8.2.2.2 Lurgi

Lurgi declined to provide any data on their technology, quoting high current work load. The following summary has been prepared by Raytheon based upon information available in the public domain.

8.2.2.2.1 Background.

Lurgi have extensive experience in both Partial Oxidation/gasification (POx) and AutoThermal Reforming (ATR) technologies. The Shell POx units at Shell's Bintulu complex were engineered by Lurgi.

8.2.2.2.2 Current Status.

Lurgi's syngas production technology is all commercially proven. Lurgi have shown interest in the GTL area, but have not to our knowledge entered into any agreements with F-T technology licensors. The syngas production technologies are available for license.

8.2.2.2.3 Process Description.

The POx and AutoThermal Reforming processes are as described in the general process descriptions in section 8.1.2.1 and Figures 8-3 and 8-4.

8.2.2.2.4 Licensor Data. (Not available)

8.2.2.3 Krupp/Uhde

8.2.2.3.1 Background.

Krupp/Uhde have significant experience in syngas technologies, including both autothermal and conventional steam methane reforming. They have also been developing the so-called Uhde Combined Autothermal Reformer (UCAR) but did not offer this in their response to the inquiry.

8.2.2.3.2 Current Status.

Krupp/Uhde have not publicly shown a lot of activity in the GTL area, but were very responsive to the inquiry.

8.2.2.3.3 Process Description.

The AutoThermal Reformer information sent by Krupp/Uhde was consistent with the general process description outlined in section 8.1.2.1 and Figure 8-3.

8.2.2.3.4 Licensor Data.

Krupp/Uhde provided technical and cost information as follows for the syngas production block only:

Natural Gas (MMSCFD)	150	500
Synthesis Gas Produced (Nm^3/Hr)	511,780	162,8220
Oxygen (Nm^3/Hr)	98,300	32,4400
Export Steam (Ton/Hr)	95	313
Power Consumed (kW)	102	408
Cooling Water (M^3/Hr)	310	1,200
Total Cap Cost (Euro)	85 MM	235 MM
Total Cap Cost ($) *	79 MM	220 MM

* Capital Cost excludes Oxygen Plant; scope same as shown in Figure 8-1. Exchange rate of 1.07 Euro= 1 US dollar was used.

8.2.3 Fischer-Tropsch

8.2.3.1 Rentech

8.2.3.1.1 Background.

Rentech was formed in 1981 to develop F-T synthesis technology for converting low value solids, liquids or gas into high value fuel products. They have built several pilot scale F-T reactors in Colorado, and one small scale commercial unit. This operated sporadically for a short period, and was sold to Donyi Polo Petrochemicals, Mumbai, India in 1995. The equipment was shipped to the site in India, and after revamping, was scheduled for startup in India in 1999 with a capacity of 350 BPD.

Rentech is unique among the licensors considered in that they have proposed iron catalyst in the F-T reactor, versus cobalt catalysts proposed by all the others. They do not have any technology in the syngas production or product work-up areas, and have no restrictions on what technologies are used in these units, or on the products produced.

8.2.3.1.2 Current Status.

No announcement regarding the Indian plant startup has been made. Rentech is very actively licensing and promoting the technology, much of their efforts in conjunction with Texaco as described in section 8.3.5. One of their strongest selling points is the claim that they are immune to patent infringement litigation from other licensors as they alone use iron catalyst, and the fact that they have built several units, albeit small scale, to date without any claims made against them.

8.2.3.1.3 Process Description.

Syngas is preheated and fed together with recycle gas to the reactor where it is converted into hydrocarbons using Rentech's iron catalyst. Liquid wax and vapor products are cooled to produce streams suitable for feed to the product work-up unit. A portion of the tail gas is recycled to the reactor, the rest is vented from the unit to the plant fuel gas system.

8.2.3.1.4 Licensor Data.

Rentech provided data for the F-T unit only. A summary of the information follows:

Natural Gas (MMSCFD)	150	500
Naphtha (BPD)	2307	*7690*
Diesel (BPD)	2802	*9340*
Linear Paraffins (BPD)	1799	*5997*
Linear alpha olefins	2485	*8283*
Wax (C_{20}-C_{50})	7086	*23620*
TOTAL Hydrocarbon Product (BPD)	16478	*54930*
Water Product (BPD)	6500	21600
Mixed Alcohol Product (BPD)	890	2900
Capital Cost ($/BBL Capacity)	7000	5800
Operating Cost: Chemicals & catalyst	$2.70/BBL	$2.70/BBL
Operating & Maintenance Staff	34	34
Power Consumption (MW)	1.5	5
Steam (450 psig) Export (lb/hr)	850,000	3,000,000

The hydrocarbon production figures for the 500 MMSCFD case were prorated from the lower capacity data provided by Rentech, and are shown in *italics* above.

8.2.3.2 PDVSA/Intevep

8.2.3.2.1 Background.

Intevep, which is the R&D unit of PDVSA, have been investigating GTL technologies since 1991. Intevep regard the syngas production step as being commercially available, and product work-up can be achieved by using existing refinery hydrocracking technology. Intevep have therefore concentrated on developing Fischer-Tropsch technology. Intevep's efforts have focused on catalyst and reactor design development for their F-T technology, DISOL.

8.2.3.2.2 Current Status.

The catalyst has been developed to the point where scaleup and commercial production have been worked out in conjunction with a catalyst vendor. Small bench scale synthesis experiments have been run, and a large amount of process, hydrodynamic and mathematical simulation have been carried out. The next step, according to Intevep, would be to build a pilot plant followed by a 1-year demonstration and data collection for commercialization. Intevep expects the technology to be available for commercialization by the year 2004.

8.2.3.2.3 Process Description.

The major distinguishing feature of the Intevep technology is the F-T reactor which is neither a slurry nor a fixed bed reactor. Rather, it is an ebullated bed, which Intevep claim combines the best characteristics of fixed and slurry beds, with few of the drawbacks. The catalyst size distribution is coarser than that in a slurry bed, and the bed is suspended by the action of a circulating liquid stream and the gas feed stream to the reactor. In comparison, a slurry bed relies on the gas velocity to suspend the catalyst. Being coarser, catalyst separation from product wax is easily achieved by settling in an expanded section inside the reactor. Catalyst storage and handling are carried out as easily as for a fixed bed reactor. The reactor is run once through, with no gas recycle. Reactor cooling is effected by generating steam in both internal and external cooling coils. The rest of the F-T unit is similar to the F-T units of the other licensors covered above.

8.2.3.2.4 Licensor Data.

For a natural gas feed of 150 MMSCFD, Intevep provided the following for the F-T unit only:

Total liquid Production		15,295	BPD
Product Slate: Naphtha	8%	1,224	BPD
Kerosene	17%	2,600	BPD

C_{11} - C_{13} Paraffins	8%	1,224 BPD
Diesel	30%	4,589 BPD
Wax	37%	5,659 BPD

Utilities:	Cooling Water:	2850 M^3/Hr
	Boiler Feed Water	885 Ton/Day
	Power	1500 kW
	Steam	885 Ton/Day export

F-T Unit Total Installed Cost:	$53MM
Catalyst and chemicals:	$5.6MM/Yr

8.2.4 Product Work-Up

8.2.4.1 UOP

8.2.4.1.1 Background.

UOP are one of the leading providers of technology in the hydroprocessing area. There are no UOP hydroprocessing plants with Fischer-Tropsch wax as feedstock. However, UOP have extensive experience in designing similar hydroprocessing plants with feedstocks derived from conventional crude oil. In addition, they have, together with the Allied-Signal Engineered Materials Research Center Inc. conducted an extensive DOE (Department of Energy) sponsored study on Fischer-Tropsch Wax Characterization and Upgrading. This study was conducted around 1987. UOP have also, in the last several years, acquired Union Oil's Hydrocracking technology. Union Oil were one of the leading licensors of Hydrocracking technology.

8.2.4.1.2 Current Status.

As mentioned earlier, there are no UOP-designed hydroprocessing plants, with Fischer-Tropsch wax as feedstock, in commercial operation. However, UOP have designed many commercial units to hydrocrack similar crude oil-derived waxy feedstocks and are deemed to have sufficient experience to be able to design commercial units to process F-T wax.UOP may have to go to a third party for "state of the art technology" in hydroisomerization.

8.2.4.1.3 Process Description.

The F-T wax is fed to a hydrocracker containing UOP's DHC-8 catalyst. For Case 1, the "short term" project with a wax feed rate of 4800 BPD and no lube production, a single stage recycle unit is used. For Case 2, the "long term" project with lube production and a wax feed rate of 16,000 BPD, a once-through unit is used. Hydrocracking reactor pressure is 1000 psig. and process conditions in the reactor are set to maximize total distillate product. A 2-year cycle length has been used for the unit. Reactor size was based on selectivity (reactor temperature and LHSV) considerations. Reactor product is fed to a stripper where the C_1-C_4 light ends and the light naphtha are taken overhead. Stripper bottoms are fed to a fractionator. Because of the highly paraffinic nature of the products, they are sensitive to thermal cracking. To minimize the thermal cracking, the fractionator is operated under vacuum.

Because of the absence of sulfur in the feed, it will probably be necessary to inject a small amount of sulfur to maintain the metals on the catalyst in the proper sulfided state.

The naphtha/jet TBP cut point of 274 °F was set by the jet flash point specification. The jet/diesel TBP cut point of 506 °F was then set to meet the jet freeze point specification. The diesel/bottoms cut point of 696°F is limited both by the diesel 90% distillation specification and the diesel pour point.

The rest of the processing (hydroisomerization and hydrofinishing) for lube production would be as indicated in the General Process Description for the Product Work-up section (See 8.1.2.3 in this section).

8.2.4.1.4 Licensor Data.

UOP supplied data only for the Hydrocracker and its downstream fractionation. The fractionation system would consist of a stripper and a vacuum column. Hydroisomerization and Hydrofinishing of the Hydrocracker bottoms to produce lubes were excluded.

	Case 1	Case 2
	"Short Term"	"Long Term"
Wax feed rate, BPD	4,800	16,000
Chemical Hydrogen Consumption, SCF/bbl	635	523
Recycle gas, SCF/bbl of fresh feed	10,000	10,000
Overall LHSV, hr^{-1} of fresh feed	1.0	1.3
Combined Feed Ratio (CFR)	1.5	
Product yields		
C_{5+} yield, volume % of feed	106.2	105
C_{5+} yield, BPD	5,096	16,792
Yield Distribution		
C_1-C_4 light ends, wt.% of feed	3.63	2.90
Naphtha (C_5-274 °F), BPD	1,289	3,408
Kerosene/Jet fuel (274 °F-506 °F), BPD	1,965	5,184
Diesel (506 °F-696 °F), BPD	1,842	5,200
Hydrocracker bottoms to lubes, BPD	-	3,000
Capital Cost Estimate, MM$	13	31

8.2.4.2 IFP

8.2.4.2.1 Background.

IFP (Institute Francais du Petrole) are also one of the leading providers of technology in the hydroprocessing area. There are no IFP hydroprocessing plants with Fischer-Tropsch wax as feedstock. However, IFP have extensive experience in designing similar hydroprocessing plants with feedstocks derived from conventional crude oil.

IFP have, in recent years, expanded their Hydroprocessing technology base with the acquisition of HRI (formerly Hydrocarbon Research Institute).

8.2.4.1.2 Current Status.

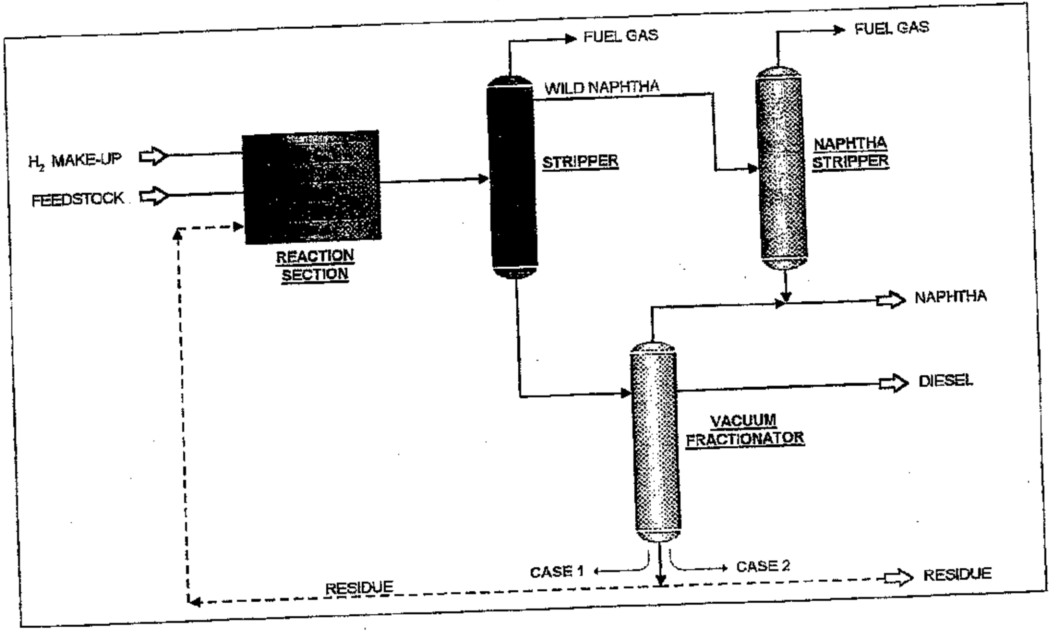
As mentioned earlier, there are no IFP-designed hydroprocessing plants in commercial operation with Fischer-Tropsch wax as feedstock. However, IFP have designed many commercial units to hydrocrack similar crude oil-derived waxy feedstocks and are deemed to have sufficient experience to be able to design commercial units to process F-T wax. The proposed catalyst for the hydrocracker, ϕ 402, has undergone extensive pilot tests on waxes from Fischer-Tropsch synthesis. According to IFP, these feedstocks were quite similar to those in this study.

IFP are developing hydroisomerization catalyst and technology, but at present (November 1999) may have to go to a third party for commercial "state of the art" technology in this area.

8.2.4.1.3 Process Description.

A "recycle" hydrocracker scheme has been proposed for Case 1, the "short term" project with a wax feed rate of 4,800 BPD. A "once through" scheme has been proposed for Case 2, the "long term" project, with a wax feed rate of 16,000 BPD.

Fig. 8-9 **IFP F-T Hydrocracking**



Reaction Section

The F-T wax is fed, together with recycle and makeup hydrogen, after being preheated via feed-effluent exchangers and a furnace, into a fixed bed catalyst reactor. Temperature in the reactor is moderated with intermediate cold hydrogen quenches. In addition to the equipment mentioned, the hydrocracker reaction section contains: high pressure hot and cold separator drums, recycle and makeup hydrogen compressors and low pressure separator drums.

Fractionation Section

The fractionation section consists of the reactor effluent stripper, naphtha stripper and a vacuum fractionator.

The reactor effluent stripper receives feed from the Reaction Section, and generates the following effluent streams:

- A vapor stream which is sent to the fuel gas header,
- A wild naphtha, as liquid distillate, which is sent to the Naphtha Stripper, and
- A bottom product which is sent to the vacuum fractionator.

The naphtha stripper produces a vapor distillate which is sent to the fuel gas system, and a stabilized naphtha which is sent to storage.

The vacuum fractionator produces the following streams:

- An overhead distillate, that can be blended with the naphtha from the Naphtha Stripper,
- A diesel sidecut, which, after passing through a side-stripper is sent to storage,
- For Case 1, a bottom residue that is recycled to the reaction section, except for a small purge stream that can be sent to either the diesel or fuel oil pools.

For Case 2, a bottom residue that is sent to a hydroisomerization/ hydrofinishing to produce lubes.

The rest of the processing (hydroisomerization and hydrofinishing) for lube production would be as indicated in the General Process Description for the Product Workup section *(See 8.1.2.3* in this section).

8.2.4.1.5 Licensor Data.

IFP supplied data only for the hydrocracker and its downstream fractionation. Hydroisomerization and Hydrofinishing of the Hydrocracker bottoms to produce lubes were excluded.

	Case 1	**Case 2**
	"Short Term"	**"Long Term"**
Wax feed rate, BPD	4,800	16,000
Chemical Hydrogen Consumption, SCF/bbl	518	520
Product yields		
Liquid yield, volume % of feed	102.6	102.5
Liquid yield, BPD	4,927	16,395
Yield Distribution		
Fuel Gas, wt.% of feed	2.96	2.31
Naphtha, BPD	541	1804
Diesel, BPD	1,842	5,200
Residue/Lube cut	47*	2,831
Capital Cost Estimate, MM$	20	40

* Raytheon's opinion is that this stream could, most probably, be blended into diesel.

8.3 LICENSOR EVALUATION

The licensor evaluation was primarily focussed on the heart of the process, the Fischer-Tropsch unit, in the context of the entire GTL facility. Unless a F-T technology supplier is known to have alliances or preferred technology position for the upstream and downstream processing units, Raytheon has used its judgment to pair these units in a cost effective manner to develop the overall scenario for comparision with other technologies. Raytheon's proprietary LP model, RAYSPONSE™ - **GTL**, with generic yield and cost database was used to develop a reasonable stream balances, unit capacities and investment and operating cost of the entire complex. A detail write-up on this software is provided in Section 9.0.

Evaluation Methodology

Raytheon's standard methodology to evaluate technologies is elaborate and requires extensive data from the technology suppliers. For emerging technologies, it is not unusual that such extensive data are not available. Added to that, licensors often decline to provide data, which are confidential in nature and yet vital for evaluation purposes, in order to protect such information.

Evaluation Criteria

The evaluation was based upon the following major criteria:

- Liquid Yield (Gas to hydrocarbon conversion efficiencies).
- Thermal Efficiency
- Capital cost
- Operating cost
- Experience — Pilot Plant.
  — Commercial Scale.

Technology providers who did not participate in the study (Shell, Exxon) are represented by information available in the open literature. The yield and cost data were interpreted as follows:

8.3.1 Exxon

Very little technical or cost data have been published by Exxon. The yields in Table 8-1 are prorated from the published data referenced in Section 8.2.1.1.4. As for the case with Shell, it was confirmed that the yield data can be directly prorated; see Appendix.

The literature search identified an article by Morgan Stanley Dean Witter with projected cost of $24,000 of daily barrel for a 50,000 BPSD plant.

8.3.2 Shell

The data in Table 8-1 is prorated from the yields derived from published information in Section 8.2.1.1.4.

The capital cost figures are based on rough estimates quoted in this and other Shell publications for plants built in remote locations with limited existing infrastructure or utility facilities.

8.3.3 Sasol

Yield for the 150 MMSCFD case presented as provided. Sasol provided data for a 465 MMSCFD plant which is currently the maximum for a three train design. For the purposes of consistency, the information provided was prorated to the 500 MMSCFD capacity, and it was assumed that by the time such plant would be developed that Sasol would be able to increase the maximum train capacity to accommodate it.

Capital cost was supplied as total complete plant cost, and a typical unit breakdown was indicated. This was used to calculate the unit capital costs shown in Table 8-1.

8.3.4 Syntroleum

Both the yield and cost data, which cover the full plant are presented as supplied by Syntroleum.

8.3.5 Rentech

Data were provided for the F-T unit only. The yields in Table 8-1 are for primary F-T products, not final products. Rentech presented the yields as follows for the 150 MMSCFD feed gas case:

Product	BPD
Naphtha	2,307
Diesel	2,802
Linear Paraffins	1,799
Linear α-olefins	2,485
Wax (C_{20}-C_{50})	7,086
TOTAL	16,478

To keep the products in a consistent format with the other licensors, the linear paraffins and linear α-olefins were added into the diesel production figure, since this is where they would naturally occur due to their boiling point range.

8.3.6 PDVSA/Intevep

Data were provided for the F-T unit only. The yields are presented as supplied by Intevep for the 150 MMSCFD case. The yields for the 500 MMSCFD case are prorated.

Intevep have provided a capital cost of $53MM for a 15,000 BPSD F-T unit. No backup was provided for Raytheon to verify.

8.3.7 Summary of Licensor Data

Table 8-1 below summarized technology related data for all the licensors as provided by licensors and/or developed by Raytheon from literature sources for the purpose of comparative evaluation.

Table 8-1 **Summary of Licensor Data**

Note: Figure in italics are Raytheon generated data based on published information by Technology providers.

		Sasol		Shell		Exxon		Syntroleum		Rentech		Intevep	
FEED GAS	**MMSCFD**	**150**	**500**	**150**	**500**	**150**	**500**	**150**	**500**	**150**	**500**	**150**	**500**
Naphtha	**BPD**	3940	13120					3000	10000	2307	7690	1224	4080
Kerosene	**BPD**	NA	NA					3000	10000	0	0	2600	8667
Diesel	**BPD**	11350	37850					6000	20000	7086	23620	4589	15297
Lube Base Oil	**BPD**	NA	NA					NA	NA	NA	NA	0	0
Lin. Paraffin	**TPD**	NA	NA					NA	NA	NA	NA	1224	4080
Wax	**TPD**	NA	NA					NA	NA	7086	23620	5659	18863
Total HC Product	**BPD**	15290	50970	*17347*	*57822*	*17000*	*56700*	12000	40000	16479	54930	15296	50987
Power Export	**MW**	15 Max.	50 Max.					100 Max.	300 Max.	NA	NA	NA	NA
Number of trains		1	*3*							*5*	*16*	1	3
Utilities													
Water	**m³/hr**	990	3300					NA	NA	NA	NA	NA	NA
Power	**MW**	35	115					NA	NA	NA	NA	NA	NA
Thermal Eff.	**No power**	0.561	0.561	*0.628*	*0.628*	*0.616*	*0.616*	0.426	0.426	0.614	0.614	0.562	0.562
Thermal Eff.	**Power export**	0.570	0.570	*NA*	*NA*	*NA*	*NA*	0.486	0.480	NA	NA	NA	NA
Capital Cost													
Syngas	**MM$**	119	309					235	750				
FT	**MM$**	59	155										
Prd WU	**MM$**	40	103										
Other Process	**MM$**	40	103					70.5	225				
Utilities	**MM$**	59	155										
Offsites	**MM$**	79	206										
Total	**MM$**	395	1030	*550-1000*	*<1800*			351	1097				
Op Cost	**$/BBL**	5.56	3.7					5.36	4.96				
	MM$/yr	28.90	64.12					21.87	67.46				

8.3.8 Ranking of Licensors

A quantitative evaluation and comparison of various technologies following Raytheon's Licensor Evaluation Methodology was attempted. However, due to lack of adequate data, a conclusive ranking of various technology providers was not possible. Instead, Raytheon has used the same technology providers to perform a qualitative comparison to group the technology providers to indicate relative ranking under different categories. A summary follows, group A having the highest ranking, group C the lowest.

A. Liquid Yield

Group A:	Shell, Exxon, Rentech
Group B:	Sasol & Intevep
Group C:	Syntroleum

B. Thermal Efficiency

Similar trend as above.

C. Experiences - Pilot Plant

Group A:	Sasol, Shell, Exxon
Group B:	Syntroleum & Rentech
Group C:	(Intevep - only bench-scale experiences)

D. Experiences - Commercial Plant

Group A:	Sasol, Shell
Group B:	(Exxon claims to be ready for commercial plant design)
Group C:	(Syntroleum & Rentech claim to have sufficient data for commercial plant design)

E. Capital Cost

	"Short Term" Project	"Long Term" Project
Group A:	Sasol, Intevep	Exxon, Sasol, Intevep
Group B:	Shell, Exxon	Shell
Group C:	Rentech, Syntroleum	Rentech, Syntroleum

F. Internal Rate of Return

	"Short Term" Project	"Long Term" Project
Group A:	Intevep, Sasol, Shell	Exxon, Sasol, Intevep
Group B:	Exxon, Rentech	Shell
Group C:	Syntroleum	Rentech, Syntroleum

G. Overall

	"Short Term" Project	"Long Term" Project
Group A:	Sasol, Shell	Exxon, Sasol
Group B:	Exxon	Shell
Group C:	Rentech, Syntroleum	Rentech, Syntroleum

Based on the information provided by Intevep on the PDVSA/Intevep's DISOL F-T technology, it is Raytheon's opinion that even though the technology shows promise, it is in its infancy and will not be ready for the "short term" project slated for the years 2003 to 2006. However, for the "long term" project, it is prudent that the technology be re-evaluated in 2-3 years which will allow Intevep to further develop the technology via pilot plant runs to confirm its commercial viability in a large scale operation. Should the technology be ready for commercialization, an alternative option may be considered installing a relatively small scale F-T unit (~10,000 BPD) in conjunction with a more mature and commercially and well-proven technology.

8.4 FUTURE ADVANCEMENTS IN GTL TECHNOLOGY

The major direction of current developments is to reduce the cost of syngas production. The most promising area currently under development is the use of ceramic membranes to separate oxygen from air and react with natural gas in a single piece of equipment. If successful, this would remove the need for a cryogenic air separation unit, and has the potential to reduce the capital cost of syngas production by 25% to 30% (ref: Chemical Week, May 28, 1997, p. 13; ECN Chemscope, Sept., 1997, pp. 24-25).

Two consortia are underway with developing the technology:

- A group led by Air Products, with some support from the US DOE. This technology is called Ionic Transport Membrane. Other members of the consortium are ARCO, Argonne National Laboratory, McDermott Technology, Cerametec, Chevron, Eltron Research, Norsk Hydro, Pacific Northwest National Laboratory, Pennsylvania State University, and the University of

Pennsylvania. The planned eight -year program started in 1997, and is being carried out in three stages. The final stage will be a semi-commercial scale of 15 MMSCFD, which is scheduled to be demonstrated by 2006.

- The Oxygen Transfer Membrane Alliance, consisting of BP Amoco, Praxair, Sasol, Statoil, and Phillips Petroleum, was formed in 1998. It has not made public a development timetable, but the "long term" goals are similar to those of the Air Products led group.
- The basic ceramic membrane materials have already been developed, and current and future efforts are focused on reactor and system design. Given the high caliber of the groups working on the problem, Raytheon expect that a commercial design will be available by about 2008.
- The next largest area for development is F-T synthesis catalysts. Increasing the catalyst activity and lowering catalyst cost will both improve project economics. While this has been a major thrust of R&D at all the F-T technology providers, it is expected to be a gradual, evolutionary type of development which will only really take off once the first few GTL plants are built.
- Finally, once several plants have been built and general experience is gained in all areas of design, particularly the integration of process and utility units, the capital cost is expected to come down in much the same way as LNG plant costs have declined over the past twenty years.

8.5 DISCUSSION

Due to lack of sufficient reliable information either, provided by licensors specifically for this study, or available in the open literature, a definitive recommendation for a single technology provider could not be made. However, the following observations are relevant relative to developing a strategy for GTL projects in Venezuela for both "short term" and "long term" projects.

8.5.1 General

- Shell, Exxon, and Rentech all claim similar total yields, which are somewhat higher than those for Sasol and Intevep, followed by Syntroleum, whose liquid yields are significantly lower. A similar trend is seen in the thermal efficiencies, which are estimates based on the licensor data provided, assuming a self contained plant in all cases (i.e., no import or export of energy in any form other than natural gas feed in and liquid product out). In F-T synthesis the overall conversion can be increased by varying recycle streams, reactor size, catalyst amount and activity, among the major factors. Overall thermal efficiency can by increased both by increasing conversion efficiency and by maximizing the amount of exothermic heat recovery from the two major units, the Syngas unit and the F-T unit. Typically increasing efficiency is a trade-off against capital cost as extra catalyst, or bigger compressors, or more heat exchange surface area, is required to effect the thermal efficiency gain. It may be that Sasol and Intevep have intentionally limited the liquid yield in the design to reach an economic optimum. There does not appear to be anything restricting either of these technologies from achieving yields and thermal efficiencies similar to those claimed by Shell, Exxon, and Rentech.
- In the case of Syntroleum, the low yields would appear to be a function of feeding air instead of nitrogen to the reformer. There are inherent efficiency losses from heating, cooling, and circulating the nitrogen that passes through the plant essentially as an inert. Recycle is not an option in this case, as the inerts would rapidly become prohibitively high. In addition, the high vapor flow rates associated with the nitrogen, can be expected to lead to hydrocarbon losses in the tail gas from the F-T unit. This is confirmed by examining the estimated thermal efficiencies with and without power export. Only Sasol and

Syntroleum provided data on potential power export. Syntroleum's thermal efficiency increases from 42.6% to 48.0% if credit is taken for the maximum power export, but Sasol's increases proportionately less, from 56.1% to 57.0%. This is presumably due to a smaller tail gas stream from a Sasol unit compared to a Syntroleum unit, leaving less available energy for recovery by combustion in a gas turbine.

- These drawbacks could perhaps be acceptable if they resulted in a substantial capital cost savings. The data provided, however, show that there is little, if any, savings. Within the accuracy of the data, the Syntroleum capital costs are considered to be equivalent to Sasol's.

8.5.2 Exxon

Exxon have made a sizeable investment in developing the AGC-21 technology, and claim to be at the stage where very large commercial designs are possible. Even less information is publicly available than in the case of Shell, and although Exxon also declined to provide information for this study, it is recommended that the technology also remain under consideration for both the "short term" and "long term" cases. Given the smaller scale experience (pilot plant units only) the issues of process risk and guarantees will have to be carefully monitored in the next phase. It is Raytheon's opinion that the larger scale 50,000 BPSD "long term" project will provide a more attractive ROI compared with other technology providers due to possible single train configuration of the Syngas unit.

8.5.4 Shell

Shell are the only technology provider considered in the study to have full commercial scale experience in each of the major process steps, hence their top ranking in the evaluation. The technical and economic merits of the technology relative to others is difficult to judge as they did not supply information for the study. Nevertheless, based on the track record of the operation in Malaysia and Shell's stated interest in developing a GTL facility in Venezuela, it is recommended that they remain under consideration for the next phase.