5. ECONOMICS OF INDIRECT LIQUEFACTION

The SASOL projects are the first commercial synfuel development projects of significant size. The SASOL plants are of commercial reality as a consequence of driving forces unique to South Africa. No other commercial ventures based on the SASOL technology exist.

The SASOL technology is a modified version of the Fischer-Tropsch (F-T) process developed in the 1930s and 1940s (63). The reaction is based on nonselective polymerization that produces a very broad product slate. The SASOL plants produce over 20 saleable products (64). While SASOL is planning a third expansion program, called SASOL-III, there are other efforts to improve on the F-T technology or to develop entirely new synfuel processes. For example, the development of ZSM-5 catalyst has advanced Mobil's MTG process to investigation of commercialization (62).

This chapter discusses economic perspectives of the impact of advanced technologies on overall synfuel production. A major study conducted by Mitre Corporation is used as a guideline for this discussion.

5.1 SASOL ECONOMICS

The economics of a SASOL-like plant have been described by Mobil (65) and Mitre (66). The Mitre study was based on the Mobil report, adding several cases of its own. Because the Mitre report contains more comprehensive information, it is reviewed here. All costs in the Mitre report are in 1977 U.S. dollars. These data are quoted directly because it is felt that the perspectives developed using them are still valid. The base case in the Mitre report is a grass-roots plant featuring the Lurgi dry-ash gasifier and the Synthol F-T reactor, as in the SASOL-II plant. The coal is a 28%-moisture Wyoming subbituminous having a higher heating value of 8,509 Btu/lb and an assumed cost of $7/ton. In terms of heating value, the coal cost is 41¢/mmBtu. The principal processing steps in the grass-roots plant are shown in Figure 5-1.

The plant consumes 2,317,000 lb/h of coal, of which 1,901,000 lb/h are gasified and 416,000 lb/h are used to raise process steam. The base case is divided into two subcases: one producing SNG and liquids, which is called the "mixed-output" case, and the other producing "all liquid." In the all-liquid case, methane produced from the coal gasification and the F-T steps is recovered and steam-reformed (autothermal reforming) to produce syngas, which is recycled to the F-T section.

Table 5-1 summarizes the evaluation of both cases in terms of material balance and economics. In the mixed-output case, the plant thermal efficiency, defined as the fuel-oil equivalent of the products divided by the heating value of the coal, is 57%. In the all-liquid case, the efficiency is 44%. This lower value reflects the inefficiency of methane recycle and the increased energy used in oxygen production for methane autothermal reforming. The methane recycle requires autothermal reforming and additional capacities for steam generation, oxygen generation, and F-T synthesis, thus increasing the investment cost. Table 5-2 lists the construction costs of the plant sections in both cases.

The construction costs listed in Table 5-2 (mixed-output) are shown in Figure 5-2 as a pie chart. This chart illustrates the relative magnitude of some key process sections. For example, the F-T synthesis and CO shift sections, the focal points of some of the current research ativities (Section 3), account for $76.4 million and $12.8 million, respectively. In terms of total synfuel plant cost, the F-T synthesis is 6.4% and the CO shift is 1.1%. These values are surprisingly small and suggest that only limited benefits will be accrued from cheaper process replacements. Thus, the emphasis of research and development should be on aspects such as thermal efficiency, product selectivity, and unit operability.

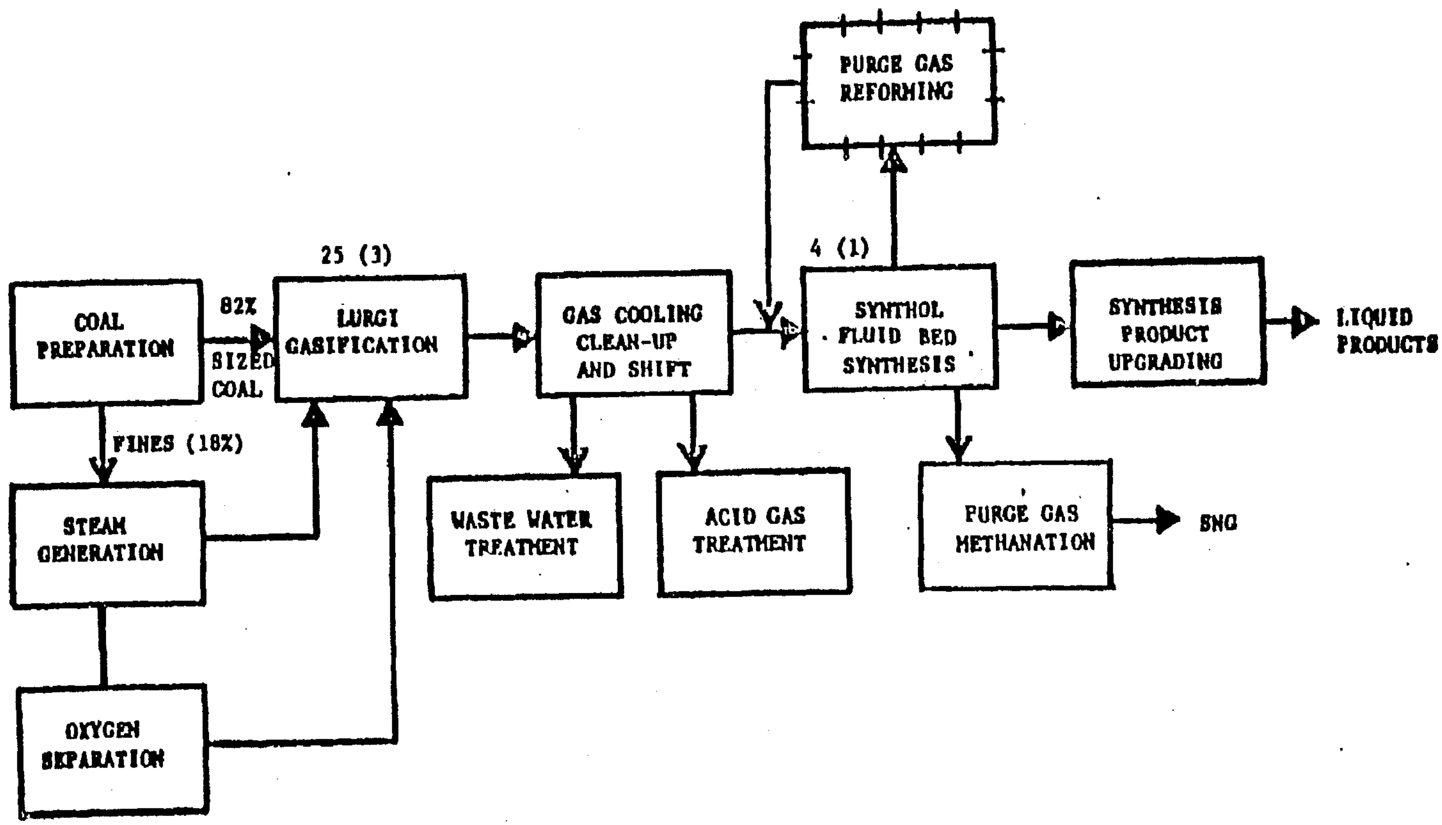


Figure 5-1. Grass-roots F-T Plant Base Case: Lurgi (Dry-ash)-Synthol-Wyoming Subbituminous Coal

Reference: (66)

Table 5-1

Summary of Base Case Reactor

	Mixed-output	All-liquid Output
Output:		
SNG (MM SCF/D)	173.3	------
Gasoline (B/D)	13,580	28,090
Other Liquid Fuels (B/D)	6,011	13,140
Total Liquid Fuels (B/D)	19,591	41,230
Total FOE (B/D)*	44,950	33,652
Input:		
Total Coal Used (M T/D)	27.8	27.8
Coal to Steam Plant (M Lbs/h)	416	416
Coal to Gasifier (M Lbs/h)	1,901	1,901
Steam to Gasifier (M Lbs/h)	1,700	1,700
Oxygen to Gasifier (M Lbs/h)	458	458
Efficiency (HHV)	57	44
Liquid Fuel Bbls. C_4^+/Ton Dry Coal	.92	1.94
Plant Construction Cost (MM $)	1,186.1	1,382.7
Capital Cost (MM $)	1,887	2,199
Gasoline Cost ($/Gal)**	1.33	1.51

*Fuel-oil Equivalent assuming 6 MMBtu/B.

Reference: (66)

Table 5-2

Construction Costs for Base Case Reactor
[$Million (1977)]

	Mixed-output Base Case	All-liquid Base Case
Coal and Ash Handling	71.4	71.4
Steam Plant	195.3	212.9
Oxygen Plant	110.1	148.5
Gasification	200.7	200.7
Shift	12.8	12.8
Gas Cooling & Cleaning	118.1	118.1
Sulfur Recovery	59	59
Gas/Liquor Separation & Product Recovery	51.4	51.4
Waste Water Treatment	26.3	26.3
F-T Synthesis	76.4	109.1
F-T Product Upgrading	128.9	172.1
F-T Catalyst Preparation	27.7	48.0
Auto Thermal Reformer		40.7
Miscellaneous	108	108
TOTAL	1186.1	1382.7

Reference: (66)

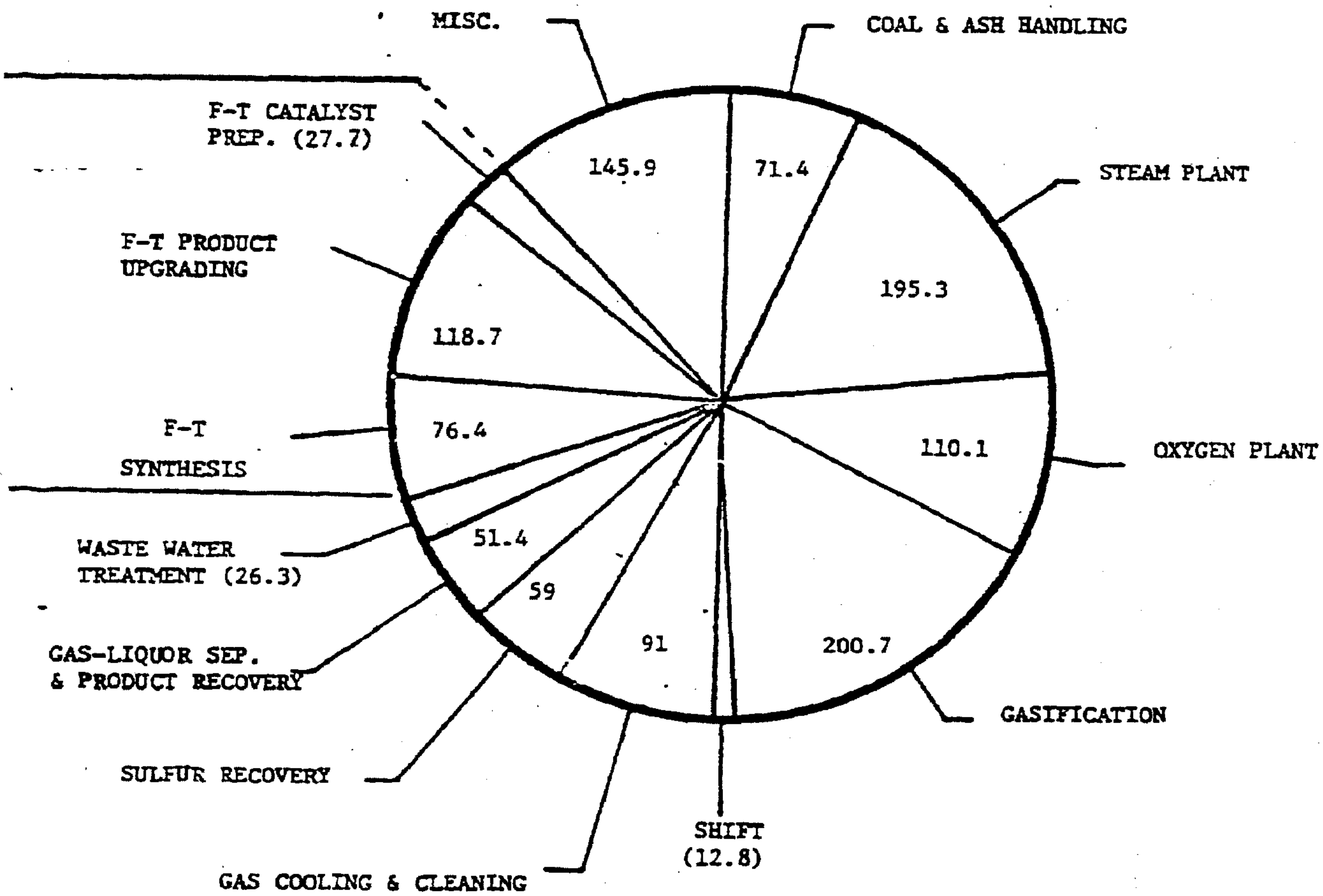


Figure 5-2. Plant Construction Costs for Mixed-output Case

Reference: (66)

5.2 . ADVANCED GASIFIERS

The Lurgi dry-ash gasifier is well-known for excessive use of steam to keep the gasifier hot zone from reaching ash-slagging range. For example, Mitre assumed a value of 1.34 lb steam/lb coal. An improved version of the Lurgi gasifier, called the BGC slagging gasifier, operates on an ash-slagging mode requiring much less steam (for example, 0.36 lb/lb), according to Mitre's comparative evaluation of this gasifier.

According to Mitre, a grass-roots plant featuring the BGC gasifier has the comparative construction costs shown in Table 5-3. The lower steam use by the BGC gasifier is reflected in the steam plant cost. The gasifier also has a much higher throughput, which reduces the construction cost.

Higher gasifier efficiency means more syngas to process and more products to upgrade. This results in net cost increases in the following areas:

- CO shift: the raw gas from the BGC gasifier has an H_2/CO ratio of 0.5 mol/mol, compared with 2.07 from the Lurgi dry-ash unit. Thus, the BGC gases require more CO shifting.

- F-T synthesis, gas cooling and cleaning, and F-T product upgrading: Because of higher gasification efficiency, more syngas is available for F-T synthesis. Correspondingly, larger capacities are required in these plant sections.

As seen in Table 5-3, use of the BGC gasifier in place of the Lurgi dry-ash unit results in a net investment savings. In addition, the BGC cases have higher product yields, as shown in Table 5-4. For example, the total liquid yield is 42% higher than the base case in the mixed-output cases and 12% higher in the all-liquid cases.

The other near-term coal gasifiers investigated by Mitre are those of Texaco and Shell-Koppers (66). They both operate in an entrained ash-slagging mode. These have the following advantages and disadvantages as compared to the Lurgi dry-ash gasifier (and, for some items, to the BGC gasifier):

Table 5-3

Construction Cost Comparison--Base Case vs. BGC Case
[$Million (1977)]

	Mixed Output		All Liquid Output	
	Base Case	BGC Synthol	Base Case	BGC Synthol
Coal & Ash Handling	71.4	71.4	71.4	71.4
Steam Plant	195.3	156.4	212.9	172.8
Oxygen Plant	110.1	124.3	148.5	155.5
Gasification	200.7	100.4	200.7	100.4
Shift	12.8	30.0	12.8	30.0
Gas Cooling & Cleaning	118.1	127.9	118.1	127.9
Sulfur Recovery	59	64.8	59	64.8
Gas/Liquor Separation & Product Recovery	51.4	15.5	51.4	15.5
Waste Water Treatment	26.3	16.3	26.3	18.4
F-T Synthesis	76.4	99.0	109.1	147.7
F-T Product Upgrading*	128.9	154.4	172.1	186.9
F-T Catalyst Preparation	27.7	35.9	48.0	53.6
Auto Thermal Reformer			40.7	36.5
Miscellaneous	108	108	108	108
TOTAL	1186.1	1104.3	1382.7	1289.4

*Includes methanation and SNG preparation, where applicable.

Reference: (66)

Table 5-4

Comparison of Products After Downstream Processing (BGC/Synthol and SASOL-U.S. For Mixed and All-liquid Output)

	Mixed Output		All-liquid Output	
	Base Case	BGC/Synthol	Base Case	BGC/Synthol
SNG MM SCF/D	173.3	147.9	-	-
Gasoline B/D	13,580	19,137	28,090	31,514
C_3 B/D	1,107	1,604	2,436	2,738
C_4 B/D	146	212	321	361
Deisel B/D	2,307	3,343	5,078	5,706
Fuel Oil B/D	622	901	1,369	1,538
Alcohol B/D	1,829	2,650	4,026	4,524
Total Liquids B/D	19,591	27,847	41,230	46,381
FOE B/D	44,950	47,418	33,652	37,776
Efficiency (HHV)	57	60.1	42.7	47.9
Liquid Fuels/Ton Dry Coal (B)	.98	1.37	2.07	2.32
Liquid Fuels C^+_4/Ton Dry Coal (B)	.92	1.31	1.94	2.18

Reference: (66)

Advantages

- Processes entire mine output (that is, can handle coal fines)
- Processes caking and noncaking coal; no pretreatment required to process caking coals
- Coal residence time is short and gasifier throughput is relatively high
- High carbon utilization
- No tars and minimal methane
- Excellent environmental compliance as regards emissions and solid wastes

Disadvantages

- Higher-moisture coal requires drying for maximum gasification efficiency
- Low H_2/CO molar ratio raw gas product requires external CO water shift to achieve the higher ratios required for purified synthesis gas
- Recovery of the sensible heat from the gasifier product is required if a high net thermal efficiency is to be achieved; design of waste heat boilers to recover this heat is difficult because of the high temperature and the presence of molten ash.

When these gasifiers are integrated with the Synthol unit as in the preceding cases, Mitre estimates that the product slates will be as shown in Table 5-5. (Mitre estimates the all-liquid cases only).

The Texaco gasifier uses water-coal slurry as the means of feeding coal into the gasifier. Thus water consumes heat energy when it vaporizes. The Shell-Koppers gasifier avoids this energy loss by dry-feeding coal. This is the essential difference between the two gasifiers. As seen in Table 5-5, the Shell-Koppers gasifier enjoys substantially higher liquid yields, making this gasifier the best of the four evaluated by Mitre.

Mitre also provides the construction cost breakdown for the synfuel plants featuring both gasifiers (all-liquid cases only). These are tabulated in Table 5-6 along with those for the preceding cases (all-liquid only).

Table 5-5

Comparison of Product Slates from Grass-roots F-T Plants

	Mixed-output		All-liquid Output			
	Base Case	BGC	Base Case	BGC	Texaco	Shell-Koppers
SNG MM SCF/D	173.3	147.9	-	-	-	-
Gasoline B/D	13,580	19,137	28,090	31,514	31,445	34,455
C_3 B/D	1,107	1,604	2,436	2,738	2,876	3,157
C_4 B/D	146	212	321	361	382	417
Diesel B/D	2,307	3,343	5,078	5,706	6,004	6,579
Fuel Oil B/D	622	901	1,369	1,538	1,617	1,774
Alcohol B/D	1,829	2,650	4,026	4,524	4,737	5,204
Total Liquids B/D	19,591	27,847	41,230	46,381	47,061	51,586
FOE B/D	44,950	47,418	33,652	37,776		
Efficiency (HHV)	57	60.1	42.7	47.9	48.6	53.3
Liquid Fuels/Ton Dry Coal (B)	.98	1.37	2.07	2.32	2.35	2.58
Liquid Fuels C_4+/Ton Dry Coal (B)	.92	1.31	1.94	2.18	2.21	2.42

Reference: (66)

Table 5-6

Construction Cost Comparisons [$Million (1977)]

	ALL-LIQUID OUTPUT PLANTS			
	Base Case	BGC/Synthol	Texaco/ Synthol	Shell-Koppers/ Synthol
Coal & Ash Handling	71.4	71.4	95.2	89.0
Steam Plant	212.9	172.8	48.7	48.7
Oxygen Plant	148.5	155.5	245.7	245.7
Gasification	200.7	100.4	53.0	53.0
Raw Gas Cooling	13.3	—	67.0	67.0
Shift	12.8	30.0	30.0	30.0
Gas Cooling & Cleaning	104.8	127.9	149.8	157.7
Sulfur Recovery	59.0	64.8	69.3	83.0
Gas/Liquor Separation & Product Recovery	51.4	15.5	6.3	7.1
Waste Water Treatment	26.3	18.4	9.7	19.3
F-T Synthesis	109.1	147.7	149.2	159.1
F-T Product Upgrading	172.1	186.9	179.8	191.8
F-T Catalyst Preparation	48.0	53.6	54.1	57.7
Auto Thermal Reformer	40.7	36.5	23.2	30.1
Miscellaneous	108.0	108.0	108.0	108.0
TOTAL	1,382.7	1,289.4	1,289.0	1,347.2

All four cases in Table 5-6 have fairly similar construction costs, with the BGC and Texaco cases being equal and lowest, at $1,289 million. The Shell-Koppers case is 4.5% higher. The base case is the highest at $1,383 million, which is 7.3% higher than the Texaco or BGC case. These differences are surprisingly small considering the fact that the gasifier costs and performances are substantially different. Apparently, the differences are balanced out by the costs of other equipment that is required for an integrated synfuel plant.

The important difference is in gasifier performance, because this affects the thermal efficiency and producet yields of the synfuel plant. This point is illustrated in Table 5.5. With the Lurgi dry-ash gasifier (base case), the overall thermal efficiency is 42.7% and the C_4^+ liquid yield per ton of dry coal feed is 1.94 barrels. Compare these data with, for example, the Shell-Koppers case, which has a 53.3% efficiency and yields of 2.42 barrels/ton of liquids. The difference between the two is 25% for both thermal efficiency and liquid yield.

Mitre evaluated the price of gasoline in each of the four cases, based on the following parameters:

Plant life:	20 yr
Return on investments:	12% discounted cash flow
Investment data:	Table 5-7
Coal cost:	$7/ton (as received, 28% moisture)
Products yield:	Table 5-5
Products' selling prices:	Table 5-7

The results are tabulated in Table 5-8. Remembering that these are the gasoline selling prices necessary to assure the 12% return on investments, the Shell-Koppers case ranks as the best, with the lowest selling price of $1.16/gal. This is 23% lower than the required price of $1.51/gal for the base case. The difference between the base case and the BGC mixed-output case is 41¢/gal, which is greater than the corresponding difference of 27¢/gal in the all-liquid case. This suggests that the benefit of advanced gasifiers is greater in a marketplace where methane can be sold as SNG instead of being converted to liquids.

Table 5-7

Prices Assumed for Products Other Than Gasoline

PRODUCT	UNIT	$/UNIT
SNG & LPG*	MMBtu	6.17
Butanes	MMBtu	Gasoline - 30c/MMBtu
Diesel	BBL	Gasoline - $1.70/B
Fuel Oil	BBL	Gasoline - $3.50/B
Alcohols	lb	15¢/lb
Sulfur	Ton	$25/Ton
Ammonia	Ton	$155/Ton

*Based on production cost at plant designed to product SNG ONLY

Reference: (66)

Table 5-8

Gasoline Selling Cost for Various Synfuel Plants
($ per Gallon)

Mixed-output		All-liquid			
Base Case	BGC	Base Case	BGC	Texaco	Shell-Kopper
1.33	0.92	1.51	1.24	1.23	1.16

5.3 CO SHIFT

As shown in the preceding section, the advanced gasifiers have an important impact on the overall economics of synfuel production. These gasifiers, however, generate raw gases having a low H_2/CO ratio. For the Wyoming subbituminous coal, Mitre estimated the following H_2/CO ratios (66):

Gasifier	H_2/CO, mol/mol
Lurgi dry-ash	2.06
BGC	0.50
Texaco	0.68
Shell-Koppers	0.48

The Synthol step requires H_2/CO ratios in the range of 2.4-3.0. Mitre assumed a value of 2.54 for the cases described in the preceding sections (66). To achieve a H_2/CO ratio of 2.54, a certain percentage of CO in each gasifier output must be shifted. These percentages are shown in the Table 5-9.

All advanced gasifiers require more than 50% of the CO to be shifted. This may lead to substantial steam requirements, because the CO shift is done in the presence of excess steam. For example, in the BGC case Mitre assumed the material balance around the CO shift reactor to be as shown in Table 5-10. This table illustrates the depth of the CO shift and the corresponding steam requirement. A total of 52,300 lb-mole/h of steam are present at the inlet, of which 14,000 lb-mole/h is the makeup. The rest comes from the gasification step, which includes the particulate scrubbing stage where the hot gasifier stream is scrubbed with water and becomes equilibrated at the scrubber temperature. If the gas stream is cooled below this temperature, there will be a loss of steam by condensation; the loss must be compensated as the makeup at the CO-shift.

The shift step reduces the CO content from 59% to 25% (dry basis). The total steam requirement in terms of moles per mole of dry gases is 0.49. The value is a design parameter. Naturally, a higher steam concentration is required if a

Table 5-9

CO Shift for Advanced Gasifiers in an F-T Plant

Gasifier	H_2/CO, mol/mol Raw Gas	After CO Shift	%CO Shifted
Lurgi	2.06	2.54	14
BGC	0.50	2.54	58
Texaco	0.68	2.54	53
Shell-Koppers	0.48	2.5	58

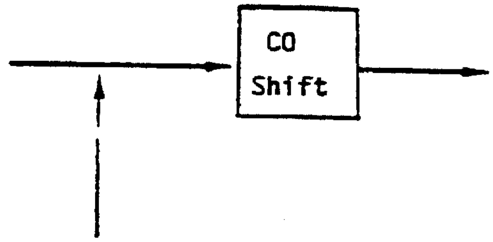
Reference: (66)

Table 5-10

Material Balance around CO Shift Reactor in BGC Case

Raw Gases, lb mole/h

CO	63,800
H_2	31,900
Steam	38,300
Others	11,700



Steam (Makeup)
14,000

Shift Outlet, lb mole/h

CO	27,000
H_2	68,700
Steam	15,500
Others	45,500

Reference: (66)

deeper CO shift (lower residual Co) is desired. For evaluation of the present accuracy, a value of 0.5 mole/mole dry gas may be taken as a guideline for the advanced gasifiers in conventional F-T plants.

The major cost items in the CO shift are the following:

- Fuel to raise the makeup steam to the CO shift step
- Capital cost of that part of the steam plant to produce the makeup steam
- Capital cost of CO shift battery limits.

There are also minor costs such as catalyst, chemicals, labor, and utilities.

For the examples cited in Table 5-10, the following values can be derived based on the Mitre data (66):

- Fuel = (14,000 lb mole/h) (18 lb/lb mole) (1670 Btu/lb)
  = 421 million Btu/h
  Using the feed coal as fuel and at 41¢/mmBtu, this amounts to $4,100/day
- Construction cost of the part of steam plant with 14,000 lb mole/h capacity is about $15 million
- Construction cost of the CO shift plant is $30 million.

The fuel cost of $4,100/day is very small. If this is spread evenly over the total liquid products listed in Table 5-5, it amounts to 15¢/bbl, or 0.35¢/gal or about 0.3% of product selling cost. The construction costs for the steam plant and CO shift battery limits add up to $45 million, about 3% of the synfuel plant construction cost.

5.4 ADVANCED SYNTHESIS PROCESSES

In Section 5.3, it was shown that the advanced gasifiers produce raw gases of low H_2/CO ratio, and they require substantial CO shifting to be integrated with the Synthol process. The slurry-phase synthesis processes currently under development are capable of an in situ CO shift, among others, thus eliminating the external shift step. The cost impact of eliminating the CO shift has been shown to be small (Section 5.3). To be worthy of development, the advanced synthesis process should have other advantages over the Synthol process. Mitre has explored the economic impact of the slurry-phase synthesis process (66). The results are reviewed below.

Tabel 5-11 lists products from three synfuel plants of the mixed-output mode featuring the BGC gasifier and Kolbel slurry-phase synthesis process (Chapters 3 and 4), BGC/Synthol and Lurgi/Synthol. The last two cases have been discussed in the preceding sections. The Kolbel process is not a well-established process; thus the product slate shown should be taken in this light. Table 5-12 lists products from the same three cases operating in all-liquid mode, in which methane is recycled to extinction through autothermal reforming (Section 5.1). In both modes of operation, the Kolbel process boosts the gasoline yield as well as the total liquid yield per ton of feed coal. The percentages relative to the base case are as follows:

	BGC/Kolbel	BGC/Synthol	Lurgi/Synthol
Mixed-output			
Gasoline, %	227	141	100
C_4^+ liquids, %	193	142	100
All-liquid			
Gasoline, %	142	112	100
C_4^+ liquids, %	119	112	100

These percentages show the desirability of the Kolbel process, provided, of course, that the performance predicted here can be demonstrated in a commercial-scale operation.

The construction costs of the Kolbel-based plants have been estimated by Mitre. These are shown in Tables 5-13 and 5-14 for the mixed-output and all-liquid modes, respectively.

Table 5-11

Products After Downstream Processing (Mixed-product Case)

	BGC (KOLBEL)	BGC/SYNTHOL	LURGI/SYNTHOL
SNG MM SCF/D	94.2	147.9	173.3
Gasoline (B/SD)	30,766	19,137	13,580
C_3 LPG (B/SD)	3,084	1,604	1,107
C_4 LPG (B/SD)	-	212	146
Diesel (B/SD)	3,821	3,343	2,307
Fuel Oil (B/SD)	398	901	622
Alcohol (B/SD)	618	2,650	1,829
Total Liquids (B/SD)	38,687	27,847	19,591
FOE* (B/SD)	47,636	47,418	44,950
Efficiency, percent**	60.4	60.1	57
B Liquid Fuels/Ton Dry Coal	1.93	1.37	0.98
B Liquid Fuels C^+_4/Ton Dry Coal	1.78	1.31	0.92

*Fuel Oil Equivalent = $\sum$HHV/6.0 x 10^6
**Product HHV/Coal HHV x 100

Reference: (66)

Table 5-12

Products after Downstream Processing (All-liquid Case)

	BGC (KOLBEL)	BGC (F-T)	SASOL (US)
Gasoline (B/SD)	39,945	31,514	28,090
C_3 LPG (B/SD)	4,055	2,738	2,436
C_4 LPG (B/SD)	-	361	321
Diesel (B/SD)	5,025	5,706	5,078
Fuel Oil (B/SD)	523	1,538	1,369
Alcohol (B/SD)	813	4,524	4,026
Total Liquids (B/SD)	50,361	46,381	41,320
FOE* (B/SD)	41,506	37,776	33,652
Efficiency, percent**	52.5	47.9	42.7
B Liquid Fuels/Ton Dry Coal	2.52	2.32	2.06
B Liquid Fuels C_4^+/Ton Dry Coal	2.31	2.18	1.94

*Fuel oil equivalent = HHV/6.0×10^6
**Product HHV/Coal HHV x 100

Reference: (66)

Table 5-13

BGC/Kolbel Impact on Construction Cost
(Mixed-output Case)
[$Million (1977)]

	Δ Relative to BGC/F-T	
REFERENCE CONSTRUCTION COST (BGC/F-T)		1,104.3
Synthesis Gas Preparation Including Shift	-31.8	
By-Product Recovery	-31.9	
Synthesis	+20.8	
SNG Preparation	- 5.8	
F-T Liquid Product Upgrading	+27.2	
Oxygen Plant	+ 1.3	
Steam Plant	-11.4	
Waste Water Treatment	- 4.8	
TOTAL CHANGE		-36.4
BGC-KOLBEL CONSTRUCTION COST		1,067.9
CAPITAL COST (1.59 x Construc. Cost)		1,698.0

Reference: (66)

Table 5-14

BGC/Kolbel Impact on Construction Cost
(All-liquid Case)
[$Million (1977)]

	Δ Relative to Mixed Output Case	
REFERENCE CONSTRUCTION COST (BGC-KOLBEL MIXED OUTPUT		1,067.9
Synthesis	+31.8	
Add Autothermal Reformer	+26.5	
Delete SNG Preparation and Methanator	-15.9	
F-T Liquid Product Upgrading	+31.0	
Oxygen Plant	+26.0	
Steam Plant	+13.9	
Waste Water Treatment	- 0.8	
TOTAL CHANGE		+112.5
BGC-KOLBEL CONSTRUCTION COST		1,180.4
CAPITAL COST		1,877.0

Reference: (66)

Table 5-13 compares the BGC/Kolbel case with the BGC/Synthol case. Mitre assumed a 20% cost increase for the Kolbel reactor over that of the Synthol reactor, which they think may be an overestimate. There are several trade-offs between the two cases; the net result is that the construction costs differ only slightly. A slightly lower cost for the Kolbel case suggests that the differential between the two would be small even if the cost of the Kolbel reactor had turned out to be 100% more than that of the Synthol design. A study by UOP indicates that the capital cost of the Kolbel unit could be about one half that of the Synthol unit (68). This would, of course, present the Kolbel-based plant in a more optimistic light than does the Mitre study, but it should hold true that the synthesis part of the synfuel plant is only a small fraction of the cost, and that the important economic contribution would most likely come from performance improvements and not from capital savings.

Table 5-14 compares the mixed-output mode with the all-liquid mode of the BGC/Kolbel case. It shows that the liquid mode is $112.5 million, or 11% more expensive than the mixed mode. The mixed mode is, therefore, $1,180.4 million. This is $109 million lower than the cost of the BGC/Synthol in all-liquid mode (Table 5-3). Again, in view of the uncertanties in the estimate, it may be concluded that the construction costs of the BGC/Kolbel and BGC/Synthol in all-liquid mode are about the same despite the important design and performance differences.

Table 5-15 shows the costs of gasoline from BGC/Kolbel compared with the BGC/Synthol and Lurgi/Synthol cases. Percentage data with the base case (Lurgi/Synthol) as 100% are included to show the relative contribution of the use of a BGC gasifier and Kolbel synthesis in both mixed-output and all-liquid modes. The desirability of the Kolbel process over the Synthol process is again illustrated here. Also shown is the desirability of the BGC gasifier over the Lurgi dry-ash gasifier. The contribution of the BGC gasifier is particularly great in the mixed-output mode. In fact, the impact of the Kolbel process in this mode is relatively small. In the all-liquid mode, the BGC gasifier and the Kolbel process contribute almost equally to reducing the gasoline cost from the base case cost.

Table 5-15

Gasoline Costs for BGC/Kolbel and Other Cases

	BGC/Kolbel	BGC/Synthol	Lurgi/Synthol
Mixed-output Case			
$/gallon	0.84	0.92	1.33
%	63	69	100
All-liquid Case			
$/gallon	1.03	1.24	1.51
%	68	82	100

Reference: (66)

Table 5-16 shows the cost of gasoline from four synfuel cases in all-liquid mode featuring the Kolbel process in combination with different gasifiers. As in Table 5-15, percentage data, with the base case as 100%, are included to show the relative contributions of the gasifier and synthesis processes.

The cost reduction is greatest with the Shell-Koppers combined with Kolbel process. The use of this gasifier in place of the Lurgi dry-ash gasifier reduces the gasoline cost by 23%. An additional 15% reduction is achieved by the combined use of the Shell-Koppers gasifier and the Kolbel process. It is noteworthy that a greater cost reduction occurs in replacing the gasifier rather than in replacing the Synthol with the Kolbel process. An important implication of this is that a major economic improvement is possible with near-term technology (Shell-Koppers); while the ultimate technology (Kolbel) provides some improvement, it is not as significant as the gasifier.

Table 5-16

Gasoline Costs for a Combination of Kolbel with Gasifier (All-liquid mode)

	BGC/Kolbel	BGC/Synthol	Lurgi/Synthol
$/gallon	1.03	1.24	1.51
%	68	82	100

	Texaco/Kolbel	Texaco Synthol	Lurgi/Synthol
$/gallon	1.01	1.23	1.51
%	67	81	100

	Shell-Koppers/Kolbel	Shell-Koppers/Synthol	Lurgi/Synthol
$/gallon	0.94	1.16	1.51
%	62	77	100

Data are not available for the mixed-output mode for the cases listed in Table 5-16. It is, however, speculated that the impact of the advanced gasifiers and Kolbel technologies follows a pattern similar to the BGC case listed in Table 5-15.

5.5 SUMMARY AND CONCLUSIONS

In a typical coal-based grass-roots F-T plant, the construction costs of the F-T synthesis and CO shift sections account for 6.4% and 1.1%, respectively. These values are surprisingly small and suggest that only limited benefits will be accrued from cheaper process replacements. Thus, the emphasis of research and development should be on aspects such as thermal efficiency, product selectivity, and unit operability.

The gasoline selling price for three synfuel cases estimated by Mitre are given in Table 5-17 in $/gallon and percent relative to a base case (Lurgi). In the mixed-output mode, replacing the Lurgi gasifier with BGC gasifier reduces the cost by 31%. A further reduction of 6% is achieved by replacing the Synthol and the Kolbel process. This relatively minor contribution by the Kolbel technology is rather surprising. The main reason is in the pricing of SNG, which Mitre has set at $6.17 per million Btu. Where methane can be sold at this price, converting it to gasoline and fuel oils apparently does not offer a significant incentive. The situation is different in the all-liquid mode, where methane is given zero value and is recycled to extinction via auto thermal reforming. Here, the Kolbel technology contribution is equal to that of BGC gasifier.

In summary, approximately equal economic incentives exist for the advanced gasifier and for the slurry F-T process. The noteworthy item of the Mitre study is the impact of the advanced gasifier, indicating that a synfuel plant of improved economics is as near as development of the improved gasification

Table 5-17

Required Gasoline Selling Price
(1977 $)

Gasifier/F-T:	Lurgi/Synthol	BGC/Synthol	BGC/Kolbel
Mixed-output mode			
$/gallon	1.33	0.92	0.84
%	100	69	63
All-liquid mode			
$/gallon	1.51	1.24	1.03
%	100	82	68

technology. Some additional improvement is expected from a Kolbel-type technology, but its prospect is believed not as near-term as the advanced gasifiers.

The major cost items in the CO shift are the following:

- Fuel to raise the makeup steam to the CO shift step
- Capital cost of that part of the steam plant to produce the makeup steam
- Capital cost of CO shift battery limits.

There are also minor costs such as catalyst, chemicals, labor, and utilities. It is estimated that the fuel cost is about 0.3% of the total product selling price and the shift-related capital is about 3% of the total plant construction cost.

In both mixed-output and all-liquid modes, replacing the Synthol with a Kolbel type synthesis increases the liquids output by substantial margins. This is illustrated in Table 5-18. These percentages show the desirability of the Kolbel process, provided, of course, that the performance predicted here can be demonstrated in a commercial-scale operation.

Table 5-18

Relative Liquid Yields

	BGC/Kolbel	BGC/Synthol	Lurgi/Synthol
Mixed-output			
Gasoline, %	227	141	100
C_4^+ liquids, %	193	142	100
All-liquid			
Gasoline, %	142	112	100
C_4^+ liquids, %	119	112	100