1.0 INTRODUCTION

The study reported in this volume was undertaken as an extension of work reported in MITRE Technical Report MTR-80W326, "The Impact of Developing Technology on Indirect Liquefaction," November 1980.(1) The prior study evaluated the processing and economic improvements to a U.S. built plant incorporating SASOL technology which would result from the substitution of more advanced gasifiers and synthesis units. Slagging BGC Lurgi, Texaco and Shell-Koppers gasifiers were considered as replacements for the dry-ash Lurgi units used at SASOL. Fischer-Tropsch synthesis units using slurry phase reactions based on Kolbel technology were considered as replacements for the SASOL synthol fast fluid bed reactors. A Wyoming subbituminous coal was assumed as the feedstock.

The work presented herein extends the prior effort to include consideration of a fluid bed gasifier and to evaluate the influence on performance of use of a mildly caking bituminous coal feedstock. The fluidized bed gasifier considered is the single-stage agglomerating ash gasifier under development by Westinghouse. The bituminous coal evaluated is Illinois #6; the second most plentiful coal east of the Mississippi. Properties assumed for Illinois #6 coal and for the Wyoming Subbituminous C coal assumed in the earlier study are presented in Table 1-1.

TABLE 1-1

COAL ANALYSES

	Wyoming Subbituminous	Illinois #6
Proximate Analysis (wt. %) (as-received)		
Moisture	28.0	10.23
Ash	5.1	9.10
Fixed Carbon	33.8	45.97
Volatile Matter	33.1	34.70
Ultimate Analysis (wt. %) (DAF)		
C	74.45	79.53
H	5.10	5.38
O	19.25	10.04
N	0.75	1.50
S	0.45	3.48
Cl	--	0.07
Calorific Value (Btu/lb)		
HHV (as-received)	8,509	11,464
HHV (DAF)	12,720	14,211
LHV (as-received)	7,893	10,951
LHV (DAF)	12,236	13,707
Coal Cost/Ton		
1977 $	7.00	20.38
1980 $	9.66	28.12

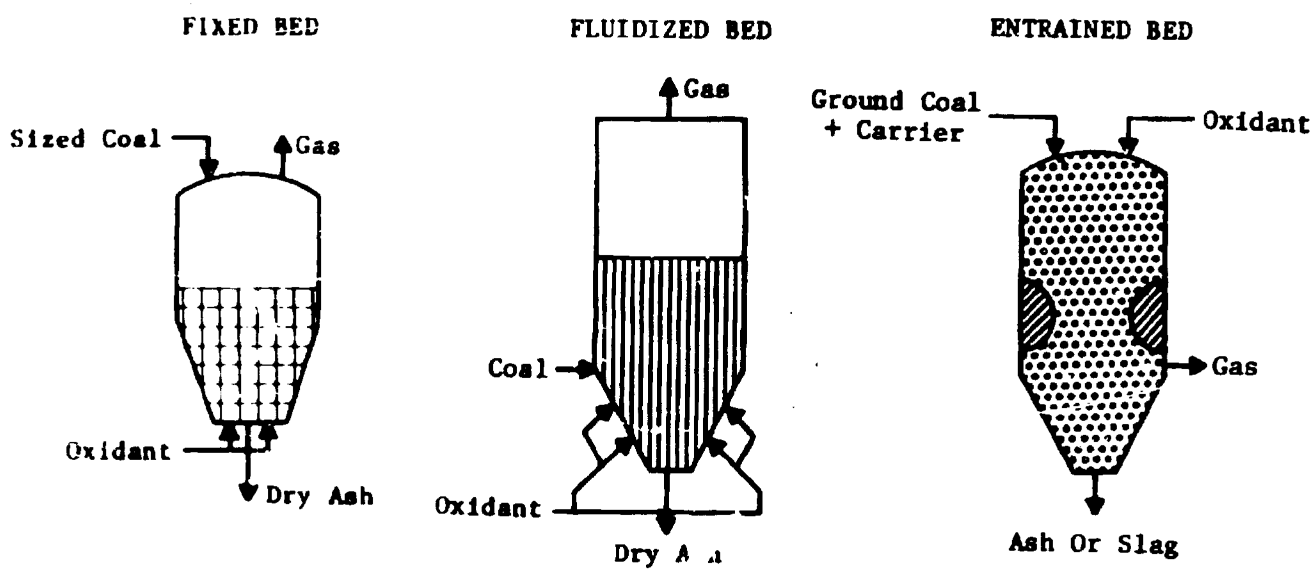
The section immediately following summarizes the results of the current effort, with the results of the prior effort shown for comparison.

2.0 EXECUTIVE SUMMARY

2.1 Westinghouse Gasifier Performance With Western Coal

Figure 2-1 shows the basic operation of fixed bed, fluid bed and entrained flow gasifiers. The fluid bed system theoretically enjoys an intermediate position between the extremes of counterflow fixed bed gasifiers and entrained flow gasifiers. Fluid beds may thus operate at an intermediate temperature which permits destructive reactions of the tars and oils released upon coal devolatilization without reaching the very high temperatures, which make waste heat recovery and vessel integrity troublesome in entrained-flow systems. This is illustrated in Table 2-1 which compares the raw gas output of the five gasifiers considered in this study. Note that the Westinghouse gasifier output contains significant methane, while the entrained systems contain little or none. The production of methane would be an advantage in MBTU or HBTU gasification systems, but is a disadvantage in an indirect liquefaction system since the methane must ultimately be reformed if all-liquid plant outputs are desired.

Figure 2-2 shows the impact of gasifier selection on the total construction cost of indirect liquefaction plants employing the five gasifiers considered. All the plants employ Synthol Fischer-Tropsch reactors of the type used at SASOL. All plants are designed to produce an all-liquid product slate from 27.8 M T/D of western subbituminous coal. Note that the construction costs of all plants,



	Fixed Bed	Fluidized Bed	Entrained Bed
Gas temperature	900-1100°F	1600-1800°F	2500-2800°F
Product contaminants	Tars, oil	Particulate	Slag, Particulate
Gas velocity	< 1 fps	1-10 fps	> 10 fps
Coal type	Non- and moderate-caking	Caking	Caking
By-products	Dry ash, tars, oils, sludge, sulfur	Dry agglomerates, sulfur	Slag-water slurry, sludge, sulfur
Materials problems	Corrosion	Corrosion	Corrosion, erosion, high temperature
Process response	Slow	Moderate	Fast

FIGURE 2-1
COMPARISON OF REACTOR TYPES

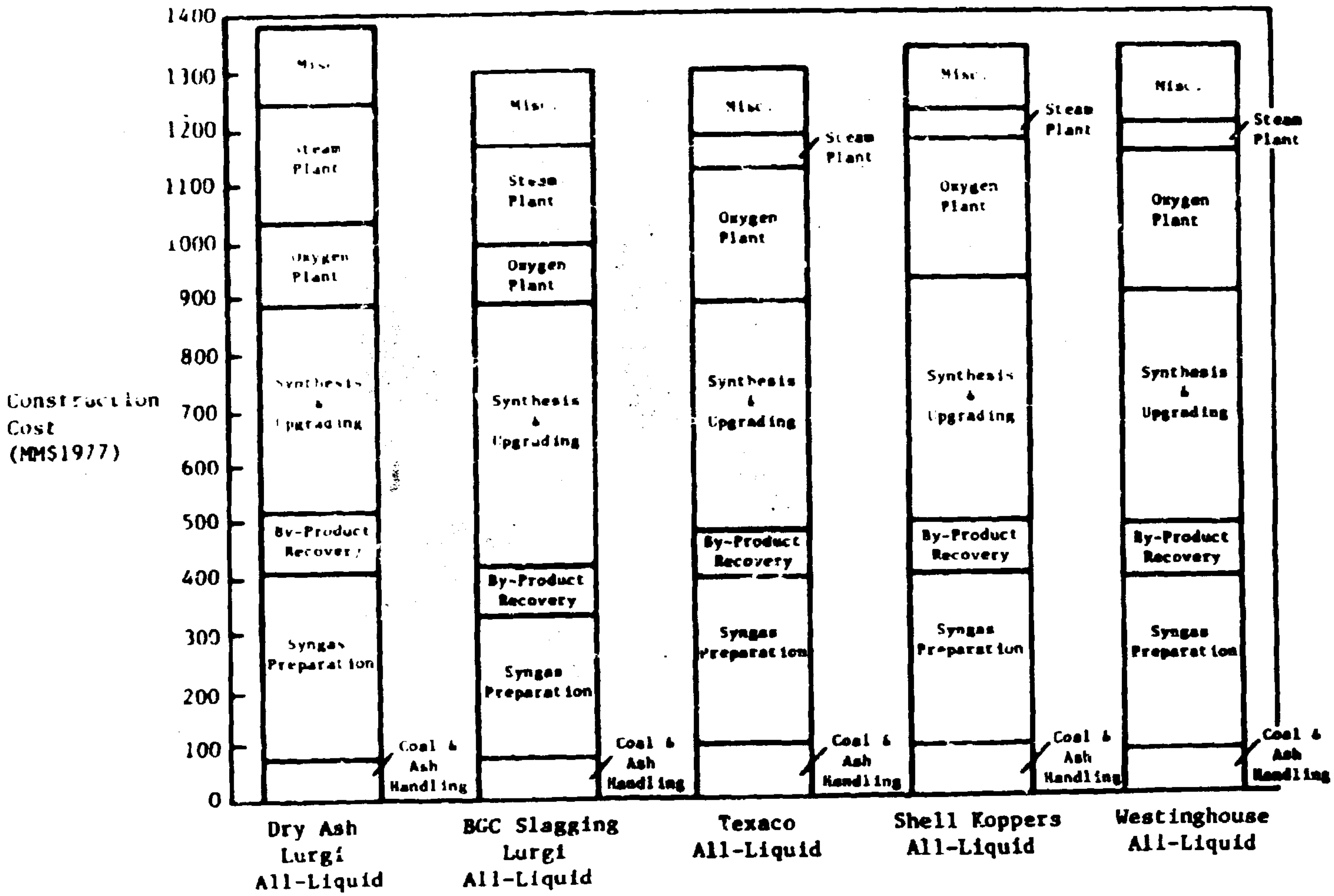
TABLE 2-1

GASIFIER PERFORMANCE COMPARISONS
(WYOMING SUBBITUMINOUS COAL)

	Dry Ash Lurgi	BGC Lurgi	Westinghouse	Texaco	Shell-Koppers
<u>Gas Composition</u> (Mole %)					
H_2	23.0	21.9	24.9	27.6	30.9
CO	11.1	43.8	32.7	40.6	64.4
CH_4	6.7	5.2	4.25	.1	Nil
C_2H_4, C_2H_6	.3	.3	0	Nil	Nil
CO_2	17.6	2.1	16.6	12.2	2.4
H_2O	41.0	26.3	20.8	18.9	1.4
Miscellaneous	.3	.3	.75	.6	.9
H_2/CO Ratio	2.07	.5	0.76	0.68	.48
<u>Energetics</u> (MMBtu/hr LHV)					
Total Coal Used*	18,959	18,959	18,959	18,959	18,959
H_2 + CO Output	7,187	11,079	11,428	14,334	15,735
CH_4 + C_2 Output	4,854	3,067	2,546	52	Nil
Naphtha Output	314	341	0	Nil	Nil
Tars/Oils/Phenols**	1,645	1,791	0	Nil	Nil
Total Output	12,355	14,487	13,979	14,386	15,735
Net Gasifier Efficiency	65.2	76.4	73.7	75.9	83.0

*DAF basis. Includes steam coal requirements for dry ash and BGC Lurgi. Does not include fuel for coal drying for Texaco and Shell-Koppers.

**Not included in totals--used for steam generation. Defined as clean product LHV/total coal LHV.



All Plants Process 2317 M#/Hr Wyoming Sub-Bituminous Coal

FIGURE 2-2
PLANT CONSTRUCTION COST COMPARISONS

including the base case plant employing dry-ash Lurgi gasifiers, lie in a range of plus or minus 5 percent.

Table 2-2 shows product slates and resulting plant gate gasoline costs for the five plants configured for all-liquids output. Gasoline costs are based on 100 percent equity financing, a 12 percent discounted cash flow (DCF) and a 25-year plant life using methods fully described in Appendices C and D of Reference 1.

Table 2-3 shows results for all-liquid plants employing the five gasifiers but employing Kolbel slurry phase Fischer-Tropsch synthesis units.[1] The use of Kolbel reactors reduces gasoline cost because of the much lower content of methane in the synthesis output, which results in lower losses when the methane is ultimately reformed to produce an all-liquid product slate. Further, the Kolbel synthesis units are well suited to advanced gasifiers since they accept a synthesis gas having an H_2/CO (mole) ratio on the order of 0.68, very near the H_2/CO ratio of the output of advanced gasification systems. An extensive amount of water gas shift is required if the advanced gasifiers are used with Synthol reactors, which require an H_2/CO ratio of 2.54.

The results show that all advanced gasifiers have the ability to effect a substantial gasoline cost reduction of 15-20 percent compared to the dry-ash Lurgi. Advanced gasifiers combined with Kolbel synthesis result in savings in the range of 25 to 30 percent. The

TABLE 2-2

SUMMARY DATA FOR PLANTS USING SYNTHOL SYNTHESIS
AND ADVANCED GASIFIERS
(All-Liquid Output)
Wyoming Subbituminous Coal
(27.8 M Tons/Day)

	SASOL-U.S. BASE CASE	BGC LURGI GASIFIER	WESTINGHOUSE	TEXACO GASIFIER	SHELL KOPPERS GASIFIER
OUTPUT:					
SNG (MM SCF/D)	--	--	--	--	--
Gasoline (B/D)	28,090	31,514	30,805	31,445	34,455
Other Liquid Fuels (B/D)	13,230	14,867	--	15,616	17,131
Total Liquid Fuels (B/D)	41,320	46,381	46,138	47,061	51,586
Total FOE (B/D)*	33,652	37,776	37,552	38,308	41,996
INPUT:					
Total Coal Used (M T/D)	27.8	27.8	27.8	27.8**	27.8**
Coal to Steam Plant (M Lbs/Hr)	416	247	--	--	--
Coal to Gasifier (M Lbs/Hr)	1,901	2,070	2,316	2,316	2,316
Steam to Gasifier (M Lbs/Hr)	1,700	453	579	--	46
Oxygen to Gasifier (M Lbs/Hr)	458	545	1,233	1,588	1,283
Efficiency (HHV) (%)**	43	48	47.6	49	53
Liquid Fuel (Bbls C_5^+/Ton Dry Coal)	1.94	2.18	2.16	2.21	2.42
Plant Construction Cost (MM 1977$)	1,383	1,289	1305.4	1,285	1,347
Capital Cost (MM 1977$)	2,199	2,050	2075.6	2,044	2,142
Gasoline Cost (1977$/Gal)	1.51	1.24	1.28	1.23	1.16
Gasoline Cost (1980$Gal)	2.00	1.65	1.70	1.64	1.55

*Fuel Oil Equivalent assuming 6 MM Btu/B.

**Does not include fuel used to dry coal; treated as an operating cost.

TABLE 2-3

SUMMARY DATA FOR PLANTS USING KOLBEL SYNTHESIS
AND ADVANCED GASIFIERS
(All-Liquid Output)
Wyoming Subbituminous Coal
(27.8 M Tons/Day)

	SASOL-U.S. BASE CASE	BCC LURGI/ KOLBEL	WESTINGHOUSE/ KOLBEL	TEXACO/KOLBEL	SHELL KOPPERS/ KOLBEL
OUTPUT:					
SNG (MM SCF/D)	--	--	--	--	--
Gasoline (B/D)	28,090	39,945	38,848	40,407	44,166
Other Liquid Fuels (B/D)	13,230	10,416	--	10,983	12,007
Total Liquid Fuels (B/D)	41,320	50,361	49,407	51,390	56,173
Total FOE (B/D)*	33,652	41,506	40,700	42,332	46,272
INPUT:					
Total Coal Used (M T/D)	27.8	27.8	27.8	27.8**	27.8**
Coal to Steam Plant (M Lbs/Hr)	416	216	—	--	--
Coal to Gasifier (M Lbs/Hr)	1,901	2,100	2,316	2,316	2,316
Steam to Gasifier (M Lbs/Hr)	1,700	460	579	--	46
Oxygen to Gasifier (M Lbs/Hr)	458	533	1,233	1,588	1,283
Efficiency (HHV) (%)	43	53	51.6	54	59
Liquid Fuel (Bbls C_4^+/Ton Dry Coal)	1.94	2.31	2.26	2.35	2.57
Plant Construction Cost (MM 1977$)	1,383	1,180	1,205	1,176	1,194
Capital Cost (MM 1977$)	2,199	1,876	1,916	1,870	1,898
Gasoline Cost (1977$/Gal)	1.51	1.03	1.08	1.01	0.94
Gasoline Cost (1980$Gal)	2.00	1.36	1.44	1.34	1.23

*Fuel Oil Equivalent assuming 6 MM Btu/B.

**Does not include fuel used to dry coal.

plant employing the Westinghouse gasifier is shown to be slightly inferior to other advanced gasification systems on a gasoline cost basis. Differences are well within analysis error, however, and are believed to be due to a relative conservatism in the data obtained from Westinghouse rather than to a relative deficiency in the gasification system. These factors are described in detail in the body of this report. The Westinghouse gasifier may enjoy substantial operability benefits relative to the entrained gasifiers due to its lower operating temperature, which allows state-of-the-art refractory liners and heat recovery systems to be employed. The carbon utilization assumed for the Westinghouse gasifier is 96 percent versus 99 percent plus for the entrained flow gasifiers.

2.2 Indirect Liquefaction of Illinois #6 Coal

The performance of all plants considered in the prior section has also been evaluated for an Illinois #6 coal feedstock having properties shown in Table 1-1. The properties of the Wyoming subbituminous coal used in the prior study are shown for reference. Also shown are the assumed coal costs in 1977 and 1980 dollars. Plants were sized to accept 27.8 M T/D as-received Illinois #6 coal, the same quantity as was assumed for plants employing Western coal. Tables 2-4 and 2-5 show product output and computed gasoline costs for plants employing Synthol and Kolbel synthesis, respectively. Table 2-6 shows a direct comparison of gasoline product costs with Western and Illinois #6 coals.

TABLE 2-4

SUMMARY DATA FOR PLANTS USING SYNTHOL SYNTHESIS
AND ADVANCED GASIFIERS
(All-Liquid Output)
Illinois #6 Coal
(27.8 M Tons/Day)

	SASOL-U.S. BASE CASE	BGC LURGI/ GASIFIER	WESTINGHOUSE	TEXACO GASIFIER	SHELL KOPPERS/ GASIFIER
OUTPUT:					
SNG (MM SCF/D)	--	--	--	--	--
Gasoline (B/D)	30,458	38,255	41,222	40,584	44,170
Other Liquid Fuels (B/D)	14,285	18,014	20,518	20,201	21,986
Total Liquid Fuels (B/D)	44,743	56,269	61,740	60,785	66,156
Total FOE (B/D) *	36,456	45,844	50,249	49,472	53,844
INPUT:					
Total Coal Used (M T/D)	27.8	27.8	27.8	27.8	27.8
Coal to Steam Plant (M Lbs/Hr)	652	372	--	--	--
Coal to Gasifier (M Lbs/Hr)	1,665	1,945	2,316	2,316	2,316
Steam to Gasifier (M Lbs/Hr)	4,181	690	1,158	--	144
Oxygen to Gasifier (M Lbs/Hr)	756	969	1,343	1,904	1,687
Efficiency (HHV) (%)**	34.8	43.8	48.0	47.2	51.4
Liquid Fuel (Bbls C4+/Ton Dry Coal)	1.65	2.12	2.32	2.29	2.49
Plant Construction Cost (MM 1977$)	1670.5	1527.9	1492.3	1536.1	1541.4
Capital Cost (MM 1977$)	2656.1	2428.4	2372.8	2442.4	2450.8
Gasoline Cost (1977$/Gal)	2.32	1.39	1.24	1.27	1.16
Gasoline Cost (1980$Gal)	3.01	1.81	1.61	1.66	1.51

*Fuel Oil Equivalent assuming 6 MM Btu/B.

***Prices for products other than gasoline are given on Table 1 inset.

TABLE 2-5

SUMMARY DATA FOR PLANTS USING KOLBEL SYNTHESIS
AND ADVANCED GASIFIERS
(All-Liquid Output)
Illinois #6 Coal
(27.8 M Tons/Day)

	SASOL-U.S. BASE CASE (SYNTHOL)	BGC LURGI/ KOLBEL	WESTINGHOUSE/ KOLBEL	TEXACO/KOLBEL	SHELL KOPPERS/ KOLBEL
OUTPUT:					
SNG (MM SCF/D)	--	--	--	--	--
Gasoline (B/D)	30,458	47,668	51,944	52,022	56,637
Other Liquid Fuels (B/D)	14,285	12,396	--	14,140	15,394
Total Liquid Fuels (B/D)	44,743	60,064	66,063	66,162	72,031
Total FOE (B/D)*	36,456	49,504	54,420	54,500	59,336
INPUT:					
Total Coal Used (M T/D)	27.8	27.8	27.8	27.8	27.8
Coal to Steam Plant (M Lbs/Hr)	652	372	--	--	--
Coal to Gasifier (M Lbs/Hr)	1,665	1,945	2,316	2,316	2,316
Steam to Gasifier (M Lbs/Hr)	4,181	690	1,158	--	144
Oxygen to Gasifier (M Lbs/Hr)	756	969	1,343	1,904	1,687
Efficiency (HHV) (%)	34.8	47.3	52.0	52.0	56.6
Liquid Fuel (Bbls C_4^+/Ton Dry Coal)	1.65	2.21	2.43	2.43	2.65
Plant Construction Cost (MM 1977$)	1670.5	1378.0	1366.9	1385.2	1355.7
Capital Cost (MM 1977$)	2656.1		2173.4	2202.5	2155.6
Gasoline Cost (1977$/Gal)	2.32	1.16	1.05	1.05	.94
Gasoline Cost (1980$Gal)	3.01	1.55	1.40	1.40	1.25

*Fuel Oil Equivalent assuming 6 MM Btu/B.

TABLE 2-6

COMPARISON OF GASOLINE COSTS FROM INDIRECT LIQUEFACTION PLANTS[1] (All-Liquid Output)*

	SASOL-U.S. Base Case	BGC Lurgi	Westinghouse Fluid Bed	Texaco	Shell-Koppers
Synthol Synthesis					
Western Coal	1.51 (2.00)	1.24 (1.65)	1.28 (1.70)	1.23 (1.64)	1.16 (1.55)
Illinois #6 Coal	2.32 (3.01)	1.39 (1.81)	1.24 (1.61)	1.27 (1.66)	1.16 (1.57)
Kolbel Synthesis					
Western Coal	(2)	1.03 (1.36)	1.08 (1.44)	1.01 (1.34)	.94 (1.25)
Illinois #6 Coal	(2)	1.16 (1.55)	1.05 (1.40)	1.05 (1.40)	.94 (1.25)

(1) Costs shown are 1977$, $/gallon; product basis 1980$ costs are shown in parentheses.

(2) Not analyzed.

* Plants sized for 27.8 M Tons/Day as received coal. Complete cost data for all-liquid and mixed output plants are tabulated in Appendix C.

The base case plant employing dry-ash Lurgi gasifiers was found to suffer substantial performance penalties when used with the Illinois #6 coal feedstock. Based on runs performed for the Energy Research and Development Administration at Westfield,[2] dry-ash Lurgi gasifiers have a 33 percent lower coal throughput, and about 40 percent higher steam and oxygen requirement per pound of DAF coal with Illinois #6 coal than when more reactive western subbituminous coals are processed. The reduced throughput results in the requirement for more gasifiers, which adversely impacts plant cost. The higher steam and oxygen requirements also impact plant cost and increase the percentage of coal which must be diverted for steam generation, which reduces syngas production. When these factors are combined with the high cost of the Illinois #6 coal, the net result is a gasoline cost increase of about 25 percent when Illinois #6 coal is used. The same factors degrade performance of the BGC Slagging Lurgi, but to a lesser degree, resulting in a gasoline cost increase of about 10 percent when Illinois #6 is substituted for the Wyoming subbituminous coal.

With all other gasifiers, gasoline costs with Illinois #6 coal are competitive with those computed using a Western coal feedstock. This implies that the advantages of the Illinois #6 coal compensate for its higher cost per ton. The primary advantage is a lower moisture content, which results in higher gasification efficiency in the fluid-bed and entrained-flow gasifiers, obviates the need for coal drying, simplifies the gas purification systems, and reduces waste-water treatment requirements. However, the advantages are small and would not reasonably be expected to compensate for a coal cost which is 210 percent higher on an LHV basis. In a typical comparison, coal accounts for about 9 percent of product cost when western coal is used, but about 19 percent if Illinois #6 is used. An analysis of these results showed that an additional advantage had accrued to the Illinois #6 coal in these comparisons because of the use of a fixed quantity of as-received coal on the basis of plant size. The Illinois #6 plants are thus larger in terms of energy throughput and enjoy some economics of scale because of the scaling factors which were used to estimate the costs of individual units common to each system.

A sensitivity analysis was performed to determine the extent to which this scale factor had influenced gasoline cost. In the sensitivity analysis, all plants were scaled to the size requiring a $1,300 MM construction cost, and the HHV output scaled accordingly. The gasoline prices which resulted from this analysis are presented in Table 2-7. When all plants are sized to require equal plant investment, the higher price of Illinois #6 coal is fully reflected in the plant-gate gasoline cost with the result that gasoline costs are higher when the Illinois #6 coal is used.

TABLE 2-7

GASOLINE COST COMPUTATIONS
(SYNTHOL SYNTHESIS)

(Plants Sized for Equal Plant Construction Cost of $1.3 Billion (1977)

Gasifier Type	Mode	Coal	Plant Construction Cost 1977 $	Plant Output MMBtu/hr HHV(1)	Cost per MMBtu/hr of Output: Capital Recovery	Plant O&M(2)	Coal Cost	Total	Gasoline Cost per Gallon: 1977 $ Thermal Basis(3)	1977 $ Market Basis(4)	1980 $ Thermal Basis(5)	1980 $ Market Basis(4)
Dry Ash Lurgi	AL	W	1,300	7,703	8.7[illegible]	2.57	1.05	12.34	1.48	1.56	1.97	2.07
BGC Lurgi	AL	W	1,300	9,555	7.03	2.07	.84	9.94	1.19	1.23	1.58	1.61
Texaco	AL	W	1,300	9,694	6.93	2.04	.83	9.80	1.17	1.21	1.56	1.61
Shell-Koppers	AL	W	1,300	9,977	6.73	1.99	.81	9.53	1.14	1.17	1.51	1.53
Westinghouse	AL	W	1,300	9,132	7.35	2.17	.89	10.41	1.24	1.30	1.65	1.72
Dry Ash Lurgi	AL	III #6	1,300	6,170	10.54	3.11	3.71	17.36	2.08	2.25	2.78	3.00
BGC Lurgi	AL	III #6	1,300	8,979	7.47	2.20	2.63	12.3[illegible]	1.47	1.56	1.96	2.08
Texaco	AL	III #6	1,300	9,745	6.39	2.03	2.42	11.35	1.36	1.43	1.82	1.9[illegible]
Shell-Koppers	AL	III #6	1,300	10,554	6.36	1.88	2.26	10.48	1.25	1.31	1.61	1.69
Westinghouse	AL	III #6	1,300	10,014	6.70	1.98	2.31	11.0[illegible]	1.32	1.38	1.76	1.85

(1) Does not include by-product sulfur and ammonia.

(2) O&M costs are net of by-product recovery costs.

(3) All products sold for same cost per MMBtu.

(4) Products priced per relative price schedule given in Table 3-14.

(5) 1980 prices are determined by escalating 1977 capital costs by 1.26 and O&M costs by 1.38. (Nielson Index.)

2.3 Conclusions and Recommendations

2.3.1 Westinghouse Gasification

The Westinghouse gasifier is believed to offer a level of performance comparable to the BGC/Lurgi, Texaco and Shell-Koppers gasifiers studied in Reference 1. This conclusion holds whether a highly reactive western coal such as Wyoming Subbituminous C, or a less reactive, mildly caking coal such as Illinois #6 is used as the feedstock. The Westinghouse gasifier shares important advantages with the entrained-flow systems relative to BGC, in that it permits operations without a separate coal-fired steam plant. It has advantages relative to either Texaco or Shell-Koppers in that it can employ state-of-the-art heat recovery systems and refractories.

We have noted that the heat balances for the plants employing Westinghouse, Texaco and Shell-Koppers gasification should be analyzed in more detail than was possible in this study, before it is finally concluded that any of the three gasifiers permit operation on steam and power from waste heat sources only. The heat balances of plants employing Westinghouse are the least critical of the three systems. Should either the Westinghouse or the entrained-flow systems require steam and power from sources other than waste heat, these would most logically be supplied by diversion of clean synthesis gas to a small combined cycle plant, rather than from an autonomous coal-fired steam plant. With BGC or the dry-ash Lurgi, a separate coal-fired steam plant is the preferred solution because of the availability of coal fines unsuitable for gasification in these fixed bed units.

We recommend that Westinghouse gasification be given careful consideration for any indirect liquefaction facility built in the U.S. The full-scale Westinghouse gasifier recently contracted for delivery to SASOL should be tested with a variety of U.S. coals, either prior to delivery or after installation in South Africa, in order to provide commercial scale operating data for potential U.S. users.

2.3.2 Indirect Liquefaction of Illinois #6 Coal

Our investigations have resulted in the conclusion that fluid-bed gasifiers, such as Westinghouse or entrained-flow gasifiers such as Texaco and Shell-Koppers, offer significant advantages over the BGC Lurgi gasifier when Illinois #6 coal is employed as the feedstock. Dry-ash Lurgi gasification has additional disadvantages which appear to make it unsuitable for applications with mildly caking coal such as Illinois #6.

With the financial assumptions employed in this study, coal costs account for about 19 percent of finished fuel costs when Illinois #6 coal is used versus about 9 percent when the lower cost Wyoming Subbituminous C coal is used. If plants requiring similar investment expenditures are compared, the higher coal cost is fully reflected in the calculated plant gate cost of gasoline. This unfavorable cost impact of employing Illinois #6 coal is magnified when fixed bed gasifiers are employed.

The results of our analyses of Illinois #6 coal do not alter our prior conclusions regarding the use of advanced gasification systems for indirect liquefaction. BGC/Lurgi, Westinghouse, Texaco and Shell-Koppers gasifiers offer significant advantages over dry-ash Lurgi and should be given detailed consideration for a U.S. liquefaction facility. The final decision will probably be driven by the relative state of development at the time a decision is required, process license and guarantees which could be negotiated, the market value of an SNG co-product, and the specific characteristics of the coal feedstock to be used. Again, it should be stressed that all these potential improvements are contingent upon performance levels being achieved for both Kolbel synthesis and advanced gasifiers that are equal to those reported in the literature sources used in this study.