Greenhouse Gases Mitigation CO_2 Capture and Utilization

Topic No: 3

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Power industry – great issue!

- During the 20th century there was an increase:
  - Population by 250%
  - Energy by 915%
  - CO_2 in the atmosphere from 295 to 371 ppm_v
- The increase in the first third of the 21st century (2001 – 2030) is:
  - CO_2 in the atmosphere from 371 through 420 ppm_v (2023) to….?
  - Energy by 57% (according to the International Energy Agency, IEA)
- CO_2 concentrations measured continuously by the laboratories:
  - 1st worldwide lab commissioned on the Hawaiian island of Mauna Loa

Mauna Loa observatory

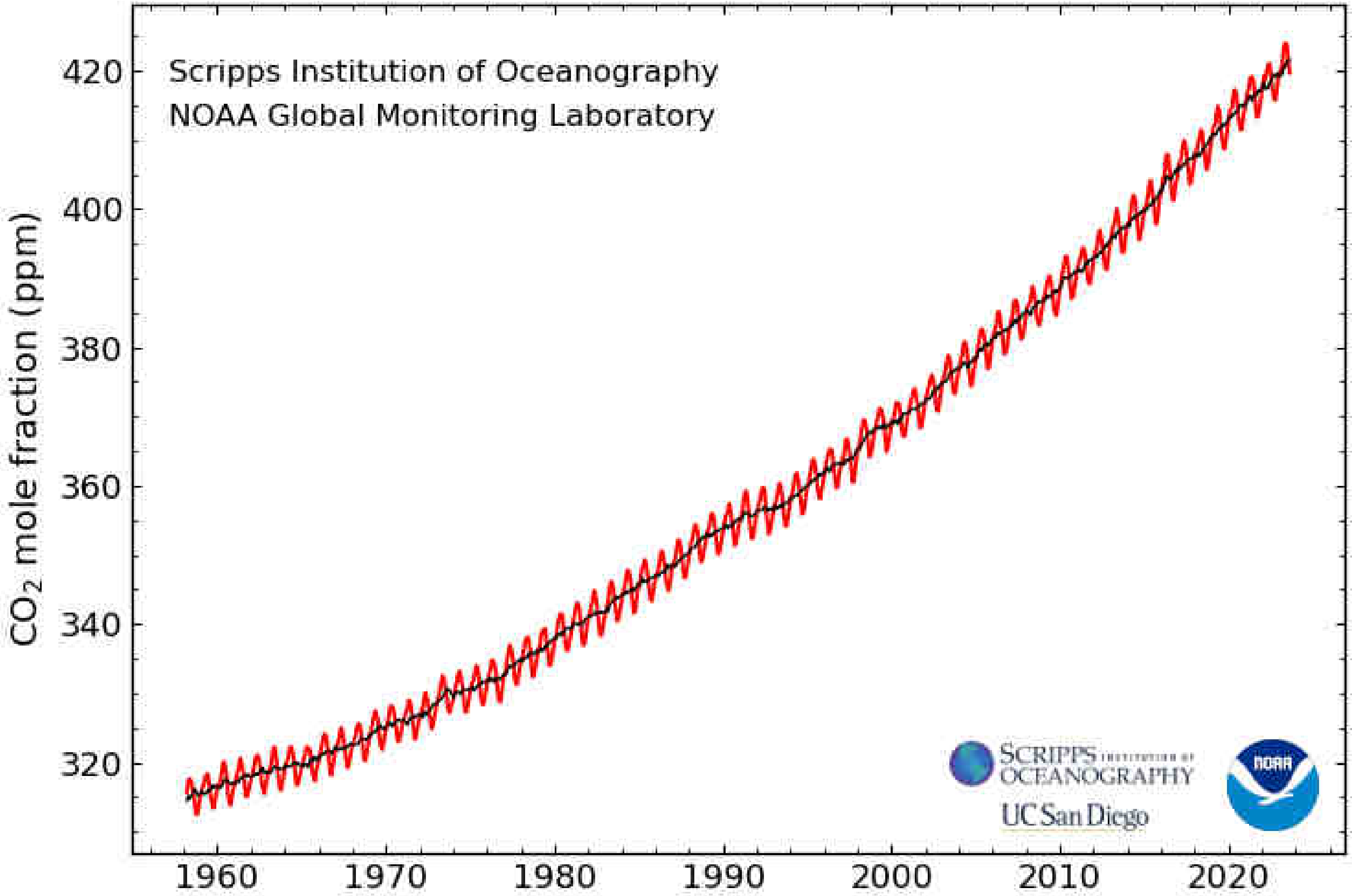
- Operated by National Oceanic and Atmospheric Administration (NOAA)

Global Monitoring Laboratory
Earth System Research Laboratories

- Mauna Loa observatory is:
  - located on the north flank of Mauna Loa Volcano
  - at an elevation of 3,397 meters above sea level
  - first lab continuously monitoring data related to atmospheric change
- Link to datasets: https://gml.noaa.gov/dv/data/

Mauna Loa observatory – CO_2 trends

- Data available since March 1958
- Link to trends: https://gml.noaa.gov/ccgg/trends



What follows from the Kaya’s equation?

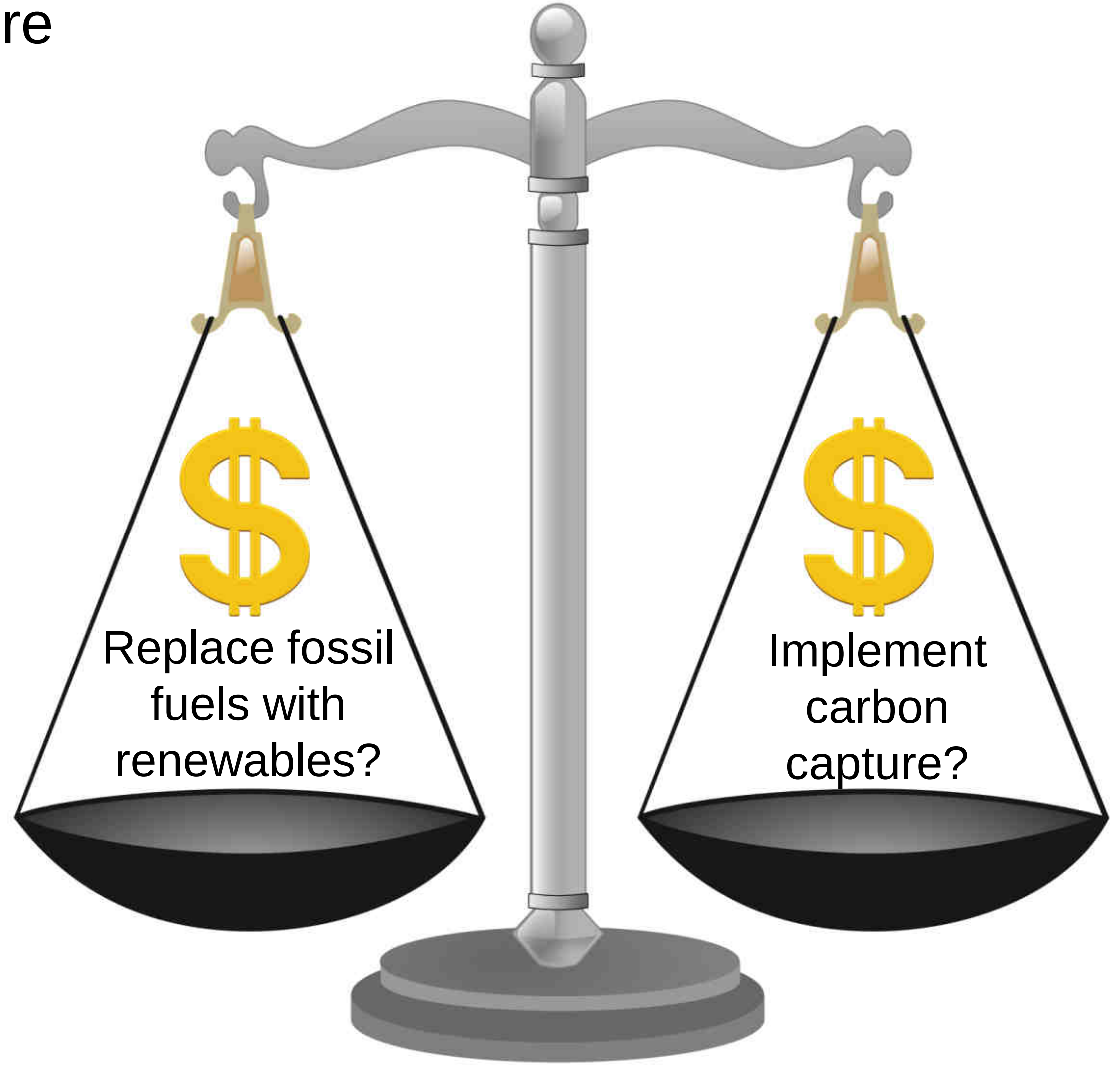
- CO_2 = the most concentrated GHG ⇒ only CO_2 taken into account.
  - What must be changed if other parameters remain unaffected:

Pathways to reduce GHGs emissions

- reduce world population
- reduce GDP per capita
- reduce energy consumption per GDP
  - increase efficiency of technologies + new technol.
- reduce CO_2 released per consumed energy
  - increase power production efficiency
  - replace fossil fuels with renewable sources
  - capture CO_2 produced (by power industry)
    - oxy-combustion processes
    - post-combustion processes
    - pre-combustion processes

Can we burn fossil fuels but not emit CO_2?

- Technically yes – decision will be based on costs
- Possible solution = carbon capture
- 3 approaches possible:
  - post-combustion processes
  - pre-combustion processes
  - oxy-combustion processes

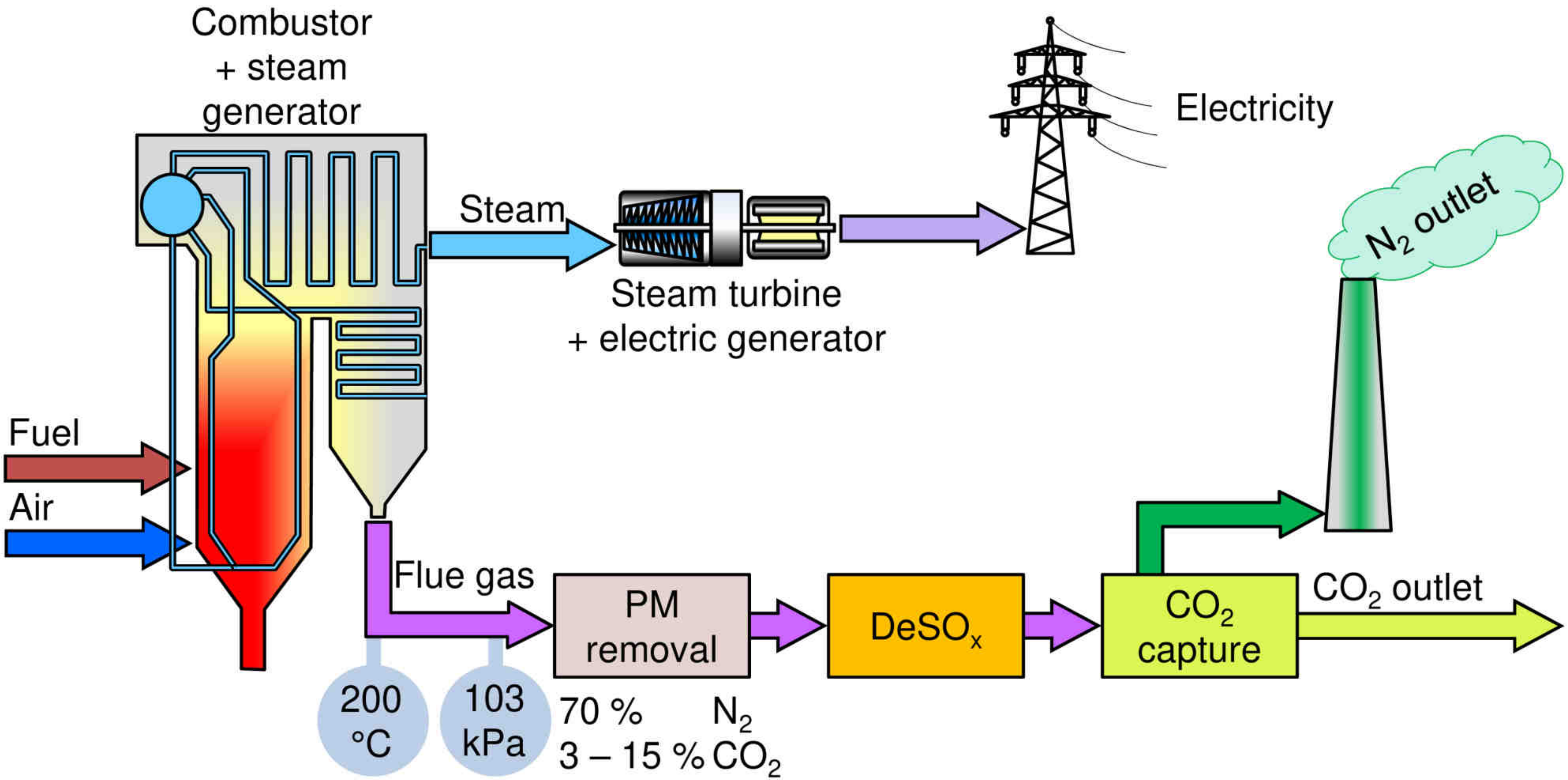


Summary of post-, pre- and oxy-combustion

- Post-combustion processes
  - fuel is incinerated → energy utilized → flue gas cleaned up → CO_2 captured
- Pre-combustion processes
  - fuel is gasified → syn gas cleaned up → CO_2 captured → pure H_2 incinerated → energy utilized
- Oxy-combustion processes (or “oxy-fuel”)
  - O_2 separated from the air → fuel is incinerated → energy utilized → CO_2-rich gas cleaned up → pure CO_2 recovered

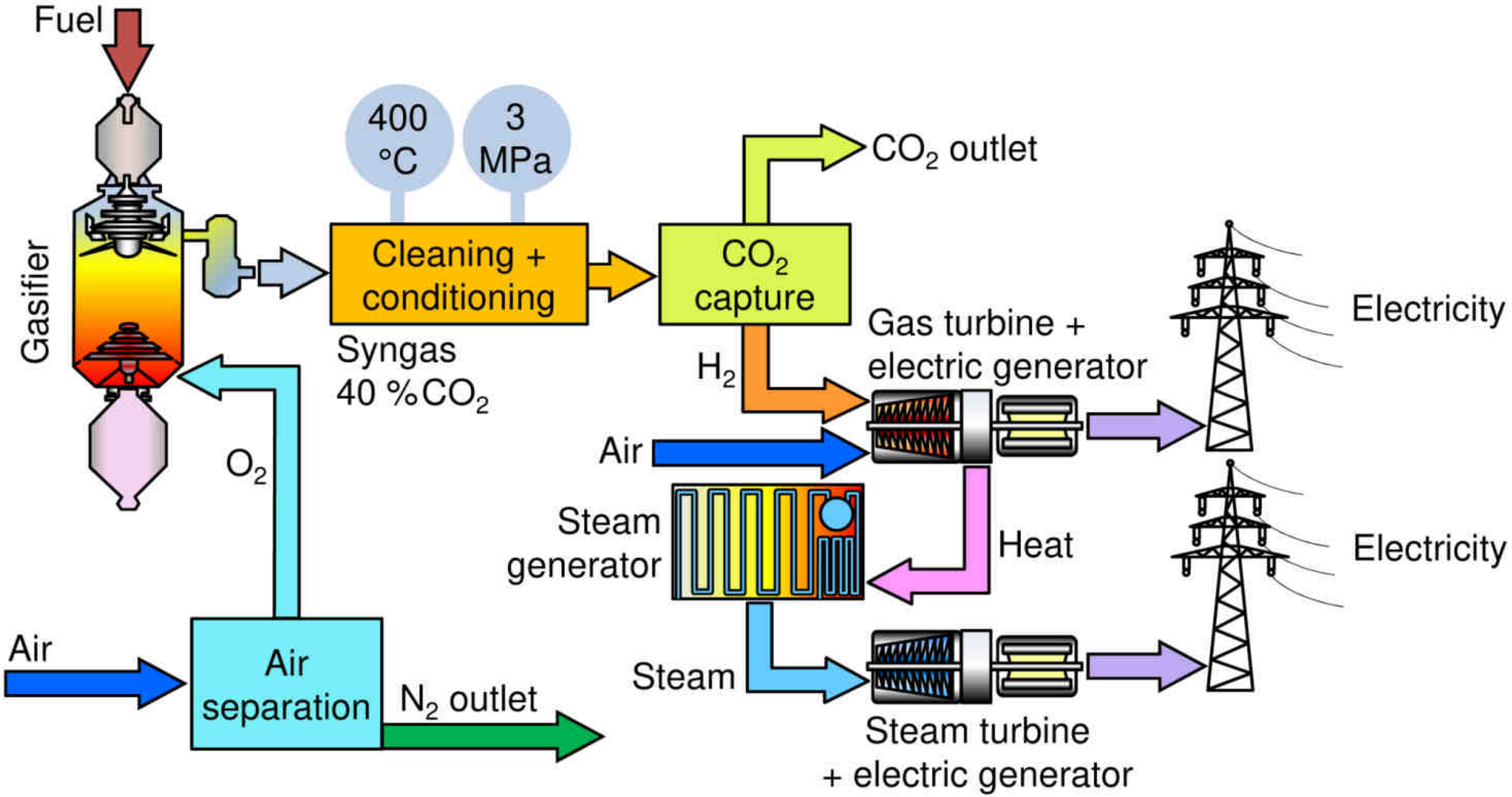
Post-combustion processes

- Huge flue gas flows: e.g. 200 MW unit produces 1.0 – 1.2 10^6 m^3h^{-1}
- CO_2 diluted by large volume of N_2, flue gas wet and dirty (SO_2…)



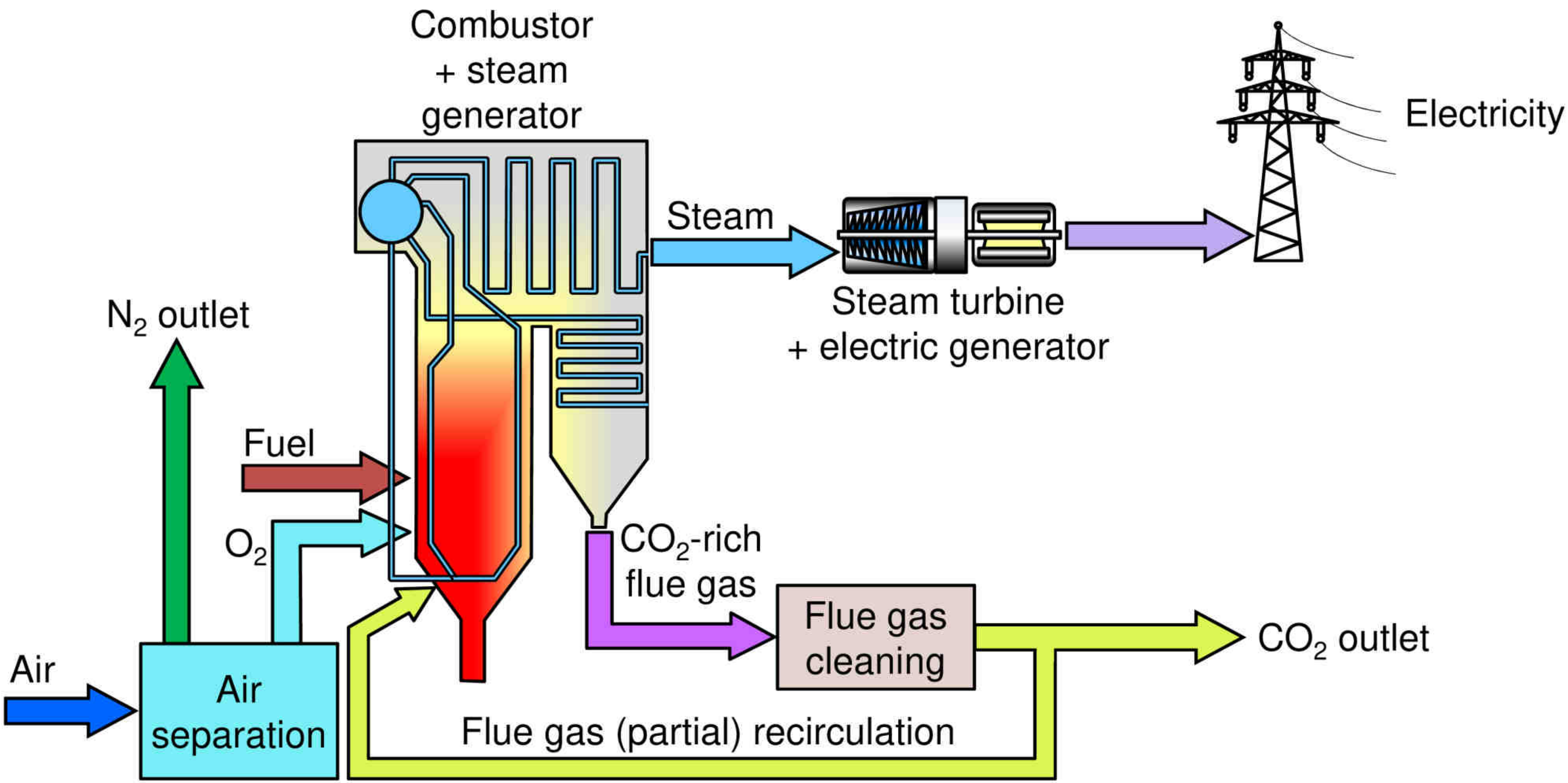
Pre-combustion processes

- Not suitable for older power stations retrofit – too high purchase cost
- Based on the IGCC principle (Integrated gasification combined cycle)

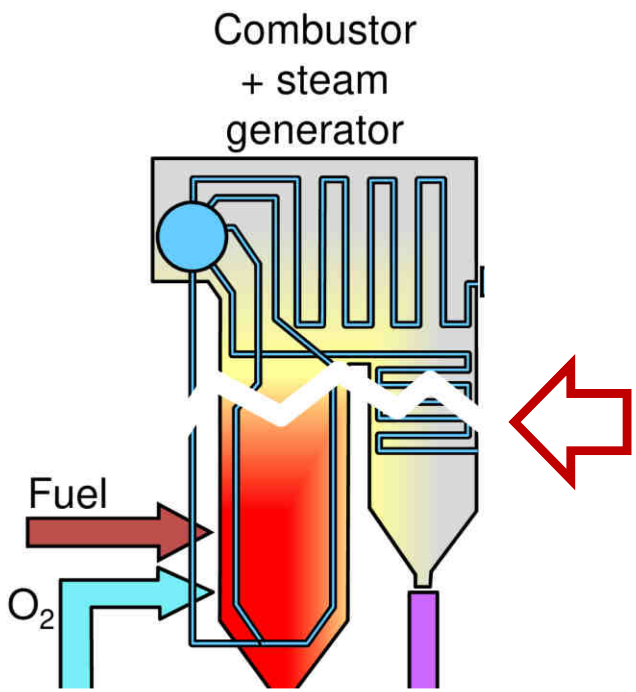


Oxy-combustion processes

- Very expensive air separation to N_2 + O_2 (big volumes)
- Warning: Flue gas recirculation necessary to reduce the combustion temperature.



- Why is incineration with pure oxygen problem?
- Example: 2 H-C≡C-H (acetylene) + $3O_2 \rightarrow 2CO_2 + 2H_2O$
  - flame temperature 3,100 - 3,150 ℃
  - acetylene-oxygen torch used for steel welding!
  - risk of serious damage
  - pure O_2 must be diluted!



Post-combustion: advantages/disadvantages

Post-combustion processes

Advantages

- applicable for retrofitting older combustors
- no need to build a new power plant

Disadvantages

- inlet CO_2 highly diluted
- flue gas at atmospheric pressure
- low partial pressure of CO_2
- high performance or high recirculated flue gas volumes needed to reach high capture efficiency
- low outlet CO_2 pressure (for further use)

Pre-combustion: advantages/disadvantages

Pre-combustion processes

Advantages

- inlet syngas with high CO_2 concentrations
- high total pressure
- high partial CO2 pressure
- sufficient pressure gradient for CO_2 separation
- higher number of suitable capture technologies
- good ratio: lower operating costs (OPEX)/CO_2 separation technology loading

Disadvantages

- suitable for new power stations
- retrofitting older power stations economically not feasible
- many subsystems = technically complicated
- high capital costs (CAPEX)

Oxy-combustion: advantages/disadvantages

Oxy-combustion processes

Advantages

- very high CO_2 concentrations in flue gas
- retrofitting older combustors potentially possible

Disadvantages

- very high operating costs for O_2 production
- cooled flue gas recirculation needed to protect materials of the combustors
- lover overall efficiency

Reference(s): 1

Pre-combustion processes require syngas

- Two main ways:
  - solid fuels gasification 700 – 1,700 ℃ 10 – 80 bar

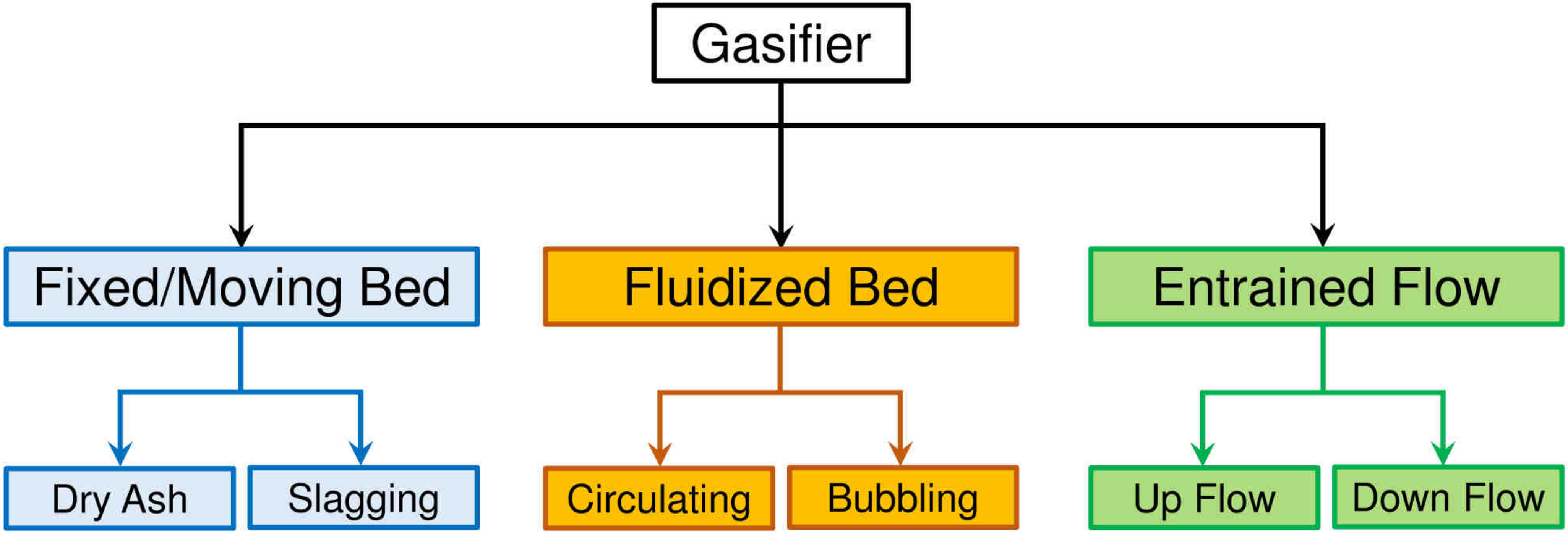
Boudouard reaction	CO2 + C ⇌ 2CO
Water–gas shift reaction (WGSR)	$CO + H_2O \rightleftharpoons CO_2 + H.$
Steam gasification of char	$C + H_2O \rightleftharpoons CO + H_2$
Partial oxidation of char	$C + ½O_2 \rightarrow CO$
Complete oxidation of char	C + O2 → CO

  - gaseous fuels reforming & partial ox. 700 – 1,000 ℃ 3 – 25 bar

Steam reforming of methane	$CH_4 + H_2O \rightarrow CO + 3H_2$
Partial oxidation of methane	$CH_4 + ½O_2 \rightarrow CO + 2H_2$

…… but we need pure H_2 !

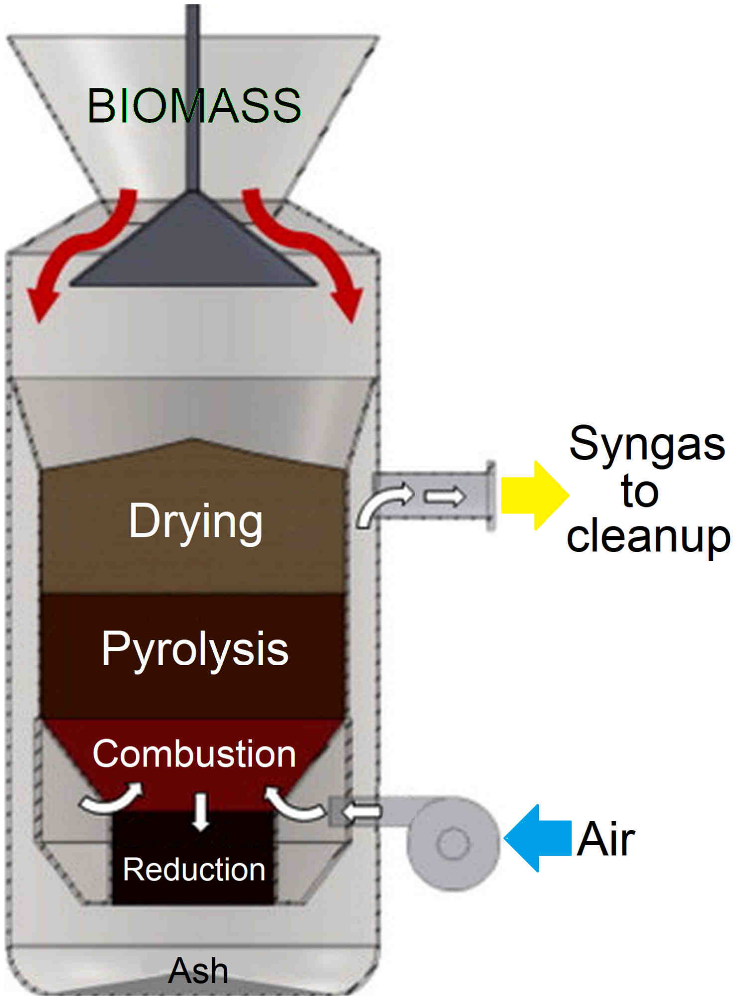
- Possible feedstocks:
  - coal (black coal or hard coal, lignite aka brown coal, coal sludge etc.)
  - biomass (wooden chips, crop residues, wastewater sludge etc.)
  - wastes (municipal solid waste, refuse derived fuel etc.)



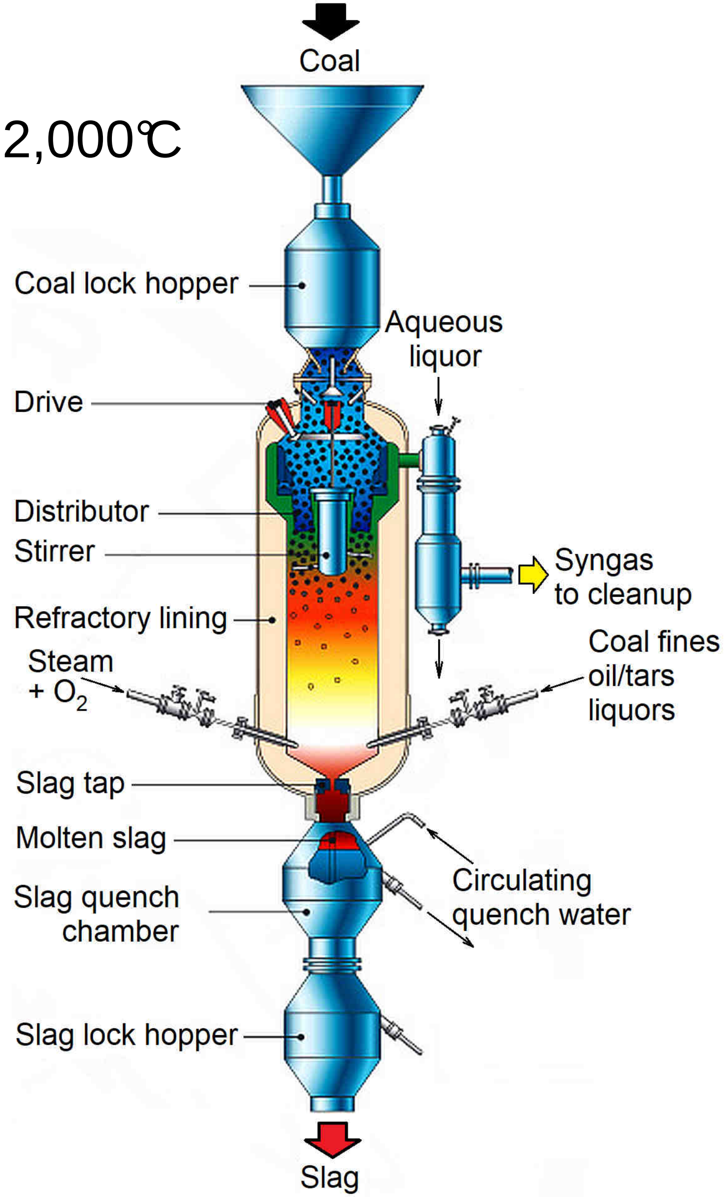
- + Plasma Torch Gasifier (special case not included above)

Fixed/Moving Bed Gasifiers

- Examples of downdraft gasifiers:
  - dry ash 700 – 1,000℃, slagging 1,400 – 2,000℃

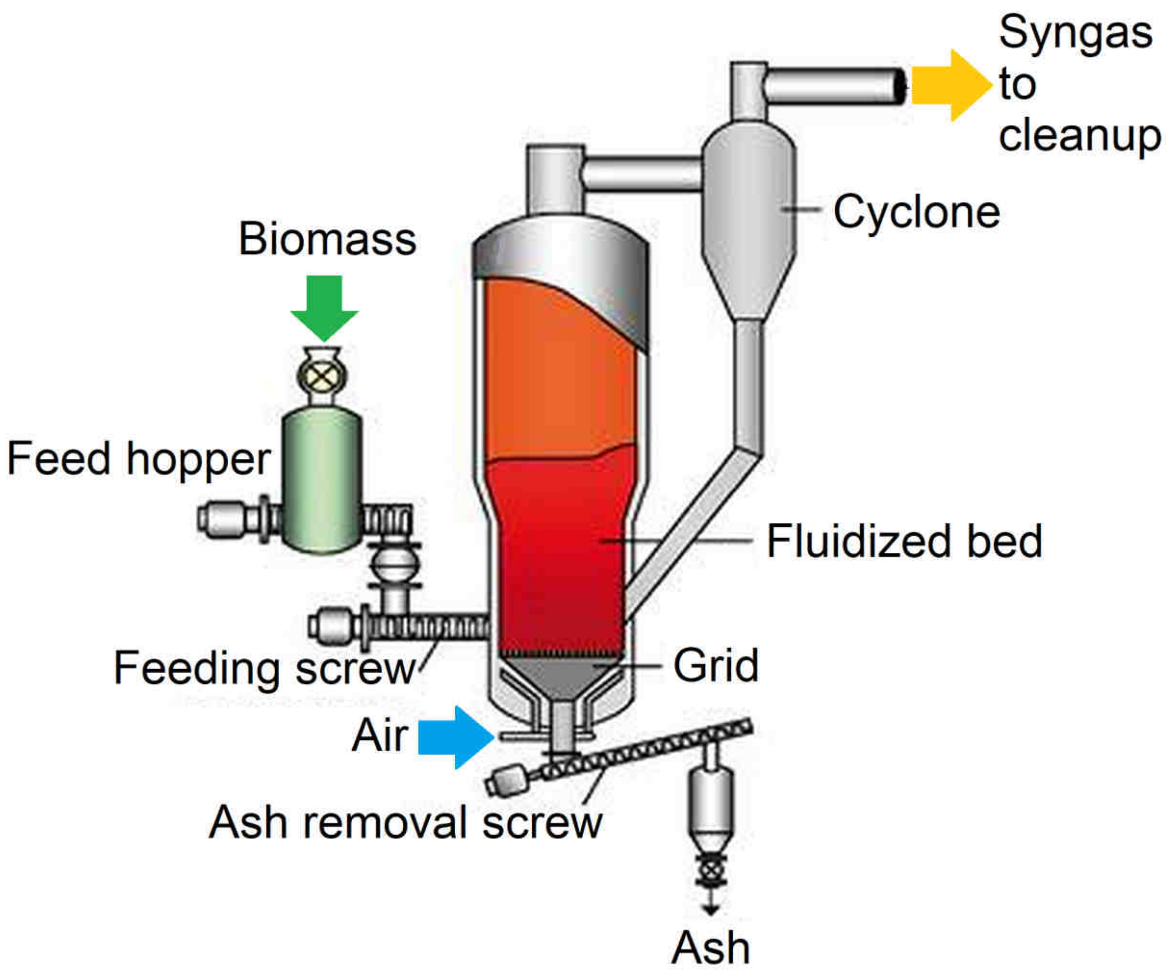


Downdraft dry ash gasifier

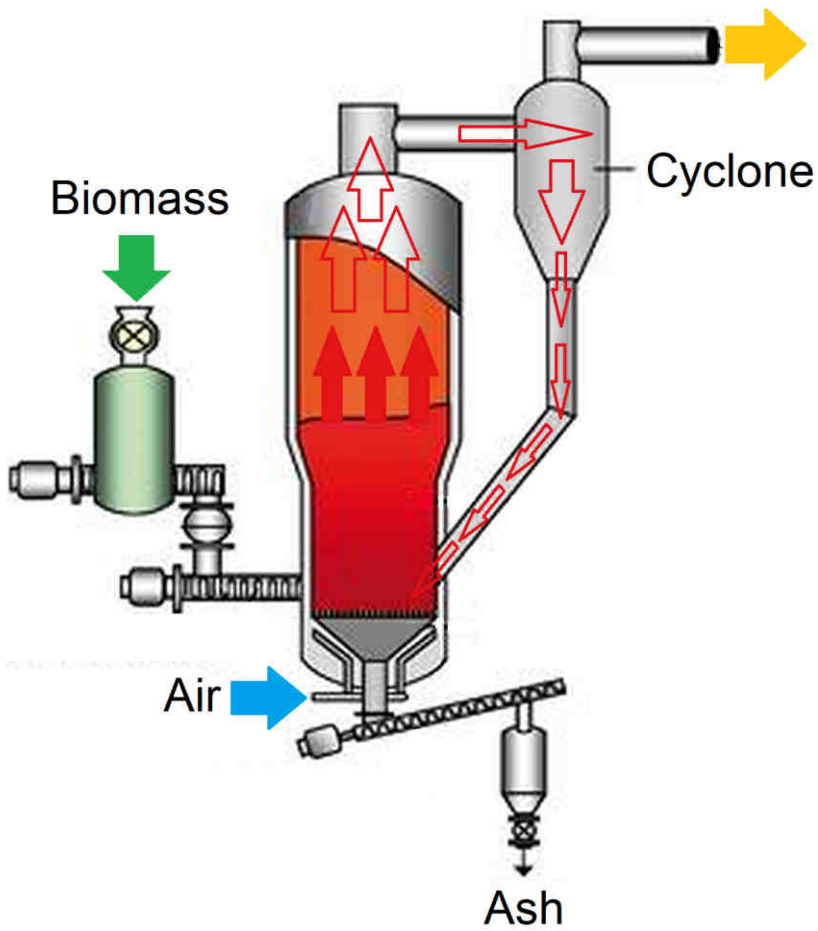


Downdraft Slagging Gasifier (Lurgi)

- Examples of fluidized bed gasifiers:
  - 700 – 1,050℃



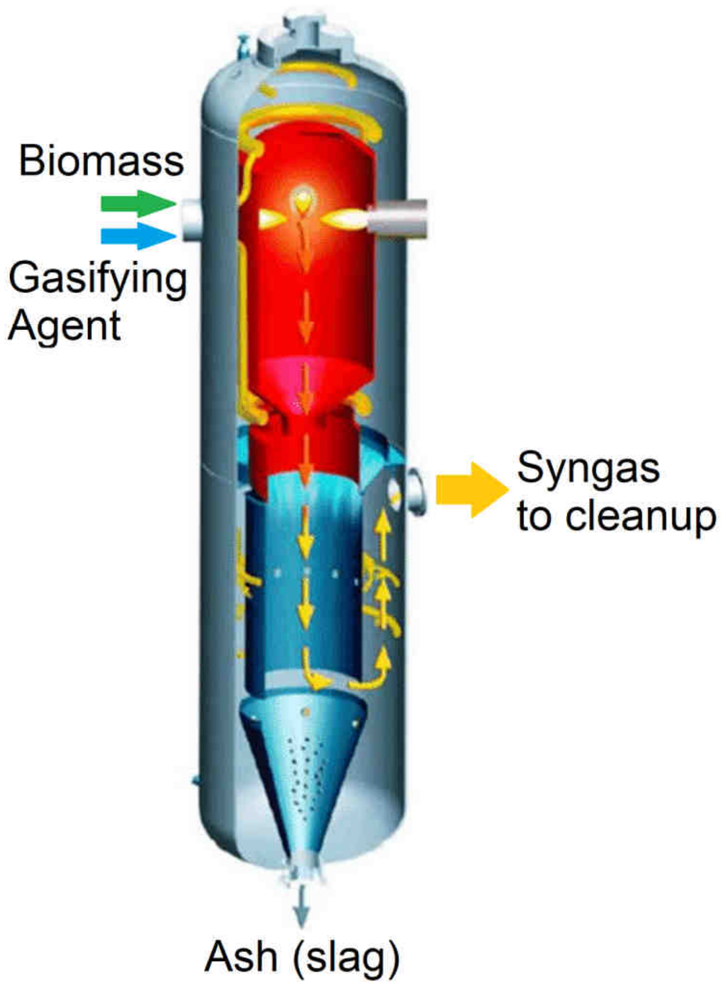
Bubbling fluidized bed



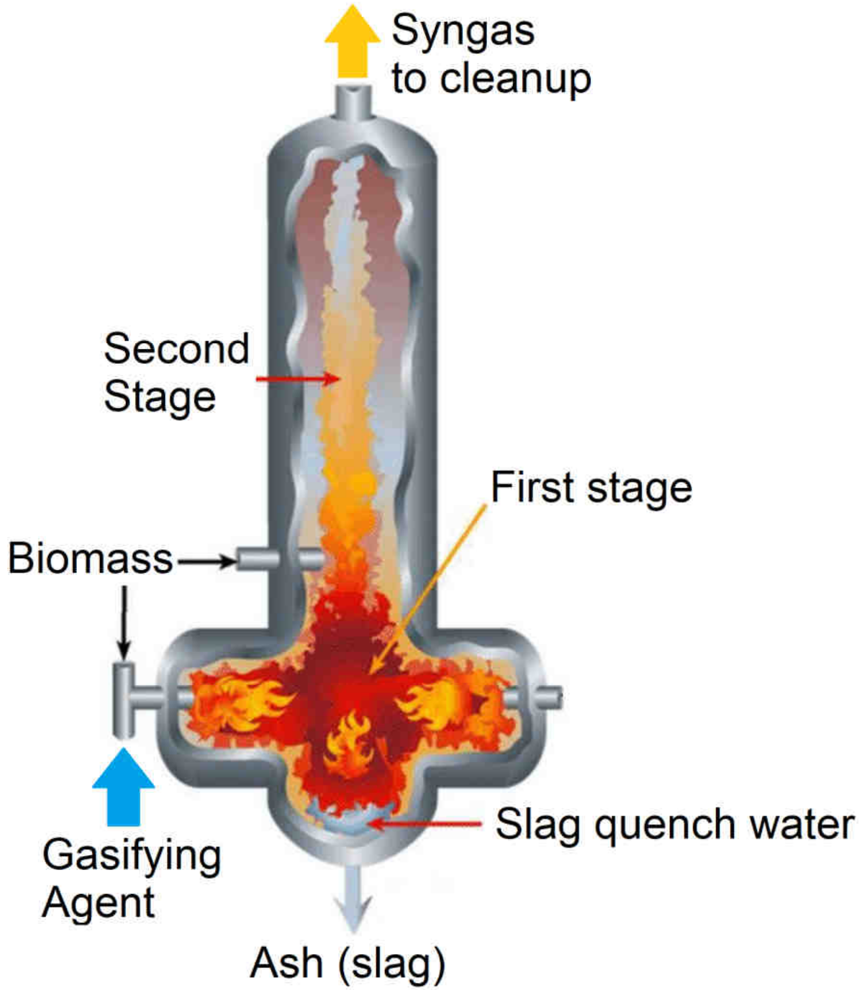
Circulating fluidised bed (CFB)

Entrained Flow Gasifiers

- Examples of entrained flow gasifiers:
  - 1,400 – 1,700 ℃

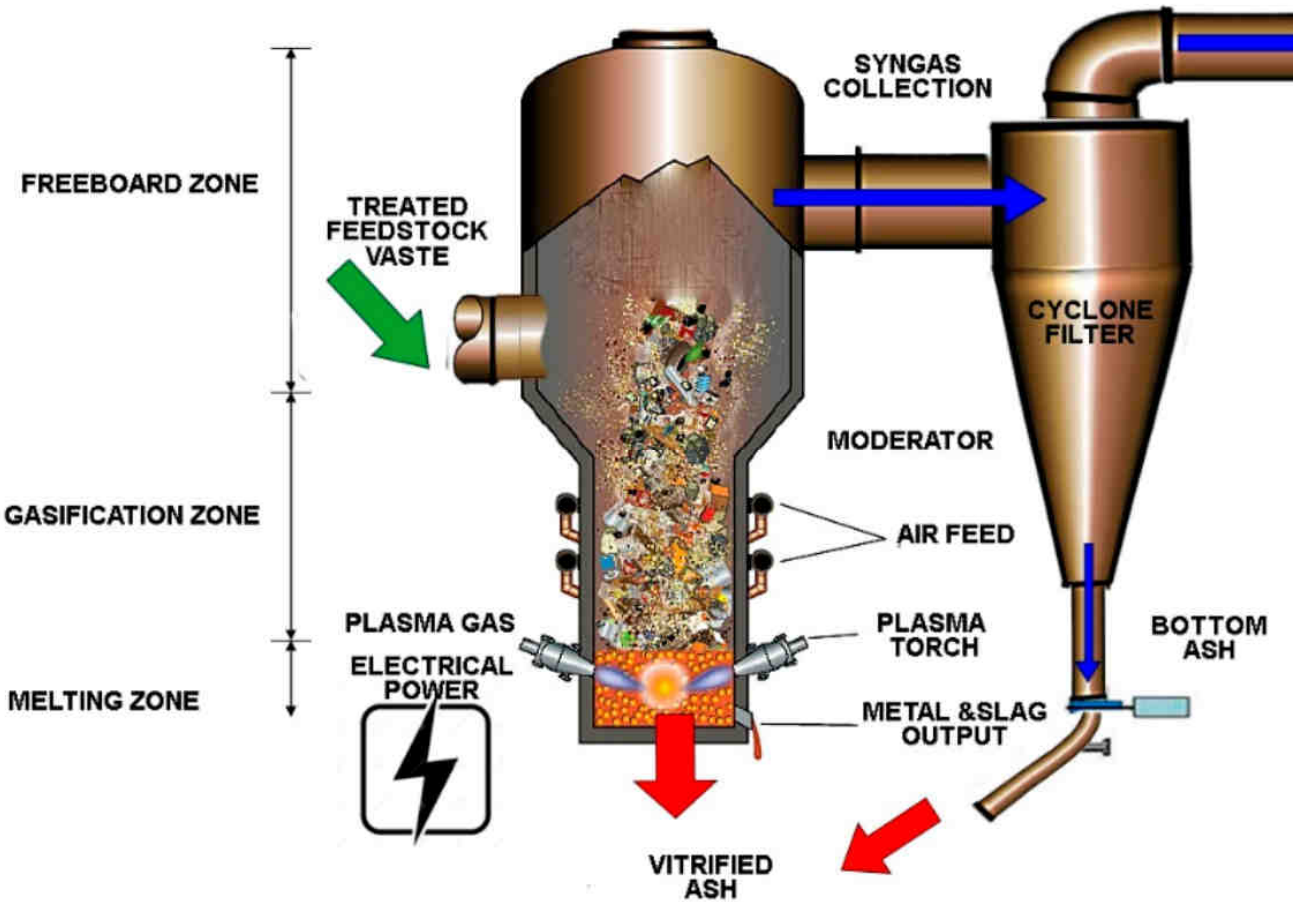


Downflow entrained f. gasifier



Upflow entrained f. gasifier

- Example of plasma torch gasifier:
  - 4,000 – 4,500℃

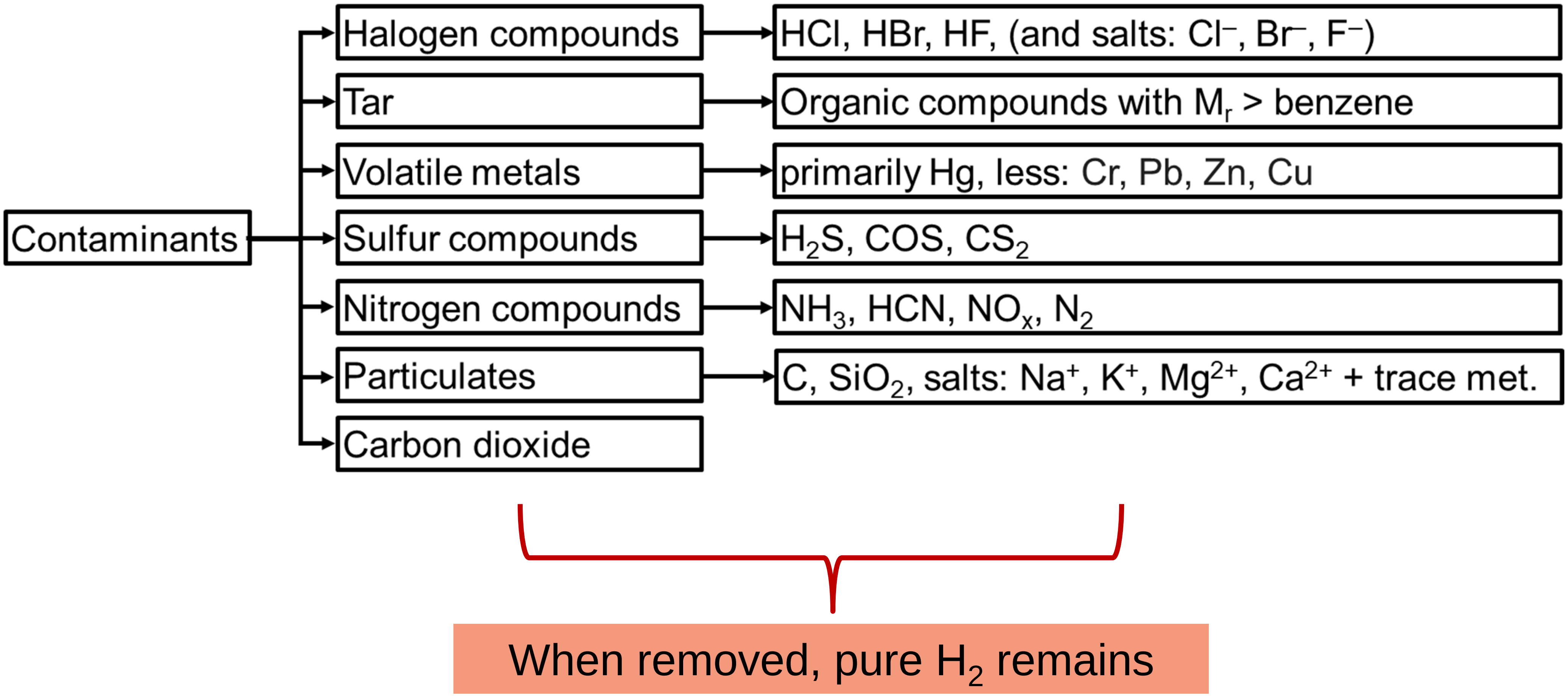


Plasma torch gasifier

Plasma torch construction

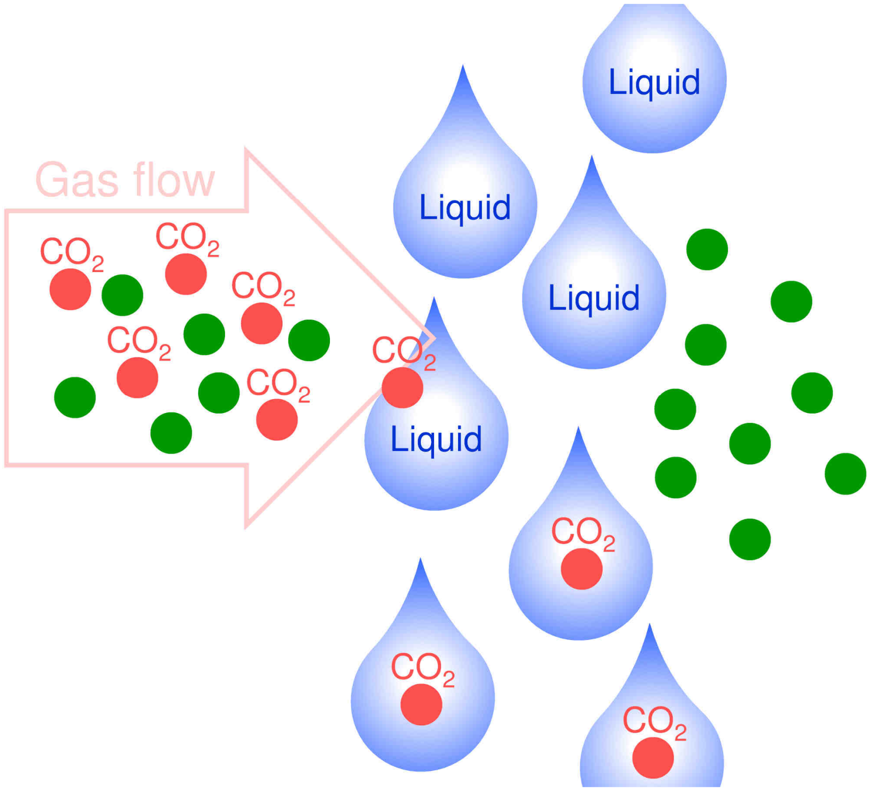
Syngas cleaning and conditioning

- Species contaminating syngas:
  - depending on raw materials and gasification conditions

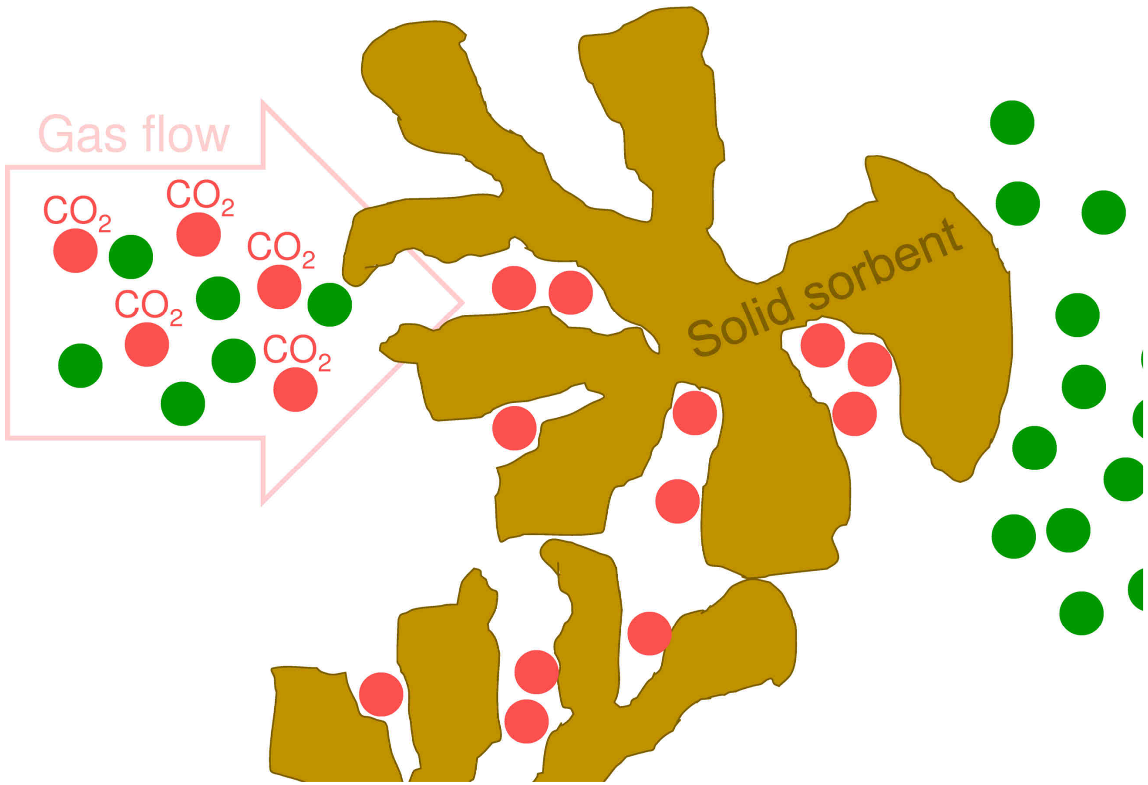


CO_2 separation for pre- and post-combustion

- 4 main approaches:
  - absorption in liquids
  - adsorption on solid materials
  - membrane separation
  - chemical looping combustion (CLC) or chemical looping gasification (CLG)



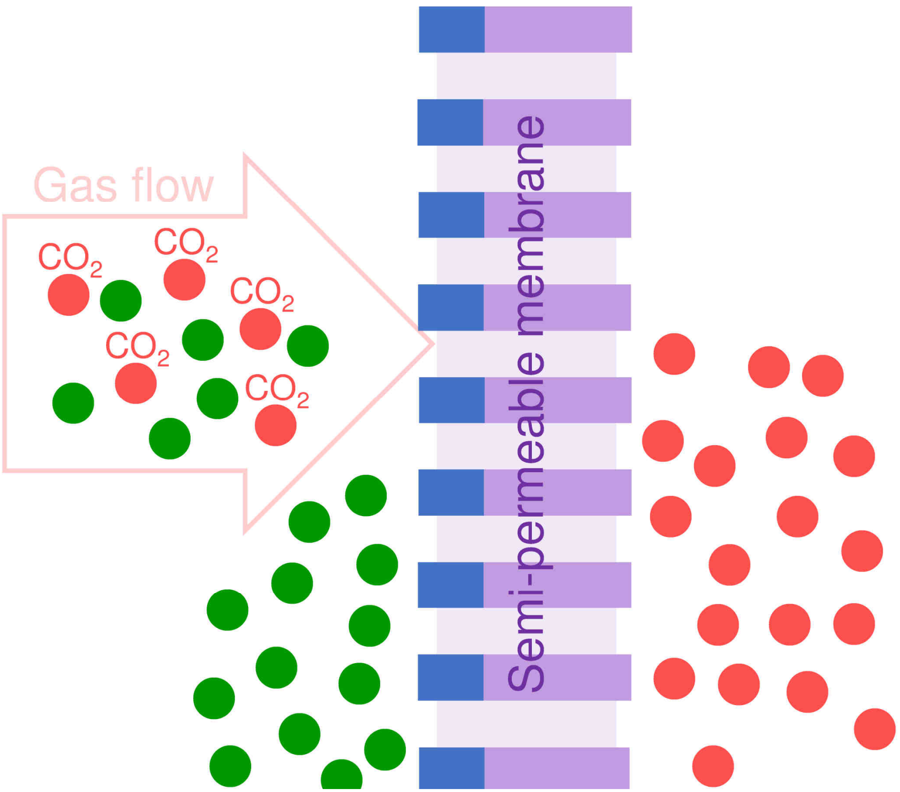
Absorption



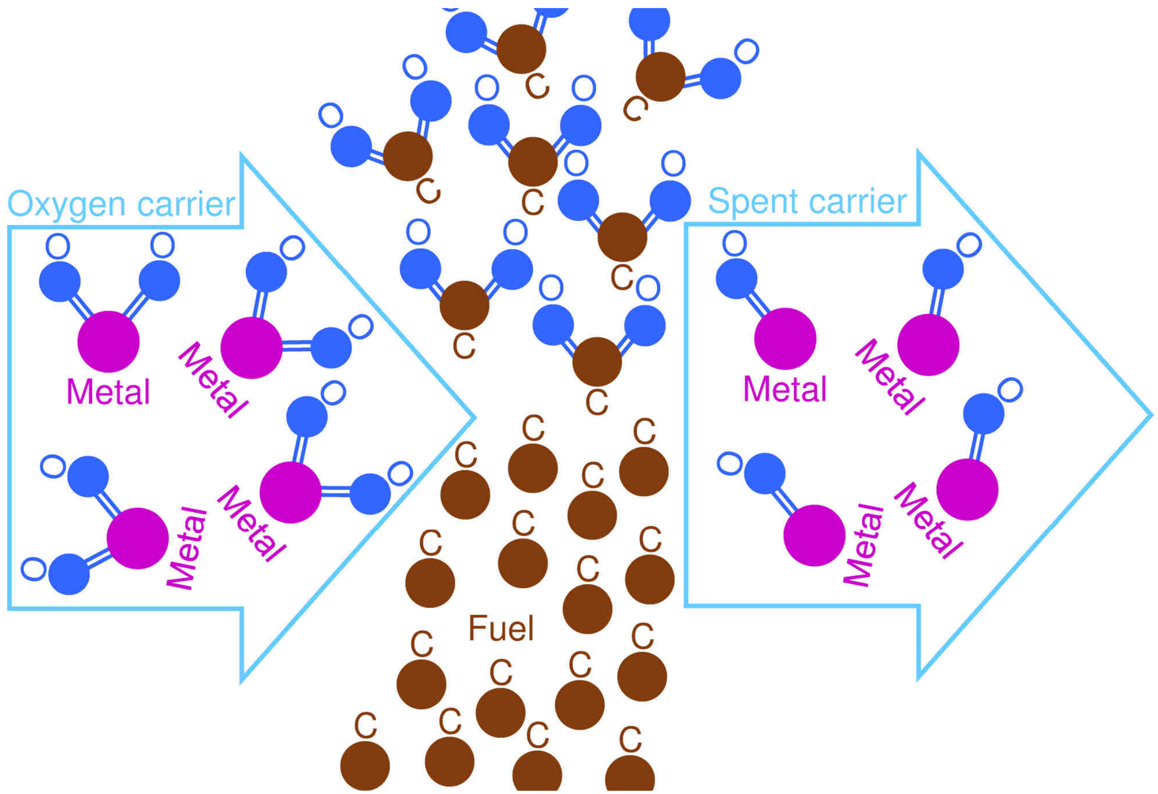
Adsorption

CO_2 separation for pre- and post-combustion

- 4 main approaches:
  - absorption in liquids
  - adsorption on solid materials
  - membrane separation
  - chemical looping combustion (CLC) or chemical looping gasification (CLG)



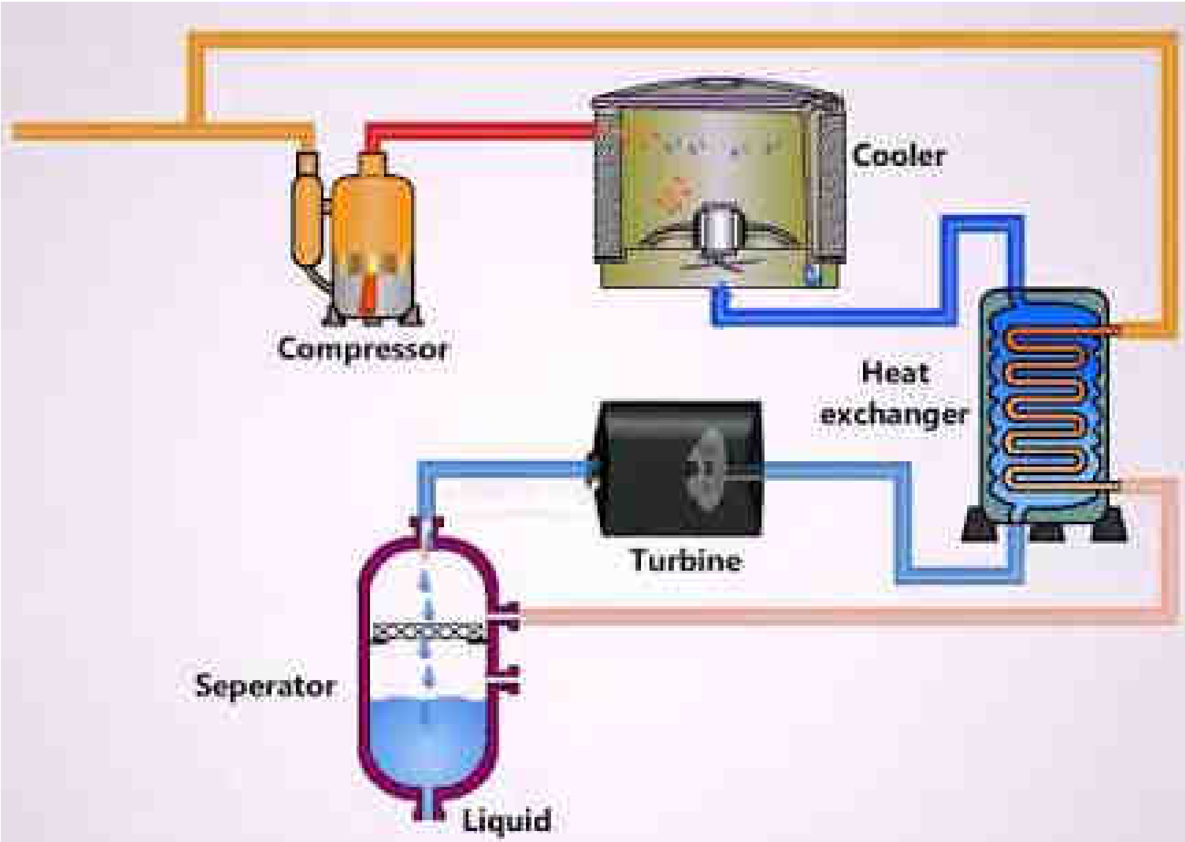
Membrane separation



CLC

O_2 separation for oxy-combustion process

- Air separation into $N_2 + O_2$ = the key process:
  - Linde liquefaction process
  - Adsorption separation (e.g. PSA)
  - Membrane separation



Example: Linde unit = highly energy consuming!

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