Economics of secondary energy from GTL regarding natural gas reserves of Bolivia

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Abstract

This work aims the economics and the viability of Natural Gas Industrialization in Bolivia, by producing secondary fuels like gas to liquid (GTL)-diesel from natural gas (cleaner than the oil by-product), looking for a clean development with that environmentally well energy using this GTL process. Bolivia has resources that could fulfill these secondary energy resources from GTL. It is possible to process 30 MCMpd of gas obtaining profits from the gas and also from the liquid hydrocarbons that are found in it. Then the Bolivian GTL would present the following advantages: it would export diesel and/or gasoline and would not have to import it anymore.; the exportations of GTL-FT would reach 35 Mbpy, acquiring competitive prices; it would increase productive jobs not only due to the GTL itself, but also from secondary economy linked to GTL market; the use of GTL-FT diesel would bring a “cleaner” environment especially in the urban areas; finally, from the macroeconomic perspective, the investment in the plant construction and supporting works would generate a great amount of job offers.

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1. Introduction

The objective of this work is the technical and economical analysis of secondary fuels from hydrocarbons in order to identify the possibility of manufacturing the Bolivian Natural Gas using gas to liquid (GTL) to produce by-products. Technically and economically speaking, it is important to identify the industrialization, technology investment amounts and production costs of a GTL project. Commercially speaking, the aim is to identify the current and future situations of GTL in the market and what that represents. From the economic point of view, the intention is to determine the financial issues (amounts, interest fees, benefit periods) linked to investments in GTL. Juridically and politically speaking, the present legal situation will be compared to the most appropriate regulatory issues related to the GTL process (SIRESE, 2005).

1.1. Natural Gas Industry outlook in Bolivia

To understand some basic information it is necessary to establish some quantitative and geographic elements consolidated in 2002. In this way, it is good to begin by indicating that Bolivia has an area of 1,098,051 km² and a population of 8,822,197 (MDE, 2002). Fig. 1 shows the geographic situation of Bolivia.

Bolivia has abundant natural resources, especially water and hydrocarbons (Udaeta et al., 2001); there are also bio-energy resources used domestically, as firewood. Because of the Bolivian position in the regional context, the country has become the articulator of the main activities in energetic integration. The Gross Domestic Product (GDP) reached US$ 7.79 billion in 2002: an annual rising of 2.75% (in 2003 this was of 2.45%). The electric sector
was responsible for a share of 2.04% in 2002, its highest level in the last years.

Bolivia is in transition, a phase that implicates in little or no evolution in the Bolivian Energy Industry (EI). In the beginning of 2004, Bolivia presented some sociopolitical problems, which define the country’s present stability and its future development which is strongly connected to the Bolivian EI. These problems were: the government had to consult the people’s opinion in the so called linking referendum (referendum vinculante), about the issue of natural gas (NG) exportation to Chile; the government had to reform the hydrocarbon’s law, solve the nationalization problem, and reconstruct the estate oil enterprise YPFB’s (Yacimientos Petrolíferos Fiscales Bolivianos); finally the constitutional assembly had to establish a new Bolivian State’s Political Constitution. It is important to mention that this whole process, which took place in 2004, has reached its peak socio-politically due to the effectiveness of the current Bolivian government, which was headed by Carlos Mesa. Mesa is former Bolivian Vice-President, who was in charge since October of 2003, after Gonzalo Sanchez de Lozada’s resignation and who presented his resignation in June of 2005.

In 2004, the hydrocarbon’s sector presented an unstable scenario for a short time, which led to a low trust rate (2005 presented the same performance). Under these circumstances, the capacity of exporting NG to Brazil had reached (until October, 2005) 28 million m³ per day and there was also an agreement for NG exportation to Argentina. In these sense, it is good to mention that the so-called Pacific liquefied natural gas (LNG) had been forgotten since the end of 2003. Internally, the distribution system is being expanded as a part of the government’s policy to increase the use of NG. The sector regulation has a good experience and does not present bigger problems, but improvements; problems could be foreseen due to the

![Bolivian geographic location](image)
fact that NG is one of the factors that hold the dynamic sociopolitical situation in the Bolivian countryside. The reformulation and restrictions to the Bolivian exportation model always depends on the NG and its great reserves (SH, 2005).

As 2003 went by, the development of energetic activity as an industry brought direct effects on the complex sociopolitical activity, affecting the country’s economic status. Despite the fact that the official circles still agree with consistent information, it is possible to assure that minimum investments have been made, and that the LNG exportation to the USA has been almost forgotten (as was above mentioned). It is important to mention that the project of LNG exportation to USA was considered the most important solution to bringing development to the country until then. Also in the same year, more specifically in October, the sociopolitical dynamics led to the resignation of the former president, Gonzalo Sanchez de Lozada, starting socioeconomic instabilities all over the country. Because of this, 2003 was a negative period to the energetic sector. Still, a big amount of NG enterprises are pending, as they need great expenditure (exportation to other countries, thermoelectric and petrochemical plants, GTL projects and others).

The hydrocarbons’ exploration in 2003 has been the smallest in the past six years. Not surprisingly, the Gas production has slightly grown. In this way, the NG was the most exported product in Bolivia in 2003. The NG selling brought a 381.1 million dollars profit, passing that of soya bean (336.5 million dollars). It is important to mention that in 2002 the profit that came from the gas was of 226.2 million. Even more, in 2003, as the reserves of 54.9 TCF were made official. It is also known that Bolivia exported in that year a daily average of 14 million m$^3$ of NG to Brazil. In 2005 the gas exportation was increased, not only due to the increase of the Brazilian demand but also due to exportation to Argentina. It is important to bring up that, despite it all, Bolivia had a record of 1.648 billion dollars in exportations in 2005, which consists in taking the gas, by means of a pipeline, to a port where it will be cooled down to temperatures of −161 °C. At this temperature, methane is transformed, 1

1.2. Basics of gas to liquids (GTLs)

In order to illustrate the industrialization of the Bolivian Gas, firstly it is required to know its chemical composition, which, generally, has a majority of methane. Table 1 and Fig. 3 show the composition of the gas exported to Brazil.

From this consideration, thinking about the relatively great Bolivian proven gas reserves (49 Tcfs in 2005), it is possible to identify three great applications to the NG: (a) NG for energy needs; (b) gas-chemical (traditionally knowing as petrochemical) industry development; and (c) methane raw material industrialization (International Forum, 2003).

1.2.1. Gas as energy source

The hydrocarbons that are part of the NG, methane, ethane, propane, butane, etc., are good combustibles. When mixed with the oxygen in the air, they burn perfectly, generating thermal energy, carbon dioxide and water. In comparison to other fossil fuels, such as carbon and oil derivates, the NG:

- Generates less carbon dioxide and practically no sulfur oxides.
- Generates less carbon dioxide due to its relatively higher percentage of hydrogen, which, when burnt, produces water that can be used in agriculture or industries.

In the light of the above evidences, it is considered a friendly and cleaner fuel relative to the any other fossil fuels, preferred by the electricity generation industry, in residential nets and in the Bolivian industrial park.

To make use of the qualities of the Gas as an energy resource, it has been developed in Bolivia future policy actions, to attend internal and external requirements, like:

- 250,000 residential gas interconnections;
- 70,000 vehicle transformations, from gasoline to compressed natural gas (CNG);
- Electricity generation by thermoelectric plants.

The Gas exportation to Brazil and Argentina. These projects, known by most of the Bolivians, nowadays are fully functional;

The LNG project, of NG exportation in liquid form, which consists in taking the gas, by means of a pipeline, to a port where it will be cooled down to temperatures of −161 °C. At this temperature, methane is transformed, from gas to liquid. This change in physical state helps in the oversea transportation, once the substance in the liquid state has a volume 600 times smaller than in the gaseous state. When it gets to the centers of consumption, it is degasified and distributed.

1.2.2. Fundamentals for a gas-chemical in bolivia

The hydrocarbons that come with methane in the NG, such as ethane, propane and butane (n-butanex and iso-butane), could be applied in by-product production, by
means of a traditional petrochemical, because this industry uses, among others, the same hydrocarbons above, however, those are obtained in the extraction of crude oil (the propane and the butane condensed are named generically as LPG, “Liquefied Petroleum Gas”), which is distributed in flagons to residential consumption. Fig. 3 presents a summarized diagram with the processes and some of the products associated to the traditional petrochemical industry, of crude oil refinement.

<table>
<thead>
<tr>
<th>Main components</th>
<th>Chemical formula</th>
<th>Number of carbons in hydrocarbon structure</th>
<th>Percentage in volume (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>1</td>
<td>89.10</td>
</tr>
<tr>
<td>Ethane</td>
<td>C₂H₆</td>
<td>2</td>
<td>5.83</td>
</tr>
<tr>
<td>Propane</td>
<td>C₃H₈</td>
<td>3</td>
<td>1.88</td>
</tr>
<tr>
<td>Butanes</td>
<td>C₄H₁₀</td>
<td>4</td>
<td>0.74</td>
</tr>
<tr>
<td>Pentanes</td>
<td>C₅H₁₂</td>
<td>5</td>
<td>0.23</td>
</tr>
<tr>
<td>Hexanes</td>
<td>C₆H₁₄</td>
<td>6</td>
<td>0.11</td>
</tr>
</tbody>
</table>


Particularly, the area within the dotted line in Fig. 3 is associated to the petrochemical (gas-chemical), based specially in the transformation of ethane, propane and butane that come from the crude oil refinement, in a process called “steam cracking”. This process allows obtaining oils, such as ethylene and propylene, from which is possible to get, for example, polypropylene and polyethylene, plastic materials highly used and known (Kinn, 2004).

In a similar way ethane, propane and butane, companions of methane that come within the Bolivian NG, can be applied in the traditional petro-chemical processes, here named gas-chemical. However, since the mentioned companions are found in low quantities in Bolivian most important Gas reserves, it is concluded that only the massive exportation of the methane will allow obtaining sufficient quantities of the above named “liquids of natural gas” to generate a gas-chemical industry in the country.

In summary, the creation of a gas-chemical in Bolivia depends on the LNG project, since this is a project of massive exportation of methane, and, with that, it will be possible to dispose of great amounts of liquids from NG and then develop a Bolivian gas-chemical industry.
1.2.3. The CH$_4$ industrialization

Considering that the previous themes have been widely discussed, it is possible to imagine a third topic of discussion, the methane industrialization as a petrochemical (gas-chemical) and energetic strategy to build the industrialization of the country. As the Bolivian NG, in the most important gas fields, is mostly constituted of methane, it is important to talk about the methane industrialization, and, onto this basis, the other components that come with it (GTL, GTO, GTM, etc.).

2. Viability of the GTL in the Bolivian NG

The first stage in the industrialization of methane is to obtain the syngas. The synthesis gas is a mixture of carbon monoxide and hydrogen, obtained from chemical reactions of methane with substances easily found in nature, such as carbon dioxide, oxygen and water. As its name shows, the synthesis gas is the basis to synthesize many compounds that are important both economically and industrially. Depending on the desired compounds, the synthesis gas is prepared with different proportions of carbon monoxide and hydrogen, as shown in Table 2.

2.1. The synthesis gas as vector for secondary fuels

From the reaction of the components of the syngas (synthesis gas), using different catalysts, many products can be made (see Figs. 4 and 5); among the most important products, depending on the proportion of carbon monoxide/hydrogen in the syngas, it is possible to have:

- LPG, petrol, diesel, jet fuel and ultra pure paraffin, all of those with the Fischer–Tropsch process. The NG transformation to the products above, all liquid, is denominated GTLs process.
- Hydrogen, denominated the Combustible of the Future.
- Ammonia, basis of the fertilizing industry, which is the product of the reaction of the nitrogen in the air with hydrogen from the methane.
- Dimethyl ether, substitute to diesel and LPG, which can also be used in the electricity industry.
- Methanol, from which is possible to synthesize olefins, such as ethylene and propylene, and, from these, the products in Fig. 4 (industrialization of the NG).

3. By-Products of a GTL for the Bolivian Gas

First of all, it is necessary to consider these general aspects:

- The technology;
- The present and future markets;
- The possibility of getting to these markets;
- The amount of investments;
- The advantages;

As an example, to obtain a synthesis gas in which the carbon monoxide and hydrogenate are in a proportion from 1 to 2, respectively, a partial combustion of the methane with the oxygen of the air is made, reaction that in addition generates considerable amounts of thermal energy.

Table 2

<table>
<thead>
<tr>
<th>Reacting compounds</th>
<th>Chemical reactions (under adequate conditions of pressure and temperature)</th>
<th>Proportion (mol to mol) of carbon monoxide and hydrogen in syngas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane with carbon dioxide</td>
<td>CH$_4$ + CO$_2$ → 2CO + 2H$_2$</td>
<td>1:1</td>
</tr>
<tr>
<td>Methane with air oxygen</td>
<td>2CH$_4$ + O$_2$ → 2CO + 4H$_2$</td>
<td>1:2</td>
</tr>
<tr>
<td>Methane with water</td>
<td>CH$_4$ + H$_2$O → CO + 3H$_2$</td>
<td>1:3</td>
</tr>
</tbody>
</table>

As an example, to obtain a synthesis gas in which the carbon monoxide and hydrogenate are in a proportion from 1 to 2, respectively, a partial combustion of the methane with the oxygen of the air is made, reaction that in addition generates considerable amounts of thermal energy.
And the specifically Bolivian aspects, such as:

- Benefits to the country and areas of production;
- Mediterranean Climate;
- Juridical security.

Considering all the general and specific aspects mentioned above, it is necessary to decide carefully the best industrialization route to be taken.

The following text analyses the possibility of developing in Bolivia the gas to liquids (GTL) project, based on the Fischer Tropsch (FT) process. The aim is to obtain synthesis gas (syngas) from the partial combustion of methane with the oxygen in the air. The resulting synthesis gas would be transformed in liquid combustibles of massive use, such as gasoline, diesel and jet fuel; even more, with the same process, it is possible to obtain lubricants, mineral oils and solid paraffin, also of massive use.

3.1. Gas to Liquid in the Fischer-Tropsch process

The transformation of the Syngas to liquid hydrocarbons was discovered in 1923 by the German chemists, Hans Fischer and Franz Tropsch.

Mixture \( (CO + H) \rightarrow \text{Liquid hydrocarbons} + H_2O + \text{energy} \).

When the mixture of carbon monoxide and hydrogen is transformed using catalysts, the products obtained are liquid hydrocarbons, such as naphtha, gasoline and diesel, among the most important. Nowadays, it has been proved that using methane is more convenient, in comparison to coal, in order to produce the synthesis gas, since the methane is easier to purify and control.

The basic gas-to-liquids-Fischer-Tropsch (GTL-FT) process begins with the methane separated from its liquid companions (dry gas). Companions as the ethane, propane, butane and pentane, can be manufactured independently of the GTL-FT project (Fig. 5).
From what has been exposed, the conclusion is that the GTL-FT technology is developed industrially, allowing the projections of investments and production to commercial levels.

4. Market for products of a GTL-FT industry

If Bolivia were to process 30 million m³ of NG daily (the same quantity firmed with Brazil and the same expected to be exported to the USA), approximately 100 thousand bpd of mostly liquid hydrocarbons, gasoline and diesel would be produced. This amount, as Table 3 shows, is minimal if compared to the worldwide demand.

There is, in Bolivia, an internal market to 14 thousands bpd, from which 5 thousands bpd are imported. Considering the price of US$35.00 per diesel barrel, the money spent on this activity is of US$64 millions per year. There are two very tempting markets available to Bolivia for diesel selling: Chile and Brazil.

(a) Market in the Pacific side—Chile

Chile would be a great buying potential for Bolivia’s diesel-GTL since it consumes 250 thousands bpd of oil and their derivatives and 95% of what it consumes come from imports. Due to the high environmental degree of contamination that it presents, Chile would become a guaranteed buying of GTL diesel. Fig. 6 shows the distribution of the oil import in Chile according to the origin.

In order to export eco-diesel (diesel-GTL) to Chile, also a South American Country, and countries on the other side of the Pacific Ocean, the port of Arica (used normally for Bolivian exportations) would be used for exporting to other countries like China.

(b) Market in the Atlantic side—Brazil

Brazil is another potential buyer of Bolivian eco-diesel. For instance, in 2002 the diesel importation was of 110 thousands bpd and in 2010 the diesel and gasoline importation will be of 860 thousands bpd. Refinement capacity will lack, according to the National Oil Agency (ANP).

The diesel consumption in the neighboring districts of Rondonia, Matogrosso do Sul, Matogrosso and Goias, in the year of 2002 was of 120 thousands bpd and that diesel is mainly obtained from São Paulo, though it is possible to obtain fuel from Bolivia (diesel-GTL). As seen in Fig. 7, the eco-diesel produced in Bolivia would be more economic for the mentioned states, better still if the project is implanted joining Brazil and Bolivia.

Brazil needs to invest great amounts in refineries (Fig. 8) to avoid the diesel importation for diesel engines. The Brazilian state oil enterprise, Petrobras, has gas reserves without market in Bolivia, this makes it possible to manufacture eco-diesel from the gas reserves and export it to Brazil. It is worth mentioning that both countries would gain from that.

---

### Table 3
Projected hydrocarbons demand

<table>
<thead>
<tr>
<th>Products</th>
<th>Estimated demand in the year of 2005(^a) (millions bpd)</th>
<th>Estimated demand in the year of 2010(^a) (millions bpd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphtha</td>
<td>5.2</td>
<td>5.7</td>
</tr>
<tr>
<td>Gasoline</td>
<td>20.9</td>
<td>22.3</td>
</tr>
<tr>
<td>Kerosene</td>
<td>6.6</td>
<td>7.7</td>
</tr>
<tr>
<td>Diesel</td>
<td>22.2</td>
<td>25.1</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>9.2</td>
<td>9.1</td>
</tr>
<tr>
<td>Other</td>
<td>8.8</td>
<td>9.6</td>
</tr>
</tbody>
</table>

\(^a\)California Energy Commission (2005).
5. Market for liquid hydrocarbons

The price and the quality of GTL-FT products will determine, as for any other product, their capacity to gain access and to compete in the worldwide hydrocarbon market in favorable conditions. Their nearest competitors are the products of the oil distillation process. In a GTL-FT diesel projected production of 100 thousands bpd, only 0.3% would be covered by the international market (Table 3).

In Fig. 9 there is, for example, a comparison between the qualities of GTL diesel and the conventional one, also referred to as ‘dirty’ diesel. Compared to the conventional diesel, GTL-FT diesel contains much reduced amounts of aromatic hydrocarbons and sulfur, and for that reason emits reduced amounts of detrimental compounds to the atmosphere. For that same reason, GTL-FT diesel totally satisfies the most demanding specifications of the developed countries legislation. Fig. 9 corresponds to a standard proposal of a rule in the United States on the maximum quantities or limits of aromatic compounds (10%) and sulfur (15 ppm) contained in the diesel (this norm is hoped to be in use from 2006).

Regarding the price, it is important to indicate that the possibilities for this to be competitive are going to depend on the costs structure of the company. In Fig. 10, an attempted costs structure appears, elaborated by the company Foster Wheeler (2002) for the production of clean diesel on commercial scale. It can be observed that the GTL-FT diesel cost of production is of approximately US$ 19.80 per barrel, far below even the present international price of the diesel, of around US$ 35.00 per barrel, the reason why the profits would be very attractive, considering that the ecological clean diesel has an additional benefit in quality.

If the production cost of a barrel of GTL-FT ‘clean’ diesel with the present sale price is compared to the diesel originating from oil distillation (around US$ 35.00 by barrel), it is possible to conclude that GTL-FT diesel is a very competitive product in price.

As we see in Fig. 10 the production cost of the clean diesel is of US$ 18.00 per barrel. For illustration this cost has been calculated considering that:

- 9 thousands cubic feet of gas are required to produce a barrel of diesel.
The cost of one thousand cubic feet of dry NG is of US$ 0.70. The capital expenses are about US$ 9.00 per barrel. The operation expenses are about of US$ 4.50 per barrel.

Table 4 displays a production cost sensibility analysis for a barrel of GTL-FT diesel, that uses as control variable the price of the raw material (of the NG) to be used in the GTL plant clean diesel production. The price was calculated so that the plant could buy the Gas, and is expressed in dollars per thousand cubic feet and their equivalent in dollars per barrel of diesel. In addition, the costs of capital and the shown costs of operation in Fig. 11 have remained without alterations, and are expressed in US$ per barrel.

### 6. Required investment for a GTL-FT Project

Table 5 shows that the considered investment capital of five companies, in order to produce around 50 thousand barrels of GTL-FT byproducts, is a total cost of within 1300 and 1750 million dollars. For plants of 100 thousand barrels per day, the investment amount is of approximately 3 billion dollars.

#### 6.1. Timing for a GTL-FT project implementation

To have an idea of the time taken to develop and implement a GTL-FT project, we need to consider the following as points of reference:

- The agreement subscribed in September 11th, 2000, between Shell and Iranian companies, that stated the installation of a GTL-FT plant with a production capacity of 70 thousands bpd, contemplated the following timing: the study had to be concluded in the first trimester of 2001 and the plant was to be in production in the end of the year 2005.
- The agreement between Qatar Petroleum and Shell, subscribed in October 20th, 2003 that stated the

#### Table 4

Gas price and the diesel GTL costs

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>6.3</td>
<td>9.0</td>
<td>4.5</td>
<td>19.8</td>
</tr>
<tr>
<td>1.0</td>
<td>9.0</td>
<td>9.0</td>
<td>4.5</td>
<td>22.5</td>
</tr>
<tr>
<td>1.4</td>
<td>12.6</td>
<td>9.0</td>
<td>4.5</td>
<td>26.1</td>
</tr>
<tr>
<td>1.8</td>
<td>16.2</td>
<td>9.0</td>
<td>4.5</td>
<td>29.7</td>
</tr>
<tr>
<td>2.0</td>
<td>18.0</td>
<td>9.0</td>
<td>4.5</td>
<td>31.5</td>
</tr>
<tr>
<td>2.2</td>
<td>19.8</td>
<td>9.0</td>
<td>4.5</td>
<td>33.3</td>
</tr>
<tr>
<td>2.5</td>
<td>22.5</td>
<td>9.0</td>
<td>4.5</td>
<td>36.0</td>
</tr>
<tr>
<td>2.8</td>
<td>25.2</td>
<td>9.0</td>
<td>4.5</td>
<td>38.7</td>
</tr>
<tr>
<td>3.0</td>
<td>27.0</td>
<td>9.0</td>
<td>4.5</td>
<td>40.5</td>
</tr>
</tbody>
</table>

**Source:** Own elaboration.

#### Table 5

Investment for a GTL-FT Plant

<table>
<thead>
<tr>
<th>Company</th>
<th>Conversion efficiency (MMBTU/bbl)</th>
<th>Capital costs (US$MM)</th>
<th>Total production costsb (US$/bbl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONOCO</td>
<td>8.20</td>
<td>1.423</td>
<td>23.10</td>
</tr>
<tr>
<td>Company A</td>
<td>8.44</td>
<td>1.671</td>
<td>28.68</td>
</tr>
<tr>
<td>Company B</td>
<td>9.39</td>
<td>1.744</td>
<td>31.71</td>
</tr>
<tr>
<td>Company C</td>
<td>9.70</td>
<td>1.350</td>
<td>20.79</td>
</tr>
<tr>
<td>Company D</td>
<td>10.20</td>
<td>1.291</td>
<td>26.73</td>
</tr>
</tbody>
</table>

**Source:** Adapted from Gas To Liquids brochure—(www.gassolutions.s.conoco.com), 2006.

*The participant companies were Conoco, ExxonMobil, Sasol, Shell and Sontroleum.

*The total costs of production include the labor costs of the used gas and the catalyst, services, labor and general expenses, maintenance, taxes, depreciation of capital assets and the return of the investment.

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Fig. 11. Potential of the Bolivian natural gas.
construction of a plant in Ras Laffan, with the production capacity of 140 thousands bpd, in which an investment of 5 billion dollars was necessary to account for the production in two stages: the first stage, for a production of 70 thousands bpd, will be concluded in 2008/2009, and the second phase in the following years (2010/2011).

From the above timing for the complete installation of the facilities, one can conclude that the study and the construction of a GTL-FT industrial plant, endure for about 5 years.

7. Benefits for Bolivia

In order to process 30 million of m$^3$ of Gas per day (7.8 TCF in 20 years), it is necessary to extract that gas from the gas fields. Consequently, regional and national benefits from royalties would be obtained due to the extraction, not only of the gas, but also of the liquid hydrocarbons that accompany it. Therefore, a GTL project does not change the present situation of the extraction of the Bolivian NG, basically because the relatively big Bolivian gas reserves have a capacity of around 50 TCF.

The Gas industrialization, by the GTL project, would have the following advantages:

- Bolivia would export diesel and/or gasoline, and would not have to import it any longer, with the economic benefits that this implies.
- The GTL-FT liquid fuel exportations would reach 35 million barrels per year: that is more than 3 times the annual crude oil consumption of Bolivia.
- From the productive uses and jobs point of view, these would be increased, not only due to GTL project, but also and mainly due to the associated economy activity generated to any project of development.
- The availability of GTL-FT diesel in the country, by its better quality and consequent better yield, would make Bolivian agro-industry and transports more competitive.
- The transport and distribution of liquids would be cheaper and more versatile.
- The better quality of GTL-FT diesel (cleaner than diesel oil byproduct) would make our atmosphere, especially urban one, healthier.
- From a macroeconomic point of view, the investment in the plant construction and ancillary works would generate job sources immediately.

7.1. Benefits for the producing regions

In addition to the state royalties for the NG extraction, of the investments inside the country, the secondary economic activity and the generation of local jobs, a GTL-FT project would generate water and electricity in sufficient amounts for developing other industrial and farming activities. When we quantify these sub-products, the following average volumes are obtained:

- 100 thousands bpd of water, equivalent to a quarter of the daily water consumption of the La Paz city (nearly 2 million habitants). The water is a sub-product of GTL-FT process, since a water barrel is formed for each hydrocarbon barrel produced.
- Around 250 MW of power capacity, a significant amount considering that the power demanded by Santa Cruz (Bolivian second state) is, for example, of approximately 220 MW. This power capacity could be generated from the energy contained in the residual heat in the process of obtaining of the syngas (synthesis gas) from 30 million m$^3$ of gas per day; and during the corresponding liquid hydrocarbon production in a FT process. The energy contained in that abundant residual heat would facilitate the generation of electricity and/or heat for other industrial activities. In the case of electricity, knowing that the marginal cost of generation is of US$ 4.36 per MWh, theoretically an extra gain of US$ 26,160.00 per day with the diesel production can be achieved by commercializing the electrical energy to SIN (Interconnected National System).
- In addition, the producing regions could be benefited with the installation of a fertilizer plant from the ammonia obtained in the reaction of the nitrogen of the air with hydrogen of the syngas.
- By the nature of GTL project, a secondary economic activity would be developed in the producing regions, that could be as much or more beneficial than the project itself.

7.2. Economics of GTL project

To have an idea of how financially attractive the GTL-FT projects are, a part of the manuscript “The Banks Endorse Qatar GTL Project”, is transcribed. This article was published in the Petroleum Economist of March 2003:

The bankers consider that GTL schemes offer a triple advantage on the traditional projects of oil and gas, which is true in the oil product market as well as for pipelines or LNG.

- The products are commercialized globally in a mature market, such that the sponsor does not have to depend on a specific buyer for long-term agreement.
- The gain margins are much greater than for the traditional oil refinement that seems to remain under pressure in the next future.
- The GTL Gas chain is much shorter than in the traditional Gas schemes.

Further more, N. White, Director of Energy Economy (of the company Arthur D. Little), says: “the advantage of GTL is that there is not an obligation to construct a new
logistic system. It is possible to use the existing distribution system to bring products to the markets”.

7.3. Gas availability to implement a GTL-FT project

The Bolivian NG fields are appropriate to implement one or more GTL projects from the qualitative and quantitative point of view:

From the quantitative point of view, to produce around 100 thousands bpd of GTL byproducts, during 25 years, is necessary to process 30 million of m$^3$ of gas per day, which demands 10 TCF of the economic gas reserves. Bolivia has, among proven and probable reserves, about 50 TCF in the beginning of 2005, satisfying this requirement totally.

From the qualitative point of view, the Bolivian reserves are of non-associated Gas, what means that it does not have many accompanying liquid hydrocarbons, which allows minimum investments to separate the methane from other hydrocarbons. Bolivia has the greatest non-associated Gas reserves in South America: greater than, for example, the ones in the 226 TCF of total Gas reserves in Venezuela (the greatest Gas reserves of South America), but only 14 TCF are of non-associated Gas (PDVSA, 2004).

Another important aspect is that, generally, the sulfur contents of Bolivian hydrocarbons are low, which avoids investments in desulphurization plants and, on the other hand, avoids the poisoning of the catalysts, fundamental aspect in the process.

Fig. 11 illustrates the flow of the potential projects and products of exportation and industrialization of the Bolivian NG (Oliva, 2006).

8. Conclusions

Independently of other elements as the ones tied to the local and global geopolitical interests, it is possible to conclude, without doubts that the Natural Gas Industrialization in Bolivia, with the production of a fuel environmentally friendly like the GTL-FT diesel is technically and economically feasible. It is evident, from the physical establishment that Bolivia has gas reserves, and in great quantity, to satisfy the process of this clean-diesel elaboration. The analysis shows that 30 million m$^3$ of Gas per day (less than 8 TCF in 20 years, nearly 15% of the present well known reserves) can be processed obtaining the regional and national benefits due to the extraction, not only by the Gas, but also by the liquid hydrocarbons that accompany it.

From the obtained analysis and results, it is concluded that:

- Besides the exportation of eco-fuels (diesel and/or gasoline), Bolivia would no longer need to worry about importing diesel from outside the country, considering all the economic benefits that this implies;
- About 35 million barrels per year of GTL-FT liquid fuels, would be produced with a very competitive price in comparison to the diesel from oil, more still when the high oil present prices come to knowledge (without indications of significant lowing);
- The productive jobs would be increased by the GTL project and the associated socioeconomic activities generated by the project;
- With the full availability of eco-diesel, Bolivia would be more competitive for exportation, for instance in the agro-industry and transport;
- GTL-FT Diesel makes possible a greater step towards the sustainable development, once it brings with itself a clean environment, especially local urban.
- The transportation and distribution of liquids are cheaper and versatile.

In the context of the macroeconomic analysis, the results allow us to visualize that the investment in the GTL-FT plant construction and accessory hard activities and facilities would generate job sources immediately. And with it, the Bolivian Natural Gas Industry would be consolidated. This way, the following are also evident conclusions:

- The Natural Gas fields in Bolivia are appropriate to implement one or more projects of GTL, from a quantitative and qualitative point of view.
- The GTL projects will have as an objective the consolidation of the Bolivian Gas Industry, through adding value to the Natural Gas production in the country.
- It is necessary to consider that for a production of 100,000 bpd of GTL, within 25 years, is necessary to process 30 million of m$^3$ per day, which demands 10 TCF throughout that period of time.
- The production of 100,000 bpd of clean diesel will produce a considerable amount of water and electrical energy, what brings a secondary market: electricity exportation. This means that, besides exporting Natural Gas (business already consolidated) the country would export clean environmentally friendly GTL-diesel and electricity, and so certainly Bolivia would become the center of energy distribution in its region (MERCOSUR and CAN).

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