Tara Shirvani and Oliver R. Inderwildi provide a futuristic view of gas-to-liquid technology

The search for alternative fuels is relentlessly under way with 90 percent of transport fuels being oil-derived and uncertainty around depletion levels of conventional oil reserves mounting. Global vehicle ownership is forecast to reach two billion in the near future and climate change concerns, induced by anthropogenic greenhouse gas (GHG) emissions, expected to rise. The central challenge involves the transformation of our oil dependent transport industry, as we face the so-called input problem of dwindling conventional crude oil reserves as well as the so-called output problem of increasing GHG emissions. Liquid fuels derived from gas, coal or unconventional oil sources may be able to offset the input problem of diminishing oil supplies, but will inevitably exacerbate the output problem of rising GHG emissions. Biofuels can be a viable substitute for fossil fuels, most notably when produced in a sustainable manner and from feedstock that is not in direct competition with food or animal feed. The transition towards advanced biofuels may contribute towards a low carbon, sustainable fuel mix, but is unlikely to be sufficient to meet the current energy demand of our global transport system. Recently, the interest in synthetic fuel production from unconventional resources has been revived through the rise in crude oil prices. Global production from unconventional sources has been projected to increase by 2030 to 7.4 million barrels per day or 10 percent of global conventional oil supply. The industry's expectation illustrates that there are other factors at play aside from the rise in global petrol prices, which will facilitate the rapid introduction of synthetic fuels into the market.

Historically, in 1942 Germany avoided the fatal economic damages

of a long-lasting oil embargo and a prolonged war by deriving almost 90 percent of its total energy consumption from coal-based Fischer-Tropsch (FT) fuel production. Similarly, the Apartheid regime in South Africa was responding to an oil boycott in 1950 by using their vast coal reserves to produce liquid fuels and meet their domestic transport fuel demand. Even today, the South African energy industry still obtains 30 percent of its road transport fuels from indigenous coal reserves.

The search for alternative fuels is relentlessly under way with 90 percent of transport fuels being oil-derived

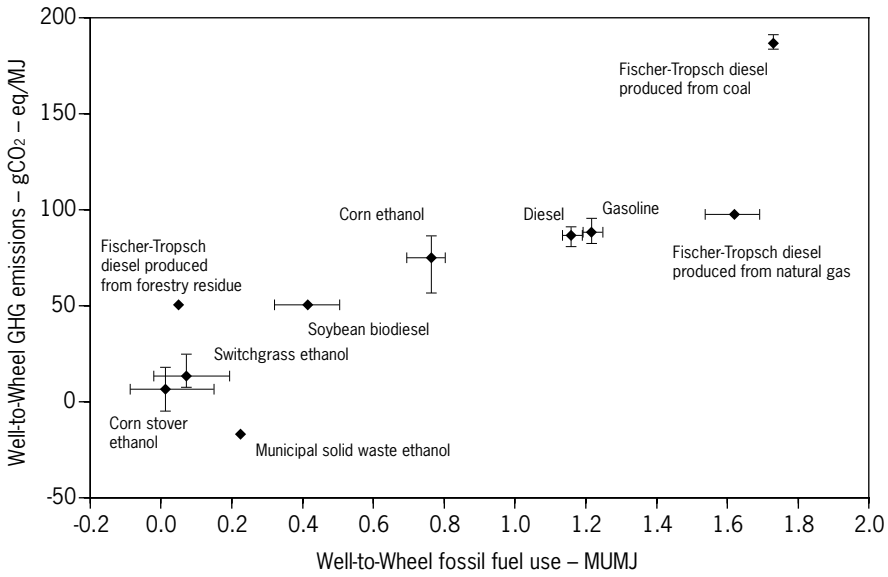
Synthetic fuels, made from natural gas are referred to as gas-to-liquid (GtL) fuels. Analogously fuels manufactured from biomass or from coal are referred to as biomass-to-liquid (BtL) and coal-to-liquid (CtL), respectively. Through a fuel conversion process which includes FT technology, natural gas is converted into longer chain hydrocarbons which can be refined to yield gasoline, kerosene or diesel. In the first step, sulphur components and other impurities are removed from the methane-rich natural gas feedstock, which is later cooled down to separate methane from other hydrocarbons. Through a catalytic partial oxidation or steam reforming process, methane is reacted with oxygen to produce a mixture of carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2) and water (H_2O). In the second stage, the gaseous mixture of H_2 and CO is fed into the FT reactor which yields long-chain, waxy hydrocarbons and considerable volumes of water as by-product. In the presence of zeolite catalysts and hydrogen the waxy hydrocarbons are catalytically cracked into shorter hydrocarbons as part of the final upgrading phase. The synthetic crude is then distilled into a variety of fuel products ranging from kerosene to diesel, oils and naphtha. Overall, the GtL production process is estimated to produce 75 percent middle distillates and 25 percent non-fuel chemical products.

Due to in part the success of the synthetic fuel production process, FT-diesel is considered to be a strong technical candidate for the substitution of conventional diesel. FT-fuel products have received considerable attention for their favourable characteristics for use in compression ignition engines as for instance the Diesel. These high quality fuels benefit from superior autoignition characteristics and can replace conventional fuels at any ratio (0 to 100 percent) as they are fully miscible. The energy density is comparable to conventional diesel, which qualifies them for use in unmodified diesel engines. Experimental studies have further shown that the thermal efficiency of diesel engines is improved when GtL blends are used. In addition, GtL fuel properties are also environmentally advantageous, outlining a high cetane number of 75, virtually zero sulphur and aromatic hydrocarbon content. As a result, combustion of GtL fuels yields 12 percent less nitrogen oxide (NOx) and 30 percent less particulate matter (PM) emissions making them superior fuels especially in urban environments.

GtL fuel products therefore may help to address energy security concerns and drastically improve local air pollution levels, but are by no means considered environmentally friendly fuels. In comparison to conventional petroleum-derived diesel, GtL fuel products result in increased GHG emissions over their lifecycle, see Figure 1.

This is partly due to the high energy requirements of the FT process and the conversion of a hydrocarbon feedstock such as methane which leads to significant CO_2 emissions during the production stage. On average the carbon footprint of GtL-fuels is 10 percent higher than that of conventional fossil fuels. However, compared to synthetic fuels from other unconventional resources such as coal or oil shale, Gtl fuels highlight a lower carbon footprint (see Figure1). Nevertheless, with a global consumption of liquid transport fuels in 2009 resulting in 11.3 billion metric tons of CO_2, substituting 50 percent of this conventional fuel supply with GtL fuel products would have increased emissions by 0.5 billion metric tons of CO_2. The fuel synthesis process may not even be economically feasible

Figure1: Life cycle Fossil Fuel Use and GHG Emissions per MJ Fuel for Biofuels and Synthetic fuels in the USA



Source: X. Yan, O. R. Inderwildi and D. A. King, *Energy & Environmental Science*, **3**, 190–7.

when carbon capture and storage (CCS) facilities are considered, since the improved environmental balance will result in lower efficiency levels and reduced energy gains.

"On average the carbon footprint of GtL-fuels is 10 percent higher than that of conventional fossil fuels"

When it comes to the availability of natural gas reserves required to satisfy the rise in liquid fuel demand, fuel consumption is not expected to be limited by a resource constraint per se. Geographically, natural gas reserves are disproportionately distributed globally, with three countries, Iran, Qatar and Russia holding more than 50 percent of global conventional reserves. In particular, the North-Dome-South-Pars complex within the Persian Gulf accounts on its own for 50 thousand cubic metres (tcm) of natural gas, an amount that equals 23 percent of proven natural gas reserves. The IEA estimates the remaining volume of recoverable natural gas reserves at 405 tcm. With a projected rise in annual natural gas demand around 71 to 77 tcm p.a. by 2030 and the current level of technology, a surplus reserve of 333 to 327 tcm of conventional gas resources can be estimated. The additional on-line capacity could be used to produce more than 1 trillion barrels of GtL syncrude and Liquefied Petroleum Gas (LPG) products which would be enough to replace the demand for crude oil with syncrude for the next two decades. However, the geopolitical turmoil within most of the producing nations, the exorbitant capital requirements for the development of GtL production plants and the significant lead-times for additional on-stream capacity, prevent GtL fuels from being produced on a sufficiently large scale. Currently, global GtL production capacity is limited to 151,500 barrels a day (b/d), a volume that merely replaces 0.2 percent of global transport fuel demand. In-house research at the Smith School of Enterprise and the Environment, at Oxford University, estimates that under a high oil price scenario the share of global GtL fuel products will increase to 1.2 million b/d by 2030. Compared to the projected increase in global fuel demand to 107 million b/d by 2030, the share of GtL fuels will remain marginally low at a maximum of 1.14 percent of global crude demand.

Availability of large volumes of low-priced and stranded natural gas feedstock is critical to the economics of GTL plants. We refer to stranded gas as cheap gas that is uneconomic to develop due to transport distances or lack of infrastructure. Feedstock costs may not remain low enough to make GTL economically attractive in the mid-term future. Another option for the monetisation of stranded gas would be liquefied natural gas (LNG) production for which the cost of LNG liquefaction terminals is declining and demand from South East Asia is increasing. This trend will increase the opportunity costs of stranded gas and negatively influence the economic viability of GTL plants. At present, assuming an average natural gas price of $180/tcm, GtL fuel products would enter the market at a corresponding oil price of 70 $/b, see Table 1.

Table 1: Market Entrance Crude Oil Prices for Liquid Fuel Production from Different Resources

Resources	*Market entrance oil price ($/barrel)*
Tar sands	38
Extra-heavy oil	30
Oil shale	70 (short run) 30 (long run)
CTL	86
GTL	70
Corn ethanol	40

GtL fuels are economically unfeasible when prices are below 40 $/b. This figure would be higher, where carbon-intensive energy sources are used throughout the production process and a high carbon tax is applied. Even, under a high oil price scenario of 120 $/b combined with a low carbon tax, natural gas prices would only have to reach $15/thousand cubic feet for GtL fuel products to become economically unfeasible compared to petroleum-based fuels.

To conclude, GtL fuels are high quality fuel products which are virtually zero in sulphur and aromatics and consequently emit significantly less local pollutants. The supply of GtL fuels in urban areas can therefore drastically improve local air quality. However, given the energy-intensive nature of the FT fuel production process and the use of a fossil energy source, the transition from petroleum-based fuels to synthetic fuels from natural gas would lead to a considerable rise in GHG emissions from transport. As part of a larger mission to diversify the source of transport fuels, GtL technology will need to complement our current fuel mix alongside unconventional fuel supplies from tar sands as well as biofuels. GtL fuel production may not be limited by feedstock availability and could theoretically mitigate future oil supply shocks; however, due to significant lead times for additional capacity of GtL fuels and the high upfront investment needed, it is unlikely that a substantial volume will go on-line in time to absorb future oil supply shocks. Analysis of earlier studies on the economics of GtL plants leads us to the conclusion that when large stranded gas reserves and cheap gas are available, GtL is profitable and allows international oil companies a certain degree of independence from OPEC oil. These endeavours are consequently part of a larger strategy that would allow energy companies to strengthen their supply security and be more independent from national energy security undertakings.

