

**ADVANCES IN GAS TURBINE LOW BTU COMBUSTION THAT ENABLE
INTEGRATION OF POWER AND PROCESS MARKETS.**

**"INTEGRATION OF THE ENERGY MARKETS: A CHALLENGE FOR LATIN
AMERICA AND THE CARIBBEAN"**

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ABSTRACT

The Syntroleum Gas-to-Liquids (GTL) Process provides a unique Process / Power cogeneration opportunity for Latin America and the Caribbean. With this process, indigenous natural gas reserves can be monetized into ultra clean diesel fuel for use in the Latin America and the Caribbean fuels market, thus reducing importance of high sulfur diesel fuel that is harmful to the environment. Additionally, electrical power can be co-generated from the process in two ways. First, an air blown process produces a low Btu tail gas from its Fischer Tropsch reactors that can be used to fuel gas turbines to generate electricity. Second, steam generated from the exothermic Autothermal Reformers and Fischer Tropsch reactors can be used to drive steam turbines to produce electrical power. It should be noted that the low Btu tail gas, when combusted as a fuel in a gas turbine, produces significantly lower NOX emissions than natural gas, and lowers maintenance costs, as well. The integrated approach of a GTL facility combined with an electrical power plant produces a steady stream of GTL clean diesel and a stable supply of electrical power.

This paper will describe the advances in gas turbine technology in recent years that allow the utilization of low Btu fuels in gas turbines for the power generation sector. In particular, the low Btu combustion testing funded by Syntroleum and the equipment now available from two major gas turbine vendors will be discussed. Specific gas turbines well suited for integrating the GTL Process with the Power Sector will be reviewed.

I. INTRODUCTION

In Latin America and the Caribbean seven countries have substantial Natural Gas reserves totaling 269 TCF, (See Figure 1). The pressing question remains, how should this valuable natural resource be best utilized. Natural gas to electrical power is the obvious choice for much of these reserves, however, some Latin America and the Caribbean countries may find that for base load electrical power needs, there is emerging an integrated approach that will meet their needs through Power / Process integration with the Syntroleum GTL Process. This integrated approach is to use natural gas to produce clean synthetic diesel fuels and combust the low Btu “tail gas” in newly developed industrial gas turbines low Btu combustion chambers. With this co-generation approach, a higher valued product of clean diesel fuel, will be developed from the countries natural gas reserves, while electricity produced from the GTL low Btu process gas can be dispatched at rates closer to that of traditional Latin America and the Caribbean hydro-electrical power generation. Latin America and the Caribbean have been suffering through below average rainfall, which has impacted electrical power generation due to the traditional dependence on hydro-electrical power generation. Seasonal drought coupled with an anticipated 5% per year electrical growth per year have accelerated the regions interest in alternates fuels for power, co-generation and distributed generation.⁽¹⁾ Industrial and commercial users must be willing to consider both traditional and non-traditional approaches in meeting this anticipated electrical power demand. Electrical power producers should note that Syntroleum’s air blown Fischer Tropsch process is the only GTL process that produces and utilizes low Btu tail gas and provides this power generation option. (Table 1). The total potential for GTL production in Latin America and the Caribbean is shown in Table 2.

Table 1

Technology Owner	Process	Pilot Plant Experience/ Years of Operation	Scale up Plant BPD
BP	O ₂	Intermittent research in the past	None
Conoco	O ₂	3 pilot plants over the past 10 years; continue to operate two	None
ExxonMobil	O ₂	3 pilot plants over the past 20 years; continue to operate one	300 BPD
Sasol/Chevron	O ₂	5 pilot plants over the past 45 years; continue to operate two	127,000 BPD 22,5000 BPD
Shell	O ₂	5 pilot plants over the past 25 years; continue to operate two	12,500 BPD
Syntroleum	Air	2 pilot plants over the past 10 years; continue to operate one	70 BPD

Table 2

	TCF	Conversion Plants	50 MBPD	25 MBPD	10 MBPD	5 MBPD	Total MBPD
Trinidad	25	3	2		1		110
Venezuela	146	3		3			75
Bolivia	46.8	2	1		1		60
Argentina	25.7	1	1				50
Peru	13.32	2	1		1		60
Brazil	8.0	2	1		1		60
Chile	4.41	1				1	5
Total	269.23	14	6	3	4	1	420

II. SCOPE

The air blown GTL process is extremely versatile and can be configured for land and barge mounted facilities in the 5,000 BPD size range, to 10-15,000 BPD land based or FPSO deep water ships. (See Figure 2 and 3). Larger land based GTL facilities can be designed to be constructed in multiple blocks or modules of 15,000 or 35,000 BPD and in turn generate exothermic energies that can be tapped for power production at the same dispatch rate as hydro-electric power. (See Figure 4). By merging the process and power technologies, Latin America and the Caribbean countries can tap their natural gas resources for ultra clean diesel fuels and clean base load electrical power. This presentation will address the advantages of combining the air blown GTL process with Latin America and the Caribbean immediate power generation needs.

III. WHAT IS AIR BLOWN GTL

The Air blown process, on the other hand, incorporates nitrogen into the process; this is possible because its F-T section has no recycle loop. The one-pass design avoids any build-up of nitrogen in the system, thus allowing the use of nitrogen-diluted syngas without impairing performance. The air blown F-T reactor configuration is comparable in size but less complicated than the comparable systems with recycle because the compressor recycle loop, which must handle and be rated for hydrogen service has been eliminated. (See Figure 5)

IV. WHERE DO GAS TURBINES FIT INTO AIR BLOWN GTL

In the air blown GTL process, most but not all of the nitrogen diluted syngas is converted to Fischer Tropsch products. The unconverted gas exiting the process (tail gas) may have a lower heating value (LHV) as low as 50 Btu/scf. Advances in low and ultra low Btu fuel combustion, in the past four years, now make available commercial gas turbine combustion chambers that will combust this nitrogen laden fuel. It is possible to drive the air blown process in the traditional fashion with steam turbines that can be described as Generation I. However, with the use of the low Btu combustion gas turbine can be integrated into the air blown GTL process. (See Figure 6); This configuration is called Generation II.

The concept is not to use valuable CH₄ natural gas to drive air for the process, but rather save that methane for conversion into a valuable salable clean diesel fuel. As the Btu/Scf of the tail gas goes lower increased operational costs savings are realized for the air blown process. (See Figure 7)

V. GAS TURBINE REQUIREMENTS IN GTL

The advent of economical GTL conversion promises to create significant requirements for plant equipment and machinery. In the air blown process, one of the key components in most applications is a gas turbine (Table 3). The size of the emerging market is difficult to project at this early stage, but the potential is quite large.

Table 3

Machine Class		Plant Size	
HP	MW	Min. BPD	Max. BPD
25,000+	15+	5,000	10,000
75,000+	50+	10,000	20,000
150,000+	100+	20,000	30,000

Latin America and the Caribbean are poised on the threshold of developing an estimated 269 TCF natural gas reserves and certainly GTL will be a prime candidate in its development. With each separate reserve in Latin America and the Caribbean being a varying size, these fields offer the potential for more than 14 conversion plants in the capacity range of 5,000 to 50,000 BPD of synthetic fuels. For the air blown process this translates to a requirement for nearly 27 industrial gas turbines of varying sizes to accommodate the array of GTL plant sizes. (See Table 4). Not all of these fields will be developed and, of those that are, not all will become GTL sites. Nevertheless, the projects announced and those known to be on the drawing boards already point to a significant market opportunity for equipment vendors to support this new emerging technology.

Table 4

Turbines by Class					
	50 MBPD	25 MBPD	10 MBPD	5 MBPD	Total
17MW				1	1
25MW			8		8
75MW		6			6
100MW	12				12
				Total	27

? INDUSTRIAL GT

For the most part industrial gas turbines hold the most promise for application in the air blown GTL process. In the larger GTL facilities 100 – 120 MW class D or E gas turbines will be incorporated into the design. The reason for this is that they have the ability to have their combustion systems converted into low Btu configuration with the least

amount of re-engineering. Single shaft industrials can be configured in mechanical drive, electrical drive, or combination configurations.

? **LOW BTU COMBUSTION BURNERS**

Gas turbines have been used for many years in IGCC process applications in steel mills with blast furnace gas or process pet-coke application. These gas turbines are designed with larger than normal combustion chambers that are needed to combust this high volume low Btu "tail gas".

? **GAS TURBINES AIR EXTRACTION CAPABILITY**

Of the total airflow going into the gas turbine, a portion of compressed air may be able to be extracted for combined process feed air. It is obvious that using gas turbines as mechanical drives for axial air compressors assist greatly in starting the air blown facility, however, an alternate advantage of extracting air from the gas turbine allows for additional volume of low Btu tail gas to be used in the gas turbine. In this fashion the fuel itself begins acting as power augmentation (PAG) even in extremely warm climates. Some gas turbine vendors will limit the use of the gas turbine inlet guide valves (IGV), thus reducing the mass flow into the gas turbine and making more room for the low Btu fuel to enter the combustion chamber. Use of air extraction from the gas turbine axial air compressor in effect incorporates the gas turbine into the process and adds an extra dimension to the controls of the process gas turbine.

? **MECHANICAL DRIVES FOR PROCESS**

Not all gas turbine vendors have adapted their product lines into process application that incorporate large amounts of air to be extracted from the gas turbine compressor case. In these cases axial air compressors driven by gas turbines can reach the 70-80 MW size range. With the goal of selecting equipment that is "off the shelf", it is less capital intensive to use existing axial compressors over developing special "process" gas turbines initially. (See Figure 8)

? **POWER GENERATION DRIVE TRAINS**

Some industrial gas turbine vendors may not have mechanical driven axial air compressors in their inventory and may not have commercial associations with the traditionally steam turbine driven compressor vendors. In the case of smaller GTL facilities one might consider producing electricity with the gas turbine combusting low Btu fuel and then some of that electricity is used to drive electrical motors that in-turn drive axial air compression for the GTL process. Electrical motors above 20 MW will require special attention to design and application due to the difficulty in start-up. (See Figure 9)

VI. GTL BY-PRODUCTS OF INTEREST TO THE POWER SECTOR

The air blown Fischer-Tropsch reactor will produce the following:

- ? **MEDIUM PRESSURE STEAM PRODUCTION**
- ? **NAPHTHA (C1-C5)**
- ? **SYN CRUDE C6-C20**
- ? **SYN CRUDE WAX C21-C60**
- ? **LOW BTU TAIL GAS**

The medium pressure steam created from the exothermic reaction is a source of efficient power for power generation and mechanical drives in the power / process sector. Naphtha that is a by-product of the Fischer-Tropsch reactor can be stored on site and burned as fuel burns, peak electrical power periods in specially configured naphtha burning combustion chambers in a power generation gas turbine. (See Figure 10)
Low Btu “tail gas” will be sent a short distance to the nearby co-generating power plant for base load power generation 24 hours a day.

VII. INTEGRATION OF TECHNOLOGY ISSUES

It will be through Integration of the power and process sector that Latin America and the Caribbean will receive the optimum benefit from their domestic natural gas resources. Traditionally these two sectors have seldom integrated and little is known of the others potential. Diverse companies that have experience in bridging these sectors will be pivotal in successfully merging the two technologies for Latin America and the Caribbean. The air blown GTL facility will be located in close proximity to the integrated power plant and the GTL facility will send low Btu fuel, steam and naphtha to the power plant and in turn the power plant will send boiler feed water and electricity back to the GTL plant. Creative commercial terms will be generated in order to make co-generation between these two sectors financially mutually beneficial.

With regard to the gas turbines operations and maintenance costs will be greatly reduced for the expensive hot gas path parts time between overhauls (TBO). This will be the case due to the low firing temperature found when a gas turbine is operating on low Btu “tail gas”. Turbine Inlet Temperatures will be in the 1500 to 1800 Deg F temperature range at full rated power. Since the gas turbine will be fired in sub D and E class temperatures the more expensive F and H class gas turbines will not be needed for comparable heat rates.

VIII. LOW BTU COMBUSTION TECHNOLOGY ADVANCES

Advances in alternate fuel have taken on greater interest in the power sector due to the high cost of natural gas pricing in year 2001. Low Btu fuel from a Fischer-Tropsch reactor qualifies as an alternate fuel and has been under serious development by Syntroleum in order to improve the Air Blown process economics to its optimum level. Medium Btu fuels have been used successfully in IGCC Blast furnace and Pet Coke applications in the past ten years. Pushing the envelope of low Btu fuel is relatively new development in the past four years. And the development of ultra low Btu fuels is an advance theoretically possible in the next five years of additional combustion research. (See Table 5)

Table 5

MEDIUM BTU FUELS	~ 120-350 Btu/Scf
LOW BTU FUELS	~ 80-120 Btu/Scf
ULTRA LOW BTU FUELS	~ 40-80 Btu/Scf

IX. AIR BLOWN LOW BTU FUEL TESTING

In 1997, Syntroleum entered into a Joint Development Agreement with Marathon Oil to develop a low Btu combustor for gas turbines. A Kawasaki M1A13A 1.5 MW gas turbine was retrofitted with a low Btu combustion system that was specifically designed for the air blown low Btu from the Syntroleum process. During a series of increasingly successful hardware modifications, it was technically proven that tail gas of 55- 90 Btu/Scf could be successfully combusted in a gas turbine. Based on this technical advance two major gas turbine vendors launched into test programs that would incorporate these findings into their existing medium Btu IGCC combustion systems. Please note Table 6 below:

Table 6

KAWASAKI	1998	SYN/MARATHON
ALSTOM	1999	ASME 2001-GT-4
GE	1999 to 2000	SYN/GE Test

The combustion region of low Btu tail gas is of great interest as to where the actual lowest limits exist for these fuel mixtures to be commercially applied in an air blown process.

In January 1999, Syntroleum and General Electric entered into an agreement to design, fabricate and test a GE gas turbine combustor on low Btu fuels similar to the tail gas produced in the Syntroleum Process. Eight individual low Btu combustion tests were conducted by GE at their Schenectady, NY, combustion test facilities. The successful tests were concluded in 2000. These low Btu combustion systems are available for the Frame (9E, 7EA and the PGT10) gas turbines. In the future it is hoped that the Frame 5 and 6 will be added to the list of low Btu Combustion engines. (See Figure 11)

X. GAS TURBINE AVAILABLE TODAY FOR GTL FLEET SERVICE

Over the past four years low Btu combustion chambers have been developed not only by GE but also by Alstom as well. The following table illustrates the Model numbers and vendors that offer gas turbines suitable in combusting low Btu tail gas from the air blown Fischer-Tropsch process. (See Table 7)

Table 7

Model	Rating	Vendor
FRAME9E	123 MW	GENERAL ELECTRIC
FRAME7EA	85 MW	GENERAL ELECTRIC
PGT10B	10MW	GENERAL ELECTRIC
GT11N2	120MW	ALSTOM

XI. POTENTIAL GT FOR GTL SMALL PLANTS

Once the market is fully realized gas turbine vendors have confided that these additional gas turbines and others maybe suitable for retrofit into low Btu combustion service for the air blown GTL process. (See Table 8)

Table 8

Model	Rating	Vendor
GT8C2	52MW	ALSTOM
GTX100	43MW	ALSTOM
GT10	24MW	ALSTOM
GT35C	17MW	ALSTOM
CYCLONE	12MW	ALSTOM

XII. NOX EMISSION REDUCTION

One of the best environmental consequences of combusting air blown low Btu tail gas in a gas turbine is the fact that the GT exhaust emissions will be extremely environmentally friendly. Sulfur in the low Btu tail gas fuel will be non-existent because it has been removed before it enters the process; therefore, hot corrosion issues will be greatly reduced in the areas of maintenance and time between overhauls. NOTE: When a standard gas turbine combusts methane the combustion chamber firing temperature reaches 4,000 + Deg F. NOX formation in an industrial gas turbine burning methane is in the 50-60 PPM for a standard burner and 25 PPM for DLN technology. In the air blown GTL process the firing temperature of the low Btu tail gas is well below 2,600°F Deg F where NOX begins forming. In repeated tests conducted by Syntroleum with the GE and single digit NOX was observed, i.e. (3-5 PPM). (See Figure 12)

XIII. WORLD WIDE COMODITY TRADING NOX CREDITS

Even though the Kyoto Protocol has had difficulty in being ratified by many of the countries in attendance and the Bonn Accord has attempted to address the issue of environmental “credits” between nations. These so called “carbon sinks,” regions of heavy vegetation that absorb CO2 are to be added to the equation. In the case of the newly emerging air blown GTL facilities, which have extremely low emissions, may qualify for similar emission credits that may be able to be traded as a commodity.⁽²⁾

XIV. GTL TAIL GAS AND ITS PAG CHARACTERISTIC

As a gas turbine is converted to low Btu fuel, another interesting benefit is the effect that the high volume fuel has on the performance of the gas turbine in warm climates, above ISO conditions. Warm and hot operating conditions present a de-rating of a normal industrial gas turbine due to the reduction of mass flow to the gas turbine compressor and also due to the effect of increased ambient temperature with regards to (TIT) turbine inlet temperature limits. As long as the fuel has enough oxygen to burn the low Btu tail gas, the gas turbine no longer needs to rely solely on the GT compressor for mass flow to sustain the rated power of the GT expander section. In the case of low Btu combustion, the extra mass of the nitrogen that accompanies the fuel provides power augmentation (PAG) to the gas turbine.

Example: A 100MW Industrial Gas Turbine would normally be de-rated about 25% in a hot 120 Deg F ambient condition to 75MW, but that same gas turbine reconfigured to low Btu operation would produce the same ISO+ 100MW of rated power due to the PAG (power augmentation) effect of the low Btu fuel. (See Figure 13)

XI. BASIC MODULAR DESIGN WITH FLEXIBILITY IN GTL DESIGN TO CUSTOM DESIGN AND OPTIMIZE FOR POWER PRODUCTION OR CLEAN FUELS PRODUCTION

By approaching a GTL plant design using steam turbines it is relatively easy to meet the desired size of the facility by scaling and customizing the steam system to meet the design point. With gas turbines the reverse is true, in that once the gas turbine and corresponding low Btu combustion chamber is selected the size of the air blown GTL facility is determined by that selection. Gas turbines come in set sizes and cannot be scaled to fit the need as a steam turbine system can. This allows the air blown GTL facility to be constructed in modular blocks of :

- ? 5-15,000 BPD
- ? 10-30,000 BPD
- ? 20-60,000 BPD
- ? 60-180,000 BPD

XV. TYPICAL LATIN AMERICA AND THE CARRIBBEANN CANDIDATE PROJECT CONFIGURATION

As the Fischer- Tropsch GTL industry is first developed in Latin America and the Caribbean, smaller plants in the 5,000 BPD to 10,000 BPD are envisioned in order to initially meet domestic needs of that nation; however, it is very conceivable that shortly thereafter a new period will begin where much larger facilities will be developed for export to larger North American or European markets. Where the integration of the power and process sectors take place, Latin America and the Caribbean will prosper in both markets with reduced operating costs for the energy that Latin America and the Caribbean is so much in need of in order to reach their true potential in the domestic and world market.

XVII. CONCLUSION

With the implementation of new air blown GTL technologies with traditional power generation technologies, Latin America and the Caribbean can become a leader in technology integration. This integration will lower the capital and operation costs to the traditional power project approach for the benefit of all Latin America and the Carib bean nations.

(1) Diesel & gas Turbine Worldwide July/August 2001

(2) World Fuels News 2001

Latin American and Caribbean Natural Gas Reserves



Figure 1



Figure 2

Barge Mounted Plant



Figure 3 FPSO



Figure 4 Sweetwater

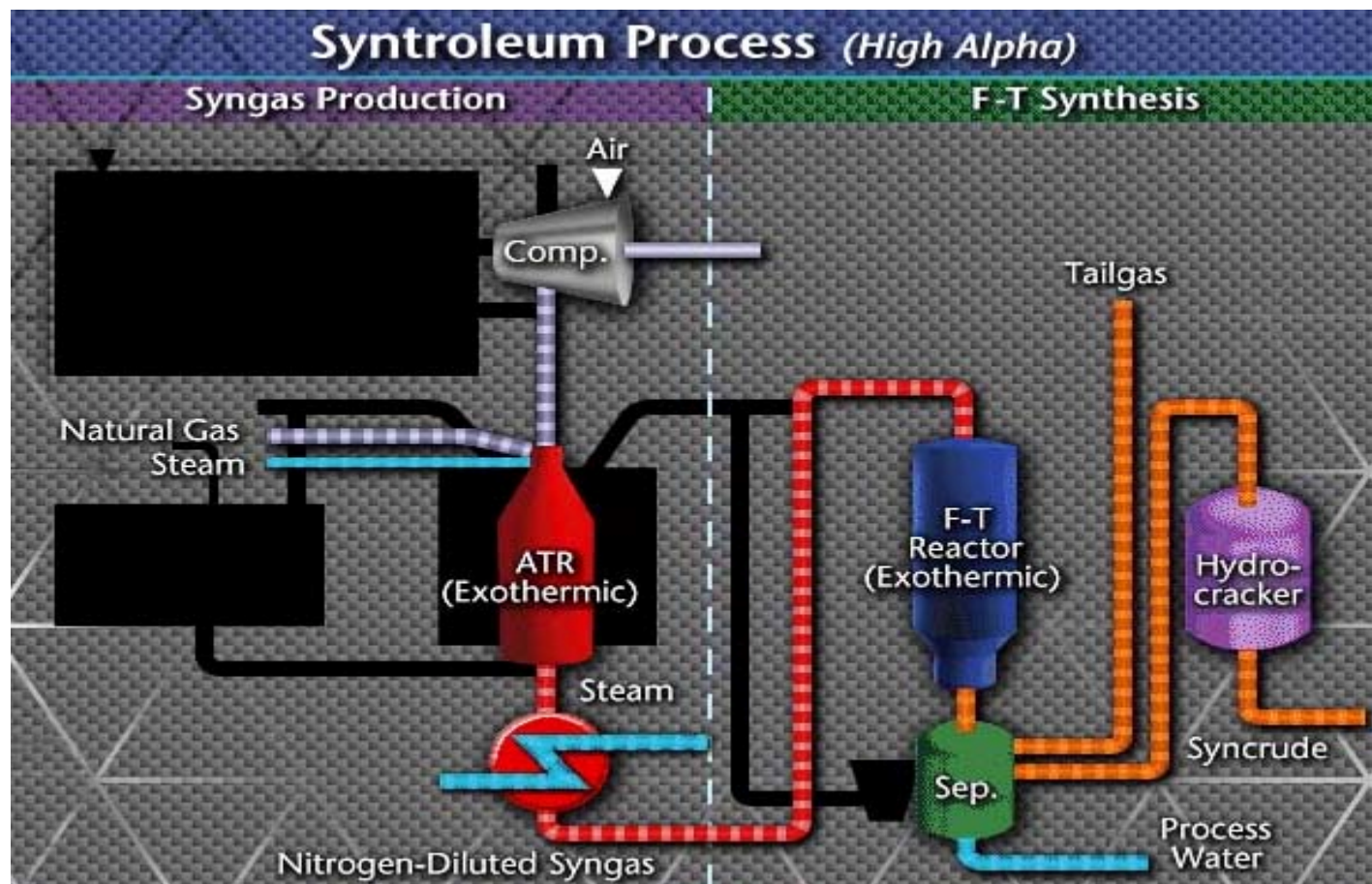
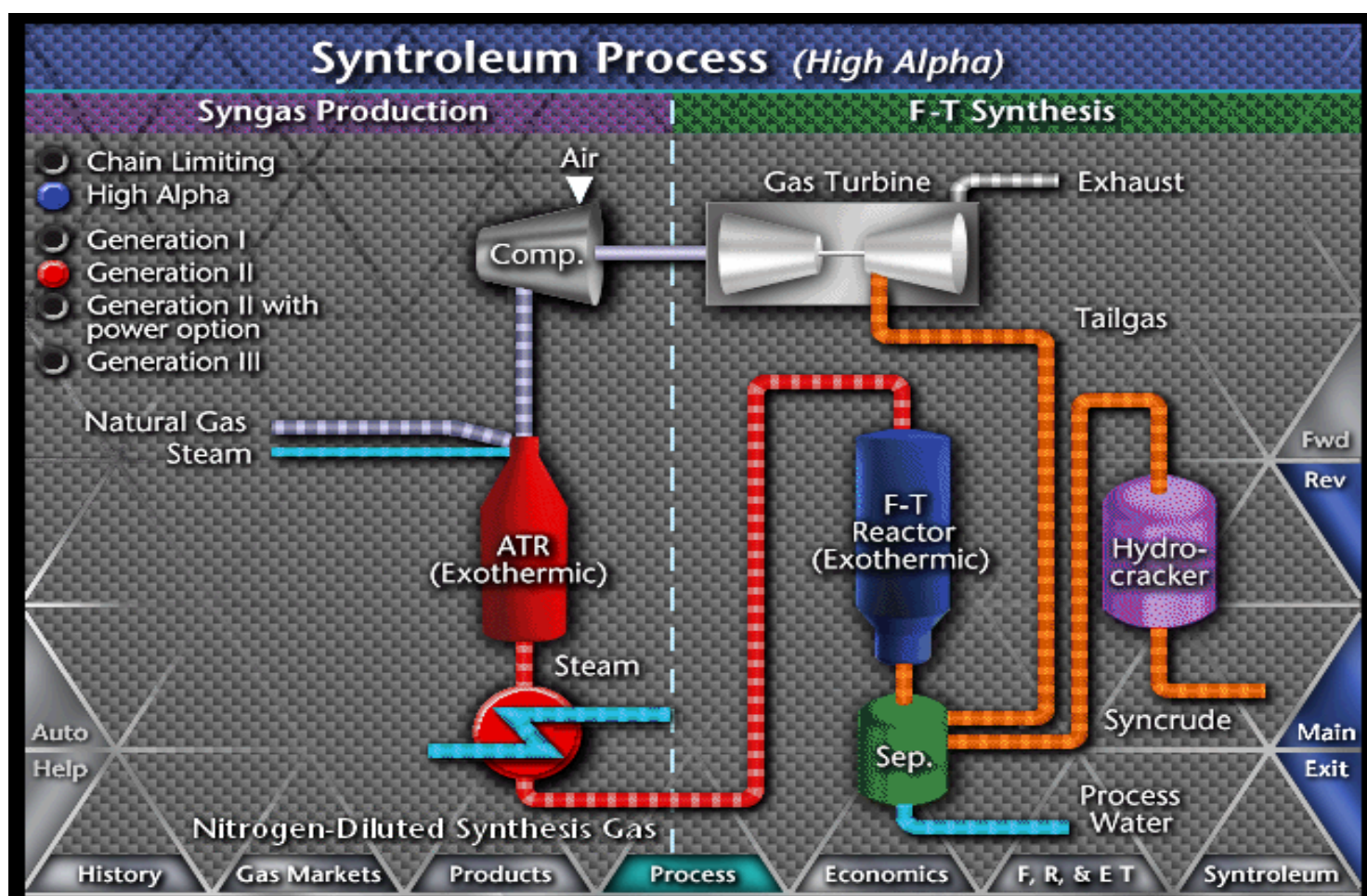


Figure 5 and 6



Gas Turbine Fuel Net Heating Value Vs F-T Liquids Production

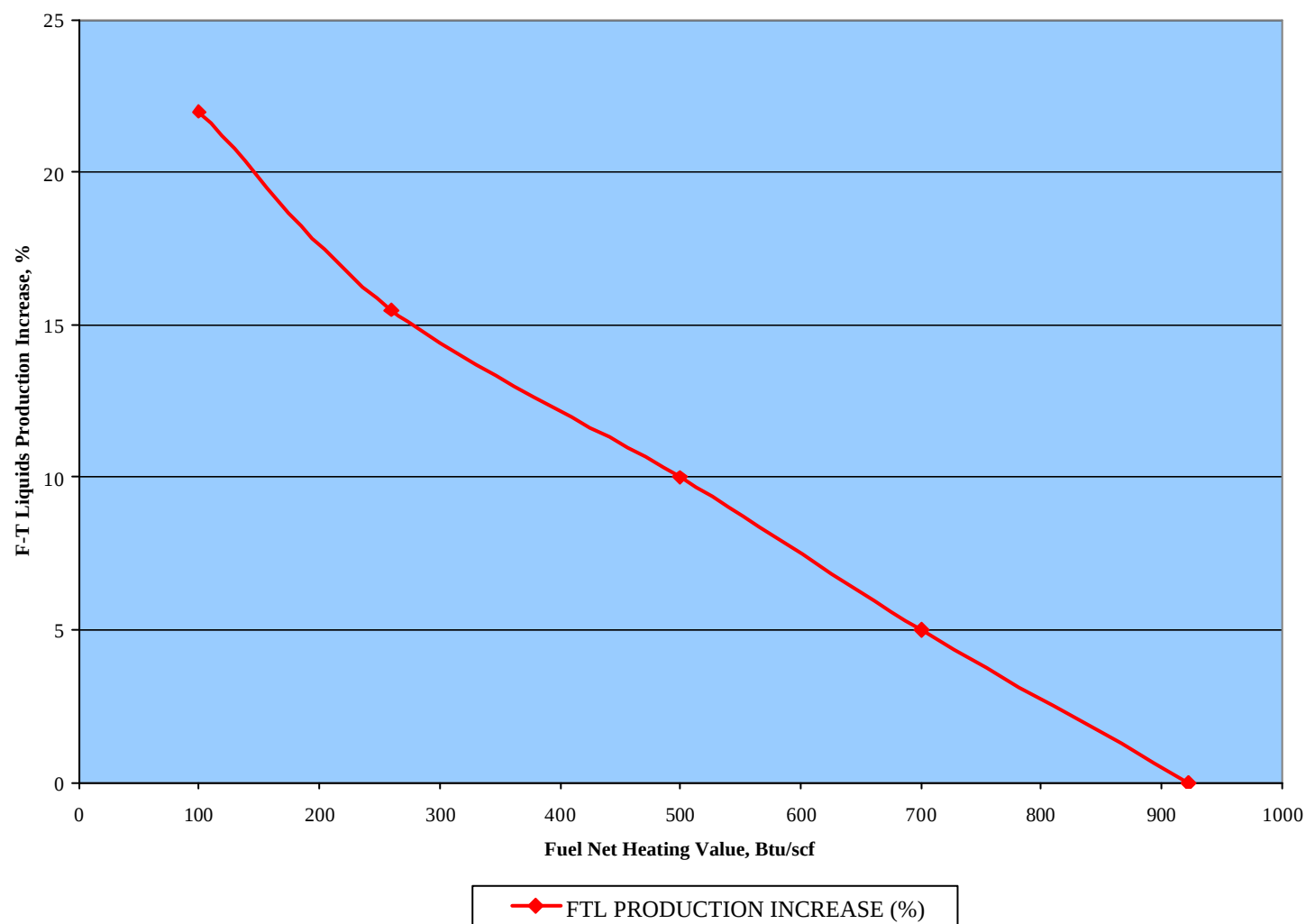


Figure 7



Syncrude Molecular Distribution

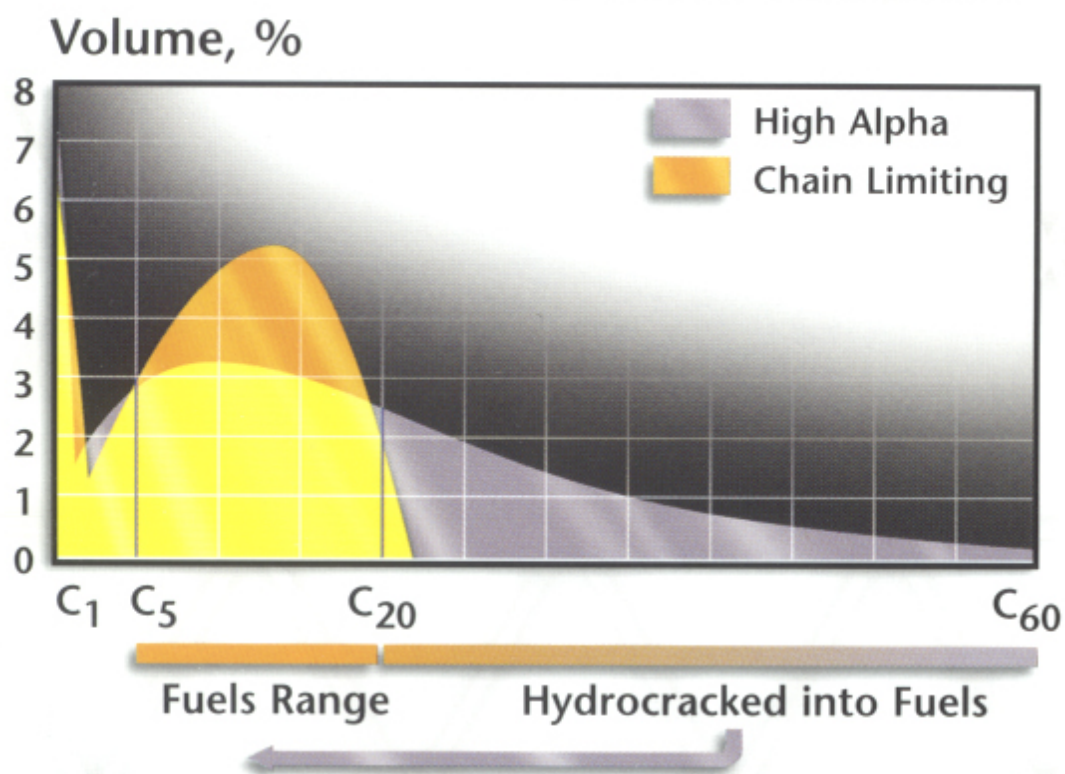


Figure 10

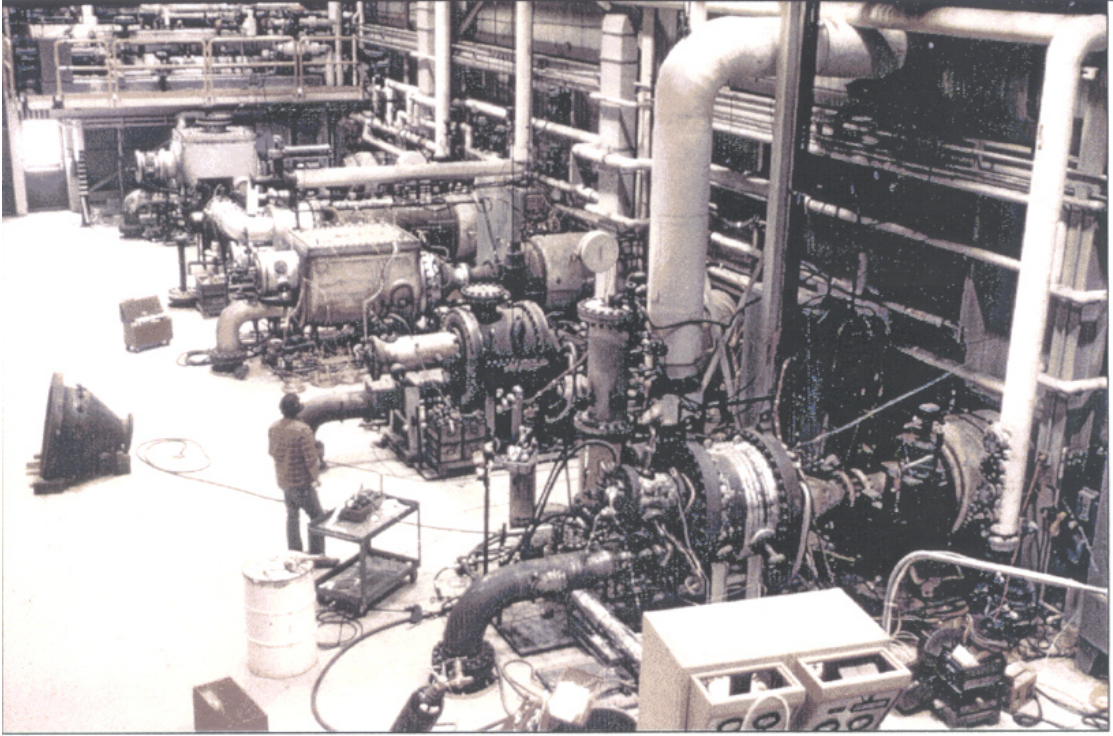


Figure 11 GE PGE Combustion Laboratory

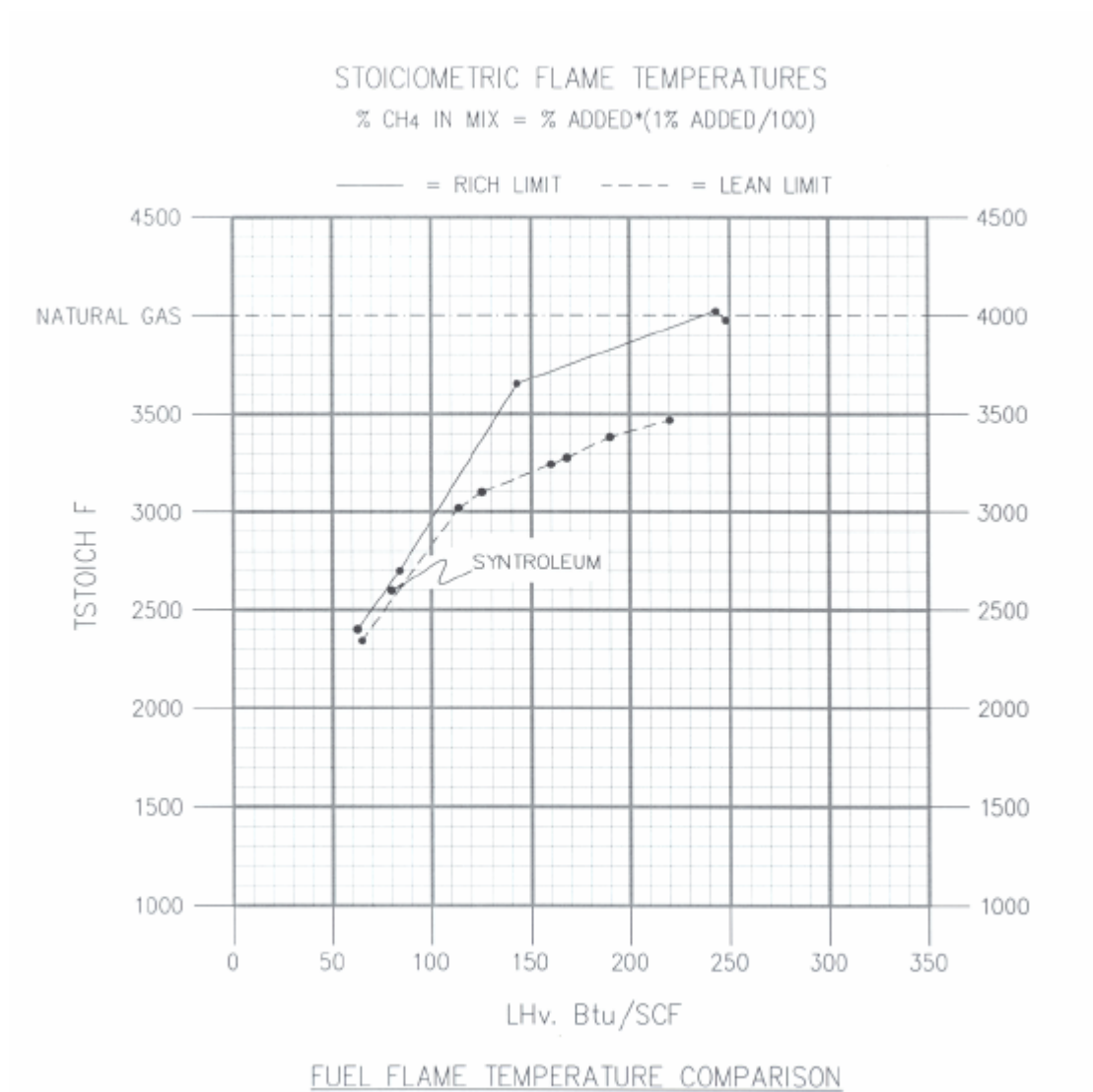
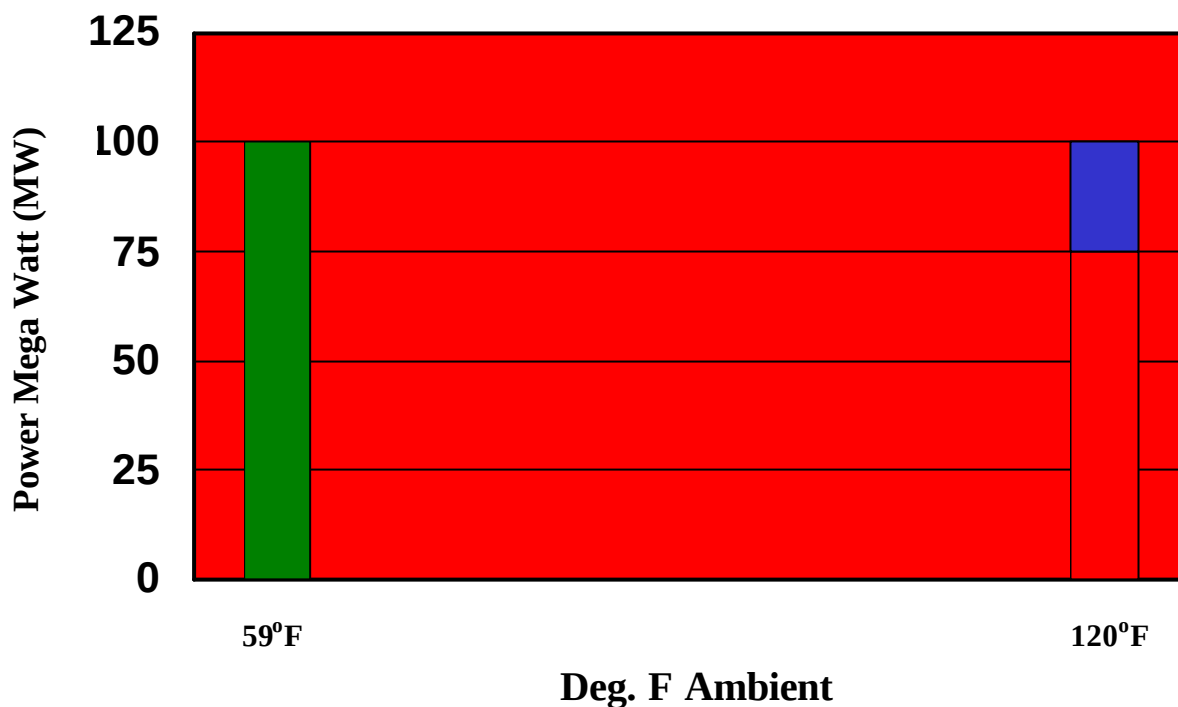


Figure 12



- 100MW Gas Turbine @ 59°F
- 100MW Gas Turbine Derated to 75MW @ 120°F inlet temperature
- 100MW Gas Turbine operating on low BTU fuel as power augmentation back to ISO 59°F power rating

Figure 13