4.0 ECONOMIC EVALUATION OF MOBIL TWO-STAGE SLURRY F-T CONCEPTUAL COMMERCIAL PLANTS

This section provides economic evaluations of the Mobil Two-Stage Slurry Fischer-Tropsch (SFT) conceptual commercial plants. These evaluations are based on the material and energy balances for the conceptual commercial plants detailed in the previous section of this report.

Six cases are examined in this section. Three of these six cases represent different estimates of the performance and economics of conceptual commercial-size, Mobil two-stage slurry Fischer-Tropsch (SFT) plants.

These three cases include the original Mobil low-wax case,[1] a high-wax case developed by MITRE on the basis of data provided by Mobil for this case, and a MITRE version of the Mobil low-wax case. As indicated in Section 3.0, the Mobil low-wax case design basis for the first stage synthesis reactor (i.e., SFT reactor) was material balance Period 22 of BSU Run CT-265-3. The basis for the MITRE version of Mobil low-wax case first-stage reactor was Period 11 of the same BSU Run CT-265-3. Transformation of the raw BSU data into scaled estimates of commercial performance require detailed energy, elemental and material balance calculations. The results of these transformations by MITRE and Mobil have resulted in slightly different estimates of overall yield, product selectivity, and efficiency for the two versions of the low-wax case. Both Mobil and MITRE used Test Period 34 of BSU Run CT-256-3 as the design basis for the Mobil second-stage ZSM-5 product upgrading reactor. Simulated BSU test run data for Run CT-265-4 were provided by Mobil to be used by MITRE for the evaluation of the Mobil high-wax case.

The remaining three cases examined in this section are the SASOL(U.S.) case,[2] the BGC/Synthol case, and the BGC/Koelbel case. These latter three cases have already been examined in a previous MITRE Report MTR-80W326[3]. The economics of these cases have been updated from the original 1977 report to a 1983 dollar basis and included here for the purposes of comparison to the Mobil two-stage SFT/ZSM-5 cases. The thermal output of all these plants was also recalculated on a lower heating value basis.

The objective of this phase of the MITRE study is to carry out a comparative economic analysis aimed at identifying process modifications which offer a significant impact on ultimate product cost.

The BGC slagging Lurgi gasifier selected by Mobil in their Scoping Study[1] was also used by MITRE. This gasifier produces 20 percent of the thermal output as methane and ethane. For an all-liquids output, reforming of methane/ethane results in an energy penalty of 40 percent of the methane and ethane heating value. If a more efficient gasifier with a lower methane/ethane output, like a Shell gasifier, were selected, further reductions in product cost would be realized.

4.1 Mobil Conceptual Process Design

4.1.1 Design Basis

In both the Mobil low- and high-wax cases, the first stage SFT reactor is designed to handle a syngas feed rate of 106,742-lb mol per hour (i.e., 2,111,070 lb/hour).(1) The clean syngas feed composition is based on the gasification of 27,800 tons per day of as-received Wyoming subbituminous coal in an advanced gasifier of the BGC/Lurgi type. The rates and mol percent of the various syngas feed components are shown in Table 4-1. As shown in this table, the molar ratio of H_2 to carbon monoxide (i.e., H_2/CO) is 0.5, which is typical for a BGC/Lurgi gasifier. To raise this ratio to 0.67 as practiced in Run CT-235-3, the syngas must either be internally shifted within the SFT reactor or externally shifted. In the Mobil scoping study, sufficient steam is added with the syngas feed to the Mobil SFT reactor to promote the water-gas shift reaction within that reactor.

It should be noted, however, that the actual molar ratio of hydrogen to carbon monoxide used in both the Koelbel(4) pilot plant and the Mobil BSU Test Run CT-265-3 for the low-wax case was 0.67. A similar ratio was also used for Mobil BSU experiments for the high-wax case. Later modifications were made to the Mobil BSU SFT reactor to allow simultaneous introduction of steam and syngas to that reactor. No results are available to MITRE on the impact of such a modification. Because of this, the MITRE design basis for the conceptual commercial plant externally shifts the gas to the required ratio of 0.67.

TABLE 4-1

SYNGAS FEED RATE AND COMPOSITION

	Rates (lb-mol/hr)	Composition (mol %)
H_2	31,841	29.83
CH_4	7,490	7.02
CO	64,319	60.26
CO_2	2,360	2.21
N_2	365	0.34
Ethylene	26	0.02
Ethane	341	0.32
Total:	106,742	100.00
Total lb/hr	2,111,070	

4.1.2 General Process Description

Simplified flow-sheets of the synthesis and refining sections of Mobil's low-wax conceptual two-stage SFT/ZSM-5 plant have been given in Figures 3-2 and 3-3 in the previous section. The synthesis and refining section consists mainly of a synthesis/upgrading reactor section and a product recovery section. In the synthesis/upgrading reactor section, clean syngas is fed into the first stage SFT synthesis reactor where the syngas is converted into a mixture of hydrocarbons. The overhead SFT reactor effluent stream includes carbon dioxide, water vapor, hydrocarbon vapor products, and the unconverted synthesis gas, all of which are introduced into the second stage fixed-bed ZSM-5 reactor for further upgrading. High molecular weight, waxy liquid hydrocarbon remains in the SFT reactor and is continuously recovered and filtered for removal of residual catalyst particles. The filtered wax is stored for preparation of fresh slurry and, in the high-wax case, further upgrading. After cooling, the ZSM-5 reactor effluent enters a three-phase product separator where the liquid hydrocarbon, the vapor, and the wastewater are separated. The wastewater stream is sent to a wastewater treatment plant.

The vapor and the liquid hydrocarbon streams are handled by the product recovery section (See Figure 3-3). To increase the efficiency the hydrocarbon recovery section, the carbon dioxide component of the vapor stream is removed, using a hot potassium carbonate absorption system, and is subsequently discharged to the atmosphere. In the product recovery section, the recovered propylene, butene, n-butane, and i-butane fractions, from the product fractionation unit, together with an additional quantity of imported i-butane (Mobil design basis only), are processed in an alkylation unit to maximize gasoline production. Light hydrocarbon gases leaving the product fractionation unit as an overhead offgas stream undergo further upgrading, in the methanation unit, to SNG.

No processing flow sheet was provided by Mobil for their high-wax case conceptual design. A conceptual design process flow sheet was, therefore, developed by MITRE for this case, as shown in Figure 4-1. In this figure, the reactor section is changed to include an additional unit for wax filtration and hydrocracking, as detailed in Section 3.0. The product separation and recovery section is also modified to receive the hydrocracking unit output in addition to the ZSM-5 reactor output.

4.1.3 Process Equipment

At the design syngas feed rate of 2,111,070 lbs/hr, which is equivalent to 973 x 10^6 SCFD, and an assumed syngas linear velocity of 0.3 ft/S, which is similar to that used by Koelbel in his Rheinpreussen-Koppers demonstration reactor,[(4)] a total of 40 Slurry Fischer-Tropsch reactors are required. To minimize the use of valves and piping, the reactors are grouped in clusters of five. The overhead effluent stream of two clusters is handled by one fixed-bed, downflow, adiabatic ZSM-5 reactor. At any time, four ZSM-5 reactors are onstream. A fifth reactor permits the periodic removal of one reactor for catalyst regeneration.

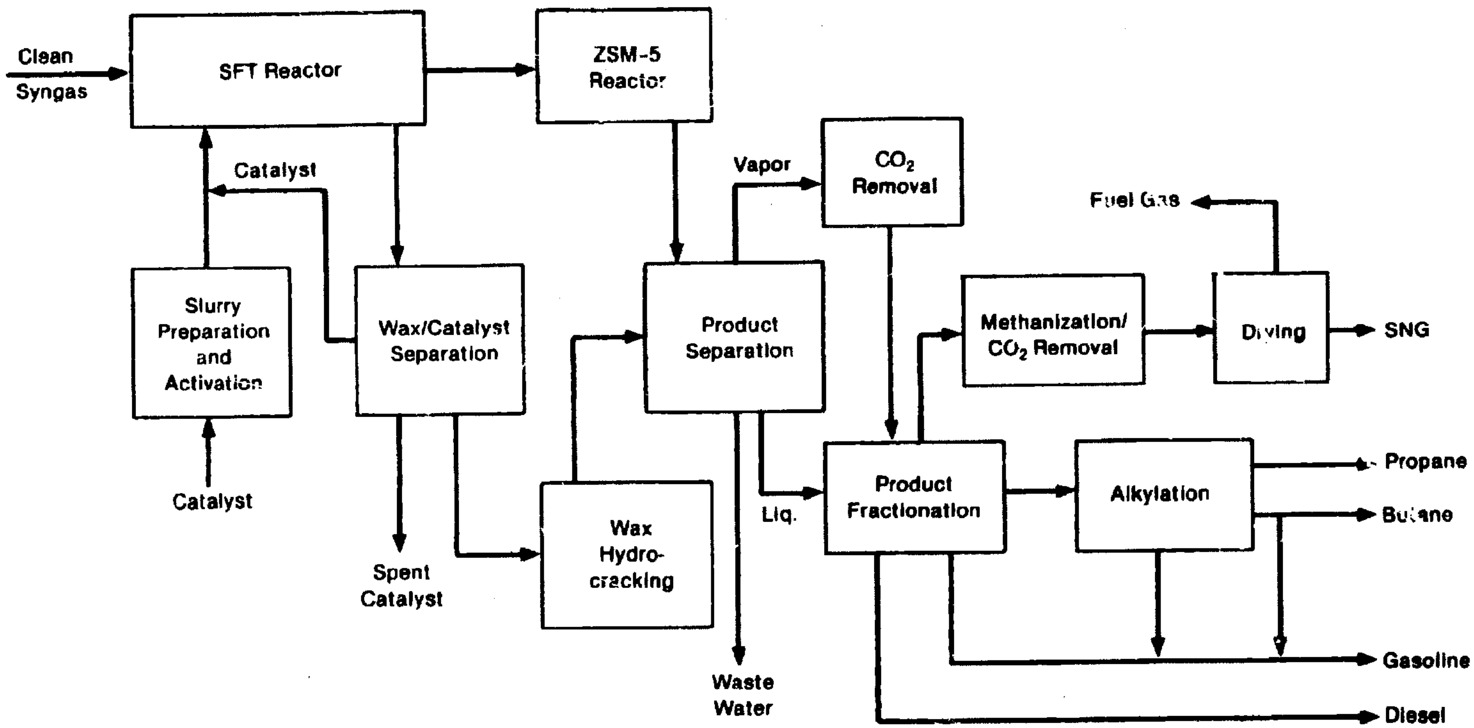


FIGURE 4-1
A SIMPLIFIED FLOW CHART FOR MOBIL HIGH-WAX CASE

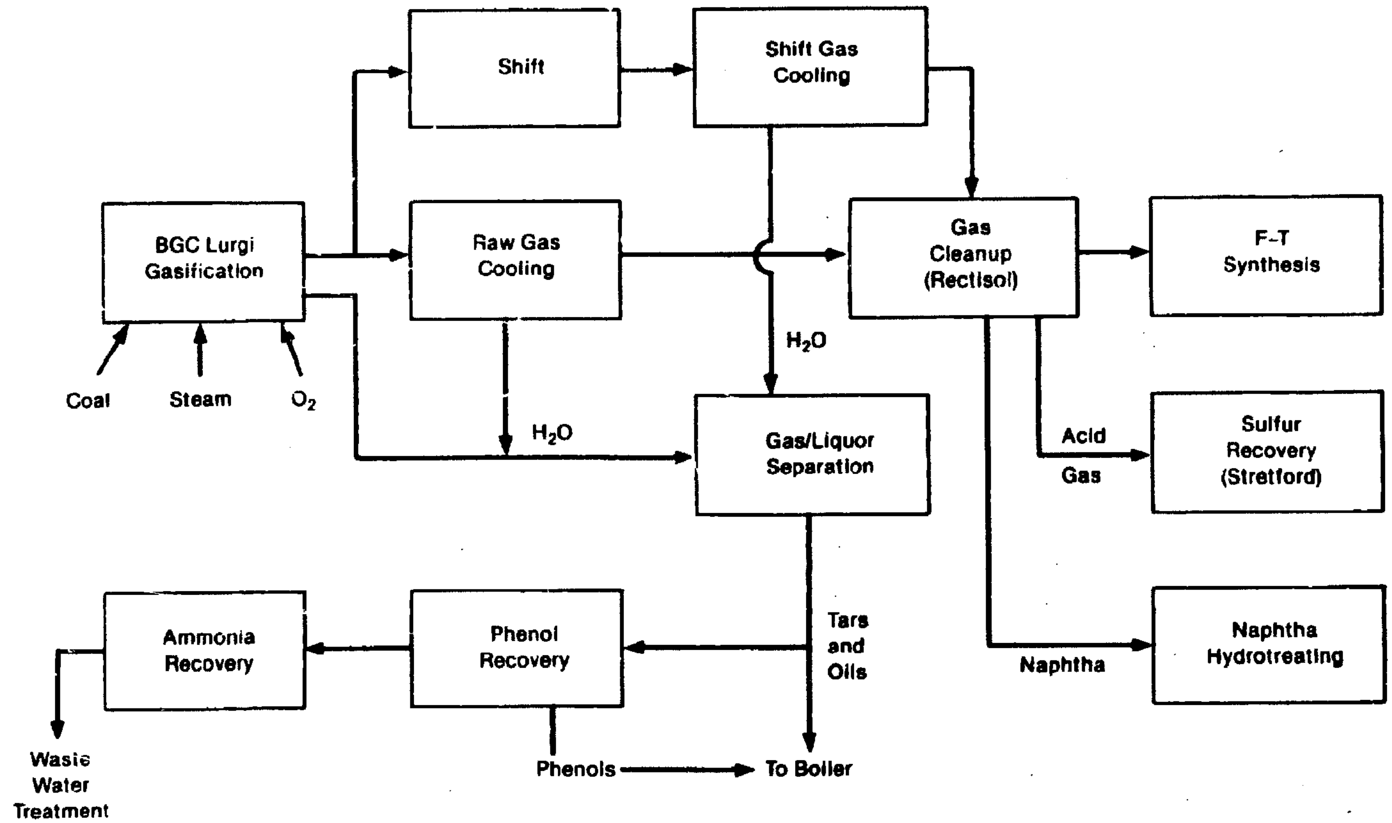
At the end of the SFT catalyst life, which is assumed to be 60 to 70 days, the slurry from each cluster of SFT reactors is transferred to a surge tank for later filtration to remove the deactivated SFT catalyst and recover the reactor-wax. Facilities are also included for new slurry preparation and SFT catalyst activation. Also included are the facilities required for the ZSM-5 catalyst regeneration. The allowed regeneration time is three days and the time between successive regenerations is 30 days.

Syngas preparation and cleanup equipment constitute the front-end section of the conceptual commercial plant. A typical flowsheet of the facilities included in the syngas preparation and cleanup section is shown in Figure 4-2. The plant is designed to handle 27,800 tons per day of Wyoming subbituminous coal. Further details of these plant areas can be found in the previous MITRE report.[3]

4.2 Definition of Reference Plants

For a comparative economic evaluation of the Mobil two-stage SFT/ZSM-5 process, it is necessary to compare its economics with an already established baseline. To date, the only established commercial-scale F-T process is the SASOL plant in South Africa.

In a study conducted for the U.S. Department of Energy (DOE), the Mobil Research and Development Corporation (MRDC) prepared a preliminary design of a U.S. SASOL-like plant.[2] As shown in Figure 4-3, this design represents a grassroots plant using the Lurgi dry-ash gasifier, the Synthol F-T synthesis reactor, and a



Note: Shift and Shift Cooling Not Included in Mobil Design Bases.

FIGURE 4-2

SYNTHESIS GAS PREPARATION FOR BGC/KOELBEL AND MOBIL PLANT CONFIGURATIONS

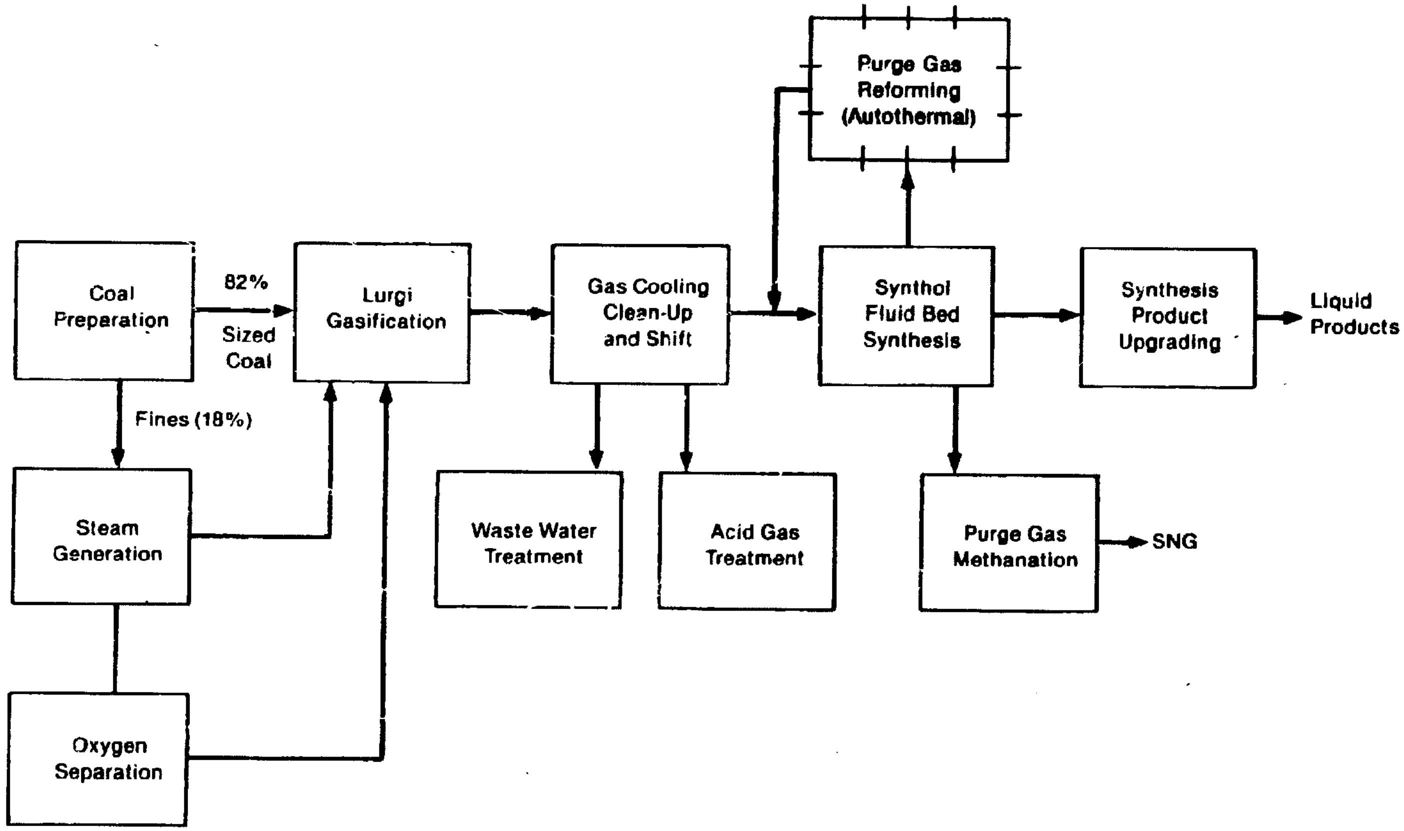


FIGURE 4-3
MOBIL SASOL (U.S.) PROCESS FLOW

sophisticated refinery to upgrade and maximize the yield of specification motor fuels from the Synthol reactor output. This plant is also designed to handle 27,800 tons per day of Wyoming subbituminous coal.

Figure 4-4 indicates two alternative processing modes; one in which light ends from the Synthol unit are methanated to produce a substitute natural gas (SNG), and one in which they are autothermally reformed to produce additional synthesis gas for recycle to the Synthol reactor. The differences in product outputs for the two modes of operation of the U.S. SASOL-like plant, or SASOL(U.S.), are depicted in Figure 4-4. In the all-liquid mode, about 10 percent of the recycle stream must be purged to prevent buildup of inert product (principally methane) in the Synthol reactor.[2] These gases are burned in the boiler to generate the additional steam required to produce oxygen for the autothermal reformer. Only 61 percent of the energy in the SNG produced in the mixed product case is recovered as liquid output in the all-liquid case.[2]

The operating mode also has a significant impact on the plant thermal efficiency, defined here as the lower heating value of the products divided by the lower heating value of total plant coal, and on the plant economics (i.e., capital cost, operating cost, and unit product cost). The all-liquid mode has a lower thermal efficiency than the mixed output mode. This reflects the inefficiency of methane reforming and the increased energy used in oxygen production for methane autothermal reforming. The autothermal reforming, in the

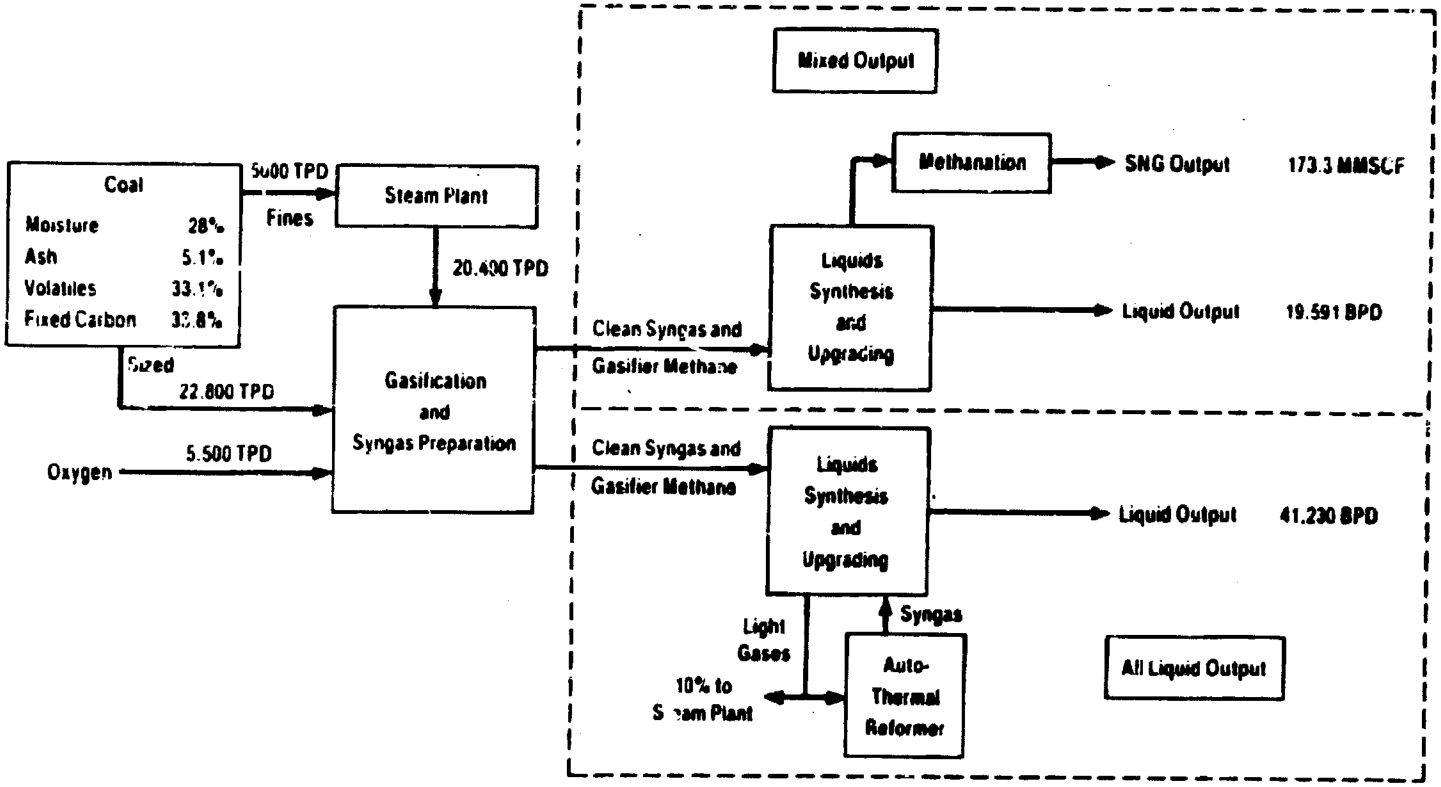


FIGURE 4-4

SASOL (U.S.) PLANT INPUT/OUTPUT FOR MIXED PRODUCT AND ALL-LIQUID CASES

all-liquid mode, also requires additional capacities for steam generation, oxygen generation, and F-T synthesis and upgrading, thus increasing the investment cost over that required for the mixed-output mode of operation.

For a more realistic comparison, the U.S. SASOL plant must be modified. The Lurgi dry ash gasifier in the SASOL U.S. configuration must be replaced by a BGC Lurgi slagging gasifier as is used in the Mobil two-stage conceptual design. This identifies as the BGC synthol reference. In addition, the fluidized synthol reactor in these two cases must be replaced by a Koelbel slurry F-T reactor similar to the type used in the Mobil conceptual design and tested in the Mobil BSU. The cost impact of these modifications on the SASOL U.S. plant was examined in the previous MITRE study,[3], MTR-80W326, and is summarized in Table 4-2. The plant construction costs in Table 4-2 have been obtained by updating the 1977 dollar costs from Reference 3 to 1983 dollars by using an inflation factor of 1.61.

As shown in this table, the lower steam consumption of the BGC/Lurgi gasifier, compared to the dry-ash Lurgi, is reflected in a lower steam plant cost. On the other hand, the higher gasification efficiency of the BGC/Lurgi compared to the dry-ash Lurgi results in more syngas to process and more products to upgrade, and hence in correspondingly larger capacities and higher cost, for F-T synthesis, gas-cooling and drying, and F-T product upgrading. Replacing the Synthol reactor by a Koelbel slurry F-T synthesis

TABLE 4-2

CONSTRUCTION COSTS OF SASOL (U.S.), BGC/SYNTHOL, AND BGC/KOELBEL REFERENCE PLANTS (IN MM$, 1983)

	SASOL (U.S.)		BGC/SYNTHOL		BGC/KOELBEL	
	Mixed Output	All-Liquid Output	Mixed Output	All-Liquid Output	Mixed Output	All-Liquid Output
Coal and Ash Handling	115	115	115	115	115	115
Synthesis Gas Preparation	533.7	533.7	415.8	415.8	364.6	364.6
Gasification	323	323	161.6	161.6	161.6	161.6
Raw Gas Shift	20.6	20.6	48.3	48.3	18.3	18.3
Gas Cooling and Cleaning	190.1	190.1	205.9	205.9	184.7	184.7
By-Product Recovery	178	178	129.2	129.2	77.9	77.9
Sulfur Recovery	95	95	104.3	104.3	39.5	39.5
Gas/Liquor Separation and Product Recovery	83	83	24.9	24.9	38.4	38.4
F-T Synthesis	167.6	252.9	217.2	324.1	250.7	302
Synthesis Reactor	123	175.6	159.4	237.8	213.8	257
Catalyst Preparation	44.6	77.3	57.8	86.3	36.9	45
F-T Product Upgrading	207.5	342.6	248.5	359.7	282.8	349.7
Gasifier Naphtha Treatment	20.1	20.1	21.4	21.4	21.2	21.2
SNG Preparation or Reforming	39.1		34.9		25.6	
F-T Liquid Product Recovery	148.3	257.0	192.2	279.5	236.0	285.9
Autothermal Reforming		65.5		58.8		42.6
Offsites and Miscellaneous	708.1	804.1	652.4	732.3	628.3	691.2
Oxygen Plant	177.3	239.0	200.1	250.4	202.2	244.1
Steam Plant	314.4	343.0	251.8	278.2	233.5	255.8
Wastewater Treatment	42.3	48.0	26.4	29.6	18.5	17.2
Power Generation	17.1	17.1	17.1	17.1	17.1	17.1
Interconnecting Piping, Infrastructure, and Other Miscellaneous	157.0	157.0	157.0	157.0	157.0	157.0
TOTAL CONSTRUCTION COST	1,910	2,226	1,778	2,076	1,719	1,900

reactor has the effect of eliminating or substantially reducing the capacity of the external carbon monoxide shift step, because the Koelbel reactor can use a carbon monoxide-rich syngas. Other important impacts of the Koelbel slurry F-T reactor is that it has a high conversion of syngas per pass, increases the gasoline yield as well as the total liquid yield per ton of feed coal and therefore increases the required liquid product recovery, upgrading and storage capacity. The cost of a Koelbel reactor in Reference 3 is assumed to be 20-percent higher than the Synthol reactor, which is probably conservative, based on other reported figures.[5]

4.3 General Comparative Evaluation

The BSU test runs of the Mobil two-stage SFT/ZSM-5 process indicate that this process was tested in two modes of operation--the low-wax and the high-wax modes. As already indicated, the basis for the Mobil conceptual design of their two-stage SFT/ZSM-5 commercial-size plant is BSU Test Run CT-256-3. This test run was operated as a low-wax case.

In the low-wax operating mode, the amount of wax produced represents less than 9 percent of the total hydrocarbon output of the SFT reactor. At this low level of production, wax may not represent an economic penalty and may not warrant the need for additional processing to convert it to more valuable products (e.g., gasoline or diesel).

The high-wax operating mode, however, results in an amount of wax that exceeds 43 percent of the hydrocarbon output of the Mobil SFT reactor. This large amount of wax, therefore, must be hydrotreated to produce more marketable products such as gasoline and diesel oil. The economic impact of both the low- and high-wax operating modes is compared to the baseline plant economics below.

The coal and ash handling, as well as the BGC/Lurgi gasifier sections, are common to the Mobil two-stage SFT/ZSM-5 and the reference case plants. It must be noted, however, that the cost of these two sections (i.e., coal handling and gasification sections) represents a significant portion of the total plant cost for either the Mobil or the reference case plants.

Both the Koelbel synthesis reactor, which is used in one of the reference plants, and the Mobil SFT reactor used in the Mobil two-stage SFT/ZSM-5 plant are of similar type and have the advantage of a high conversion per pass of over 85 percent. The two reactors differ, however, in many other aspects. In particular, the Koelbel SFT reactor seems to be in a more advanced stage of development, based on scale of operation. Although no commercial Koelbel synthesis units are in operation, it has already been demonstrated at Rheinpreussen, Germany, from 1938 to 1953 on a pilot plant scale.[4] The Mobil SFT reactor, however, has only been tested on a laboratory bench-scale unit and only for a steady run of less than 90 days. The scale-up experience at Rheinpreussen is available to Mobil. The Mobil bench-scale unit was patterned after the Rheinpreussen unit.

As already indicated in Section 3.0 of this report, the most significant difference between the performance of the Koelbel reactor and the Mobil SFT reactor is in their product distribution. The Koelbel SFT reactor product distribution is typically characterized by a low gas-make and no wax production. On the other hand, when the Mobil SFT reactor is operated to produce low levels of C_1 and C_2 (i.e., low gas-make mode), the associated wax produced represents more than 43 percent of the total hydrocarbon output of the reactor. This constitutes an economic penalty on the Mobil two-stage SFT/ZSM-5 plant, unless the wax is further processed to produce more valuable products such as gasoline and diesel oil. The economic impact of this additional processing of the wax is discussed later.

The product upgrading section of the Mobil two-stage SFT/ZSM-5 plant is radically different from that used in the reference plants. The second-stage ZSM-5 product upgrading reactor used in the Mobil plant essentially replaces the refinery in the reference plants. The offsite section of the Mobil two-stage SFT/ZSM-5 process is similar to that of the reference plants.

4.4 Economic Evaluation of Mobil Low-Wax Case

4.4.1 Capital Cost Requirement

The capital cost quoted by Mobil for the battery limits facilities of the Mobil Two-stage SFT/ZSM-5 conceptual design(1) is 700 million dollars based on July 1983 dollars and Wyoming location. In this estimate, the capital cost of the reactor section (i.e., SFT and ZSM-5 reactors and their related equipment) represents 70 percent, or 490 million dollars, of which the cost of the ZSM-5 reactors is 122.5 million dollars, or 25 percent of the SFT/ZSM-5 combination.

The Mobil estimate includes contingencies and other elements of capital cost other than construction cost for which the precise methodology of determination is unknown.

The Mobil battery limit capital cost is only a partial cost estimate which does not include coal and ash handling, coal gasification, gas cleanup, utilities and offsites, and other necessary facilities. In order to assure that the costing methodology employed for the Mobil conceptual design were compatible with the alternative to which it is compared, we have elected to follow the same cost methodology adopted in MITRE MTR-80W326[3] as detailed in Appendix A. This costing approach provides a complete, instantaneous* construction cost estimate of all the sections required in the Mobil two-stage SFT/ZSM-5 plant, except for the ZSM-5 reactor. To obtain an estimate of the ZSM-5 reactor, we have employed the Mobil estimate that the ZSM-5 reactor represents 25 percent of the SFT/ZSM-5 combination. We have thus multiplied our own estimate of the SFT reactor construction cost by 1.33 in order to obtain an estimate of the SFT/ZSM-5 combination. The methodology and other assumptions employed by MITRE yield a total capital cost of all items estimated by Mobil which very closely approximates the $700 million Mobil estimate.

*Instantaneous construction cost estimate means that it does not include allowance for construction loan interest. That is to say, it assumes a zero construction time.

A breakdown of this Mobil plant construction cost is summarized in Table 4-3. The total construction cost is 1,701 million dollars when the plant is designed to operate in the mixed output mode, and is 11-percent higher at 1,902 million dollars in the all-liquid mode of operation.

The additional costs which make up the capital cost requirement or total plant investment, amount to 59 percent[2] of the construction cost. The capital cost requirement for the complete BGC-Mobil plant, therefore, is estimated to be 1.59 times the construction cost. Table 4-4 shows the resulting total capital costs to be 2,705 million dollars for the mixed-output mode, and 3,024 million dollars for the all-liquid output mode.

4.4.2 Operating Cost

Coal cost estimated at $7.95 per ton amounts to $73 MM per year for both the Mobil and the reference cases. The remaining operating costs such as maintenance, local taxes and insurance, and administrative overhead, as well as labor and utility costs, are treated as capital-related costs and are estimated as percentages of the total plant investment. For the reference plant cases, the operating cost multiplier is indicated in a previous MITRE MTR-80W326 to be 0.081 or 8.1 percent of the total plant investment in 1977 dollars. After adjustment by escalation to 1983 dollar value, it becomes 0.092. A lower operating cost multiplier is used for the Mobil plant case to reflect the expected lower maintenance required for this plant due to the elimination of much of the product

TABLE 4-3

A SUMMARY OF ITEMIZED CONSTRUCTION COSTS FOR BGC/MOBIL PLANT--LOW WAX CASE
(IN MM$, 1983)

	BGC-MOBIL	
	Mixed Output	All-Liquid Output
Coal and Ash Handling	115	115
Synthesis Gas Preparation	364.6	364.6
Gasification	161.6	161.6
Raw Gas Shift	18.3	18.3
Gas Cooling and Cleaning	184.7	184.7
By-Product Recovery	81.1	81.1
Sulfur Recovery	39.5	39.5
Gas/Liquor Separation and Product Recovery	41.6	41.6
F-T Synthesis	311.5	402.0
Synthesis Reactor	276.0	356.0
Catalyst Preparation	35.5	46.0
F-T Product Upgrading	200.1	248.3
Gasifier Naphtha Treatment	21.4	21.4
SNG Preparation or Reforming	30.0	
F-T Liquid Product Recovery	148.7	176.0
Autothermal Reforming		50.9
Wax Hydrotreating		
Offsites and Miscellaneous	628.7	691.2
Oxygen Plant	202.7	243.2
Steam Plant	233.4	255.4
Wastewater Treatment	18.5	18.5
Power Generation	17.1	17.1
Interconnecting Piping, Infrastructure, and Other Miscellaneous	157.0	157.0
TOTAL INSTANTANEOUS CONSTRUCTION COST	1,701.1	1,902.2

TABLE 4-4

ECONOMIC DATA FOR THE BGC/MOBIL LOW-WAX CASE

	BGC/MOBIL	
	Mixed Output	All-Liquid Output
Plant Costs and Revenue, MM$, 1983		
Total Construction Cost	1,701	1,902
Total Capital Cost	2,705	3,024
Annual Capital Charge	717	801
Coal Cost	73	73
ZSM-5 Catalyst Cost	5	5
Operating Cost	241	269
By-Product Cost	(10)	(10)
Annual Revenue Requirement	1,026	1,138
Plant Output		
Annual Thermal Output, MMBtu/yr (LHV)	87,199,200	73,378,800
Gasoline Equivalent, Barrels/yr	14,710,177	14,994,341
Unit Product Cost		
Thermal Basis, $/gallon ($/MMBtu)	1.31 (11.77)	1.72 (15.51)
Market Basis, $/gallon	1.66	1.81

refinery section. The resulting multiplier for the Mobil plant case is thus estimated to be 0.089.

No ZSM-5 catalyst life or cost figures were provided by MRDC for their two-stage SFT/ZSM-5 process. These figures, therefore, are based on catalysts with similar nature. Thus, the annual cost for ZSM-5 catalyst is estimated to be $5.0 MM, assuming a catalyst cost of $40 per pound and a catalyst charge of 400,000 pounds every three years. Reducing catalyst cost to $10 per pound represents less than 0.5-percent change in product cost.

From Table 4-4, the total annual operating cost for the Mobil plant is $309 MM for the mixed-output operating mode, after allowing for a by-product revenue credit of $10 MM per year. The operating cost per year for the Mobil case in the all-liquid operating mode is $337 MM.

4.4.3 Annual Revenue Requirement

The revenue requirements for the Mobil and conceptual low-wax plants are calculated as the sum of the net annual operating costs and the annual capital charges shown in Table 4-4. In each case, the annual capital charge is the product of the total capital cost (i.e., total investment) and a capital charge factor of 0.265 determined by using a MITRE simplified discounted cash flow, DCF program on the basis of the tax data and financial assumptions listed in Table 4-5.

TABLE 4-5

TAX DATA AND FINANCIAL ASSUMPTIONS - 100% EQUITY

(1) Plant operating life at 20 years

(2) Depreciable life - 13 years

(3) Investment tax credit at 7% in year of expenditure

(4) Construction timing - 6 years

(5) Depreciation - Sum of the year digits

(6) Income Tax - 51.9%

(7) Startup penalty - 50% production in first operating year

(8) Unit cost basis at 12 DCF

Source: MTR-80W326

4.4.4 Unit Product Cost

Table 4-4 shows the cost of gasoline from the candidate plants for two different bases of estimation. The computation of gasoline cost on a thermal basis assumes that all products are sold at the same price on a Btu basis. One million Btus of SNG would thus have the same value as one million Btus of gasoline or the other liquid fuel products. On this basis, the previously estimated annual revenue requirement would be realized if the cost of one million Btu of any product of the Mobil plant is $11.77 for the mixed-output mode and $15.51 for all-liquid output mode.

The thermal basis for estimating the unit product cost will result in an unrealistic cost for SNG of about $12 per million Btu. This cost is more than twice the normal market-place selling price for SNG of less than $5.0 per MMBtu. If the SNG, which constitutes about 40 percent of thermal output of the Mobil plant, must be sold for a lower, more realistic price, then a substantial premium must be added to the price of liquid products, in order to realize the estimated annual revenue requirement.

On a market basis, all products other than gasoline are priced according to their value relative to gasoline. The relative values are indicated in Table 4-6. The product costs for gasoline from both Mobil plants are, under these assumptions, substantially higher. As shown in Table 4-4, the differences between the gasoline costs on thermal basis and those determined on market basis is more pronounced

TABLE 4-6

GASOLINE EQUIVALENT FACTOR*

Product	Barrels of Gasoline Equivalent	Btu Equivalent
SNG (MMSCFD)	96.5	.5
Gasoline	1.0	1.0
C_3	0.758	1.0
C_4	0.861	1.0
Diesel Oil	0.95	.89
Heavy Fuel Oil	0.57	.50
Alcohol	0.73	1.0
Wax	0.62	.50

*In order to calculate product costs, the volumes of each fuel are adjusted based on their value versus gasoline, using factors listed in Column 1. The SNG conversion is based on MMSCF. The total number of adjusted barrels of all fuels in gallons is divided into the required revenue to calculate dollars/gallon of equivalent gasoline in Tables 1 and 2 for the market basis values.

in the mixed-output mode where the SNG represents a significant percentage of the thermal output.

4.5 Comparison with Reference Fischer-Tropsch Plants

Table 4-7 compares the Mobil plant with SASOL(U.S.) and the BGC-Synthol reference plants employing conventional F-T technology. The beneficial cost impact of the combined advanced gasifiers and the improved SFT synthesis and ZSM-5 upgrading technology in the Mobil plant becomes obvious when the Mobil plant is compared with the SASOL(U.S.) plant in Table 4-7. On a market basis, the Mobil plant unit product cost is 30- to 26-percent lower than that of the SASOL(U.S.), depending on the mode of operation, whether all-liquid or mixed-output. The separate cost effect of the advanced synthesis and upgrading technology in the Mobil plant can be determined by comparing the Mobil plant to the BGC/Synthol plant. In this comparison, the Mobil plant unit product cost, on a market basis, is 13-percent lower than that of the BGC/Synthol plant, independent of the mode of operation.

Table 4-8 compares the Mobil plant with the economic performance of the reference BGC/Koelbel plant. Operating data for this plant were obtained from Reference 4. This slurry-phase Fischer-Tropsch unit was operated to produce a maximum yield of gasoline range hydrocarbons. The low-wax Mobil plant approaches the product cost on a market basis of the Koelbel plant by 3 percent in the mixed mode and 6 percent in the all-liquid mode.

TABLE 4-7

A SUMMARY OF THE COMPARATIVE COST DATA FOR MOBIL LOW-WAX PLANT CASE AGAINST CONVENTIONAL FISCHER-TROPSCH PLANTS

Plants Compared / Items of Comparison	SASOL (U.S.) Mixed Output	SASOL (U.S.) All-Liquid Output	BGC SYNTHOL Mixed Output	BGC SYNTHOL All-Liquid Output	BGC-MOBIL Mixed Output	BGC-MOBIL All-Liquid Output
Plant Costs and Revenue, MM$, 1983						
Total Construction Cost	1,910	2,226	1.778	2,076	1,701	1,902
Total Capital Cost	3,037	3,540	2,827	3,301	2,705	3,024
Annual Capital Charge	805	938	749	876	717	801
Coal Cost	73	73	73	73	73	73
ZSM-5 Catalyst Cost					5	5
Operating Cost	279	326	260	304	241	269
By-Product Cost	(10)	(10)	(10)	(10)	(10)	(10)
Annual Revenue Requirement	1,147	1,329	1,072	1,243	1,026	1,138
Plant Output						
Annual Thermal Output (MMBtu/year, LHV)	81,163,000	62,008,000	85,973,580	69,599,000	87,199,200	73,378,800
Gasoline Equivalent (Bbls/year)	11,584,000	12,758,000	13,342,439	14,319,507	14,710,177	14,994,341
Unit Product Cost						
Thermal Basis, $/gallon	1.57	2.38	1.38	1.98	1.31	.72
Market Basis, $/gallon	2.36	2.48	1.91	2.07	1.66	31

TABLE 4-8

COMPARATIVE DATA FOR THE BGC/KOELBEL PLANT
AND THE BGC/MOBIL PLANT--LOW-WAX CASE

	BGC/KOELBEL		BGC/MOBIL	
	Mixed Output	All-Liquid Output	Mixed Output	All-Liquid Output
Plant Costs and Revenue, MM$, 1983				
Total Construction Cost	1,719	1,900	1,701	1,902
Total Capital Cost	2,733	3,021	2,705	3,024
Annual Capital Charge	724	801	717	801
Coal Cost	73	73	73	73
ZSM-5 Catalyst Cost	--	--	5	5
Operating Cost	251	278	241	269
By-Product Cost	(10)	(10)	(10)	(10)
Annual Revenue Requirement	1,038	1,142	1,026	1,138
Plant Output				
Annual Thermal Output, MMBtu/year (LHV)	86,935,530	76,546,140	87,199,200	73,378,800
Gasoline Equivalent, Barrels/year	15,345,634	16,053,733	14,710,177	14,994,341
Unit Product Cost				
Thermal Basis, $/gallon ($MMBtu)	1.32 (11.9)	1.66 (14.92)	1.31 (11.77)	1.72 (15.51)
Market Basis, $/gallon	1.61	1.70	1.66	1.81

4.6 MITRE Analysis of Low-Wax Case

As noted previously, MITRE conducted an independent evaluation of the new Mobil BSU data for the low-wax case. Transformation of this raw bench-scale data into estimated commercial-scale performance involves computations of elemental, material and energy balances which have resulted in different estimates of product selectivity, output, and efficiency than from the Mobil Scoping Study.[(1)] As already indicated in Section 3.0, the selected set of data for the MITRE version of Mobil low-wax case resulted in a more conservative thermal efficiency. The product selectivity in the MITRE version was also more representative of what was actually realized in the BSU test runs conducted by MRDC.

The cost impact of the MITRE version is compared in Table 4-9 with the corresponding figures for the Mobil low-wax case. As indicated in this table, the MITRE version of the Mobil low-wax case results in a slightly lower capital cost, operating cost, and revenue requirement. Because of its lower thermal output, however, the MITRE version of the Mobil low-wax case results in a 4-percent higher product cost on a market basis in the mixed-output mode. In the all-liquid mode, however, the MITRE and Mobil versions differ by only one percent. It should be noted that in the Mobil case, isobutane is imported to balance the alkylate yield. The thermal value of this import is netted off the thermal outputs for the Mobil case.

TABLE 4-9

A SUMMARY OF THE COMPARATIVE COST DATA FOR MOBIL LOW-WAX CASE AGAINST MITRE-MOBIL LOW-WAX CASE

Plants Compared	MITRE DESIGN OF MOBIL LOW-WAX CASE		BGC/MOBIL LOW-WAX CASE	
Items of Comparison	Mixed Output	All-Liquid Output	Mixed Output	All-Liquid Output
Plant Costs and Revenue, MM$, 1983				
Total Construction Cost	1,678	1,873	1,701	1,902
Total Capital Cost	2,668	2,978	2,705	3,024
Annual Capital Charge	707	789	717	801
Coal Cost	73	73	73	73
ZSM-5 Catalyst Cost	5	5	5	5
Operating Cost	237	265	241	269
By-Product Revenue	(10)	(10)	(10)	(10)
Annual Revenue Requirement	1,012	1,122	1,026	1,138
Plant Output				
Annual Thermal Output, MMBTU/yr (LHV)	84,276,720	71,010,720	87,199,200	73,378,800
Gasoline Equivalent, Barrels/yr	13,927,741	14,542,147	14,710,177	14,994,341
Unit Product Cost				
Thermal Basis, $/gallon ($/MMBtu)	1.33 (12.0)	1.75 (15.8)	1.31 (11.77)	1.72 (15.51)
Market Basis, $/gallon ($/MMBtu)	1.73	1.83	1.66	1.81

4.7 Comparative Economic Evaluation of Mobil High-Wax Case

The original Mobil BSU test run CT-256-4 for the high-wax case, suffered a number of operational upsets and loss of catalyst and resulted in a low conversion of syngas ($CO + H_2$) per pass of about 40 percent. As such, it was not considered suitable for the purpose of this study. Instead, MRDC provided the results of a simulated modified test run CT-256-4 which had a higher conversion per pass of over 85 percent and was therefore used by MITRE to conduct the following analysis. The simulated run data was substantiated in an ongoing run in the Mobil BSU.

4.7.1 Capital Cost Requirement

No cost data or process flows were provided by MRDC for the high-wax case. As for the Mobil low-wax plant, the capital cost requirement for the high-wax case was therefore determined by MITRE as 1.59 times the total instantaneous construction cost shown in Table 4-10. In this table, the itemized construction cost is determined by the same costing method used for the low-wax case and detailed in Appendix A. The only exception is the construction cost for the wax hydrotreatment unit. The cost for this unit is prorated from the cost in a Chevron study[6] for an SRC-II Syncrude hydrocracking unit which can handle 30,000 barrels per day after adjusting it to a 1983 dollar value. The itemized costs shown in Table 4-10 for the Mobil high-wax plant also reflect the necessary modification in the capacity of the different sections of that plant compared to the corresponding sections in the Mobil low-wax plant.

TABLE 4-10

A SUMMARY OF ITEMIZED CONSTRUCTION COSTS FOR
BGC/MOBIL HIGH-WAX CASE

(MM$, 1983)

	Mixed Output	All-Liquid Output
Coal and Ash Handling	115.00	115.00
Synthesis Gas Preparation	364.60	364.60
Gasification	161.60	161.60
Raw Gas Shift	18.30	18.30
Gas Cooling and Cleaning	184.70	184.70
By-Product Recovery	81.10	81.10
Sulfur Recovery	39.50	39.50
Gas/Liquor Separation and Product Recovery	41.60	41.60
F-T Synthesis	315.00	397.00
Synthesis Reactor	279.00	352.00
Catalyst Preparation	36.00	45.00
F-T Product Upgrading	214.80	287.40
Gasifier Naphtha Treatment	21.40	21.40
SNG Preparation or Reforming	29.00	-
F-T Liquid Product Recovery	133.40	177.00
Autothermal Reforming	-	49.50
Wax Hydrotreater	31.00	39.50
Offsites and Miscellaneous	628.70	691.20
Oxygen Plant	202.70	243.20
Steam Plant	233.40	255.40
Wastewater Treatment	18.50	18.50
Power Generation	17.10	17.10
Interconnecting Piping, Infrastructure, and Other Miscellaneous	157.00	157.00
TOTAL INSTANTANEOUS CONSTRUCTION COST	1,718.00	1,936.30

Other modifications will also be necessary as a result of the additional wax hydrocracking products such as SNG, diesel oil, and gasoline. These products must be accommodated for by proper adjustment of product recovery and fractionation unit as well as the storage capacity of the Mobil low-wax plant. The impact of all these modifications on the itemized construction cost of the Mobil high-wax plant is indicated in Table 4-11 in comparison with the corresponding cost figures for the Mobil low-wax plant.

4.7.2 Operating Cost

Table 4-12 shows a comparison of the high-wax and low-wax cases. The additional wax processing (i.e., hydrocracking) required in the high-wax case increases the complexity and cost of the Mobil high-wax plant and hence increases its maintenance, labor cost, and other capital-related costs. It is, therefore, assumed that the operating cost in the high-wax case amounts to 9.2 percent of its capital cost, as was assumed earlier for the BGC-Koelbel reference case.

The cost of wax hydrocracking catalyst is an additional operating cost to the high-wax case. This catalyst cost is estimated on the basis of cost data provided by Chevron[6] for that catalyst. The total operating cost for the high-wax case thus ranges from $321 MM for the mixed-output operating mode, to $353 MM for the all-liquid output mode. Both these operating costs are about 3-percent higher than the corresponding costs for the low-wax case.

TABLE 4-11

A SUMMARY OF ITEMIZED CONSTRUCTION COSTS FOR BGC/MOBIL PLANT
LOW-WAX VS. HIGH-WAX (MM$, 1983)

	LOW-WAX		HIGH-WAX	
	Mixed Output	All-Liquid Output	Mixed Output	All-Liquid Output
Coal and Ash Handling	115	115	115	115
Synthesis Gas Preparation	364.6	364.6	364.6	364.6
Gasification	161.6	161.6	161.6	161.6
Raw Gas Shift	18.3	18.3	18.3	18.3
Gas Cooling and Cleaning	184.7	184.7	184.7	184.7
By-Product Recovery	81.1	81.1	81.1	81.1
Sulfur Recovery	39.5	39.5	39.5	39.5
Gas/Liquor Separation and Product Recovery	41.6	41.6	41.6	41.6
F-T Synthesis	311.5	402.0	315.0	397.0
Synthesis Reactor	276.0	356.0	279.0	352.0
Catalyst Preparation	35.5	46.0	36.0	45.0
F-T Product Upgrading	200.1	248.3	214.8	287.4
Gasifier Naphtha Treatment	21.4	21.4	21.4	21.4
SNG Preparation or Reforming	30.0		29.0	
F-T Liquid Product Recovery	148.7	176.0	133.4	177.0
Autothermal Reforming		50.9		49.5
Wax Hydrotreating			31.0	37.5
Offsites and Miscellaneous	628.7	691.2	628.7	691.2
Oxygen Plant	202.7	243.2	202.7	243.2
Steam Plant	233.4	255.4	233.4	255.4
Wastewater Treatment	18.5	18.5	18.5	18.5
Power Generation	17.1	17.1	17.1	17.1
Interconnecting Piping, Infrastructure, and Other Miscellaneous	157.0	157.0	157.0	157.0
TOTAL INSTANTANEOUS CONSTRUCTION COST	1,701.0	1,902.2	1,718.0	1,936.0

TABLE 4-12

COMPARATIVE DATA FOR THE MOBIL LOW- AND HIGH-WAX CASES

Plants Compared / Items of Comparison	HIGH-WAX Mixed Output	HIGH-WAX All-Liquid Output	LOW-WAX Mixed Output	LOW-WAX All-Liquid Output
Plant Costs and Revenue (MM$, 1983)				
Total Construction Cost	1,718	1,936	1,701	1,902
Total Capital Cost	2,732	3,079	2,705	3,024
Annual Capital Charge	724	816	717	801
Coal Cost	73	73	73	73
Operating Cost	251	283	241	269
ZSM-5 Catalyst	5	5	5	5
Hydrotreatment Catalyst	2	2	-	-
By-Product Revenue	(10)	(10)	(10)	(10)
Annual Revenue Requirement	1,045	1,169	1,026	1,138
Plant Output				
Annual Thermal Output (MMBtu/yr)	88,292,160	75,200,400	87,199,200	73,378,800
Gasoline Equivalent (Bbls/yr)	14,796,452	15,408,620	14,710,177	14,994,341
Unit Product Cost				
Thermal Basis, $/gal ($MMBtu)	1.31(11.83)	1.73(15.5)	1.31(11.77)	1.72(15.51)
Market Basis, $/gal	1.68	1.80	1.66	1.81

4.7.3 Annual Revenue Requirement

The annual revenue requirement for the Mobil high-wax case is determined in the same way as for the low-wax case. A capital charge rate of 0.265 is thus applied to determine the annual capital charge component of the total revenue requirement for the high-wax case. This capital charge rate is based on the same tax data and financial assumptions listed in Table 4-5.

The annual revenue requirement is determined as the sum of the annual capital charge and the previously determined total operating costs. For the high-wax case, these revenues are estimated to be $1,045 MM for the mixed-output mode of operation and $1,169 MM for the all-liquid mode. As indicated in Table 4-12, these revenue requirements are higher than the corresponding figures for the low-wax case.

4.7.4 Unit Product Cost

As previously indicated in the low-wax case, the unit product cost differs with the basis of estimation, whether thermal or market basis. On a thermal basis, the cost per MMBtu for Mobil high-wax case ranges from $11.83 to $15.5 depending on the mode of operation (i.e., mixed-output or all-liquid) as compared to a range of $11.77 to $15.51 for the low-wax case.

The relative gasoline equivalent factors shown in Table 4-6 are used to determine the market basis unit product cost for the high-wax case in a similar fashion to that used for the low-wax case. As shown in Table 4-12, the unit product costs for the high-wax case on a market basis are very slightly higher than the corresponding unit cost figures for the low-wax case for the mixed-output mode. For the all-liquid mode, however, the unit product costs are almost identical.

It should be noted that the relative market gasoline cost basis for the high-wax and low-wax cases is influenced by product make assumptions, particularly by the relative value of gasoline and diesel fuel. We have assumed that the diesel fuel value is 95 percent of the value of gasoline on a barrel basis, which approximates the present pricing structure for the two products. If the U.S. fuel market shifts toward diesel oil in the future, as many analysts anticipate, then the relative price of diesel will escalate, since the cost of producing diesel from other than the straight-run distillate fraction of crude is relatively high. The diesel produced from the Mobil high-wax plant might, in fact, command a considerable premium in a high diesel demand scenario, since it is of excellent quality (65 to 75 cetane number) and could serve as a blending stock for the upgrading of marginal crude-derived diesel fuels.

To investigate these possibilities, we have computed gasoline costs for two diesel price alternatives--one in which gasoline and diesel are considered to be equivalent on a $/Bbl basis, and one in which the two products are equivalent on a $/Btu basis. In the latter case, the $/Bbl value of diesel is 6.6-percent higher than that of gasoline.

The results of this analysis are graphically illustrated in Figure 4-5 for the all-liquid output configuration for the BGC/Koelbel and high-wax Mobil plants. (The computed cost of gasoline from the Mobil plant is not affected by the assumed diesel value, since no diesel is produced.) In the Mobil high-wax case, however, diesel makes up almost 40 percent of the total output. An increase in the price of diesel relative to gasoline thus results in a sizeable reduction in the gasoline price required to meet plant revenue requirements. If diesel and gasoline prices are equivalent or greater on a $/Btu basis, the required selling price (e.g., cost) of gasoline from the Mobil high-wax plant would be slightly lower than from the Koelbel slurry F-T plant.

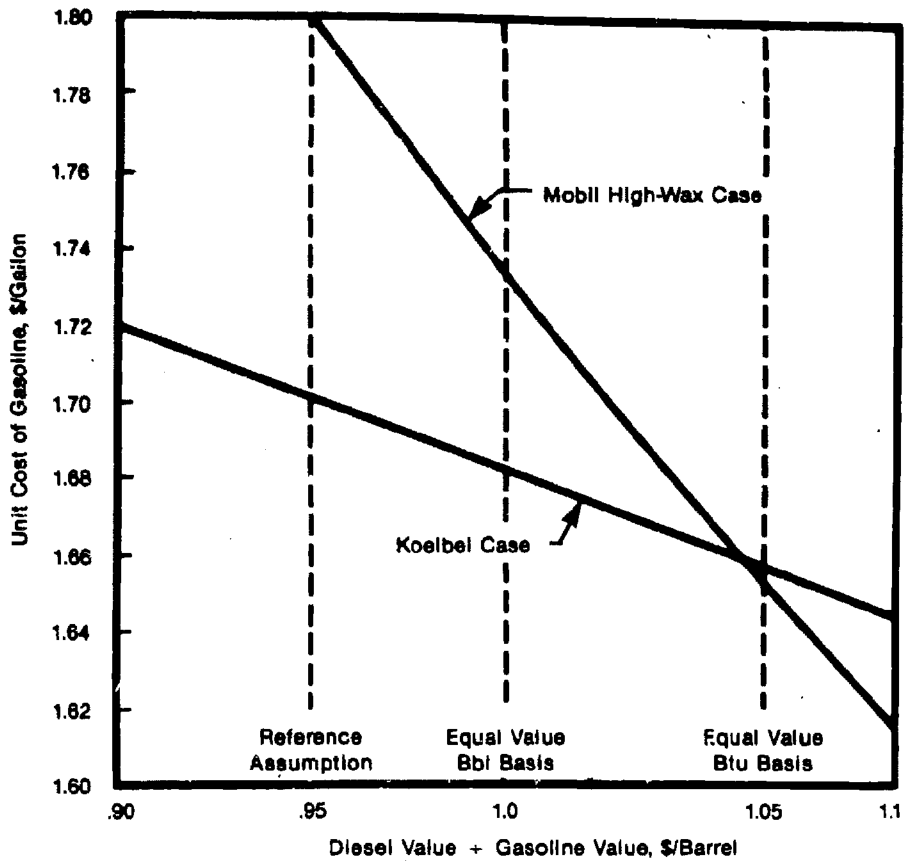


FIGURE 4-5
SENSITIVITY OF GASOLINE COST TO DIESEL VALUE ASSUMPTIONS FOR ALL-LIQUID PLANT CONFIGURATION

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