PDVSA

7.0 MARKETING STUDY

Raytheon
Raytheon Engineers & Constructors

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7.1 OVERVIEW

Venezuela has large gas reserves, ranking seventh in the world, that remain mostly untapped. Most of this gas, about 91%, is "associated" with oil production. The remaining 9% is "unassociated". Venezuelan law prohibits flaring of associated gas. The current situation with the produced associated gas is that it is in balance with domestic consumption as fuel with some amount of reinjection taking place. Venezuela's current strategy is to increase gas production significantly to maximize NGL recovery and take advantage of international market opportunities. Production and export of LNG to the international market is highly capital intensive and is considered to be commercially feasible only on a very large scale. The demand for LNG and resulting prices are high in the Far East and Asia. However, the costs of transporting LNG from the Venezuelan coast to these distant markets is also extremely high.

The Gas-To-Liquid technology via the Fischer-Tropsch process, with its recent technology developments, has opened up opportunities to produce liquid products that can be transported more economically than LNG in conventional liquid cargo vessels. Coupled with excellent physical characteristics and environmentally friendly properties, these F-T derived products command a premium price over similar products derived from conventional crude sources. Venezuelan heavy crudes, in particular, require deep hydroprocessing, an expensive processing step, to upgrade products derived from them to meet specified quality requirements. A GTL derived product, such as diesel, would therefore provide a premium blending component to the local refiners.

Many valuable fuel and non-fuel products with exceptional properties can be derived from the Fischer-Tropsch (F-T) paraffinic reactor effluent. Their "close to zero" sulfur, nitrogen and aromatic content make them, especially the middle distillates, extremely "environment friendly" in comparison to similar products derived from crude oil. However, being highly paraffinic, the products are generally lower in density and higher in pour point than equivalent products derived from crude oil. The issue for these high quality products is the size of their market, and how much of a premium can reasonably be expected over conventional products.

A typical reactor effluent composition from a low temperature Fischer-Tropsch process, together with the possible ultimate markets for the products, is presented in Table 7-1 below:

Table 7-1 **Fischer-Tropsch Reactor Products and Their Ultimate Market**

Fraction	%Wt *	Ultimate Market
C_1-C_4 (Gas + LPG)	5 – 10	• Petrochemical Feedstock • Fuel
C_5-C_9 (Naphtha)	15 – 20	• Olefin Plant Feedstock • Feedstock for Catalytic Reforming Unit to produce gasoline and/or aromatics
C_{10}-C_{16} (Kerosene)	20 – 30	• Jet Fuel • Normal Paraffins
C_{17}-C_{22} (Diesel)	10 – 15	• Diesel Fuel • "Environment friendly" drilling muds
C_{22} + (Wax)	30 – 40	• Waxes • Synthetic Lubricants

* Based on typical F-T reactor effluent composition.

Small quantities of oxygenate byproducts (mainly methanol, ethanol, n-propanol, n-butanol, and acetone) can also be recovered from the reaction water stream.

Wax produced in the Fischer-Tropsch process can, via hydroprocessing, be converted to produce additional quantities of kerosene, jet fuel, solvents, and specialty products.

Based upon Raytheon's discussion with PDVSA to narrow down the GTL products of possible interest to PDVSA, the following GTL products were listed for the marketing study:

- LPG
- Diesel
- Lube Oils
- Naphtha
- Linear Paraffins
- Oxygenated Chemicals
- Kerosene
- Waxes
- Synthetic Crude

Two projects were also identified:

- A "short term" project, defined as one that would be put into operation during the period 2003-2006, with a plant capacity equivalent to 100-200 MMSCFD of natural gas feed, and
- A "long term" project, defined as one that would be put into operation during the year 2007 or after, with a plant capacity equivalent to a natural gas feed rate of 500-750 MMSCFD.

SUMMARY

Raytheon's marketing study concluded that, for the "short term" project, GTL products should be limited to fuels and normal paraffins. The demand for high quality F-T waxes can be fulfilled from the production capacities of the Sasol and Shell plants. Additionally, South and Central America are expected to be self-sufficient in high quality wax production from the CERAVEN plant currently under construction at the Cardon Refinery in Venezuela. The demand for VHVI base oils in Central and South America is very small due to the predominant use of monograde base oils in older vehicles. Multinational companies are meeting this small demand by importing from the US and/or Europe. Also, there is no regulatory pressure to use VHVI lubes.

For the "long term" project Raytheon recommend production of fuels, normal paraffins, and a small amount of VHVI lubes at an economical plant capacity. High quality F-T wax demand will grow at a very slow pace, and is expected to be satisfied from the capacities of existing plants.

Table 7-2 summarizes the recommended product slate and corresponding production capacities for the GTL plant for both the short and "long term" projects. Based on the pricing study, strategies for the product mix were developed and have been noted in the summary table. The base case prices in the table are in constant dollars and are related to a West Texas Intermediate (WTI) crude price of $ 20/bbl.

Table 7-2 **Strategies Resulting from Market Study and Products Slates**

		"SHORT TERM"	"LONG TERM"
PLANT CAPACITY		**15,000 BPD Total Liquid Products 150 MMSCFD Natural Gas Feed**	**50,000 BPD Total Liquid Products 500 MMSFD Natural Gas Feed**
LPG	**Strategy**	Use as plant fuel.	Investigate "value added options", such as recovery and sale of LPG, and use as petrochemical feedstock, sale to refinery for gasoline / aromatics production, etc.
	Rate	Minimize the amount co-produced.	Minimize the amount co-produced.
	Price, $/bbl	Fuel value (Same $/MMBtu as natural gas feed).	$ 11.31 (base case).
NAPHTHA	**Strategy**	Minimize production.	• Investigate "value added options" such as petrochemical feedstock, etc. • Install flexibility in hydrocracker to vary product slate.
	Rate, BPD	About 2,300.	7,000 to 12,000.
	Price, $/bbl	14.53 at the plant gate for the base case.	14.53 at the plant gate for the base case.
KEROSENE	**Strategy**	Neutral.	• Investigate possible premium in jet fuel market. • Install flexibility in hydrocracker to vary product slate.
	Rate, BPD	About 2,000.	9,500 to 21,000.
	Price, $/bbl	22.35 at the plant gate for the base case.	22.35 at the plant gate for the base case.

(Table to be continued on next page)

PDVSA

Table 7-2 **Strategies Resulting from Market Study and Products Slates** (Cont'd)

		"SHORT TERM"	"LONG TERM"
PLANT CAPACITY		**15,000 BPD Total Liquid Products 150 MMSCFD Natural Gas Feed**	**50,000 BPD Total Liquid Products 500 MMSFD Natural Gas Feed**
DIESEL	**Strategy**	Maximize production.	• Investigate "long term", high value, niche markets" such as use for "environment friendly drilling muds". • Install flexibility in hydrocracker to vary product slate.
	Rate, BPD	9,000.	11,750 to 28,200.
	Price, $/bbl	28.44 at the plant gate for the base case.	25.59 at the plant gate for the base case.
N-PARAFFINS	**Strategy**	Maximize production.	Maximize Production.
	Rate, BPD	1,800.	2,300.
	Price, $/bbl	$ 400/metric ton (f.o.b. U.S.A). $ 47.62/bbl (f.o.b. U.S.A.).	$ 400/metric ton (f.o.b. U.S.A). $ 47.62/bbl (f.o.b. U.S.A.).
WAX	**Strategy**	No production.	No production.
	Rate, BPD	None.	None.
	Price, $/bbl	$ 1300 to $2600/ton (f.o.b. U.S.A.).	$ 1300 to $2600/ton (f.o.b. U.S.A.).
LUBE OILS	**Strategy**	Install unit when market develops. No production until 2008.	Install minimum economical size unit.
	Rate, BPD	3,000	3,000.
	Price, $/bbl	120 (f.o.b. U.S.A.).	120 (f.o.b. U.S.A.).

*Product rate will vary depending upon the selected F-T technology and other design variables. Rates noted in table are estimated range based on the selected plant capacities that can also be supported by market demand.

7.3 PRODUCTS

This section of the report evaluates the present and future global, South American, and Venezuelan supply/demand situation for the various GTL products: LPG, Naphtha, Kerosene, Diesel, Normal Paraffins, Waxes, Synthetic Lubricants, and Oxygenates.

Recommended ways to market or utilize the products are briefly discussed.

Current or estimated product prices are also provided.

7.3.1 LPG

LPG material from a Fischer-Tropsch unit is highly olefinic (about 70% olefins).

Possible ways to utilize this stream are:

- Hydrogenate it and produce an LPG product
- Use it as fuel in the plant
- For the "long term" project, if the plant is located at Jose, export this stream to the future Pequiven olefin complex, where it should realize a high value as petrochemical feedstock or to produce propylene. If the plant is located at Anaco, the saturated LPG from the hydrocracking and hydroisomerization units could be sent to the gas plant for extraction of LPG, if contamination of the residue gas with hydrogen is low enough to not present a problem.

We believe that the best strategy for PDVSA is to minimize front end plant investment by using the LPG as plant fuel at the beginning, while investigating alternate, higher value options at that time. If the analysis indicates that the C3/C4 components are worth recovering, hydrogenating, fractionating and selling as LPG, the "long term" plant should be equipped to do so.

7.3.1.1 <u>Supply and Demand</u>

Venezuela is a net exporter of LPG. In 1998, production was about 170 MBPD in 1996, and demand 112 MBPD.

7.3.1.2 Price

For the "short term", Raytheon assumed that the LPG would have fuel value (ie. the same $/MMBtu as the natural gas feed).

From PDVSA's information for the "actual" scenario*, LPG in Venezuela is expected, on the average, to sell at a price $3.87/bbl below West Texas Intermediate (WTI) crude. Plant netback is expected to be 85%, and fractionation costs are expected to be around $2.40/bbl. Therefore, for economic evaluation purposes, Raytheon used the following equation for the price of LPG at the plant gate [Eq. 7-1]:

$$\text{LPG Price} = \left[(\text{WTI} - 3.87)\cdot 0.85\right] - 2.40 \qquad \text{[Eq. 7-1]}$$

If a WTI price of $ 20/bbl is used for the base case, the corresponding LPG price to be used in the economic analysis for the "long term" option is $11.31/bbl.

7.3.2 Naphtha

The C_5 to C_9 fraction produced in the Fischer-Tropsch reactor is highly paraffinic and as such constitutes an excellent ethylene cracker feedstock. The lighter fraction of the naphtha can be isomerized and blended into the gasoline pool. The heavier fraction can be fed to a Catalytic Reforming Unit (CRU) to produce gasoline and/or aromatics. The full range naphtha can also be blended with petroleum derived naphtha or "natural gasoline" from NGL units and exported for petrochemical use.

The global demand for naphtha as a petrochemical feedstock grows about five times faster than the demand for fuel uses.

7.3.2.1 Supply and Demand

Globally, the use of naphtha as a petrochemical feedstock is growing much faster than non-petrochemical uses as shown in Figures 7-1 and 7-2 and Table 7-3 [(2)]:

* "Normal" scenario

Fig. 7-1 **Global Naphtha Demand**

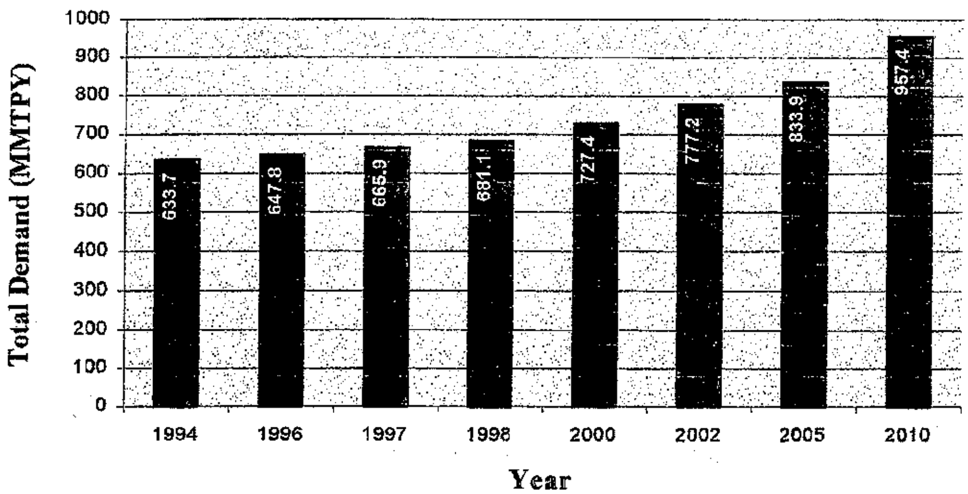


Fig. 7-2 **Naphtha Uses vs. Average Growth Rate**

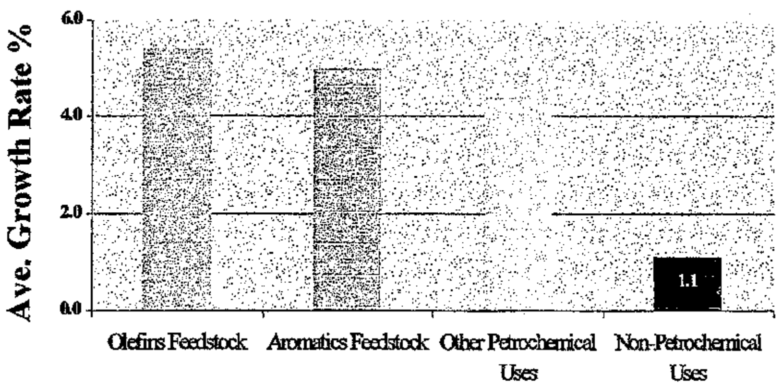


Table 7-3 **Global Naphtha Demand**

	1994	1996	1997	1998	2000	2002	2005	2010	AVE. GROWTH RATE
	Million Tons per Year								%
Olefins Feedstock	116.0	126.6	132.6	140.7	153.5	171.2	203.6	264.8	5.4
Aromatics Feedstock	111.7	121.0	132.6	139.1	161.3	175.0	188.0	239.9	5.0
Other Uses	2.2	2.3	2.3	2.3	3.0	3.2	3.4	4.2	4.4
Total Petrochemical Demand	229.9	249.9	271.2	282.1	317.7	349.4	395.0	509.0	5.2
Non-Petrochemical Uses	403.9	397.9	394.6	399.0	409.7	427.8	438.9	463.6	1.1
TOTAL DEMAND	633.7	647.8	665.9	681.1	727.4	777.2	833.9	957.4	2.8

Regionally, the demand for petrochemical naphtha is expected to increase substantially in the US, Europe, and the Far East. All the steam crackers producing ethylene in Venezuela use ethane or LPG as feedstock. There is therefore no local market for naphtha as a feedstock for ethylene plants. However, the GTL naphtha could be blended with crude oil derived naphtha or "natural gasoline" and exported. In 1997, Venezuela exported 74 MBPD of "natural gasoline" and naphtha.

7.3.2.2 Price

From PDVSA's "actual" scenario*, on the average, naphtha will

* "normal" scenario

be priced $4.71/bbl lower than West Texas Intermediate (WTI) crude. Based on PDVSA's experience, net back at the plant gate is 95% of the Naphtha price. Therefore, for economic purposes, we propose using the following equation [Eq. 7-2]:

$$\text{Naphtha Price} = (\text{WTI} - 4.71) \cdot 0.95 \qquad \text{[Eq.7-2]}$$

A WTI price of $20/bbl will be used for the base case. This translates to a naphtha price of $14.53/bbl. Economic parameter sensitivities will be examined at WTI prices of $15/bbl and $25/bbl, which correspond to naphtha prices of $9.78/bbl and $19.28/bbl respectively.

7.3.2.3 Recommended Capacity

It is projected that Venezuela will produce 155-190 MBPD of naphtha between 2005 and 2010.

Venezuela already exports excess naphtha. To produce ethylene, steam crackers in Venezuela use C_2-C_3 feeds, not naphtha. It is recommended that the naphtha production be minimized, given the relatively low value of this product.

7.3.3 Kerosene

7.3.3.1 Supply and Demand

In 1996, world demand for kerosene range petroleum products was 6 MMBPD, with the bulk, 4 MMBPD, being used as jet fuel. After highway diesel, jet fuel is expected to be the fastest growing refined product. Annual growth rate is forecasted to be 2.5 % through 2010. The largest market is the United States, where in 1996 the demand was 1.6 MMBPD for jet fuel and less than 0.1 MMBPD for other uses. In 1996, the demand in South and Central America was 176 MBPD for jet fuel and 70 MBPD for other products. Demand in 1996, in Venezuela, was 10 MBPD of jet fuel, and 2 MBPD for other kerosene-range products. Venezuela is a net exporter of kerosene/jet fuel: in 1996 about 97 MBPD of kerosene/jet fuel was exported to the US.

Fischer-Tropsch kerosene, because of its excellent properties, can be used to upgrade kerosene fractions having low smoke point and high aromatics, and thus contribute to fulfilling the increased volume demand. Its low density prevents it from meeting current minimum density specifications without blending. Our view is that with the trend to reduce aromatics in fuels, minimum density specifications will be revised downward. However, if cut to the same boiling range, GTL kerosene, being highly paraffinic, can be expected to have a freeze point higher than conventional jet fuel/kerosene, and this will have to be taken into account during blending. Alternatively, the jet fuel can be cut to a lower end point.

7.3.3.2 Price

Based on PDVSA's "actual" scenario, kerosene is expected to sell, on the average, at a price $3.53/bbl above West Texas Intermediate (WTI) crude. PDVSA's experience has been that the netback at the plant gate is 95% of the diesel price. Therefore we propose to use the following equation [Eq. 7-3] to calculate kerosene prices:

$$\text{Kerosene Price} = (\text{WTI} + 3.53) \cdot 0.95 \qquad \text{[Eq. 7-3]}$$

A WTI price of $20/bbl will be used for the base case. This translates to a kerosene price of $22.35/bbl. Economic parameter sensitivities will be examined at WTI prices of $15/bbl and $25/bbl, which correspond to kerosene prices of $17.60/bbl and $27.10/bbl respectively.

7.3.3.3 Jet Fuel/Kerosene Quality

The typical quality of jet fuel/kerosene from a GTL plant based on Fischer-Tropsch technology as compared to the conventional jet fuel/kerosene from refineries is as indicated below [9] [14] in Table 7-4

Table 7-4 **Comparison of Jet Fuel/Kerosene from GTL with that from Conventional Refinery Sources**

Property	Unit	GTL	Conventional	Method
Density @ 15 °C	kg/m^3	738	750-840	ASTM D 1298
Saybolt Color		+30		ASTM D 156
Distillation Range				ASTM D 86
IBP	°C	155		
FBP	°C	191	<300	
Sulfur	ppmw	Not detectable	< 3000	ASTM D 1266
Cetane Number		58		ASTM D 976
Smoke Point	Mm	> 50	> 20	ASTM D 1322
Flash Point	° C	42	> 37.8	ASTM D 93 for GTL ASTM D 56 for conventional
Freeze Point	°C		Below –30 to -50 depending on grade	ASTM D 2386
Aromatics	%V	Not detectable	< 20	ASTM D 5186 for GTL ASTM D 1319 for conventional

7.3.4 Diesel

Refinery products in the diesel boiling range find several end uses:

- As fuel for on-road and railroad diesel engines
- Residential and commercial heating (No. 2 fuel oil)
- Electric power generation
- Industrial and agricultural purposes

7.3.4.1 Supply and Demand

Total world demand for refinery product in the diesel boiling range was about 18.5 MMBPD in 1996*, and is expected to increase at an average rate of 2% per year. The largest market is the United States, where in 1996 the demand was about 3.4 MMBPD.

* The most recent historical statistics available from the US Dept. of Energy (DOE) Internet Web Page were for 1996 and have been used here.

The demand in South and Central America was about 1.2 MMBPD in 1996. In Venezuela the demand in 1996 was 67 MBPD. Domestic diesel production in Venezuela far exceeds demand: the country exported 192 MBPD of diesel in 1996. About 30% of this went into the US heating oil market (0.3 wt.% sulfur, 40 Cetane Index). The remaining went into Latin American markets with sulfur ranging from 0.2 to 0.7 wt.% and a Cetane Index of 45.

Of the end uses indicated above, the transportation market (on-road and railroad diesel engines) is by far the largest, accounting for about 50% of the total. In 1996, the worldwide demand for transportation diesel was about 10 MMBPD. In North America and Western Europe, diesel fuel is expected to gain in market share at the expense of gasoline. The gain in market share in the United States will, to a large extent be as a result of new light trucks and the increasingly popular Recreational/Sports Utility Vehicles (RUV's/SUV's) being diesel, rather than gasoline, driven.

Because the diesel production from a GTL project, in both the short and "long term" cases, is small in comparison to the total market, it can be assumed that all the diesel produced could be sold into the Venezuelan export market for final sale in the US. The price premium that can be obtained, however, is highly dependent on the future specifications for diesel fuel in the US.

Although the negligible sulfur content of Fischer-Tropsch product in the diesel boiling range could gain it some premium in non-transportation markets, the high cetane (about 70) coupled with negligible aromatics and sulfur, should result in F-T diesel commanding the highest premium in the transportation market where it can be used as blendstock to upgrade diesel streams that cannot, by themselves, meet specifications.

7.3.4.2 Diesel Fuel Specifications

The current (November 1999) specification for diesel in South and Central America are 0.5 wt.% maximum sulfur, and a minimum Cetane Index of 45. Aromatics level is not a key specification in these markets. Proposed specifications are a minimum Cetane Number of 47 for the year 2001 with sulfur remaining at the current level. For the year 2005, it has been proposed that the sulfur specification be changed to 0.25 wt.% maximum and that aromatics be limited to 30 vol.%.

The European Union agreed on new specifications for the quality of diesel transport fuel. According to these specifications, the maximum permissible sulfur content of diesel will be 350 ppm from the year 2000, and 50 ppm from the year 2005. It is expected that the final specifications will also require lower density, lower PolyAromatic Hydrocarbon (PAH) content, lower 95 % boiling point, and higher cetane number.

The World-Wide Fuel Charter issued in January 1999 by the Engine Manufacturer's Associations (EMA) of USA, Japan, and Europe provides some indication of what the specifications will be for these properties in the year 2005 (See Table 7-5).

Table 7-5 **New Diesel Specifications**
(figures in *italics* are proposed specifications)

	EU Adopted 2000	**Parliament Proposal 2005**	**EMA Fuel Charter**	**CARB Reference**	**Alternative CARB Formulation**
Sulfur, wppm (max.)	350	50	*30*	500	200
Gravity,°API Min. Max.	36	*40*	*37* *41*	33 39	
Aromatics Content (max.)			*15* wt%	10 vol%	15-25 vol%
Polyaromatics Content PAH, wt % max.	11	*1*	*2*	1.4	2.2-4.7
Cetane No, min.	51	*58*	*55*	48	55-59
95 % B.P.,°F, max.	680	*644*	*644*		579-662

In the United States, the most severe current specifications for diesel fuel are found in California where the total content of aromatic compounds of diesel is limited to 10 vol % and 1.4 wt % PAH. The Californian Air Resources Board (CARB) allows refiners to use "alternate formulations" as long as the engine emissions from those formulations equal or are lower than those from the "reference diesel".

From 1993 to 1997, Californian refiners, such as Paramount Petroleum Corporation and Tosco, were using F-T diesel from Shell's Bintulu plant to upgrade EPA diesel, containing 30 vol % aromatics, to CARB (California Air Resources Board) diesel. Most major refiners were using "alternate formulations" with aromatics levels around 20%, but with higher Cetane Numbers, between 55 and 60, than those for the "reference diesel", which had a minimum cetane of 48 [(10)].

Some studies indicate that other than sulfur content, diesel fuel composition does not have a significant impact on emissions and aftertreatment device performance for state-of the-art heavy-duty diesel engines [(11)]. The EPA, in the Advance Notice of Proposed Rulemaking of May 13, 1999, states that the most promising change would be fuel desulfurization for the purpose of enabling new engine and aftertreatment technologies[(12)]. A second scenario, therefore, is that the EPA will impose tight sulfur specifications, in the 30 ppmw to 50 ppmw range, and leave cetane (and hence aromatics) specifications unchanged.

A third scenario is that the U.S. will follow European countries like the United Kingdom in giving tax credits for "clean diesel".

7.3.4.3 <u>Price</u>

The price that a GTL plant can get for the high quality (high cetane, negligible sulfur and aromatics) diesel it produces will be dependent on and sensitive to:

- The prevailing crude oil price at a particular time
- The premium it will command as a blendstock for upgrading refinery streams to diesel specifications. This, in turn, will depend on the specifications imposed on diesel in the future.

7.4.3.2.1 Effect of the Prevailing Crude Oil Price.

The effect of crude oil price is obvious. Since almost all the world's diesel production is crude oil based, diesel prices will go up and down with crude oil prices, as they have done in the past. The negligible volume of diesel produced via GTL processing will have no impact on prevailing diesel prices. The future crude oil price uncertainty has probably been a major factor in discouraging the installation of GTL capacity. For refiners, crude oil prices and product prices move in the same direction, albeit with a time lag, so that the impact on refinery margins is relatively small. New "fuel product" GTL plants, on the other hand, while they can secure "long term" feed gas contracts to remove uncertainties at the feed end, will still have to contend with future fluctuating product prices, and hence variable profit margins, while getting a return on the front end investment.

We propose to link future prices of diesel to a benchmark crude, West Texas Intermediate (WTI), when looking at the feasibility of the proposed GTL plant.

7.3.4.3.2 Premium As Blendstock.

The premium that F-T diesel will command over diesel from refineries will depend on several factors. As blendstock for upgrading lower value refinery streams, such as FCC Light Cycle Oil (LCO) the premium will, as would be expected, depend on the diesel specifications in the marketplace at a particular time. Future specifications that will prevail in the United States are in a state of flux at this time (October 1999).

Raytheon have analyzed a number of scenarios to determine a reasonable premium that F-T diesel is likely to realize over the price of diesel meeting the prevailing "road diesel" specifications. These scenarios are examples of how the F-T diesel premium may vary depending on regulatory requirements and the specific situations that refiners will have to confront.

Scenario No. 1

In this scenario, future EPA "road diesel" specifications will mirror those currently (October 1999) enforced by the CARB. If history is a guide, we believe that in this scenario, F-T diesel will fetch a 10 cents per gallon ($4.20 per barrel) premium over "specification diesel" being sold, as it did in California.

Scenario No. 2

In this scenario, the EPA would reduce the sulfur specification on "road diesel" to 50 ppmw but leave the specifications on cetane and aromatics unchanged. From the point of view of sulfur reduction, F-T diesel would command little or no premium for blending because blending "500 ppmw sulfur" diesel to 50 ppmw requires a 9:1 ratio of "F-T diesel" to "500 ppmw sulfur diesel". We believe that most US refiners will address the lower sulfur specification by:

- Adding hydrotreater reactors in parallel to those they currently have, so that they can maintain their hydrotreater run lengths in spite of the higher average reactor temperatures required to get down to the lower sulfur level.
- Segregating No.2 fuel oil and "off road diesel" from "road diesel" and blending the high sulfur streams into "off road" uses. Until October 1993,when the 500 ppm sulfur specification came into force in the US, most US refiners were producing a "fungible" diesel/fuel oil product. Since that time, many refiners have installed facilities to segregate "road diesel" from "offroad diesel"/fuel oil so as to take advantage of the looser specifications on "offroad diesel"/fuel oil. The price differential between "road diesel" and No.2 heating oil has historically been negligible.

The F-T diesel could still command a high* premium over "road diesel" in sales to some refiners by virtue of its ability to upgrade hydrotreated light cycle oil, currently going into their No. 6 fuel oil pool, to diesel via blending to the cetane specification. However this "niche market" will be small, scattered, and "short term". This is because most refiners have, or will have, the ability to get No.2 fuel oil value for their light cycle oil by blending it into that pool, resulting in an insignificant downgrade. Any light cycle oil going into the continually declining refinery No. 6 fuel oil pool will be limited to that required as "cutter stock" to meet viscosity specifications. It is our opinion that premiums calculated in this manner should be ignored.

* Calculated to be as much as $17/bbl assuming a price differential of $8/bbl between diesel and No.6 fuel oil, 28 cetane for hydrotreated light cycle oil, and 70 cetane for the F-T diesel.

Scenario No. 3

In this scenario the US could follow the lead of the United Kingdom by providing tax incentives (in the range of $ 7/bbl) for Ultra Low Sulfur Diesel (ULSD) having a sulfur level less than 50 ppm. Finland and Sweden also have tax incentives encouraging low sulfur diesel fuel. Finland's tax incentive applies to diesels with sulfur levels below 50 ppm, which accounts for 90% of the Finnish market. Sweden's tax incentive applies to diesel with sulfur levels below 10 ppm. It is our understanding that similar tax incentives are expected in Germany and Austria and that other European countries are discussing the issue of providing tax incentives for high quality fuels.

Scenario No. 4

In this scenario, it is assumed that both sulfur and cetane/aromatics specifications will be imposed. Addition of a low pressure hydrotreating facility for sulfur reduction alone will not be adequate and the refiner could be faced with having to install hydroprocessing (such as hydrocracking, mild hydrocracking or hydrodearomatization) and hydrogen production facilities to improve both sulfur and cetane number specifications. In this scenario Raytheon's estimate is a premium of $ 6-8 per barrel for the F-T diesel because of its blending value. This will be more applicable to refiners using low value, heavy crudes with a high aromatic content.

Scenario No. 5

PDVSA have performed an internal analysis of the premium value for the F-T diesel. Based on this analysis, PDVSA's projection is a premium of $ 7/bbl for the "short term" project, reducing to $ 4/ bbl for the "long term" project. It should be emphasized that this scenario is specific to PDVSA's situation and applicable only in the Venezuelan market.

7.3.4.3.3 Diesel Price Recommended for Use in the Study.

PDVSA projections of diesel prices indicate a differential of $2.94, on the average, between WTI and diesel. Also PDVSA's experience is that 95% of the selling price is the netback at the plant gate. Based on the preceding discussion, the premium that GTL diesel would have over "road diesel" from refinery sources, could vary from zero to $7/bbl. Raytheon recommend that base case premiums of $7/bbl and $4/bbl be used for the "short term" and "long term" projects respectively, specific to the Venezuelan scenario.

Sensitivities of economic parameters (such as IRR) will be assessed at premiums of \$5/bbl to \$9/bbl for the "short term" case, and \$0/bbl to \$7/bbl for the "long term" case.

The equation for calculating diesel netback to the refinery becomes:

For the "short term" base case,

$$\text{Refinery Netback Price} = (\text{WTI} + 2.94 + 7.0) \cdot 0.95 \qquad \text{[Eq. 7-4]}$$

and for the "long term" base case,

$$\text{Refinery Netback Price} = (\text{WTI} + 2.94 + 4.0) \cdot 0.95 \qquad \text{[Eq. 7-5]}$$

It is recommended that a WTI price of \$20/bbl be used for the base case, and economic parameter sensitivities run at \$15 and \$25/bbl.

The base case diesel price to be used in the economic analysis then becomes \$ 28.44 /bbl for the "short term" project and \$ 25.59/bbl for the "long term" project.

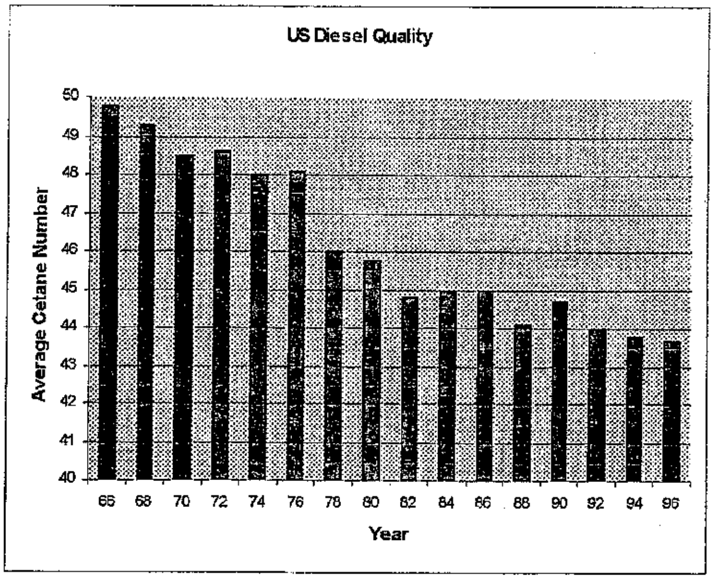
In the best case scenario (high WTI crude price and high GTL diesel premium), the GTL diesel price would be \$ 35.09/bbl for the "short term" case, and \$33.19/bbl for the "long term" case.

In the worst case scenario (low WTI crude price and low GTL diesel premium), the GTL diesel price would be \$21.79/bbl for the "short term" case, and \$17.04/bbl for the "long term" case.

7.3.4.4 Diesel Quality

Cetane values of the United States diesel pool have been trending downward as shown in Fig.7-3. This is because the US refining industry, unlike that in Western Europe is geared to gasoline, rather than diesel production. As a result, Fluid Catalytic Cracking (FCC) capacity is high. As US refiners also handle heavier crudes, coking capacity is high. These factors, coupled with the increase in diesel demand and decrease in No.6 fuel oil demand, has resulted in an increasing amount of diesel boiling range low-cetane cracked stocks in the diesel pool. Until October 1993, when the 500 ppmw sulfur came into force on "road diesel" , most US refiners were producing one "fungible" product that could go either into the "road diesel" or "off road diesel" markets. Since October 1993 many refiners have installed facilities to segregate diesel boiling range streams into two separate pools: one for "road diesel" and the other for "off road"/No.2 fuel oil.

Figure 7-3 **Cetane Trend of the United States Diesel Pool**



GTL diesel, being highly paraffinic, is of very high quality and characterized by:

- High cetane number (over 70 compared to 45-50 for conventional diesel)
- No sulfur
- No aromatics
- Low cloud point (-10° C)
- Low emissions (compared to U.S. average diesel fuel, based on Southwest Research Institute Study).

- 8% less NOx
- 30% less particulate matter
- 38% less hydrocarbon
- 46% less CO
- Even lower emissions possible in engines optimized for F-T diesel.

Typical properties of GTL diesel in comparison to US "road diesel" are as indicated in Table 7-6 below [9][14].

Table 7-6 **Properties of GTL Diesel Compared to US "Road Diesel"**

Property	Unit	GTL Diesel	EPA "road diesel"	Method
Density @ 15 °C	Kg/m^3	780	No spec.	ASTM D 1298
Distillation range IBP FBP	 °C °C	 201 358	 < 385	ASTM D 86
Sulfur	ppm	Not detectable	< 5000	ASTM D 1266 for GTL ASTM D 2622 for EPA
Cetane number		76	>40	ASTM D 976 for GTL ASTM D 613 for EPA
Flash point	° C	88	> 38-55 Depending on grade	ASTM D 93
Aromatics	%V	Not detectable	< 35	ASTM D 5186 for GTL ASTM D 1319 for EPA

The high n-paraffin content of the F-T diesel results in a lower density than that for diesel from conventional crude sources. Therefore, without blending, it will not be able to meet minimum density specifications for some diesels.

However, it is expected that minimum density specifications for diesel will be reduced to allow high cetane/high paraffin "premium" diesels to be used as fuels without blending.

7.3.5 Normal Paraffins

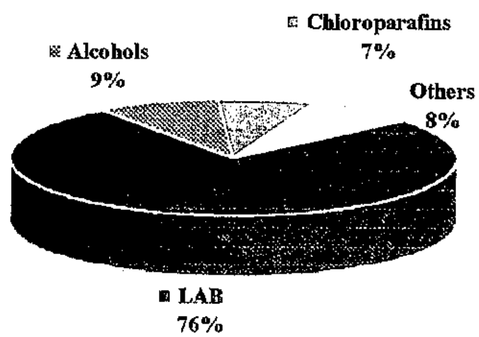
The normal paraffins considered here are linear aliphatic C_{11} to C_{13} hydrocarbons. Their major use is a raw material for the production of olefins or monocholoroparaffins used to manufacture linear alkylbenzene (LAB). LAB is the primary raw material for the production of linear alkylbenzene sulfonate (LAS), a surfactant detergent intermediate.

Shell reports [9] that normal paraffins can be produced via hydrogenation (to remove small amounts of oxygenates, primarily alcohols) and fractionation of the kerosene-diesel cut from the F-T reactor product. These products are suitable for the production of LAB without requiring a further extraction step.

7.3.5.1 Supply and Demand

The primary use for linear paraffins is the production of LAB, as shown on Figure 7-4.

Fig. 7-4 **Global n-Paraffin Demand by End Use** [2]



Little growth is expected in the LAB markets in the United States, Canada, Western Europe, and Japan. Significant growth is projected in the less developed areas of the world as LAB continues to replace the non-biodegradable dodecylbenzene made from propylene tetramer (Table 7-7).

Table 7-7 **Global LAB Demand**

	Demand (000 MT)			**Annual Growth Rate %**
	1995	**2003**	**2010**	
West Europe	385	416	443	0.9
East Europe	225	358	373	6.0
North America	435	517	610	2.4
South & Central America	222	370	579	6.6
Africa/Middle East	237	350	509	5.0
Far East	615	831	1154	4.0
Total	**2119**	**2842**	**3668**	

Global demand for linear paraffins was 2.0 million tons in 1996. Demand is expected to rise at the same rate as LAB to reach over 2.5 million tons by 2005 and 3.0 million tons by 2010 as shown in Table 7-8.

Table 7-8 **Worldwide n-Paraffin Demand**

	Demand (000 MT)				Annual Growth Rate
	1996	**2000**	**2005**	**2010**	**%**
West Europe	640	664	694	726	0.9
East Europe	50	63	84	113	6.0
North America	380	418	470	530	2.4
South & Central America	135	174	240	330	6.6
Africa/Middle East	90	109	140	178	5.0
Far East	680	796	968	1178	4.0
Total	**1975**	**2224**	**2596**	**3055**	

7.3.5.2 Price

U.S. price, f.o.b. plant site, for linear paraffins is about 400 $/ton.

Quimica Venoco, the primary importer of linear paraffins into Venezuela, bought the product in the international market at a price around $ 400/ton in 1998.

7.3.5.3 Recommended Capacity

Excess linear paraffin capacity exists in the U.S., Western Europe, and Japan (Table 7-9).

The South American market, growing at about 6.6 % per year, presents an opportunity for the production of linear paraffins. The only producers at present are YPF (40,000 MTA in Ensenada) and PETROBRAS (100, 000 MTA in Cubatao). In Venezuela, VENOCO is the main user of linear paraffins. These are used for the production of LAB sold to detergent manufacturers. All of it is imported and VENOCO used around 42,000 MTA in 1997, representing 85 % of the total Venezuelan consumption (50,000 MTA).

The Venezuelan consumption is expected to grow to 73,000 MTA in 2003 and 89,000 MTA in 2006, based on the growth rate mentioned above.

Table 7-9 **Supply/Demand for C_9 - C_{17} Normal Paraffins by Major Region - 1996**

	United States	Western Europe	Japan 2010
Capacity	413	785	160
Production	346	620	139
Imports	11		31
Exports	54	80	0
Consumption	302	540	170

It is therefore recommended that the n-paraffin capacity be set at the maximum available (about 70,000 MTA) for the short-term option (2006) and 90,000 MTA for the long-term (2007+)

7.3.5.4 Product Properties

Typical product properties are listed in Table 7-10 below:

Table 7-10 **Product properties of n-Paraffins from Fischer-Tropsch**

Property	Unit	Value	Method
Saybolt Color		+30	ASTM D156
Bromine Index	mg Br/100g	5.0	ASTM D2710
Sulfur	ppm	0	ASTM D3120
Carbon Distribution	wt %		DHA GC
- C_9 and lighter		0.0	
- C_{13} and lighter		99.3	
- C_{14} and heavier		0.7	
n-Paraffins content	wt %	96.1	

7.3.6 Waxes

The Fischer-Tropsch wax stream can be hydrogenated and distilled to give narrow molecular weight fractions. The synthetic waxes produced are similar to paraffin wax in structure, but are higher in melting point and harder, due to their higher molecular weight.

Their physical properties make them suitable for many applications, including: hot melt adhesives, inks, paints and coatings, textiles, plastics lubrication, color concentrates, and as additives to many wax blends.

The lower melting point grades can compete against petroleum waxes.

7.3.6.1 Supply and Demand

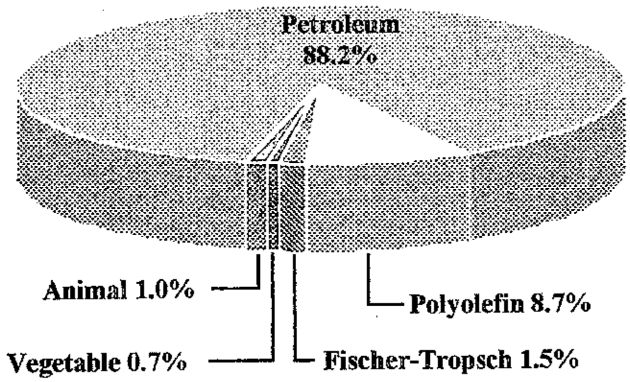
The consumption of waxes in the three major industrialized regions of the world is estimated at about 2 million metric tons per year, and is distributed by origin as shown in the Table 7-11 and in Figure 7-5:

Table 7-11 **Wax Consumption in Industrialized Regions by Origin**

Type	Consumption (000 MTA)
Vegetable	13
Animal	20
Petroleum	1720
Polyolefin	169
Fischer-Tropsch	29

The demand is fulfilled in majority by petroleum waxes, with Fischer-Tropsch waxes representing less than 2 % of the total wax consumption (Figure 7-5).

Fig. 7-5 **Consumption of Waxes by Type for the United States, Western Europe and Japan**



This percentage is expected to grow, particularly in the areas of the world where petroleum wax is in short supply.

Projected world supply/demand for petroleum waxes [8] shows that the world will remain in slight oversupply (Table 7-12). North America will change from being a net exporter to a net importer of petroleum wax, due to the closing of conventional lube oil production facilities. It is expected that other countries, in Western Europe, and particularly China, will make up this shortfall by increasing their exports.

PDVSA

Table 7-12 World Supply / Demand Petroleum Waxes

	PRODUCTION	CONSUMPTION	EXPORT (IMPORT)	PRODUCTION	CONSUMPTION	EXPORT (IMPORT)	PRODUCTION	CONSUMPTION	EXPORT (IMPORT)	PRODUCTION	CONSUMPTION	EXPORT (IMPORT)
	1995	1995		2000	2000		(2005)	2005		2010	2010	
	(000 MT)											
WEST EUROPE	610	505	105	630	505	125	651	505	146	672	505	167
EAST EUROPE	160	170	-10	180	190	-10	203	212	-10	228	237	-10
NORTH AMERICA	955	920	35	940	1000	-60	925	1087	-162	911	1181	-271
SOUTH & CENTRAL AMERICA	185	235	-50	220	260	-40	292*	288	4	322	318	4
ASIA & NERA EAST	1120	1065	55	1490	1360	130	1982	1737	246	2637	2218	419
AUSTRALIA & NEW ZEALAND	10	25	-15	15	30	-15	23	36	-14	34	43	-9
AFRICA	105	170	-65	125	190	-65	149	212	-64	177	237	-60
TOTAL	**3145**	**3090**	**55**	**3600**	**3535**	**65**	**4224**	**4077**	**147**	**4980**	**4740**	**240**

* Includes 51,000 MT/Y Schumann/Sasol addition.

Raytheon
Raytheon Engineers & Constructors

Schumann Sasol is presently the sole producer of Fischer-Tropsch waxes. Shell began producing F-T waxes in Malaysia. An explosion shut down this plant in 1997. The plant is expected to restart in 2000 with a 50 % higher wax production capacity.

South and Central America are expected to become self-sufficient in petroleum wax by 2000-2005. The wax plant that Schumann Sasol are building in Cardon has enough installed capacity (51,000 tons per year) to satisfy the local and Latin American markets in the short and mid-term.

The South and Central American market for Fischer-Tropsch waxes is estimated at about 3,000 metric tons per year and is presently supplied by Schumann Sasol. This market is expected to grow at about 6% per year.

7.3.6.2 Price

FOB US prices for refined paraffin and microcrystalline petroleum waxes are at 550 - 650 $ per metric ton and 700 - 800$ per metric ton respectively.

Based on a July 29, 1998 letter from Schumann-Sasol to PDVSA, the price of crude petroleum wax in Venezuela was $550/ton in 1998 and was expected to go up to $700/ton in 2005.

List prices for Fischer-Tropsch waxes are generally in the range of 1300 - 2600$ per metric ton, depending on grade.

7.3.6.3 Recommended Capacity

The world market in Fischer-Tropsch waxes is expected to be adequately supplied with the restart in 2000 of the expanded Shell Bintulu facility.

Synthetic wax production does not appear warranted in the short or "long term" due to the relatively small size of the Fischer-Tropsch wax market in South America, the expected self-sufficiency in petroleum waxes, and the high cost of marketing and developing applications for synthetic waxes.

7.3.6.4 Product Properties

Typical wax product properties are listed in Table 7-13.

Table 7-13 **Typical Fischer-Tropsch Wax Product Properties**

Property	Unit	Soft Wax	Hard Wax	Method
Congealing Pt	°C	50	100	ASTM D938
Saybolt Color		+30	+30	ASTM D156
Odor		1.0	0.5	ASTM D1833
Oil Content @ -32 °C	Wt %	2.5	0.0	ASTM D721
UV Absorptivity		<0.01	<0.01	ASTM D2008

7.3.7 Synthetic Lubricants

Automobile manufacturers are recommending lower viscosity grade engine oils, namely SAE 5W/30 and 10W/40, over heavier weight oils presently found in the marketplace in order to meet tighter environmental regulations in Western Europe, the United States, and Japan. Concurrently, volatility specifications are becoming more stringent in order to reduce oil consumption and exhaust emissions. To meet these conflicting requirements, lube manufacturers must use an increasing proportion of non-conventional, high quality lube basestocks in the formulation of engine oils [(1)].

Very high viscosity index (VHVI) basestocks can be produced by hydroisomerizing and dewaxing Fischer-Tropsch waxes[(2,9)]. These high quality lubricants, having a Viscosity Index (VI) higher than 120, can be marketed as synthetic base oils.

7.3.7.1 Supply and Demand

The worldwide demand and production of VHVI base oils, driven by environmental regulations in North America, Europe, and Asia, and aimed at energy savings and lower emissions is about 15,000 bpd, and is projected to grow by about 20 % per annum (Figures 7-6 and 7-7).

Fig. 7-6 **Supply of VHVI Base Oils** (5)

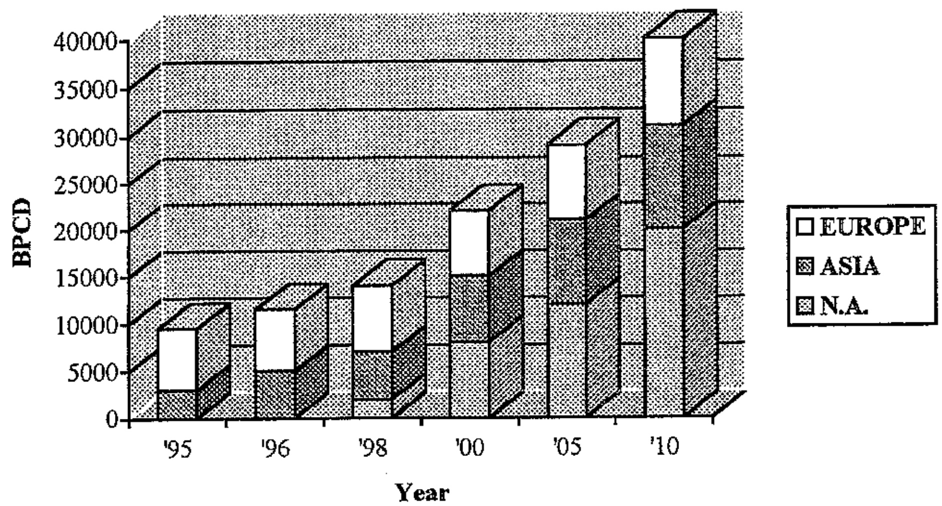
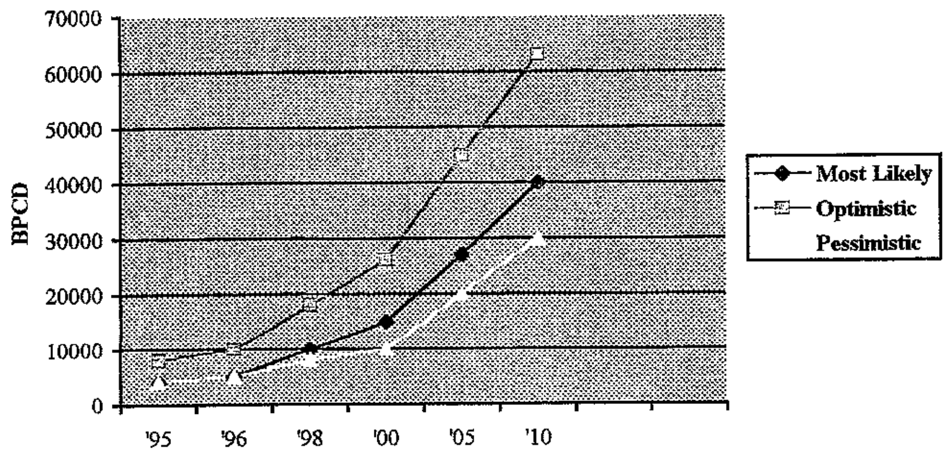


Fig. 7-7 **Worldwide Demand for VHVI Base Oils** (5)



The resulting estimated worldwide demand is shown in Table 7-14 (BPCD):

Table 7-14 **Worldwide Demand for VHVI Base Oils**

	Pessimistic	Optimistic	Most Likely
"Short-term"	16,000	37,000	22,000
"Long Term"	26,000	56,000	35,000

Many lube oil producers have both hydrocracker bottoms and spare dewaxing capacity available, and are therefore able to increase supply to satisfy the demand.

The South American demand for VHVI and synthetic base oils is still small, due to strong consumer preference for monogrades, climate conditions that do not require lubricants viscosity below 10W-30, and an aging vehicle fleet still in use. The regional demand for these oils constitutes however a significant portion of the imports of basestocks into the region [7]. Imports of these high quality base oils are expected to continue to rise as the multinational oil companies increase regional blending capacity and source base oils from the US and Europe.

In 1997, Venezuela produced 5600 bpd of lube base stocks and finished products. 1800 bpd was consumed internally, and the rest exported. Synthetic lubricants represented only about 2.5% of the internal demand.

7.3.7.2 Price

A significant premium exists for VHVI base oils market over Group I (95 VI) and even Group II (100-120 VI) base oils. Current market US fob prices in $/bbl for lube base oils are listed in Table 7-15 below [3,4]:

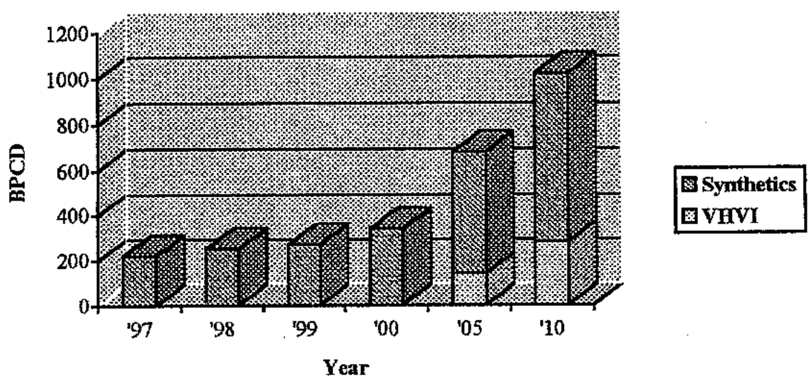
Table 7-15 **Current (Sep 1999) Market Prices for Lube Base Oils (US f.o.b.)**

Grade	$/BBL
150N, 95VI	37
250N, 95VI	37
500N, 95VI	42
Brightstock, 95VI	42
150N, 105VI	50
250N, 105VI	51
500N, 105VI	52
Brightstock, 110VI	60
100N, 130 VI	95
100N, 140 VI	120

7.3.7.3 Recommended capacity

The market for high quality lubricants in the South American region is not expected to become significant until 2010 (Figure 7-8). This production should therefore only be considered for the "long term" option, with a capacity set at the minimum economical unit size for the process, or 3,000 bpd. This would cover the needs of the South American market (1, 000 bpd), the remainder of the production being absorbed by the US, Japan, or European markets

Fig. 7-8 **South American Synthetics and VHVI Base Oils Demand** (6)



7.3.7.4 Product Properties

Typical properties of the synthetic lubricants produced are presented in Table 7-16 below:

Table 7-16 **Typical Properties of Synthetic Lubricants Produced via Fischer-Tropsch**

Property	Unit	Value		Method
Kinematic Viscosity	cSt @ 100°C	7.5	6.7	ASTM D445
	cSt @ 40°C	39	34	
Viscosity Index		163	159	ASTM D2270
Pour Point	°C	-9	-22	ASTM D 97

7.3.8 Synthetic Crude

Instead of producing final products, it is possible to combine the hydrocarbon streams from the Fischer-Tropsch synthesis and produce a "synthetic crude" or "syncrude". This syncrude could then be processed in a conventional refinery. Raytheon considered this approach, and decided against it for the following reasons:

- The syncrude produced will have a high pour point, around 250°F, because of its highly paraffinic nature. Therefore, it cannot be moved in conventional crude pipelines unless it is heated and kept hot.
- Of the total investment for a GTL plant, the "product workup" section contributes a fairly small (about 10%) portion. Producing "syncrude" instead of final products would not, therefore, result in a significant reduction in investment for the GTL plant.
- If the syncrude is further processed in a conventional refinery, the products from the GTL syncrude would, in most cases, get mixed with the products from the conventional crude being processed. The premiums that GTL products are likely to command due to their "environmentally friendly" nature would not be realized.

7.3.9 Oxygenates

The Fischer-Tropsch reaction generates a water stream containing small amounts of alcohols, ketones, carbonyls, and acids. No detailed composition of the Fischer-Tropsch water was received from the licensors. It is believed that the total amount of oxygenates produced is about 20,000 MTA for the "short term" option.

Posted prices of the main components that can be recovered are listed in Table 7-17 below:

Table 7-17 **Posted Prices of The Main Components that Can Be Recovered From Fischer-Tropsch Water**

Main Components	Posted Price ($/Kg)
Methanol	13
Ethanol	20
n-Propanol	55
n-Butanol	50

The table shows that ethanol, propanol and butanol offer the greatest incentive for recovery.

7.3.9.1 Supply and Demand

There are major producers of both Methanol and Ethanol in the region. South America and Venezuela are, however, importers of oxo alcohols. Propanol and Butanol are used mainly in solvent applications.

The investment cost required to recover these chemicals is estimated to be in the order of 15 MM$ ("short term" option) to 30 MM$ ("long term" option), and is probably only justified economically for the "long term" option.

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