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The Future of Gas to Liquids as a Gas Monetisation Option

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Abstract: The paper introduces gas to liquids (GTL) as a monetising option from a technology, marketing and project perspective. GTL is complementary to LNG and pipelines. At the same time, using natural gas as a source for fuels in the form of GTL helps countries around the world to diversify their energy supplies. Furthermore, gas-based products are inherently cleaner than oil products. Shell's proprietary GTL technology or SMDS (Shell Middle Distillates Synthesis), is discussed in some detail. The paper also covers the challenges for successful implementation of GTL projects and why Shell is well positioned to take a lead in the industry on the basis of its long standing and broad experience in GTL research, plant operations, marketing and excellent track record in mega projects in the last thirty years. Shell's commitment to GTL is best demonstrated by the recent signing of a Heads of Agreement with Qatar Petroleum for the construction of the world's largest GTL plant. A key success factor is Shell's experience with marketing quantities of high quality GTL products from its 12,500 barrels per day plant at Bintulu, Malaysia since 1993. Further marketing opportunities will arise when new GTL capacity comes on-stream in the middle east when more quantities will become available to bulk users. Amongst the most interesting market will be automotive transportation, where clean GTL fuels can be positioned as an 'alternative fuel beyond oil' providing energy security to host countries. Shell is actively engaging with a number of regulators, automotive companies and governments worldwide including China, to demonstrate the performance of GTL and its cost effectiveness in reducing local emissions. An added benefit is that GTL can use existing infrastructure and requires no investment. Finally, the paper briefly discusses the coal to liquids (CTL) process as an alternative route to produce high quality GTL products and the key issues relating to the process.

Key words: gas to liquids (GTL), coal to liquids (CTL), liquefied natural gas (LNG)

1. Gas commercialisation options: GTL complementary to LNG

Towards the end of the last century, the world, and in particular the Asia-Pacific region, experienced a period of strong gas growth. Gas consumption in Asia-Pacific grew to 305 billion cubic meters (bcm) in 2001, or 12.7% of world total. Over the previous decade, demand in Asia-Pacific outpaced the growth in global gas consumption (80% versus 20%). Likewise, since 1980 the region's share of global primary energy has risen from 18% to 26%. Demand is set to double by 2020 to about 35%–40% which means that two-thirds of the world's incremental energy will be consumed in this region.

The current proven oil and gas reserves in the Asia-Pacific region however are much less than the share of its energy needs. Over the last 150 years, there was a steady fall in carbon intensity of the world primary energy and we expect this "decarbonisation" trend to continue. Hence, coal, although readily available in *e.g.* China, will require a technology breakthrough to be part of the clean energy solutions for Asia.

Until recently, there were only two ways to transport large quantities of natural gas to the ultimate

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customer, either by pipeline or as liquefied natural gas (LNG). LNG was really the only viable alternative when the reserves were located far from the major customers, as is the case of the Middle East.

A constraint however on the growth of LNG has always been the 'slow' build up of new LNG markets and the construction of regasification capacity. Given this situation, the increasing commercial viability of gas-to-liquids (GTL) technology, with a "world-scale" plant concept (70000 barrels-per-day (bpd) or higher), will undoubtedly have an effect on the demand side of the gas balance equation.

Owners of gas supplies far from existing and potential markets now have an alternative to develop their resource. If they do not want to wait for a suitable LNG or natural gas market to open up, they have an option of turning their gas into valuable liquid fuels. With a middle distillate market at around 20 times the size of the current LNG market, the potential market for GTL is almost unlimited.

There are other driving forces behind the current interest in GTL. Major gas reserves are in many cases not located in the same places as major crude oil reserves. Hence, the increased use of gas to produce liquid fuels provides an opportunity for consumers to diversify their supply sources.

"Market-pull" on clean fuels will also be a catalyst in GTL commercialisation. Tomorrow's global energy markets will be very different from those in the nineties. The global trend towards cleaner fuels and advances in drive train technology present a major opportunity for GTL. For example, GTL fuel (diesel) is a gas-based fuel, that fits well in existing diesel infrastructure and is also compatible with many possible directions of the future transportation fuel markets.

Shell is playing a leading role in the development and promotion of GTL technology and market and is actively seeking opportunities around the world for several second-generation GTL developments. In October 2003, Shell signed a Heads of Agreement with Qatar Petroleum to build the world's largest GTL plant in Ras Laffan, Qatar which will produce 140,000 bpd of products primarily naphtha and transport fuel. The project will be developed in two phases with the first phase operational in 2009 producing around 70,000 bpd of GTL followed by the second phase two years later. This project provides further evidence of Shell's leadership in GTL technology and provides Qatar with an attractive alternative to commercialize their enormous gas reserves.

2. GTL technology development: past and present

The conversion of GTL products was pioneered in Germany during the 1920s, using a process, which came to be known as Fischer-Tropsch (F-T) synthesis, when Germany found itself short of petroleum but with ample reserves of coal. A concerted effort to secure the supply of liquid fuels resulted in the development of high-temperature F-T plants, which turned coal into gas and then into liquids.

Although a technical success, the F-T process could not compete economically with the refining of crude oil and consequently, early applications were limited to fulfill supply shortage where economic competitiveness was less relevant. Today we see a renewed interest in F-T synthesis in the form of GTL, using low-temperature F-T conversion of natural gas primarily into middle distillates such as gasoil, naphtha and optionally kerosene.

This has eventuated not just as a result of the abundant supply of economically priced gas, but is also driven by the global development in fuel qualities and the need to improve local air quality in many cities around the world.

At the same time, increased efficiencies in the process, the ability to build bigger plants to capture economies of scale based on operational experience, have combined to make GTL commercially viable.

3. Shell GTL process: a unique and competitive technology

Shell's state-of-the-art proprietary GTL process, the Shell Middle Distillate Synthesis (SMDS), is currently used in Shell's Bintulu plant in Malaysia. This is the world's first and only integrated low-temperature Fischer-Tropsch GTL plant at a commercial scale.

The three main process stages used in SMDS are common to most gas-to-liquids technologies. In SMDS they are called syngas manufacture, F-T synthesis and hydrocracking.

Synthesis gas or more commonly known as syngas is a mixture of carbon monoxide with hydrogen which can be produced from natural gas in several ways. The most suitable way for SMDS is to use the Shell Gasification Process with oxygen supplied from an adjacent air separation unit. Used in commercial plants since 1956, the process has several advantages.

It is a direct process without the need for a catalyst; it has very high process efficiency; and is reliable as well as cost effective.

The F-T (or heavy paraffin) synthesis stage is the key to the commercial success of the GTL process. Here the syngas reacts on a F-T catalyst to produce paraffinic hydrocarbons and water. High yields of desirable middle distillates products are essential for low unit cost.

Traditional high temperature F-T catalysts based on iron and cobalt are best suited for production of motor gasoline and other light products, from other feedstocks such as coal.

Figure 1. Shell Middle Distillate Synthesis (SMDS) plant in Bintulu, Malaysia

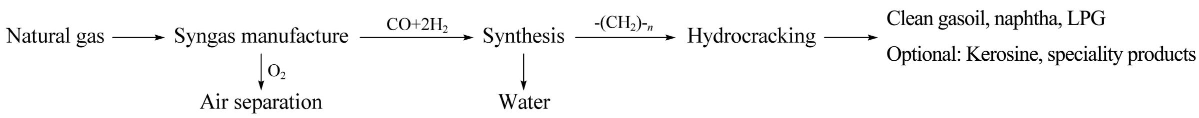

Figure 2. Simplified GTL scheme of SMDS Bintulu plant

The way the catalyst is deployed in the synthesis stage is also very important. The SMDS process offers several distinct advantages. Firstly, the design is comparatively simple to scale up, a crucial factor for large-scale commercial plant success and, secondly the catalyst can be regenerated in-situ. Another advantage is the ability to operate at lower temperatures while maintaining reactor productivity, which results in better levels of production of higher paraffins and lower syngas consumption.

In the final stage of the SMDS process, the raw synthesis product is hydrocracked over a proprietary catalyst and the output is fractionated. In this stage oxygenated compounds are removed and the long chain paraffins are cracked and isomerised to produce middle distillates with a small proportion of gaseous products.

A recent Shell-sponsored study by PricewaterhouseCoopers shows that compared to a crude oil refinery system, an SMDS system has much less impact on air acidification, far lower impact on smog formation and no greater impact on global warming. To ensure that the total environmental impact was assessed, the study utilised a comprehensive life-cycle assessment methodology in accordance with ISO standards. [1]

4. Learnings from Bintulu: key to the success of 2nd generation SMDS projects

Nine years of operational experience in Bintulu plant has confirmed the SMDS process on a commercial scale. Experience gained during ramp-up and ongoing operations have provided a sound basis for the scale-up from 12500 to 70000–75000 bpd for the second-generation SMDS plants.

A wealth of experience has been gained in operating a highly integrated gas plant, and at the same time, abundant knowledge and expertise have been developed on SMDS products and their applications. The operational staff and technical experts went through an intensive learning experience, rectifying 'new' problems along the way such as design and engineering, gas supply reliability and gaining better understanding of process dynamics, such as integrating a complex steam and utilities system. Key operational procedures like start-up/shut-down, safeguarding and catalyst regeneration were optimised.

These teething problems served as essential learnings for future success. One measure of plant reliability is system effectiveness (SE) defined as available production capacity over sustainable maximum production at 100% availability. After commissioning, the SE gradually improved to more than 90% within two years. Vital learnings and remedies are captured in a comprehensive incident database, which proved valuable in plant troubleshooting and problem solving.

On the marketing front, pre-marketing of SMDS products started three years prior to plant commissioning with samples produced from the pilot plant. The first few years were spent on identifying and developing differentiated markets-refinery blending for ultra low sulphur diesel, chemical and detergent feedstocks, odourless solvents and various wax applications. Among the challenges encountered in the early period were consistency of quality and security of supply but these were resolved with improved quality control and plant reliability.

Close integration between marketing, operations and technology allowed optimisation in the value chain with strong support from affiliated companies. Staff development and training remained a priority to preserve continuity in market and applicational knowledge. The success of marketing is best demonstrated by the gradual increase in average product price from 1993 to 2001 reflecting a richer product slate and a shift in market segmentation towards specialities.

Figure 3. Heavy paraffin synthesis reactors in SMDS plant, Bintulu, Malaysia

5. Next generation: world-scale SMDS plants

Building on the experience of the low-temperature F-T catalyst used at Bintulu, and further success in research work, Shell has developed a new second-generation catalyst. When used in the Shell proprietary multi-tubular reactor, this catalyst yields more than 90% selectivity for desirable middle distillate products. Its activity is sufficient to provide a reactor capacity of around 9000 bpd, compared to the existing reactor capacity of some 3000 bpd.

The breakthrough in the low-temperature F-T catalyst used in the SMDS synthesis stage has markedly increased process productivity. This, coupled with the valuable experience gained from the operations and commercial-scale testing program at Bintulu, provided a sound basis to the scale-up of SMDS technology from the current 12500 to around 70–75000 bpd and beyond.

The combination of economies-of-scale and improved process efficiency has resulted in a significant reduction of unit capital expenditure in the second-generation SMDS technology for future projects, thus making it a viable alternative for the monetising of stranded gas reserves.

6. SMDS diesel: a cost-effective gas-based fuel

The SMDS process converts natural gas into clean distillate products such as naphtha, diesel and/or kerosene and also speciality products. SMDS products are clear, odourless liquids of a high quality with some unique properties. In particular, SMDS diesel (or GTL fuel) has properties that exceed all anticipated future diesel requirements anywhere in the world. It has a high cetane number, low density and negligible sulphur and poly-aromatics content.

In automotive applications, GTL fuel can be used either as a blend or as a neat product. As a blending component, it can bring fuels, which are below specification up to the required standard.

GTL fuel is a gas-based fuel that work well in existing diesel engines and can use existing infrastructure, rather than just a cleaner version of refinery diesel. As such it has many advantages over other alternative fuels, which we believe make it the most cost-effective alternative fuel for now and the foreseeable future:

GTL fuel represents a "Drop-in Solution" that can use the existing infrastructure and engine technology of standard diesel fuel. From the perspective of a consumer, investment in new facilities is not required and used vehicles will have a ready access to supply. This is not usually the case for many other alternative fuels that require customised vehicle modifications. A smooth transition can significantly increase the speed of introducing GTL as an alternative fuel into the market.

The fuel's technical performance compared to competing systems is also good. From a fleet operator's perspective it offers similar vehicle performance to diesel fuel combined with safe and easy handling.

Emissions benefits for NO_x, CO, hydrocarbons and particulates—either as a blend or a 100% GTL fuel—are significant when compared to any standard diesel. The low sulphur content of GTL fuel could be used to enable more effective vehicle after-treatment systems. Shell's results show that in blends with standard diesel, disproportionately high benefits are seen from the first 10%–30% addition of GTL Fuel. Indeed addition of 30% GTL fuel upgrades the performance of a standard fuel to the levels normally only seen with ultra-low sulfur diesel.

In a joint fleet test with 25 series Golf GTI equipped with the most advanced Euro IV diesel engines conducted by Shell and Volkswagen in Berlin in May 2003 (see Figure 4), the vehicles covered more than 220000 km without technical problems confirming that Shell GTL is ready to cope with everyday driving conditions. GTL fuel gave significant emission improvements compared to sulphur free diesel (<10 ppm sulphur): 26% reduction in particulates, 63% reduction in hydrocarbons, 91% reduction in carbon monoxide and 4% reduction in NO_x as illustrated in Figure 5. The fleet trial is also a part of the joint programme of the two companies for development of new engine technologies and fuels.

Figure 4. Launching ceremony of Shell GTL trial with Volkswagen

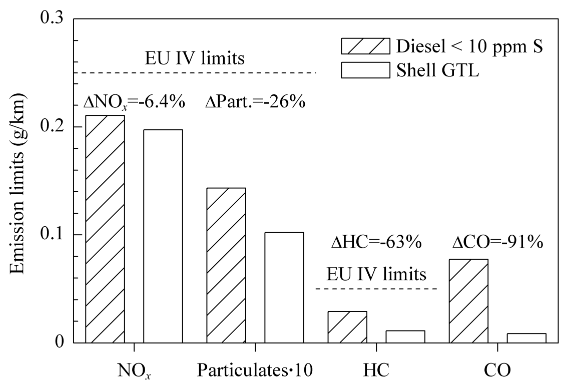

Figure 5. Emissions performance from Shell GTL trial with Volkswagen

These emissions benefits can contribute to improving air quality in larger cities.

Epidemiological work conducted over several decades has suggested that long-term residence in cities with elevated ambient levels of air pollution from combustion sources is associated with increased mortality. Although this type of epidemiological environment can not separate a causal relationship from a statistical association due to a number of confounding factors (*e.g.* socio-economic status, level of health care), there seems to be enough evidence to suggest an increased risk of mortality and disease is consistently associated with urban air pollution. This risk may be attributed to more than one component of the complex mix of ambient air pollutants in urban areas (*e.g.* fine particles, sulphate and sulphur dioxide).

The non-toxic nature of SMDS products is well established. They are also immiscible with water.

GTL fuels are "future-proof". They are compatible with many possible directions of the transportation fuel market, since they can be used in:

• standard diesel engines, either as a blend with standard diesel fuel or as a 100% product;

• specially adapted vehicles that make use of the high cetane number and/or low sulphur content of GTL fuel;

• diesel/electric hybrids;

• hydrocarbon powered fuel cells.

Strategic diversification of energy supply. GTL fuels are produced from natural gas, and as such provided consuming countries with a diversification of energy supply away from oil-based products.

Shell is working with a number of regulators, automotive OEMs and governments including China to further demonstrate the performance of GTL fuel and position it as a cost-effective alternative gas-based fuel. A study carried out in the USA by a consultant (TIAX) concluded that GTL fuel is more cost effective in reducing local emissions in vehicles compared to other alternative fuels (*e.g.* LPG, CNG) and diesel.

The availability of commercial quantities of products from SMDS Bintulu has allowed Shell to extensively characterise the properties of the product-not just on a laboratory scale, but firstly with extensive trials both in-house and with third parties in the USA, Japan and Europe (see Figure 6) and then with commercial supply. It became apparent that the unique properties of the SMDS products required a marketing, rather than trading, approach to fully tap their potential. An example of this approach is the launch of a specially formulated gasoil containing GTL fuel in Shell Thailand under the brand name “Pura” (see Figure 7) and as Shell Diesel 2004 in Greece.

Figure 6. Shell GTL Trial in London-a collaboration between Shell, London Bus and Daimler Chrysle

Figure 7. Shell Pura diesel, a blend of GTL fuel in Thailand

7. Project development: more than just EPC

Developing a second-generation GTL plant requires a wide spectrum of capabilities, ranging from skills at the ‘atomic’ level, for example, analysing and understanding the interactions of carbon monoxide (CO), hydrogen (H_2) and C_nH_n with cobalt atoms on the synthesis catalyst surface; to dealing with the dynamics of global marketing of a variety of GTL products.

The sheer size and quantity of a GTL plant can be daunting and illustrates the complexity and the significant level of funding required in developing a world-scale GTL plant. Proper integration of upstream, downstream and marketing is a crucial aspect of GTL project development.

The challenge in project financing is just one example to illustrate how the development of a world-scale GTL project is more than merely awarding an Engineering, Procurement and Construction (EPC) contract. Other key challenges are:

• Establishment of commercial and corporate structure with partners;

• Agreements for leasing of land, purchase of feedstock, technology licenses, technical service, insurance and marketing of products;

• Obtaining all necessary operational, environmental and other permits;

• Development of management structures and systems;

• Recruitment of local and expatriate staff;

• Training and development of local staff to replace expatriates.

With 92 operating plants in 38 countries, and excellence in a vast range of capabilities, Shell is uniquely placed to work together with host governments to develop a highly complex world-scale GTL project. Shell’s recent track record of mega projects includes the successful completion of Seraya Petrochemical Complex in Singapore; Malampaya Integrated Gas Development in Philippines; and the LNG plants in Oman and Nigeria.

Shell’s commitment to GTL is testified by the recent signing of a Heads of Agreement for the construction of the world’s largest gas-to-liquids plant in Ras Laffan, Qatar between Qatar Petroleum and Shell. Shell plans to invest around US$ 5 billion to develop upstream gas and liquids facilities and GTL plant that will produce 140000 bpd of products primarily naphtha and gasoil with smaller quantity of normal paraffins and base oils.

Shell is also committed to contributing to sustainable development-in finding innovative ways of meeting present and future needs that are socially and environmentally sustainable. Shell believes it is good business-increasing operational effectiveness, promoting innovation and supporting reputation.

8. Coal-to-liquids: another option based on GTL

One of the basic building block in GTL is syngas manufacture which can be produced from three sources-natural gas, biomass or coal. Coal gasification provides another potential route to produce clean liquid fuels (Coal-to-Liquids or CTL) via Fischer-Tropsch (F-T) synthesis. This is illustrated in Figure 8 in which syngas from any three gasification processes undergoes F-T synthesis to produce high quality, clean fuels like naphtha and gasoil. There are particularly real advantages in combining coal gasification with F-T synthesis, such as Shell GTL technology for indirect coal to liquid manufacturing.

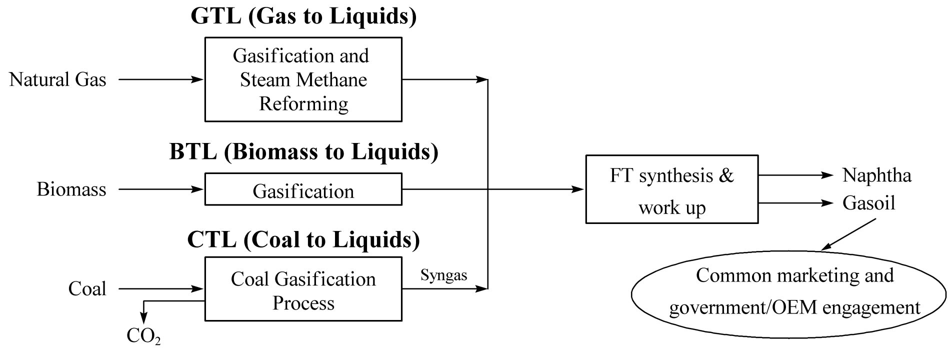

Figure 8. Potential routes to clean liquid fuels based on F-T synthesis

Shell is interested in putting Shell's coal gasification and GTL technologies to work in China. Both these technologies are commercially applied with world-scale units currently in operation. Although the combined indirect coal to liquid route is not yet proven economically, we believe that it could become attractive in time with developments, especially in a country like China which has relatively low plant construction costs, abundant coal resources and a rising crude oil import bill. We believe that these technologies will make a significant contribution to China's vision of a modernised coal sector and 'sustainable industrialisation'.

There are two key issues with CTL that need to be addressed:

• coal gasification is considerably more capital intensive compared to 'natural gas' gasification for the feed preparation and syngas treating

• coal has a higher C:H ratio compared to other feedstocks and consequently produce more carbon dioxide (CO_2); hence CO_2 capture and sequestration has to be managed.

As China pushes to utilise clean coal technologies, coal gasification would seem to be the most efficient way to both reduce and capture CO_2 emissions. However, all coal based industries converting coal into liquid fuels will produce significant amount of CO_2; hence the importance of finding a solution to CO_2 management. Shell is participating in international CO_2 sequestration programmes, and is a leading company in EOR (Enhanced Oil Recovery).

We believe using coal gasification as a pre-cursor for liquid transportation fuels manufacture can be commercially viable in the next ten years. Moreover, F-T synthesis products ("Coal-to-Liquids" CTL; "Gas to liquids" GTL; "Biomass-to-liquids" BTL) fuels, in particular GTL, can provide a more cost-effective route than other alternative fuels.

Shell is already proceeding with a 140000 b/d world-scale GTL project in Qatar, on stream in 2009. We are optimistic that Coal-to-Liquids technology could thereafter become a reality (combining Coal Gasification and GTL technology), although much development work remains to be done to demonstrate the solution in CO_2 management.

9. Conclusions

In conclusion, the gas-to-liquids technology offers excellent prospects to countries with gas resources with potential for monetisation. GTL has proven to be an attractive and complimentary alternative to LNG with substantial benefits in terms of economic, social and environmental sustainable development. The Shell GTL process (or SMDS) is a unique and competitive technology to convert natural gas into high quality products for the feedstocks and fuels market. With extensive operational experience from SMDS Bintulu and recent advances in the process and technology, Shell is ready to commercialise large gas reserves to fulfill the growing demand for clean transportation fuels from host countries to reduce emissions and improve air quality.

Shell GTL fuel possess several unique properties that exceed all future anticipated diesel requirements and can use existing infrastructure with no additional investment. It is 'future proof' and compatible with many possible directions of the transportation fuel market. It is also more cost effective in reducing local emissions in vehicles compared to other alternative fuels and diesel.

The realisation of worldscale GTL projects requires one to adopt a long term view of the GTL business, invest substantially in R&D (research and development) and D&E (design and engineering) and be excellent over a range of capabilities. In addition, operational and marketing experience in a medium sized commercial plant is essential to minimise risks.

On Coal-to-Liquids, Shell believes there is a future in this technology by combining Coal Gasification and GTL technology but key issues on gasification cost and CO_2 capture and sequestration have to be managed elegantly.

Reference

[1] Gas to Liquids Life Cycle Analysis Study — the report can be downloaded from www.shell.com ⇒ Shell for businesses ⇒ Shell Gas & Power ⇒ What is Gas to Liquids ? ⇒ Benefits