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For the chemical conversion of natural gas to petroleum products, a new chapter is beginning. Many R&D projects have been undertaken in recent years and a large-scale unit is scheduled to come onstream in Qatar in 2006. In this way, a new pathway for the exploitation of natural gas should gradually make a place for itself on the world energy scene.

1920 to 2000: R&D and Early Projects

The story of the Fischer-Tropsch gas-to-liquids process (FT GTL) used to convert gas into petroleum products began in 1920. For the first time, two German chemists, Hans Fischer and Franz Tropsch, succeeded in producing syngas (a mix of CO and H_2) from coal with an iron-based catalyst. The first applications took place in Germany during World War II to produce motor fuel. The next step did not come until 1955 when, under specific political circumstances, South Africa undertook a massive program for the production of motor fuels from coal.

The first GTL unit using natural gas was opened in 1991 by Mossgas (now Petro SA). It implemented the slurry phase distillate (SPD) process developed by Sasol. Today, if one includes the units producing from coal, South Africa is the country that leads the world in FT synfuel production, with capacity of nearly 200,000 barrels per day (bpd). In 2005, in cooperation with Foster Wheeler, Sasol launched a new R&D program to build a demonstration unit.

Shell was responsible for the first commercial project outside South Africa. In 1993, Shell started operating a GTL unit in Bintulu, Malaysia (capacity: 14,500 bpd) based on research on the Shell Gasification Process conducted in the Fifties. This technology was used to process heavy cuts. In the 1970s, Shell focused on the Fischer-Tropsch process. In the early '80s, it developed a pilot that was tested at full scale in Malaysia, but had to close between 1997 and 2000 following an accident in the air separation unit. This accident was not connected to the Shell Middle Distillate Synthesis (SMDS) process.

Since 1993, no project has been taken to industrial scale. An unfavorable economic balance sheet constituted a serious handicap for early units, whose unit cost of investment exceeded $50,000/bpd compared to $10/15,000/bpd for a refinery. Moreover, this technology still needed to be improved, especially with respect to energy efficiency and catalyst performance.

In the area of R&D, projects carried out in the United States and Europe have been supported by public authorities (the Department of Energy and the European Union, respectively). For example, IFP and Agip Petroli are working on development projects to develop a high-performance Fischer-Tropsch process. This project, partially funded by the European Thermie and Eureka programs, led to the construction of a pilot installation (capacity: 20 bpd) that started up in November 2001.

Several other pilot installations were erected between 1990 and 2000. Some were built by the American companies Rentech and Syntroleum, both specialized in GTL. Oil majors also invested specifically in this sector, among them BP, ExxonMobil, ConocoPhillips and Statoil. In 2004, the latter opened a semi-commercial unit (1,000 bpd) in South Africa in cooperation with Petro SA. More recently, in November 2005, Total announced its intention to develop a pilot in cooperation with Batelle for the development of a new syngas production technology, this being the first step in the conversion process before the Fischer-Tropsch reaction.

Collectively, these R&D programs have significantly improved the technical and economic performance of this type of unit. Operators hope to see the unit cost of investment, which currently stands at about $25/35,000/bpd, eventually fall below $20,000/bpd.

The Early 2000s: Positions Taken by Market Players and New Products

The early 2000s saw the announcement of major projects, marking a real turning point for the industrial development of GTL. Having teamed up with Chevron in June 1999, Sasol announced the first agreements bearing on projects in Qatar and Nigeria in 2001. Shell signed a protocol with Egypt in 2000 and, two years later, disclosed that it was launching a project in Qatar. A letter of intent signed by ExxonMobil and Qatar gave rise to an agreement in 2004.

After considering projects in South America (Bolivia, Chile and Peru), Syntroleum turned to Russia and a cooperative agreement with Gazprom and to Nigeria for an offshore

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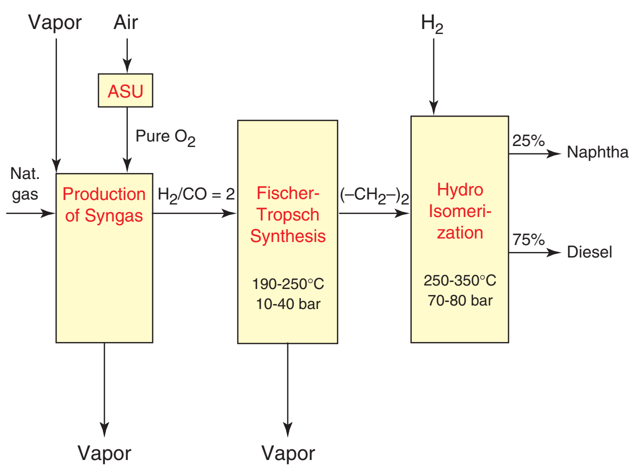
Basic diagram for a gas-to-liquids unit



The Fischer-Tropsch Technology

An FT gas-to-liquids (GTL) plant has 3 main units:

- First, **syngas** is produced from natural gas using vapor and/or oxygen. The syngas obtained should have a ratio of H_2 to CO of about 2. In addition to these 2 elements, a small amount of CO_2 is generated (about 5% of the total gas), which is problematical. In general, two basic processes are used to make syngas from natural gas: steam reforming and partial oxidation.

Steam reforming:

$$CH_4 + H_2O + Heat <==> 3 H_2 + CO$$

Partial oxidation:

$$CH_4 + 1/2\ O_2 <==> 2H_2 + CO + Heat$$

- Next comes the most important step in the GTL production chain: **Fischer-Tropsch synthesis**, used to convert syngas into long paraffinic chains of hydrocarbons. A Fischer-Tropsch process can be identified by the type of reactor, which in turn depends on the type of catalytic system used:
  - **Fixed bed**: This is the simplest FT process, in which syngas is sent through tubes filled with solid catalysts. Each reactor has a relatively limited capacity, but many reactors can be operated in parallel. This is the basic principle behind Shell's SMDS process.
  - **Fluidized bed**: Following the fluid catalytic cracking model, one can expect fairly large reactor capacities, but operation can be rather tricky. Sasol's Synthol process is based on this technology.
  - **The 3-phase (or slurry) reactor** : This type of process has been developed by Sasol (under the name Slurry Phase Distillate or SPD) and also by ExxonMobil. It combines the possibility of obtaining larger per-line capacities with greater operating flexibility. IFP and ENI are currently developing such technology with a pilot unit in Italy.
- These long chains must be broken and reshaped. This is done by **hydroisomerization** (a gentle hydrocracking method at about 70-80 bar), then products undergo conventional fractioning to obtain a naphtha cut (about one-quarter) and a diesel cut (about three-quarters).

barge-mounted project. Ivanhoe Energy declared in October 2005 that it was considering a 45-to-90,000 bpd project in Egypt based on the process developed by Syntroleum. Rentech has several undertakings in mind, including gas-to-liquids projects in Indonesia, Bolivia and Papua New Guinea and coal-to-liquids projects in the United States, Australia and China. Rentech is one of the rare operators whose units use iron instead of cobalt as a catalyst. Iron enables a broader range when it comes to selecting the feedstock (e.g. natural gas, coal, heavy residues), albeit to the detriment of the efficiencies obtained.

From all of these announcements, we can retain two things:

– After the Shell plant in Malaysia, the next large-scale GTL units will be those built by Sasol and Shell in Qatar (scheduled start-up: 2006 and 2009, respectively).

– A country holding large gas reserves, Qatar is a key target for the GTL sector. Six projects representing 800,000 bpd are under consideration by large operators from the oil industry (Chevron, Shell, ExxonMobil, ConocoPhilips and Marathon).

Under the name of Oryx, Qatar Petroleum and Sasol (with Chevron) have undertaken Project Qatar gas-to-liquids, representing 34,000 bpd. Started in early 2003 the unit will be built by Technip and should come onstream in 2006. In 2004, an initial contract to expand Oryx GTL (+68,000 bpd) and launch a second project (130,000 bpd) was entered into. This project represents a significant turning point for GTL technology, given its size and the players involved.

In 2004, QP also awarded Shell a $5 billion contract bearing on an integrated project (upstream and GTL) representing

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two units with a capacity of 70,000 bpd each. The design contract has been entrusted to the Japanese firm JCC. Phase One of this facility should start operation in 2009.

Most important GTL projects

Country/ Project	Company	Capacity bpd	Capex $billion	Start-up date
Qatar/Oryx GTL	Sasol/QP + 68,000	34,000	0.9 2009	2006
Nigeria/ Escravos GTL	Sasol Chevron/ NNPC	34,000	1.7	2007
Qatar/Pearl GTL	Shell/QP + 70,000	70,000 (upstream + facility)	5 2011	2009
Qatar QP	Sasol Chevron/	130,000	?	2010 (+)
Qatar	ExxonMobil	154,000	7	2011
Qatar	ConocoPhilips	160,000	?	2009 (+)
Qatar	Marathon (Syntroleum)	120,000	?	(+)
	Total	**840,000**		

(+): Projects postponed by QP.

Since the planned GTL projects represent between 50,000 and 130,000 bpd in capacity, they must be convenient to gas fields of a good size. For example, the production of 50,000 bpd requires 5 bcm of gas a year, or 130 to 150 bcm of available reserves, i.e. quantities equivalent to the requirements of a liquefaction line.

Taken collectively, the projects represent capacity of more than 800,000 bpd (or about 40 Mt/year) by the year 2010, if one includes the SasolChevron project in Nigeria and the undertakings now being considered by other oil companies using their own process or a process on offer from Syntroleum or Rentech.

Strengths and Weaknesses of GTL

Now that we have completed this project inventory, let's take a look forward at the future of GTL, which is hard to predict. The IEA forecasts 2.4 Mb/day of installed capacity by 2030, which appears high for this new technology yet low when compared to expected growth on the oil market (consumption may reach 120 Mb/day by 2030). Will the GTL sector do better or worse than this prediction? A brief review of the existing “brakes and accelerators” should give us an idea, in qualitative terms, of the future outlook.

The high unit cost of investment is definitely a brake. It is often two or three times higher than the unit cost for a refinery. As a result:

– Large-scale projects (50,000 bpd and larger) cost over a billion dollars, and this does not include upstream development. Only companies with very sound finances can undertake such a capital-intensive project.

– Operating costs need to be as low as possible to offset high capital expenditure. Not only must operating costs be kept under strict control, but the raw material (natural gas) must be available at relatively low cost ($0 to 1 $/Mbtu).

These cost imperatives restrict the development of large GTL projects to a few regions like the Middle East, Asia and Africa. Roughly speaking, LNG exporting countries are all likely to meet this criterion. GTL is thought of as complementing the LNG pathway, not as a competitor. This is a way of diversifying for most of these countries, as Qatar has already shown. Other countries are also considering GTL, including Algeria, which called for bids in 2005, as well as Indonesia, Iran and Australia.

Rough comparison: Capex for LNG and for GTL

For an annual gas production of 6 bcm, it is possible to develop:

– A liquefaction line (capacity: 4/5 Mt). Capex: $1,000 to 1,200 million.

– A GTL unit (60,000 bpd). Capex: $1,500 to 2,100 million (and eventually $1,200, if the $20,000/bpd target is reached).

(*Observation*: Cost differences are reduced by taking transport into account. For LNG, a methane carrier of 140,000 m^3 costs $150-200 million).

One strong point is that GTL gives smaller operators access to niche markets (10-20,000 bpd). A case in point is Syntroleum, which plans to develop barge-mounted GTL production units with capacities of about 20,000 bpd and with very low production costs (under $13/b). If this type of unit turns out to be profitable and technically feasible, this solution could be used to exploit smaller fields.

One downside of this technology is that its environmental balance needs to be improved. Total CO_2 emissions for the entire chain (production/vehicle), are at best equivalent to those obtained for the conventional refining pathway, given an energy efficiency that is significantly lower and below 60%. Very specific conditions are required to improve the

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CO_2 balance, for instance, the use of flare gas. From the economic standpoint, initial estimates indicate that it would cost an extra $2-4/b to reduce CO_2 emissions by 17 to 25%.

Another item in the "plus" column: the star product of the GTL pathway is a diesel cut of high quality, containing practically no sulfur or aromatics and with a very high octane number.

This diesel outperforms a standard diesel product from the environmental perspective, generating lower levels of pollutants of all types, especially NOx, CO and tailpipe emissions. Being highly paraffinic, it does have one slight disadvantage: a density of only 780 kg/m^3. Given the specifications currently in force, that means that it can only be used in blends, in Europe at least. However, this restriction is regulatory and not technical in nature. A lower density does not cause any technical problems in diesel engines.

After 2006

The GTL industry is still in its early days. Gradually, technological and design advances will no doubt help reduce the unit cost of investment to $20,000/bpd or lower. That's what happened for LNG. There is every reason to think that this pattern will repeat itself for GTL.

Estimated cost of producing FT diesel
(For a unit cost of investment of $20-35,000/bpd)

Capex :	$7.5-13/b (base: service life of 20 years)
Opex :	$4-5/b
Natural gas:	$4-10/b (or $0.5-1/Mbtu)
Total cost:	**$16-28/b**

→ Minimum crude price needed to achieve a rate of return of 10%: $14-23/b

The big question is whether this goal can be achieved for small units (capacities below 20-30,000 bpd) and offshore units. If so, it would favor the development of a large GTL market outside the natural group of target countries consisting of the large gas producers (at low cost).

As for large-scale projects, all eyes will be on the Sasol unit in Qatar when it starts up in 2006. The development of GTL will only continue at such a fast pace if this project goes smoothly and is a technical success, and also if the crude price stays higher than $20-25/b.

In the longer term, a technological leap forward is expected in syngas production. Many hopes are centered on ceramic membranes, used to separate oxygen from air while producing syngas from methane at the same time. Many R&D programs are underway, especially in the United States, where they enjoy strong support from the DOE.

Finally, FT diesel has all of the requisite characteristics to become the clean diesel of choice for large cities. Furthermore, it is consistent with the political objective of diversifying in the transport sector by means of providing alternative motor fuels produced from natural gas, coal or biomass, pending the possible advent of the age of hydrogen.

Bright Prospects

In the light of:

- The clear interest in GTL shown by LNG exporting countries;
- The probability of future technological and economic advances;
- The political will to diversify resources in the transport sector;
- Surging growth for diesel motor fuel and kerosene;

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– The probability that the crude price will stay high (over the $20/b threshold) for a long time;

it seems evident that FT diesel has a bright future and that it fits into a general trend in favor of developing new motor fuel production pathways, such as CTL (Coal-to-Liquids), BTL (Biomass-to-Liquids) and, in the longer range, hydrogen.

It seems plausible that total output could reach about 2.5 Mb/day by 2030. This would correspond to installed capacity of 100,000 bpd a year and represent annual capital expenditure of $2-2.5 billion. Whether the first industrial projects are a technical, economic and commercial success will be decisive in determining whether this market actually emerges in the near future.

Guy Maisonnier
guy.maisonnier@ifp.fr

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