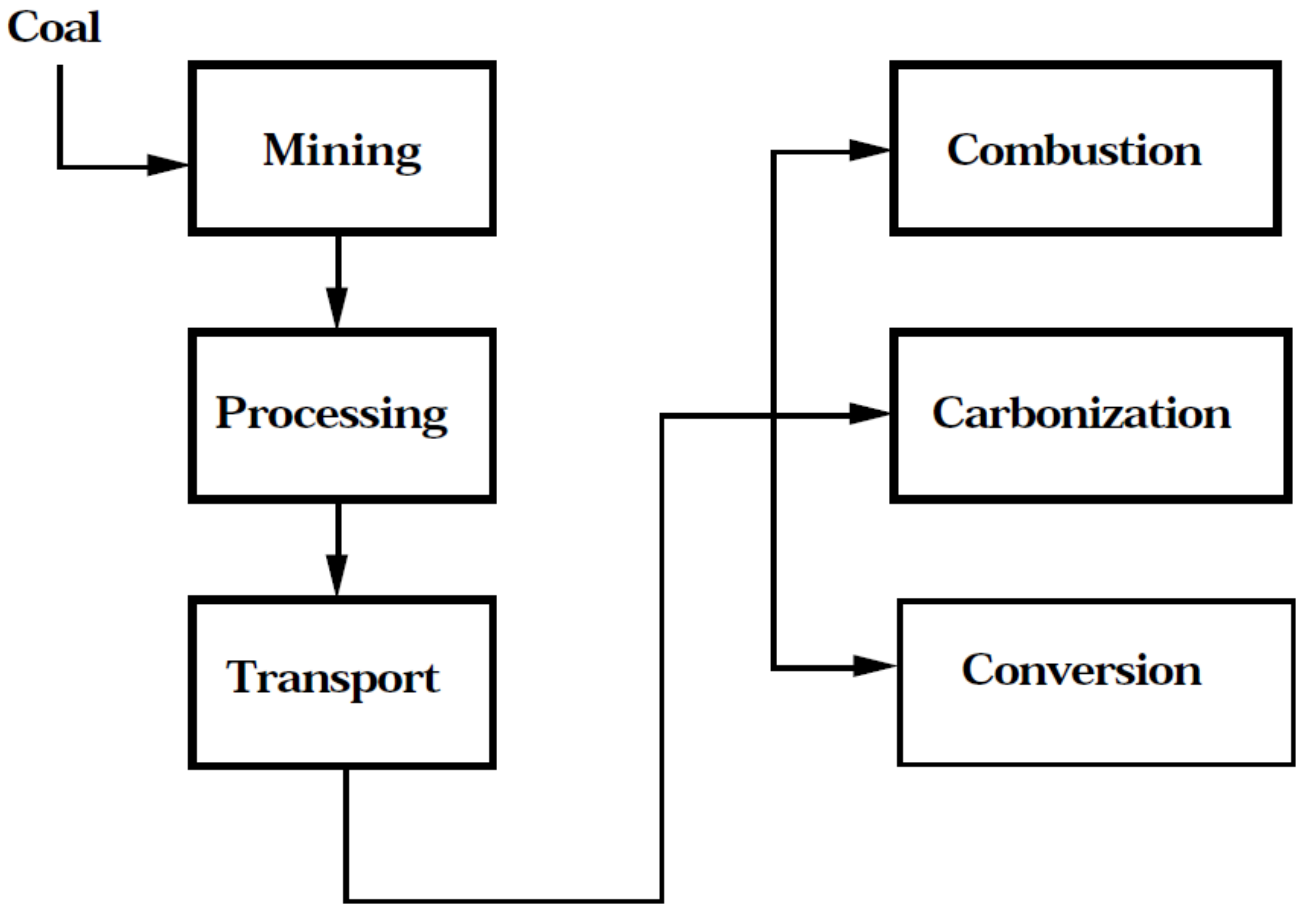
Coal Utilization

Conversion processes

Pathways to coal utilization

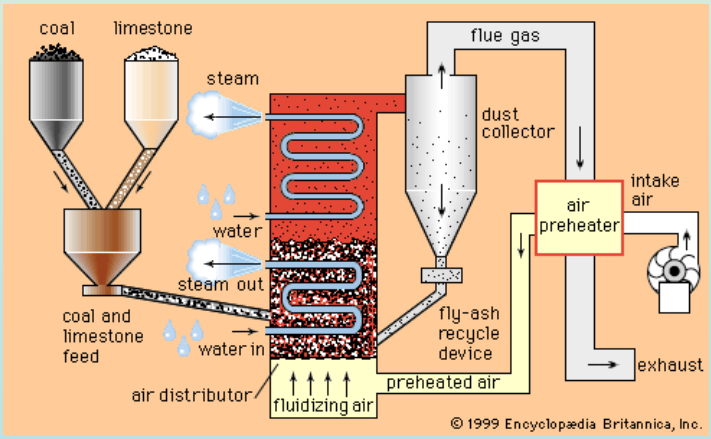


Main Sectors of Coal field

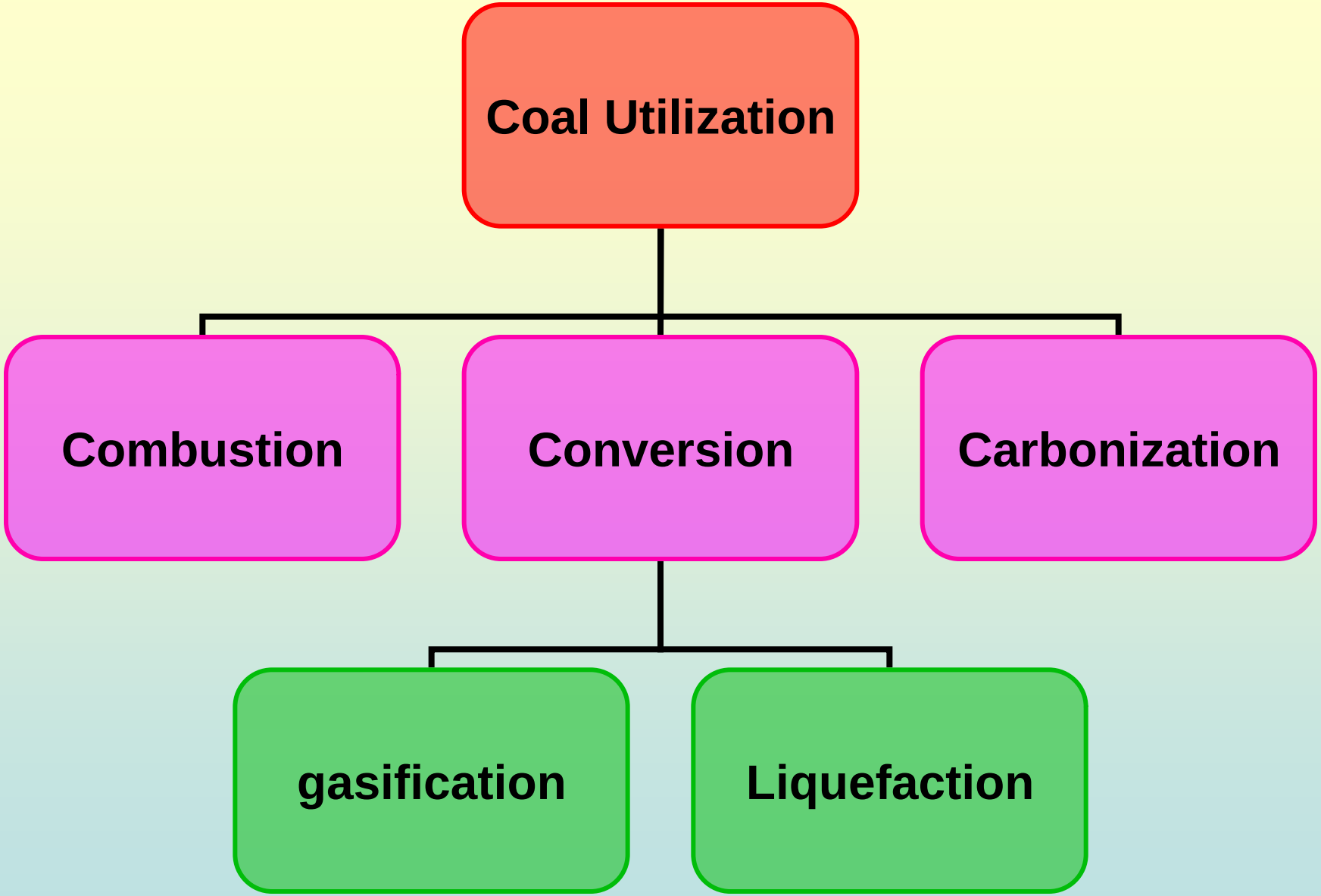
- **Exploration** "finding new coal deposits"
- **Mining (Surface mining, Underground mining)**
- **Coal Utilization & Conversion**

Surface mining

Underground mining



Coal Utilization


Coal Utilization
Combustion
Conversion
Carbonization
gasification
Liquefaction

Combustion

- Thermal conversion of organic matter with an oxidant (normally oxygen) to produce primarily carbon dioxide, water and heat.
- The oxidant is in stoichiometric excess, i.e., complete oxidation.

Coal Conversion

- Coal conversion is the process in which the dirty coal material is converted to a cleaner and more useful fuel.
- The following table shows the principle of coal conversion to gas or liquid fuels:

Conversion Table

Fuel	C/H (mass)	C/H (molar)	State
Bitum. Coal	15	1.25	Solid
Crude oil	9	0.77	Liquid
Gasoline	6	0.50	Liquid
Natural gas	3	0.25	Gaseous

Conclusion:

It is clear that coal is a hydrogen-deficient fuel when compared to petroleum and natural gas.

In general,

$$\text{Coal} + H_2 \rightarrow \text{Gaseous or liquid Fuels}$$

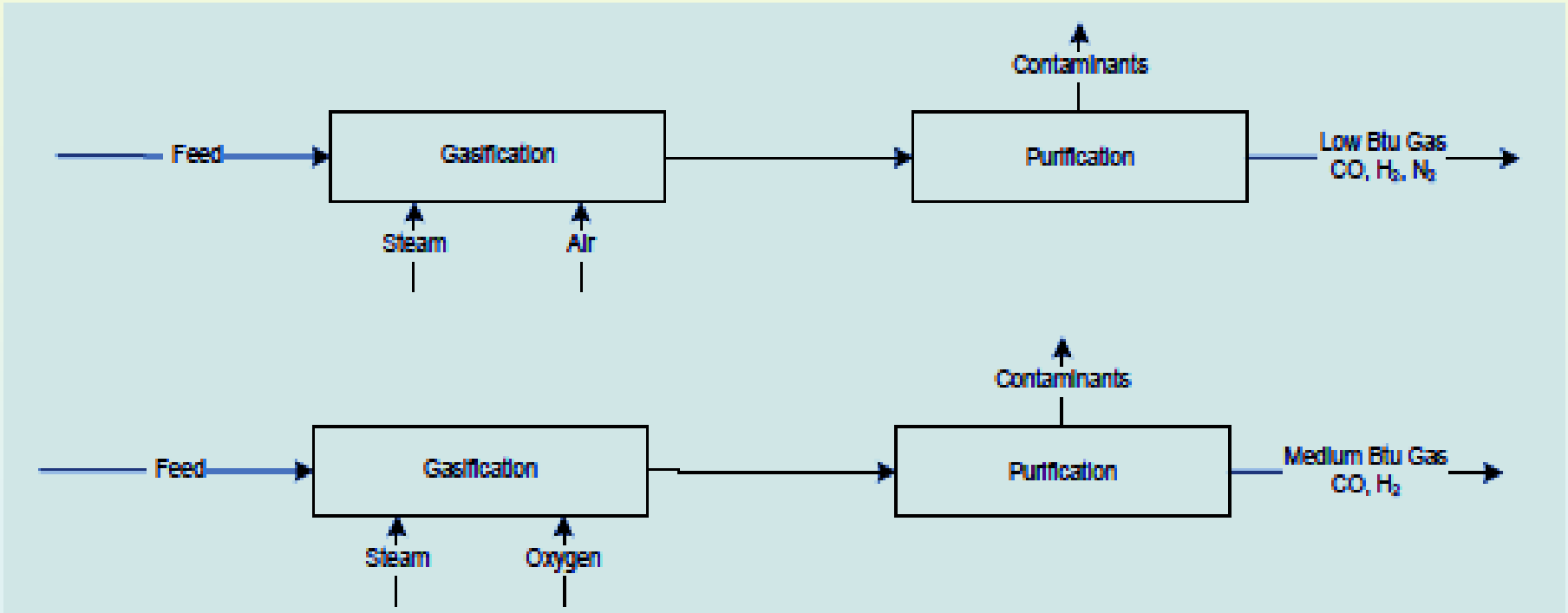
At 400°C solid coal is converted to a liquid fuel that is similar to petroleum {*coal liquefaction process*}. This process is a complex one and H_2 is expensive. It becomes attractive when the price of a barrel of crude oil exceeds $30-35.

At $\geq$ 700°C; coal reacts with H_2 to yield gaseous fuel Or coal reacts with steam to give gaseous fuel [coal + H_2O $\rightarrow$ CO + H_2]. This process is called *coal gasification*. It is commercially available technology.

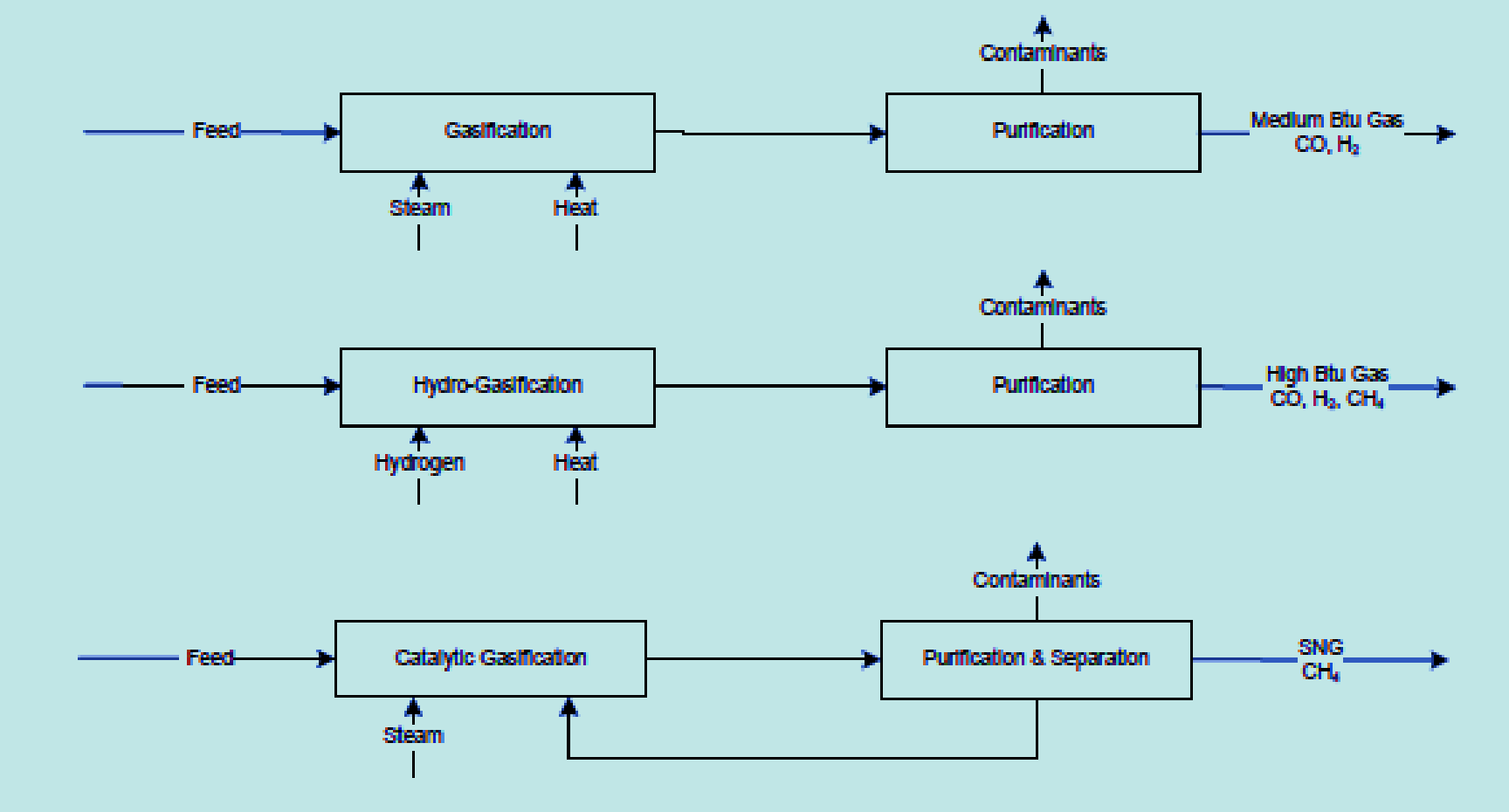
Note

The product CO and H_2 can be used either as a clean gaseous fuel or as a raw material for gasoline production.

Principles of Gasification

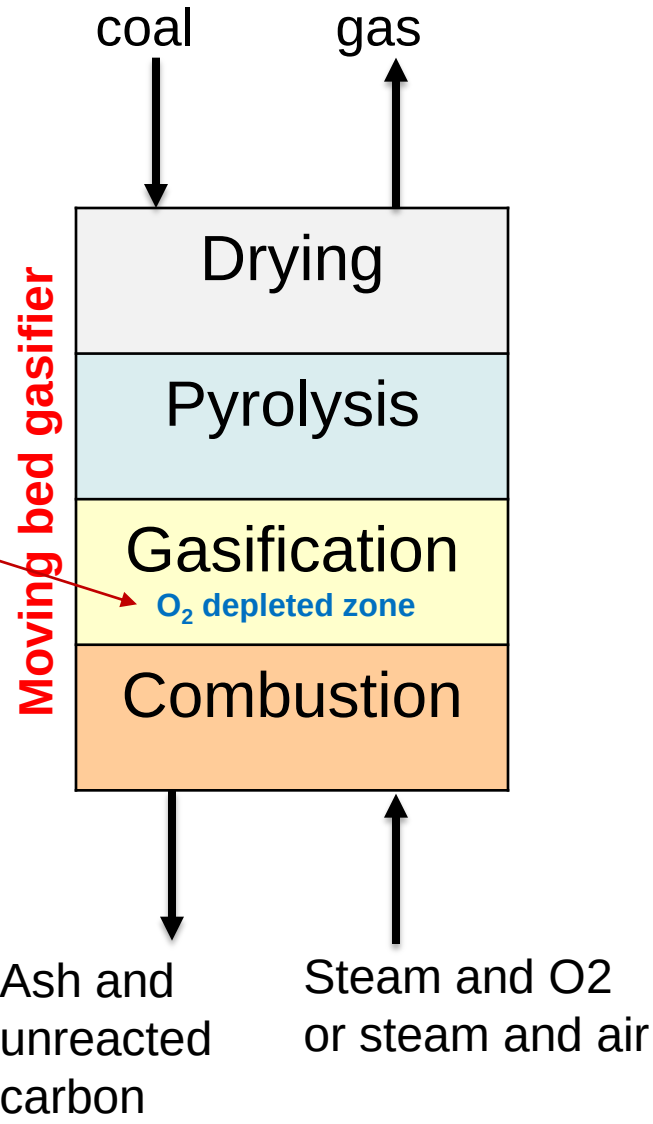


Principles of Gasification



Gasification

- Thermal conversion of organic materials at elevated temperature {750-1000°C} and reducing conditions to produce primarily permanent gases, with char, water, and condensable as minor products.
- Primary categories are partial oxidation and indirect heating



Gasification Reactions

- Oxygenolysis : reaction with O_2 to form CO and CO_2.

  $C + O_2 \rightarrow CO_2$ {combustion Zone}

  $C + CO_2 \rightarrow 2CO$ {gasification Zone}

- Hyrogenolysis: reaction with H_2 to form CH_4

$$C + 2H_2 \leftrightarrow CH_4$$

- Hydrolysis: reaction with water

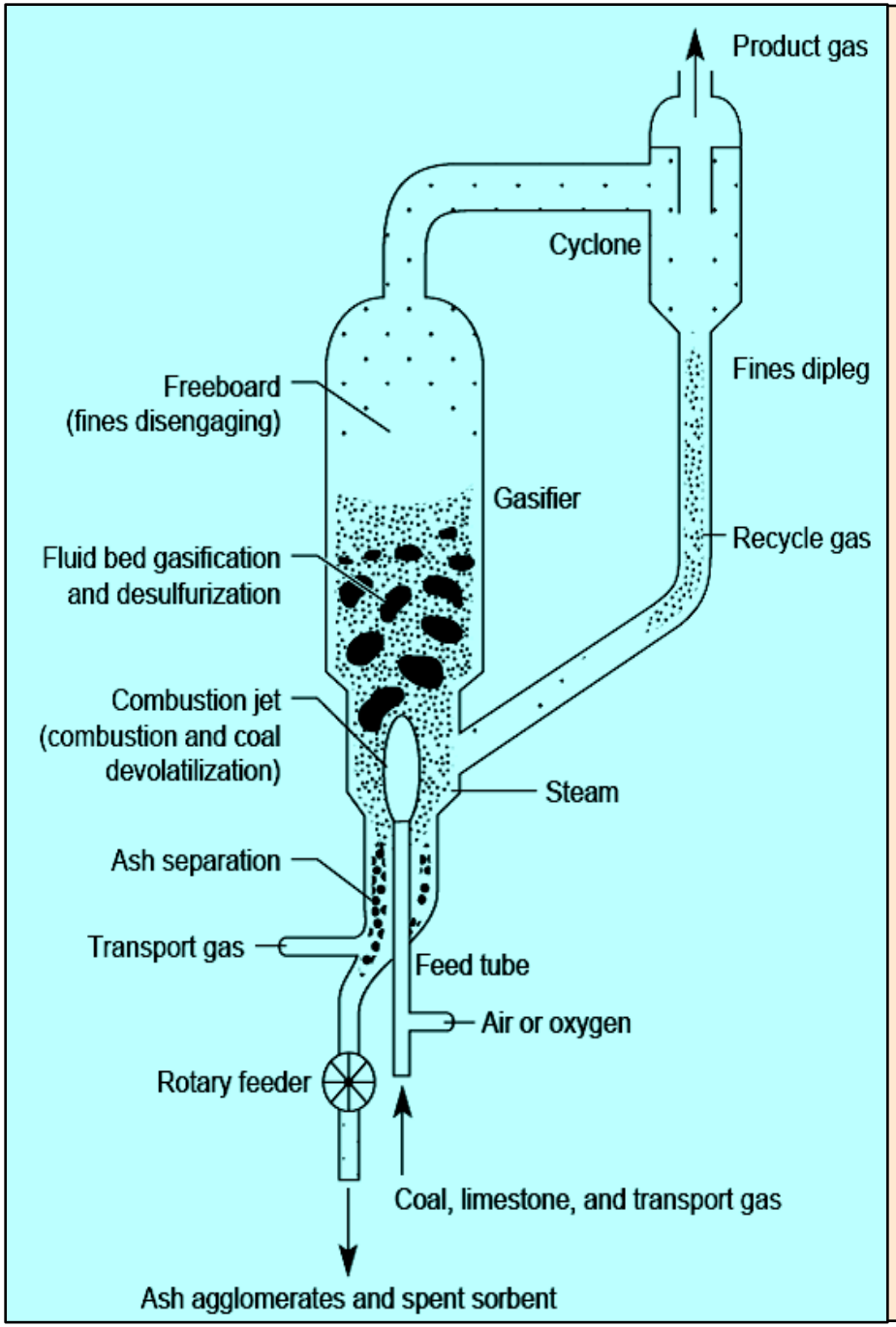
$$C + H_2O \leftrightarrow CO + H_2$$

Under some conditions we may have:

$$C + 2H_2O \leftrightarrow CO_2 + 2H_2$$

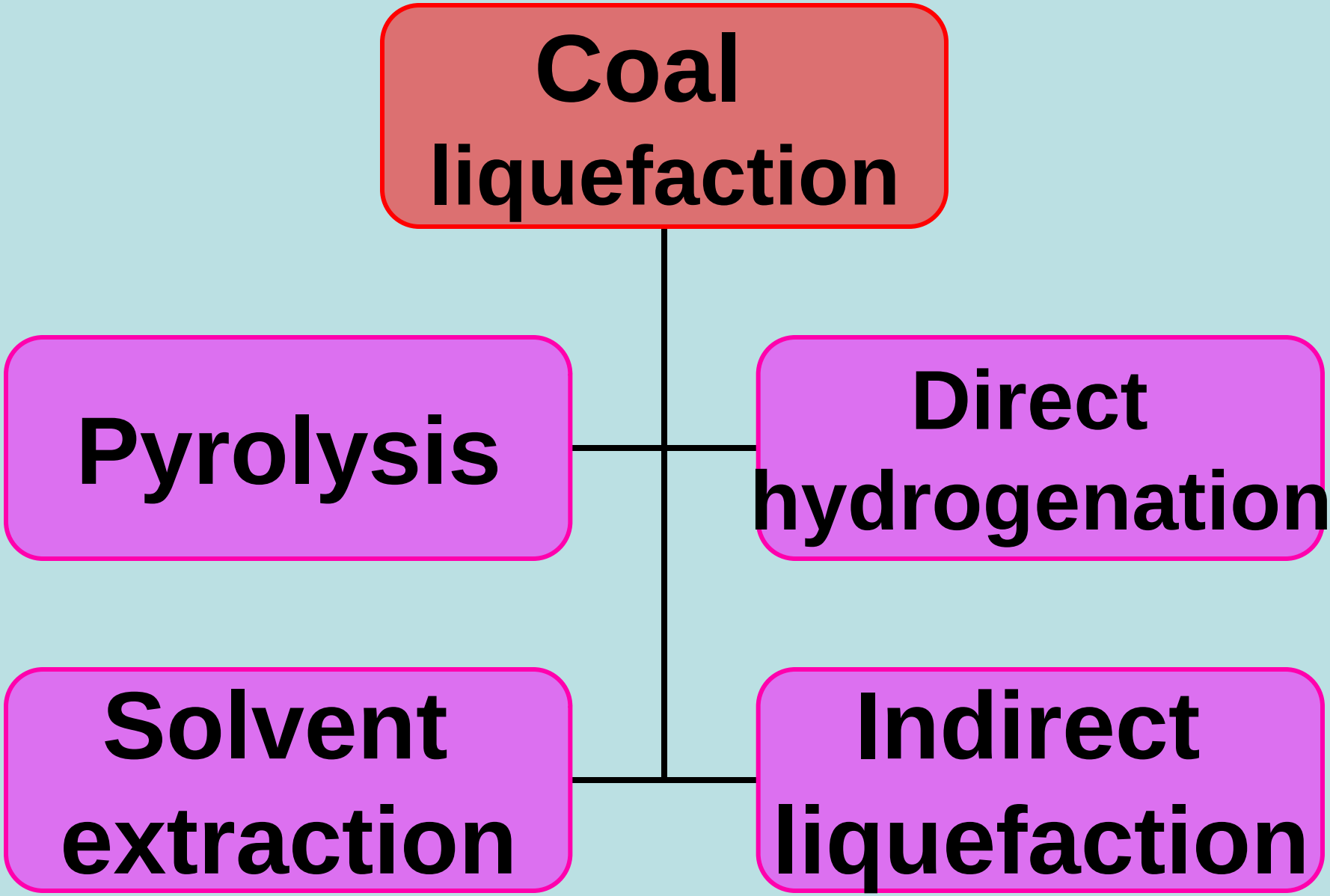
or

$$C + H_2O \leftrightarrow \tfrac{1}{2}CO_2 + \tfrac{1}{2}CH_4$$



Fluid-Bed Gasifiers

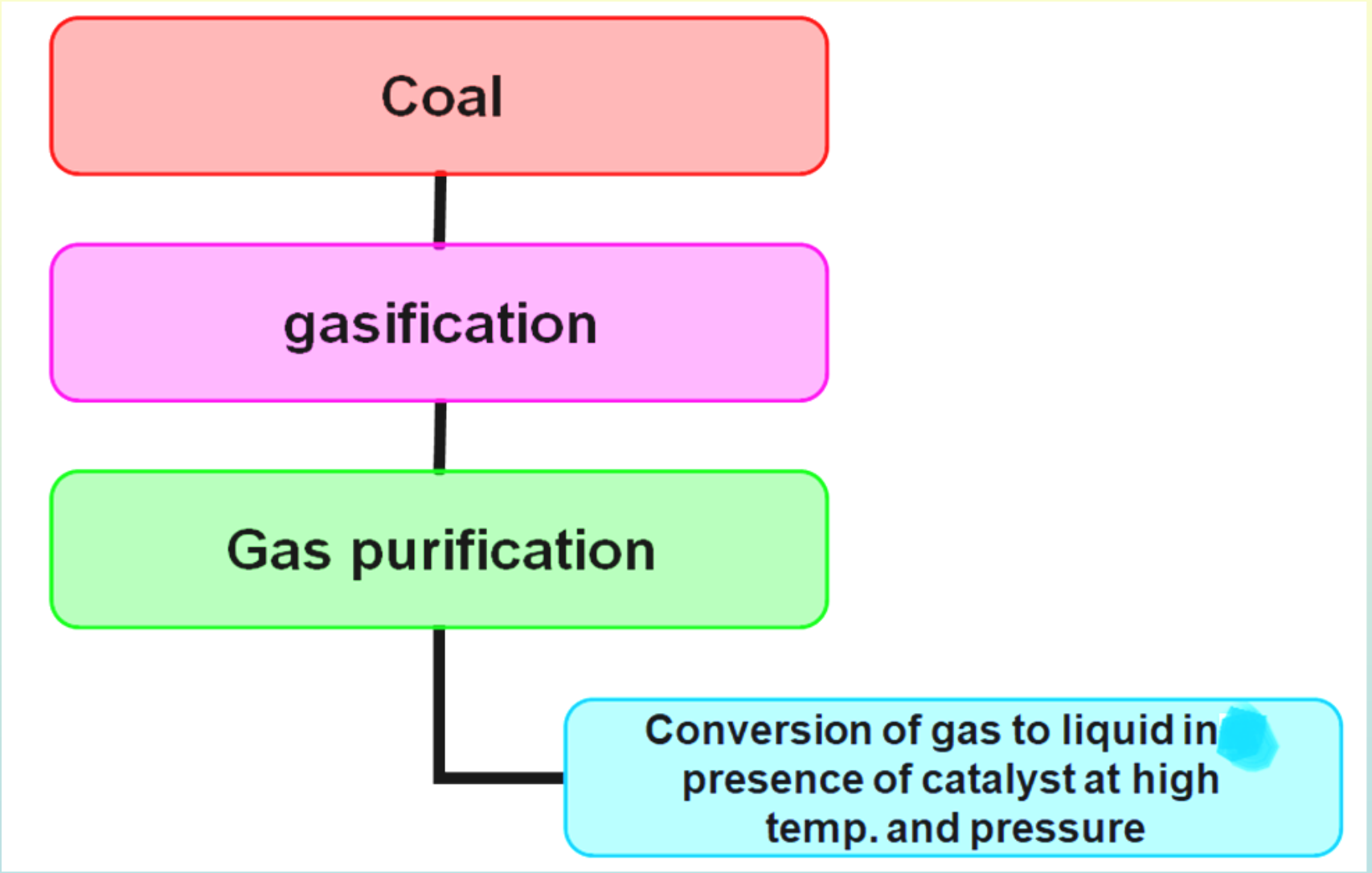
- The coal is quickly pyrolyzed in the jet, which supplies the endothermic heat for reaction. This permits a high proportion of fines to be used.
- The agitation of this region and the rapid approach to high temperature permit the use of highly caking coals.
- Operating conditions are 1,040 to 1,050°C, at pressures to 300 psig (21 bar). Further, the combination of retention time and temperature cracks tars and oils to CH_4 , CO, and H_2 .
- Product gas is removed through cyclones, where carbon dust and ash are collected and recycled to the gasifier.
- The gas has a residual concentration of H_2S and COS so that desulfurization may be required.


Coal liquefaction
Pyrolysis
Direct hydrogenation
Solvent extraction
Indirect liquefaction

Pyrolysis

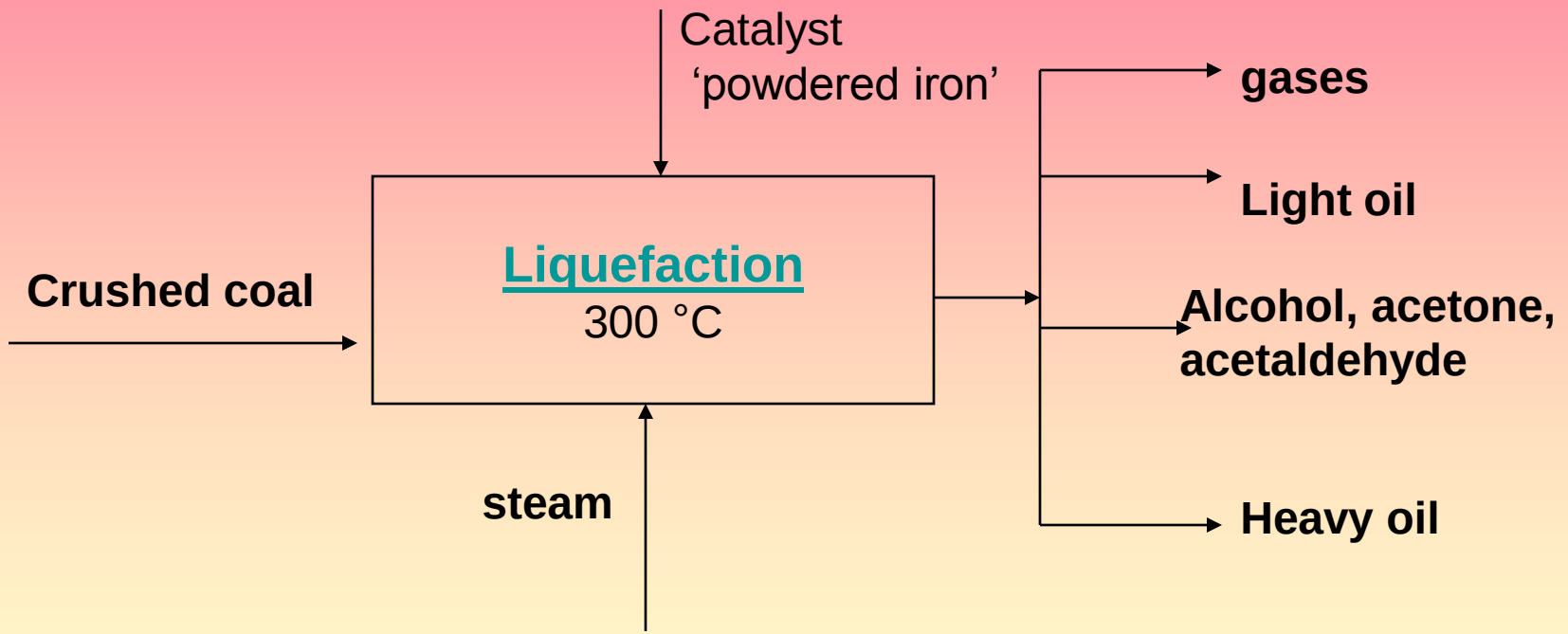
- Thermal conversion (destruction) of organics in the absence of oxygen (usually under nitrogen atmosphere).
- This commonly refers to thermal processes producing liquids as the primary product plus other products.
- Process can be achieved under slow or rapid heating rate.
- Parameters affect the process: properties of solid fuel, heating rate and the final temp. attained.

Indirect liquefaction
Fisher Tropsch Process



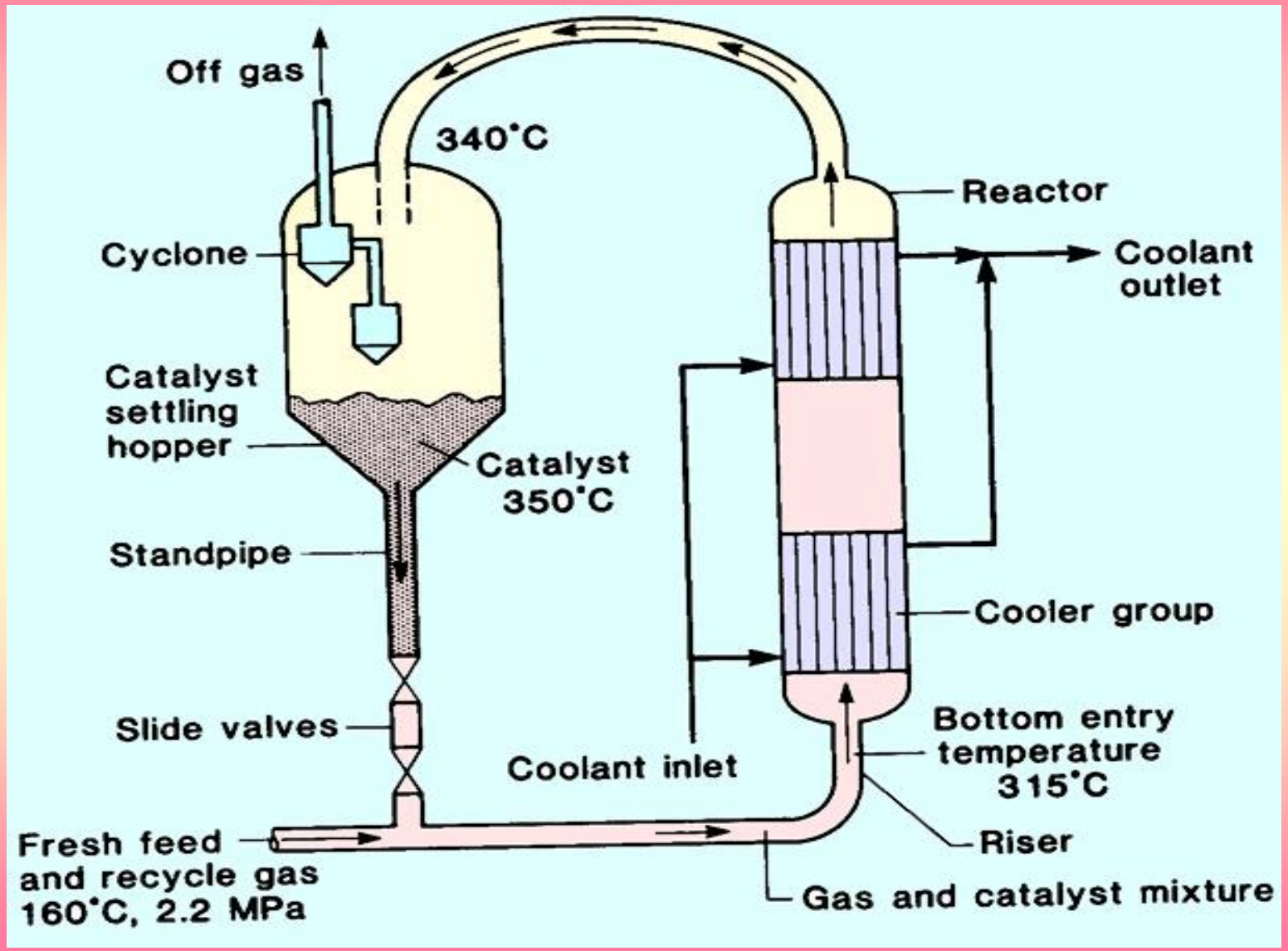
Coal liquefaction

- Concepts



- about 1 bbl of oil is given from each tonne of coal

Synthol Fischer-Tropsch Reactor



Main reactions of coal liquefaction

Fisher-Tropsch reactions involves:

$$nCO + (2n+1)\,H_2 \longrightarrow C_nH_{2n+2} + nH_2O$$ Paraffins

$$nCO + 2nH_2 \longrightarrow C_nH_{2n} + nH_2O$$ Olefines

$$nCO + 2nH_2 \longrightarrow C_nH_{2n+1}OH + (n-1)H_2O$$ Alcohols

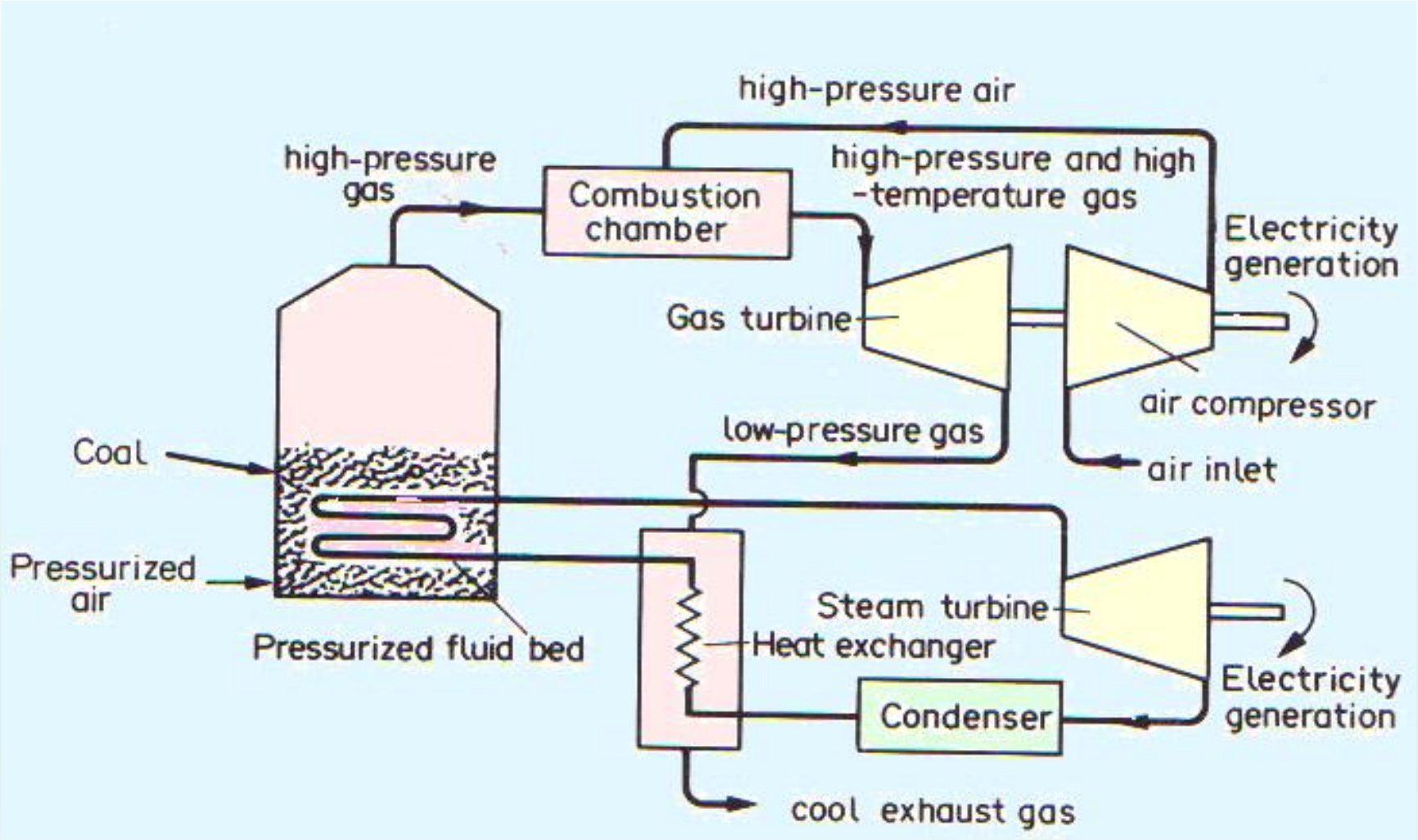
$$CO + 3H_2 \longrightarrow CH_4 + H_2O$$ Methane

$$CO + 2H_2 \longrightarrow -CH_2- + H_2O$$ Methyl species

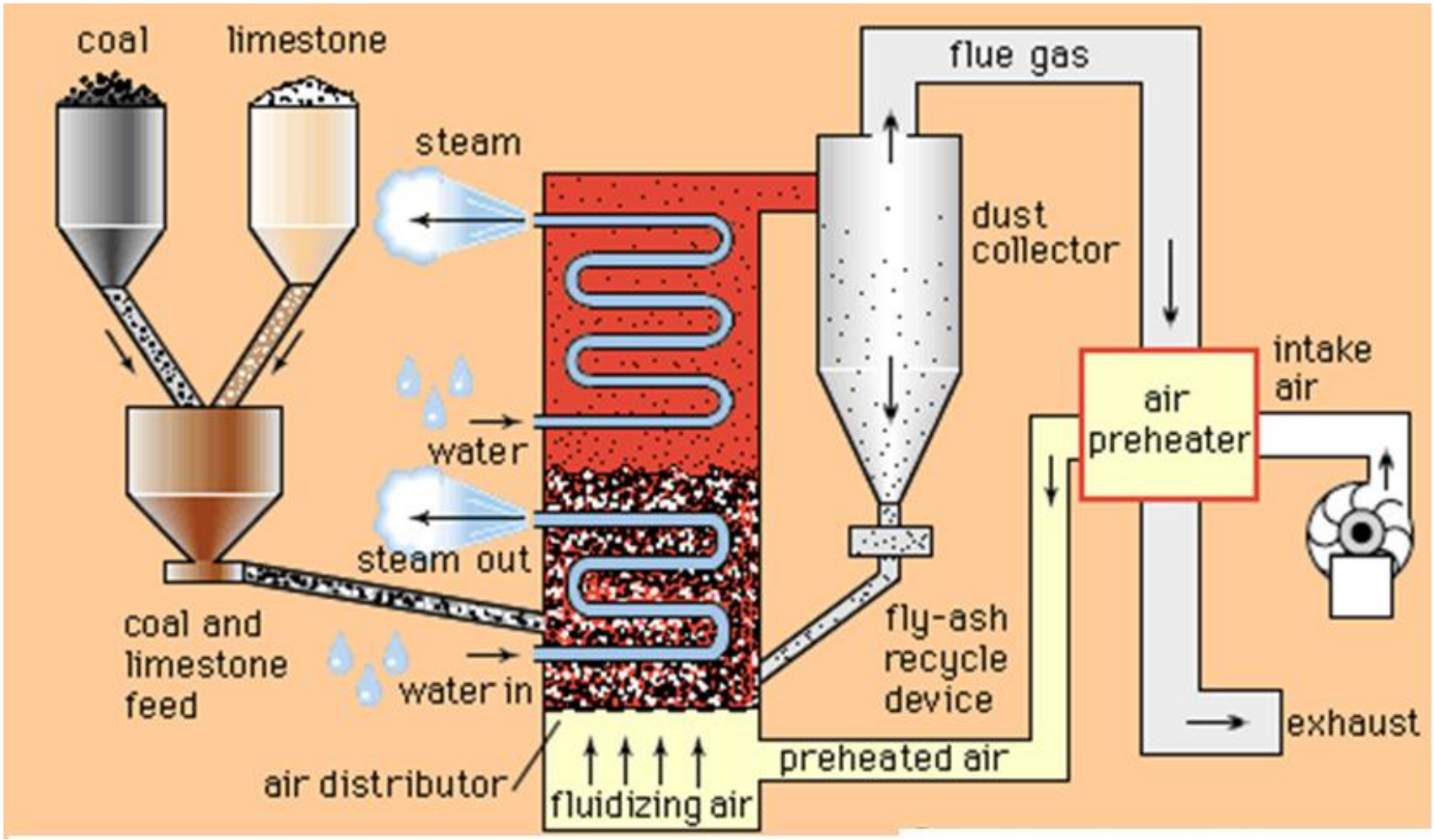
and water-shift reaction

$$CO + H_2O \longrightarrow CO_2 + H_2$$ Hydrogen

Combined fluidized-bed coal combustion cycle (Gas and steam Turbines)

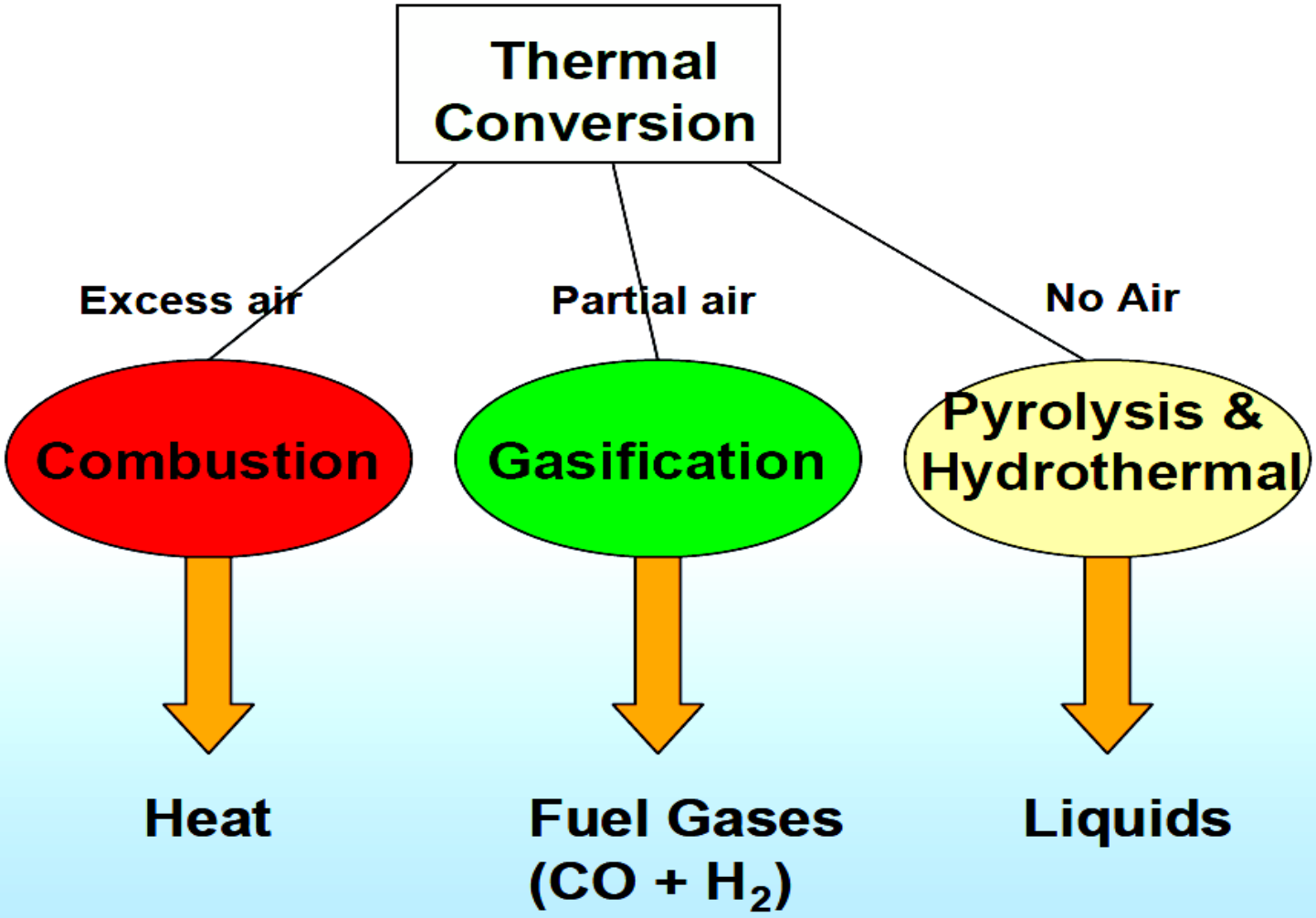


FBC _ Concept



Explain the reasons of the limestone addition to the combustion process.

Summary


Thermal Conversion
Excess air
Partial air
No Air
Combustion
Gasification
Pyrolysis & Hydrothermal
Heat
Fuel Gases (CO + H_2)
Liquids

Note 1

- Gasification is achieved by partial oxidation of carbon to CO (exothermic reaction). To obtain a mixture of CO and H_2 , water is introduced, typically as steam, which reacts endothermically with the coal. The partial oxidation supplies heat to the endotherm.
- The heating values of the producer gas were approximately 120 Btu/SCF (1,068 kcal/m^3) for air-blown units, 250 Btu/SCF (2,225 kcal/m^3) or more for oxygen-blown units, and as much as 500 Btu/SCF (4,450 kcal/m^3) for the oil-carbureted units.
- Look natural gas has HHV : 9000 kcal/m^3

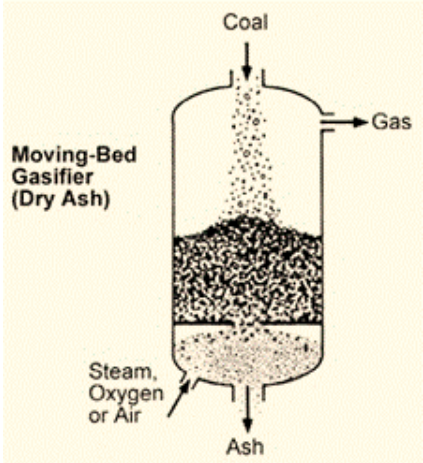
Note 2
Lurgi process fixed bed gasifier

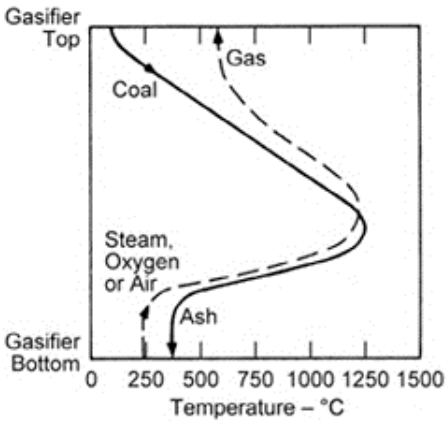
The **Lurgi process** advanced this concept of a pressurized, oxygen-blown system. Gasifier pressure is 350 to 450 psig (24 to 31 bar). Typical composition of gas from the gasifier with oxygen blowing is as follows:

	Vol % dry basis
C_2H_4	0.42
C_2H_6	0.62
CH_4	11.38
CO	20.24
H_2	37.89
N_2	0.33
CO_2	28.69
H_2S + COS	0.49

Carbonyl sulfide

$COS + H_2O \rightarrow CO_2 + H_2S$





Factors influence coal choice

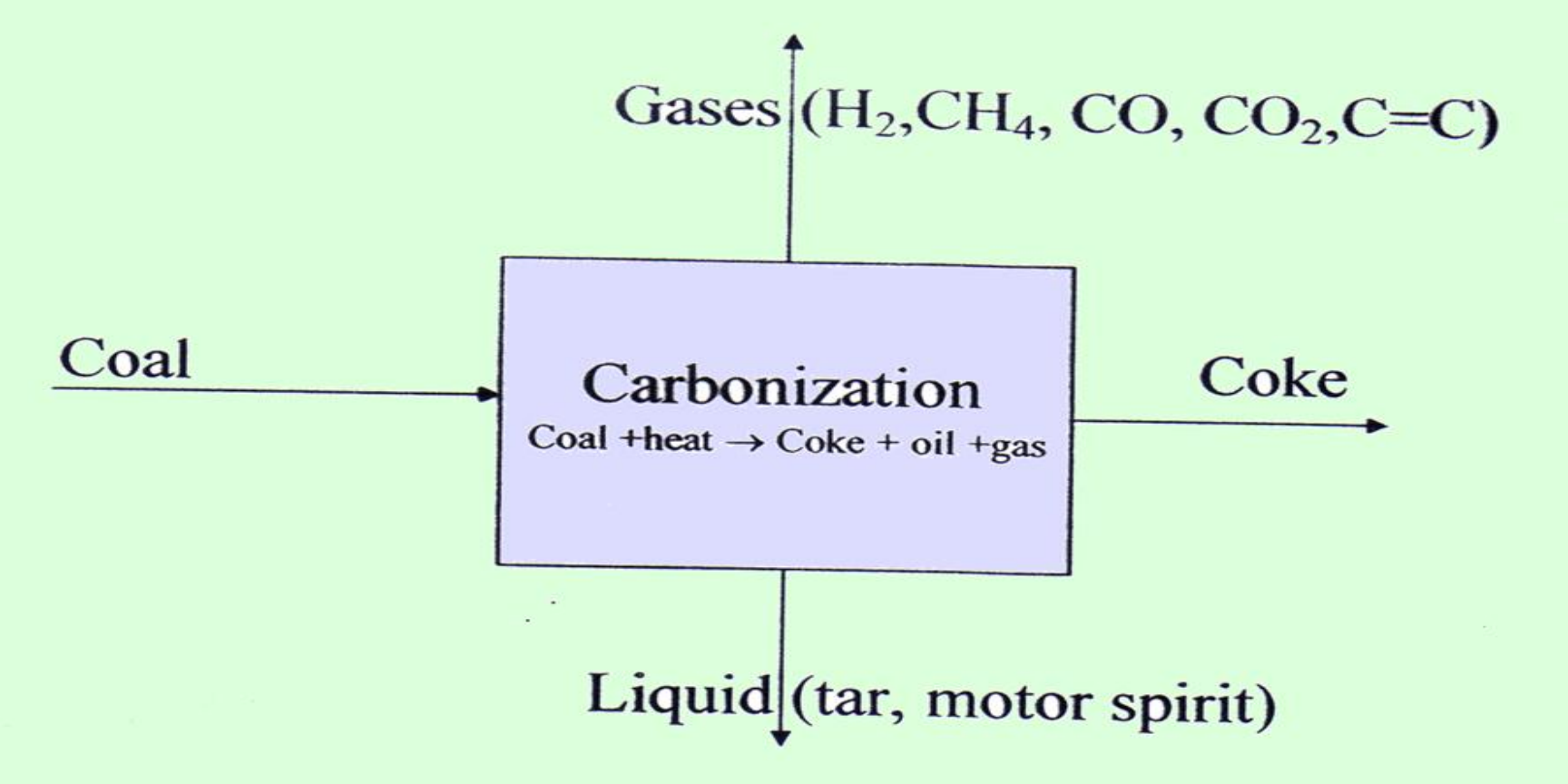
1. Low rank coals with high VM easy to ignite, require adequate secondary air for carbon burnout.
2. High rank coals burn smoke-Lesley but not easy to ignite.
3. Increased moisture retards ignition.
4. High rank coal requires more power to grind than low rank one.

5. Low ash-softening temp. is desirable for systems that handle the ash as molten slag, whilst high ash-softening temp. is appropriate for systems that handle the ash as a solid (fluid bed combustors).
6. High sulfur coals is not suitable for low stack, economizer, or recuperator temperatures.
7. Weatherability (the ability of the coal to withstand against weather variations without excessive crumbling) of a coal must be high.

Carbonization

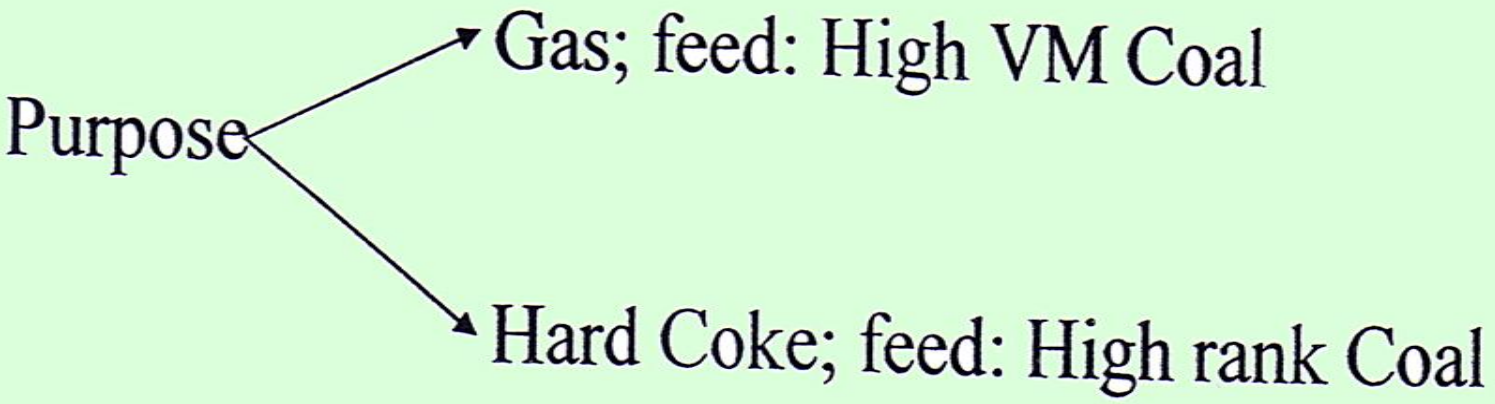
Coke Production + Gases as by-product

Carbonization Process



Carbonization

The process takes place in absence of air

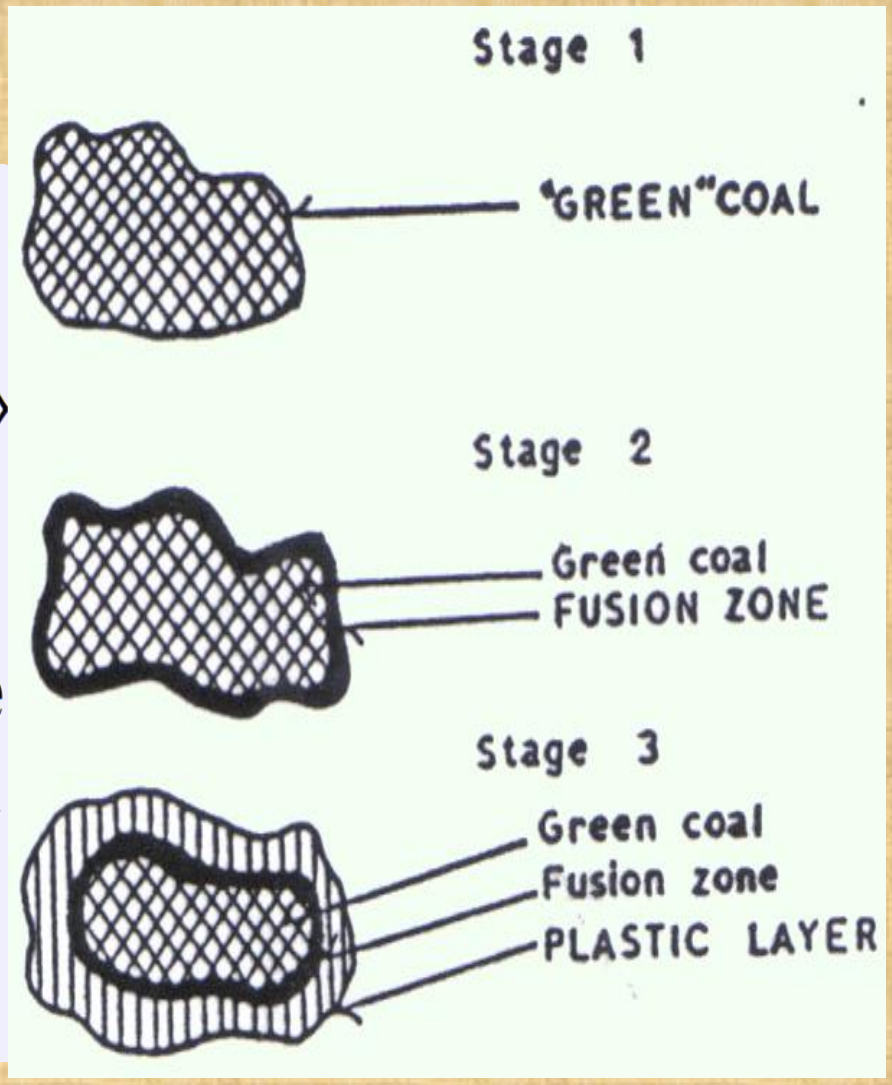


Stages of coke formation

Stage 1 drying; expansion

Stage 2 350-400°C, outer layer melts ⇒ fusion zone

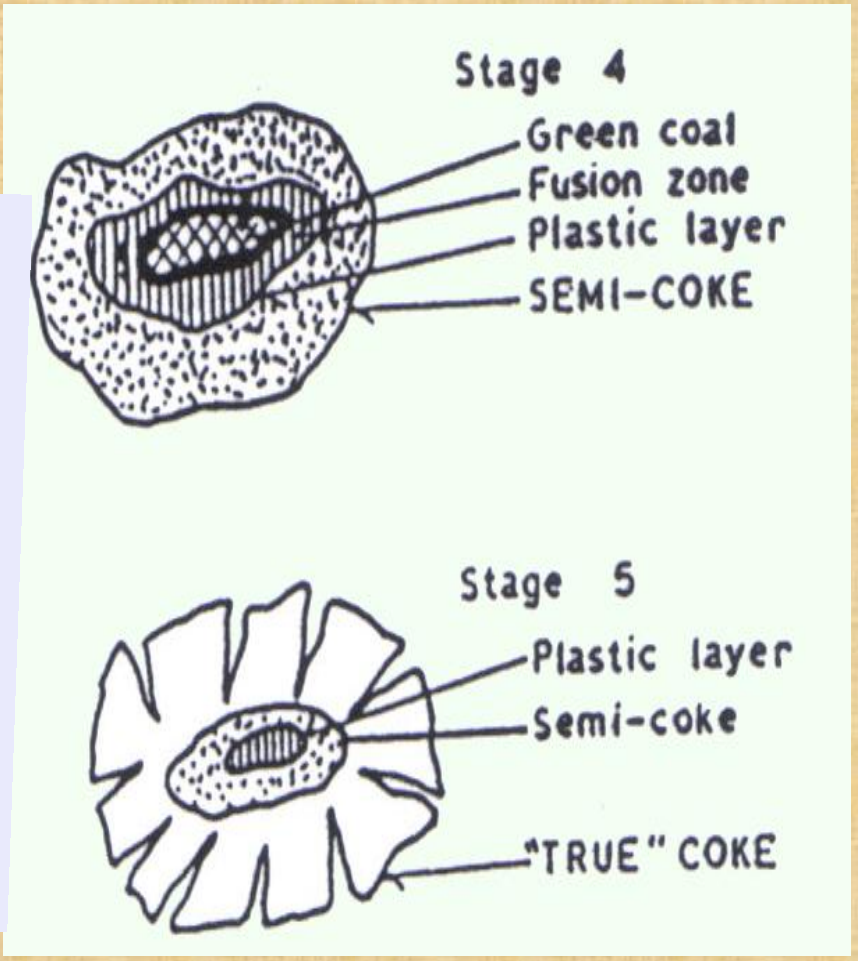
Stage 3 continuous heatig advances the fusion zone inward meanwhile a plastic layer is developed at the exterior.



Stages of coke formation

Stage 4 at 500 °C semi-coke is created due to re-solidification of plastic layer.

Stage 5 above 550 °C ⇒ H_2, CH_4 and CO release in large quantities. Semi-coke becomes more hard and a porous coke is produced.



Notes

- **The previous stages can be investigated by studying the 'plastic properties of coal'.**
- **When coal is heated through the range of 350 – 500 °C, it will pass through a plastic stage.**
- **In the first stages of heating, coal partially melts or fuses and loses its original structure.**
- **As T↑ , Fluidity ↑. Around 500 °C, coal solidifies again after losing most of its VM.**
- **The process may or may not be associated by swelling or caking.**

Coke Classification

Gas Coke

- Weak in structure
- Contains open pores
- Used in domestic applications
- Used in production of producer gas.

Hard coke

- Hard material
- Used in metallurgical industries

Properties and Test

Proximate Analysis

M	VM	A	FC
< 3%	< 1%	10 % or less (Silica and alumina)	85 % or more

Ultimate analysis (dafb):

C	H	N	S	O
95 %	1 %	1 %	1 %	2 %

- **Reactivity**:

Industrial fuel

Blast furnace

Water gas

- means the ability of coke to react with O_2, CO_2 and H_2O.

- depends on carbonization conditions ; temperature, time, pore structure and impurities*.

* impurities (Fe, Na_2O) act as catalyst:

$$Fe + O_2 \longrightarrow 2\ FeO$$

$$2\ FeO + 2\ C \longrightarrow 2Fe + 2\ CO$$

$$Na_2O + CO_2 \longrightarrow Na_2CO_3$$

$$Na_2CO_3 + C \longrightarrow Na_2O + 2\ CO$$

- **CV** : less than anthracite or bituminous coal due to the higher ash content

  In general, CV = 36,560 kJ / kg 'dry base'
- **Density**: real; apparent. ρ_b = 1000 kg /m^3.
- **Porosity**: ε = 45 – 55 %
- **Hardness**: it depends on the carbonization conditions. The hard coke is usually used in metallurgical industries (Blast furnace).

Bulk density

Coke Type	ρ_b, kg /m^3
Coke oven	430 – 525
Horizontal retort	380 – 430
Continuous vertical retort	335 – 350
Low temperature retort	235 - 350

General considerations

1. **The heating value of coke may be calculated from the following formula**

$$Q = 14{,}600 \frac{(100 - \%\ \text{ash})}{100} \quad \text{Btu}$$

carbon

2. **Coking process carried out in narrow retorts or ovens**
   Dimensions of oven 40 ft long, 18 to 20 ft high, 14 to 20 inches wide.

General considerations

3. Low temp coke: - produced at about 540°C
   -formed during the manufacturing of city gas.

4. High-temp coke:- produced at about 1000°C
   - used in metallurgical industries

Some major chemicals derived from coal

Organic chemicals	Acetic acid
	Acetone
	Acrylonitrile
	Benzene
	Carbon tetrachloride
	Cumene
	Cyclohexane
	Ethylene
	Ethylene oxide
	Formaldehyde
	Isopropyl alcohol
	Methanol
	Perchloroethylene
	Phenol
	Phthalic anhydride
	Propylene
	Propylene oxide
	Styrene
	Toluene
	Urea
	Vinyl acetate
	0-xylene
	p-xylene
Inorganic chemicals	
	Ammonia
	Sulphuric acid

Production of Chemicals from coal