CONVERSION OF COAL TO LIQUIDS BY FISCHER-TROPSCH AND OIL/GAS TECHNOLOGIES

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INTRODUCTION

Conversion of coal to liquid and gaseous fuels as well as chemical products has been practiced on a commercial scale in several areas of the world. Projections of U.S. supply and demand balances for crude oil and natural gas to the year 2,000 indicate that coal conversion plants are a candidate in the U.S. for production of environmentally acceptable liquid and gaseous fuels. To be competitive with alternative energy sources, second generation production complexes for coal conversion should be large, efficient, simple and reliable.

This paper describes the characteristics and projected economics for two candidate second-generation technologies, "Oil/Gas" and a U. S. version of Fischer-Tropsch.

The term "Oil/Gas" was coined during the 1974 Project Independence Blueprint campaign. The process uses a type of coal hydroliquefaction similar to SRC II, with reaction severity designed to produce a significant amount of light hydrocarbons. These are in turn processed to yield substitute natural gas (SNG) as a prime product. Liquid products include LPG, naphtha, and fuel oil.

The suggested U.S. version of Fischer-Tropsch incorporates flame-sprayed catalyst on extended heat-exchanger surfaces yielding several potential advantages including increased thermal efficiency. Flame-sprayed catalyst systems have been under development by what is now the Pittsburgh Energy Research Center (PERC) for about 15 years.

The information presented here is based primarily on conceptual designs and economic evaluations prepared by The Ralph M. Parsons Company for the Major Facilities Project Management Division of Energy Research and Development Administration - Fossil Energy (ERDA-FE).[1,2] The conceptual design given for each process incorporates certain process and equipment items now under development, primarily within ERDA programs. The designs are intended to define the potentials for second generation coal conversion complexes incorporating results of in-progress development work. In concept, these complexes might be constructed and operated in the mid-'80's to mid-'90's.

This paper will describe the processing, projected product characteristics, and projected economics for the Fischer-Tropsch and Oil/Gas complexes. These factors will then be compared, recognizing that each produces significantly different products. In addition, the Oil/Gas design[1] will be extended by hydrotreating fuel oil to produce lower percent sulfur products at increased cost, to further illustrate the flexibility of the technology.

Each of these conceptual designs represents only one of numerous possible configurations. For a given industrial application with a defined coal source and required product mix, the design would in actual practice be tailor-made for that particular case.

OIL/GAS

Design Criteria

Preliminary design criteria have been published.[3] Key elements of the completed conceptual design are:

Plant Location	Eastern region of the U.S. Interior Coal Province, which includes portions of the states of Illinois, Indiana, and Kentucky.
Coal Source	Illinois No. 6 seam coal produced in a captive surface coal mine.
Capacity	Approximately 47,000 tons per day (TPD) of run-of-mine (ROM) coal which is cleaned, washed and sized to produce about 36,000 TPD of coal feed to the process plants. All daily figures are in stream days. Products include about 165 million standard cubic feet per day (MM SCFD) of SNG and approximately 75,000 barrels per day (BPD) of liquids consisting of LPG, naphtha, and fuel oil.
Plant Availability	The plant is considered to operate at capacity 330 stream days per year, resulting in an availability factor of 90.4%.
Characteristics	The complex is a grass roots facility which captively produces all utilities and oxygen requirements. All effluent streams are treated to meet environmental standards.
Raw Material and Product Storage	Facilities are provided for a 14-day coal inventory and a 30-day liquid product inventory.

Facility Description

An artist's conceptual drawing is presented in Figure 1. A photograph of a model of the complex is shown in Figure 2. The complex would occupy approximately 600 acres, exclusive of the coal mine. Plant population is about 2,350 people. About 17,500 gallons of water per minute would be drawn from the source river.

Coal Mine	The mine is an integrated strip mine with five separate areas or mining units to produce 47,000 TPD of ROM coal operating 350 days per year. The average overburden is 60 feet and average coal seam thickness is 5 feet. The primary overburden removal is with 170 cubic yard draglines. The ROM coal would pass through a primary separation step located in the mining area

and then be transferred by conveyor to a coal preparation plant area where it is cleaned and sized to produce feed coal to the process plant.

Over the 20-year project operating life, approximately 57 square miles would be mined out.

Process Plant

A process block flow diagram is shown in Figure 3.

Key to the process is the SRC II hydroliquefaction step. Here, 20,000 TPD of cleaned, sized feed coal is slurried in coal-derived recycle solvent; two-thirds of the solvent is unfiltered and contains undissolved coal and ash, while the remaining one-third has been filtered to remove the solids. The coal slurry is pumped to 2,050 psig, mixed with hydrogen, preheated to 700°F, and reacted in the dissolver vessel. The dissolver product passes through a pressure let-down system with the resulting liquid phase going to a low pressure fractionator. Fractionation products are naphtha, light distillate used as fuel oil constitutent, heavy distillate used as filer wash oil and as a product fuel oil constitutent, and the bottoms which contain solids. The bottoms are split; about half are recycled to the feed coal slurry system and the remainder goes to the filters.

The naphtha is hydrotreated to produce saleable product. The light distillate, a portion of the heavy distillate, and the filtrate are combined to form the product fuel oil.

Gases emitting from the dissolver pressure let-down system, fractionation, and the naphtha hydrogenation steps are combined and fed to a monoethanolamine (MEA) acid gas removal system to take out the hydrogen sulfide, carbon dioxide and carbonyl sulfide. The resulting sweet product gas is then processed in a cryogenic unit for hydrocarbon recovery/separation as described below. Sour acid gas is sent to a sulfur plant which removes the sulfur-containing contaminants and produces saleable sulfur.

In the SNG and LPG production train, sweet gas produced in the MEA system is dried with molecular sieves and then sent to a cryogenic unit. Here 98.5 volume percent hydrogen is recovered. A portion of this hydrogen stream is used to methanate residual carbon monoxide. Then the high purity hydrogen is fed to the naphtha hydrotreater while the remainder of the hydrogen stream is recycled to the coal dissolving step. Methane-rich gas produced in the cryogenic unit is compressed, cooled to remove condensible fractions, and then passed through a zinc oxide guard chamber to reduce the hydrogen sulfide content. It is then processed in a final methanation unit and sent to the SNG product line. Ethane and heavier fractions produced in the cryogenic unit are fractionated to remove ethane and some propane overhead which is mixed with final methanator product to produce specification grade SNG, which is compressed to 1,000 psig for delivery. Remaining propane and heavier material is separated into propane LPG as an overhead product and a bottoms product. Bottoms are debutanized to produce butane LPG as an overhead product, leaving pentane-and-heavier bottoms which are fed to the naphtha hydrogenation unit. Butane LPG is hydrotreated

and transferred to product storage.

The make-up hydrogen stream for the coal dissolving step is produced in a coal-fed gasifier operated at about 1,000 psig. Significant methane is produced at this pressure. The gasifier is a two-stage entrained slagging type. Solids are removed from the gasifier effluent gas stream and the hydrogen-to-carbon monoxide ratio adjusted in a sour shift conversion unit. The shifted gas is processed in a physical solvent acid gas removal system to produce a sweet gas for feed to the dissolver section, a hydrogen sulfide-rich gas stream for feed to the sulfur plant, and a carbon dioxide-rich vent gas stream. The Rectisol process was used as a representative process.

A fuel gas gasifier system is included to generate the necessary steam and power to operate the complex. This gasifier is fed by the dried dissolver filter cake plus coal. The filter cake is previously dried to recover the wash solvent as a saleable product. Fuel gas generated in the gasifier is treated in an acid gas removal system to remove hydrogen sulfide and carbon dioxide before passing to the power and steam generation section.

Power and Steam Generation

The in-plant produced fuel gas is used to produce electrical power in two condensing turbine generator units with three extraction points. Four steam boilers are also included. The utility system is closely integrated with the process plant operation.

Material Balance

The overall material balance for the process plant is shown in Figure 4. Material inputs consist of coal, water, and oxygen (from the air separation plant). The coal amounts to about 36,000 TPD. Saleable products, including fuels, sulfur and ammonia, add to approximately 19,000 TPD.

Energy Balance

The energy balance is depicted in Figure 5. The projected thermal efficiency, coal to saleable products, is about 77%.

FISCHER-TROPSCH

Design Criteria

Preliminary design criteria have been described.[4] Key elements of the completed conceptual design are:

Plant Location	Eastern Region of the U.S. Interior Coal Province.
Coal Source	Illinois No. 6 seam coal produced in a captive surface coal mine.
Capacity	Approximately 40,000 TPD of ROM coal will be mined and 30,000 TPD of cleaned, sized coal will be fed to the process plant. The products will have an energy value of approximately 525 billion Btu per day consisting of 260 MMSCFD of SNG and approximately 50,000 BPD of liquid products which are LPG's, light and heavy naphthas, dissel fuel, fuel oil and oxygenates.

Plant Availability	350 stream days per year; availability factor = 90.4%.
Characteristics	Grass roots facility producing all utilities plus oxygen and treating all effluent streams to meet environmental standards.
Raw Material and Products Storage	Fourteen-day coal storage and 30day liquid product storage.

FAcility Description

The complex is depicted in the artist's conceptual drawing shown in Figure 6 and a photograph of model of the complex is presented in Figure 7. Land area required for the complex, without the coal mine, is about 500 acres. Plant population is about 2,100 people. Approximately 12,000 gallons per minute (GPM) of water would be required.

Coal Mine

As in the Oil/Gas design, a strip mine with an average overburden of 60 feet and average seam thickness of 5 feet would produce the required 40,000 TPD of ROM coal. The mine would consist of four integrated mining faces. The primary separation and coal preparation units are similar to those previously described for the Oil/Gas complex with the exception that the ground coal has a smaller particle site; minus 20 mesh by 0 for Fischer-Tropsch vis-a-vis 5% plus 20 mesh, 25% minus 200 mesh for the Oil/Gas plant.

Process Plant

All of the feed coal is fed to two entrained slagging-type steam oxygen gasifiers operated at approximately 470 psig. Gasifier effluent gas stream is exhaustively cleaned to remove solid particles. The ratio of hydrogen to carbon monoxide in the cleaned gas is increased by subjecting about 50% of the gas stream to a shift conversion reaction; the H_2/CO ratio is thereby adjusted to the target value of 1.45. Shifted gas is then fed to an acid gas removal unit where it is contacted with a physical solvent to remove the hydrogen sulfide, carbon dioxide and organic sulfur compounds. The Selexol process was used as a representative process for this design. The absorbed acid gases are stripped for further processing; the hydrogen sulfide is converted to saleable sulfur in the sulfur plant and the CO_2 stream is vented. Sulfur content of the cleaned syngas is reduced to about 0.1 part per million, volume (ppmv).

Cleaned syngas is fed to the Fischer-Tropsch synthesis unit at about 400 psig and 570°F. It first passes through zinc oxide guard chambers to remove trace quantities of sulfur compounds. Then it is processed in 18 parallel synthesis reactors designed for isothermal operation. The reactors have flame-sprayed iron catalyst deposited on the external surface of extended surface heat exchangers. Reaction takes place on the shell side and 1,250 psig steam is generated on the tube side by the heat of reaction. Shift and methanation reactors have a similar geometrical design but differ in the composition of the flame-sprayed catalyst.

Fischer-Tropsch reactor feeds contain a ratio of recycle to fresh feed of approximately 1.4. Extensive heat exchange is used to maintain a high plant thermal efficiency.

Fischer-Tropsch products go to a liquid product recovery unit to recover light hydrocarbons from the Fischer-Tropsch gas and to fractionate the liquids into the product streams.

Two gas streams are recovered and fed to the methanation unit which produces SNG. One consists of a mixture of residual lean gas after absorption of the C_3^+S in a presaturated lean oil stream and a CO-rich stripper overhead product produced by stripping a lean oil fractionator overhead stream. This mixed stream is fed to the first methanation stage. It contains gases produced in the Fischer-Tropsch reactor, including methane and some C_2's and C_3's to increase the heating value of the SNG. An additional feed stream, which goes to the second-stage methanator, consists of C_3's and C_4's which are produced in a depropanizer in the liquid product refining train; they serve to increase the heating value of the SNG.

Fischer-Tropsch liquids are preheated and fed to a lean oil fractionator where light ends are removed overhead for further processing and feed to the methanator section as described previously. The bottoms are fed to the fuels vacuum fractionator where the heavy naphtha, diesel oil and heavy fuel oil are produced. Naphtha is removed as an overhead product. Diesel oil is withdrawn as a side stream and is steam-stripped to obtain the flash point specification. Heavy fuel oil is produced by steam stripping in the bottom section of the fractionator, cooled, and sent to storage.

Light naptha is produced in a naphtha stabilizer fed by the bottoms from the depropanizer. C_4 LPG's are recovered as overhead from the stabilizer.

Oxygenate produced in the Fischer-Tropsch reactor, containing a high alcohol content, are recovered and refined. Feed to the oxygenate recovery system is produced in a water extraction of the Fischer-Tropsch liquids. This feed is preheated and the oxygenates taken overhead from a fractionator with the bottoms returned to the extraction system. A hot alcohol-salt solution, produced by caustic neutralization of the Fischer-Tropsch reactor effluent to destroy acids produced in the reaction, is stripped and the oxygenates recovered as an overhead product are also fed to the oxygenate fractionator previously discussed. The stripper bottoms are evaported to produce a concentrated salt solution for disposal and a consensate stream used as boiler feed water.

Product SNG is produced in the methanation section. The primary feed is sulfur-free stripped gas produced in the liquid product recovery section. The methanation section consists of a first-stage recycle reaction unit containing three methanators in parallel, and a second-stage one-pass finishing reactor.

Feed gas to the first stage methantor is mixed with 1.25 parts of recycle gas, preheated to about 570°F, and reacted at 380 psig in isothermal reactors of design similar to those used for the Fischer-Tropsch reaction. A flame-sprayed nickel catalyst is deposited on the outside surface of a finned tube heat exchanger and the high heat of reaction removed by boiling dowthern in

the tubes -- the hot dowthern in turn is used to generate 1,300 psig steam for use in the plant utility system. Reaction conditions in the first-stage methanator favor CO methanation to assure that the product SNG does not contain more than 0.1 mol% CO. Product from this first-stage methanator is cooled, condensate removed, and about three-fourths of the gas recycled with the remainder going to the second-stage methanator which is an adiabatic fixed-bed radial-flow reactor using a pelleted, reduced, nickle-type catalyst. Here the CO_2 is methanated; it will also methante CO if a breakthrough should occur in the first stage. The CO_2 content of the product SNG is maintained below 2.5%.

The product from the second-stage methanator has a higher heating value of about 910 Btu/SCF. This is combined with the vaporized mixed light hydrocarbon stream produced in the liquid product recovery section and fed to a hydrotreater for saturation of alkenes by the residual hydrogen in the stream. The product SNG stream is cooled, condensate removed, compressed, dried, and fed to the product pipeline at 1,000 psig.

POWER AND STEAM GENERATION

The process produces all steam required for operations, heating, and power generation. Therefore, conventional steam boilers are not provided for normal operation. A start-up boiler is provided.

Electrical power is generated by four 120-megawatt extraction steam turbine generators. These generators provide all power required for operation of the complex plus approximately 140 MW for sale.

MATERIAL BALANCE

Overall material balance for the process units is presented in Figure 8. Results indicate that approximately 13,000 tons per day of saleable fuel products plus sulfur are produced from 30,000 tons per day of cleaned, sized feed coal.

ENERGY BALANCE

Energy balance is summarized in Figure 9. Estimated thermal efficiency in converting coal to saleable products is approximately 70%.

PRODUCT CHARACTERISTICS

Projected product characteristics for the Fischer-Tropsch and Oil/Gas conceptual designs are summarized in Table 1. These have been projected based on review and analysis of product characteristics reported by process investigators for similar, but not identical, process conditions[5,6] plus minor adjustments to reported product characteristics using the characteristization factor to assure consistency with the basic data. For more radical adjustments to reported product characteristics as a result of subsequent treatment, for example, hydrogenation, reference was made to published work[8,9] in this area to establish change of characteristics resulting from treatment. There are not yet reports of production-analysis-functional product testing of large quantities of the naphtha, diesel fuel, and fuel oil streams. However, the projection of these characteristics based on analysis of existing data and comparison of expected values based on analogy to other coal-derived liquids

and similar crude oil-based products provides a basis for projecting comparative results for these two technologies and defining incentives for pilot plant production to permit confirmation or modification of the projections.

The most significant differences are that the Fischer-Tropsch liquid products contain nil sulfur, nitrogen and particulate matter, and are composed primarily of aliphatic compounds, while the Oil/Gas products contain sulfur, nitrogen, and solids and consist primarily of aromatics. The Fischer-Tropsch liquids therefore have higher potential for use as petrochemical feedstocks and for fuel applications with stringent environmental restrictions. Oil/Gas products show promise for us in gasoline manufacture and for selected fuel applications. Additional comments will be presented later regarding possible market values of these products.

FIXED CAPITAL INVESTMENTS

All economics are expressed in Fourth Quarter 1976 dollars.

The projected fixed capital investments (FCI) for the two conceptual complexes are compared in Table II. The results indicate that the Fischer-Tropsch complex would require a FCI of approximately 1.55 billion dollars to produce about 85,000 barrels of fuel oil equivalent per day (BOE/D); the FCI per BOE/D is therefore about $18,000. The Oil/Gas complex would require a FCI of about $1.3 billion to produce approximately 110,000 BOE/D for a FCI per BOE/D of about $12,000.

A comparison of the relative costs of the separate sections of the complex is shown in Table III. A significant contributor to the higher FCI per BOE/D for the Fischer-Tropsch plant lies in the gasification section where the cost of the oxygen plants and gas cleanup are much higher. Note that the FCI's for the conversion sections, per daily barrel of oil equivalent, for the two complexes are about equal.

TOTAL CAPITAL INVESTMENTS

Total capital investments are presented in Table IV. Total capital includes fixed capital investment, initial catalyst and chemicals, start-up costs, construction financing, working capital, and land/rights of way. Projected total capital requirements are 2.0 and 1.7 billion dollars for the Fischer-Tropsch and Oil/Gas complexes, respectively. Example construction financing costs are presented in each case.

Estimated time to mechanical completion was approximately 57 months in each case. This included design, engineering, procurement and construction.

OPERATING COSTS

Projected annual operating costs for the complexes are given in Table V. The operating costs include royalty allowance of $1.50 per ton of cleaned, sized coal produced.

Projected annual operating costs are 205 million dollars for both the Fischer-Tropsch and Oil/Gas complexes, respectively. For analytical purposes, the complexes were divided into cost centers.

REQUIRED PRODUCT SELLING PRICE

Average required product selling price was projected for three project financial structures. In all cases, the project operating life was 20 years.

- 100% equity capital
- Borrowed capital: 65% of the total investment borrowed at 9% interest, with the principal repaid in equal installments over a 20-year project operating term; all working capital borrowed at 9% interest for the 20-year term; a loan commitment fee of 0.75% on funds not drawn down during the construction period.

- A nonprofit (0% discounted cash flow rate of return) or break-even boundary case.

A 12% discounted cash flow rate of return (DCF) was selected as a base case, and the revenue required to achieve this DCF calculated for each financial structure. Required average product selling price was then calculated using the required revenue and the quantity of energy products produced.

Results are summarized in Table VI. Here we see that for the 65/35 debt/equity financial structure, the projected average required product selling prices, fourth quarter 1976 basis, (RPSP) are $2.55 and $1.95 per million Btu's for the Fischer-Tropsch and Oil/Gas cases, respectively. The 100% equity financing cases are about 30 percent higher in each case. The breakeven cases are about $1.50 and $1.20 per million Btu's, respectively.

In dollars per barrel, the 65/35 debt/equity case RPSP's would be about $15.25 and $12.00; this is based on an arbitrary 6 million Btu per barrel reference value. A key factor in the economic projections is the inclusion of large captive coal mines in the complexes.

SENSITIVITIES

Sensitivities of the average required product selling price to changes in key economic parameters are shown in Table VII. The RPSP is most sensitive to changes in fixed capital investment. To illustrate, for Fischer-Tropsch a 10% reduction in fixed capital investment would result in an 8.7% reduction in RPSP for the 100% equity case. The sensitivities to operating costs are in the range of 15-20%.

Effect of variations in DCF on the RPSP is presented in Figure 10 for the 65% debt case. Sensitivity is greater for the 100% equity case, which is not shown.

POSSIBLE PRODUCT MARKET VALUES

A brief assessment of possible product market values and the effect of the resulting project revenues on profitability was completed. To obtain these possible market values, the project characteristics of the products were compared with those of conventional crude oil-based products. Discussions were held with representatives of fuel producers and consumers and industry reports were reviewed.

Industry representatives strongly qualified their opinions on possible prices by stating that laboratory and field product performance tests must be conducted before firm dollar values could be assigned to the products.

With the above caveats clearly in mind, possible unit sales values and annual revenues for a fourth quarter 1975 basis are presented in Table VIII for Fischer-Tropsch and Table IX for Oil/Gas; these are taken from the published reports.[1,2] The SNG sales value was based on value allowed for sale of SNG produced commercially from naphtha, and possible values for SNG from coal at that time. These possible sales values are presented to illustrate the effect of product sales value on the economics and also to perhaps stimulate further effort to establish firm product values and marketability.

The Tables VIII and IX possible annual revenues were then updated to a fourth quarter 1976 basis using Federal Energy Administration data which indicated that fuel prices escalated approximately 9 percent from fourth quarter 1975 to fourth quarter 1976.

Results of this second-order exploratory analysis indicate that possible average annual revenues (Fourth Quarter 1976 dollars) are $730 and $560 million dollars for the Fischer-Tropsch and Oil/Gas cases, respectively. Projected DCF's calculated using these revenues and the project structures developed earlier are shown in Table X. To illustrate, for the 65/55 debt/equity case, the projected DCF's for Fischer-Tropsch and Oil/Gas are 27 and 20 percent, respectively. This result indicates the incentive for accurate assessment of the marketability and profitability of synfuel products to be produced in second generation coal conversion plants in the U.S.

ECONOMIC COMPARISON FOR LOW SULFUR CONTENT FUEL PRODUCTS.

Projected sulfur content of the Oil/Gas fuel oil is 0.45. A brief and very preliminary analysis of the effect of further hydrotreating to reduce the sulfur content on cost and product composition was made; this is an extension of the design previously reported.[1] The result provides guidance regarding the costs and implications of producing very low sulfur fuels from coal by Oil/Gas type technology for environmental reasons.

The data basis for predicting process and cost results for hydrotreating the coal-derived liquids is limited. However, some information is available to guide the projections.[8,9,10]

Preliminary process designs were developed for incremental hydrotreating of the Oil/Gas fuel oil. Hydrotreating conditions were nominally 650°F and 2,500 psig with a nickel-molybenum type catalyst. A 6 months catalyst life was assumed for the purpose of this preliminary assessment.

Projected product distribution as a function of fuel oil sulfur content is depicted in Figure 11. With decreasing sulfur content, the amount of fuel oil decreases and the lighter products increase.

Figure 12 presents projections of hydrogen consumptions and Figure 13 shows projected required average product selling price at 12% DCF, 65% debt as a function of fuel oil sulfur content. Also shown on Figure 13 is the projected

RPSP for nil sulfur Fischer-Tropsch products. Results indicate that at about 98% sulfur reduction in Oil/Gas fuel oil, the required product selling prices are approximately equal.

SUMMARY AND CONCLUSIONS

Conceptual designs'economic evaluations for two condidate second generation coal conversion technologies have been completed by the Ralph M. Parsons Company. These are a suggested future version of a Fischer-Tropsch complex, and an Oil/Gas Complex which uses SRC II technology. Each conceptual design incorporated certain process and equipment concepts currently under development. The designs are based on the presumption that these development programs will be successful.

The conceptual complexes process 30,000-36,000 tons per day and produce 85,000-110,000 barrels per stream day of oil equivalent. Projected fixed capital investments for the Fischer-Tropsch (F-T) and Oil/Gas (O/G) complexes are 1.55 and 1.3 billion dollars, respectively; all economics are presented in fourth quarter 1976 dollars. Unit fixed capital investments, expressed as dollars per daily barrel oil equivalent (BOE/D) are about $18,000 and $12,000, respectively.

Projected product characteristics from the complexes differ; Fischer-Tropsch produces primarily aliphatic liquids and Oil/Gas primarily aromatics.

Projected required selling prices to achieve a 12% DCF using a 65% debt, 9% interest case are about $15.25 and $12.00 per equivalent barrel. A second order assessment of possible product sales values has led to the conclusion that DCF's of the order of 20% might be achieved; this is presented to illustrate the incentive to produce and test enough of the synfuels to determine their market values.

Projections of possible costs for hydrotreating a 0.4% sulfur Oil/Gas fuel oil to reduce its sulfur content have been presented. Results indicate that reducing the sulfur content to 0.1% would add an incremental $500 million to the fixed capital investment and reduce the quantity of fuel oil by about 6 percent while increasing the quantities of LPG's and naphtha. A further result is a 15 percent increase in the average required product selling price (RPSP). The average RPSP at this sulfur level is projected to be about 90% of the nil sulfur F-T RPSP. At 98% sulfur reduction in Oil/Gas fuel oil, the RPSP's are about equal. Limited information is available for this hydrotreating step. An incentive exists to develop a firm basis for design and prediction of economics.

Fischer-Tropsch and Oil/Gas coal conversion technologies each offer different advantages and potential problems to be overcome. They must be considered candidates for any future synfuels-from-coal programs.

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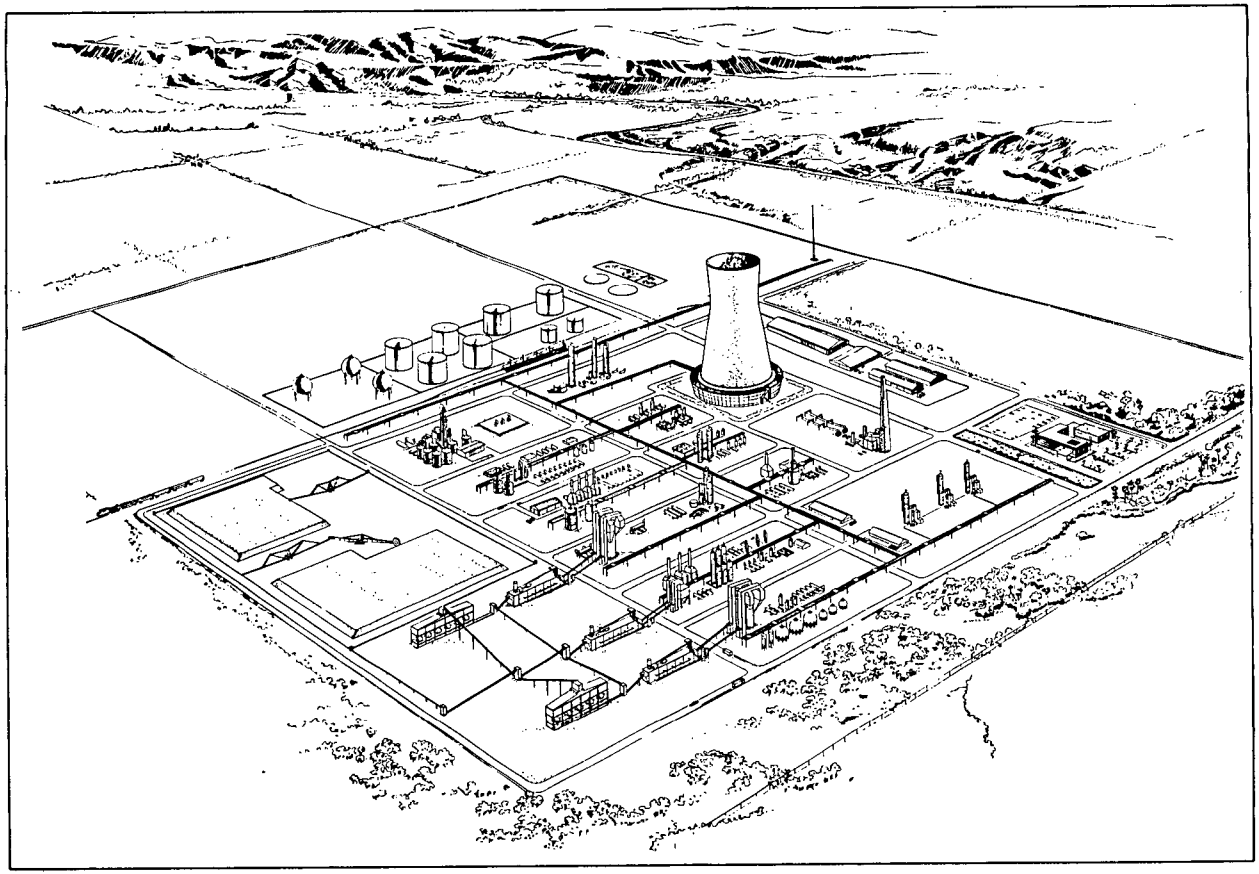


Figure 1 - Artist's Concept, Oil/Gas Plant

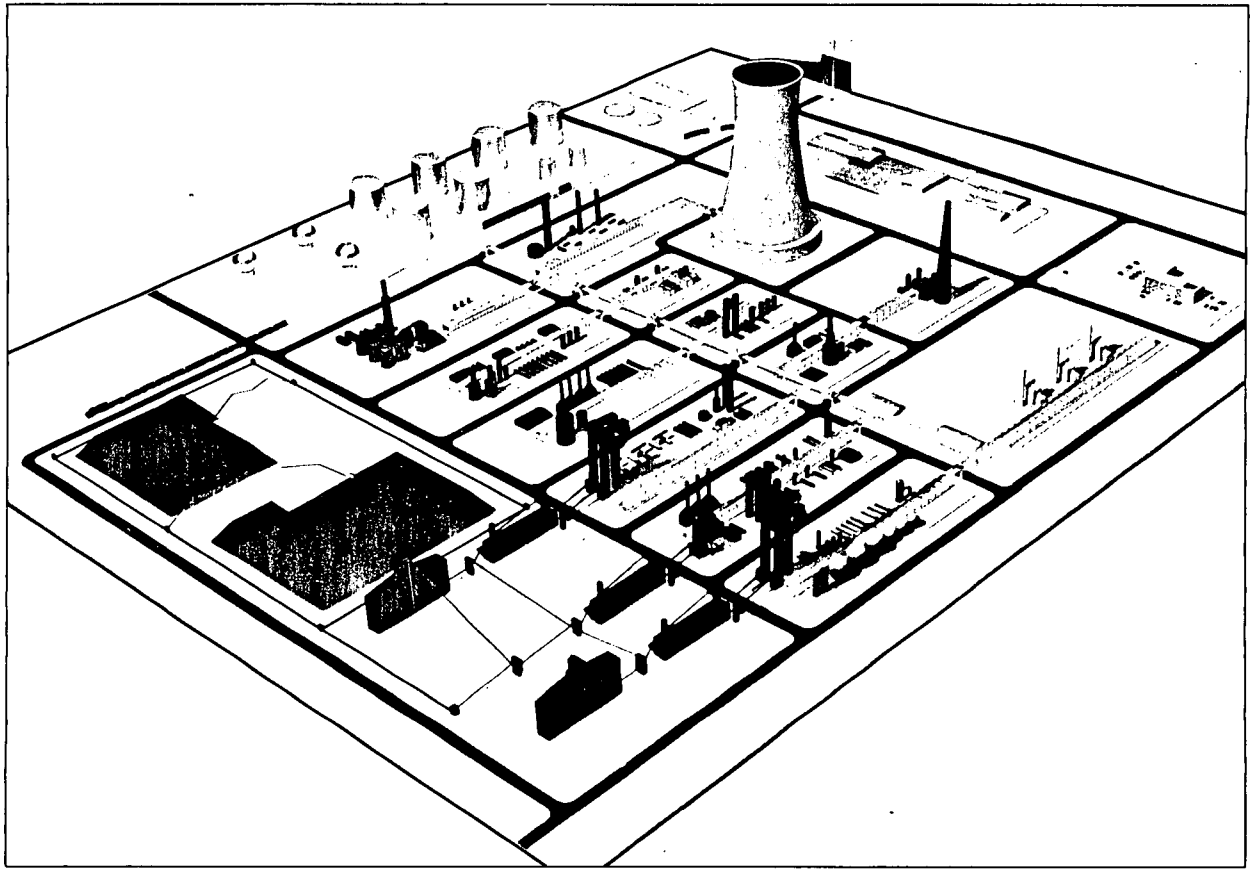


Figure 2 - Model of Conceptual Oil/Gas Plant Design

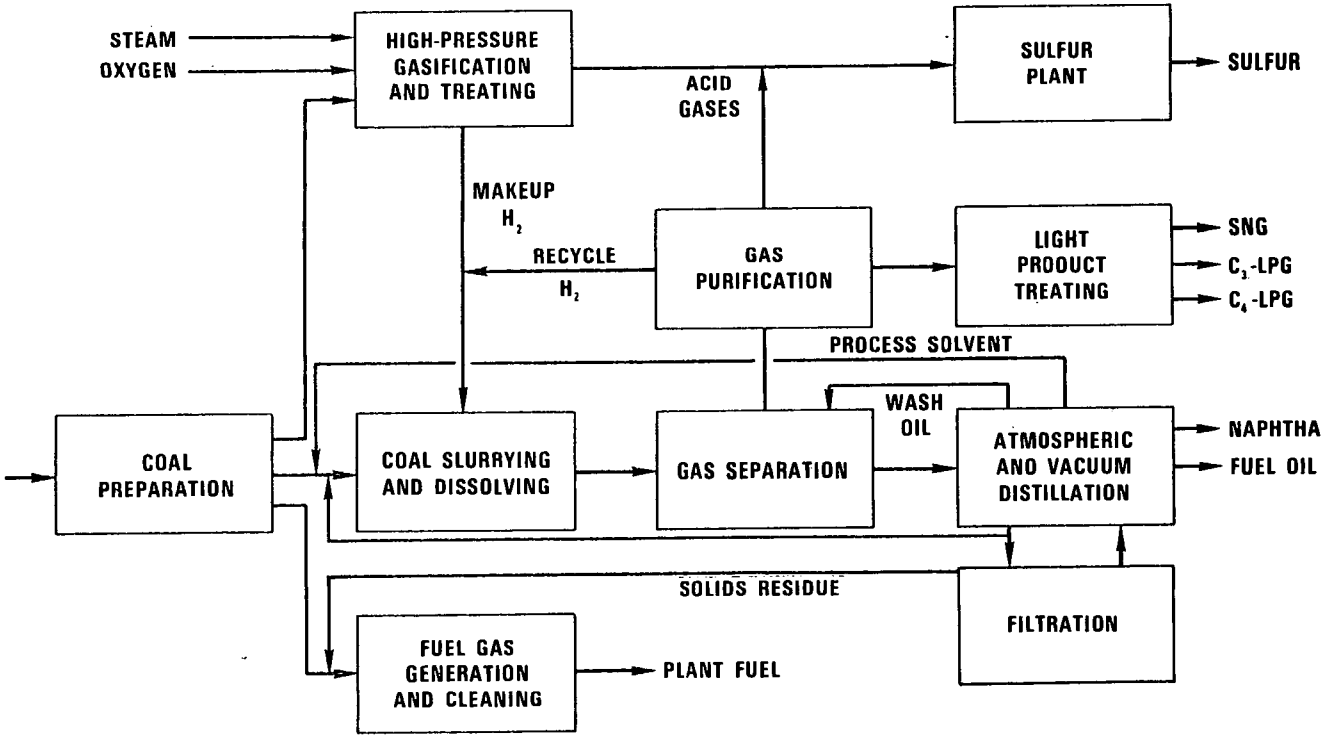


Figure 3 - Oil/Gas Plant
Simplified Block Flow Diagram

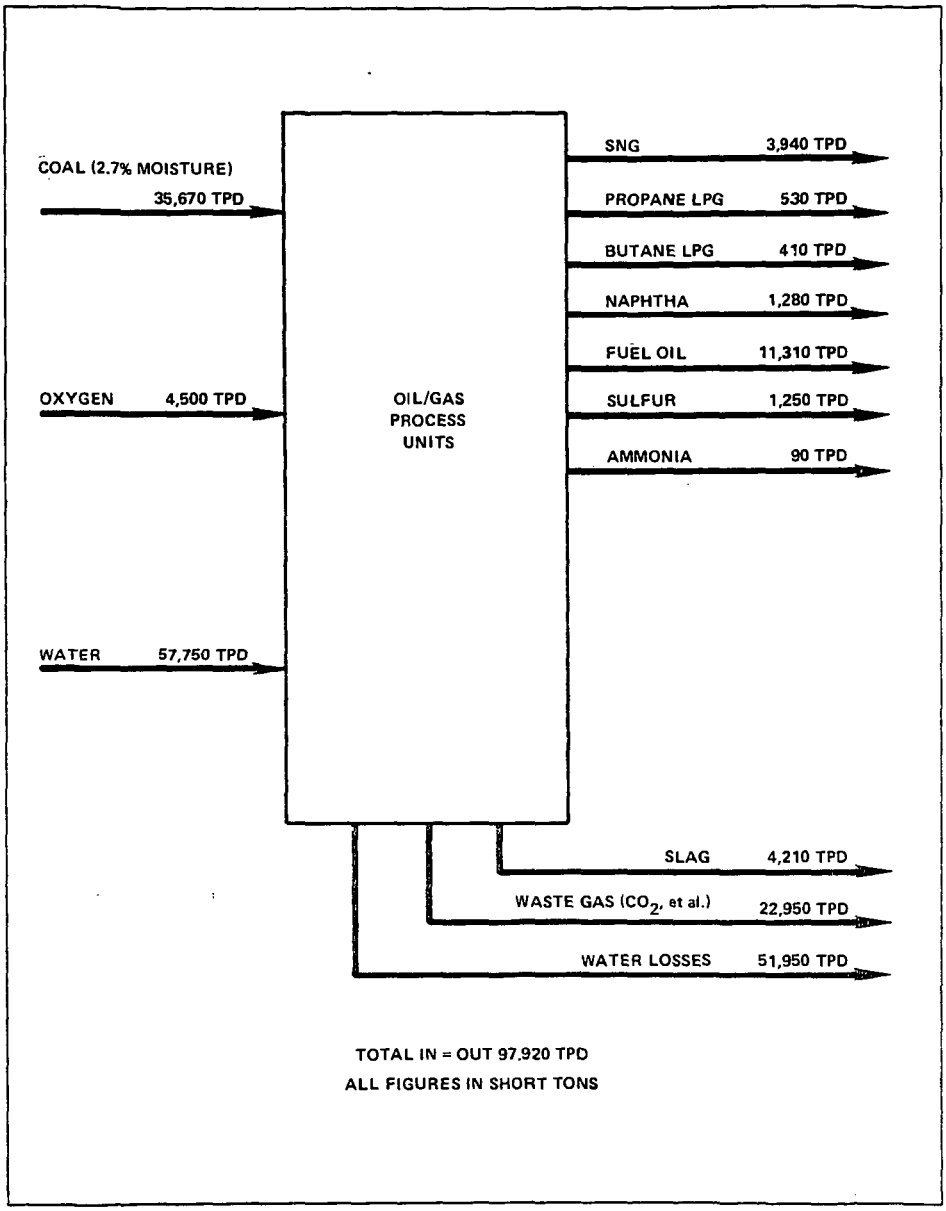
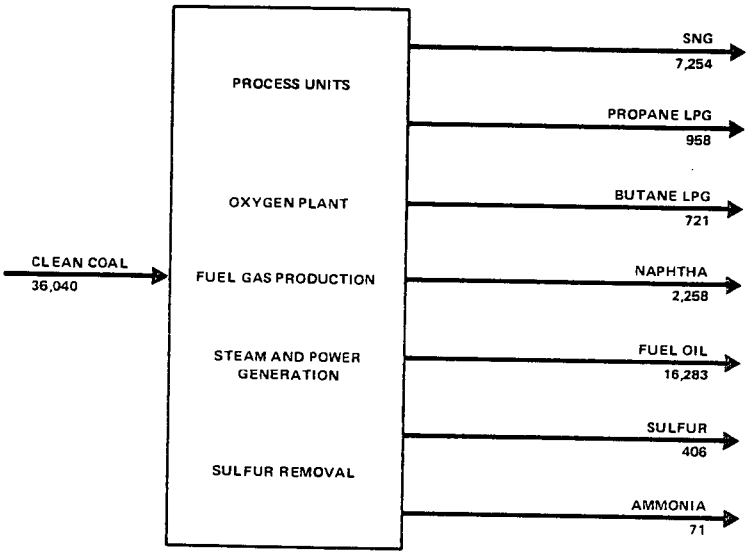


Figure 4 - Overall Material Balance
Oil/Gas Plant



ALL FIGURES ARE MM BTU/HR, HHV

$$\text{THERMAL EFFICIENCY} = \frac{7{,}254 + 958 + 721 + 2{,}258 + 16{,}283 + 406 + 71}{36{,}040} = 77.6\%$$

Figure 5 - Thermal Efficiency, Oil/Gas Plant

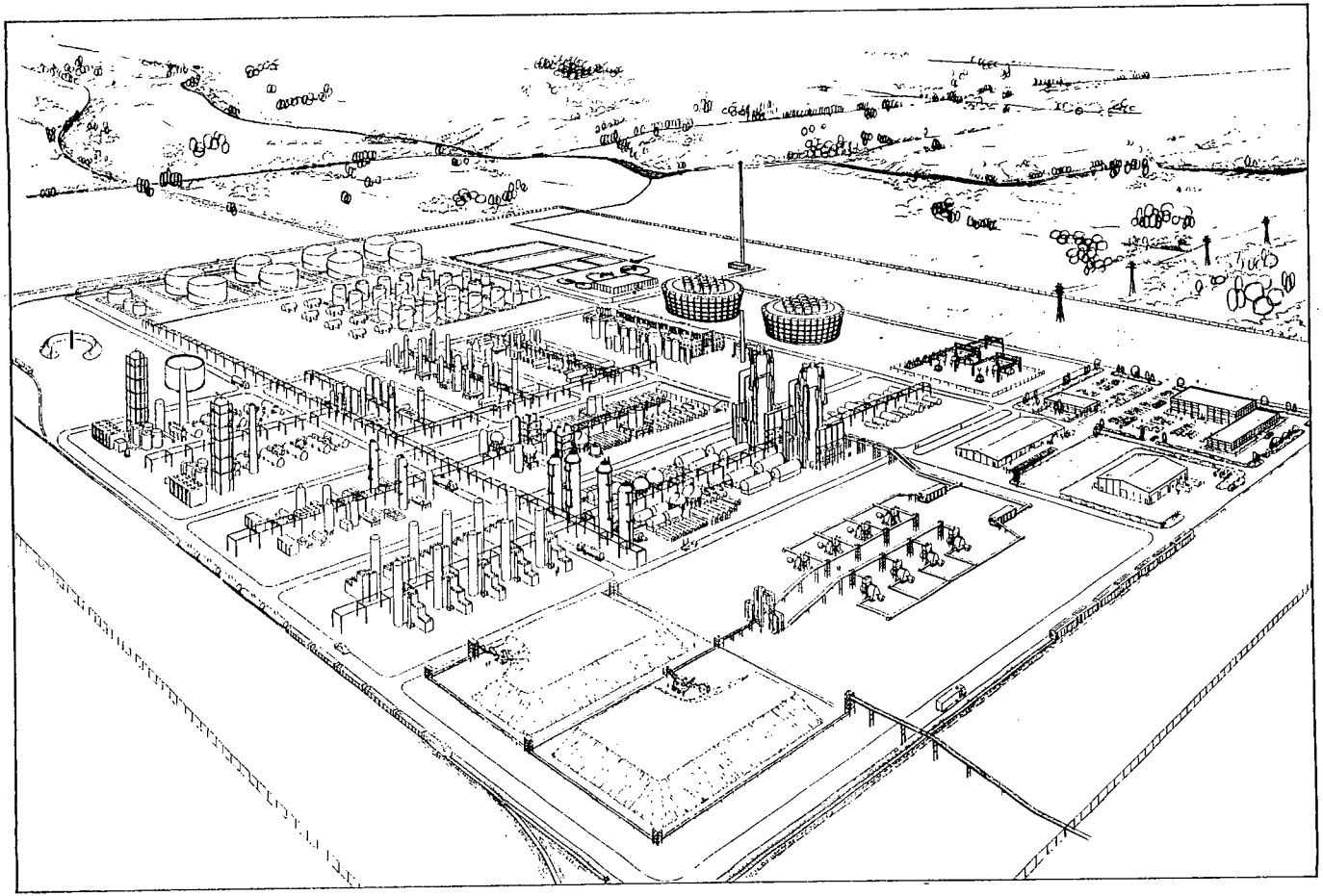


Figure 6 - Artist's Conceptual Drawing
Fischer-Tropsch Plant

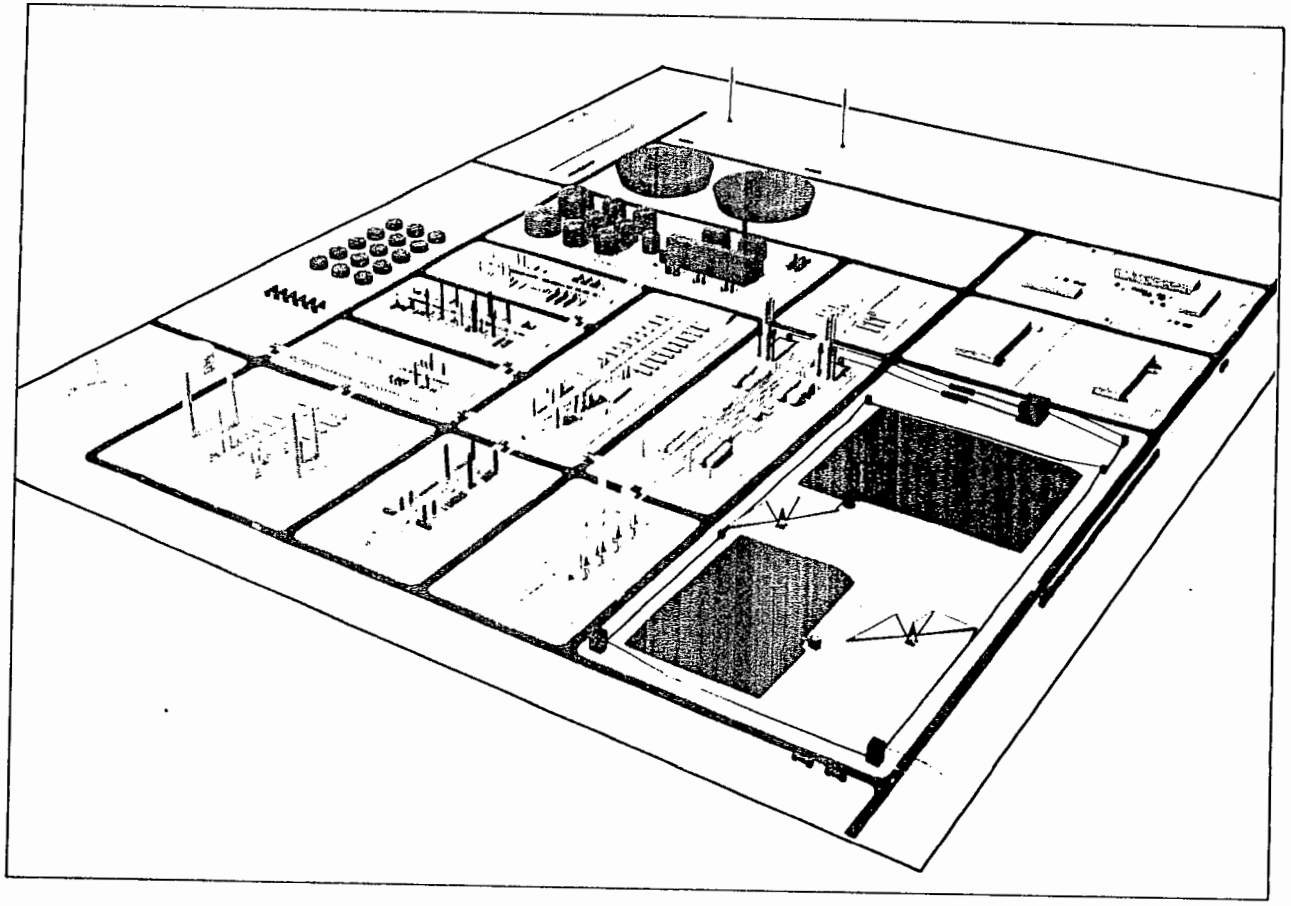


Figure 7 - Model of Conceptual Fischer-Tropsch Plant Design

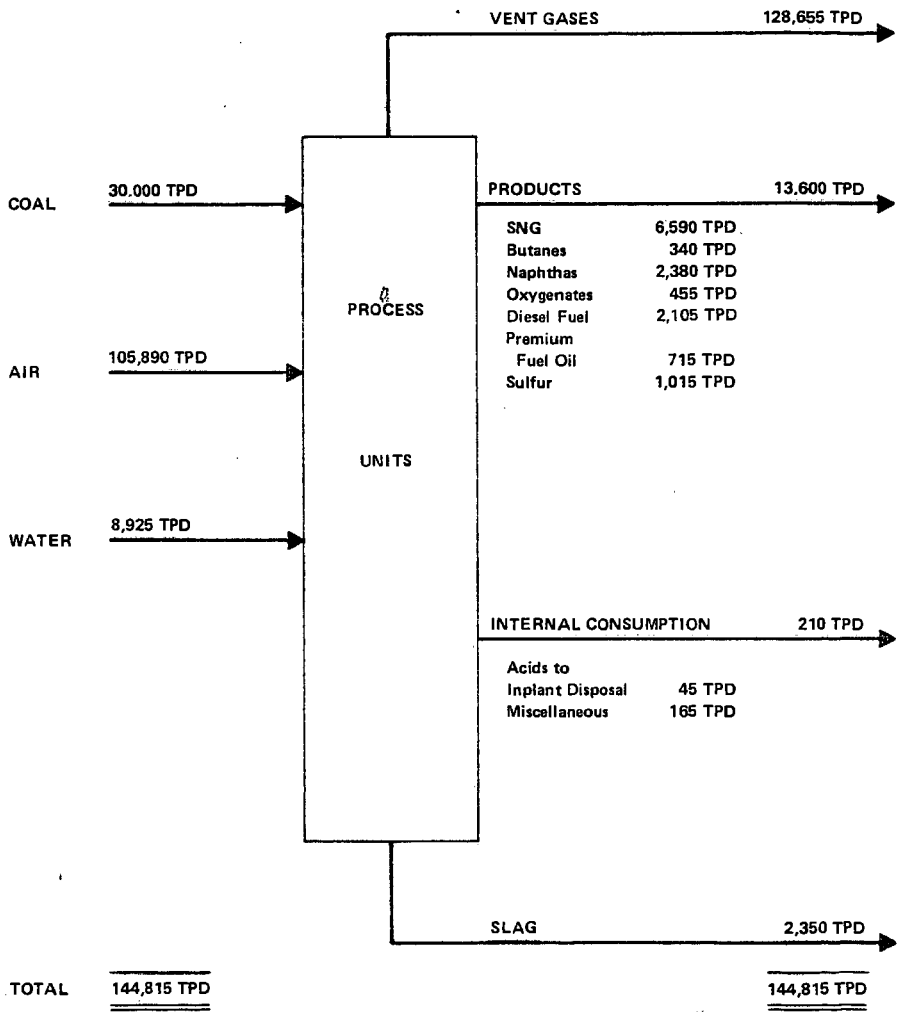
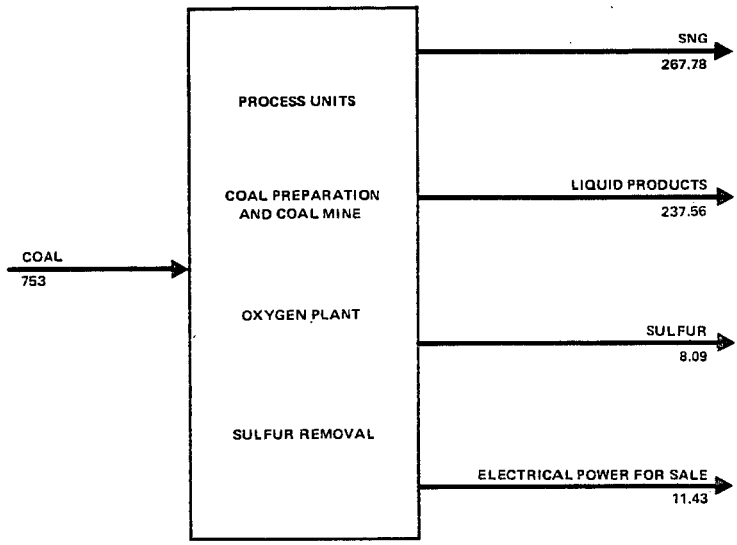


Figure 8 - Overall Material Balance
Fischer-Tropsch Plant



ALL FIGURES ARE MMM BTU/D, HHV

$$\text{THERMAL EFFICIENCY} = \frac{267.78 + 237.56 + 8.09 + 11.43}{753} = 69.7\%$$

Figure 9 - Thermal Efficiency
Fischer-Tropsch Plant

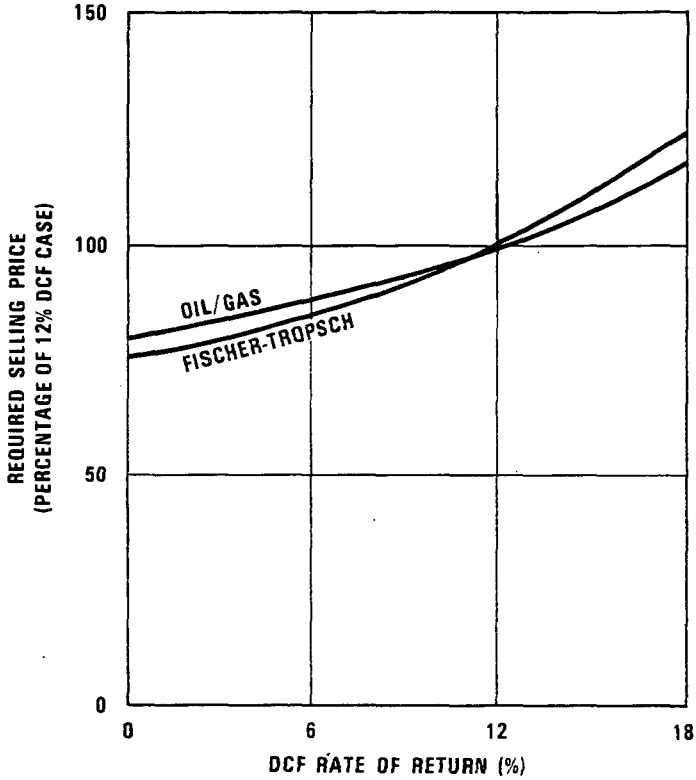


Figure 10 - Sensitivity of Required Product Selling Price to DCF, 65% Debt Case

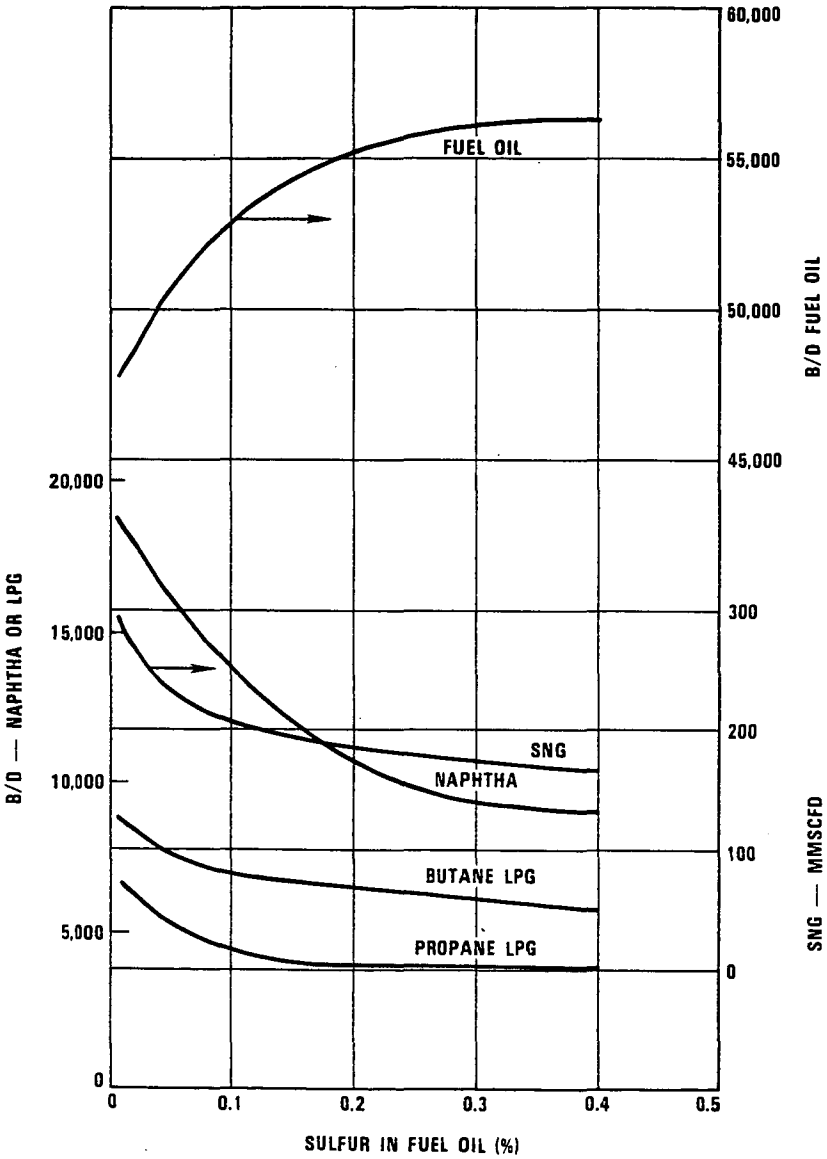


Figure 11 - Projected Product Distribution
Product Yield vs. Fuel Oil Sulfur Content
Oil/Gas Plant

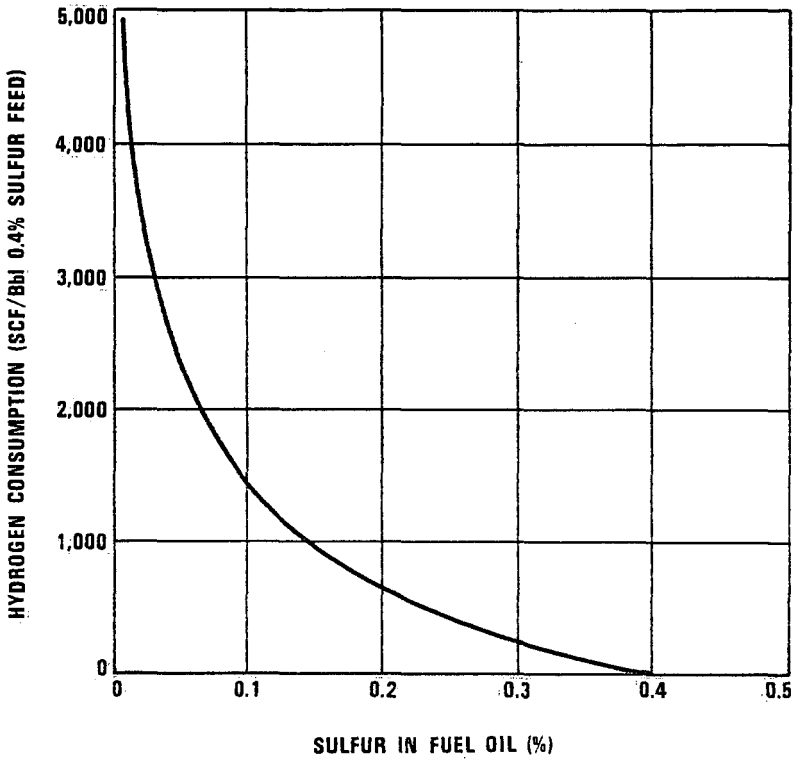


Figure 12 - Projected Hydrogen Consumption
Hydrogen Consumed vs. Fuel Oil Sulfur Content
Oil/Gas Plant

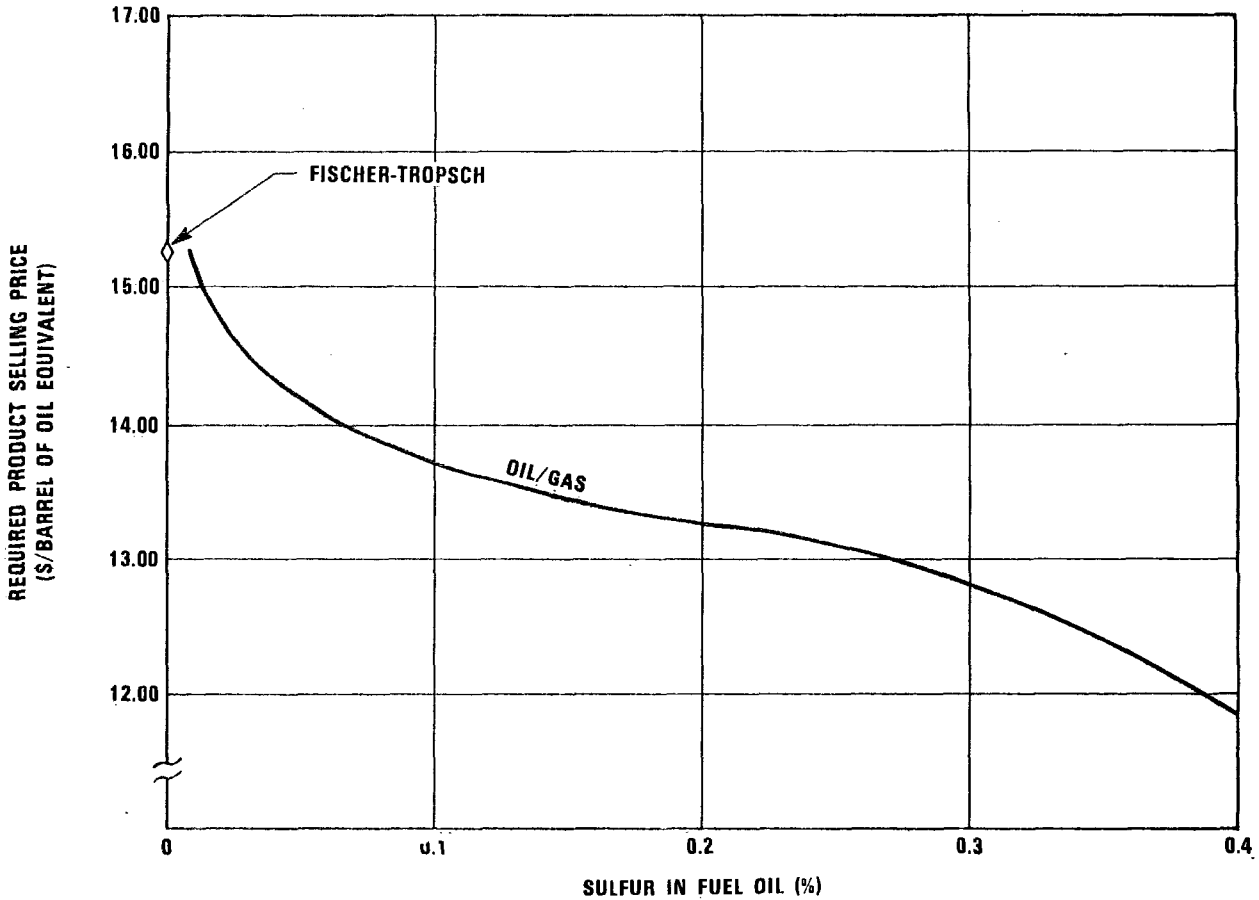


Figure 13 - Required Average Product Selling Price as a Function of the Sulfur Content of Oil/Gas Fuel Oil

Table I. Comparison of Projected Product Characteristics

Product	Projected Characteristics	
	Fischer-Tropsch	Oil/Gas
SNG	Pipeline Quality	Pipeline Quality
C_3 LPG	--	Propane 210 psia Vapor Pressure
C_4 LPG	Mixed Butane - Butylene 37 psia Vapor Pressure	Mixed Propane-Butane, 70 psia Vapor Pressure
Full Range Naphtha	--	50° API Gravity C_5 to 380°F ASTM EP High Naphthene
Light Naphtha	Nil Sulfur 185°F ASTM EP 85.5°API Gravity	--
Heavy Naphtha	Nil Sulfur 300°F ASTM EP 71.3 API Gravity	--
Diesel Fuel	57°API Gravity 60 plus Cetane Number Nil Sulfur, Nil Nitrogen	--
Fuel Oil	41°API Gravity Nil Sulfur Higher Heating Value: 19,900 Btu/lb	-8.2°API Gravity 0.4 wt % Sulfur Higher Heating Value: 17,200 Btu/lb

Table II. Comparison of Fixed Capital Investments (FCI) for Fischer-Tropsch and Oil/Gas Complexes

Barrels Fuel Oil Equivalent/Day (BPOE/D): F-T = 86,000
O/G = 110,000

Description	Fischer-Tropsch $ Millions	Oil/Gas $ Millions
Mine and Coal Preparation		
Mine	175.6	211.6
Coal Preparation	22.0	30.0
Coal Storage	11.2	13.0
Crushing and Drying	13.0	15.1
Subtotal	221.8	269.7
Conversion		
Fischer-Tropsch Synthesis	204.6	--
Oil Recovery and Fractionation	30.5	--
Chemical Recovery	15.9	--
Slurry and Dissolving	--	216.8
Filtration	--	42.0
Distillation	--	31.6
Dissolver Acid Gas Removal	--	20.3
Subtotal	251.0	310.7
Process Gas Production		
Gasification	37.3	45.4
Heat Rec. and Part. Removal	151.2	--
Acid Gas Removal	100.3	47.7
Shift	18.9	59.5
Power Generation	119.6	86.8
Subtotal	427.3	239.4
SNG Separation and Treatment		
Methanation	60.6	0.6
SNG and LPG Treating	--	48.3
Subtotal	60.6	48.9
Product Finishing		
Sulfur Plant	22.1	15.4
Naphtha Hydrogenation	--	9.2
Subtotal	22.1	24.6
Utilities		
Oxygen Plant	305.3	90.2
Instrument and Plant Air	5.6	2.4
Potable and Sanitary Water	0.4	--
Raw Water System	23.8	--
Fuel Gas Gasify	--	71.2
Fuel Gas Acid Gas Removal	--	17.9
Raw Water Treating	--	16.5
Subtotal	335.1	198.2
Environmental and General Facilities		
General Facilities	19.5	37.2
Water Reclaiming	40.4	--
Effluent Water Treating	3.0	5.5
Product Storage	21.2	32.2
Sour Water Stripping	--	5.9
Subtotal	84.1	80.8
Total Constructed Cost	1,420.0	1,172.3
Home Office Costs	140.2	117.2
Sales Tax	28.1	23.5
Total Fixed Capital Investment (FCI)	1,570.3	1,313.0
FCI/(BPOE/D)	18,250	11,950

Table III. Comparison of Relative Fixed Capital Investments of Fischer-Tropsch and Oil/Gas by Unit

Description	Ratio of Fischer-Tropsch to Oil/Gas	
	Fixed Capital Investment	FCI/BOE
Mining & Coal Preparation	0.82	1.05
Conversion	0.81	1.03
Process Gas Production	1.78	2.28
SNG Separation & Treatment	1.24	1.58
Product Finishing	0.90	1.15
Utilities	1.69	2.16
Environmental & General Facilities	1.04	1.33
Total	1.19	1.53

Table IV. Comparison of Projected Total Capital Requirements for Fischer-Tropsch and Oil/Gas Complexes

Item	Fischer-Tropsch $ MM	Oil/Gas $ MM	Ratio F-T - O/G
Fixed Capital Investment	1550	1300	1.19
Initial Catalyst & Chemicals	11	9	1.22
Start-Up Costs	110	86	1.28
Construction Financing[a]	212	188	1.13
Working Capital	113	107	1.06
Land, Rights of Way	1	1	1.00
TOTAL	1997	1691	1.18
Say	2000	1700	

a) Example: For 65/35 debt/equity, 9% interest, 0.75% commitment fee case.

Table V. Comparison of Projected Annual Operating Costs for Fischer-Tropsch and Oil/Gas Complexes

Cost Center	Annual Operating Costs - $MM	
	Fischer-Tropsch	Oil/Gas
Coal Mine	84.5	104.2
Coal Prepartion	2.3	3.2
Process Plant	101.5	84.4
Power Plant	7.7	--
Offsites	7.8	14.4
TOTAL	203.8	206.2
Say	205	205

Table VI. Comparison of Projected Average Required Product Selling Price at 12% DCF

Project Financial Structure	Required Average Product Selling Price in Dollars per Million BTU		
	Fischer-Tropsch	Oil/Gas	Ratio F-T - O/G
100% Equity	3.30	2.50	1.32
65/35 Debt/Equity	2.55	1.95	1.28
Breakeven	1.50	1.20	1.20

Table VII. Sensitivities of Average Required Product Selling Price to Key Economic Parameters

Economic Parameter	Sensitivity of Average RPSD, %			
	Fischer-Tropsch		Oil/Gas	
	100% Equity	65% Debt	100% Equity	65% Debt
Fixed Capital Investment	87	81	82	78
Operating Costs	15	19	21	27
Run of Mine Coal Costs	21	25	30	34

Table VIII. Possible Product Sales Values for Fischer-Tropsch Complex

Product	Daily Production	Possible Unit Sales Value in Dollars	Annual Gross Revenue in $ Million
SNG	260.0 MMscfd	4.25/Mcf	362.8
Liquids			
C_4s	3,535 BPD	12.00/bbl	14.0
Naphthas			
Light	10,620 BPD	15.50/bbl	54.3
Heavy	9,555 BPD	17.00/bbl	53.6
Alcohols	3,910 BPD	25.00/bbl	32.3
Diesel Fuel	16,960 BPD	14.50/bbl	79.9
Premium Fuel Oil	4,960 BPD	15.00/bbl	24.5
			241.6
Power	3,352 MW/hr	0.03/kW-hr	33.2
Total Energy			651.6
Sulfur	1,015 Ton	60/ton	20.1
Total 4th Qtr. 1975			671.7
Escalation (9% from 4th Qtr. 1975 to 4th Qtr. 1976)			60.5
Total 4th Qtr. 1976			732.2

Table IX. Possible Product Sales Values for Oil/Gas Complex

Product	Daily Production	Possible Unit Sales Value in Dollars	Annual Gross Revenue in $ Million
SNG	170 MMscfd	4.25/Mcf	238.425
Propane	6,030 BPD	11.00/bbl	21.890
Butane	4,100 BPD	12.00/bbl	16.235
Naphthas	9,400 BPD	15.50/bbl	48.080
Fuel Oil	56,400 BPD	9.75/bbl	181.470
Total Energy			506.100
Sulfur	118 LT/D	60/ton	2.335
Ammonia	90 ST/D	120/ton	5.565
Total 4th Qtr. 1975			514.000
Escalation (9% from 4th Qtr. 1975 to 4th Qtr. 1976)			46.000
Total 4th Qtr. 1976			560.000

Table X. DCF's for Possible Product Revenues

Project Financial Structure	DCF	
	Fischer-Tropsch	Oil/Gas
100% Equity	17	13
65/35 Debt/Equity	27	20