7.0 COMMERCIAL ESTIMATES

The 18 pilot plant runs described in Section 6 provide input for estimates of commercial yield and capital and operating costs. In this section, LPG compositions expected from four commercial F-T operations are defined. Next, commercial yield estimates (based on pilot plant results) are summarized. Direct and Indirect Cyclar yield estimates were prepared for each case, for a total of eight cases (see Figure 7.1). Finally, estimates of capital and operating costs for each case are summarized.

7.1 FEEDSTOCK DEFINITIONS

For the commercial yield estimates, LPG is defined as C_3 plus C_4 hydrocarbons; C_5 is not included in the LPG. The C_5 material produced by the F-T reactor is included in the naphtha stream rather than being sent to the Cyclar unit (Figure 7.2). The F-T naphtha is sent to a two-stage hydrotreater. Diolefins are hydrogenated, and some monoolefins are saturated in the first stage. Saturation is completed in the second stage, along with the dehydration of oxygenates. The C_5 is fractionated between stages and sent to the gasoline pool.

Products from three different F-T reactors (7,8) are summarized in Table 7.1. Reactor technology has a tremendous impact on the relative amount of LPG produced as well as on the LPG composition (Table 7.2). If a hydrocracker were used to upgrade the Arge F-T wax and the hydrocracker were operating to maximize gasoline production, the LPG from the hydrocracker would be a large stream (Figure 7.3). The combined LPG composition is estimated in Table 7.3. This combined LPG was chosen to supplement the LPG's produced directly by the three F-T reactors described above. Operating conditions were chosen for the wax hydrocracker (400°F product end point) to provide a high conversion case. This case is intended to represent the maximum amount of hydrocracked LPG that could reasonably be sent to a Cyclar unit relative to straight-run LPG from the Arge F-T reactor.

A constant basis of 5,675.5 MT/day of F-T reactor products (methane through F-T wax, including water-soluble acids and non-acids) was chosen to be consistent with a previous F-T wax hydrocracking study (1). Because the relative amount of LPG produced in each situation varies, the size of the LPG stream sent to the Cyclar unit also varies (Table 7.4).

The feed rates for each of the four upgrading situations differ, and so care must be exercised when comparing yield and cost estimates. The Direct Cyclar and Indirect Cyclar estimates for each F-T reactor technology are comparable, but the Direct Cyclar estimate for Arge LPG (Case No. 1) is for a unit less than half the size in terms of fresh feed as the Direct Cyclar estimate for Mobil Slurry LPG (Case No. 5). This size differential does not affect product yields (wt-% fresh feed basis), but it does affect capital and operating cost numbers as well as numbers related to catalyst requirements and catalyst circulation rates. A more general treatment of Direct and Indirect Cyclar economic data is included in Section 8 ("Economic Evaluation").

7.2 COMMERCIAL YIELD ESTIMATES

A yield estimate makes the transition from pilot plant data to a prediction of commercial performance. Input to the commercial yield estimate includes catalytic activity, conversion stability, and product selectivity data obtained with the design feedstock. Output from the commercial yield estimate includes combined feed definition, mass-balanced yields, and catalyst requirements.

Eight cases were evaluated. Four of the cases (Indirect Cyclar) required Huels CSP yield estimates in addition to Cyclar yield estimates. The four Huels CSP estimates are described first because they define the Indirect Cyclar fresh feeds.

7.2.1 Huels CSP Commercial Yield Estimates

In the Indirect Cyclar process, olefinic LPG is saturated in a Huels CSP unit upstream from the Cyclar unit. Mass-balanced yield estimates for each of the four F-T LPG's defined in Section 7.1 were prepared. The estimates are summarized in Tables 7.5 through 7.8. The positions of feed and product streams cited in these Tables are illustrated in Figure 7.4. The product from the Huels CSP is fresh feed to a Cyclar unit in the four Indirect Cyclar yield estimating cases.

7.2.2 Cyclar Commercial Yield Estimates

In addition to process yields, a Cyclar yield estimate specifies information critical to the design of the catalyst regeneration section of the unit. Continuous Catalyst Regeneration (CCR) technology is an integral part of the Cyclar process. The regenerator size and operating specifications depend on catalyst coking. More severe reactor conditions or a change in feedstock may produce more coke on the circulating catalyst. The catalyst must be circulated (regenerated) at a sufficiently high rate to maintain catalyst activity. Based on pilot plant catalyst deactivation rates and spent catalyst carbon levels, the yield estimate will define a catalyst circulation rate specific for the design feedstock and process conditions. The regenerator size depends on the catalyst circulation rate, as well as any additional considerations necessary to provide the correct environment for catalyst regeneration.

7.2.2.1 Indirect Cyclar Commercial Yield Estimates

The Huels CSP yield estimates provides Cyclar fresh feed definitions. Commercial yield estimates are summarized in Tables 7.9 through 7.12. These estimates account for the Cyclar unit only; they consider neither the hydrogen consumed nor the vent gas (fuel gas) produced by the CSP unit. These two pieces of an Indirect Cyclar yield estimate (CSP plus Cyclar) are integrated in Table 7.13 and presented

graphically in Figures 7.5 through 7.8. Notice the assumption that 10 wt-% of the hydrogen produced will not be recovered and will end up in the fuel gas as a result. The hydrogen product is assumed to be 95 vol-% pure, with the balance being methane. Finally, the hydrogen sent to the Huels CSP unit from the Cyclar unit was assumed to be pure hydrogen. This simplifying assumption has minuscule overall impact.

7.2.2.2 Direct Cyclar Commercial Yield Estimates

The four olefinic LPGs defined in Section 7.1 were specified for the Direct Cyclar yield estimates. The individual estimates are summarized in Tables 7.14 through 7.17. Results from all four Direct Cyclar estimates are integrated in Table 7.18 and depicted in Figures 7.9 through 7.12. The same assumptions with respect to hydrogen recovery and purity described in the previous section were also made in the Direct Cyclar estimates. Naturally, the simplification regarding Huels CSP hydrogen was not applicable in the Direct Cyclar cases.

7.2.2.3 Direct vs. Indirect Cyclar Yield Estimates

The yield estimate is a tool for process optimization. Pressure, temperature, LHSV, unconverted feed recycle, product separator conditions, and product purification conditions can be independently varied. Indirect Cyclar feed is similar to feeds for which the process was developed, and so the optimal conditions are well-explored base conditions. For the Direct Cyclar process, a pressure exceeding base pressure was chosen to exploit higher conversion at the expense of aromatics yield. This significantly reduces the combined feed ratio and compression requirements. The combined feed ratio drops because higher conversion reduces the size of the feed recycle stream. Compression requirements drop at elevated pressure, reflecting a smaller pressure differential between the product separation and the LPG recovery sections of the plant.

The catalyst circulation rates are considerably higher for the Direct Cyclar cases. Both the high olefins level of the feed and the higher Direct Cyclar operating pressure result in more catalyst coke. In turn, more catalyst coke increases the regeneration severity.

7.3 ESTIMATES OF CAPITAL AND OPERATING COSTS

The yield estimate serves as the basis for preparation of the estimated erected cost (EEC). The EEC is a collection of process component costs. The major components of the Cyclar process are the reactor, charge and interheaters, compressor, LPG recovery and product purification, and CCR sections. The EEC also includes detailed engineering and construction expenses (contractor fees, etc.). A more detailed account of what is included in the EEC is in Appendix C.

The capital cost of the reactor section depends on the combined feed rate, temperature, and pressure. The compressor cost is largely a function of process pressure and compressor capacity. Compressor and driver capital costs are significant in most refinery processes and may be up to 25% of the ISBL EEC. Once specifications for feed recovery and product purification are set, these capital costs are a function of capacity.

Operating costs are determined by information in the yield estimate. Utility consumption is largely a function of feed conversion per pass and unit capacity. Other costs, such as maintenance, property taxes, and insurance, were estimated as a percentage of the EEC.

Estimates for capital and operating costs for the Indirect Cyclar cases are summarized in Table 7.19. The Direct Cyclar cases are summarized in Table 7.20. These estimates are specific to the eight cases defined above. A more general discussion of Direct and Indirect Cyclar capital and operating costs is included in the economic analysis, Section 8.

TABLE 7.1

Fischer-Tropsch Reactor Selectivities

	Arge (7) Fixed-Bed, Wt-%	Synthol (7) Fluidized-Bed, Wt-%	Mobil (8) Slurry Low-Wax Case, Wt-%
Methane	2.0	10	7.5
Ethylene	0.1	4	3.0
Ethane	1.8	4	1.6
Propylene	2.7	12	8.0
Propane	1.7	2	2.0
Butylene	3.1	9	6.6
Butane	1.9	2	2.1
C_5-C_{11} Gasoline	17.9	40	39.7
C_{12}-C_{18} Diesel	13.9	7	14.8
C_{19}-C_{23}	7.0		3.0
C_{24}-C_{35} Med. Wax	19.9	4	7.5
C_{35+} Hard Wax	24.8		
Water-Sol. Non-Acids	3.0	5	3.9
Water-Sol. Acids	0.2	1	0.3
	100.0	100	100.0

Note: Carbon number selectivities used directly as estimates for actual reactor effluent composition for Arge and Synthol. Published wt-% distributions are not available for these reactor products.

TABLE 7.2

LPG from F-T Reactors

	Arge Fixed-Bed, Wt-%	Synthol Fluidized-Bed, Wt-%	Mobil Slurry Low-Wax Case, Wt-%
Propylene	28.7	48.0	42.8
Propane	18.1	8.0	10.7
Butylenes	33.0	36.0	35.3
Isobutane	1.0	3.4	0.8
n-Butane	19.2	4.6	10.4
	100.0	100.0	100.0
Total Olefins	61.7	84.0	78.1

Note: Butane i/n ratios estimated from published C_5-C_{11} data (7,8).

TABLE 7.3

Arge F-T Complex Combined LPG Stream

	LPG from Arge Rx		LPG from Hydrocracker		Combined LPG Streams	
	Wt-%	MT/Day	Wt-%	MT/Day	Wt-%	MT/Day
Propylene	28.7	153.1	0.0	0.0	14.8	153.1
Propane	18.1	96.6	20.0	100.3	19.0	196.9
Butylenes	33.0	176.1	0.0	0.0	17.0	176.1
Isobutane	1.0	5.3	55.2	276.9	27.3	282.2
n-Butane	19.2	102.4	24.8	124.4	21.9	226.8
	100.0	533.5	100.0	501.6	100.0	1035.1
LPG Paraffins	38.3	204.3	100.0	501.6	68.2	705.9
LPG Olefins	61.7	329.2	0.0	0.0	31.8	329.2

Basis:
- 5,675.5 MT/day total hydrocarbon from Arge Rx.
- C_{10}+ portion of Arge Rx effluent (= 52 wt-% of Total HC) sent to hydrocracker (Figure 7.3).
- Hydrocracker LPG yields based on UOP proprietary data.

TABLE 7.4

Summary of Fischer-Tropsch Derived LPGs

	Arge Fixed-Bed	Synthol Fluidized-Bed	Mobil Slurry Rx	Arge Fixed-Bed
LPG Source, wt-%				
From F-T Rx	100.0	100.0	100.0	51.5
From Hydrocracker	0.0	0.0	0.0	48.5
LPG Flow Rates				
MT/day	534	1,419	1,061	1,035
kg/hr	22,229	59,120	44,221	43,129
BPSD (*)	6,014	16,153	12,018	11,715
LPG Breakdown, wt-%				
Propylene	28.7	48.0	42.8	14.8
Propane	18.1	8.0	10.7	19.0
Butylenes	33.0	36.0	35.3	17.0
Isobutane	1.0	3.4	0.8	27.3
n-Butane	19.2	4.6	10.4	21.9
	100.0	100.0	100.0	100.0
LPG Paraffins, wt-%	38.3	16.0	21.9	68.2
LPG Olefins, wt-%	61.7	84.0	78.1	31.8
	100.0	100.0	100.0	100.0
Total C_3, wt-%	46.8	56.0	53.5	33.8
Total C_4, wt-%	53.2	44.0	46.5	66.2
	100.0	100.0	100.0	100.0
API Gravity, °API	121.884	124.37	123.019	122.877
Specific Gravity	0.5584	0.5530	0.5559	0.5563
Mole Weight	49.3023	47.5854	48.0372	51.7555

* BPSD = Barrels per stream day

TABLE 7.5

Huels CSP Estimate for Case No. 2
(Indirect Cyclar -- Arge LPG)

	CSP Fresh Feed	Hydrogen Feed	Vent Gas	CSP Product
Stream Number (Figure 7.4)	1	2	3	4
Component Flow Rates, kg/hr				
Hydrogen	0	586	15	2.3
Propylene	6,380	0	0	0.2
Propane	4,023	0	230	10,479.0
Butylenes	7,336	0	0	0.8
Isobutane	222	0	4	586.5
n-Butane	4,268	0	48	11,449.2
	22,229	586	297	22,518.0

TABLE 7.6

Huels CSP Estimate for Case No. 4
(Indirect Cyclar -- Synthol LPG)

	CSP Fresh Feed	Hydrogen Feed	Vent Gas	CSP Product
Stream Number (Figure 7.4)	1	2	3	4
Component Flow Rates, kg/hr				
Hydrogen	0	2,188	55	8.5
Propylene	28,378	0	0	0.5
Propane	4,730	0	851	33,616.1
Butylenes	21,283	0	0	2.1
Isobutane	2,010	0	91	11,288.6
n-Butane	2,720	0	78	15,318.2
	59,121	2,188	1,075	60,234.0

TABLE 7.7

Huels CSP Estimate for Case No. 6
(Indirect Cyclar -- Mobil Slurry LPG)

	CSP Fresh Feed	Hydrogen Feed	Vent Gas	CSP Product
Stream Number (Figure 7.4)	1	2	3	4
Component Flow Rates, kg/hr				
Hydrogen	0	1,512	38	5.6
Propylene	18,926	0	0	0.4
Propane	4,732	0	622	23,944.8
Butylenes	15,610	0	0	1.5
Isobutane	354	0	12	1,485.3
n-Butane	4,599	0	100	19,523.4
	44,221	1,512	772	44,961.0

TABLE 7.8

Huels CSP Estimate for Case No. 8
(Indirect Cyclar -- Arge Plus Hydrocracker LPG)

	CSP Fresh Feed	Hydrogen Feed	Vent Gas	CSP Product
Stream Number (Figure 7.4)	1	2	3	4
Component Flow Rates, kg/hr				
Hydrogen	0	586	14	3.2
Propylene	6,383	0	0	0.3
Propane	8,195	0	161	14,721.5
Butylenes	7,332	0	0	1.4
Isobutane	11,774	0	53	15,920.4
n-Butane	9,445	0	27	12,813.2
	43,129	586	255	43,460.0

TABLE 7.9

Cyclar Yield Estimate, Case No. 2
Arge F-T LPG -- Indirect

	Fresh Feed from CSP	Light Ends	Liquid Product
Component, kg/hr			
Hydrogen	2.3	1,244	--
Methane	0.0	3,707	--
Ethylene	0.0	312	--
Ethane	0.0	2,459	--
Propylene	0.2	34	--
Propane	10,479.0	163	--
Butylenes	0.8	11	--
Butanes	12,035.7	39	--
Pentanes	0.0	3	--
Hexanes	0.0	0	--
Benzene	--	--	4,333
Toluene	--	--	6,124
Ethylbenzene	--	--	293
p-Xylene	--	--	710
m-Xylene	--	--	1,365
o-Xylene	--	--	611
A9	--	--	284
A10	--	--	51
A11	--	--	77
A12+ (incl. Naphthalenes)	--	--	698
Total, kg/hr	22,518.0	7,972	14,546
BPSD	6,285.0	--	2,517
MMSCFD	--	19.21	--

Component Yields, wt-% of Cyclar Fresh Feed

Hydrogen	= 5.5
$C_1 + C_2$	= 28.8
$C_3 + C_4$	= 1.1
Aromatics	= 64.6

Combined Feed LHSV, 1/hr	= 1.45 x Pilot Plant LHSV 1
Combined Feed Ratio wt/wt	= 1.93
Olefins in Combined Feed, wt-%	= 3.3
Process Pressure	= P1
Ave. Rx. Temp., °C	= 540
Catalyst Required (Rx Section), MT	= 1.00 x Base (By Definition)
Catalyst Regeneration Rate, kg catalyst/hr	= 1.00 x Base (By Definition)
Relative Carbon Level, wt-%/wt-%	= 0.65 (Spent Catalyst carbon level relative to pilot plant run No.3 spent catalyst)

TABLE 7.10

Cyclar Yield Estimate, Case No. 4
Synthol F-T LPG -- Indirect

	Fresh Feed from CSP	Light Ends	Liquid Product
Component, kg/hr			
Hydrogen	8.5	3,363	--
Methane	0.0	10,052	--
Ethylene	0.0	813	--
Ethane	0.0	6,574	--
Propylene	0.5	89	--
Propane	33,616.1	464	--
Butylenes	2.1	26	--
Butanes	26,606.8	90	--
Pentanes	0.0	7	--
Hexanes	0.0	0	--
Benzene	--	--	11,695
Toluene	--	--	16,250
Ethylbenzene	--	--	747
p-Xylene	--	--	1,860
m-Xylene	--	--	3,604
o-Xylene	--	--	1,621
A9	--	--	732
A10	--	--	131
A11	--	--	189
A12+ (incl. Naphthalenes)	--	--	1,927
Total, kg/hr	60,234.0	21,478	38,756
BPSD	17,214.0	--	6,732
MMSCFD	--	52.14	--

Component Yields, wt-% of Cyclar Fresh Feed

Hydrogen	= 5.6
$C_1 + C_2$	= 29.0
$C_3 + C_4$	= 1.1
Aromatics	= 64.3

Combined Feed LHSV, 1/hr	=	1.41 x Pilot Plant LHSV 1
Combined Feed Ratio wt/wt	=	1.93
Olefins in Combined Feed. wt-%	=	3.1
Process Pressure	=	P1
Ave. Rx. Temp., °C	=	540
Catalyst Required (Rx Section), MT	=	1.00 x Base (By Definition)
Catalyst Regeneration Rate, kg catalyst.hr	=	2.78 x Base (Case No. 2 defined as base catalyst requirement)
Relative Carbon Level wt-%/wt-%	=	0.65 (Spent Catalyst carbon level relative to pilot plant run No.3 spent catalyst)

TABLE 7.11

Cyclar Yield Estimate, Case No. 6
Mobil Slurry F-T LPG -- Indirect

	Fresh Feed from CSP	Liquid Light Ends	Product	
Component, kg/hr				
Hydrogen	5.6	2,503	--	
Methane	0.0	7,476	--	
Ethylene	0.0	611	--	
Ethane	0.0	4,908	--	
Propylene	0.4	67	--	
Propane	23,944.8	341	--	
Butylenes	1.5	20	--	
Butanes	21,008.7	70	--	
Pentanes	0.0	5	--	
Hexanes	0.0	0	--	
Benzene	--	--	8,708	
Toluene	--	--	12,156	
Ethylbenzene	--	--	565	
p-Xylene	--	--	1,396	
m-Xylene	--	--	2,699	
o-Xylene	--	--	1,213	
A9	--	--	552	
A10	--	--	99	
A11	--	--	144	
A12+ (incl. Naphthalenes)	--	--	--	1,428
Total, kg/hr	44,961.0	16,001	28,960	
BPSD	12,718.0	--	5,028	
MMSCFD	--	38.79	--	

Component Yields, wt-% of Cyclar Fresh Feed

Hydrogen	= 5.6
$C_1 + C_2$	= 28.9
$C_3 + C_4$	= 1.1
Aromatics	= 64.4

Combined Feed LHSV, 1/hr	= 1.43 x Pilot Plant LHSV 1
Combined Feed Ratio wt/wt	= 1.93
Olefins in Combined Feed, wt-%	= 3.2
Process Pressure	= P1
Ave. Rx. Temp., °C	= 540
Catalyst Required (Rx Section), MT	= 2.05 x Base (Case No. 2 defined as base catalyst requirement)
Catalyst Regeneration Rate, kg catalyst/hr	= 2.05 x Base (Case No.2 defined as base rate)
Relative Carbon Level, wt-%/wt-%	= 0.65 (Spent Catalyst carbon level relative to pilot plant run No.3 spent catalyst)

TABLE 7.12

Cyclar Yield Estimate, Case No. 8
Arge F-T Plus Wax Hydrocracker LPG -- Indirect

	Fresh Feed from CSP	Light Ends	Liquid Product
Component, kg/hr			
Hydrogen	3.2	2,363	--
Methane	0.0	7,020	--
Ethylene	0.0	626	--
Ethane	0.0	4,752	--
Propylene	0.3	69	--
Propane	14,721.5	283	--
Butylenes	1.4	23	--
Butanes	28,733.6	89	--
Pentanes	0.0	7	--
Hexanes	0.0	0	--
Benzene	--	--	8,257
Toluene	--	--	11,949
Ethylbenzene	--	--	603
p-Xylene	--	--	1,409
m-Xylene	--	--	2,683
o-Xylene	--	--	1,194
A9	--	--	578
A10	--	--	104
A11	--	--	164
A12+ (incl. Naphthalenes)	--	--	1,287
Total, kg/hr	43,460.0	15,232	28,228
BPSD	11,990.0	--	4,853
MMSCFD	--	36.30	--

Component Yields, wt-% of Cyclar Fresh Feed

Hydrogen	= 5.4
$C_1 + C_2$	= 28.5
$C_3 + C_4$	= 1.1
Aromatics	= 65.0

Combined Feed LHSV, 1/hr	=	1.52 x Pilot Plant LHSV 2
Combined Feed Ratio wt/wt	=	1.92
Olefins in Combined Feed, wt-%	=	3.5
Process Pressure	=	P1
Ave. Rx. Temp., °C	=	540
Catalyst Required (Rx Section), MT	=	1.82 x Base (Case No. 2 defined as base catalyst requirement)
Catalyst Regeneration Rate, kg catalyst/hr	=	1.82 x Base (Case No.2 defined as base rate)
Relative Carbon Level, wt-%/wt-%	=	0.65 (Spent Catalyst carbon level relative to pilot plant run No.3 spent catalyst)

TABLE 7.13

Summary of Indirect Cyclar Yield Estimates

	Case No. 2	4	6	8	Comment
CSP Flow Rates, kg/hr					
(1) Hydrocarbon Fresh Feed	22,229	59,121	44,221	43,129	From CSP Y.E.
(2) Hydrogen Feed	586	2,188	1,512	586	From CSP Y.E.
(3) Vent Gas	297	1,075	772	255	From CSP Y.E.
(4) Saturated Product	22,518	60,234	44,961	43,460	From CSP Y.E.
Cyclar Flow Rates, kg/hr					
(5) Fresh Feed from CSP	22,518	60,234	44,961	43,460	(5)=(4)
(6) Hydrogen in Light Ends	1,244	3,363	2,503	2,363	From Cyclar Y.E.
(7) C1-C5 in Light Ends	6,728	18,115	13,498	12,869	From Cyclar Y.E.
(8) Aromatics	14,546	38,756	28,960	28,228	From Cyclar Y.E.
Hydrogen Flow Rates, kg/hr					
(9) Total Hydrogen	1,244	3,363	2,503	2,363	(9)=(6)
(10) Recovered Hydrogen (a)	1,120	3,027	2,253	2,127	(10)=0.9x(9)
(11) Hydrogen to Fuel Gas	124	336	250	236	(11)=0.1x(9)
(12) Hydrogen to CSP (b)	586	2,188	1,512	586	(12)=(2)
(13) Net Hydrogen (100% H_2)	534	839	741	1,541	(13)=(10)-(12)
Hydrogen Product Flow Rates, kg/hr (c)					
(14) Net Hydrogen (100% H_2)	534	839	741	1,541	(14)=(13)
(15) Methane in Hydrogen Product	224	351	310	646	(15)=0.4188x(14)
(16) Product Hydrogen (95 vol-% H_2)	758	1,190	1,051	2,187	(16)=(14)+(15)
Fuel Gas Product Flow Rates, kg/hr					
(17) CSP Vent Gas	297	1,075	772	255	(17)=(3)
(18) Cyclar C1-C5	6,728	18,115	13,498	12,869	(18)=(7)
(19) Hydrogen from Cyclar	124	336	250	236	(19)=(11)
(20) Methane to Hydrogen Product	224	351	310	646	(20)=(15)
(21) Net Fuel Gas Product	6,925	19,175	14,210	12,714	(21)=(17)+(18)+(19)-(20)
Product Yields, wt-% of CSP Hydrocarbon Feed					
(22) Hydrogen (95 vol-% H_2)	3.4	2.0	2.4	5.1	(22)=(16)/(1)
(23) Fuel Gas	31.2	32.5	32.1	29.5	(23)=(21)/(1)
(24) Aromatics	65.4	65.5	65.5	65.4	(24)=(8)/(1)
	100.0	100.0	100.0		

(a) Assumes 90 wt-% recovery of total hydrogen and 10 wt-% remains with fuel gas.

(b) Hydrogen to CSP assumed to be 100 vol-% pure as a simplification.

(c) Hydrogen product from Cyclar assumed to be 95 vol-% pure. Five volumes CH_4 (mole-wt = 16.043) per 95 volumes H_2 (mole-wt = 2.016) translates to 0.4188 kg CH_4 per 1.0 kg H_2.

TABLE 7.14

Cyclar Yield Estimate, Case No. 1
Arge F-T LPG -- Direct

	Fresh Feed from CSP	Light Ends	Liquid Product
Component, kg/hr			
Hydrogen	0	660	--
Methane	0	3,658	--
Ethylene	0	231	--
Ethane	0	3,078	--
Propylene	6,380	8	--
Propane	4,024	55	--
Butylenes	7,335	0	--
Butanes	4,490	3	--
Pentanes	0	0	--
Hexanes	0	0	--
Benzene	--	--	3,706
Toluene	--	--	6,147
Ethylbenzene	--	--	290
p-Xylene	--	--	641
m-Xylene	--	--	1,387
o-Xylene	--	--	669
A9	--	--	382
A10	--	--	43
A11	--	--	98
A12+ (incl. Naphthalenes)	--	--	1,173
Total, kg/hr	22,229	7,693	14,536
BPSD	6,014	--	2,474
MMSCFD	--	36.30	--

Component Yields, wt-% of Fresh Feed

Hydrogen	=	3.0
$C_1 + C_2$	=	31.3
$C_3 + C_4$	=	0.3
Aromatics	=	65.4

Combined Feed LHSV, 1/hr	=	LHSV 1 (Same as Pilot Plant LHSV 1)
Combined Feed Ratio wt/wt	=	1.18
Olefins in Combined Feed, wt-%	=	52.9
Process Pressure	=	P2
Ave. Rx. Temp., °C	=	540
Catalyst Required (Rx Section), MT	=	0.87 x Base (Case No. 2 defined as base catalyst requirement)
Catalyst Regeneration Rate, kg catalyst/hr	=	1.58 x Base (Case No. 2 defined as base rate)
Relative Carbon Level, wt-%/wt-%	=	4.1 (Spent Catalyst carbon level relative to pilot plant run No.3 spent catalyst)

TABLE 7.15

Cyclar Yield Estimate, Case No. 3
Synthol F-T LPG -- Direct

Component, kg/hr	Fresh Feed from CSP	Light Ends	Liquid Product
Hydrogen	0	1,535	--
Methane	0	8,643	--
Ethylene	0	582	--
Ethane	0	7,647	--
Propylene	28,378	20	--
Propane	4,730	122	--
Butylenes	21,283	0	--
Butanes	4,730	5	--
Pentanes	0	0	--
Hexanes	0	0	--
Benzene	--	--	10,103
Toluene	--	--	17,133
Ethylbenzene	--	--	835
p-Xylene	--	--	1,789
m-Xylene	--	--	3,862
o-Xylene	--	--	1,859
A9	--	--	1,149
A10	--	--	128
A11	--	--	268
A12+ (incl. Naphthalenes)	--	--	3,441
Total, kg/hr	59,121	18,554	40,567
BPSD	16,153	--	6,900
MMSCFD	--	36.30	--

Component Yields, wt-% of Fresh Feed

- Hydrogen = 2.6
- $C_1 + C_2$ = 28.6
- $C_3 + C_4$ = 0.2
- Aromatics = 68.6

Combined Feed LHSV, 1/hr	= LHSV 1 (Same as Pilot Plant LHSV 1)
Combined Feed Ratio wt/wt	= 1.15
Olefins in Combined Feed, wt-%	= 73.7
Process Pressure	= P2
Ave. Rx. Temp., °C	= 540
Catalyst Required (Rx Section), MT	= 2.29 x Base (Case No. 2 defined as base catalyst requirement)
Catalyst Regeneration Rate, kg catalyst/hr =	= 3.69 x Base (Case No.2 defined as base rate)
Relative Carbon Level, wt-%/wt-%	= 8.4 (Spent Catalyst carbon level relative to pilot plant run No.3 spent catalyst)

TABLE 7.16

Cyclar Yield Estimate, Case No. 5
Mobil Slurry F-T LPG -- Direct

	Fresh Feed from CSP	Light Ends	Liquid Product
Component, kg/hr			
Hydrogen	0	1,192	--
Methane	0	6,680	--
Ethylene	0	442	--
Ethane	0	5,827	--
Propylene	18,927	15	--
Propane	4,731	97	--
Butylenes	15,610	0	--
Butanes	4,953	4	--
Pentanes	0.0	0	--
Hexanes	0.0	0	--
Benzene	--	--	7,507
Toluene	--	--	12,659
Ethylbenzene	--	--	612
p-Xylene	--	--	1,322
m-Xylene	--	--	2,855
o-Xylene	--	--	1,375
A9	--	--	834
A10	--	--	93
A11	--	--	199
A12+ (incl. Naphthalenes)	--	--	2,508
Total, kg/hr	44,221	14,257	29,964
BPSD	12,018	--	5,097
MMSCFD	--	24.46	--

Component Yields, wt-% of Fresh Feed

- Hydrogen = 2.7
- $C_1 + C_2$ = 29.2
- $C_3 + C_4$ = 0.3
- Aromatics = 67.8

Combined Feed LHSV, 1/hr	=	LHSV 1 (Same as Pilot Plant LHSV 1)
Combined Feed Ratio wt/wt	=	1.16
Olefins in Combined Feed, wt-%	=	68.1
Process Pressure	=	P2
Ave. Rx. Temp., °C	=	540
Catalyts Required (Rx Section), MT	=	1.71 x Base (Case No. 2 defined as base catalyst requirement)
Catalyst Regeneration Rate, kg catalyst/hr	=	3.16 x Base (Case No.2 defined as base rate)
Relative Carbon Level, wt-%/wt-%	=	7.2 (Spent Catalyst carbon level relative to pilot plant run No.3 spent catalyst)

TABLE 7.17

Cyclar Yield Estimate, Case No. 7
Arge F-T Plus Wax Hydrocracker LPG -- Direct

	Fresh Feed from CSP	Light Ends	Liquid Product
Component, kg/hr			
Hydrogen	0	1,508	--
Methane	0	7,913	--
Ethylene	0	442	--
Ethane	0	6,362	--
Propylene	6,383	16	--
Propane	8,194	117	--
Butylenes	7,332	0	--
Butanes	21,220	6	--
Pentanes	0	0	--
Hexanes	0	0	--
Benzene	--	--	7,087
Toluene	--	--	11,348
Ethylbenzene	--	--	508
p-Xylene	--	--	1,164
m-Xylene	--	--	2,525
o-Xylene	--	--	1,219
A9	--	--	601
A10	--	--	65
A11	--	--	175
A12+ (incl. Naphthalenes)	--	--	2,073
Total, kg/hr	43,129	16,364	26,765
BPSD	11,715	--	4,557
MMSCFD	--	29.52	--

Component Yields, wt-% of Fresh Feed

Hydrogen	= 3.5
$C_1 + C_2$	= 34.1
$C_3 + C_4$	= 0.3
Aromatics	= 62.1

Combined Feed LHSV, 1/hr	= LHSV 1 (Same as Pilot Plant LHSV 1)
Combined Feed Ratio wt/wt	= 1.20
Olefins in Combined Feed, wt-%	= 27.3
Process Pressure	= P2
Ave. Rx. Temp., °C	= 540
Catalyst Required (Rx Section), MT	= 1.66 x Base (Case No. 2 defined as base catalyst requirement)
Catalyst Regeneration Rate, kg catalyst/hr	= 2.63 x Base (Case No.2 defined as base rate)
Relative Carbon Level, wt-%/wt-%	= 1.3 (Spent Catalyst carbon level relative to pilot plant run No.3 spent catalyst)

TABLE 7.18

Summary of Direct Cyclar Yield Estimates

	Case No. 1	3	5	7	Comment
Cyclar Flow Rates, kg/hr					
(1) Fresh Feed	22,229	59,121	44,221	43,129	From Cyclar Y.E.
(2) Hydrogen in Light Ends	660	1,535	1,192	1,508	From Cyclar Y.E.
(3) C_1-C_5 in Light Ends	7,033	17,019	13,065	14,856	From Cyclar Y.E.
(4) Aromatics	14,536	40,567	29,964	26,765	From Cyclar Y.E.
Hydrogen Flow Rates, kg/hr					
(5) Total Hydrogen	660	1,535	1,192	1,508	(5)=(2)
(6) Recovered Hydrogen (a)	594	1,382	1,073	1,357	(6)=0.9 x (5)
(7) Hydrogen to Fuel Gas	66	153	119	151	(7)=0.1 x (5)
Hydrogen Product Flow Rates, kg/hr(b)					
(8) Recovered Hydrogen	594	1,382	1,073	1,357	(8)=(6)
(9) Methane in Hydrogen Product	249	579	449	568	(9)=0.4188 x (8)
(10) Product Hydrogen (95 vol-% H_2)	843	1,961	1,522	1,925	(10)=(8)+(9)
Fuel Gas Flow Rates, kg/hr					
(11) Cyclar C_1-C_5	7,033	17,019	13,065	14,856	(11)=(3)
(12) Hydrogen from Cyclar	66	153	119	151	(12)=(7)
(13) Methane to Hydrogen Product	249	579	449	568	(13)=(9)
(14) Net Fuel Gas Product	6,850	16,593	12,735	14,439	(14)=(11)+(12)-(
Product Yields, wt-% of Fresh Feed					
(15) Hydrogen (95 vol-% H_2)	3.8	3.3	3.5	4.5	(15)=(10)/(1)
(16) Fuel Gas	30.8	28.1	28.8	33.5	(16)=(14)/(1)
(17) Aromatics	65.4	68.6	67.7	62.0	(17)=(4)/(1)

(a) Assumes 90 wt-% recovery of total hydrogen and 10 wt-% remains with fuel gas.

(b) Hydrogen product from Cyclar assumed to be 95 vol-% pure. Five volumes CH_4 (mole wt = 16.043) per 95 volumes H_2 (mole wt = 2.016) translates to 0.4188 kg CH_4 per 1.0 kg H_2.

TABLE 7.19

Capital and Operating Cost Estimates for Indirect Cyclar Cases

	Case No. and Description			
	2 Arge	4 Synthol	6 Mobile Slurry	8 Arge Plus Wax HCU
CSP Feed Rate, kg/hr	22,229	59,121	44,221	43,129
Estimated Erected Cost, $MM (a)				
CSP Unit (ISBL)	0.5	1.0	0.8	0.8
Cyclar Unit (ISBL)	30.7	52.2	44.2	42.1
Total EEC (ISBL)	31.2	53.2	45.0	42.9
Utilities Consumption (CSP + Cyclar) (b)				
Power, kw	3,142	7,678	5,942	5,076
600 psig, 400°C Steam, MT/hr	(18.46)	(42.32)	(36.83)	(34.84)
50 psig Saturated Steam, MT/hr	3.17	8.44	6.40	5.99
Boiler Feed Water, MT/hr	21.50	53.34	43.04	40.55
Condensate, MT/hr	(5.17)	(14.02)	(10.43)	(10.[illegible]
Cooling Water, MT/hr	331.6	921.1	680.8	579.[illegible]
Fuel Fired, MM Btu/hr	118.4	293.2	236.8	222.9
Catalyst Inventory, $MM				
CSP Catalyst	0.84	3.08	2.13	0.90
Cyclar Catalyst	4.85	12.55	9.49	8.36
Total Catalyst	5.69	15.63	11.62	9.26
Operating Labor				
Operators Per Shift	2	2	2	2
Boardmen Per Shift	1	1	1	1
Maintenance Allowance (all cases)	2% of ISBL EEC Per Year			
Property Taxes and Insurance (all cases)	1.5% of ISBL EEC Per Year			

(a) Inside Process Battery Limits (ISBL) only, 3rd, Quarter, 1988 erection on U.S. Gulf Coast to UOP standards.

(b) ( ) Denotes net export of utility.

TABLE 7.20

Capital and Operating Cost Estimates for Direct Cyclar Cases

	Case No. and Description			
	1 Arge	3 Synthol	5 Mobile Slurry	7 Arge Plus Wax HCU
Cyclar Feed Rate, kg/hr	22,229	59,121	44,221	43,129
Estimated Erected Cost, $MM (a)				
Cyclar Unit (ISBL)	26.2	54.4	47.0	33.4
Utilities Consumption (b)				
Power, kw	3,288	10,019	7,949	4,368
600 psig, 400°C Steam, MT/hr	(3.63)	(11.38)	(8.30)	(13.65)
50 psig Saturated Steam, MT/hr	1.86	4.40	3.40	3.95
Boiler Feed Water, MT/hr	6.35	19.19	14.06	18.87
Condensate, MT/hr	(4.26)	(11.29)	(8.98)	(8.25)
Cooling Water, MT/hr	212.6	557.5	424.7	403.3
Fuel Fired, MM Btu/hr	34.6	51.7	85.6	103.8
Catalyst Inventory, $MM	5.40	15.39	11.97	8.45
Operating Labor				
Operators Per Shift	2	2	2	2
Boardmen Per Shift	1	1	1	1
Maintenance Allowance (all cases)	2% of ISBL EEC Per Year			
Property Taxes and Insurance (all cases)	1.5% of ISBL EEC Per Year			

(a) Inside Process Battery Limits (ISBL) only, 3rd. Quarter, 1988 erection on U.S. Gulf Coast to UOP standards using open shop labor.

(b) ( ) Denotes net export of utility.

FIGURE 7.1

SUMMARY OF EIGHT COMMERCIAL YIELD ESTIMATE CASES

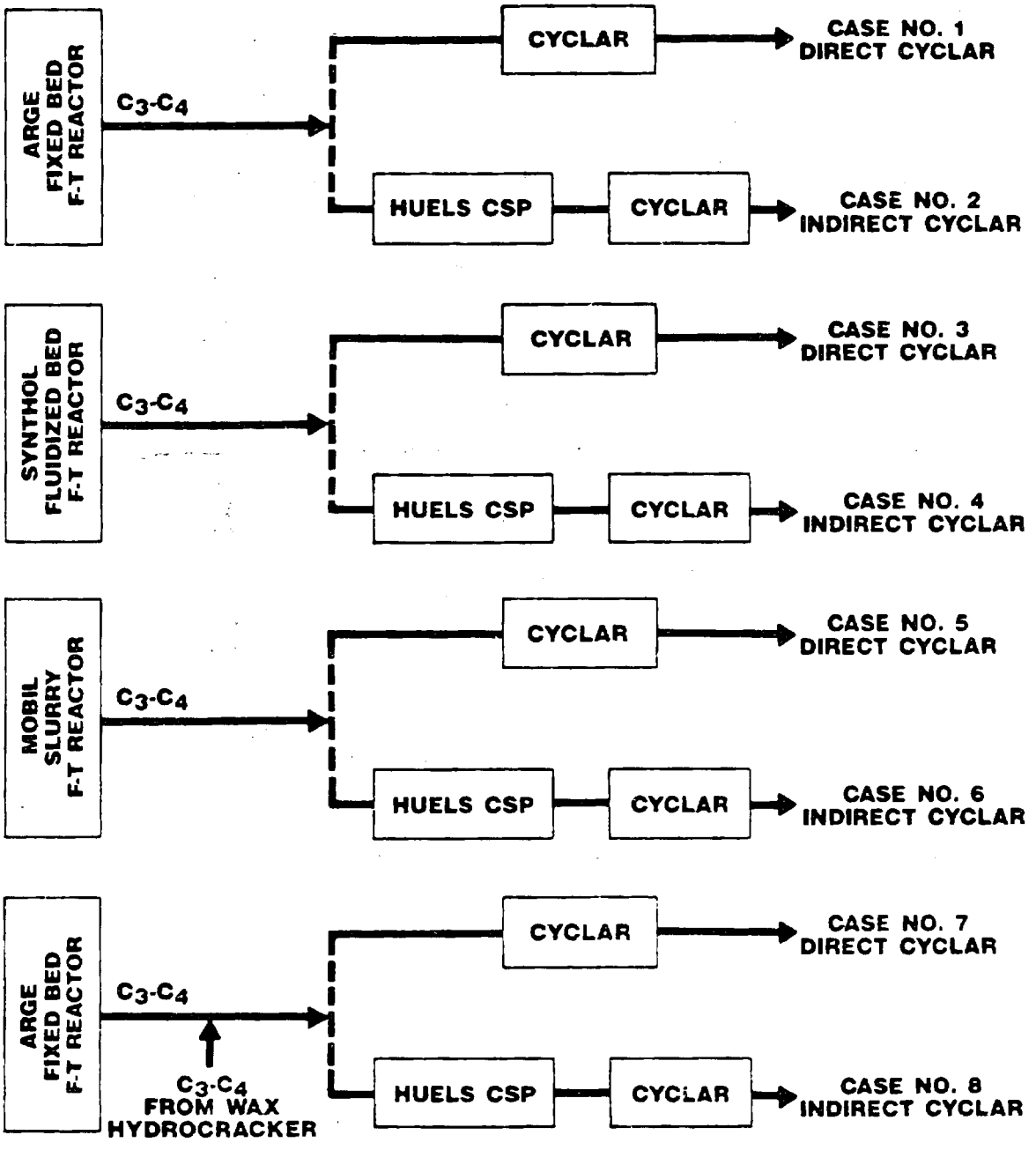


FIGURE 7.2

FLOW SCHEME FOR LPG AND NAPHTHA UPGRADING

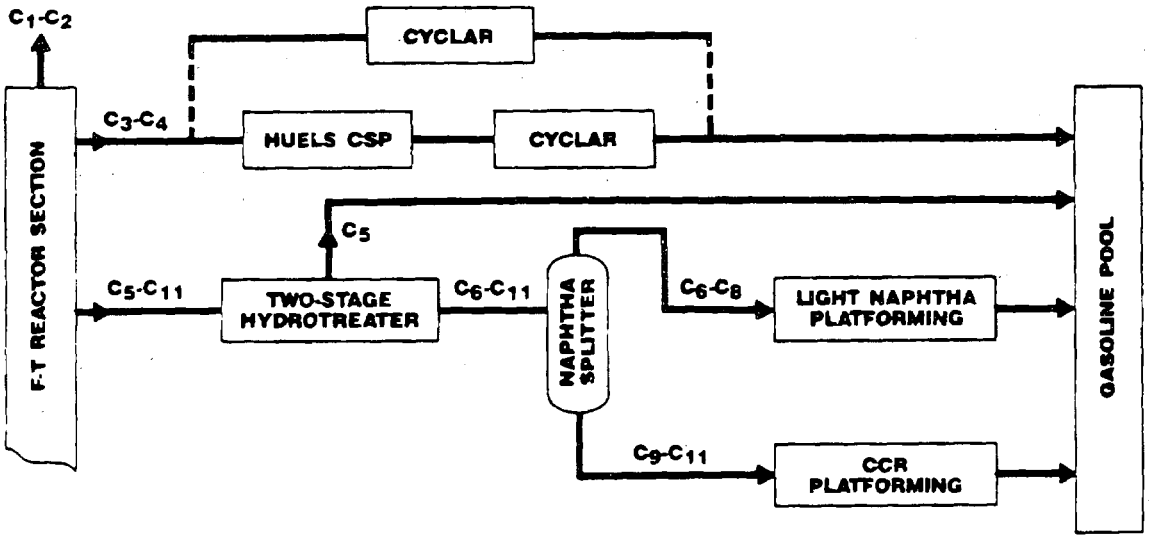
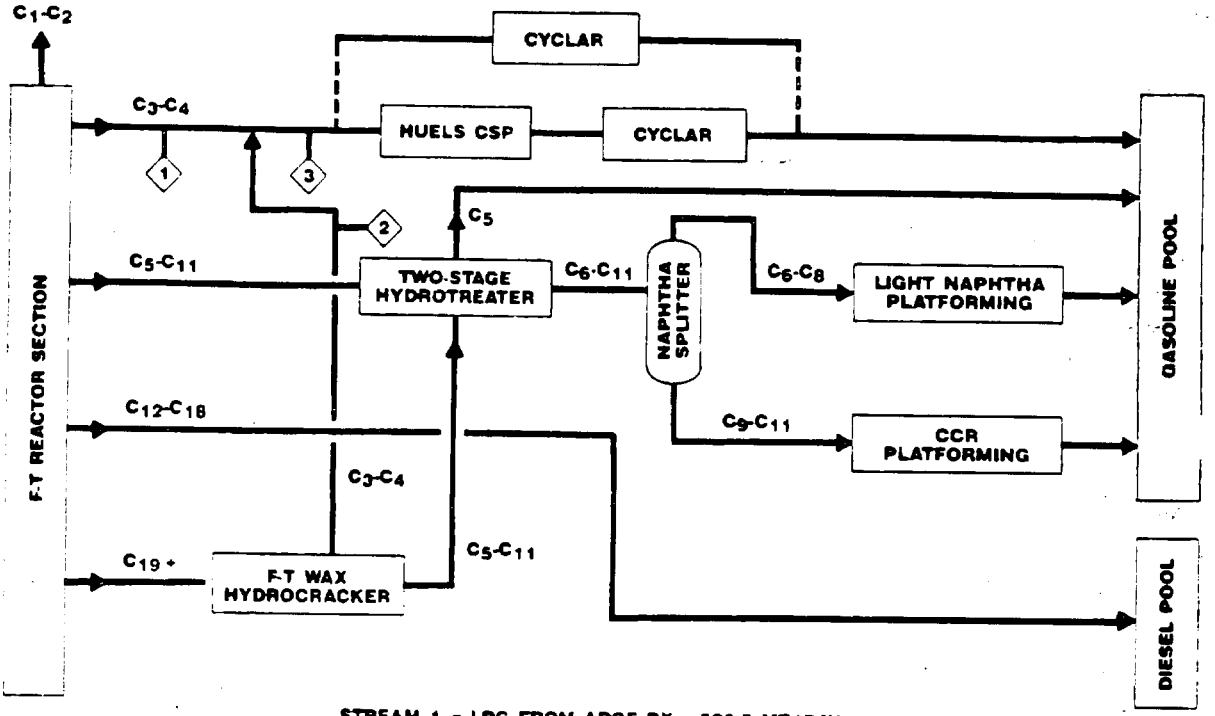


FIGURE 7.3

COMBINED LPG FROM ARGE F-T REACTOR AND WAX HYDROCRACKER



STREAM 1 = LPG FROM ARGE RX = 533.5 MT / DAY
STREAM 2 = LPG FROM HYDROCRACKER = 501.6 MT / DAY
STREAM 3 = COMBINED LPG = 1,035.1 MT / DAY

FIGURE 7.4

IDENTIFICATION OF HUELS CSP YIELD ESTIMATE STREAMS

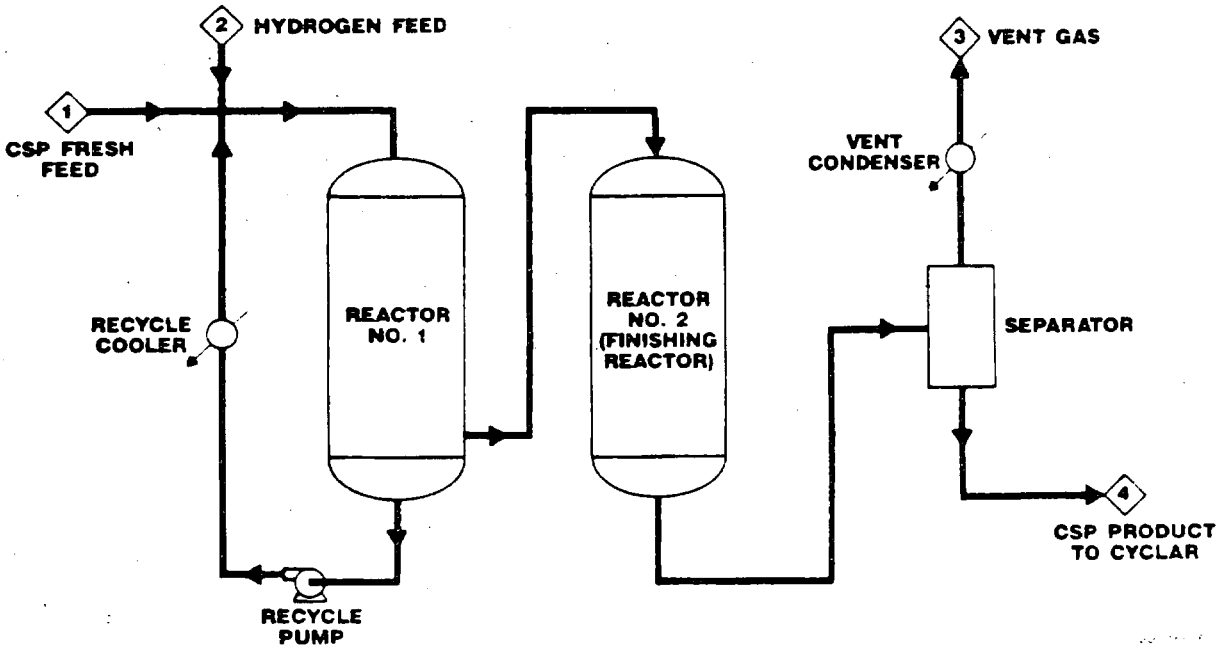
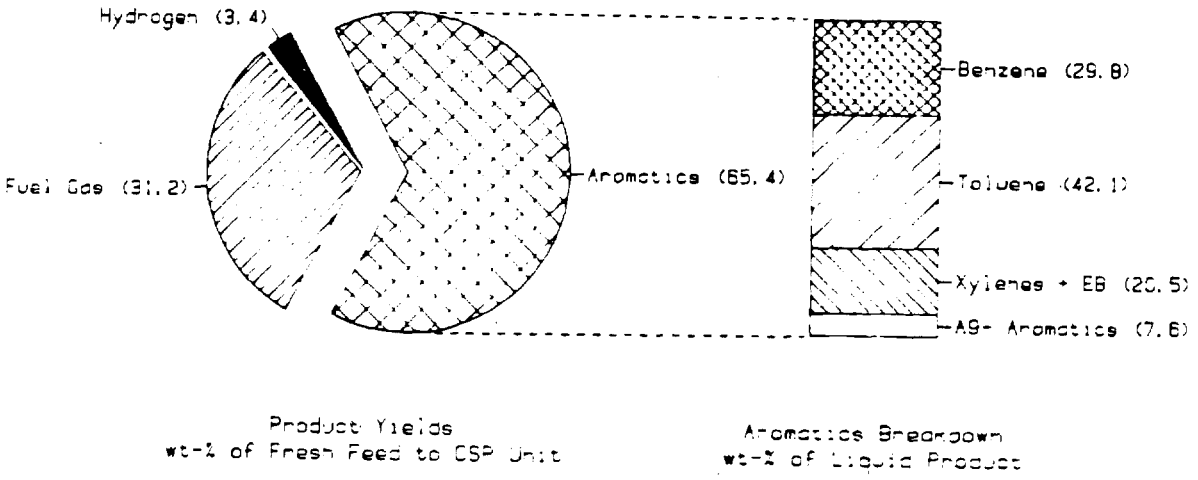


FIGURE 7.5

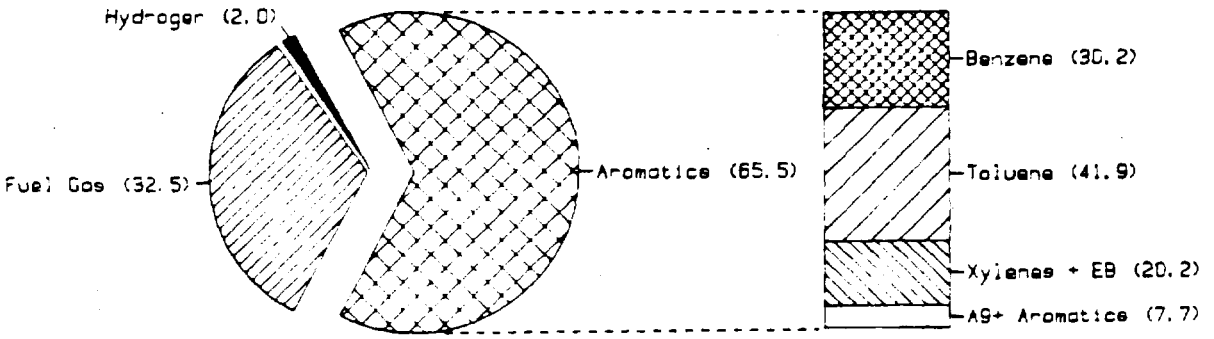
Indirect Cyclar Yield Estimate, Case No. 2
Saturated LPG From Arge F-T Reactor



Cyclar hydrogen product 95 vol-% purity
Fuel gas product includes CSP vent gas
CSP hydrogen feed subtracted from H2 prod yield

FIGURE 7.6

Indirect Cyclar Yield Estimate, Case No. 4
Saturated LPG From Synthol F-T Reactor



Product Yields
wt-% of Fresh Feed to CSP Unit

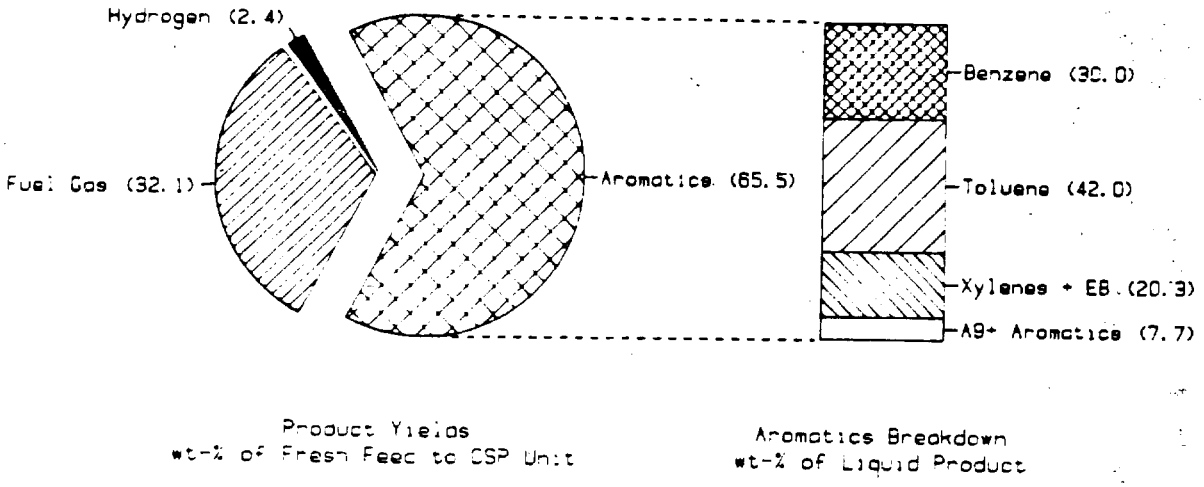
Aromatics Breakdown
wt-% of Liquid Product

Cyclar hydrogen product 95 vol-% purity
Fuel gas product includes CSP vent gas
CSP hydrogen feed subtracted from H2 prod yield

UOP 1581-65

FIGURE 7.7

Indirect Cyclar Yield Estimate, Case No. 6
Saturated LPG From Mobil Slurry F-T Reactor

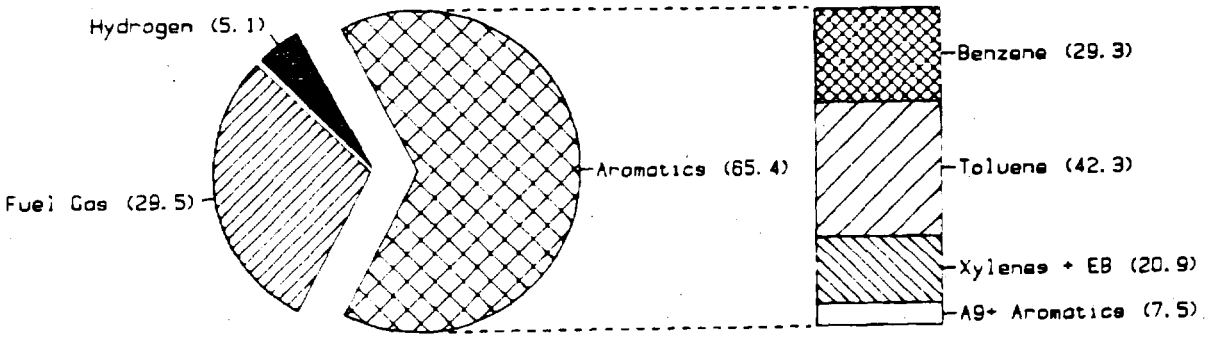


Cyclar hydrogen product 95 vol-% purity
Fuel gas product includes CSP vent gas
CSP hydrogen feed subtracted from H_2 prod yield

UOP 168-66

FIGURE 7.8

Indirect Cyclar Yield Estimate, Case No. 8
Saturated LPG From Arge Rx and Wax Hydrocracker



Product Yields
wt-% of Fresh Feed to CSP Unit

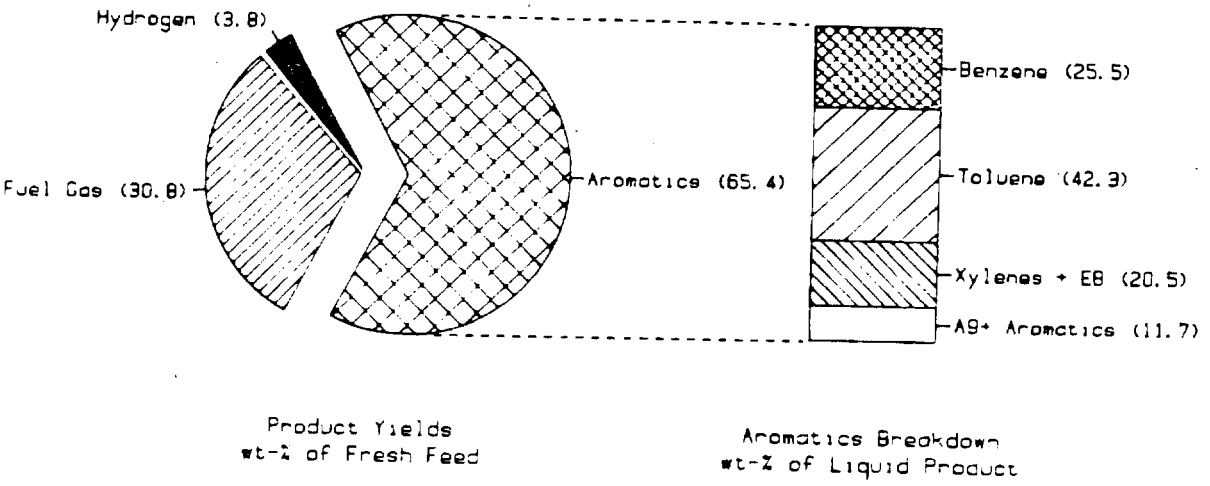
Aromatics Breakdown
wt-% of Liquid Product

Cyclar hydrogen product 95 vol-% purity
Fuel gas product includes CSP vent gas
CSP hydrogen feed subtracted from H2 prod yield

UOP 5811-67

FIGURE 7.9

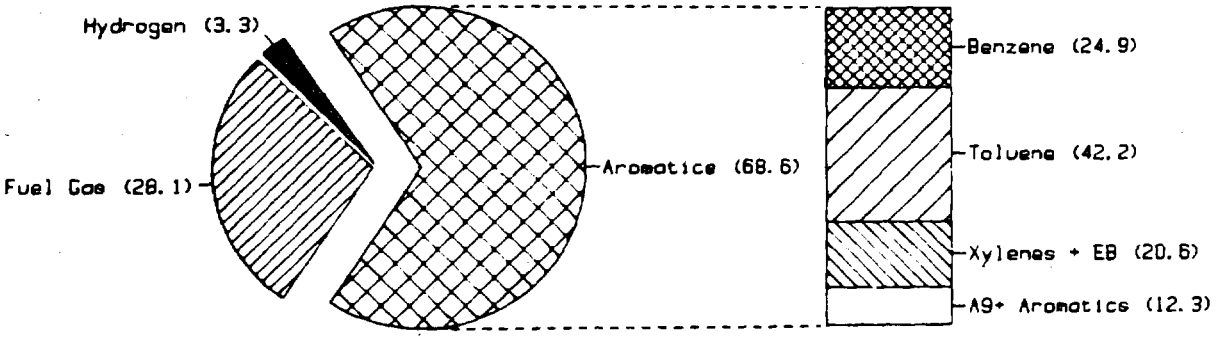
Direct Cyclar Yield Estimate, Case No. 1
LPG From Arge F-T Reactor



Hydrogen product 95 vol-% purity.

FIGURE 7.10

Direct Cyclar Yield Estimate, Case No. 3
LPG From Synthol F-T Reactor



Product Yields
wt-% of Fresh Feed

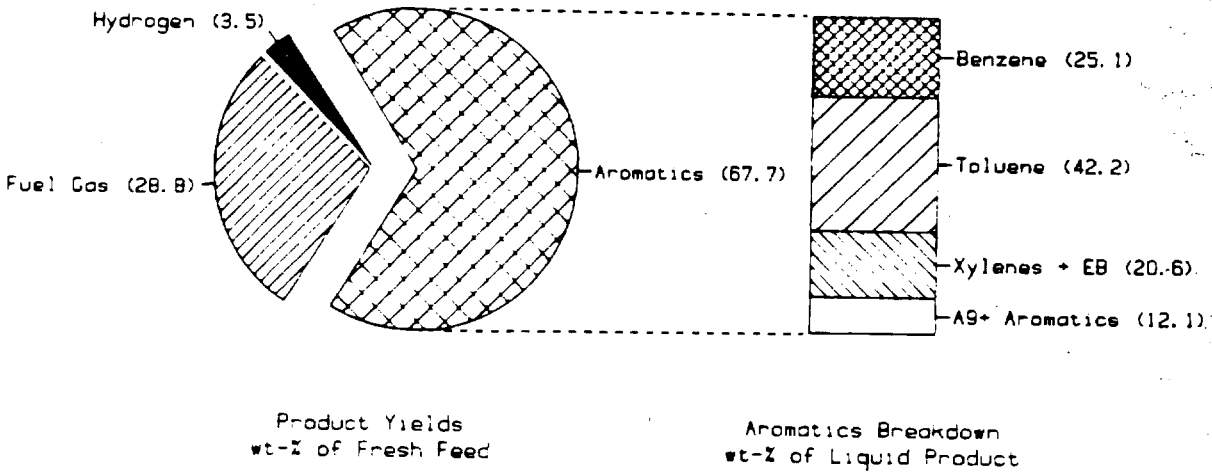
Aromatics Breakdown
wt-% of Liquid Product

Hydrogen product 95 vol-% purity

UOP 168-69

FIGURE 7.11

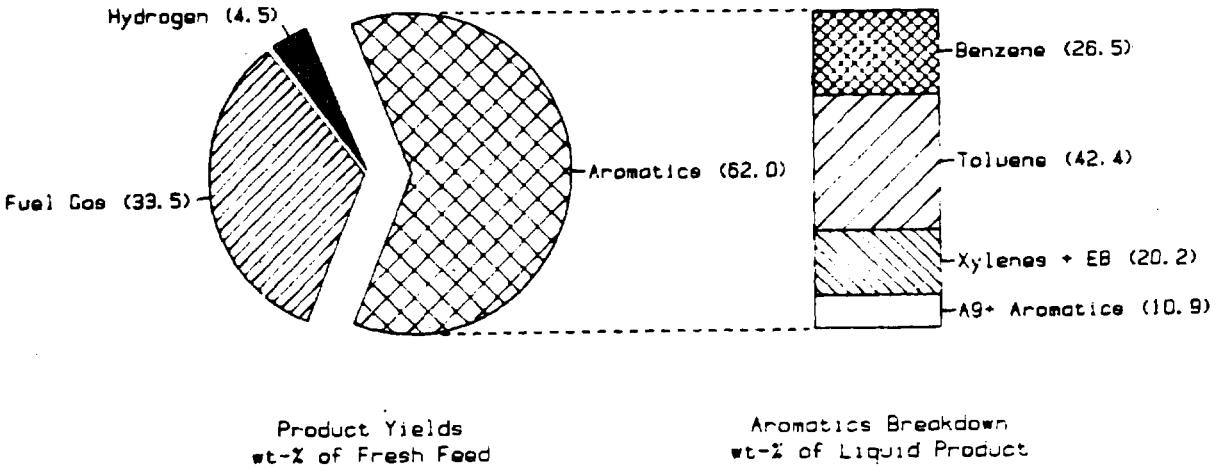
Direct Cyclar Yield Estimate, Case No. 5
LPG From Mobil Slurry F-T Reactor



Hydrogen product 95 vol-% purity

FIGURE 7.12

Direct Cyclar Yield Estimate. Case No. 7
Combined LPG From Arge Rx and Wax Hydrocracker



Hydrogen product 95 vol-% purity