For the higher capital charge rate, methanol costs vary from $9.56 to $12.24/mBtu.

Since the present state-of-the-art gasification of lignite using the Texaco gasifier is costly due to the effect of the lignite water slurry concentration, the Davy McKee costs will be used in preference. The Davy McKee study utilizes the proven Winkler gasification which does not require a coal slurry feed. Thus, the product cost of methanol varies from $5.70/mBtu for the low CCR to $9.56/mBtu for the high CCR.

D. <u>Production of Gasoline from Coal via Fischer-Tropsch and Mobil's MTG Technology</u>

There are three original studies available which investigate the technical feasibility of producing gasoline from coal-derived methanol. These studies are:

1. "Coal-to-Methanol-to-Gasoline Commercial Plant," Badger Plants, Incorporated, Cambridge Massachusetts, FE-2416-43-V1,2, March 1979.[10]

2. "Research Guidance Studies to Assess Gasoline from Coal by Methanol-to-Gasoline and Sasol-Type Fischer-Tropsch Technologies," Max Schreimer, Mobil Research and Development Corporation, FE-2447-13, August 1978.[7]

3. "Screening Evaluation: Synthetic Liquid Fuels Manufacture," Prepared by the Ralph Parsons Co. for EPRI.[1]

The Badger study is based on a "slag bath" gasifier which is a new concept and may still require developmental work. (See a more detailed discussion above in Section IV.) Lurgi technology is used for methanol synthesis, and Mobil fixed bed technology is used for methanol-to-gasoline conversion.

The Mobil study actually includes three cases, designated Cases 1, 2, and 3. Cases 1 and 2 utilize Lurgi technology for coal gasification and methanol synthesis, and Mobil fixed bed technology for methanol-to-gasoline conversion. These cases differ in that Case 1 produces approximately 50 percent gasoline and SNG, whereas Case 2 produces approximately 100 percent gasoline. Case 3 uses Lurgi gasification technology's but employs Fischer-Tropsch technology for product synthesis.

The Parsons study is based on the BGC/Lurgi gasifier which still needs to be commercially demonstrated. Fischer-Tropsch technology is used for product synthesis.

<u>Depth of Design</u>: Both the Badger and the Mobil studies are based on a comparable level of engineering design. The investment estimates are of budget or scoping quality. The Badger study is

based on process licensors economic data for proprietary processes and on vendor quotes derived from in-house equipment specifications for non-proprietary processes. Badger states their cost estimate represents an accuracy of minus 5 percent, plus 20 percent. The Mobil study is of the same order of accuracy as the Badger study. The Parsons study is a screening evaluation, and could be expected to be less accurate than the other two studies.

Ultimate Analysis of Coal-to-Gasoline Feedstock: Ultimate analysis for the coal feedstocks are presented in Table 27. The Badger study uses a Southern Appalachian bituminous coal; whereas Mobil uses a Wyoming subbituminous coal, and Parsons uses an Illinois No. 6 bituminous coal. The coal considered in the Badger study is a low sulfur coal which would meet the sulfur dioxide emissions standard for large power plants.[12] It is unlikely that a coal of this quality would be used for synfuels production.

For the Badger study, the coal, free of debris, cleaned, sized, and washed is delivered to the plant site. Thus, this case excludes coal preparation costs which has been included in the other studies.

Material Balance and Efficiencies: Feedstock and product rates for each case are presented in Table 28. All rates are based on 50,000 FOEB/CD of products (excluding by-products). For the Badger study gasoline represents almost 100 percent of the product slate. The efficiency for this case is 49 percent. For Case 1 of the Mobil study the major products are SNG and gasoline and the overall process efficiency is 63.2 percent. The production of SNG increases the overall process efficiency over the all-gasoline cases since the isolation of SNG produced in the Lurgi gasifier requires less energy than gasoline-production. Gasoline is the main product from Case 2; the efficiency of this case is 46.6 percent which is comparable to the Badger plant efficiency. A variety of products are produced from Case 3 (Fischer-Tropsch) with the main products being SNG and gasoline. The efficiency of this case is 57 percent. The efficiency of the Parsons case is 56 percent. While both the Parsons and Mobil (Case 3) studies are based on Fischer-Tropsch technology, their product slates vary widely. For the Parsons case 15,000 FOEB/CD of heavy fuel oil is produced compared to 700 for the Mobil case; whereas 190 mscf/CD of SNG is produced for the Mobil case and only 112 mscf/CD for the Parsons case.

Both of the Fischer-Tropsch synthesis cases produce significant quantities of SNG and/or residual oil. For a transportation fuels oriented synthetic fuels industry, their product slates would be unacceptable. Both cases produce approximately 33 percent transportation fuels (gasoline and diesel fuel). However, currently transportation fuels (jet fuel, diesel fuel, and gasoline) account for 51 percent of the refined petroleum products and this percentage is expected to increase to nearly 55 percent by

Table 27

Coal to Methanol to Gasoline: Ultimate Analysis of Coals

Study:	Badger[10]	Mobil[7]	Parsons[1]
Coal Type:	Southern Appalachian	Wyoming Sub-Bituminous	
HHV, Dry, Btu/lb	12,840	11,818	12,771
LHV, Dry, Btu/lb	-	10,963	11,709
Ultimate Analysis of Dry Coal, Wt. Percent			
C	73.8	70.84	69.5
H	4.8	4.85	5.3
O	6.4	18.32	10.0
N	1.6	0.71	1.3
S	1.1	0.43	3.9
Ash	12.3	4.85	10.0
Total	100.0	100.0	100.0
% Moisture (as received)	2.4	28.0	4.2

Table 28

Coal-to-Gasoline: Feedstock and Product Rates
(Normalized to 50,000 FOEB/CD of Product)

	Badger[12]	Mobil[7] Case 1	Case 2	Case 3	Parsons[1]
Feedstocks					
Coal (tpd)	23,147	29,467	37,219	30,406	21,528
Electricity (mBtu/day)	7,572	-	-	-	
Methanol	-	-	-	4.4	
Products					
Propane bpd	2,911	1,678	3,606	1,211	-
Isobutane, bpd	4,544	-	-	-	-
Butane, bpd	-	2,380	5,162	160	2,005*
SNG, mSCF/d	-	160	-	190	112
Alcohols, tpd	-	-	-	255	951*
Gasoline, bpd	46,729	23,795	50,843	14,853	10,160
Diesel Fuel, bpd	-	-	-	2,523	6,014*
Heavy Fuel Oil, bpd	-	-	-	680	14,849
By-Products					
Power, mBtu/d	-	470	153	296	-
Coal Fines, mBtu/d	-	22,043	-	-	-
Sulfur, tpd	207	66	83	67	762
Ammonia, tpd	-	111	140	113	-
Energy Basis mBtu/d					
Feedstocks					
Coal	593,497	501,471	633,392	517,454	526,790
Electricity	7,572	-	-	-	-
Methanol	-	-	-	85	-
Products					
LPG	10,897	6,405	13,814	4,619	-
Butane	-	9,975	21,633	690	11,829
SNG	-	157,139	-	190,129	94,524
Alcohols	-	-	-	7,603	5,613
Gasoline	264,855	121,474	259,555	74,607	59,942
Diesel Fuel	-	-	-	13,487	35,484
Heavy Fuel Oil	-	-	-	3,865	87,608
Total	294,552	295,000	295,000	295,360	295,000
Thermal Efficiency, %	49	63.2	46.6	57.1	56.0

* = FOEB

the year 2000 (see Table 7[36]). At the expense of an increased product cost, both of these plants could be altered to meet a more desirable product slate.

Product Qualities: The main products from the Badger and Mobil studies are SNG and gasoline. Chemical and physical analyses of these products are presented in Table 29. Analyses of the products from the Parsons study were not available. The SNG from Cases 1 and 3 of the Mobil study is of satisfactory quality and is compatible with natural gas. The unleaded gasolines presented in Table 29 meet all 1976 ASTM specifications. Compared to typical present-day gasolines these are slightly lower in API° gravity. It would be preferable if the durene content of the gasoline were less than 4 wt. percent since durene contents of 5 wt. percent in conventional gasolines have caused carburetor icing and stalling. The olefinic concentration of the Case 3 gasoline (20 vol. %) is higher than that of conventional gasolines, and experience with higher olefinic gasolines is limited. Consequently, marketing such a gasoline would require further testing.

All of the propane and butane products are satisfactory fuels. The isobutane from the Badger study is of high purity and may be used as a petrochemical or as a refinery feedstock. The diesel fuel from Case 3 of the Mobil study could be marketed as a premium diesel fuel, No. 1-D. The heavy fuel oil from this case contains no sulfur or metals and thus could be marketed as a premium gas turbine fuel. The alcohols from these case are a mixture of C_2-C_6 alcohols, and are essentially free of acids, aldehydes, ketones and water.

MTG Process Economics: Table 30 presents capital investment costs broken down into individual process unit costs. An inspection of this table shows that the estimates of the total instantaneous plant investment for the MTG process range from about $2.6 billion for the Badger study and Case 1 of the Mobil study, to about $3.6 billion for Case 2 of the Mobil study. The Badger study and Case 2 of the Mobil study are both designed to produce gasoline as the major product. Since both of these cases are based on Mobil's methanol-to-gasoline technology and produce similar product slates, it is expected that their investment costs would be comparable, but this is not the case. Mobil's capital estimate is nearly $1 billion more than Badger's. Even though the capital cost of a subbituminous coal plant is expected to be greater than a bituminous coal plant, this difference is much too large. Table 30 shows that the "gasification, et al" costs for these cases are almost identical, even though the Mobil case is slightly less efficient and operates with subbituminous coal as a feedstock as opposed to bituminous coal for the Badger study. On this basis one would expect Mobil's gasification costs to be greater than Badger's, which would tend to make the investment difference between the two studies even greater.

Table 29

Product Qualities: Coal-to-Gasoline

Study:	Mobil[7] Case 1	Mobil[7] Case 3
1) SNG		
Composition, %		
Hydrogen	1.7	3.8
Methane	95.5	89.7
Ethene	–	1.0
Ethane	0.2	2.3
Propene	–	1.0
Propane	0.1	0.1
Butane	0.1	–
Carbon Dioxide	0.5	0.5
Inerts (N_2 + Ar)	1.9	1.6
Total	100	100
Heat of Combustion, Btu/scf	980	1000
Water	0.01%	0.01%
Sulfur	None	None
Carbon Monoxide (0.1% Max)	0.02%	0.07%

Study:	Badger	Mobil[7] Case 1,2	Mobil[7] Case 3
2) Gasoline			
Gravity, °API	62.7	61.4	67.2
Research Octane Number	92.7	93	91
Motor Octane Number	82.7	83	83
Volatility			
Reid Vapor Pressure, lb.	10.0	10.0	10.0
Distillation, °F			
IBP	79	85	86
10%	106	110	108
30%	140	146	137
50%	187	200	186
70%	259	262	249
90%	339	336	335
EP	390	388	420
Sulfur, Wt.%	Nil	Nil	Nil
Composition, Vol. %			
Paraffins	54	51	60
Olefins	12	11	20
Napthenes	7	9	3
Aromatics	27	29	17
Durene Content	4 Vol.%	4.6 Wt.%	–

Table 30

Coal-to-Gasoline: Capital Cost Summary
(Million of First Quarter 1981 Dollars

Study:	Badger[10]	Mobil[7] Case 1	Mobil[7] Case 2	Mobil[7] Case 3	Parsons[1]
Technology (Gasification/ Synthesis)	Slag Bath/ Lurgi/MTG	Lurgi/ Lurgi/MTG	Lurgi/Lurgi/ MTG	Lurgi/ Fischer-Tropsch	BGC Lurgi/ Fischer-Tropsch
Investment Costs					
Coal and Lime Preparation	78	-	-	-	41
Coal Gasification	210	304	-	307	147
Shift Conversion	63	49	-	49	57
Acid Gas Removal	216	109	-	110	244
Sulfur Recovery	18	89	-	90	44
Hydrocarbon Recovery	-	-	-	30	-
By-product Separation and Recovery	-	78	-	19	100
Syngas Compression	36	-	-	-	70
Methanol Synthesis	220	82	-	-	-
Cyrogenic Hydrogen Recovery	18	4	-	9	31
Total Gasification, et al	859	715	840	614	733
SNG Production	-	38	-	37	-
Gasoline Production	216	106	370	-	-
F-T Synthesis and F-T Product Processing	-	-	-	218	342
Oxygen Production	351	167	261	168	266
Steam and Power Generation	121	231	266	274	11
Cooling Water and Make-up, WWT	90	69	128	77	-
Environmental	63	-	-	-	-
Waste Disposal	-	104	-	109	-
Storage and Shipping	11	34	-	13	-
General Facilities	118	-	286	-	-
Infrastructure	-	70	83	71	-
Other Project Costs	-	376	510	270	-
Engineering and Design	246	189	288	208	-
Miscellaneous	138	107	-	169	212
Sub-Total	2197	2206	3022	2228	1624
Contingency	330	331	455	343	244
Contractor's Fee	56	55	76	57	41
Total Instantaneous Plant Investment	2583	2592	3563	2628	1909

Operating costs are presented in Table 31. Operating costs for the Mobil Case 2 study are $150 million more than those for the Badger study. Unfortunately, not enough information was available to reconcile these capital and operating cost differences.

Tables 32 and 33 present economic summaries and average product costs when using capital charge rates (CCR) of 11.5 and 30 percent. The average product costs for the MTG processes range from $7.37-9.75/mBtu for the low CCR and from $12.94-17.43 for the high CCR. In addition to average product costs, product costs for the various studies based on the product value method discussed in a previous report are also presented in these tables.[10a]

While the cost estimates of these two studies are difficult to reconcile, the incremental product cost to produce gasoline from methanol using the MTG process can be determined and may be more consistent. To accomplish this the incremental investment and operating costs will be determined between: 1) the Badger methanol plant (from the bituminous coals section) and the Badger gasoline from methanol plant, and 2) the Mobil methanol plant (from the subbituminous coals section) and the Mobil (Case 1) gasoline from methanol plant. Then the incremental product costs for each case will be compared. Mobil's Case 1 MTG unit is sized to produce 20,600 FOEB/CD of gasoline while Badger's was sized to produce 45,000 FOEB/CD. Therefore, in the economics to be presented below the Mobil study MTG unit has been scaled up to 45,000 FOEB/CD.

The incremental instantaneous plant investments are:

1. $634 million - Badger Study

2. $596 million - Mobil Study

The incremental operating costs are:

1. $97 million - Badger Study

2. $53 million - Mobil Study

After determining the total annual charge per the procedure discussed in a previous report,[10a] the incremental charge to produce 45,000 FOEB/CD of gasoline (50,000 FOEB/CD of total product) from methanol via the Mobil MTG process is:

	$/mBtu	
	Capital Charge Rate	
	11.5%	30%
Badger	1.76	3.12
Mobil	1.45	2.87

Table 31

Coal-to-Gasoline: Operating Cost Summary
(Millions of First Quarter 1981 Dollars Per Year)

	Badger[10]	Mobil[7] Case 1	Mobil[7] Case 2	Mobil[7] Case 3	Parsons[1]
Raw Materials					
Coal	232	184	232	186	216
Limestone	8.4	-	-	-	-
Catalysts and Chemicals	27.3	7.9	-	9.4	11
Utilities					
Power	28.3	-	-	-	-
Water	-	2.2	-	2.2	-
Labor and Related					
Operations	19.5	9.6	-	14.2	-
Maintenance	13.4	46.5	-	53.1	-
Supervision	1.7	-	-	-	-
General Services	3.1	-	-	-	-
Capital Related					
Operating	-	2.4	-	3.5	-
Maintenance	38	31.1	-	35.5	-
Administration and General Overhead	-	34.6	-	41.7	-
Local Taxes and Insurance	7.5	71.9	-	80	-
Interest on Working Capital	5.2	5.3	8.2	5.5	7.0
Other Operating Cost	32	-	295	-	135
Gross Annual Operating Cost	416	396	535	431	
By-product Credit	(3.8)	(17.4)	(11.0)	(9.6)	(13.9)
Net Annual Operating Cost	412	378	524	422	355

Table 32

Coal-to-Gasoline: Economic Summary, CCR = 11.5%
(Millions of First Quarter 1981 Dollars)

	Badger	Mobil Case 1	Mobil Case 2	Mobil Case 3	Parsons
Total Instantaneous Plant Investment	2583	2592	3563	2688	1904
Total Adjusted Capital Investment	2929	2939	4040	3048	2159
Start-up Cost	182	181	249	188	133
Pre-paid Royalties	26	26	34	20	9
Total Capital Investment	3136	3146	4323	3256	2301
Working Capital	182	181	249	188	133
Total Capital Requirement	3319	3327	4572	3444	2434
Annual Capital Charge	382	383	526	396	280
Annual Operating Costs	412	378	524	422	355
Total Annual Charge	794	761	1050	818	635
Average Product Cost					
$/FOEB of Product	43.51	41.68	57.52	44.83	34.79
$/mBtu of Product	7.37	7.06	9.75	7.60	5.90
Product Costs, $/mBtu					
LPG	5.82	6.17	7.72	6.56	5.31
Butane	5.82	6.17	7.72	6.56	5.31
SNG	-	6.41	-	6.82	5.52
Alcohols	-	-	-	8.52	6.90
Gasoline	7.55	8.01	10.03	8.52	6.90
Diesel Fuel	-	-	-	7.67	6.21
Heavy Fuel Oil	-	-	-	6.56	5.31

Table 33

Coal-to-Gasoline: Economic Summary, CCR = 30%
(Millions of First Quarter 1981 Dollars)

	Badger	Mobil Case 1	Mobil Case 2	Mobil Case 3	Parsons
Total Instantaneous Plant Investment	2,583	2,592	3,563	2,688	1,904
Total Adjusted Capital Investment	2,883	2,893	3,976	3,000	2,125
Startup Cost	182	181	249	188	133
Pre-paid Royalities	26	26	34	20	20
Total Capital Investment	3,091	3,100	4,259	3,208	2,278
Working Capital	182	181	249	188	133
Total Capital Requirement	3,273	3,281	4,508	3,396	2,411
Annual Capital Charge	982	984	1,352	1,019	723
Annual Operating Costs	412	378	524	422	355
Total Annual Charge	1,394	1,362	1,876	1,441	1,078
Average Product Cost					
$/FOEB of Product	76.37	74.65	102.82	78.95	59.09
$/mBtu of Product	12.94	12.65	17.43	13.38	10.01
Product Costs, $/mBtu					
LPG	10.19	11.06	13.80	11.36	9.04
Butane	10.19	11.06	13.80	11.36	9.04
SNG	-	11.49	-	11.80	9.39
Alcohols	-	-	-	14.75	11.74
Gasoline	13.25	14.36	17.93	14.75	11.74
Diesel Fuel	-	-	-	13.28	10.57
Heavy Fuel Oil	-	-	-	11.36	9.04

The costs from the Badger study are slightly higher than those from Mobil. Since Mobil has researched and developed the MTG process, it is believed that their study is more reliable; therefore, their costs will be used in preference to Badger's.

Fischer-Tropsch Process Economics: This section examines the investment cost differences between the two Fischer-Tropsch studies. The instantaneous plant investment of the Mobil/Fischer-Tropsch case is $719 million more than that of the Parsons case. When inspecting onsite process equipment costs, the Parsons case cost $343 million more. However, the cost of offsite type equipment is $908 million more for the Mobil case. Therefore, even though there is a large onsite investment cost difference, the major differences between the two studies appears to be in offsite investment costs. The Mobil study is probably more accurate since it is based on a more thorough design. Operating costs from the Mobil/Fischer-Tropsch study are $75 million greater than those from the Parsons study. Unfortunately not enough information was available to reconcile these differences.

Tables 32 and 33 present economic summaries and average product costs for both CCR's. The average product costs for the two Fischer-Tropsch studies ranged from $5.90-7.60/mBtu for the low CCR to $10.01 to 13.38/mBtu for the high CCR. Product costs based on the product value method are also presented in these tables. Since the Parsons' study is based on a less thorough design than the Mobil study, the Parsons' study will not be further investigated.

To determine the average product cost difference between a Fischer-Tropsch synthesis plant and a methanol synthesis plant, the Mobil study (Lurgi gasification/Fischer-Tropsch synthesis) can be compared with Mobil's Lurgi gasification/Lurgi methanol synthesis case from Table 17. Differences in investment and operating costs between these two cases reflect the differences in synthesis technology. The instantaneous plant investment difference is $355 million and the operating cost difference is $67 million with the Fischer-Tropsch case being greater. These figures translate into an average product cost difference of $1.00/mBtu.

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