8.5.5 Sasol

Sasol are clearly qualified and capable of supplying a design package for a full GTL plant together with their partners Haldor Topsoe and Chevron. They have the research, pilot and commercial (or at least near-commercial) experience in each of the important processing steps to be a credible technology supplier.

8.5.6 Syntroleum

Syntroleum's concept of feeding air instead of oxygen to the reformer, and allowing the nitrogen to pass through the entire process, at first appears attractive as it eliminates a very high capital unit: the air separation unit. At the same time, the syngas and F-T units must increase in size to process the larger gas volume. Syntroleum's cost estimates show that the net effect is a capital cost very similar to, for example, Sasol's, with significantly lower yields. For this reason, no benefit is seen to including this technology in the next phase.

8.5.7 Rentech

Rentech have developed the F-T technology to a scale (250 BPD) that can be considered either a large pilot plant or a very small commercial unit. Based on the information provided, the technology may be competitive at small scale (up to about 4,000 BPD) as this is the single train capacity limit. For the capacities envisioned for even the smaller, "short term" case, four or five trains would be required. This puts the technology at an inherent disadvantage economically compared to others whose single train capacities are higher (Shell: 9,000 BPD, Sasol: 15,000 BPD, Exxon: estimated 15,000 BPD). Rentech does, however, have the advantages of being available for a third party license, and of being immune from potential patent infringement suits from the various developers of cobalt catalyzed slurry bed processes. On the whole it is felt that the advantages outweigh the drawbacks, and it is recommended that Rentech be included in the next phase.

8.5.3 PDVSA/Intevep

The nature of the information provided by Intevep appears to be quite preliminary in nature, and the process has not yet been developed beyond bench scale. For these reasons, Intevep's F-T technology should not be considered for

the "short term" case. For longer term projects it is possible that it may provide some benefits over third party licensed technology, particularly if PDVSA were to take a controlling or large equity interest in the operating plant. Such an in-depth evaluation of the relative merits of developing indigenous technology versus licensing imported technology is beyond the scope of this study.

PDVSA

ATTACHMENT A
LICENSOR ENQUIRY DOCUMENT # 1

LICENSOR ENQUIRY DOCUMENT

for

NATURAL GAS TO LIQUIDS CONVERSION PROJECT

PROJECT NO. 79006.001

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LICENSOR ENQUIRY DOCUMENT

1.0 Introduction

Raytheon Engineers and Constructors have been retained by PDVSA Gas to evaluate the feasibility of converting natural gas to liquid products in Venezuela. This study includes a technology licensor evaluation, and *company name* is invited to participate by supplying specific requested information. This letter provides the basis for the study and the scope of the requested information.

2.0 Confidentiality

This information is being requested on a non-confidential basis; should the need arise from any party to divulge information of a confidential nature, then secrecy agreements covering all parties will be executed. As this study is being carried out under a grant from the United States Trade and Development Agency (TDA), the non-confidential information provided will be included in a report that will become public. Confidential information will be provided in supplemental reports that will be made available only to those parties covered by secrecy agreements, and will not be sent to the TDA.

3.0 Business Scope

PDVSA is having this study conducted to determine the short and mid/long term viability of converting natural gas to liquids. PDVSA's main objective is to define the business strategy for these scenarios, in order to develop the best opportunity to monetize natural gas reserves.

The short term strategy should consider:

- Opportunity to be developed by third parties.
- PDVSA's option for a minority share in the venture.
- That PDVSA will guarantee gas supply and may commit to some product offtake.
- The possibility that PDVSA may invite potential investors or licensors to bid for the gas contract.

The mid/long term strategy should consider:

- That PDVSA's aim is to maximize the long term value of the Venezuelan gas reserves by exploiting market needs and opportunities.
- Third Party or Joint Venture opportunities are options as far as PDVSA is concerned.
- Gas supply guarantees and product off-take commitments that may be required from PDVSA.

4.0 Technical Scope

Two cases are being considered as indicated in the table below:

CASE	SHORT TERM	MID/LONG TERM
Feed	Natural Gas	Natural Gas
Feed Rate	150 MMSCFD	500 MMSCFD
Feed Composition		
CH_4 mol %	80.95	80.95
C_2H_6 mol %	8.00	8.00
C_3H_8 mol %	1.50	1.50
C_4H_{10} mol %	0.55	0.55
C_5+ mol %	0.30	0.30
N_2 mol %	0.20	0.20
CO_2 mol %	8.50	8.50
H_2S ppmv	10	10
Pressure	27 barg	27 barg
Temperature	45°C	45°C
Products (preliminary)		
Diesel	Maximize	Maximize
Naphtha	Minimize	Minimize
Lube Base Oil	3,000 BPD	6,000 BPD
Wax	65 MTD	70 MTD
Linear Paraffins (C11-C13)	130 MTD	170 MTD

The study scope includes the following three major process steps:

- Synthesis gas production from natural gas
- Conversion of syngas to hydrocarbon liquids by Fischer-Tropsch (F-T) synthesis.
- Product workup to produce diesel, naphtha, lube base oils, wax, and linear paraffins .

Each **process step** will involve **one or more process units.** For example, lube production may require fractionation, dewaxing and finishing units.

5.0 Information Requested

For any or all of the three major process steps (depending on *company name's* areas of expertise and interest), and for each capacity case, please provide the following information:

1. Please provide stream rates, compositions (with as detailed a breakdown as available) and properties of all process streams in and out of each **process unit** together with a simplified block flow diagram showing the arrangement of the process units.
   Streams of particular interest are:
   - Synthesis gas from the syngas production unit
   - Primary FT products, namely wax, liquid hydrocarbons, reaction water and tail gas.
   - Final products, namely diesel, naphtha, lube base oil, wax, and linear paraffins.

   Include major properties of products as indicated in Attachment 1.

   If only providing FT information, specify H_2/CO ratio required in the syngas feed. Also assume the following for the syngas feed: maximum CO_2 content of 10 vol. %, pressure 23 barg, and temperature 65 °C.

2. A brief description of the technology employed in each process unit, its development status and commercial experience.

3. Inside battery limit capital investment for each process unit (US Gulf Coast basis). Please specify the scope of supply for the quoted investment data to enable Raytheon to complete the project investment estimate.

4. Operating cost information, specifically chemicals and catalysts, and estimated operating and maintenance staff requirements. Assume experienced and qualified staff are available.

5. Hydrogen consumption for hydroprocessing units.

6. Utility consumption and, if applicable, production.
   Assume the following:
   - Electric power is the only utility to be exported from the facility.
   - Critical equipment will be driven by 600 psig steam turbines. All other drivers are electric
   - Air cooling is to be maximized
   - Cooling water is available

7. Information on environmental considerations, such as the rate and composition of the Fischer-Tropsch water byproduct, and other air and water emissions. Suggestions on effluent water treatment requirements would be helpful.

6.0 Schedule

Please provide a response by September 13, 1999. If any problems are foreseen, please advise us as soon as possible.

7.0 Address for Responses

Please address the responses to Mr. Uday Hattiangadi at :

Raytheon Engineers & Constructors, Inc.
1250 W. Sam Houston Parkway S.,
Houston, TX 77042

If you have any questions, please contact Mr. Uday Hattiangadi, by telephone at (281) 529-3591 or by fax at (281) 529-7746.

ATTACHMENT 1

NAPHTHA				
Property	**F-T (Straight Run) Naphtha**	**Hydrotreated Naphtha**	**Hydrocracker Naphtha**	**Units**
Octane number Research Motor				
Paraffins				Weight%
Olefins				Weight %
Naphthenes				Weight %

KEROSENE			
Property	**F-T (Straight Run) Kerosene**	**Hydrocracker Kerosene**	**Units**
Freezing point			°C
Smoke point			mm
Flash point			°C

DIESEL			
Property	**F-T (Straight Run) Diesel**	**Hydrocracker Diesel**	**Units**
Density			Kg/m^3
Cetane number			
Pour point			°C
Distillation 90 vol % point 95 vol % point			

LUBE OIL PRODUCTS				
Property	**Light Base**	**Medium Base**	**Heavy Base**	**Units**
Viscosity Index				
Pour point				°C

WAX PRODUCTS			
Property	**Medium Wax**	**Hard Wax**	**Units**
Flash point			°C
Viscosity at 210°F			CSt
Melting Point Range			°C
Refractive Index at 100 °C			
Average molecular weight			
Carbon no. range			
Penetration at 25°C			1/10 mm
Color			

Note: Concentrations of benzene and other aromatics have been assumed to be negligible. If this is not the case, please advise.

PDVSA

ATTACHMENT B
LICENSOR ENQUIRY DOCUMENT # 2

LICENSOR ENQUIRY DOCUMENT

for

NATURAL GAS TO LIQUIDS CONVERSION PROJECT

HEAVY WAX

PRODUCT WORK-UP

Job No. 79006.001

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ENQUIRY DOCUMENT

1.0 Introduction

Raytheon Engineers and Constructors have been retained by PDVSA Gas to evaluate the feasibility of converting natural gas to liquid products in Venezuela. This study includes a technology licensor evaluation, and *company name* is invited to participate by supplying specific requested information. This letter provides the basis for the study and the scope of the requested information.

2.0 Confidentiality

This information is being requested on a non-confidential basis; should the need arise from any party to divulge information of a confidential nature, then secrecy agreements covering all parties will be executed. As this study is being carried out under a grant from the United States Trade and Development Agency (TDA), the non-confidential information provided will be included in a report that will become public. Confidential information will be provided in supplemental reports that will be made available only to those parties covered by secrecy agreements, and will not be sent to the TDA.

3.0 Technical Scope

Two cases are being considered as indicated in the table below:

CASE	SHORT TERM	MEDIUM TERM
Feed	Fischer-Tropsch Heavy Wax	Fischer-Tropsch Heavy Wax
Feed Rate	4,800 BPD	16,000 BPD
Feed Composition	See Attachment 2	See Attachment 2
Products		
Diesel	Maximize	Maximize
Naphtha	Minimize	Minimize
Lube Base Oil	0 BPD	3,000 BPD

The study scope includes the following three major process steps:

- Synthesis gas production from natural gas (by others)
- Conversion of syngas to hydrocarbon liquids by Fischer-Tropsch (F-T) synthesis (by others)
- Product workup to produce naphtha, kerosene, diesel, and lube base oils. The object of this inquiry is limited to upgrading of the heavy wax portion of the feed.

4.0 Information Requested

For each capacity case, please provide the following information:

1. Stream rates and properties of all process streams in and out of each **process unit** together with a simplified block flow diagram showing the arrangement of the process units. Streams of particular interest are the final products, namely, naphtha, diesel, and lube base oil.

   Include major properties of products as indicated in Attachment 1.

2. A brief description of the technology employed in each process unit, its developmental status, and commercial experience.

3. Inside battery limit capital cost for each process unit (US Gulf Coast basis). Please specify the scope of supply for the quoted cost data to enable Raytheon to complete the project cost estimate.

4. Operating cost information, specifically chemicals and catalysts, and estimated operating and maintenance staff requirements. Assume experienced and qualified staff are available.

5. Utilities, hydrogen, and chemicals consumptions.

5.0 Schedule

Please provide a response by September 13th. If any problems are foreseen, please advise us as soon as possible.

6.0 Address for Responses

Please address the responses to Mr. Uday Hattiangadi at :

Raytheon Engineers & Constructors, Inc.
1250 W. Sam Houston Parkway S.,
Houston, TX 77042

If you have any questions, please contact Mr. Uday Hattiangadi, by telephone at (281) 529-3591 or by fax at (281) 529-7746.

ATTACHMENT 1

Property	Hydrocracker Naphtha	Units
Octane number Research Motor		
Paraffins		Weight%
Olefins		Weight %
Naphthenes		Weight %

Property	Hydrocracker Kerosene	Units
Freezing point		°C
Smoke point		mm
Flash point		°C

Property	Hydrocracker Diesel	Units
Density		Kg/m³
Cetane number		
Pour point		°C
Distillation 90 vol % point 95 vol % point		

LUBE OIL PRODUCTS				
Property	Light Base	Medium Base	Heavy Base	Units
Viscosity Index				
Pour point				°C

ATTACHMENT 2

Composition of F-T Product being fed to the "Product Workup" Step

Carbon No.	Mass Fraction	Carbon No.	Mass Fraction	Carbon No.	Mass Fraction
21	7.02E-02	47	1.01E-02	73	1.01E-03
22	6.62E-02	48	9.30E-03	74	9.25E-04
23	6.23E-02	49	8.54E-03	75	8.44E-04
24	5.85E-02	50	7.85E-03	76	7.70E-04
25	5.48E-02	51	7.20E-03	77	7.02E-04
26	5.13E-02	52	6.61E-03	78	6.40E-04
27	4.79E-02	53	6.06E-03	79	5.83E-04
28	4.47E-02	54	5.56E-03	80	5.32E-04
29	4.17E-02	55	5.09E-03	81	4.84E-04
30	3.88E-02	56	4.67E-03	82	4.41E-04
31	3.61E-02	57	4.28E-03	83	4.02E-04
32	3.35E-02	58	3.92E-03	84	3.66E-04
33	3.11E-02	59	3.59E-03	85	3.33E-04
34	2.88E-02	60	3.28E-03	86	3.04E-04
35	2.67E-02	61	3.00E-03	87	2.76E-04
36	2.47E-02	62	2.75E-03	88	2.52E-04
37	2.29E-02	63	2.51E-03	89	2.29E-04
38	2.11E-02	64	2.30E-03	90	2.08E-04
39	1.95E-02	65	2.10E-03	91	1.90E-04
40	1.80E-02	66	1.92E-03	92	1.73E-04
41	1.66E-02	67	1.75E-03	93	1.57E-04
42	1.53E-02	68	1.60E-03	94	1.43E-04
43	1.41E-02	69	1.46E-03	95	1.30E-04
44	1.30E-02	70	1.33E-03		
45	1.20E-02	71	1.22E-03	TOTAL	1.00
46	1.10E-02	72	1.11E-03		

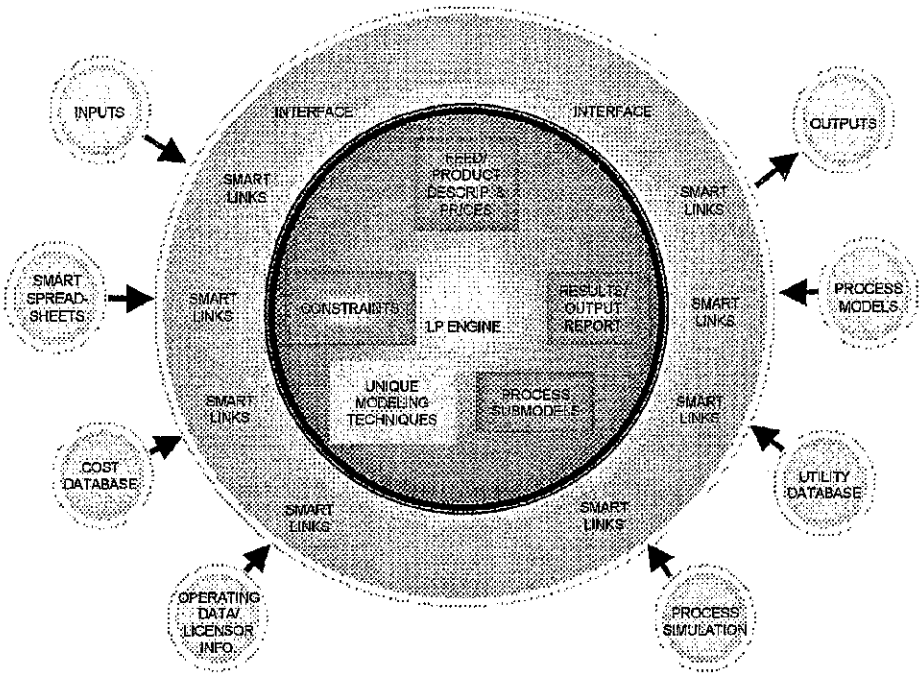
PDVSA

9.0 PROCESS MODELING

Raytheon Engineers & Constructors have utilized its proprietary model, RAYSPONSE™ — GTL, in this study to develop a conceptual definition of the overall GTL plant based on licensor data and also to perform economic and sensitivity analysis. Where only partial data were supplied by a licensor in response to our enquiry, generic data from the model's databank were used. This model enabled Raytheon to compare the overall performance of individual licensors technologies on the same basis, specifically relative to the overall investment costs and the costs of support services and infrastructure.

The model is based on RAYtheon's Screening, Planning & OptimizatioN SoftwarE (RAYSPONSE) proprietary modeling concept. It is an innovative concept and approach to construct software models based on integrated modeling technique as illustrated in the Figure 9-1. The technique utilizes linear programming methods with other mathematical and economic models coupled with numerous smart spreadsheets to provide built-in intelligence for performing multiple tasks. The model develops in a single step, a conceptualized definition of the configuration of the GTL plant, a block diagram with major stream flows and unit capacities based upon the product mix, desired product rates, and prices. Simultaneously, a total investment cost of the project with cost breakdown of individual units and systems, rate of return on investment, gross revenue and operating costs are developed on a consistent basis for all licensors.

Fig. 9-1 RAYSPONSE™ Integrated Modeling Concept



Represent Conventional LP Modeling. All Others Are Newly Developed For The RAYSPONSE™ Integrated Modeling.

The **RAYSPONSE™ — GTL** model developed on the above concept also incorporated the use of other third party process models and Raytheon developed design spreadsheets to perform a number of tasks specific to GTL plant design. Examples are:

- Aspen-Plus based reactor models for Partial Oxidation (Pox) and Autothermal Reformer (ATR) units.
- Shultz-Flory Distribution model for the Fischer-Tropsch reactor.
- Process models to predict yield and energy balance of Air Separation unit, Gas and Steam turbines, Hydrogen Manufacturing unit and utility systems and others.

The model has built-in databank to predict generic yield data, capital and operating costs of all the units shown in the attached structural block flow diagram.

A structural block flow diagram of the RAYSPONSE™ — **GTL** model is shown in Figure 9-2.

The model was customized with individual licensors data where available. Venezuelan economic parameters and local marketing constraints were included to obtain a conceptual configuration and related investment analysis for a GTL plant built in Venezuela.

Other key features of the model are:

Energy Integration — GTL plants are highly energy intensive and an effective energy management is the key to a project's viability. The **RAYSPONSE™ — GTL** model is able to integrate the energy producers and consumers within the complex and evaluate its impact on the overall economic feasibility. Given the cost of export power or HP steam, the model decides on the economic feasibility of incremental investment required for export/ no export scenario.

Utility Balances and Integration — The model develops utility balances for each unit, globalizes the overall utility demand after integrating utility producers and consumers and then determines the capacity requirement for each of the utility systems prior to calculating the net purchases outside of the battery limit. This approach allows the model to estimate the capital costs of the utility systems and operating costs of net purchases are estimated more precisely on a consistent basis from one licensor to another.

Economic Model — An economic model that calculates the internal rate of return (IRR) has been developed to study the project feasibility. The capital and operating costs calculated by the model are automatically downloaded to this economic analysis model for this purpose. **RAYSPONSE™** modeling technique has been used to develop complex investment cost curves for the GTL units. The method allows the model to predict more accurate capital costs taking into consideration the minimum feasible unit size and maximum train capacities.

Additional features incorporated are built-in inflation factors and site specific cost factors. These features expand the applicability of the model to different geographic locations and time frames.

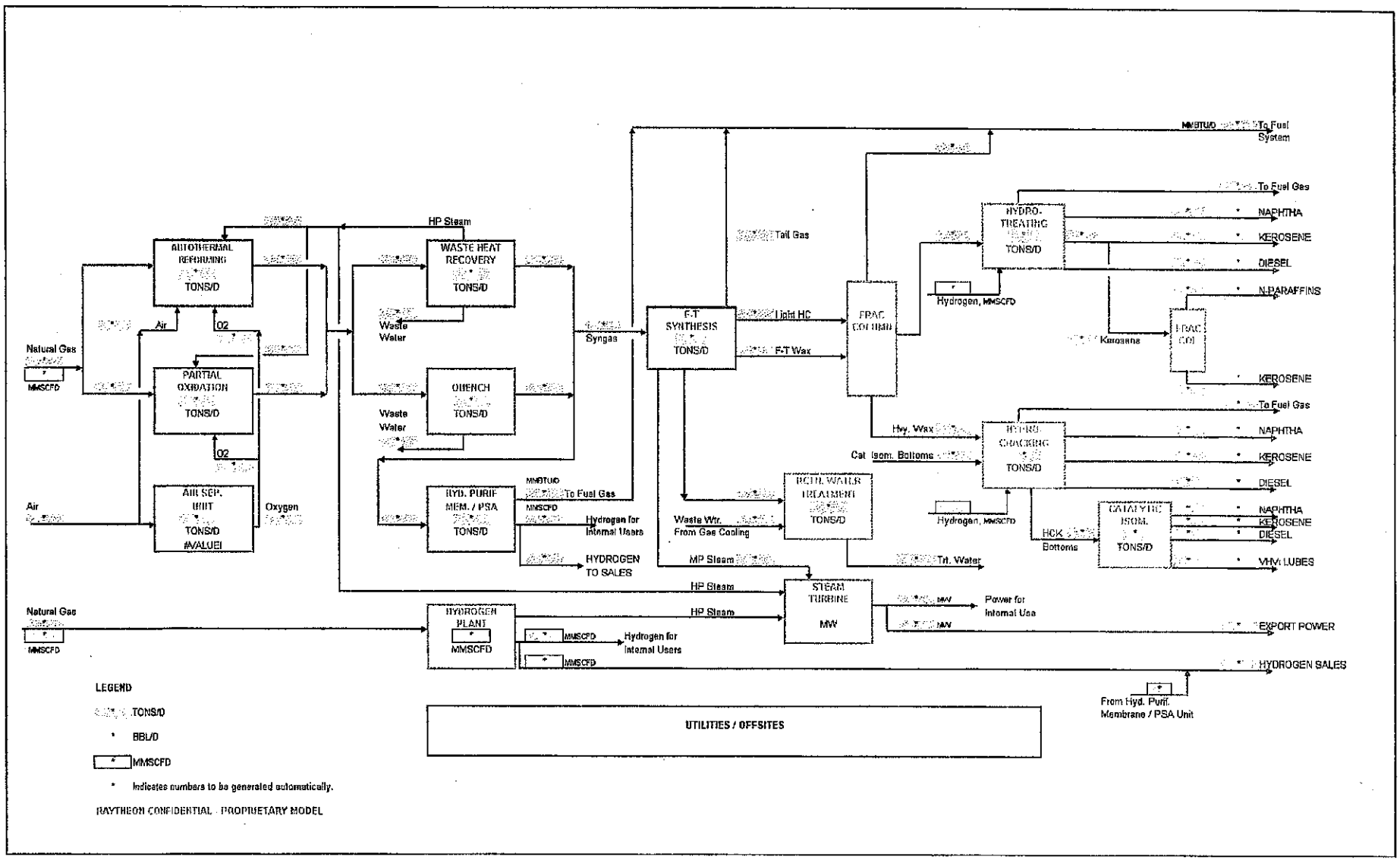
Risk Analysis — The RAYSPONSE™ — GTL model has the capability of performing risk and sensitivity analysis utilizing the integrated Palisade @ Risk, a third party software. This capability allowed the model to perform sensitivity and risk analysis for a variety of scenarios. For example: crude and product pricing, gas prices, total investment costs.

Use of the RAYSPONSE™ — GTL model:

Raytheon has used this proprietary software model to conceptually define the processing route, develop a block diagram with unit capacities consistent with the product mix optimized to maximize the profitability of the project. Sensitivity and risk analysis were performed. The results of the marketing study provided guidelines for the product mix and range for the "short term" and the "long term" projects. The results are included in Section 10, Economic Analysis.

PDVSA

Fig. 9-2 RAYSPONSE™ — GTL Model Block Flow Diagram



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