Coal

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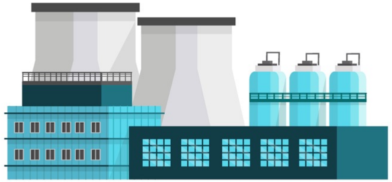
Lausanne – 23/10/2023

École polytechnique fédérale de Lausanne

Introduction

– How do we produce electricity today?



HEAT → HEAT ENGINE → ELECTRICITY

Chemical / Nuclear energy (Biomass, Coal, etc.)

MECHANICA
L → Dams, windmills (turbines) → ELECTRICITY

Kinetic / Potential energy (Wind, Hydro)

LIGHT → Photovoltaics → ELECTRICITY

Solar radiation
(Light)

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Introduction

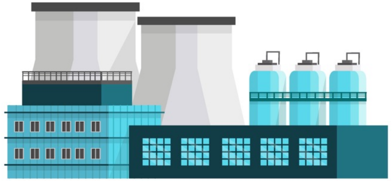
– How do we produce electricity today?

SOLID FUELS (COAL / BIOMASS)

GASEOUS FUELS (NATURAL GAS/BIOG

LIQUID FUELS (OIL/BIO-OIL)

HEAT → HEAT ENGINE → ELECTRICITY



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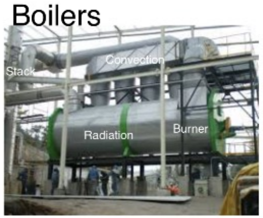
Introduction

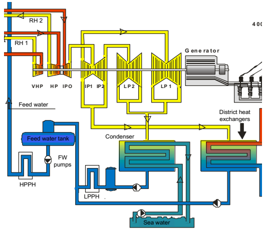
– How do we produce electricity today?

SOLID FUELS (COAL)



Heat production
(Combustion)

HEAT



Heat – to – Power
(Rankine cycle)

ELECTRICITY

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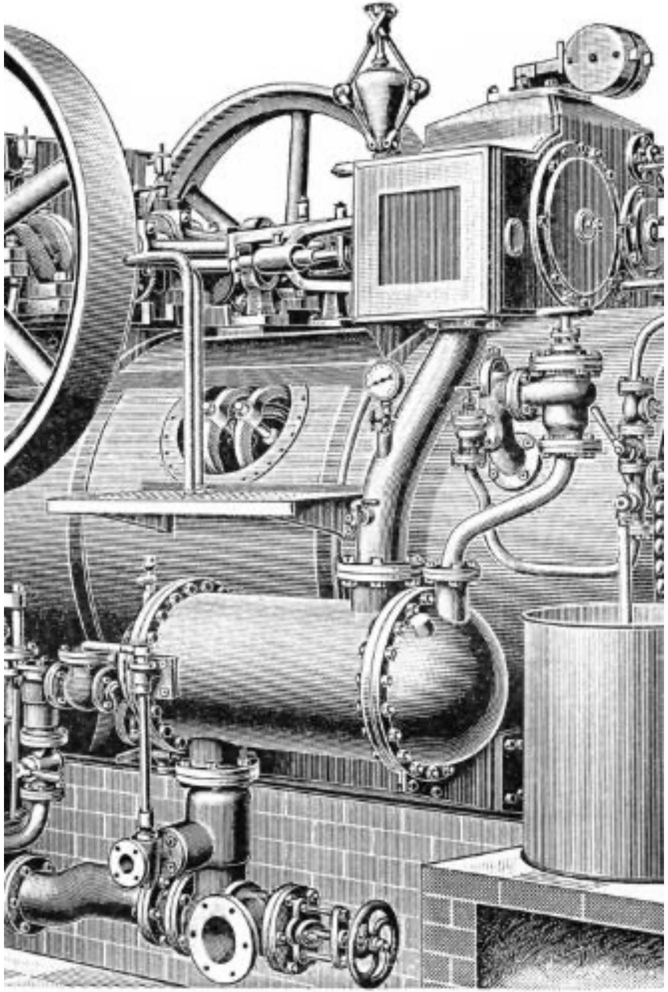
Goals

- **Describe** the types of **coal power plants**
- **Evaluate** the efficiency and electricity generation costs
- **Estimate** the emissions of CO_2 and pollutants and techniques to reduce them



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Introduction

The story behind Coal

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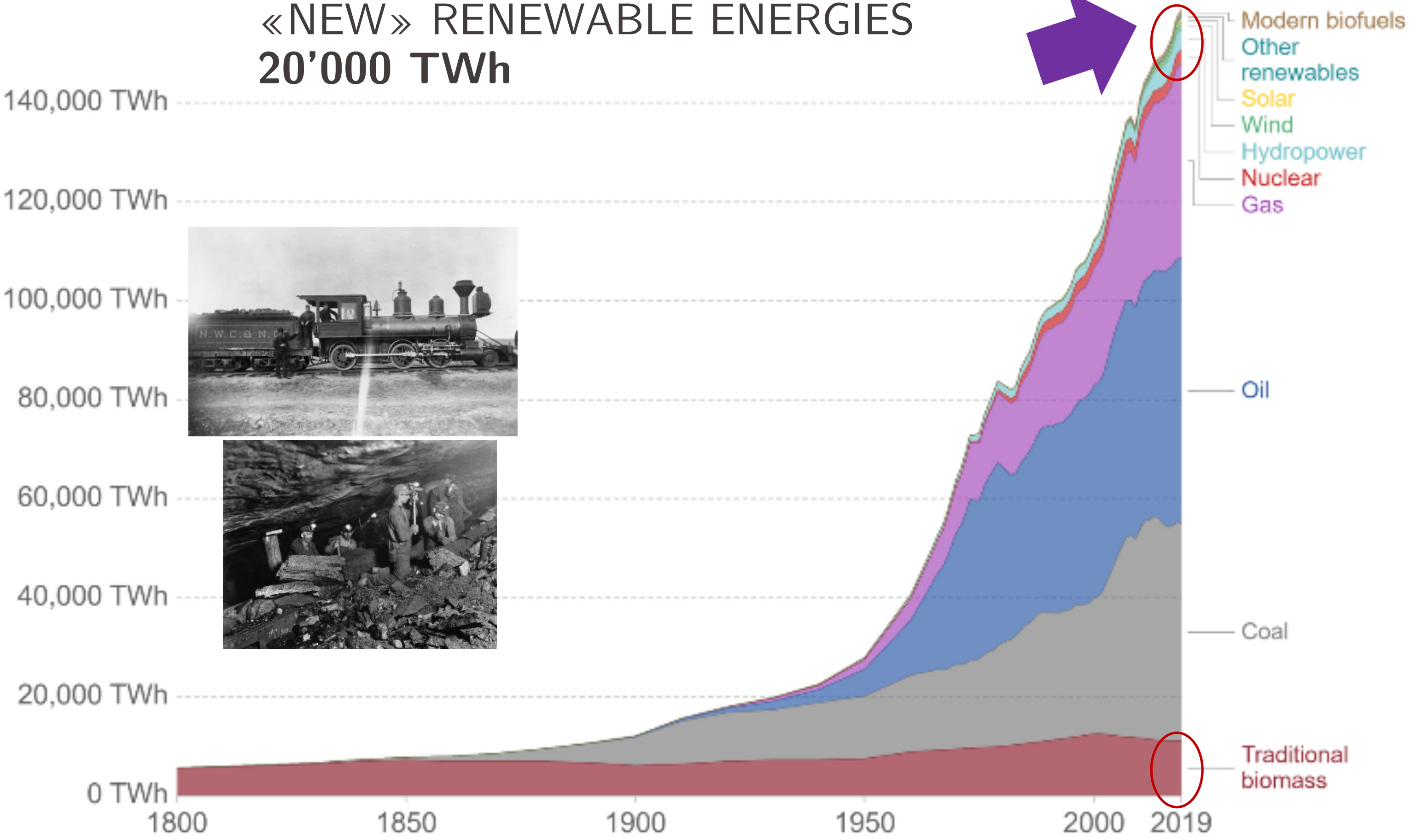
Introduction

«NEW» RENEWABLE ENERGIES
20'000 TWh



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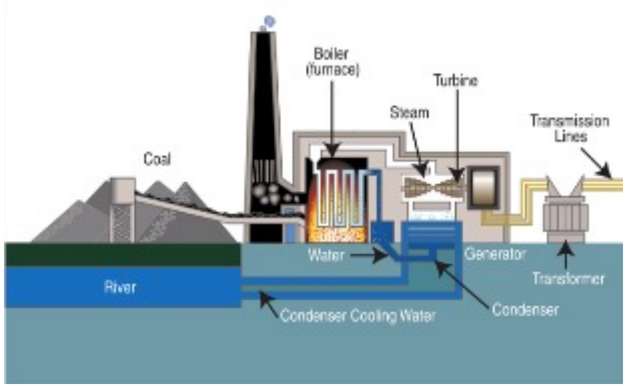
Coal

PROS and CONS

- **Cheap**
- Abundant and widespread
- **Mature** conversion technologies



- **Non-renewable resource**
- **Global warming**
- **Human health**

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Reserves and resources

Formation

Properties

Reserves and resources

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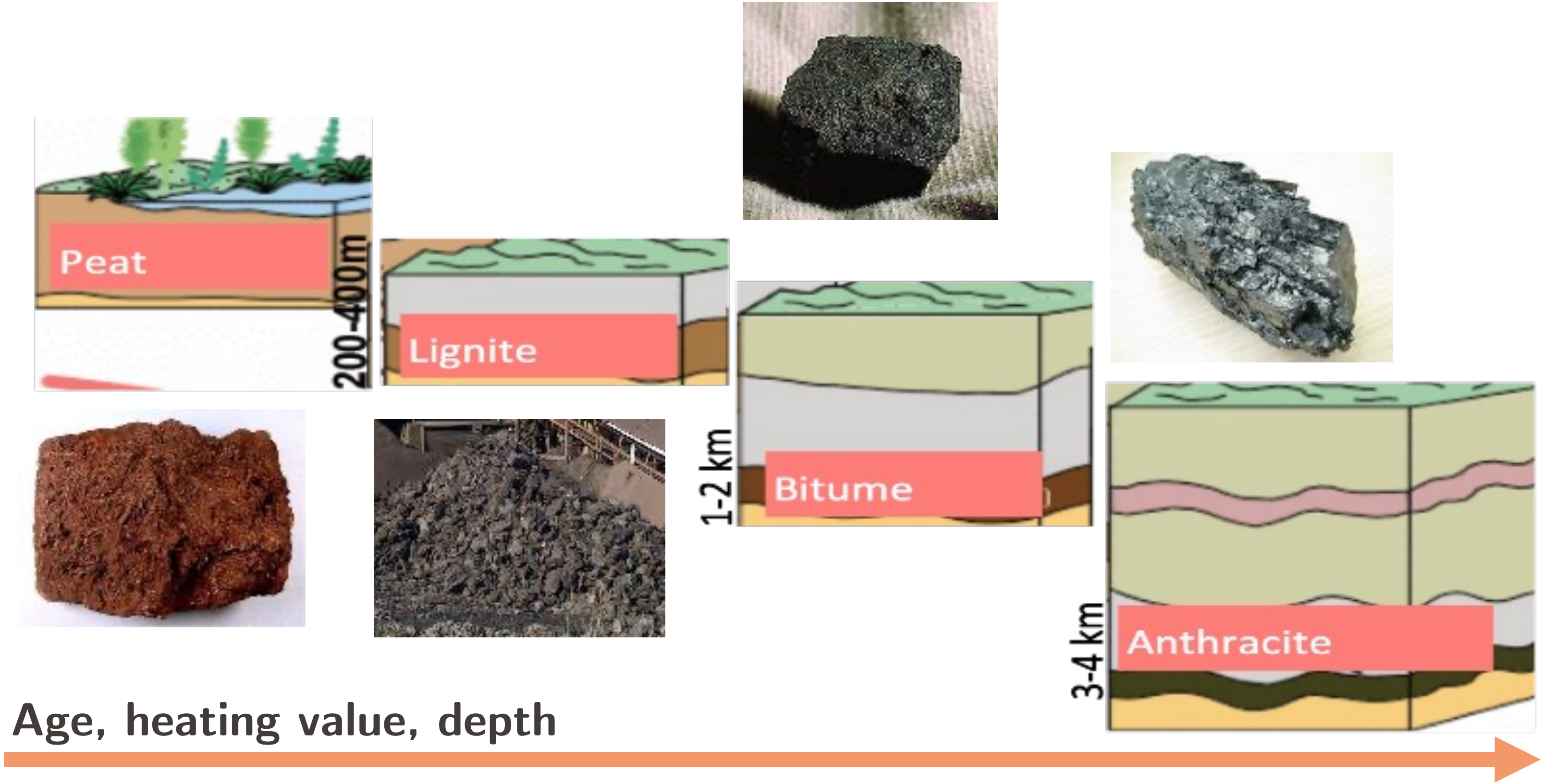
Coal origin and reserves

Coalification



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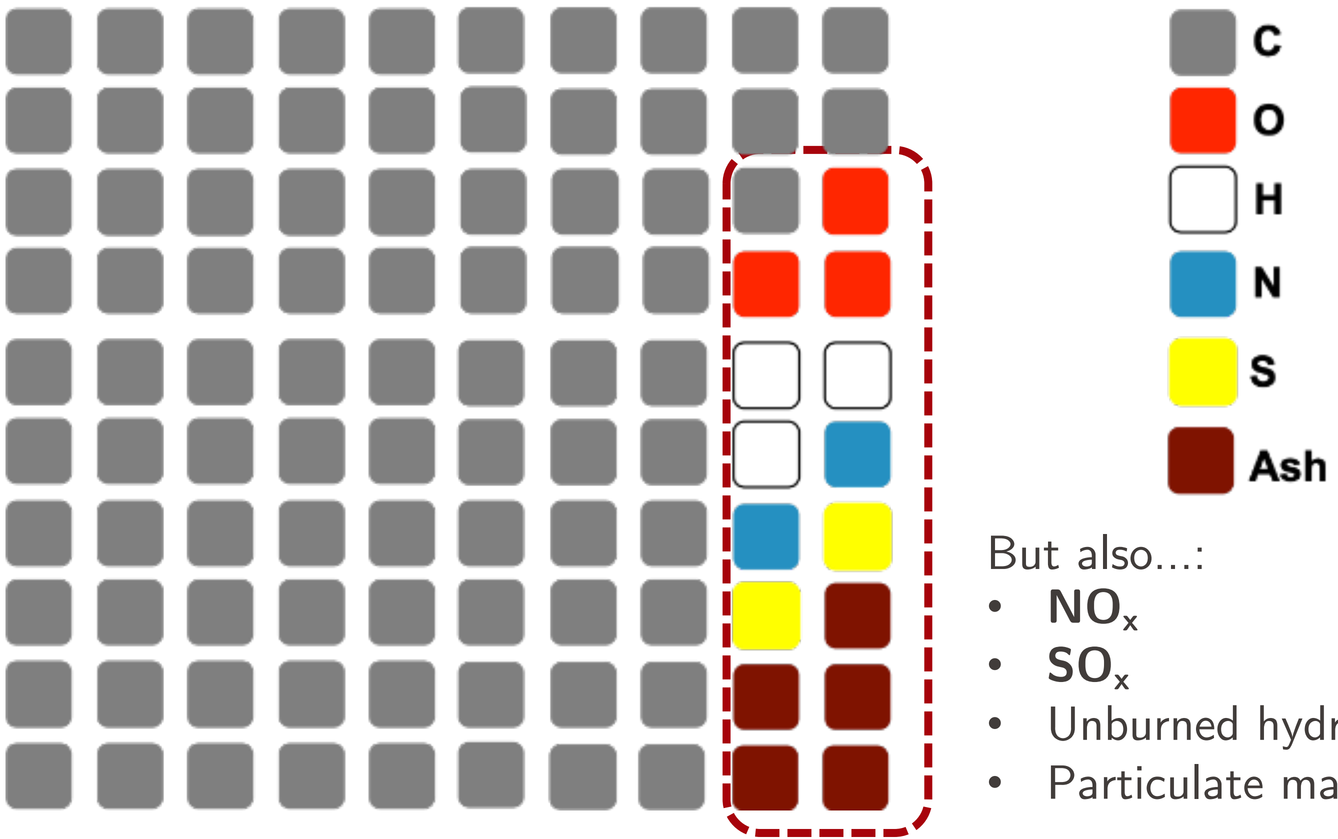
Coal origin and reserves

Standard coal?



But also...:

- **NO_x**
- **SO_x**
- Unburned hydrocarbons **HCs**
- Particulate matters **PM**

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Coal origin and reserves

Comparison

$> 85\%$ (wt) C

Coal – anthracite

33 MJ/kg

$< 60\%$ (wt) C $> 30\%$ (wt) O

Coal – lignite

25 MJ/kg

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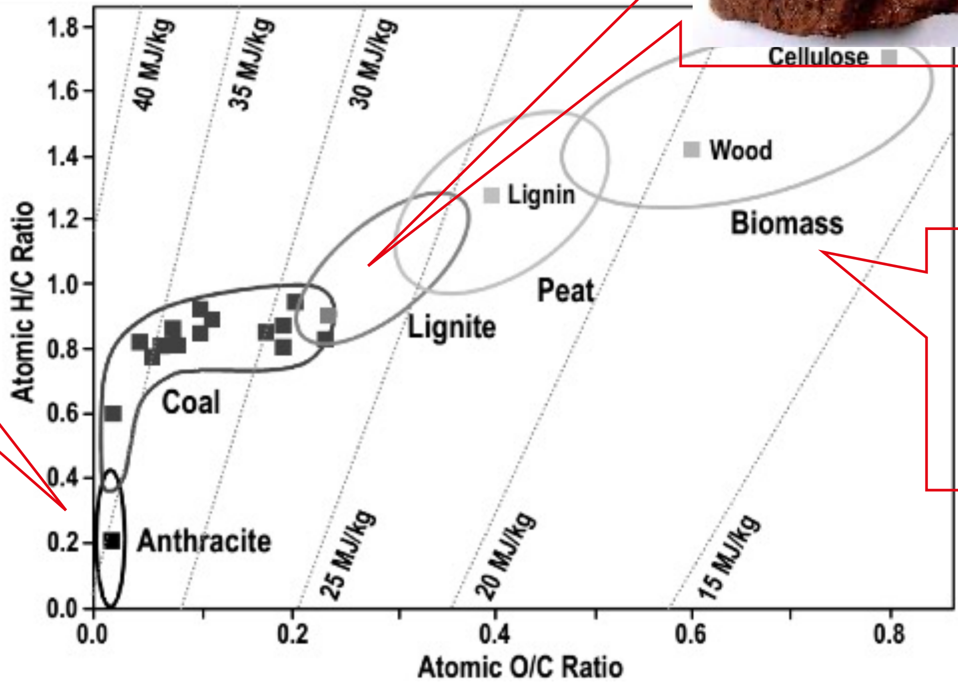
Coal heating values



Age, heating value, depth

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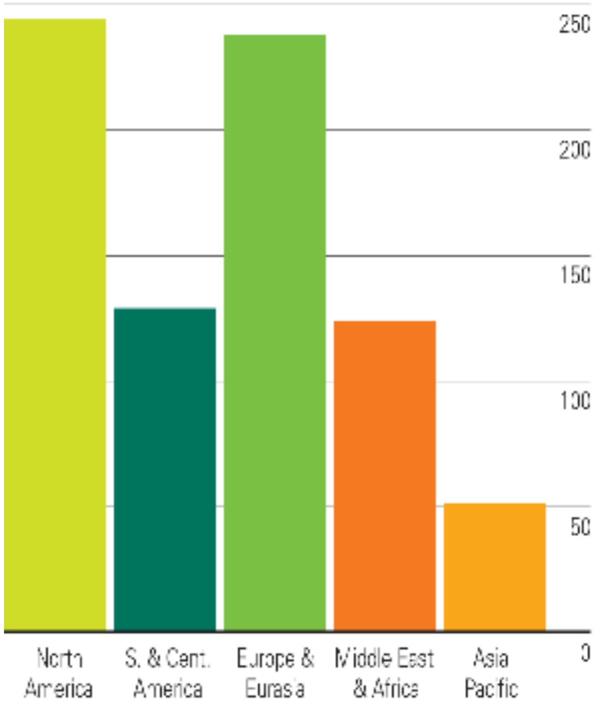
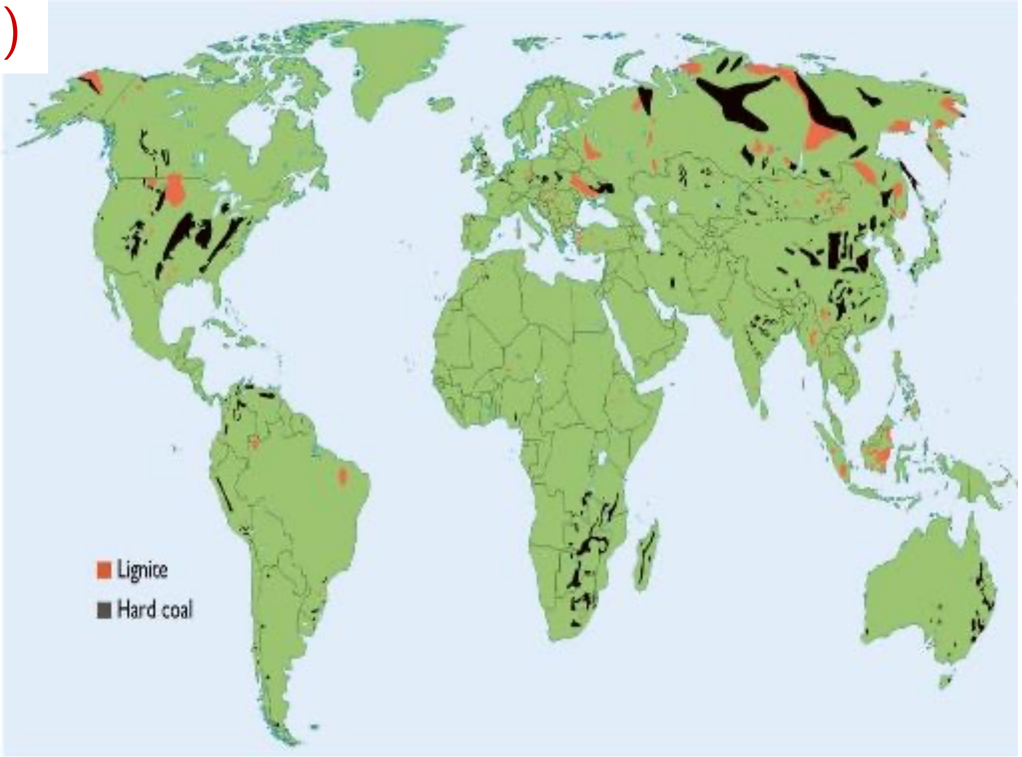
Coal origin and reserves

Reserves / production (years)





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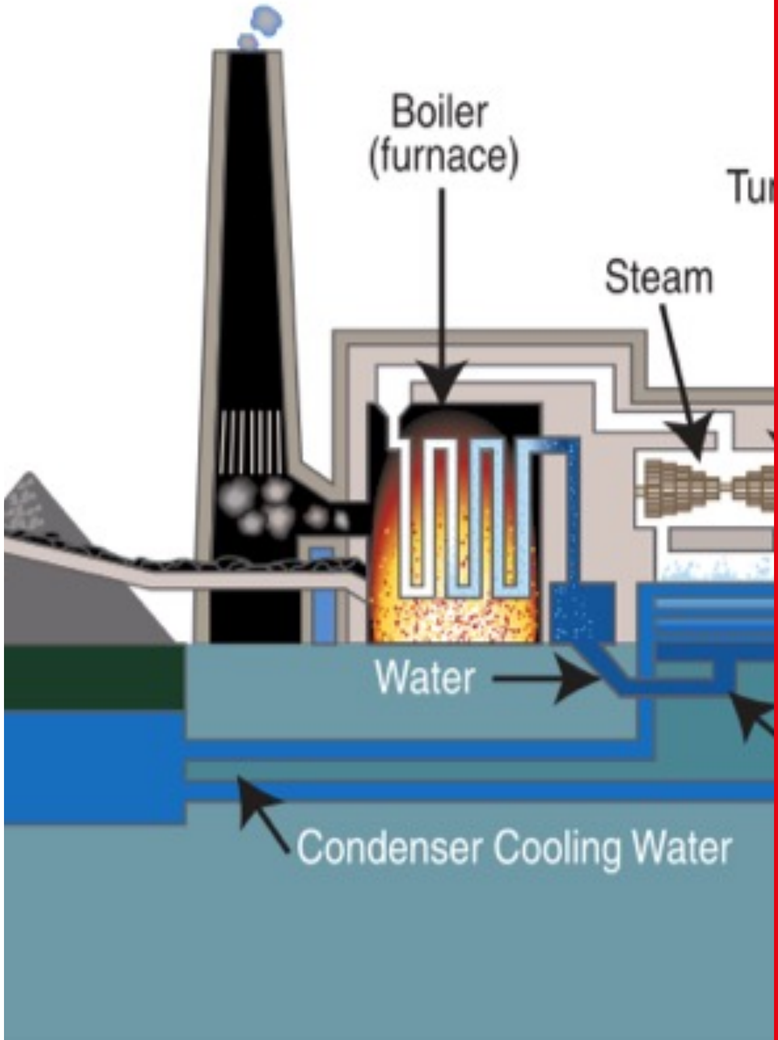
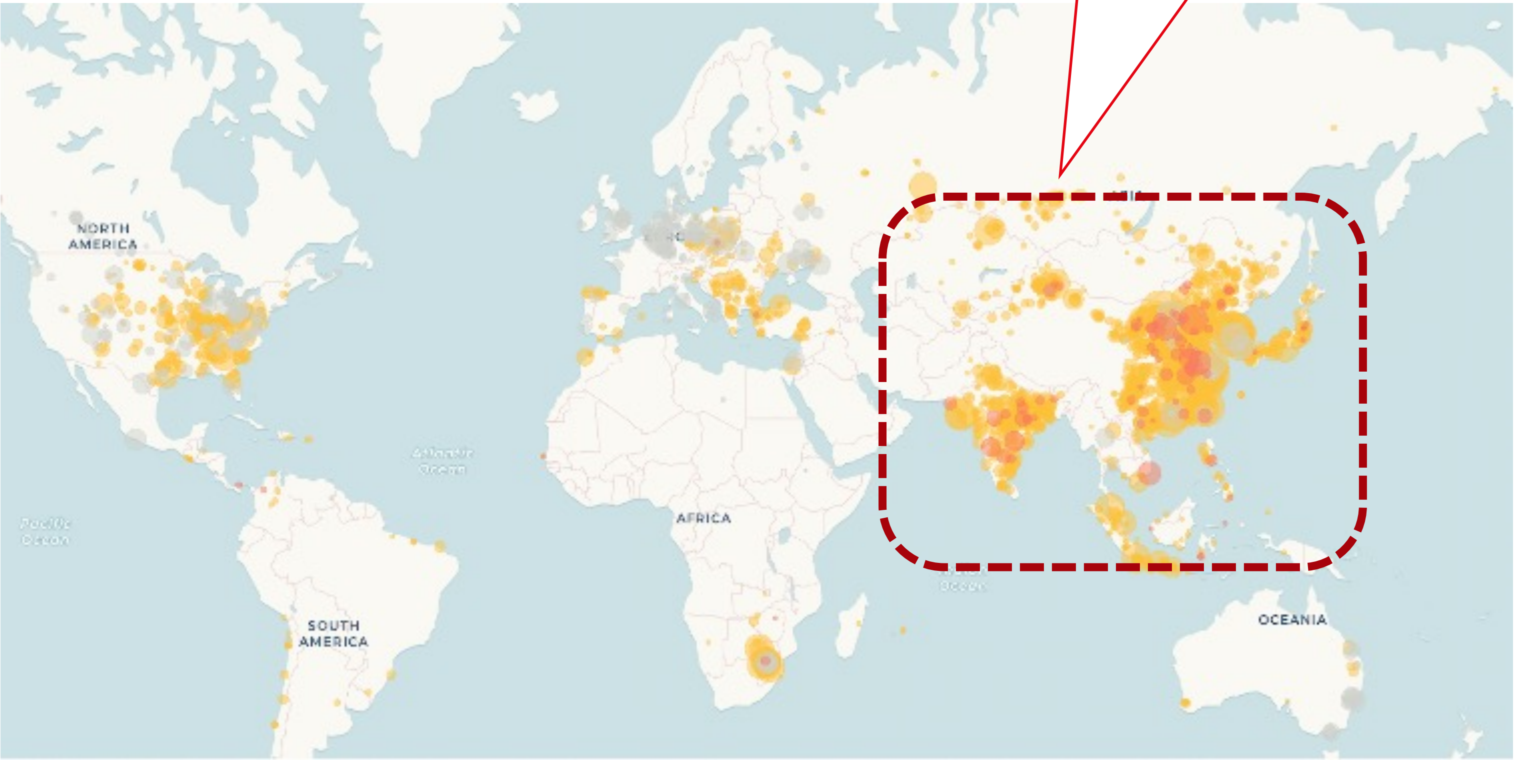


Demands

Coal demand

2018 – 2025 GW

Strong expansion in China/India



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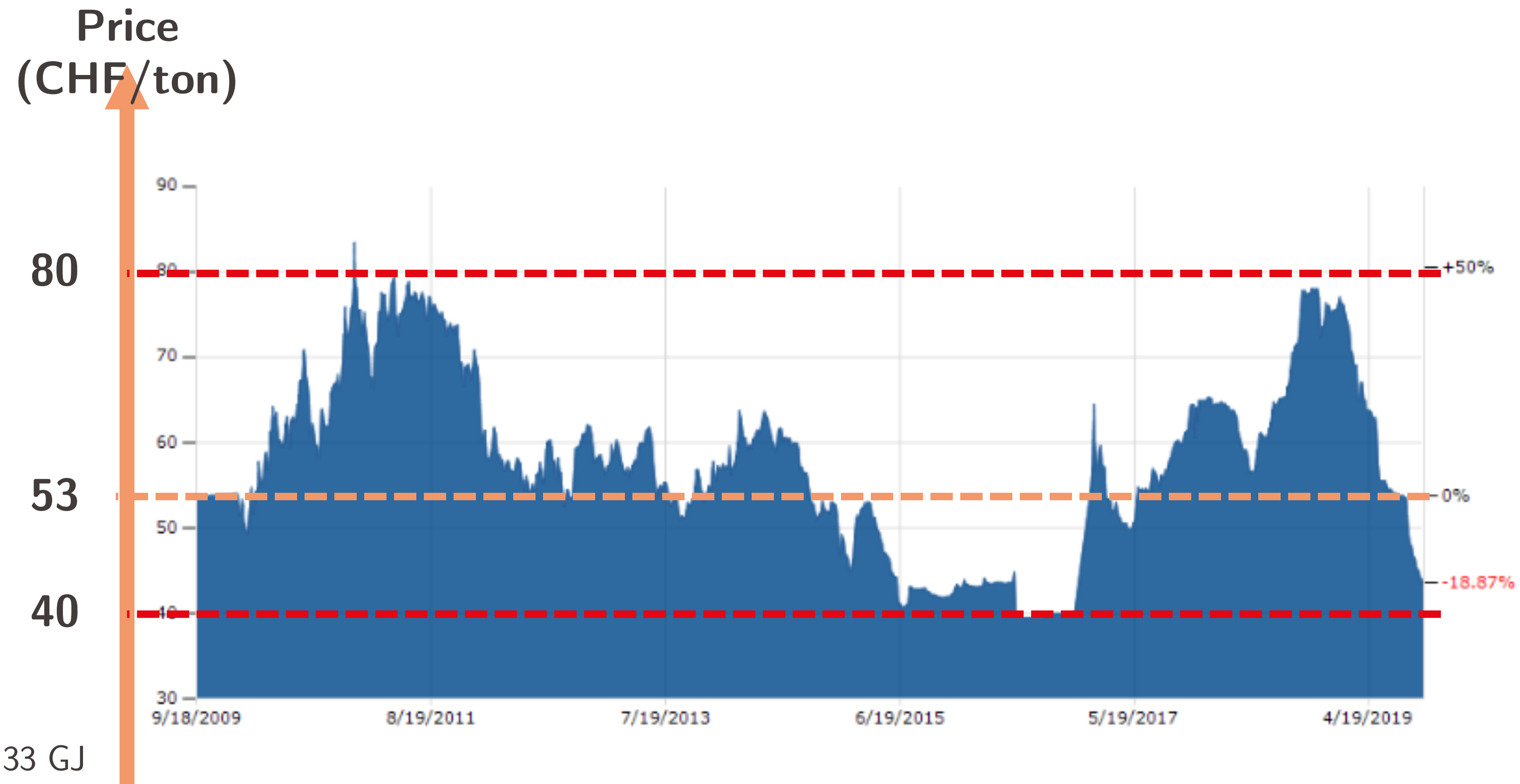
Coal

Historical prices : low variations



1 ton= 33 GJ

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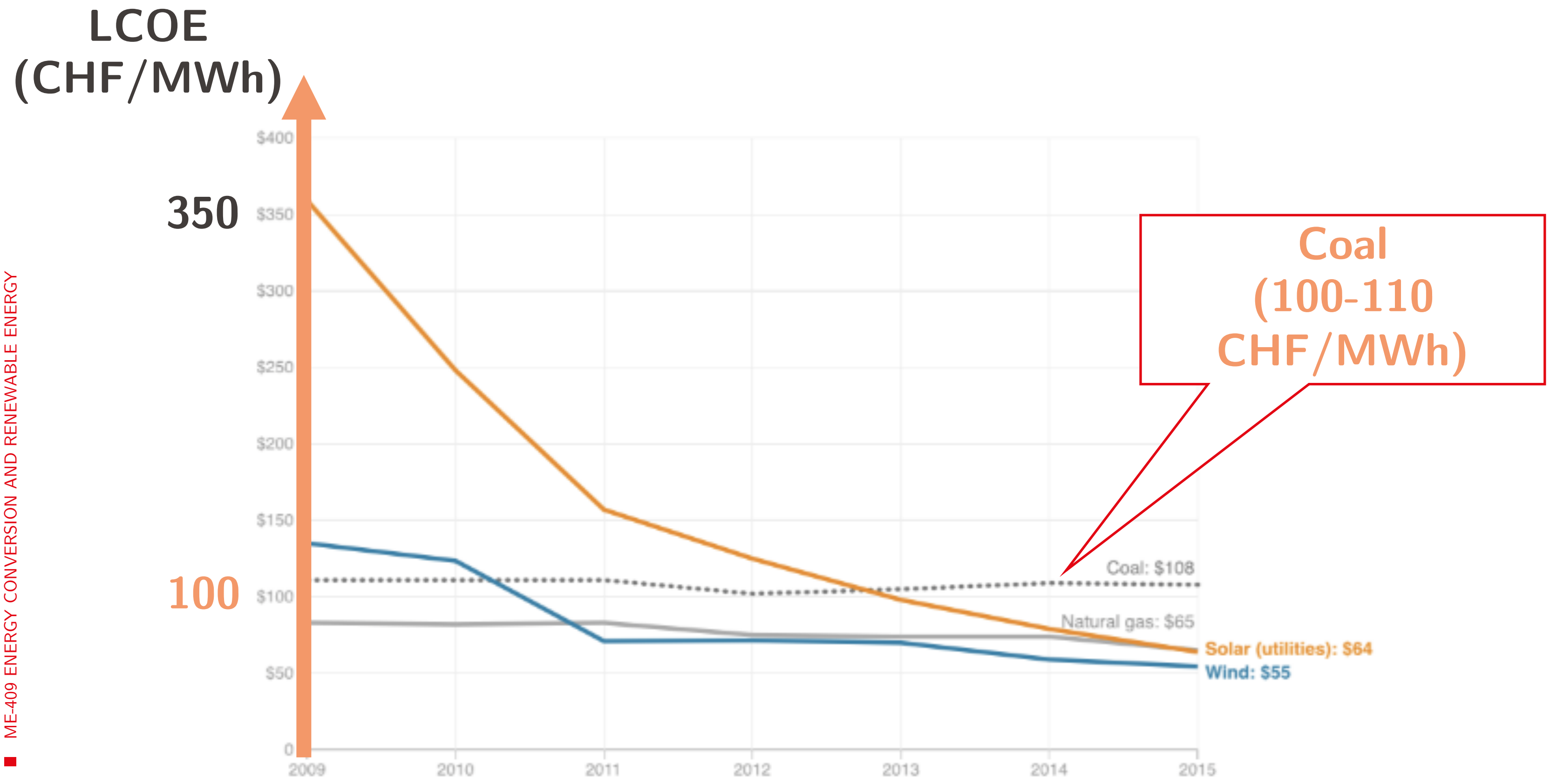
Coal demand

Levelized cost of electricity (USA)



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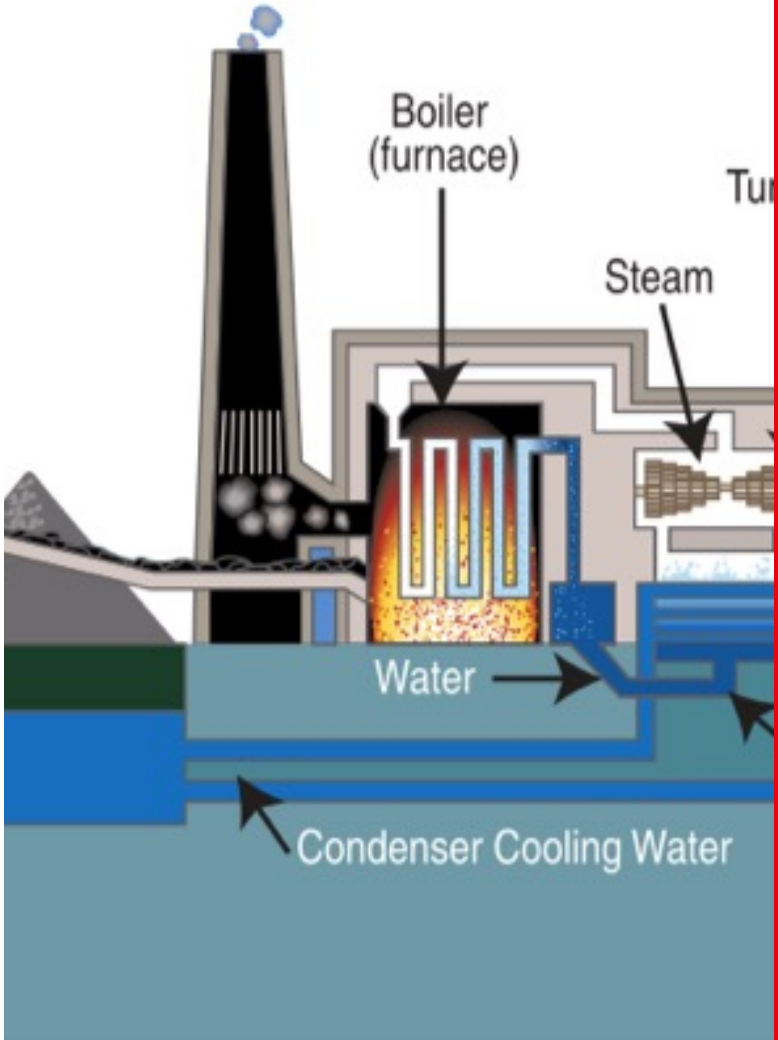

Coal conversion

Standard thermal power plants

Emissions and mitigation

Advanced conversion plants

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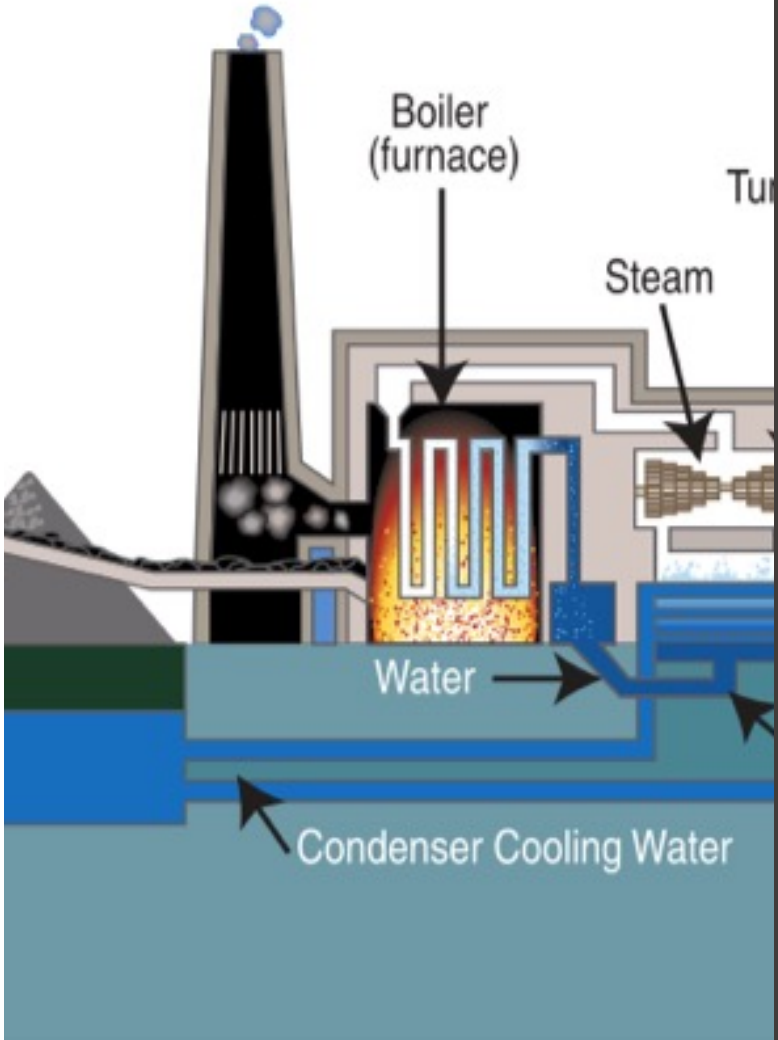

Standard coal power plants

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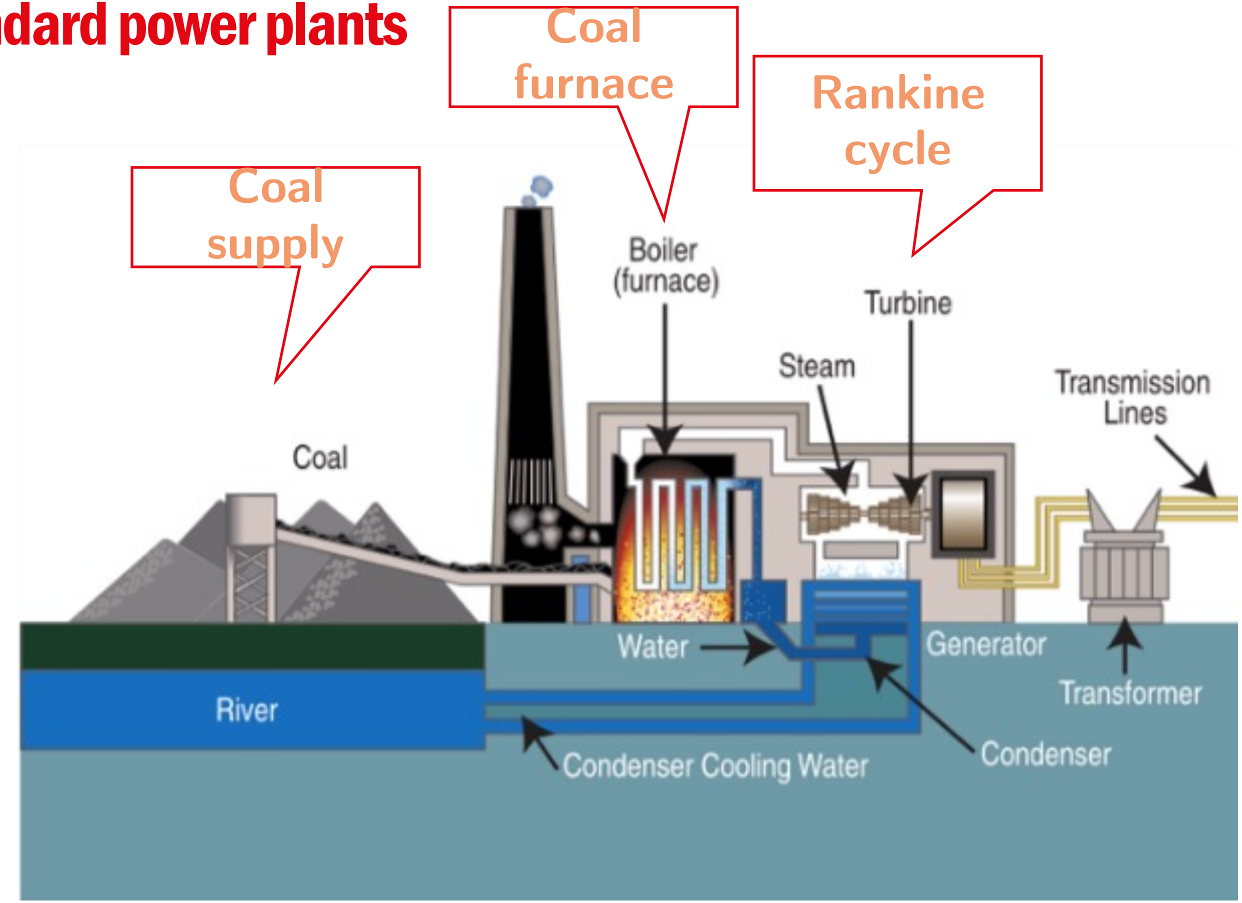
Coal conversion

Standard power plants



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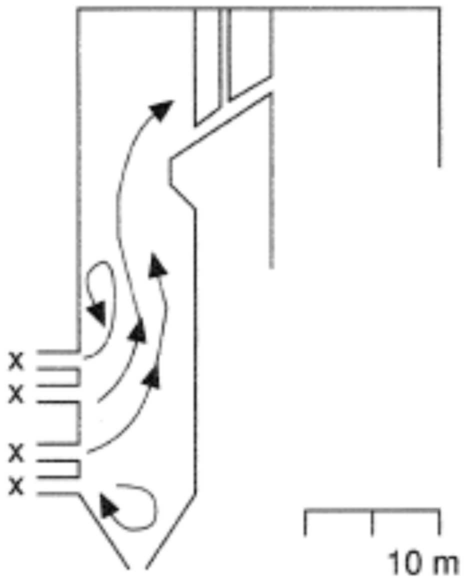
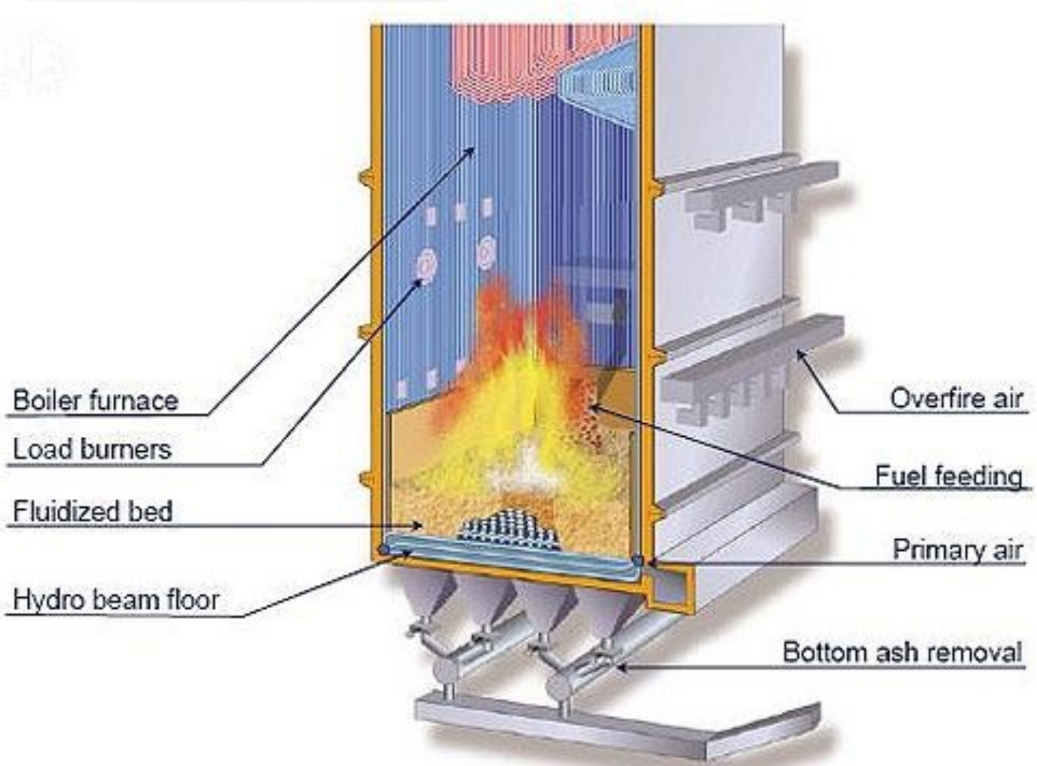
Coal conversion

Standard power plants





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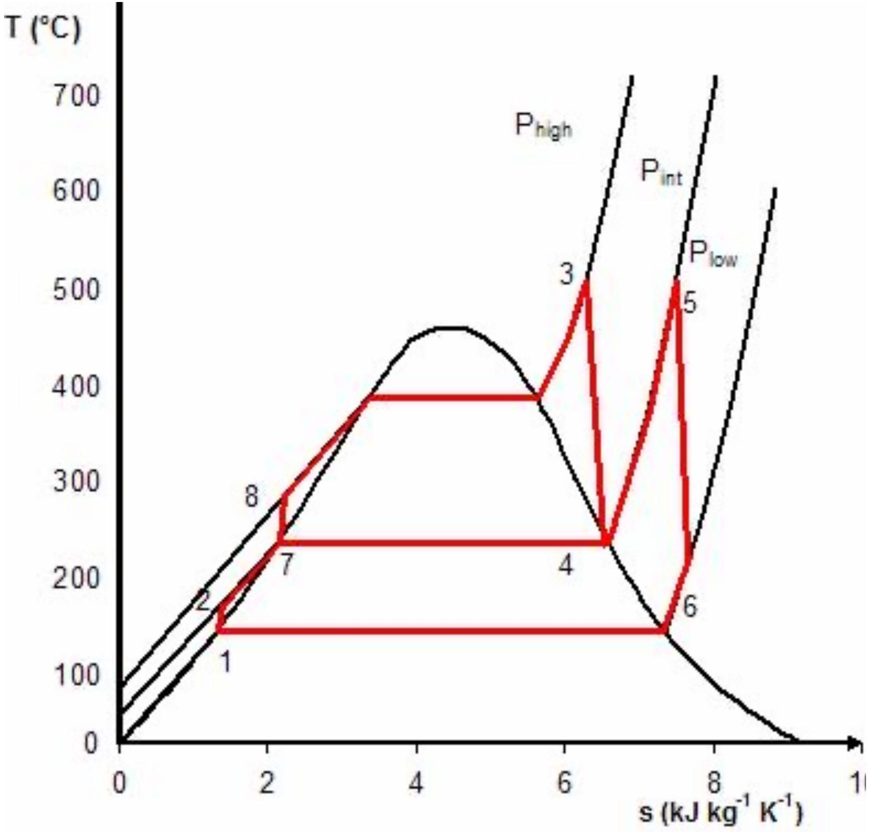
Coal conversion

On a Temperature-Entropy (T-s) diagram

- **Rankine cycle**
  - High pressures and temperatures
  - Superheating
  - Reheating

- **Efficiency (first law):**
  - Best practice: 42%
  - Average: 38%



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Environmental impacts and mitigation

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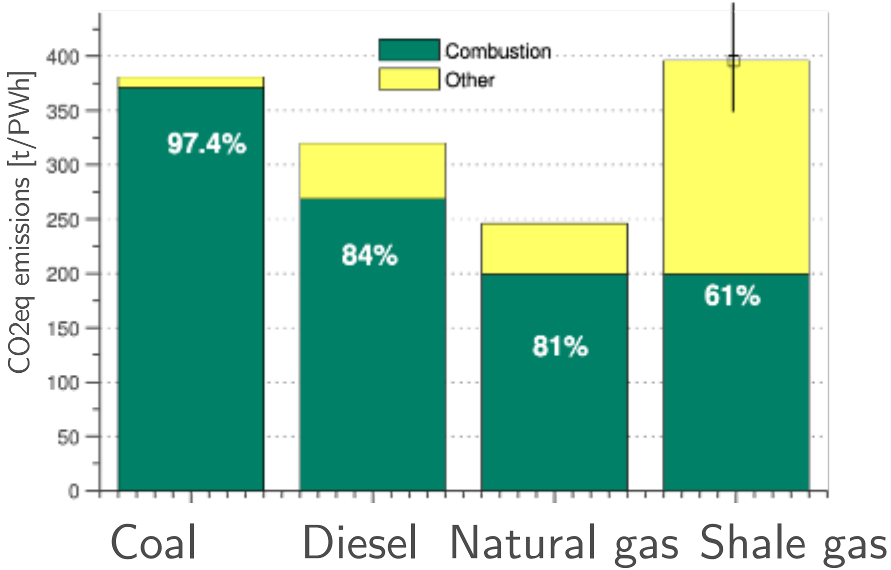
Coal

Environmental impact

- Importance of the life cycle

  - Extraction
  - Conditioning
  - Transport
  - Refining
  - Distribution
  - Combustion

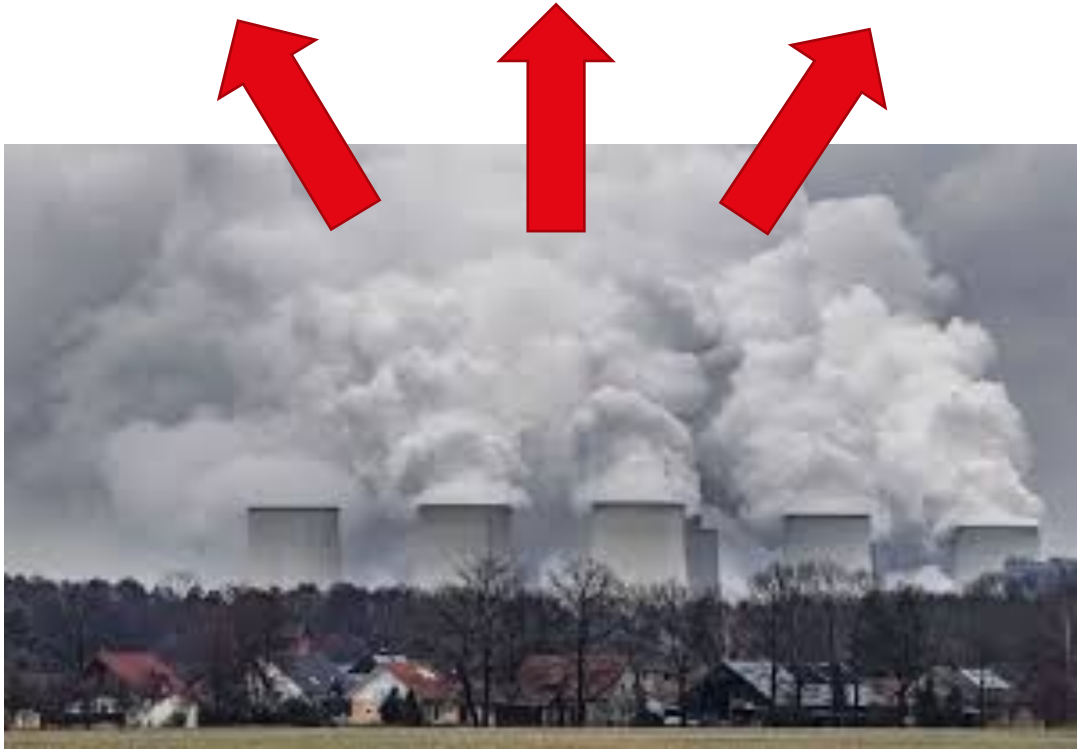


CO2 eq : is a measure of the global warming potential of the emissions over the overall conversion chain up to combustion.
The global warming potential is considering not only the CO2 emissions
but also other emissions like CH4 (that has a GWP of 20 CO2 eq), NOx and other gases in the complete life cycle chain.

Coal conversion

Environmental and health impacts

CO_2 NO_x, SO_x PM, HCs



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Coal conversion

Environmental and health impacts

- Global warming (CO_2)

- Human health (NO_x, PM)

- Mining

- Water pollution (NO_x, ash)

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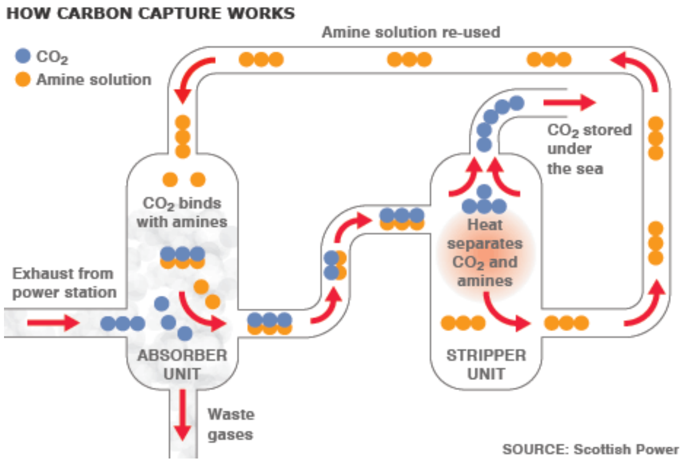
Coal conversion

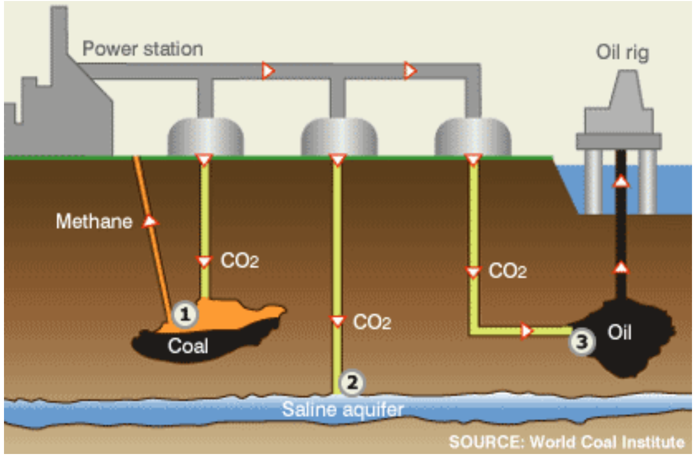
CO_2-mitigation

- Chemical absorption for carbon capture
  - MEAH + CO_2 → MEACOOH

Monoethanolamine

- Storage or chemical production





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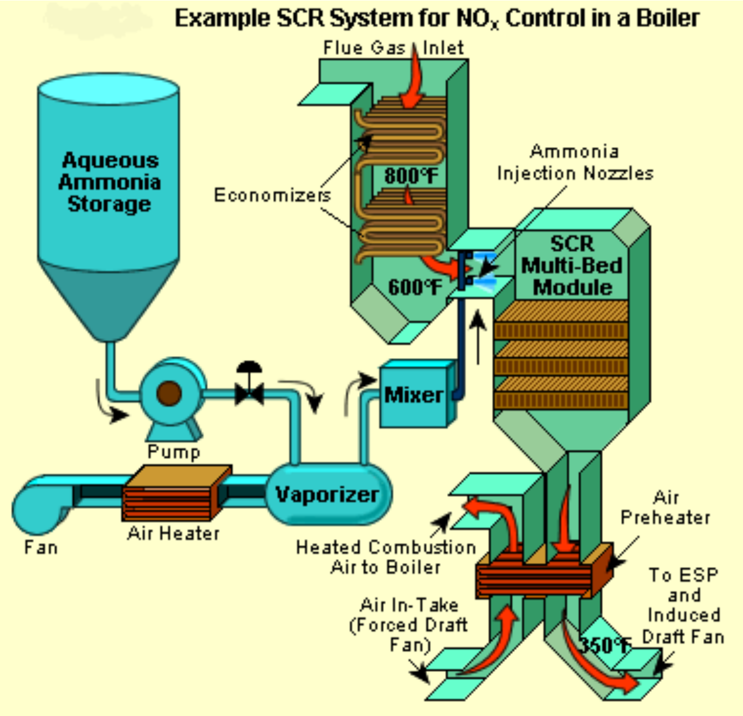
Coal conversion

NO_x-mitigation

- **Selective Catalytic Reduction**

  - $4\ \mathbf{NO} + 4\ \mathbf{NH_3} + O_2 \rightarrow 4\ N_2 + 6\ H_2O$
  - $2\ \mathbf{NO_2} + 4\ \mathbf{NH_3} + O_2 \rightarrow 3\ N_2 + 6\ H_2O$

Ammonia



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Coal conversion

SO_x-mitigation

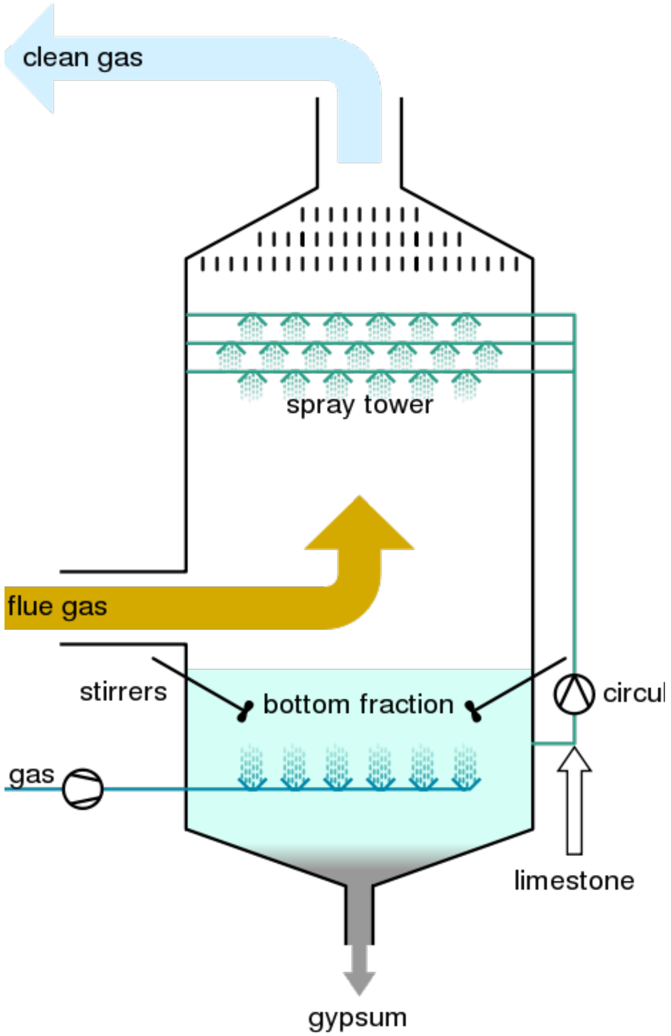
- **Scrubbers**

- 678 units **worldwide** (229 GW)

Limestone

- $CaCO_3 + \mathbf{SO_2} \rightarrow CaSO_3 + CO_2$

(solid)



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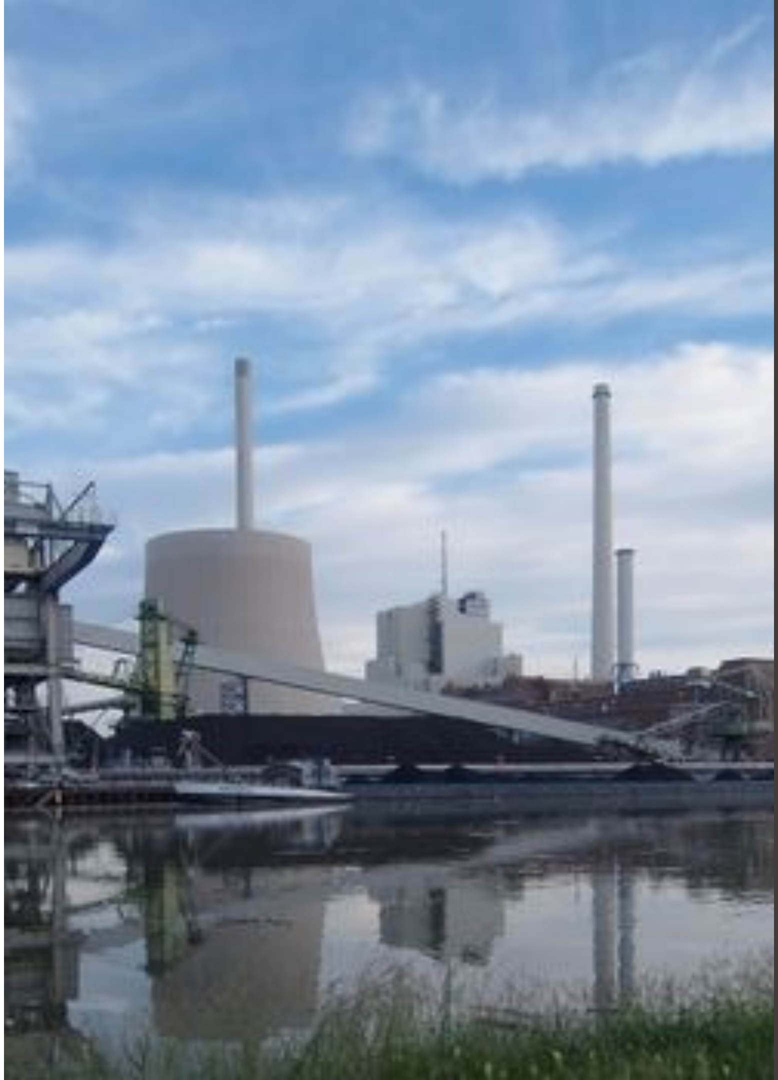

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Advanced plants

Fluidized bed combustion

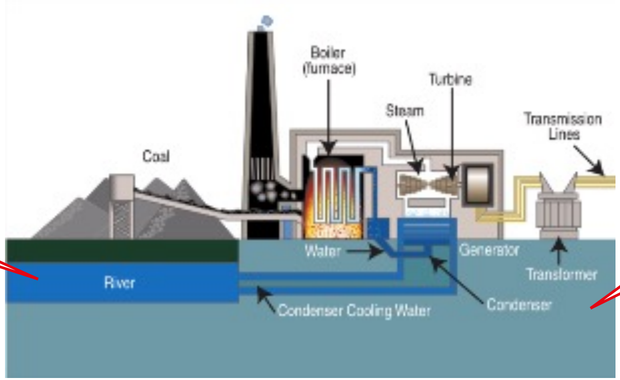
Integrated gasification

Supercritical plants

Advanced plants

Towards higher efficiency and less impact

33-37% efficiency



250-300 $kgCO_2/MJe$

- **Supercritical** power plants

- Fluidized bed combustion
- Integrated gasification

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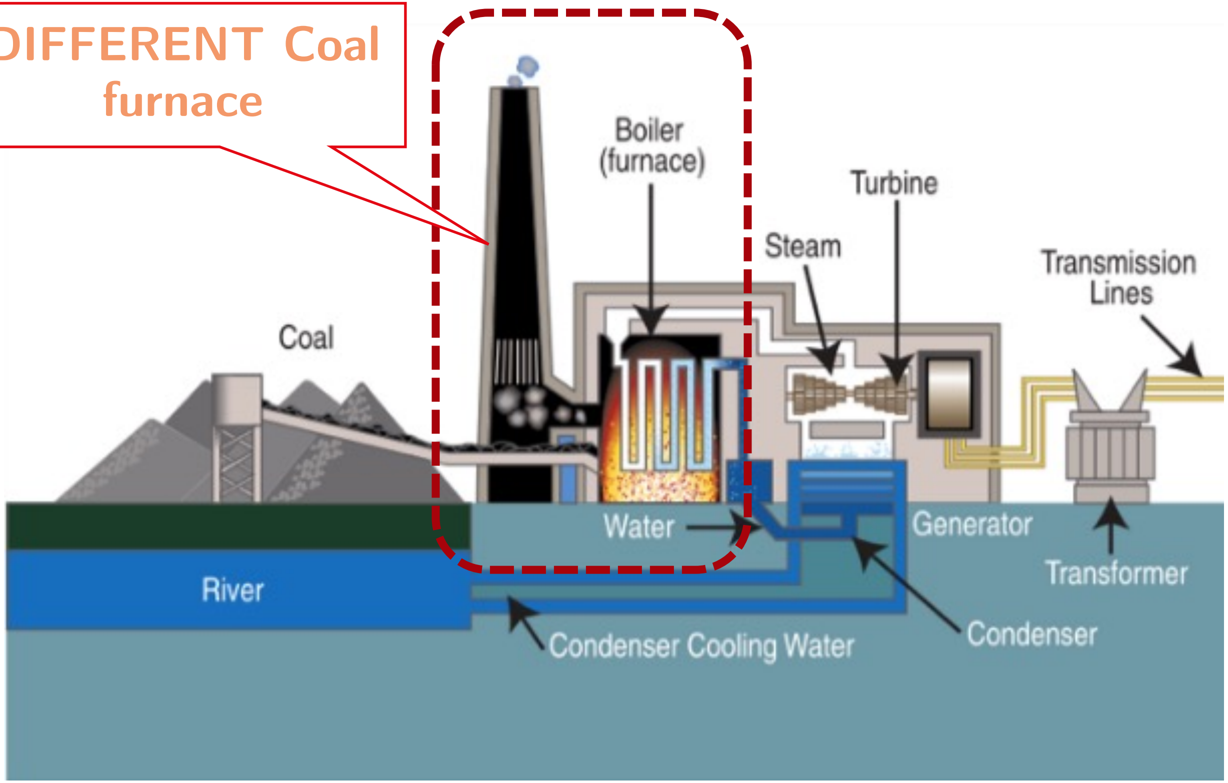
Advanced plants

(1) Fluidised bed combustion

DIFFERENT Coal furnace



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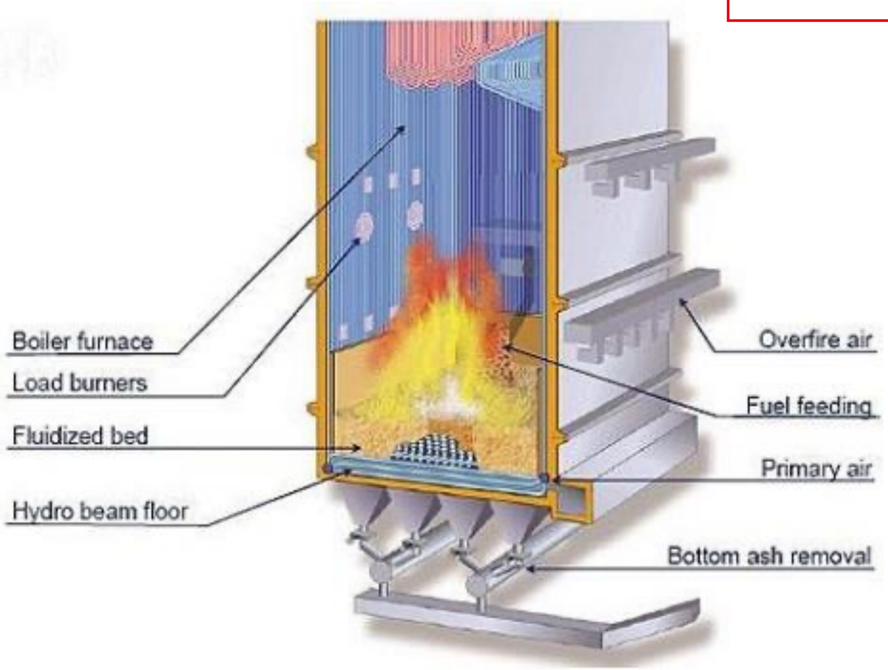
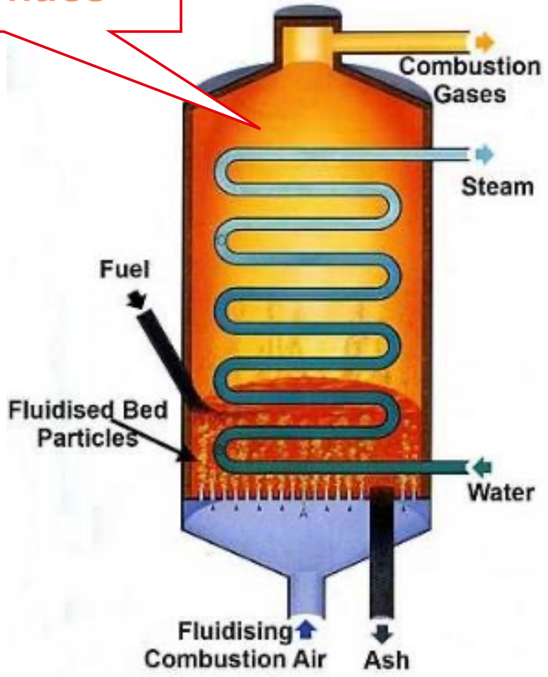
Advanced plants

(1) Fluidised bed combustion

DIFFERENT
Coal furnace





- Standard coal furnace
- Fluidised bed combustion

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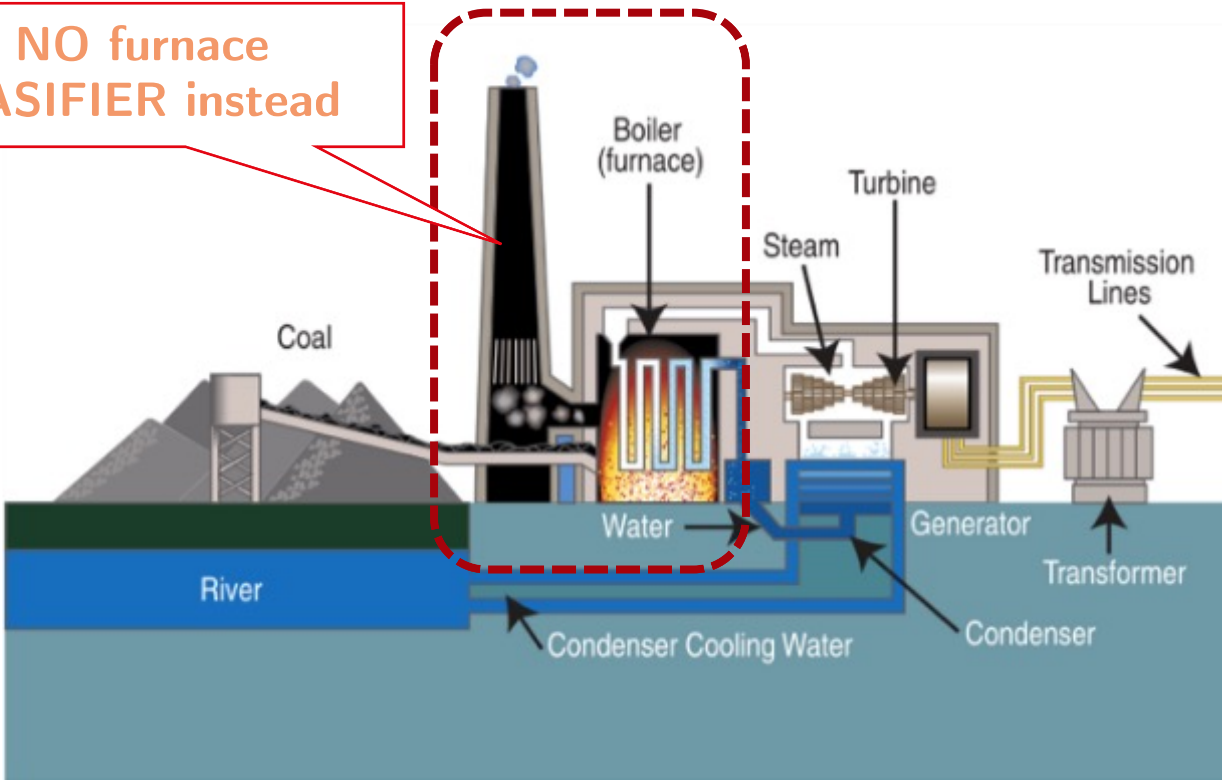
Advanced plants

(2) Integrated gasification

NO furnace
GASIFIER instead



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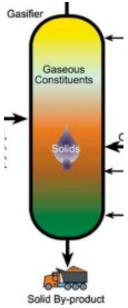
Advanced plants

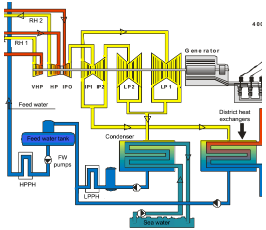
(2) Integrated gasification

SOLID FUELS (COAL)



Gas production & cleaning (Gasification)

HEAT



ELECTRICITY

Heat production (Combustion)

Heat – to – Power (Rankine cycle)

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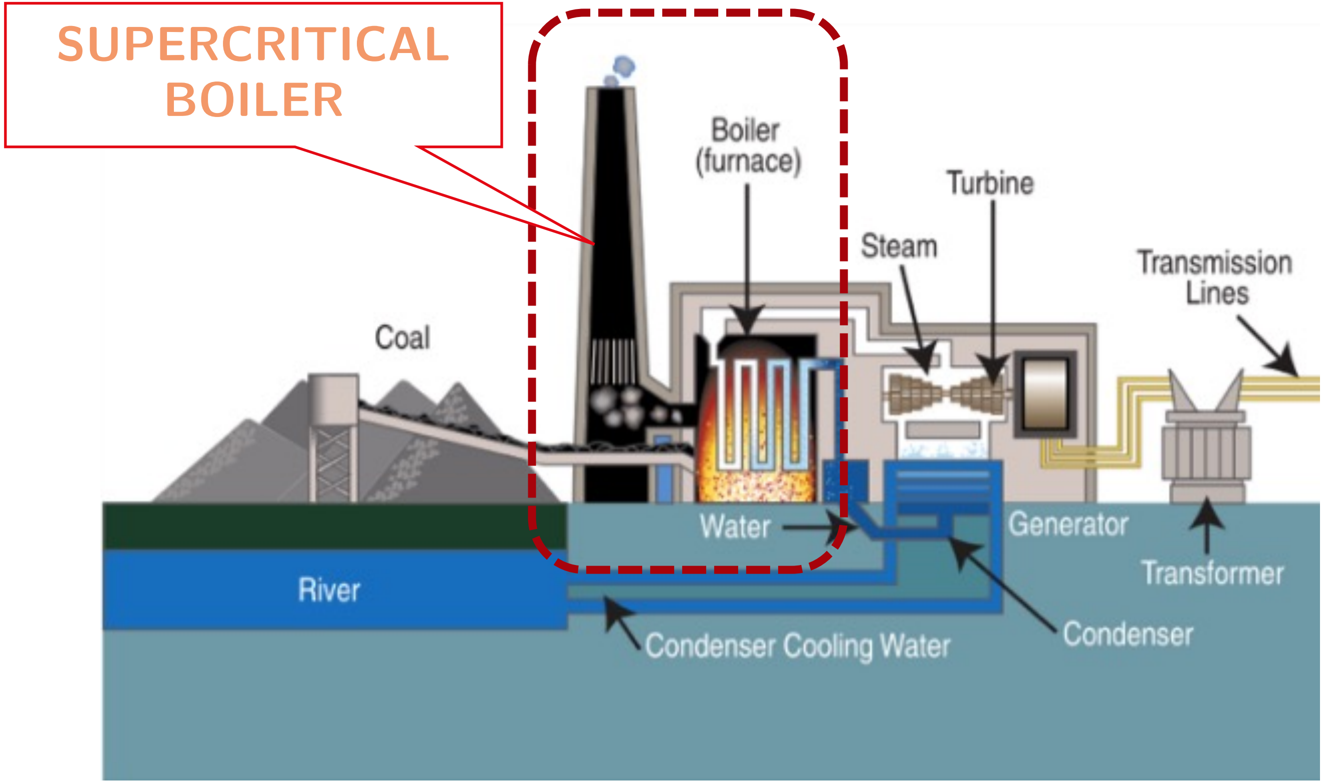
Advanced plants

(3) Supercritical



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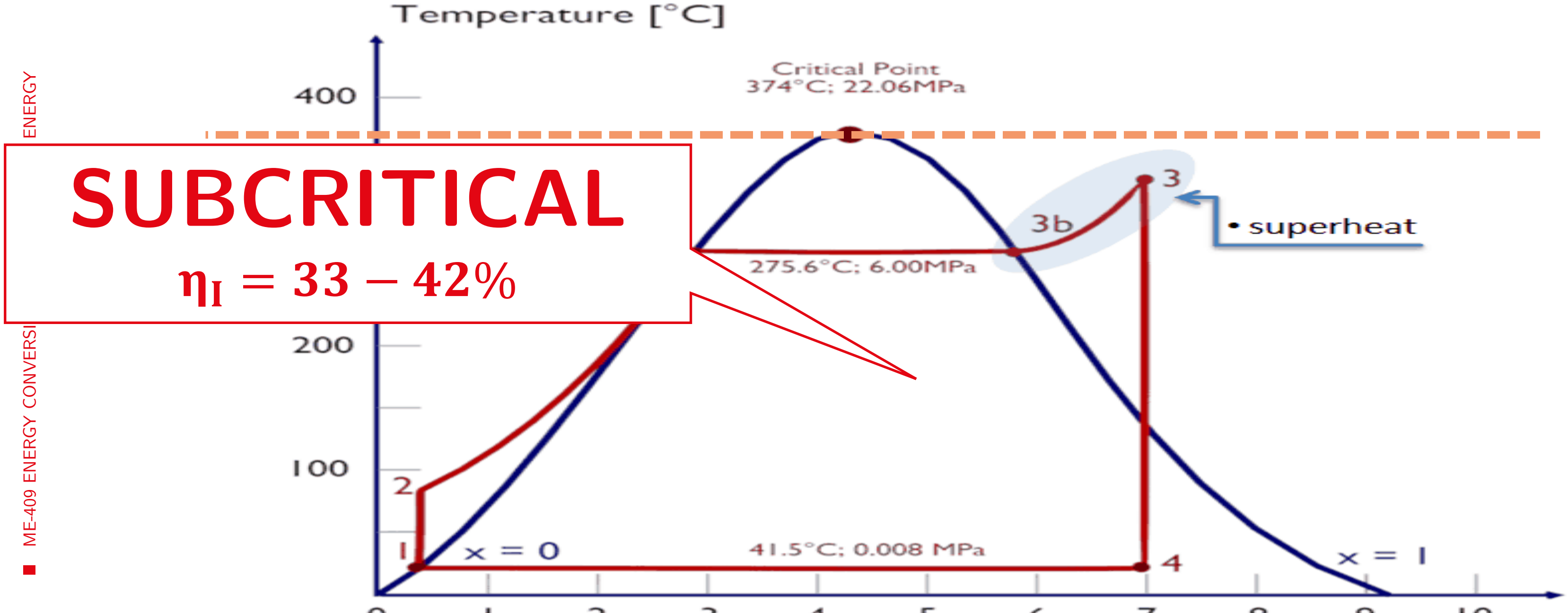
Advanced plants

(3) Supercritical



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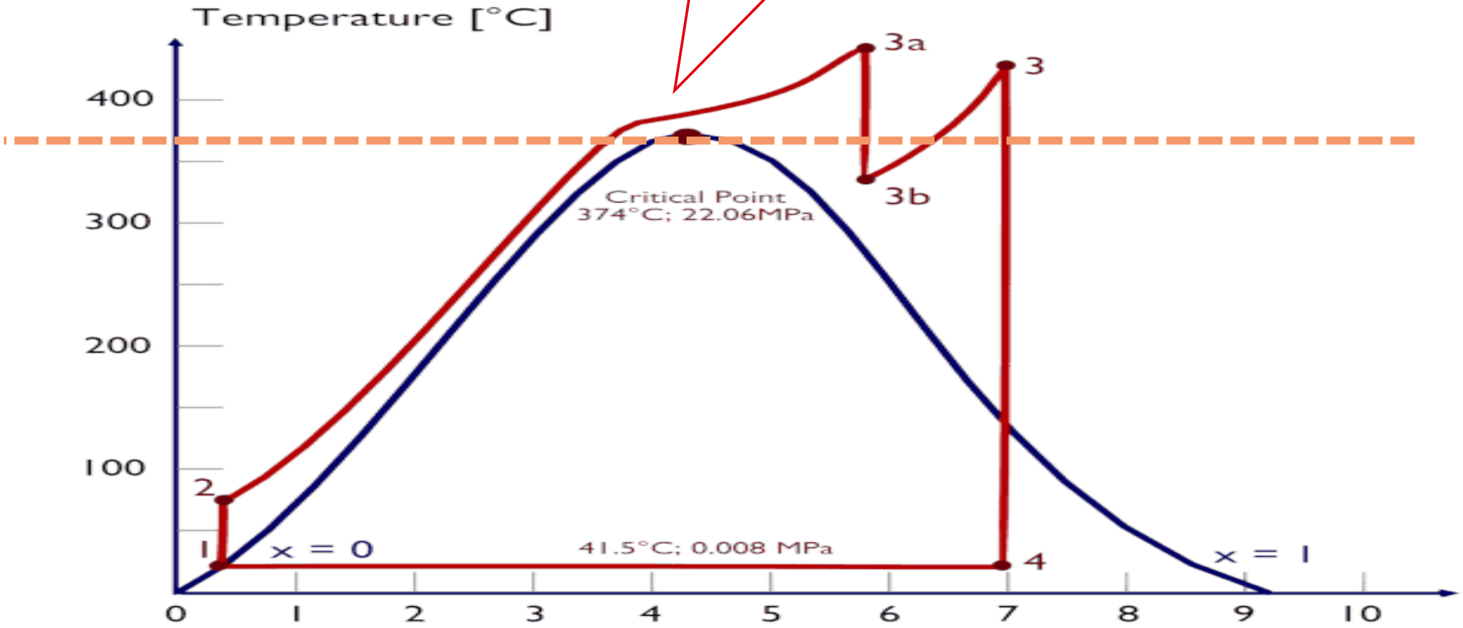
Advanced plants

(3) Supercritical

SUPERCRITICAL

$\eta_I = 47\%$



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$$\eta_e = 42 - 47\%$$

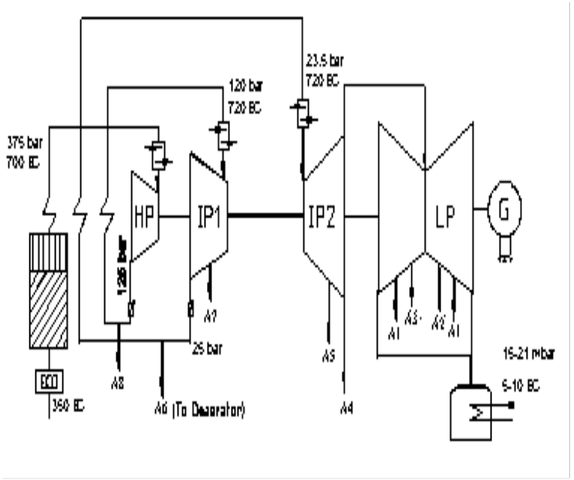
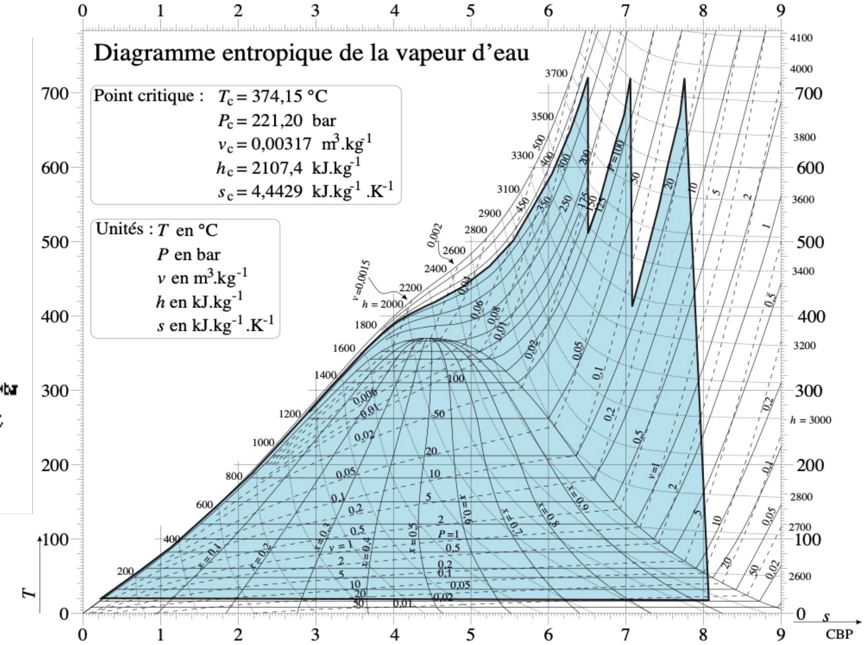
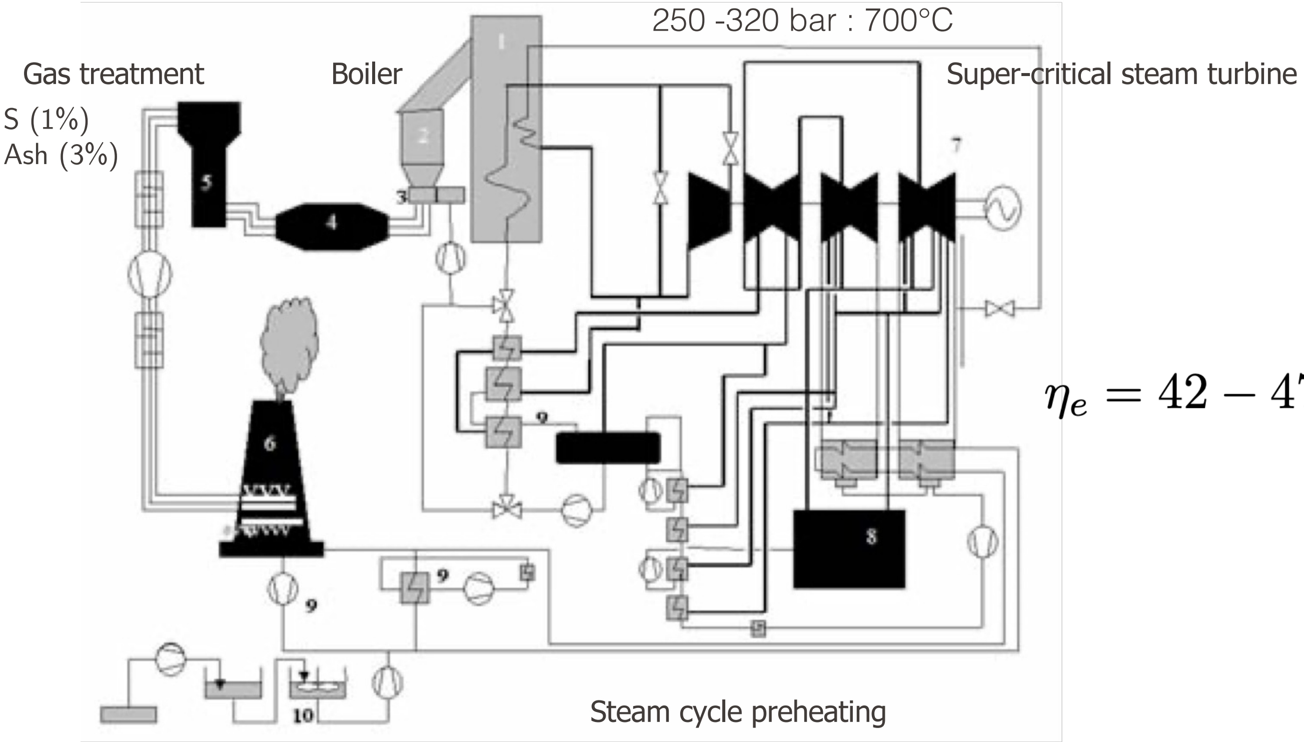


Fig. 3.30. Advanced water/steam cycle in the year of 2010 [44].



Pulverised Coal with flue gases treatment



$$\eta_e = 42 - 47\%$$

Ultrasupercritical power plants

- Supercritical Rankine cycle: pressure above the critical pressure (220 bar)
  - Higher pressure → higher efficiency
  - Higher temperature → Higher efficiency
  - Smooth evaporation curve → Lower exergy destruction in the heat exchange → Higher efficiency

- Power plant efficiency comparison:

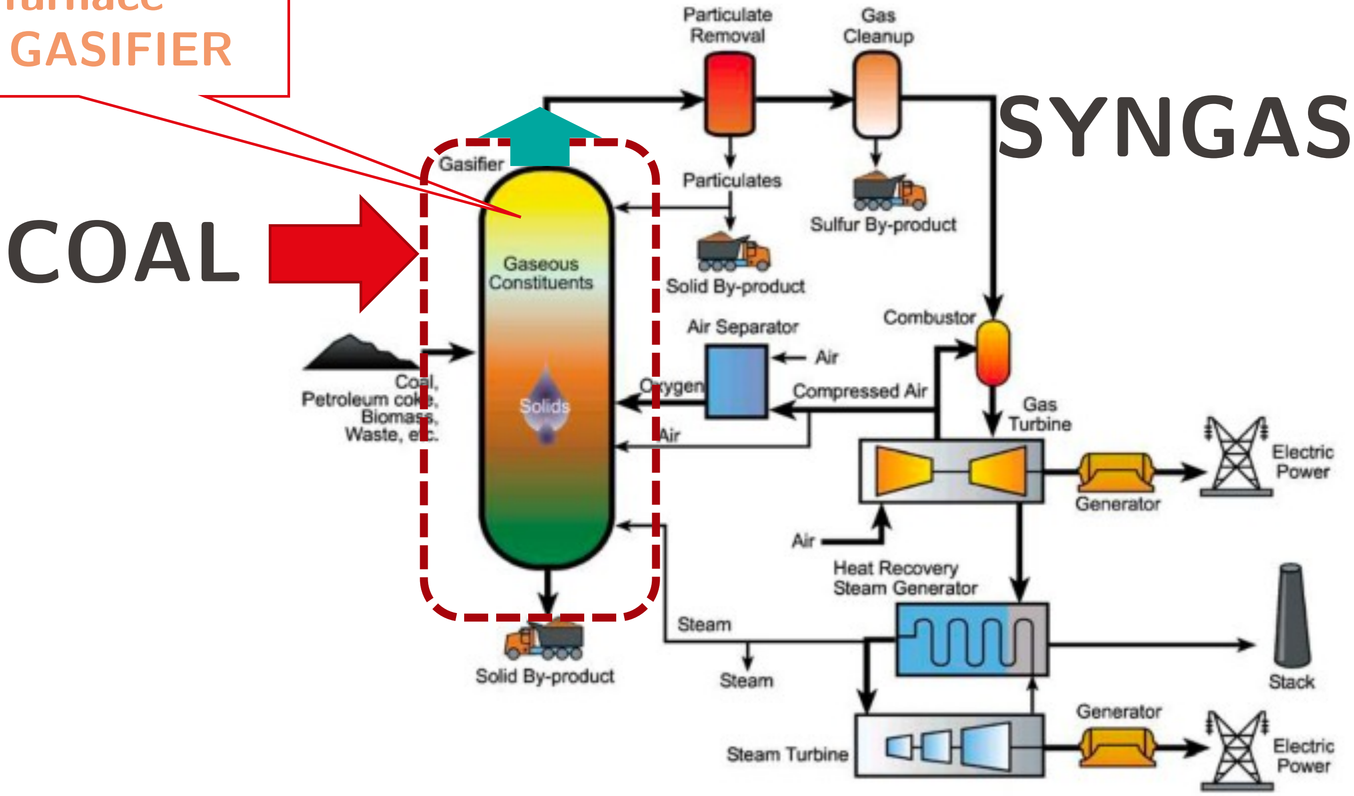
Type	Max pressure [bar]	Max steam temperature [°C]	Efficiency
Subcritical	160	540	42%
Supercritical	240	565	44%
Ultrasupercritical	320	610	50%

Advanced plants : Integrated Gasification

The heating value is chemically transferred to CO and H2

$$C + (1-k/2-z/2)O_2 + xH_2O \Rightarrow kCO + z\,H_2 + (1-k)CO_2 + (x-z)H_2O$$

NO furnace
BUT a GASIFIER



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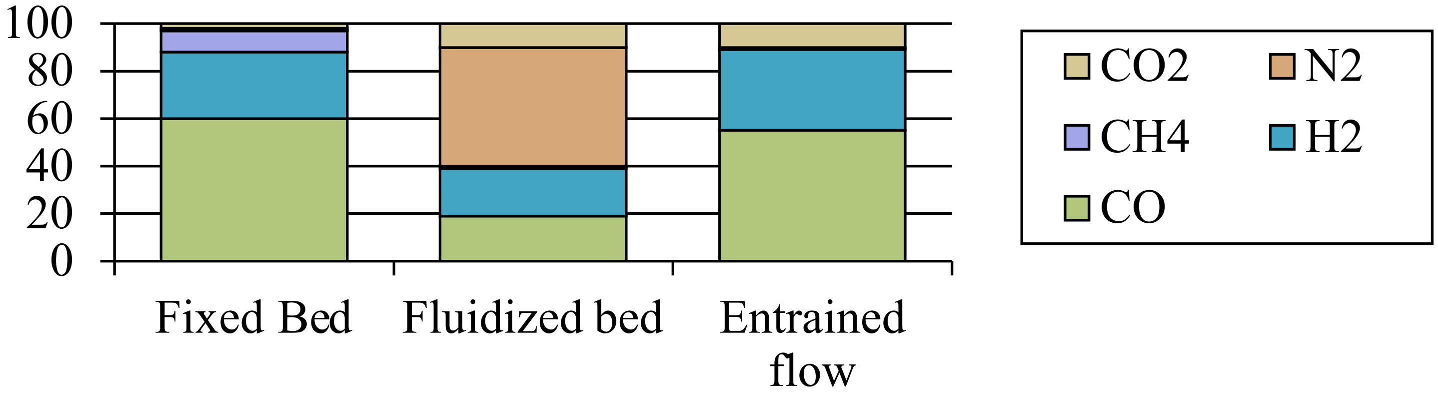
Advanced plants : Integrated Gasification

The heating value is chemically transferred to CO and H2

Table 3.8 Operating conditions of main gasification process

Gasifier type	Fixed bed	Fluidized bed	Entrained flow
Process	BGL	KRW,Winker	Texaco, Shell
Operating temperature,	800-1200	1000	1300-1800
Operating pressure, MPa	0.1- 10	0.1- 3	0.1- 4
Gasifying medium	Steam+O_2	Steam+air or steam+O_2	O_2
O_2/steam ratio	1:8 to 1:4	1:2	2:1
Coal rank	Bituminous coal Anthracite Petrol coke	Lignite	Bituminous coal Lignite
Coal particle size, mm	3-30	1-10	<0.1
Gas flow scheme	Counterflow	Parallel flow	Parallel flow
Residence time	30-60 min	1-10 min	<0.1s



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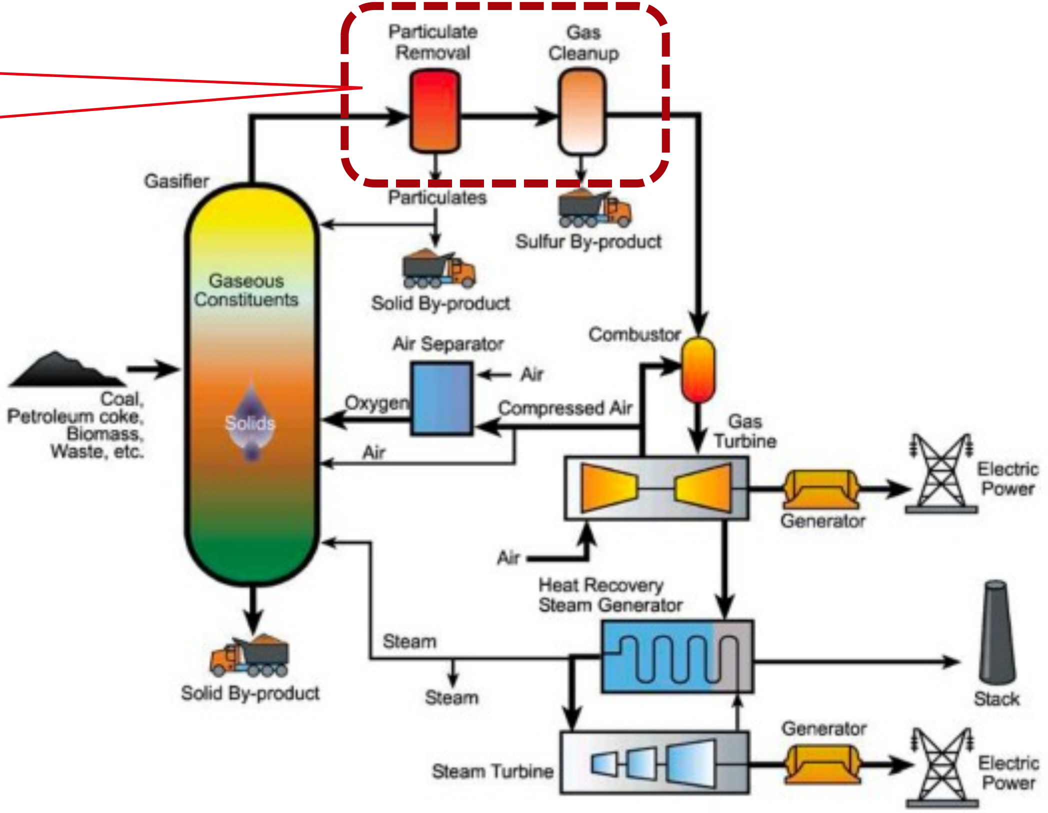
Advanced plants : Integrated Gasification

(2) Integrated gasification

Gas treatment
(S and N removal)



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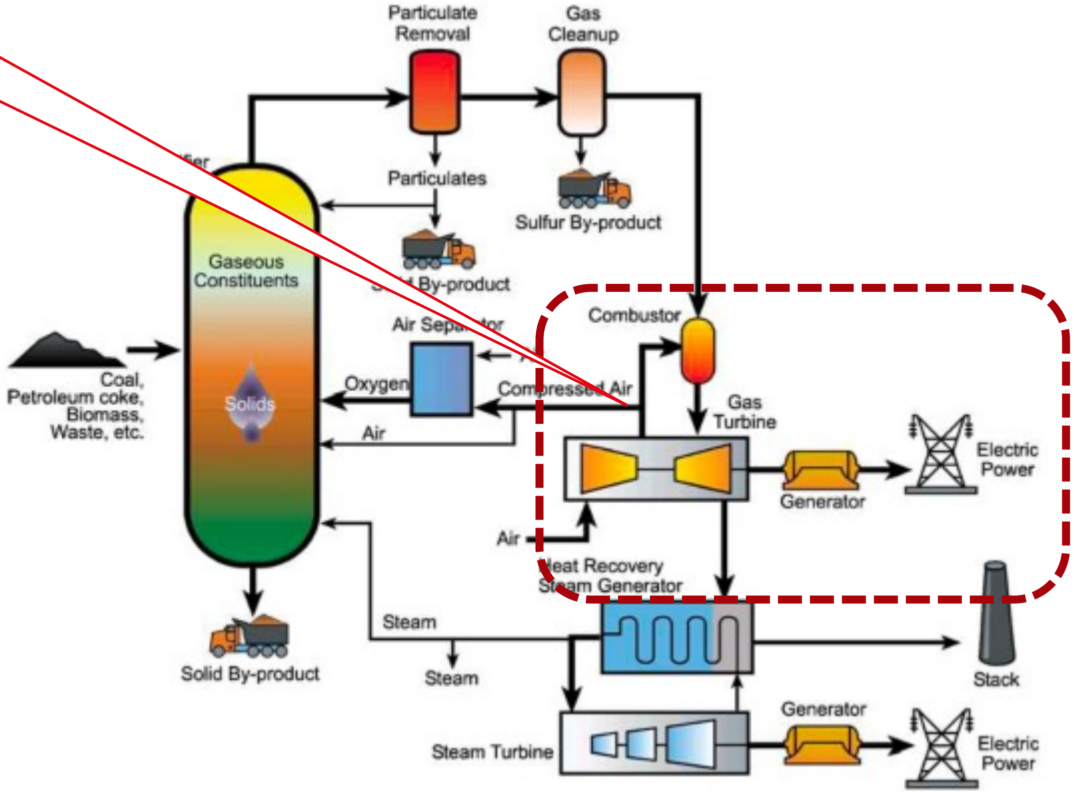
Advanced plants : Integrated Gasification

(2) Integrated gasification

Gas turbines



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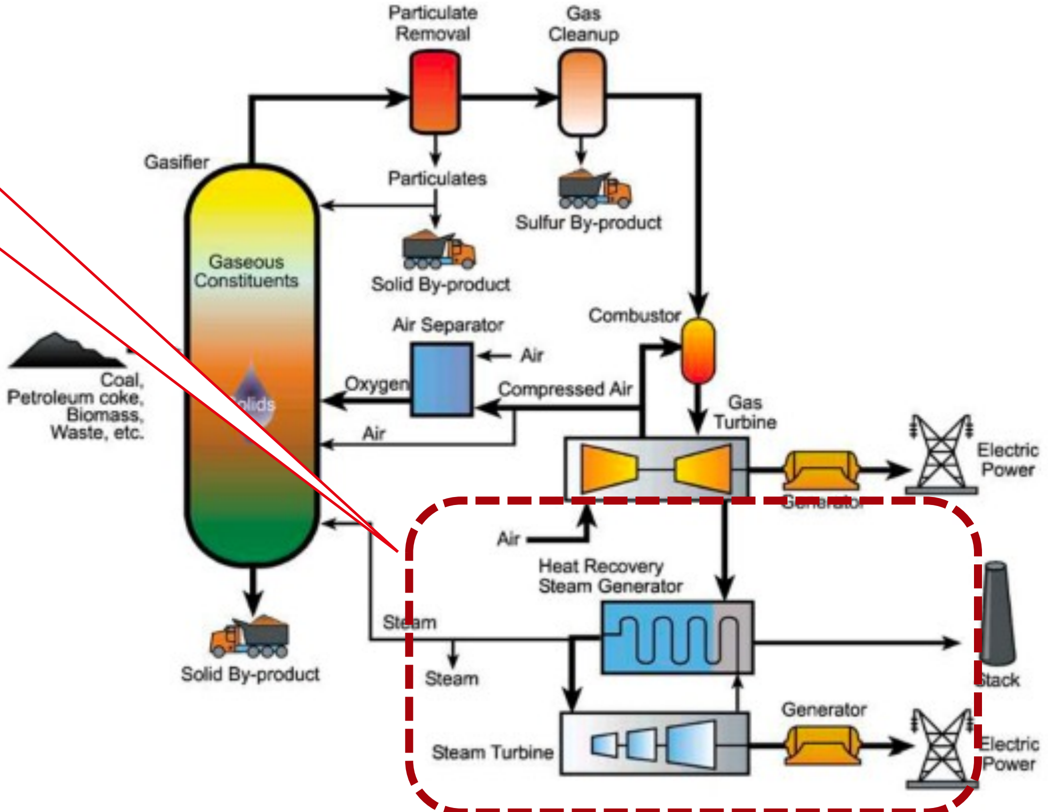
Advanced plants : Integrated Gasification

(2) Integrated gasification

Rankine cycle



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Pre-combustion capture of CO2

Gasification process : $C + (1-k/2-z/2)O_2 + xH_2O \Rightarrow kCO + z\,H_2 + (1-k)CO_2 + (x-z)H_2O$

Shift : transfer heating value from CO to H2

$CO + H_2O \Rightarrow CO_2 + H_2$

Separation CO2/H2 easy or well known

(used in the fertiliser industry)

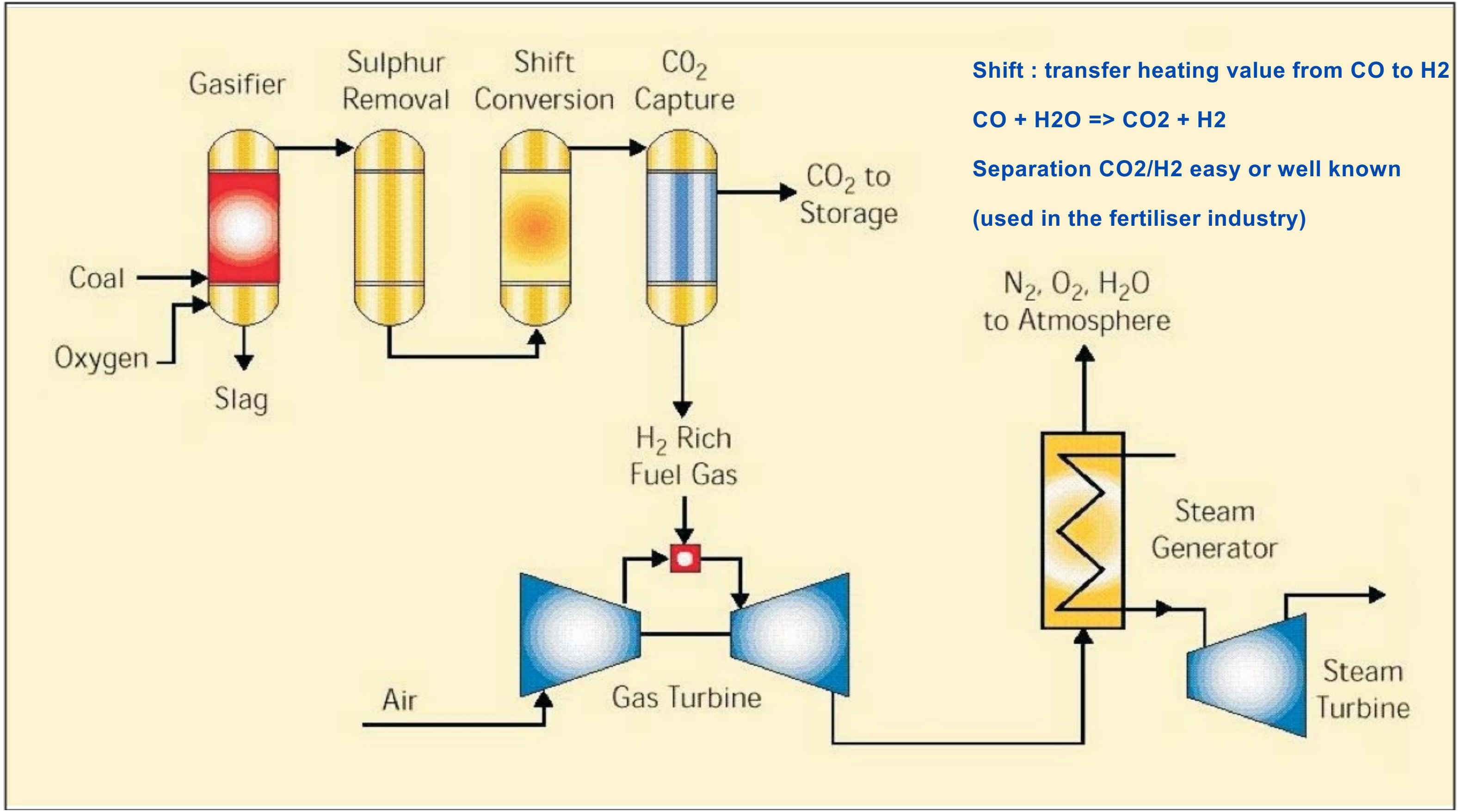
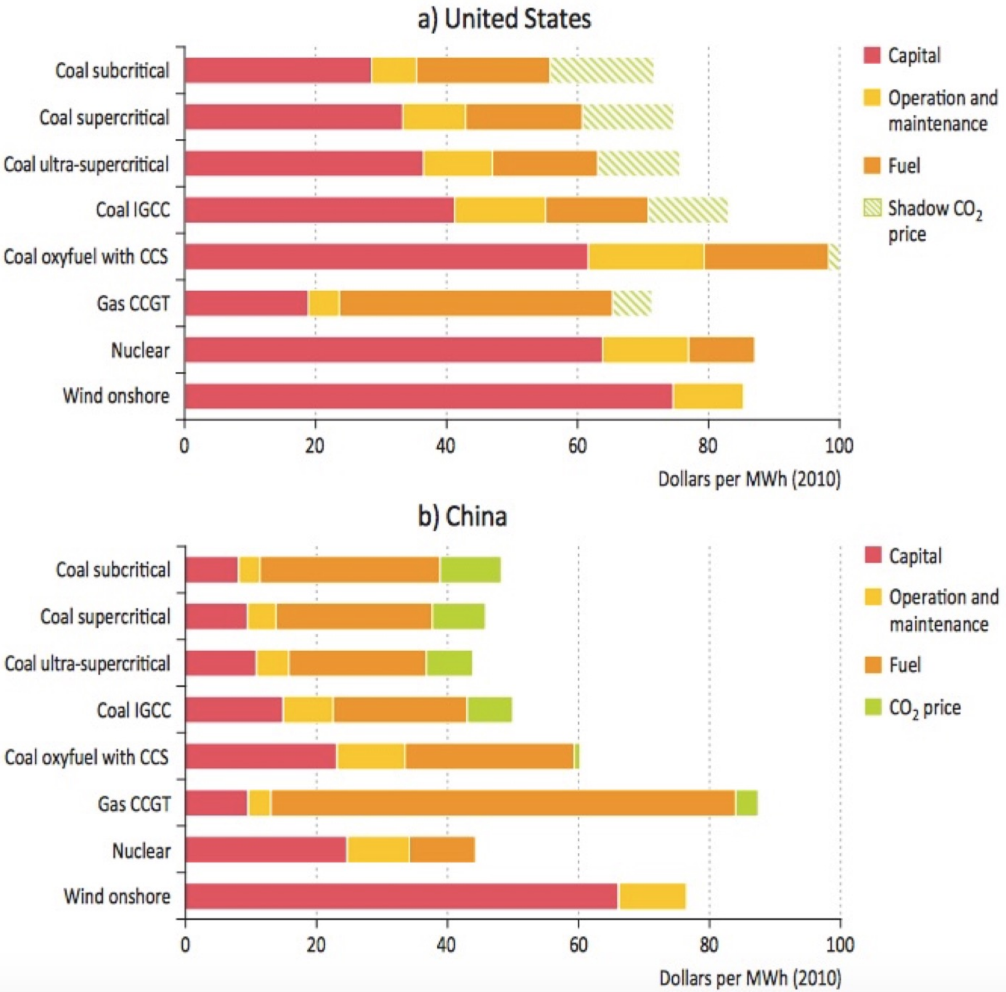


Figure 10.10 • **Levelised electricity generating costs by component for selected technologies and countries in the New Policies Scenario, 2020**



IEA World Energy outlook, 2011

Take-home message

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Take-home message

- Coal **dirty** resource, to be used **for a while**

- Coal **use**
  - SO_X, NO_X, PM, CO_2
  - **BUT** mitigation technologies

- **New technological developments** in coal power

- **Bottom line:**
  - **coal is a mature/cheap technology**
  - **but CO2 emissions recommends its phase out !**

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Questions?

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