ABSTRACT

The primary purpose of this study is to provide a technical and economic comparison between the commercial Fischer-Tropsch technology and the new Mobil methanol-to-gasoline technology for the production of motor gasoline. Several technical sensitivity cases are also part of the study.

Two conceptual plant complexes - Base Case I: Mobil Technology and Base Case II: Fischer-Tropsch Technology - have been developed. They are self-supporting, grass roots facilities assumed to be located in a Wyoming coal field. Plant size is equivalent to the proposed large commercial SNG plants. Except for the Mobil methanol conversion technology, all processes used are commercial. Co-production of all products has been assumed. Products have been upgraded to meet U.S. market specifications.

A summary comparison between the two base cases is as follows:

	Base Case I	Base Case II
Technology	Mobil Methanol Conversion	Fischer-Tropsch
Net Coal Input, MST/SD	26.1	27.7
Product Output, Bbl/SD(1)	50,075	48,760
SNG, %	48.5	59.4
Gasoline, %	44.0	27.9
Others, %	7.5	12.7
Thermal Efficiency (HHV), %	62	58
Processing Steps (2)	9	18

(1) SNG converted to barrels FOE @ 6.0 MMBtu/Bbl
(2) From clean syn gas to final co-products

The Mobil technology is somewhat more efficient and more effective in producing gasoline. Moreover, the number of processing steps required is considerably fewer.

All products meet the target specifications.

The technical discussions of the sensitivity cases and the economic phase of the study will be added in the final report.

SUMMARY

The following interim report only covers the technical development of the two base cases. In the final report, the technical development of the sensitivity cases, the economic phase and the conclusions will be added.

The primary purpose of this scoping study is to provide a technical and economic comparison between the commercial Fischer-Tropsch technology and the new Mobil methanol-to-gasoline technology for the production of motor gasoline. The primary coal gasification step uses the commercial Lurgi dry-ash, moving-bed pressure gasifier. Several technical sensitivity cases are also part of the investigation. The base and sensitivity cases developed are summarized below:

	Base Cases I	Base Cases II	Sensitivity Cases I-A	Sensitivity Cases I-B	Sensitivity Cases I-C	Sensitivity Cases I-D	Sensitivity Cases II-A
Capacity Basis	Constant Syngas	Constant Syngas	Constant Syngas	Constant Syngas	Constant Syngas	BaseCaseI Gasoline	Constant Syngas
Technology							
Gasification*	L	L	L	L	L	W	L
Conversion	Mobil Fixed Bed	Fischer-Tropsch	MeOH only	Mobil Fixed Bed	Mobil Fluid Bed	Mobil Fixed Bed	Mobil Direct Route
Major Products							
SNG	X	X	X	-	X	-	X
Gasoline etal	X	X	-	X	X	X	X
Methanol	-	-	X	-	-	-	-

*L - Commercial Lurgi moving-bed pressure gasifier.
W - Winkler fluid-bed pressure gasifier under development.

The study bases adopted, essentially, follow those established in "Coal Gasification Commercial Concepts Gas Cost Guidelines", Reference 1. The conceptual plant complex developed for each case is a self-supporting, grass roots facility, assumed to be located adjoining a strip mine in Wyoming. Plant size is equivalent to the large 280 MMSCF/SD commercial SNG plants under consideration for Western coal. Except for the Mobil technology, all processes used are commercially available.

Co-production of all products has been generally assumed. No marketing restrictions have been imposed. Products, however, have been upgraded to meet U.S. market specifications, or in the case of SNG, to be interchangeable with pure methane.

The overall material balances for Base Case I and II are shown below:

Technology	Case I Mobil Methanol Conversion	Case II Fischer-Tropsch
Input		
Coal, as received, T/SD	27,334	27,698
Water, gpm	8,320	8,750
Output		
SNG, MMSCF/SD	148.5	173.3
C_3 LPG, Bbl/SD	1,555	1,107
C_4 LPG, Bbl/SD	2,205	146
10 RVP Gasoline, Bbl/SD	22,045	13,580
Diesel Oil, Bbl/SD	--	2,307
Heavy Fuel Oil, Bbl/SD	--	662
Alcohols, Mlb/SD	--	510
Sulfur, T/SD	61	61
Ammonia, T/SD	102	102
Coal Fines (excess), T/SD	1,230	0
Power (excess), MW	6.0	6.0
Thermal Efficiency (HHV), %	62.2	57.8

The Mobil technology is somewhat more efficient and more effective in producing gasoline. The different yield patterns of the two technologies are readily seen. A higher hydrocarbon liquid/SNG thermal split (HHV) is obtained with the Mobil technology.

	HC Liquid/SNG
Case I:	47/53
Case II:	34/66

The steam/power balance is satisfactory for both cases as only minor amounts of surplus power are obtained. In Case I, the thermal balance does not require the usage of all the coal fines produced during coal crushing. Greater energy requirements result in an additional 1,594 T/SD of coal being fired in Case II. For both cases, about 6 barrels of water are required per barrel of total FOE product.

The plant complexity necessary to convert the synthesis gas into marketable products is much greater when using the Fischer-Tropsch technology. The conceptual plant designs call for 18 units in Case II compared to only 9 units in Case I.

The SNG properties are summarized below:

Technology	Case I Mobil Methanol Conversion	Case II Fischer-Tropsch
Composition, %		
H_2	1.7	3.8
C_1	95.5	89.7
$C_2=$	--	1.0
C_2	0.2	2.3
$C_3=$	--	1.0
C_3	0.1	0.1
C_4	0.1	--
CO_2	0.5	0.5
Inerts	1.9	1.6
	100.0	100.0
Heat of Combustion (HHV), Btu/SCF	980	1,003
Compatibility Indexes (vs. Pure Methane)		
Lifting (I_1)	1.03*	0.99
Flash-Back (I_f)	1.02	1.06
Yellow-Tip (I_y)	1.05	0.97*

*Between preferable and objectionable values.

The SNG compositions differ reflecting the nature and amount of the offgases from the methanol conversion and Fischer-Tropsch sections. Both appear interchangeable with pure methane.

The estimated unleaded 10 RVP gasoline properties are in summary:

Technology	Case I Mobil Methanol Conversion	Case II Fischer-Tropsch	Target
Gravity, °API	61.4	67.2	--
Octane, Unleaded			
Research	93	91	--
Motor	83	83	82 min.
(R+M)/2	88	87	87 min.
Volatility			
Reid Vapor Pressure, lb.	10	10	--
V/L Ratio (=20), °F	@ 129.5	@ 127.3	@ 140 max.
Composition			
Olefin, %	11	20	20 max.
Durene, %	4.6	--	5 max.

Both gasolines meet all target specifications. Case I gasoline, however, bests the octane targets by one number.

The F-T fuel oils are of excellent quality, except perhaps their somewhat high cloud (pour) points. The diesel fuel could be marketed under specifications for engines in service requiring frequent speed and load changes. The clean, non-metal heavy fuel oil would be a superior turbine fuel.

Further investigation of the cooling tower design parameters, after the completion of this report, has reduced significantly the fresh water requirements. In addition, offsite unit vendors have provided more accurate utility requirements for their units. These data will be incorporated in the final report.

SECTION 1
STUDY SCOPE

This study has been prepared as a joint effort by Mobil Research and Development Corporation, Lurgi Mineraloeltechnik GmbH and American Lurgi Corporation.

1.1 BASE CASES

The primary purpose of this scoping study is to provide a technical and economic comparison between the commercial Fischer-Tropsch technology and the Mobil methanol-to-gasoline technology for the production of motor gasoline from a U.S. coal. The primary coal gasification step uses the Lurgi dry-ash, moving-bed pressure gasifier.

Base Case I is the co-production of gasoline and SNG using the Mobil methanol-to-gasoline technology currently being developed through joint funding by ERDA and Mobil Research and Development Corp. The methanol is first produced from the coal derived synthesis gas.

Base Case II is the co-production of gasoline and SNG using the state-of-the-art Sasol-type Fischer-Tropsch technology. The F-T products undergo extensive upgrading to become marketable under U.S. specifications.

1.2 SENSITIVITY CASES

In addition to the above base cases, the following technical sensitivity cases have also been evaluated:

Case I-A uses the same technology and synthesis gas production as in Base Case I, except the Mobil methanol-to-gasoline technology is eliminated and methanol and SNG are the co-products.

Case I-B uses the same technology and synthesis gas production as in Base Case I except the co-production of SNG is eliminated. A reforming unit converts methane into synthesis gas which is recycled to produce additional methanol and, ultimately, additional gasoline.

Case I-C uses the same technology and synthesis gas production as in Base Case I except the Mobil methanol-to-gasoline process uses a fluid-bed reactor in place of the fixed-bed reactor used in Base Case I.

Case I-D uses the non-commercial Winkler fluid-bed pressure gasification technology in place of the commercial Lurgi gasification technology. The Winkler technology is under active development in Germany. The methanol synthesis was adjusted for the different synthesis gas composition. The gasification and methanol synthesis steps yield the same quantity of methanol as obtained in Base Case I. Because of the low methane production in the Winkler gasifier, SNG manufacture has been eliminated.

Case II-A uses the same technology and synthesis gas production as in Base Case II except the Mobil direct route technology currently under development through joint funding by ERDA and Mobil Research and Development Corp. is substituted for the Sasol-type Fischer-Tropsch.

1.3 PLANT COMPLEX DEFINITION

For each base case, a conceptual plant complex has been developed. This complex is a self-supporting, grass roots facility encompassing all process and offsite units. Except for the Mobil and Winkler technologies, all technologies used in the plant design are commercially available. Location has been assumed to be adjacent a strip coal mine in the State of Wyoming. Products manufactured are available at the plant gate for shipment to the market place.

1.4 DATA SOURCES

The process information contained in this scoping study is based on either published or licensor data. (See References.) Much of the coal gasification information was derived from the proposed commercial Western SNG plants. In fact, the conceptual plant complexes developed in this study are nearly identical to these plants up through the production of clean synthesis gas. The combining of the processes used to obtain marketable SNG and gasoline from the synthesis gas, for the most part, is based on the in-house experience of the study participants. Licensors were not contacted for information specific to this report.

No process or design optimization back-up studies have been made. In addition, no specific laboratory work was done for this study. As needed, in-house correlations, data banks, engineering programs, cost estimating programs, etc., were used.

Investment estimates are principally derived from in-house data. Where obtainable, vendor quotes, however, have been used for the offsite units.

1.5 SCOPE OF WORK

The work performed for each of the two base cases includes:

- material balance
- utility balance
- plant thermal efficiency
- block flow diagram
- simplified process flow diagrams
- equipment lists with major equipment dimensions

Each process unit is identified and briefly described with pertinent design considerations indicated. For the hydrocarbon upgrading processes, a technology critique is also included. In addition, the design bases used for the methanol-to-gasoline and the Fischer-Tropsch units have been outlined in some detail.

For each sensitivity case, the work performed has been reduced to include only:

- overall simplified material balance
- approximate utility balance
- plant thermal efficiency
- simplified block flow diagram

Discussion is limited to the changes in the base case brought about by the sensitivity. The discussion of the Winkler pressure gasifier and its application in Sensitivity Case I-D, as supplied by the Davy Powergas Inc., however, is included in Appendix C.

Scoping or budget quality investment estimates have been developed for the base cases. The investment for each process and offsite unit is identified. Estimates of the manpower catalyst requirements and chemical wages are also provided. The investment estimates for the sensitivity cases, for the most part, have been factored from the base cases. New sensitivity unit investments, e.g., Winkler gasifier, have been developed.

The plant complex economics have been calculated using both utility financing and private investor financing. Sensitivity of the unit cost towards coal price, SNG price, byproduct values and investment and operating cost shifts has also been developed for the base cases. An abbreviated economic analysis is presented for the sensitivity cases.

1.6 UNIT SUMMARY - BASE CASES

The plant complex is comprised of a series of inter-connected process units, utility and support facilities (offsite units) and general plant facilities (infrastructure) as defined below:

PROCESS UNITS

Unit No.	Description
	Base Case I
101	Gasification (Lurgi Coal Pressure Gasification)
102	Raw Gas Shift
103	Raw Gas Cooling
104	Shifted Gas Cooling
105	Gas Purification (Rectisol)
106	Sulphur Recovery (Stretford)
107	Gas Liquor Separation
108	Phenol Recovery (Phenosolvan)
109	Ammonia Recovery (Chemie Linz/Lurgi)
110	Methanol Synthesis (Lurgi Low Pressure Process)
111	H_2 Recovery (Pressure Swing)
112	Methanation
113	CO_2 Recovery (MEA Wash)
114	SNG Drying (TEG Wash)
150	Methanol Conversion (Mobil)
151	Naphtha Hydrotreating
152	Fractionation
153	HF Alkylation
	Base Case II
201 to 209	Identical to Base Case I
210	Hydrocarbon Recovery (Heptane Wash)
211	H_2 Recovery (Pressure Swing)
212	Methanation
213	CO_2 Removal (MEA Wash)
214	SNG Drying (TEG Wash) and Compression
250	F-T Synthesis
251	Naphtha Hydrotreating
252	F-T Product Fractionation
253	F-T Product Hydrotreating
254	Hydrotreated Product Fractionation
255	Catalytic Reforming
256	C_5/C_6 Isomerization
257	Catalytic Polymerization
258	HF Alkylation
259	Poly Gasoline Hydrogenation
260	Light Ends Recovery
261	H_2 Purification
262	Alcohol Recovery

OFFSITE UNITS
(Base Case I and II)

Unit No.	Description
121/221	Oxygen Production (Air Separation)
122/222	Boiler
123/223	Main Superheater
124/224	Superheater
125/225	Electrostatic Stackgas Precipitator
126/226	Stackgas Clean-Up
127/227	Instrument and Plant Air
128/228	Coal Handling
129/229	Ash Handling
131/231	BFW Preparation (Deaerator & Demineralizer)
132/232	CW Make-Up Preparation
133/233	CW Towers
134/234	Electric Power Generation
135/235	Waste Water Treatment (Biological)
136/236	Relief and Blow Down Facilities
137/237	Storage
138/238	Interconnecting Piping
141/241	Refrigeration Unit
154/270	Gasoline Blending
271	F-T Catalyst Preparation

INFRASTRUCTURE
(Base Case I and II)

Office Buildings
Cafeteria
Maintenance Shops
Warehouse
Laboratory
Fire Protection System
Electric Distribution System
Truck and Railroad Unloading/Loading Facilities
Sewers
Roads and Parking Lots
Fencing
General Lighting
Communication and Security

SECTION 2
STUDY DESIGN BASES

Where applicable, the plant design bases adopted for this study are generally those established by C.F. Braun & Co. for ERDA in "Coal Gasification Commercial Concepts Gas Cost Guidelines" (Reference 1). A discussion of the principal bases follows.

2.1 PLANT CAPACITY

For both base cases, the plant capacity is based upon the gasification of 1,272 Mlb/hr of DAF coal. This amount of coal produces 742 MMSCF/SD of dry, purified synthesis gas for feed to methanol synthesis (Base Case I) or feed to Fischer-Tropsch synthesis (Base Case II). For reference, this capacity is equivalent to the capacity of the large 280 MMSCF/SD commercial SNG plants under consideration for the United States and, thus, is similar to the Guidelines plant size.

In the sensitivity cases, the gasification rate and synthesis gas yield are the same as used in the base cases, except for Sensitivity Case I-D. In this sensitivity, the 10 RVP gasoline product is the same as the Base Case I.

Because of differing energy requirements, the total coal charge, however, is not the same among the various cases.

2.2 DESIGN PHILOSOPHY

The overall plant complex has been designed using multiple trains, spare equipment and intermediate storage to provide an overall onstream factor of 92 percent. (See Sub-Sections 3.7 and 4.7.)

2.3 FEEDSTOCKS

The only feedstocks to the plant complex, besides air, are mined coal and fresh water. In addition, small quantities of chemicals, solvents and catalysts are required.

2.3.1 Coal

Gasification and boiler-firing are based on a coal having the properties listed in Table 2.1. This coal is a low sulfur, Wyoming sub-bituminous coal. Its properties differ slightly from the base Montana sub-bituminous coal in the Guidelines.

TABLE 2.1
STUDY COAL PROPERTIES
(Wyoming Sub-Bituminous Coal)

	As Received	Dry and Ash Free (DAF)
Proximate Analysis, wt. %		
Moisture	28.0	--
Ash	5.1	--
Fixed Carbon	33.8	50.5
Volatile Matter	33.1	49.5
	100.0	100.0
Ultimate Analysis, wt. %		
C		74.45
H		5.10
O		19.25
N		0.75
S		0.45
		100.00
Calorific Value, Btu/lb		
High Heating Value (HHV)	8,509	12,720
Low Heating Value (LHV)	7,893	12,236

Fusion Properties of Ash, ^{o}F	Atmosphere: Oxidizing	Atmosphere: Reducing
Softening Point	2,335	2,335
Melting Point	2,360	2,360
Flow Point	2,440	2,430

Mineral Analysis of Ash	Wt. %
SiO_2	19.0
Al_2O_3	14.0
Fe_2O_3	6.0
MgO	7.8
CaO	36.0
Na_2O	2.7
K_2O	0.2
SO_3	7.0
BaO	0.2
TiO_2	1.0
P_2O_5	1.8
Undetermined	4.3
	100.0

2.3.2 Fresh Water

The quality of the untreated fresh water assumed is the Western location water quality established in the Guidelines. In summary, the total dissolved solids are 496 ppm and the total hardness is 232 ppm $CaCO_3$. It has been assumed that the water is available at the plant gate.

2.4 CLIMATIC CONDITIONS

Essentially, the climatic conditions established in the Guidelines have been used. In summary, they are:

Atmospheric pressure, psia	12.3
Air temperature (average), ^oF	50
Relative humidity (average), %	70
Summer wet bulb, ^oF	66
Summer dry bulb, ^oF	95

2.5 PLANT SITE CONDITIONS

No major site development, other than leveling and grubbing, has been assumed. No piling is assumed to be required.

2.6 ENVIRONMENTAL REGULATIONS

The plant complex has been designed to meet all existing local and federal environmental regulations, as of July, 1977, for liquid and gaseous effluents.

Boiler stack gas clean-up facilities for SO_2 removal are provided to reduce the SO_2 emissions to 0.2 pounds of SO_2 per million Btu of fired heat. This emission target is more severe than the boiler SO_2 limitation in the Guidelines, but it is representative of the design limits placed on the latest proposed Western SNG plants. In addition, an electrostatic precipitator is included to reduce the particulate matter from the boiler to 0.1 pound per million Btu of fired heat. (Note: For the purposes of determining the "boiler" fired duty, the main superheater is included and LHV is the basis.)

Sulfur emissions from the process units are reduced by treating all sulfur containing offgases in a sulfur recovery unit. The tail gas stream containing 10 ppm H_2S from this unit is incinerated in the boiler to eliminate the hydrocarbons and to convert the COS and H_2S to SO_2 for removal in the stack gas clean-up facility. Only about 5% of the sulfur in the total coal charge escapes as SO_2, amounting to about 5 T/SD of sulfur.

All aqueous liquid effluents are treated and recycled. Blowdown water is used for ash slurrying, dust control, etc..

The wet ash and solid wastes, e.g., from stack gas clean-up and water treating, are sent to the mine for disposal.

2.7 PRODUCTS

Except as discussed below, this study is based on the concept that all products are marketable. Other than quality specifications, no marketing restrictions have been imposed. Products have been credited with their highest potential market value. The major products, however, are SNG and motor gasoline. A product summary is tabulated below:

	Base Case		----Sensitivity Case----				
Product	I	II	I-A	I-B	I-C	I-D	II-A
SNG	X	X	X	-	X	-	X
Methanol	-	-	X	-	-	-	-
Gasoline	X	X	-	X	X	X	X
Propane LPG	X	X	-	X	X	X	X
Butane LPG	X	X	-	X	-	X	X
Diesel Oil	-	X	-	-	-	-	-
Heavy Fuel Oil	-	X	-	-	-	-	-
Alcohols	-	X	-	-	-	-	-
Ammonia	X	X	X	X	X	-	X
Sulfur	X	X	X	X	X	X	X
Electric Power (excess)	X	X	X	X	X	X	X
Coal Fines (excess)	X	-					

The Lurgi gasifier produces phenols, naphtha, oil and tar which are recovered during raw gas cooling. For expediency, the phenols, oil and tar are used as boiler fuel. Although technically possible, the upgrading of these materials into saleable products would have little, if any, effect on the plant complex economics. On the other hand, the gasifier naphtha is hydrotreated for gasoline blending, principally, because this aromatic stock is needed to yield a satisfactory 10 RVP gasoline in the Fischer-Tropsch case.

The Fischer-Tropsch reaction produces a small quantity of acids. They have been neutralized with caustic as recovery is not economical (8).

Ammonia and hydrogen sulfide obtained during raw syn gas purification are recovered as anhydrous ammonia and sulfur.

2.8 PRODUCT SPECIFICATIONS

2.8.1 SNG

The SNG product is interchangeable with pure methane in accordance with procedures described in the Guidelines. In addition, it meets the following limitations:

Carbon monoxide	0.1 vol. %
Hydrogen sulfide	0.25 grains/100 SCF
Total sulfur	10 grains/100 SCF
Water	4 lb/MMSCF,

and is available at the plant gate @ 1,000 psig.

2.8.2 Hydrocarbon Products

The target specifications are primarily based on the 1976 Annual Book of ASTM Standards and represent industry guidance for establishing product properties between buyer and seller. Properties and comments specific to the various hydrocarbon products can be found in the discussion and tables included in Sub-Section 3.2 and 4.2.

2.8.3 Alcohols

No specifications have been established. The alcohol product has been upgraded to be essentially free of water, acids, aldehydes and ketones.

2.8.4 Byproducts

Ammonia: Agriculture grade is produced.(With a relatively small increase in costs, chemical grade ammonia could be produced by the ammonia recovery process used in the study.)

Sulfur: The product is a liquid at 95.5% purity.

Electric Power: Excess electric power is produced at 6,000 volts.

2.9 COAL BALANCE

The minimum coal size specification for the Lurgi gasifier used in the study is 1/4 inch. The minus 1/4 inch coal is used as boiler fuel. When crushing the study coal, it has been estimated that the coal preparation plant yields 83.5% 2" to 1/4" gasifier coal and 16.5% minus 1/4" fines. Since the study basis calls for the combustion rather than recovery of the gasifier tar, oil and phenols, a surplus of fine coal is possible. When this occurs, the excess fines are sold in accordance with the Guidelines.

2.10 UTILITY BALANCE

The general design bases calls for in-plant power and steam generation and, if possible, no export of these items. The utility balances were developed towards this goal, but detailed utility rebalancing calculations are outside the limits of this scoping study. Thus, a small surplus of electric power is available for export. In the base cases, it amounts to less than 5% of the total steam and electric power required to operate the complex.