

# **Sustainable Management in the Synfuels Sector in South Africa**

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## **Abstract**

The debate about the decline in petroleum reserves, the worries over peak oil, the Middle East tension and oil price speculation challenges has made it important to focus on sustainable management and utilization of alternative fuels. The use of alternative fuels to supply the energy needs of the world is not a new concept. This paper reviews coal as a recoverable hydrocarbon-rich resource found in abundant quantities in South Africa (SA). This study review shows that coal will continue to provide a key for the unlocking many of the future global requirements for high-quality energy and chemical building blocks. The historical premise that coal is a dirty fuel is being countered with the continued development and operation of technology to significantly reduce the environmental footprint of coal-sourced energy is investigated. Conclusions are drawn. Firstly, the study brings to our attention that technology is available and is continually being improved to turn coal into synthetic natural gas, transportation fuels, chemicals, chemical intermediates and hydrogen in a way that reduces GHG emissions. Secondly, the study shows that there is a viable coal-to-liquids (CTL) industry in South Africa supplying high-quality middle distillates, in particular diesel fuel, jet kerosene and middle distillate blend stocks. The CTL economics, the potential role of the government and how large-scale development of this industry might impact the environment is analysed on sustainable management.

## **Keywords**

Synthetic fuels, Coal to liquids, sustainable management

## **1. Introduction**

Are synthetic fuels derived from coal viable alternatives to conventional fuels (derived from crude oil refining) today? What are some of the issues associated with synthetic fuels as alternatives to conventional fuels from an LCA perspective? What are the benefits of using of alternative transportation fuels to the South African case study? This paper aims at address these questions and discusses the successful use of alternative fuels in South Africa (SA) with particular attention to the LCA, price and environmental effects. This paper will trace development path for FT fuels, based on data on existing technologies and bottom-up simulations of new technologies. For the narrative in this work, it is assumed that increases in fuel demand will be covered to a significant degree by coal derived FT fuel plants, fed initially with coal and or natural gas reserves. Potential well to wheel (WTW) chains will be compared with regard to cost and the emissions of green-house gas (GHG) for various options to produce FT diesel with existing and emerging technology (such as carbon capture and storage).

Many analysts including International Energy Agency (IEA, 2008) subscribe to the theory that the world oil production has reached 'Peak Oil' (Brandt, 2007). Peak oil is the point in time when the maximum rate of global petroleum extraction is reached, after which the rate of production enters terminal decline. This concept is based on the observed production rates of individual oil wells, and the combined production rate of a field of related oil wells. Hubbert M .K created and first used the models behind peak oil in 1956 to accurately predict that United States oil production would peak between 1965 and 1970 (Brandt, 2007). It is estimated that the world has peaked in

petroleum production, and world petroleum consumption has outpaced new-found reserves (Deffeyes, 2007). A means of reducing the dependency on petroleum will be to use fuels derived from natural gas, biomass, or coal. For this reason, methanol, ethanol, Fischer–Tropsch fuels, dimethyl ether (DME) and biodiesel are being researched as alternative fuels. From the beginning of the 21st century the prices of crude were relatively stable. The prices were at an average of between \$10 and \$20/barrel in current dollars and crude oil was a forgotten subject for most analysts. However, the picture changed drastically with the coming of the 21st century. Prices shot up from \$12/barrel in 1999 to close to \$80/barrel in August 2006 and then continued to break all records by approaching \$100/barrel in November 2007 (IEA, 2008). The Global economic development is threatened by such massive price increases, including SA as the cost of energy continue to climb to new heights. This has resulted in many countries choosing to focus on other transportation energy alternatives like Fischer-Tropsch fuels from coal. Coal a hydrocarbon-rich resource still found in abundant quantities in many parts of the world provides a key for unlocking many of our future global requirements for high-quality energy and chemical building blocks. Sasol, a South African-based company is the world’s leading commercial user of CTL technology and has been producing synfuels and chemical feedstock from coal for over 50 years using the Slurry Phase Distillate™ process used at Sasolburg and the high temperature Sasol Advanced Synthol™ process used at Secunda. The company accounts for accounts 100% production of synfuels in SA at the present time of study.

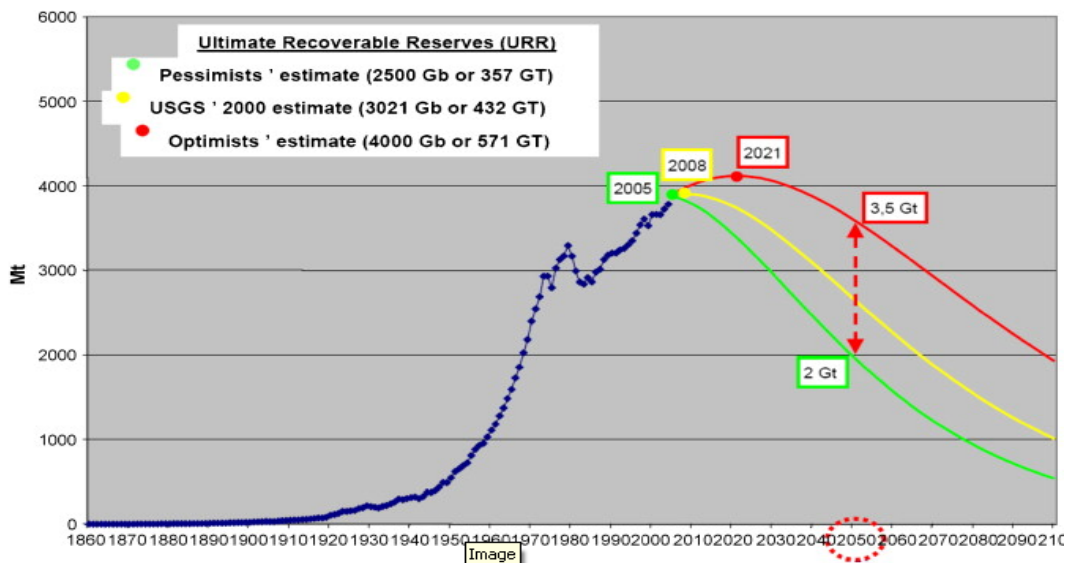


Figure 1: Predictions of the peak in conventional oil (crude oil) production using Hubert’s curve (Bauquis 2006)

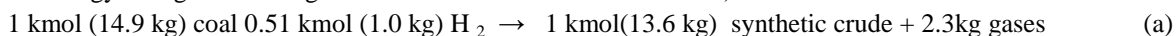
Coal liquefaction is a capital-intensive as because of coal mining and the bulk weight of coal it can however benefit from the economics of scale. Though difficult to assess how much the scale-up can affect the project economics, a number of studies have shown that the coal liquefaction plants will be economically feasible, if a full-scale commercial plant would produce 50 000-100 000 bbl/day of liquid products. Such a plant would process 20 000-40 000 tons/day of bituminous coal (3-4 million tons oil equivalent (mtoe)/year) (Campbell and Laherrere, 1998). On the other hand, as a general principle Coal to Liquid (CTL) plants should be in the country of origin, or preferably at the point of origin. This reduces the feedstock cost, since coal is difficult to transport. LCA studies with an effort will assist in the lowering of GHG emissions. The life-cycle assessment (LCA) on CTL projects will help investigate the applicability of novel process system design tools in the improving the environmental benefits of utilizing coal in the CTL processes. The life cycle assessment is chosen as the appropriate tool for evaluating the impacts throughout the life cycle and the projected environmental performance of CTL. Cheap workforce would also reduce the overall costs. In addition, there must be sufficient reserves for a project life time of 25-30 years. Thus, the CTL projects should be implemented where there is at least 100 mtoe coal (150 Mt and minimum reserves/production (R/P) ratio of 25 (Campbell and Laherrere, 1998). SA has surpassed these thresholds by far.

## 2. Historical background of coal-to-liquid fuels and Fischer-Tropsch synthesis in SA

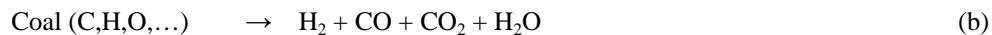
Fischer-Tropsch (FT) synthesis was discovered in the 1920s by the German chemists, Fischer and Tropsch. It was briefly used by Germany before and during World War II to produce fuels, and has generated varying levels of interest worldwide since that time. Today, it is used commercially to produce transportation fuels and chemicals in SA. In South Africa, the Sasol plants are located in Secunda and Sasolburg and they gasify more than 30 million tons per annum of bituminous coal to synthesis gas, which is converted to fuels and chemicals via the Fischer-Tropsch process both from coal and natural gas. Sasol's history began in 1927 when the South African Government White paper was tabled in Parliament for a formal investigation into the merits of establishing an oil-from-coal industry in SA. At the time, the Government expressed concerns about SA's dependence on imported crude oil while having no known oil reserves of its own. The two biggest concerns were the need to protect the country's balance of payment and to strengthen security of energy supply. In 1945, a South African industrial company, Anglovaal, asked the South African Government to create a fiscal dispensation to enable oil-from-coal to compete with conventional crude oil refining. After extensive research and negotiations, Anglovaal secured the licence needed to build and operate a Fischer-Tropsch oil-from-coal plant in SA. This company, however, was unable to secure a loan from the World Bank and abandoned its plans to develop a commercial oil-from-coal venture in SA. The South African Government however continued its investigations into the feasibility of developing an oil-from-coal venture and formed a state-owned enterprise in 1950, the South African Coal, Oil and Gas Corporation (later to be renamed Sasol). Extensive government support at the time and, again during the 1970s and 1980s – was essential for the establishment of what is still the only commercial coal based synfuels industry in the world. To ensure a reasonable rate of return for SA's emerging synfuels industry particularly during down turns in the crude oil commodity cycles, the SA Government provided tariff protection and imposed a fuel levy. To the South African Government's benefit, the establishment of Sasol and the country's synfuels industry increased energy self-sufficiency, provided employment opportunities, reduced crude oil imports and saved foreign exchange. In short, coal based synfuels enabled the country to fulfil 30% of its fuel requirements (Sasol 2009). Sasol has for many years been renowned for pioneering world-leading technologies to produce quality synfuels and petrochemicals from coal. Today, more than 50 years after the initial start-up, Sasol produces the equivalent of 150 000 barrels per day of fuels and petrochemicals from coal via its indirect liquefaction process (Van Dyk et al., 2002).

## 3. Basic chemistry of the Coal to Liquids (CTL) synthesis.

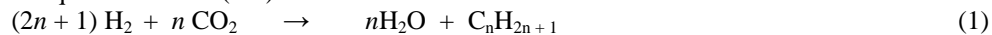
The basis for all types of CTL syntheses is a carbon source combined with a hydrogen source, such as steam. Chemical reactions between carbon and hydrogen molecules will eventually fabricate hydrocarbon molecules of the desired length. The approximate analytical formula for the coal is **CH**(81%)**O**(8%)**S**(2%)**N**(1%)Ash and other(8%), the overall energy changes occurring are summarised in the reaction below).



The general formula for the gasification of coal is shown above by (a), then followed by subsequent reactions (1-4) mentioned above. Coal is initially pyrolysed to produce carbon monoxide, carbon dioxide and hydrogen which then becomes the raw materials of the whole Fischer-Tropsch chain reaction process. The reaction below shows the pyrolysis of coal.



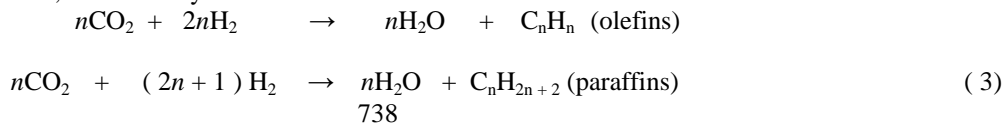
This is followed by the subsequent reactions (1-4) below.



Carbon monoxide also can be produced by gasification of coal or another carbon-rich compound. The necessary reaction energy is applied by adding oxygen or steam (reaction 2).



The resulting mixture of carbon monoxide and hydrogen is usually called synthesis gas (syngas). It is used to construct hydrocarbon chains of different lengths using condensation and the FT catalysts. Generally, the FT process yields two types of products, described by two different reactions:



The type of resulting products depends on the FT catalysts used and the reactor-operating conditions. Olefin-rich products with  $n$  in the range 5–10 (naphtha) can be used for making synthetic gasoline and chemicals in high-temperature FT processes. Paraffin-rich products with  $n$  in the range of 12–19 are suitable for making synthetic diesel and waxes in low temperature FT processes. The Bergius process is the basis of direct coal liquefaction (DCL). Splitting coal into shorter hydrocarbons, resembling ordinary crude oil is done by adding hydrogen under high pressure and temperature, thus eliminating the need for a gaseous middle stage.

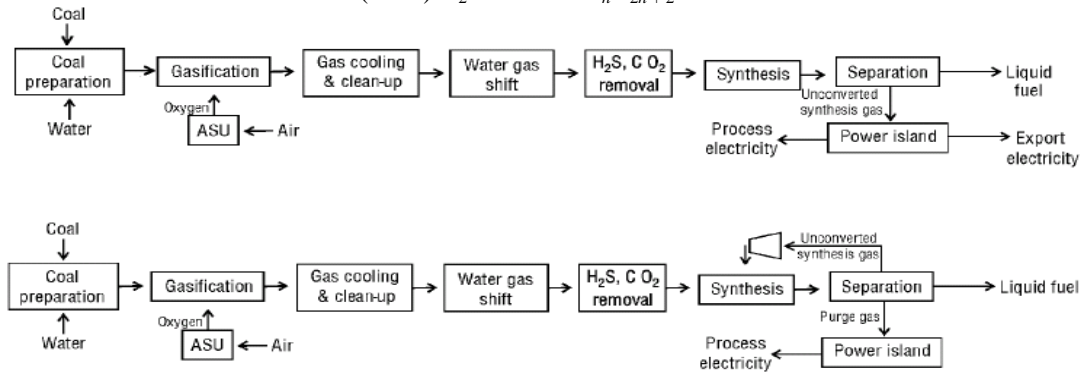


Figure 2: Basic process flow configurations for CTL systems producing FTL fuels from coal while venting all CO<sub>2</sub>: Two processes shown in Figure 2 are: (a) “recycle” (RC) synthesis, with only modest net exportable electricity; and (b) “once-through” (OT) synthesis, with significant exportable electricity co-product (Larson et al., 2011)

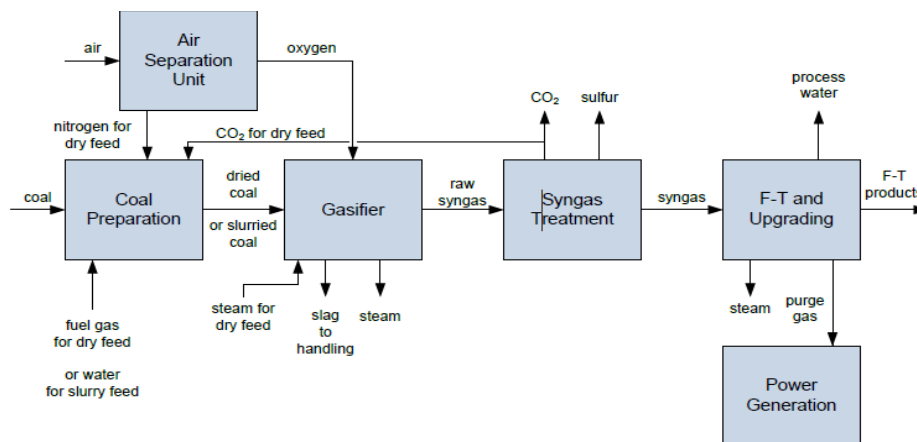


Figure 3: A Coal to liquid plant frame block diagram

CTL process description CTL can be characterised as the conversion of syngas generated from coal via gasification to a slate of hydrocarbon products. In the simplest terms, CTL is a process whereby coal or petroleum coke is converted first to a gas stream rich in carbon monoxide (CO) and hydrogen (syngas (CO + H<sub>2</sub>)). The syngas is then treated for removal of impurities, before being fed to a Fischer-Tropsch (FT) catalytic conversion reactor (gas synthesis). The raw product slate from the synthesis process unit ranges from a tail gas suitable as a fuel to waxy products that are solids at ambient conditions. Once syngas is generated and cleaned, it can be utilised to produce power, hydrogen, steam or hydrocarbon liquids. Captured CO<sub>2</sub> could be utilised for enhanced oil recovery applications or sequestered.

The overall product distribution from a CTL plant depends upon the type of catalyst utilised, reactor technology and overall operating conditions. With additional processing, a variety of end products such as liquefied petroleum gases (LPG), paraffinic naphtha, middle distillates, synthetic waxes and lubricating base oils can be produced. Due to the

market size, high quality transportation fuels in the middle distillate range are the preferred output. A typical configuration for a CTL plant (Figure 3) designed for the production of middle distillates (diesel and jet fuel blend) consists mainly of six major sections as shown in the diagram above (Figure 3). For maximum production of CTL diesel fuel, a low-temperature gas synthesis process is desired. The coal gasification-based conversion technologies are assumed to have a relatively large potential for technological improvements in the future (Nakicenovic et al., 1998). Because this paper focuses on the sustainable management and potential for FT synfuels as an alternative liquid fuel, all of the synthetic liquid fuel production technologies assessed here are based on the full conversion concept, which aims at maximizing the yield of synthetic liquids by recycling unconverted syngas (reformed or partially oxidized light hydrocarbon fractions in the case of the FT process) back to the synthesis reactor. Among several types of proprietary FT processes, the most common design is the low-temperature slurry reactor using iron-based catalysts for the coal-based design and the low-temperature fixed-bed reactor using cobalt-based catalysts for the natural gas-based and biomass based designs (Marsh et al., 2003; Tijmensen et al., 2002). The major FT technology companies appear to target at supplying middle distillates, for which demand growth is highest. Sasol South Africa is one such company. The refinery process streams for FT liquids have been modelled in the following manner. The FT liquids are first introduced into the hydro-cracking process and then fractionated into FT-diesel, FT-kerosene, and FT-naphtha at a FT liquids production site. In the model, two typical product distribution patterns are available: the diesel model as shown in Table 1.

Table 1: Two typical product distribution patterns of FT Diesel and Kerosene models (Marano and Ciferno, 2001)

	Weight Distribution Diesel model	Weight Distribution Kerosene model
FT diesel	60%	50%
FT kerosene	25%	25%
FT-Naptha	15%	25%

#### 4. Current developments in the Synthetic fuels from CTL

The early technology of the FT produced mainly fuel with and a limited amount of chemical due to inadequate research and other considerations technology (Sasol I) produced mainly fuels with limited chemicals due to strategic considerations. From the mid 1970s the production was orientated more to chemicals (Sasol II and III), which led to significant improvements in plant economy. Starting from this that time, the technology was advanced due to continued research in synfuels and characterized by higher product flexibility, direct production of chemicals and lower separation costs (Gibson, 2007). This advancement in evolution was facilitated by continued development in reactor engineering and catalysts of the FT process for CTL production as indicated in Fig. 4 below.

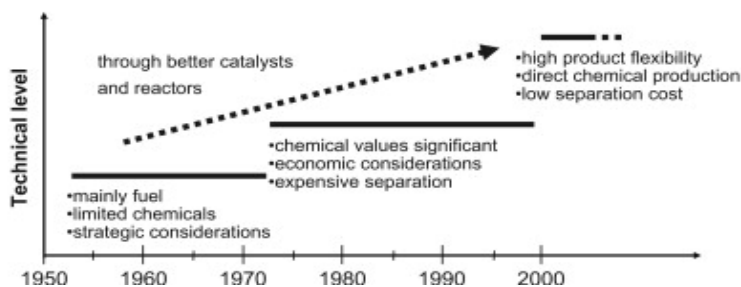


Figure 4: Current development of the Sasol FT process in the past 50 years from the 1950s (Collins, 2002)

#### 5. GHG Emissions from Synthetic fuels

The environmental attributes of the conventional and synthetic fuel technologies are assessed by measuring the impact caused through production, transportation and fuel usage, the so-called well to wheel basis or life cycle assessment.

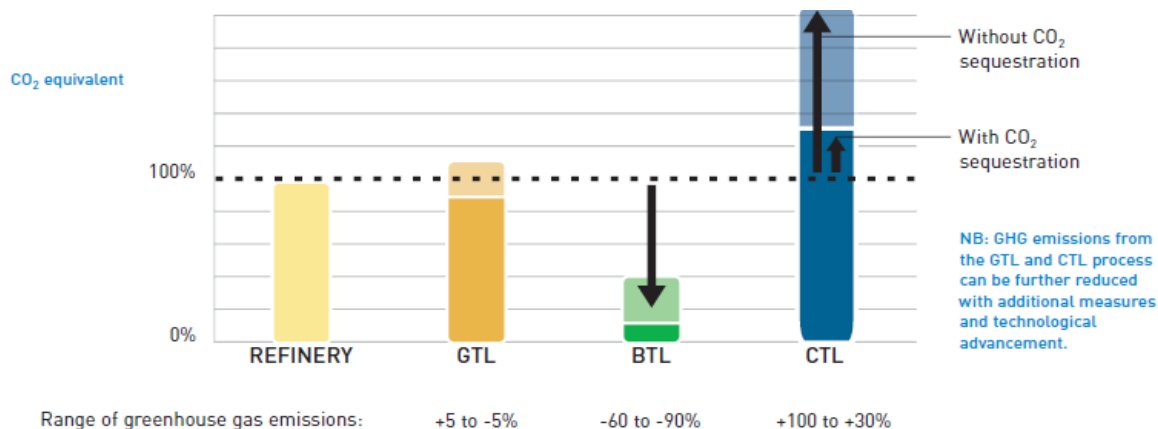


Figure 5: Comparison of GTL, BTL and CTL processes with refinery systems on well-to-wheel basis (ASFE, 2007)

Industry studies show that greenhouse gas emissions of the GTL process are comparable to a refinery system ( $\pm 5\%$ ). Relative to a refinery system, BTL offers clear benefits in the range of 60 to 90% improvement (ASFE, 2007). CTL has a carbon penalty, which can be reduced through CO<sub>2</sub> sequestration. By linking development of advanced engine and synthetic fuels production technology, it is expected that greater vehicle efficiency gains will lead to further reductions in CO<sub>2</sub> emissions.

The two important processes used for CTL are (direct coal liquefaction) DCL and (indirect coal liquefaction) ICL technologies. Both processes have higher emissions (2-8 times more) than a crude oil -refining process if no CO<sub>2</sub> capture/storage is implemented (Anders and Bridgewater). This is due to high carbon content of coal with an approximate analytical **C**(81%), **O**(8%), **S**(2%), **N**(1%), and Ash and others (8%). Present studies in the US show that there is room for substantial reduction by CO<sub>2</sub> capture/storage, especially for ICL processes. This is due to the fact that in all ICL configurations, some CO<sub>2</sub> can be removed (together with H<sub>2</sub>S) from the syngas before the synthesis reactor, and thus a relatively pure stream of CO<sub>2</sub> is available at ICL facilities. This results in the reduction of particulate matter (PM) from synthetic diesel as will be shown in the emission properties of CTL fuels in the next section. The CO<sub>2</sub> captured could be used in two main cases firstly Injection into deep beds of unmineable coal beds and to enhance coal-bed methane recovery. However this application is not of economic interest at current situations for SA or injection into deep saline aquifers for storage purposes. There is large potential for storage in deep saline aquifers, for which there are no enhanced resource recovery opportunities in SA. The total area of these aquifers amounts to 70 million km<sup>2</sup> worldwide, leading to a capacity to store 2 700-13 000 GtC. For comparison, estimated remaining recoverable fossil fuel resources (excluding methane hydrates) contain 6 000-7 000 GtC. This potential is now in the research phase, with several pilot projects like Statoil Aquifer Project (Korbol and Kaddour, 2005) which injects CO<sub>2</sub> to an aquifer under the North Sea Sleipner West. The injection has been done continuously from 1996 and seems to be secure. However, there still are some technical issues for this type of injection including the insufficient strength of geological structure of the aquifers to store high pressure CO<sub>2</sub>. Therefore, several demonstration operations will be required until 2014 to validate potential commercial use is expected for 2020.

## 6. Local Emission benefits from Synthetic fuels

A number of road and laboratory trials of synthetic fuels in several European capitals and in the US demonstrate that synthetic fuels provide significant local air quality improvement by reducing tailpipe emissions (particulate matter, nitrogen oxides, carbon monoxide and hydrocarbons). Whereas the application of successive Euro-standards applies to new vehicles only, the introduction of synthetic fuels will have an immediate positive impact on the local emissions from the existing vehicle fleet, particularly in urban areas. When engines are optimized to run on synthetic fuels further reductions of nitrogen oxides can be obtained (ASFE, 2007).

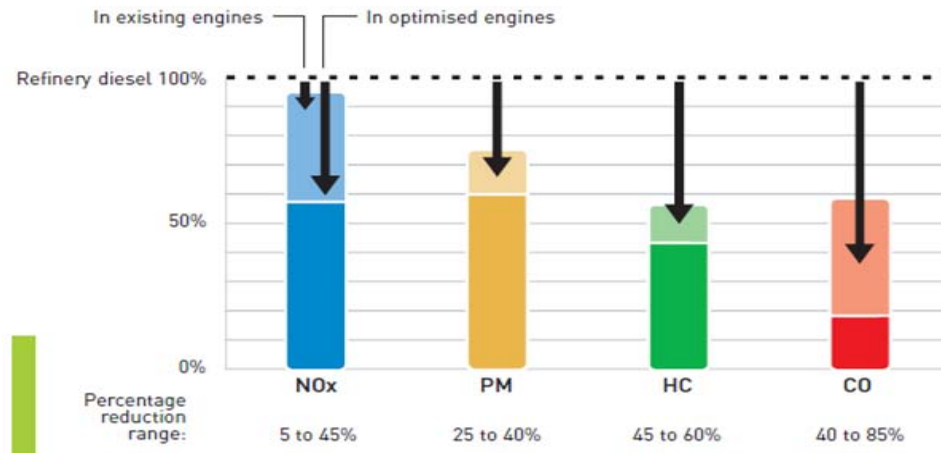


Figure 6: Local emissions benefits from synthetic fuels in an optimised engine (source: ASFE, 2007)

The emission standards for the EU are applicable to the South African emission standards. ASFE's vision is for synthetic fuels to play a bridging role from today's conventional fuels to the future renewable transportation fuels and associated vehicle technologies. ASFE sees synthetic fuels as a vital part of developing a less polluting vehicle park together with creating energy security that enables transportation in to the future. The Argonne National Laboratory developed the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model (Wang & Huang, 1999). The GREET is a widely used model that performs life cycle analyses (a.k.a. cradle-to-grave or well-to-wheel) for alternative transportation fuels. This model calculates relative performances of various transportation fuels (e.g., Fischer-Tropsch diesel, methanol, DME, kerosene etc.) and vehicle technologies (e.g., hybrid, compression ignition).

Table 2: Typical DCL and ICL properties for synthetic fuel products from bituminous coal (U.S. Department of Energy, 2009)

	DCL (direct coal liquefaction)	ICL (Indirect coal liquefaction )
Distillable product mix	65% diesel	80 % diesel
	35 % naphtha	20 % naphtha
Diesel cetane	42-47	70-75
Diesel sulphur	<5ppm	<1ppm
Diesel specific gravity	0,865	0,780
Naphtha octane number (RON)	>100	45-75
Naphtha Sulphur content	< 0.5ppm	Nil
Naphtha aromatics	5%	2%
Naphtha specific gravity	0,764	0,673

## 7. The strategic role of synthetic fuels and potential to future of SA

Synthetic fuels have offered an opportunity for SA to reduce its petroleum import needs by producing petroleum products, such as diesel and petrol, from domestic coal resources. Most reports have focused on CTL due to the cost and transportation issues associated with CTG. Another important outcome from this study is to view and understand the inputs and assumptions from various publications and the range of production estimates from CTG and CTL technology. The benefits of synthetic fuels to the South African energy needs are summarised as follows:

- The FT synfuels become a major alternative energy carrier and have a noticeable share in the SA and thus contributing up to 33% in final energy mix in transportation fuels.
- Synfuels are sulphur-free, low aromatic, odourless, colourless liquid synthetic fuels.
- Synfuels allow significant reduction of regulated and non-regulated vehicle pollutant emissions (NOx oxides of nitrogen, SOx oxides of sulphur, PM (particulate matter), (volatile organic compounds VOCs, Carbon monoxide CO). The installation of CCS facilities will further to lower the GHG emissions from an

LCA perspective. Among the first noted is an immediate reduction in particulate emissions. F-T jet fuel has been shown in laboratory combustors and engines to reduce PM emissions by 96% at idle and 78% under cruise operation. Validation of the reduction in other turbine engine emissions is still under way. Concurrent to the PM reductions is an immediate reduction in CO<sub>2</sub> emissions from F-T fuel (William and Larson, 2003 )

- Synfuels contribute to crude oil substitution, diversification and security of energy supply compensating for the scarcity of conventional crude oil resources without the CO<sub>2</sub> stabilization constraint.
- Synfuels can be used in existing diesel fuelling infrastructure and diesel engines without modification.
- Synfuels enable the development of new generation of internal combustion and engine technologies with improved engine efficiency.(Wang et al.2001)
- Synfuels are readily biodegradable, and non-toxic / not harmful to aquatic organisms.
- The CTL synfuels are less dense than conventional jet fuel; aircraft can fly further on the same fuel load
- The other important role of synthetic fuel production the cost effective pricing pattern of interregional FT synfuels trade and the resulting monetary flows between world regions in Southern Africa and could provide a significant source of income for developing world .
- The FT process is used to commercialize stranded gas reserves and blended with syngas from coal gasification to produce liquid fuel products.
- The FT synfuels play a crucial role in meeting the growing energy demand in the transportation sector regardless of CO<sub>2</sub> policy: the FT-diesel for trucks play a leading role until around 2050 and an increasing portion of FT liquids are refined to FT kerosene to be provided for the rapidly growing aviation sector.
- Improved Petroleum Supply Chain is likely to be realized in SA due to the broad regional dispersion of the S.A. coal resource base and the fact that CTL plants are able to produce certain finished fuel products that are ready for retail distribution; developing a CTL industry should increase the resiliency of the overall petroleum supply chain. In particular, a CTL industry will likely reduce the fraction of finished fuels imported. Also, a domestic CTL industry should reduce SA dependence on imports of finished petroleum products. In particular, imports of highly volatile products (e.g., petrol) are projected to continue over the next 20 years (EIA, 2008). Reducing such imports would result in a significant decrease in the amount of hazardous material entering .S.A ports and waterways.

Finally, in view of the above summarised facts the overall benefit of the FT synfuels production in SA is that projects are being implemented mostly in the form of a joint venture between private sector with a patented FT process technology. The resource holders and the South African companies (Sasol and PetroSA) are the leaders in the world synfuel industry hence their noticeable contribution could bring larger profits to SA and become direct and indirect drivers of the development in Africa through technological contributions of these South African companies.

## **8. Coal consumption overview of synthetic fuels production in SA**

Coal is a finite natural resource, putting limitations to the amount of fuels that can be produced by liquefying coal. The limitations are often with regard to accessibility, mining, transportation and production they directly will impact CTL feasibility. SA is the sixth largest producer and second largest exporter of bituminous in the world, beaten only by Australia(ESI-Africa,2004). A number of coal consumption estimates by CTL have been performed in the literature. Couch and Malhotra state yields of approximately three barrels of unrefined syncrude per ton of bituminous coal for DCL, with less efficiency for low-rank coal. The Monash Energy CTL project aims to produce liquid fuels, using 1.2 ton lignite per barrel (Monash, 2006). Milici gives conversion ratios of 1.3–1.8 barrels per ton bituminous coal, also mentioning lower yields for lower coal ranks. National Petroleum Council (NPC, 2007) has compiled other American studies and gives conversion rates ranging from 1 to 2 barrels/ton of coal. On the other hand Sasol has produced CTL yields that have been applied in many studies as the empirical yields since they are the world's leading CTL producer.

The Secunda site consists of two CTL plants with a combined capacity of 150 000 b/d and more than 40 million tons of coal per year is consumed (Sasol, 2009). In 2003, the South African synthetic fuel industry consumed 24% of all coal produced in SA ( ESI-Africa,2004 ) , since Sasol's CTL facilities are the only producer of synthetic fuels in SA, this must also reflect their coal consumption see (Figure 7). South African coal production was 238Mton that year (BP, 2008) and consequently, the coal consumption of the CTL sector was 57 Mton. All South African coal is



classified as bituminous (BP, 2008). The Sasol process converts mainly bituminous coal into FT liquids, so that over 33% of SA's fuel consumption (8 billion liter/year) and a large portion of chemicals production (2 billion liter/year) are produced by the three Sasol plants at Sasol I, II, III plants (Scholtz, 2008). On the basis of current global reserve estimates and consumption rates, the world has enough fossil fuels to meet human needs for about 300 year (WEC, 2004). While crude oil and natural gas reserves are expected to last for about 40 years and 60 years, respectively, coal reserves could be usable for another 200 to 225 years based on current consumption rates. Coal, by far, is the world's most abundant recoverable hydrocarbon resource. The world's proven coal reserves are estimated to be 985-billion tons, with the largest known reserves being in the United States, Russia, China, India, Australia, Germany and SA.

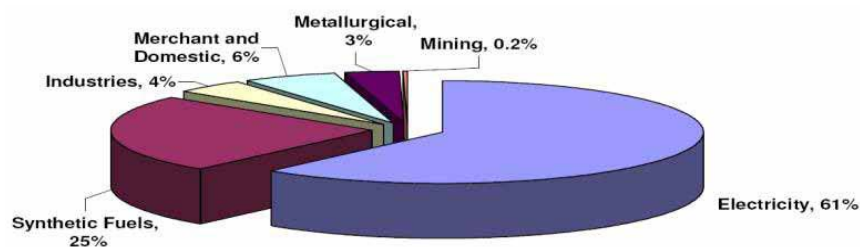


Figure 8: Distribution of coal consumption in SA (Department of Energy SA, 2011)

### 9. Current progress in coal to liquids synthetic fuels production around the world

There is some interest in CTL technology around the world, especially in China. However, all but two CTL projects were recently suspended. The objective was initially to produce 10 Mton annually of crude oil equivalents by 2010 from domestic coal and CTL technology and total output was expected to rise to 30 million tons of crude oil equivalents by 2020, approximately 16% of China's present crude oil production (Gao and Zhang, 2004). Currently, China is reconsidering this plan and the future path remains uncertain. Petroleum & Chemical Corp. (Sinopec) and Syntroleum Corporation announced the grand opening of the Sinopec/Syntroleum demonstration facility (SDF) located in Zhenhai, China. SDF is an 80 bpd facility utilizing the Syntroleum-Sinopec Fischer Tropsch technology for the conversion of coal, asphalt and petroleum coke into high value synthetic petro-chemical feedstocks. China has Shenhua's direct-liquefaction facility scheduled to begin operations in late 2008. Supporting the design of this plant is a six-ton-per-day pilot plant (Li, 2007).

### 10. Environmental Impacts of coal-to-liquids Production

Greenhouse gas emissions for Coal to liquid (CTL) without carbon capture and sequestration (CCS) is expected to result in a significantly higher carbon footprint than conventional petroleum-derived fuels (+147%) (Kaddour et al. 1995 and 2010). Generally, CTL without CCS has a higher greenhouse gas footprint. CTL with CCS has a 9-15% reduction in lifecycle greenhouse gas emissions compared to that of petroleum derived diesel. Based on current research findings from major energy producers, market and technical advances in clean coal technology, the overall commercial viability of CTL production appears to be gaining momentum in investment in CTL plants. In SA the CTL projects development is dependent upon possible permitting restrictions of a process design that is chosen that will meet local requirements for clean air, water, and increasingly, lifecycle carbon emissions. SA is a participating member state and signatory to all the annexures of the Kyoto Protocol on CO<sub>2</sub> which aims to "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". (UNFCCC, 2002). Climate change predictions and consideration of scenarios in which CO<sub>2</sub> levels are monitored will also be important to the CTL and synthetic project in SA. An international consensus exists that the only effective way to begin reducing greenhouse-gas emissions and slow global climate change would be to associate a cost with emitting carbon dioxide and other greenhouse gases through some type of policy instrument, whether a market-based mechanism (such as a carbon tax or a cap-and-trade emission program) or direct regulation. Already Sasol faces a challenge of reducing the GHG emissions. With such a price tag, businesses are continuing to make the investments in technology and changes in energy use that are required to dramatically reduce those emissions. (Scholtz, 2008). A CTL plant is a complex facility and affords a number of unit operations that are potential sources of emissions of hazardous or noxious and odorous air pollutants.

Although some of these sources are unique to coal processing, most are associated with operations encountered in petrochemical facilities. Ensuring that such releases do not occur or are within acceptable limits is an inherent part of the environmental permitting process and front-end engineering design and detailed design of a CTL plant.

## 11. CTL Plant-Site Impacts.

Consistent with regulations and modern engineering practice, CTL plants will be built with zero discharge of water. Plant-site threats to water quality would be associated with the management of the solid wastes generated by the plant. The most hazardous solid wastes will likely be generated from the evaporation of cooling and process water. These wastes will contain toxic metals and will need to be handled as hazardous wastes, per applicable regulations. In terms of bulk, the major waste product generated at the plant site will be coal ash. Coal ash is formed by the inorganic constituents of coal, which generally represent between 5 and 15 percent of the weight of coal. Assuming 10 percent, a 30,000 bpd CTL plant would generate about 0.5 million tons per year of ash (White et al (2007)). Coal gasification generally occurs at sufficiently high temperatures to cause most of this ash to be produced as a slag, an amorphous, glassy substance. Compared to coal ash, gasification slag is much less susceptible to leaching when placed in contact with water; therefore, its disposal presents lower hazards to groundwater resources. Gasification slag has been used as an additive for concrete production and possibly in road and construction materials.

## 12. Conclusions and Recommendations

Diversification of energy supply, sustainable management and further emission reductions with synthetic fuels can best be achieved through the coordinated efforts of fuel suppliers and automotive manufacturers working together with government policy makers. The Alliance for Synthetic Fuels in Europe (ASFE) is a collaboration of Daimler Chrysler, Renault, Royal Dutch Shell, Sasol-Chevron, Volkswagen and Toyota are trying to promote GTL, BTL and CTL technology development in Europe. A similar concept in SA will be quite invaluable given the advances in the synthetic fuel sector and the need to achieve sustainable management. The current development of CTL technologies using FT synfuels in SA has entered an advanced stage beyond the stage of pursuing commercialization considerations. The current challenge is to find a way to reduce GHG emissions from an LCA perspective. Government, through fiscal and national policy can increase penetration of all synthetic fuels, more specifically to:

- Include CTL, GTL fuels as an alternative fuels that can help SA lower dependence on imported crude oil.
- Put in place mechanisms to help achieve alternative fuels targets in a cost effective manner.
- Increase support, including R&D, for CTL production pathways.
- Increase R&D support for advanced engines optimized around synthetic fuels in conjunction with car manufacturers e.g., ethanol blends, DME as an automotive fuels as well.
- Recognise advanced fuel and engine technologies could provide SA automotive and synfuels industry with more business opportunities.

Over the longer term, for environmental, energy security and continued economic development reasons petroleum derived transport fuels will need to be supplemented by alternative fuels.

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