THE RENEWAL OF THE GAS-TO-LIQUIDS TECHNOLOGY: PERSPECTIVES AND IMPACTS

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INTRODUCTION

The Gas to Liquids technology (GTL) consists of a chemical conversion of natural gas into a stable liquid by means of the Fischer-Tropsch Process. This conversion makes possible to obtain products that can be consumed directly as a fuel (for example, Diesel) or special products such as lubricants.

The products that are derived from the GTL technology have two types of economic advantages: i) Their transport cost is much less than that of the transport of natural gas, which due to its volume, that is 1000 times more than the volume of petroleum, not only presents high transport costs but also requires specific assets (gas pipelines or methane ships); ii) The products produced by GTL plants present important environmental advantages compared to traditional products, as they are derived from a clean fuel: natural gas.

The decade of the 1990s witnessed the return of the Fischer-Tropsch Process to the centre of attention in the world petroleum and natural gas industry. This technology, developed in the 1920s and put into large-scale operation by Germany[1], was abandoned due to the low prices of petroleum and the development of abundant markets for natural gas. Nevertheless, a radical transformation in the sphere of the application of this technology has opened the door for the renovation of the GTL technology. The increase of stranded gas reserves and the development of niches in the market for synthetic fuel, due to environmental legislation, prompted the renewal of interest of petroleum companies in this technology. The development of several projects for the construction of GTL plants in the sphere of application can be observed, as part of a truly technological rush to seek the development of more efficient and cheaper processes.

The success of the innovation process in the GTL technology has a very important potential impact on the dynamics of the world markets of oil and gas. The GTL technology represents the maximum limit for the long-term petroleum prices in the oil market. In case this price is maintained above the cost of GTL, new companies will be attracted to this business, transforming into cash great gas reserves, which are today stranded because of the limits of traditional transport technologies. The GTL technology represents a minimum level for gas prices in the gas market. GTL is an alternative option for monetizing gas reserves.

This article seeks to analyse the process of innovations in the GTL technology focusing on three dimensions of this process. The first part of the article analyses in depth the evolution of the environment for the application of GTL technology, seeking to show the prevailing forces in the renewal of interest for this technology. The second part of the article focuses on the innovative effort in the different lines of ongoing

[1] For the history of the GTL technology see Stranges (1993 and 1997).

research. Finally, the third part of the article focuses its analysis on the competitive process and the corporate technological strategy to be well positioned in the GTL market.

1 – CHANGES IN THE ENVIRONMENT OF THE TECHNOLOGICAL APPLICATION

A combination of a series of factors prompted the transformation in the environment of the application of this technology: i) the great increase in the gas reserves (especially associated) considered stranded by the conventionally utilized technologies (transport by gas pipelines and the chain of liquefied natural gas– LNG), due to the increase in exploratory efforts after the petroleum shocks of the 1970s; ii) the renewed activity of environmental legislation making the creation of niches in the market for clean fuels viable; iii) finally, the liberation of the natural gas and electricity industries in the main world markets, with the greater volatility of gas prices, making its sale by long term contracts difficult, and consequently, creating important obstacles for the financing of great gas pipelines and LNG projects.

1.1– Increase of stranded reserves

The great effort in the search for alternative reserves to Arab petroleum after the petroleum shocks in the decade of the 1970s had a great impact on the increase of tested gas reserves, which jumped from 40 tmc (tera cubic meters) in 1970 to 140 tcm in 1996. The reserves/production ratio increased from 59 years at the end of 1985 to 65 years at the end of 1996. The Natural Gas Industry – NGI is thus experiencing a period of abundant gas reserves. However, this abundance is not a reality in the regions where the markets are concentrated (United States, Western Europe, Japan and Southeast Asia) (see Table 1).

Table 1 – Distribution of world reserves and consumption of gas 2000

	Reserves	Production	Consumption
North America	4,90%	31,30%	31,90%
Central and South America	4,60%	3,90%	3,80%
Europe	3,50%	12%	19,10%
Former Soviet Union	37,80%	27,80%	22,80%
Meadle East	35%	8,70%	7,90%
Africa	7,40%	5,30%	2,40%
Asia	6,80%	11%	12,10%

Source: Infopetro (www.ie.ufrj.br/infopetro).

The concentration of gas reserves in countries with a low demand potential (All of Western Africa, and Bolivia, Venezuela, Peru and the Brazilian Amazon in Latin America are typical examples) makes the transformation of these reserves into business difficult. A large part of the reserves located more than 5,000 kms from the great centres of consumption are not able to utilize traditional transport technologies, due to the risks associated with such investments. Nevertheless, the volume of low cost gas reserves that could be monetized via GTL is becoming larger.

1.2 – Increase in environmental restrictions

The pressure of environmental legislation constitutes one of the main factors that calls for the development of GTL technology, especially due to two factors: i) a growing number of restrictions on the flaring and venting of gas related to the production of petroleum ; ii) the increase in control of the emissions in the transport sector.

The restrictions on the burning of associated gas, by means of the application of fines or even a higher tax base, aided the emergence of a great supply of gas at very low prices. This is the case, for example, of the associated gas in Nigeria or in Angola, the non-utilization of which represents a cost for the petroleum producer. This agent is willing to make its utilization viable, even if the price received for the product does not totally remunerate the investments made for such. Therefore, a niche of an important market for GTL projects emerges, seeking to utilize reserves that have a negative cost of opportunity.

The environmental restrictions imposed on the quality of fuel represents a great incentive for GTL. First, these demands represent an increase in cost for the traditional refineries. They should confront an increasingly more difficult situation in which they must produce a cleaner product with a worsening raw material (oils which are becoming heavier). This task is even more difficult in a context of growing competition and tighter margins. Nevertheless, it is not the long-term competition between refineries and GTL plants that represents the most important incentive. It is the opening of niches in the short-term market. The metropolitan diesel is a great market that is already available for future GTL producers.

1.3 – increased of demand for flexibility

The technological trajectory of the transport of natural gas by pipelines or via the LNG chain, characterized by the exploration of large-scale economies, resulted in a great lack of flexibility in the interaction among the various articulated spaces. The gas pipelines, liquefying plants and methane-carrying ships represent specific assets, once they are dedicated to specific economic transactions. Therefore, the economic transactions can only occur among those spaces that are interconnected by that specific network[2]. Both the operational and investment decisions of the agents present in each space are made in a context characterized by interdependence.

Inflexibility is a synonym of high specificity of assets and, therefore, of higher transaction costs (Williamson, 1993). The economic coordination of the several steps of the chain emerges to reduce these costs and to make this operation and the expansion of this set of activities interdependent, removing the possibility of the exercise of an opportunist behaviour practiced by one agent in the chain whose position has been benefited by a change in the context that was not foreseen in a contract. Considering that the inflexibility of the chain obliges the agents to maintain the transactions among themselves, mechanisms that tackle opportunism is always welcome, easing the restlessness and making investments viable.

The great problem in confronting the utilization of the reserves via traditional means (gas pipelines and GNL) is the difficulty of negotiating mechanisms of coordination to by-pass the risks of business deals characterized by great interdependence among the actors. The liberalization of the energy markets, especially the gas and electricity markets, has made the engagement of long term contracts difficult to achieve. The volatility of the prices increases the risks to buy or sell gas at pre-set prices, in addition to increasing the probability of unpredictable contingencies.

The technological trajectory of GTL represents a radical departure from former movements. The spatial integration that originates from this course presents a much larger flexibility than that present in the previous configurations. The possibility of transporting a stable liquid opens the doors to the utilization of the entire pre-existing infrastructure for the transport of petroleum and petroleum products. In addition to this, the production of GTL plants can be commercialised in a global and extremely liquid market. In this manner, the assets are no longer specific, as they can be dedicated to a large number of transactions. The risk of opportunism becomes almost non-existent as the product can be sold by short-term contracts with a reduced interdependence between buyers and sellers.

GTL thus represents an appropriate response to the new context of the international market of natural gas, which demands greater flexibility in contracts and less interdependence between buyers and sellers.

1.4 – Impacts of the effort of innovation

The opening of technological opportunities beginning from the changes in the environment of the application of GTL technology had an immediate response from the companies involved in the petroleum and gas sector. These companies' efforts to innovate gained new impetus beginning in the 1990s. The intensification of this technological effort can be confirmed by analysing its results in terms of the production of patents.

The number of patents directly or indirectly associated to the GTL technology presented sustained growth beginning in the 1980s. Nevertheless, in the mid 1990s, a great leap in the number of patents took place, practically doubling. This can be explained by the increase in the number of companies involved in research. As the technology gets close to its commercial phase, other companies besides the pioneers have launched efforts to innovate. Practically all of the great petroleum companies currently have their own program of research and development or make up part of consortiums that research GTL technology.

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[2] Obviously, the flexibility of the LNG chain is larger than the transport of gas via pipelines. However, the degree of specificity of the assets are still high since, taking into account the scales of production and the size of the world LNG market, it is not possible that a project designed to serve a specific market can be redirected to another market. The interdependence between buyers and sellers of gas is very high.

Table 2 – Growth of the Number of Patents Related to GTL Technology[3]

Period	Synthetic Gas	Fischer-Tropsch Process
1996 to 2002	433	1008
1991 to 1995	250	514
1986 to 1990	265	443
1981 to 1985	190	394
1976 to 1980	51	334
Before 1975	0	0
TOTAL	1189	2693

Source: www.uspto.gov

2 – PROCESS OF INNOVATION AND NEW TECHNOLOGICAL OPTIONS

The processes of conversion of natural gas into liquid products can be divided into two types: direct conversion and indirect conversion.

The direct conversion processes utilize catalysts and specific synthesis routes to chemically transform the molecules of methane, the main component of natural gas, into more complex chained substances with heavier molecules. The liquid products that can be obtained include the alcohols (mainly methanol), the olefins (ethylene and acetylene) and the aromatics (benzene, toluene and naphthalene). However, the high stability of the methane molecule creates a series of technical problems to make the chemical reactions involved viable. Thus, the research and development efforts of the direct conversion processes are focused on the improvement of the catalysts in the elucidation of the mechanisms of reaction and the development of new equipment (Martin, 2001).

The indirect route is technically easier than that of the direct conversion processes. The technologies of the processes involved have been better studied and several pilot and commercial plants are already in operation. The processes of indirect conversion are characterized by a preliminary stage of transformation of natural gas into synthesis gas – syngas - (a mixture of carbon monoxide - CO and hydrogen - H2). After being produced, the syngas is converted into liquid hydrocarbon through the Fischer-Trospch Process (FT) (Vosloo, 2001 and Wilhelm, 2001).

The production of hydrocarbons by this means does not directly result in products of commercial interest. To do so an additional step is needed, the hydroprocessing, in which the heavy molecular hydrocarbons are decomposed into smaller molecules according to the products that one wishes to attain (naphtha, Diesel oil, lubricant oil, paraffin and others). Therefore, the conversion of natural gas into hydrocarbons can be better characterized by three distinct types: 1) generation of syngas, 2) conversion of syngas and 3) hydroprocessing.

Although the three stages of the GTL process by indirect means have been individually well studied and are available for commercialisation, a optimal combination that permits the reductions of costs of the commercial production plants still doesn't exist. In addition to the technical aspects, this optimal combination must consider the size of the plants, the availability of energy and water sources, the volume of natural gas available in the fields to be explored and other factors.

Due to its potential, the efforts to innovate carried out by research institutes, universities and mainly by companies in the sector are concentrated in the processes of conversion by indirect route. The search for the reduction of capital costs for the implementation of the processing plants that would permit an improved economic viability of the projects is the main objective of the innovation efforts. The identification of the studied routes, their potential for success and possible impacts now follow.

[3] The research on patent database considered the keywords Fischer-Tropsch and Synthesis Gas, researched separately. Therefore, patents that deals with both subjects are considered in the two columns of the table.

2.1 – GENERATION OF SYNGAS

The synthetic gas generation plants correspond to about 50% of the capital costs of the units of conversion of natural gas into liquid hydrocarbons, which explains the great innovative effort carried out by the companies. (Wilhelm, 2001, Sundset et. al. 1994 and Jager et al. 2001).

At least five different types of technologies are available for the generation of syngas. The auto-thermal process – ATR - stands out among them. As a combination of the classic processes, the steam reform and the partial oxidation of methane, this process occurs in the presence of catalysts with the utilization of water steam and oxygen at a temperature of about 1,000 degrees Celsius (Rostrup-Nielsen, 2000 and Dybkjaer and Christensen, 2001).

Several technological efforts have been carried out to perfect this technology. The main technical problem to be solved is the generation of syngas in a H2/CO ratio equal to 2. This ideal proportion permits a maximum efficiency of the conversion process by Fischer-Tropsch. Despite indications to the contrary, tests utilizing materials with low steam/carbon ratios conducted by the Haldor-Topsoe and Sasol companies have been successful. These developments significantly increased the global efficiency of the process, improving the economic viability of the plants and the perspectives for commercialising technology by these companies.

Of equal importance, Syntroleum has allocated research efforts to the development of a processing route that substitutes the employment of pure oxygen by atmospheric air, thereby reducing the capital costs of the syngas generation units. Exxon Chemical is similarly developing a fluidized bed reactor for the generation of synthetic gas with the employment of atmospheric air. The process has been tested in a pilot unit producing 220 barrels per day - bpd.

A new technology has also drawn the attention of companies and researchers in recent years. The reform process by catalytic membrane preserves the same basic characteristics of the ATR process. This technology, however, substitutes the oxygen plant by a selective membrane to this gas, joining the separation of air and the partial oxidation in one single operational unit.

Two consortiums of companies have conducted the researches. The first is composed of: Air Products, ARCO, Ceramatec, Eletron Research, Agonne National Laboratory, McDermott Tecnology, Babcock&Wilcox, Chevron, Norsk Hydro, Pacific Northwest National Laboratory, Pennsylvania State University and the University of Alaska, with 35% of costs paid by the U.S. Department of Energy. The second consortium is composed of: BP-Amoco, Praxair, Statoil, Philips Petroleum and Sasol. The option to form consortiums, rather than conducting isolated research, shows that the sector companies are willing to divide the risk, as the development of this technology is pointed out as one of the most promising routes to make the GTL plants economically viable (Wilhelm, 2001 and Rostrup-Nielsen, 2000).

2.2 – Conversion of Syngas

The process of the conversion of synthetic gas into hydrocarbons is based on the Fischer-Tropsch Process (FT). There are currently two well-defined routes; one at a low temperature and another at a high temperature. The first is employed in the production of waxes, which are converted into naphtha or Diesel oil after the hydroprocessing. The second process is employed in the production of gasoline and alfa-olefins (Wakatsuki, 2001 e Voss, 2002).

Since the conversion reaction is very exothermic, several research studies have been conducted with the goal of developing new equipment configurations allowing more efficient energy utilization. Besides deactivating the catalysts, the high temperatures provoke the formation of fuel soot, which is deposited on the surface of the reactors with losses of productivity. Sasol has conducted significant research and developmental attempts in this area (Hill, 1998).

2.3 - Hydroprocessing

Hydroprocessing is employed in the treatment of wax produced by the FT technology at a low temperature. The wax is basically composed of linear paraffin and small quantities of olefins and oxigenates. The hydrogenation of the olefins and the oxygenated compounds, besides hidrocracking of wax can be conducted in conditions that are not very severe, with the production of naphtha and Diesel oil.

There are several suppliers of this technology, widely employed in the traditional refinery operations. Nevertheless, Chevron has stood out as a supplier of technology for its interest in the processes of the conversion of natural gas into hydrocarbons. Chevron and Sasol are currently participating in several commercial joint venture projects.

The stages of conversion and hydroprocessing are the most well studied of the three stages necessary for the conversion of natural gas into liquid hydrocarbons. The stage of the generation of synthetic gas, however, has different possible routes for the development of innovations. The technology of reform by means of a catalytic membrane stands out clearly among the others.

Nevertheless, the processes by direct means are those which present the best long term perspectives The practical implementation of these processes would mean the total elimination of capital costs associated to the construction and operation of the units of syngas, which today represent about 50% of the investments in GTL plants. These routes are the potential radical innovations in the sector. The potential of this route is so large that in 2001 BP signed a ten-year contract with the Universities of California, Berkeley and Caltech, allocating US$ 1 million yearly to each institution to conduct research utilizing the direct conversion routes.

In case the research dealing with the catalysts that can directly convert natural gas into products of commercial interest is successful, the holders of the patent will certainly have a an advantage in costs that even the best of the increased innovations of the indirect processes will not be able to offer.

3 – TECHNOLOGICAL STRATEGIES

The strategies of the companies involved in the GTL technologies must be examined inside the context of renovation of a mature technology, the development of which was interrupted more than 50 years ago with the petrochemical advances and dominance. The technology has been restricted in the last decades, from the operational point of view, to the activities of Sasol, which installed and operated syngas production plants using coal as raw material, in South Africa[4]; and the activities of Shell, which built a plant in Malaysia at a cost of US$ 600 million with a capacity of 12,500 bpd.

The return to the GTL conversion can be seen today as a definition of a new trend that would thus have characteristics assimilated to the fluid phase of the life cycle of the technologies, in the meaning of Utterback, 1994. The essential characteristic of the fluid phase is the existence of numerous competing options, seeking definitions to be validated by the market in order to constitute the dominant project. This search for convergence among the several possible conceptions of technology makes the competitive scenario particularly complex as well as uncertain for the participants who must make their bets, confronting the risk of making options that could become losers as there is a natural reduction of the number of technological options utilized. It must be therefore emphasized that the case in question essentially relies on the process innovations. The products to be obtained are in the best hypothesis superior versions of established products of which the markets are well known.

The strategic positioning of the actors is thus characterized by the search for positions in a still open environment, in which a certain number of options are competing. Some of these options are to be hereby presented.

3.1- The scales of the plants

The scales of the GTL plants currently present an important dimension for strategic positioning in the GTL market. On the one hand, some actors are positioning themselves in search of greater scale, part of the natural trajectory (Nelson e Winter, 1977) of chemical processes industries, aiming to reduce the cost of production and increase profitability on the large investments demanded. The large petroleum companies which possess great reserves of stranded natural gas (for example, Shell and ExxonMobil) are the most interested in large-scale plants. On the other hand, some companies seek efficient plants on a smaller scale (fewer than 10,000 barrels per day), capable of exploring a large number of small stranded natural gas fields[5].

The barge-mounted plants proposed by Syntroleum expressively represent the concept of small scale (from 2000 to 10,000 bpd), whereas the petroleum companies' projects, which would produce about 80,000 or more bpd, give priority to the reduction of cost as well as the competitiveness of the GTL technologies compared to the established technologies of natural gas exploration.

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[4] In the 1990s a commercial GTL plant was built in South Africa employing natural gas as fuel. This is the Mossgas Plant that utilizes Sasol technology.

[5] An onshore plant with a production capacity of 5,000 bpd requires a reserve of 12 bcm, supposing the life cycle of the project is 25 years. According to the World Bank, in Western Africa there are about 97 natural gas fields with a capacity of up to 14 billions cubic meters in stranded reserves and only 13 larger fields.

3.2 – Direct conversion versus conversion via synthetic gas

Parallel to the positioning on the question of the size of the plants, there is also a lot of space for strategic positioning on the research effort as to the different technological routes of gas conversion. This positioning is not taking place independently of the objectives in terms of the scale of plants, but rather extrapolates this question. The strategic game is related to the choice of a route to be given priority. The concentration of research efforts of one route can result in great competitive advantages in case the effort is successful. Nevertheless, the selection of a route presents risks at the same time, since other routes are no longer given priority.

Efforts of maximization of the traditional route compete to the research, although at a beginning stage, that are attempting to develop catalysts capable of eliminating the step of producing syngas, thus drastically reducing the investment in the plants. Research and development efforts are, at the same time, seeking new options for the production of syngas, trying to make it more efficient by means of radically new processes, as, for example, the reform by catalytic membrane. Table 2 summarizes the various directions of research and their characteristics in terms of the actors involved, the nature of the effort of innovation and the stage at what stage the research is found.

Chart 1 – Different directions of research and their characteristics

Technology	**Main Actors**	**Nature of the innovative effort**	**Stage**
Direct Conversion	British Petroleum Universities	Radical	Basic research
Use of small ratios of vapour/carbon in ATR plants	Haldor Topsoe Sasol	Incremental	Applied research and development
Use of atmospheric air substituting oxygen	Syntroleum	Incremental	Applied research and development
Fluidic bed reactor	Exxon Chemical	Incremental	Pilot plant in operation
Reform by catalytic membrane	Consortium 1 Consortium 2	Radical	Basic research
Conversion by Fischer-Tropsch Process	Sasol	Incremental	Applied research and development

Source: Own elaboration

Consortium 1: Air Products, ARCO, Ceramatec, Eletron Research, Agonne National Laboratory, McDermott Tecnology, Babcock&Wilcox, Chevron, Norsk Hydro, Pacific Northwest National Laboratory, Pennsylvania State University and University of Alaska

Consortium 2: BP-Amoco, Praxair, Statoil, Philips Petroleum and Sasol

3.3 – The product lines

One line of motivation of the GTL technologies sets as a target market the ultra-clean fuels, without sulphur, aromatics and heavy metals. In this case, the products would receive a prize compared to the traditional fuels. However, if other solutions make the production of ultra-clean fuels viable, the GTL technologies would directly compete with the refineries and the prize would be reduced or even disappear. In this case, a considerable reduction in the cost of production would be demanded so that the plants become competitive, and thus give priority to scale economies.

Another option also mentioned refers to the markets of chemical specialities that offer much higher prices than those of the fuels, but demand small volumes of products, limited to niches of applications. The dilemma of the lines of products is less restrictive than the previous ones, although they are related to them, especially the question of the scale of production.

3.4 – Main actors and their strategic lines

It should be noted that the current installed capacity is modest, about 54,000 bpd, and it is estimated that the total capacity of the projects being implanted is about 80,000 bpd and the total capacity of announced projects is 800,000 bpd [6]. The main operators are Shell, ExxonMobil, Syntroleum and Sasol. These four companies synthesize well the strategic diversity in the competition for positions in the future of GTL technologies.

Shell declared that it has conducted research and development activities in GTL technologies since the end of the 1940s, which led to the development of the Shell Middle Distillate Synthesis (SMDS) focused on the production of average distillates, mainly kerosene and gasoil. Shell, one of the pioneers is the industry in its renaissance phase, has operated a plant producing 12,000 bpd in Bintulu, Malaysia since 1993. The plant is characterized by its great flexibility as to the products which vary among naphtha, Diesel oil, kerosene, solvents, refined greases and raw material for detergents.

ExxonMobil has recently announced the development of a second generation of its process known as Advanced Gas Conversion (AGC-21). This deals with a process employing the slurry reactor and a cobalt catalyst. The strategy of the ExxonMobil developments focuses on incremental improvements in the generation of synthetic gas and in the Fischer Tropsch reaction system.

Syntroleum is a technology company, which was founded in 1984, became publicly traded in 1998, and acts in the energy industry. It possesses a process of natural gas conversion into liquid hydrocarbons, commercially available since 1997. The main characteristic of this process is the employment of air in place of oxygen in the preparation of synthetic gas, which eliminates the significant capital cost of the plant separating the air. The research and development strategies seem to be mainly focused on the perfection of the Syntroleum process, in addition to reducing the capital and operational costs.

In addition to widely offering licenses to the petroleum and gas industry, Syntroleum also has as its goal the establishment of joint ventures to build and operate their own plants for the production of specialties or Diesel oil. Syntroleum thus seeks to transform itself from the role of licenser to producer. It has currently proposed several projects of the joint-venture type to petroleum companies that possess stranded gas reserves in Latin America (PDVSA in Venezuela, Petrobras in Brazil, Enap in Chile and consortiums in Peru). The company seeks to make some GTL plants viable with a stake in the capital invested in these projects, thus demonstrating that its technology can be commercialised.

Sasol[7] is a particularly interesting competitor. It is the only one with effective operational experience in Fischer Tropsch plants, which the company has maintained in South Africa producing liquid hydrocarbons from coal since the 1950s. The renaissance in the GTL technologies represents an opportunity to employ its accumulated knowledge in the Fischer Tropsch conversion. The company considers the leverage of its technology in the Fischer Tropsch conversion one of the five fundamental drivers of its growth. The company has considered several GTL plant projects, one of which is in association with Chevron. In addition to announced associations with petroleum companies, Sasol has also sought to strengthen its position in technology, as is the case of the association with the Norwegian company specialized in technologies for the production of synthetic gas, Haldor Topsoe.

It should also be mentioned that, besides several petroleum companies, such as BP, Conoco and Statoil that have announced GTL initiatives, there is also the presence of gas industries, especially Praxair and Air Products. These companies are leading two consortiums involving a petroleum companies and companies specialized in specific fields of knowledge for research and development projects in the reform by catalytic membrane. In this case, the industrial gases companies are attempting to mobilize their technological specialties to seek a radical innovation in the processes of synthetic gas production.

4 - CONCLUSIONS

This article has shown that the GTL technology is undergoing a renewal of its innovative process. Several factors are conspiring to increase the competitiveness of this technology. First, a rapid increase can be

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[6] GTL, route open for UFCs, European Chemical News, 25 Feb 2002.

[7] Sasol has annual sales of some US$ 2.4 billion, of which 57% is outside of South Africa; its main activity area is chemical.

verified in the reserves considered stranded with the conventional gas transport technologies. Second, the renewal of environmental legislation has contributed to create niches in the market for clean fuels. Finally, the opening of the natural gas and electricity industry in the main world markets with greater volatility in the prices of gas and electricity has increased the demand for flexibility of the contractual arrangements, which is difficult to be obtained in a project with a concentration of investments in specific assets (gas pipelines and the LNG chain).

The patents statistics show evidence of the renewal of the process of innovation in the GTL technology. The number of patents has increased, especially in the last five years. However, what is interesting is that the process of innovation has sought not only the perfection of the technologically traditional routes (incremental innovations) but also radical innovations. The research agendas dealing with different technological options that are not only incremental but also radical are clear to the agents. Currently, a strategic game is forming around the positioning of research efforts in the different options presented herein. The associations of actors involved in the GTL technologies can be understood as strategies in search of the complement and reduction of risks, which is justified in a phase of the life cycle of technology with fluidic characteristics.

The observation of the strategies of the companies involved in the GTL technologies permits the identification of two groups of companies: the companies focused on the energy markets and the companies focused on technologies. The petroleum and gas companies are naturally in the first group. Their base of interest in the GTL technologies originates in their activities as petroleum and gas operators. With few exceptions they have technological limitations to advance their projects and are thus seeking associations with companies of the second group.

The group of companies that has technology as its form of participation in the GTL industry is typically represented by Syntroleum, a company of a technological base created to act in this market. It can be noted that the company has performed movements that could also make it a company with a market base, if such movements become concrete. The companies of industrial gases are in a similar position to the original position of Syntroleum, as eventual developers and providers of technology.

Sasol has a unique profile in that it was neither a technology company nor an important company in the operation of petroleum and gas markets. It lies at an intermediate point, holding a base of single knowledge in operation. Its associations with both petroleum companies and technology companies justify its unique position.

5 – REFERENCES

DYBKJAER, I. B and CHRISTENSEN, T (2001). “Syngas for large scale conversion of natural gas to liquid fuel. *VI Natural gas conversion symposium.* **,** Alaska, 17-22 June.

HILL, Caravan (1998). “What makes a natural gas to liquid fuels project viable? *Middle east petroleum & gas conference*. Dubai15-17, March.

JAGER, B., P. et al. (2001). “Developments in Fischer-Tropsch technology and its application”. *VI Natural gas conversion symposium,* Alaska, 17-22 June.

MARTÍN, Juan pedro Gómez (2001). “Tecnologías de conversión de gas natural a líquidos - Parte I: producción de gas de síntesis”. *Boletín de Informaciones Petroleras.* Repsol-Ypf.

NELSON, R. et WINTER, S. (1977). « In search of a useful theory of innovations ». *Research Policy*, vol. 6, pp. 36-76.

ROSTRUP-NIELSEN, Jens R. (2000). “New aspects of syngas production and use”. *Catalysis today,* 63.

________________________ (1993). “Production of synthesis gas”. *Catalysis today* , n.18.

STRANGES, A. N (1997). “The US Bureau of Mines’Synthetic Fuel Programme, 1920-1950: German Connections and American Advances”. *Annals of Science, 54,* 29-68.

_________________. (1993). “Synthetic Fuel Production in Prewar and Word War II: Japan, a Case Study in Technological Failure. *Annals of Science,* 50, 229-265.

SUNDSET, T. et al. (1994). “Evaluation of natural gas based synthesis gas production technologies”. *Catalysis today,* 21.

UTTERBACK, J (1994). *Mastering the dynamics of innovation*. Harvard Business School Press, Boston.

VOSLOO, Anton C. (2001) “Fischer-Tropsch: a futuristic view”. *Fuel processing technology,* n. 71.

VOSS, David (2002). “Hitting the natural gas”. *Technology review*. *- january/february, pp.69-72.*

WAKATSUKI, T. et al.(2001). “Development of a high efficiency GTL process based on CO2/steam reforming of natural gas and slurry phase FT synthesis”. *VI Natural gas conversion symposium*. Alaska, 17-22 June.

WILHELM, D.J. et al. (2001). “Syngas production for gas-to-liquids aplications: tecnologies, issues and a outlook”. *Fuel processing technology, n.*71.

WILLIAMSON, O. (1993).” Transaction Cost Economics: The Governance of Contratual Relations. *Journal of Law Economics*, Vol. 22, n. 2.