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2d Session }

COMMITTEE PRINT

# PRODUCTION OF AVIATION JET FUEL FROM COAL

## STAFF REPORT

PREPARED FOR THE USE OF THE

## COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES UNITED STATES SENATE

JUNE 1, 1976

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# LETTER OF TRANSMITTAL

U.S. SENATE,
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
*Washington, D.C., June 3, 1976.*

Hon. FRANK E. MOSS,
*Chairman, Committee on Aeronautical and Space Sciences,*
*U.S. Senate, Washington, D.C.*

DEAR MR. CHAIRMAN: I am transmitting herewith a staff report entitled "Production of Aviation Jet Fuel from Coal", the principal findings of which are shown in the summary on page 1. It should be of special interest to you that this report is a direct outgrowth of recommendation number 6 of Senate Report 94–633 which was prepared by the Committee. That recommendation states:

> 6. Serious study should be given to the possibility of the development of alternative fuels such as those derived from coal and oil shale, synthetic hydrocarbons, liquid hydrogen, and nuclear propulsion.

This new staff report indicates that the production of aviation fuels from the vast quantities of American coal is an alternative which should be given serious consideration.

Sincerely,

GILBERT W. KEYES,
*Staff Director.*

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# GLOSSARY

Acids—Organic acids, such as formic acid, acetic acid, etc., produced in Synthol reaction.

Alcohols—Organic compounds, such as methyl alcohol, ethyl alcohol, etc., produced in Synthol reactor.

Aldehydes—Organic compounds, such as formaldehyde, acetaldehyde, etc., produced in Synthol reactor.

Arge—A process developed in Germany to convert synthesis gas into heavy oils and waxes.

Aromatic—A class of hydrocarbons in which carbon atoms are arranged in six member rings like the ring in benzene.

Benzene—An aromatic compound containing six carbon atoms and 6 hydrogen atoms and characterized by alternate double bonds between the carbons.

BPD—Barrels per day.

Butane—A paraffin hydrocarbon containing four carbons and ten hydrogens in the molecule.

BTX—A mixture of benzene, toluene and xylene.

Cash flow—Annual profit plus annual depreciation.

Catalyst—A material which accelerates the rate of a chemical reaction without itself undergoing a permanent chemical change.

Claus—A process for converting hydrogen sulfide to sulfur.

Converter—A reactor vessel in which materials undergo chemical change.

Countercurrent—A method of contact between streams of materials flowing in opposite directions.

Cyclone—A conical vessel used to classify dry powders or separate dust from gases by centrifugal action.

DCF—Discounted cash flow. Sum of each year's cash flow generated by a project with each cash flow discounted at a selected interest rate to the year of start up. The sum of all DCF's over the plant life is set equal to the total investment committed to the plant at start up less salvage value at the end of plant life.

Fractionator—A multi-stage distillation tower used to separate components of a mixture by successive vaporization and condensation.

Gasifier—A reactor to convert coal to gaseous fuels.

Gum—A shellac-like material formed by thermal decomposition of olefin-containing fuels. Gum can interfere with fuel feeding devices.

Hexane—A paraffin hydrocarbon containing six carbon atoms and fourteen hydrogen atoms per molecule.

Hydrocarbon—A compound of carbon and hydrogen.

Hydrogenation—Chemical reaction involving the addition of hydrogen to another chemical usually in the presence of a catalyst under high pressure.

Hydrotreater—A reactor in which hydrogenation is carried out.

Isomerization—A reaction converting straight chain hydrocarbons to branch chain hydrocarbons.

Ketones—A class of organic compounds including a carbonyl bond consisting of oxygen attached through a double bond to carbon. Ketones are usually good solvents.

LPG—Liquefied petroleum gas. A mixture of light hydrocarbons from petroleum.

Lurgi—The Lurgi process gasifies lump coal by countercurrent contact with steam and oxygen rising through the coal.

Methanation—A reaction converting synthesis gas to methane.

MM—Million.

Molecular weight—The weight of all the atoms contained in a molecule of a material.

Naphtha—A light fraction of petroleum generally used as a gasoline component but also used as a petrochemical feedstock.

Octane—A gasoline property that measures fuel performance in automotive engines. Also a paraffin hydrocarbon containing eight carbons and eighteen hydrogens per molecule.

Olefins—Hydrocarbons containing two less hydrogens than paraffins per molecule and possessing some instability with respect to gum formation.

Oxygenated chemicals—Compounds of carbon, hydrogen and oxygen produced in the Synthol reaction and including aldehydes, alcohols, ketones and acids.

Paraffins—Hydrocarbons containing maximum possible hydrogen and exhibiting stability to chemical reactions including gum formation.

Pentane—A hydrocarbon containing five carbon atoms and 12 hydrogen atoms per molecule.

Pilot plant—Plant of a scale intermediate between laboratory-scale and large-scale units to evaluate integrated, continuous operations of chemical processes or to provide engineering design data.

Phenol—An aromatic compound containing a hydroxyl group (an oxygen atom attached to a hydrogen atom) such as carbolic acid.

Psig—Pressure in pounds per square inch gage.

Pyrophoric—A material that burns when exposed to air.

Rectisol—A process developed in Germany to purify synthesis gas prior to its catalytic conversion to hydrocarbons.

SASOL—South African Coal, Oil and Gas Corporation, Ltd., a South African company operating the only commercial coal liquefaction plant.

Solvent extraction—Selective transfer of specific components from one liquid into an immiscible solvent for ultimate recovery of the components.

Standpipe—A vertical column of powder used to develop static pressure needed for circulation of powder through a (reactor) system.

Steam reforming—A catalytic reaction to convert hydrocarbons to synthesis gas of which the active components are carbon monoxide and hydrogen.

Straight chain—A characteristic of hydrocarbon molecules in which all carbon atoms are connected to adjacent carbons in a straight linear manner.

Synthesis—The reaction converting carbon monoxide and hydrogen contained in synthesis gas into hydrocarbons and oxygenated chemicals.

Synthesis gas—A mixture of gases containing hydrogen and carbon monoxide.

Synthol—A synthesis reaction developed in the United States and used by SASOL in South Africa.

Toluene—An aromatic hydrocarbon containing seven carbons and eight hydrogens per molecule.

Water gas shift—A reaction converting carbon monoxide to hydrogen by reaction with steam to adjust the ratio of hydrogen to carbon monoxide in synthesis gas for desired operation of the synthesis reaction.

Weir scrubber—A process for removing sulfur oxides pollutants from stack gases in boiler plants.

Xylene—An aromatic hydrocarbon containing eight carbons and ten carbons per molecule.

# PRODUCTION OF AVIATION JET FUEL FROM COAL

(Prepared for Senate Committee on Aeronautical and Space Sciences by George T. Skaperdas, Pullman Kellogg, Division of Pullman Incorporated)

## SUMMARY

The SASOL plant was designed and has been operated in South Africa to produce motor gasoline rather than aviation fuel and, therefore, does not furnish direct commercial demonstration of aviation jet fuel production from coal. But the basic Synthol process, which accounts for most of current SASOL production and which will be used exclusively in the current expansion, can be modified to maximize jet fuel production rather than gasoline. Using information available from pilot plant operations carried out during the development effort in Synthol in Pullman Kellogg's laboratories (then located in Jersey City), the product distribution to be expected when running the process for aviation fuel has been estimated. The results show a wide variety of co-products along with the jet fuel and reflect the same range of co-products as produced at SASOL.

A plant to produce jet fuel from coal has been designed in a preliminary manner in order to provide an estimate of the economics for further evaluation of this system. A plant charging 17,100 tons per day of coal and producing some 9,400 barrels per day of jet fuel will require a total investment of 780 million dollars and will produce jet fuel that would have to be sold at 76 cents per gallon to provide a 15 percent discounted cash flow rate of return on the investment. Such commercial operation is difficult to justify as long as petroleum jet fuel remains available at less than half this price. But jet fuel production from coal could be set up as a matter of national security to minimize the dependence of aviation jet fuel on petroleum which is being imported at an increasing rate. Under these conditions, funds for construction could be supplied by the Government and no return on these funds would be required of the operation. The resulting facility could then be operated under contract and jet fuel could be supplied to the Government at no cost by the contract operator who would have as his incentive income from sale of byproduct chemicals.

This incentive seems attractive for a single plant producing some 2 percent of the Nation's military aviation fuel. If ten plants were to be considered in order to provide 20 percent of the nation's needs for military jet fuel, disposal of chemicals may raise some problems particularly with ethanol. Several methods of handling these problems appear to be available.

## 1. Liquefaction of Coal

Conversion of coal to hydrocarbons can be of national interest because such conversion can free important national energy requirements from dependence on imported petroleum and can then supply these energy needs from abundant, indigenous coal.

This is particularly important in the case of aviation jet fuels. These are currently derived from petroleum which is now significantly and increasingly dependent on imports. Thus a prolonged embargo by overseas petroleum exporters could seriously impair ready availability of aviation jet fuels for both civilian and military use. Conversion of coal to hydrocarbon liquid fuels suitable for aviation does, therefore, merit consideration as a means of providing freedom from disruption of aviation due to unfriendly actions of oil exporting countries.

Coal has been converted into hydrocarbon liquid fuels either by complete gasification followed by synthesis or by hydrogenation. Hydrogenation was widely used in Germany during World War II to produce liquid hydrocarbons but the processing conditions are severe and this process approach is no longer being used in any commercial-scale operation, having been abandoned in the post-war period. Development work is currently underway in several laboratories to improve the hydrogenation method by carrying out the reactions very rapidly. This will serve to retain hydrocarbon structures that occur naturally in coal and thus minimize the chemical work that must be done in synthesizing liquid hydrocarbons. But this effort, though potentially promising, is in the early research stages and is not available for the near future.

In contrast the gasification-synthesis approach has been in commercial use for two decades at a plant of the South African Coal, Oil and Gas Corporation, Ltd. (SASOL) in South Africa. In this operation coal is essentially completely gasified to synthesis gas which is largely a mixture of carbon monoxide and hydrogen. The synthesis gas is then converted to liquid hydrocarbons by reaction in the presence of a suitable catalyst. Conversion of the coal substance to simple gases does require substantial energy but the synthesis step does make it possible to make a more closely controlled liquid product that is not burdened with the more complex molecular fragments that are produced from coal by direct hydrogenation. Thus a cleaner fuel is possible from synthesis and costs of purifying or upgrading hydrogenation product are not necessary.

The synthesis approach goes back to experiments reported in 1923 by Franz Fischer and Hans Tropsch on their work at the Kaiser Wilhelm Institute. This early work dealt with catalyst preparation and catalyst properties since the catalyst proved to influence the course of the synthesis reaction very significantly. Further development of the process led to the Arge process which used a pelleted cobalt-based catalyst held in tubes. The Arge synthesis is used at SASOL to produce relatively small quantities of lubricating oils and waxes composed of paraffins, products also produced by this route in Germany during the war. A second development of the Fischer-Tropsch chemistry was completed by Pullman Kellogg in its laboratories some thirty years ago. This development, known as the Synthol process, uses an iron catalyst in powdered form and circulates the catalyst at high flow rates together with the synthesis gas through the reactor. Improved process and temperature control provided by the Synthol catalyst and reactor design permits better control of product characteristics and the Synthol process has been used at SASOL to produce most of the product output, which is largely motor gasoline. The SASOL plant is now being expanded very substantially after some twenty years of operating both the Arge and Synthol syntheses. It has been reported that the Synthol process will be used exclusively in the planned expansion.

### 2. Synthol Product Characteristics

The Synthol process was developed to produce motor gasoline which is the major Synthol product at SASOL. This motor gasoline is quite high in olefins which account for 60–70% of the material in the gasoline. The olefins are desired for motor gasoline because they provide a much better octane rating than is provided by paraffins made in the Arge process. In addition to gasoline, the Synthol process produces a spectrum of other products ranging from methane (which can be sold as substitute natural gas) through light olefins (basic petrochemicals), light paraffins (petrochemical feedstock or LPG), naphtha or motor gasoline, diesel fuel and some wax. In addition to these hydrocarbons, Synthol produces oxygenated straight chain organic chemicals such as aldehydes, alcohols, ketones and acids. Thus, the Synthol process produces a variety of byproducts along with its major gasoline product. The same is true of the Arge synthesis.

But the product distribution of the SASOL operation does not contain any aviation jet fuel and, as a result, the two decades of commercial coal liquefaction experience at SASOL cannot be used directly to evaluate the gasification-synthesis approach for converting coal to aviation jet fuel.

### 3. Aviation Jet Fuel Characteristics

There are several important differences between SASOL or Synthol gasoline and aviation jet fuel. First, the hydrocarbon molecules of aviation jet fuel are larger, containing more carbon atoms. Gasoline, for instance, contains hydrocarbons ranging from butane (four carbons) to dodecane (twelve carbons) while aviation jet fuel contains hydrocarbons up to at least hexadecane (sixteen carbons). As a result, jet fuel has the advantage of a higher flash point and is, therefore, less subject to fire from accidental sources of ignition during use or storage.

The hydrocarbons of Synthol gasoline are largely olefins and thus provide the necessary octane rating to prevent engine knock in automotive internal combustion engines. This advantage of olefins, however, is accompanied by the disadvantage of relative instability to gum formation at the higher temperatures prevailing in the fuel systems of jet engines. As a result, an olefin specification of less than 1% has been set for aviation jet fuel. It may be noted that this specification has been set for olefin content of petroleum materials that contain olefins produced by cracking reactions. These reactions produce small quantities of diolefins which form gums very much more readily than do olefins and the low olefin specification may reflect the unwanted characteristics of accompanying diolefins more than the inherent instability of olefins themselves. The Synthol olefins are free of diolefins and may, therefore, be much more acceptable than the more familiar, but contaminated, olefins produced by cracking petroleum. Since Synthol olefins have not been considered or used for aviation jet fuel there is no information on their performance in jet engines and it appears best, at this time, to accept the 1% limitation on olefins even though this may, in fact, be unnecessary.

Olefins can be hydrogenated to paraffins in order to meet the olefin specification for jet fuel stability but this increases the freezing point of the hydrocarbon. It becomes necessary, therefore, to consider what further processing of the Synthol product, after its hydrogenation may be needed in order to meet aviation jet fuel freezing point specifications.

## 4. Modifications of the Synthol Process

A number of modifications of the SASOL-Synthol operations are necessary in order to meet the three requirements of aviation jet fuel, namely (1) larger or heavier hydrocarbons containing more carbon atoms in the molecule (2) very low olefin content to provide stability against gum formation and (3) satisfactorily low freezing point.

The extensive research and development program on the Synthol process carried out in the laboratories of Pullman Kellogg some thirty years ago prior to the SASOL project has shown that the size of the hydrocarbon molecules produced can be varied over a wide range by changing the catalyst composition and the reaction conditions imposed on the synthesis reaction producing the hydrocarbons. The following tabulation illustrates this by showing how the distribution between gasoline molecules and heavier molecules, including jet fuel molecules, varied in one set of tests.

TEST CONDITION

| Percent | A | B | C | D |
|---|---|---|---|---|
| Gasoline in product | 94.4 | 88.4 | 84.4 | 70.6 |
| Heavier than gasoline | 5.6 | 11.6 | 15.6 | 29.4 |

These results, all obtained on one of the many catalysts studied, show that conditions selected for the reaction can effect a very substantial change in product distribution, increasing the portion of product containing jet fuel from 5.6% to better than 29.4% of the hydrocarbons produced. Furthermore, modest changes in catalyst formulation also provide substantial additional changes in hydrocarbon molecular weight distribution further increasing the ability to maximize aviation jet fuel production. Review of these factors has led to the conclusion that the Synthol process can be modified to yield a hydrocarbon mixture having the following distribution of naphtha (essentially motor gasoline), aviation jet fuel and the still heavier fuel oil.

| | *Percent (by volume)* |
|---|---|
| Naphtha | 27 |
| Aviation jet fuel | 50 |
| Fuel oil | 23 |
| Total | 100 |

From this liquid product distribution and the demonstrated variation of other products as the liquid product yield varied, an overall product composition expected for aviation jet fuel production was estimated and is shown in Table 1 in Section 6 of this report. The variety of co-products is illustrated in this table.

It may be noted that this desired distribution of hydrocarbons was not produced in any test operation in the Synthol development program. The objective of that program was to maximize motor gasoline and the research, therefore, concentrated on this objective. Variations in test conditions did, however, show that jet fuel components can be increased substantially relative to gasoline, and the knowledge of Synthol reactions provided in the development program makes it possible to conclude with confidence that the proposed jet fuel operation can be achieved successfully.

Should the decision be made to proceed with a project to make jet fuel from coal it will be necessary to confirm the proposed product distribution. A relatively short development program should be sufficient, however, to provide the necessary confirmation of the projected product distribution.

Such a program will require a minimum level of effort if the hydrocarbon type of molecules produced is the same as the SASOL material and only the size of the molecules is increased. Under these conditions the product in the aviation jet fuel range of molecular weights will contain some 60% to 70% olefins. As already pointed out, this is unsatisfactory for aviation jet fuel because of relative instability of olefins with respect to gum formation. Reference to the Standard Specifications for Aviation Turbine Fuels (ASTM Designation: D 1655–73) shows that olefins in aircraft turbine fuels should be limited to about 1 percent or less. It is, therefore, necessary to hydrogenate the raw jet fuel from the modified Synthol process to convert the olefins to paraffins. This hydrogenation requires hydrogen which, fortunately, can be made from co-product methane produced in the Synthol reactor. Conversion of methane by reaction with steam in a conventional reformer furnace to a hydrogen-rich gas which can then be refined to essentially pure hydrogen is a well-known, thoroughly-demonstrated industrial operation. Furthermore only a modest portion of Synthol-produced methane is needed to generate the necessary hydrogen so that it is not necessary to import hydrogen into the proposed plant. In addition the hydrogen manufacturing process, itself, and the Synthol olefin hydrogenation process, also a well-known industrial operation, require very little additional capital and impose very little economic burden on the conversion of coal to aviation jet fuel. Consequently the facilities proposed for evaluating production of jet fuel from coal include a hydrogen manufacturing plant and an olefin hydrogenation plant and all the necessary support facilities making use of plant-produced methane as the source of hydrogen. No experimental test or demonstration program is considered to be necessary for these two units.

When Synthol olefins are hydrogenated the paraffins produced will easily pass the gum stability test specification. The skeletal structure of the paraffins will depend on the structure of the olefins produced in the Synthol reactor and, as a result, the paraffins will be a mixture of normal paraffins and isoparaffins. (In normal paraffins the carbon atoms of the molecule are attached to each other in tandem in a straight line while in isoparaffins one or more of the carbons are attached to the remaining straight-chain carbons as branches off the straight line). The normal paraffins in the jet fuel range have boiling points some 70°F above the freezing point of —58°F specified for aviation jet fuel in ASTM D 1655–73. The isoparaffins have freezing points, fortunately, that are up to 100°F below the freezing points of normal paraffins. Thus isoparaffins will easily meet the freezing point specification. The actual jet fuel material will be a blend of normal and isoparaffins reflecting the comparable olefin type distribution in the untreated Synthol jet fuel fraction. The actual concentration of the two types for the jet fuel materials to be produced by the modified Synthol process is not known in full detail. Consequently it appears prudent for the current technical and economic evaluation study to include the process step of isomerization of the Synthol jet juel material after hydrogenation. This should ensure the presence of sufficient branch chain isomers to permit the jet fuel to meet the freezing point specification.

Isomerization of normal paraffins has been practiced commercially for almost four decades. The hydrocarbons isomerized commercially have ranged from four to six carbon atoms per molecule and thus are lower in molecular weight than the jet fuel material which ranges from eleven to sixteen carbon atoms per molecule. Though no commercial demonstration is available for isomerizing the jet fuel range of normal paraffin hydrocarbons (there has been no commercial need for such a reaction when dealing with petroleum-derived materials), the reaction is a relatively simple one. It seems probable that a suitable isomerization process can be demonstrated easily starting with the established isomerization technology on lighter hydrocarbons and can then be used to meet freezing point specifications.

A further approach is available to meet the freezing point specification. This reaction is polymerization and has also been demonstrated commercially for many years. In this approach the lighter portion of the gasoline-range naphtha can be separated out and can then be polymerized into the heavier jet fuel range of hydrocarbons. In this case the two smaller straight chain olefins combine to make larger branch-chain olefins. When these compounds are hydrogenated, branch-chain paraffins are produced of much lower freezing point than the straight chain equivalents formed directly in the Synthol reactor. This route is also available to meet the low freezing point specification. In addition, this incremental process step can transfer some 1,300 barrels per day of hydrocarbons from naphtha to aviation jet fuel, increasing the jet fuel production from 9,381 to about 10,600 barrels per day.

In addition, incorporation of selected aromatics into the hydrogenated and isomerized jet fuel is available to lower the freezing point still further. Thus, the ASTM specification permits 20% aromatic content by volume in aviation jet fuel. Substituted benzenes except for the xylenes have low freezing points and these materials will be available in the benzene-toluene-xylene fraction (BTX) that will be distilled from coal along with tar in the upper part of the slagging Lurgi gasifiers used in the process sequence adopted for this study. It is a simple operation to recover low freezing point aromatics by simple fractional distillation from the BTX and use these to depress further the freezing point of the jet fuel product. This would also provide some increase in jet fuel output. From the aromatics condensed out of the coal gasification unit an additional 400 barrels per day could be blended into the aviation jet fuel which would then be produced at the rate of 11,000 barrels per day.

It is clear that a number of alternate process steps are available to decrease the freezing point of the hydrogenated jet fuel material produced by the Synthol process. These alternates include isomerization, addition of polymer made from the light naphtha and addition of aromatics. Additional study, probably including some experimentation with actual Synthol fractions will be needed to select the best of the alternates which may turn out to be a combination of these possibilities operating each at a partial level of conversion to obtain best performance.

Still another alternate that is possible and may prove most economic is to use insulation and engine exhaust gases to maintain the aircraft jet fuel tanks at a temperature above the high altitude levels so that the hydrogenated olefins are satisfactory with no further processing. Such a temperature may be about +40°F if no further processing is adopted, but, again, a combination of some insulation and some processing may prove most economic.

Of the several alternates available for meeting all aviation jet fuel specifications, the following combination has been selected for the current evaluation. The olefins from the modified Synthol process will be hydrogenated and then isomerized. Facilities for making hydrogen from part of the fuel as produced in the plant will also be included. This arrangement is felt to provide an evaluation of reasonable, though less than maximum, aviation jet fuel production. As a result a conservative evaluation should result. Furthermore the petroleum industry technology that is to be modified for use in the proposed plant has been developed to a high degree of sophistication and it is reasonable to conclude that the necessary technology adaptations of hydrogenation and isomerization can be developed with a very high degree of probability of success and at modest cost.

## 5. Process Description

The overall plant arrangement required for converting coal to aviation jet fuel and the accompanying co-products is shown in Figure 1, which shows the relationship of the Synthol unit to the many other units that must be operated with the Synthol unit.

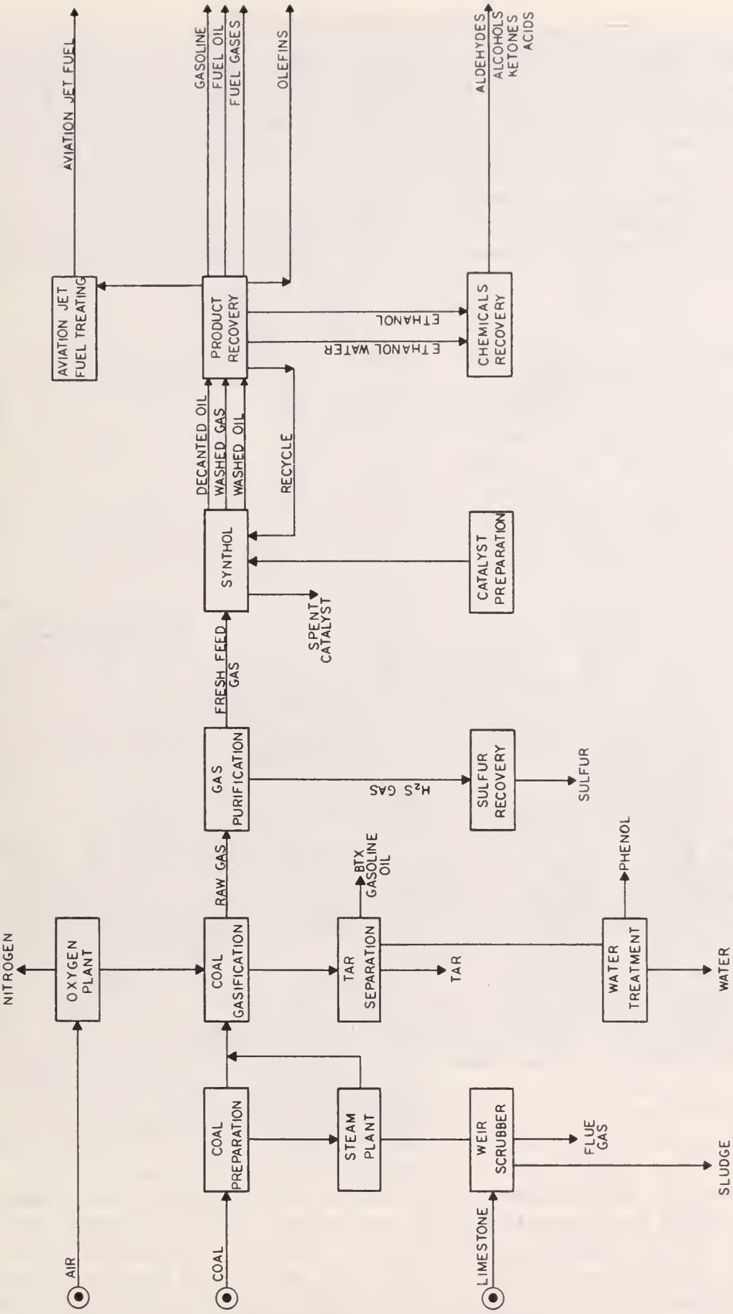

FIGURE 1.—Manufacture of aviation jet fuel by SASOL-Synthol process overall flow diagram.

### (A) COAL PREPARATION

Coal delivered to the plant site goes first to a coal preparation unit where it is crushed and dried to 2 percent moisture content. A portion of the coal is transferred to the steam plant to be used for generating utility steam required in all other operating units of the plant. Flue gases from the steam plant are treated in a Weir Scrubber which removes sulfur oxides to permit compliance with air quality standards and also removes fly ash that has escaped the precipitators. Limestone is fed to the Weir Scrubber and sludge is discharged for disposal.

### (B) COAL GASIFICATION

The major portion of the crushed, dried coal is transferred to the Coal Gasification Unit where it reacts with oxygen generated in an Air Separation Unit and steam generated in the steam plant. Lurgi gasifiers have been used in the proposed plant for this study, but operation with ash slagging has been postulated. In contrast, the Lurgi gasifiers (See Figure 2 for example.) used at SASOL operated at lower temperatures and discharged a granular ash. Slagging operation is being successfully demonstrated in a Lurgi gasifier that had been used commercially at Westfield, Scotland before its dedication to this development program. This program is sponsored by a group of American Companies and is being conducted by the British Gas Corporation with some participation by Lurgi. The more modern slagging operation was selected for this study because it offers economics in both capital investment, operating costs and the necessary environmental control facilities in comparison with the Lurgi gasifiers discharging a granular ash as installed at SASOL for operation in 1952. The selection has been made on the premise that slagging operation will be fully demonstrated by the time that plans for a coal-based aviation jet fuel plant can be completed. This seems reasonable in view of the fact that two runs of 1-week duration have already been successfully completed and a longer run is in the final stages of preparation. Ash slag flows from the bottom of the reactor to be quenched in water. The resulting slurry of ash is then transferred to disposal. Raw synthesis gas produced by the gasifiers leaves the top of the gasifier after countercurrent contact with the feed coal which is charged to the top of the gasifier and flows downward. This contact reduces the temperature of the gas from temperatures approaching 2000°F where gasification is occurring to about 1000°F at the top gas outlet.

The raw gas is composed primarily of carbon monoxide and hydrogen along with some methane and carbon dioxide from gasification, but to these components are added distillation products from coal generated by distillation of the coal before it reaches the gasification zone. These components include aromatics such as benzene, toluene, xylene (BTX), gasoline, heavier oils and tar. In addition the gas contains unconverted steam as well as sulfur and nitrogen contaminants. This gas requires important purification and adjustment before it can be used as a satisfactory synthesis gas in the Synthol reactor. (See for example, Figure 3, page 16.)

FIGURE 2.—Lurgi coal gasification building—Steam generation in background.

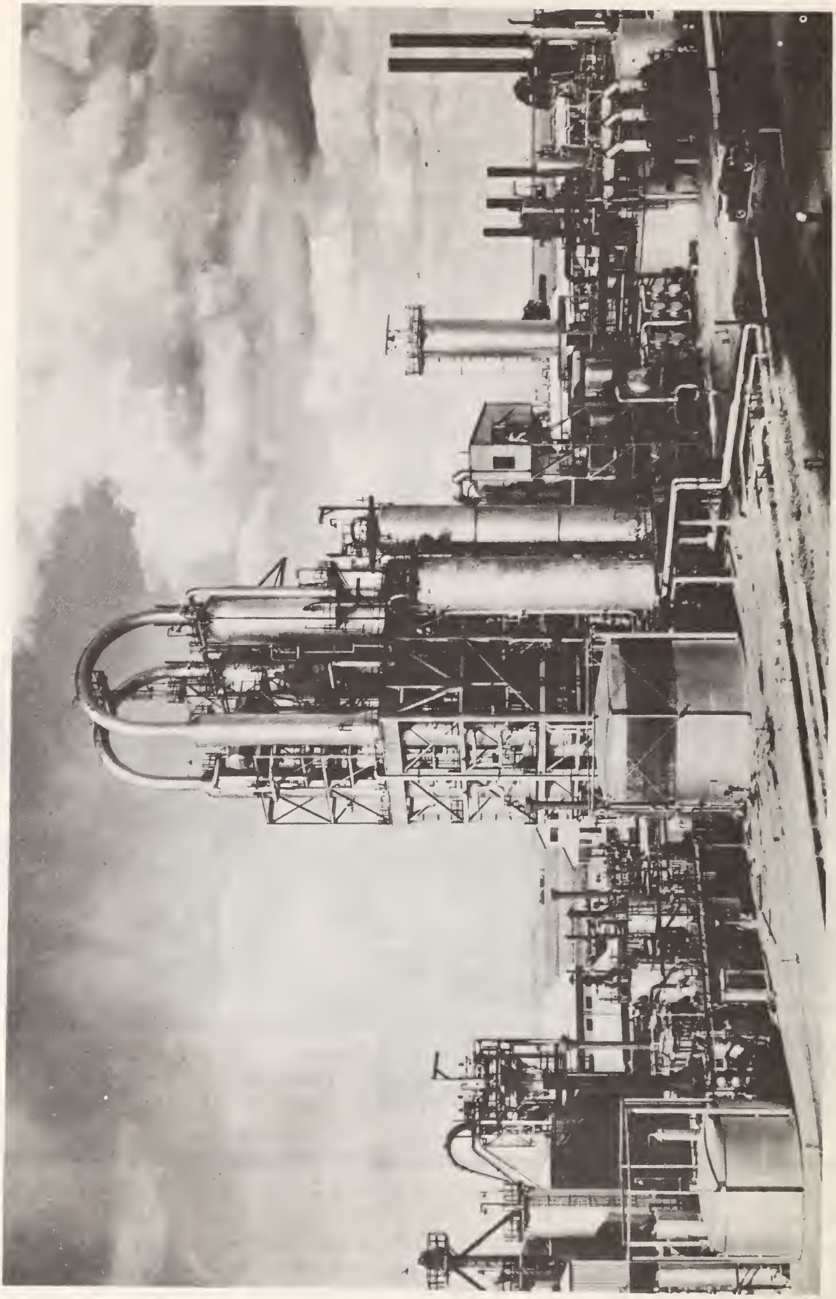

FIGURE 3.—Synthol reactors of SASOL plant.

### (C) GAS PURIFICATION

The first step in gas purification is cooling including recovery of some of the heat content in a waste heat boiler which supplements the coal-fired steam generator. Tar is condensed out of the gas on cooling and is used as additional fuel in the steam plant and then the lighter hydrocarbons, which are highly aromatic, are separated out and sent to the Product Recovery section of the plant. In addition a phenolic, oily water is condensed from the gas during cooling and this water stream flows to a solvent extraction plant where phenol is extracted from the water for sale. The extracted water then enters a secondary treatment plant where it is further purified so as to meet effluent control standards before being discharged from the plant.

Gas leaving the cooling section of the Gasification Unit then flows to the Gas Purification Unit where it first undergoes water gas shift reaction. Here the carbon monoxide content of the gas is reacted with steam to generate hydrogen and carbon dioxide. The purpose of this operation is to raise the ratio of hydrogen to carbon monoxide in the subsequent synthesis gas to permit effective use of the synthesis gas in chemical conversion to liquid products. Following water gas shift, the gas flows to a Rectisol unit where sulfur and nitrogen compounds, final traces of gum-forming compounds and excess carbon dioxide are removed. Purification in the Rectisol unit is provided by counter-current washing of the contaminated gas with a refrigerated, regenerated methanol stream. (See for example Figure 4.) The recovered sulfur compounds, mostly hydrogen sulfide, are converted to sulfur in a Claus unit.

### (D) PRODUCT SYNTHESIS

Gas leaving the Rectisol unit now contains hydrogen and carbon monoxide in the right ratio together with some methane, carbon dioxide and nitrogen. This highly purified synthesis gas is now ready for reaction in the Synthol unit and is fed to the suction of the synthesis converter recirculating blower, where it is combined with the washed gas leaving the converter system. The combined gas streams are preheated in a heater exchanger by the oil slurry circulated over the product scrubber and enter the bottom part of a Kellogg converter. The high velocity gas stream entrains the desired amount of iron catalyst fed to it through a slide valve. The gas carrying the suspended particles flows upward through the reactor body. The reactor body is provided with heat exchanger coils through which cooling oil is circulated maintaining a temperature of about 600°F in the reactor space. Hot oil is cooled in a waste heat boiler where it generates 450 p.s.i.g. steam which is used to drive the main power consumers in the Synthol plant and also provides heating steam for reboilers in the product recovery section.

Reacted gases carrying the catalyst leave at the top of the converter and enter the catalyst settling hopper in which the bulk of the catalyst is removed from the reaction gases. The gases then pass through a system of cyclones in which most of the fine particles remaining in the gases are knocked out. The combined streams of the catalyst fall by gravity into a vertical leg from which they are reintroduced into the gas stream entering the converter through the slide valve mentioned above. Fresh catalyst is introduced into the bottom part of the stand pipe and used catalyst removed from its upper part.

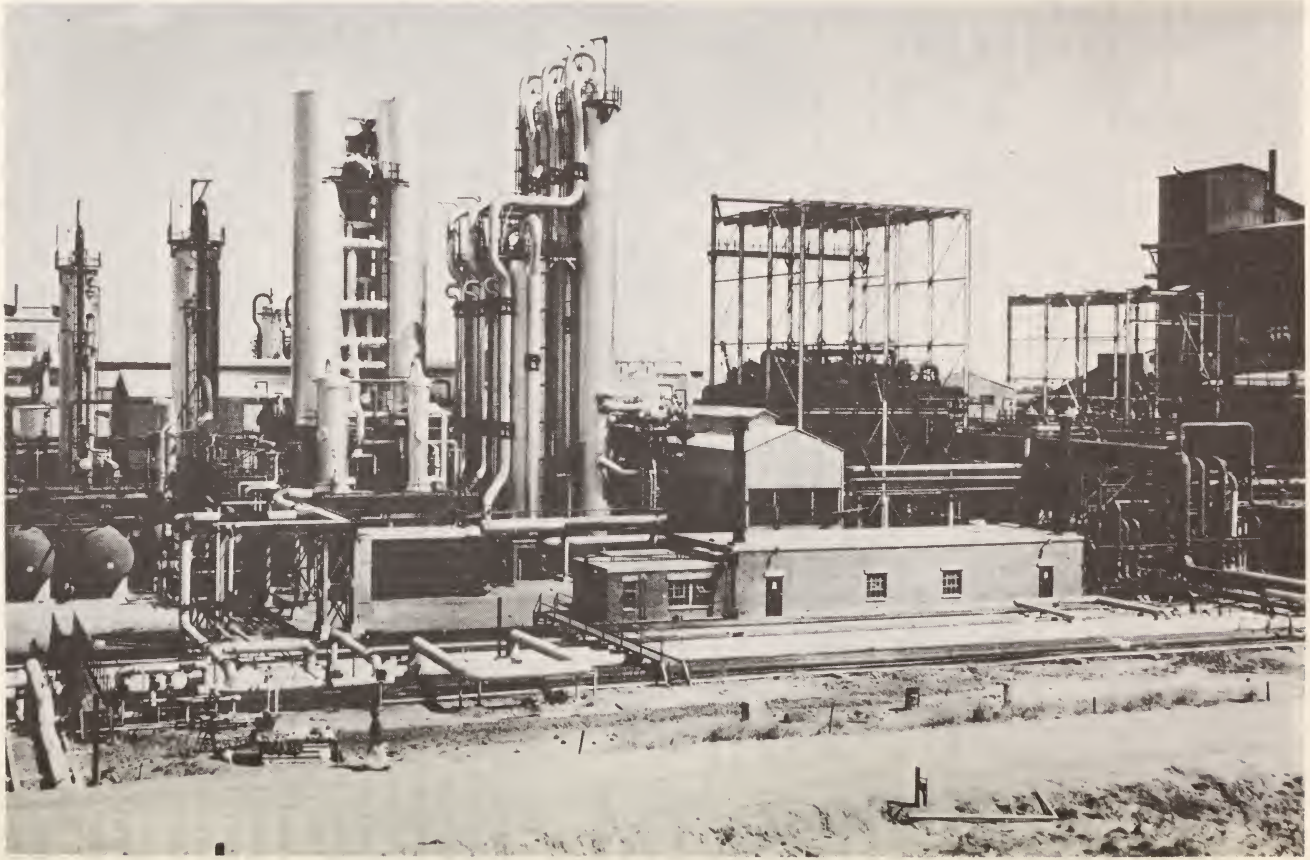

FIGURE 4.—Rectisol gas purification unit.

The gases leaving the cyclones enter a scrubber in which they are washed by recirculating oil. The temperature in the scrubber is controlled so that the gases leaving the top of the scrubber would contain all of the desired products. The sensible heat removed from the hot gases by the recirculating oil is used to preheat the reactor feed gas and boiler feed water entering the waste heat boiler. Catalyst fines collected in the oil are returned to the reactor body as a suspension in oil. Heavy oil collected in the lower part of the scrubber is taken to the vacuum flash tower in the recovery section. Hot gases leaving the top of the tower are cooled first in a Boiler Feed Water heater, and finally to 100°F in a condenser. Condensate and cooled gases enter the wash tower in which the liquid products are separated from the gas stream.

Liquid products from the wash tower are taken to the oil wash tower where synthesis products soluble in water are washed out of the oil by a counter-current stream of process water. Washed oil from this tower flows to the oil treaters in the recovery section. Wash water from the oil wash tower is combined with wash water from the wash tower and is taken to the recovery section for separation of soluble chemicals. These chemicals are mainly lower alcohols, aldehydes, ketones, and acetic and propionic acids. Washed gas from the top of the wash tower is separated into two streams: recycle and product.

The recycle stream passes through a mist entrainment separator drum, is combined with the fresh feed gas, as mentioned above, and returned by the recycle compressor to the bottom of the synthesis converter. The product gas stream passes through another mist separator drum for removal of droplets and enters a scrubbing system in which $CO_2$ is removed from the gases which are then taken to the product recovery section.

### (E) PRODUCT RECOVERY

The product gas leaving the $CO_2$ removal system is compressed to about 600 psig, last traces of $CO_2$ removed by scrubbing with a sodium hydroxide solution, water is removed in gas driers and the dried gas is chilled in a multistep chilling system to about −200°F. At the lowest temperature, light gases are flashed off, and then stepwise, methane, and mixtures of ethylene-ethane, propylene-propane, butylene-butane are flashed off, and finally the liquid containing pentanes and higher hydrocarbons is directed towards the fractionator. Liquids separated in the first chilling steps are passed over a liquid drier to the methane removal step. In the fractionator, gasoline, the aviation jet fuel fraction and fuel oil products are separated. Washed light oil from the synthesis section is combined with the overhead from the vacuum flash tower, is vaporized and passed over silica-alumina catalyst to raise the octane number of the gasoline components; some cracking of the oil takes place, and olefins are produced. Effluent from this treatment is cooled and condensed and the liquid introduced into the main fractionator column. Bottoms from the fractionator are combined with the heavy oil separated from the product gases in the scrubber, and introduced into the Vacuum Flash Tower. Overhead from this tower is taken to the silica-alumina catalyst reactor, as mentioned above, the bottoms are the fuel oil product.

### (F) CHEMICALS RECOVERY

The combined wash water streams are taken to the Primary Distillation Tower; alcohols, ketones and aldehydes are distilled overhead, and separated into desired individual products in distillation towers. Main product is ethanol; propanol, butanol, higher alcohols, acetones, acetaldehyde and methyl-ethyl ketone are also produced. Bottoms stream of the distillation tower is mixed with ethyl acetate in a system of extractors. Acids dissolve in ethyl acetate, the solution is separated from water, ethyl acetate recovered and organic acids separated by distillation. Main product is acetic acid; some propionic acid and higher homologs are also formed.

### (G) AVIATION JET FUEL TREATING

The aviation jet fuel fraction produced in the Synthol reactor is transferred to a final treating section to produce specification grade product. Here the material is treated with hydrogen in a hydrotreater unit over a cobalt-molybdenum catalyst to reduce olefins to less than 1%. Hydrogen for this purpose is generated in this section of the plant from natural gas using the known combination of steam reforming, water gas shift, carbon dioxide removal and methanation. Methane for this purpose is available from the Product Recovery section of the plant. The hydrogenated stream is finally isomerized to produce isoparaffins that will permit freezing point requirements to be met.

### (H) CATALYST PREPARATION

The catalyst used in the Kellogg Synthol Process is basically pure metallic iron. Because its life is short (about 60 days) and large amounts are needed, catalyst preparation is considered as part of the overall plant. Mill scale or magnetic ore are fused in an electric fusion furnace at 3000°F, activators added, and fused product is quenched in water, ground, and reduced to metallic iron by a stream of pure hydrogen prepared in the plant. The catalyst is pyrophoric and must be kept under an inert or reducing atmosphere.

## 6. Plant Design and Estimate for Evaluation of Economics

A preliminary plant design was selected, using the sequence of operations described in the preceding section, to serve as a basis for economic evaluation of aviation jet fuel produced from coal. This plant will require a coal supply of 17,100 tons per day of a coal having an ash and moisture content of 10.2% and 10% respectively and a heating value of 11,030 Btu per pound when dried tc 1% water content. These coal characteristics are readily available at the location of the plant design used in this study.

The net production of materials, after allowing for all internal consumption within the plant, including the hydrogen, hydrogenation and isomerization units, is shown in Table 1. The oxygenated chemicals produced in the plant are shown in Table 2 along with the revenues that can be generated by the chemicals when sold at typical market prices.

The investment in the completely erected plant ready for operation has been estimated to be $780,000,000 in current dollars. This investment includes all the process units needed to prepare coal, gasify it, purify the gas, synthesize the products and, finally, recover the products for sale. In addition, all offsites including all utilities generation, effluent control facilities, plant utility distribution systems, maintenance facilities and product storage and handling are included in the estimated cost of the plant, Thus all costs necessary to operate the plant on run-of-mine purchased coal have been included.

The overall plant, containing fourteen individual units as shown on the block flow diagram of Figure 1, requires a substantial amount of processing to upgrade coal to the clean fuels and chemicals that are produced. Each step is designed with due attention to energy conservation and the overall energy efficiency is 64%. That is, the heating value of all the products is 64% of the heating value of all the coal fed to the plant.

The plant design selected for this study required a water supply of some 30,000 gallons per minute or about 40,000 acre feet per year. This water is used for process cooling since water was readily available. In other areas where water may be less available, air cooling can be used for process purposes and the water requirement can readily be brought down to about 5,000 gallons per minute or 7,000 acre feet per year.

TABLE 1.—*Products from SASOL-Synthol plant modified for aviation jet fuel production*

| | *Pounds per hour* |
|---|---|
| Fuel gas (6,450,000,000 Btu per day) | 14, 335 |
| Substitute natural gas (4,130,000,000 Btu per day) | 8, 835 |
| Ethylene | 10, 034 |
| Liquefied petroleum gas (6,950,000,000 Btu per day) | 14, 335 |
| Propylene | 34, 045 |
| Butylene-Butane | 17, 560 |
| Gasoline (5054 BPD) | 53, 039 |
| A–1 aviation jet fuel (9,381 BPD) | 109, 662 |
| Fuel oil (4350 BPD) | 55, 548 |
| Oxygenated chemicals | 50, 172 |
| Sulfur | 48, 738 |
| Benzene, toluene, xylene, gasoline, oil (18,200,000,000 Btu per day) | 37, 987 |
| Total | 454, 290 |

TABLE 2.—PRODUCTION OF OXYGENATED CHEMICALS FROM SASOL-SYNTHOL PLANT MODIFIED FOR AVIATION JET FUEL PRODUCTION

| | Pounds per hour | Annual income |
|---|---|---|
| Acetaldehyde | 810 | $960, 000 |
| Methanol | 216 | 256, 000 |
| Acetone | 2, 500 | 2, 760, 000 |
| Methylethyl ketone | 925 | 1, 310, 000 |
| Ethanol | 27, 500 | 18, 400, 000 |
| Propanol | 6, 060 | 11, 000, 000 |
| Isobutanol | 844 | 1, 400, 000 |
| Normal butanol | 2, 030 | 2, 720, 000 |
| Heavy alcohols | 2, 950 | 6, 970, 000 |
| Acetic acid | 4, 570 | 5, 950, 000 |
| Propionic acid | 1, 040 | 1, 470, 000 |
| Higher acids | 720 | 1, 700, 000 |
| Total | 50, 172 | 54, 896, 000 |

## 7. ECONOMICS FOR AVIATION JET FUEL PRODUCTION

Economic factors in the operation of the selected plant are summarized in Table 3, which lists all operating costs, including return on investment, and balances these costs against revenues to be earned from all the co-products made in the operation.

A coal cost of $5.00 per ton has been used in the economic evaluation of the plant set up for aviation jet fuel production. This is a lower price than the average price of $15.46 per ton, including delivery charges, paid by the electric utility industry or the average price of $15.75 per ton, f.o.b. mines, paid by all users of coal in the United States in 1974. The $5.00 price is judged, however, to be more reasonable because of the following considerations. It is highly unlikely that the very large investment in the coal conversion processing plant will ever be made without a very strong assurance that dependable, uninterrupted supply of coal at an acceptable price is available through the life of the plant. Such assured supply essentially mandates the commitment of a mine of sufficient size to serve this coal conversion plant and no other customers so that unforeseen and uncontrollable market factors do not interfere with continued, dependable supply of coal. As a matter of interest, the three proposed coal gasification plants designed to produce pipeline quality substitute natural gas (SNG) commercially have all been set up with an adjacent coal mine dedicated fully to the individual SNG plant. Applications to the Federal Power Commission in connection with these three plants have detailed the cost to the plant of coal produced by the dedicated mine. The most recent of these applications, made early in 1974, details all mining costs including taxes, royalties and capital return, and reports a total cost of coal delivered to the process plant of $4.25 per ton. The mine capacity for the SNG plant is about the same as for the aviation jet fuel plant and the cost of coal to the two plants should, therefore, be comparable. Allowing about 20% escalation since the SNG coal cost figure, it is concluded that $5.00 per ton is a reasonable cost for coal to the liquefaction plant. In this connection, it may be of interest to note that a recent report by the Council on Wage and Price Stability concluded that surface-mined coal should be rather stable in price and should be available at $5.00 to $6.00 per ton f.o.b. mine for the next decade, regardless of how much coal demand should increase in this period.

In any event, coal cost will depend on mine location and mine characteristics and a definitive coal cost can only be determined for a specific site at the time of operation. Until such factors have been determined it does appear that $5.00 per ton is a satisfactory figure for economic evaluation of the proposed operation. Furthermore, the cost of coal is not a major item in the estimated cost of jet fuel. The effect of coal cost on jet fuel price is shown later to be a modest one.

Finally, coal consumption by the proposed plant is equivalent to that of a conventional electric utility generating 1700 megawatts.

The cost of catalyst and chemicals consumed in the plant as well as the labor required have been estimated by itemizing and adding individual requirements for each of the dozen odd units in the overall plant. Overhead and maintenance and local taxes and insurance costs are judged to be typical values. Capital return is based on 15 percent discounted cash flow (DCF) return of all investments less salvage value after the life for the plant assumed to be 20 years. Total investment used in the calculations included working capital and interest over the three-year period assumed for construction of the plant.

The figures in Table 3 show clearly that capital return and Federal income tax are the most important cost items, the two together accounting for almost 76 percent of total operating costs.

Distribution of costs among the eight major products listed in Table 3 may, of course, be made in a number of ways. The specific method used in Table 3 used the following bases. First, the olefins were assumed to be sold at typical values of 12 cents, 10 cents and 6.2 cents per pound, respectively, for the ethylene, the propylene and the butylene-butane mixture. The oxygenated chemicals were assumed to bring in the revenues shown in Table 2 while sulfur was set at a value of $40 per long ton and the BTX, gasoline and oil were taken at 8 cents per pound. The remaining revenues needed were derived from the individual liquid and gaseous fuel streams assuming each fuel to be sold at the same value per unit of heating value.

On this basis the three liquid fuel streams would have to be sold at the following prices.

| | *Cents per gallon* |
|---|---|
| Aviation jet fuel | 76 |
| Motor gasoline | 69 |
| Fuel oil | 85 |

The price of 76 cents per gallon for aviation jet fuel may be compared with spot prices for refined petroleum products in intrastate commerce as published weekly by the Oil and Gas Journal. For kerosene, which is largely used for aviation jet fuel, these spot prices have been ranging recently from about 30 cents to 34 cents per gallon. Thus the modified SASOL-Synthol operation bears a very heavy burden if it must earn a capital return characteristic of industrial operations.

If the plant were to be operated at 10 percent DCF rate of return, the aviation jet fuel price at the plant would drop to 44 cents per gallon but if 20% DCF were needed, the jet fuel price would become $1.15 per gallon. These figures simply emphasize the sensitivity of jet fuel price to the rate of return because of the extremely high capital intensity of this coal-based operation. Even at 10 percent DCF rate of return, which seems low for the very large risks involved, the price of aviation jet fuel is too high to justify commercial investment and operation of the proposed coal conversion facility.

TABLE 3.—OPERATING COSTS AND REVENUES SASOL-SYNTHOL PLANT MODIFIED FOR AVIATION JET FUEL PRODUCTION: PLANT INVESTMENT, $783,000,000; PLANT OUTPUT PER TABLES 1 AND 2

| | Amount (millions per year) | Percent |
|---|---|---|
| Operating costs: | | |
| Coal at $5 per ton | $30.19 | 8.7 |
| Catalyst and chemicals | 3.04 | .9 |
| Operating labor | 3.45 | 1.0 |
| Overhead | 4.0 | 1.2 |
| Maintenance at 4 percent | 31.3 | 9.1 |
| Local taxes and insurance at 1½ percent | 11.7 | 3.4 |
| Income tax (48 percent) | 107.0 | 30.9 |
| Capital return (15 percent DCF) | 155.0 | 44.8 |
| Revenues needed | 346.0 | 100.0 |
| Revenues: | | |
| Aviation jet fuel at 76 cents per gallon | 99.0 | 28.6 |
| Motor Gasoline at 69 cents per gallon | 48.4 | 14.0 |
| Fuel Oil at 85 cents per gallon | 51.1 | 14.8 |
| Olefins | 29.4 | 8.5 |
| Fuel gases | 32.5 | 9.4 |
| Oxygenated chemicals | 54.9 | 15.8 |
| Sulfur | 6.9 | 2.0 |
| BTX, gasoline and oil | 24.0 | 6.9 |
| Total | 346.0 | 100.0 |

If the price of coal delivered to the SASOL-Synthol plant were to rise from $5 per ton to $10 per ton, which does not appear to be expected, the effect of this would be to increase jet fuel price from 76 cents per gallon to 86 cents per gallon at a 15 percent DCF rate of return. Thus a doubling of coal price would have a much smaller effect (10 cents per gallon) on jet fuel price than an increase to 20 percent DCF rate of return which would lead to a jet fuel price increment of 39 cents per gallon. Jet fuel cost is much more sensitive to financial factors than it is to coal price because of the very high capital intensity of the operation and, also, the relatively good thermal efficiency.

The proposed operation can, however, make jet fuel as well as other important fuels and chemicals from domestic coal. Such an operation can minimize disruption to domestic aviation, both military and civilian, that could result from future oil embargoes particularly as imported oil grows in its share of the domestic market. Should this factor be considered important enough for the national security, it becomes of interest to examine the cost relationships if the plant investment is treated as an item of national defense and no capital return is judged necessary. The total annual operating costs drop to $84 million dollars per year and income from the petrochemicals will be $114 million dollars per year. This assumes no income from the aviation jet fuel, motor gasoline, fuel oil and fuel gases. Thus a Government-built plant could be operated under contract permitting supply of fuels to the Government at no cost and leaving a potential income to the operator of some $30 million per year for purchasing coal under contract, operating the complex plant and marketing the wide spectrum of chemicals. This interesting possibility is but one of many and again illustrates the effect of the high capital intensity of the process.

The production of the plant is about 9,400 barrels per day of jet fuel which is about 2 percent of the military jet fuel used in the United States. If 20 percent of the military fuel were to be supplied it would be necessary to build ten of the proposed plants for a total plant investment of about $8 billion dollars.

Should ten such plants be built, the quantity of co-products to be produced and sold are listed in Table 4 and compared with recent figures on national production of these materials. It may be seen that the national markets can absorb the co-product output in most cases without undue disruption of commerce in these materials. But in the case of ethyl alcohol, the output of ten plants would equal the total current industrial production. It would be unacceptable to release so much new material into the market and it will be necessary, therefore, to find another outlet. Such an outlet can be the jet fuel itself, into which the ethanol can be blended. This may well be undesirable because of water solubility induced by ethanol. Such water solubility appears unacceptable because it would probably raise the freezing point above the −58°F specification. If, however, the ethyl alcohol were to be converted to esters or ethers, this advantage would be overcome. Such a solution, however, would lower the heating value of the jet fuel because of the oxygen content and would decrease the aircraft range for a given weight of fuel. Another, and possibly better, solution would be blending of ethanol into the fuel oil where it should make a boiler fuel of superior quality because of its freedom from sulfur content. Protection of such fuel against water freezing problems should be relatively simple in boiler fuel applications. Still another option is available. Ethanol can be converted to motor gasoline using a recently-announced process now under development. This gasoline could be absorbed by the motor fuel market quite easily.

TABLE 4.—MODIFIED SASOL-SYNTHOL PLANT; OUTPUT OF COPRODUCT CHEMICALS

| | Output, millions of pounds per year | | National capacity |
|---|---|---|---|
| | 1 plant | 10 plants | (Millions of pounds per year) |
| Ethylene | 79.1 | 791 | 23,500 |
| Propylene | 342.0 | 3,420 | 9,821 |
| Butylene-butanes | 138.0 | 1,380 | -------- |
| Acetaldehyde | 6.4 | 64 | 1,500 |
| Methanol | 1.7 | 17 | 6,660 |
| Acetone | 19.7 | 197 | 2,015 |
| Methylethyl ketone | 7.3 | 73 | 5,056 |
| Ethanol | 216.0 | 2,160 | 2,120 |
| Propanol | 47.8 | 478 | -------- |
| Isobutanol | 6.6 | 66 | 115 |
| Normal butanol | 16.0 | 160 | 551 |
| Heavy alcohols | 23.2 | 232 | -------- |
| Acetic acid | 36.0 | 360 | 2,265 |
| Propionic acid | 8.2 | 82 | 60 |
| Higher acids | 5.7 | 57 | -------- |
| Sulfur | 384.0 | 3,840 | 23,600 |
| Benzene, toluene, and xylene | 294.0 | 2,990 | 24,290 |

In short, disposal of the chemicals should be no impediment for operation of a single plant and, indeed, may provide an attractive incentive for contract operation of a Government-owned facility. But for operation of 10 plants to supply some 20% of the Nation's military aviation jet fuel, it will be necessary to consider and select from several alternates for disposal of ethyl alcohol co-product.

If polymerization and aromatics blending were to be used, aviation jet fuel would increase from 9,400 to 11,000 barrels per day and 8 rather than 10 plants would be needed to supply about 20 percent of the military jet fuel. The cost of eight plants would be about $6.5 billion dollars and the problem of disposing of ethanol would be eased somewhat, though not eliminated.

Aviation jet fuel supply can also be insulated from imported oil embargoes even though it is made from domestic petroleum if imported petroleum were to be replaced by fuels from oil shale, tar sands, secondary or tertiary oil recovery, coal liquefaction to made syncrude or coal gasification for high or low Btu gas to replace oil uses. These alternate approaches, in general, have the same characteristics as the proposed jet fuel operation. They require very high capital investments and fuels made by these alternate approaches are also very heavily burdened by capital return requirements characteristic of commercial operations. At the current state of development of these alternate technologies, the uncertainties in capital requirements appear large enough so that it is not truly possible to determine the relative economics of the several approaches. It does appear that the national interest in developing energy independence or energy supply assurance would be best served by constructing and operating demonstration plants of each alternate approach, including the SASOL-Synthol approach. This would provide basic cost data on the economics of the various technologies so that a sound selection of the most economically advantageous processes can be made when the switch to domestic resources must be faced. The cost of such a program is not small, but it can be repaid very rapidly because it will permit selection of the most economic method of using indigenous resources.

## 8. Conclusions

The SASOL plant in South Africa has been producing motor gasoline as primary product along with a large number of co-products. Aviation jet fuel, however, is not one of the co-products and the SASOL operation, therefore, does not provide commercial demonstration of the production of jet fuel from coal.

Aviation jet fuel differs from SASOL gasoline in the following respects. Aviation fuel must have (1) a higher boiling range and the associated higher flash point, (2) less than 1 percent olefins compared to a very olefinic SASOL gasoline and (3) a much lower freezing point specification of −58°F. The Synthol process, which accounts for the bulk of the SASOL production, can be modified to make jet fuel boiling range material as a major product. This conclusion is available from pilot plant data accumulated during development of the Synthol process in the Research Department of Pullman Kellogg. Information from this program has provided a basis for estimating the product slate and properties of the raw jet fuel fraction when operating to make aviation fuel boiling range material. The raw material must then be hydrogenated and isomerized to meet existing ASTM aviation fuel standards for olefins and freezing point.

A commercial-scale plant making jet fuel and associated co-products from coal using the general SASOL approach but modified, as indicated, for aviation product is expected to require a plant investment of $780 million when making 9,400 barrels per day of jet fuel from 17,100 tons per day of coal. This preliminary estimate shows the proposed operation to be very capital intensive. In fact some 76 percent of the total operating costs are associated with capital charges to earn 15 percent on the plant investment on a discounted cash flow basis and to pay income tax on the needed return. As a result of these capital-related factors, aviation jet fuel would have to be sold at 76 cents per gallon and the operation bears a very heavy burden as long as aviation jet fuel from petroleum is available at 30 to 34 cents per gallon.

If production of aviation jet fuel from coal were to be justified on a national security basis it is possible to consider operation of a Government-owned plant on which return on capital investment is not required in contrast to the situation with commercial operation. One option under these circumstances would be to contract out the operation of the plant to a company that could assume the entire operation of the plant, provide the aviation jet fuel to the United States at no cost and perform these services in return for the chemical co-products as its incentive.

This arrangement appears attractive for a single plant of the size selected but such a plant provides only some 2 percent of the national military jet fuel requirement. Should ten such plants be contemplated to meet 20 percent of military aviation fuel needs, the volume of ethanol produced would be so great as to disrupt these markets and remove this incentive, which is a major component of the suggested incentive for the proposed operator. This problem could be handled by further processing the ethanol for blending into aviation fuel or by blending it directly into fuel oil. These options would reduce the income from chemical co-products and would require income from aviation fuel or the other fuels to restore the contract operator's incentive. It is of interest to note, in this connection, that erosion of co-product chemical income to 50 percent of the income in Tables 2 and 3 can be made up by a charge of about 8 cents per gallon for aviation jet fuel, motor gasoline and fuel oil turned back to the Government.

Thus it is concluded that commercial operation of a modified SASOL-Synthol process to make aviation jet fuel from coal is not attractive, but arrangements appear possible to operate such a facility with Government supply of the needed capital for national security considerations.

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