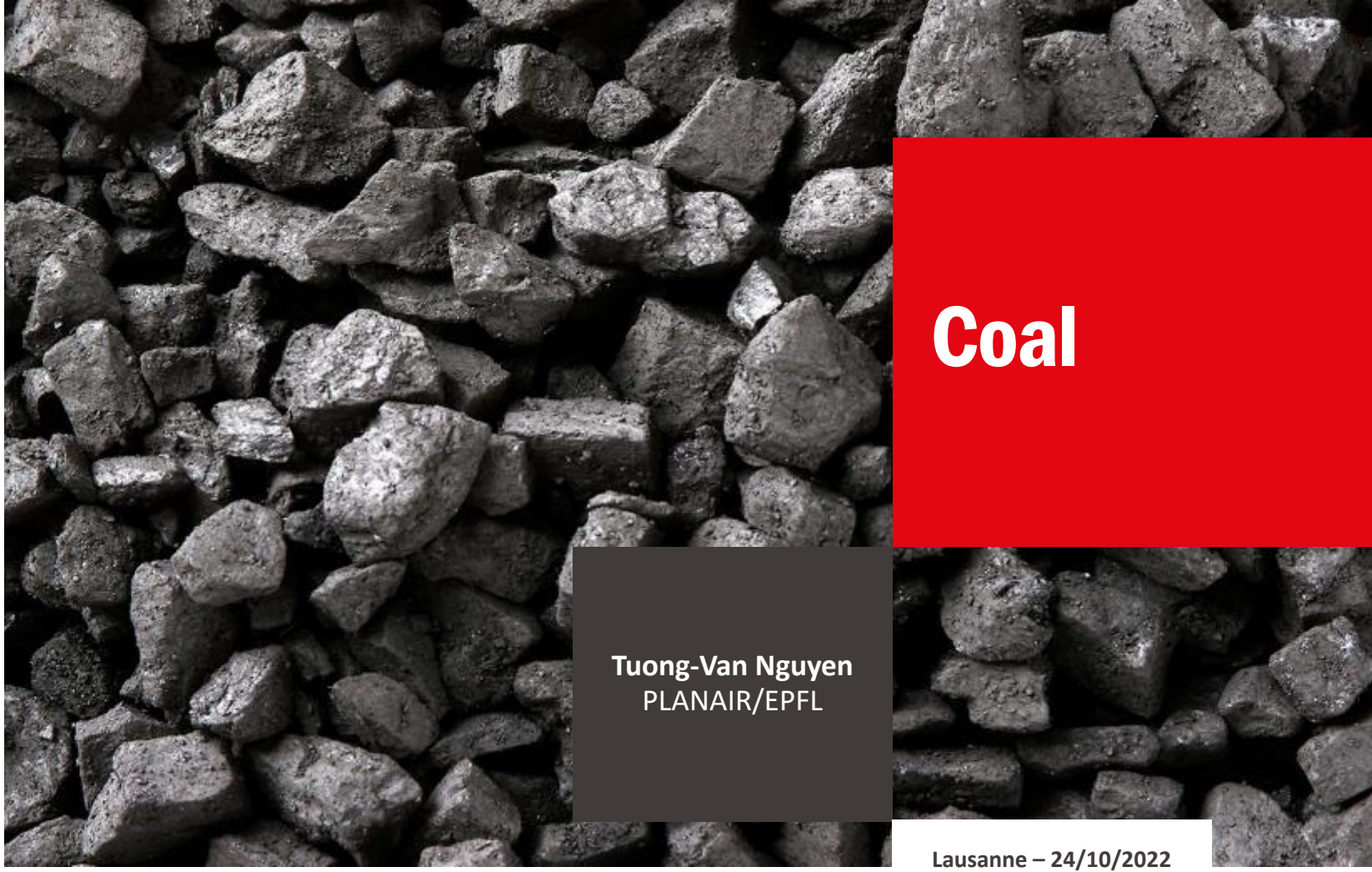


Coal

Tuong-Van Nguyen
PLANAIR/EPFL

Lausanne – 24/10/2022

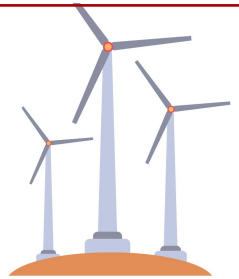
École polytechnique fédérale de Lausanne

Introduction

– How do we produce electricity today?

HEAT → **HEAT ENGINE** → ELECTRICITY

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



MECHANICAL → Dams, windmills (turbines) → ELECTRICITY

Kinetic / Potential energy (Wind, Hydro)

LIGHT → Photovoltaics → ELECTRICITY

Solar radiation (Light)

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

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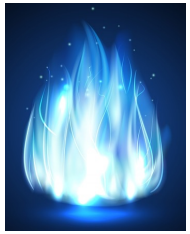
Introduction

– How do we produce electricity today?

SOLID FUELS (COAL / BIOMASS)



GASEOUS FUELS (NATURAL GAS/BIOGAS)

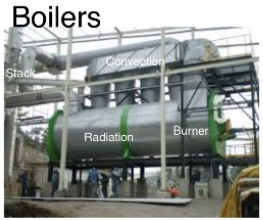
LIQUID FUELS (OIL/BIO-OIL)

HEAT → HEAT ENGINE → ELECTRICITY

Introduction

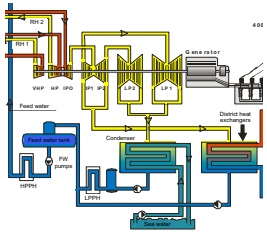
– How do we produce electricity today?

SOLID FUELS (COAL)



Heat production (Combustion)

HEAT



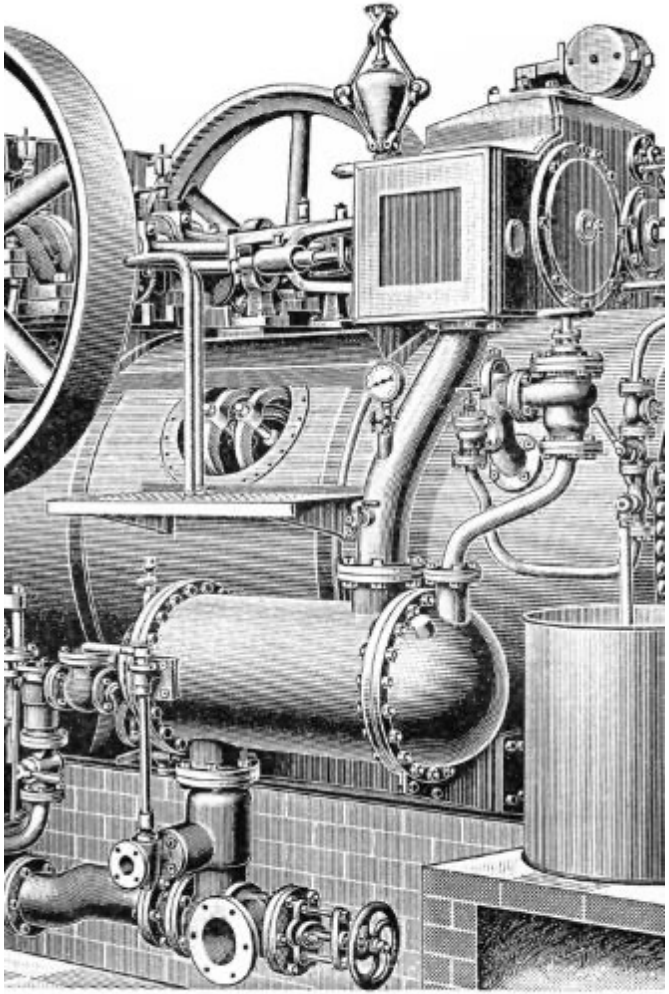
Heat – to – Power (Rankine cycle)

ELECTRICITY

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

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



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Introduction

The story behind Coal

Introduction

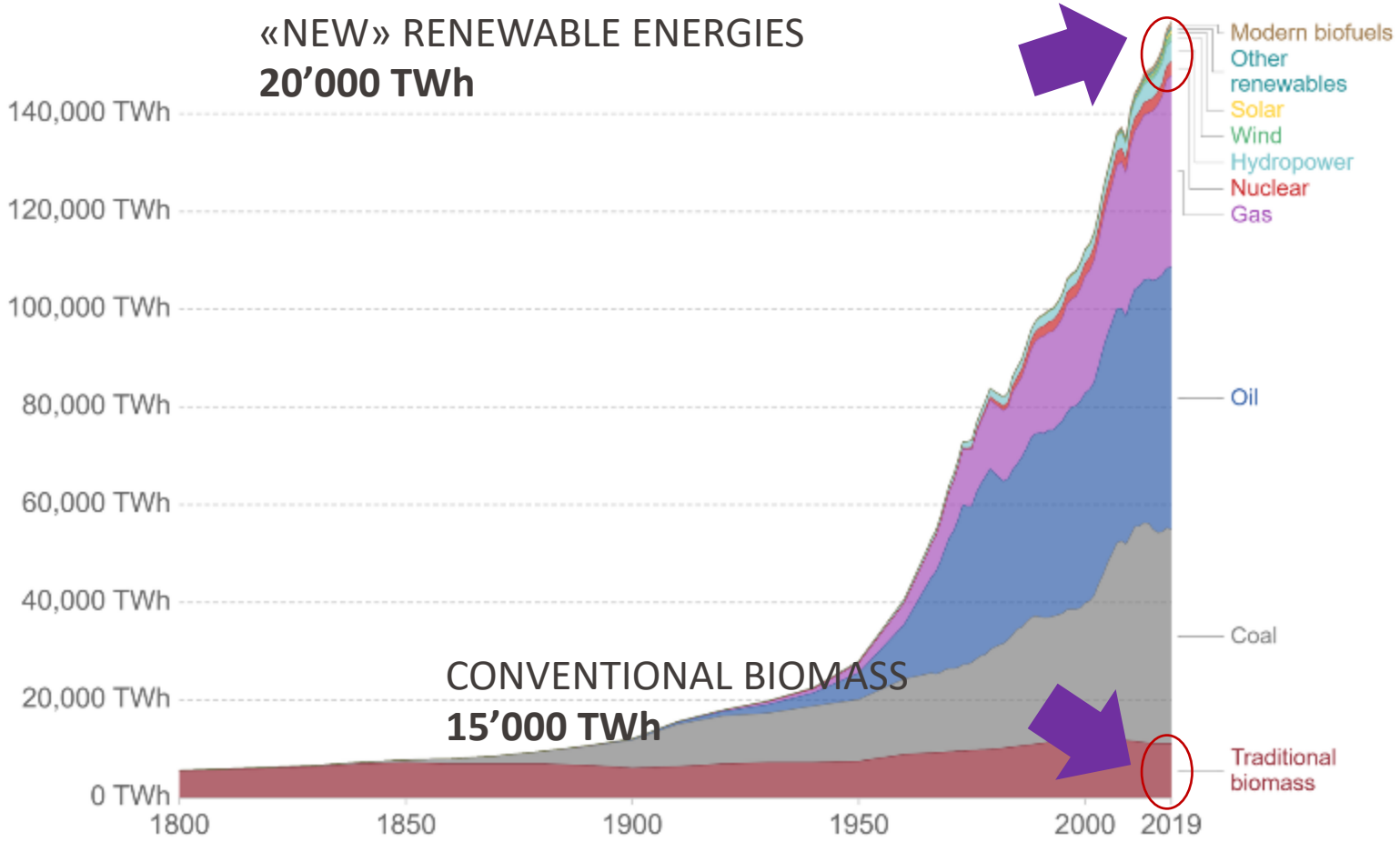
History of Coal

- **Industrial Revolution**

- Coal **mining**

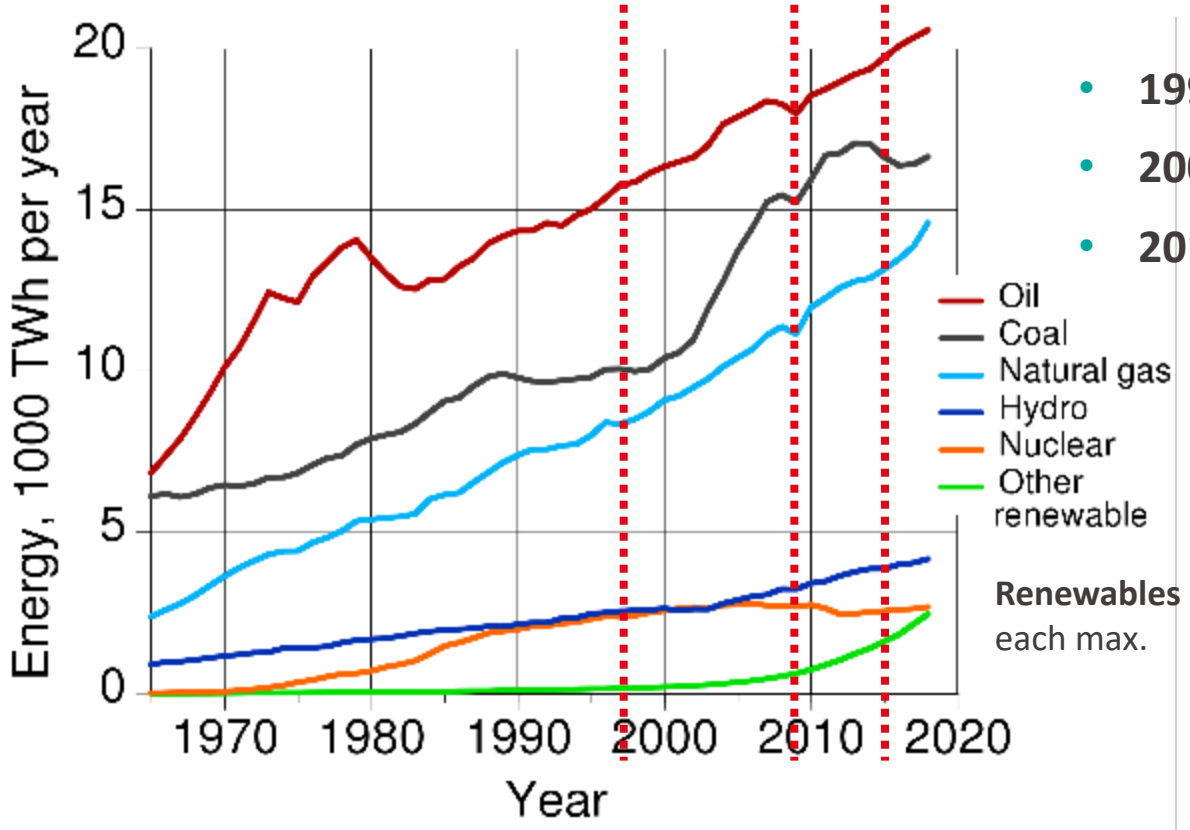
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Introduction



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Introduction



- **1997** : Kyoto Protocol
- **2009** : Copenhagen
- **2015** : Paris agreement

Renewables & nuclear, only about 5 to 10% each max.

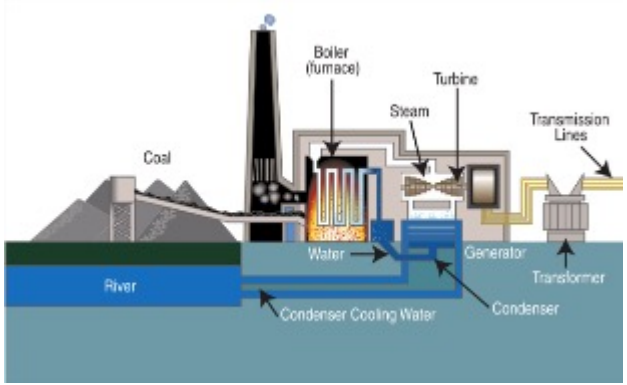
Source : BP Statistical Review of World Energy (2017)

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Coal

PROS and CONS

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



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

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Reserves and resources

Formation

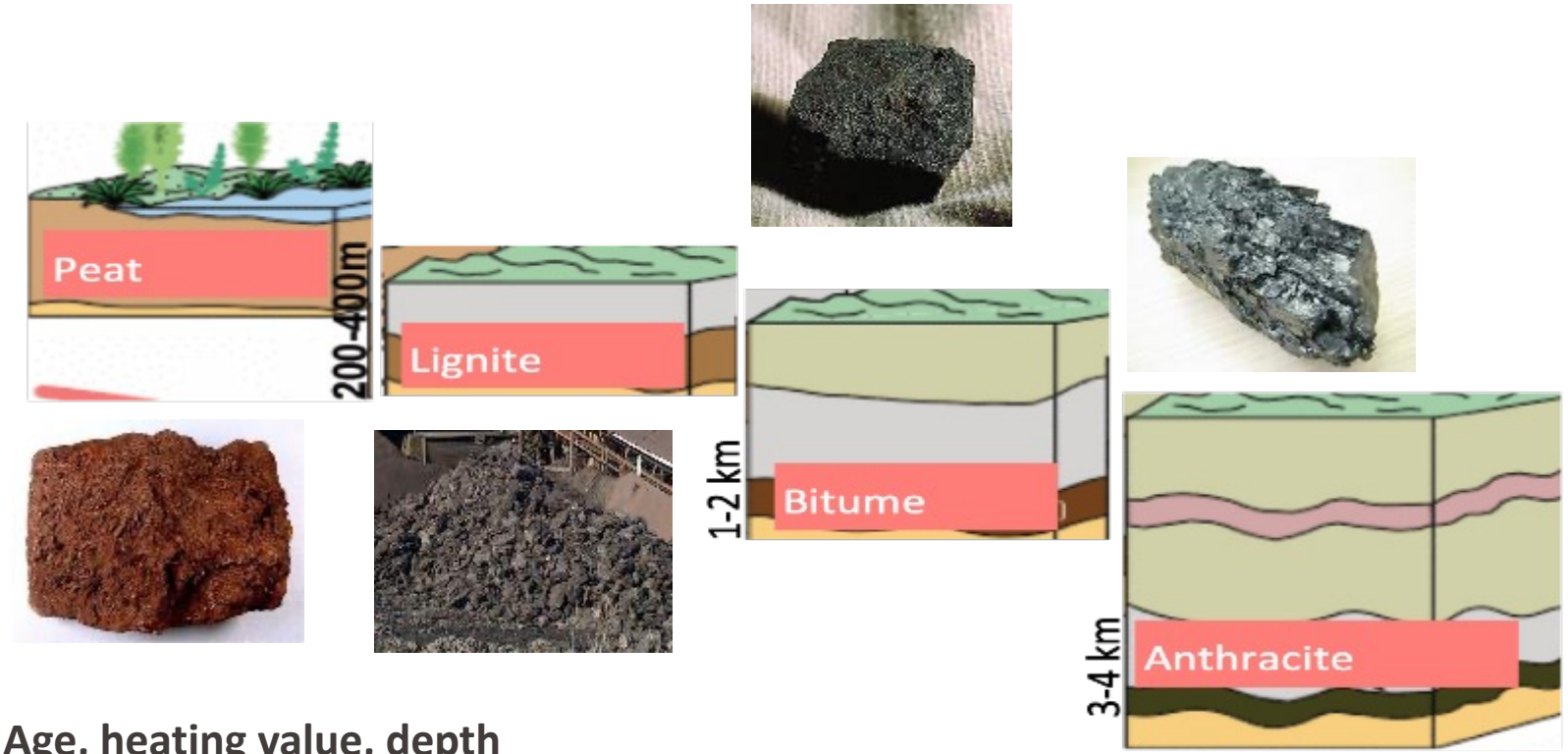
Properties

Reserves and resources

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Coal origin and reserves

Coalification

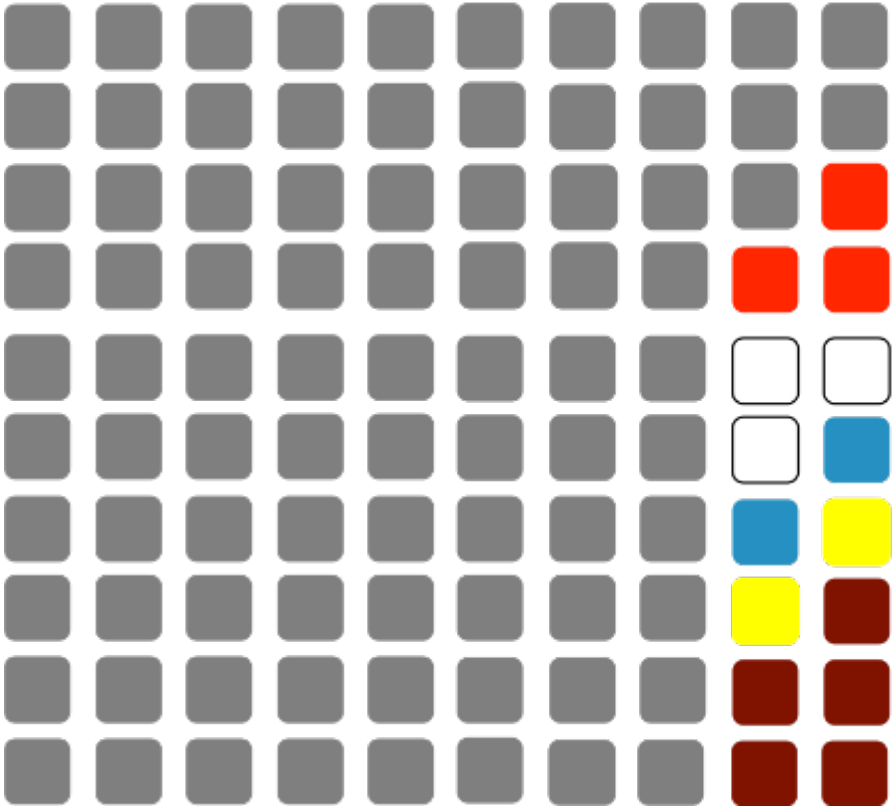


Age, heating value, depth

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Coal origin and reserves

Standard coal?



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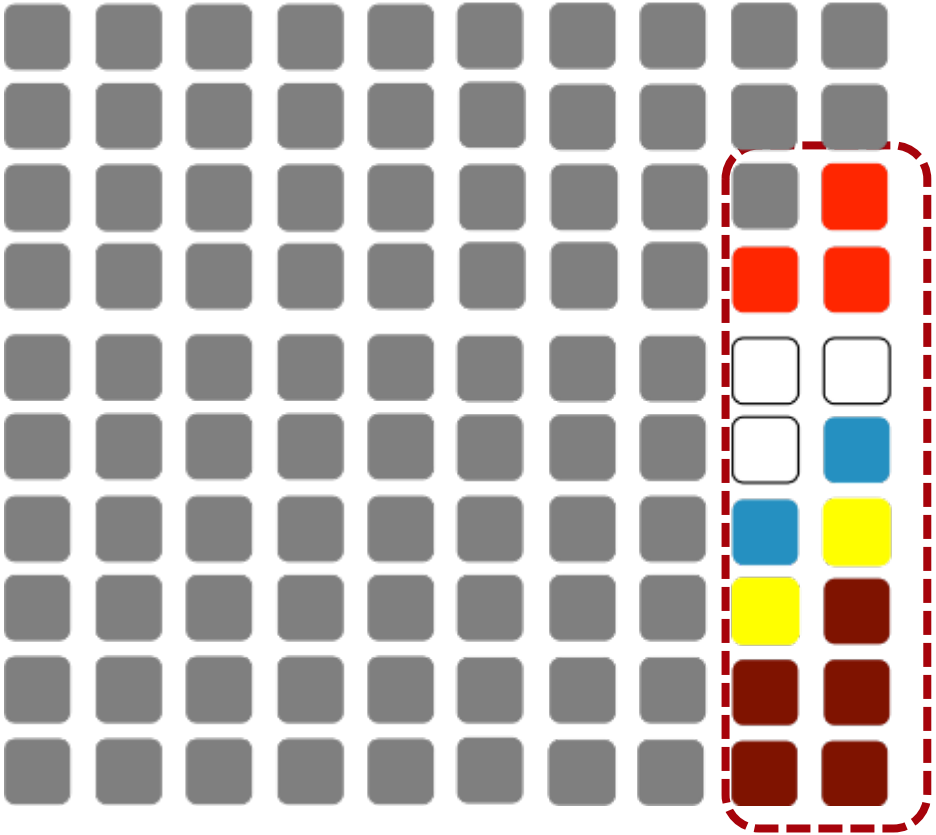
Coal origin and reserves

Standard coal?



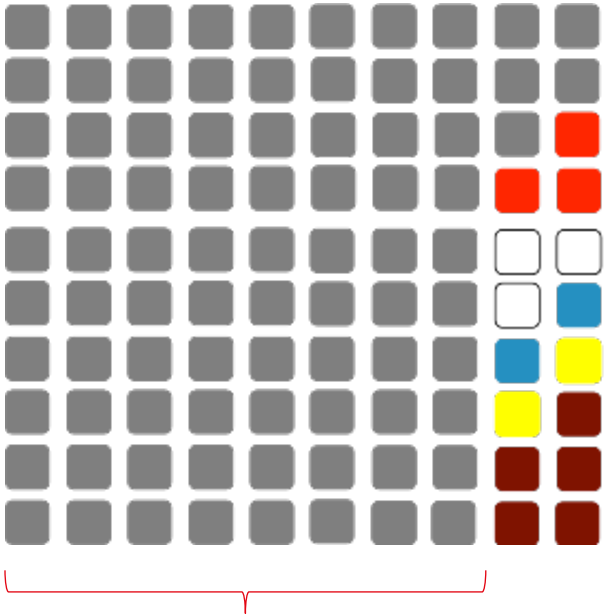
But also…:

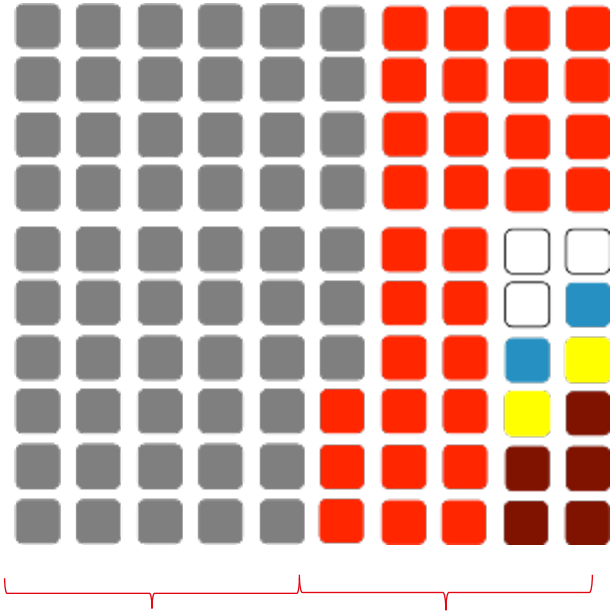
- **NO_x**
- **SO_x**
- Unburned hydrocarbons **HCs**
- Particulate matters **PM**

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

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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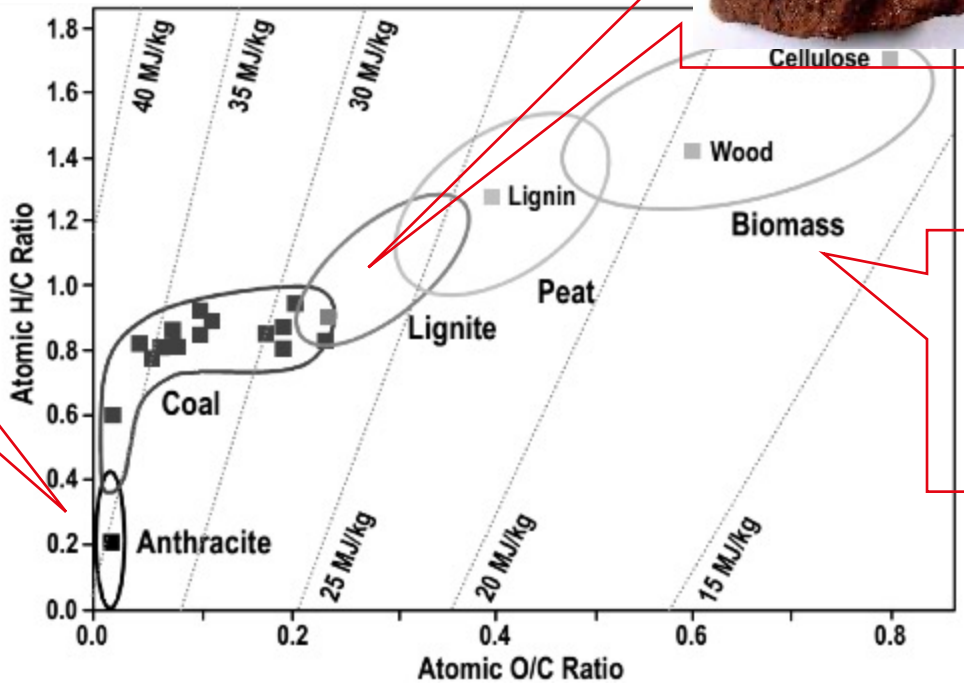
Coal heating values

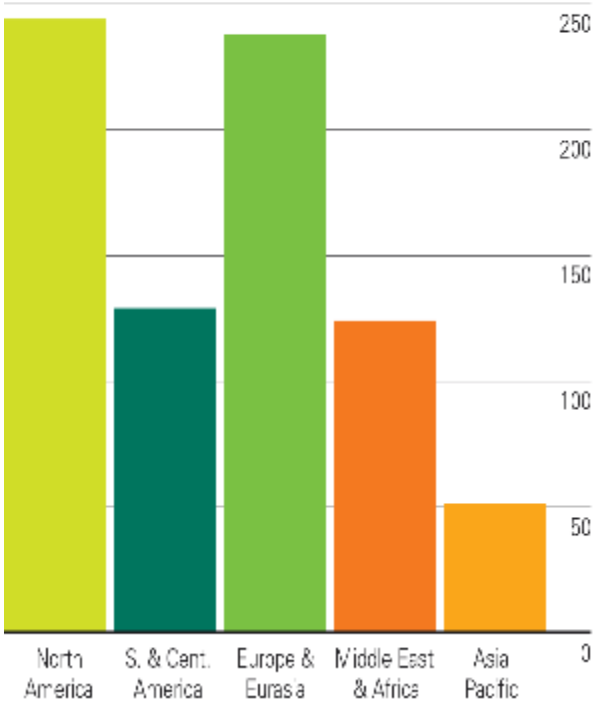


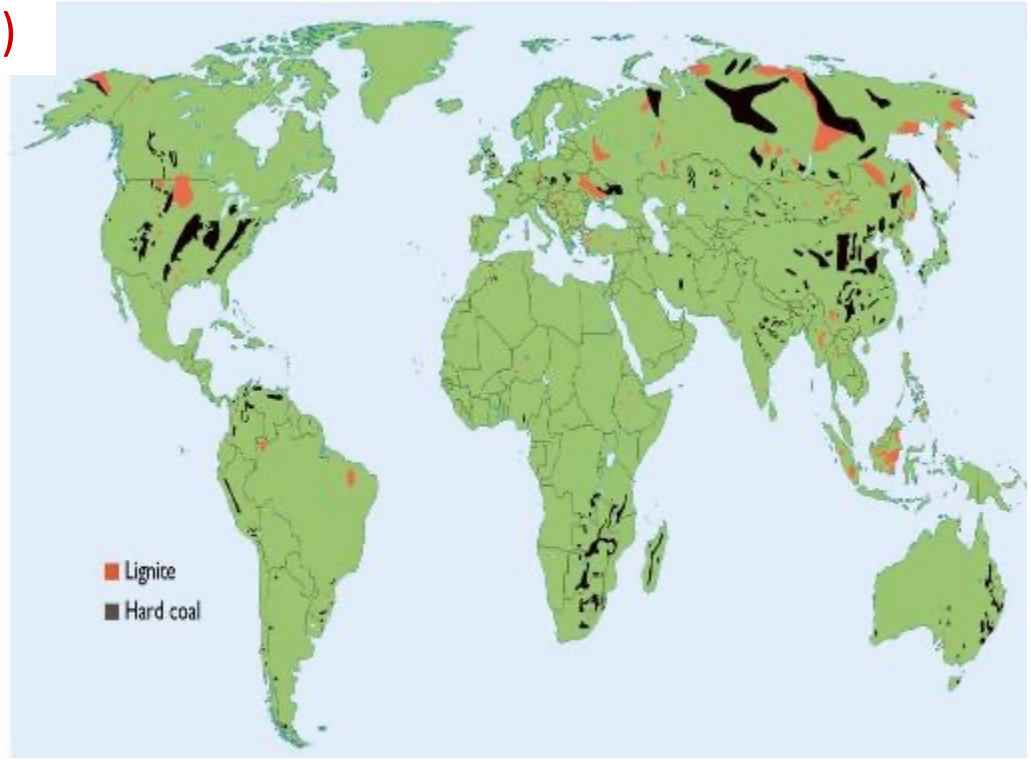
Age, heating value, depth

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Coal origin and reserves

Reserves / production (years)





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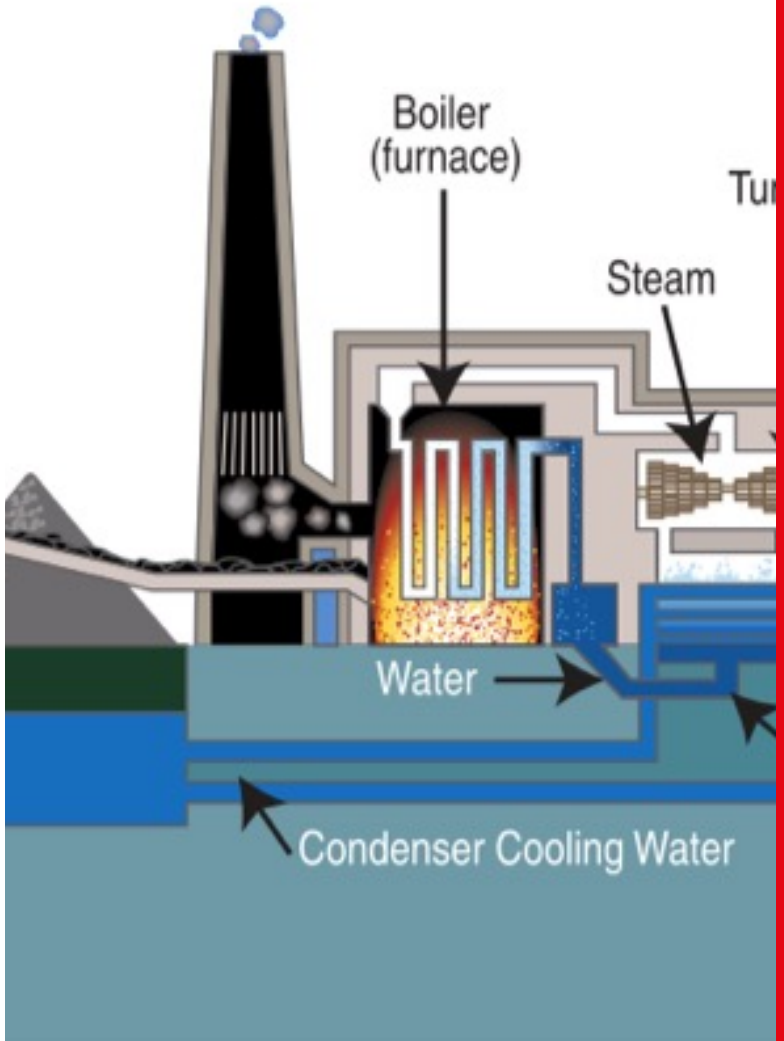
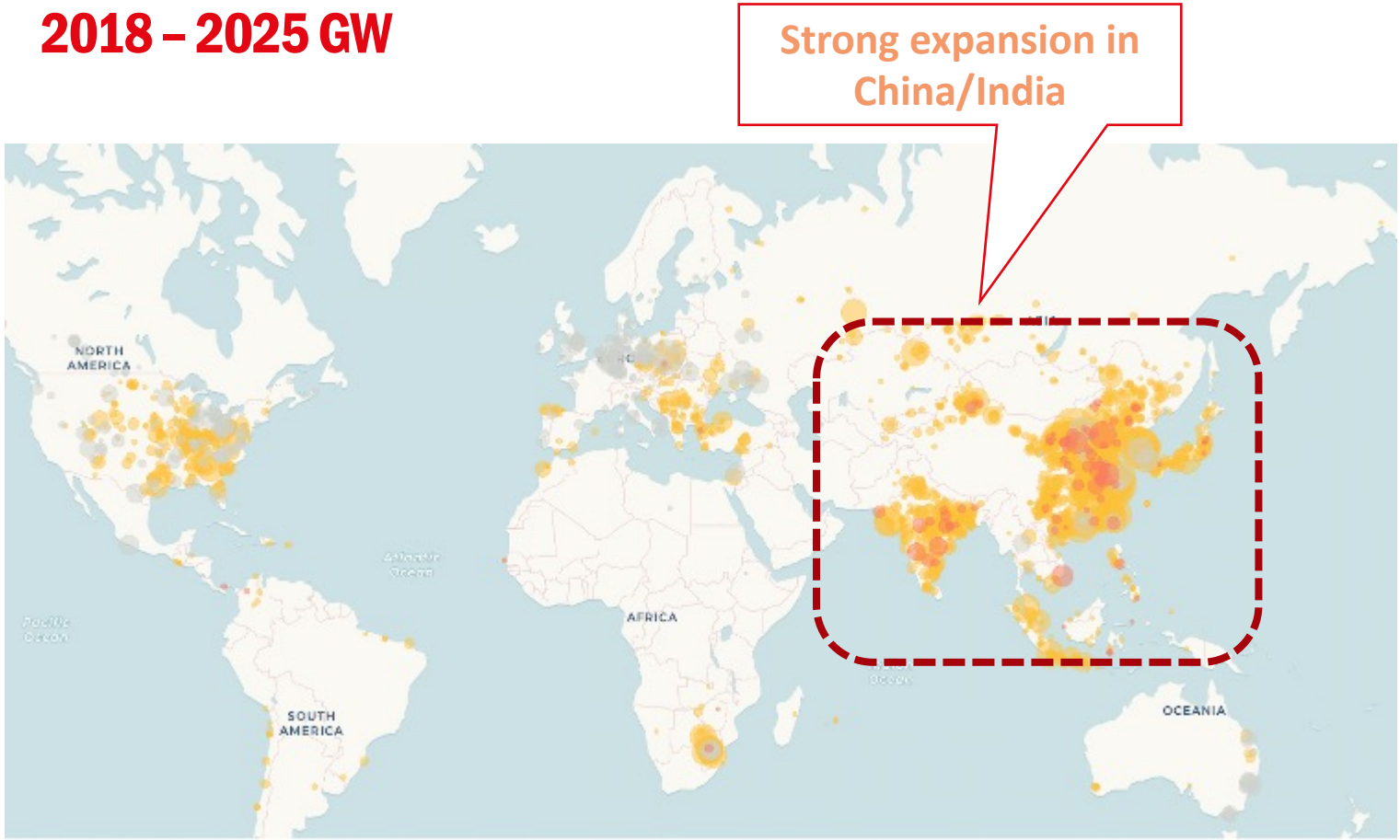
Demands



Coal demand

2018 – 2025 GW



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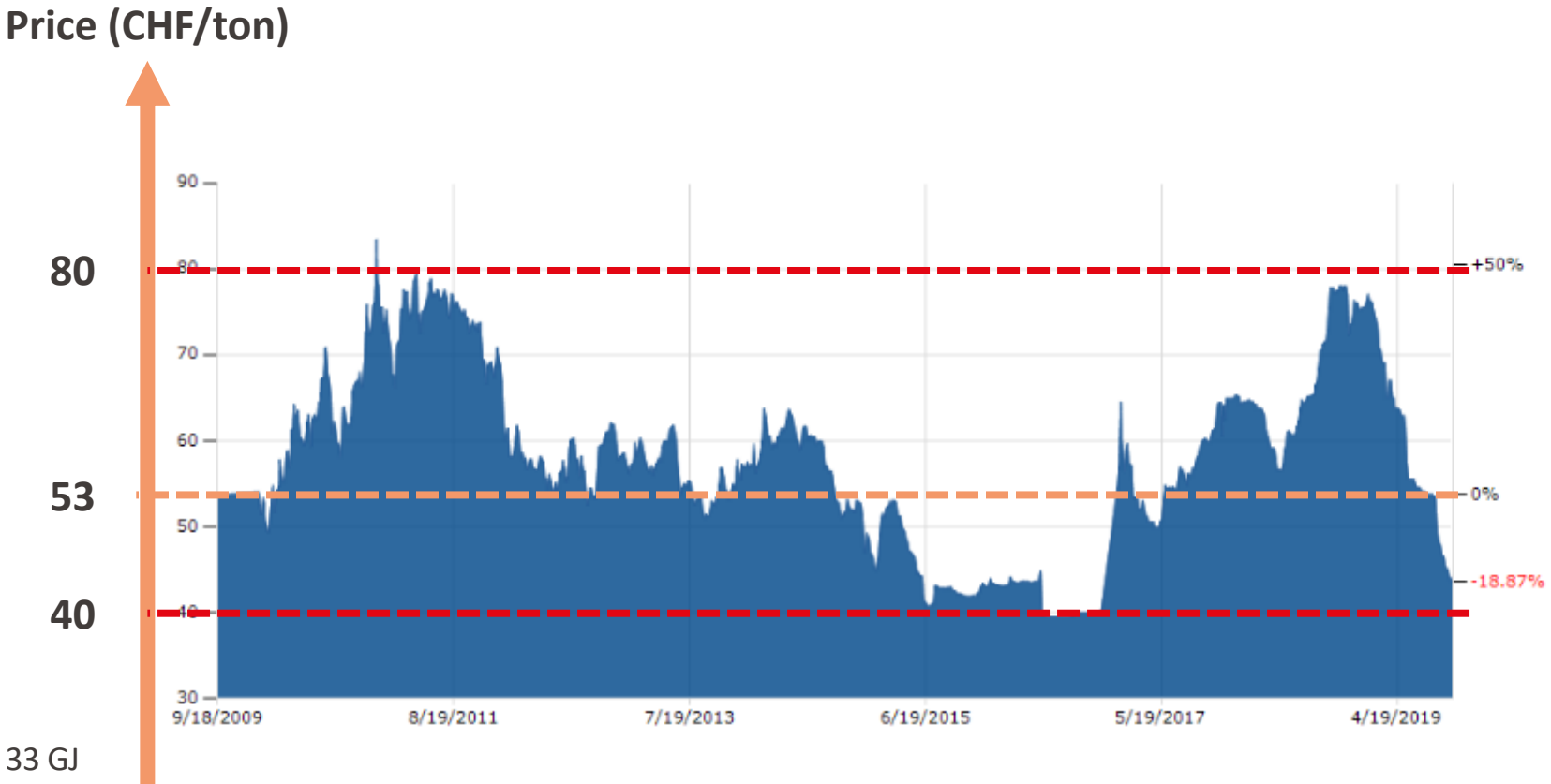
Coal

Historical prices : low variations



1 ton= 33 GJ

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

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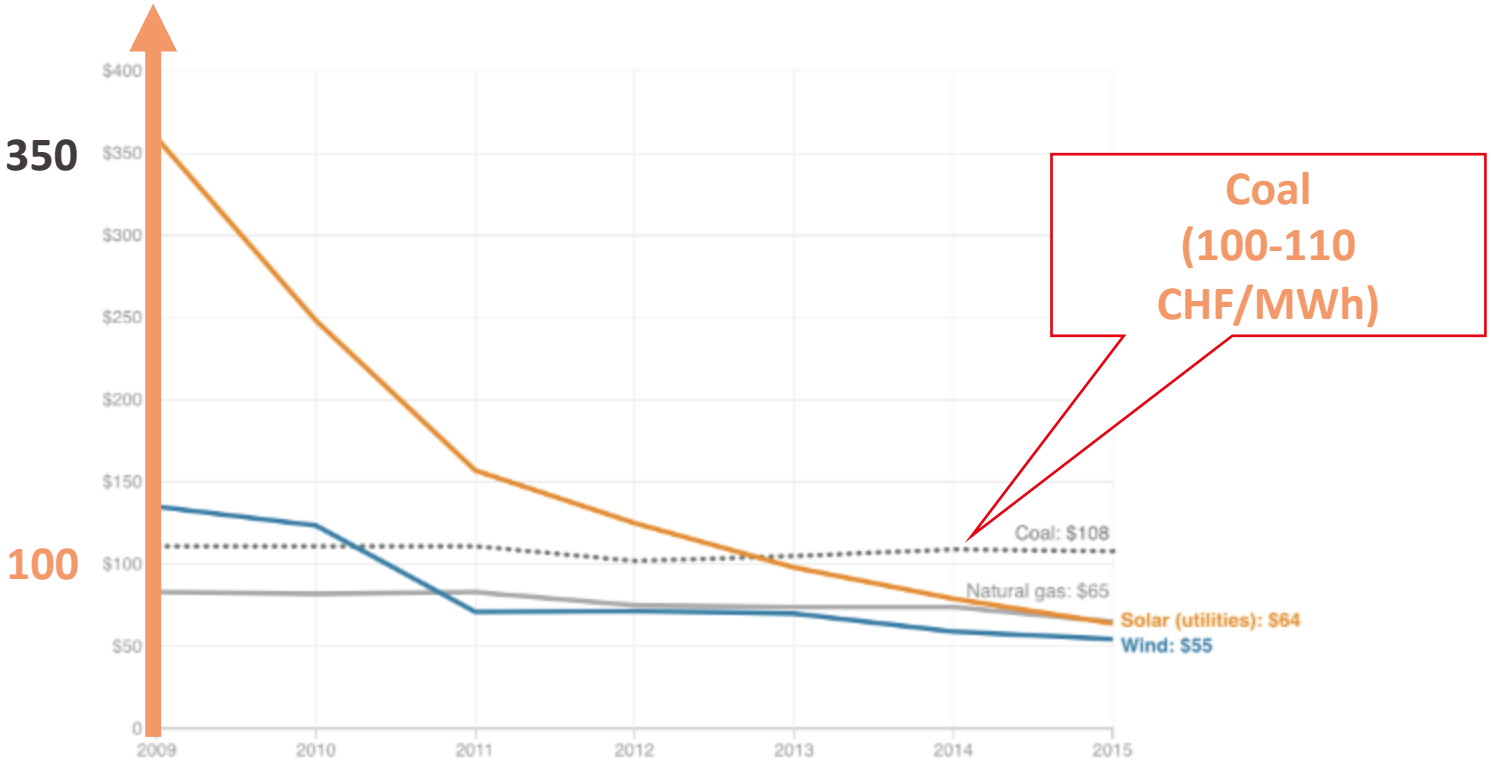
Coal demand

Levelized cost of electricity (USA)

LCOE (CHF/MWh)



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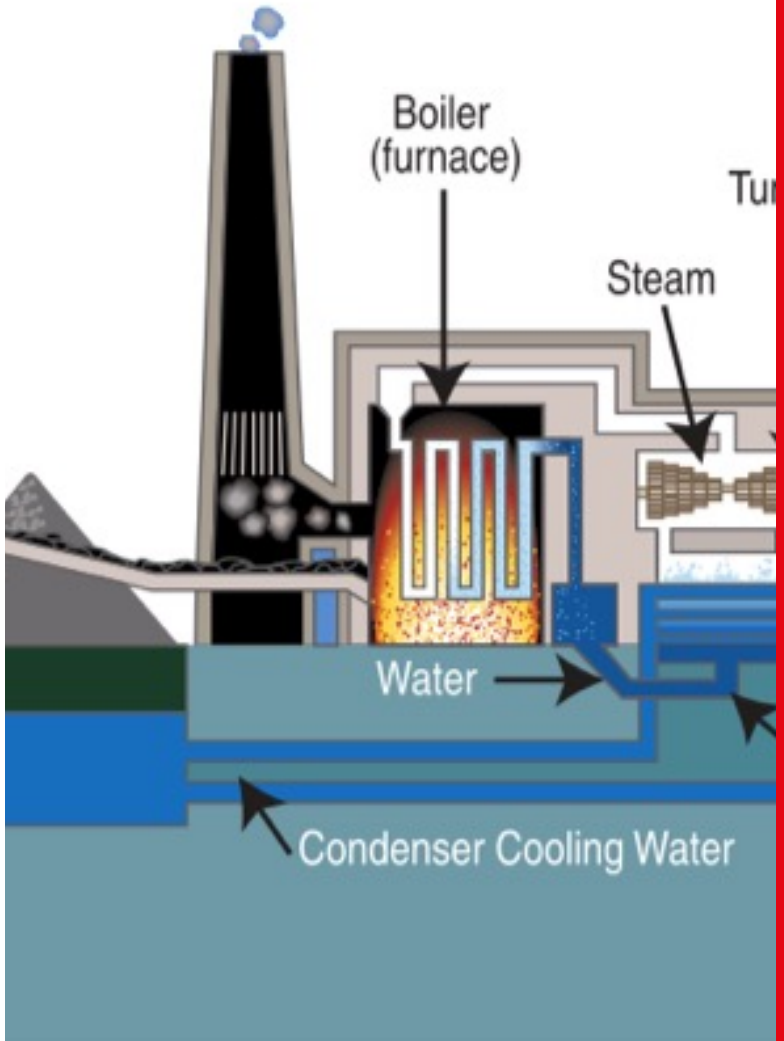


Coal conversion

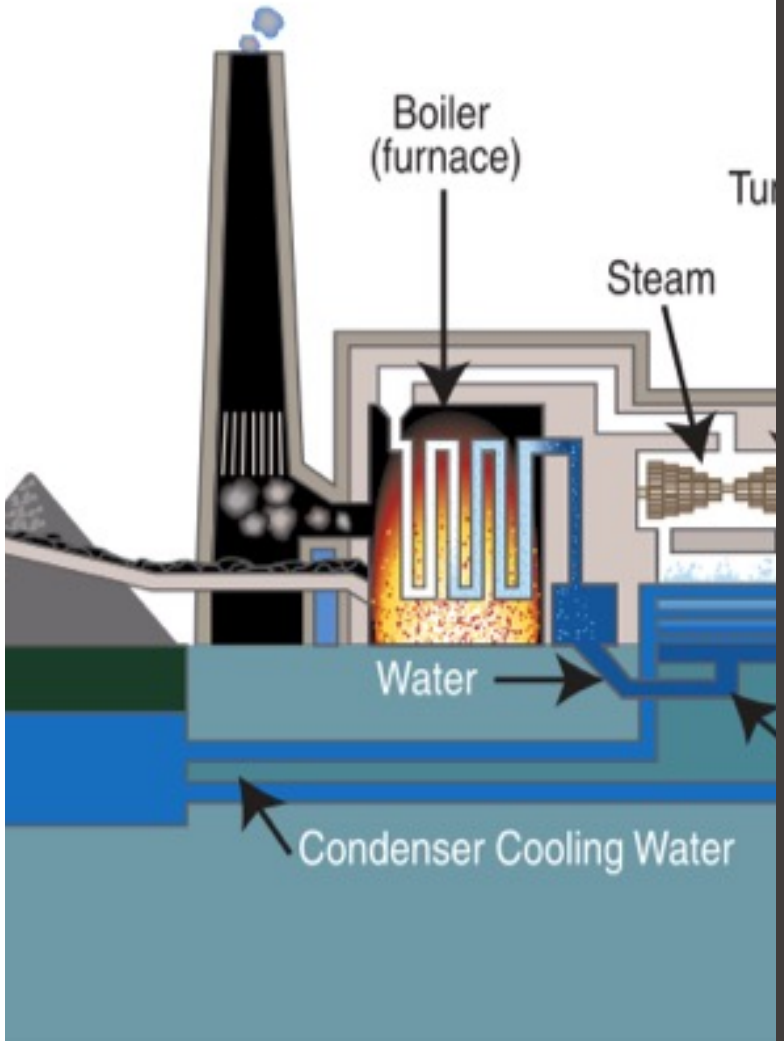
Standard thermal power plants

Emissions and mitigation

Advanced conversion plants

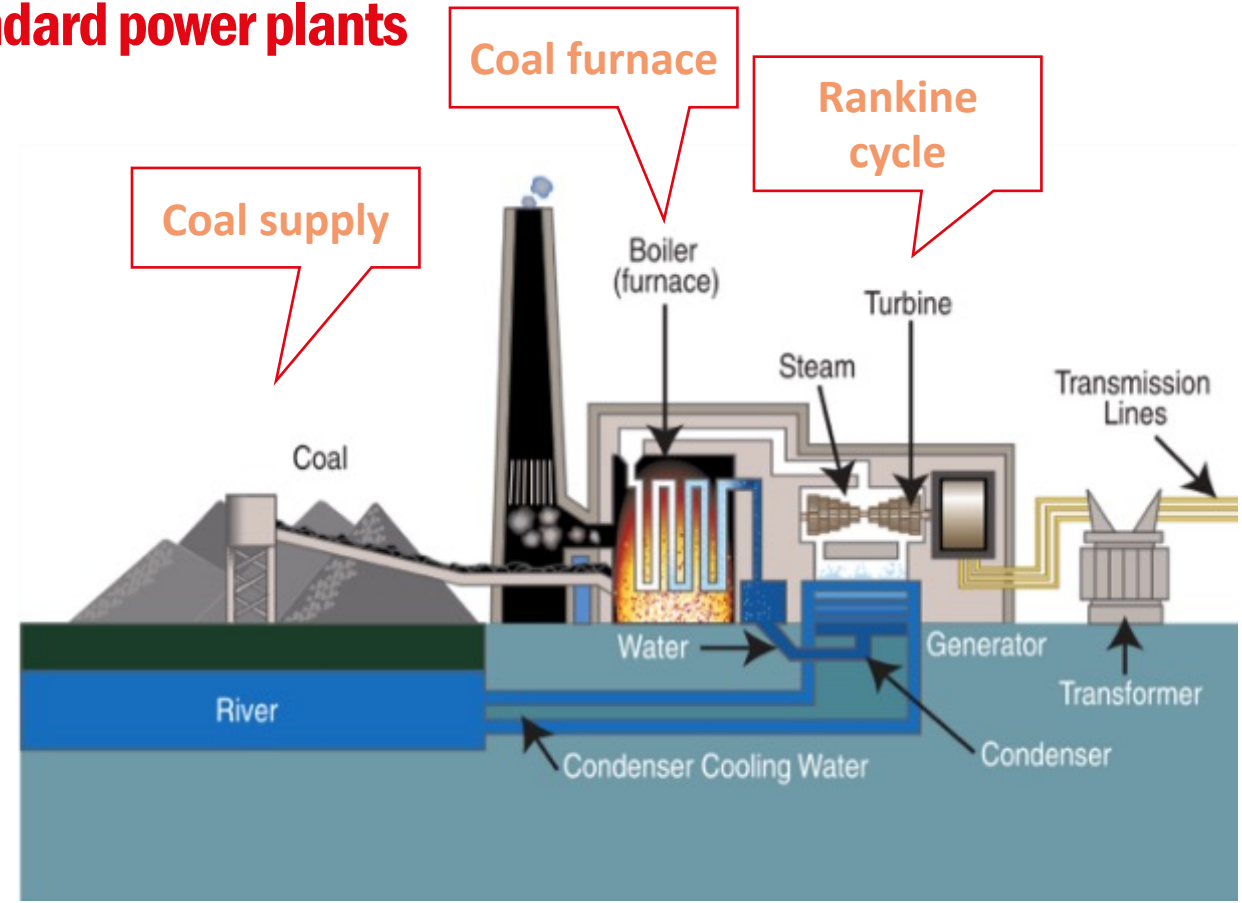
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Standard coal power plants



Coal conversion

Standard power plants



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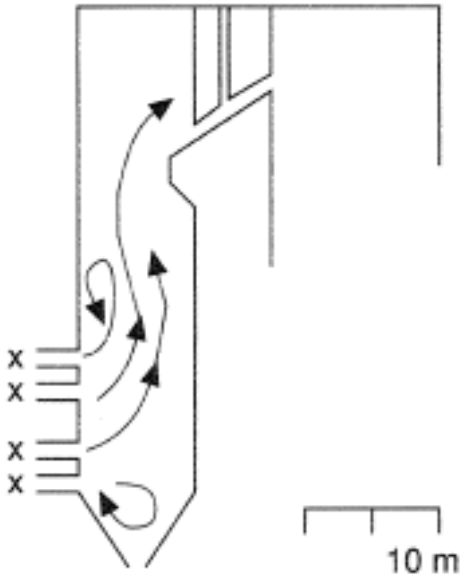
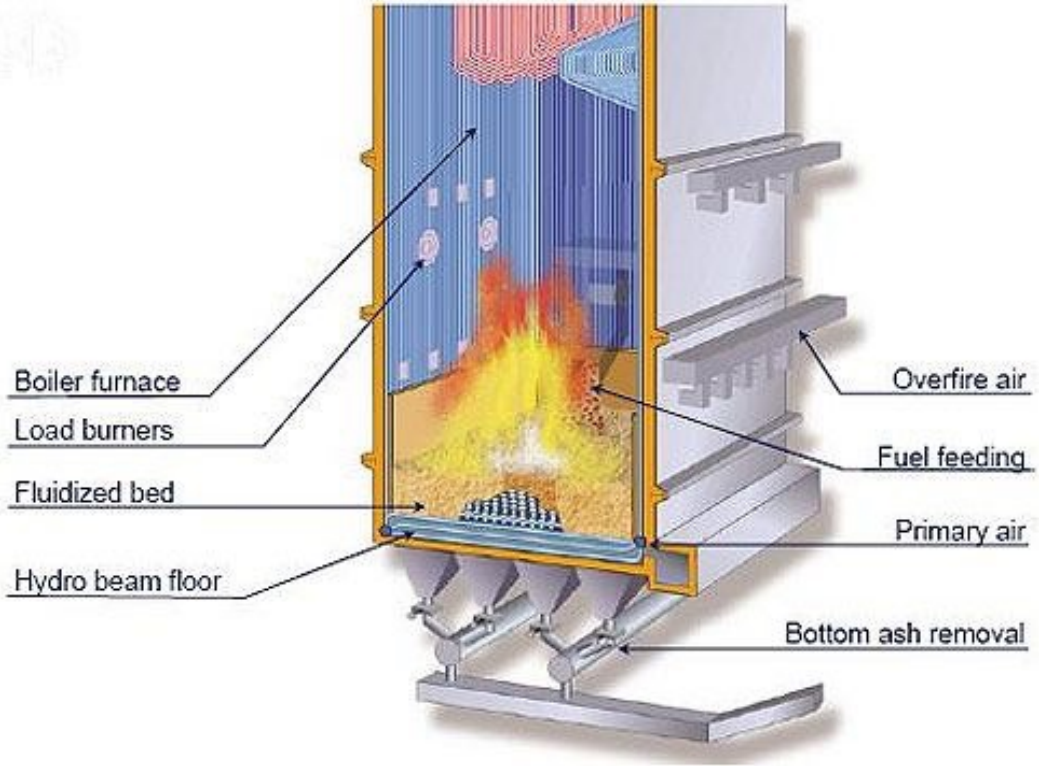
Coal conversion

Standard power plants



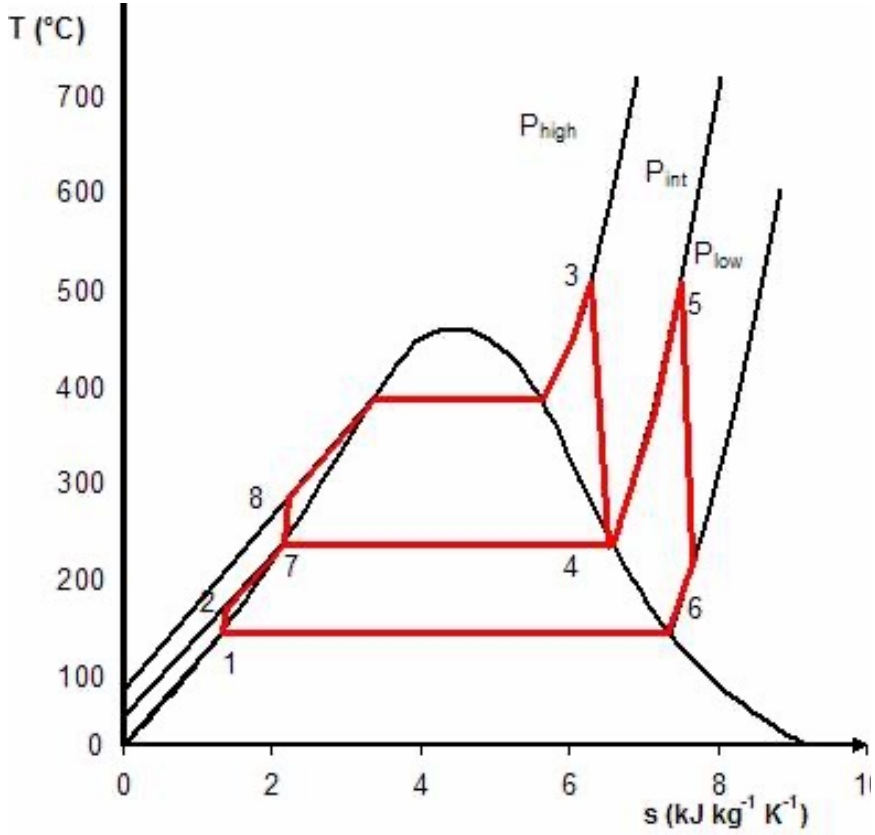


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

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%



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Environmental impacts and mitigation

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Coal

Environmental impact

- Importance of the life cycle

- Extraction

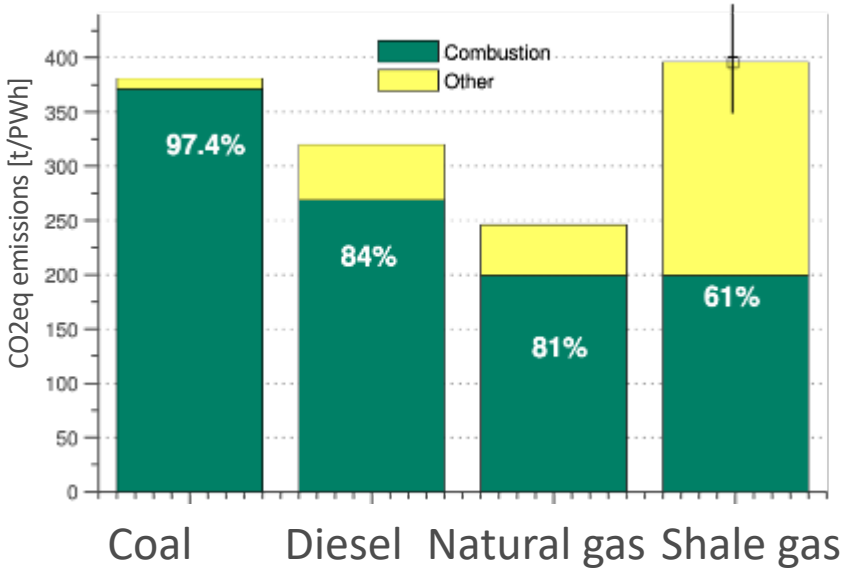
- Conditioning

- Transport

- Refining

- Distribution

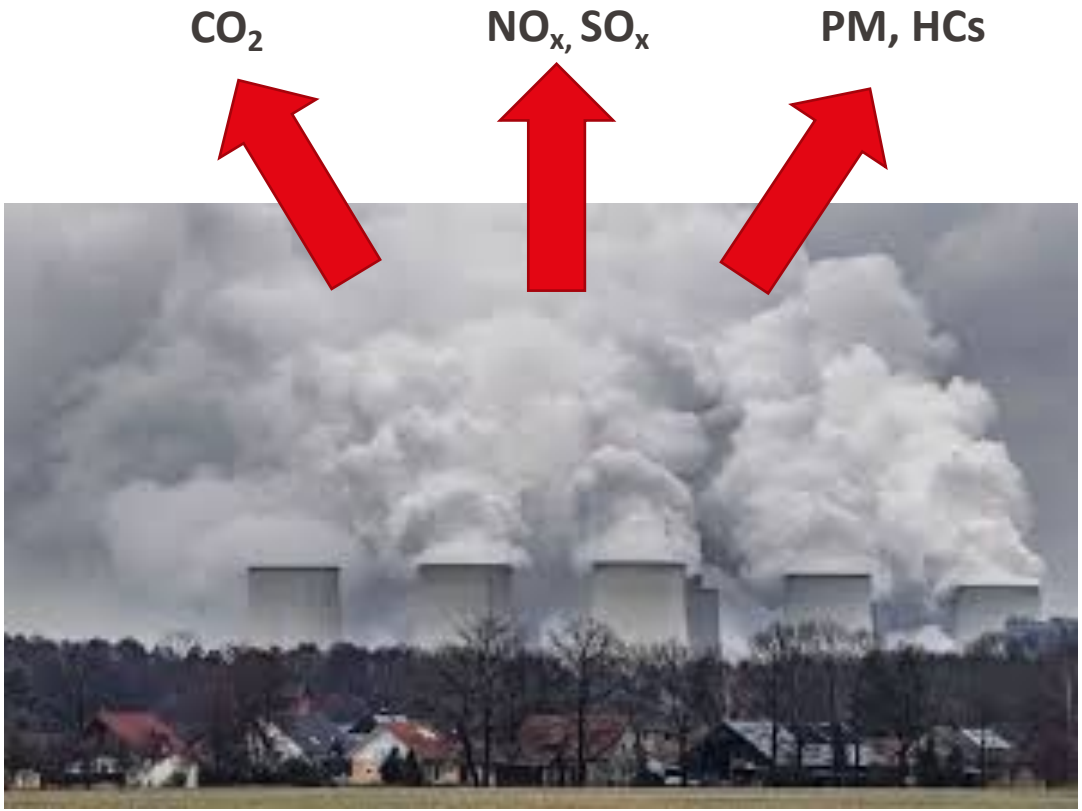
- Combustion



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



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Coal conversion

Environmental and health impacts

- Global warming (CO_2)

- Human health (NO_x, PM)

- Mining

- Water pollution (NO_x, ash)

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

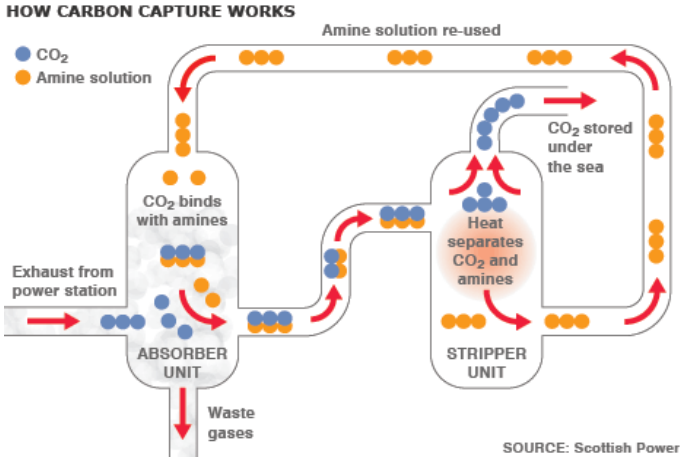
Coal conversion

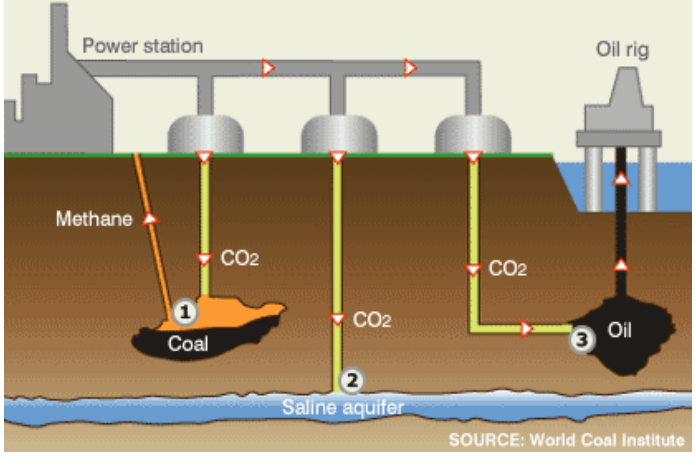
CO_2-mitigation

- **Chemical absorption for carbon capture**
  - $\mathrm{MEAH} + CO_2 \rightarrow \mathrm{MEACOOH}$

Monoethanolamine

- **Storage** or **chemical production**





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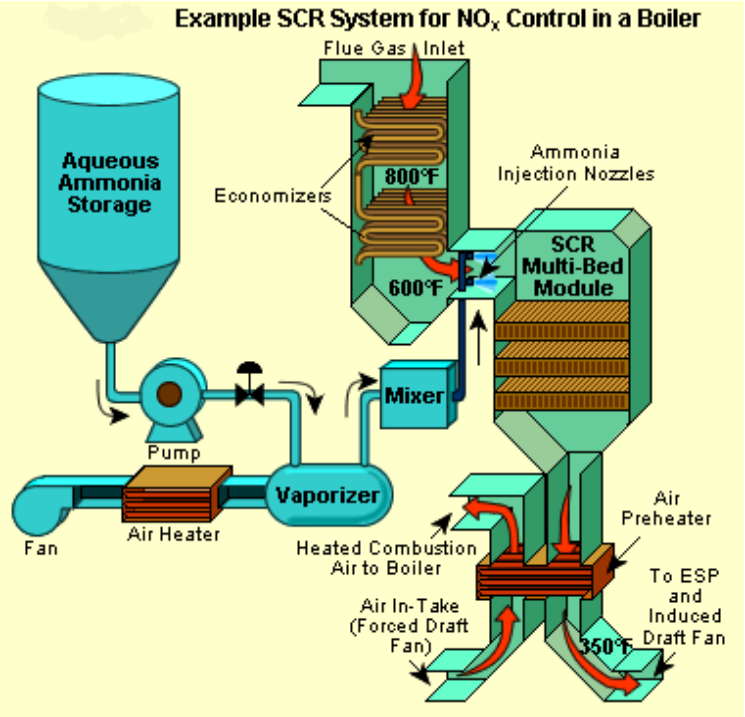
Coal conversion

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



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Coal conversion

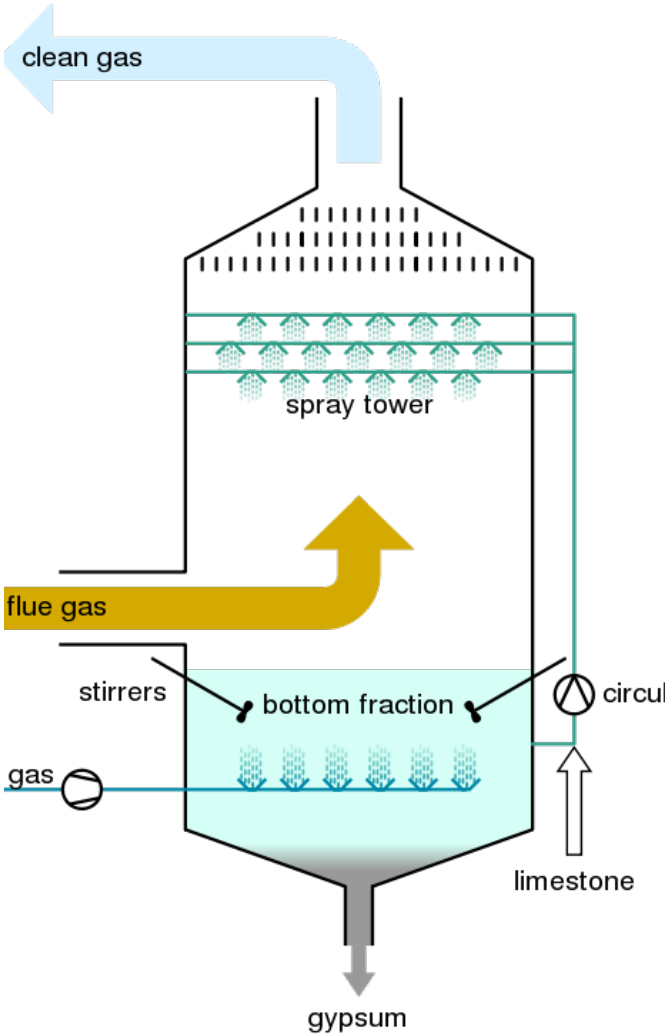
SO_x-mitigation

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

Limestone

- $CaCO_3 + SO_2 \rightarrow CaSO_3 + CO_2$

(solid)



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

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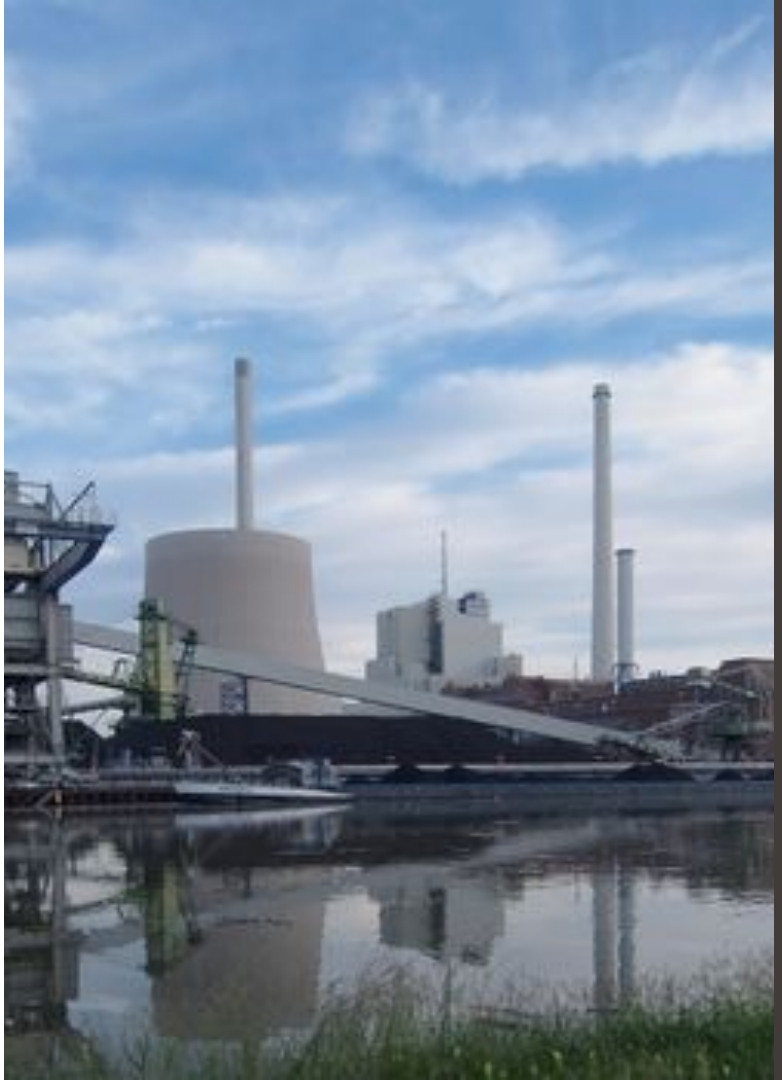


Advanced plants

Fluidized bed combustion

Integrated gasification

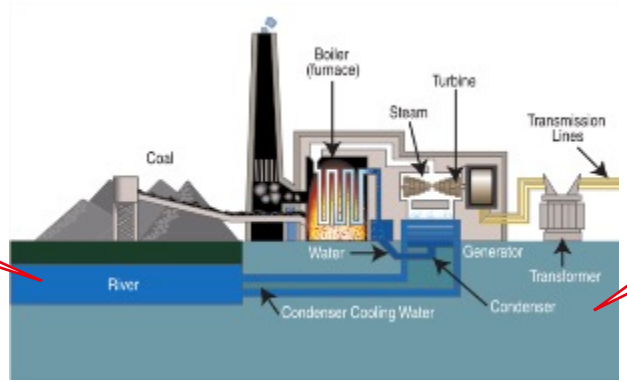
Supercritical plants

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Advanced plants

Towards higher efficiency and less impact

33-37% efficiency



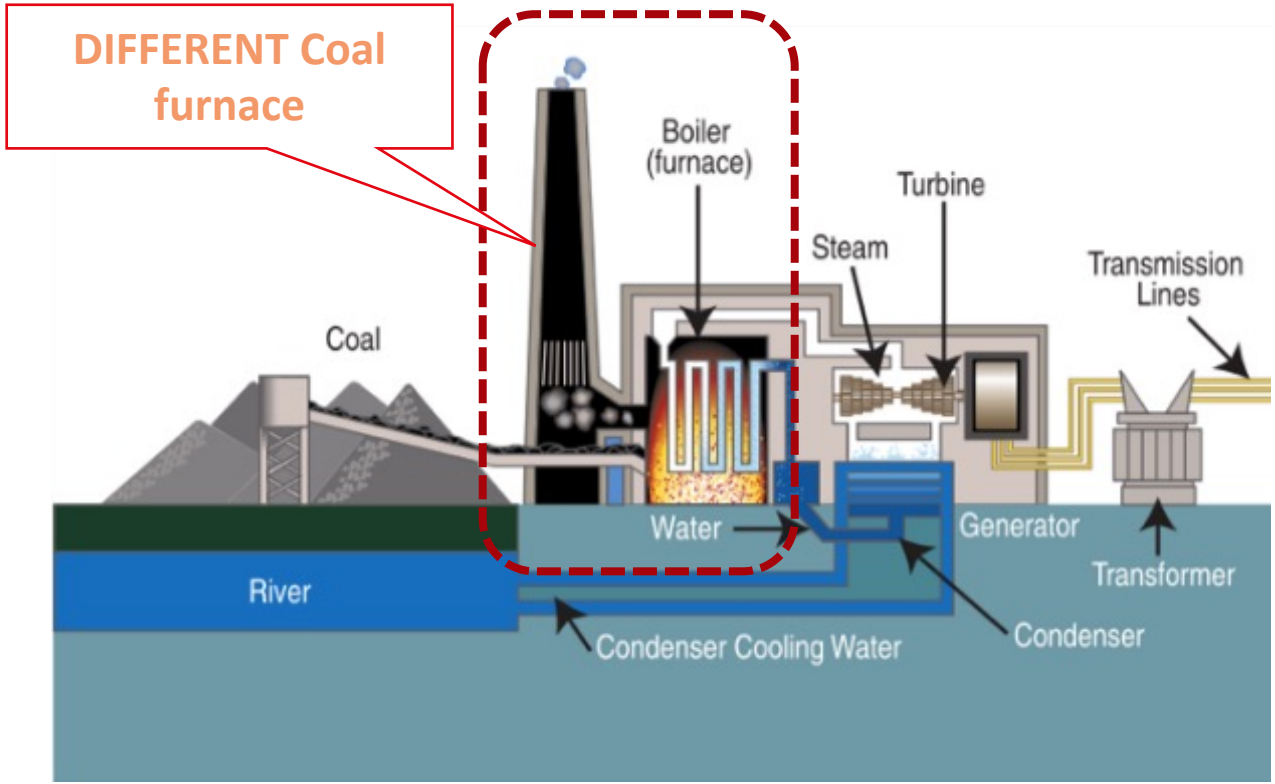
250-300 $kgCO_2/MJe$

- **Supercritical** power plants

- Fluidized bed combustion
- Integrated gasification

Advanced plants

(1) Fluidised bed combustion



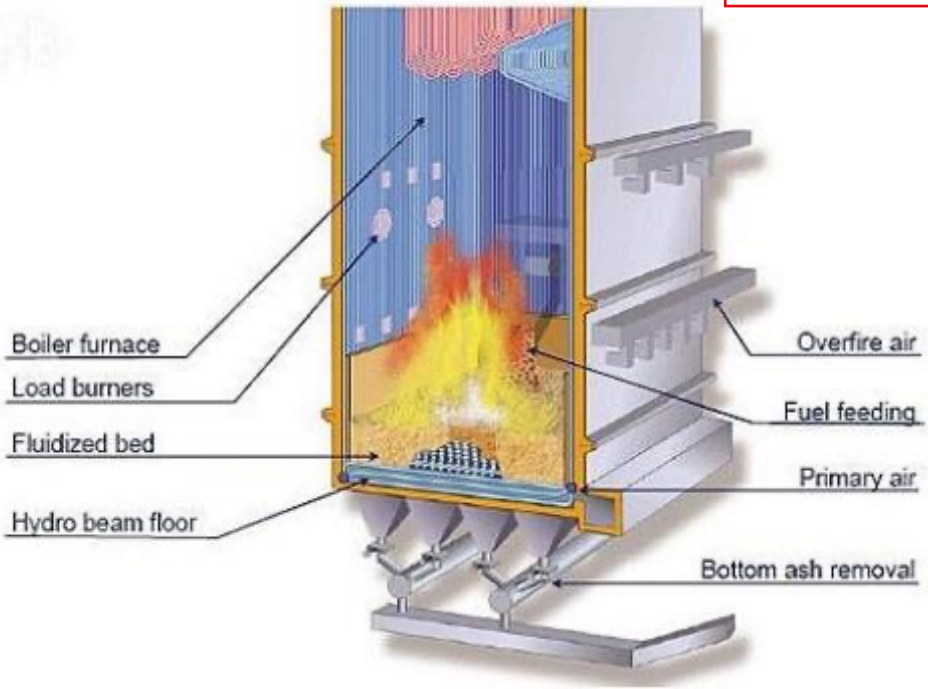
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

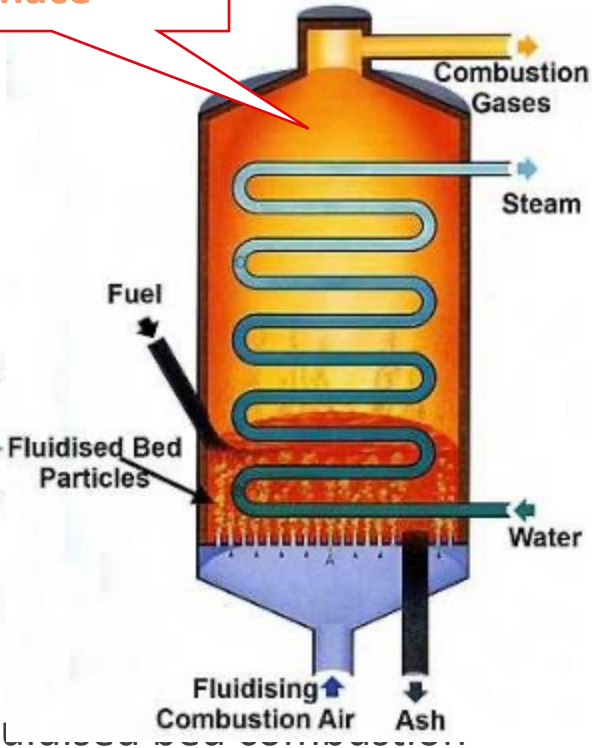
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Advanced plants

(1) Fluidised bed combustion

DIFFERENT Coal furnace

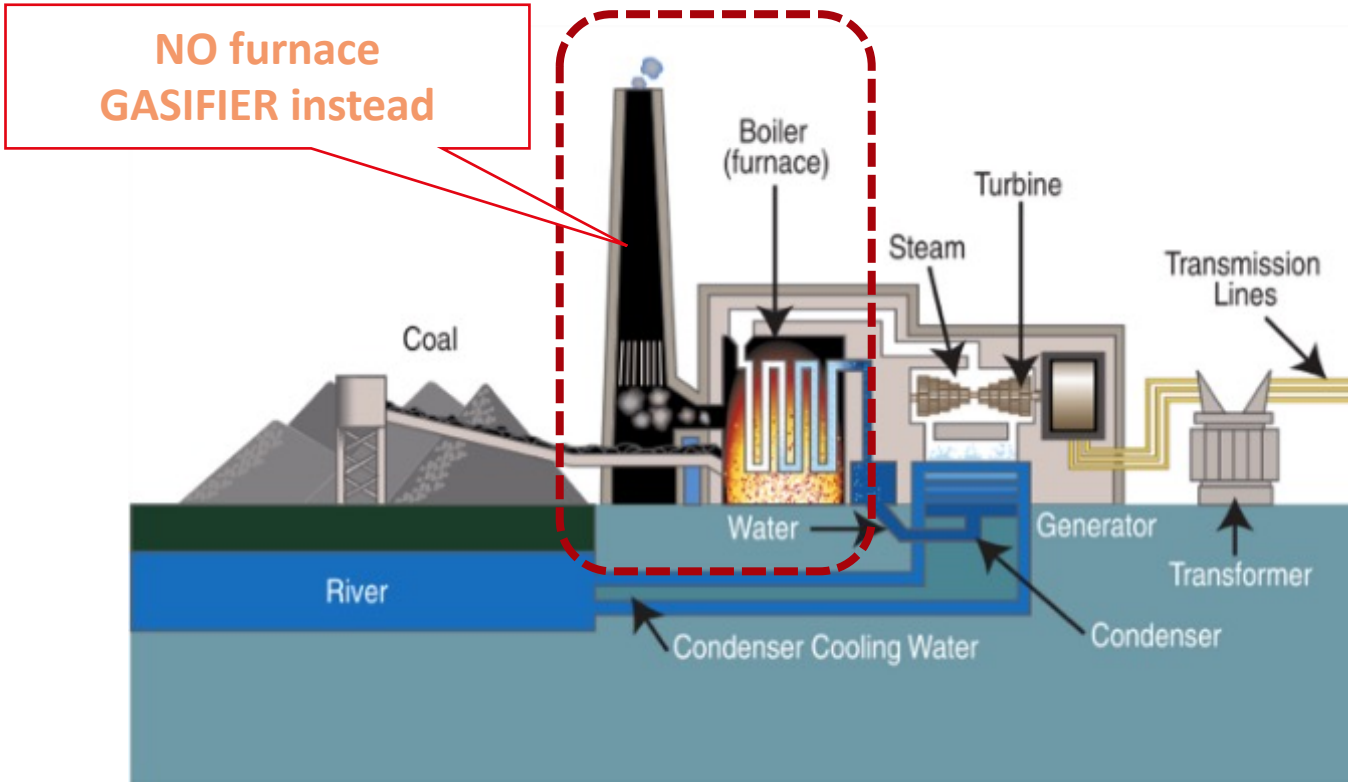




- Standard coal furnace
- Fl...

Advanced plants

(2) Integrated gasification



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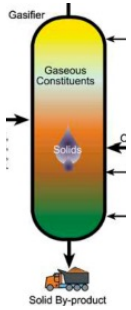
Advanced plants

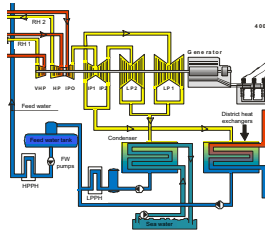
(2) Integrated gasification

SOLID FUELS (COAL)



Gas production & cleaning (Gasification)

HEAT



ELECTRICITY

Heat production (Combustion)

Heat – to – Power (Rankine cycle)

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Advanced plants

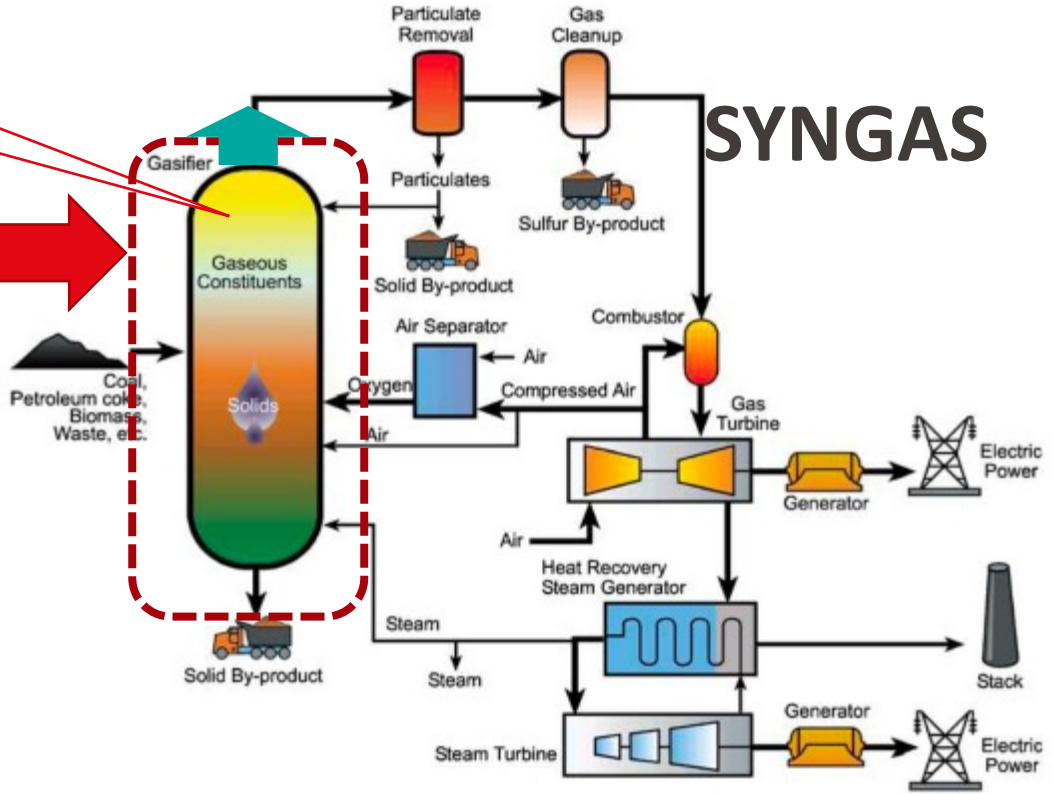
The heating value is chemically transferred to CO and H2

NO furnace
BUT a GASIFIER

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

COAL

SYNGAS



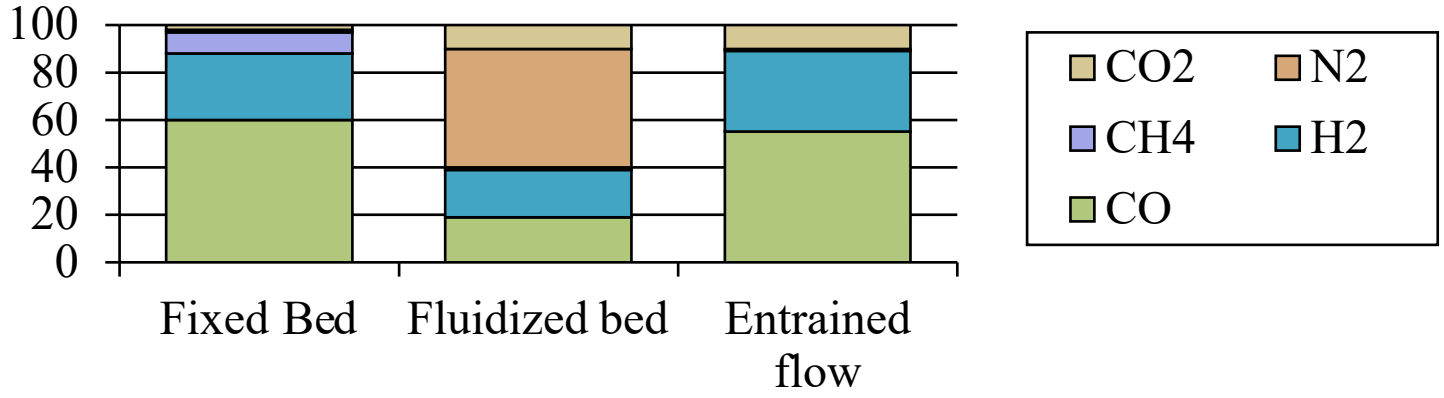
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Advanced plants

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

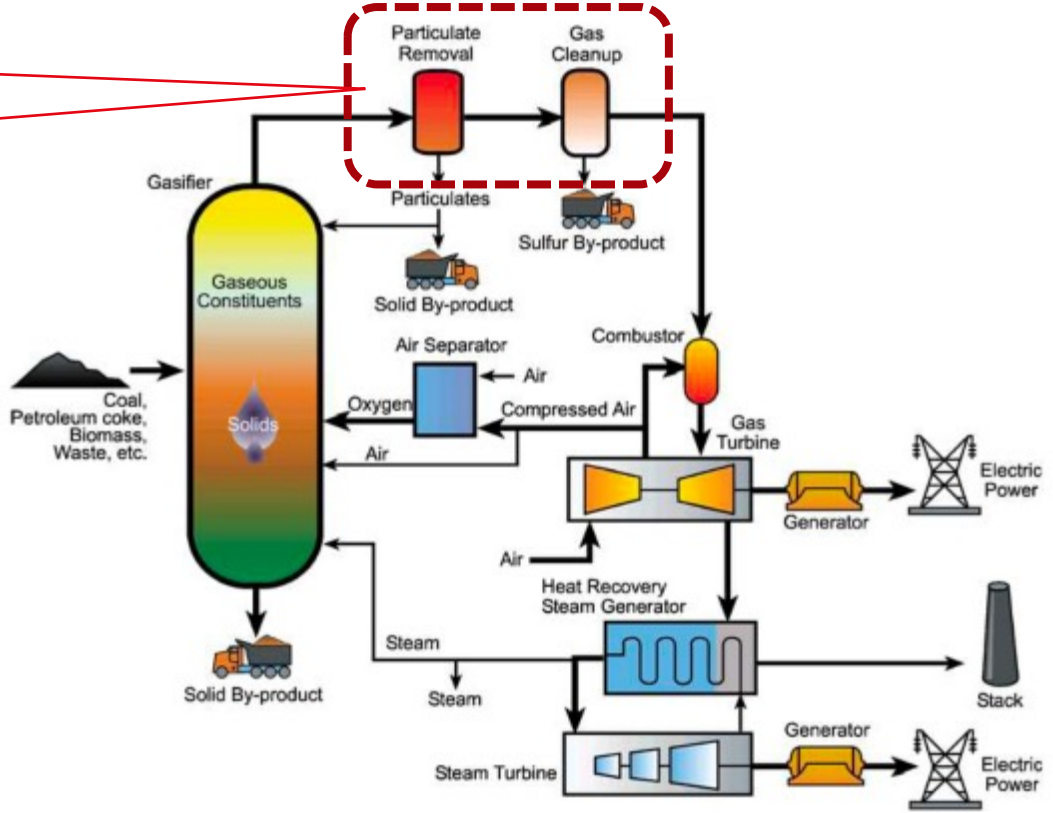


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Advanced plants

(2) Integrated gasification

Gas treatment
(S and N removal)

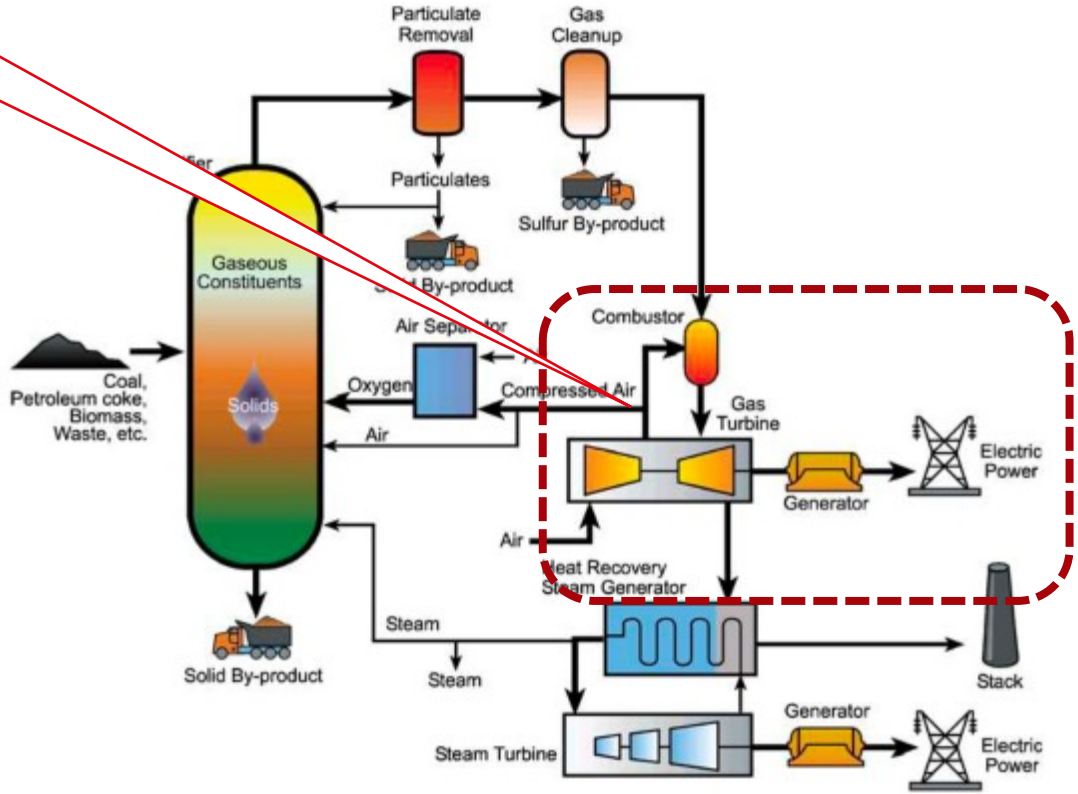


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Advanced plants

(2) Integrated gasification

Gas turbines



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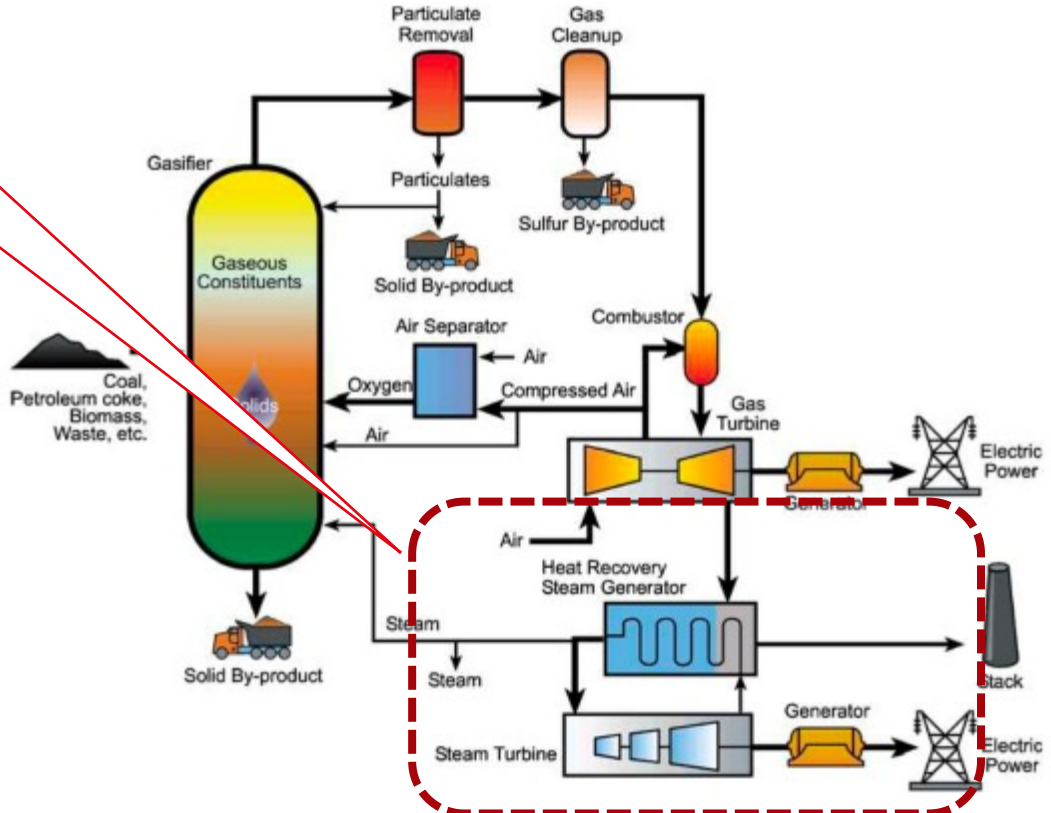
Advanced plants

(2) Integrated gasification

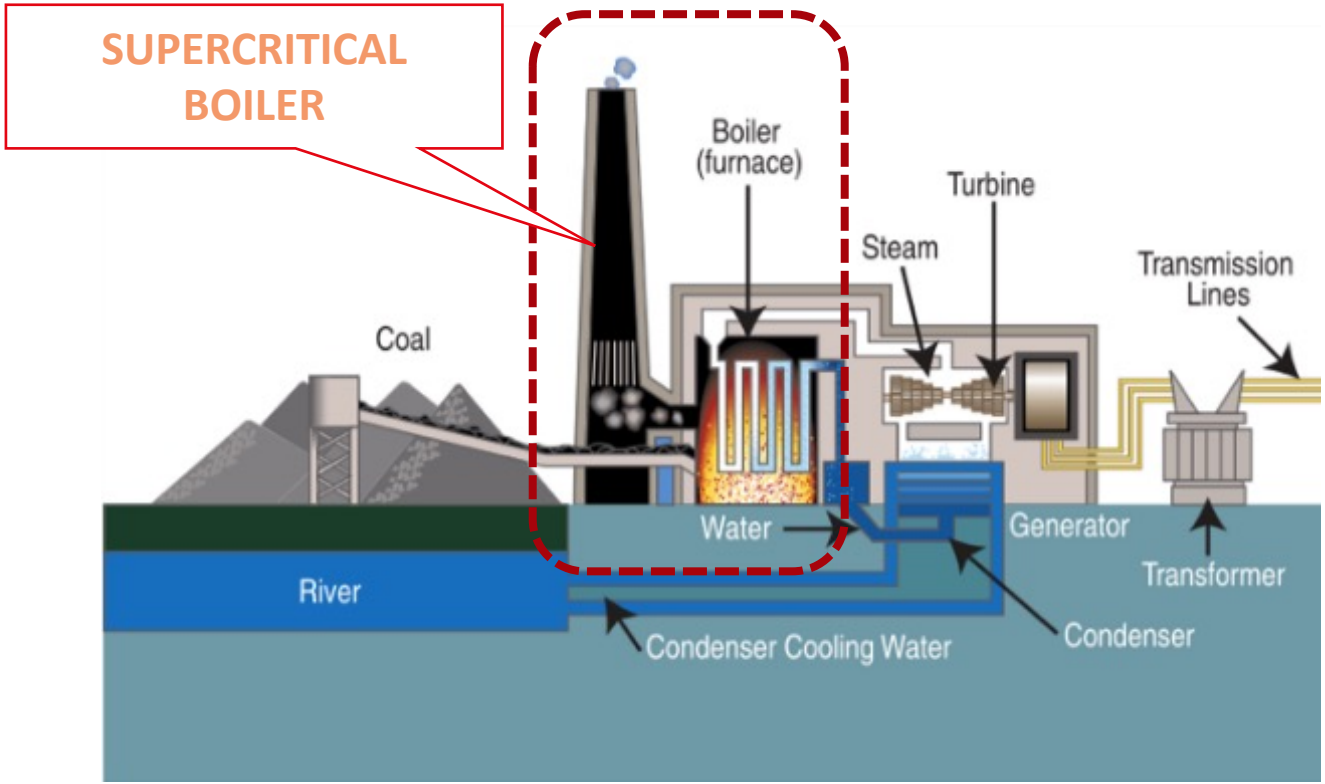
Rankine cycle



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Advanced plants

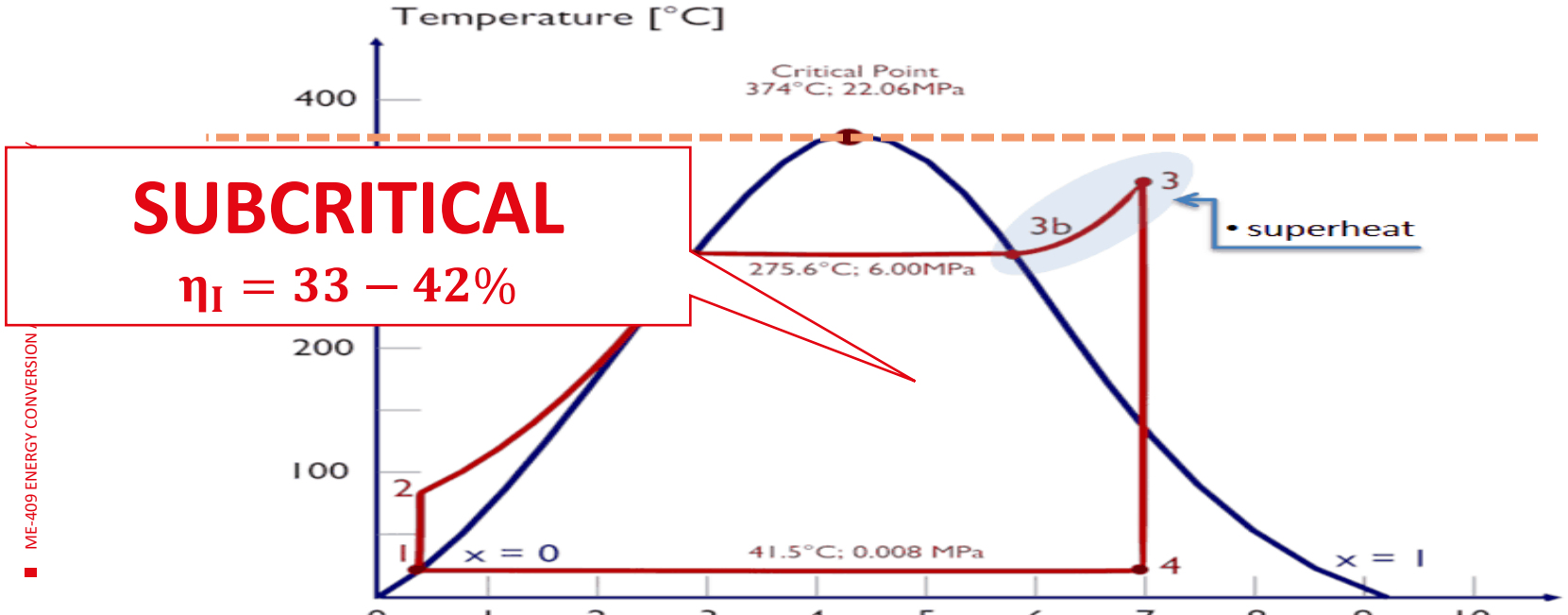
(3) Supercritical



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Advanced plants

(3) Supercritical



SUBCRITICAL

$\eta_I = 33 - 42\%$

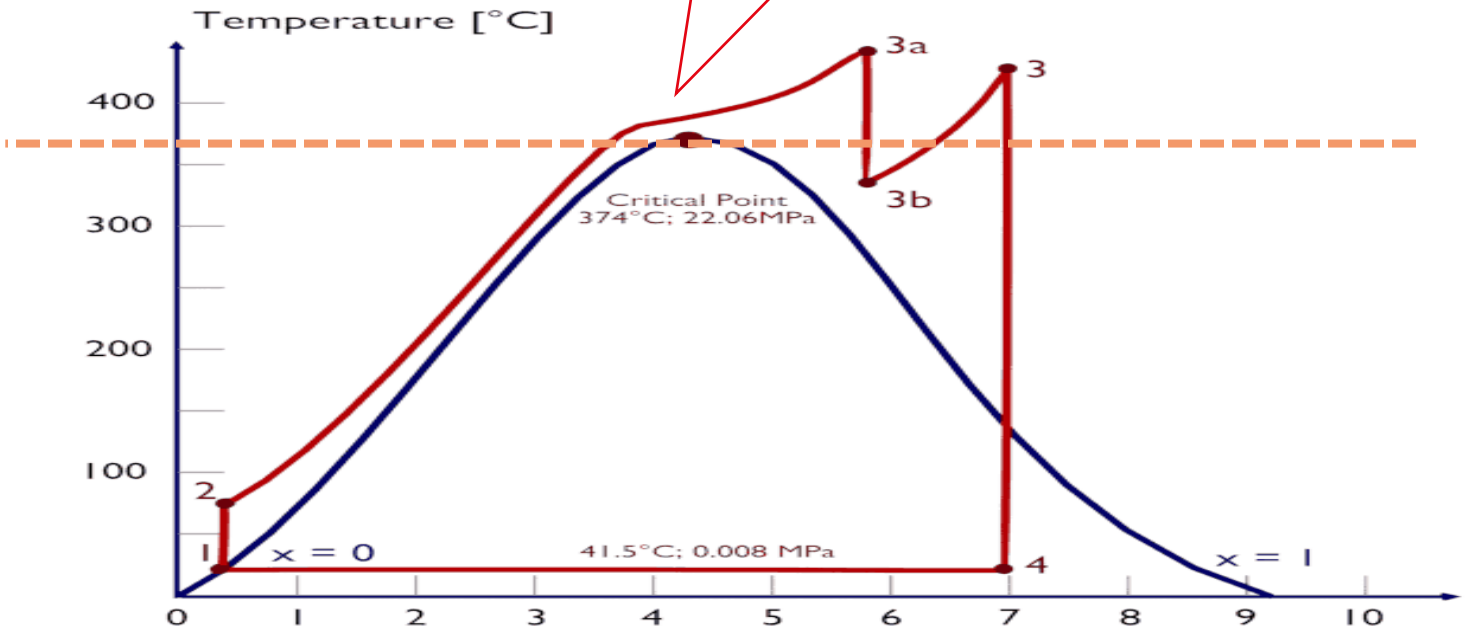
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Advanced plants

(3) Supercritical

SUPERCRITICAL

$\eta_I = 47\%$



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Take-home message

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

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 bad, but it could be worse**

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Questions?

Tuong-Van Nguyen