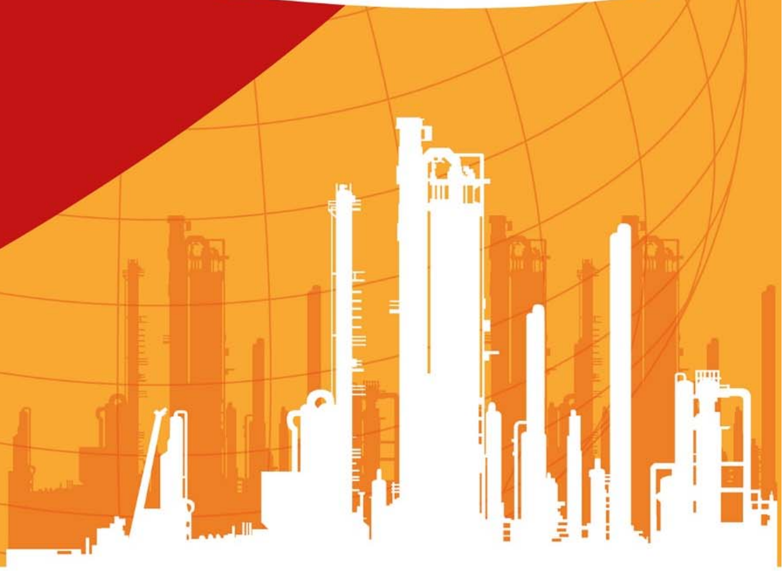
World CTX

Carbon To X Processes

Processes and Commercial Operations



World CTX: let's Optimize the Use of Carbon Resource

Carbon To X Processes

Carbon To X technologies are operated in more than 50 plants in South Africa, the USA, India, China and soon South Korea, mostly with coal as feedstock, while the largest gasification capacity is presently getting started with petroleum coke.

Most commercial operations are:

- Coal To Liquid Fuels
- Coal To Chemicals
- Coal To SNG
- Low Rank Coal Pyrolysis, Low Rank Coal Upgrading
- Syngas for DRI

These processes are briefly described in the following pages, which have been prepared and improved with the support of World CTX network members.

We are sure that this document can still be improved: you are welcome to email your suggestions to management2018@wordctx.com, thank you.

Coal To Liquid Fuels

In this page, “CTL” will stand for “Coal To Liquid Fuels” only. “CTL” is also often used as a general expression for all liquid products produced from coal including petrochemicals. Coal To Chemicals is dealt with on a specific page here.

Processes

Several processes are available to convert coal to liquid fuels. The ones which today are the most frequently applied and studied are (i) the “indirect route” and (ii) the “direct route”.

1) Indirect route

It is called “indirect” because it is composed of two clearly separated steps.

Coal is first gasified with steam and oxygen to produce a synthetic gas or “syngas”, composed of carbon monoxide (CO), hydrogen (H2) and to a lesser extent carbon dioxide (CO2) and methane (CH4) as well as impurities.

The [H2]/[CO] ratio in the syngas generally needs to be increased, which is achieved in a “water-gas shift” reaction, where CO and water are converted to CO2 and H2. Syngas is then cleaned to eliminate dust, tar and acid gases.

The second step can consist in either one of the two following processes:

- The “Fischer-Tropsch” catalytic synthesis, which has benefitted from numerous experiences and is used in most demonstration plants and projects;

- The “Methanol to Gasoline” or “MTG” process: methanol (CH3OH) is first produced from syngas by a catalytic reaction of H2 and CO. Methanol is then dehydrated to give first DME (dimethyl ether, CH3OCH3) and then gasoline.

2) Direct route

In the “direct” route, coal is pulverized and mixed in a recycled slurry in which hydrogen is added under pressure. The mix reacts in an ebullated bed reactor to produce hydrocarbons which are refined under conventional refinery processes.

Both indirect and direct Coal To Liquid routes have respective advantages, in terms of versatility and quality of outputs (naphtha and diesel respectively). Most projects today are based on indirect processes, mainly thanks to the higher level of knowledge accumulated by experience and research so far.

Use of biomass

Liquid fuels can be produced from any hydrocarbon including biomass.

The main advantage is in decreasing the environmental footprint, as biomass is carbon-neutral.

Challenges come from the chemical nature of biomass, with lower calorific value, higher moisture content and tar formation, as well as seasonal supply variations.

Combining coal and biomass presents major advantages in terms of reaction temperature, as well as regular supply and the environmental footprint.

Operations and projects

Up to 2009, Coal To Liquid was commercially operated in South Africa only.

Four demonstration plants are in operation in China, where capacity has reached 29,000 barrels per day and is expected to rise to 200,000 bbl/day by 2017.

Projects exist in Australia, Botswana, India, Mongolia, USA and Russia.

Coal To Liquids plant
Secunda, South Africa

Coal To Liquid plant
Ordos, Inner Mongolia, China

Coal To Chemicals

In this page, “chemicals” stands for “chemicals except liquid fuels and methane”.

One can note that the term “Coal To Chemicals” is sometimes used to embrace the production of any hydrocarbon from coal including liquid fuels and natural gas, as long as liquid fuels and natural gas are “chemicals” – in fact, any material on the earth is a “chemical”.

Coal To Chemicals represents the main application of gasification, which is the first step in most coal conversion processes.

Petrochemicals can be produced from hydrocarbons other than coal, such as biomass.

Products

Products can be split into families: ammonia and urea on the one hand, methanol and the “chemistry of methanol” on the other hand.

Coal To Chemicals Processes

Coal is first gasified with steam and oxygen to produce a synthetic gas or “syngas”, composed of carbon monoxide (CO), hydrogen (H_2) and to a lesser extent carbon dioxide (CO_2) and methane (CH_4) as well as impurities.

The [H_2]/[CO] ratio in the syngas classically needs to be increased, which is achieved in a “water-gas shift” reaction, where CO and water are converted to CO_2 and H_2. Syngas is then cleaned to eliminate dust, tar and acid gases.

Two families of chemicals are produced from coal.

- Ammonia and urea
Hydrogen (H_2) extracted from syngas reacts with nitrogen (N_2) to form ammonia (NH_3). Ammonia then reacts with carbon dioxide (CO_2) to produce urea ($CO(NH_2)_2$).

- Chemistry of methanol
Once the [H_2]/[CO] ratio is adjusted to [2]/[1], H_2 and CO react on a catalyst to produce methanol (CH_3OH).
Almost any petrochemical can be produced from methanol by classical processes.

Operations and projects

Most Coal To Chemicals operations and projects are in China, in addition to an ammonia-urea plant in Kansas, USA.

Production is often a mix of several types of chemicals.

Main chemicals produced from coal are urea on one side and, on the methanol side, methanol itself, olefins (ethylene, polyethylene, polypropylene), MEG (monoethylene glycol), DME (dimethyl ether) and acetic acid.


Coffeyville fertilizer plant
Kansas, USA


Baotou Coal To Olefins plant
Inner Mongolia, China

Coal To SNG (Substitute Natural Gas)

Natural gas can be produced from coal or petroleum coke. It is then called "Substitute Natural Gas" or SNG. SNG is nothing more than methane, which is the main component of natural gas. It usually accounts for more than 90% of natural gas.

SNG is sometimes referred to as “Synthetic Natural Gas”, in which the association of “Synthetic” and “Natural” seems incongruous. "Synthetic Methane" could be a more appropriate name.

Coal to SNG is similar to producing methane from petroleum coke and biomass.

This website also proposes introduction to "Coal to Liquid Fuels" and "Coal to Chemicals".

Coal to SNG Processes

Three processes are commonly mentioned in literature: steam-oxygen gasification, catalytic steam gasification and hydrogasification. As steam-oxygen gasification is the only process being operated and studied in projects, it is the most developed below.

1) Steam-oxygen gasification

Coal is first gasified with steam and oxygen to produce a synthetic gas or “syngas”, composed of carbon monoxide (CO), hydrogen (H_2) and to a lesser extent carbon dioxide (CO_2) and methane (CH_4) as well as impurities.

The [H_2]/[CO] ratio in the syngas needs to be increased to [3]/[1], which is achieved in a “water-gas shift” reaction, where CO and water are converted to CO_2 and H_2. Syngas is then cleaned to eliminate dust, tar and acid gases.

The last step is methanation, where the syngas is purified and converted to methane and water in a fixed-bed catalytic reactor.

2) Catalytic steam gasification

This process is under development.

Gasification and methanation occur in the same reactor in the presence of a catalyst.

Advantages are that there is no requirement for pure oxygen (no air separation unit), a thermal compensation occurs between exothermic (methanation) and endothermic (gasification) reactions and lower temperatures are required. Disadvantages are lack of experience, separation of catalyst from solids and the loss of catalyst reactivity.

3) Hydrogasification

This process is in the research stage.

Coal is gasified with H_2, meaning that a source of H_2 is necessary. Gasification can play this role.

Advantages and disadvantages are similar to catalytic steam gasification.

Use of biomass

SNG can be produced from any hydrocarbon by steam-oxygen gasification, including biomass. When produced from biomass, it is called “bio SNG”.

The major advantage is the environmental footprint, as biomass is carbon-neutral, and can generate negative carbon emissions if emitted CO_2 is sequestrated.

Disadvantages are the chemical nature of biomass, with lower calorific value, higher moisture content and tar formation, and seasonal supply variations.

Combining coal and biomass presents major advantages in terms of reaction temperature, regular supply and environmental footprint.

Operations and projects

Coal To SNG has been limited to Great Plains plant in North Dakota (USA) up to 2012. Several Coal To SNG units are in operation in China (four units totaling 17 Mm3/day by the end of 2014, 95 Mm3/day by 2017 and will be in Korea (1.9 Mm3/day capacity in 2015). India hosts the largest SNG project in Jamnagar (Gujarat), where main feedstock will be petroleum coke.

Coal To SNG
Great Plains, North Dakota, USA

Coal To SNG
Keshiketeng Xi, Inner Mongolia, China

Low Rank Coal Pyrolysis, Low Rank Coal Upgrading

Low rank coal upgrading technology refers to a class of technologies developed to remove moisture, volatiles and certain pollutants from low rank coals such as sub-Bituminous coal and lignite (brown coal) and raise their calorific values. Coal upgrading through thermal treatment or low rank coal pyrolysis technology produce chars as primary product, and gases, tar as byproducts.

Low Rank Coal Pyrolysis, an upgrading technology

A number of approaches have been investigated in an effort to reduce the moisture content and certain pollutants of low-rank coals. These include simple drying followed by coating the solid with oil, drying in oil, drying with steam, low-temperature pyrolysis, and pelletizing followed by drying. Low-temperature pyrolysis is being paid more attention and studied in for Low Rank Coal Pyrolysis projects, it is the most developed below.

1) Direct contact heating to upgrading the coal

Three kinds of heat carriers have been used to pyrolyze coal: hot gas, steam and solid.

Coal is heated by contacting heat carrier directly to produce char, tar and gas. Fluidized bed, tubular bed, rotary bed and moving bed have been used in this process.

2) Indirect contact heating to upgrading the coal

Coal and heat carrier are into two parts of the reactor separately.

The heat from heat carrier is transferred to coal by reactor/heat exchanger wall which is heated by heat carrier. Tubular/channeling bed is widely used in this technology.

Tar Upgrading

Tar as byproduct of low rank coal upgrading is the third option to produce liquid fuel from coal, together with DCL (Direct coal liquefaction) and ICL (Indirect coal liquefaction) processes described above. Compared to DCL and ICL, coal pyrolysis process needs 1/3 to 1/5 of the overall capital investments to process the same quantity of coal.

Tar contains sulfur, nitrogen, oxygen and solids contaminants. It is deficient in hydrogen and therefore must be further refined. Hydro-processing of tar is now widely pursued not only because it is commercially attractive but also because it is environmentally benign.

However, tar is a challenging feedstock for hydro-processing. As compared to petroleum-based residue oil, tar contains more heteroatoms (O, N), asphaltene, resin and ash. It is unstable due to high concentration of active species. Asphaltene, resin, ash content and active species are prone to re-condense or solidify in pipes and valves, significantly increasing process maintenance costs and reducing the operation turnaround cycle.

In terms of economics, the relatively low yield of high-valued products affects revenues compared to DCL or ICL.

Whole Fraction Tar Upgrading Pilot Plant,
National Institute of Clean
and Low Carbon Energy (NICE), China

600 kt Coal Upgrading Plant
Yulin, Shaanxi, China

This article has benefited the major contribution of National Institute of Clean and Low Carbon Energy (NICE), China

Syngas for DRI

DRI (Direct Reduced Iron) is a solid form of elemental iron produced by reducing iron oxide to remove the oxygen and leave only elemental iron.

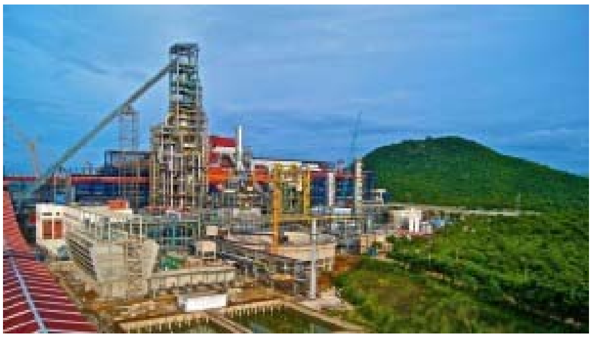
The DRI reducing reactions are:
- $Fe_2O_3 + 3 H_2 \rightarrow 2 Fe + 3 H_2O$
- $Fe_2O_3 + 3 CO \rightarrow 2 Fe + 3 CO_2$

These reactions are conducted at 800 – 900°C, which is below the melting point of iron (1536°C or 2797°F).

A blast furnace is the primary competitive option to making elemental iron. In a blast furnace, iron oxide is reduced at high temperature to make a liquid form of elemental iron.

Advantages of Syngas for DRI:
• Low quality feedstocks, such as low rank coal, can be used for gasification while blast furnaces require coking coal, a high quality feedstock.
• DRI plants have significant turndown capabilities, while blast furnaces do not
• Gasification+DRI is much more environmentally friendly than a blast furnace.

In 2015, DRI production is about 5% of the total global iron production (blast furnaces produce remaining 95%).



Syngas for DRI
Angul, Orissa, India

Syngas for DRI
Saldanha Bay, South Africa