The current status of coal liquefaction technologies

In 2008, a first coal liquefaction unit to produce motor fuel (20,000 BPSD) will come onstream in Shenhua, China (in the Ercos region of Inner Mongolia). Other, more ambitious projects have been announced in China for between now and 2020. Since oil production is expected to peak in the medium term, this technology may develop regionally in the next 20 years to cover ever-increasing demand for motor fuel.

Background

From the start, two radically different approaches to the liquefaction of coal (Coal to Liquids, or CtL) have co-existed:

- A direct process based on work done by Bergius between 1910 and 1927 in Germany.
- An indirect process, based on a patent taken out by BASF in 1913 and work by two German chemists, Hans Fischer and Franz Tropsch, who succeeded in producing motor fuels from coal in 1922 by first producing "syngas" (H_2+CO), then performing synthesis with an iron-based catalyst.

During World War II, Germany applied this technology industrially on a large scale, producing a total of about 120,000 barrels per stream day (BPSD) primarily by means of direct liquefaction. Using coal from the Ruhr, it was able to keep nearly the entire Luftwaffe fleet in the air, in spite of the Allies' restrictions on the supply of crude oil. In 1955, the petrochemicals company Sasol gradually installed nearly 190,000 BPSD in capacity in South Africa, using the indirect method and domestic coal supplies (5% of world reserves) in response to the international embargo imposed against the apartheid regime.

Clearly, no country wanted to develop these processes, still in their early days, unless geopolitical reasons made it necessary. The cost of synfuels was much higher than petroleum-based motor fuels, mainly because of the heavy investment required and the then low price of crude.

It's important to keep in mind that GtL production of synfuels from natural gas, whose development is now attracting some attention, and the BtL production of so-called "second generation" biodiesels, as well as CtL processes, are all based on Fischer-Tropsch synthesis.

Available technologies

Process diagrams

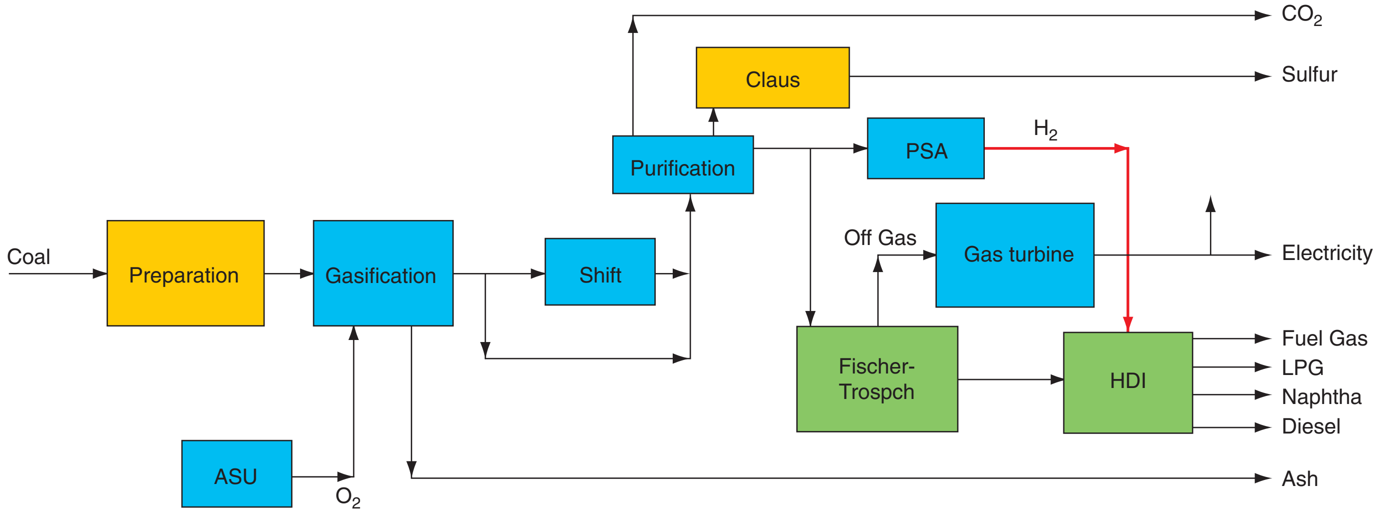
Indirect coal liquefaction (ICL)

There is only one coal liquefaction facility in service today, operated by Sasol in South Africa. Unlike the Shenhua project in China, scheduled to start up in 2008, this facility uses the indirect process (Figure 1).

This very robust process is compatible not only with conventional bituminous and sub-bituminous coals, but also less mature coals such as lignites or even biomass. After a preparation stage, the coal is converted to syngas under pure oxygen. The H_2/CO ratio for this gas (between 0.5 and 0.8) is adjusted to the value required for the Fischer-Tropsch reactor (usually H_2/CO = 2) by means of a shift reactor, then all of its impurities are removed. The product obtained in the Fischer-Tropsch reactor is sent to an isomerization stage or cold-process isomerizing hydrocracking (HDI) to bring the properties of the final product into conformity with the specifications in effect. Generally, one obtains a selectivity of about 30% paraffinic naphtha, an excellent steam-cracking feedstock (petrochemicals), for 70% diesel with a very high cetane number and no impurities, because it is composed only of paraffinic molecules (Table 1).

The current status of coal liquefaction technologies

Fig. 1 - Basic diagram of an indirect coal liquefaction unit (ICL)

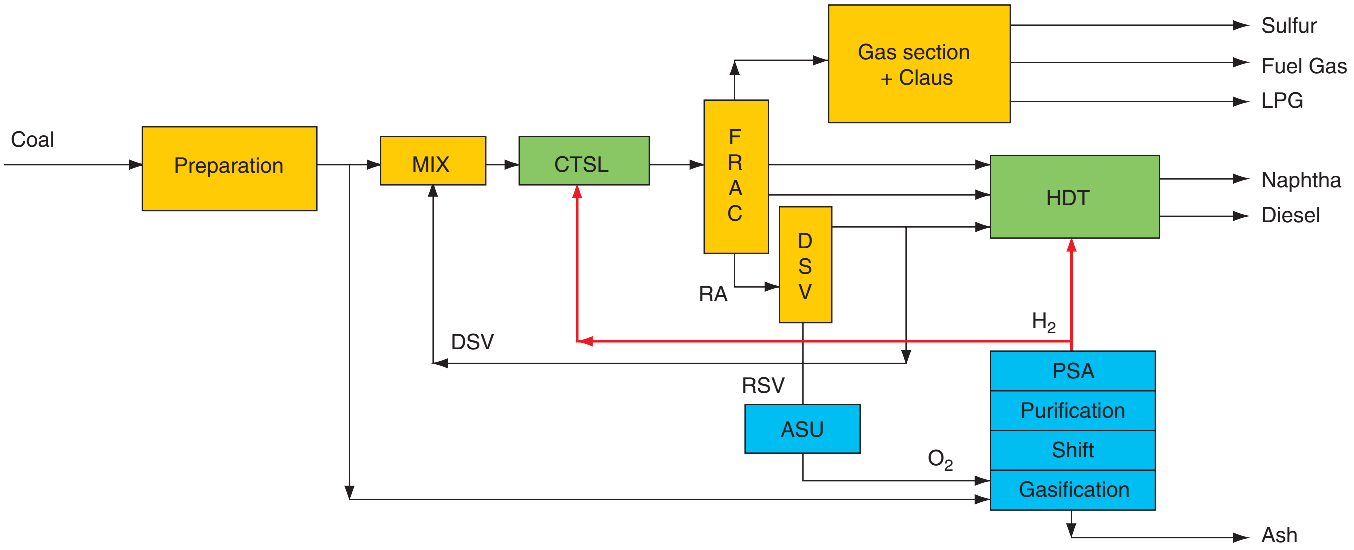


Source: IFP/Economic Studies Division

Table 1

	Coal (bituminous/ sub-bituminous)	DCL diesel (post HDT)	DCL diesel (post HDK)	ICL diesel	Diesel Europe
% H (%wt) Specific gravity at 15°C Cetane number	**4.5/5.0**	**13.0/13.5** 0.860/0.870 40-45	**13.5/14.0** 0.820/0.830 50-55	**15** 0.770-0.780 > 65	**About 13.5** 0.820< d < 0.845 > 51

Fig. 2 - Basic diagram of a direct coal liquefaction unit (DCL)



Source: IFP/Economic Studies Division

Direct coal liquefaction (DCL)

This process is only used with bituminous and sub-bituminous coals, which represent about 80% of current reserves (Figure 2).

The coal is first ground to a powder then mixed with the vacuum Gasoil (VGO) generated at the unit (hydrogen donor). It then goes to hydrocracking, generally two reactors. After product separation and partial hydrotreatment, the bulk of the VGO is sent back to the reactor whereas the diesel (generally mixed with naphtha), which has naphthenoaromatic characteristics, is sent either to severe hydrotreatment (HDT) or hydrocracking (HCK) to bring it into conformity with the specifications in effect (especially those applicable to the cetane number and specific gravity). The hydrogen needed for the reaction is supplied by a coal gasification unit or produced from natural gas by means of steam reforming, depending on local availabilities and the cost of raw materials.

The hydrotreated naphtha can be used as a steam-cracking feedstock for petrochemicals or sent to a catalytic reforming unit to produce a component of gasoline.

Comparing the performance of these two processes

The main difference resides in the quality of the diesel produced:

- The direct method yields a diesel with naphthenic characteristics, even after relatively advanced hydrogenation (or even hydrocracking), it has a high specific gravity and a cetane number below European standard. A hydrocracking step would have to be added to raise the cetane number to the required level. This would significantly decrease diesel output and significantly boost investment.
- The indirect process does the reverse. It yields a product that is purely paraffinic, thus clearly above standard, but the market does not really account for the value-add of this "overquality".

We might mention that IFP is the only licensor for both direct and indirect liquefaction technologies.

These two liquefaction processes differ in terms of product quality: one yields a product that is below standard and the other a product that is above standard. Since they are complementary, some projects under review may combine the direct and indirect processes. The idea is to blend naphthenic and paraffinic diesel to get closer to the targeted specifications while avoiding overquality. In the Philippines, a project of this type is in the planning.

We should note that hydrogen content is of key importance in the liquefaction of coal (Table 1).

Owing to its hydrogen-poor composition, coal cannot be used to produce commercial-grade diesel unless hydrogen is added in massive quantities. When coal is the only available source of primary energy (e.g. when the facility is located next to a mine), the necessary hydrogen can be supplied by ensuring the gasification of sufficient quantities of additional coal.

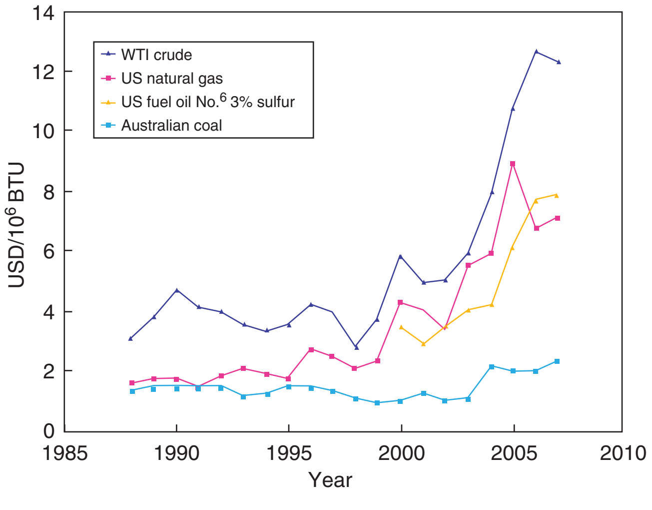
Economic performance

Let's assume that this type of facility can generate the hydrogen it needs from local coal. Normally, its naphtha and diesel output would be:

- DCL process: 3.5 bbl/ton of organic coal material ("moisture and ash free" or MAF coal).
- ICL process: 2.5 bbl/ton of MAF coal.

For this coal technology, economic performance depends heavily on the price of this coal, which is still relatively inexpensive compared to other energy sources and largely independent of the crude price, as illustrated Figure 3.

Fig. 3 - Price of fossil energies (per unit of energy)



Source: IFP based on annual data published by Platts

Figure 4 gives an estimation of the rate of return on investment (after tax) for a large ICL unit, as a function of the reference crude price (Brent). The difference between curves indicates the influence of the coal price on unit profitability. This type of facility should be located at the mine to avoid the cost of shipping coal, which is much more expensive to ship than finished products (liquid). For industrially demonstrated liquefaction processes, the estimated investment is USD 110,000 per barrel per day for the finished product (base: USA early 2007). For instance, a facility with a capacity of 50,000 bbld represents an investment of more than 5 billion dollars, roughly equivalent to the cost of a complete oil refinery producing three times more motor fuel. The reduction of investment costs per baril, especially by increasing the size of installations, is one of the most important ways to achieve progress for this technology. We might recall that the recent increase in the price of steel (up 80% in 4 years) has had a substantial impact on the economics of CtL technology as well as other technologies including GtL and refining. It has been estimated that, using current processes, the threshold of profitability for USD 20/ton coal may reached for a crude price of about USD 70/bbl, a figure that has been largely exceeded on the spot market in 2007. The cost of USD 20/ton of coal is attained at top-performing mines, but it remains well below international prices. That's why, initially, projects like this will only be of interest to countries that not only possess coal resources in abundance but are also seeing high domestic demand for liquid motor fuels.

The economic performance reported for direct liquefaction is comparable to that of indirect liquefaction.

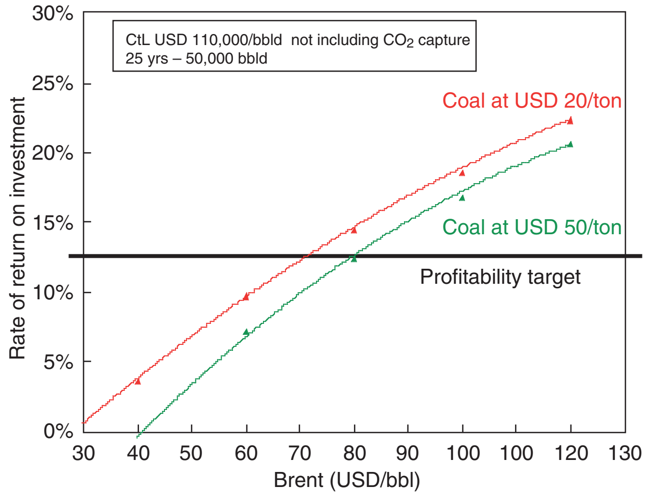
Greenhouse gas emissions generated by CtL technologies

It would not be realistic to discuss coal liquefaction without any reference to greenhouse gases (Figure 5). Total well-to-wheel emissions for the ICL stream correspond to about 230% of the emissions generated by conventional diesel (oil). In other words, less than half of the carbon contained in the coal ends up in the fuel tank of the vehicle. Most of it is converted into CO_2 at the liquefaction plant, especially during the hydrogen production stage, added to correct the H/C ratio of the coal. This ratio is low compared to that required to produce diesel. In the production of petroleum products, one should note, more than 90% of the carbon present in the oil ends up in the tank. Obviously, this amount of "excess" pollution is unacceptable at a time when the international community has prioritized the reduction of greenhouse gases (GHGs). It is generally accepted that it will not be possible to develop ICL technology to any significant extent unless it integrates carbon capture and storage (CCS), or uses hydrogen produced externally to the unit by sources that do not emit GHGs. The few exceptions are projects announced in developing countries that did not sign the Kyoto Protocol. At ICL units based on gasification, CO_2 capture can take place in relatively favorable economic conditions, thanks to the high pressure and high CO_2 concentrations found at the absorber. Under these conditions, the well-to-wheel performance comes much closer to that of conventional diesel (but is still slightly more unfavorable with 125% of carbon emissions).

Planned projects

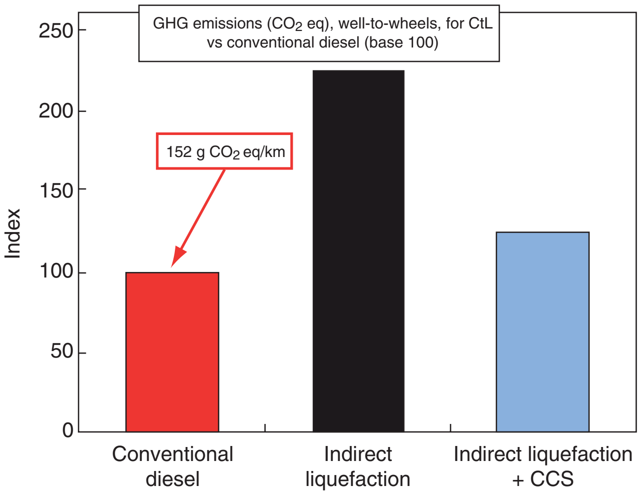
In the last two or three years, a number of coal liquefaction projects have come under review, either because this technology has become more profitable as the price of crude oil rises, or because it fits into strategies to guarantee a supply of energy. All of these projects are at different stages of the decision-making process and not all of them will be built.

Fig. 4 - Economic performance of coal liquefaction



Source: IFP/Economic Studies Division based on Q1 2007

Fig. 5 - LCA for ICL technology



Source: Well-to-wheels study JRC EUCAR CONCAWE 2006

The current status of coal liquefaction technologies

China is to bring the Shenhua DCL unit (20,000 bbld) onstream in 2008 and expand its capacity to 50,000 bbld by 2015. It has announced other large projects as well. All in all, it plans to add 700,000 bbld in capacity (direct and indirect processes) by 2020.

In the Philippines, H&WB Corp. has announced a project for a hybrid production unit (60,000 bbld) combining direct and indirect coal liquefaction technologies.

Sasol is looking to increase capacity by 80,000 bbld, either in South Africa or India.

In the United States, at least six coal liquefaction projects are in the works (aggregate capacity: nearly 150,000 bbld). Some have already reached the stage of filing for official approval, while others have not got beyond the feasibility study.

The sum of these capacities converges with data published by the International Energy Agency, which estimates that world capacity for the production of liquefiates will reach 750,000 bbld by 2030, mainly in China (source: IEA, World Energy Outlook 2006).

Given the crude price hikes of recent years and greater awareness that the production of petroleum is probably peaking, various governments and companies are considering large-scale coal liquefaction projects. This situation is very different from that of the fifties when, as in the case of South Africa, a country would only develop significant capacity if warranted by particular geopolitical circumstances. Moreover, liquefaction technologies have recently reached economically acceptable thresholds of profitability. All the same, it is highly probable that liquefaction capacity will long remain marginal compared to that of oil: 750,000 bbld represents less than 1% of world refining capacity, or the equivalent of four medium-sized refineries.

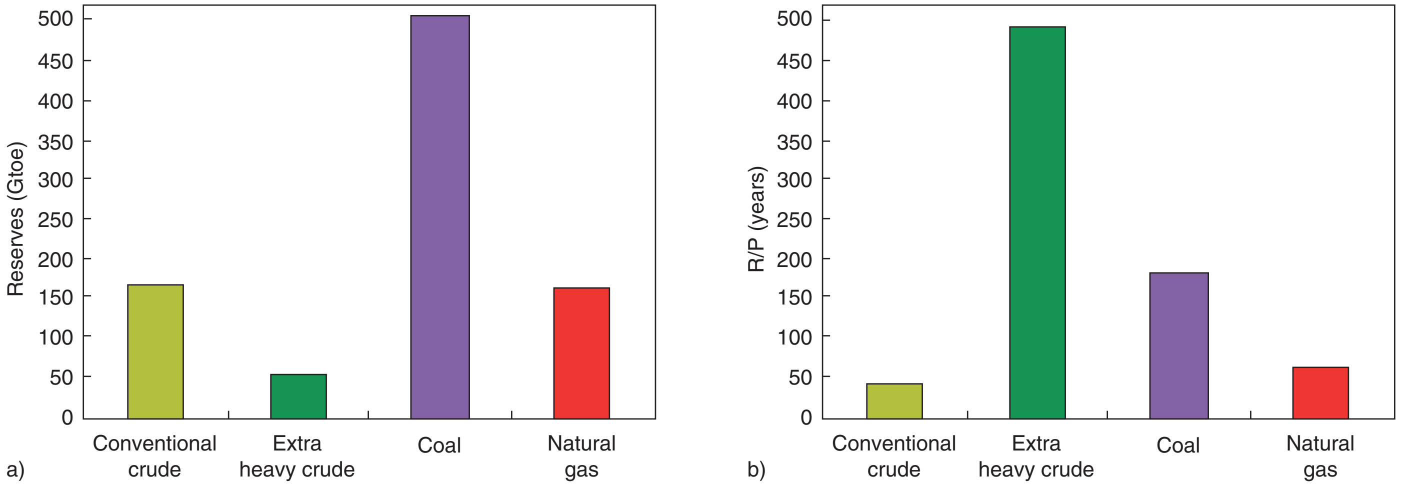
Conclusion: why take an interest in coal liquefaction today?

Many recent studies based on an average scenario for 2006-2030—annual growth of 3.1% (US Department of Energy) and a world population of more than 8 billion by 2030 (the UN)—predict that the number of motor vehicles in circulation worldwide could double by 2030, therefore motor fuel consumption will continue to grow at a high annual rate. One reason among others is the low elasticity of motor fuel demand to the crude price. Of course, trend forecasts do not account for the possibility of changes in individual behavior, government measures to reduce greenhouse gases or the introduction of biofuels or fuel-saving technologies (e.g. hybrid or all-electric propulsion systems). However, it's likely that the basic trend for the next few years will be an increase in world demand for motor fuels.

If that be the case, then coal represents a credible solution as a supplemental source of energy for the transport sector. Coal reserves are still plentiful in terms of volume (nearly 500 billion tons oil equivalent, or 3.5 times the oil reserves) and production (more than 150 years at the present rate).

The present time frame, with the oil price curve intersecting the motor fuels ex-coal curve, may be regarded as a turning point. It can be argued that the CtL technology reached the threshold of profitability for the first time in 2006 and more markedly in 2007. It can be expected to do so in future, if technological advances

Fig. 6 - Hydrocarbon reserves (worldwide)



Source: IFP DEE

make it possible to offset the cost of CO_2 coproduct disposal as well as the problematical increase in investment costs, especially due to the soaring price of steel.

Despite their high production costs and environmental performance, open to criticism, CtL projects will probably emerge in countries that possess abundant coal reserves and import oil on a large scale. In many instances, a country will give higher priority to national security issues (covering a percentage of its energy supply with local resources) than to strictly economic criteria. It is not surprising if China has recently embarked upon CtL projects. China is a net oil importer with vast reserves of coal that can be produced at unbeatably low costs (USD 5/ton at the best mines). Other countries with a similar energy profile may follow suit: projects are under review in the United States, India and the Philippines.

This being said, it's likely that CtL will not be developed on a massive scale in the next 20 years, for two reasons. The first is the prohibitive cost of producing liquefiates from coal purchased at international prices. Second, the technology must compete with the power production sector, which absorbs nearly all of the coal extracted. CtL is only expected to develop to a limited extent and in a few geographic areas.

Still, in light of global warming and knowing that CtL generates GHG emissions "from mine to wheel" that reach all-time highs (230% compared to the conventional petroleum stream), any CtL development, even partial, will have to be integrated with CO_2 capture and storage solutions to help cover world energy demand while minimizing impact on the environment.

Pierre Marion - pierre.marion@ifp.fr
Final draft submitted in December 2007