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1.0 INTRODUCTION

Venezuela has extensive proven gas reserves (146 trillion Standard Cubic Feet), the seventh largest in the world, and hence considers it in the national interest to be involved in all aspects of the development of this resource and its commercialization. The Venezuelan National Gas Company, **PDVSA GAS** (an affiliate of **PDVSA** that reports to a sister company, **PDVSA PETROLEO Y GAS**), is committed to the development of the Natural Gas Business as part of its overall strategy.

PDVSA PETROLEO Y GAS entered into a contract with **RAYTHEON ENGINEERS & CONSTRUCTORS, INC.** in July 1999, to perform a feasibility study for a Natural Gas to Liquids Conversion Project. The feasibility study was funded by the **U.S. Trade and Development Agency** ("**TDA**") pursuant to a grant agreement between the **TDA** and **PDVSA PETROLEO Y GAS**, dated October 29, 1997. An earlier Definitional Mission Report, also funded by the USTDA, TDA No. 97-Q-091, performed by Intratech Inc. of McLean, Virginia, USA, recommended the need for this feasibility study for a GTL project in Venezuela.

The study, performed by Raytheon, investigated the feasibility of utilizing Venezuelan natural gas to produce liquid products in a way that would address the issues of site, process, product selection and rates, and technology so that **PDVSA GAS** could develop a suitable strategy to use GTL Technology as an optional route to monetize the country's large natural gas reserves.

A portion of the study was subcontracted to a local contractor in Venezuela, **COSA ENGINEERS S.A.**, to perform local market analysis for GTL products and to gather site-related information for the potential sites.

RAYTHEON ENGINEERS & CONSTRUCTORS, INC. acknowledge the contribution from **PDVSA GAS** in providing local data on gas reserves, pipeline distribution network and site related data. Engineers from PDVSA were part of the task force performing this study along with COSA and Raytheon.

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2.0 EXECUTIVE SUMMARY

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Venezuela, with gas reserves that are the world's seventh largest, has large untapped gas resources. To monetize these reserves the country is considering Fischer-Tropsch (F-T) Gas To Liquids (GTL) Technology to produce clean fuels and other GTL products in addition to conventional LNG production.

GTL technology, with its recent advancements, has opened up opportunities to produce liquid products that can be transported more economically than LNG. Other major drivers for GTL products are their ability to take advantage of the large infrastructure and markets for liquid fuels currently available via the refining of crude oil. In these markets, GTL products command a premium value as blending components due to their excellent physical characteristics. The technology is also capable of producing high value products, such as superior quality waxes and lubes.

2.1 STUDY OBJECTIVE

The study objective was to recommend strategies to **PDVSA GAS** for monetizing the natural gas reserves via the GTL route. The recommendations would also address the issues of market demands for these products, product slate, site(s), and technology.

2.2 STUDY BASIS

Based on initial discussions with **PDVSA GAS** and reviews of potential sources and reserves, the study focused on two base case plant capacities at:

- 100-200 million standard cubic feet per day (MMSCFD), referred to as the "short term" case, with commissioning targeted during the 2003-2006 time period, and
- 500-750 MMSCFD, referred to as the "long term" case, with commissioning beyond the year 2007.

The GTL products of interest to **PDVSA GAS** are: LPG, Naphtha, Linear Paraffins, Kerosene, Diesel, Waxes, High VI (Viscosity Index) Lube Oils, and Oxygenates.

The economic evaluation was based on a corporate income tax rate of 34%, an investment tax credit of 10%, straight line depreciation over 10 years, a project life of 20 years, and 100% equity financing for the project.

2.3 THE GTL PROCESS

There are three major processing steps in the conversion of natural gas to liquids:

- Conversion of natural gas to synthesis gas, referred to as "Syngas Production".
- Production of liquids and wax from synthesis gas via "Fischer-Tropsch (F-T) Synthesis".
- Hydroprocessing the wax to other GTL products, referred to as "Product Work-up".

Production of syngas suitable for low temperature Fischer-Tropsch (F-T) synthesis can be accomplished either by AutoThermal Reforming (ATR), a catalytic steam assisted process, or by Partial Oxidation (POx), a non-catalytic reforming process. Both processes generally use pure oxygen to support combustion, except for Syntroleum that use air. The F-T technology offered by various licensors fundamentally differs in the type of catalyst and reactors. Most licensors offer cobalt catalyst, except for Rentech who offer iron base catalyst. Three basic types of reactor designs are offered: slurry phase by Sasol, Exxon, Syntroleum and Rentech, fixed bed by Shell, and ebullated bed by Intevep. Hydroprocessing technologies are mature technologies and are offered by several companies.

2.4 SITE SELECTION

Three potential sites were evaluated for locating the GTL plants. All three sites, Anaco, Jose & Güiria, are in the eastern part of Venezuela where most of the gas reserves are located. Anaco is a major hub for production and distribution of associated gas. The supply of associated gas to the Jose location is via the existing Anaco-Jose-Puerto La Cruz pipeline system with ample capacity available for a small scale or a large scale plant. Güiria is a potential site for a GTL plant with non-associated gas as feed from other projects already under study by PDVSA.

Of the three sites, Jose proved to be the best location for both the short and "long term" projects primarily due to existing support facilities and infrastructure. Additionally, the Jose location offers the most favorable siting for a GTL plant in view of excellent synergy prospects with the existing and/or planned industrial projects. For example: Heavy oil projects for product offtakes; Caustic/Chlorine plant for power integration and high quality GTL naphtha for an ethylene complex. The internal rate of return for a GTL plant located at Jose is expected to be at least 2% higher than plants located at Anaco or Güiria after taking into account the different gas prices at each location viz. 0.50 US$/MMBTU at Anaco, 0.60 US$/MMBTU at Jose and 1.00 US$/MMBTU at Güiria.

THE JOSE LOCATION IS RECOMMENDED FOR BOTH "SHORT TERM" AND "LONG TERM" PROJECTS.

2.5 TECHNOLOGY LICENSORS

The licensors contacted to provide economic assessment type of data for evaluation were:

- Full GTL Plant: Exxon, Shell, Sasol, Syntroleum
- Syngas Production: Texaco, Lurgi, Krupp/Uhde
- Fischer-Tropsch: Rentech, PDVSA/Intevep
- Product Work-up: UOP, IFP

Exxon, Shell & Lurgi declined to respond to Raytheon's enquiry document; Texaco referred to published data only. For these licensors, Raytheon's evaluation was based upon information available in the public domain.

Raytheon's evaluation concluded the following overall ranking of technology licensors, group "A" having the highest ranking, and group "C" the lowest:

Group	"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 at 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. Raytheon's experience has been that as processes gain more definition, and progress from bench to commercial scale, there is usually an increase in estimated investment and operating costs. 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 technology.

2.6 MARKETING STUDY

As agreed with **PDVSA GAS**, the marketing study was limited to global and Western Hemisphere markets for the GTL products of interest to Venezuela. Products demand forecast was limited to the year 2010. The marketing study was primarily oriented towards establishing a product mix and production range for the "short term" and "long term" cases.

Raytheon's marketing study concluded that for the "short term" project, the products should be limited to fuels and normal paraffins. The demand for high quality waxes will be met by the production capacities of existing Sasol and Shell plants and the CERAVEN project, currently under construction in Venezuela. Demand for the Very High VI (VHVI) lubes in South and Central America is small, and does not justify production at the outset in the "near term" project *(Add 5 yrs after)*. For the "long term" project, Raytheon recommends that the GTL product slate should, at the outset, include VHVI lube production, at a minimum size plant capacity. A summary table of recommended product mix and product rates at the proposed plant capacities is given below:

GTL Products	"Short Term"	"Long Term"
	BPD	BPD
LPG	None	Nominal
Naphtha	~2,300	7,000 to 12,000
Kerosene	~2,000	9,500 to 21,000
Diesel	~9,000	11,750 to 28,200
N- Paraffins	~1,800	2,300
Wax	None	None
VHVI Lubes	Up to 3000 BPD after 5 years.	3,000

Estimated product prices are as below in constant dollars and linked to a West Texas Intermediate (WTI) crude price of $20 per barrel (base price, in constant dollars). Also included in the table below are the estimated product prices for WTI prices of $15 and $25 per barrel.

GTL PRODUCTS	WTI=$20/BBL	WTI=$15/BBL	WTI=$25/BBL
LPG, $/BBL	11.31	7.06	15.56
Naphtha, $/BBL	14.53	9.78	19.28
Kerosene, $/BBL	22.35	17.60	27.10
Diesel (*)			
"Short Term", $/BBL	28.44	23.69	33.19
"Long Term", $/BBL	25.59	20.84	30.34
N- Paraffins (f.o.b. USA), $/MT (**)	400	400	400
Wax (f.o.b. USA), $/MT (**)	1300 to 2600	1300 to 2600	1300 to 2600
VHVI Lubes (f.o.b. USA), $/BBL (**)	120	120	120

(*) Based on a diesel premium of $7/BBL for the "Short Term" and $4/BBL for the long term.
(**) The prices of specialty products such as N-Paraffins, Wax and VHVI lubes were kept independent of the WTI price.

The pricing basis for diesel includes a premium estimated at $7/bbl for the "short term" project and $4/bbl for the "long term" project (see Section 7.3.4.3.3).

2.7 ECONOMIC ANALYSIS

Economic analyses were performed to determine the project total installed cost (TIC) and internal rate of return (IRR) based upon licensor provided data. Where licensor information was unavailable, Raytheon used information from published sources, or from its own database, to determine approximate TIC and IRR. Risk and sensitivity analyses were also performed for the selected cases. Details of the economic analyses will be found in Section 10 of this report. The following is a summary of the key economic parameters used to perform risk and sensitivity analyses for the selected cases:

Key Economic Parameters

Project Life: 20 Years.

Depreciation: 10 years, straight line.

Tax: 34 %

100 % Equity Based.

Investment Tax Credit: 10 %

Production in the First Year after commissioning: 75 % Design.

Key Risk & Sensitivity Parameters

Parameter	Base	Low	High
West Texas Intermediate (WTI) Crude Price, $/BBL	**20**	15	25
Diesel Premium, $/BBL			
"Short Term" Case	7	5	9
"Long Term" Case	4	0	7
Natural Gas, $/MMBTU			
Jose	**0.6**	0.6	1.0
Anaco	**0.5**	0.5	0.9
Güiria	**1.0**	0.8	1.0
Total Investment Cost	**100 %**	85 %	120 %
Operating Cost	**100 %**	90 %	110 %

Raytheon used its proprietary **RAYSPONSE™ — GTL** model, customized for this study with available licensor data to perform these analyses. Risk and sensitivity analyses were performed using a pro forma economic analysis model using Palisades "@Risk" software. Site specific TIC conversion factors were developed to convert the U.S.Gulf Coast (USGC) cost to specific Venezuelan sites under consideration.

The following is the summary of the TIC conversion factors developed:

Site	TIC Conversion Factors
Jose	USGC * 1.2
Anaco	USGC * 1.32 + $ 3 MM
Güiria A	USGC * 1.47 + $ 1 MM (Without LNG Plant)
Güiria B	USGC * 1.33 + $ 0.5 MM (With LNG Plant)

The results of the economic analyses for the selected cases are summarized below:

"Short Term" Case	Without Lube Oil Production @ Jose	With Lube Oil Production* @ Jose
Internal Rate of Return	12%	**14%**
Total Installed Cost ($MM)	470	**520**

* When added to the facility after five years.

Based on the risk analyses it was determined that there is a 90 % probability of obtaining 12.9 % or more IRR for the "short term" case with lube production.

The following table summarizes the differences in IRR between the GTL plant with and without lube oil production for the "long term" project:

"Long Term" Case	Without Lube Oil Production @ Jose	With Lube Oil Production @ Jose
Internal Rate of Return	14.5%	**18.4%**
Total Installed Cost ($MM)	1220	**1290**

Based on the risk analyses it was determined that there is a 90 % probability of obtaining 16.8 % or more IRR for the "long term" case with lube production.

THESE ESTIMATED IRRS FOR BOTH "SHORT TERM" AND "LONG TERM" PROJECTS DO NOT TAKE CREDIT FOR ECONOMIC BENEFITS DUE TO POTENTIAL SYNERGY POSSIBILITIES AT THE JOSE SITE.

2.8 RECOMMENDATIONS

Raytheon's recommendations resulting from the study are as follows:

- For the "short term" project, Raytheon recommend that PDVSA only consider the two technologies that have been proven on a commercial scale viz. Sasol and Shell. Based on the market study, the plant should initially produce fuels and linear paraffins. The option for lube production should be considered at a later date. Wax production is not recommended.
- For the "long term" project, Raytheon recommend a re-evaluation of all the available technologies, including PDVSA/Intevep's DISOL, in a few years time due to the rapidly evolving nature of GTL technologies. At the current state-of-the-art, Sasol and Exxon technologies show greater overall advantages over other technologies. Raytheon also recommend that the market forecast be re-confirmed at a future date. Current market forecasts indicate the product mix for the "long term" project should consist of fuels, linear paraffins and lubes.
- Both "short term" and "long term" projects are recommended to be located at Jose.

2.9 STRATEGY OPTIONS

It is recommended that **PDVSA GAS** consider the following strategy options in pursuing the GTL projects.

1. Build the "short term" smaller capacity GTL unit at Jose for production of fuels only. Review options to add-on VHVI lube production. Lube production will improve the project IRR by approximately 4% if implemented at the beginning. Some amount of pre-investment will be required at the design and construction phases.
2. Initiate discussions with third parties for synergies to improve project IRR. **OPTIONS AND OPPORTUNITIES AT THE JOSE SITE ARE EXTENSIVE AND CAN DRAMATICALLY IMPROVE THE PROJECT IRR.** A list of synergy opportunities is provided in Section 6.0 - Site Study.

3. If **PDVSA GAS** concurs with Raytheon that Jose is the best site for the "long term" larger capacity plant, options exist to incrementally expand the capacity of the "short term" plant or phase in the multiple train large capacity plant over a number of years. This will assist cash flow issues and easier penetration of the market at minimum risk.

4. PDVSA/Intevep's DISOL technology, if ready for implementation for the "long term" project, can be reevaluated on a standalone basis or by forming alliances with other F-T technology suppliers.

5. An alternate strategy for PDVSA might be to consider further co-development of the DISOL technology with a third party with strong interest in GTL technology development.

6. Raytheon considers it strategically important for PDVSA to participate in consortiums currently involved in the development of single step Syngas Production, such as ceramic membrane technology. This, coupled with their DISOL technology development program, will secure PDVSA's position in GTL technology.

7. A key strategic option is to consider co-producing GTL products in a refining scenario. Existing refineries at Cardon and at Amuay are good candidates in view of PDVSA's future plans to add fuel hydrocrackers. Co-production of hydrogen and power are options that will add value to such a consideration. A similar strategy option exists for a full distillate heavy oil upgrader at the Jose location.

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3.0 STUDY BASES

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3.1 SCOPE & BASES OF STUDY

At the beginning of the project, PDVSA and Raytheon discussed the Definitive Mission Study Report, TDA-97-Q-91, and agreed to the following overall scope of the study and bases to be used in the course of the study. This section summarizes these issues.

3.1.1 Scope of Study

The scope of this study is limited to the application of Gas-to-Liquid (GTL) technology for conversion of natural gas to liquid products via production of synthesis gas and subsequent conversion of synthesis gas to hydrocarbon products utilizing Fischer-Tropsch reaction technology. Both associated gas and non-associated gas sources are to be evaluated. Specifics of the study scope are:

- Evaluation of gas sources and transportation facilities.
- Assessment of potential sites.
- Determination of target GTL products and prices.
- Analysis of potential markets for the targeted products.
- Evaluation of technology suppliers.
- Economic evaluation of the selected process.
- Sensitivity analysis relative to gas and product prices.
- Synergy possibilities with other projects, current & planned.

3.1.2 Bases of Study

3.1.2.1. Gas Composition

The following gas composition was provided by PDVSA as typical for the purpose of this study irrespective of location.

Table 3.1 **Typical Gas Composition Used for GTL Study**

Component	Mole %
CH_4	80.95
C_2H_6	8.00
C_3H_8	1.50
C_4H_{10}	0.55
C_5+ Paraffins	0.30
Nitrogen	0.20
Carbon Dioxide	8.50
Total	**100.00**
H_2S	10 ppmv

The gas is assumed to have been processed for extraction of propane and heavier components. PDVSA confirmed that treatment of produced gas for LPG recovery, desulfurization and dehydration was not necessary, and therefore, to be excluded from this feasibility study.

3.1.2.2 Supply Pressure and Temperature

Gas supply at the battery limit for all sites is as follows:

Jose : 400 psig (27.6 barg) and ambient temperature

Anaco : 800 psig (55.2 barg) and ambient temperature

Güiria : Not known yet

3.1.2.3 Gas Price

Base price of gas at the battery limit is $0.60 for the Jose site and $0.50 at Anaco and $1.00 per million BTU at Güiria site.

3.1.2.4 Plant Capacity

PDVSA defined "short term" and "long term" capacities as:

"Short term": 100 – 200 MMSCFD (Million Standard Cubic Feet per Day),

"Long term": 500 – 750 MMSCFD.

"Short term" was defined by PDVSA as years 2003 to 2006. "Long term" was defined as the year 2007 and beyond.

3.1.2.5 Potential Sites

PDVSA has selected the following sites for possible location of GTL projects. These are:

Anaco - for associated gas.

Jose - for associated gas.

Güiria - for non-associated gas.

All these sites are located in the eastern part of Venezuela. The rationale for pre-selecting these sites is outlined in Section 6.0 under Site Study.

3.1.2.6 Market Analysis

It was agreed with PDVSA that the market forecast would be limited to the year 2010. The study will limit the market analysis on a global basis and for the Western Hemisphere only. Far East and Pacific Rim markets are to be excluded from the global market analysis.

3.1.2.7 GTL Products

The following GTL products are of interest to PDVSA and will be evaluated in this study:

- LPG
- Linear Paraffins
- Waxes
- Naphtha
- Diesel
- Base Lube Oils
- Kerosene
- Synthetic Crude
- Oxygenated Chemicals (Ethanol, Acetone)

Processing of these products to other derivatives is not part of this study.

3.1.2.8 GTL Technologies

Raytheon, together with PDVSA, pre-screened all the potential licensors of the GTL processes and agreed that the following licensors will be evaluated for the purpose of this study:

Table 3.2 **GTL Technology Licensors**

Technology	Licensor(s)
Entire GTL Plant	Exxon, Shell, Sasol, Syntroleum.
Syngas Production Step	Texaco, Lurgi, Krupp/Uhde.
Fischer-Tropsch Unit	Rentech, PDVSA/Intevep.
Product Work-up Unit	UOP, IFP.

3.1.2.9 Economic Parameters

Tax Rate:	34%
Electricity:	$0.02 per KWH
Raw Water:	$0.52 per cubic meter at Jose
	$0.70 per cubic meter at Anaco

3.1.2.10 Business Approach

PDVSA is having this study conducted to determine the "short and 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" strategies are:

- 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 "long term" strategies are:

- 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, for both "short term" and "long term" projects, will be considered.

3.1.2.11 Synergy Issues

The study will briefly address the following synergy issues:

- Availability of infrastructure to support a GTL facility.
- Possible export/import of syngas to & from Methanol and Ammonia Plants.
- Utilization of tail gas from GTL plant.
- Integration of steam, power, cooling water, hydrogen with other projects.