Addis Ababa University
Addis Ababa Institute of Technology
School of Mechanical & Industrial Engineering

Power Plant Engineering

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Course Outline

Chapter 1- Introduction to Power Plant Engineering

Chapter 2- Analysis of steam Power Plant cycle

Chapter 3- Fuel and combustions

Chapter 4- Steam generators(Boilers)

Chapter 5- Combustion mechanisms, combustion

Chapter 6- Equipment and Firing Methods

Chapter 7- Steam Turbines

Chapter 8- Steam condensers and Circulating water systems

Chapter 9- Gas Turbine Power Plants

Chapter 10- Power Plant Economy

Chapter 1- Introduction to Power Plant Engineering

Introduction

- *One only has to experience a power outage to be reminded of how much we take electricity for granted.*
- *Our lighting, heating, and cooling systems no longer operate. Computers, televisions, videos, and other communication systems become unusable.*
- *Traffic control lights become useless; elevators no longer move people; and industries, schools, and commercial buildings become virtually inoperable.*

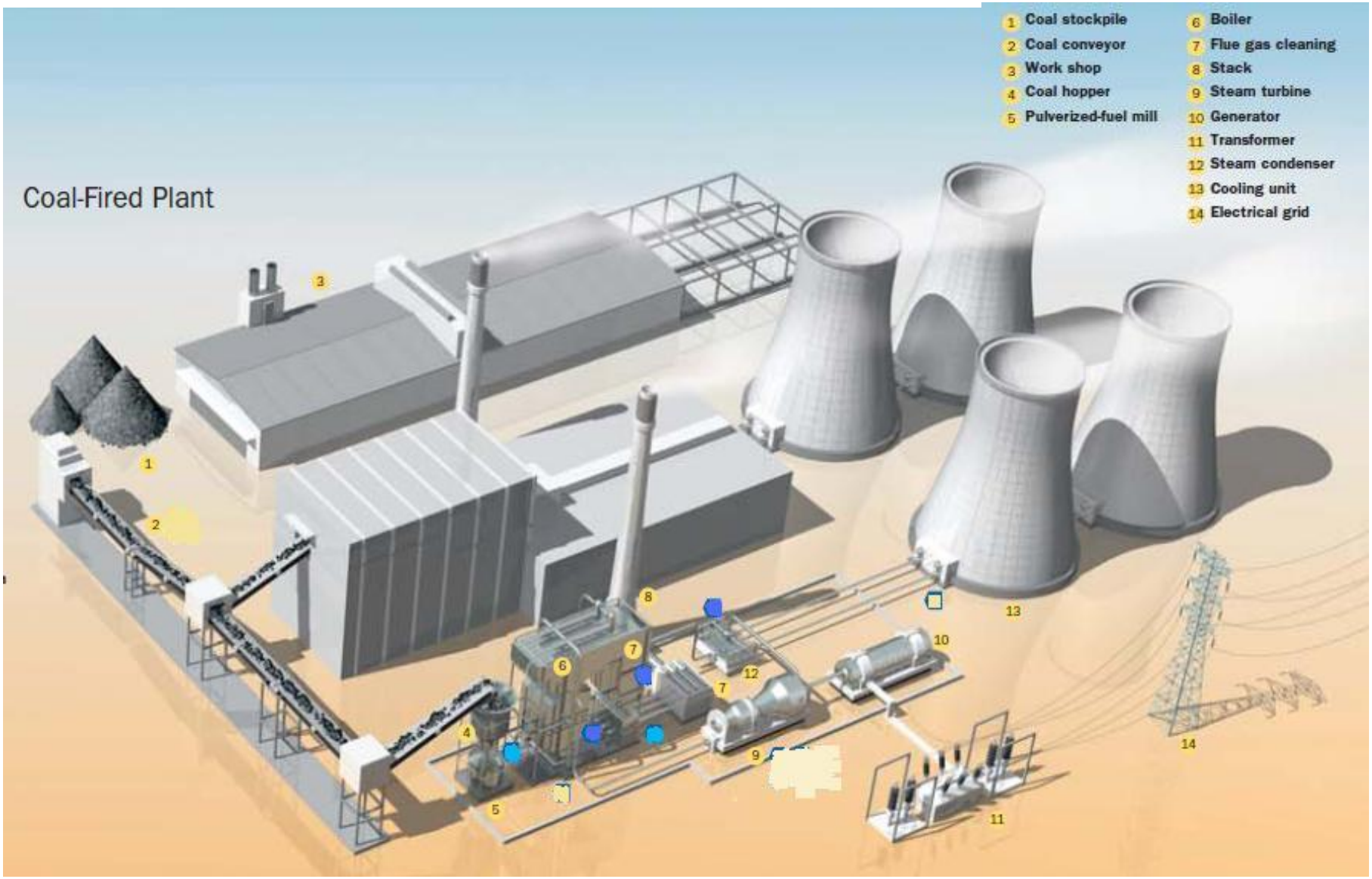
Introduction

- *We are clearly dependent on electricity for most of our everyday activities.*
- *This dependence also demonstrates why electricity is regarded as one of the most significant sociological inventions of the 20th century.*
- *A power plant is assembly of systems or subsystems to generate electricity, i.e., power with economy and requirements.*
- *The power plant itself must be useful economically and environmental friendly to the society.*

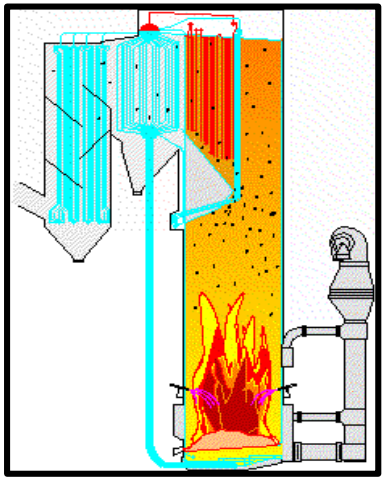
Africa at Night

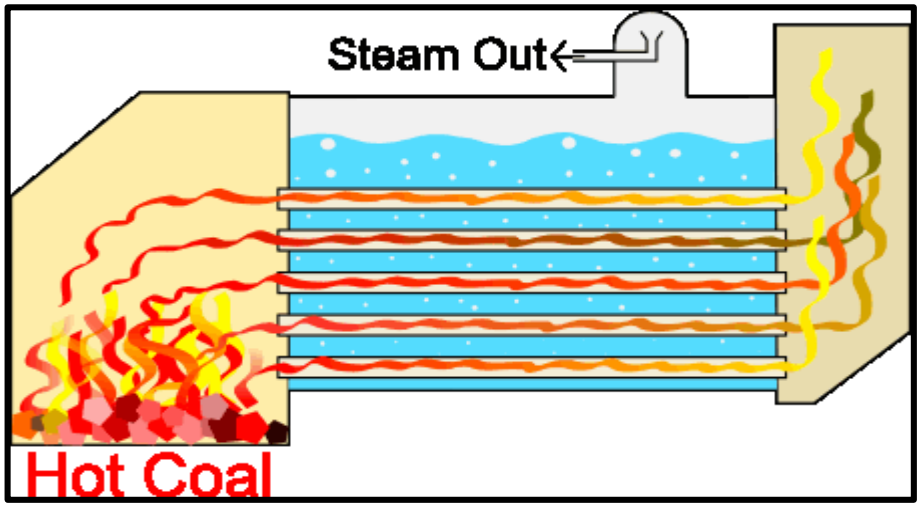
POWER PLANT ENGINEERING

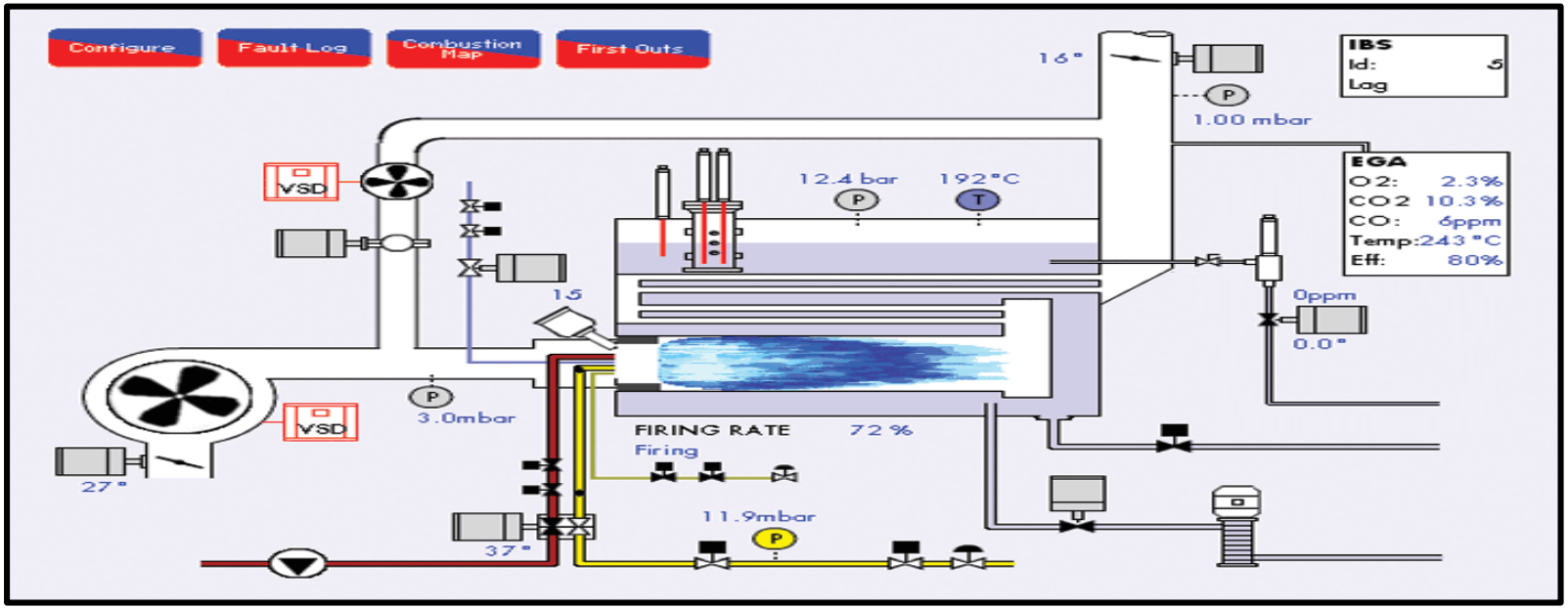
A TYPICAL COAL-FIRED THERMAL POWER STATION



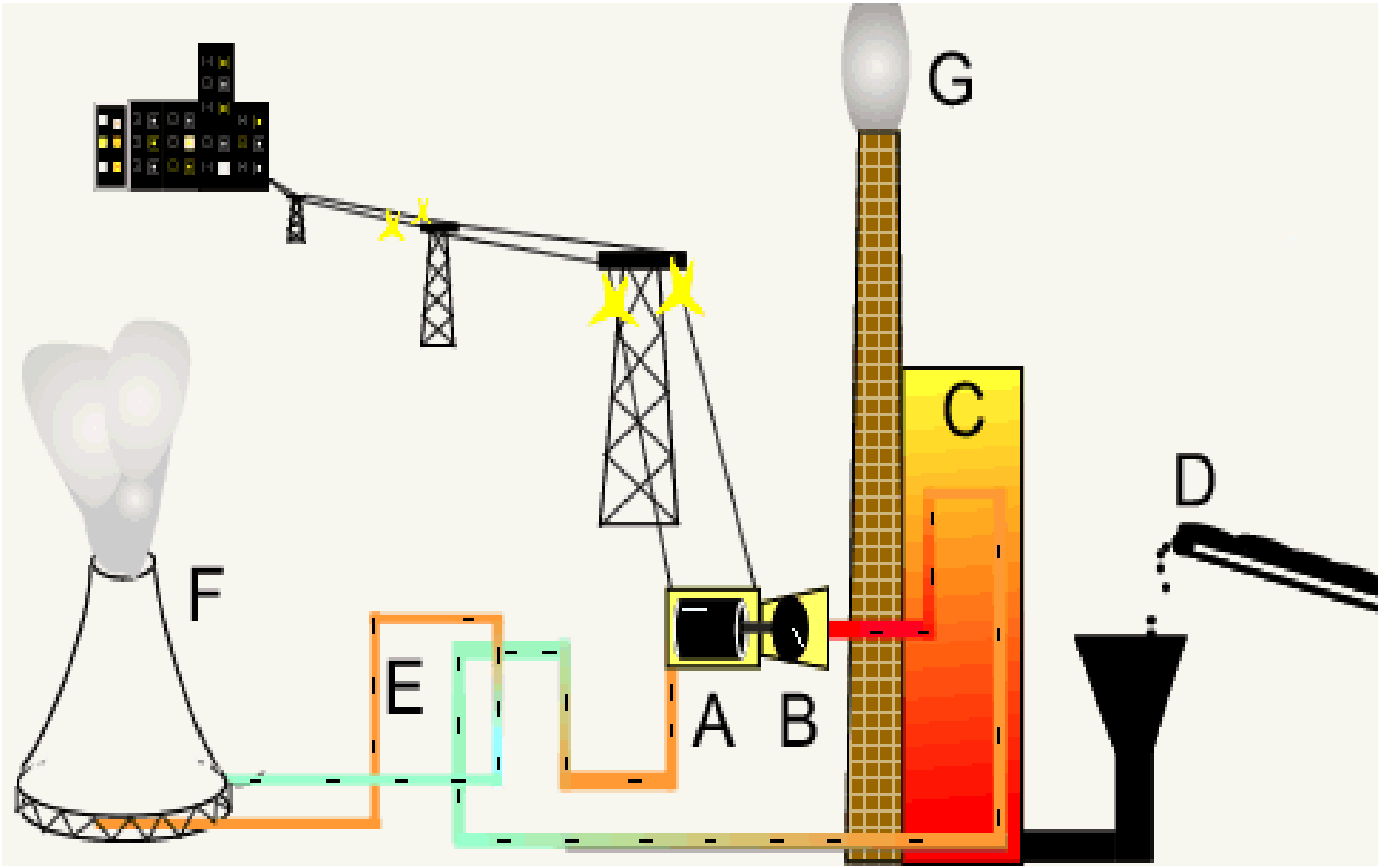
BOLIERS




Steam Out
Hot Coal


Configure
Fault Log
Combustion Map
First Outs
16°
IBS
Id: 5
Lag
1.00 mbar
EGA
O2: 2.3%
CO2 10.3%
CO: 6ppm
Temp:243 °C
Eff: 80%
VSD
12.4 bar
192°C
15
0ppm
0.0°
3.0mbar
VSD
FIRING RATE 72 %
Firing
27°
11.9mbar
37°

A TYPICAL COAL-FIRED THERMAL POWER STATION



Fundamentals of Power plant

- Power plant is assembly of systems or subsystems to generate electricity, i.e, to produce power with economy and requirements.
- So the power produced must be :
    1. Economically useful
    2. Environmental friendly to society

Power plant can be defined as :

1. ***"A machine or assembly of equipment that generate and deliver a flow of mechanical or electrical energy.***

Fundamentals of Power plant

- ***The main equipment for the generation of electric power is generator.***
- ***When coupling it to a prime mover runs the generator, the electricity is generated.*** The type of prime move determines, the type of power plants.
- ***The Steam Power Plant, Diesel Power Plant, Gas Turbine Power Plant and Nuclear Power Plants are called THERMAL POWER PLANT, because these convert heat into electric energy.***

Working Principle of Steam power plants

- *Steam power plant is also known as Thermal power plant.*
- *A steam power plant converts the chemical energy of the fossil fuels (coal, oil, gas) into mechanical / electrical energy.*
- *This is achieved by raising the steam in the boilers, expanding it through the turbines and coupling the turbines to the generators which convert mechanical energy into electrical energy as shown in fig. 1.1.*

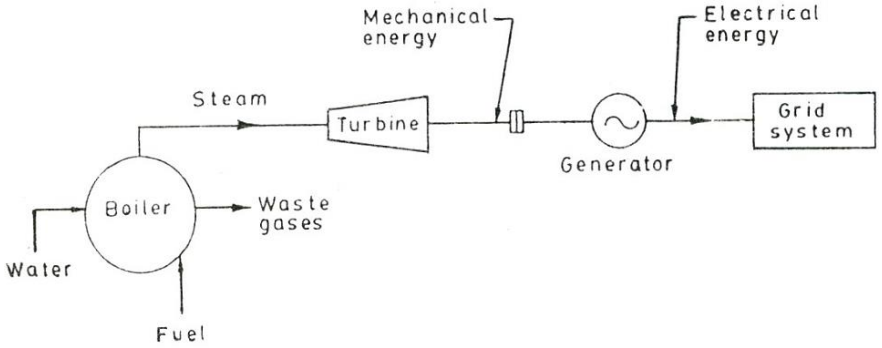


Fig. 1.1. Production of Electric energy by steam power plant

Working Model of Stephenson's STEAM ENGINE made of GLASS

The ancient invention of the steam engine by the Hero of Alexandria

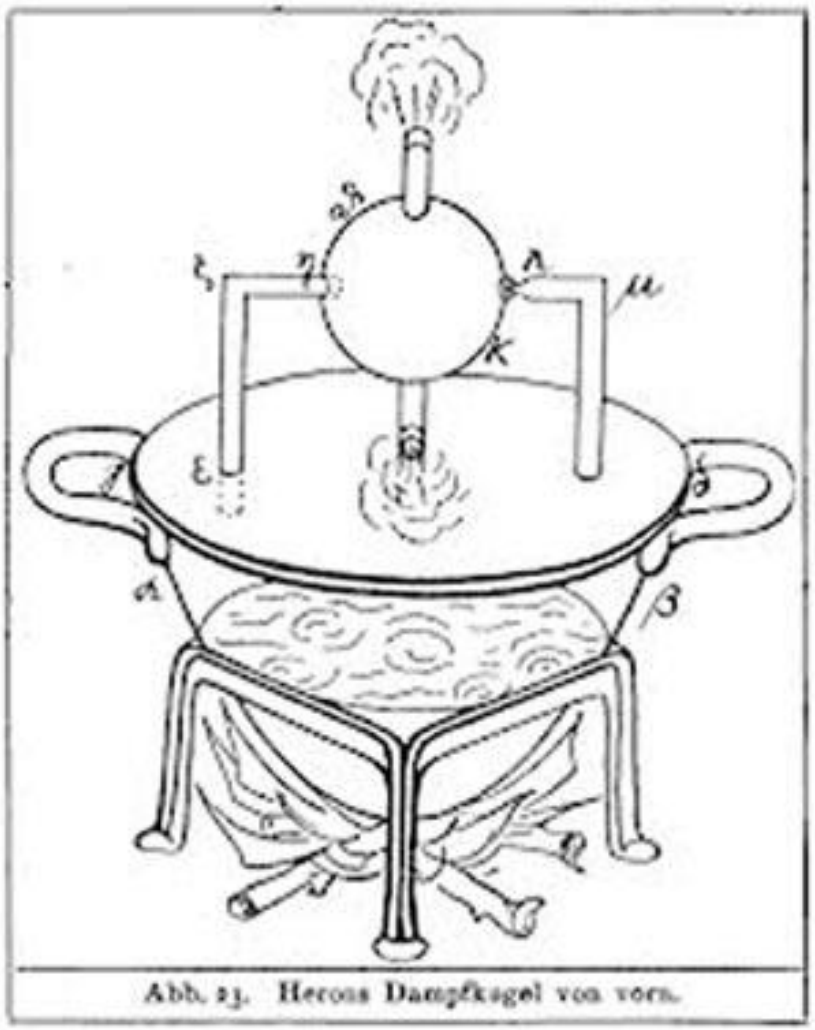
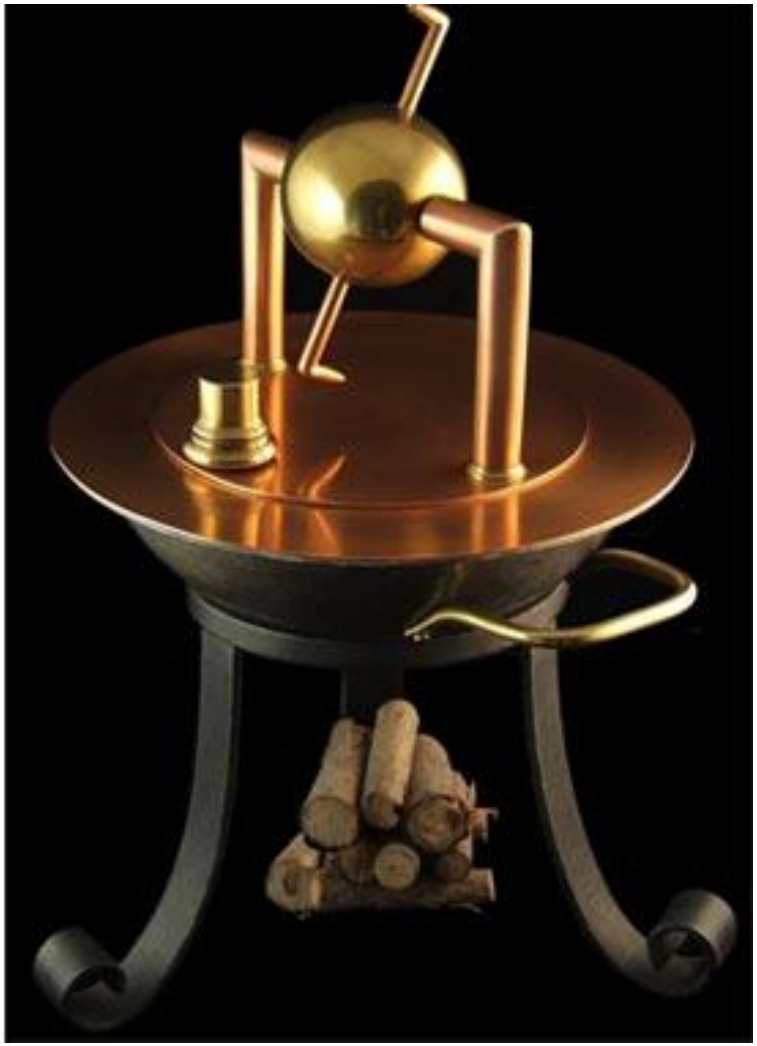


Abb. 23. Heros Dampfkugel von vorn.



Working principle of Steam power plants

- The following two purposes can be served by a steam power plant:
  1. To produce electric power
  2. To produce steam for industrial purposes besides producing electric power. The steam may be used for varying purposes in the industries such as textiles, food manufacture, paper mills, sugar mills and refineries.

Classification of Power Plant

- *Methods of general classification of electricity generation power plant are as follows :*

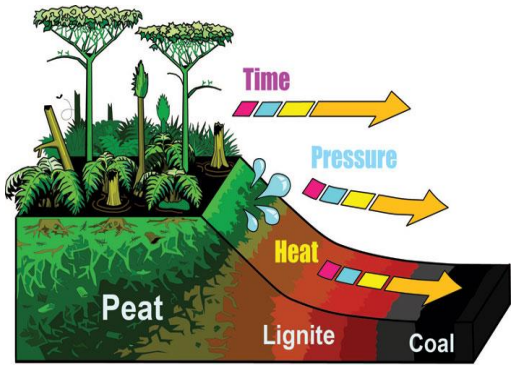
    1. ***Status***
    2. ***Fuel type***
    3. ***Capacity***
    4. ***Prime mover***

Classification of power plant

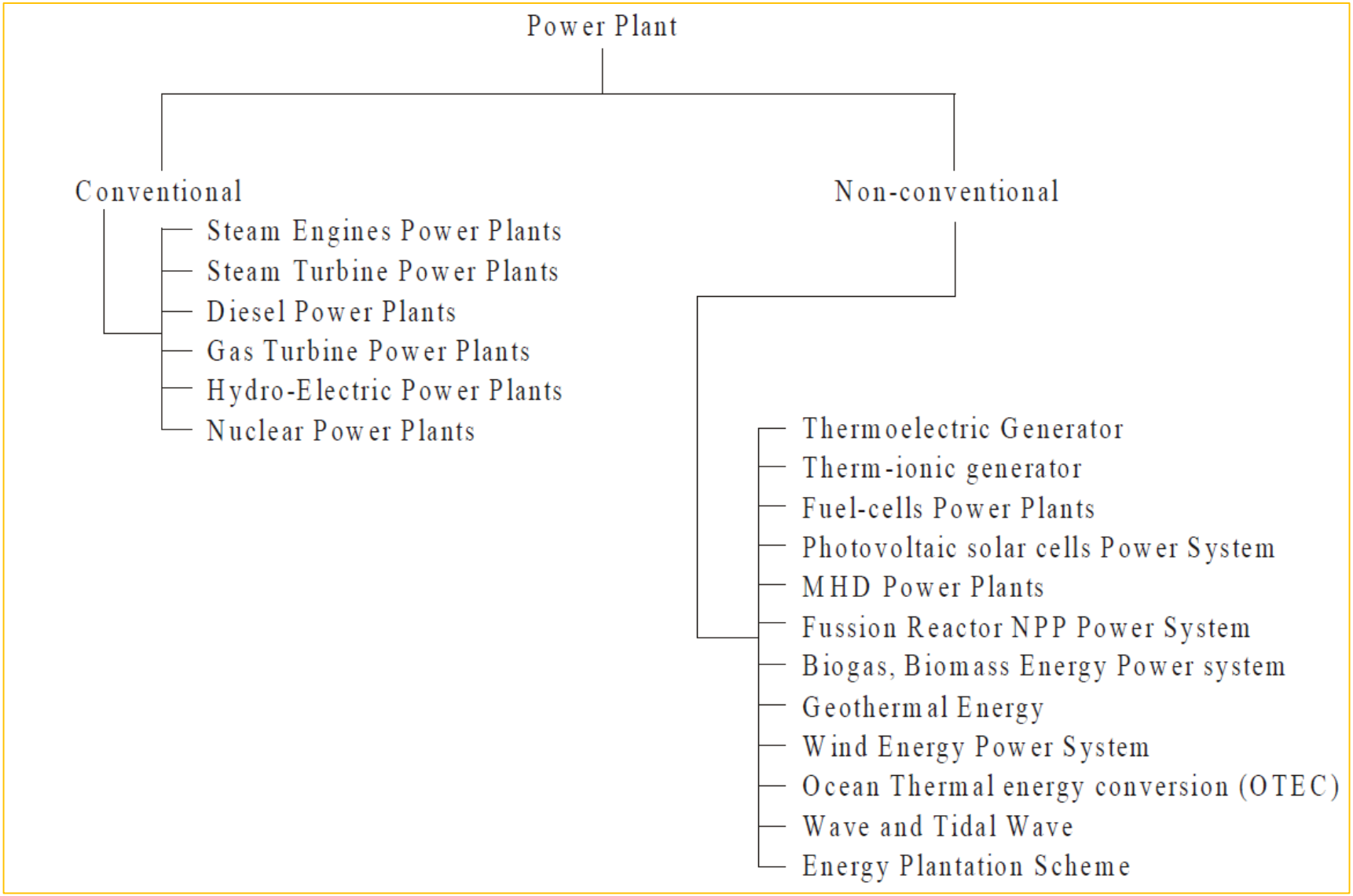
1. Status

Energy Resources

Conventional sources of energy (Or) Non – renewable sources of energy	Non conventional sources of energy or Renewable source of energy
Examples: - Fuels like coal, oil, energy Natural gas, nuclear fuels etc.	**Examples:-** Sun, wind, waves, tides, From earth core, hydro Power etc.



Classification of power plant



Non – renewable sources:

- *Most of the energy we use are from source like coal, oil, natural gas and nuclear fuels.*
- *These primary energy sources are called Non – renewable sources because once they have been used up, they cannot be replaced.*

Renewable sources:

- *Sources of energy that can be used over and over again are called renewable sources. These sources can be used to produce electricity.*
- *Some of the renewable sources are:*
  - *Energy from the sun (Heat and light energy)*
  - *Energy from the wind (Kinetic energy)*
  - *Energy from the waves and tides (Kinetic energy)*
  - *Energy from earth's core (Geothermal energy)*

Classification of power plant

2. Fuel type

- *Thermal power plant (coal)*
- *Internal combustion engine plants (petrol or diesel)*
- *Gas turbine power plant (permanent gas)*
- *Nuclear power plant (nuclear fuels)*
- *Solar power plant (suns radiation heat)*
- *Tidal power plant (tides in the sea)*
- *Hydro electric power plant (potential energy of water)*
- *Wind power (energy available in wind)*
- *Geothermal power plant (heat energy available under the ground)*

Classification of power plant

3. *Capacity*

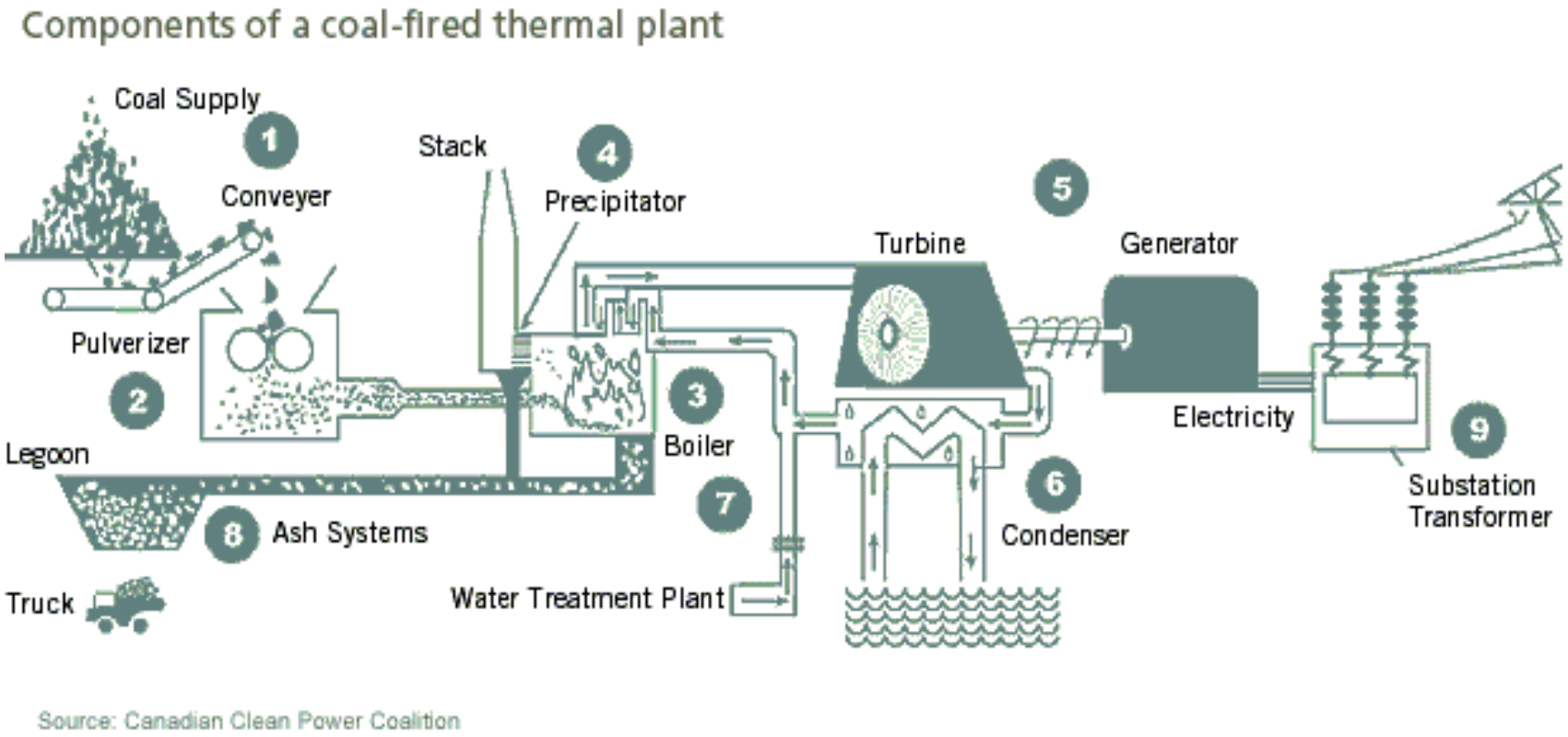
Power plant can be classified according to it's capacity :

- I -	- II -	- III –	- IV –
Small power plant : producing less than (5 MW)	Medium capacity plant :production capacity lies in the range of (5 – 100) MW	High capacity plant : Have production range of (101 – 1000) MW	Super capacity plant : Exceeds (1000) MW power production level

Classification of power plant

4. *Prime mover*
    1) *Steam turbine*
    2) *Gas turbine*
    3) *Water turbine*
    4) *Wind turbine*
    5) *Combined cycle*
    6) *Heat engine*
    7) *other sources as wave, sun light, …etc*

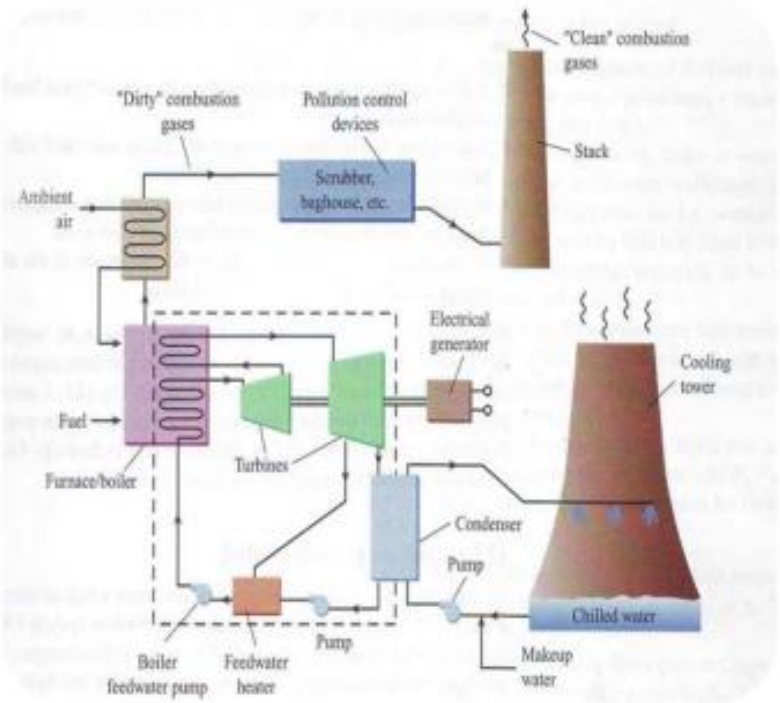
Classification of Power Plant



Classification of Power Plant

1 – steam power plant

Steam power plants use fuels such as petroleum, coal, or biomass are burned to heat water to create steam, the pressure of the steam spins a turbine turning the copper wire inside the generator.



1 – steam generator

2 – turbine

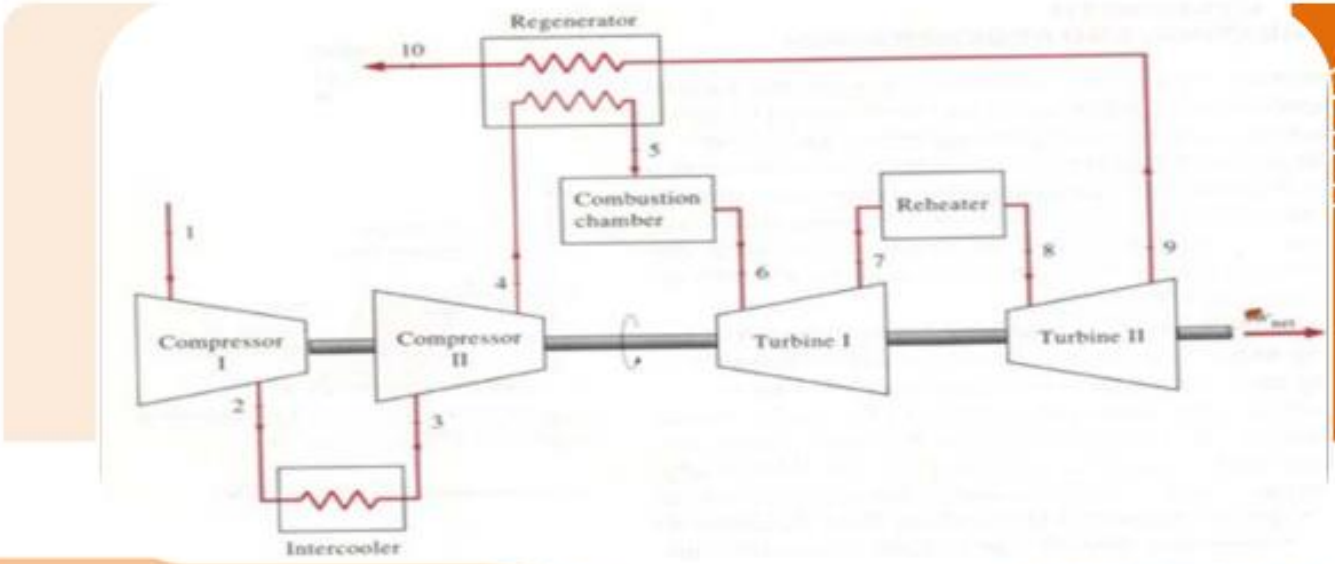
3 – condenser

4 – pressure pump

5 -Plus other parts such as water heaters, cooling water system regenerators, re-heaters, water treatment system … etc

Classification of power plant

2 – gas turbine plant



Gas turbine plant major component are :

Gas power plants uses fuels that are burned to create hot gases to spin the turbine.

1 – compressor

2 – combustor

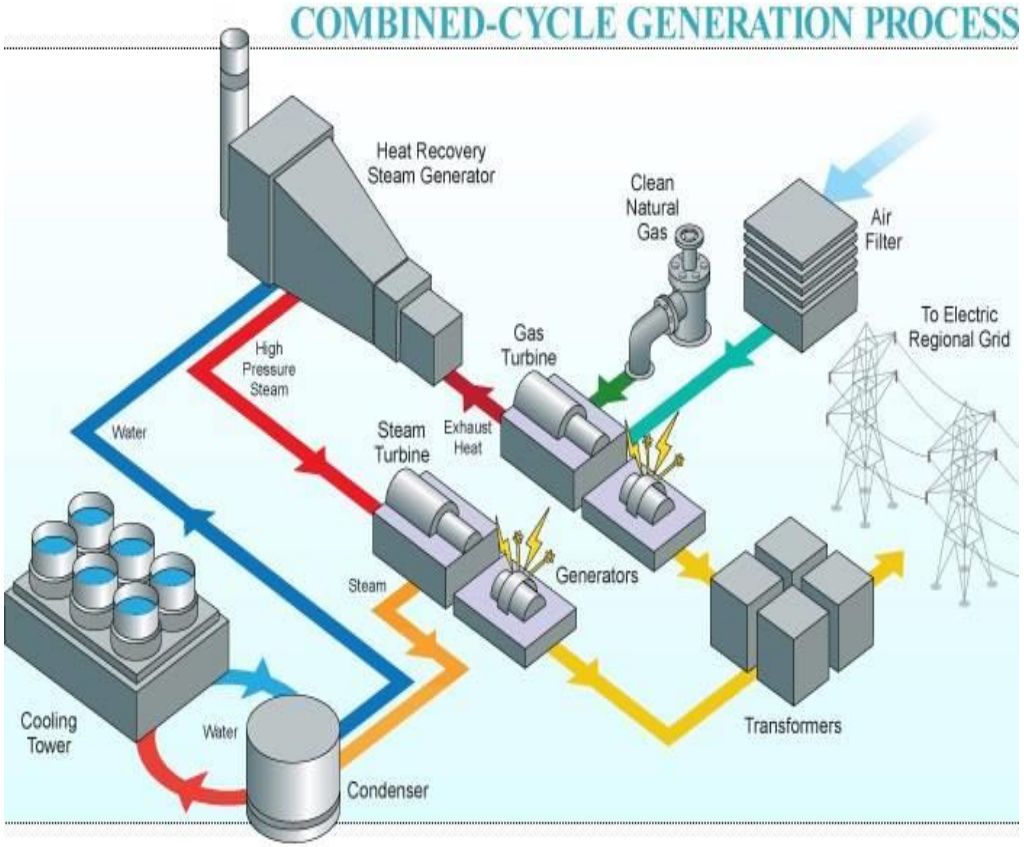
3 – gas turbine

4 - Plus others as inter-cooler, after-cooler, regenerator, re-heater, cooling water system

Classification of power plant

3 – combined cycle plant

The combined-cycle unit combines the Rankine (steam turbine) and Brayton (gas turbine) thermodynamic cycles by using heat recovery boilers to capture the energy in the gas turbine exhaust gases for steam production to supply a steam turbine as shown in the figure .



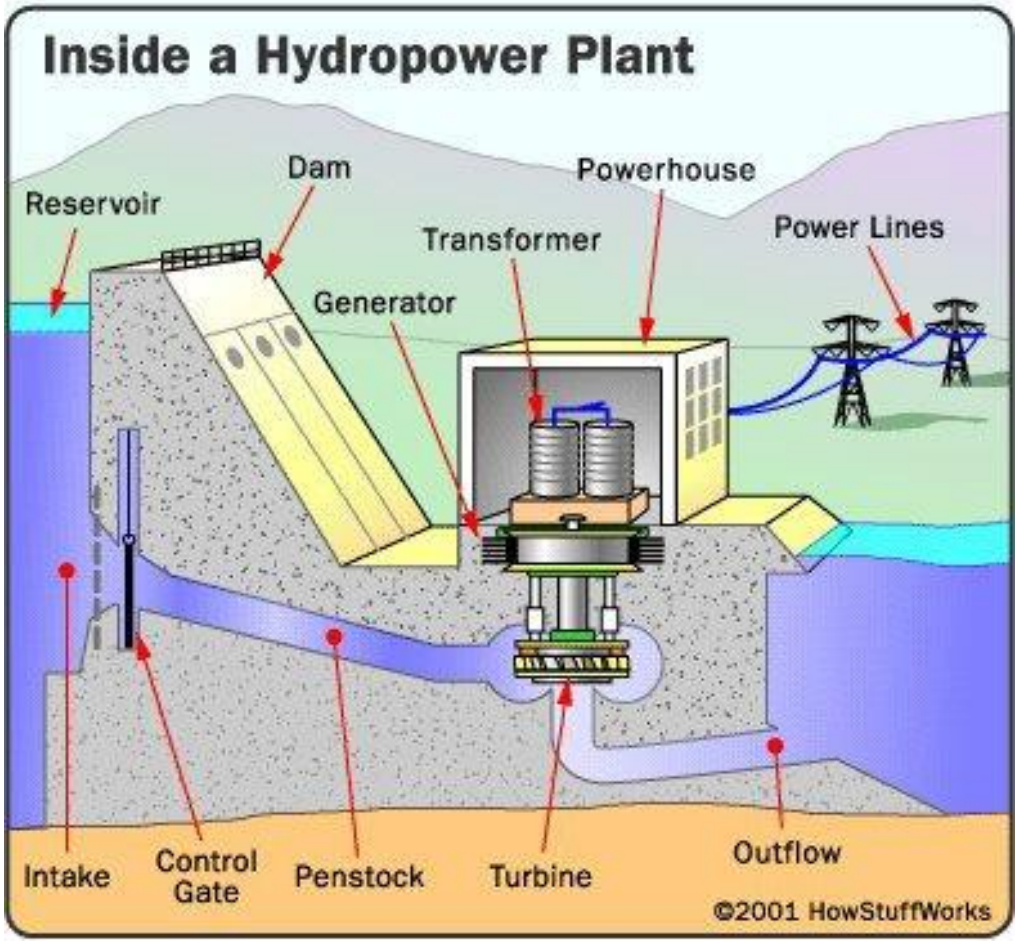
Classification of power plant

4 – hydro-electric plant

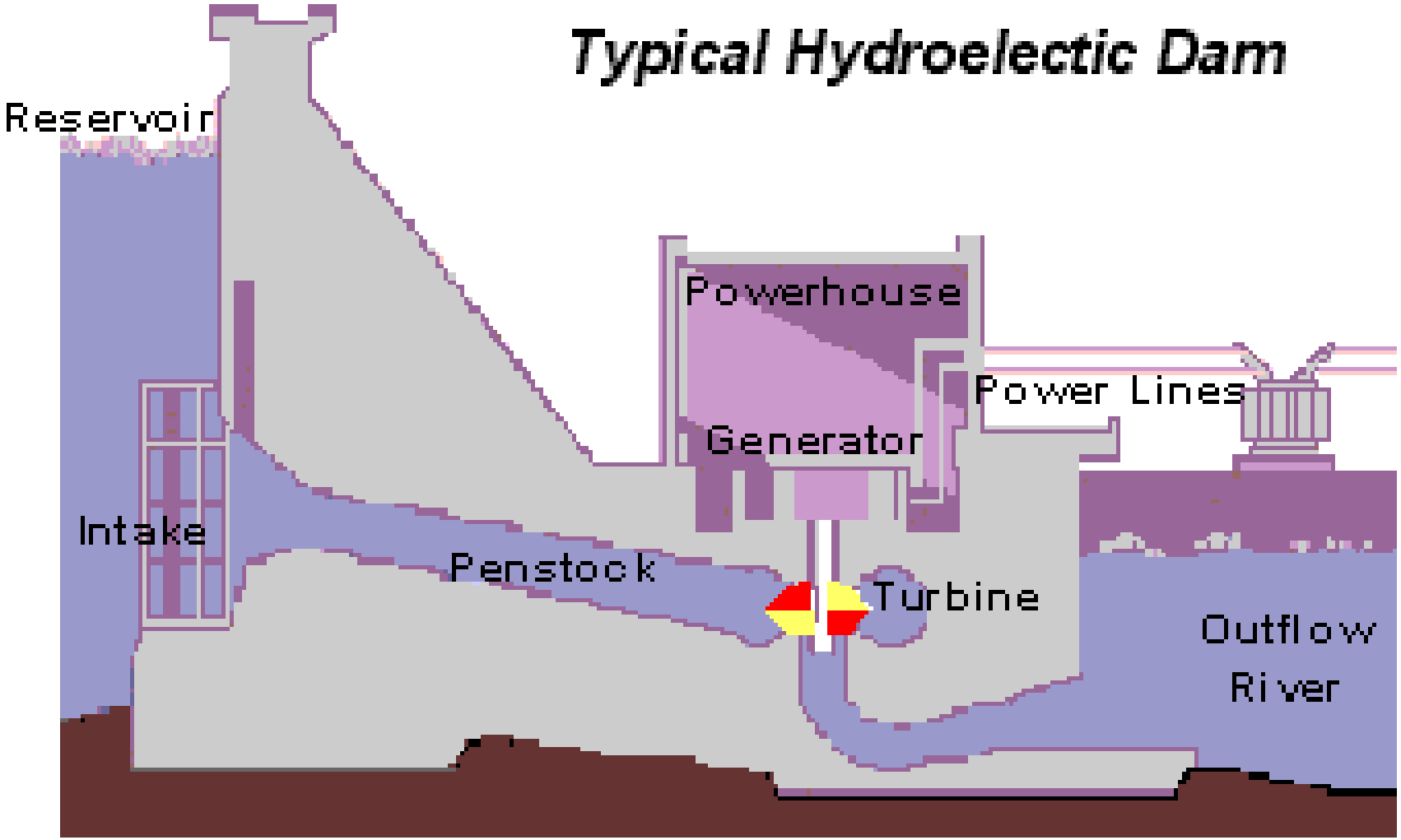
Hydroelectric plant use falling (or flowing) water to spin the turbine blades.

Water flowing in high altitude rivers is stored in a man-made reservoir as shown in the figure. The kinetic energy of the flowing water is transformed into potential energy as the water level rises. This water is carried through pipes to the turbine situated at the bottom of the dam.

A jet of moving water rotates the water turbine rapidly which in turn rotates the shaft which is attached to its centre.



Classification of power plant

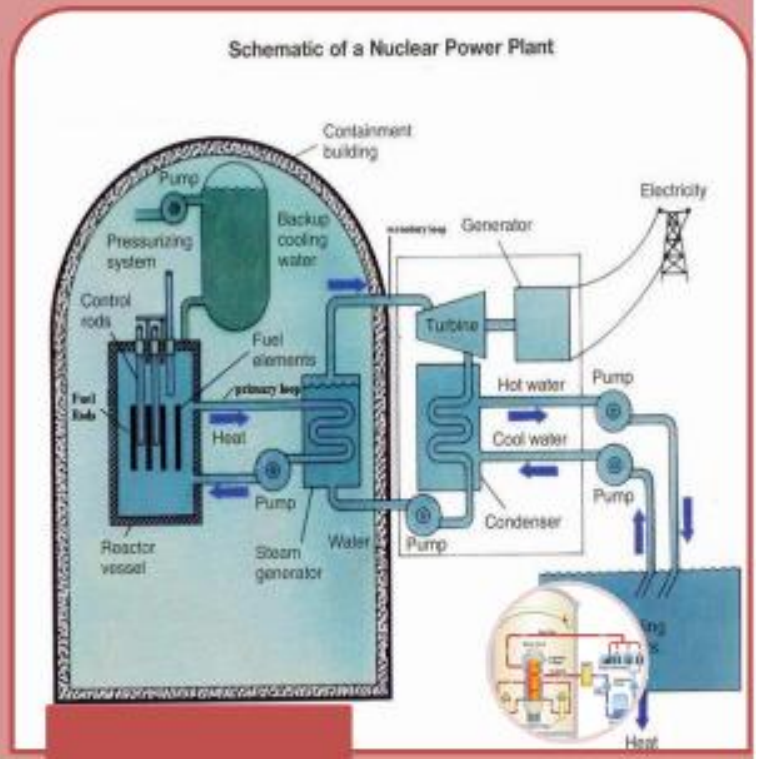


Classification of power plant

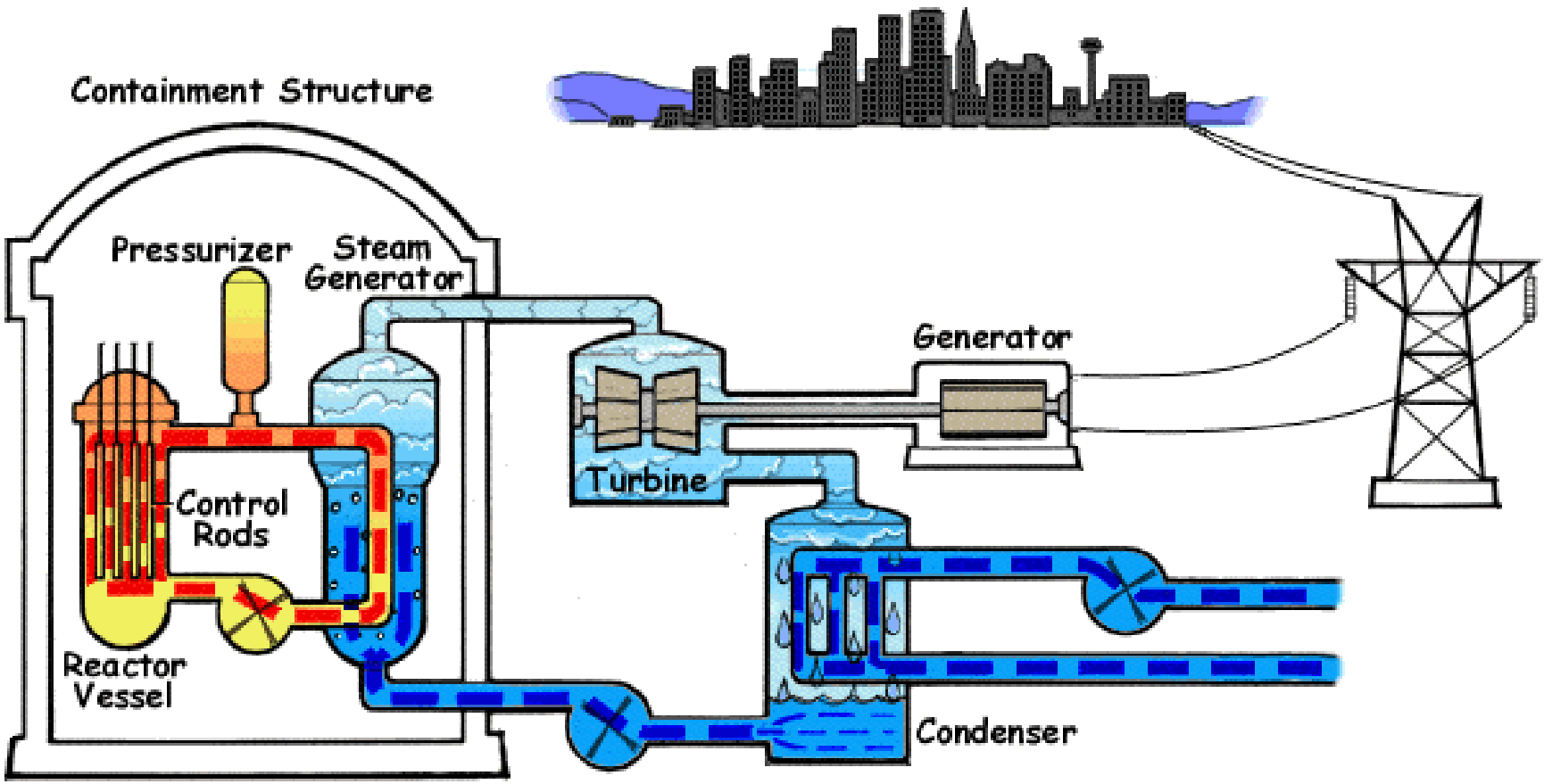
5 – nuclear power plant

- Nuclear power plants use nuclear fission to turn water into steam. This drives the steam turbine, which spins a generator to produce power.

- Grams of highly enriched uranium can power a nuclear submarine or nuclear aircraft carrier is equal to something on the order of a million gallons of gasoline.



Classification of power plant



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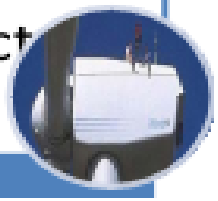
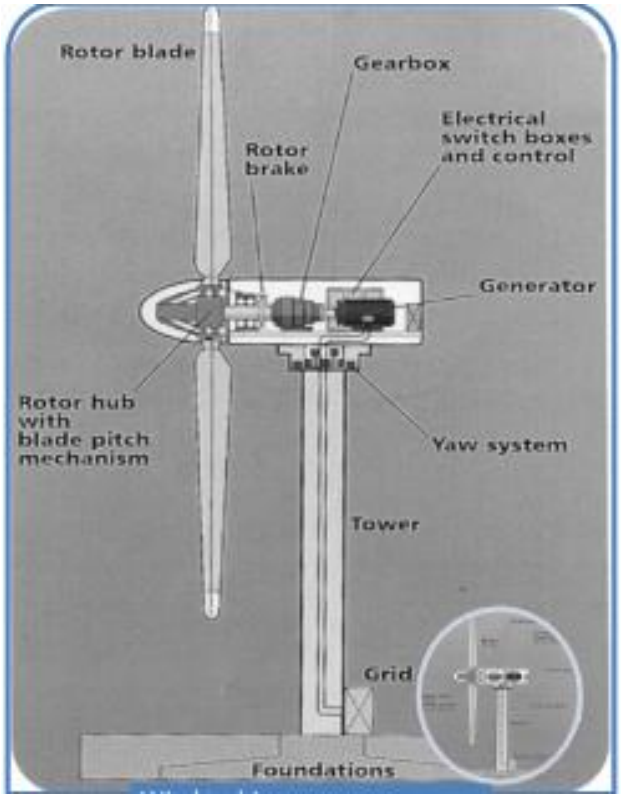
Classification of power plant

6 – wind turbine plant

- **Wind power plants** use the wind to push against the turbine blades, spinning the copper wires inside the generator to create an elect current.



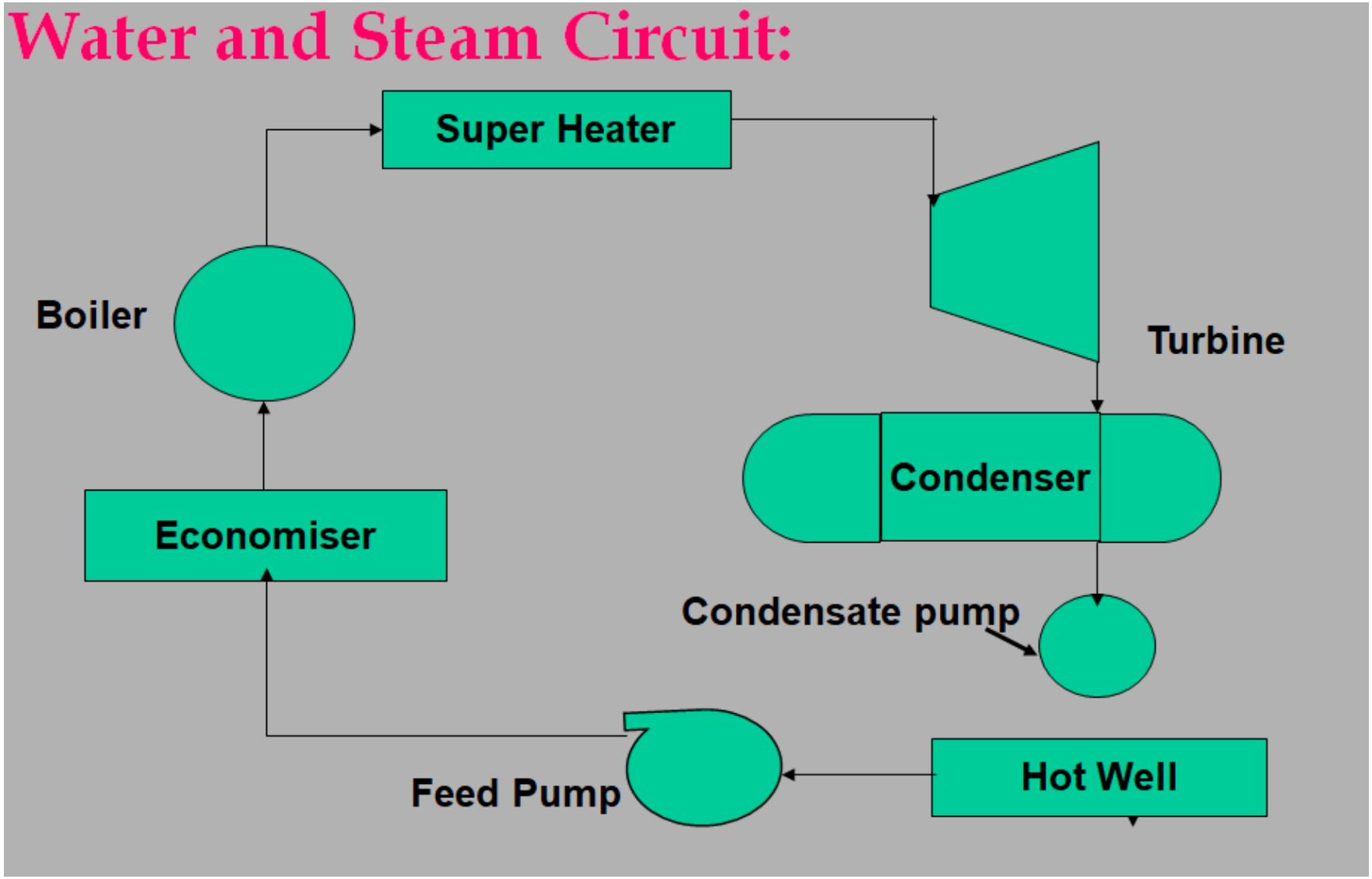


Layout of Steam Power Plant

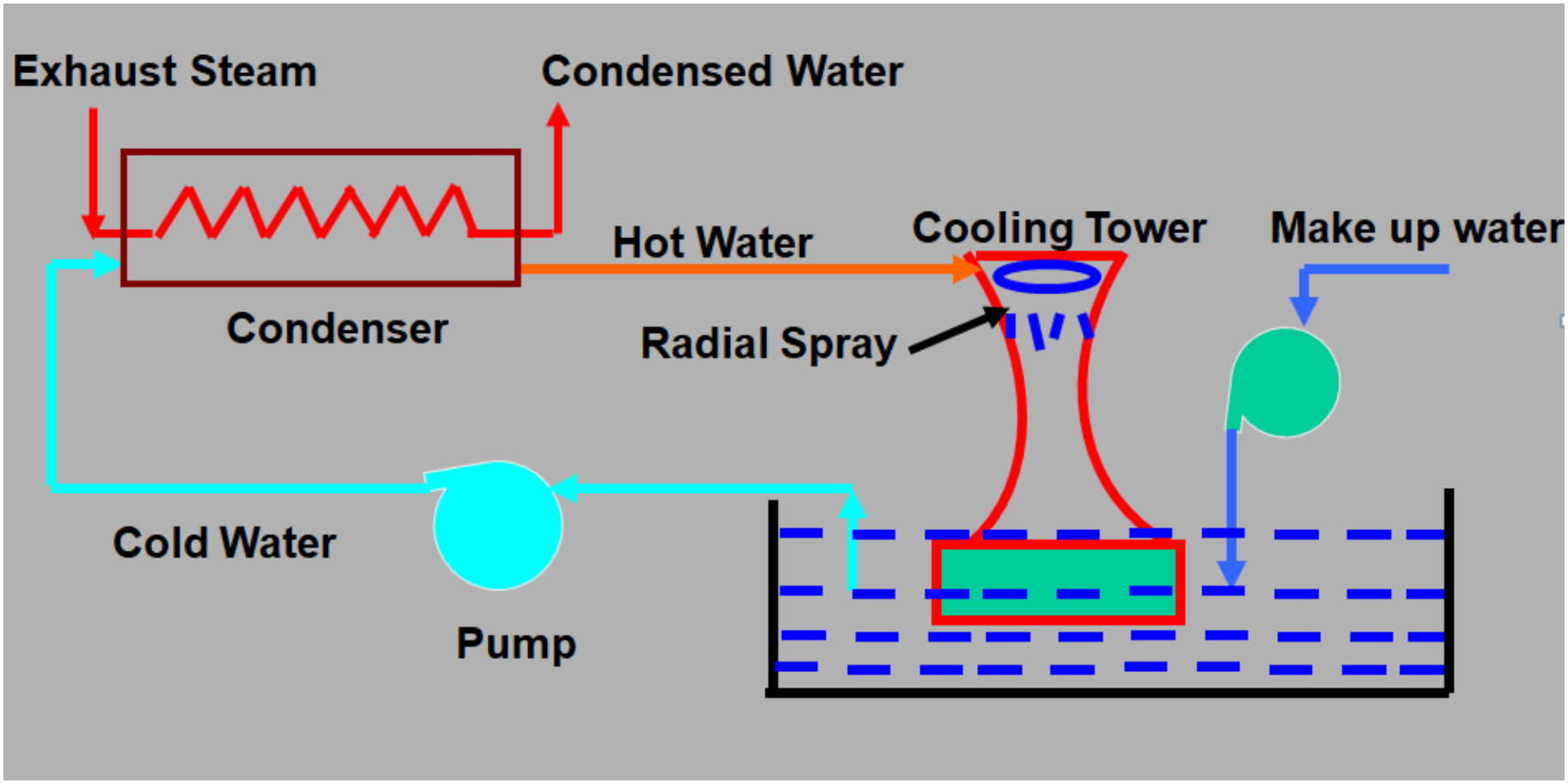
The layout of steam power plant has the following circuits:

1. *Fuel (Coal) and ash circuit*
2. *Air and flue gas circuit*
3. *Feed water and steam flow circuit*
4. *Cooling water flow circuit.*

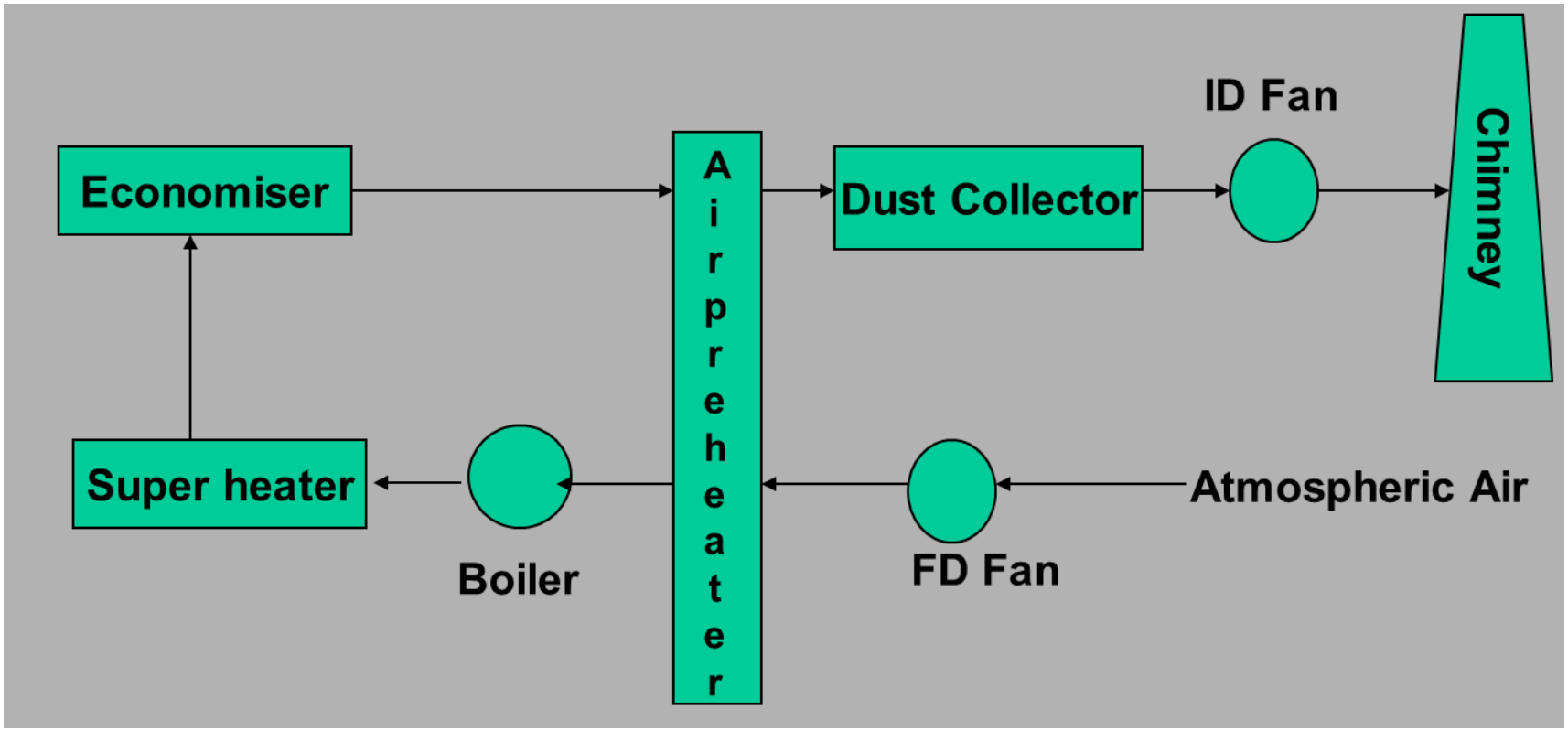
Water and Steam Circuit



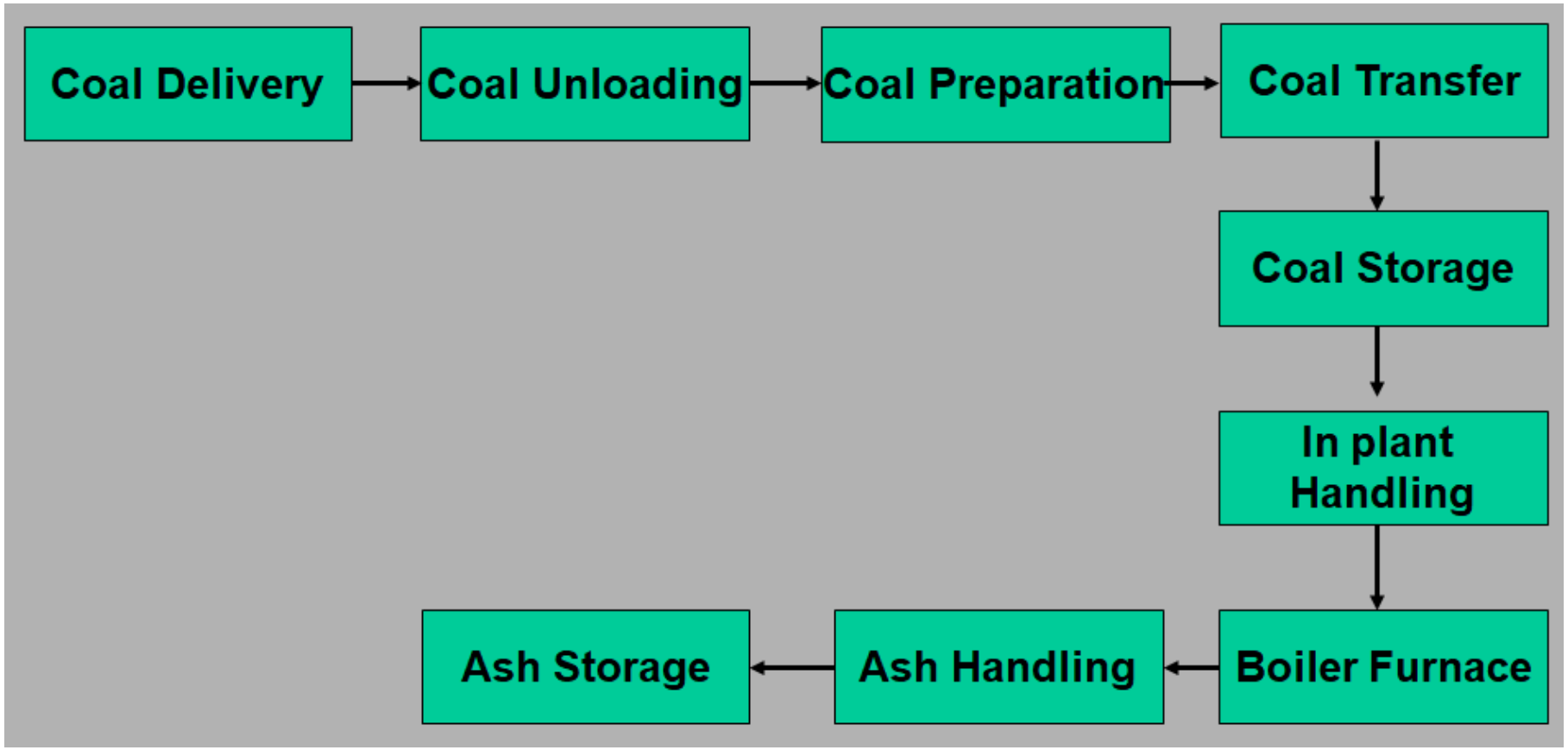
Cooling Water Circuit



Air and Flue Gas Circuit



Coal and Ash Circuit



Power Plant

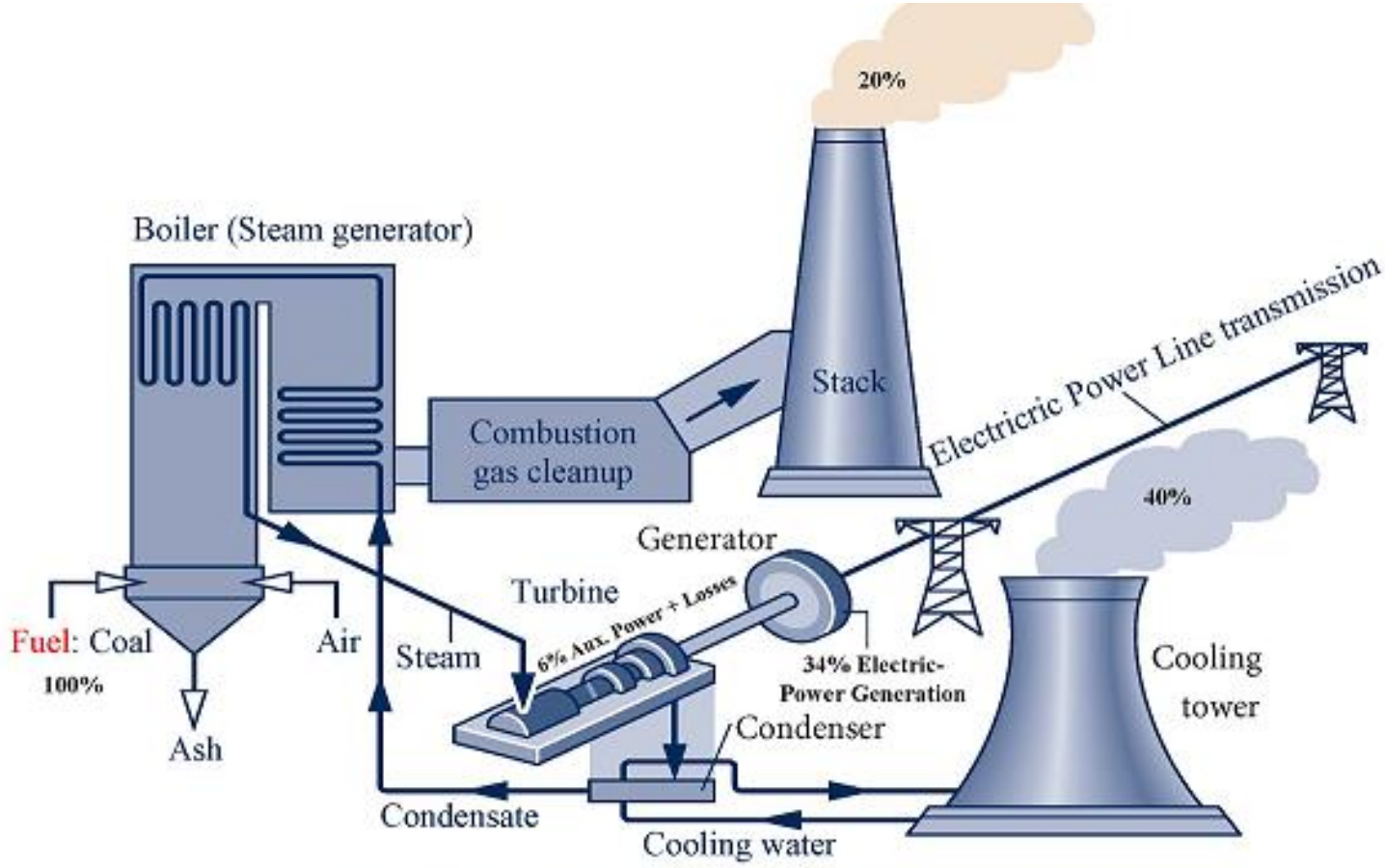
- *Though the main process in steam power station is the conversion of heat energy into electrical energy, it comprises of many steps for its proper working and good efficiency . The whole arrangement of a steam power station could be divided into following steps.*
  - ***Coal and ash handling arrangement***
  - ***Steam generating plant***
  - ***Steam turbine***
  - ***Alternator***
  - ***Feed water***
  - ***Cooling arrangement***

Main and Auxiliary equipments

1. *Coal handling plant*
2. *Pulverizing plant*
3. *Draft fans*
4. *Boiler*
5. *Ash handling plant*
6. *Turbine*
7. *Condenser*
8. *Cooling towers and ponds*
9. *Feed water heater*
10. *Economiser*
11. *Superheater and Reheater*
12. *Air preheater*

Power plant

- The whole arrangement is shown in a schematic figure given below.



Electrical power plan with 34 % thermal efficiency

1. Coal and ash handling

- *The coal is transported from different places to the station by means of rails or road and is stored in a coal storage plant.*
- *It is to use as a preserve at the time of scarcity.*
- *From coal storage plant it is transferred to coal handling plant for pulverization.*
- *Pulverization is the process by which large lumps of coal are broke to small pieces .*

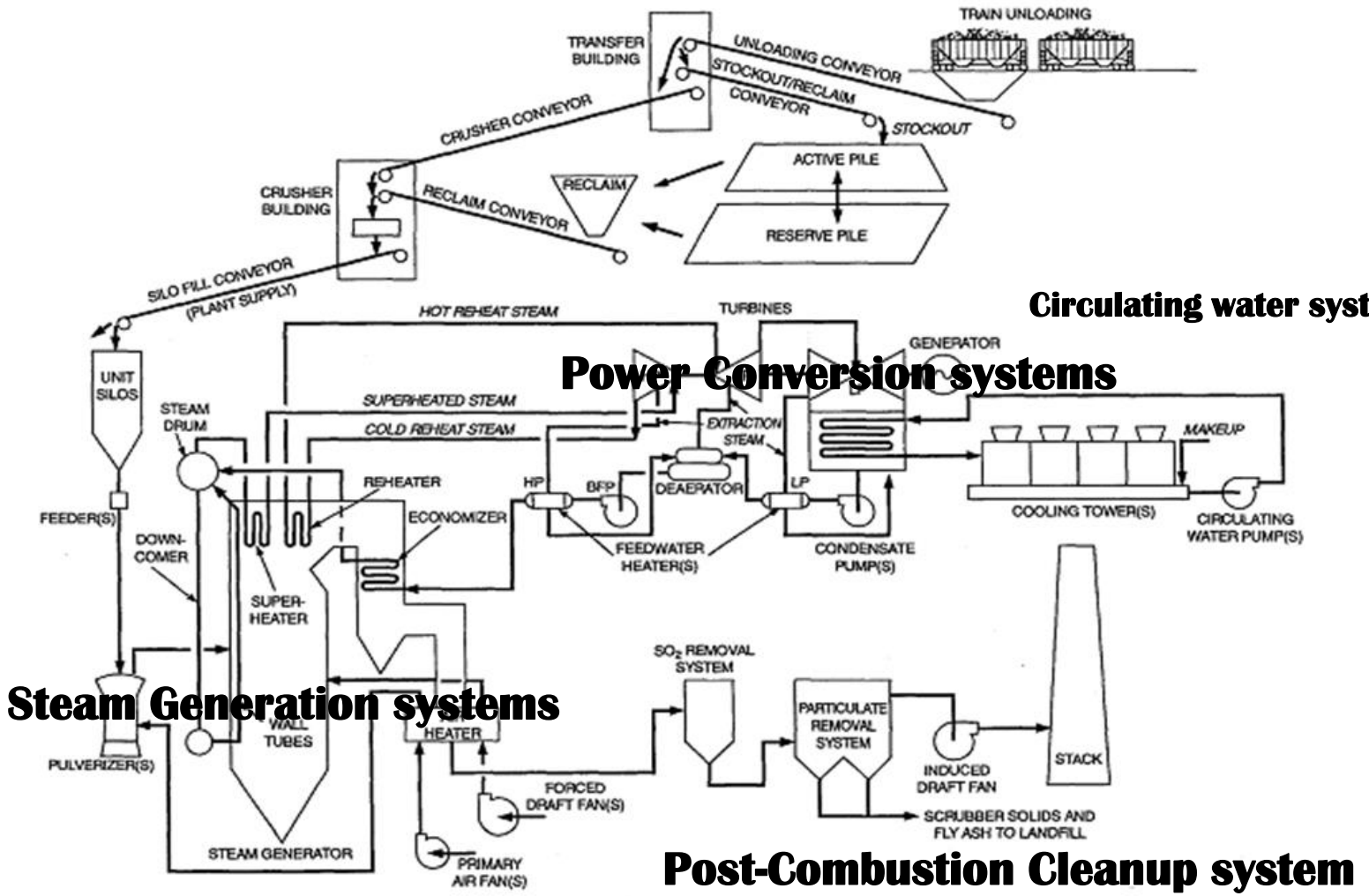
Why Pulverization is done?

- *Pulverization is done to increase the surface area of coal and thereby helping the easy combustion of coal with small intake of air.*

Why Pulverization is done?

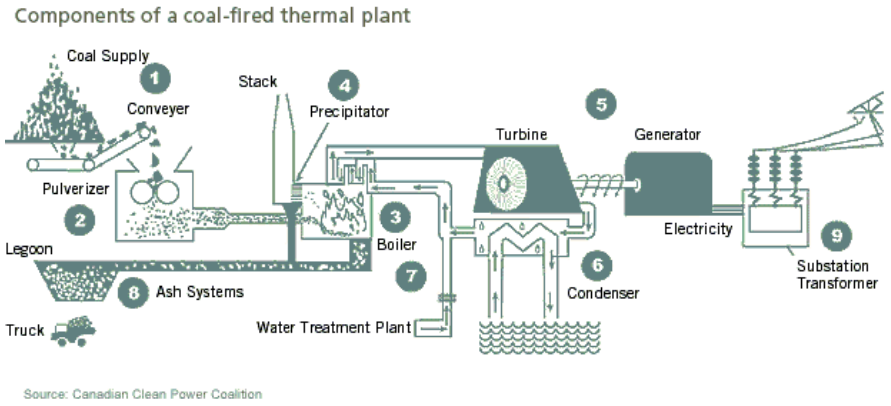
- *The pulverized coal is fed to the boiler by means of conveyor belt.*
- *The coal is burnt in the boiler and the ash so produced by burning is removed to the ash handling system and finally to the ash storage area for its disposal.*
- *This process is necessary since ash in the boiler furnace does not promote proper combustion.*

Coal handling System



Coal handling System

- Ash is the inert matter in coal and is the residue after combustion.
- This has to be collected and disposed off without letting it out into the atmosphere.
- A part of the ash, around 15 % collects as '**Bottom ash**' at the **bottom of the furnace**.
- The other part collects as '**Fly ash**' in the **Electrostatic Precipitators**.
- The collected ash is then transported to disposal yards or storage silos.



Coal handling System

- *The percentage of ash in coal varies from 5% in good quality coal to about 40 % in poor quality coal*
- *Power plants generally use poor quality of coal , thus amount of ash produced by it is pretty large*
- *A modern 2000 MW plant produces about 5000 tons of ash daily*
- *The stations use some conveyor arrangement to carry ash to dump sites directly or for carrying and loading it to trucks and wagons which transport it to the site of disposal.*

Boiler

- A boiler or steam generator is a closed vessel in which water under pressure, is converted into steam.
- It is one of the major components of a thermal power plant
- Always designed to absorb maximum amount of heat released in the process of combustion
- Boilers are of two types-

1.Fire tube boiler

Types of steam

- *As shown in the diagram below, there are three types of steam:*

1. ***Wet steam**: A mixture of water plus steam (liquid plus vapor) at the boiling point temperature of water at a given pressure.*

- *Quality of steam refers to the fraction or percentage of gaseous steam in a wet steam mixture.*

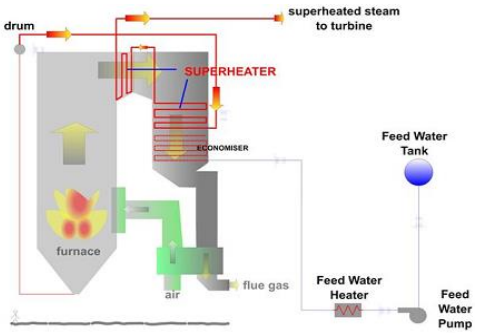
2. ***Dry steam**: Steam, at the given pressure, that contains no water (also referred to as saturated steam).*

- *The steam quality = 100 %. At the top of steam generator units for producing saturated steam, there are moisture separators used to remove residual water droplets from outgoing steam.*

3. ***Superheated steam**: Dry steam, at the given pressure, that has been heated to a temperature higher than the boiling point of water at that pressure.*

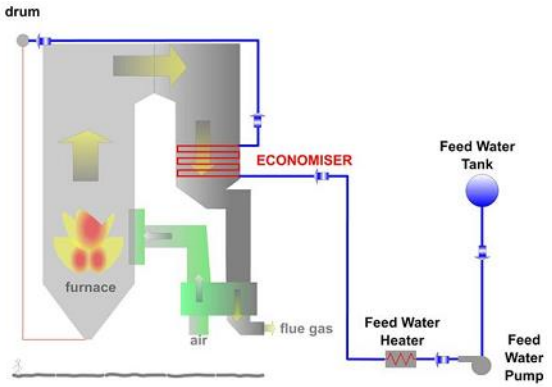
Superheater

- *A greater quantity of steam can be generated from a given quantity of water by superheating it.*
- *The steam produced in the boiler has got moisture content so it is dried and superheated (i.e. steam temperature is increased above boiling point of water)by the flue gases on the way to chimney.*
- *Super heating ensures two benefits at first the overall efficiency of the system is increased and secondly the corrosion to the turbine blades due to condensation in later stages is prevented.*
- *The superheated steam from super- heater is fed to steam turbine by means of a main valve.*



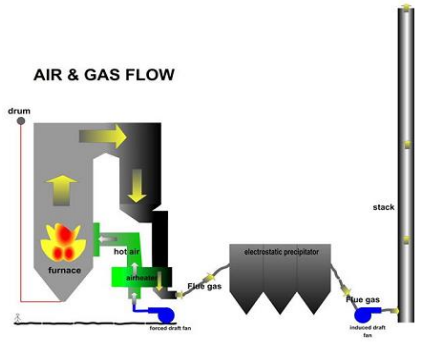
Economizer

- *Flue gases coming out of the boiler carry lot of heat.*
- *The function of economizer is to recover some of the heat from the heat carried away in the flue gases up the flue gas stack and utilize it for heating the feed water to the boiler.*
- *It is placed in the passage of flue gases in -between the exit from the boiler and the entry to the chimney.*
- *The use of economizer results in saving in coal consumption , increase in steaming rate and high boiler efficiency but needs extra investment and increase in maintenance costs and floor area required for the plant. This is used in all modern plants.*



Air pre-heater

- The remaining heat of flue gases is utilized by air pre-heater.
- It is a device used in steam boilers to transfer heat from the flue gases to the combustion air before the air enters the furnace. Also known as air heater , air -heating system.
- It is kept at a place near by where the air enters in to the boiler.
- The purpose of the air pre-heater is to recover the heat from the flue gas from the boiler to improve boiler efficiency by burning warm air which increases combustion efficiency, and reducing useful heat lost from the flue.

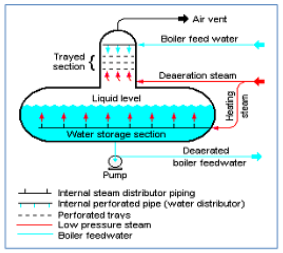


Economizer and Air Pre-Heaters are Provided for Heat Recovery

- *Boilers are provided with economizer and air pre- heaters to recover heat from the flue gases.*
- *An increase of about 20 % in boiler efficiency is achieved by providing both economizer and air pre -heaters.*
- *If a economizer alone is provided then the efficiency will increase by 8 % only.*
- *Most of the high capacity boilers firing coal operate with an efficiency of around 86 % on the Higher Heat Value basis.*
- *Loss of around 14 % can be attributed to various losses of which the dry gas loss is about 35 % of the total.*
- *When both economizers and air pre -heaters are not provided the boiler efficiency drops to around 66 % from 86 %.*
- *When air pre-heater is not provided the boiler efficiency will be around 74 % only. Thus we can conserve about 20 % extra fuel when we provide both economizers and air pre-heaters in boilers.*

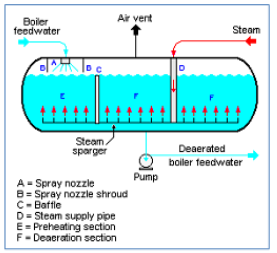
Deaerator

- *is a device that is widely used for the **removal of air and other dissolved gases** from the feed-water to steam - generating boilers .*
- *In particular, dissolved **oxygen** in boiler feed-waters will cause serious corrosion damage in steam systems by attaching to the walls of metal piping and other metallic equipment and **forming oxides** (**rust**).*
- *Water also combines with any dissolved **Carbondioxide** to form **carbonic acid** that **causes further corrosion**.*
- *Most deaerators are designed to remove oxygen down to levels of 7 ppb by weight(0. 0005cm³/L) or less.*
- *There are two basic types*
    1. *The tray- type*
    2. *The spray - type*



tray-type or cascade-type

includes a vertical domed deaeration section mounted on top of a horizontal cylindrical vessel which serves as the deaerated boiler feedwater storage tank .



The spray-type

consists only of a horizontal (or vertical) cylindrical vessel which serves as both the deaeration section and the boiler feedwater storage tank.

Flue gas stack (chimney)

- *A chimney is a structure for venting hot flue gases or smoke from a boiler, stove, furnace or fireplace to the outside atmosphere .*
- *Chimneys are typically vertical, or as near as possible to vertical, to ensure that the gases flow smoothly, drawing air into the combustion in what is known as the stack, or chimney, effect.*
- *The space inside a chimney is called a flue .*
- *Chimneys are tall to increase their draw of air for combustion and to disperse pollutants in the flue gases over a greater area so as to reduce the pollutant concentrations in compliance with regulatory or other limits.*

3. Steam Turbine

- *The dry and super heated steam from super -heater is fed to the turbine by means of a main valve.*
- *Due to the striking or reaction impact of the steam on the blades of turbine it starts rotating i.e. heat energy is converted to mechanical energy.*
- *After giving heat energy to the turbine the steam is exhausted to a condenser which condenses the exhausted steam by means of a cold water circulation.*

4. Alternator

- *The steam turbine is coupled to an alternator, the alternator converts the mechanical energy into electrical energy.*
- *The electrical output is transferred to the bus bars through transformer, circuit breaker and isolators.*

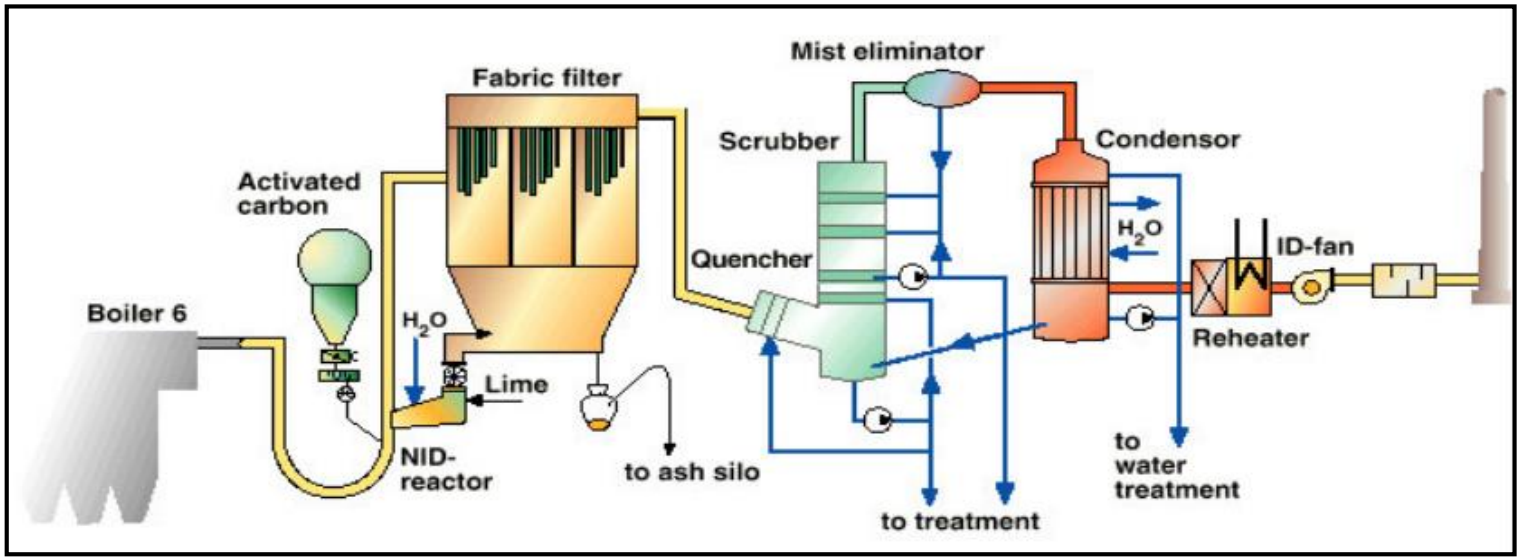
5. Feed Water

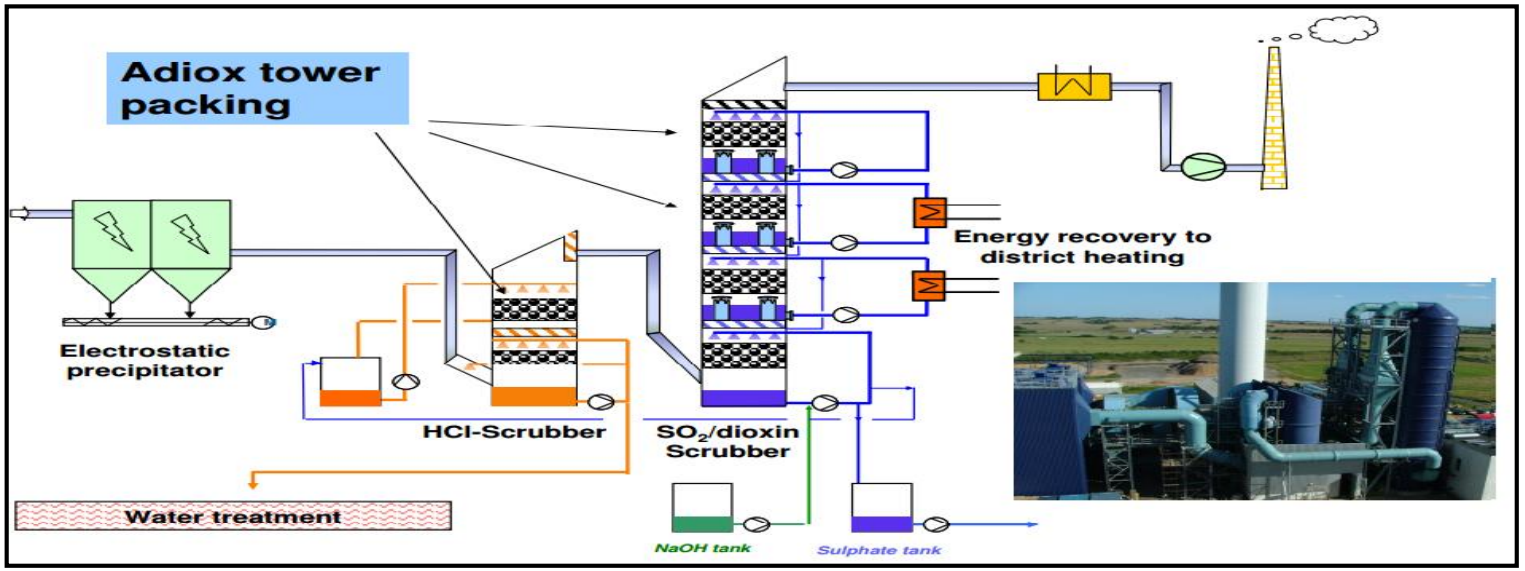
- The condensed water produced in the condenser is used as feed water.
- some amount of water may be lost in the cycle but it is compensated using an external source and the cycle repeats and gives a better efficiency to the system.

6. Cooling Arrangement

- In order to increase the efficiency of the plant the steam coming from the turbine is condensed using a condenser.
- The water circulation for cooling steam in condenser is take from a natural source like river, stream etc and the out coming hot water from condenser is discharged in some lower portion of the water source.
- In scarcity of water the water from the condenser is cooled and reused with the help of a cooling tower.

Flue gas treatment systems



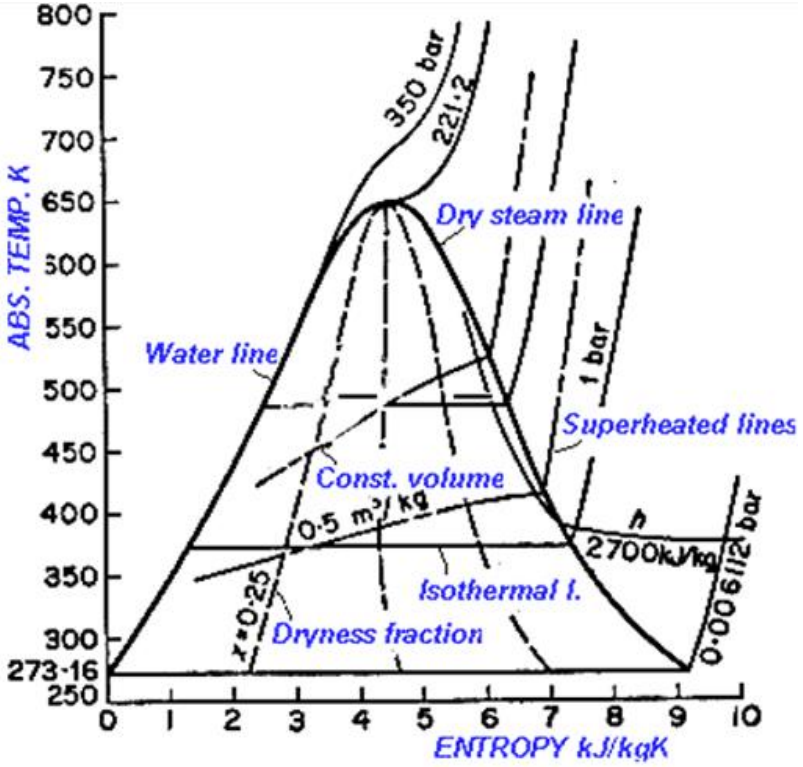


Charts & diagrams

- There are quite number of charts & diagrams associated with engineering science, all of which related in some extent to steam tables or other related specific constants, factors, or coefficients.
- However, the most widely related to power plant engineering are the followings:
  1. T –s diagram.
  2. h -s diagram.
  3. T -h diagram.
  4. P-h diagram

1. T - S Diagram

- *The entropy diagram for steam is often convenient because it shows the relationship between*
  - *Pressure*
  - *Temperature*
  - *Dryness Fraction*
  - *Entropy*
- *With two of the factors given the others can be found in the diagram. The ordinates in the diagram represents the Entropy and the Absolute temperature.*



Dryness fraction of Wet Steam

- *If the water content of the steam is 5% by mass, then the steam is said to be 95% dry and has a dryness fraction of 0.95.*
- *Dryness fraction can be expressed as:*

$$x = m_s / (m_w + m_s)$$

where

- *x =dryness fraction; m_w= mass of water (kg); m_s= mass of steam (kg)*

Enthalpy of Wet Steam

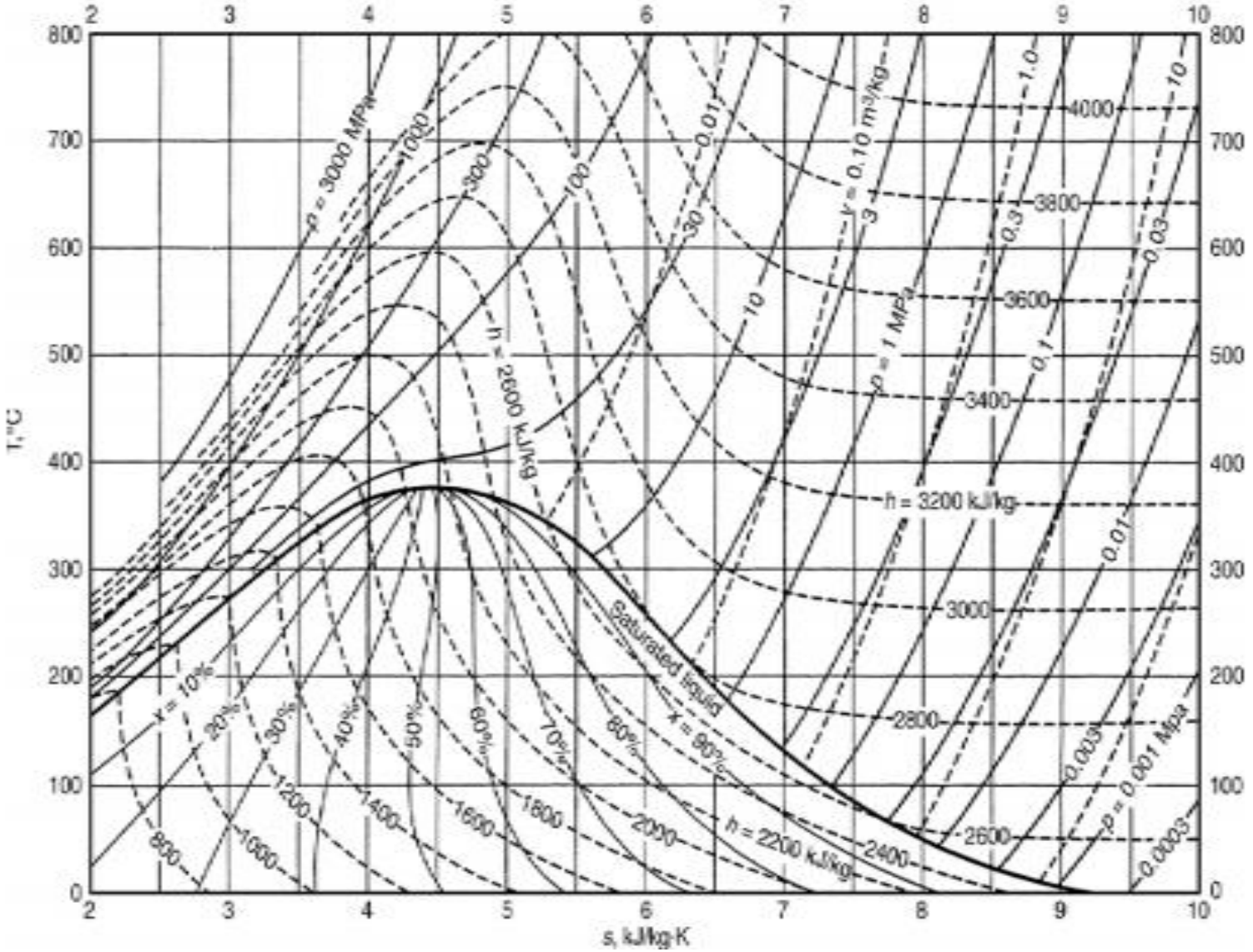
- *The actual enthalpy of evaporation of wet steam is the product of the dryness fraction(x) and the specific enthalpy(h_s) from the steam tables.*
- *Wet steam have lower usable heat energy than dry saturated steam.*

$$h_t = h_s x + (1 - x) h_w$$

where

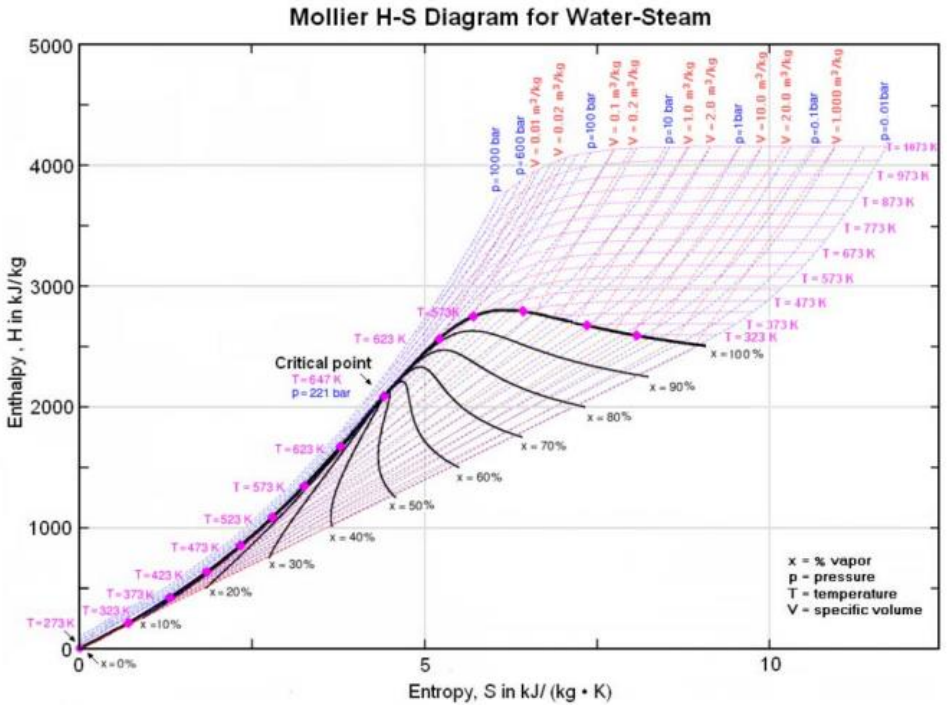
- *h_t= enthalpy of wet steam (kJ/kg), h_s= enthalpy of steam (kJ/kg)*
- *h_w= enthalpy of saturated water or condensate (kJ/kg)*

1. T - S Diagram

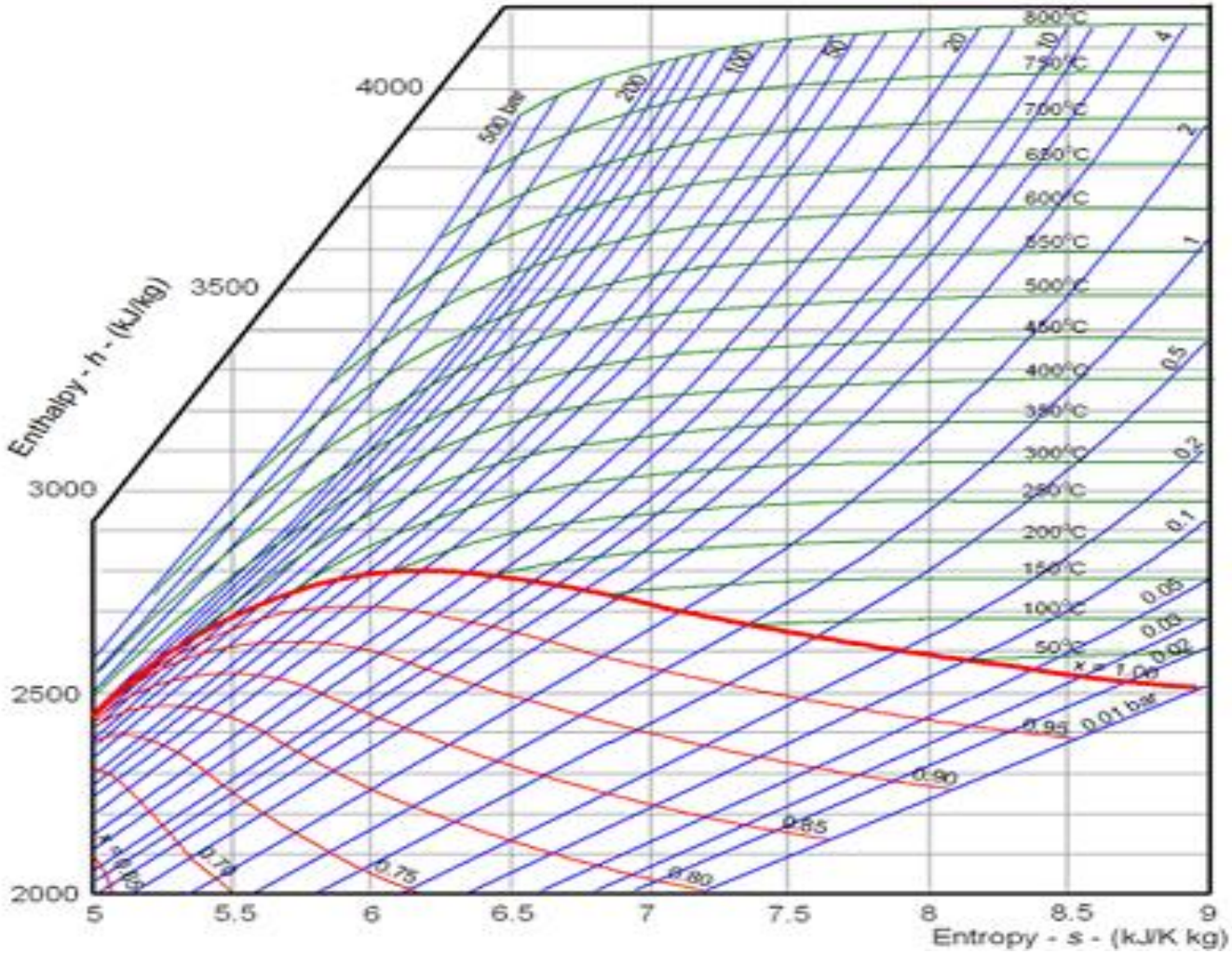

T, °C
s, kJ/kg·K
Saturated liquid
Saturated vapor
p = 3000 MPa
1000
300
100
30
10
3
1
0.3
0.1
0.03
0.01
0.003
0.001 Mpa
0.0003
v = 0.10 m³/kg
p = 1 MPa
h = 2600 kJ/kg
h = 3200 kJ/kg
h = 2200 kJ/kg
4000
3800
3600
3400
3000
2800
2600
2400
x = 10%
20%
30%
40%
50%
60%
70%
80%
x = 90%
800
1000
1200
1400
1600
1800
2000

2. h – s diagram "Mollier diagrams"

- The (h – s) diagram is also called the Mollier diagram or Mollier chart, named after Dr. Richard Mollier.
- The Mollier diagram is useful when analyzing the performance of adiabatic steady-flow processes, such as flow in nozzles, diffusers, turbines and compressors.



2. h – s diagram "Mollier diagrams"



End of Chapter Once