Liquid Fuels Production from Coal & Gas

Highlights

- **Processes and Technology Status-** The final products of the coal and gas liquefaction process are transport fuels similar to diesel and gasoline, and other liquid chemical products such as methanol and dimethylether (DME). Liquid fuels from coal may be produced using two different approaches, i.e. direct and indirect coal liquefaction (**DCL** and **ICL**), which are at a different stage of development. In both DCL and ICL, the challenge is to increase the hydrogen to carbon (H/C) ratio of the final product, and to produce molecules with appropriate boiling point at a reasonable overall cost. If (natural) gas is used as a primary feedstock instead of coal, a steam reforming process is used to convert natural gas into a synthetic gas, which is the basis for the production of synthetic liquid fuels. Coal liquefaction was first developed in 1913 in Germany, where high-pressure processes for ammonia and methanol production were applied to gasoline production from coal. In 1925, Fischer and Tropsch developed the FT process to convert syngas into intermediate wax products, which were finally converted into diesel, naphtha and kerosene using a hydro-cracking unit. During the Second World War, Germany produced large amounts of transport fuels via DCL and ICL technologies. Nowadays, the world's largest **Coal-to-Liquids** (**CTL**) production capacity is located in South Africa, based on locally available low-cost coal. A number of demonstration units have been built elsewhere, but only a few industrial plants are currently under construction. **Gas-to-Liquids** (**GTL**) plants with a capacity of almost 13 Mt are currently in operation in Indonesia, Malaysia, Qatar, Mexico, New Zealand, South Africa and Trinidad. Additional 9 Mt/yr GTL facilities are either under construction in Qatar (Pearl Island) or are planned to be commissioned by 2010.
- **Performance & Costs -** Performance and costs of coal liquefaction plants have been reconsidered recently, as a consequence of a new interest in alternative production of transport fuels driven by 2008 oil price peak. A study on liquefaction of Illinois No. 6 bituminous coal concluded that commercial CTL plants using the US Midwestern bituminous coal offer good economic opportunities. The investment cost of a CTL plant with a production capacity of 50,000 bbl/d of diesel and gasoline is around $ 4.1 billion (US$ 2006). The coal preparation and gasification in the CTL process account for almost 50% of the total investment cost, the rest is the cost of the GTL process. The economic viability of these projects depends heavily on crude oil prices. A crude oil price of $61/bbl (2006 US$) provides a 19.8% rate of return of investment (ROI). Oil prices higher than $37/bbl and $47/bbl provide ROI greater than 10% and 15%, respectively.
- **Potential & Barriers –** In principle, GTL potential is huge because synthetic fuels might in theory substitute conventional transport fuels and chemical products. In practice, GTL technology is in competition with pipeline gas transportation and with liquid natural gas (LNG) technology. It is likely to be chosen only if there is no other economically attractive use of natural gas. Therefore GTL plants are often located where abundant resources of natural gas - including gas associated to oil production - cannot be used for other purposes. CTL also has a huge potential for fuels and chemicals production. The technology however, either DCL or ICL process, is rather complex and involves considerable investment costs and risks, including oil price variations, changes in tax and regulatory regimes, especially those related to health, safety and environmental protection, notably the mitigation of CO_2 emissions. The CO_2 emissions of the CTL process are as high as the emissions arising from the final consumption of the produced fuels. The application of carbon capture and storage (CCS) technologies could reduce the CO_2 emissions of the CTL process by up to 99%. However, this possible with additional costs and with significant reduction of the efficiency of the process.

Coal to Liquid (CTL) Processes – Coal can be converted into liquid fuels using two different approaches, i.e. the direct and indirect coal liquefaction (**DCL** and **ICL**). In both cases, the challenge is to increase the hydrogen to carbon (H/C) ratio in the final product, and to produce molecules with appropriate boiling points at a reasonable overall cost. The two technologies are at different stages of development. Both processes are illustrated in Figure 1. The final products are transport fuels with properties similar to those of diesel and gasoline, and other liquid chemical products like methanol and dimethylether (DME). ■ **The DCL process** consists of the dissolution of coal in a mixture of solvents. This is followed by thermal cracking, whereby hydrogen is added as a donor solvent. There are two main DCL processes: a) The **single-stage liquefaction process** provides distillates via either a primary reactor or a train of reactors in series, with possibly a hydro-treating reactor to upgrade the primary distillates. The optimal operation temperature

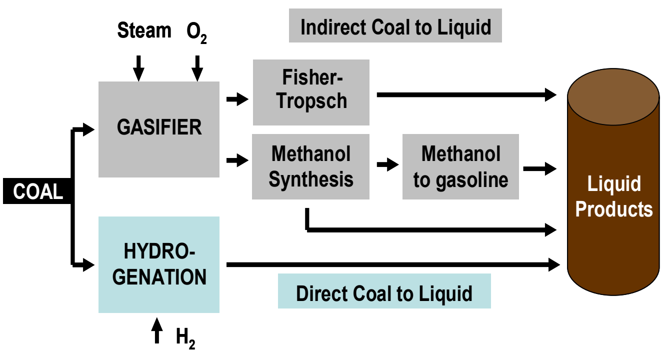

Fig. 1: Processes for producing liquid fuels from coal

for single stage direct liquefaction is around 450°C, and the molar ratio between coal and solvent should be about 2:1; b) The **two-stage liquefaction process** provides distillates via two reactors or two reactor trains in series. The first stage dissolves coal (with/out low-

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activity catalyst) and the second one provides distillate hydro-treatment in the presence of high-activity catalysts. The DCL technology is the most efficient route currently available for producing liquids from coal. Liquid yields between 60% and 70% (by weight) of the dry coal have been demonstrated. The product is quite difficult to refine due to the high share of aromatic components and the presence of nitrogen. ■ **In the ICL process**, the first step is the gasification of coal to produce a synthetic gas (syngas), which basically consists of CO and H_2. The reaction takes place at high temperatures (800-1800°C) and high pressures (10-100 bar) under oxygen shortage conditions. The syngas is then reformed by using the water/gas shift reaction, in which H_2O and CO react to form CO_2 and H_2. The syngas is purified, whereby in particular sulphur is extracted, and the CO2 may be separated and stored (see ETSAP Technology Brief S01 on coal gasification). Starting from syngas as the basic feedstock offers a number of potential advantages such as operational flexibility (syngas can be obtained from different sources such as coal, natural gas, biomass), potential for poly-generation of liquid fuels, chemicals, and power; cleanliness of products (no sulphur and aromatics); and potential production of CO_2 ready for capture and subsequent storage.

GAS TO LIQUID (GTL) PROCESSES – If natural gas is used as a primary feedstock, no gasification step is necessary. Instead, the gas is converted into syngas by a steam reforming process and the syngas is the basis for the following production of synthetic fuels. The production of liquid transport fuels, i.e. diesel and gasoline type fuels, is based on two technologies, the **Fischer-Tropsch synthesis** (FT) that produces both primary diesel and gasoline, and the **Methanol synthesis,** where the main product fuel is gasoline. The FT technology, in turn, is based on two approaches, the low temperature FT and the high temperature FT. The low temperature FT process operates in the temperature range of 200-250°C and maximises the production of diesel while the high temperature FT process operates at 300-350°C and produces mainly fractions with lighter molecular weight, thus maximising the gasoline fraction. The methanol synthesis has a slightly higher efficiency than the FT process. However, as methanol is not directly used as a transport fuel for different reasons, an additional conversion step of methanol into gasoline is required.

TECHNOLOGY STATUS – Coal liquefaction was first developed in 1913 in Germany, where high pressure processes for ammonia and methanol synthesis were modified to produce gasoline from coal. In 1925, the German scientists Fischer and Tropsch developed the FT process to convert syngas from coal into intermediate wax products, which were finally converted into diesel, naphtha and kerosene using a hydro-cracking unit. During the 2nd world war, huge amounts of transport fuels were produced in Germany from coal both via DCL and ICL technology. Nowadays, the world's coal-to-liquids production capacity (some 15 GW_{th}) is almost entirely located in South Africa and based on locally available low-cost coal (NETL, 2007). Production plants developed by Sasol use ICL with moving bed gasifiers (see ETSAP TB S01) producing a syngas which is fed into FT reactors. While there have been a number of significant advances in downstream syngas processing, the basic plants were constructed in the 1980s and hence have now largely been depreciated. In addition, in that period environmental concerns were not as stringent as they are at present. New plants should be built based on different environmental criteria and impact. After the 1980s, a number of demonstration CTL units have been built worldwide, with extensive work in Japan and in the US and using a wide range of coal types. Development work has also been carried out in Germany and in the UK, mostly based on various DCL processes. Much of this work was stopped in the 1990s because of the relatively low oil price. Over the past years, with increasing level of oil prices, coal liquefaction has been reconsidered and several units are now under construction or planned in various countries. The most ambitious program has been launched in China. It includes: the Shenhua DCL plant with a capacity of 6 kt coal per day (1.4 GW_{th}) producing 1 Mt/y of liquid products (operation tests completed in 2008); the Yitai ICL plant (0,22 GW_{th}) producing 160.000 t/y of liquid products (operation tests in April 2009); and several additional ICL plants being planned or built. In the US, the market for coal liquefaction will depend entirely on future policies for CO_2 emissions mitigation. Facilities without CO_2 capture and storage (CCS) are unlikely to be commissioned, although highly desired for improving supply security for transport fuels and reducing oil import dependence. A large CTL plant that was planned to be operational by 2011 for producing fuels for the US army has been recently cancelled for safety and environmental reasons (The Guardian, 2009). While ongoing research is trying to increase yields, reduce operational costs and catalyst consumption, and add CO_2 capture and storage technology to reduce emissions, both DCL and ICL technologies are commercialized by a number of industrial companies.

Several countries with large natural gas resources and limited domestic gas demand have embarked upon gas-to-liquids (GTL) development programs. In these countries, natural gas - mostly produced in association with oil extraction - is converted into high-value fuels or methanol in FT facilities next to the oil & gas fields. GTL plants with a capacity of almost 13 Mt (19 GW_{th}) are in operation in Indonesia, Malaysia, Qatar, Mexico, New Zealand, South Africa and Trinidad. Additional 9 Mt (11 GW_{th}) GTL facilities are either under construction at Pearl Island in Qatar and being commissioned by 2010.

PERFORMANCE & COSTS – CTL plants are large industrial undertakings using huge amounts of coal. In general, they are built at the mine-mouth with adjacent reservoirs of at least 500 Mt of coal depending on the plant capacity. As mentioned before, while the ICL process offers more flexibility in terms of variety of feedstock and products, and potential for CO_2 emission abatement, the DCL technology is more efficient, with liquid yields between 60% and 70% by weight of the dry coal. In general, the yield is approximately 500 l/t using bituminous coal and a little less using sub-bituminous coal (Couch, 2008). Performance and cost figures for coal liquefaction plants have been reassessed very recently, as a consequence of the high interest in alternative sources and processes for transport fuels production. A study on liquefaction of Illinois No. 6 bituminous coal concluded that commercial-scale CTL plants using US Midwestern bituminous coal offer promising economic opportunities. Table 1 summarizes the performance and capital cost figures for the plant. Based on a specific plant configuration, the financial analysis projected a nearly 20% return on investment, a net present value of more than $1.5 billion, and a payback period of 5 years (NETL, 2007). The capital cost of a CTL plant to produce 50,000 bbl/d diesel or gasoline is around $ 4.1 billion (2006 US$). The cost of a GTL plant would be approximately half that amount as the coal preparation and gasification account for almost 50% of the total investment cost. In developing countries capital costs are typically much lower, anywhere from 60% to 90% of those in the OECD. Labour cost is also some 20% to 40% of the OECD labour cost (Crouch, 2008). The NETL study was based upon a coal price of $37/ton. Sensitivity analysis with a coal price ranging between $27/ton and $46/ton provide higher or lower return of investment (ROI). From the economic point of view, the project viability depends heavily on crude oil price scenarios. The base case, with a crude oil price of $61/bbl, provides a 19.8% ROI. At crude oil prices greater than $37/bbl, the project would achieve ROI greater than 10%. A 15% ROI can be achieved at crude oil prices greater than $47/bbl. In any case, the economics of CTL plants will be strongly impacted by the future requirements for CO_2 capture and storage. Therefore, a plant location close to places where CO_2 can be readily stored (e.g., depleted oil wells, enhanced oil recovery sites, exhausted natural gas reservoirs) can result in synergies and cost reduction.

Tab. 1: Performance and Costs (US$ 2006) of a FT project based on Illinois No. 6 bituminous coal (NETL, 2007)

Performance	
Plant Output, bbl/d	50,000
thereof:	
● Naphtha, bbl/d	22,173
● Diesel, bbl/d	27,819
Coal Feed (dry basis), t/d	24,533
Plant Availability, %	85
Gross Power Production, MW	652
Net Power Output, MW	124
Elemental Sulfur Production, t/d	612
Carbon Dioxide Capture, t/d	32,481
Overnight Capital Cost, mln $_{2006}$	
Coal & Slurry Preparation	295
Gasifier & Gas Clean-up	1,978
FT Process	705
Power Generation Unit	237
Balance of Plant	435
Working Capital, Start-Up cost, Owner's Cost	420
Total Cost	4,070
Capital Cost/Output, $_{2006}$/bbl/d	81.400

POTENTIAL & BARRIERS – In principle, the possible long-term potential of GTL is huge, as synthetic fuels may in theory substitute conventional transport fuels and chemical products. However, the liquefied natural gas (LNG) technology and the pipeline natural gas transportation compete directly with the GTL technology. As most of today's natural gas is marketed under long-term contracts (e.g., pipeline gas normally for 20-30 years, LNG for some 10 years) and huge investments in existing infrastructure have to be repaid, GTL gas is likely to gain market share only in the case of new resources discoveries at remote locations where neither local use is possible nor infrastructure for transportation over long distance are available or economic affordable to build. CTL also holds a huge potential for substitution of conventional transport fuels and chemical products. The technology, however, either DCL or ICL, is rather complex and involves large capital investment and operational costs. The only major commercial CTL facilities in operation are the Sasol plants in South Africa. China has installed a large DCL plant and a smaller ICL plant which both have started operation test phases. All other CTL plants listed in worldwide overviews are under construction or are demonstration plants. CTL investment is accompanied by a number of risks, including variable oil price, competition from alternative technologies for producing transport fuels, changes in tax and regulatory regime, especially those related to health and safety, and to environmental protection. The long-term development of the CTL process also depends on the relative prices and costs of raw materials (coal and catalyst), energy and electricity, water, transport fuels and chemicals (for polygeneration projects). Additional uncertainties relate to local regulations for pollutants and emissions and global policies for reducing CO_2 emissions.

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Table 2 – Summary Table: Key Data and Figures for Coal and Gas Liquefaction

Technical Performance	Typical current international values and ranges					
	CTL			**GTL**		
Input	Coal, water, air			Natural gas		
Technical components	ASU, oxygen blown entrained gasifier , shift converter, FT reactor, product upgrading, (power generation, CO_2-separation)			ASU, steam reformer, shift converter, FT-reactor, product upgrading (CO_2-separation)		
Capacity, output MW_{th}	800	2400	4800	800	2400	4800
Energy input (coal or natural gas) , GJ/h	5000	15,000	30,000	5000	15,000	30,000
Output: Syncrude GJ/h	2400	7300	14,700	2,750	8350	16800
(bbl/d)	(10,000)	(30,000)	(60,000)	(10,000)	(30,000)	(60,000)
Construction time, yr	4			2		
Technical lifetime, yr	30			30		
Load factor, %	85			85		
Installed capacity power gen. system, MWel	200	600	1200	230	690	1380
Environmental data						
CO_2 emissions, kt/PJ_{output}	122	119	118	28	27	26
CH_4 emissions, kt/PJ_{output}	0.0086	0.0085	0.0084	0.0045	0.0045	0.0045
N_2O emissions, kt/PJ_{output}	0	0	0	0	0	0
Reduction of CO_2 emissions if CCS is applied, %	up to 99%			up to 99%		
Land use, acres	100			100		
Water and special materials use	amine solvent, shift catalyst			amine solvent, shift catalyst		
Costs (US$ 2006)						
Capital cost, $/GJ output	15.7 – 22.7	12.2 – 17.5	10.5 – 12.2	6.5 – 7.5	5.0 – 6.0	4.0 – 5.0
Fixed O&M cost, %/yr of capital cost	4%/yr			4%/yr		
Variable O&M cost, $/GJ output	1.4 – 1.8	1.2 – 1.5	1.0 – 1.2	0.6 – 0.7	0.5 – 0.6	0.4 – 0.5
Coal cost, $/GJ input	0.9 – 1.3	0.9 – 1.3	0.9 – 1.3			
Natural gas cost, $/GJ input				4 - 8	4 – 8	4 - 8
CO_2 capture and compression, $/t CO_2	20 - 80	20 - 80	20 - 80	20 - 80	20 - 80	20 - 80
Transport and storage of captured CO_2, $/t CO_2	6 - 20	6 - 20	6 – 20	6 - 20	6 - 20	6 - 20
Data Projections	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
Capital cost, $/GJ output	15 -22	11.5 – 16.8	9.8 – 11.7	6.0 – 7.0	4.5 – 5.5	3.5 -4.5

References and Further Information – • Baseline Technical and Economic Assessment of a Commercial Scale Fischer-Tropsch Liquids Facility", DOE/NETL-2007/1260; Final Report April 9, 2007; World Energy Outlook 2006 (IEA, 2006); • The Future of Coal, MIT 2007; • The Guardian 30 January 2009: "US air force drops plans to build coal-to-liquid fuel plant"; • National Petroleum Council (NPC): Coal to Liquids and Gas, 2007; • Van Vliet: "Fischer–Tropsch diesel production in a well-to-wheel perspective: A carbon, energy flow and cost analysis", 2009; • Rand Corporation: "Producing Liquid Fuels from Coal", 2008; Concawe, EUCAR, • JRC:" Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context" (2007). • ETSAP Technology Brief S01 "Production of Syngas from Coal"

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