

GAS TO LIQUIDS TECHNOLOGY: A FUTURISTIC VIEW

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Abstract :

Worldwide efforts aimed to the formulation of environment friendly diesel fuels able to meet the advanced fuel specifications of the 21st century and able to meet the global demand on diesel fuels. Synthetically derived gas-to-liquid (GTL) diesel fuel promises to meet these challenges and spearhead the way to the future. This technology will produce almost zero sulfur, high cetane, low aromatic diesel and naphtha which will be sold regionally and internationally.

GTL fuel is cleaner than any conventional fuel which will help the environment. It can be used in conventional diesel engines to give reductions in emission levels. Construction of such technology will reduce the gap between production and consumption by maximizing the gross profitability of natural gas.

Gas to Liquid synthetic fuel

Producing synthetic fuel from natural gas or other carbon sources with Fischer – Tropsch (FT) chemistry is not new. This technology is also referred to as gas to liquids (GTL). The FT process converts 10,000 SCF of gas into approximately 1 barrel of synthetic crude oil ⁽¹⁾. The proven reserves of natural

gas are estimated to be 5,000 trillion barrels of syncrude. the typical GTL process has three steps. The first step is converting natural gas to synthesis gas (carbon monoxide and hydrogen) using oxygen/air. This conversion requires expensive cryogenic separation of oxygen from air. In the second step, the synthesis gas is converted to long – chain paraffinic waxes by FT chemistry. In the final step, the waxes are selectively cracked to maximize the yields of synthetic fuels. Current research is focusing on eliminating the need to use pure oxygen and developing chain – limiting FT catalysts to avoid the hydro – cracking step.

Gas to Liquid Technology

It is technically feasible to synthesize almost any hydrocarbon from another; and in the past five decades several processes have been developed to synthesize liquid hydrocarbons from natural gas. There are two broad technologies for gas to liquid (GTL) to produce a synthetic petroleum product, (syncrude): a direct conversion from gas, and an indirect conversion via synthesis gas (syngas).

The direct conversion of methane, (typically 85 to 90 per cent of natural gas), eliminates the cost of producing synthesis gas but involves a high activation energy and is difficult to control ⁽²⁾. Several direct conversion processes have been developed but none have been commercialized & economically. Synthesis gas is produced by reacting methane (or carbon) with steam at elevated temperatures to yield a useful mixture of carbon oxides and hydrogen. It can be produced by a variety of processes and feedstocks. It may require the indicated compositional adjustment and treatment before use in the following major applications: Directly used for methanol synthesis.

The dried syngas can be used without further adjustment since there is a net conversion of both CO and CO₂ to methanol. Ammonia synthesis gas,

requiring maximum hydrogen production and removal of oxygen-bearing compounds. Oxo synthesis gas, requiring composition adjustment and CO₂ removal to give a 1:1 H₂:CO synthesis gas. Industrial gases, as a source of high purity CO, CO₂ or H₂, Reducing gas, a mixture of CO and H₂ requiring CO₂ removal before being used to reduce oxides ores to base metals.

Fuels either as a substitute fuel gas from a liquid or solid feedstock, or as an intermediate for Fischer-Tropsch or zeolite-based alternative liquid fuel technologies. Indirect conversion can be carried out via Fischer-Tropsch (F-T) synthesis or via methanol.

Fischer-Tropsch

Fischer – Tropsch (F-T) synthesis converts hydrogen and carbon monoxide into a wide boiling range of hydrocarbons. The hydrogen and carbon monoxide (synthesis gas) can be produced from a variety of carbon-bearing feed stocks. The resulting F-T hydrocarbon stream can be further processed to specific boiling – point fractions and upgraded to high – value products.

Of special interest is the diesel fuel fraction because it requires little processing from the F-T oil and has desirable characteristics including very low sulfur and aromatic content, high cetane index, and it burns exceptionally cleanly in a compression – ignition engine.

The discovery of F-T chemistry in Germany dates back to the 1920s⁽³⁾ and its development has been for strategic rather than economic reasons, as in Germany during World War II and in South Africa during the apartheid era. Since that time , interest in the technology has come and gone, generally in phase with increases in the cost of crude oil or supply restrictions.

Two of the first plant in the U.S. were the Carthage Hydrocol plant in Brownsville, TX in the late 1940's and the U.S. Bureau of mines plant in

Louisiana, TX in the early of 1950's⁽³⁾. Recent peak in F-T interest appears to have been stimulated by several factors including environmental issues and the resulting interest in clean – burning liquid fuels, a desire for fuels derived from secure, domestic feed stocks, interest in exploiting standard or associated gas resources and heavy residues, among others⁽⁴⁾.

Renetech, Inc., has been developing F-T technology since 1981. this work has involved catalyst development and manufacturing, pilot – plant operation, product characterization, flow sheet development, process modeling, and the design, construction and operation of full – scale plants.

F-T chemistry is an example of Complexes that containing two or more adjacent metal centers⁽⁴⁾ which, offer an added chemical dimension over those containing a single metal; not only can the metals act independently but they can also act in a cooperative manner leading to chemistry that differs appreciably from that displayed by the single metal counterparts. These compounds either have all metals the same or metals which differ, and utilize bridging groups such as the diphosphines, $\text{Ph}_2\text{PCH}_2\text{PPh}_2$ and $\text{Me}_2\text{PCH}_2\text{PMe}_2$, to hold the metals together maintaining the integrity of the complexes during the reactions as shown in Figure (1).

Currently many suppliers are modeling the involvement of adjacent metals in Fischer-Tropsch chemistry using a variety of binuclear complexes containing either Rh or Ir together with different combinations of Co, Rh, Ir, Fe, Ru or Os, and are investigating a series of complexes containing early transition metals (Ti, Zr) together with late metals (Co, Rh, Ni, Pd, Pt) for use in olefin polymerization reactions⁽⁵⁾.

Renetech's focus on iron – based F-T catalyst is based on a number of reasons including cost, availability, disposability / toxicity, and the ability to work with a wide range of synthesis gas hydrogen to carbon monoxide ratios.

Because of this last advantage of iron – based F-T catalysts, a wide range of feedstocks can be considered including natural gas or other light hydrocarbon gases, liquids including naphtha, heavy oil, asphalt, refinery bottoms, and solids including coal, bitumen, petroleum coke and biomass ^(6,7).

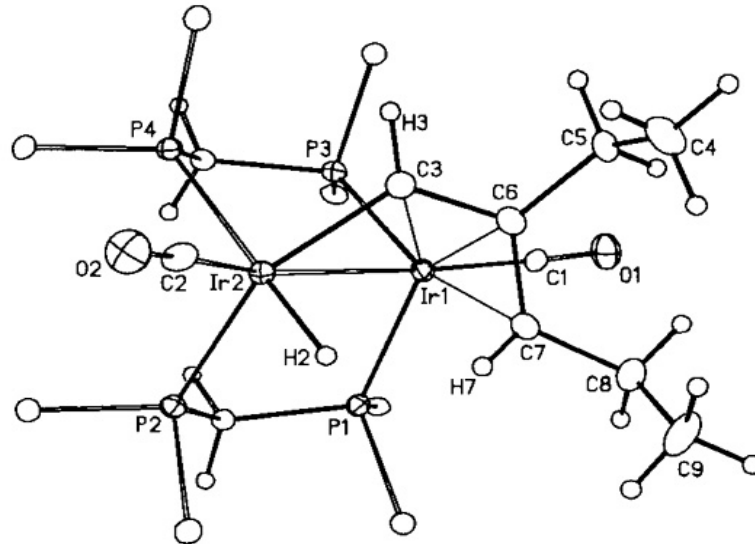
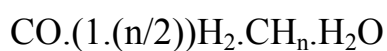


Figure (1) : Binuclear complexes containing either Rh or Ir

The FT chemical reaction can be represented as ⁽⁸⁾ :



Where n is the average H/C ratio of hydrocarbons produced.

A reaction rate expression for FT chemical reaction IS

$$\frac{(kP_{\text{CO}}P_{\text{H}_2}^2)}{(P_{\text{CO}} P_{\text{H}_2} \cdot bP_{\text{H}_2}\text{O})}$$

Where k is the rate constant; b is the adsorption parameter; P is the partial pressure.

Syngas

The syngas step converts the natural gas to hydrogen and carbon monoxide by partial oxidation, steam reforming or a combination of the two processes. The key variable is the hydrogen to carbon monoxide ratio with a 2:1 ratio recommended for F-T synthesis. Steam reforming is carried out in a fired heater with catalyst-filled tubes that produces a syngas with at least a 5:1 hydrogen to carbon monoxide ratio. To adjust the ratio, hydrogen can be removed by a membrane or pressure swing adsorption system.

Helping economics is, if the surplus hydrogen is used in a petroleum refinery or for the manufacture of ammonia in an adjoining plant. The partial oxidation route provides the desired 2:1 ratio and is the preferred route in isolation of other needs. There are two routes: one uses oxygen and produces a purer syngas without nitrogen; the other uses air creating a more dilute syngas. However, the oxygen route requires an air separation plant that increases the cost of the investment.

To convert natural gas (mostly methane) to syngas (mixture of H₂ and CO), the designer can choose from the following four well established reforming technologies⁽⁹⁾:

a) Steam reforming

An obvious advantage of steam reforming is that it does not need an oxygen plant. However, since steam reformers are more costly than either Partial Oxidation (POX) or Auto-Thermal Reformers (ATR), there is a minimum plant size above which the economy of scale of a cryogenic oxygen plant in combination with POX or ATR reformer is cheaper than a steam reformer on its own. Other disadvantage of steam reforming are: syngas with a H₂/CO ratio > 4, which is much higher than what is optimally needed by Fischer-Tropsch section; lower methane conversion due to a maximum

operating temperature of below 900°C; the high usage rate of water makes it unsuitable for arid regions.

Recycling of CO₂ and removal of the excess of H₂ by means of membranes can lower the H₂/CO ratio to a level acceptable to the F-T reaction. Since the methane conversion is also a function of the operating pressure, decreasing the operating pressure of the reformer can increase the methane conversion. Due to the costs involved with these steps, it is most likely that steam reforming will only be considered when one or more of the following conditions hold: a relatively small GTL plant with a capacity of well below 10 000 bpd; the additional H₂ can be used for other applications like methanol or ammonia production; the natural gas has a high CO₂ content; suitable water can be obtained at a low cost.

b) Partial oxidation reforming (POX)

The non-catalytic partial combustion of methane produces syngas with a H₂/CO ratio < 2 close to the premium needed by F-T synthesis. This low H₂/CO ratio gas results from the very little, if any, steam that is used in the process.

Due to the absence of catalyst, the reformer operates at an exit temperature of about 1400°C. This high temperature and the absence of catalyst have the following disadvantages as compared to ATR : formation of soot and much higher levels of ammonia and HCN, which necessitates the use of a scrubber to clean the gas; higher oxygen consumption; due to the absence of water-gas shift reaction, the unconverted methane as well as methane produced by F-T reaction can not be recycled to the reformer without removing the CO₂ from the F-T tail gas.

Depending on the energy needs of the plant, syngas from the reformer can either be cooled by means of a water quench or by the production of steam in a heat exchanger. A quench system is the less costly of the two, but is also

less thermally efficient. In designing a POX-based GTL plant, the choice between a quench or a waste heat reboiler will depend on the relative cost of capital and energy.

c) Auto-thermal reforming (ATR)

Unlike POX, ATR uses a catalyst to reform the natural gas to syngas in the presence of steam and oxygen. Due to the milder operating conditions (output temperature $\pm 1000^{\circ}\text{C}$) and the use of steam (steam/carbon (S/C) ratio normally more than 1.3), the syngas is soot-free and less ammonia and HCN are produced as compared to a POX.

However, at a (S/C) ratio of 1.3 the syngas will have a H_2/CO ratio of about 2.5, which is higher than the ratio needed by the F-T section. The H_2/CO ratio can be controlled by a combination of lowering (S/C) ratio and recycling CO_2 to the reformer. Although (S/C) ratios below 1.3 are not commercially used, Holdor Topsoe and Sasol have successfully completed low (S/C) ratio tests on a commercial scale at Sasol's synfuels plant in South Africa ⁽¹⁰⁾.

Some of the other design parameters of the syngas section that influence the cost and thermal efficiency of the GTL plant are as follows: (a) the preheat temperatures of oxygen and natural gas. The higher these temperatures are, the less oxygen will be used. The maximum preheat temperatures are determined by safety factors and by the need to prevent soot formation; (b) the pressure of the steam generated in the waste heat reboiler.

The higher the steam pressure, the more efficient energy can be recovered from the steam, but the more costly the steam and boiler feed water treatment systems become. The optimum steam pressure will be determined by the relatively cost of capital and energy.

d) Combined reforming

By combining a steam reformer with an ATR, better utilization can be obtained than with either steam or auto-thermal reforming alone. Depending on the degree of energy integration and the specific operating conditions, the thermal efficiency of the GTL plant can be improved by 1-2 percentage points. Although less expensive than steam reforming on its own, this type of reforming is more expensive than ATR and choice between combined and auto-thermal reforming will depend on the cost of natural gas.

Conversion

Conversion of the syngas to liquid hydrocarbon is a chain growth reaction of carbon monoxide and hydrogen on the surface of a heterogeneous catalyst. The catalyst is either iron- or cobalt-based and the reaction is highly exothermic ⁽¹¹⁾.

The temperature, pressure and catalyst determine whether a light or heavy syncrude is produced. For example at 330°C mostly gasoline and olefins are produced whereas at 180 to 250°C mostly diesel and waxes are produced. There are mainly two types of F-T reactors.

The vertical fixed tube type has the catalyst in tubes that are cooled externally by pressurized boiling water. For a large plant, several reactors in parallel may be used presenting energy savings. The other process is uses a slurry reactor in which pre-heated synthesis gas is fed to the bottom of the reactor and distributed into the slurry consisting of liquid wax and catalyst particles. As the gas bubbles upwards through the slurry, it is diffused and converted into more wax by the F-T reaction. The heat generated is removed through the reactor's cooling coils where steam is generated for use in the process.

Sasol's syngas conversion plants in South Africa utilize both the high and low temperature F-T processes. The high temperature process is mainly used for the production of gasoline and chemicals like alpha olefins and the low temperature process for the production of waxes.

Due to its high activity and long life, cobalt-based F-T catalyst is currently the catalyst of choice for the conversion of syngas to liquid fuels. The exothermic nature of F-T reaction combined with the high activity of the cobalt catalyst makes the removal of heat from the reactor of critical importance. In case of a tubular fixed bed reactor.

This becomes even more problematic due to the inherent temperature profiles inside the tube. This problem can be controlled by finding the balance between the tube diameter and the usage of a "quench" medium such as the recycle of the inerts.

Due to the good mixing and heat transfer characteristics of a slurry phase reactor, the temperature control in such a reactor is much less of a problem than in a tubular fixed bed reactor. Care must, however, be taken in the design of such a reactor that, during normal operating conditions and also, during the shutdown of the reactor, no stagnant zones with poor mixing occur which may result in localized hot spots.

If the catalyst is exposed to high a temperature, carbon will be formed, which may damage the structural integrity of the catalyst. Another critical design aspect of a slurry phase reactor is the separation of the catalyst from the wax. Sasol was successful in the development of a very efficient catalyst/wax separation system. By matching the characteristics of the catalyst with those of the separation system, the loss of catalyst can be restricted to a few ppm of catalyst in the wax produced by the F-T process.

Manipulating the operating conditions (e.g. temperature, pressure and gas composition) can control the product spectrum of the F-T process. Since the H₂/CO ratio of the syngas is an important design variable to maximize the

production of high quality diesel, the designs of the reformer and F-T sections can not be done in isolation.

The most effective design for both units can only be obtained by taking the mutual interaction between these units into account.

Method of Conversion

The baseline process flow diagram is shown in Figure (2). Gasification is used to generate the synthesis gas from natural gas feed plus oxygen and water. The gasifier effluent is cooled by hx1 as in figure (2) and the resulting steam is sent to the steam turbine portion of the combined cycle plant.

Syngas from gasification is sent to FT reactor. Exothermic heat of reaction from FT unit generates steam in hx2, which is sent to the steam turbine. FT overhead product is cooled by hx3 and the resulting steam is also sent to the steam turbine. The FT over head product stream is separated into five streams in the hydrocarbon unit : water / oxygenates, naphtha, diesel, wax and over head tail gas. Hydro – cracking can be used to remove the wax stream and to increase the naphtha and diesel streams.

Additionally, it is necessary to remove carbon monoxide from the recycle loop to prevent excessively low hydrogen to carbon monoxide ratios in the synthesis gas.

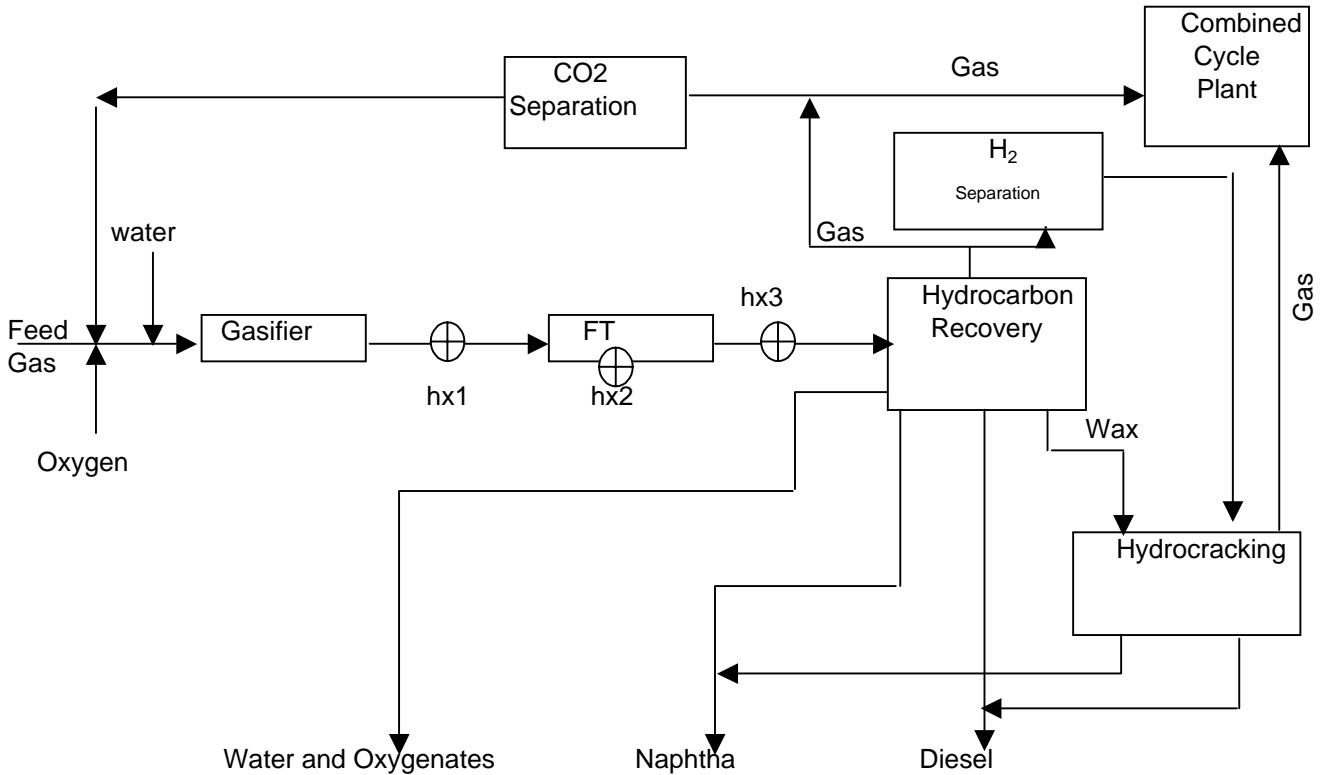


Figure (2) : Baseline flow sheet.

Hydro-processing

The wax and hydrocarbon condensate produced by the low temperature F-T process is predominantly linear paraffins with small fraction of olefins and oxygenates. The hydrogenation of the olefins and oxygenates and the hydrocracking of the wax to naphtha and diesel can be done at relatively mild conditions. In the design of the hydro-cracker, a balance must be found between the per-pass conversion, diesel selectivity and diesel properties. The higher the per-pass conversion, the smaller the cracker will be due to the lower recycle of material back to the cracker.

This will, however, be at the expense of the diesel selectivity, since over-cracking of the liquid to gases will occur. Another compliance factor is that the per-pass conversion also influences the diesel quality. The higher the

pre-pass conversion, the better the cold flow properties but the lower the cetane value will be, due to the increased degree of isomerisation ⁽¹²⁾.

GTL Technology Commercialization and development

Sasol is a synfuel technology supplier established to provide petroleum products in coal-rich but oil-poor South Africa. The Moss gas complex at Mossel Bay in South Africa was commissioned in 1993 and produces a small volume of 25 000 barrels per day. Sasol has developed high performance cobalt-based and iron based catalysts for these processes.

The company converts 100 MMscfd of natural gas into 10 000 barrels a day of liquid transport fuels, that can be built at a capital cost of about US\$250 million. In June 1999, Chevron and Sasol agreed to an alliance to create ventures using Sasol's GTL technology. The two companies have conducted a feasibility study to build a GTL plant in Nigeria ⁽¹³⁾.

With its large gas reserves, Norway's Statoil has been developing catalysts and process reactors for an F-T process to produce middle distillates from natural gas. The Statoil process employs a three-phase slurry type reactor in which syngas is fed to a suspension of catalyst particles in a hydrocarbon slurry which is a product of the process itself. The process continues to be challenged by catalyst performance and the ability to continuously extract the liquid product.

Shell has built a 12 000 bbl/day plant in Bintulu, Malaysia. The process consists of three steps: the production of syngas with a H₂:CO ratio of 2:1; syngas conversion to high molecular weight hydrocarbons via F-T using a high performance catalyst; and hydro-cracking and hydro-isomerisation to maximize the middle distillate yield. The products are highly paraffinic and free of nitrogen and sulfur.

Shell is investing US\$6 billion in gas to liquids technologies over 10 years with four plants. It announced in October 2000, agreement with the

Egyptian government for a 75 000 bbl per day (3.8 million tpa)⁽¹⁴⁾ facility and a similar plant for Trinidad & Tobago. In April 2001, it announced interest for plants in Australia, Argentina and Malaysia at 75 000 bbls/day costing US\$1.6 billion.

The Syntroleum Corporation of the USA ⁽¹⁵⁾ is marketing an alternative natural-gas-to-diesel technology based on the F-T process. It claims to be able to produce synthetic crude at around \$20 per bbl. The syncrude can be further subjected to hydro-cracking and fractionation to produce a diesel/naphtha/kerosene range at the user's discretion. In February 2000, Syntroleum Corporation announced its intention to construct a 10 000 barrel per day (requiring 130 terajoules/day or 800 000 tonnes per year of gas) natural gas-to-liquids plant for the state of Western Australia to become the first location in the world to acquire full access to Syntroleum technology.

Rentech of the Colorado USA ⁽¹⁶⁾, has been developing an F-T process using molten wax slurry reactor and precipitated iron catalyst to convert gases and solid carbon-bearing material into straight chain hydrocarbon liquids. The Statoil process employs a three-phase slurry type reactor in which syngas is fed to a suspension of catalyst particles in a hydrocarbon slurry which is a product of the process itself. During 2000, the company acquired a 75 000 tonne per year methanol plant in Colorado, USA for conversion into a GTL facility producing 800 to 1000 bbl/day of aromatic free diesel, naphtha and petroleum waxes. The facility, the first in the US will cost about \$20m to convert ⁽¹⁷⁾.

Economics

Clearly too, the feedstock gas cost will have an influence as it may vary widely depending on alternative applications. Using gas that otherwise would be flared with zero (or even negative costs by avoiding penalties for violations of environmental regulations or increased costs related to compliance with environmental restrictions) would help the production economics. As one

indication, based on current efficiencies, a change in the cost of gas feedstock of \$0.50 per thousand cubic feet (per one gigajoule) would shift the synthetic crude oil price around \$5 per barrel.

This is predicated on that in general the processes requires about 10.5 gigajoules of gas to produce 1 bbl of fuel with variations depending on scale, quality of output and variable production costs traded off against capital costs. Presently there are only three GTL facilities have operated to produce synthetic petroleum liquids at more than a demonstration level: the Moss gas Plant (South Africa), with output capacity of 23 000 barrels per day, Shell Bintulu (Malaysia) at 20 000 barrels per day and the subsidised methanol to gasoline project in New Zealand.

A joint project in Nigeria of Chevron and Sasol Ltd has been announced with a 30 000 barrel per day plant that would cost \$1 billion using the Sasol Slurry Phase Distillate process.

It is expected to begin operations in 2003 at costs claimed to be competitive with crude oil prices around \$17 per barrel. The Nigeria project will benefit from the infrastructure already in place for nearby oil and gas production and export facilities, although it is unclear whether, or to what extent, subsidies or other considerations helped to lower the estimated costs.

An USA Energy information administration assessment of a hypothetical GTL project estimated the cost of GTL fuel at almost \$25 per barrel. It is relevant to note that, one US oil company has estimated a \$5 per bbl penalty in extra refining investment to make a fuel meeting the new low (CARB's) ultra-low-aromatics and low in sulfur. While the U.S. Department of Energy estimates that F-T diesel could fetch as much as an \$8 to \$10 a barrel premium (18).

Studies done by Sasol indicated that the total installed cost of a two-train 30 000 bpd GTL plant is in the order of about U\$24000/daily barrel. It is also believed that the capital cost can be further decreased to about U\$20000/daily

barrel by: (a) the economy of scale of larger single train capacity; (b) the economy of scale of adding trains; (c) improved process integration and optimization; (d) progressing up the learning curve. The capital cost associated with the syngas generation section is more than 50% of the total ISBL cost of the plant⁽¹⁹⁾.

Environmental Benefits of the gas to liquid Process

It is worth to mention that however, GTL is not competitive against conventional oil production unless the gas has a low opportunity value and is not readily transported. GTL not only adds value, but capable of producing products that could be sold or blended into refinery stock as superior products with less pollutants for which there is growing demand.

Reflecting its origins as a gas, gas to liquids processes produces diesel fuel with an energy density comparable to conventional diesel, but with a higher cetane number permitting a superior performance engine design. A higher cetane number represents a lower flame temperature, providing a reduction in the formation of oxides of nitrogen (NO_x) that contributes to urban smog and ground level ozone.

Another “problem” emission associated with diesel fuel is particulate matter, which is composed of un-burnt carbon and aromatics, and compounds of sulfur. Fine particulates are associated with respiratory problems, while certain complex aromatics have been found to be carcinogenic. Low sulfur content, leads to significant reductions in particulate matter that is generated during combustion, and the low aromatic content reduces the toxicity of the particulate matter reflecting in a worldwide trend towards the reduction of sulfur and aromatics in fuel.

Fischer-Tropsch diesel has a cetane number in excess of 70. Naphtha produced is sulfur free and contains a high proportion of paraffinic material suitable as cracker feedstock or the manufacture of solvents.

Finally, as has been discussed before, this kind of technology produce an alternative diesel fuel with a high quality and low values of emissions as shown in Table (1) and (2) ⁽²⁰⁾.

Table (1) : Comparison of GTL synthetic diesel properties .

Property	Unit	ASTM D - 4815	EN 590 : 1999	JIS K 2204 : 1997	ESS : 2001	GTL DIESE L
Cetane index		-----	46 min	50 min	46 min	76 min
Polycyclic aromatic hydrocarbons	% (m/m)	-----	11 max	-----	-----	Not detecte d
Sulfur content	% (m/m)	0.05 max	0.035 max	0.05 max	1 max	Not detecte d
Flash point	°C	52 min	above 55	50 min	55 min	88 min
Pour point	°C	-----	-----	+5 max	***	-----
Cold filter plugging point	°C	-----	**	-----	-----	-2
90 % (V/V) recovered at 95 % (V/V) recovered at	°C	282 – 338	-----	360 max	-----	-----
	°C	-----	360 min	-----	-----	-----
Final boiling point	°C	-----	-----	-----	-----	358
ESS; Egyptian Standard Specification.						
** For climate dependent requirements options are given to allow for seasonal grades to be set nationally. The options are for temperate climates six CFPP as follow :						
Grade A	Grade B	Grade C	Grade D	Grade E	Grade F	
+5	0	-5	-10	-15	-20	
*** 3 For Dec. to Mar.; 9 for April, May, Oct., and Nov.; 15 for June to Sept.						

Table (2) : California emission standards of heavy duty diesel engines versus F-T diesel testing .

State standard	Emissions (g/bhp-hr)				
	CO	Non – methane HCO	Particulate matter	Formaldehy de	Nitroge n oxides
California diesel 1	15.50	1.20	0.10	0.05	5.00
California (LEV) 1	14.40	3.50	0.10	0.05	4.00
California (UNLEV) 1	7.20	2.50	0.05	0.03	4.00
F-T Diesel fuel	0.97	0.20	0.10	Not detected	4.60

Case Study:

Since Egypt has a proven reserve of about 65 trillion cubic feet of natural gas by the year 2004 as shown in Fig.3, it is preferable to monetize this reserve through GTL technology. There are two ways by which GTL plant can be constructed in Egypt. The first is to build up a plant of capacity 70000 bpd liquid products which yields 49413 bpd (70.59%) gas oil, 18529 bpd (26.47%) naphtha, 2058 bpd (2.94%) LPG.

Construction of such plant in Egypt will maximize naphtha, LPG and gas oil production and provide the country with gas oil self-dependence, prevent gas oil importation and narrow the consumption-production gap of LPG.

The second is to build up a plant of capacity 70000 bpd liquid products which yields 42000 bpd (60%) gas oil, 10500 bpd (15%) naphtha, 17500 bpd (25%) kerosene. Such plant will provide the country with more cash money flow and does not be efficient to fulfill gas oil self-dependence. The economic studies, herein under, are based on natural gas prices; 0.75, 0.85, 1, 1.25 US \$/MM BTU; discount rate 2,5,7,10; operating time 8000 hours (333 days)/year; life period 20 years; tax exemption 10 years; taxes 40%; average prices of the year 2004 307.53 US \$ for gas oil, 343.35 US \$ for kerosene, 328.6 US \$ for naphtha, 321.08 US \$ for LPG and 1 US \$ = 6.18 L.E. Results obtained are demonstrated in Tables 3,4.

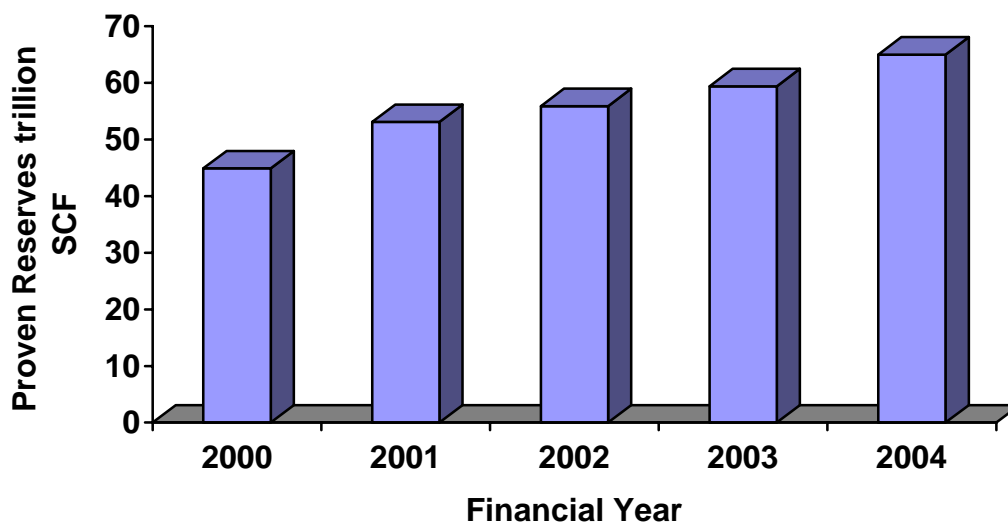


Fig.3 Egyptian proven reserves of natural gas.

Case No. 1 based on 0.85 US \$ / 1000 SCF Natural gas, Costs (bn US \$)

Intial investment	1.77	Cash Flow
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Natural Gas Purchases	3.9627	0.7605
* Operation	1.203867	
Total cost	6.936567	

Case No. 1 based on 1 US \$ / 1000 SCF Natural gas, Costs (bn US \$)

Intial investment	1.77	Cash Flow
Natural Gas Purchases	4.662	0.7182
* Operation	1.35072	
Total cost	7.78272	

Case No. 1 based on 1.25 US \$ / 1000 SCF Natural gas, Costs (bn US \$)

Intial investment	1.77	Cash Flow
Natural Gas Purchases	5.8275	0.6477
* Operation	1.595475	
Total cost	9.192975	

Case Study No. 2 based on 0.75 US \$ / 1000 SCF Natural gas, Costs (bn US \$)

Intial investment	1.77	Cash Flow
Natural Gas Purchases	3.4965	0.7887
* Operation	1.105965	
Total cost	6.372465	

* Operation costs (21% of total investment) and include labor, maintance, utilities and other costs

Case Study No. 2, Profits (bn US \$)

Product	Kerosene	Naphtha	Gas oil	Electricity	Water
Sales	5.0273	2.5574	11.652	1.08	0.06
Total Sales	20.3767				
Discount Rate	2%				
Gas Price US \$	0.75	0.85	1	1.25	
Gas Purchases	3.4965	3.9627	4.662	5.8275	
Net Present Value	8.9011	8.5322	7.9788	7.0566	
Discount Rate	5%				
Gas Price US \$	0.75	0.85	1	1.25	
Gas Purchases	3.4965	3.9627	4.662	5.8275	
Net Present Value	6.4471	6.166	5.7442	5.0414	
Discount Rate	7%				
Gas Price US \$	0.75	0.85	1	1.25	
Gas Purchases	3.4965	3.9627	4.662	5.8275	
Net Present Value	5.2683	5.0294	4.6709	4.0734	
Discount Rate	10%				
Gas Price US \$	0.75	0.85	1	1.25	
Gas Purchases	3.4965	3.9627	4.662	5.8275	
Net Present Value	3.9557	3.7636	3.4755	2.9953	

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