

*ODA-UNESCO Project for Promotion of Energy Science  
Education for Sustainable Development in Cambodia*

*Phnom Penh, February 18-21, 2014*

---

# **Theme 3: Current Energy Technology**

*Sopheak REY*

**Industrial and Mechanical Engineering Department,  
Institute of Technology of Cambodia**

# Objective the Scheme

---

2

- Understand the current energy technologies including conventional and clean energy technologies
- Merit, demerit and process of working of each technology is explained
- Current applicable energy technology that are using in Cambodia and in the region

## **Contents**

### **Part 1. Traditional energy technology**

1.1 Introduction

1.2 Conventional energy technologies

1.3 Thermal power plant technologies

### **Part 2. Technology of reducing gaseous emissions**

2.1 Clean coal technologies

2.2 Nuclear power plant technologies

# 1.1 Introduction

---

4

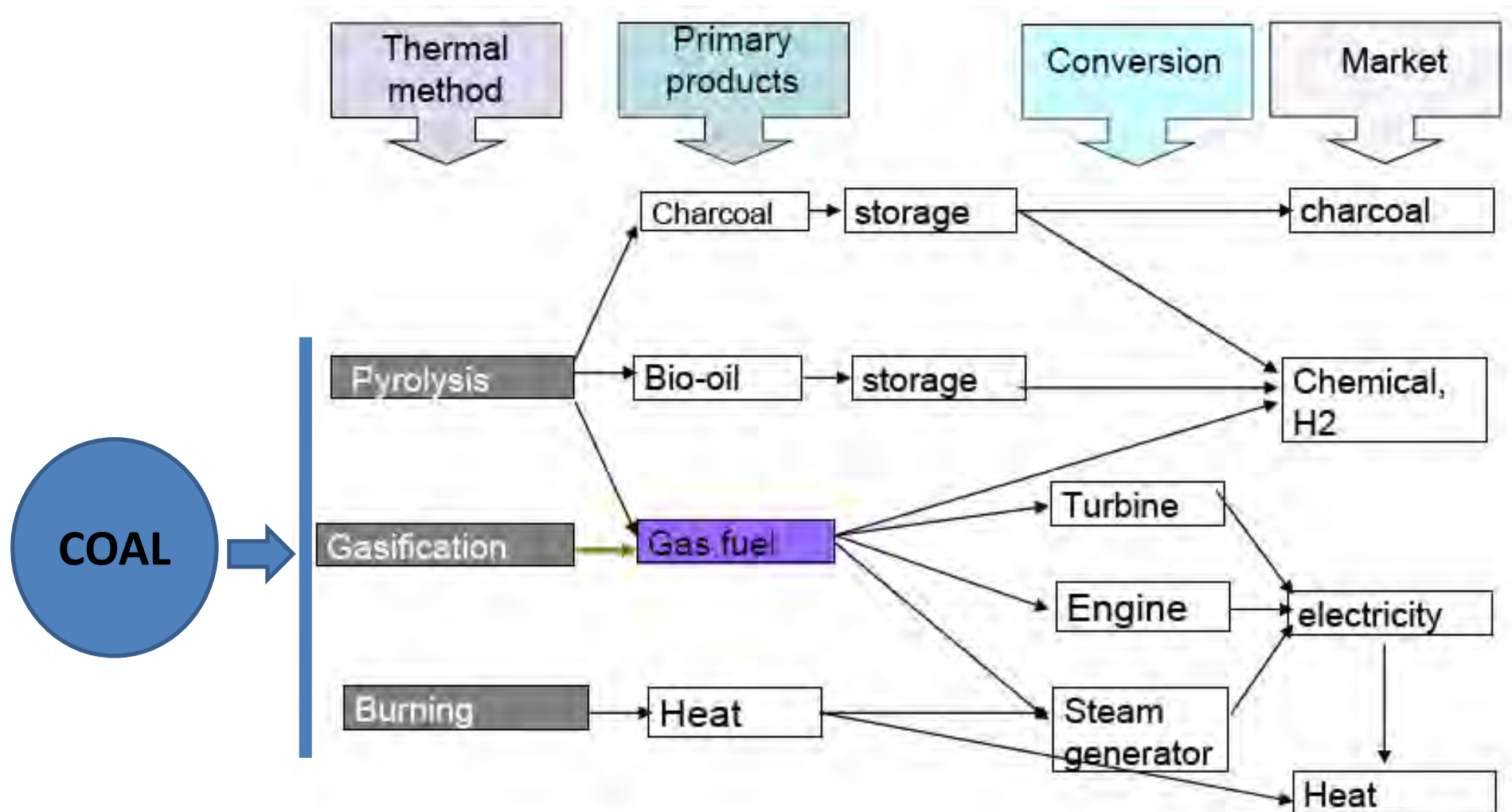
There are brief introduction about:

- **Energy conversion**
- Current energy technology
- Existing CCT and Potential

# Energy conversions/coal

5

Typical example of energy conversion from coal to other energy products



# 1.1 Introduction

---

6

There are brief introduction about:

- Energy conversion
- **Current energy technology**
- Existing CCT and Potential

There are 2 types of fluidized bed combustions which can be used for various kind of coals (lignite, anthracite and bituminous) :

- Pulverized Fuel Combustion (PFC) (for high quality coals such as bituminous and anthracite)
- Fluidized Bed Combustion (FBC) (for low quality coal such as lignite and biomass fuel)

Other types of technology that are currently used in power plant such as :

- Gas Turbine Power plants (GTP)
- Combined Cycle Power Plants (CCPPs) (Combine Gas and Steam Turbine)

# 1.1 Introduction

---

8

There are brief introduction about:

- Energy conversion
- Current energy technology
- **Existing CCT and Potential**



The Clean Coal Technology includes:

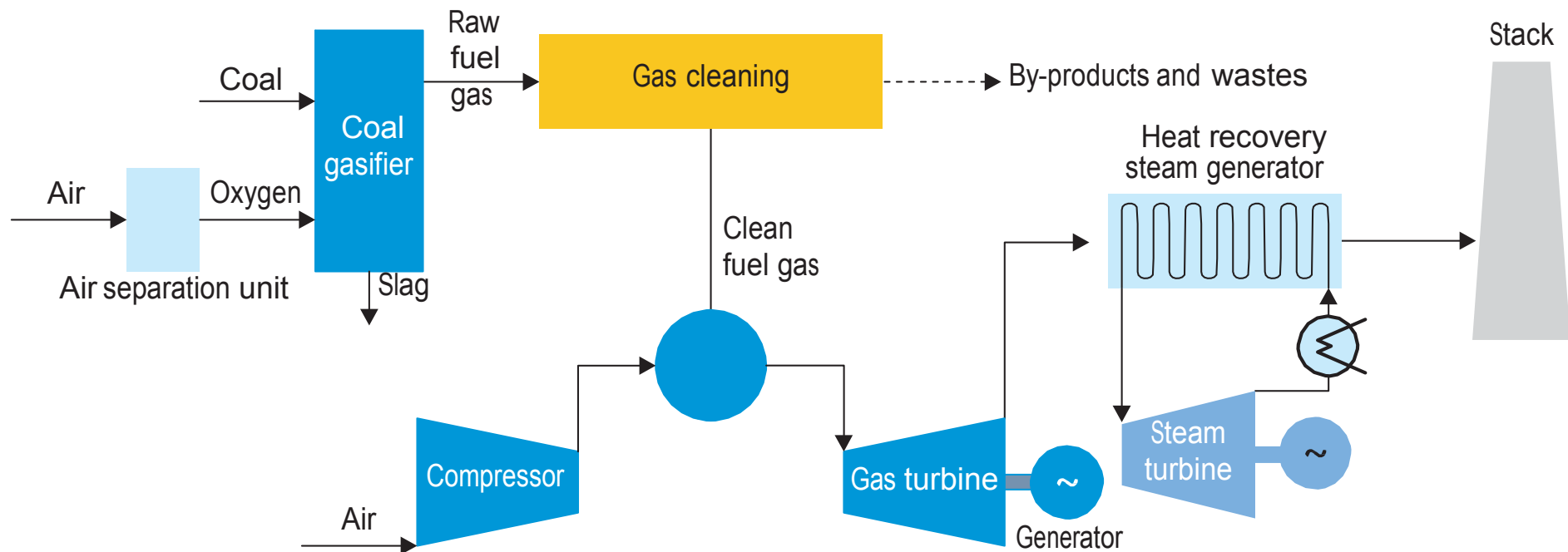
1- The reduction of exhaust gas emission:

- Reduced By Stack Gas Treatment—removal of 99% particulates, 97% SO<sub>x</sub> possible
- Emit low CO<sub>2</sub>, NO<sub>x</sub>

2- The improve of combustion by:

- Advanced Pulverized Fuel Combustion (PFC)
- Advanced Fluidized Bed Combustion (FBC)
- Integrated Gasification Combine Cycle (IGCC)
- Hybrid and Advanced Systems

## Integrated Gasification Combined Cycle (IGCC)

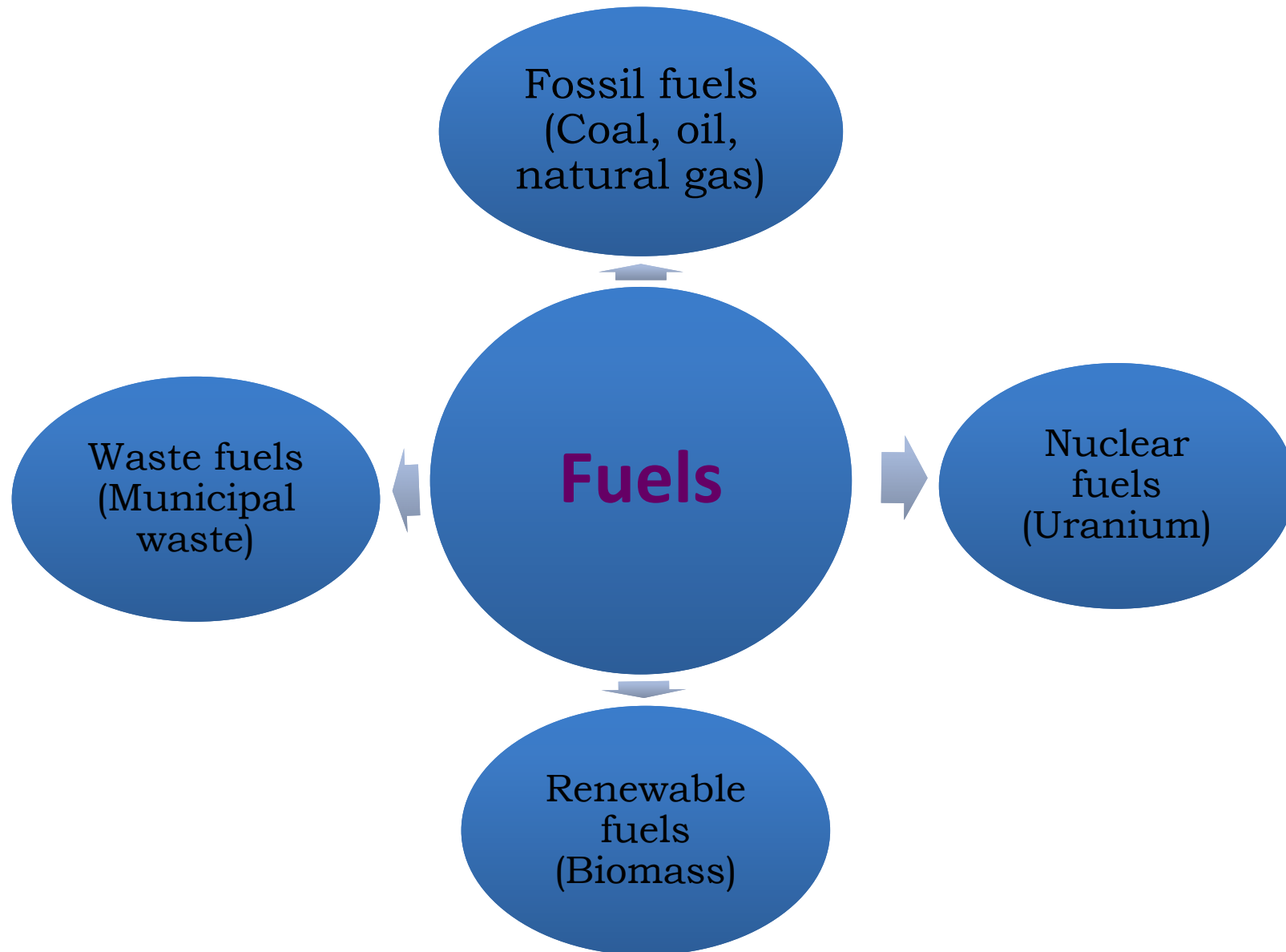


# 1.2 Conventional energy technologies

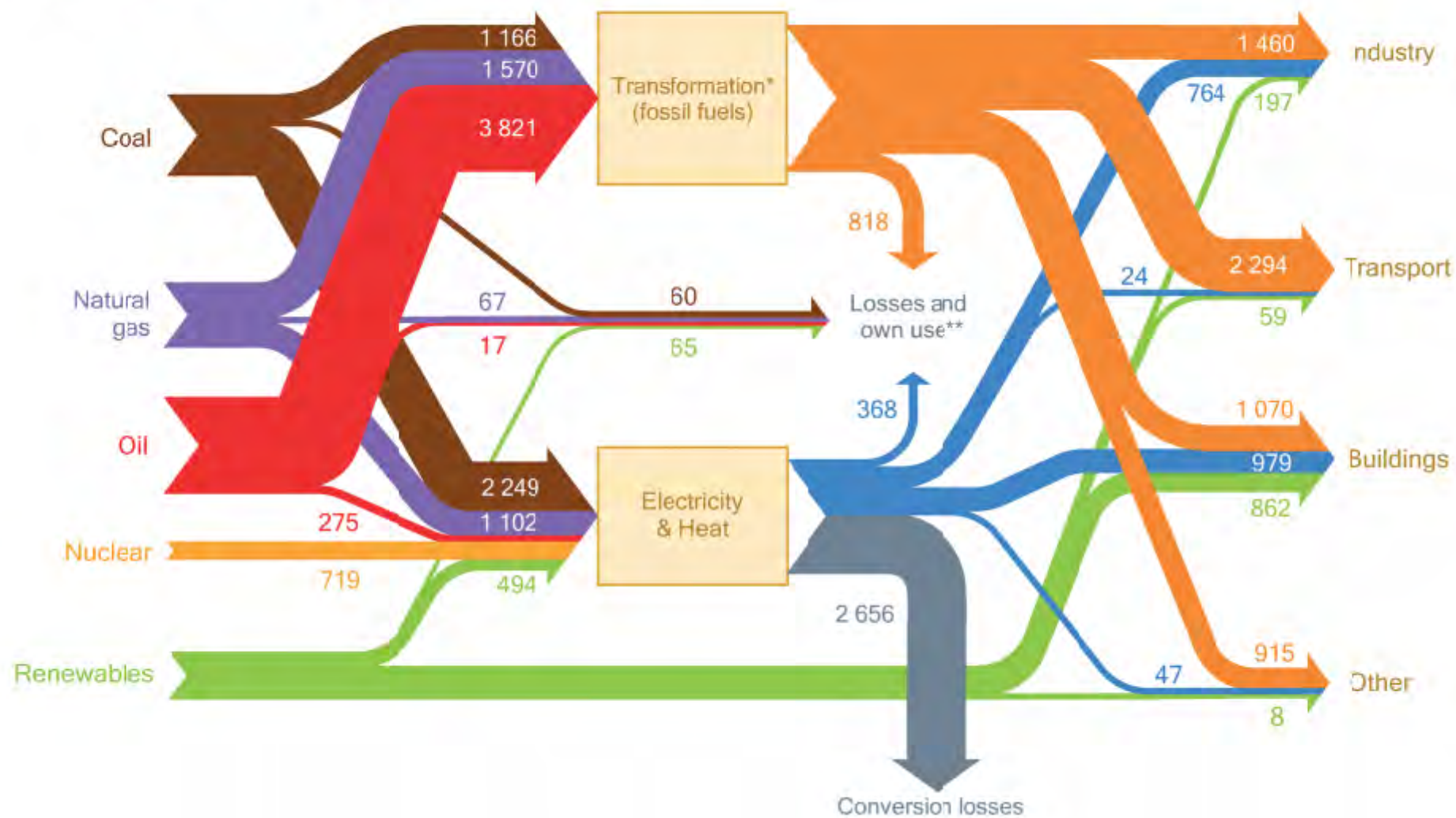
---

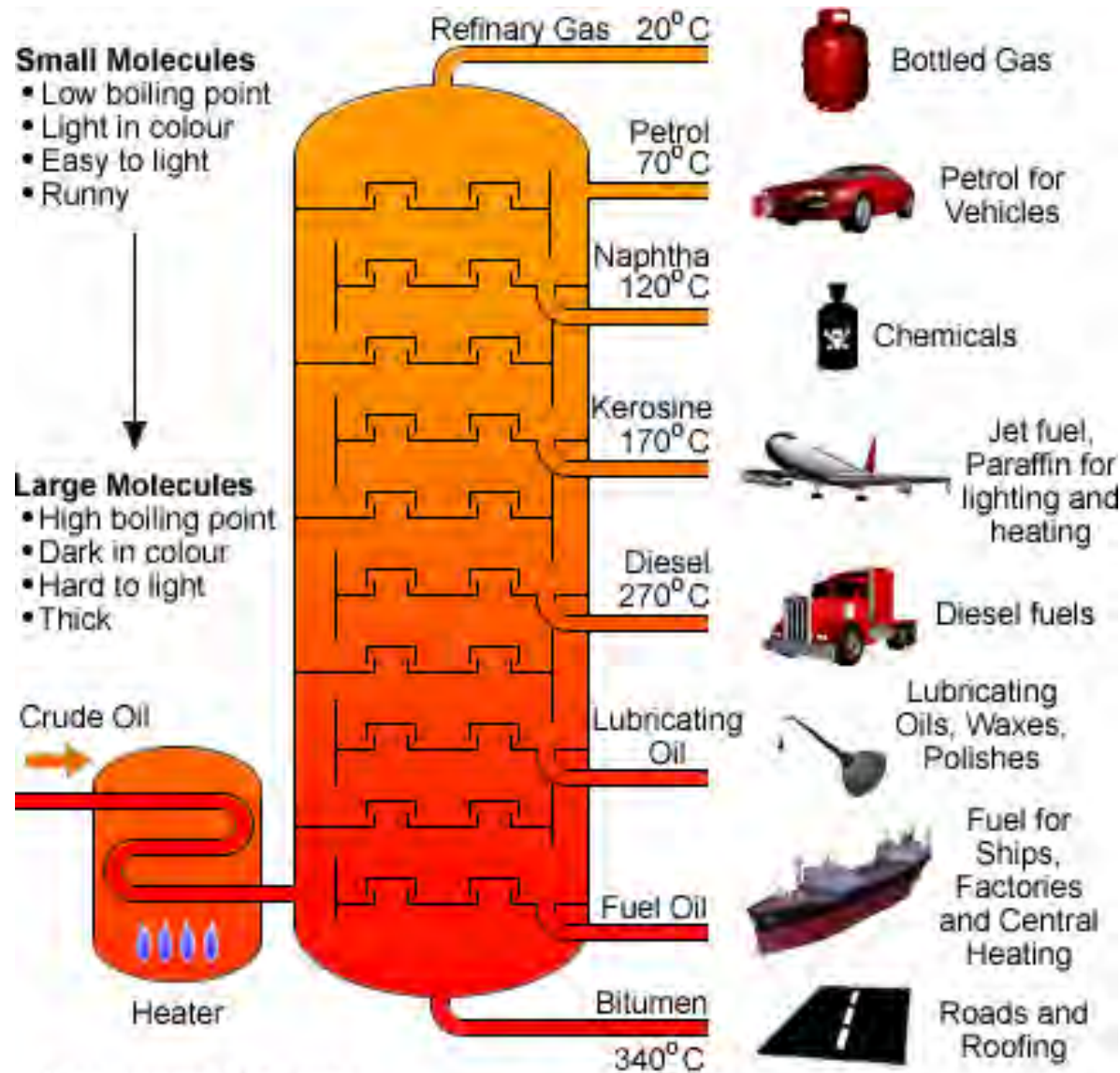
11

- **Fuels**
- Diesel engine basics
- Basic principles (Working cycles)
- Large hydro-energy technology



**Figure 2.8** ▶ The global energy system, 2010 (Mtoe)





Fractionating Column

Copyright © 2009 science-resources.co.uk

## Methods for analysing of coal composition:

### ■ Proximate analysis:

- Fixed carbon (FC),
- Volatile matter (VM),
- Moisture (M),
- Ash (A)

$M^w + VM^w + FC^w + A^w = 100\%$  (wet sample, w)

$C^d + V^d + A^d = 100\%$  (Dry sample)

### ■ Ultimate analysis:

- Carbon (C), Hydrogen (H), sulfur (S), Oxygen (O), Nitrogen (N),  
Ash (A) and moisture (M).

According to ASTM:

$C + H + S + O + N + A + M = 100\%$



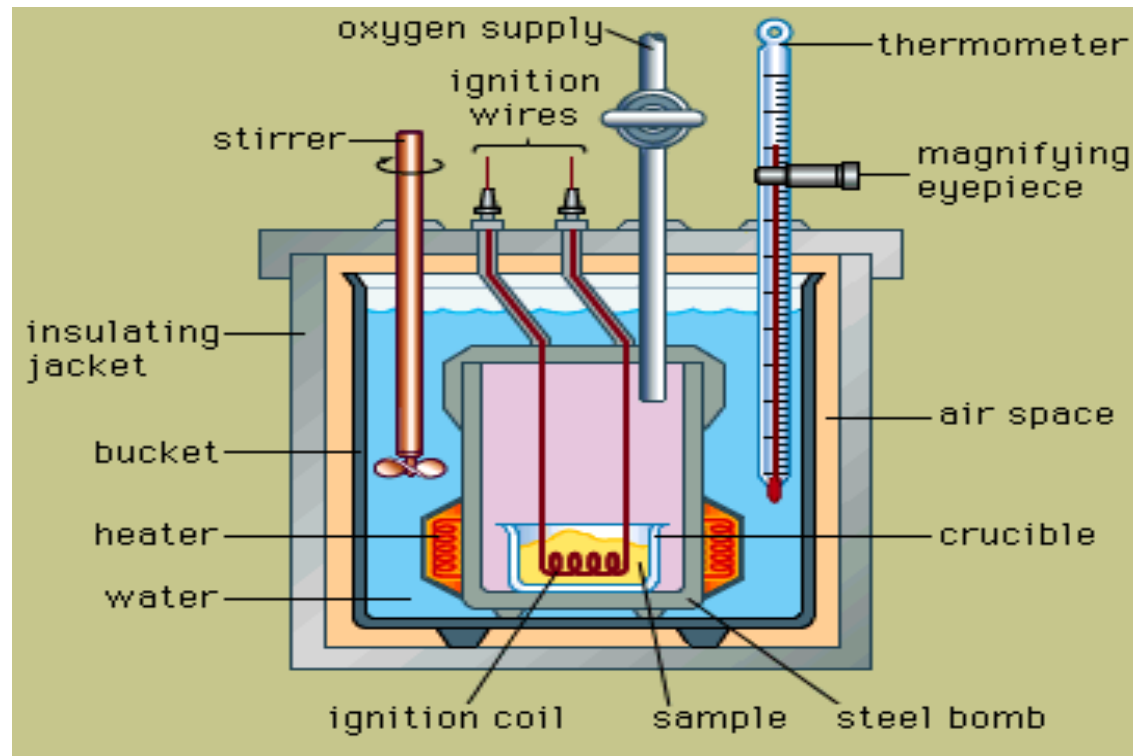


# Fuels/heating value

16

Methods for measuring heating value of fuels:

- Amount of heat released during the combustion of unit quantity of a fuel. (kJ/kg, kCal/kg).
- HHV (Higher heating value)
- LHV (Lower heating value).





# 1.2 Conventional energy technologies

---

17

- Fuels
- **Diesel engine basics**
- Basic principles (Working cycles)
- Large hydro-energy technology

## 1.2 Diesel engine basics

18

- Operation/condition
- Engine system/Operating cycle



## 1.2 Diesel engine basics/operation

19

### ■ Advantage of diesel engine

- Easy to design and install
- Available in standard capacities
- Can respond to load change without much difficulty
- Less standby loss
- Occupy less space
- Can be started and stopped quickly
- Require less cooling water
- Less capital cost
- Less operating and supervising staffs
- High efficiency from fuel to electricity
- Less civil engineering work
- Can be located near to load center
- No ash handling problem
- Easier lubrication system

### ■ Advantage of diesel engine

- High operating cost
- High maintenance and lubrication cost
- Capacity is restricted, can not be of very big size
- Noise problem
- Can not supply overload
- Unhygienic emissions

## 1.2 Diesel engine basics/operation

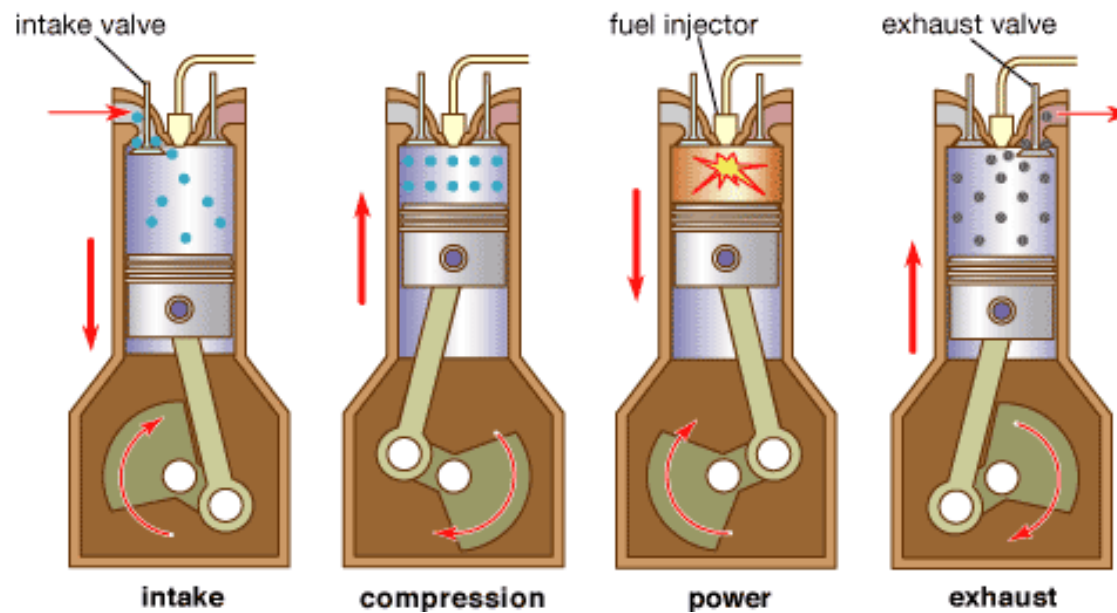
- Engine size ranging from 1-1000 kW in size.
- Electricity output can be in 2 phases or 3 phases.
- Operated mostly in factories, Hotel, public building, Rural Electrification Enterprise (REE) and EDC
- Electricity output can be costly due to consumption of high cost diesel fuel
- Unit cost of each generator is low compared to coal power plants



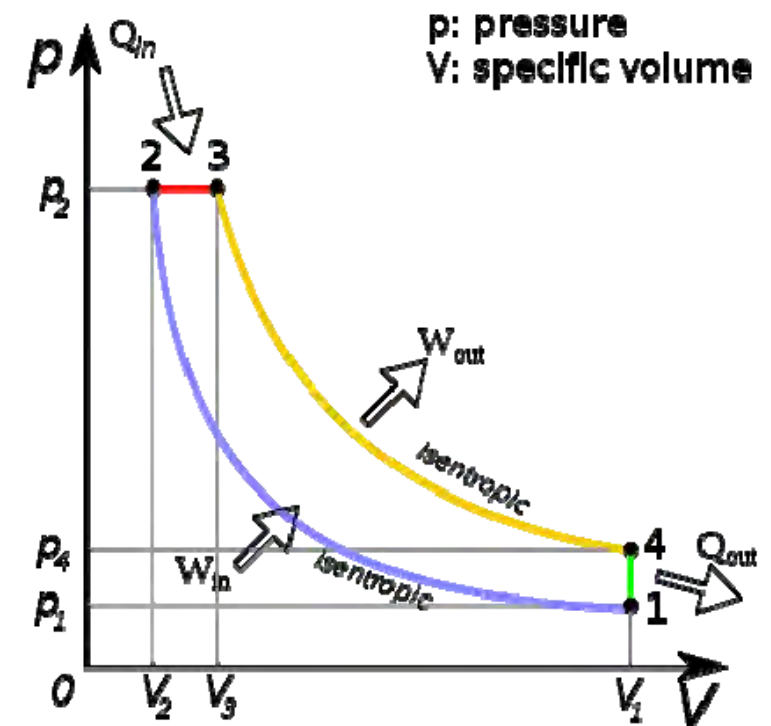
## 1.2 Engine system/operating cycle

21

Basic components of diesel engine



Working stroke of diesel engine



Working cycle of diesel engine

# 1.2 Conventional energy technologies

---

22

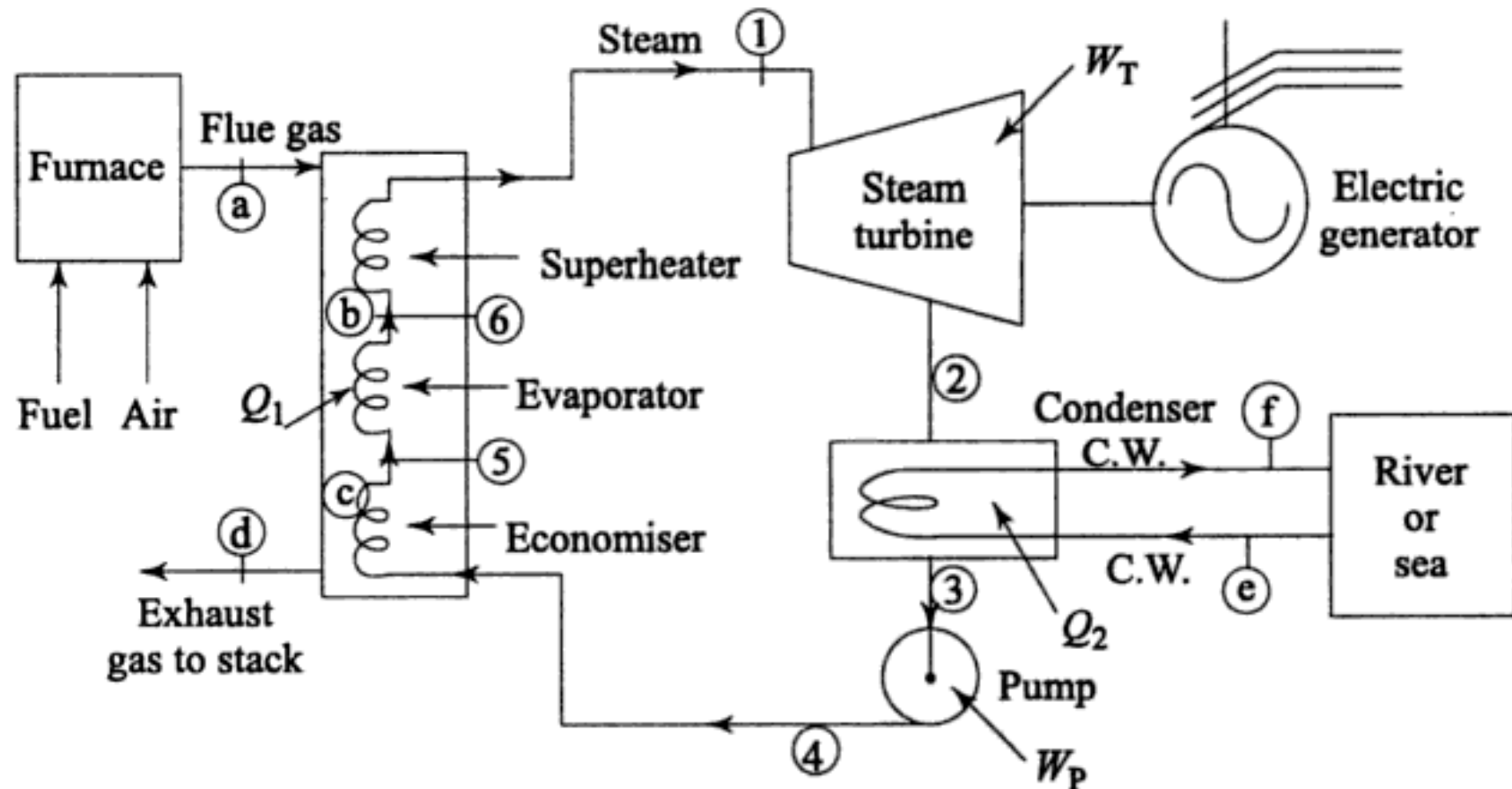
- Fuels
- Diesel engine basics
- **Basic principles (Working cycles)**
- Large hydro-energy technology

There are 3 working cycles that are mostly in use in power plants such as:

- Rankine cycle (for steam turbine)
- Brayton cycle (for gas turbine)
- Combined cycle (for gas and steam turbines)

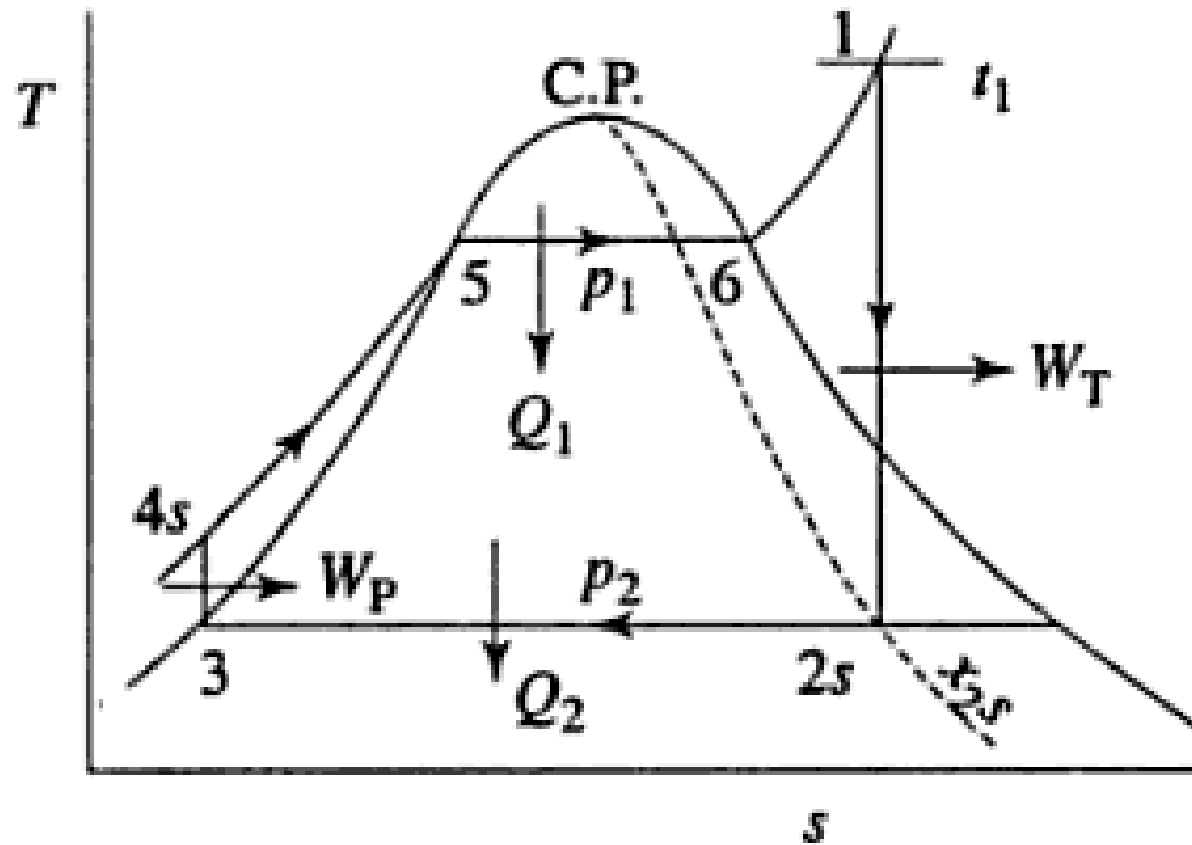
# Basic principles (working cycle)/Rankine cycle

24



A simple steam plant representing Rankine cycle





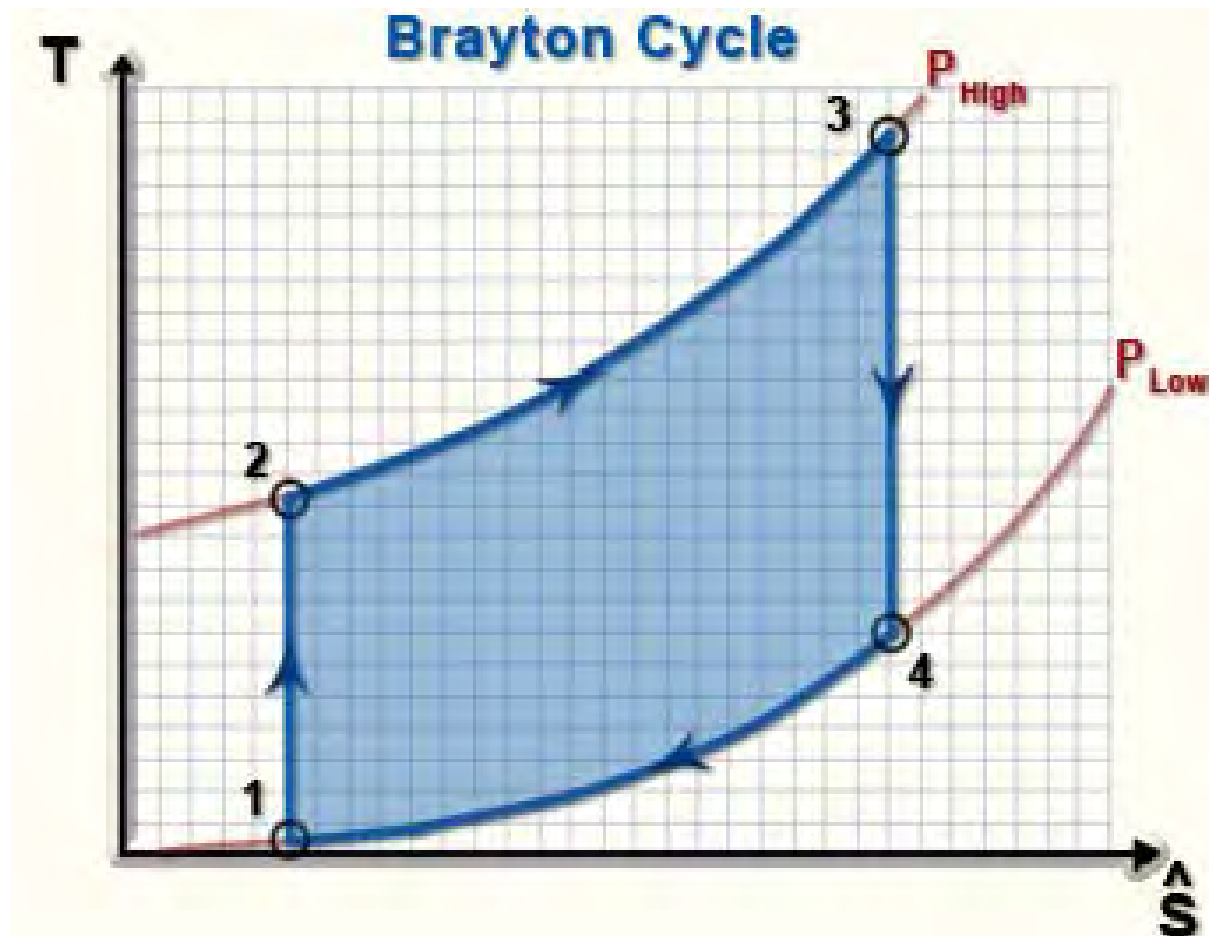
$$\eta_{\text{cycle}} = \frac{W_{\text{net}}}{Q_1} = \frac{W_T - W_P}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

## Approximate performance data of various steam power plants

	Watt's beam engine	1 MW locomotive steam engine	2 MW marine steam engine	30 MW(e) steam power plant	660 MW(e) steam power plant
Thermal efficiency (%)	2	7	20	35	44
Initial pressure (bar)	2	15	15	40	160
Initial temperature (°C)	100	300	250	450	540
Reheat pressure (bar)	–	–	–	–	40
Reheat temperature (°C)	–	–	–	–	540
Exhaust pressure (bar)	near 1	1.2	0.1	0.045	0.045
Exhaust condition	wet	near sat	wet	0.9, dry	0.9, dry
Feedwater heaters	–	–	–	4	7

## Basic principles (working cycle)/Brayton cycle

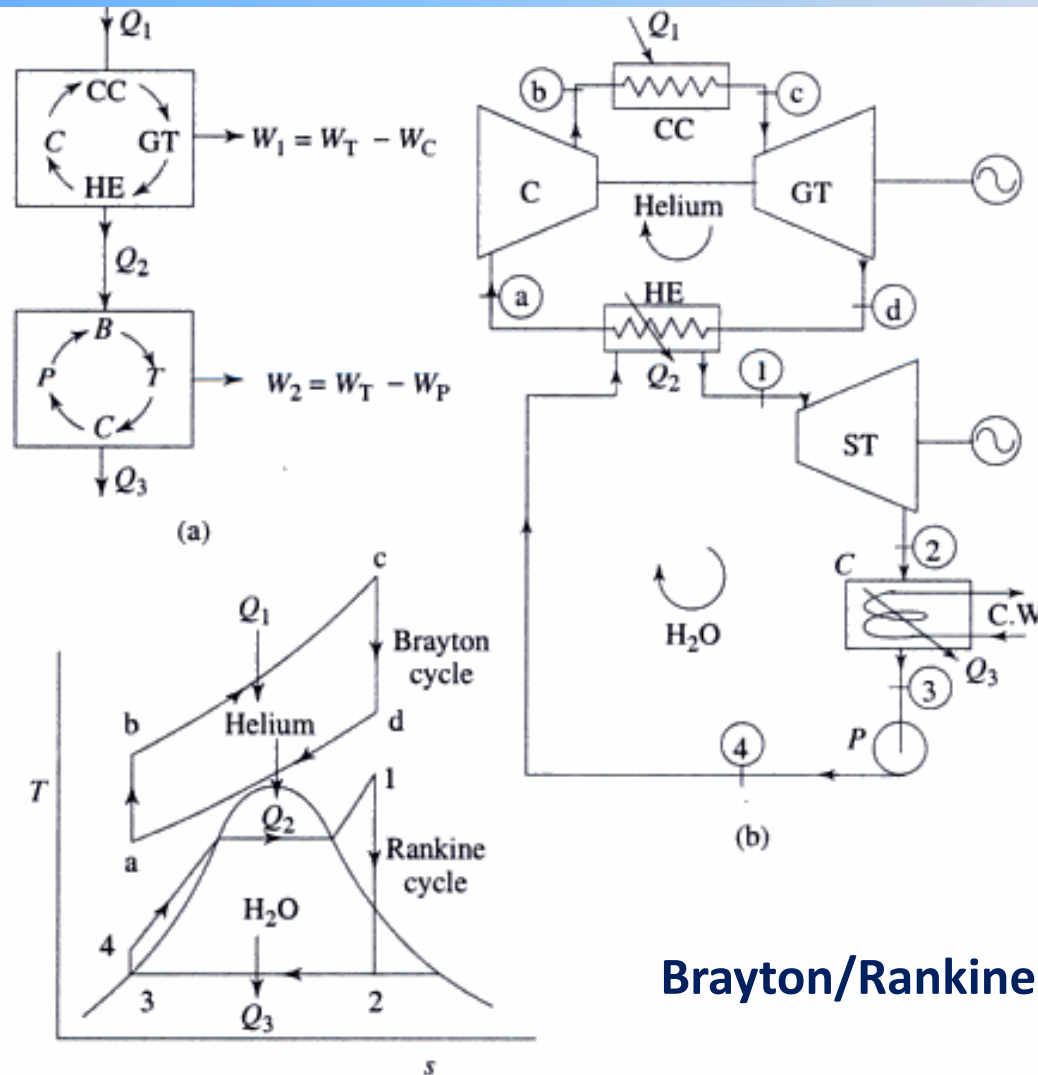
27



$$\eta_{th, \text{Brayton}} = \frac{W_{net}}{Q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{Cp(T_4 - T_1)}{Cp(T_3 - T_2)} = 1 - \frac{T_1 \left( \frac{T_4}{T_1} - 1 \right)}{T_2 \left( \frac{T_3}{T_2} - 1 \right)}$$

# Basic principles (working cycle)/Combine cycle

28



**Brayton/Rankine combine cycle plant**

$$\eta = \eta_1 + \eta_2 - \eta_1 \eta_2$$

where  $\eta_1$  and  $\eta_2$  are the thermal efficiencies of the Brayton cycle and the Rankine cycle, respectively.

Fuel	:	Natural gas
GT output	:	69.1 MW
ST output	:	78.3 MW
Station service power	:	2.1 MW
Heat input to GT (LHV)	:	230.0 MW
Heat input to the supplementary firing unit (LHV)	:	79.6 MW
Efficiency of the GT cycle	:	30.0%
Energy in the exhausts	:	159.3 MW
Efficiency of the steam cycle	:	32.9%
Net efficiency of the plant	:	46.9%

**A typical efficiency of combined cycle**

### Comparison of steam power plant before and after repowering to a combine cycle plant

	<i>Before repowering</i>	<i>After repowering</i>
Net output from power plant	30.3 MW	102.2 MW
Power output from ST	32.0 MW	35.0 MW
Power output from GT	–	68.4 MW
Station service power	1.7 MW	1.2 MW
Heat input	107 MW	228 MW
Net efficiency	28.3%	44.8%

Merit: The advantage of combine cycle is the high overall thermal efficiency. It means that it reduces the operational cost (fuel cost)

Demerit: High construction cost

# 1.2 Conventional energy technologies

---

31

- Fuels
- Diesel engine basics
- Basic principles (Working cycles)
- **Large hydro-energy technology**

# Large hydro-energy technology

32

Hydro energy is the energy from the falling/flowing of water. It can be categorized with various sizes through its output capacity. Large hydro power is called when the output capacity is more than 100 MW. Mostly, large hydro needs big water reservoir/big flow of water. It can be run in the main rivers, canal...

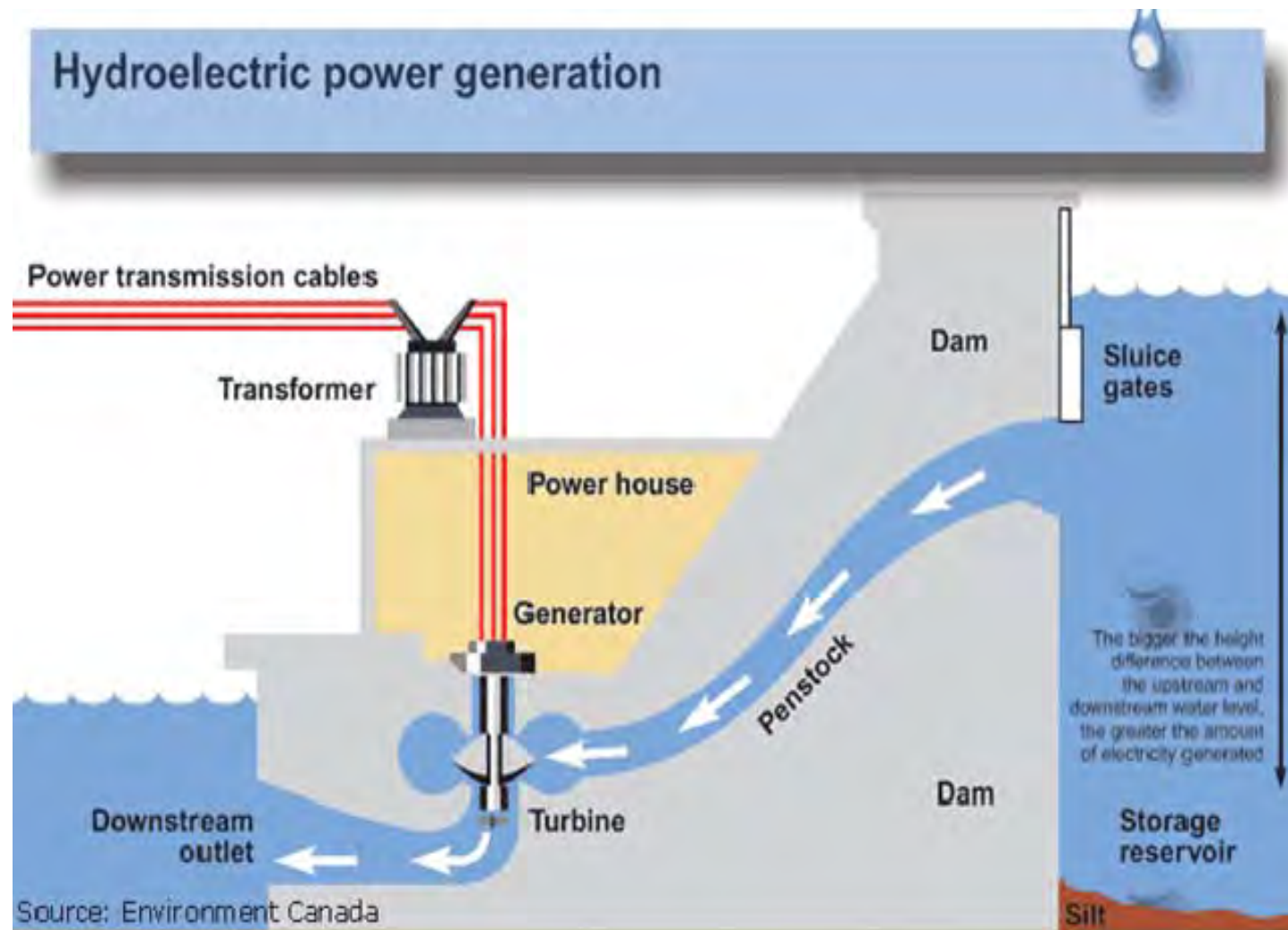


Pico	0 kW – 5 kW
Micro	5 kW – 100 kW
Mini	100 kW – 1 MW
Small	1 MW – 10 MW
Medium	10 MW – 100 MW
<b>Large</b>	<b>100 MW+</b>



# Large hydro components

33



Main components of large hydro-electric power generation are: Reservoir, Dam, Sluice gates, Penstock, Power house (Turbine, Generator, Power house), Spill ways.....

1. Fuel is not burned so there is minimal pollution
2. Water to run the power plant is provided free by nature
3. Hydropower plays a major role in reducing greenhouse gas emissions
4. Relatively low operations and maintenance costs
5. The technology is reliable and proven over time
6. It's renewable - rainfall renews the water in the reservoir, so the fuel is almost always there

1. High investment costs
2. Hydrology dependent (precipitation)
3. In some cases, inundation of land and wildlife habitat
4. In some cases, loss or modification of fish habitat
5. Fish entrainment or passage restriction
6. In some cases, changes in reservoir and stream water quality
7. In some cases, displacement of local populations
8. Large hydro power is not sustainable.

# 1.3 Thermal power plant technologies

---

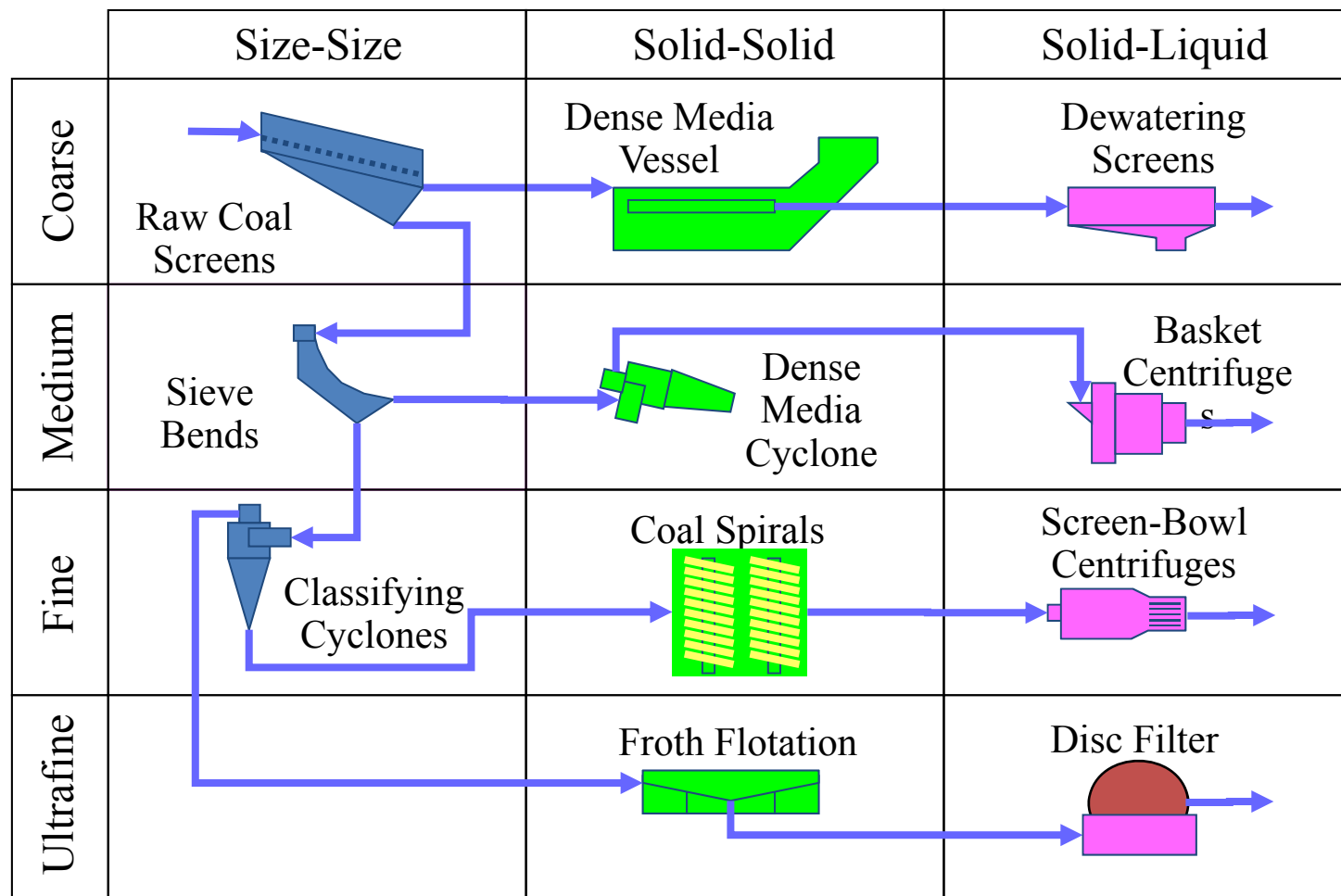
36

- Coal preparation system
- Coal combustion technologies
- Steam turbine
- Gas turbine
- Waste heat recovery
- Co-generation

# Coal preparation

37

In pulverized coal combustion, the coal is prepared through various mechanical processes to get fine size and in various states. Following diagram shows those preparation processes:

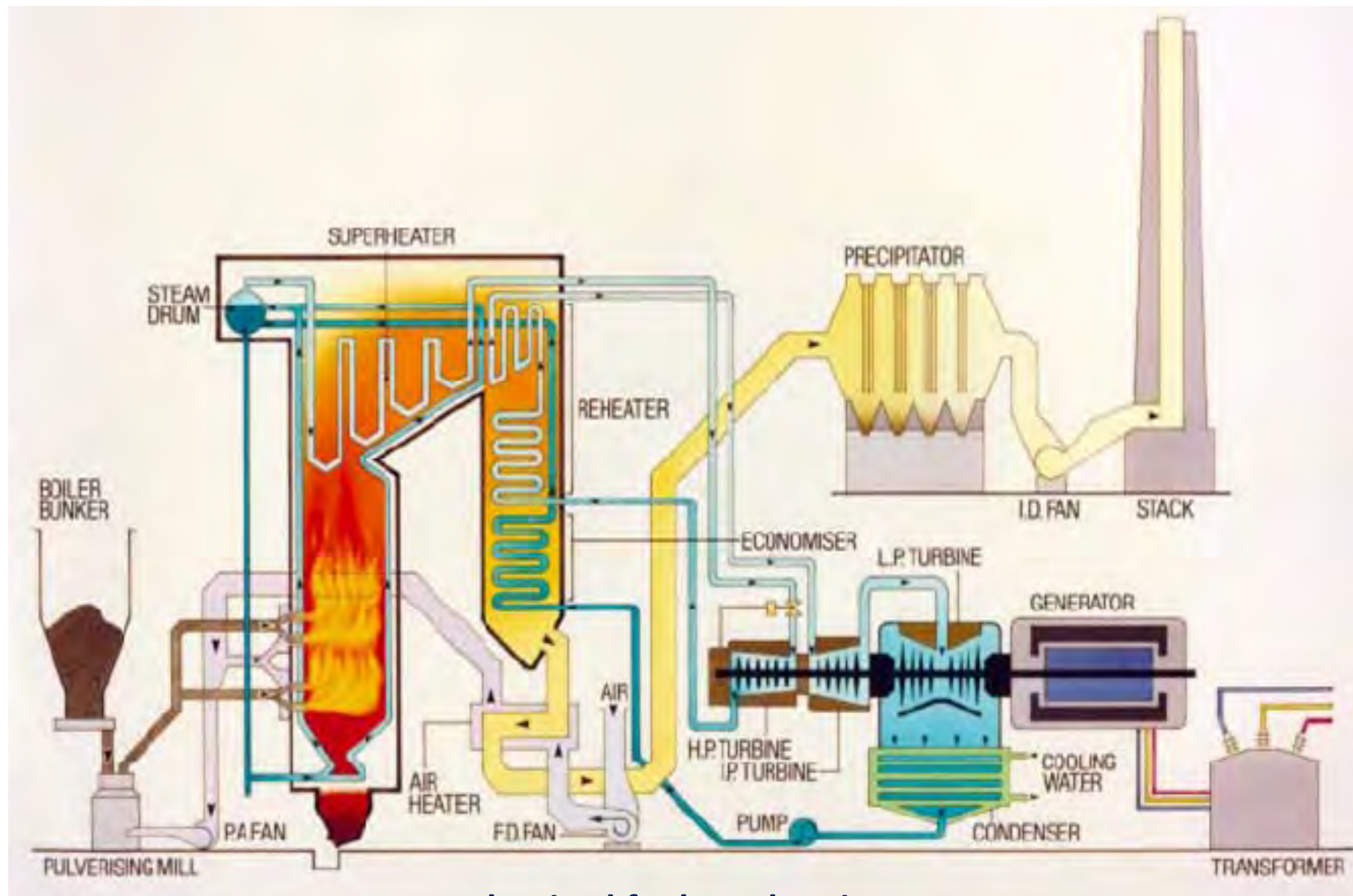


# 1.3 Thermal power plant technologies

---

38

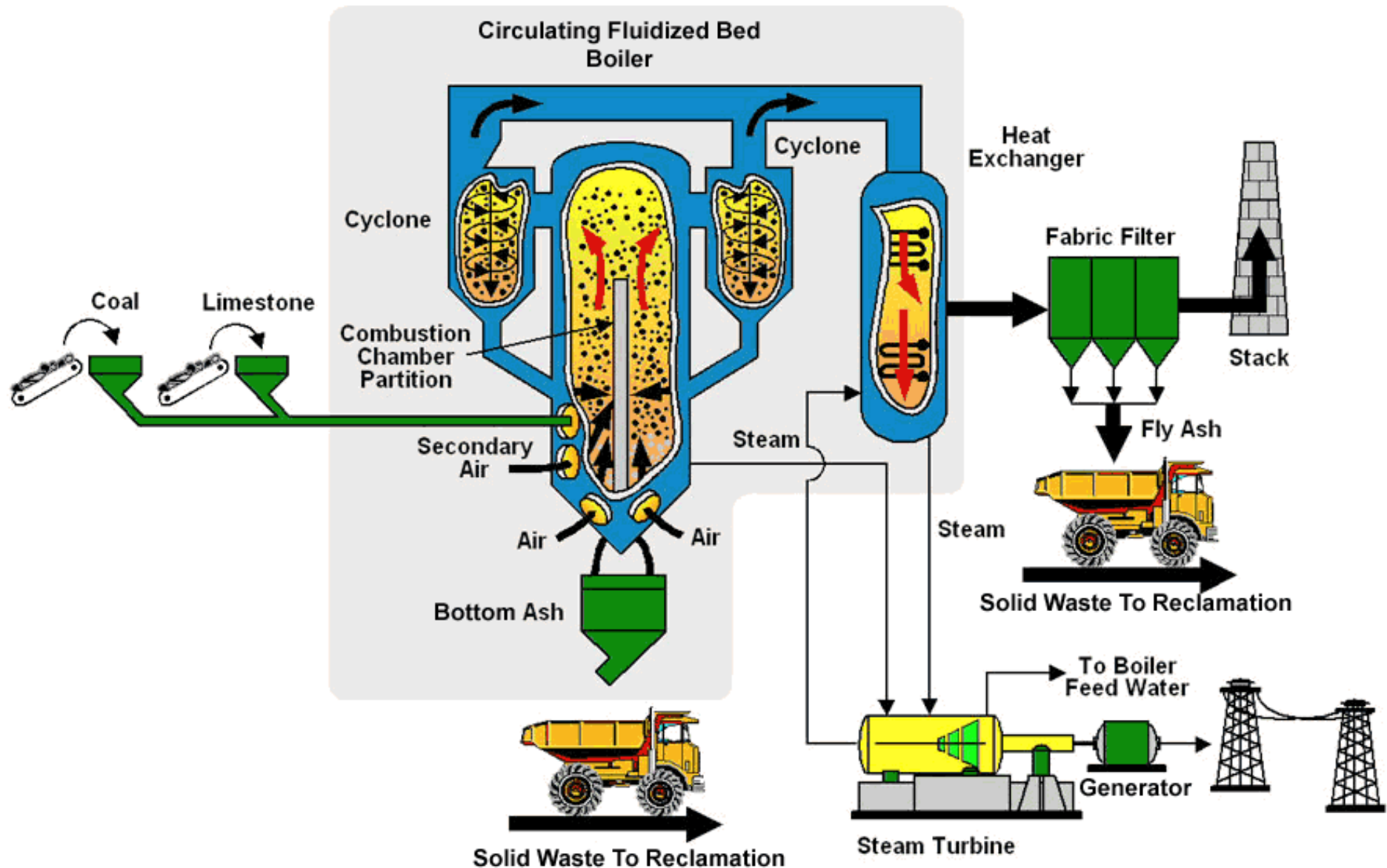
- Coal preparation system
- **Coal combustion technologies**
- Steam turbine
- Gas turbine
- Waste heat recovery
- Co-generation



**Pulverized fuel combustion system**

# Coal combustion technologies/FBC

40



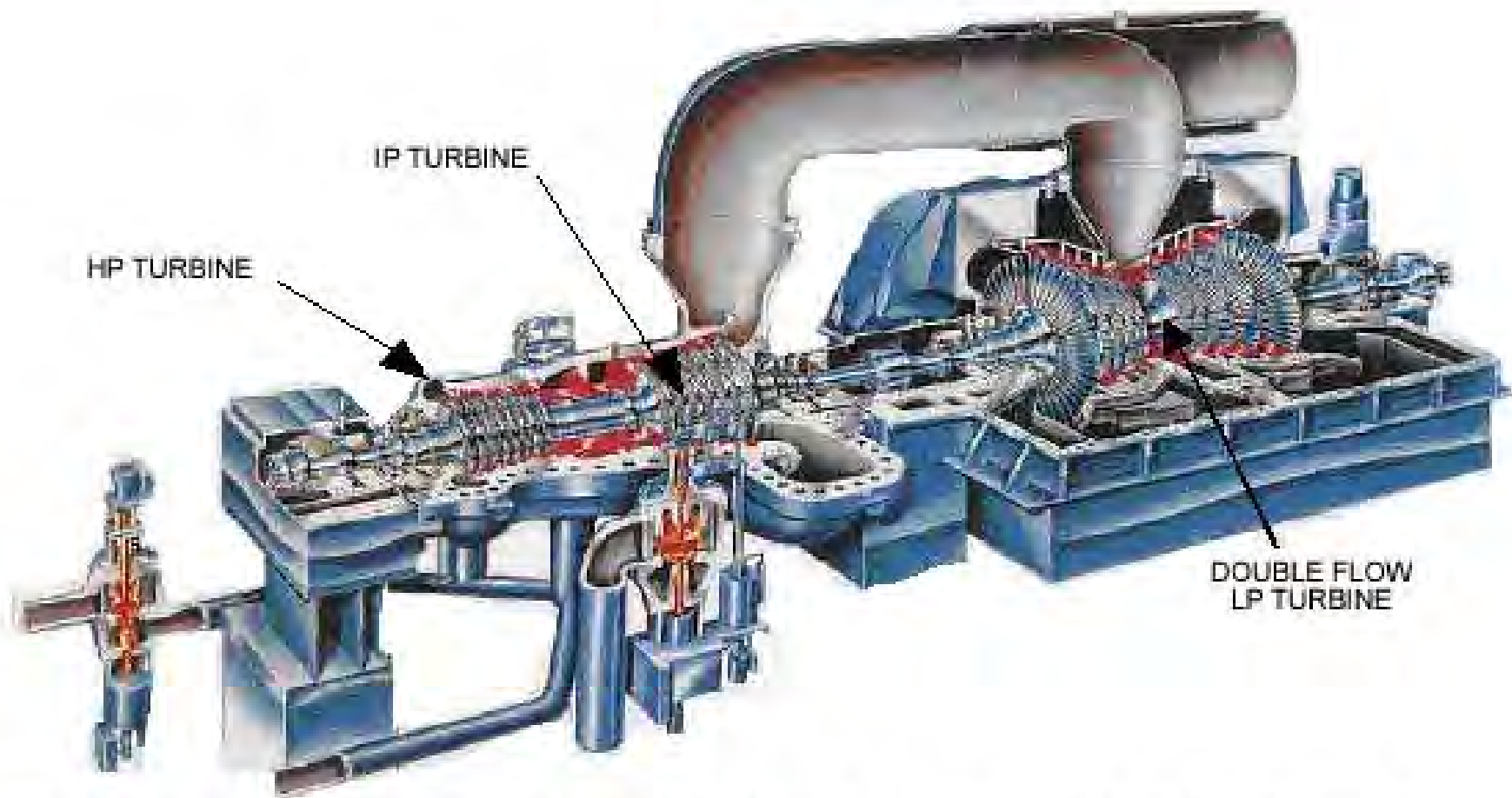


# 1.3 Thermal power plant technologies

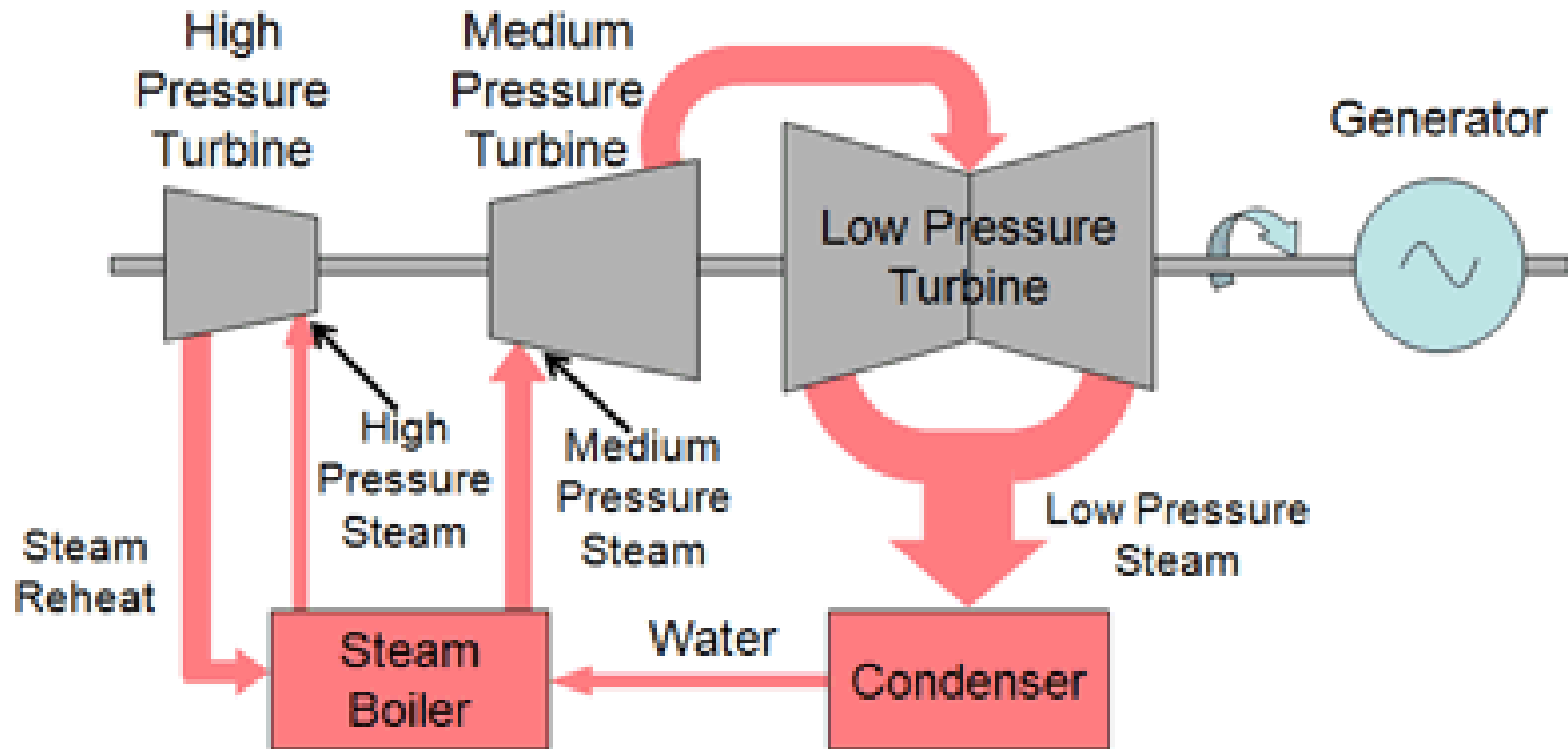
---

41

- Coal preparation system
- Coal combustion technologies
- **Steam turbine**
- Gas turbine
- Waste heat recovery
- Co-generation



**VIEW OF THE INTERNALS OF A TYPICAL POWER STATION STEAM TURBINE**



**Multi Stage Steam Turbine Generator**

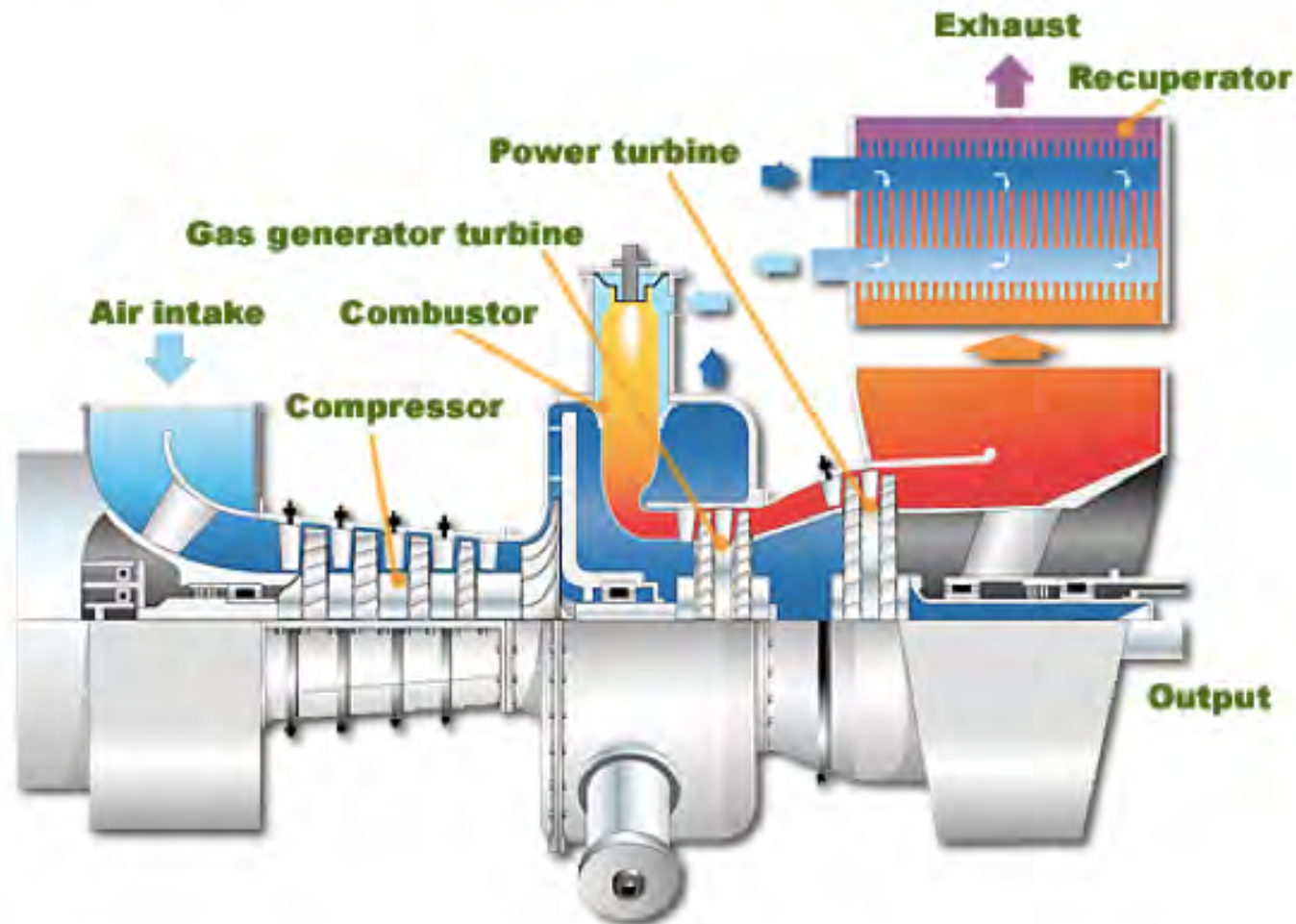
# 1.3 Thermal power plant technologies

---

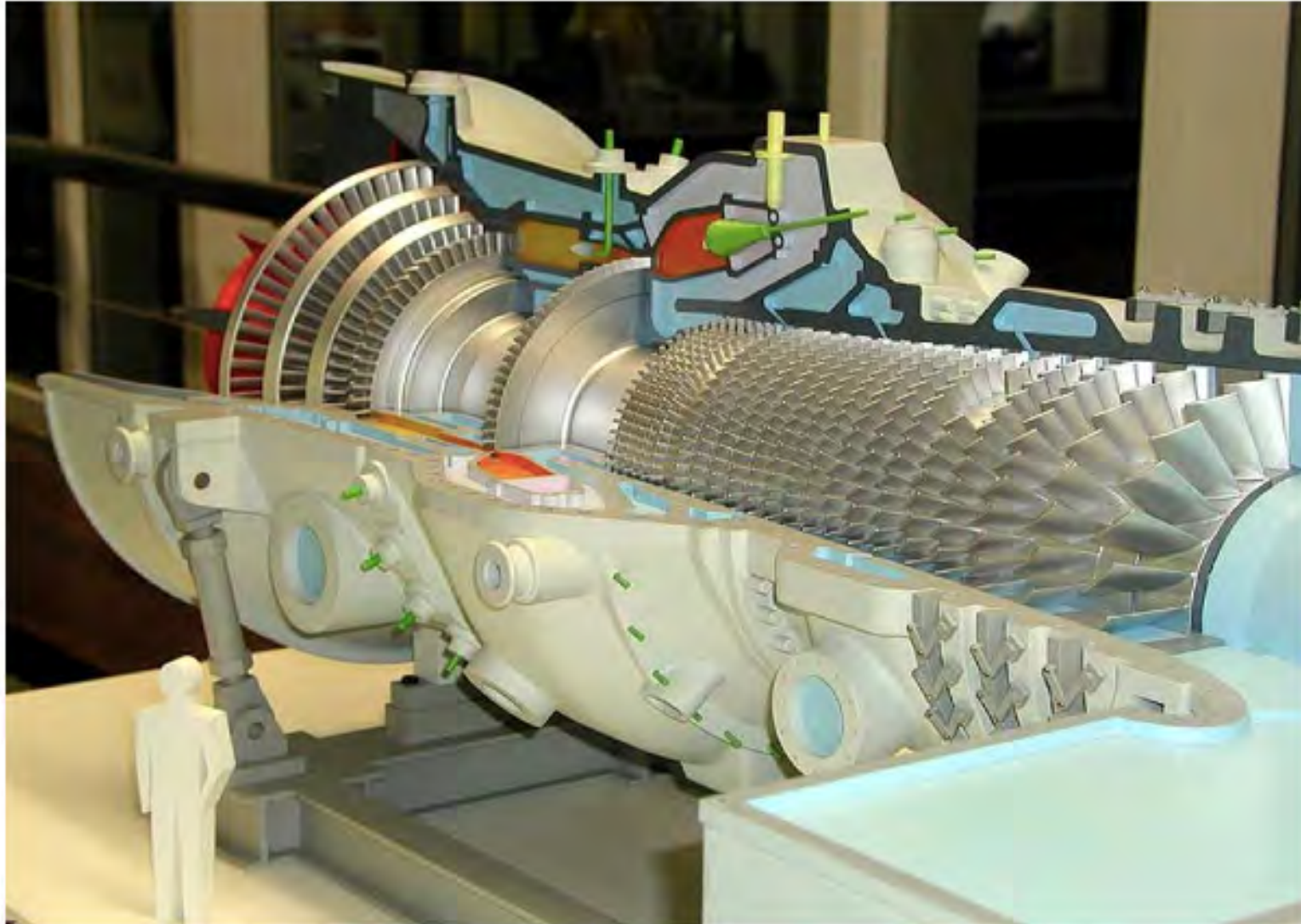
44

- Coal preparation system
- Coal combustion technologies
- Steam turbine
- **Gas turbine**
- Waste heat recovery
- Co-generation

## Components and working principle of gas turbine

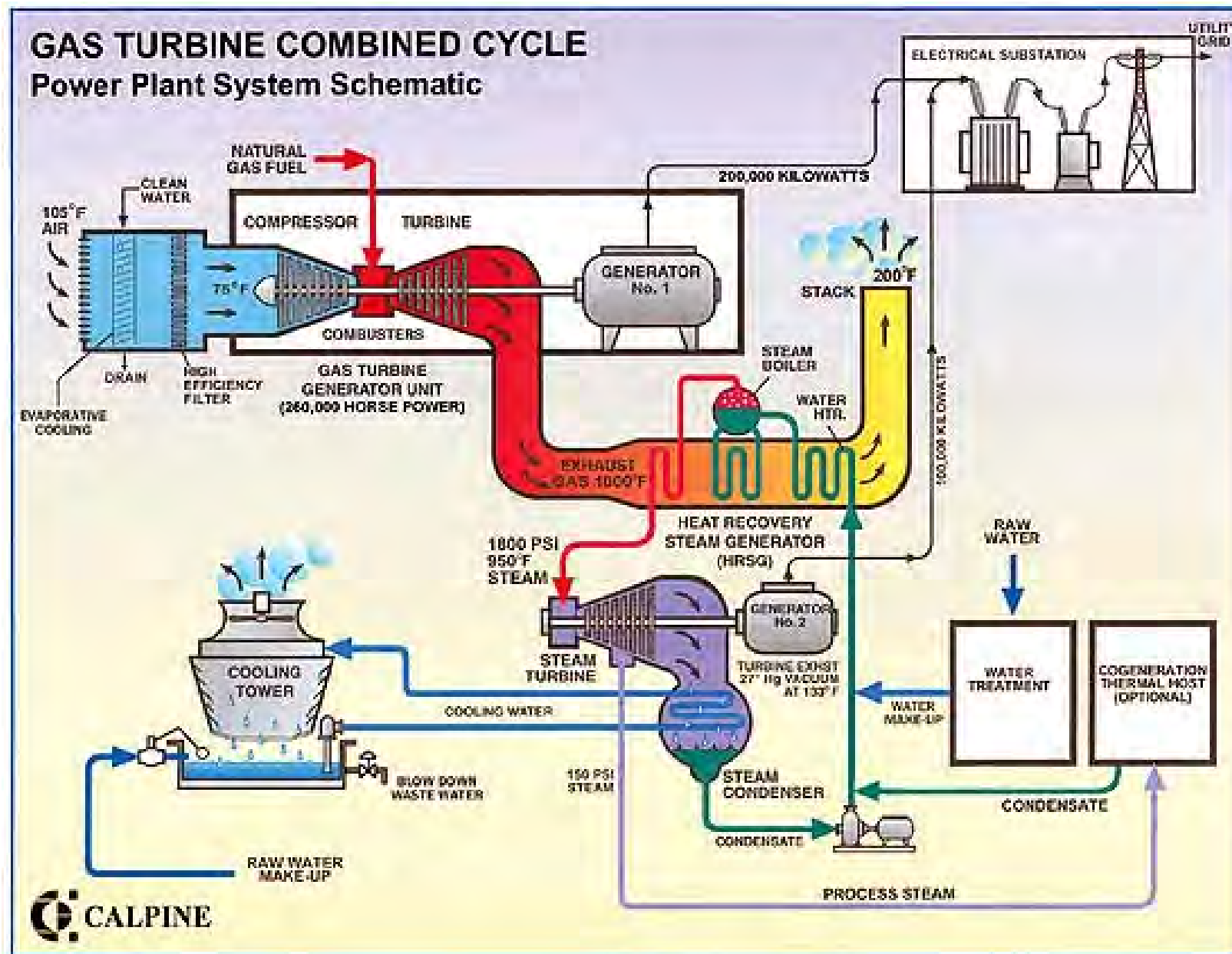


## Overall structure of gas turbine



# Combined cycle power plant (CCPP)

47



# 1.3 Thermal power plant technologies

---

48

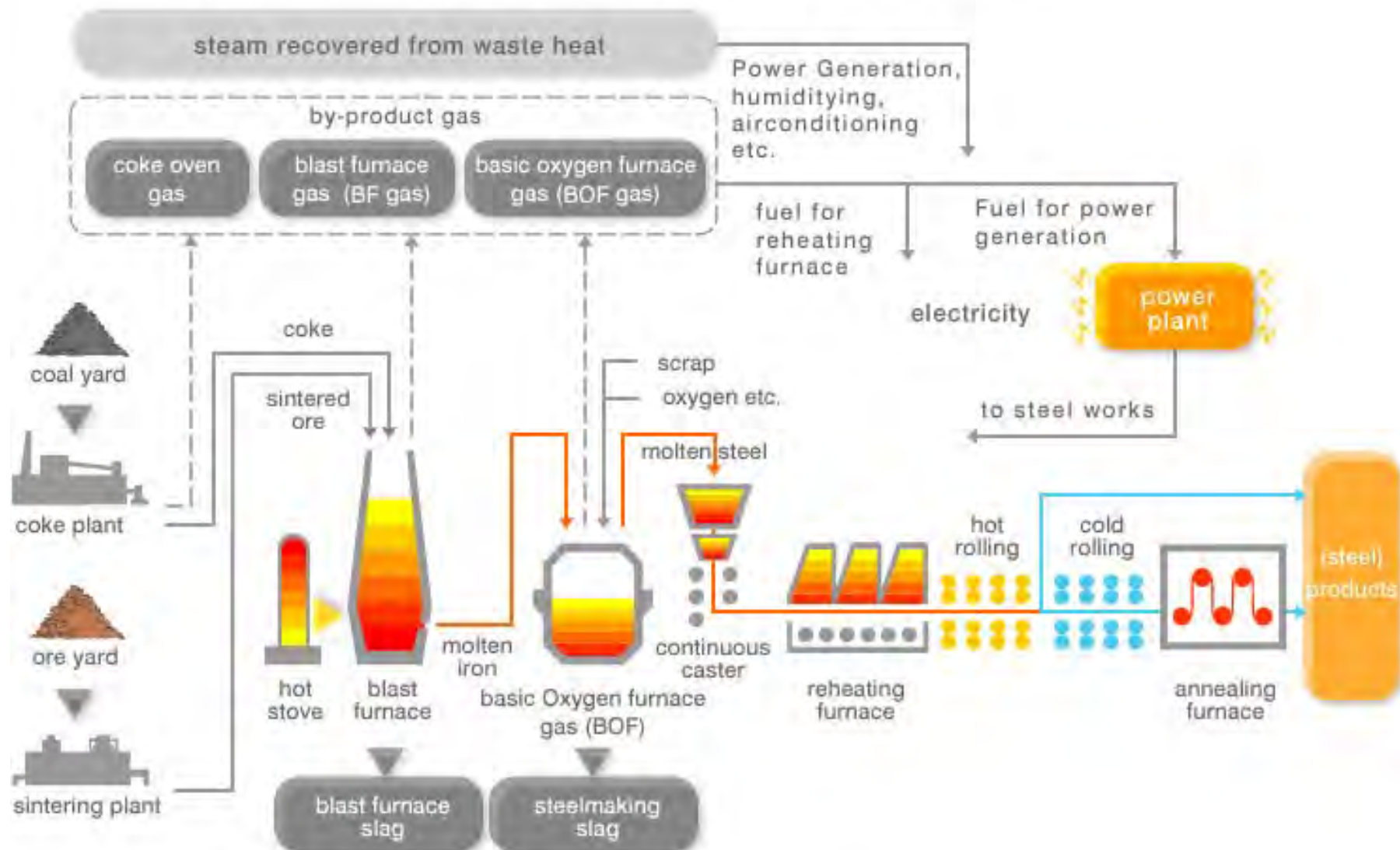
- Coal preparation system
- Coal combustion technologies
- Steam turbine
- Gas turbine
- **Waste heat recovery**
- Co-generation



# Waste heat recovery/steel industry

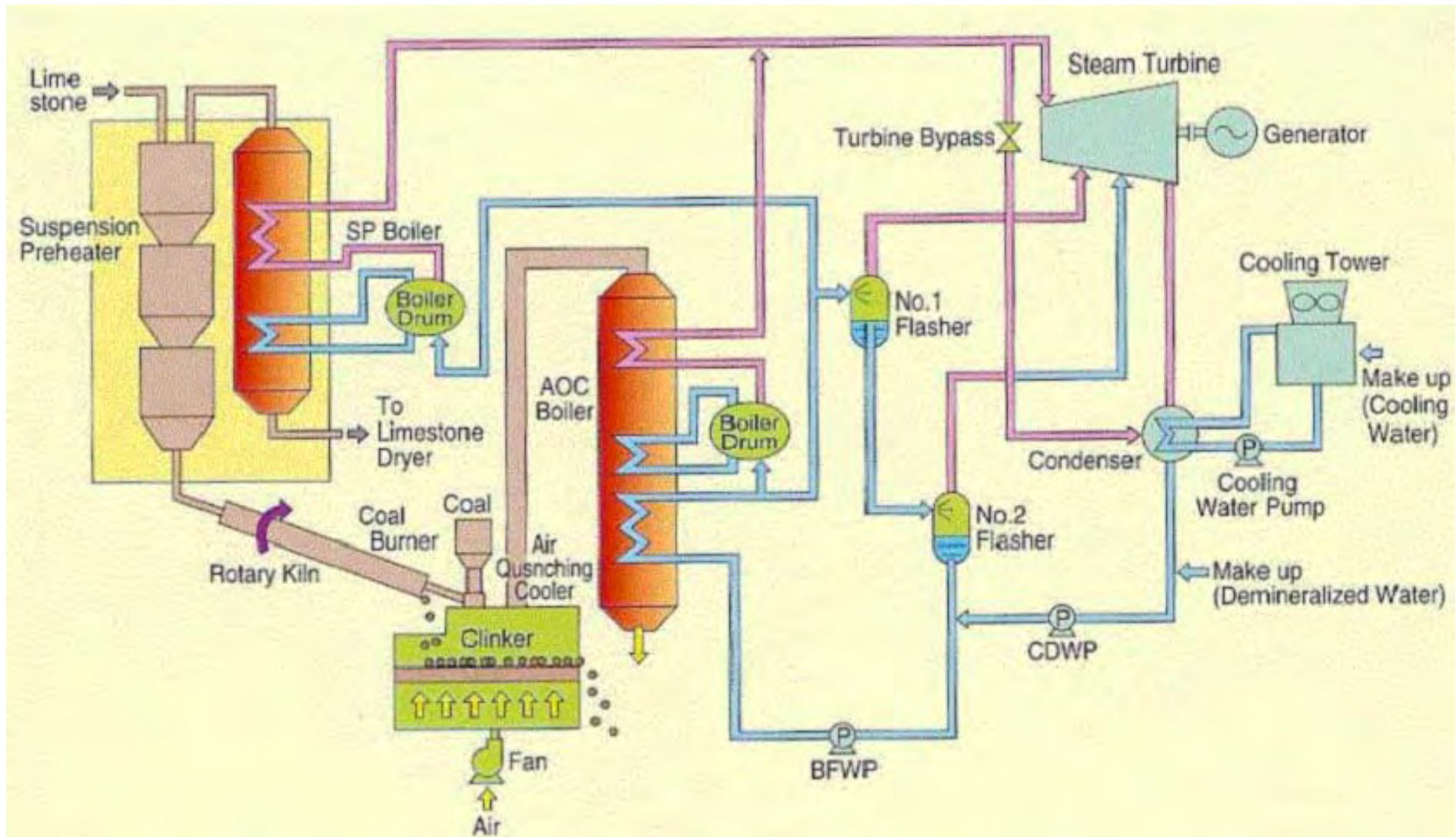
49

Current waste heat recovery in steel works



# Waste heat recovery/Cement plant

50



# 1.3 Thermal power plant technologies

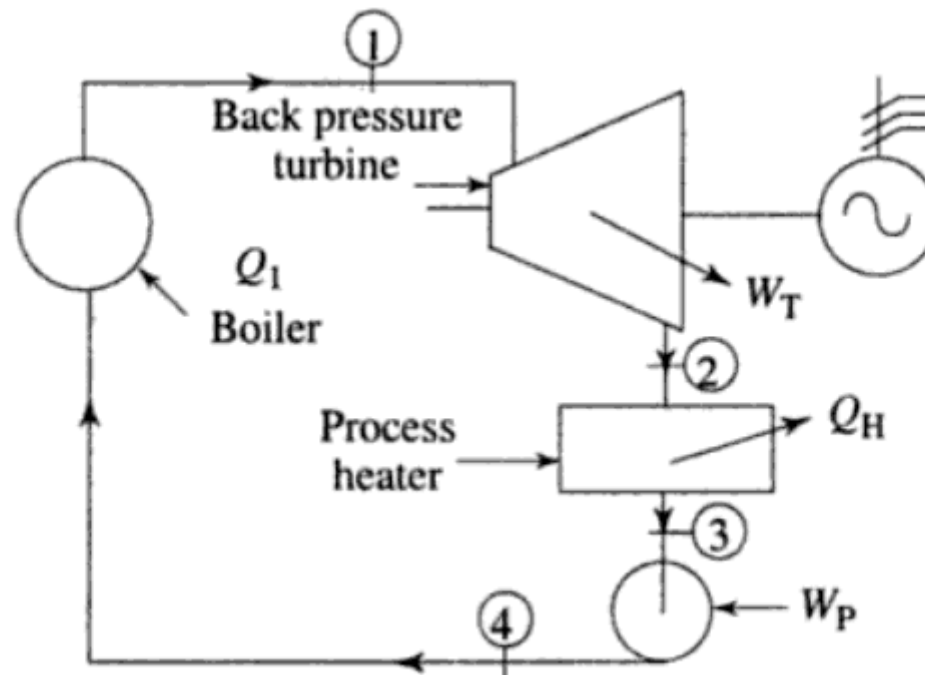
---

51

- Coal preparation system
- Coal combustion technologies
- Steam turbine
- Gas turbine
- Waste heat recovery
- **Co-generation**

Co-generation is the generation of electricity and useful heat jointly, especially the utilization of the steam left over from electricity generation for heating.

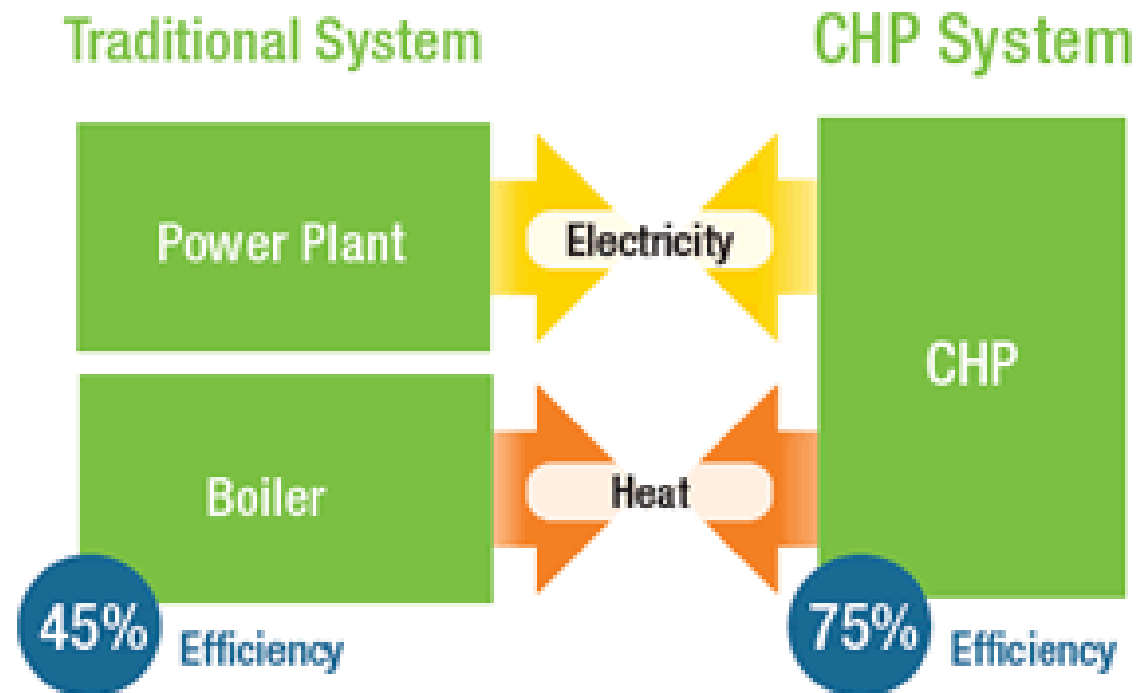
Some industries that are using co-generation such as paper mill, textile mill, chemical factories, jute mills, sugar factories, palm oil factory, rice mills and so on.

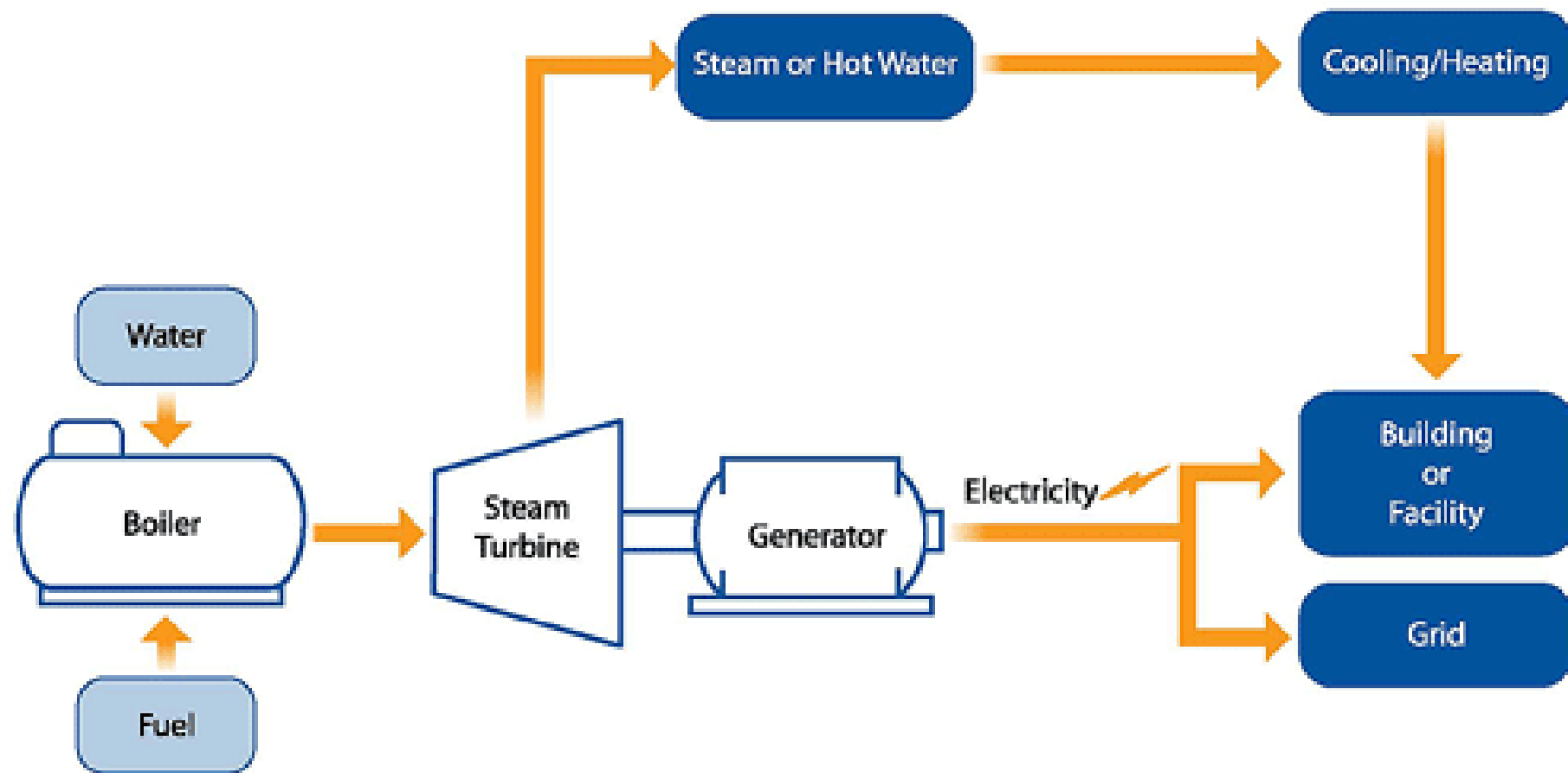


**Cogeneration plant with a back pressure turbine**

In the co-generation or combine heat and power (CHP) has the advantages such as:

- It does not need a cooling system which reduce the cost of power plant
- It increases the overall thermal efficiency which reduce the cost of operation (fuel cost)





Schematic diagram of co-generation

## Operating data of a combined cycle cogeneration plant

<i>Fuel</i>	<i>Natural gas</i>
Gas turbine power output	69.1 MW
Back pressure steam turbine output	44.7 MW
Station service power	1.4 MW
Net power output of the plant	112.4 MW
Heat input to the gas turbine (LHV)	230.0 MW
Heat input in supplementary firing (LHV)	79.6 MW
Process steam flow	65.3 kg/s
Process steam pressure	3.5 bar
Thermal energy of process steam	152 MW
Rate of fuel utilization	85.4%
Power coefficient $\left[ \frac{\text{electricity generated}}{\text{process heat supplied}} \right]$	0.74
Electrical yield	36.8%
Efficiency of power production	79.9%



## 2.1 Clean coal technology

56

**Clean coal technology** is a collection of technologies being developed to mitigate the environmental impact of [coal](#) energy generation. Gaseous emissions generated by the thermal decomposition of the coal include SO<sub>x</sub>, NO<sub>x</sub>, CO<sub>2</sub>, and other PMs are reduced/removed through clean coal technologies.

Some of the techniques that would be used to accomplish this include chemically washing [minerals](#) and impurities from the coal, [gasification](#) and [IGCC](#), treating the [flue](#) gases with [steam](#) to remove [sulfur dioxide](#), [carbon capture and storage](#) technologies to capture the carbon dioxide from the [flue gas](#) and dewatering lower rank coals ([brown coals](#)) to improve the [calorific value](#), and thus the efficiency of the conversion into [electricity](#).

**Some of those clean coal technologies will be discussed in detail such as:**

- **NO<sub>x</sub> generation and reduction**
- SO<sub>2</sub> reduction
- Carbon capture and storage



## 2.1 Clean coal technology

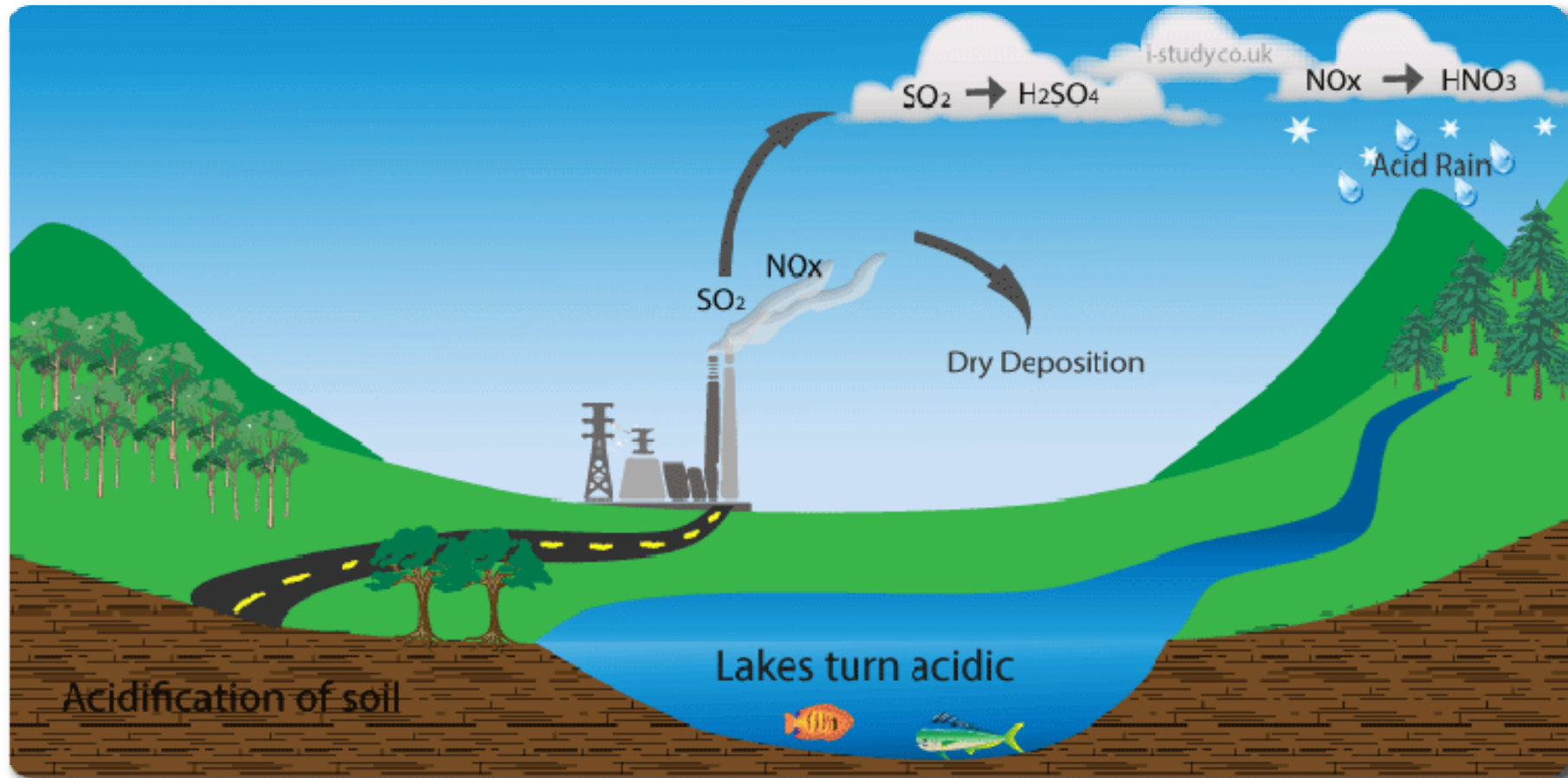
---

57

- **NO<sub>x</sub> generation and reduction**
- SO<sub>2</sub> reduction
- Carbon capture and storage

# Pollution from NOx and SOx

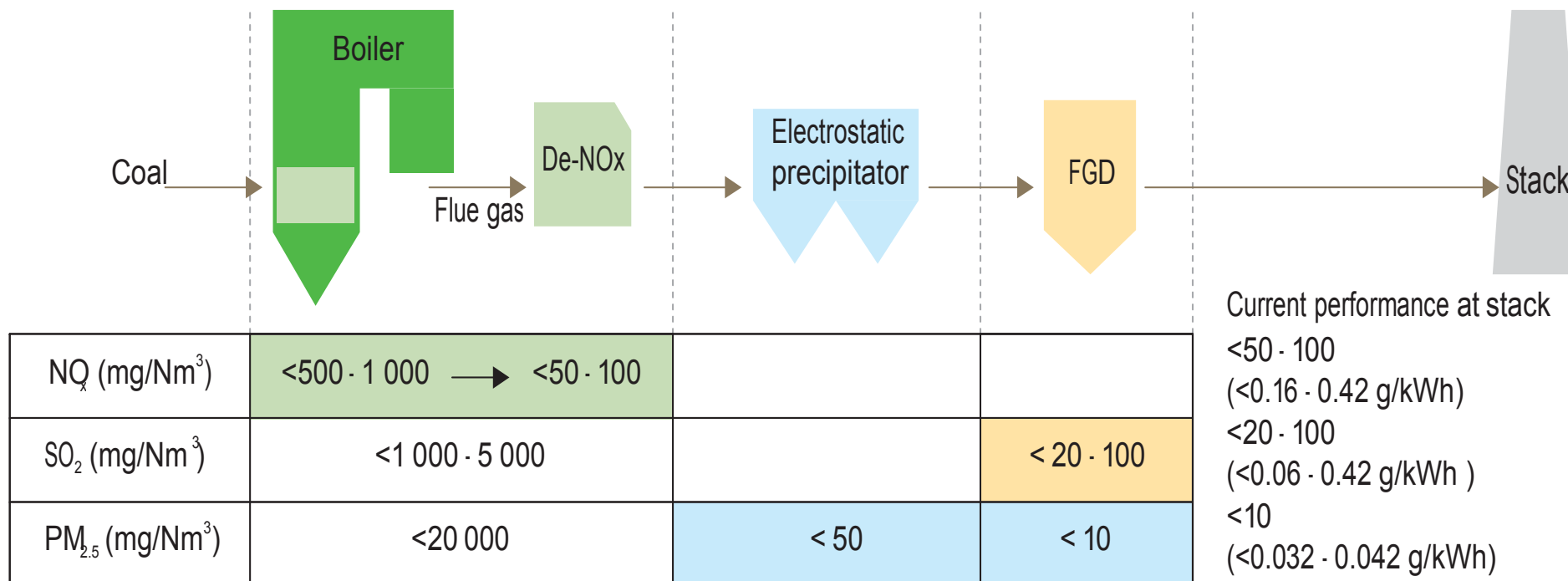
58



NOx and SOx which releases in atmosphere form acid rain and destroyed our environment and ecological system.

# Current Pollution of NO<sub>x</sub> and SO<sub>x</sub>

59



Current situation regarding emission reduction bt Stack Gas Treatment

Name	Structure	~ Relative amount	Stability
Pyridine <sup>1</sup>		15-40%	More stable
Pyrrole <sup>1</sup>		60%	Less stable
Aromatic amines		6-10%	Stable

<sup>1</sup>Including structures made up of 2-5 fused aromatic rings.

- Thermal NO
- Prompt NO
- Fuel NO: volatiles-NO and char-NO

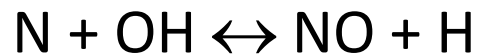
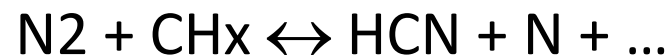
## - Thermal NO (Zeldovich mechanism)



Strong temperature-dependence: >1300-1500°C

Not a major source of NO in coal utility boilers.

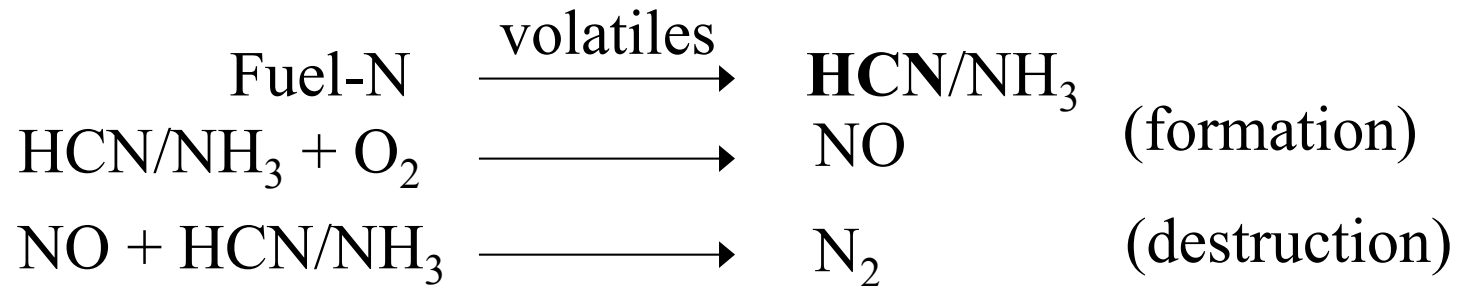
## - Prompt NO



Prevalent only in fuel-rich systems.

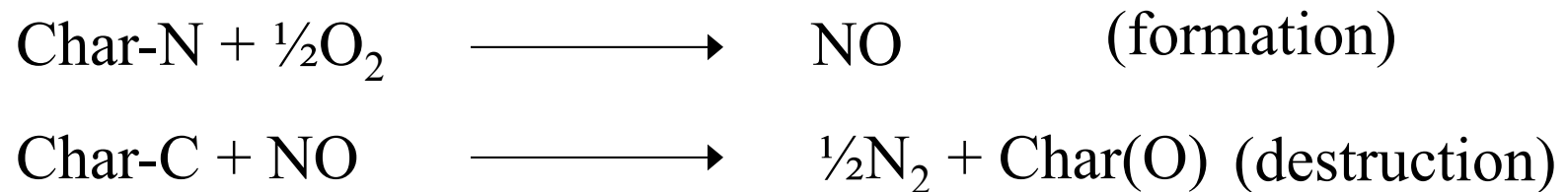
Not a major source of NO in coal utility boilers.

## - Fuel NO (-N in volatiles)



The major source of NO in coal utility boilers (>80%).

## - Char NO (-N in the char)



$$[\text{char-NO} = \sim 25\%] < [\text{volatiles-NO} = \sim 75\%]$$

## - Combustion controls:

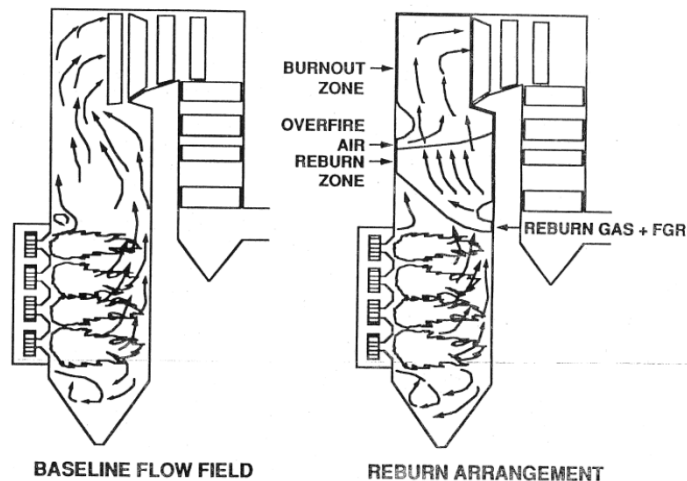
Modification of combustion configuration:

- Reburning
- Staged Combustion (air/fuel)

## - Post combustion controls:

Injection of reduction agents in flue gas.

Post-combustion denitrification processes.



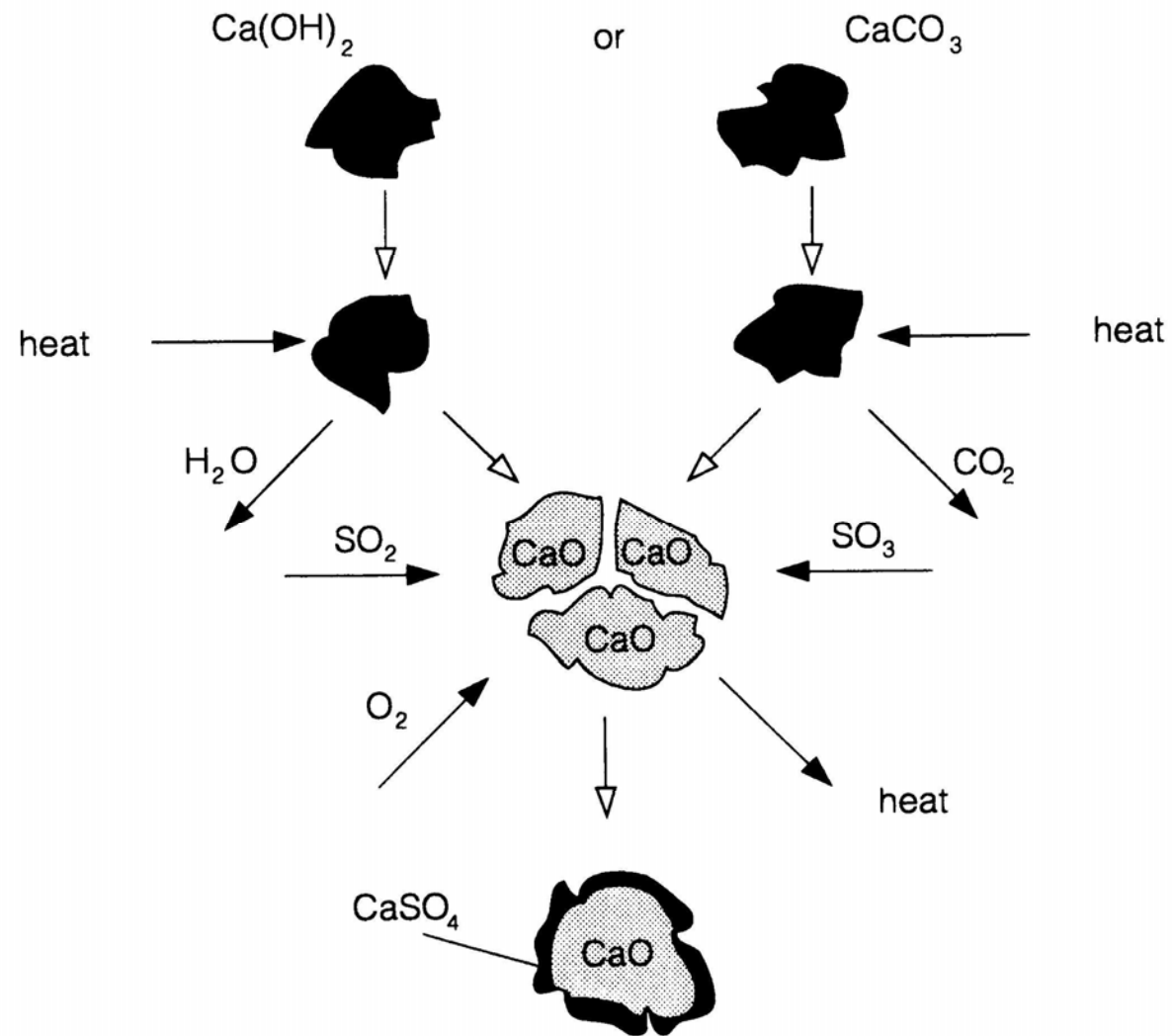


## 2.1 Clean coal technology

---

65

- NOx generation and reduction
- **SO2 reduction**
- Carbon capture and storage



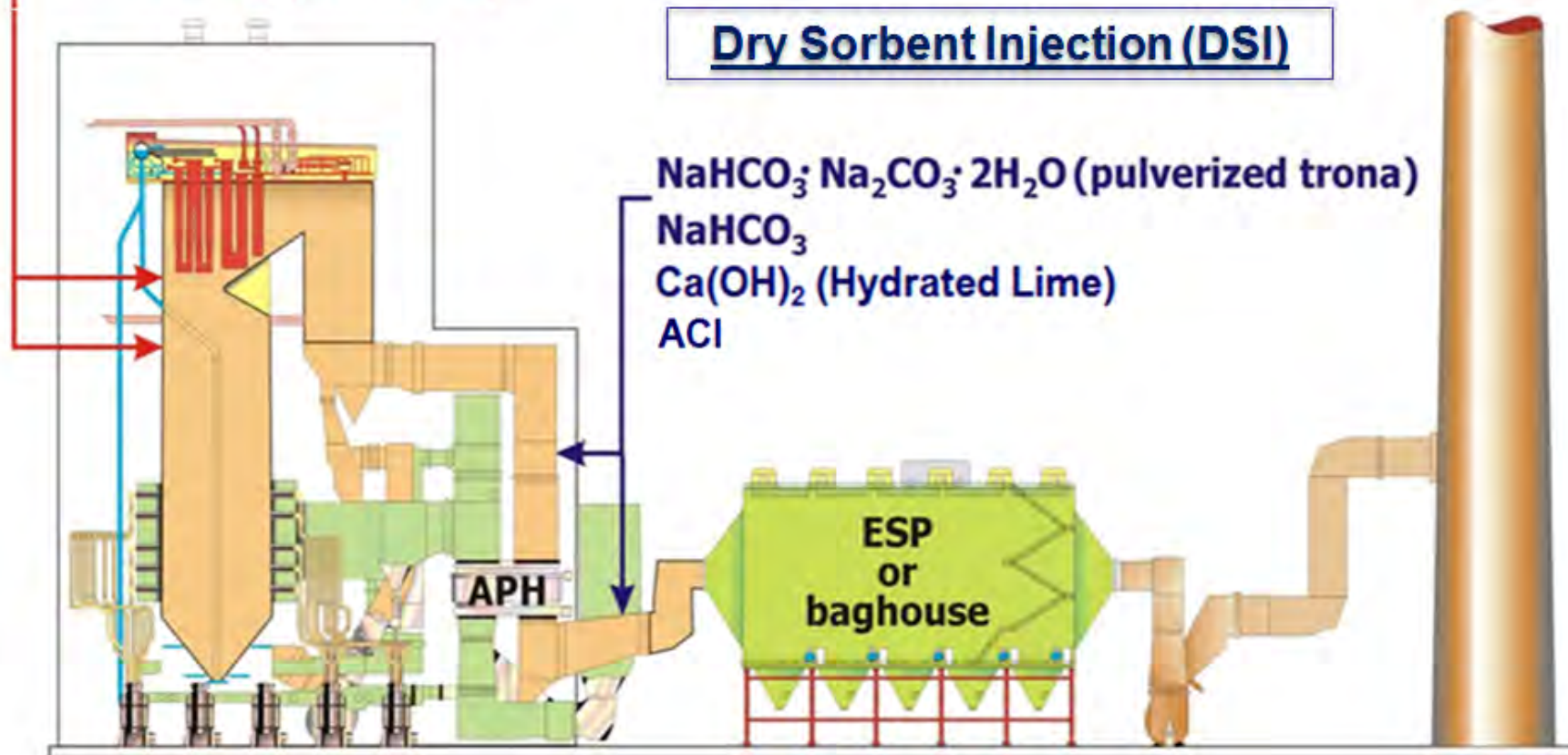
SOx reduction by sorbent injection (Limestone injection)

## Furnace Sorbent Injection (FSI)

$\text{Ca(OH)}_2$  (hydrated lime)  
 $\text{CaCO}_3$  (limestone)

## Dry Sorbent Injection (DSI)

$\text{NaHCO}_3$ ;  $\text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$  (pulverized trona)  
 $\text{NaHCO}_3$   
 $\text{Ca(OH)}_2$  (Hydrated Lime)  
ACI

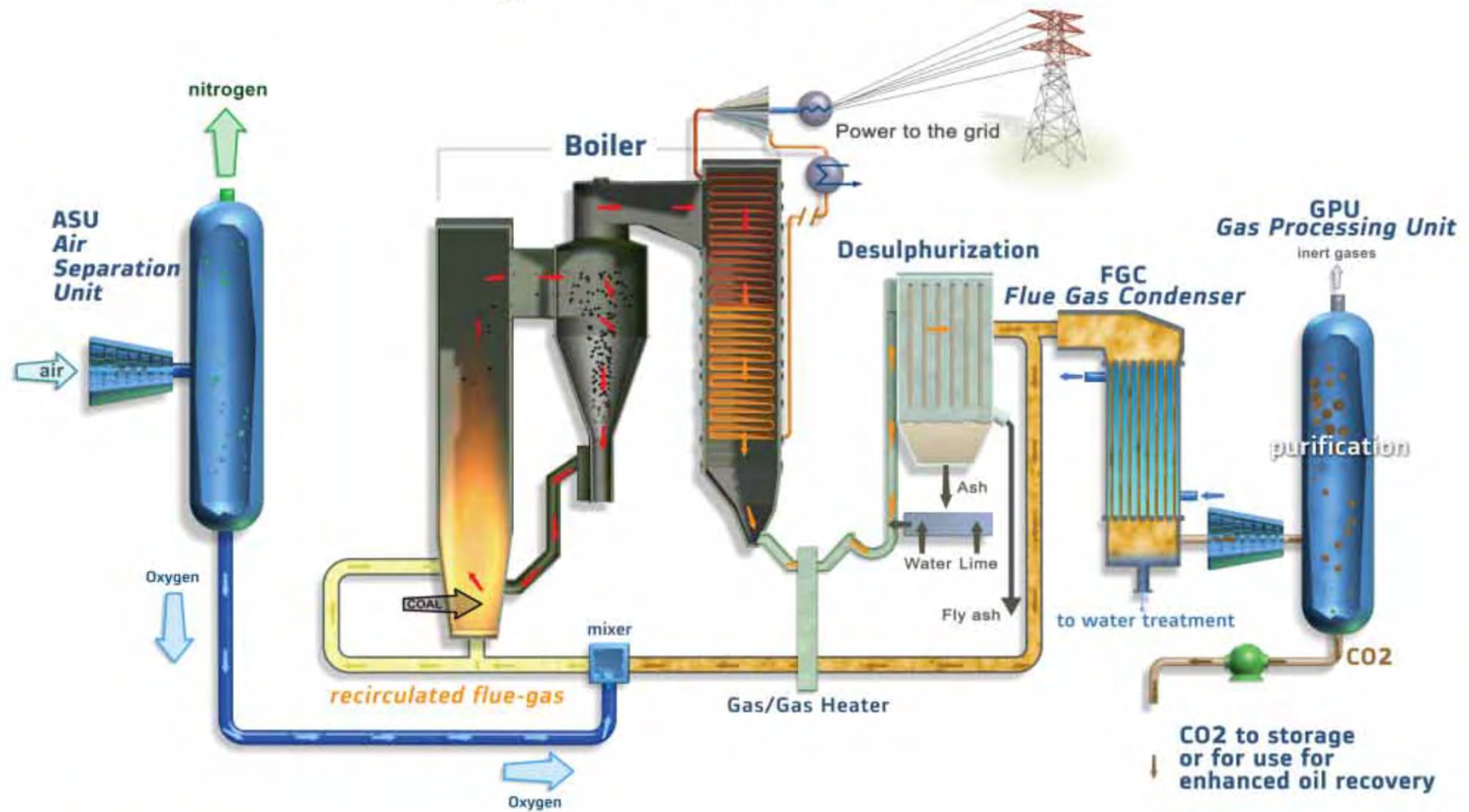


SOx reduction by sorbent injection

DSI Sorbents	Pollutants	Reduction Level
Hydrate lime	SO <sub>2</sub> , SO <sub>3</sub> , HCl	SO <sub>2</sub> : 40%-70% HCl: >90% SO <sub>3</sub> : 70%-90%
Trona	SO <sub>2</sub> , HCl	
Sodium bicarbonate	SO <sub>2</sub> , HCl	
Activated carbon	Hg	>90%

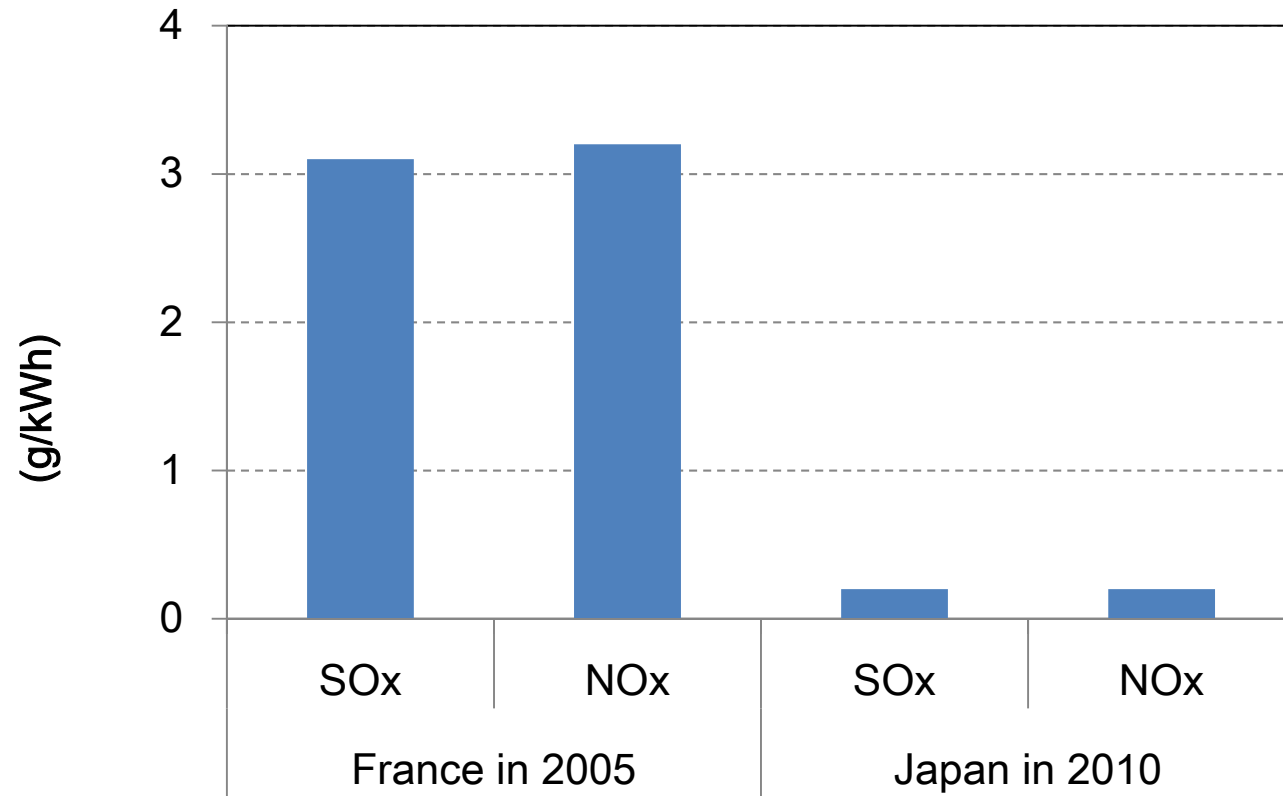
**SOx reduction by sorbent injection**

## Oxy CFB Power Plant



# NOx and SOx Reduction

70



Source

France: OECD Environmental Data Compendium 2006/2007

Japan: Federation of Electric Power Companies of Japan

## 2.1 Clean coal technology

---

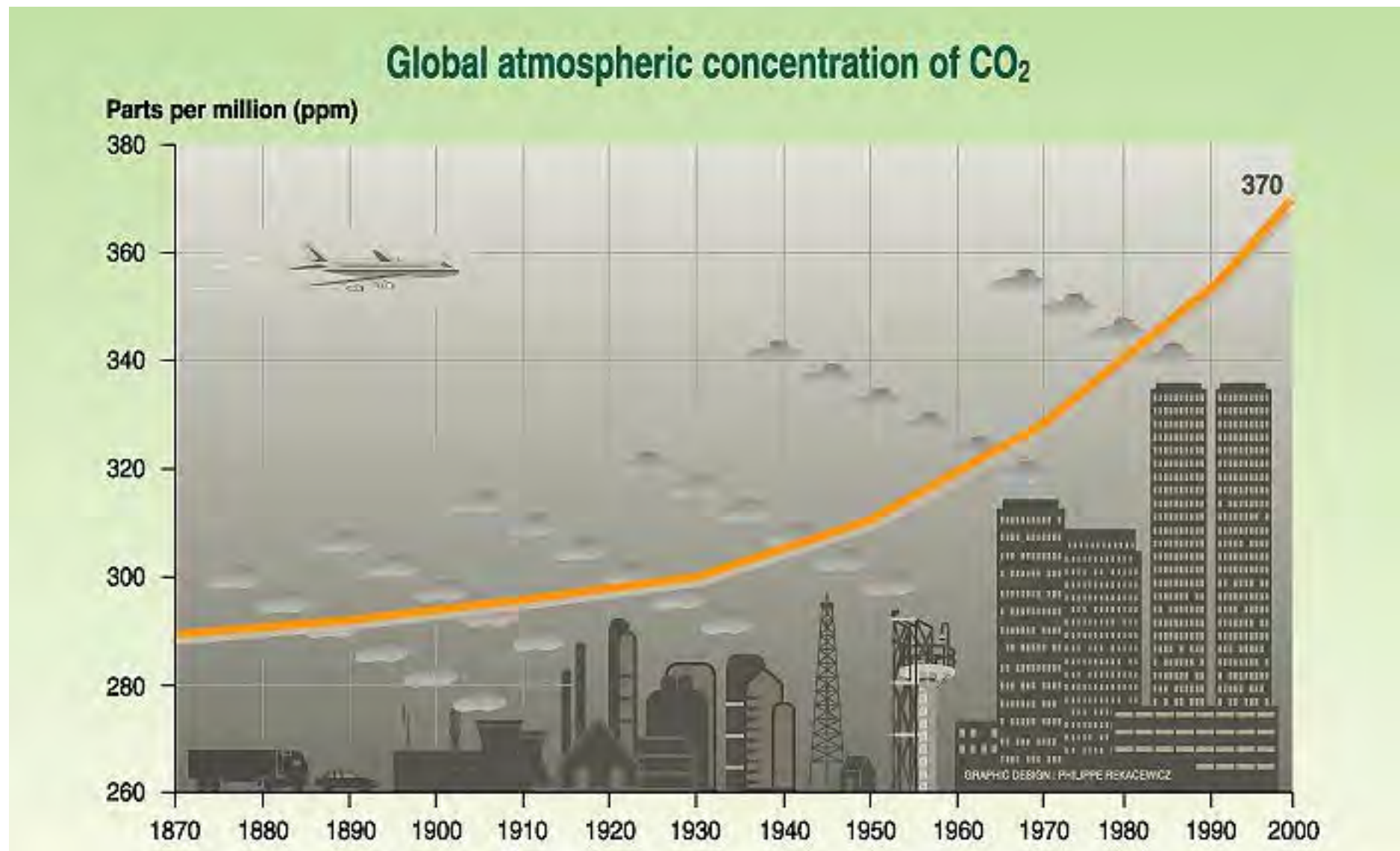
71

- NOx generation and reduction
- SO2 reduction
- **Carbon capture and storage**



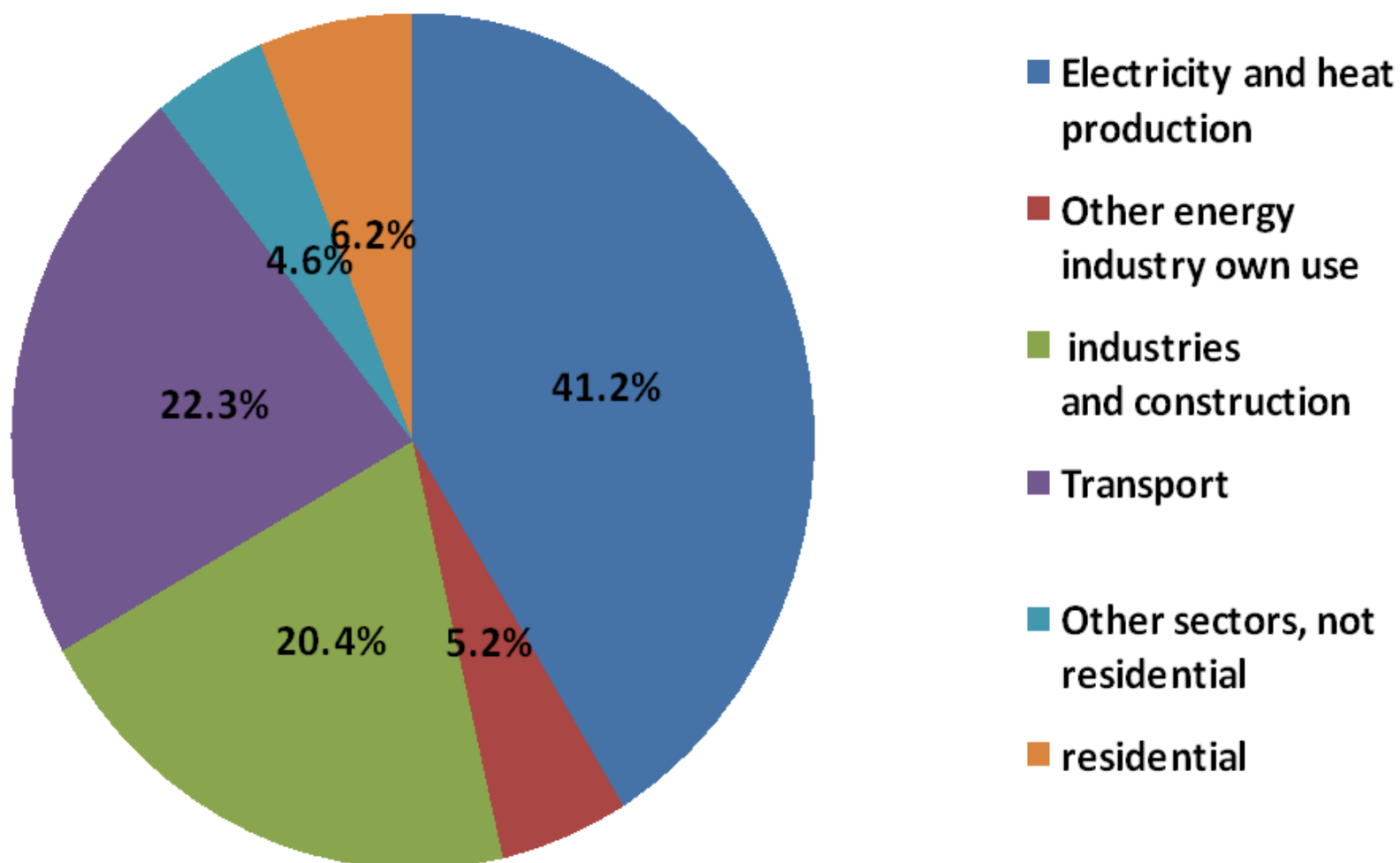
# CO<sub>2</sub> emission

72

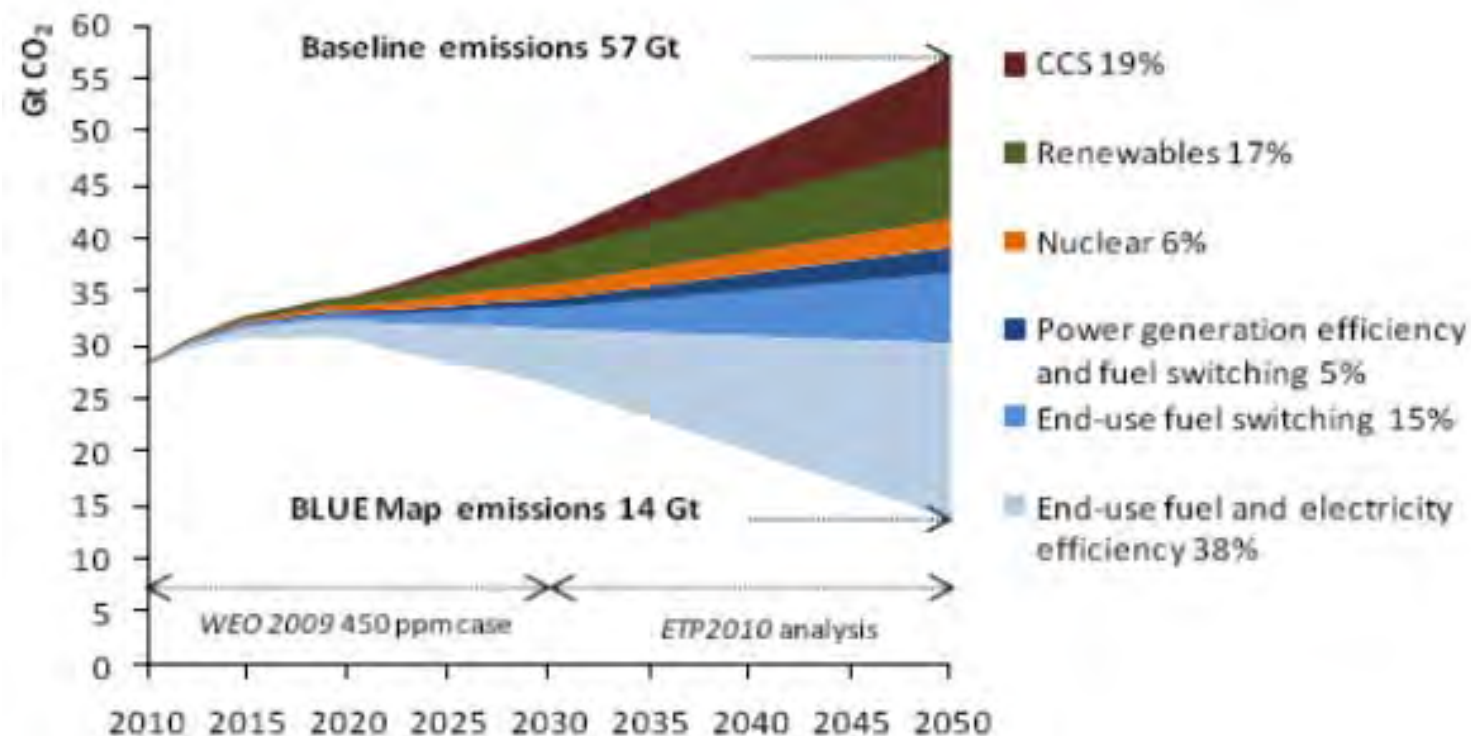




### CO2 Emissions by production sector

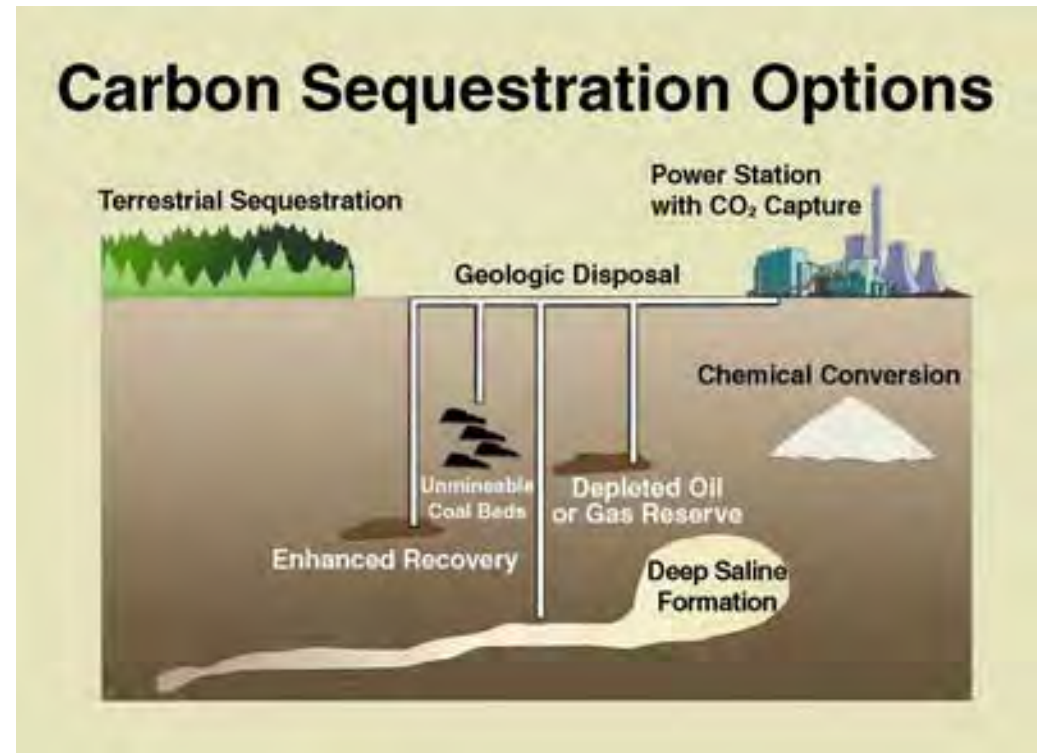


## Key technologies for reducing global CO<sub>2</sub> emissions



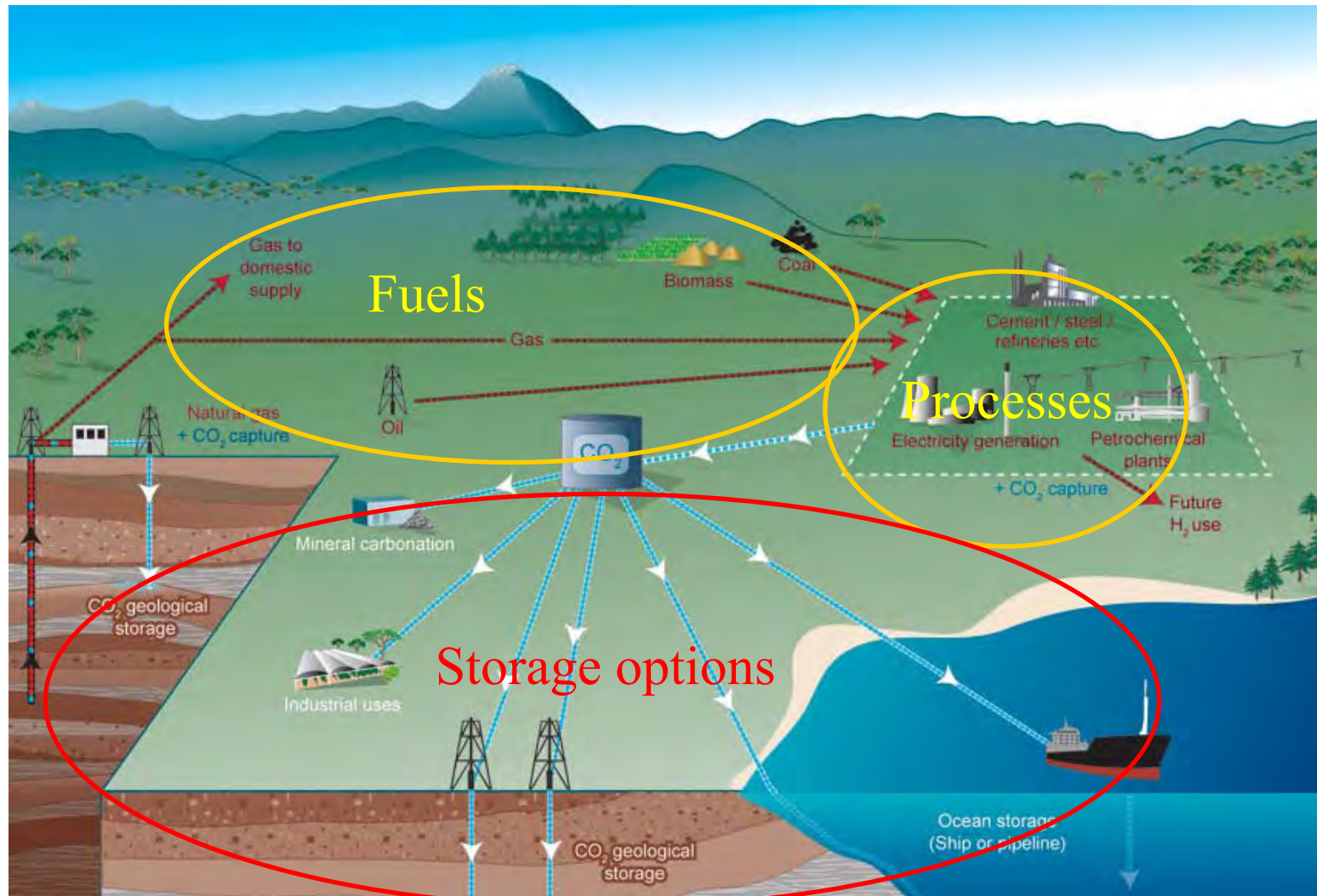
A wide range of technologies will be necessary to reduce energy-related CO<sub>2</sub> emissions substantially.

- Mitigates the contribution of fossil fuels into the atmosphere.
- Large sources are targeted, e.g coal power stations.
- Instead CO<sub>2</sub> is captured and stored underground so it can't enter the atmosphere.

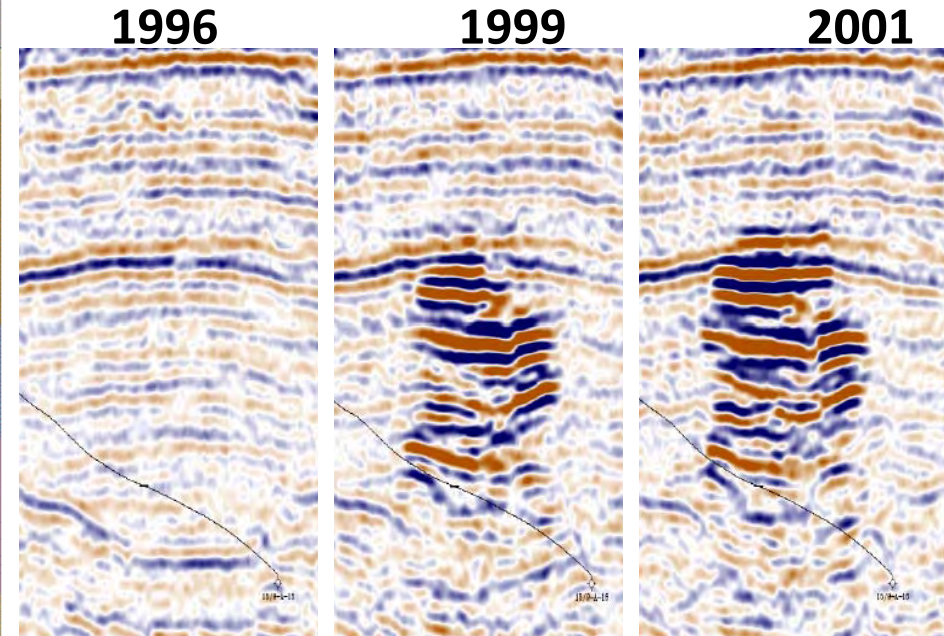
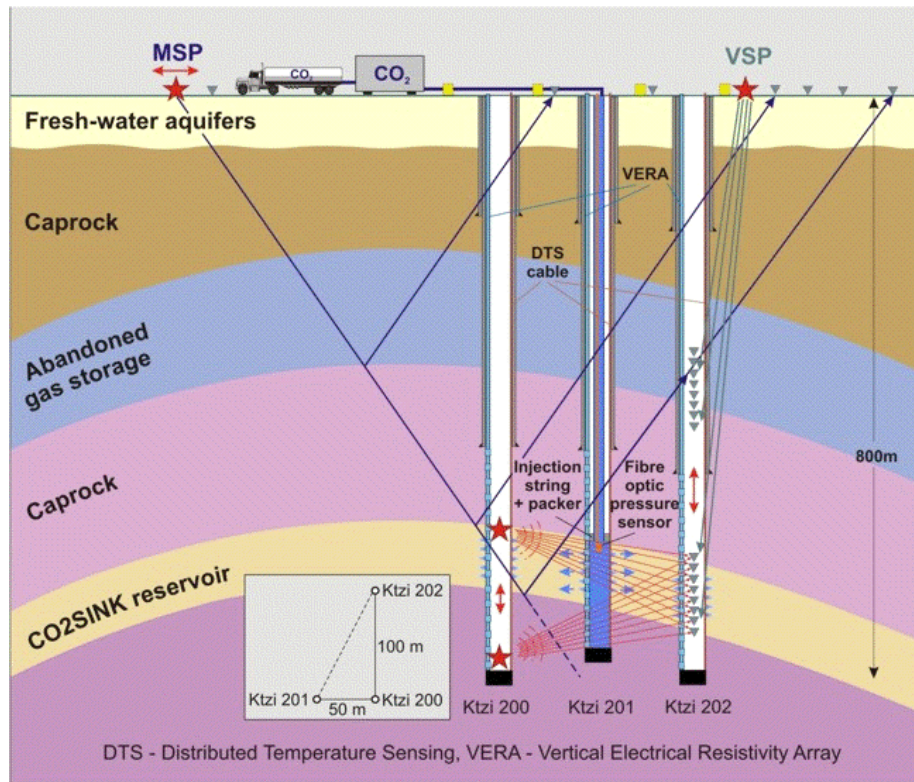


# CO2 Capture and Storage (CCS)

76







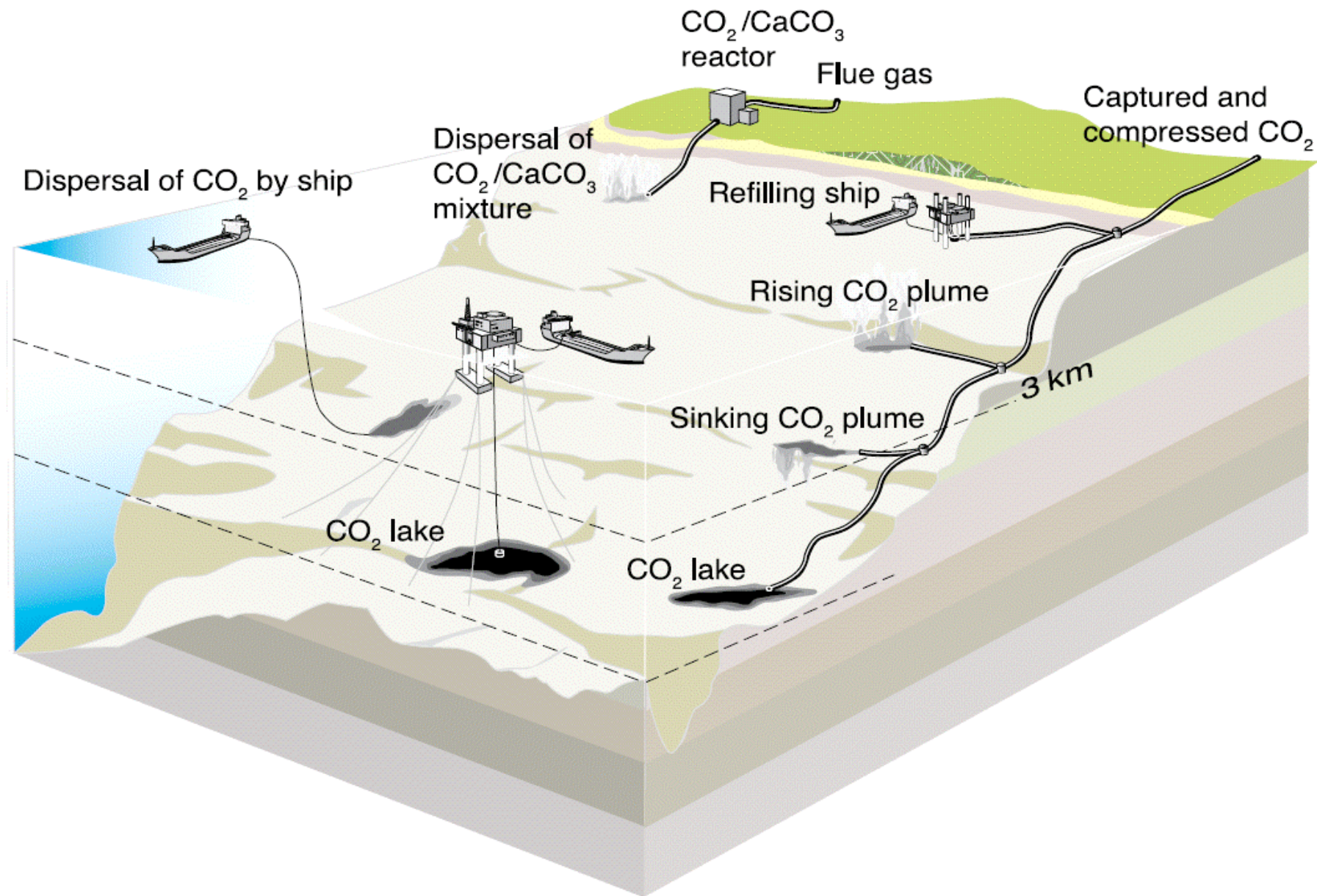
Example: Seismic monitoring at Sleipner

Measurement, Monitoring and  
Verification (MM&V) of CO2 storage



# Ocean storage of CO<sub>2</sub>

78



## 2.2 Nuclear power plant technology

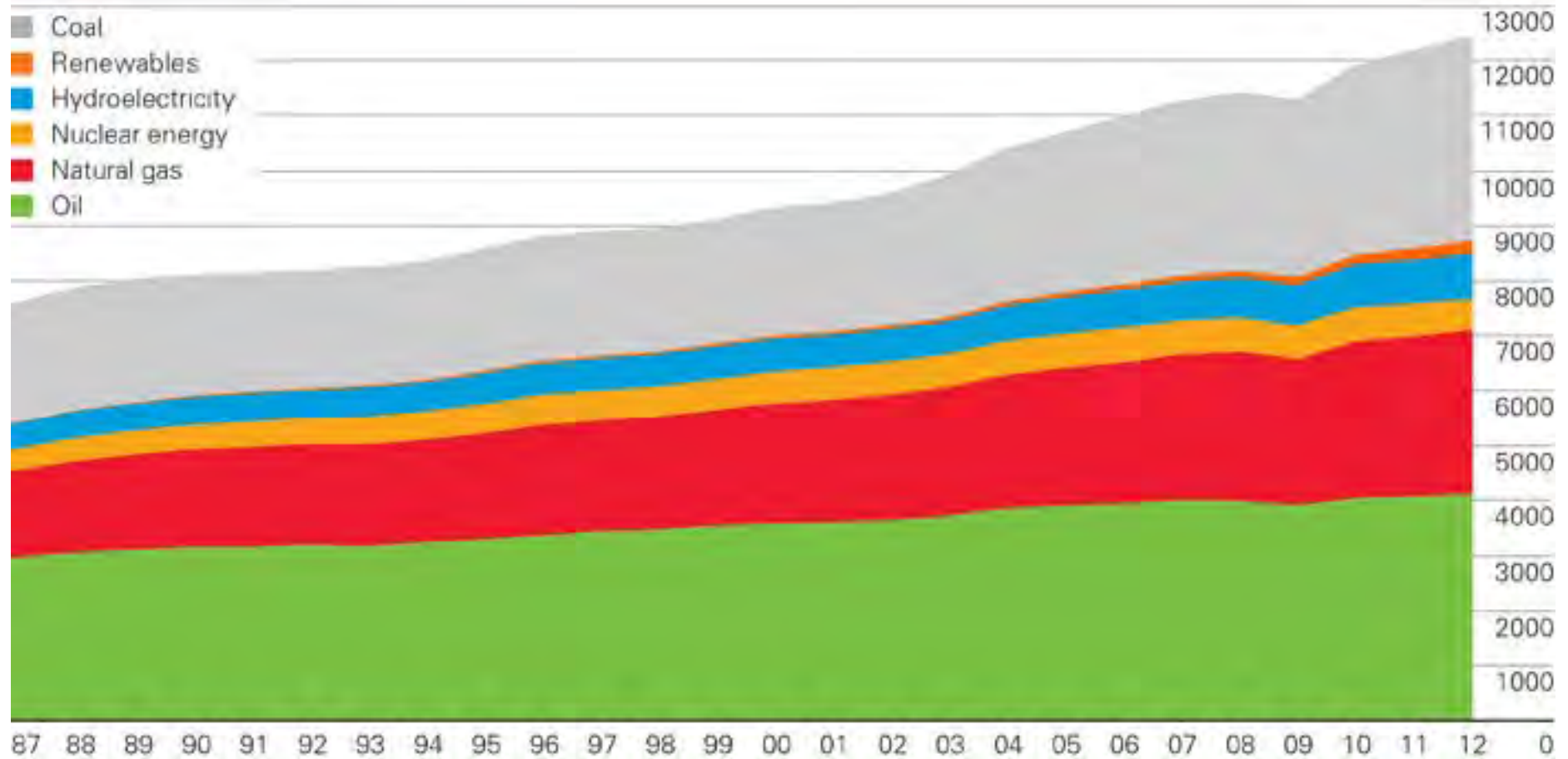
79

- **Current situation of nuclear energy**
- Working process and merits of nuclear power plant
- Radioactive level and dosages

# Current situation of nuclear energy

80

World consumption  
Million tonnes oil equivalent



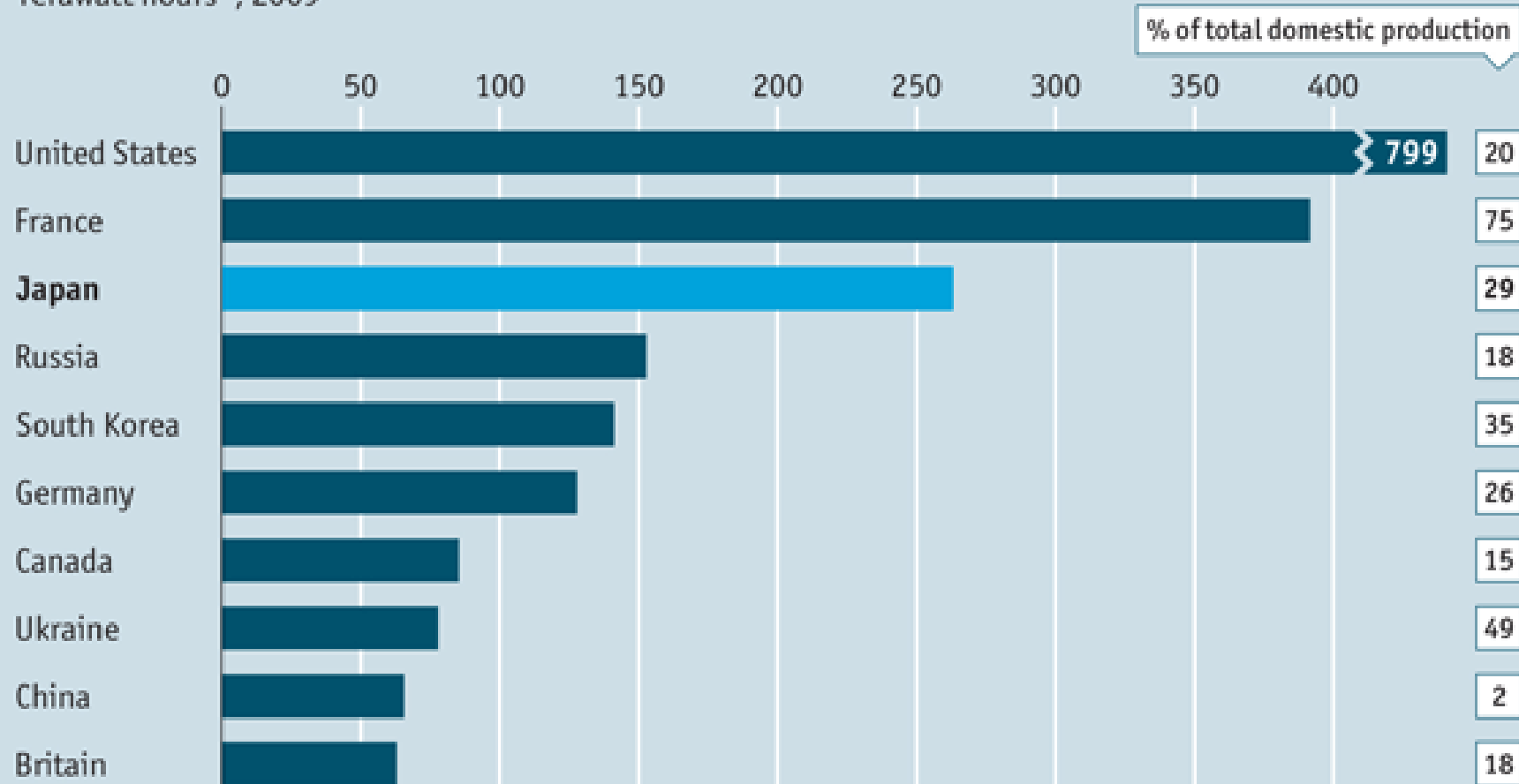


# Current situation of nuclear energy

81

## Biggest nuclear-electricity producers

Terawatt hours\*, 2009

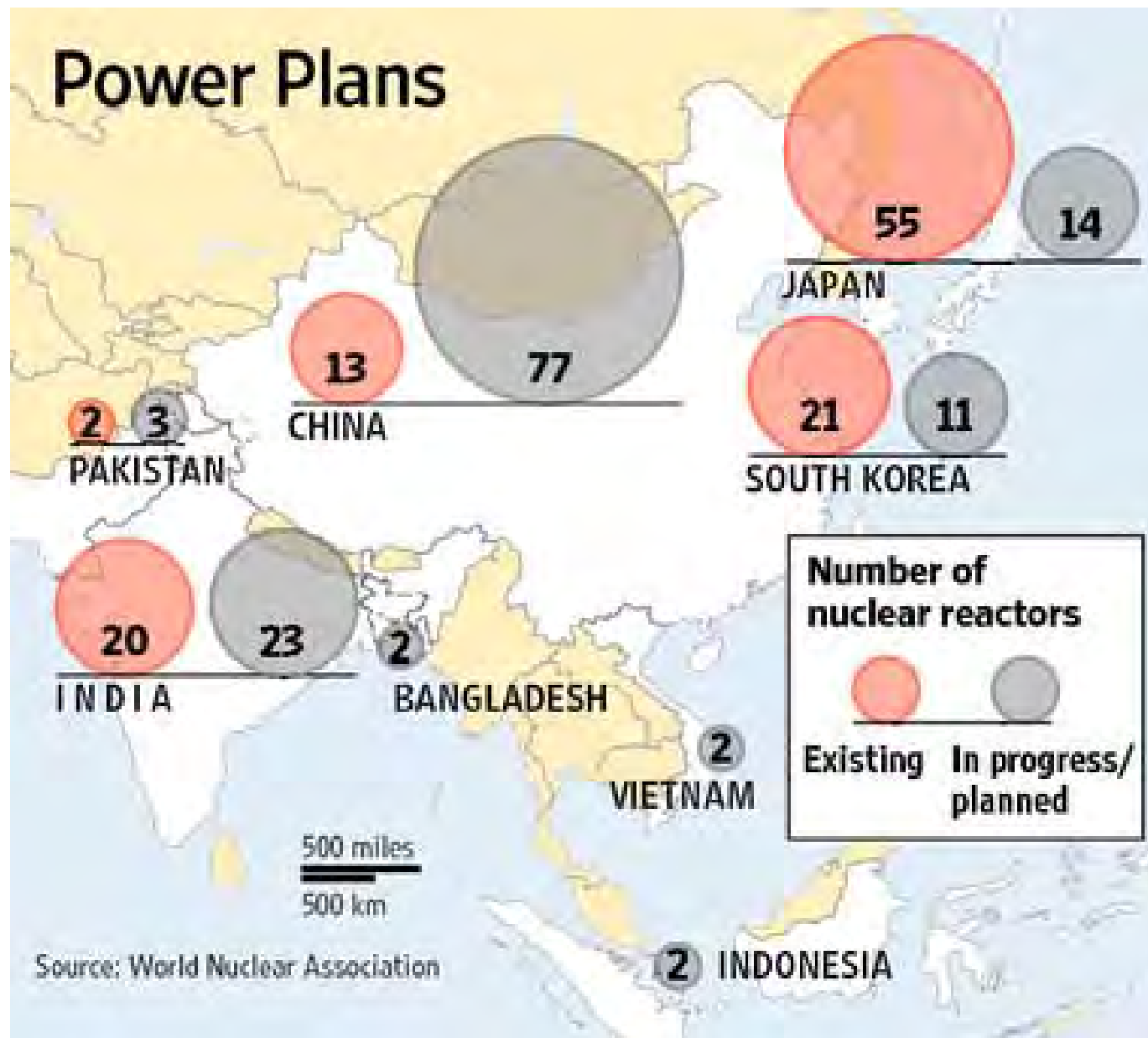


Source: World Nuclear Association

\*1 terawatt hour = 1 trillion watt hours

## Current situation of nuclear energy/ASIA

82



## 2.2 Nuclear power plant technology

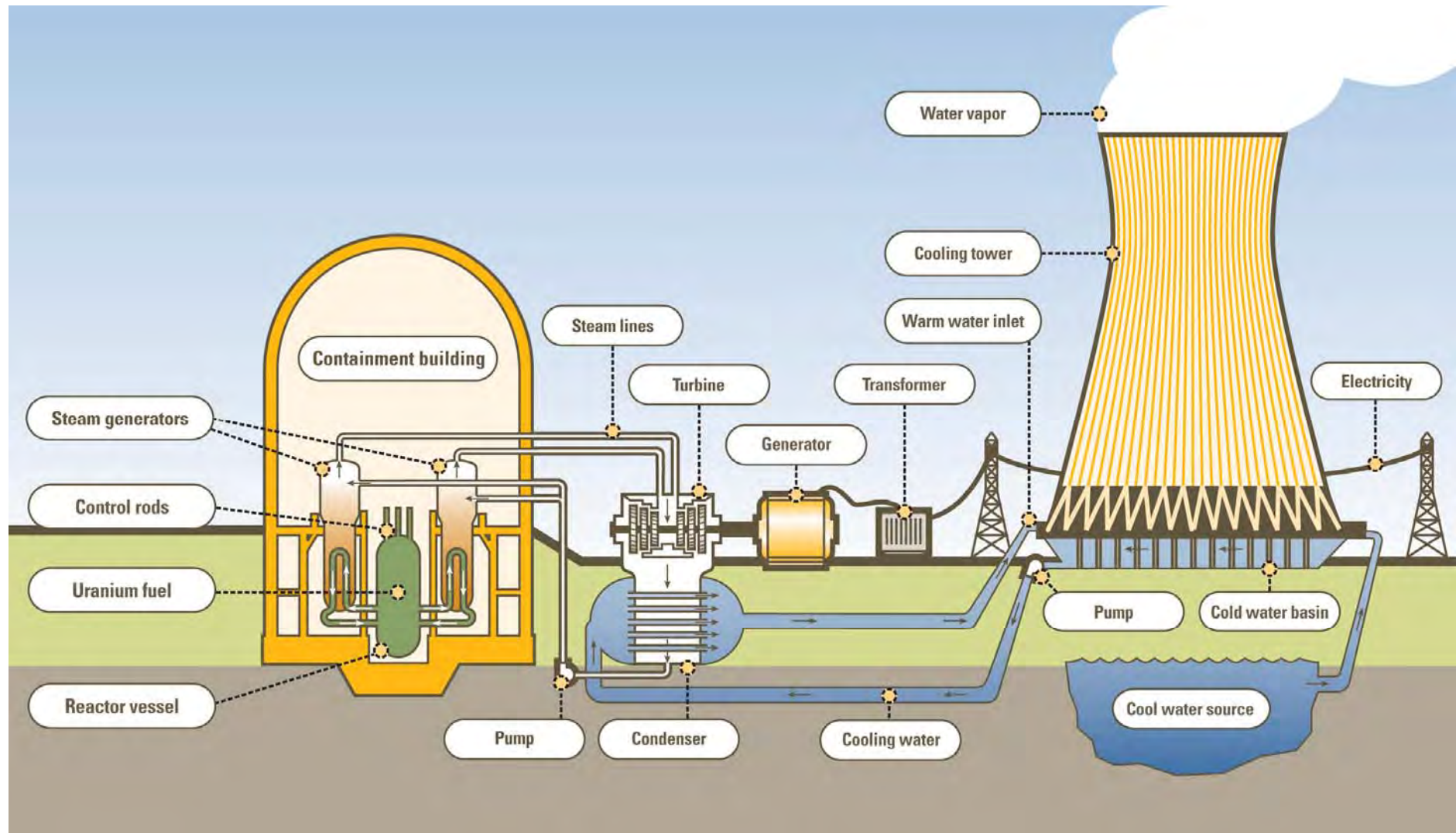
---

83

- Current situation of nuclear energy
- **Working process and merits of nuclear power plant**
- Radioactive level and dosages

# General component of nuclear power plant

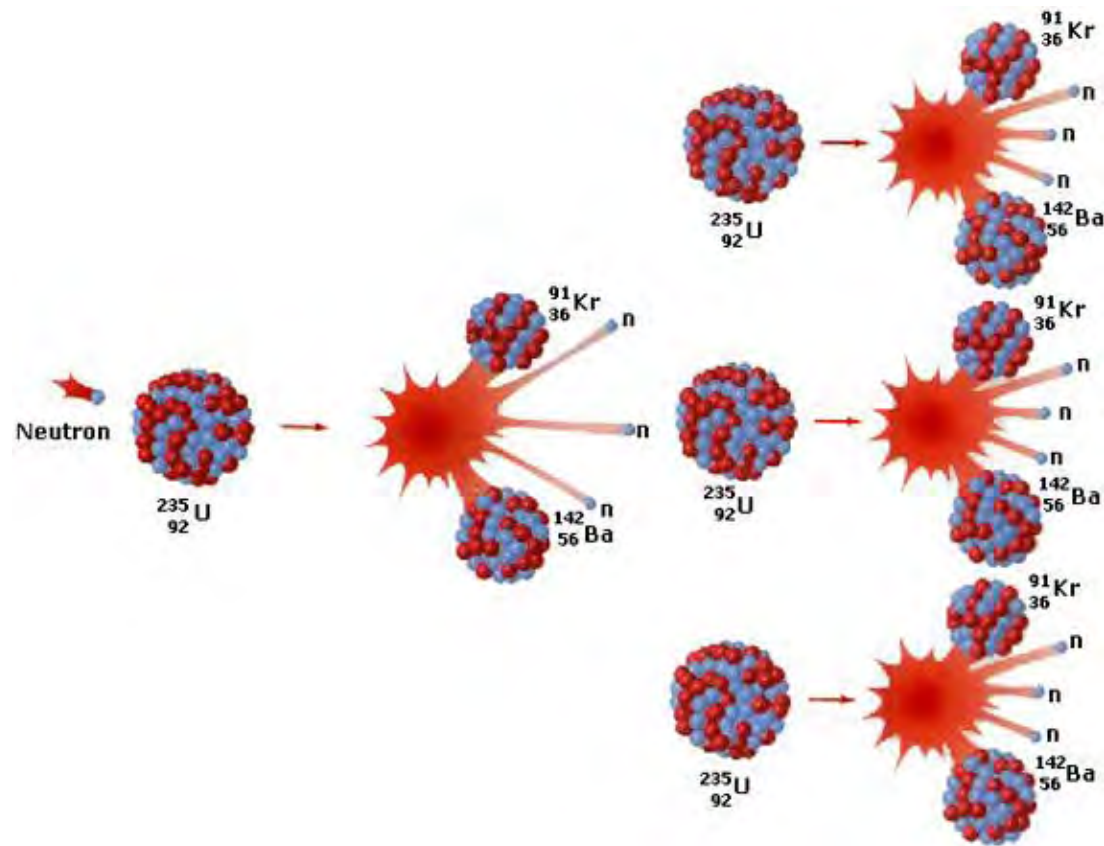
84



- Fission is the most energy for the least fuel with current technology.
- Uranium is readily available, very common in the earth's crust (about the same as tin)
- Economical - operating cost about the same as coal, fuel cost is a much smaller percentage of the total, therefore less susceptible to price fluctuations.
- Reliable - Nuclear power plants have very high capacity factors. No combustion, no CO, CO<sub>2</sub> or SO<sub>2</sub> released.
- Creates high paying, skilled jobs and fantastic safety record. .
- Reduce dependence on foreign oil/ fuel. Increase national energy security (a fill in of nuclear can be used up to 6 months)
- High temperature reactors could produce Hydrogen as well as electricity.
- A unit of nuclear power unit (1GW) can supply the whole Cambodia at present.

# Heat production through nuclear fission reaction

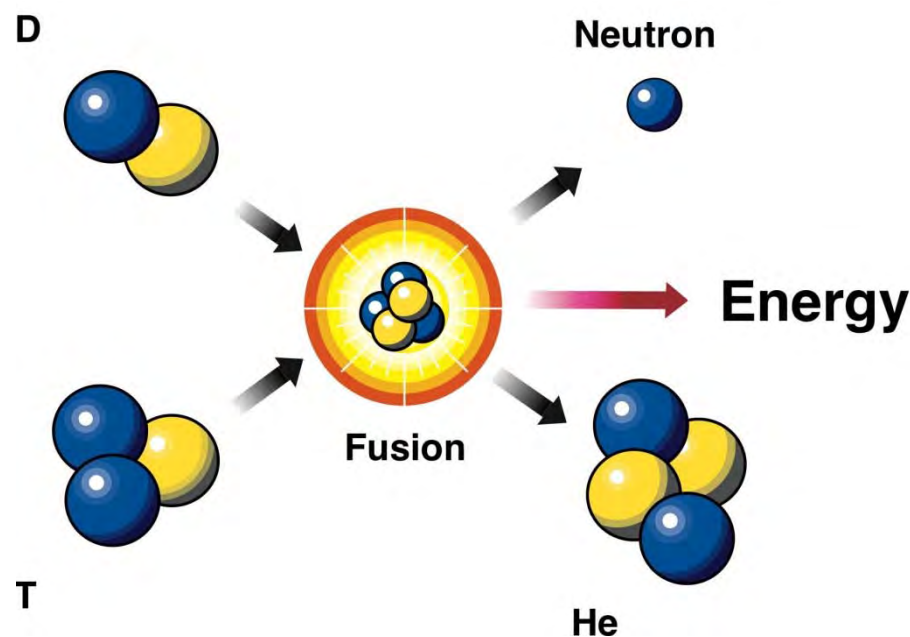
86



# Heat production through nuclear fusion reaction

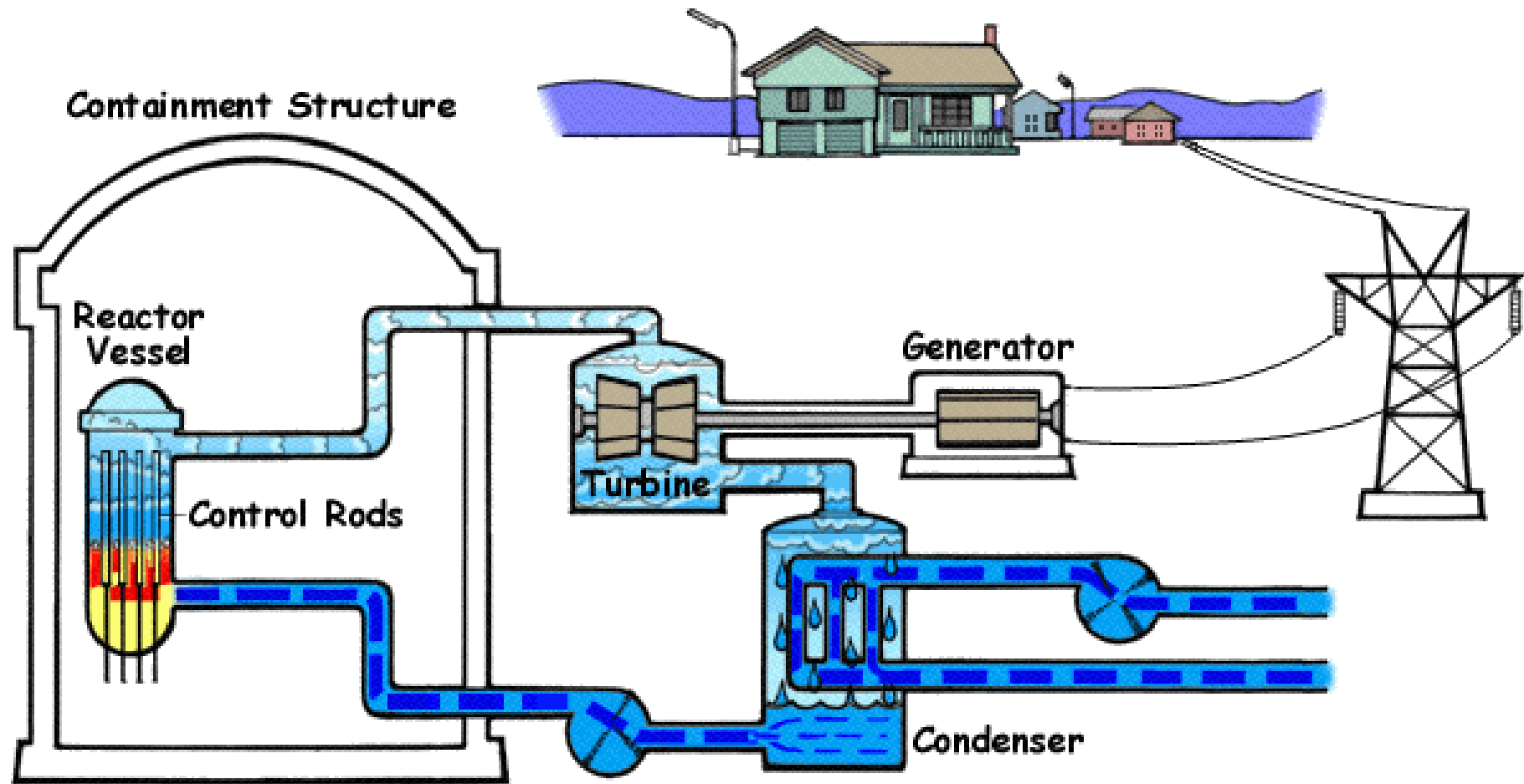
87

- A classic example of a fusion reaction is that of deuterium (heavy hydrogen) and tritium which is converted to Helium and release energy.



# Overall components of nuclear Power Plant

88

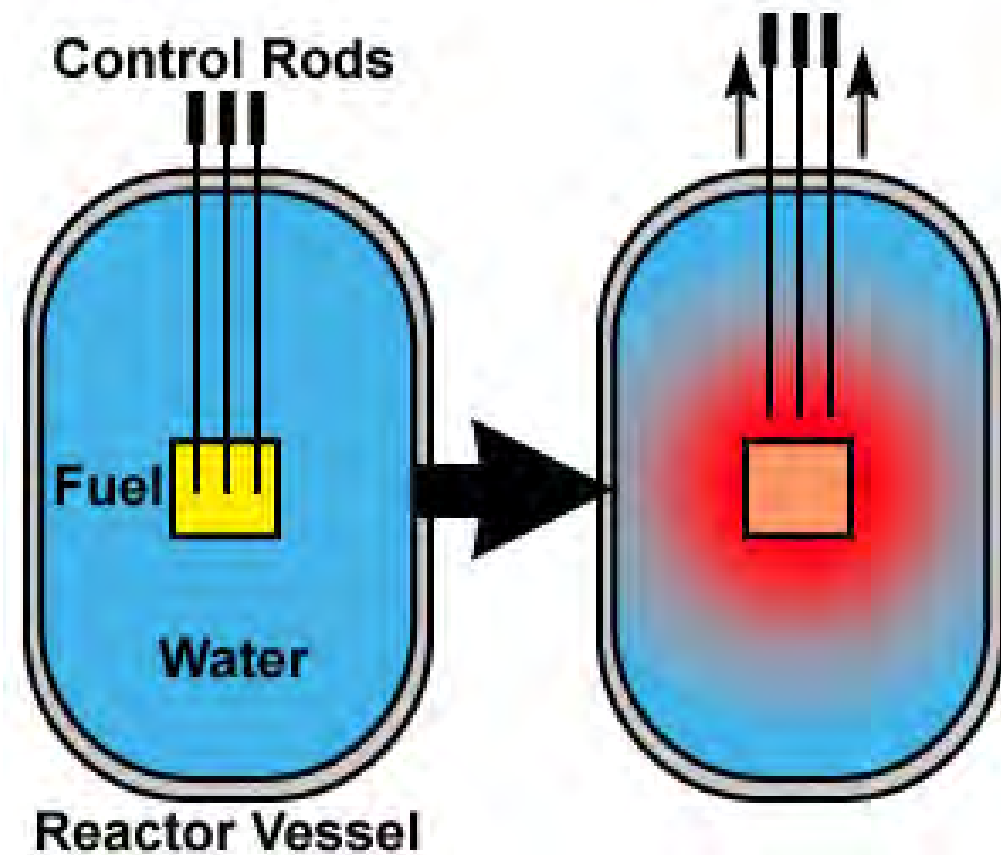
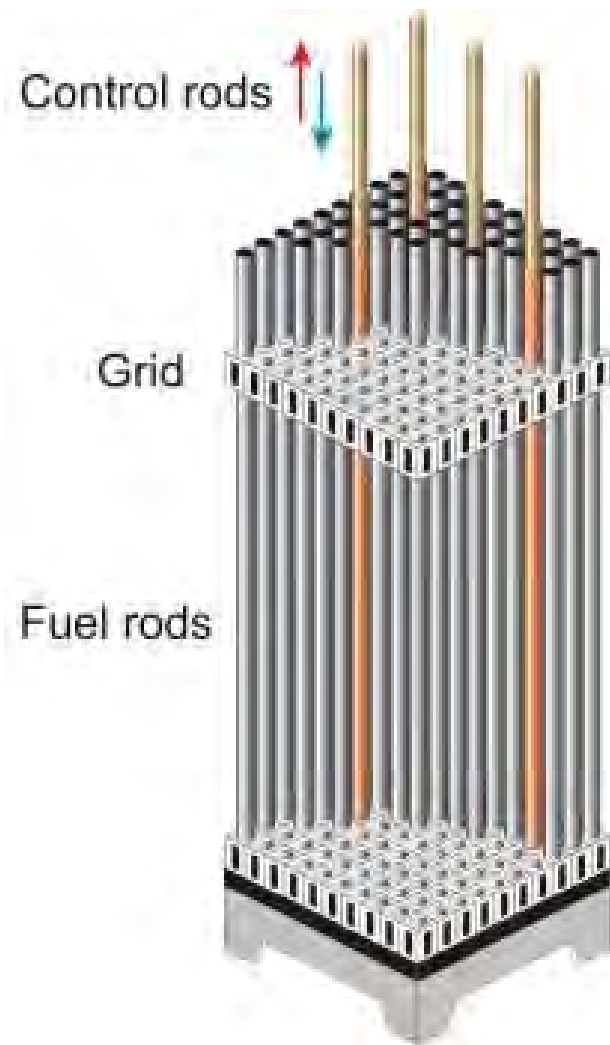


**Boiling Water Reactor (BWR)**



# Reaction control with Nuclear Fission Power Plant

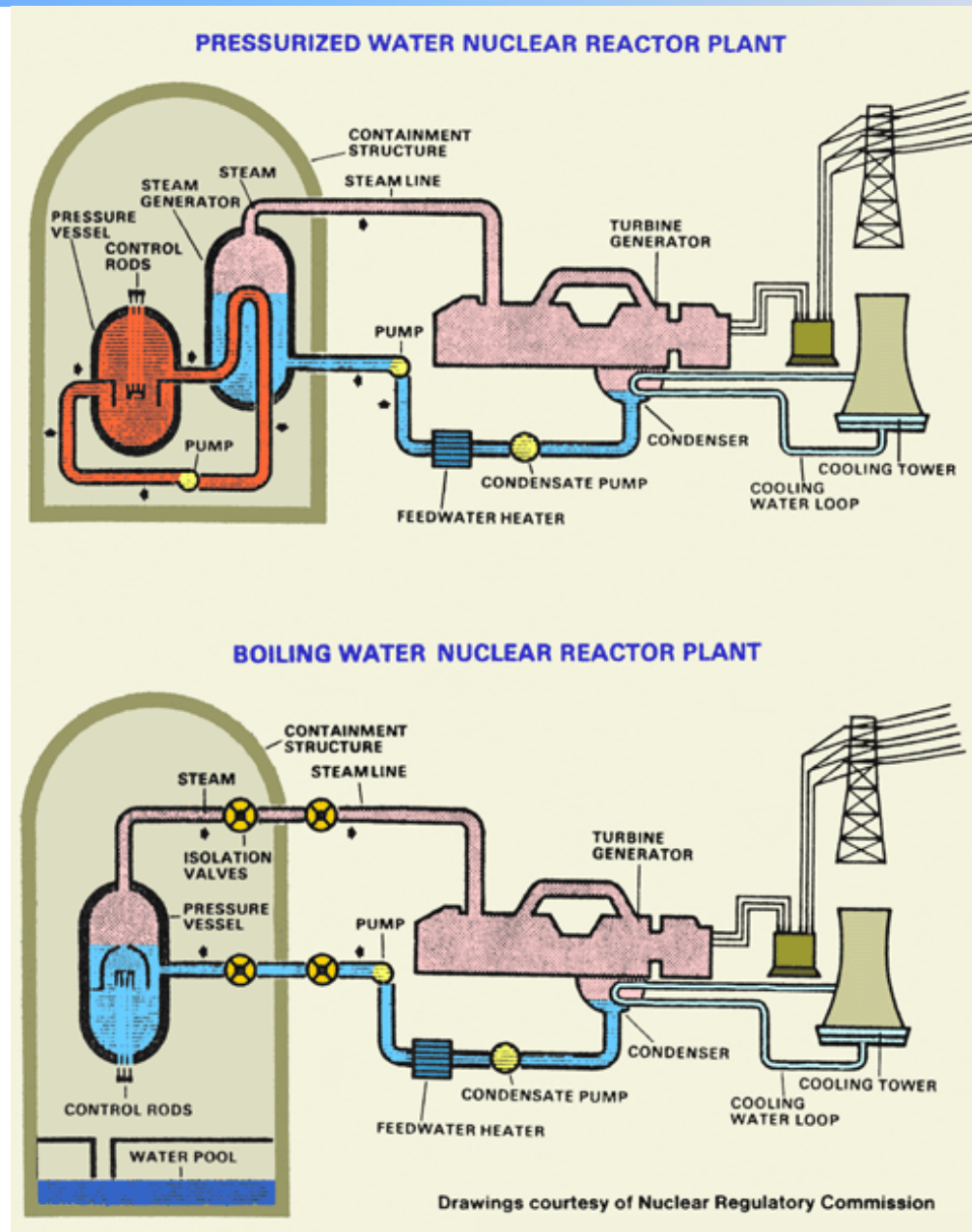
89



Fission reaction controlled by rods

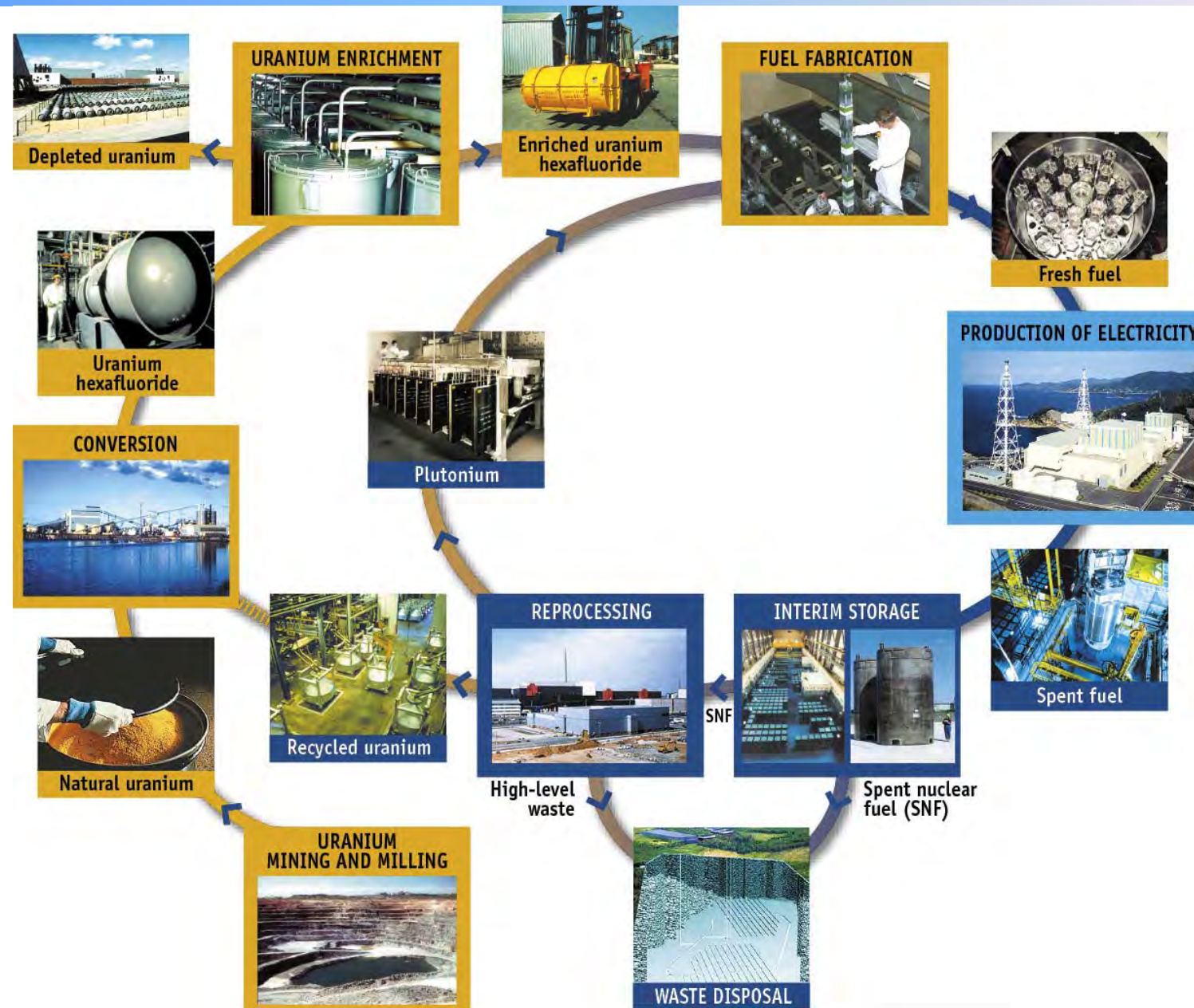
# Types of nuclear reactors

90



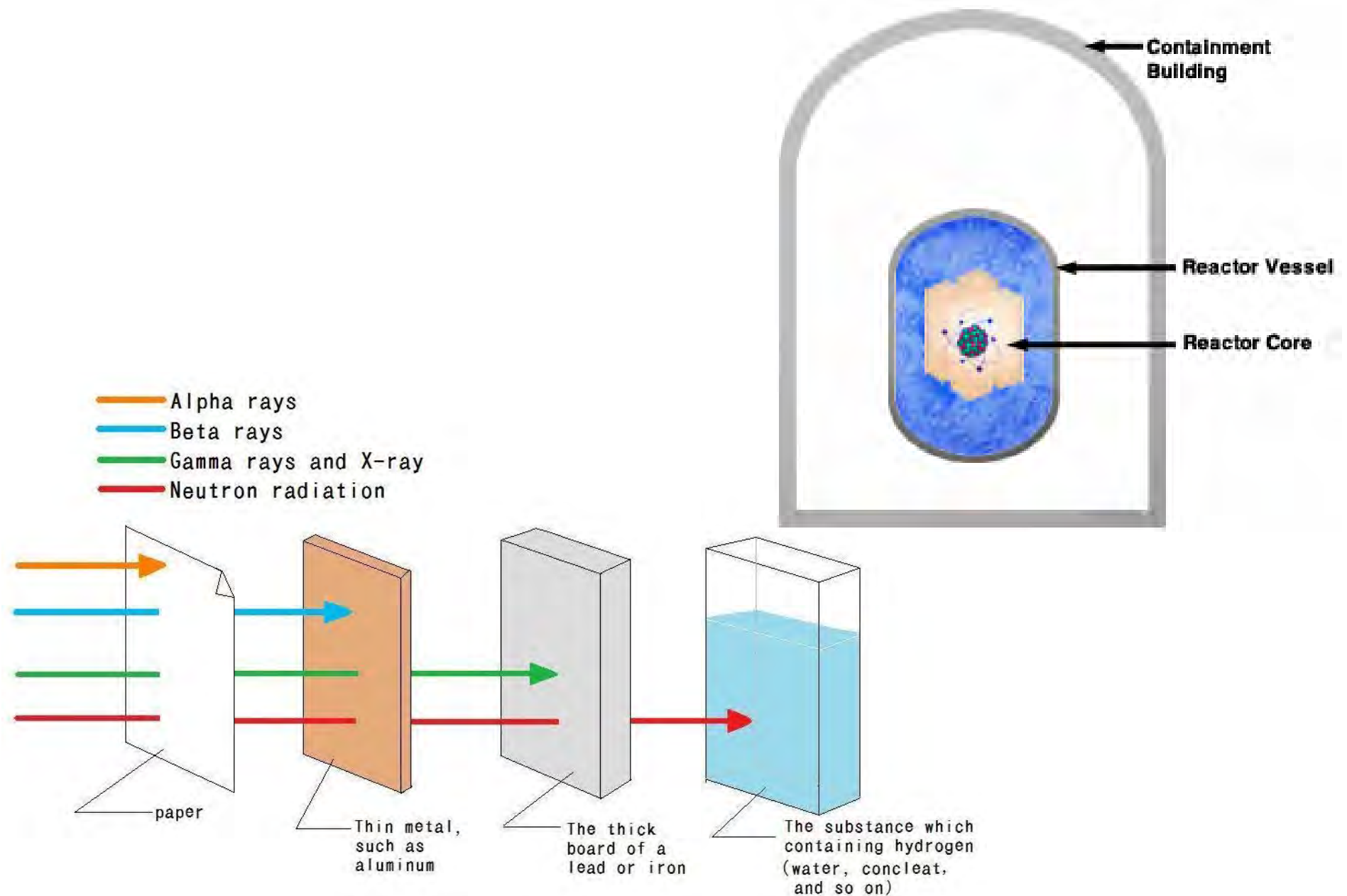
# Nuclear Fuel Cycles

91

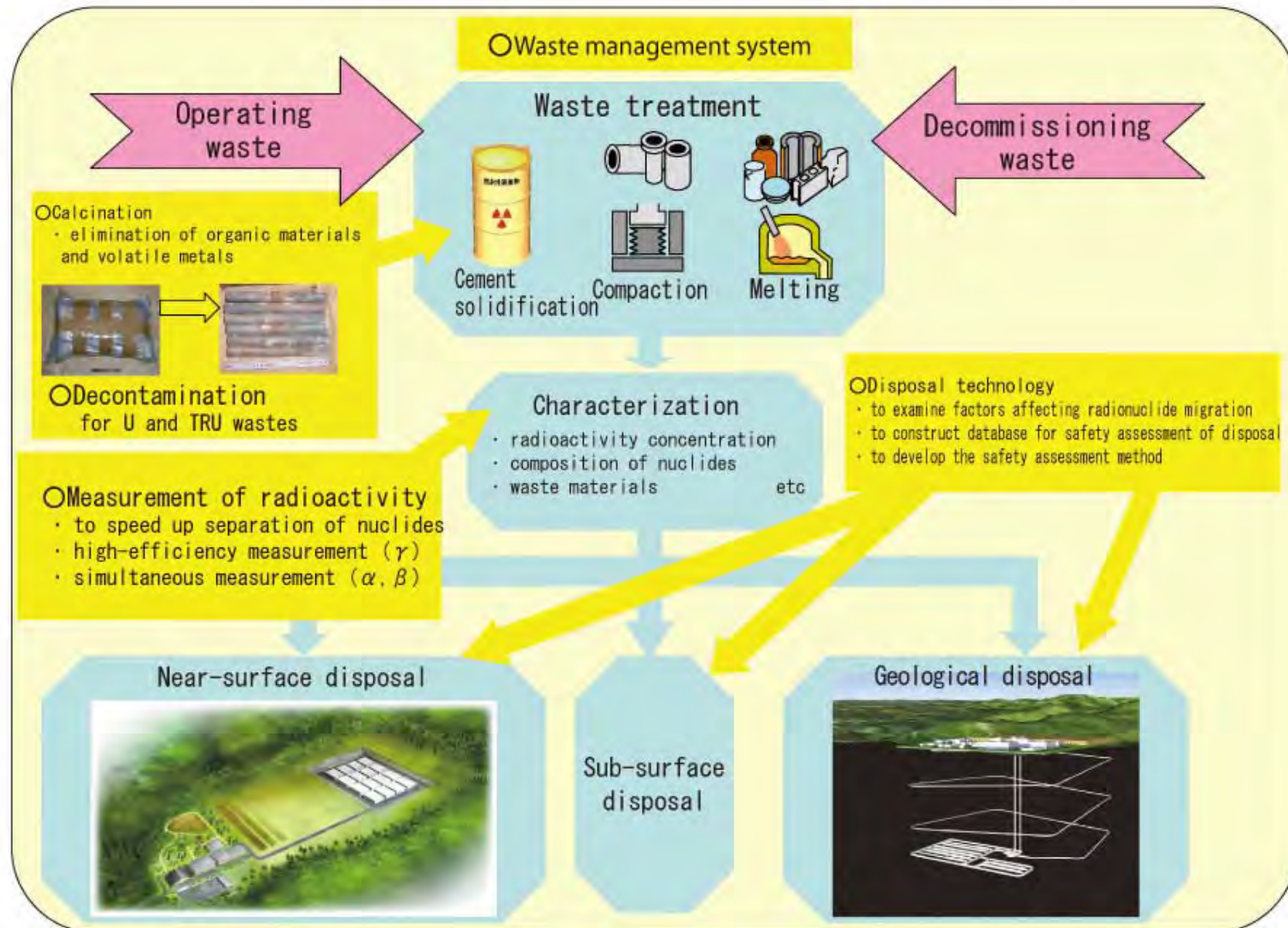


# Level of each radiation penetration on typical material

92

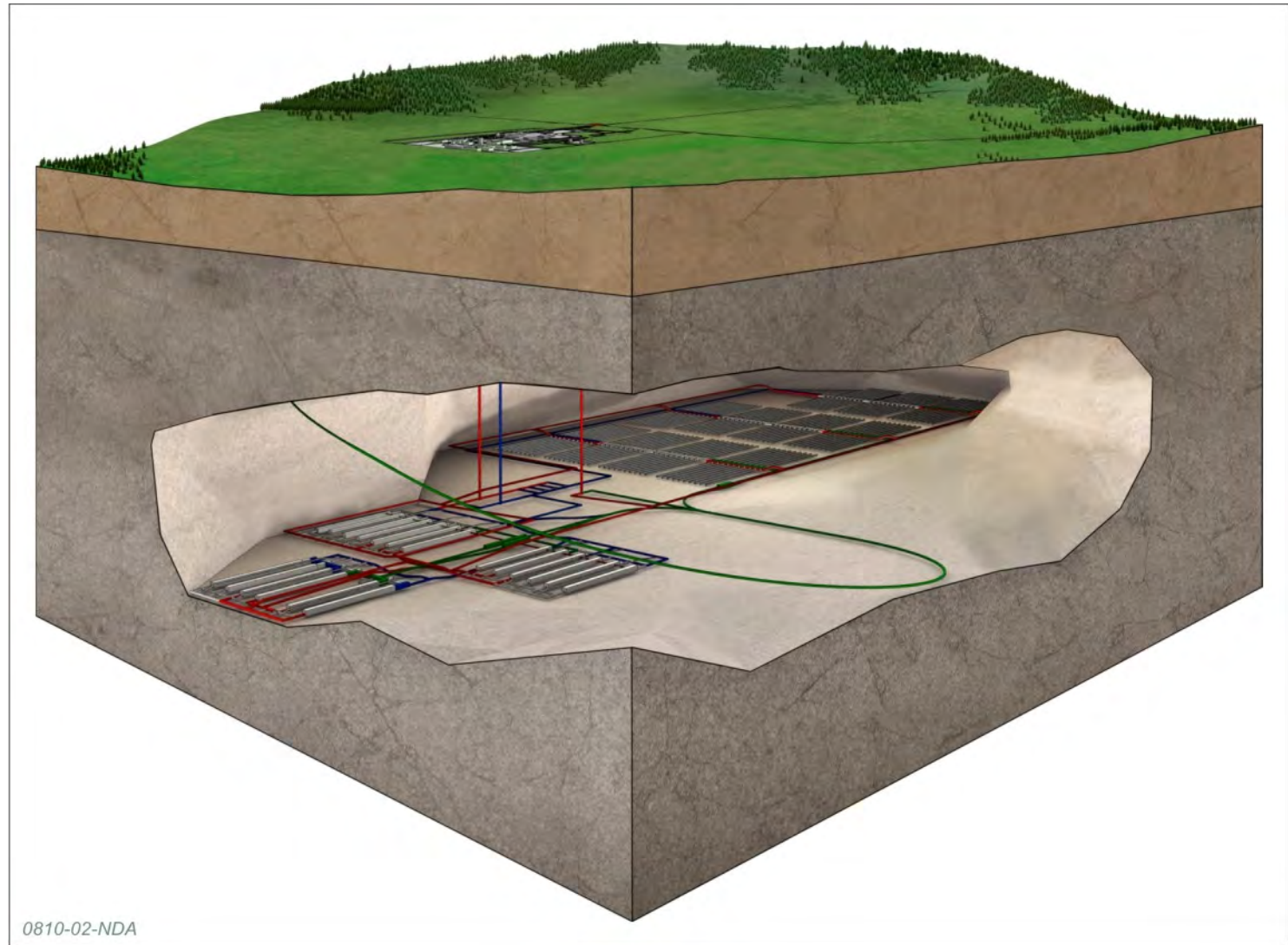






# Deep geological waste disposal

94



## 2.2 Nuclear power plant technology

95

- Current situation of nuclear energy
- Working process and merits of nuclear power plant
- **Radioactive level and dosages**

# Radioactive unit

**Activity-** disintegration rate of radioactive substance

- Becquerel- SI unit (Bq) = 1 disintegration per second (dps)
- Curie (Ci) =  $3.7 \times 10^{10}$  Bq = # dps from 1g Ra

**Absorbed dose-** energy imparted by radiation onto an absorbing material

- Gray-SI(Gy) = 1 joule per kilogram
- 1 Gy = 100 rads

**Dose Equivalent (DE)-** dose in terms of biological effect

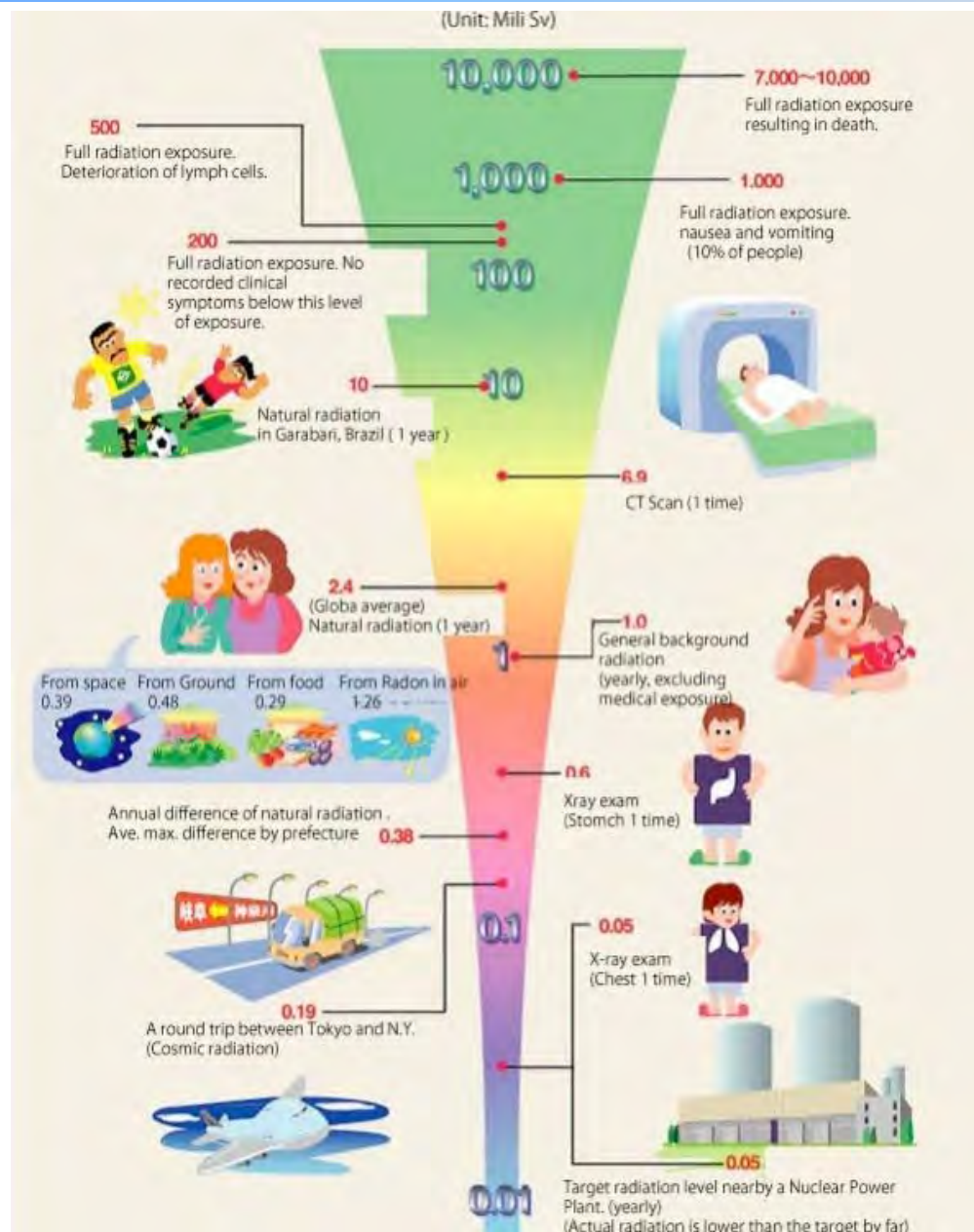
- $DE = \text{Absorbed dose} \times \text{Quality factor (Q)}$
- $Q = 1$  for beta particles and gamma/x-rays  
 $Q = 10$  for alpha particles
- Sievert- SI unit (Sv)  
 $1 \text{ Sv} = 100 \text{ rems}$





# Typical radiation level

97



**Thank You very much for your kind attention**

**Q & A**

