LECTURE 9

Two Basic Approaches To Convert Coal To A Liquid Fuel

1. . Direct Liquefaction:
   - Dissolves coal in a solvent at elevated temperature and pressure
   - Combined with hydrogen gas and a catalyst
2. Indirect Liquefaction:
   - Involves first gasifying coal, followed by reacting carbon monoxide and hydrogen together

$$nCO + (2n+1)H_2 = C_nH_{2n+2} + nH_2O$$

Comparison of Processes

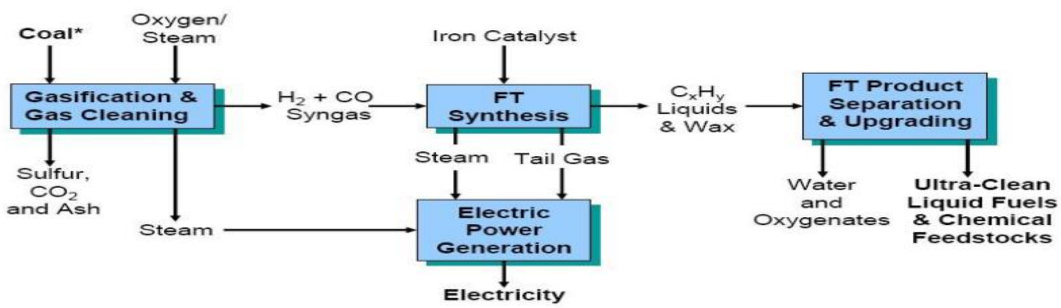
DIRECT LIQUEFACTION

- Adds hydrogen to break down the coal
- Dissolves in a solvent followed by hydrocracking
- Operates at 450 C and 170 bars
- Light products are distilled
- Medium and heavy distillates obtained from vacuum distillation
- Liquid yields of 70% of the dry weight of coal feed
- Further upgrade is needed for use as transportation fuels

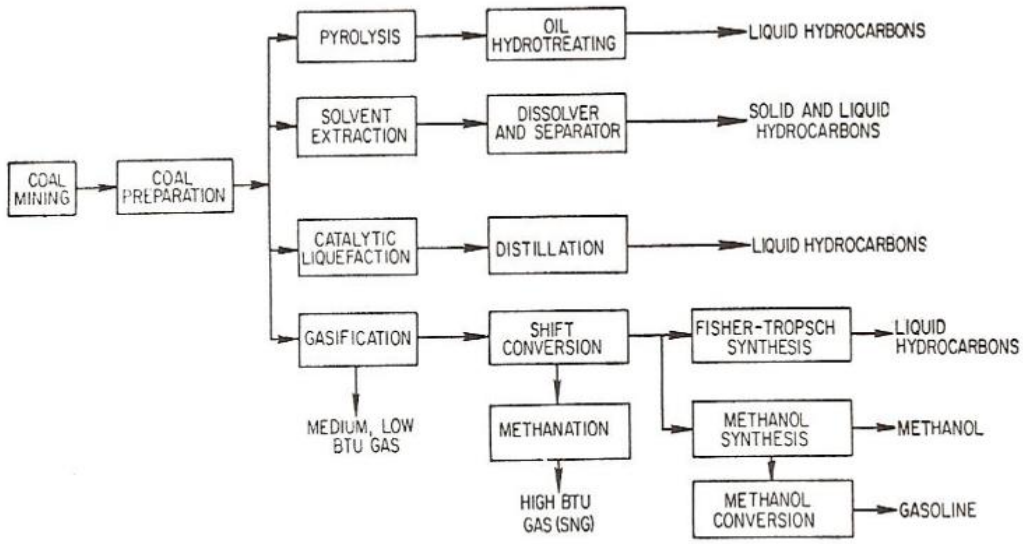
INDIRECT LIQUEFACTION

- Complete breakdown of coal with steam and oxygen
- Sulfur is removed from the syngas
- Syngas reacted over catalyst at 300 C and 20 bars
- Produces a lighter suite of products; high quality gasoline and petrochemicals
- Oxygenated chemicals

Indirect Liquefaction



- Fischer-Tropsch Indirect Liquefaction Process
  - Yields high quality transportation fuels plus other products



Schematic diagram of different coal liquefaction processes.

HYDROGEN

METHODS OF PRODUCTION

There are four main sources for the commercial production of hydrogen: natural gas, oil, coal, and electrolysis; which account for 48%, 30% 18% and 4% of the world's hydrogen production respectively. Fossil fuels are the dominant source of industrial hydrogen.[6] Hydrogen can be generated from natural gas with approximately 80% efficiency] or from other hydrocarbons to a varying degree of efficiency. Specifically, bulk hydrogen is usually produced by the steam reforming of methane or natural gas. The production of hydrogen from natural gas is the cheapest source of hydrogen currently. This process consists of heating the gas in the presence of steam and a nickel catalyst. The resulting exothermic reaction breaks up the methane molecules and forms carbon monoxide CO and hydrogen H_2. The carbon monoxide gas can then be passed with steam over iron oxide or other oxides and undergo a water gas shift reaction. This last reaction produces even more H_2. The downside to this process is that its major byproducts are CO, CO_2 and other greenhouse gases. Depending on the quality of the feedstock (natural gas, rich gases, naphtha, etc.), one ton of hydrogen produced will also produce 9 to 12 tons of CO_2.

For this process at high temperatures (700–1100 °C), steam (H_2O) reacts with methane (CH_4) in an endothermic reaction to yield syngas.

Gasification

$$CH_4 + H_2O \rightarrow CO + 3\ H_2$$

In a second stage, additional hydrogen is generated through the lower-temperature, exothermic, water gas shift reaction, performed at about 360 °C:

$$CO + H_2O \rightarrow CO_2 + H_2$$

Essentially, the oxygen (O) atom is stripped from the additional water (steam) to oxidize CO to CO_2. This oxidation also provides energy to maintain the reaction. Additional heat required to drive the process is generally supplied by burning some portion of the methane.

Other production methods from fossil fuels

Partial oxidation

The production of hydrogen from oil is achieved by partial oxidation. For this, a carefully controlled fuel-air mix is partially combusted, which results in an H2 rich gas. Like the previous process, the formation of hydrogen from oil is done with a water-gas shift reaction.[5] The energy added to the process is achieved by the combustion of fuels, which also causes a negative impact to the environment.

The partial oxidation reaction occurs when a substoichiometric fuel-air mixture is partially combusted in a reformer, creating a hydrogen-rich syngas. A distinction is made between *thermal partial oxidation* (TPOX) and *catalytic partial oxidation* (CPOX). The chemical reaction takes the general form:

$$C_nH_m + {}^{n}/_{2}\ O_2 \rightarrow n\ CO + {}^{m}/_{2}\ H_2$$

Idealized examples for heating oil and coal, assuming compositions $C_{12}H_{24}$ and $C_{24}H_{12}$ respectively, are as follows:

$$C_{12}H_{24} + 6\ O_2 \rightarrow 12\ CO + 12\ H_2$$

$$C_{24}H_{12} + 12\ O_2 \rightarrow 24\ CO + 6\ H_2$$

Coal

For the production of hydrogen from coal, coal gasification is used. The process of coal gasification uses steam and a carefully controlled concentration of gases to break molecular bonds in coal and form a gaseous mix of hydrogen and carbon monoxide. This source of hydrogen is advantageous since its main product is coal-derived gas which can be used for fuel. The gas obtained from coal gasification can later be used to produce electricity more efficiently and allow a better capture of greenhouse gases than the traditional burning of coal.

Another method for conversion is low temperature and high temperature coal carbonization.

Petroleum coke

Similarly to coal, petroleum coke can also be converted in hydrogen rich syngas, via coal gasification. The syngas in this case consists mainly of hydrogen, carbon monoxide and H2S, depending on the sulfur content of the coke feed. Gasification is an attractive option for producing hydrogen from almost any carbon source, while providing attractive hydrogen utilization alternatives through process integration.]

From water

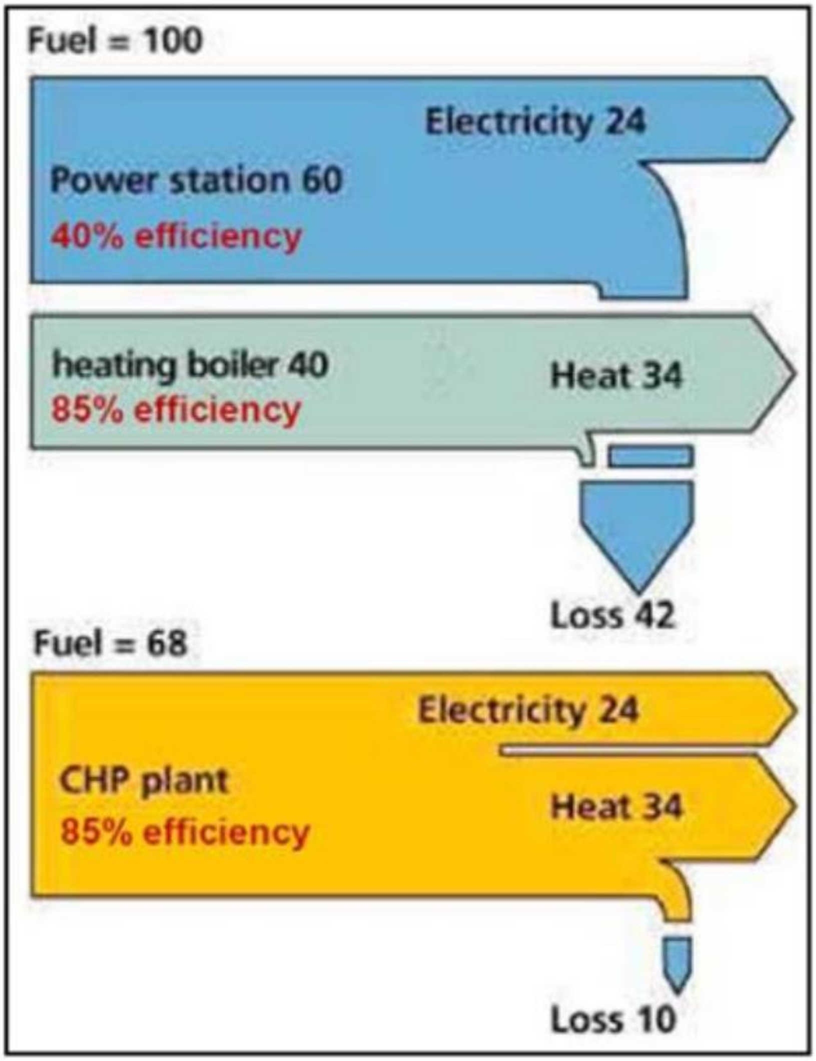
Many technologies have been explored but it should be noted that as of 2007 "Thermal, thermochemical, biochemical and photochemical processes have so far not found industrial applications. High temperature electrolysis of alkaline solutions has been used for the industrial scale production of hydrogen and there are now a number of small scale polymer electrolyte membrane (PEM) electrolysis units available commercially

Electrolysis

Electrolysis consists of using electricity to split water into hydrogen and oxygen. This source of hydrogen is by far the most expensive since the energy input required for water splitting is higher than the energy that could be obtained from the produced hydrogen. Due to their use of water, a readily available resource, electrolysis and similar water-splitting methods have attracted the interest of the scientific community. With the objective of reducing the cost of hydrogen production, renewable sources of energy have been targeted to allow electrolysis.[14] There are three main types of cells, solid oxide electrolysis cells (SOECs), polymer electrolyte membrane cells (PEM) and alkaline electrolysis cells (AECs).

Principle of Cogeneration

Cogeneration or Combined Heat and Power (CHP) is defined as the sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy may be used either to drive an alternator for producing electricity, or rotating equipment such as motor, compressor, pump or fan for delivering various services. Thermal energy can be used either for direct process applications or for indirectly producing steam, hot water, hot air for dryer or chilled water for process cooling. Cogeneration provides a wide range of technologies for application in various domains of economic activities. The overall efficiency of energy use in cogeneration mode can be up to 85 per cent and above in some cases.

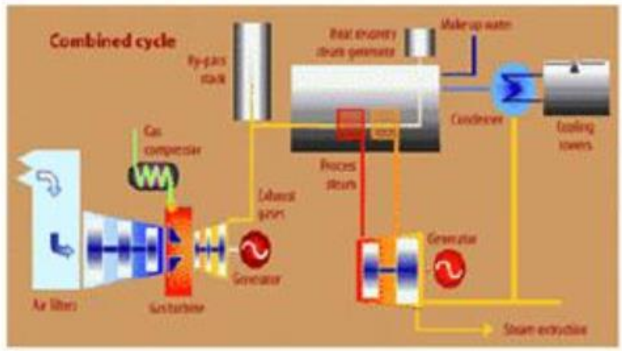
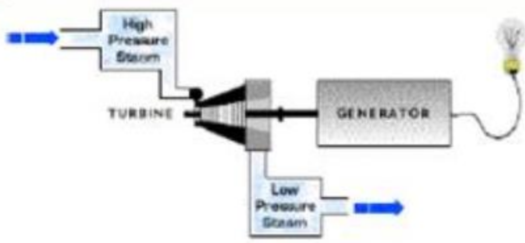
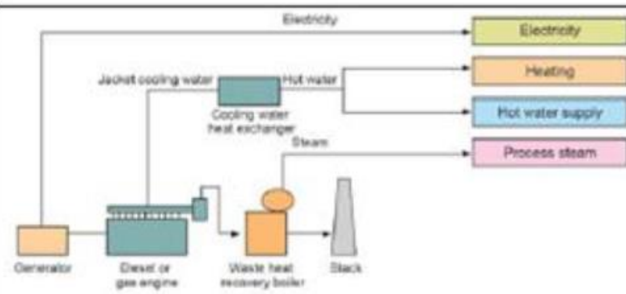
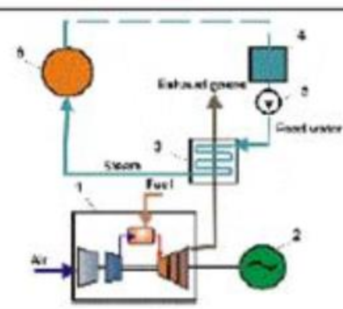


Cogeneration advantage

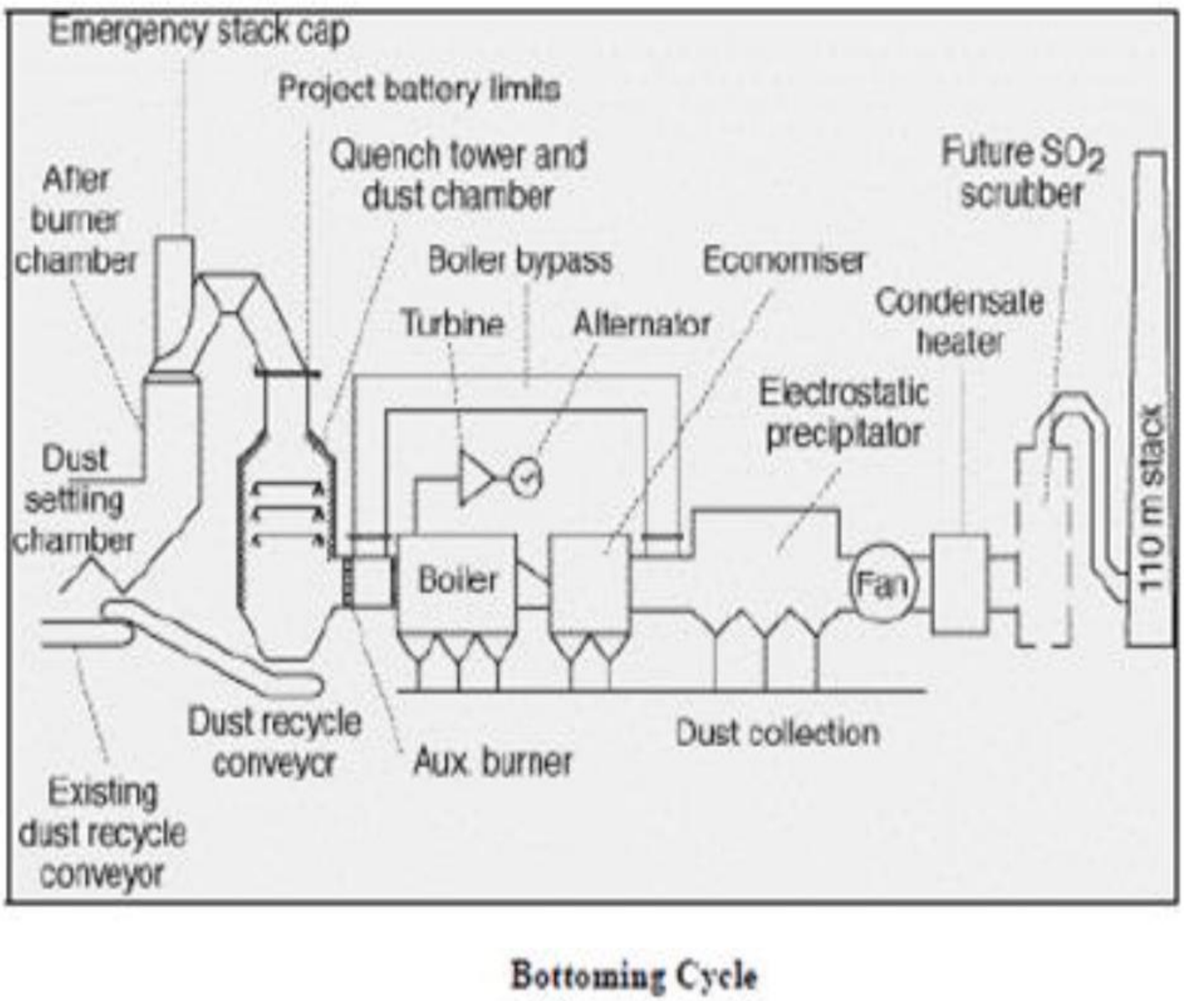
Along with the saving of fossil fuels, cogeneration also allows to reduce the emission of greenhouse gases (particularly CO2 emission). The production of electricity being on-site, the burden on the utility network is reduced and the transmission line losses eliminated. Figure 7.2 Cogeneration advantage Cogeneration makes sense from both macro and micro perspectives. At the macro level, it allows a part of the financial burden of the national power utility to be shared by the private sector; in addition, indigenous energy sources are conserved. At the micro level, the overall energy bill of the users can be reduced, particularly when there is a simultaneous need for both power and heat at the site, and a rational energy tariff is practiced in the country.

Classification of Cogeneration Systems Cogeneration systems are normally classified according to the sequence of energy use and the operating schemes adopted. A cogeneration system can be classified as either a topping or a bottoming cycle on the basis of the sequence of energy use. In a

topping cycle, the fuel supplied is used to first produce power and then thermal energy, which is the by-product of the cycle and is used to satisfy process heat or other thermal requirements. Topping cycle cogeneration is widely used and is the most popular method of cogeneration.
Topping Cycle. The four types of topping cycle cogeneration systems are briefly explained in Table below.

Types of topping Cycles	
A gas turbine or diesel engine producing electrical or mechanical power followed by a heat recovery boiler to create steam to drive a secondary steam turbine. This is called a combined-cycle topping system.	
The second type of system burns fuel (any type) to produce high-pressure steam that then passes through a steam turbine to produce power with the exhaust provides low-pressure process steam. This is a steam-turbine topping system.	
A third type employs heat recovery from an engine exhaust and/or jacket cooling system flowing to a heat recovery boiler, where it is converted to process steam / hot water for further use.	
The fourth type is a gas-turbine topping system. A natural gas turbine drives a generator. The exhaust gas goes to a heat recovery boiler that makes process steam and process heat	

Bottoming Cycle In a bottoming cycle, the primary fuel produces high temperature thermal energy and the heat rejected from the process is used to generate power through a recovery boiler and a turbine generator. Bottoming cycles are suitable for manufacturing processes that require heat at high temperature in furnaces and kilns, and reject heat at significantly high temperatures. Typical areas of application include cement, steel, ceramic, gas and petrochemical industries. Bottoming cycle plants are much less common than topping cycle plants. The Figur below illustrates the bottoming cycle where fuel is burnt in a furnace to produce synthetic rutile. The waste gases coming out of the furnace is utilized in a boiler to generate steam, which drives the turbine to produce electricity.



Bottoming Cycle