western Oil Sands, Ltd., is scheduled to begin a pilot field test of an in situ technique in January 1975.

Oil Shale

Several commercial-scale oil shale projects are progressing with development plans in spite of the current uncertainty in the industry. A summary of the commercial-scale projects in the United States is presented in Table 4. There are six major projects being undertaken: two purely corporate ventures and four corporate ventures on federal leases. One of the commercial groups (Colony) has recently suspended its development plans pending resolution of economic factors and government policy. The projection for this group is currently unclear.

It was recently announced that the lease holders (Phillips, Sun, and SOHIO) of the adjacent Utah prototype leases (U-a and U-b) have joined together and are planning a common mine (150,000 tons/day) and a single, 100,000-bbl/day processing plant. The participants of these leases are also participants in the Paraho development project currently underway at Anvil Points, Colorado. This group gives every indication of being serious about its involvement in the development of oil and shale industry. If all of the planned commercial ventures proceed on schedule, by 1980 production will be approximately 300,000 bbl/day

In addition to the commercial-scale plants mentioned, considerable effort is currently being spent on research and development efforts. A summary of the major U.S. projects currently underway and completed in recent years is contained in Table 5. The Paraho Development Group has already been mentioned. This group is using the old Bureau of Mines facility at Anvil Points, Colorado. Two retorts of a new design have been installed and are currently being tested. The largest is 8½ ft in diameter inside and is expected to process approximately 900 bbl/day of shale oil. This group has also proposed to construct, with the cooperation of the U.S. Navy, a single module of a commercial-scale retort. This module would process approximately 8000 bbl/day of shale oil. If successful, the Paraho process would be used on the Utah a and b leases and may possibly be used on the Colorado a and b leases. Arrangements have been made between Paraho and the U.S. Navy to obtain the shale oil from the pilot plant and process it into military specification fuels for evaluation testing by the U.S. Navy, Air Force, and Army, and NASA. Approximately 6000 bbl of JP-5 derived from shale oil will be available early in 1975 for evaluation.

Table 4. STATUS OF OIL SHALE SYNCRUDE COMMERCIAL-SCALE PROJECTS

Project	Principal Participants	Capacity (bbl/day)	Date Operational	Status
Colony	ARCO, TOSCO, Ashland Oil	50,000	1978	Suspended because of inflation, tight money and lack of national energy policy.
Union	Union Oil Co.	50,000	1980	Proceeding with pilot plant tests on new SGR retort.
DOI Leases Colorado - a	AMOCO/Gulf	100,000	1980	Mining studies and design of extraction project subcontracted to Morrison - Knudson Co.
Colorado - b	ARCO, TOSCO, Ashland Oil, Shell	50,000	1980	Proceeding
Utah - a	Phillips, Sun	50,000	1980	Projects merged to develop single mine (150,000 tons/day) and single (100,000 bbl/day) processing plant.
Utah - b	Phillips, Sun, SOHIO	50,000	1980	

Table 5. STATUS OF RECENT U.S. OIL SHALE SYNCRUDE R&D PROJECTS

Project	Capacity (bbl/day)	Dates of Operation	Status
Bureau of Mines	--	1947 - 56	Paraho current operator.
Union Oil (Combustion gas retort)	720	1956 - 58	Being reactivated.
Colony (TOSCO II retort)	600	1965 - 72	R&D effort successful. Commercial-scale plant next step.
Paraho (Combustion gas retort)	900	1972 - 76	2½-ft retort tests completed. 8½-ft retort tests underway.
Union (SGR retort)	1350	1974-76	Old Union combustion gas retort being converted to new, more efficient SGR retort.
IGT (Heated hydrogen retort)	Laboratory scale	1974	Novel processing using direct hydrogen retorting of shale. Sponsored by AGA.
In Situ: Bureau of Mines	--	1974	Investigating fracturing technique near Green River, Wyoming; in situ test near Rock Springs, Wyoming.
Occidental	1200 bbl total	1974	Unique fracturing technique forms underground retort.

At the present time no development plans for commercial coal liquefaction plants have been announced. Several major R&D efforts are currently underway, however. A summary of the principal U.S. research and development projects is contained in Table 6. The majority of these liquefaction projects are government sponsored (Bureau of Mines or OCR) but major development efforts have been undertaken by Gulf and EXXON. It is expected that other oil company research efforts may be directed toward coal liquefaction; however, their plans have not yet been announced. Many of the current R&D efforts involve pilot plant operations of significant scale and are scheduled to complete their research operation by the mid- and late-1970s. Based on this time schedule, none of the current process developments could probably be implemented into a commercial-scale plant before about 1985-90.

Coal seems to offer one of the greatest potentials for relieving the energy problems; however, the U.S. technology for producing liquid fuels from coal lags that of oil shale (or tar sands). The technology developed by Germany during World War II could be implemented rapidly, but would become uneconomical as newer, better processes were developed.

Table 6. STATUS OF U.S. COAL LIQUEFACTION R&D PROJECTS

Project & Location	Sponsor & Researcher	Process Type	Capacity (bbl/day)	Dates of Operation	Status
COED (Princeton, N.J.)	OCR/FMC	Pyrolysis	40	1970-74	Processing limited to batches of selected coal.
SRC (Tacoma, Wash.)	OCR/Gulf	Solvent Refining	150	1974	Pilot plant started in fall 1974.
SRC	Southern Services	Solvent Refining	3	1974	Unknown
H-Coal (Trenton, N.J.)	OCR, et al./ HRI	Hydrogenation	7	1967-74	Operational.
H-Coal (Catlettsburg, Ky)	OCR, et. al./HRI	Hydrogenation	2100	1978	Contract for pilot plant let fall 1974.
Gulf	Gulf Oil Co.	Hydrogenation	3-4	1974	Unknown.
EXXON	EXXON	Hydrogenation	Unknown	1974	Unknown
Synthoil (Bruceton, Pa)	BOM/Foster - Wheeler	Hydrogenation	24	1976	Contract issued.

V. ECONOMIC CONSIDERATIONS

The economics of the various synthetic fuels are currently clouded by uncertainties in technology, legal and regulatory factors, environmental considerations, government energy policy, and rapid inflation in key industries. These uncertainties have forced the abandonment or at least delay of one oil shale project in the United States and several tar sands projects in Canada.

The rapid changes in equipment and manpower costs make even the most carefully prepared economic analyses of the synthetic fuel projects uncertain. Nevertheless, it is necessary to make such analyses in order to determine on a preliminary basis whether synthetic fuel processes are viable. Extreme care must be exercised when using any of these estimates, however.

Over the past 8 years, several synthetic fuel plans based on coal liquefaction and oil shale processes have been designed and the economics evaluated. Since these evaluations were performed in different years and used different cost bases, they are not directly relatable to each other. These earlier analyses were used, however, to project syncrude costs by correcting the plant capital and operating costs to mid-1974 using the Nelson refinery cost inflation index and by using a consistent cost basis. A summary of the U.S. projected costs of oil shale syncrude is contained in Table 7. A considerable difference exists between the costs projected by the Bureau of Mines (Department of the Interior, DOI) and those projected by the National Petroleum Council (NPC); those of NPC are probably the more accurate.

Table 7. ESTIMATED 1974 OIL SHALE SYNCRUDE COST

Mine Type	Source	Capacity (bbl/day)	Capital Cost ($ Million)	Operating Cost ($ Million/Yr)	Equivalent Cost* ($/bbl)
Underground	DOI (1972)	50,000	289.7	29.5	4.67
Underground	DOI (1972)	100,000	486.0	49.1	3.90
Surface	DOI (1972)	100,000	497.3	44.5	3.83
30 gal/ton					
Surface	NPC (1972)	100,000	898.6	88.3	7.14
Underground	NPC (1970)	100,000	790.9	88.3	6.59

*Cost = [0.18 (Capital Cost) + Operating Cost] /Annual Production

Estimates of the capital costs, annual operating costs, and cost per barrel of coal-derived syncrude — also corrected to 1974 and a consistent economic cost model — for three different coal liquefaction processes are summarized in Table 8. The costs projected in Table 8 are sensitive to the value of the coal feed stock and to the value of any co-products, mostly synthetic fuel gas. Both the COG refinery and the COED process produce large quantities of synthetic fuel gas, and the economic estimates made for the gasification process determine the ultimate liquid fuel costs. Some uncertainty now exists in both coal and fuel gas pricing, and a range of values that are felt to be likely in the near term were selected.

The price of synthetic crude has been projected to 1977, the earliest conceivable date that synthetics could be available in commercial quantities, by assuming a 10 percent annual inflation rate for capital and operating costs. In Table 9, these costs are compared to cost projections for natural crude, which were made by the energy economics group of Chase Manhattan Bank. These cost projections suggest that oil shale is currently competitive with foreign oil and coal liquefaction may or may not be depending on the value of coal, by-product fuel gas, and the particular process used.

Table 8. ESTIMATED 1974 COAL-DERIVED SYNCRUDE COST

Process	Source	Capacity		Capital Cost ($/million)	Coal Cost ($/ton)	By-product Gas Value ($/million Btu)	Operating Cost[1] ($ million/yr)	Equivalent Cost[2] ($/bbl)
		Liquid (bbl/day)	Gas (SCFD)					
COG (SRC/Bi-gas)	OCR-Chem Sys. 1971	100,000	332 million	795.9	10.00	0.75	107.3	7.17
						1.50	14.4	4.51
					22.00	0.75	349.7	14.08
						1.50	256.7	11.43
H-Coal (Hydrogenation)	OCR AMOCO 1967	100,000	nil	687.7	10.00	—	199.3	9.23
					22.00		319.9	12.68
COED (Pyrolysis/Fluidized – Bed Gasification)	FMC Paper 1973	26,000	286,000 million Btu/day low Btu gas	256.1	10.00	0.75	64.8	12.92
						1.50	6.0	4.67
					22.00	0.75	169.8	25.16
						1.50	99.0	16.91

[1]Operating Cost = Annual Operating Cost - By-product Credit
[2]Equivalent Cost = [0.18 (Capital Cost) + (Operating Cost)] /Annual Production

Table 9. AVERAGE OIL PRICE PER BARREL

Year	Natural		Synthetic						
	Foreign[1]	Domestic Blend[2]	Oil Shale	COG[3]		H-Coal[4]		COED/FB[5]	
				$10/ton	$22/ton	$10/ton	$22/ton	$10/ton	$22/ton
1974	$10.08	$7.22	$6.59	$7.18	$14.08	$ 9.23	$12.68	$12.91	$25.16
1975	11.50	8.27	7.25	7.56	14.49	9.87	13.31	14.01	26.25
1976	12.35	8.92	7.97	8.01	14.73	10.57	14.01	15.22	27.47
1977	13.60	9.96	8.77	8.50	15.42	11.33	14.78	16.55	28.80

[1]Tar sands projections are not indicated separately but are considered as foreign crude at $10.65/bbl.
[2]Domestic Blend: average U.S. cost of old, new, and foreign oil.
[3]COG: Coal-Oil-Gas refinery which hydrogenates solvent refined coal (SRC) to a liquid product and uses the Bi-Gas.
[4]H-Coal: Hydrocarbon Research, Inc.,'s direct hydrogenation process, considered typical of hydrogenation process.
[5]COED/FB: FMC pyrolysis liquefaction process coupled with a fluidized-bed gasifier.

VI. EVALUATION OF THE SUITABILITY OF SYNTHETIC FUELS FOR NAVAL USE

It is conceptually possible to manufacture any hydrocarbon fuel from any source of hydrocarbon (coal, oil shale, tar sands, or organic waste). In reality, however, the current technological and economic constraints limit the synthetic fuel processes, and the fuels produced may have different physical characteristics than similar fuels derived from natural crude.

The military services have in recent years moved toward using fuels that have strict specifications, and power plants (diesels, gas turbines, etc.) have been refined to the point at which they will only function properly when using these specific fuels. The use of these specialized fuels causes supply and operational problems when the availability becomes limited. Also, as fuels (i.e., diesel, gasoline, JP-5, etc.) are refined from the synthetic crudes, they may not meet current fuel specifications. The alternatives available when considering the use of synthetic fuels include (1) sufficient chemical processing of the fuel to ensure that it meets current specifications, (2) modification of current specifications to allow the use – assuming that tests show these fuels to be suitable – of new synthetic fuels, (3) modifications to existing power plants to allow the use of new synthetic fuels, and (4) combinations of these three options. The U.S. Navy has recognized this problem and has undertaken a limited energy R&D program in an effort to stimulate the development of synthetic fuels for naval use, determine the extent to which the synthetic fuels meet military specifications, and test these new fuels in operational equipment. The U.S. Navy is not becoming directly involved in developing synthetic fuel technology but is more interested in stimulating the industry and in evaluating the performance and physical characteristics of synthetic fuels as they are developed.

U.S.S. *Johnston* Sea Coal I Demonstration

The U.S.S. *Johnston* program was a demonstration test designed to show that U.S. ships can successfully operate on synthetic fuels. This destroyer successfully operated for a period of 24 hours on a synthetic liquid fuel (Sea Coal I) derived from coal. The fuel was distilled from a coal syncrude manufactured with the COED process. It was necessary to distill the

COED syncrude in order to raise its flash point from 58°F, which is unsafe for shipboard use, to 160°F. This higher flash point compares to 150°F for Navy distillate fuel (NDF) and is above the minimum acceptable flash point temperature of 140°F for shipboard fuels. This particular test was of insufficient duration to fully evaluate the coal-derived fuel but did serve as a demonstration of the potential of using synthetic fuels for naval applications.

U.S. Navy, Department of the Interior, and Industry Joint Oil Shale Project

Development Engineering, Inc., (DEI) is the operating subsidiary of Paraho Development Corporation and presently operates a 2.5-ft inside diameter pilot retort, which has produced 300 bbl of synthetic crude from oil shale, and an 8.5-ft inside diameter semiworks retort, which has produced 1000 bbl at the Bureau of Mines Anvil Points facility located on Naval Oil Shale Reserves (NOSR) 1 and 3. Paraho has agreed to supply 10,000 bbl of synthetic crude to the Navy by March 1975 from the 8.5-ft retort for refining and testing. An early December meeting between the Navy and DOI resulted in an agreement that the Department of Defense (DOD) would be responsible for quality control and transportation of the syncrude and products, DOI would fund refining, and NASA would contribute to transportation and quality control. The 10,000 bbl of syncrude are expected to yield about 8000 bbl of refined product; 6100 bbl will be JP-5 for Navy. For testing, the Army and DOI will get mogas; the Air Force, JP-4; and NASA, Jet A-1.

Following approval from both the House and Senate armed services committees, the Navy and DOI have entered into negotiations with DEI to increase the quantity of shale which may be mined under the lease on the Naval Oil Shale Reserves at Anvil Points, Colorado. DEI has proposed that the increased quantity of shale mined would be sufficient to permit it to construct and operate a full-sized, 40-ft diameter retort which could produce 1-6 million bbl of syncrude within a 6-month to 3-year time frame. In the expanded project, DOD would pay for refining the syncrude produced by Paraho; the resultant products would be placed in the Prepositioned War Reserve Stocks (PWRS). At the end of the contract, the retort and plant complex will become the property of the Navy, which will enhance the readiness posture of the NOSR. A Paraho spokesman believes that the experience gained by the Paraho project at Anvil Points can accelerate the development of an oil shale industry by 2-3 years through the joint industry-government cooperation of the type proposed for the NOSR.

U.S. Tar Sands Fuel Evaluation Program

A performance/durability test fo T63-A-5A turboshaft engine has been completed by Naval Air Propulsion Test Center (NAPTC) using a synthetic JP-5 derived from Athabasca tar sands by Sun Oil Co. The fuel, known as a Unifined Kerosine, was evaluated according to the MIL-T-5624J and was found to be equivalent to the current JP-5. The fuel did have a slightly higher flash point and viscosity than current fuels but it was still within specification limits. During the tests, the engine performed normally, using the synthetic fuel. No significant differences in operation were seen between the synthetic fuel and the standard JP-5.

Summary of Additional U.S. Navy Synthetic Fuel R&D Programs

The Naval Ship Research and Development Center-Annapolis (NSRDC/A) will analyze both crude and refined petroleum products. A synthetic diesel fuel derived from tar sands at the GCOS plant met all the chemical and physical requirements of the Navy distillate and diesel fuel marine (DFM) with the exception of the cetane number requirement of DFM.

Sun Oil Company is under contract to NAPTC to refine syncrude derived from Utah and Western coal into JP-5 fuel having 0-5 percent aromatics and 20-25 percent aromatics. The results of these tests showed small variations in freeze point and smoke point in the four samples. Low space velocities were required to hydrogenate the syncrude into JP-5 fuel. One major problem was the catalyst deactivation that might have been caused by high oxygen and nitrogen concentrations in the syncrudes. A hydrogenation guard reactor may be needed to protect the catalyst. The overall yield of JP-5 per barrel of syncrude without thermal cracking varies from 31 to 35 percent.

NAPTC has conducted studies on a synthetic crude derived from coal using solvent extraction techniques. The results of these tests indicate that solvent extraction is a viable technique for converting "heart cut" syncrude into JP-5. The freeze point was the only property that did not conform to military specifications.

The Naval Research Laboratory (NRL) studies are primarily concerned with hazards and safety. Its program will examine flammability and ignition characteristics, electrostatic phenomena, fire suppression studies, and analytical support work.

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