Power Plant Engineering

Unit 1

Introduction

Source of Energy

The various type energy source.

1. **Fuels.**
2. **Energy storage of water.**
3. **Nuclear energy.**
4. **Wind energy.**
5. **Tidal energy.**
6. **Solar energy.**
7. **Geothermal energy.**
8. **Thermo electric power.**

Power Generation system.

- Thermal Power Generation system.
- Hydro electric Power Generation system.
- Nuclear Power Generation system.
- Diesel Power Generation system.
- Non conventional energy power Generation system.

Major Thermal power station

❖ Place	Number of Unit.	Total capacity
1. Dhuvaran	4×63.5 2×140.0 2×27 (Gas Turbine)	588 MW
2.Vanakbori.	6×210	1260 MW.
3.Utran.	13×3	39 MW.
4.Ghandhinager.	2×120 1×210	450 MW.
5.Shikka.	1×120	120 MW.

Major Thermal power station

Place	Number of Unit.	Total capacity
1. Ukai.	2×120 2×200 1×210	850 MW
2.Ahemedabad. (Torrent power)	4×9 1×20 1×24 3×110	410MW.
Panedhro .	1×70	70 MW.

Major Hydro & nuclear power station

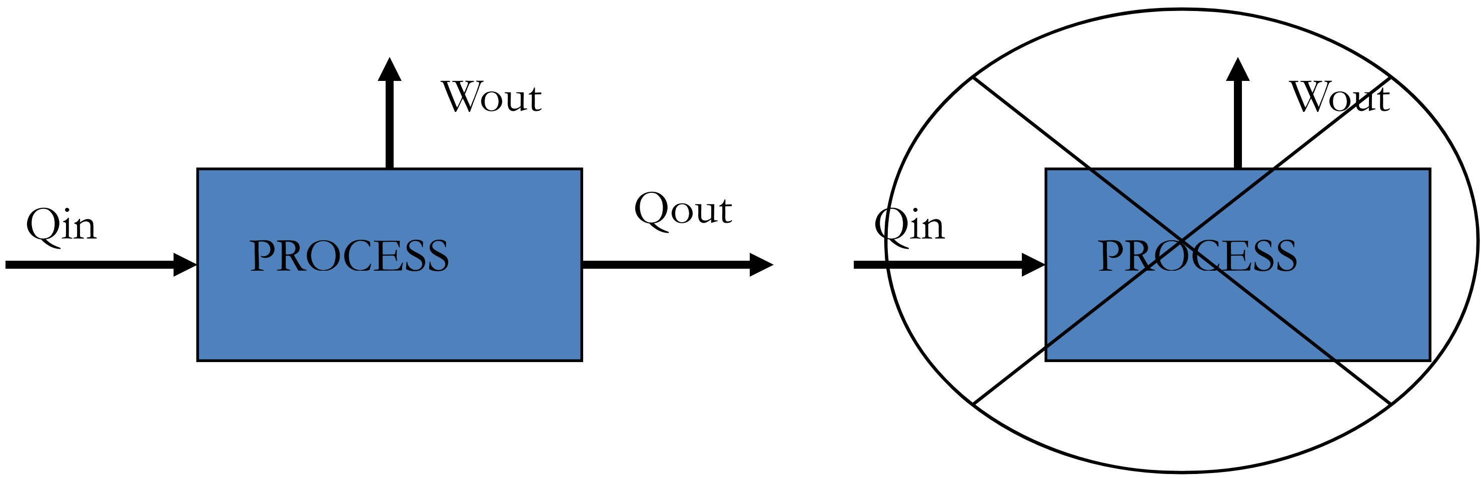
Types of power Station	Name of place.	Total capacity. In MW.
Hydro power station.	Kdana	60 MW
	Ukai	305 MW
Nuclear power station.	Kakrapar	125 MW

2ND LAW STATEMENTS

- ENERGY DEGRADES IN QUALITY IN A REAL PROCESS
- REVERSIBILITY IS AN IDEAL LIMIT FOR A PROCESS
- HEAT FLOWS FROM HIGH TO LOW TEMPERATURE
- WATER FLOWS DOWNHILL

2^{ND} LAW STATEMENTS

- NO APPARATUS CAN BE DESIGNED WHICH CONVERTS ENERGY 100% INTO WORK



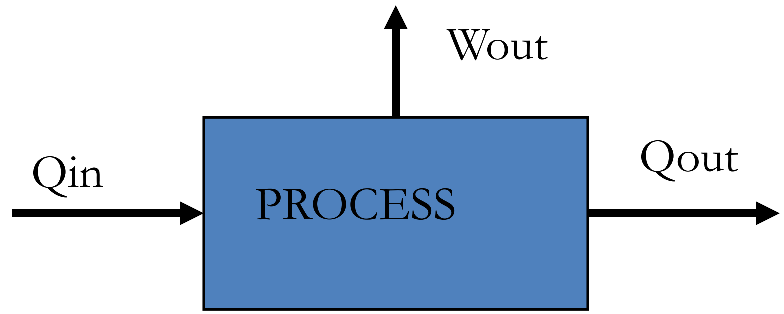
- IT IS NOT POSSIBLE TO DESIGN A PROCESS TO ONLY TRANSFER HEAT FROM A LOW TO HIGH TEMPERATURE

2ND LAW STATEMENTS

- *YOU CAN ONLY BREAK EVEN AT ABSOLUTE ZERO.*
- YOU CAN PUT MEAT INTO A GRINDER TO MAKE SAUSAGE, BUT YOU CANNOT PUT SAUSAGE INTO A GRINDER TO MAKE A PIG.
- PERPETUAL MOTION IS A FOOL'S GAME

HEAT ENGINE

- HEAT ENGINES PRODUCE WORK DUE TO THE FLOW OF HEAT
- FIRST LAW WORK CALCULATION
- EFFICIENCY CALCULATION



$$|W| = |Q_H| - |Q_C|$$

$$\eta = \frac{|W|}{|Q_H|} = 1 - \frac{|Q_C|}{|Q_H|}$$

CARNOT'S ENGINE

- USED TO DEFINE MAXIMUM POSSIBLE EFFICIENCY
- CONSISTS OF REVERSIBLE ADIABATIC AND ISOTHERMAL PROCESSES
- USED TO SHOW THE MAXIMUM POSSIBLE EFFICIENCY IS RELATED TO ABSOLUTE TEMPERATURE

$$\eta = 1 - \frac{|Q_C|}{|Q_H|}$$

$$\eta = 1 - \frac{T_C}{T_H}$$

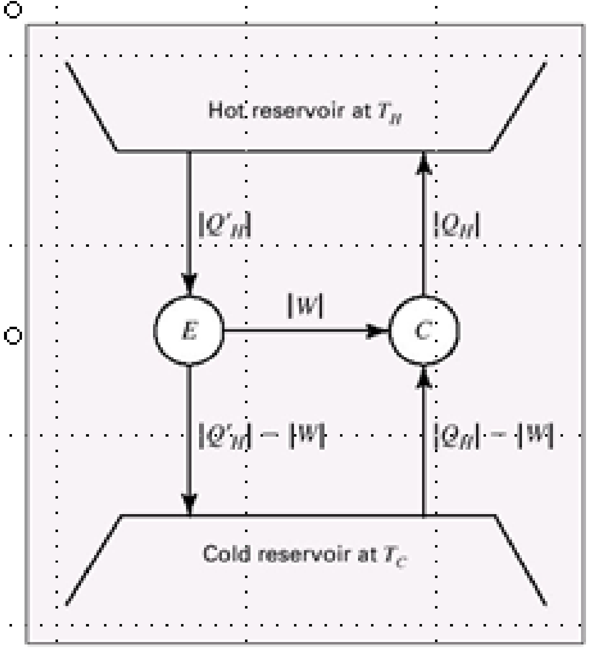


FIG. 5.1 IN TEXT

CARNOT CYCLE

- CARNOT ENGINE
  - USES IDEAL GAS AS WORKING FLUID
  - HAS TWO ISOTHERMAL STEPS
  - HAS TWO ADIABATIC STEPS
  - ALL PROCESSES ARE REVERSIBLE

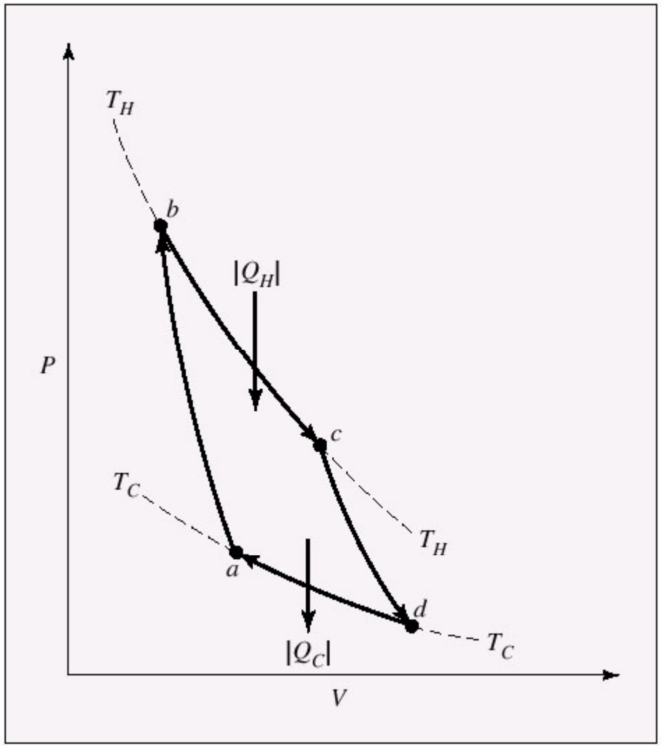


Figure 5.3: *PV* diagram showing Carnot cycle for an ideal gas.

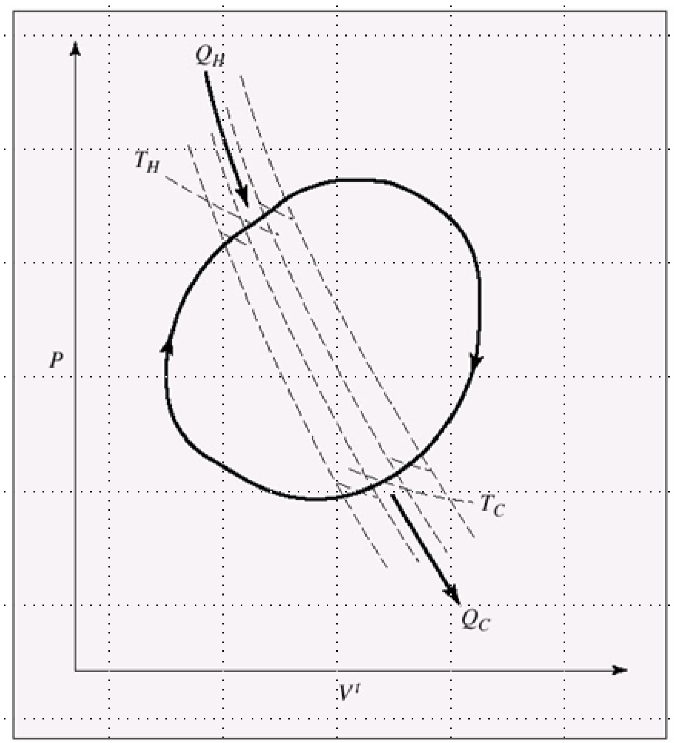
ENTROPY FUNCTION

- DIFFERENTIAL ANALYSIS FOR A PORTION OF ANY REVERSIBLE CYCLE
- DEFINED AS ENTROPY

$$\frac{dQ_H}{T_H} + \frac{dQ_C}{T_C} = 0$$

$$dS = \frac{dQ_{rev}}{T}$$

$$For\ \ the\ cycle: \oint \frac{dQ_{rev}}{T} = 0$$



ENTROPY CHARACTERISTICS

- STATE FUNCTION
- EVALUATED FOR ANY HEAT TRANSFER PROCESS (REVERSIBLE OR IRREVERSIBLE) AS

$$dS = \frac{dQ}{T} \ \& \ \Delta S = \int \frac{dQ}{T}$$

- FOR ANY REAL PROCESS, IS INCREASING.
- FOR ANY STEADY-STATE PROCESS:

$$Q_H - Q_C + W = 0$$

$$\frac{Q_H}{T_H} - \frac{Q_C}{T_C} + S_{gen} = 0$$

IDEAL WORK

- IDEAL WORK REPRESENTS LIMITS
  - MINIMUM WORK CONSUMED TO ACCOMPLISH A CHANGE
  - MAXIMUM WORK GENERATED FROM A PROCESS
- DEVELOPED FROM ENERGY BALANCE MODELS
  - SUBSTITUTE FOR Q WITH TΔS
  - WORK INCLUDES W_s AND PV WORK

LOST WORK

- REPRESENTS THE DIFFERENCE BETWEEN ACTUAL WORK AND IDEAL WORK
- $\Delta S = 0$ FOR IDEAL WORK
- SO LOST WORK IS LINKED TO GENERATION OF ENTROPY
- LOST WORK IS ALSO CALLED UNAVAILABLE ENERGY
- *EXERGY* IS A RELATED TERM THAT INDICATES THE AMOUNT OF ENERGY AVAILABLE ABOVE EQUILIBRIUM WITH THE SURROUNDINGS.

LOST WORK CALCULATION

- THE COUNTERCURRENT UNIT REQUIRES A LOWER RATE OF COOLANT FLOW
- FOR THE COUNTERCURRENT UNIT
  - ΔT IS MORE CONSTANT
  - NET COOLING FLOW IS ABOUT ½ THAT OF THE COCURRENT UNIT
  - LOST WORK IS ABOUT ½ THAT OF THE COCURRENT UNIT
- WHAT IS THE IMPACT OF A MULTI-PASS CONFIGURATION?

HOMOGENEOUS SYSTEM PROPERTY RELATIONSHIPS

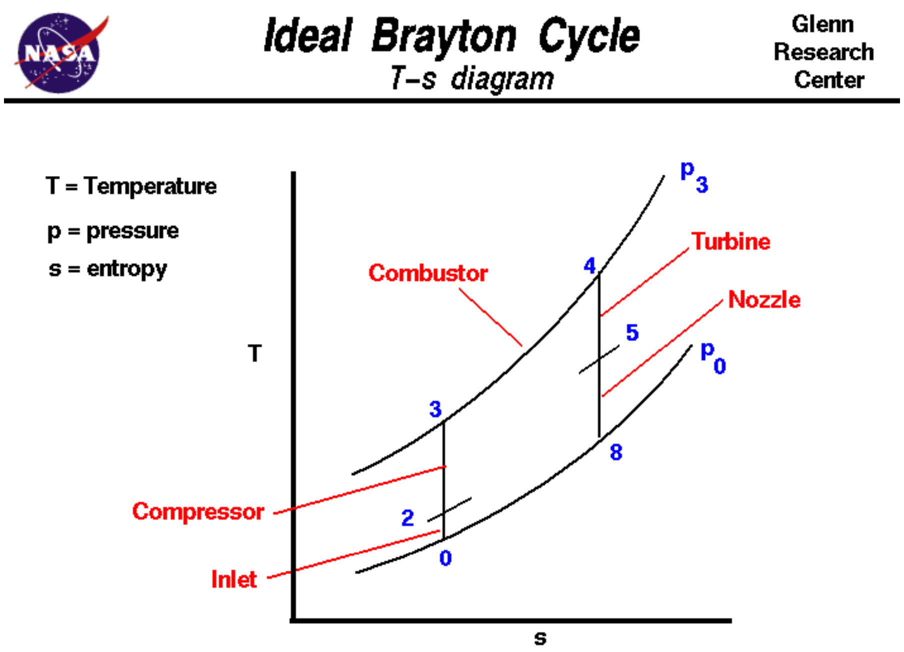
- HOMOGENEOUS = CONSTANT COMPOSITION
- DERIVATION OF PROPERTY RELATIONSHIPS FROM THE 1^{ST} LAW
- DERIVATION FOR INTERNAL ENERGY IN A CLOSED SYSTEM
- $d(nU) = dQ_{rev} + dW_{rev} = Td(nS) - Pd(nV)$ EQN. (6.1)
- $dU = TdS - PdV$ (6.7)
- INTERNAL ENERGY IS MINIMIZED AT EQILIBRIUM WHEN S AND V ARE CONSTANT
- PRIMARY (CANONICAL)VARIABLES $U = U(S,V)$

OTHER ENERGY DERIVATIONS

- DEFINED ENERGY PROPERTIES:
- ENTHALPY
  - DEFINED H = U + PV
  - PRIMARY VARIABLES H = H(S,P)
- HELMHOLTZ
  - DEFINED A = U – TS
  - PRIMARY VARIABLES A = A(V,T)
- GIBBS
  - DEFINED G = H – TS
  - PRIMARY VARIABLES G = G(P,T)

GAS TURBINE SERVICES

- POWER PLANTS
  - GAS
  - STEAM
  - WATER
- AIRCRAFT
  - TURBOJETS
  - TURBOFANS
- LOCOMOTIVES



COMPRESSION BASICS

- FLUID SYSTEMS SUBJECTED TO PRESSURE INCREASES
- MODEL IS BASED ON ENTHALPY INCREASE

$$W_{Sa} = \frac{W`_S}{\eta} \qquad \Delta H_a = \frac{\Delta H`}{\eta}$$

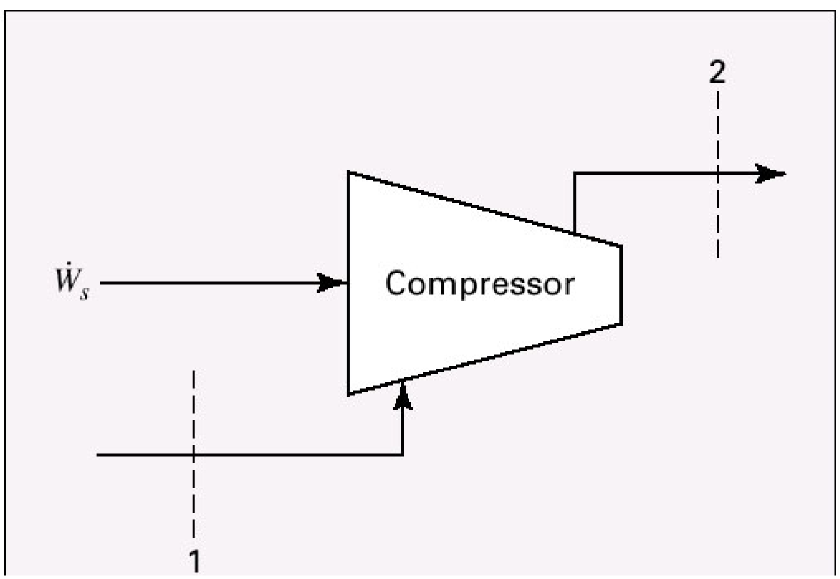
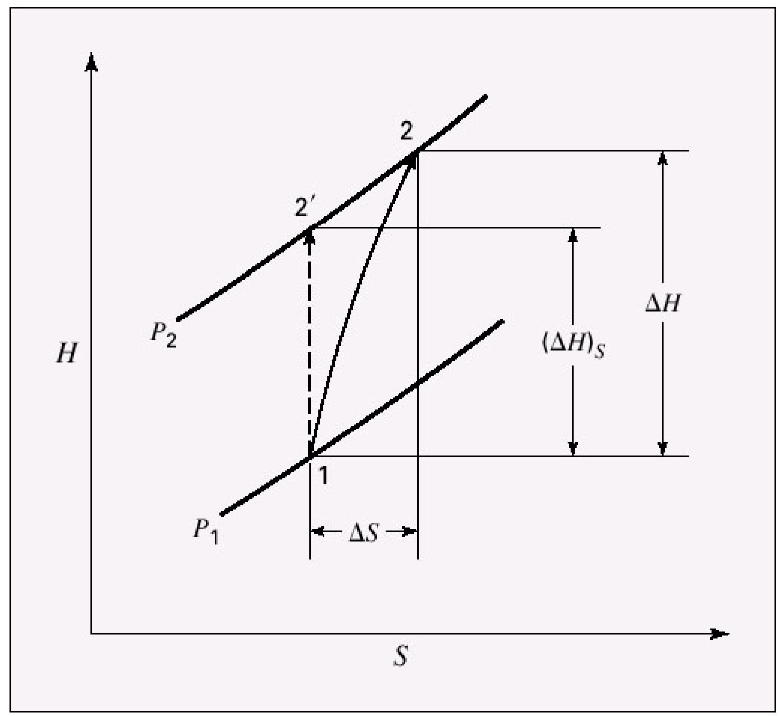


Figure 7.5: Steady-state compression process.

ADIABATIC COMPRESSION

- SHORT RESIDENCE TIME OF FLUID IN COMPRESS YIELDS ADIABATIC OPERATION

Figure 7.6: Adiabatic compression process.



PUMP SYSTEMS

- PUMPS ARE USED FOR LIQUIDS AND SLURRY TRANSFER
- FLUIDS ARE CONSIDERED NONCOMPRESSIBLE
- WORK EQUATIONS

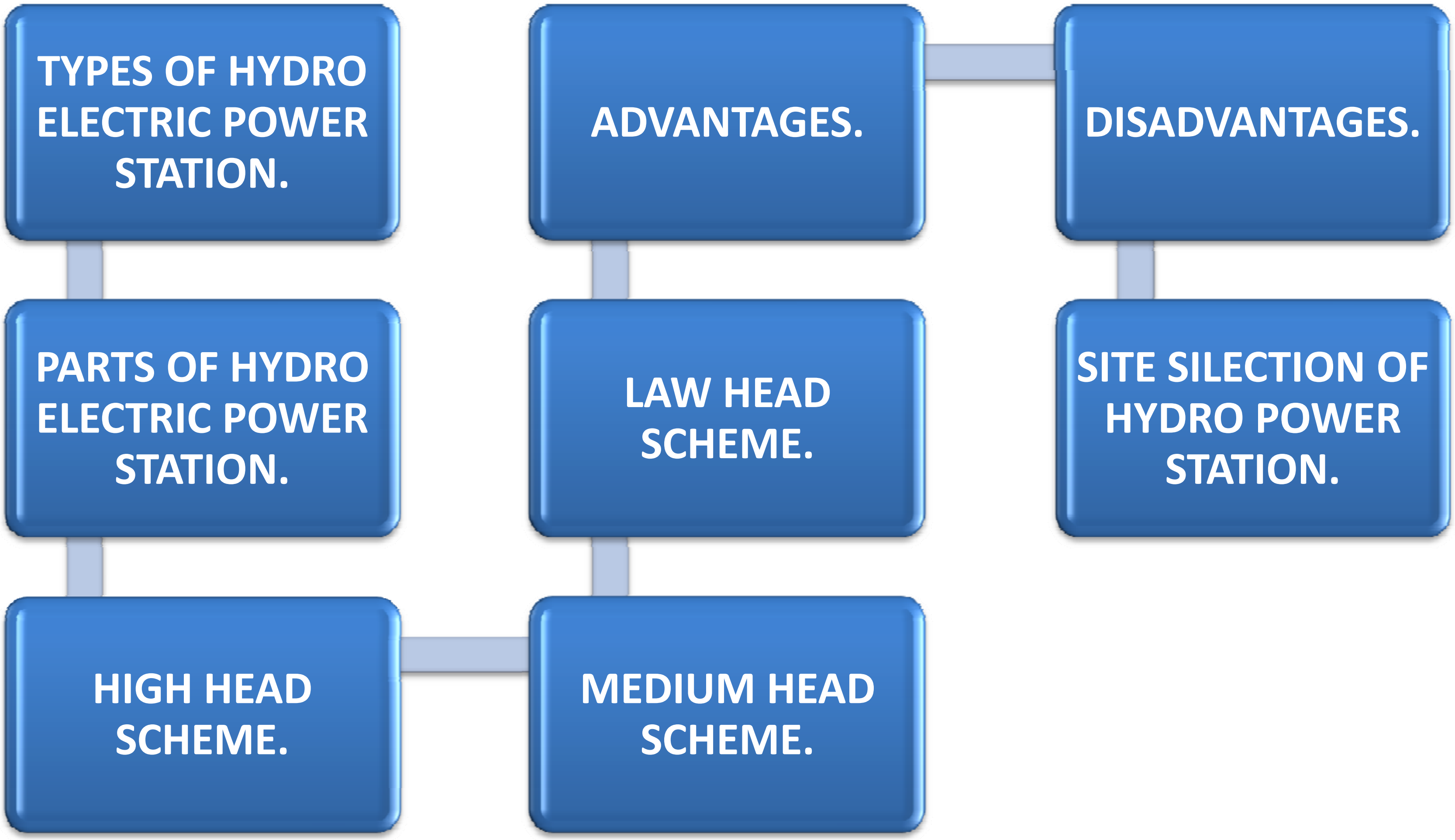
$$W`_s = \Delta H_S = \int V dP$$

$$W_{sa} = \frac{\Delta H_S}{\eta} = \frac{V \Delta P}{\eta}$$

Unit II

Hydro Electric Power Plants

Hydro electric power station.



Classification of Hydro electric power station.

- **Classification on head.**

A. High head plant (< 300 m.)

B. Medium head plant. (60m to 300 m.)

C. Low head plant. (> 60m.)

- **Classification on water condition**

A. Flaw of water plant.

B. Storage of water plant.

C. Pump storage water plant.

Classification of Hydro electric power station.

- **Classification on operation.**

A. Manual plant.

B. Automatic plant.

- **Classification on type of load.**

A. Base load plant.

B. Peak load plant.

Element of Hydro power station,

1. Reservoir.
2. Catchments area.
3. Dam.
   (a) Earthen dam.
   (b) Masonry dam.
   (c) Concrete dam.
4. Spill ways.
5. Screen.
6. Fore bay or Intake.

Element of Hydro power station,

7. Tunnel.

8. Penstock or pipe line.

9. Surge tower.

10. Draft tube.

11. Tail race.

12. Fish passes.

13. Turbine.

Different type schemes of Hydro power plant.

1.High head schemes.

2.Medium head schemes.

3.Low head schemes.

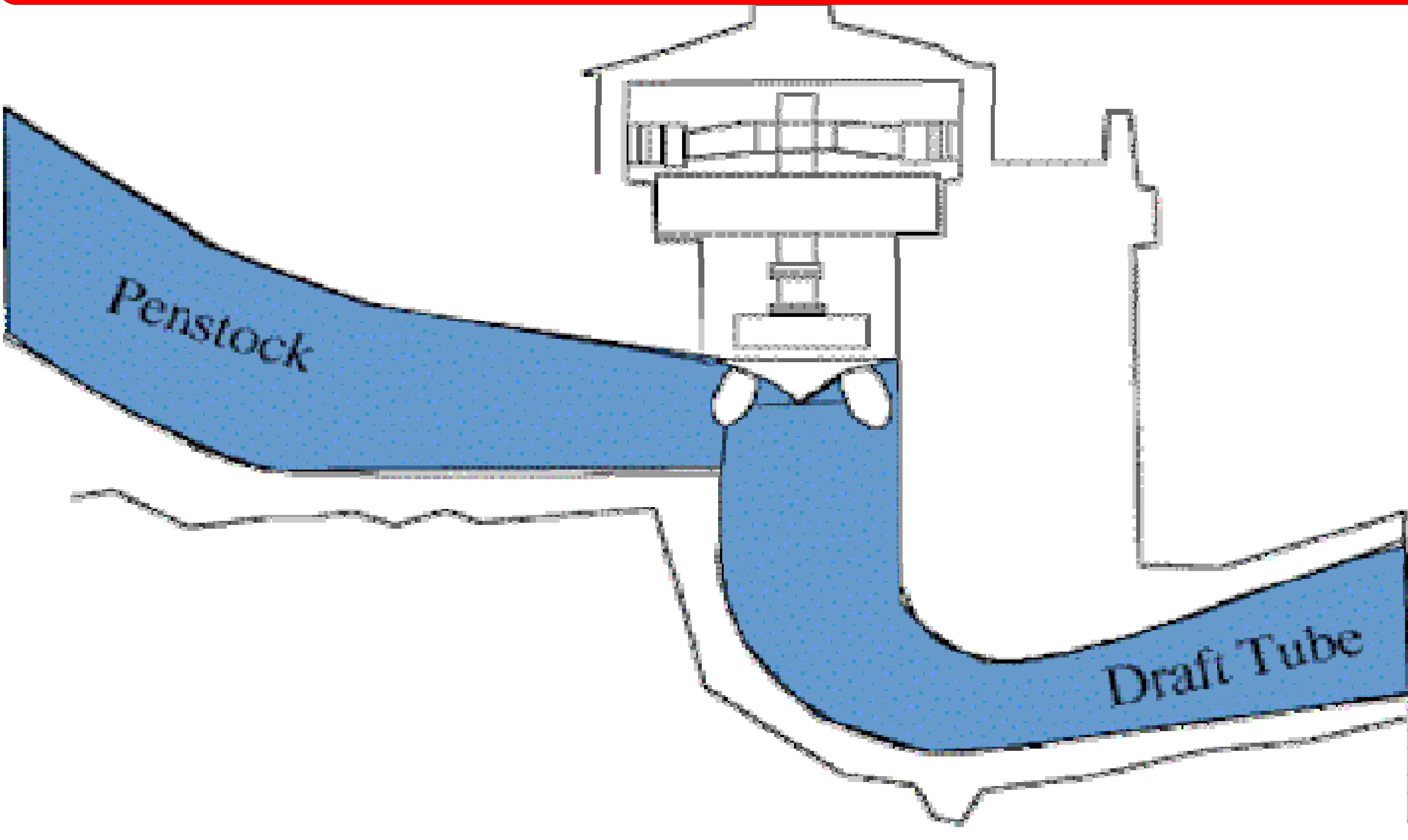
Different type of turbine use in hydro power station

1. High head schemes. (Impulse turbine-pelton wheel)

2. Medium head schemes. (reaction turbine)

3. Low head schemes. (propeller turbine)

view of penstock &draft tube in Hydro power plant.



Hydro electric power plant.`

Construction of Turbine.

Inlet *outlet*

Impulse turbine for High head plant.

Hydro electric power plant.`

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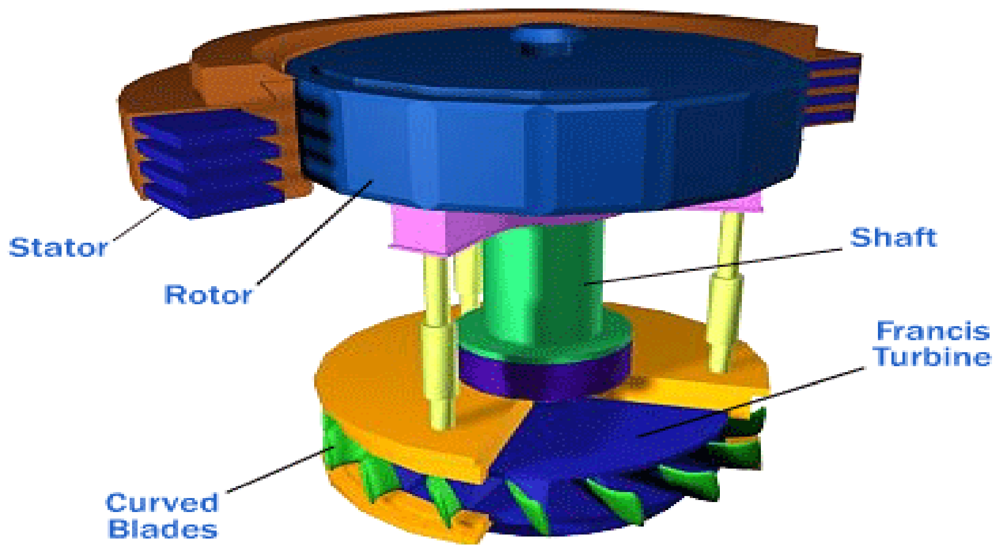
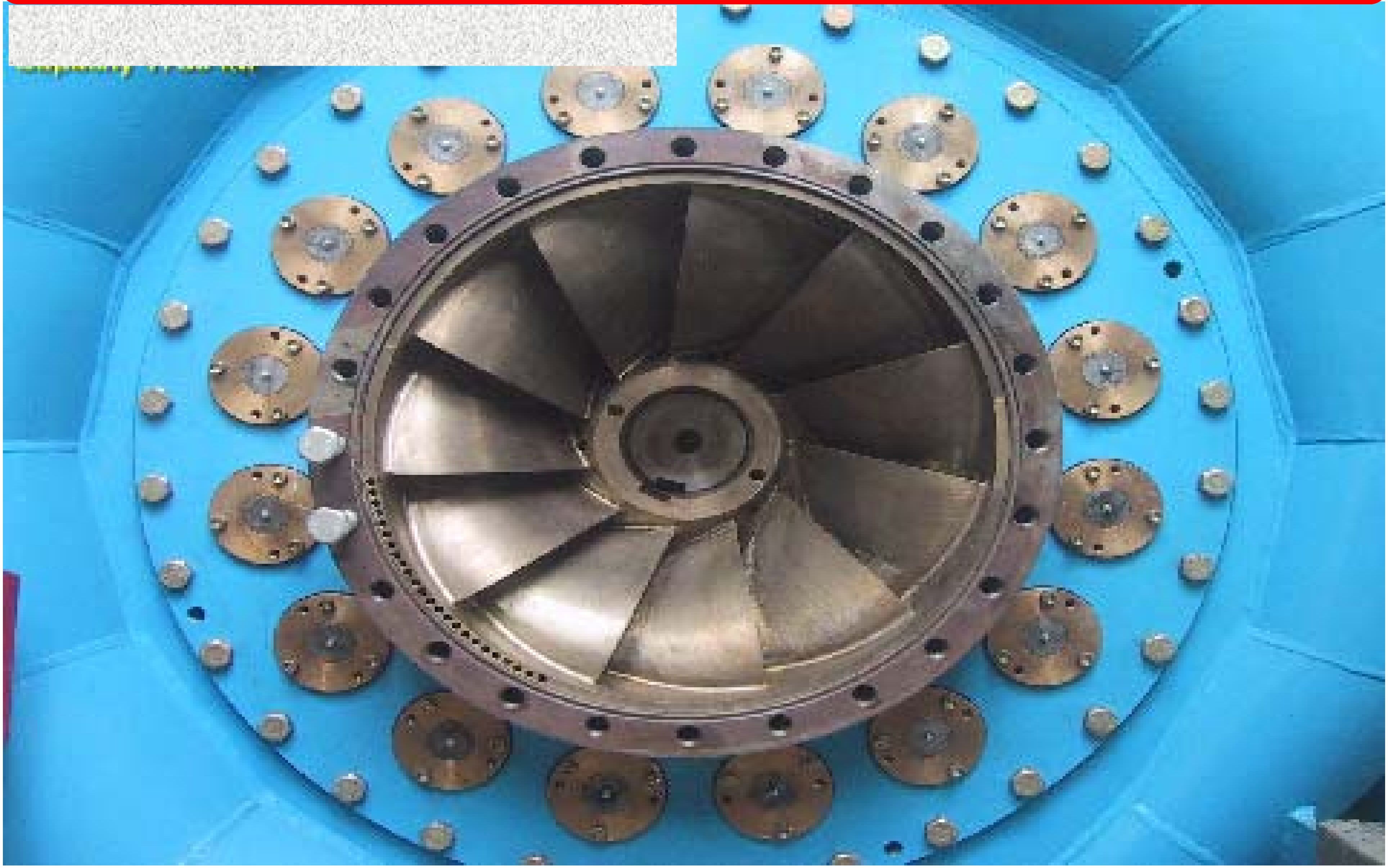


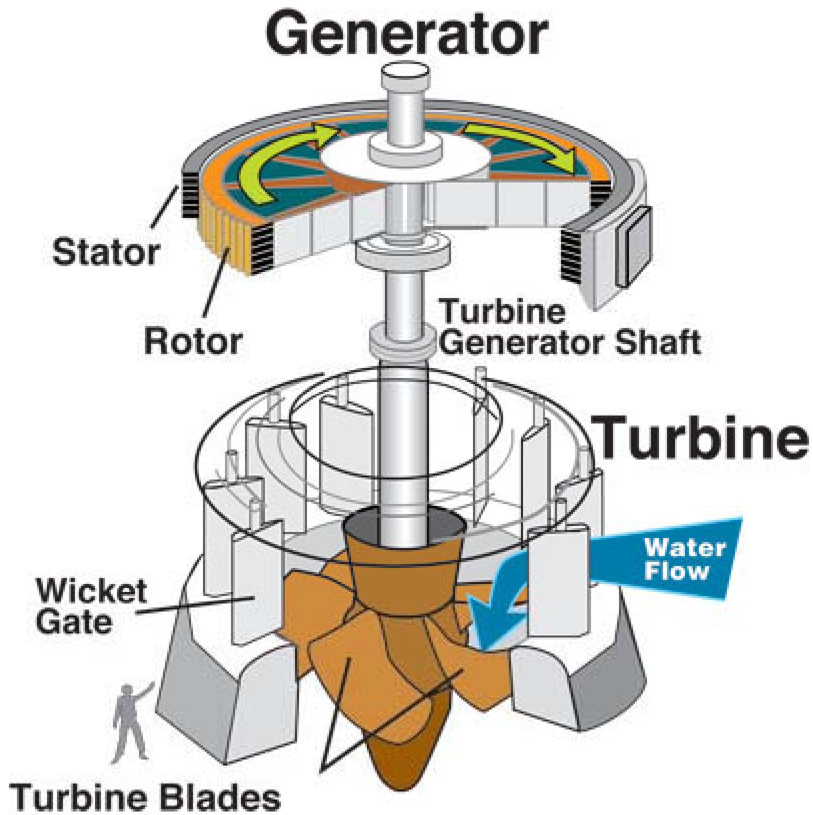
Medium head plant

Top View of Francis turbine in Hydro power station.



Hydro electric power plant.`

Propeller turbine for low head plant.



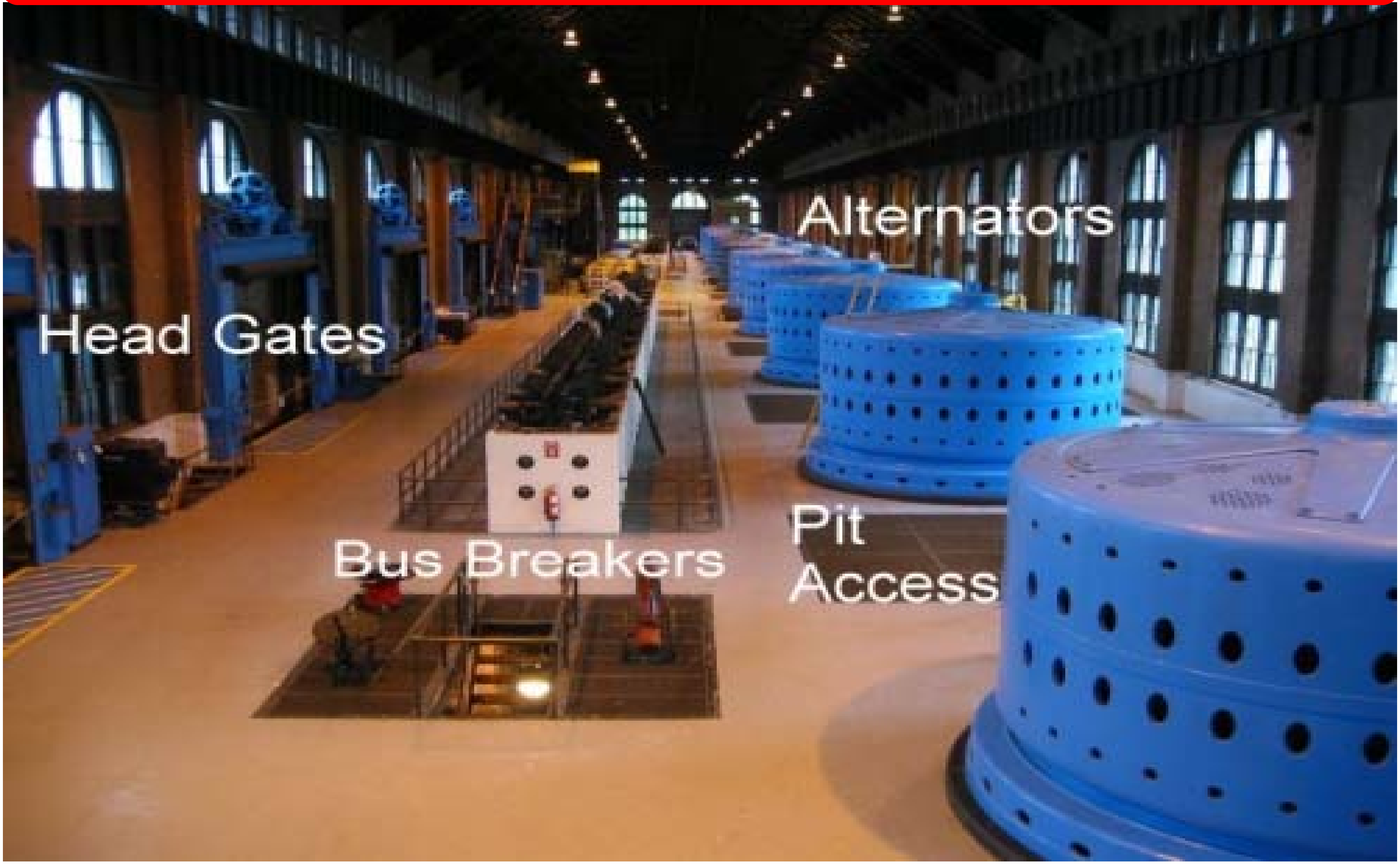
construction of penstock in hydro power station.`

View of penstock in Hydropower station.`

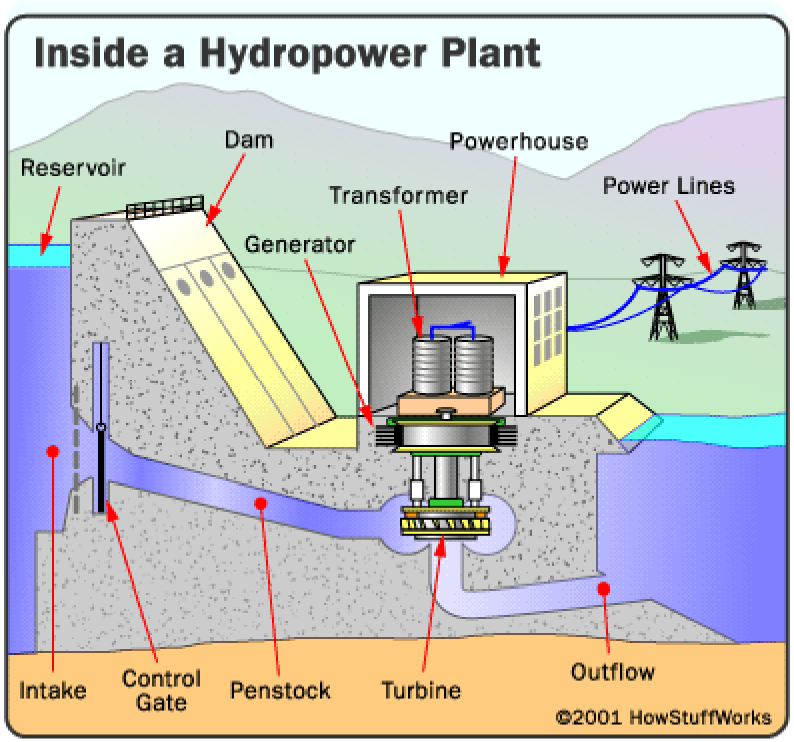
View of penstock in Hydropower station.`

View of Draft tube in Hydro electric power plant.`

Internal view of Hydro electric power plant.`



Working diagram Hydro electric power plant.`



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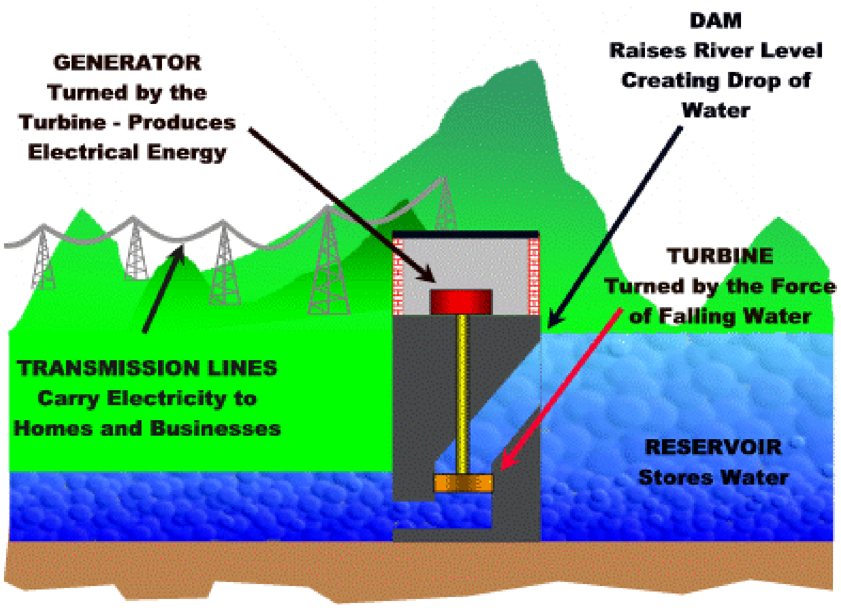

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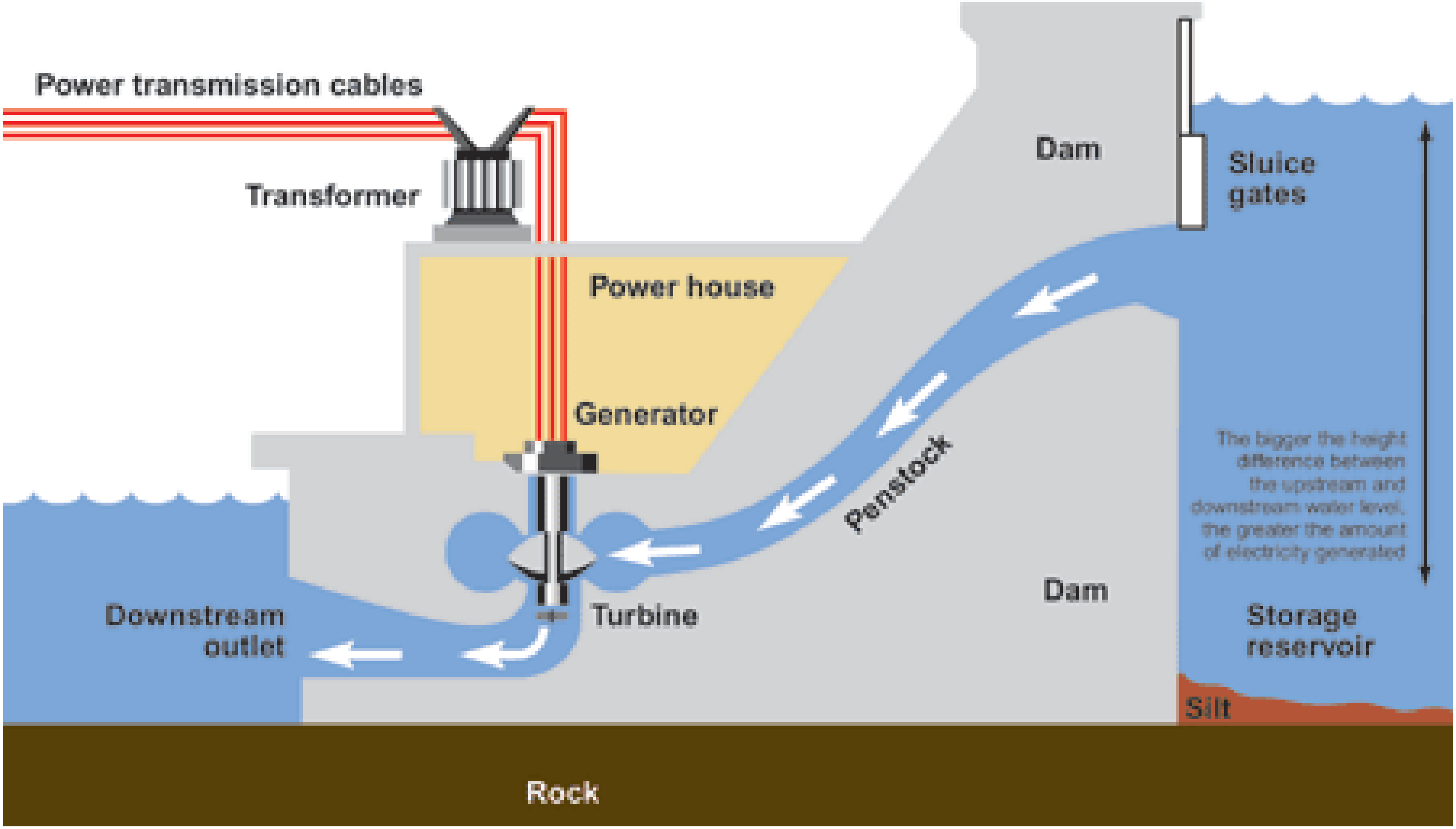

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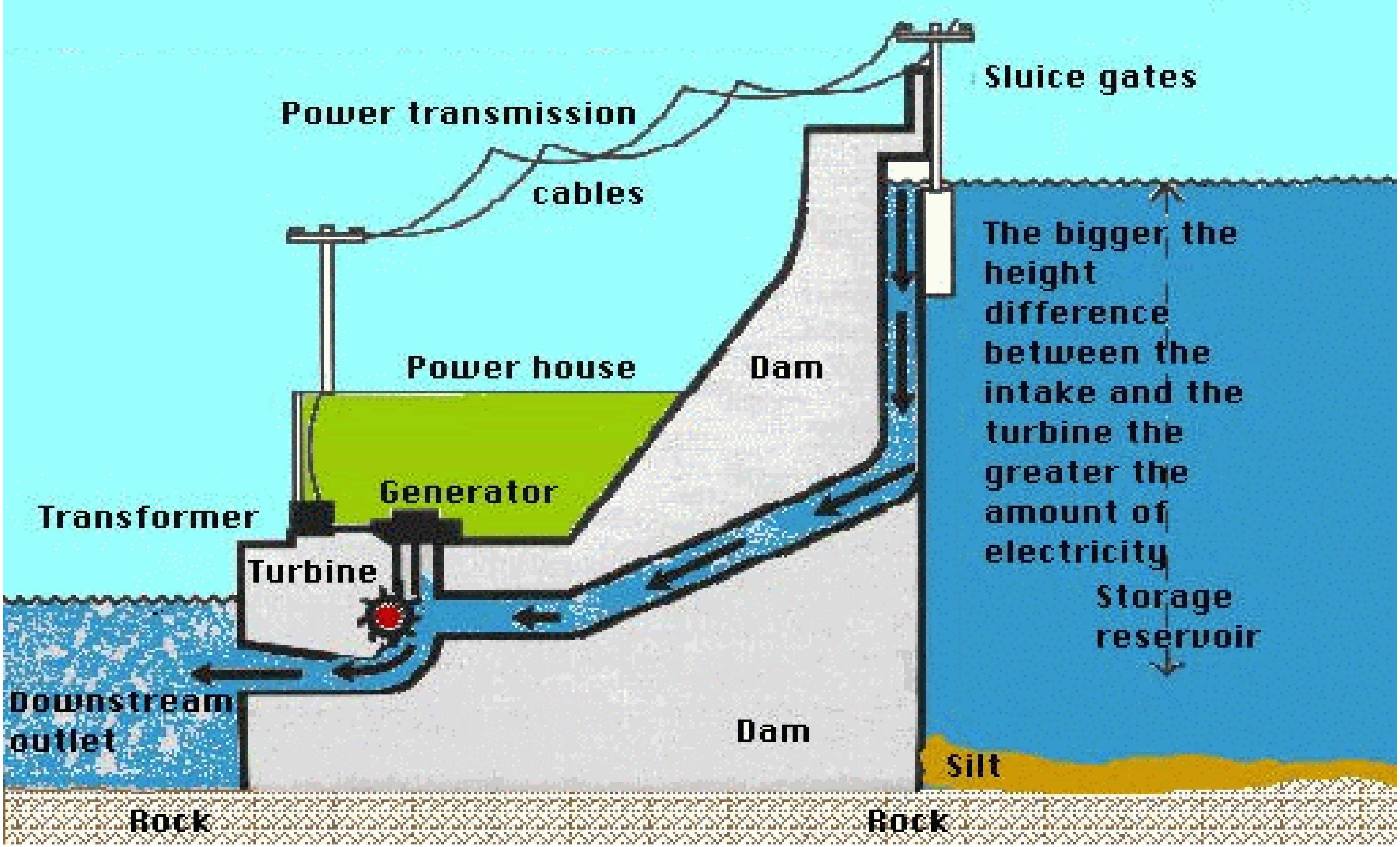


Elevation view Hydro electric power plant.`

Out side view Hydro electric power plant.`

Advantage of Hydro power station.

1. The plant is simple in construction,rubust and required low maintenance.
2. It can be put in the service instantly.
3. It can respond to changing loads without any difficulty.
4. There are no stand by losses.
5. The running charges are very small.
6. No fuels is burnt.
7. The plant is quite neat and clean.
8. The water after running the turbine can be used for irrigation and other purpose.

Disadvantage of Hydro power station.

1. The capital cost of generators, civil engineering work etc.
2. High cost of transmission lines.
3. Long dry seasons may effect the delivery of power.

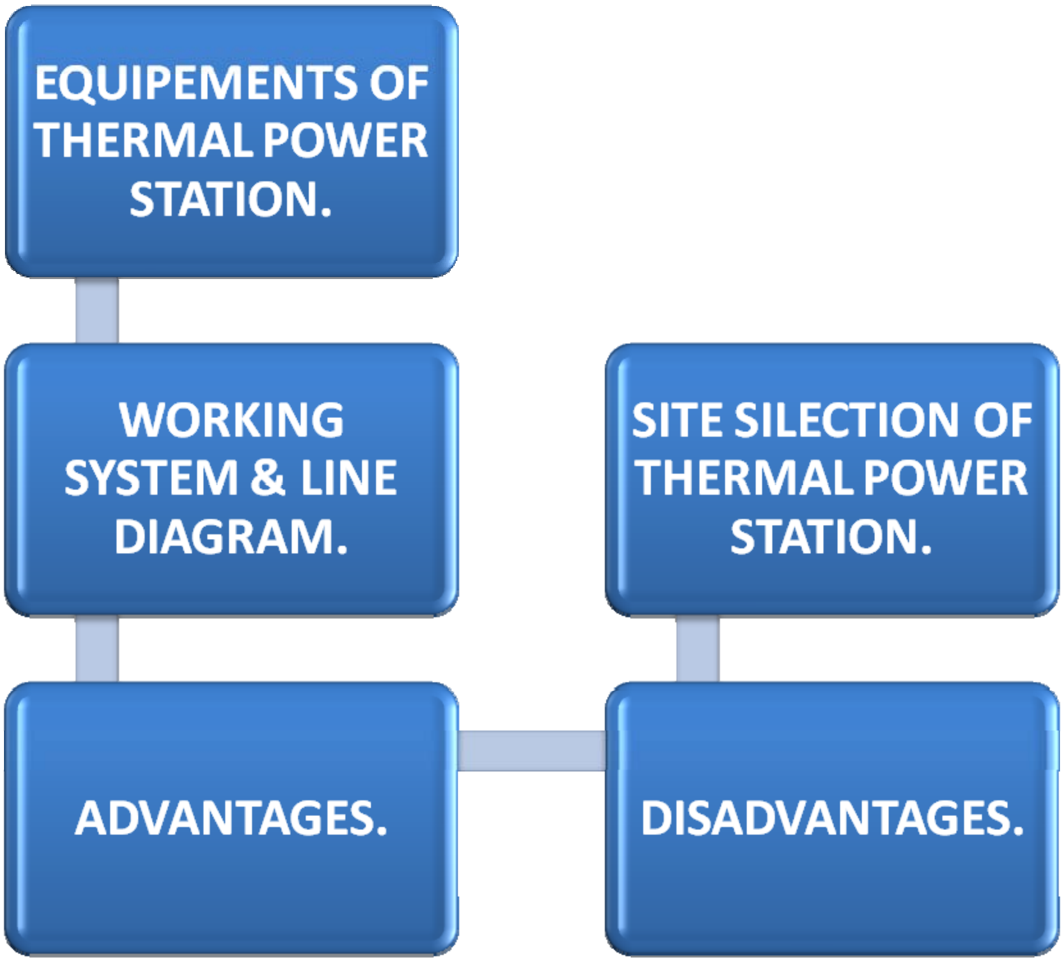
Selection of site for Hydro electric power station.

1. sufficient quantity of water at a reasonable head should be available.
2. The site should allow for strong foundations with minimum cost.
3. There should be no possibility of future source of leakage of water.
4. The selected site should be accessible easily.
5. There should be possibility of stream diversion during construction period.
6. The reservoir to be constructed should have large catchments area, so that the water in it should never full below the minimum level.

Unit III

Steam Power Plants

Thermal power station.



Electrical equipment in Thermal power station.

(1) Alternator.

(2) Exciter

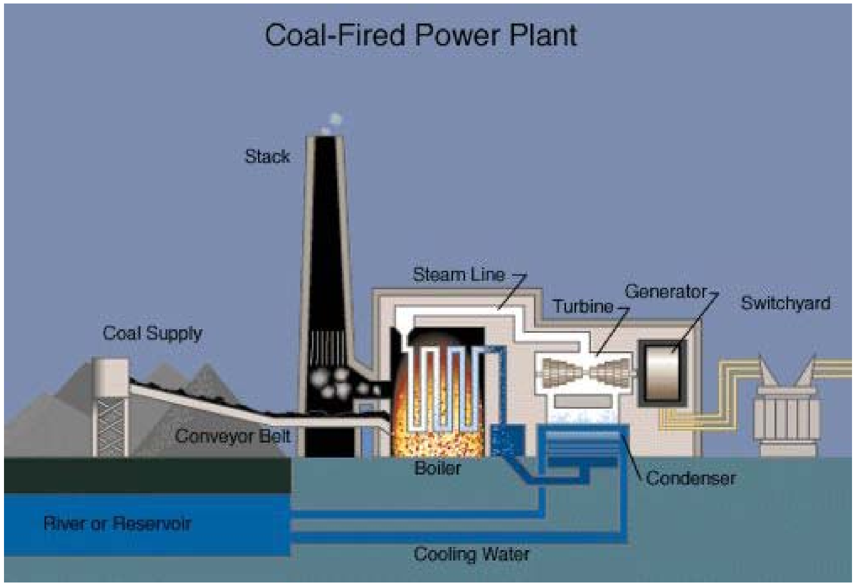
(3)Control Room.

(4) Switch Yard.

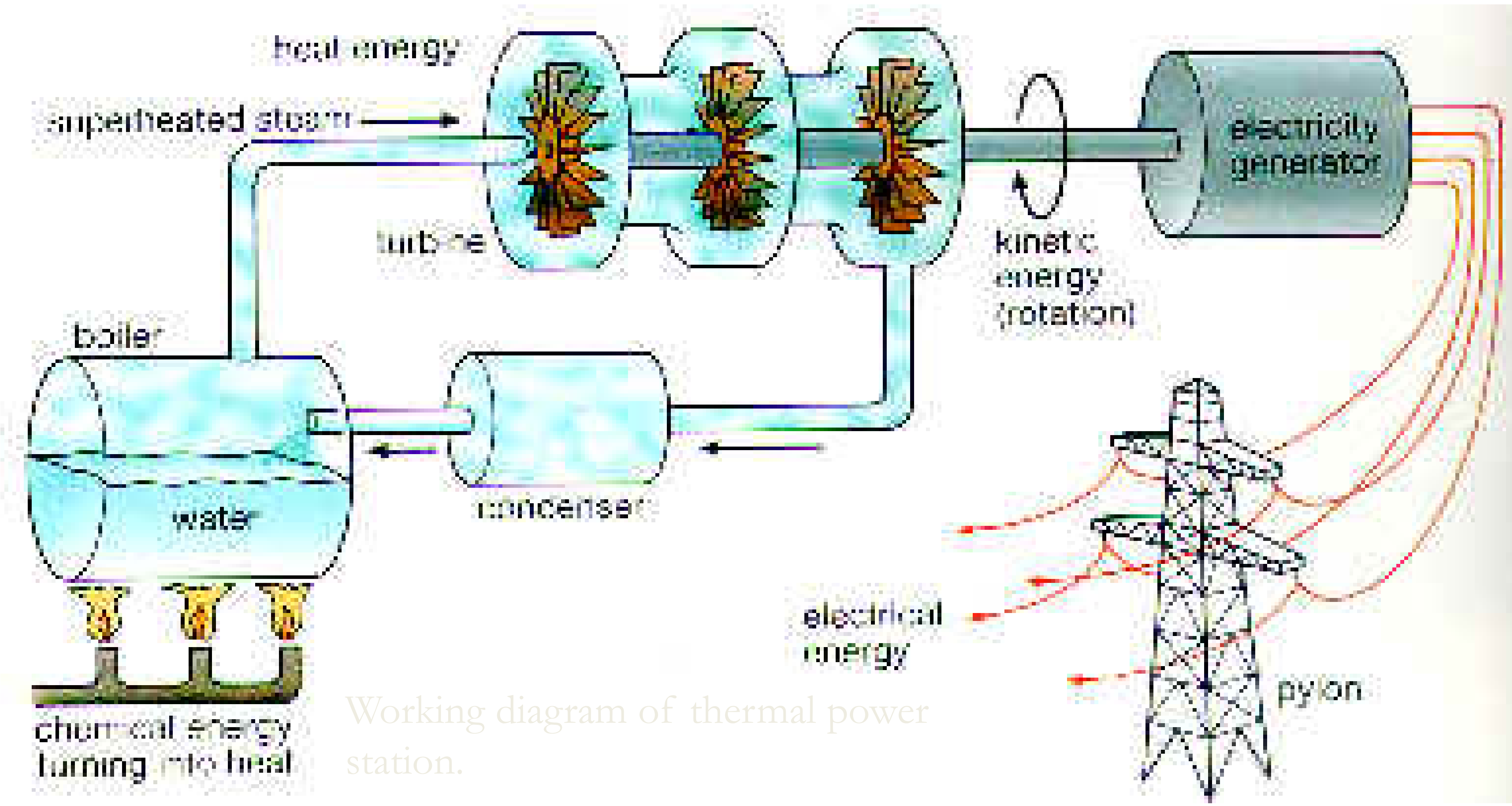
Mechanical equipment in Thermal power station.

BOILER	SUPER HEATER
ECONOMISER	AIR PREHEATER
TURBINE	CONDENSER

Working diagram Thermal power station.

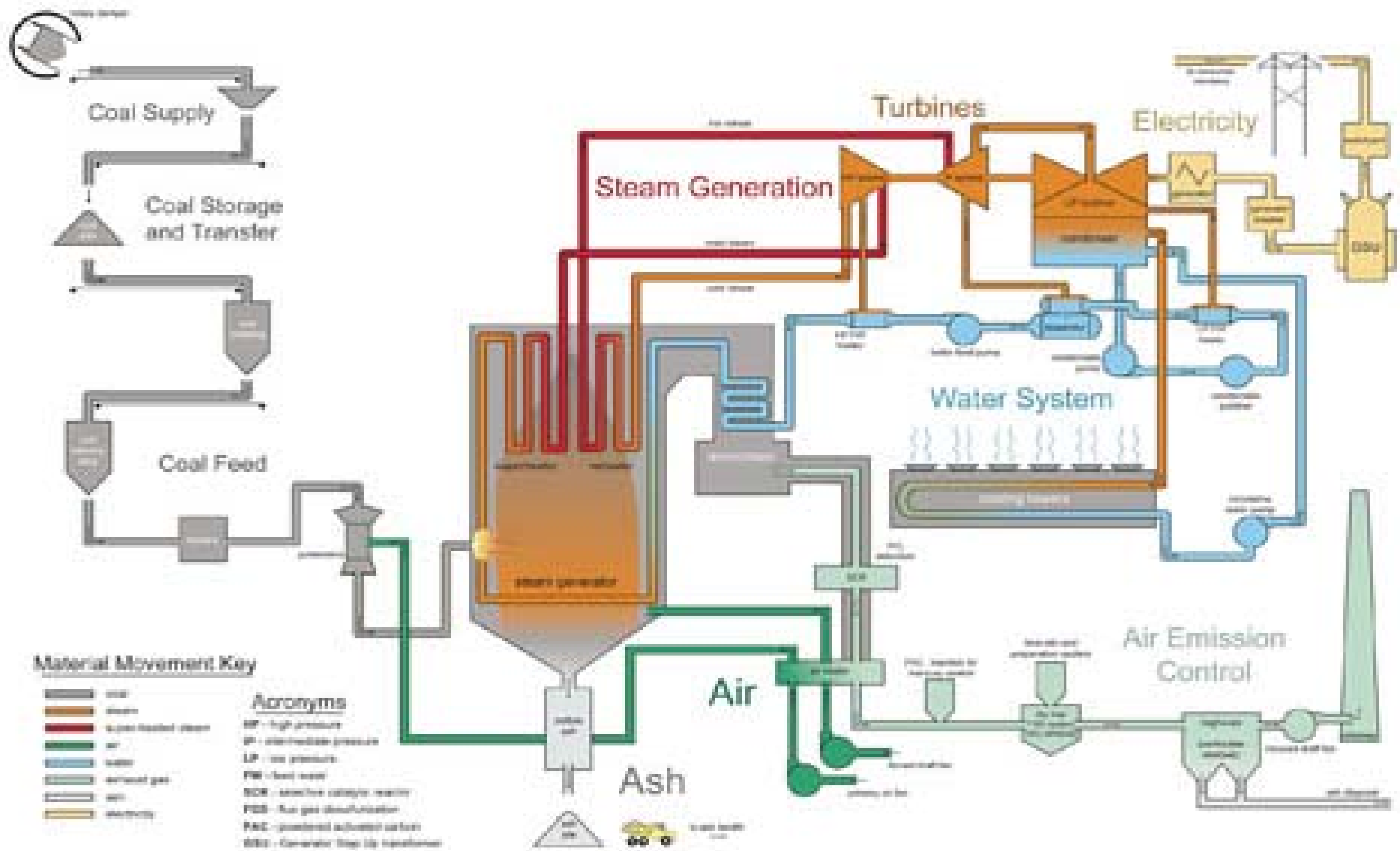


Working diagram Thermal power station.



working diagram of Thermal power station.

Working diagram Thermal power station.



Side view Thermal power station.

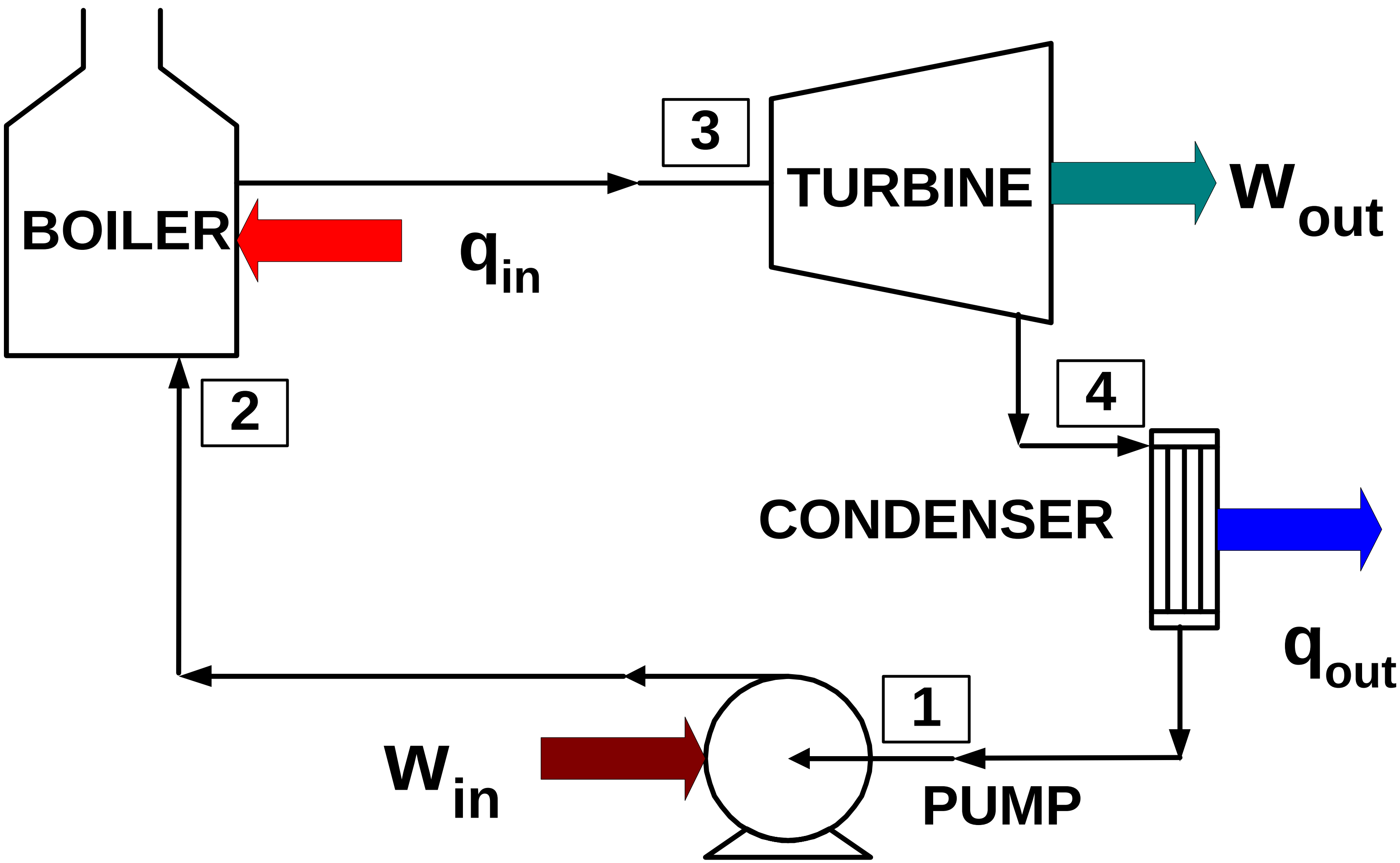
TEAMPLAY

How much does it cost to operate a gas fired 120 MW(output) power plant with a 35% efficiency for 24 hours/day for a full year if fuel costs are \$6.00 per 10^6 Btu?

Vapor Power Cycles

- The Carnot cycle is still important as a standard of comparison.
- However, just as for gas power cycles, it cannot be practically achieved in useful, economical systems.

We'll simplify the power plant



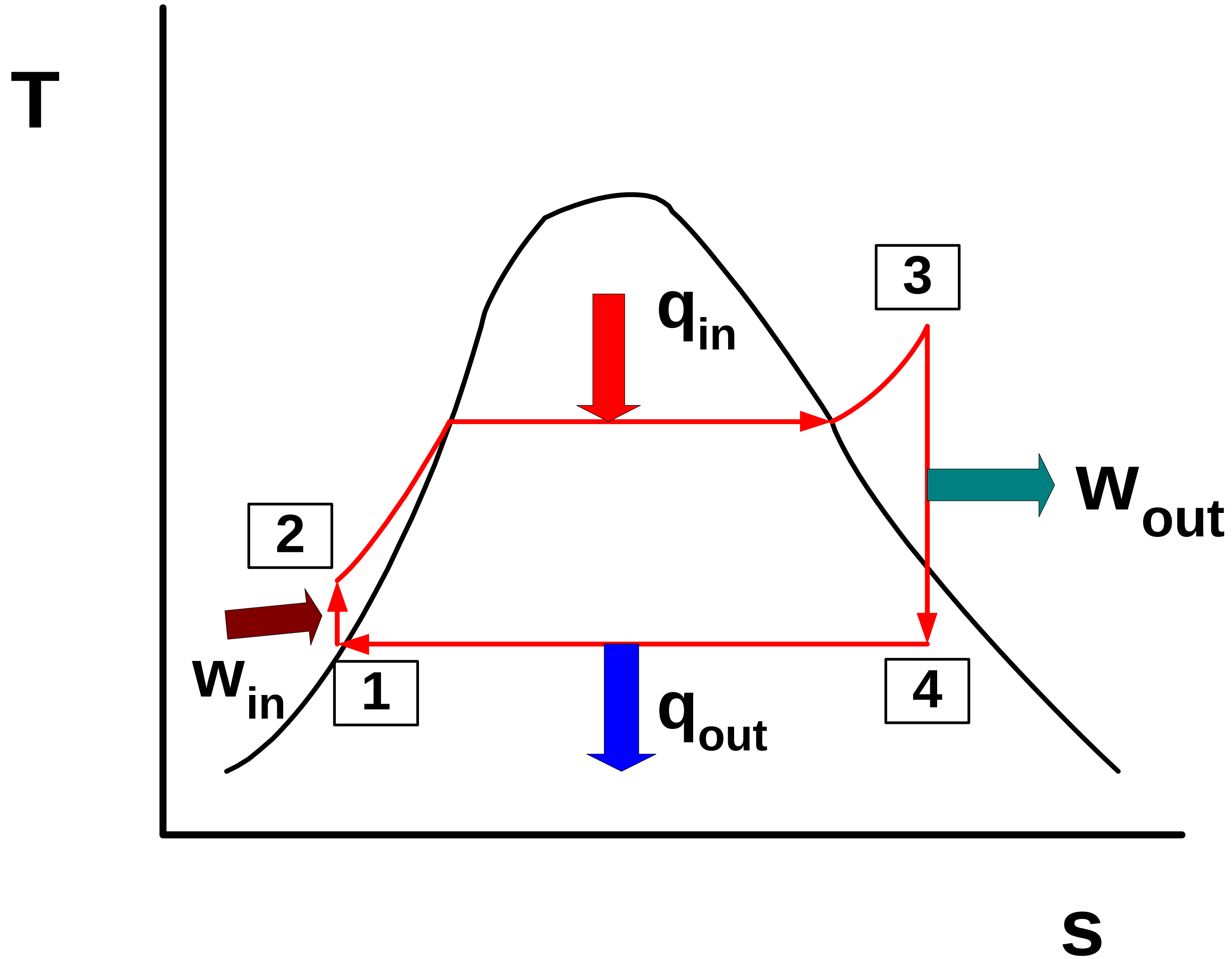
Ideal power plant cycle is called the Rankine Cycle

- 1-2 reversible adiabatic (isentropic) compression in the pump
- 2-3 constant pressure heat addition in the boiler.
- 3-4 reversible adiabatic (isentropic) expansion through turbine
- 4-1 constant pressure heat rejection in the condenser

Rankine cycle power plant

- The steady-state first law applied to open systems will be used to analyze the four major components of a power plant
  - Pump
  - Boiler (heat exchanger)
  - Turbine
  - Condenser (heat-exchanger)
- The second law will be needed to evaluate turbine performance

Vapor-cycle power plants



What are the main parameters we want to describe the cycle?

=> Net power or work output

Power

$$\dot{W}_{out} = \dot{W}_{tur} - \dot{W}_{pump}$$

Work

$$w_{out} = w_{tur} - w_{pump}$$

Main parameters....

=> Efficiency

$$\eta = \frac{\dot{W}_{net}}{\dot{Q}_{in}} \quad \text{Or} \quad \eta = \frac{w_{net}}{q_{in}}$$

General comments about analysis

- Typical assumptions...
  - Steady flow in all components
  - Steady state in all components
  - Usually ignore kinetic and potential energy changes in all components
  - Pressure losses are considered negligible in boiler and condenser
  - Power components are isentropic for ideal cycle

Start our analysis with the pump

$$0 = \dot{Q}_{pump} - \dot{W}_{Pump} + \dot{m}(h_1 - h_2 + \Delta KE + \Delta PE)$$

The pump is adiabatic, with no kinetic or potential energy changes. The work per unit mass is:

$$w_{pump} = h_1 - h_2 = v(p_1 - p_2)$$

Pump Analysis

This expression gives us **negative** value for w_p. It is standard practice in dealing with cycles to express works as positive values, then add or subtract depending on whether they're in or out.

$$w_{Pump} = \left| h_1 - h_2 \right|$$

This gives us a **positive** value for work.

Boiler is the next component.

$$0 = \dot{Q}_{boiler} - \dot{W}_{boiler} + \dot{m}[h_2 - h_3 + \Delta KE + \Delta PE]$$

- Boilers do no work. In boilers, heat is added to the working fluid, so the heat transfer term is already positive.
- So

$$\frac{\dot{Q}_{boiler}}{\dot{m}} = q_{boiler} = h_3 - h_2$$

Proceeding to the Turbine

$$0 = \dot{Q}_{turbine} - \dot{W}_{turbine} + \dot{m}[h_3 - h_4 + \Delta KE + \Delta PE]$$

Turbines are almost always adiabatic. In addition, we'll usually ignore kinetic and potential energy changes:

$$\frac{\dot{W}_{turbine}}{\dot{m}} = w = h_3 - h_4$$

Last component is the Condenser

$$0 = \dot{Q}_{cond} - \dot{W}_{cond} + \dot{m}[h_4 - h_1 + \Delta KE + \Delta PE]$$

Condensers do no work (they are heat exchangers),and if there is no ΔKE and ΔPE,

$$\frac{\dot{Q}_{cond}}{\dot{m}} = q_{cond} = h_1 - h_4$$

More condenser…

What is the sign of q_{cond} ?

As with work, we're going to want the sign of all the heat transfer terms positive.

$$\frac{\dot{Q}_{cond}}{\dot{m}} = q_{cond} = \left| h_1 - h_4 \right|$$

Ideal Rankine Cycle

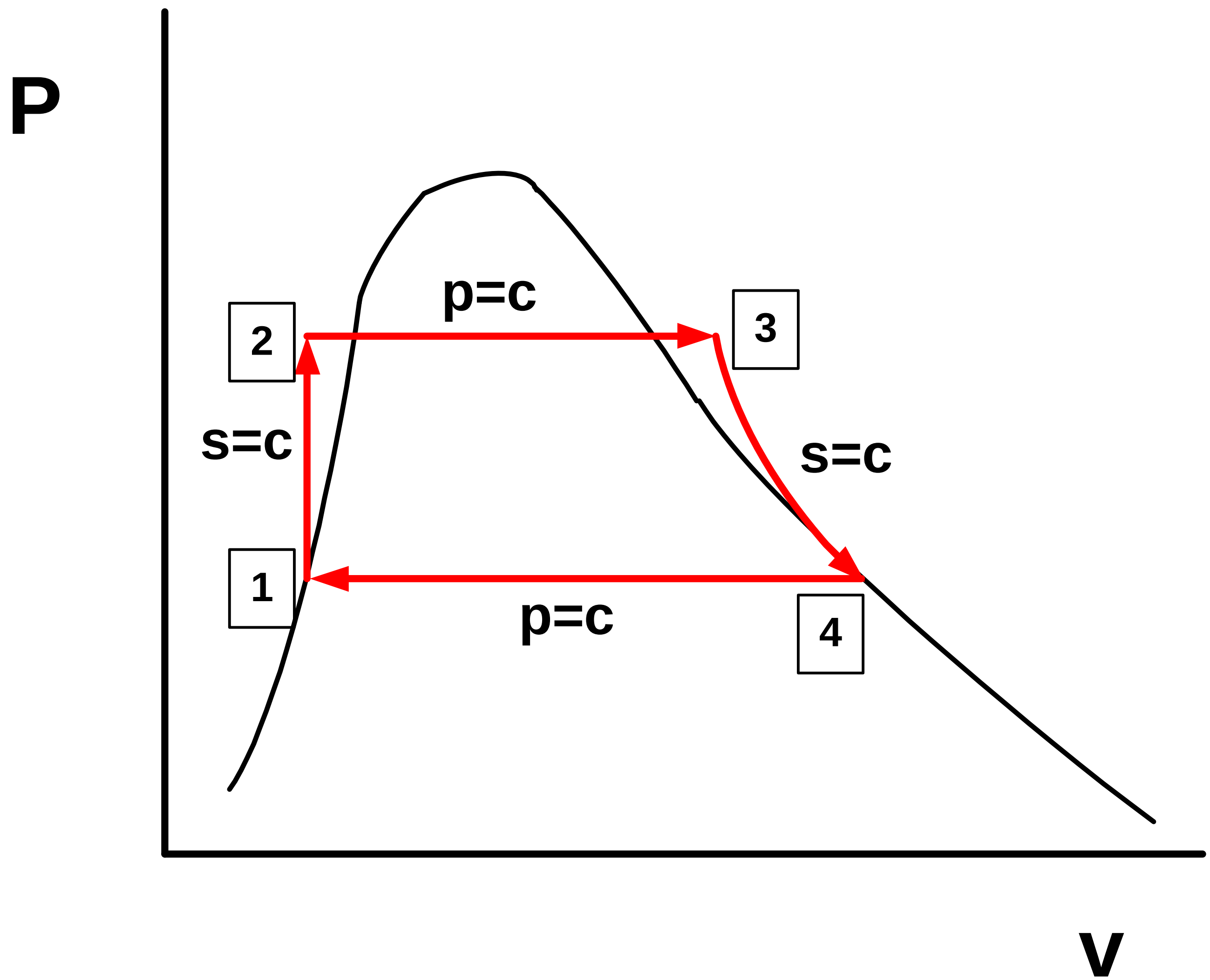
- The pump work, because it is reversible and adiabatic, is given by

$$w_P = \int_1^2 v dp = h_2 - h_1$$

- and

$$w_P = v(P_2 - P_1)$$

Ideal Rankine Cycle on a p-v diagram



Efficiency

$$\eta = \frac{w_{out}}{q_{in}}$$

$$\eta = \frac{h_3 - h_4 - v(P_2 - P_1)}{h_3 - h_2}$$

Example Problem

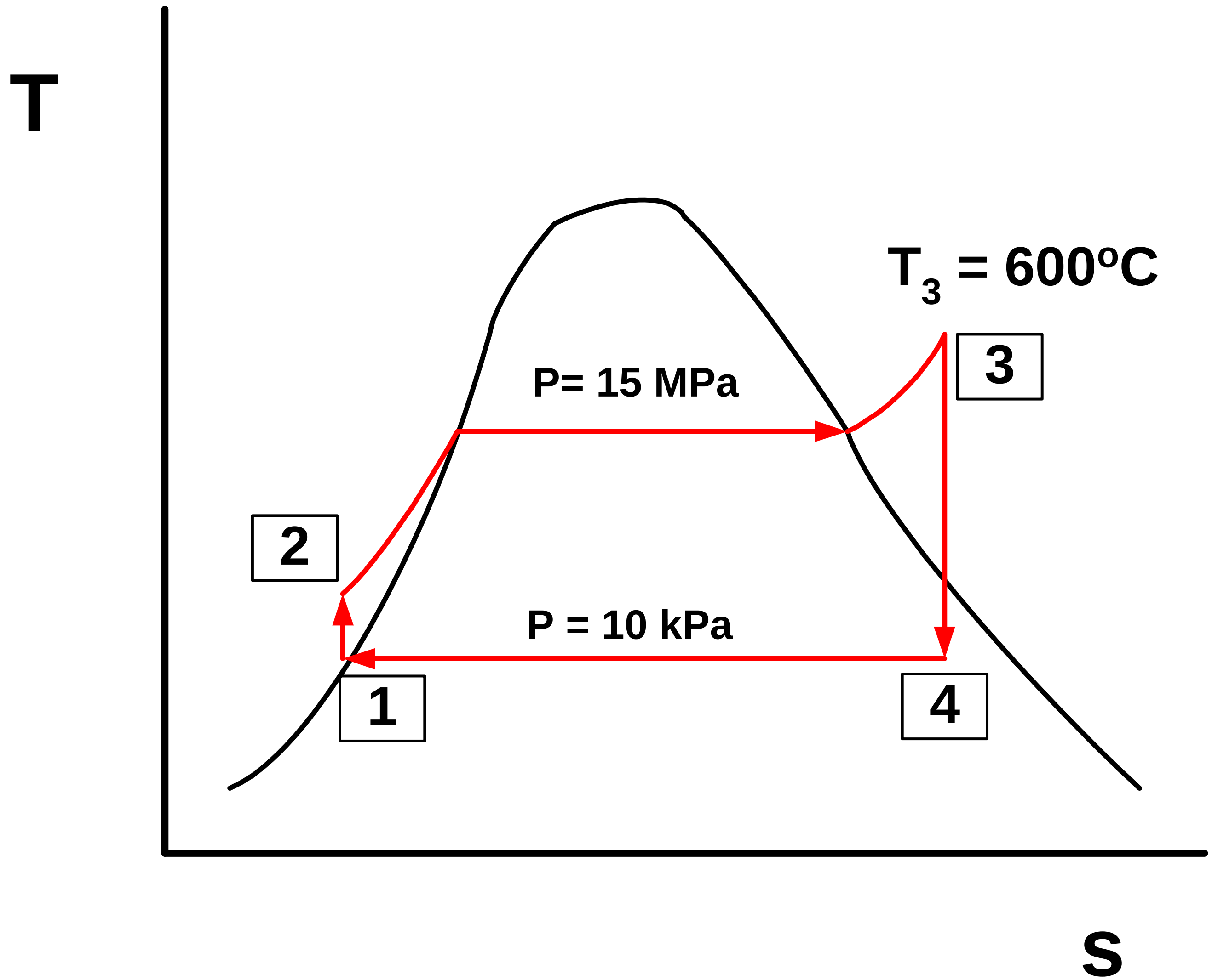
A Rankine cycle has an exhaust pressure from the turbine of 10 kPa. Determine the quality of the steam leaving the turbine and the thermal efficiency of the cycle which has turbine inlet pressure of 15 MPa and 600°C.

Start an analysis:

Assumptions:

- pump and turbine are isentropic
- $P_2 = P_3 = 15$ MPa
- $T_3 = 600°C$
- $P_4 = P_1 = 10$ kPA
- Kinetic and potential energy changes are zero

Draw diagram of cycle



Some comments about working cycle problems

- Get the BIG picture first - where's the work, where's the heat transfer, etc.
- Tables can useful - they help you put all the data you will need in one place.
- You will need to know how to look up properties in the tables!

Put together property data

State	T (C)	P(kPa)	$v(m^3/kg)$	h(kJ/kg)	s(kJ/kgK)	x
1		**10**				**0**
2		**15000**				**n.a.**
3	**600**	**15000**	**----**			
4		**10**	**----**			

Property data

- h_1=191.83 kJ/kg is a table look-up, as is h_3=3582.3 kJ/kg.

Let start with pump work

Pump work:

$$w_{pump} = \left|\nu(p_1 - p_2)\right| = \left|h_1 - h_2\right|$$

$$w_{pump} = \left|(0.00101)\frac{m^3}{kg}(0.01\text{-}15)MPa\right|$$

$$\boxed{w_{pump} = 15.1\,\frac{kJ}{kg}}$$

More calculations…

Enthalpy at pump outlet:

$$h_2 = h_1 + w_{pump}$$

Plugging in some numbers:

$$h_2 = (191.83 + 15.1)\ \frac{kJ}{kg}$$

$$h_2 = 206.93\ \frac{kJ}{kg}$$

Calculate heat input and turbine work..

Boiler heat input:

$$q_{boiler} = h_3 - h_2 = (3582.3 - 206.93)\frac{kJ}{kg}$$

$$q_{boiler} = 3375.4\ \frac{kJ}{kg}$$

Property data

- Because $s_3 = s_4$, we can determine that $x_4=0.803$ and thus $h_4=2114.9$ kJ/kg

Turbine work

$$w_{turbine} = h_3 - h_4 = (3582.3 - 2114.9)\frac{kJ}{kg}$$

$$w_{turbine} = 1467.4\ \frac{kJ}{kg}$$

We've got the exit quality, now we need efficiency

Cycle efficiency:

$$\eta = \frac{w_{out}}{q_{in}}$$

Substituting for net work:

$$\eta = \frac{w_{turbine} - w_{pump}}{q_{in}}$$

Overall thermal efficiency

$$\eta = \frac{w_{turbine} - w_{pump}}{q_{in}}$$

$$\eta = \frac{(1467.4 - 15.1)\,\frac{kJ}{kg}}{3375.4\,\frac{kJ}{kg}} = 0.430$$

Some general characteristics of the Rankine cycle

- Low condensing pressure (below atmospheric pressure)
- High vapor temperature entering the turbine (600 to 1000°C)
- Small backwork ratio (bwr)

$$\text{bwr} \equiv \frac{w_{\text{pump}}}{w_{\text{turbine}}} = \frac{|h_1 - h_2|}{h_3 - h_4} \approx 0.01$$

Types of Coal

- Fossil fuel
  - It is a readily combustible black or brownish-black sedimentary rock

Coal Mining

- Surface Mining
  - Strip Mining

- Underground Mining

Coal Power Plant Operation

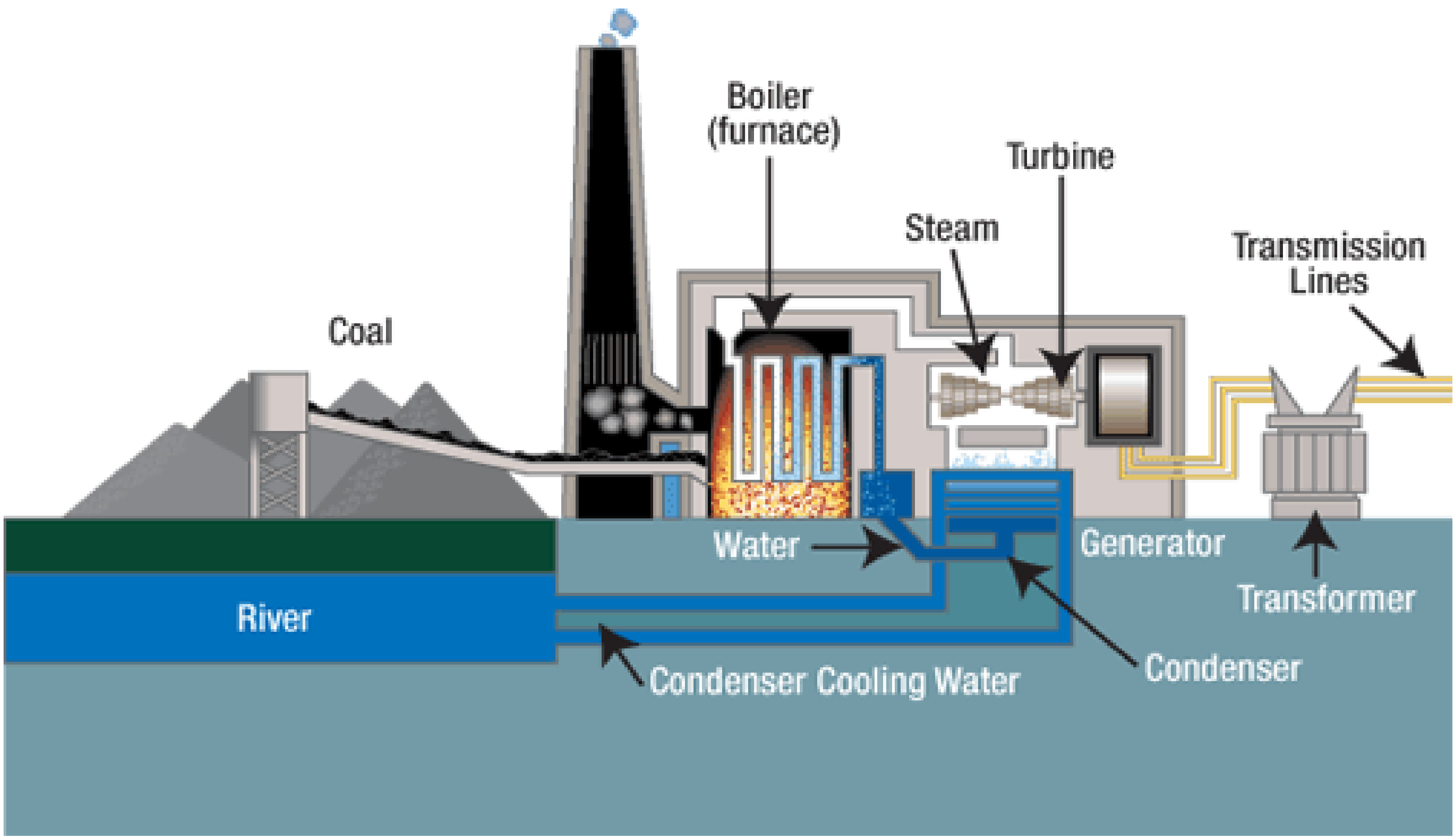
- ## Feedwater
  - Feedwater used in a steam boiler to transfer heat energy from the fuel burning area to mech. Energy of spinning steam turbine

- ## Boiler
  - Rectangular furnace, pulverized coal is blown in from fuel nozzles at 4 corners. The coal then burns quickly and forms a fireball at the center (seriously, a fireball!!!).

Coal Power Plant Operation

- ❖ Steam Turbine Generator
  - ❖ Is a series of steam turbines interconnected to each other and then a generator
- ❖ Steam Condenser
  - ❖ Steam enters from the turbine generator and is pumped into the bottom of the condenser, where pumps recycle the condensed steam from the feedwater
- ❖ Stack
  - ❖ Releases process emissions.

Coal Power Plant Operation

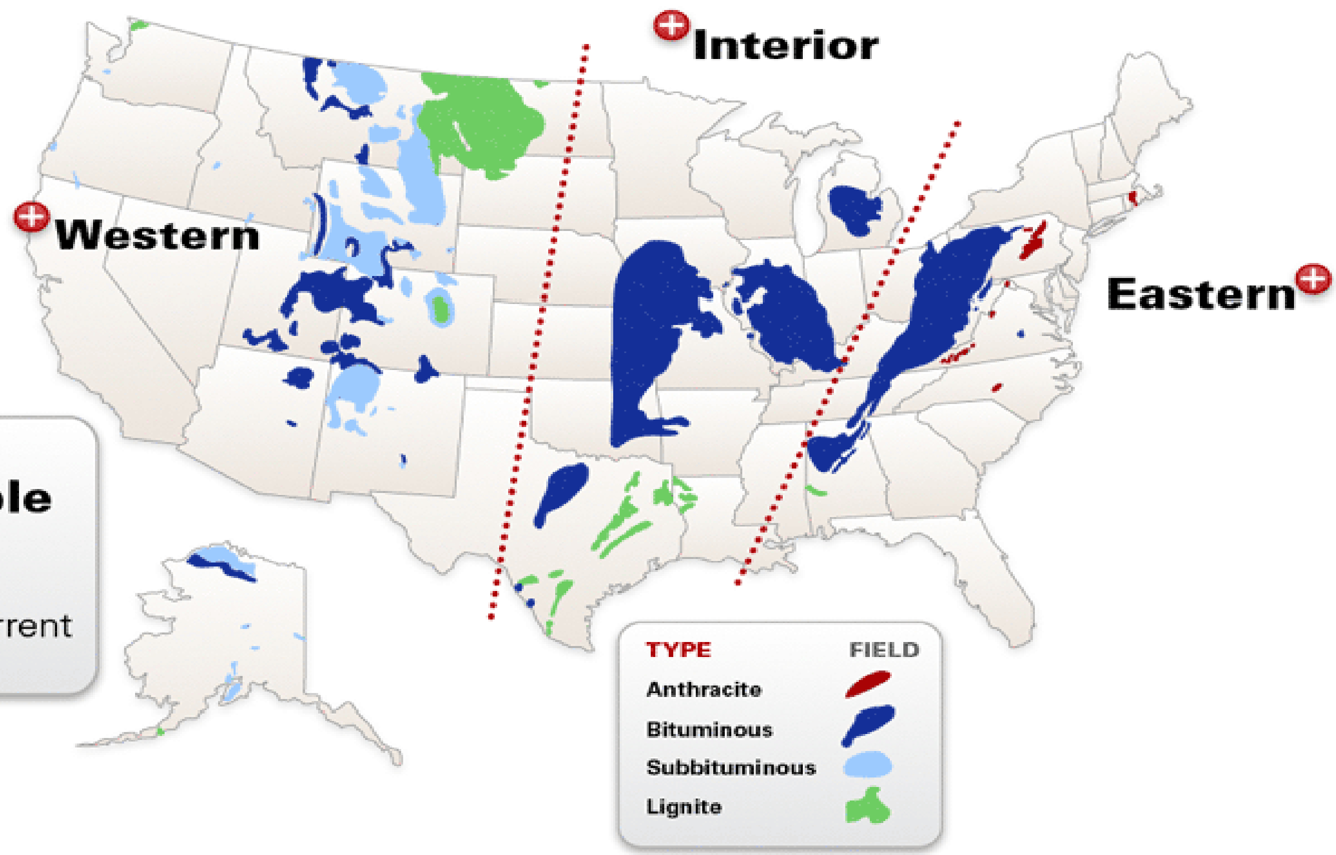


Pros of Coal Power

- Cheap
  - Cheaper per unit energy than oil or natural gas
  - Will continue to be an important global resource

- Abundance
  - Coal is the world's most abundant fossil fuel
  - Sufficient reserves for the next 250 years

U.S. COAL DEPOSITS

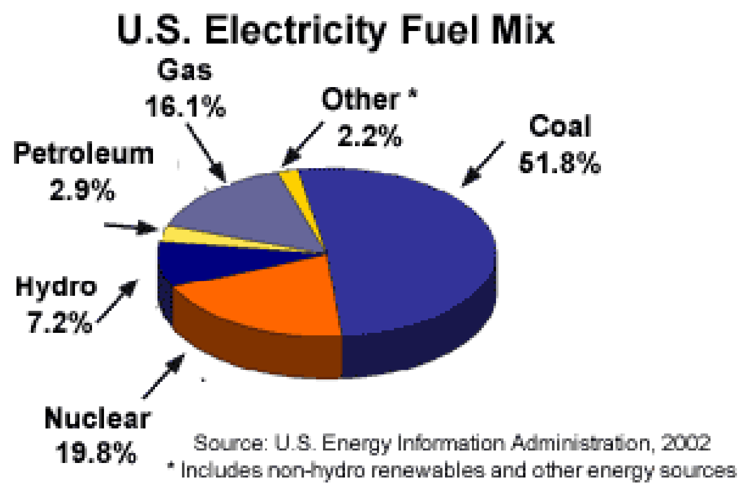


Total U.S. Recoverable Reserves

244 billion tons.
250 years at current extraction rate.

Pros of Coal Power

- Electricity
  - Supplying approximately 50% of electricity to the US



- Economy
  - Coal-mining stimulates over one million jobs in the U.S.
  - Coal contributes over $80 billion annually to the economy

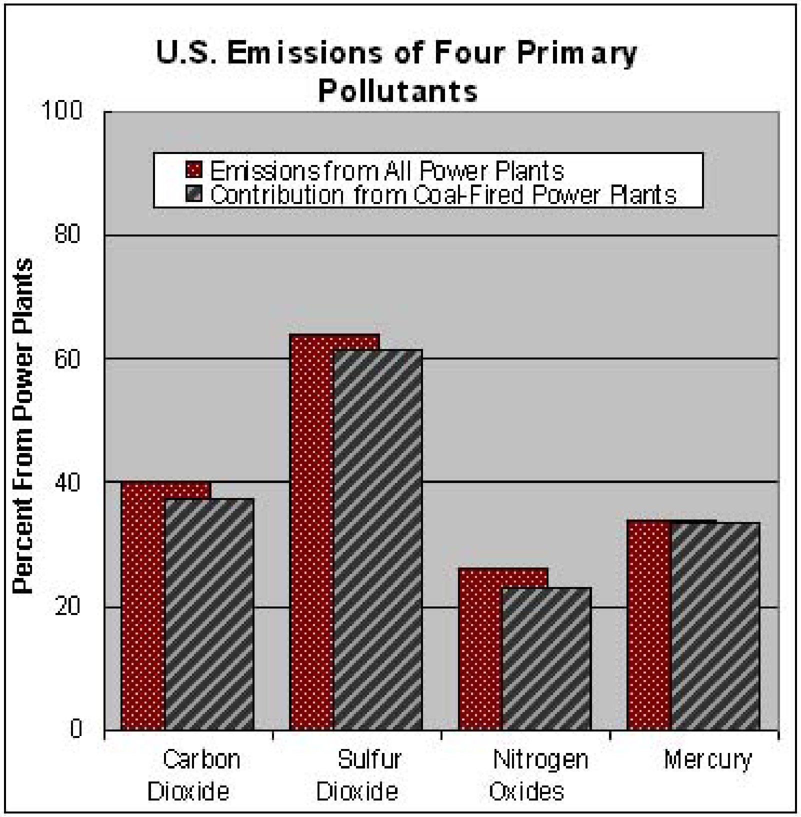
Pros of Coal Power

- Efficiency
  - Larger power plants are more efficient
  - 38% of the chemical energy is converted to energy
- Safe
  - safest fossil fuel to transport, store and use
  - scrubbers

Cons of Coal Power

- Coal-Fired Power Plants are the largest contributor of hazardous air pollutants.

  - Sulfur dioxide (SO_2)
  - Nitrogen Oxide (NO_x)
  - Carbon Dioxide (CO_2)
  - Mercury



Effects on the environment and Human health

- CO_2 ~ carbon dioxide pollution, making energy use the single largest source of greenhouse gases in the U.S. and the world

Effects on the environment and Human health

- SO_2
  - o Sulfur dioxide combined with nitrogen oxide react with water and oxygen in the atmosphere to form acidic compounds, which can mix with natural precipitation and fall to the earth as ***acid rain***.

  - o Sulfur dioxide can also combine with nitrogen oxide and other particles to form ***particulate matter***.
    - o trigger heart attacks and strokes
    - o lead to cardiac arrhythmia (irregular heartbeat)
    - o respiratory irritation, and worsen asthma.
    - o premature death (Both short-term and long-term exposure)

Effects on the environment and Human health

- NO_x
  - When nitrogen oxide (chemically) reacts with volatile organic compounds (VOC's) and sunlight ground-level ozone or smog is formed.

An estimated 140.5 million Americans live in areas with unhealthy levels of smog according to the The American Lung Association.

Effects on the environment and Human health

- Mercury
  - One of the most dangerous pollutants released into the air through the exhaust system when coal is burned.

Future of Coal

- Economy
  - US economy relies on coal importation and exportation
  - The demand for coal usage to provide electricity will continue to grow

Future of Coal

- Clean coal technology
  - A new generation of coal-burning power plants with energy processes that reduce air emissions and other pollutants.
  - Clean Air Acts

- Coal power plants technology must adapt to the changing political climate towards environmental issues.

Unit IV

Combined Cycles

TURBINES: Machines to **extract fluid power from flowing fluids**

Steam Turbine

Water Turbines

Wind Turbines

Gas Turbines

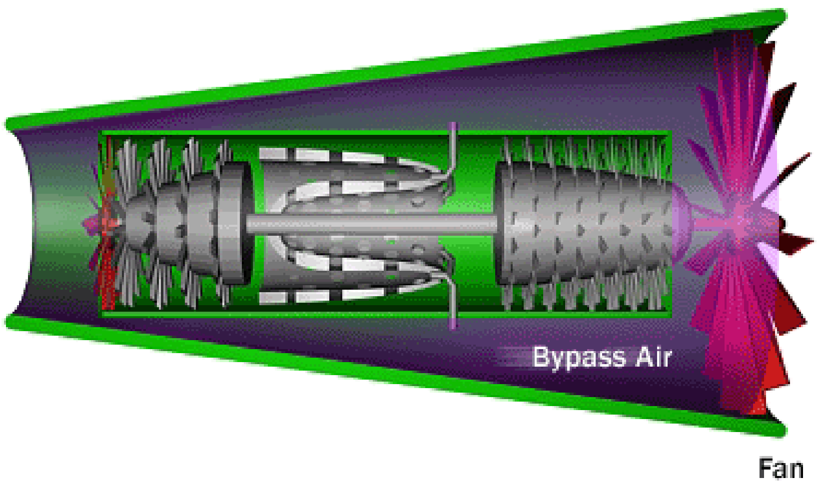
Aircraft Engines
Power Generation

- High Pressure, High Temperature gas
- Generated inside the engine
- Expands through a specially designed TURBINE

GAS TURBINES

- Invented in 1930 by Frank Whittle
- Patented in 1934
- First used for aircraft propulsion in 1942 on Me262 by Germans during second world war
- Currently most of the aircrafts and ships use GT engines
- Used for power generation
- Manufacturers: General Electric, Pratt &Whitney, SNECMA, Rolls Royce, Honeywell, Siemens – Westinghouse, Alstom
- Indian take: Kaveri Engine by GTRE (DRDO)

PRINCIPLE OF OPERATION



- Intake
  - Slow down incoming air
  - Remove distortions
- Compressor
  - Dynamically Compress air
- Combustor
  - Heat addition through chemical reaction
- Turbine
  - Run the compressor
- Nozzle/ Free Turbine
  - Generation of thrust power/shaft power

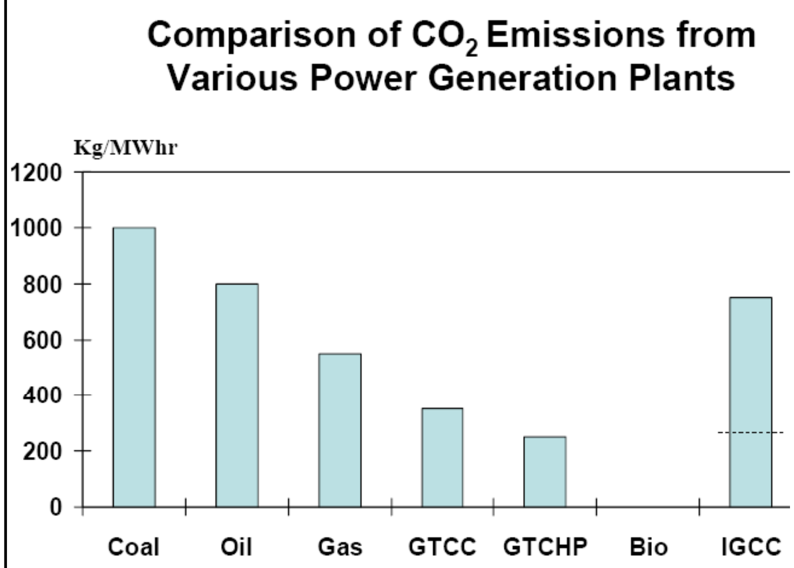
Advantages and Disadvantages

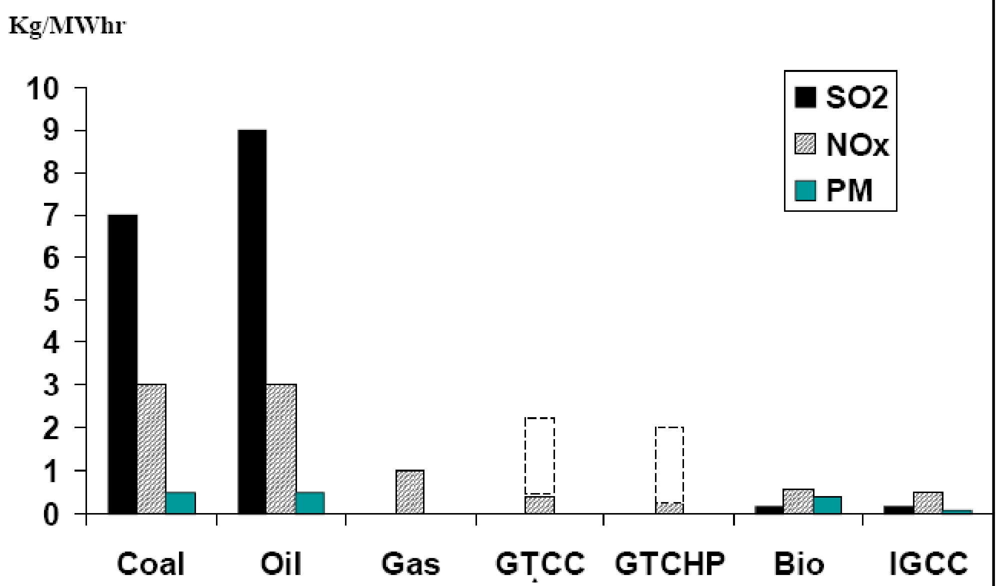
- Great **power-to-weight ratio** compared to reciprocating engines.
- **Smaller** than their reciprocating counterparts of the same power.
- **Lower emission** levels

- **Expensive:**
  - high speeds and high operating temperatures
  - designing and manufacturing gas turbines is a tough problem from both the engineering and materials standpoint
- Tend to use **more fuel** when they are idling
- They prefer a **constant rather than a fluctuating load.**

That makes gas turbines great for things like transcontinental jet aircraft and power plants, but explains why we don't have one under the hood of our car.

Emission in Gas Turbines





- Lower emission compared to all conventional methods (except nuclear)
- Regulations require further reduction in emission levels

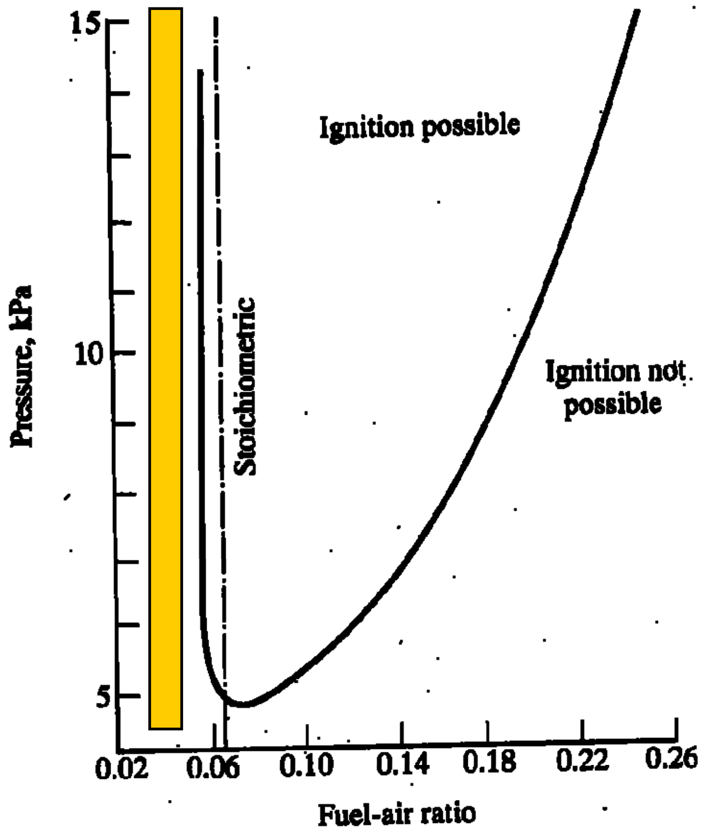
Needs for Future Gas Turbines

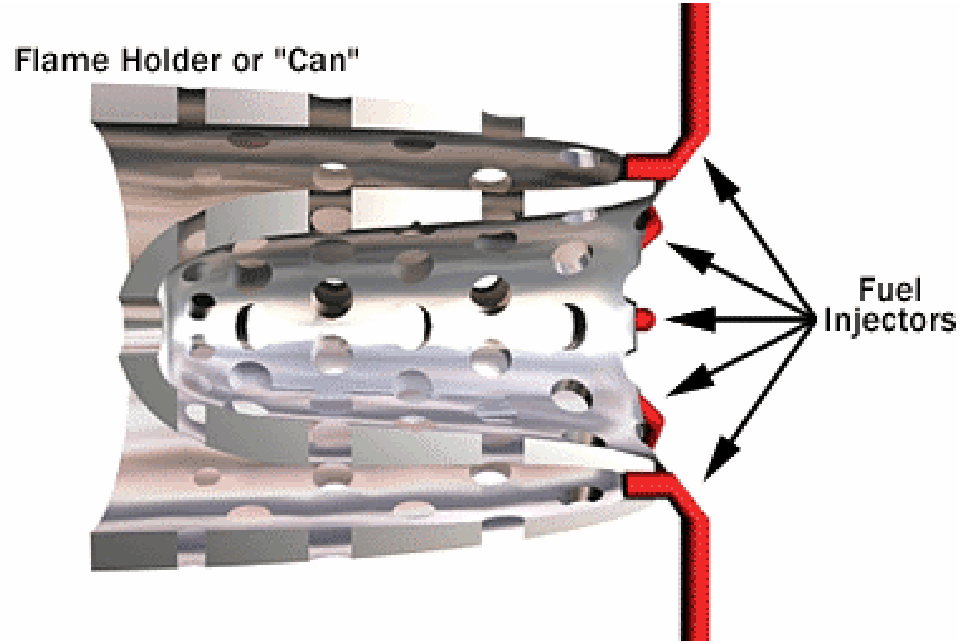
- Power Generation
  - Fuel Economy
  - Low Emissions
  - Alternative fuels
- Military Aircrafts
  - High Thrust
  - Low Weight
- Commercial Aircrafts
  - Low emissions
  - High Thrust
  - Low Weight
  - Fuel Economy

Half the size and twice the thrust

Double the size of the Aircraft and double the distance traveled with 50% NOx

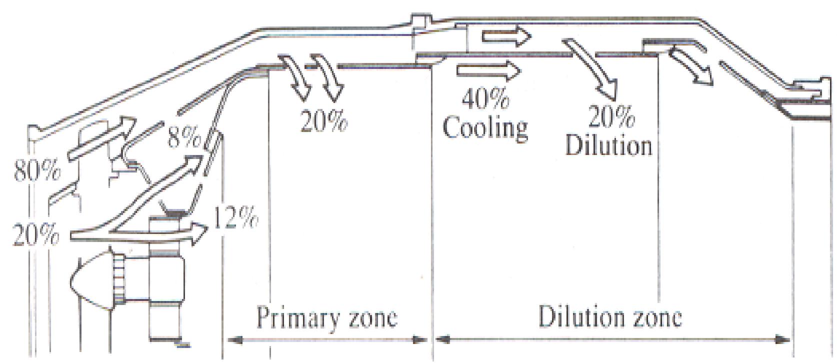
Gas Turbine Combustion



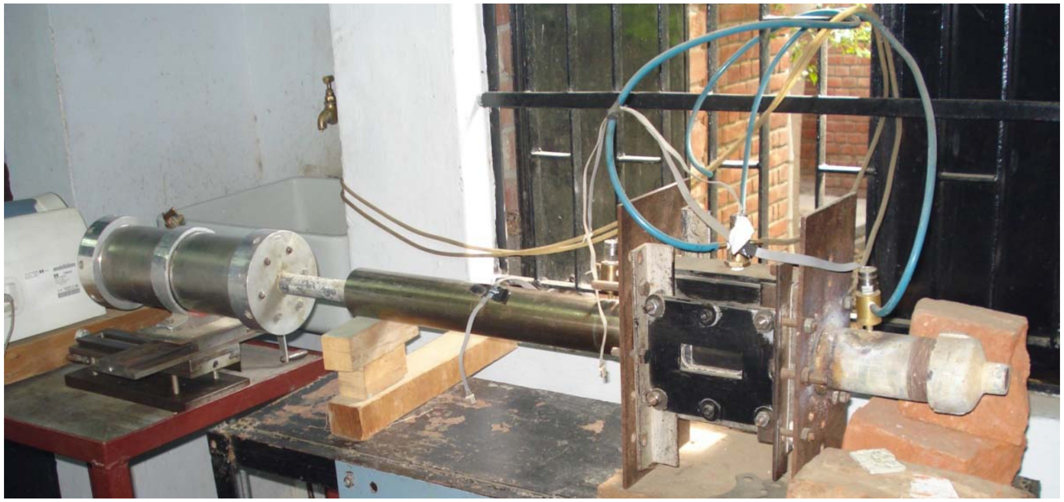


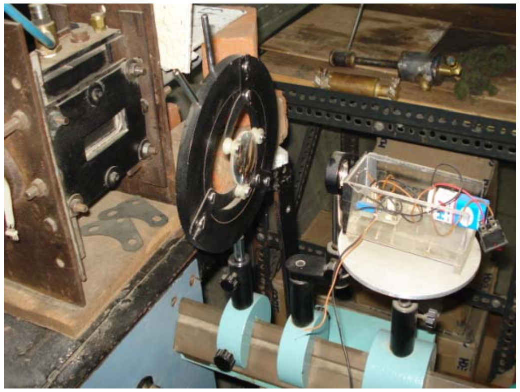
F/A – 0.01

Combustion efficiency : 98%



Effect of Inlet Disturbance



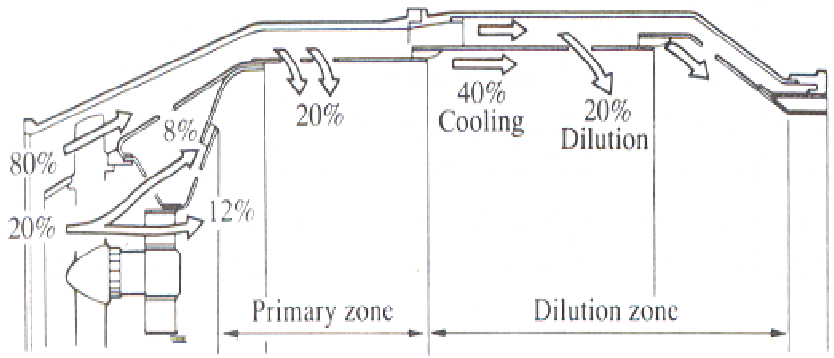


Tunable inlet to create weak disturbance of varying frequency

Bluff body stabilized flame

Unsteady pressure and heat release measurement

Recirculating Flow Dynamics



- Primary zone
- Fuel air mixing
- Intense combustion
- Short combustion length
- High turbulence
- Fuel rich combustion

Understanding recirculating flow dynamics

Time scales

Pressure transients

Energy cascading

Combustion in recirculating flows

Droplet Flow interaction

Need for controlled atomization

- Big Drops => Longer Evaporation Time => Incomplete Combustion => Unburned Hydrocarbons & Soot, Reduced Efficiency

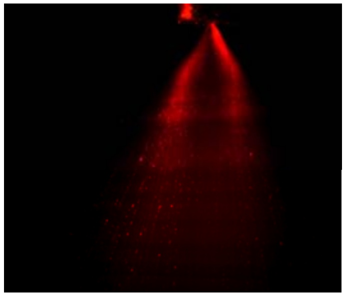
- Small Drops => Faster Evaporation and Mixing => Elongated Combustion Zone => More NOx

- Uniform size distribution for favorable pattern factor
  - Reduced thermal loading on liner and turbine

- Reduced feedline coupling

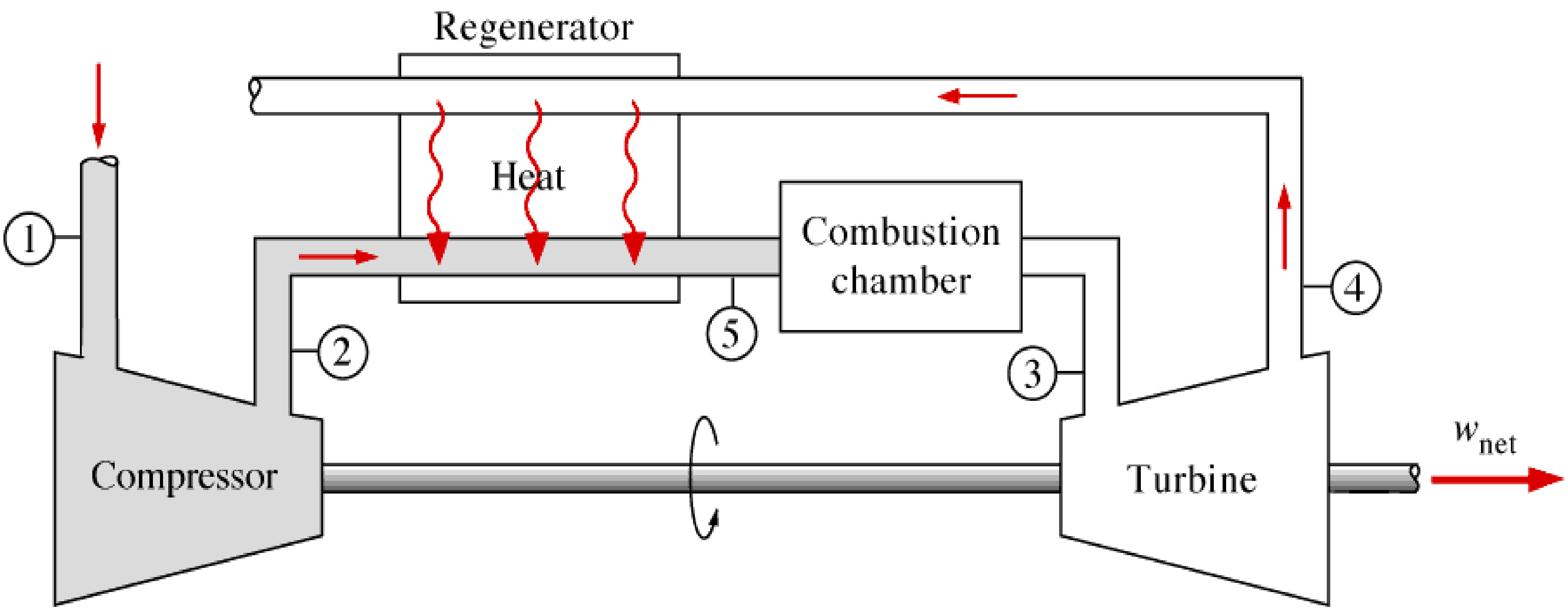
Internally Mixed Swirl Atomizer

- Good atomization with small pressure drop
- Both hollow-cone and solid cone spray from same atomizer (wide range of applications)
- Possible to atomize very viscous liquid
- Self cleaning
- Finer atomization at low flow rates
- Less sensitive to manufacturing defects
- The liquid flow rate and atomization quality can be controlled

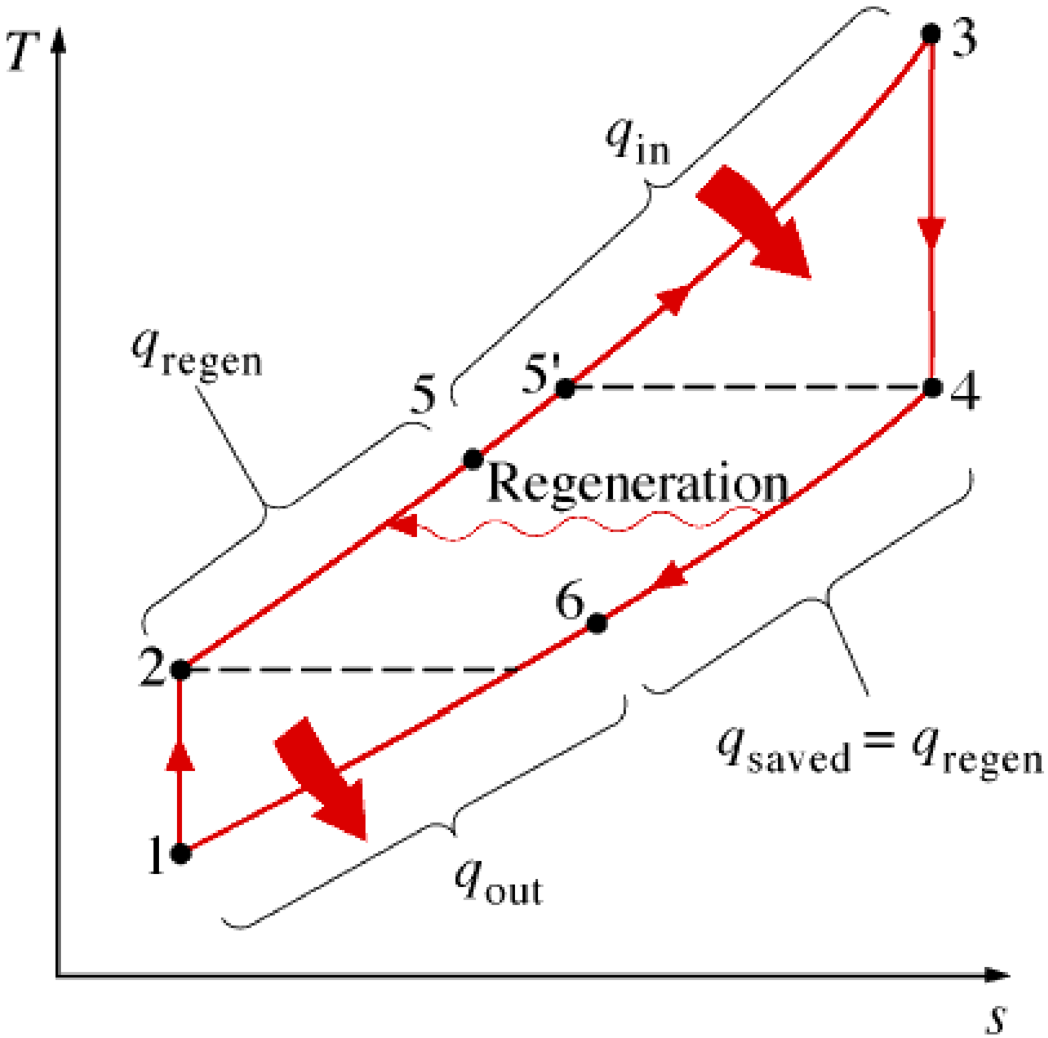


Atomization of engine oil

Improved Brayton Cycle: Add a Heat Exchanger (Regenerator)



Ts Diagram for Brayton Cycle with Regeneration



Analysis with regeneration

Heat input to the cycle:

$$q_{input} = h_3 - h_5$$

Net work of the cycle:

$$w_{net} = w_{turbine} - w_{comp} = (h_3 - h_4) - (h_2 - h_1)$$

Analysis with regeneration

Efficiency of the cycle:

$$\eta_{regen} = \frac{w_{net}}{q_{in}} = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_5}$$

For the cold-air assumption:

$$\eta_{regen} = 1 - \left(\frac{T_1}{T_3}\right)\left(r_p\right)^{(k-1)/k}$$

Regenerator in cycle

Regenerator heat transfer:

$$q_{regen} = h_5 - h_2$$

Maximum heat transfer in regenerator:

$$q_{regen,\max} = h_{5'} - h_2 = h_4 - h_2$$

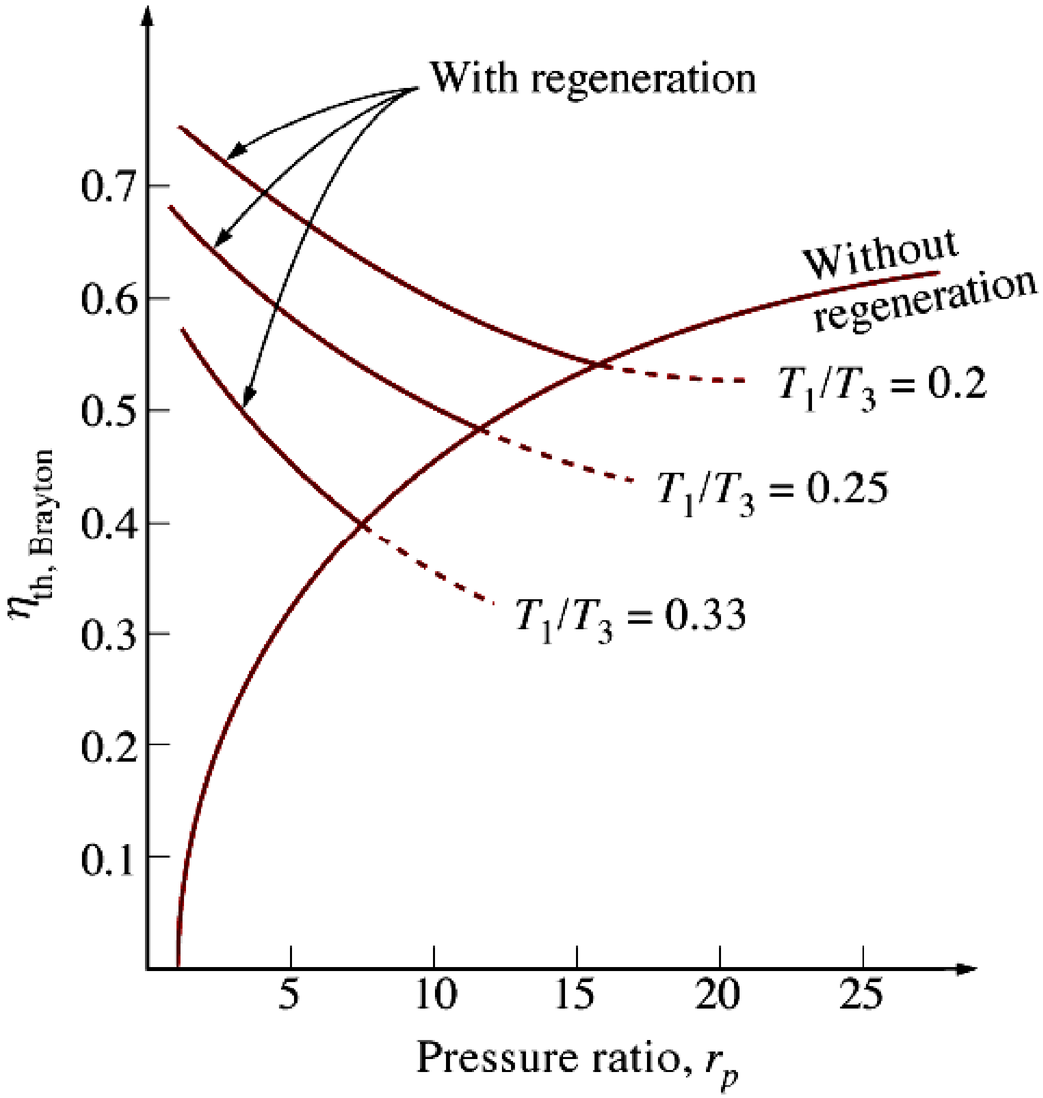
Regenerator Effectiveness

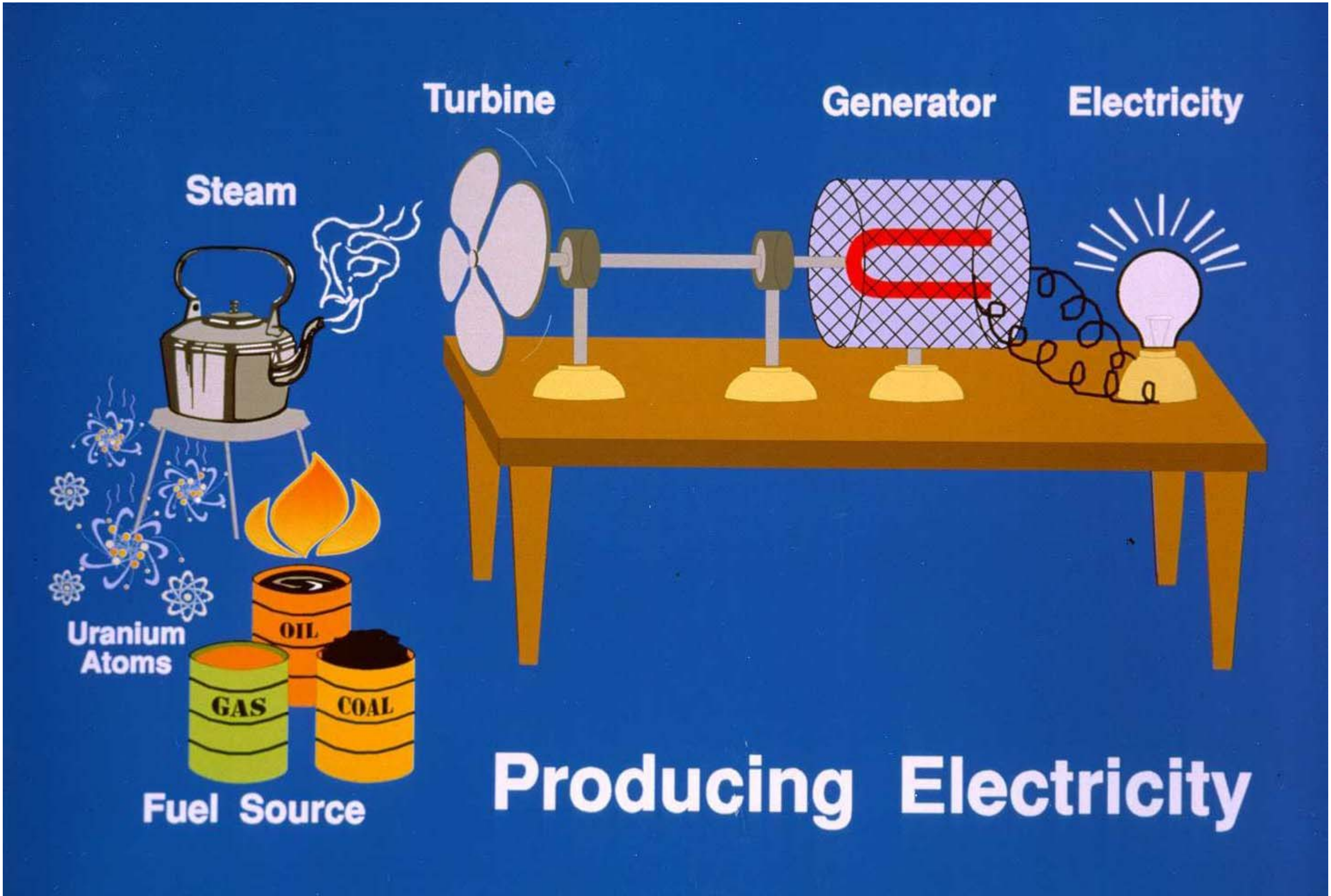
$$\varepsilon = \frac{q_{regen,act}}{q_{regen,\max}} = \frac{h_5 - h_2}{h_4 - h_2}$$

For the cold-air assumption:

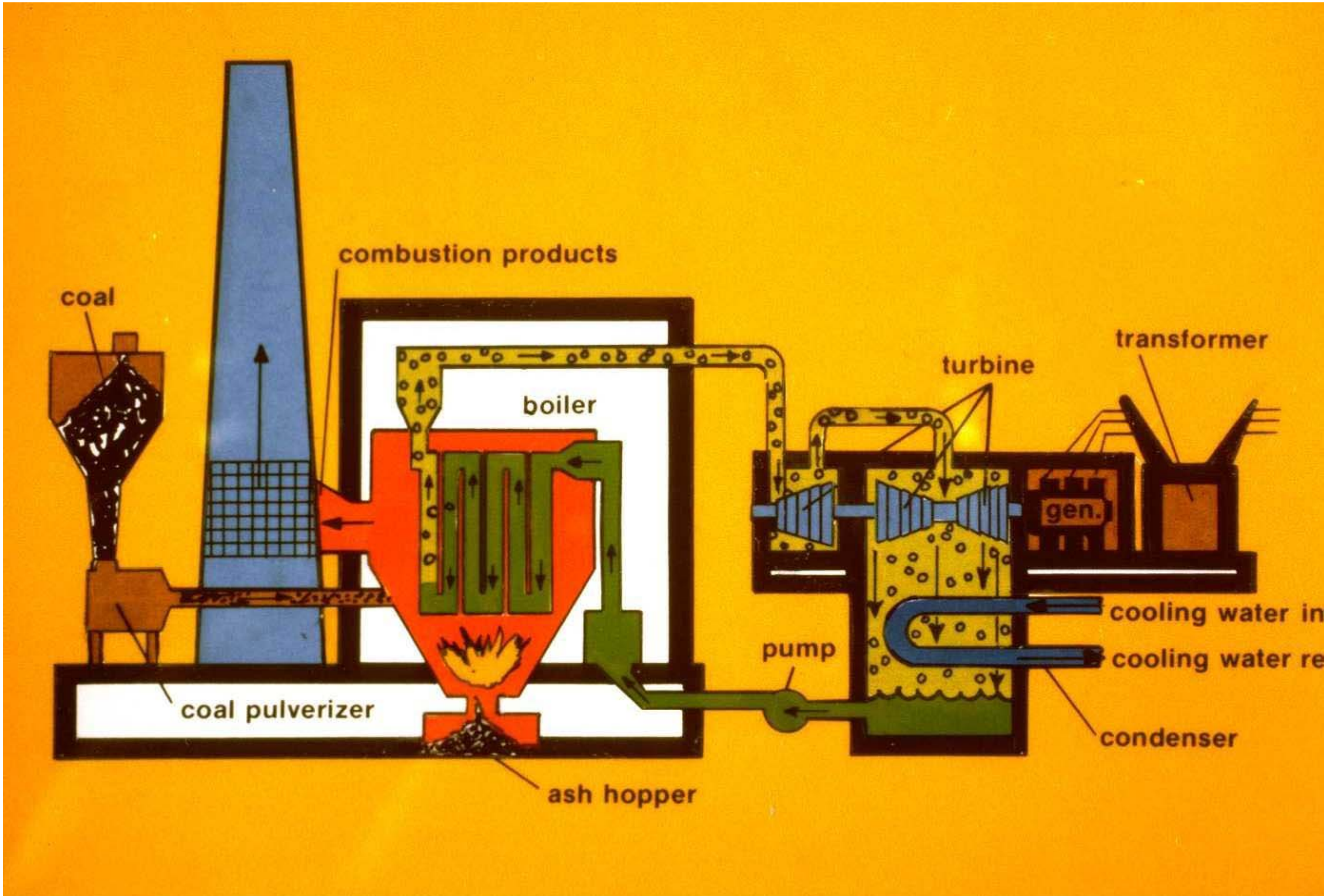
$$\varepsilon = \frac{T_5 - T_2}{T_4 - T_2}$$

Efficiency with regeneration

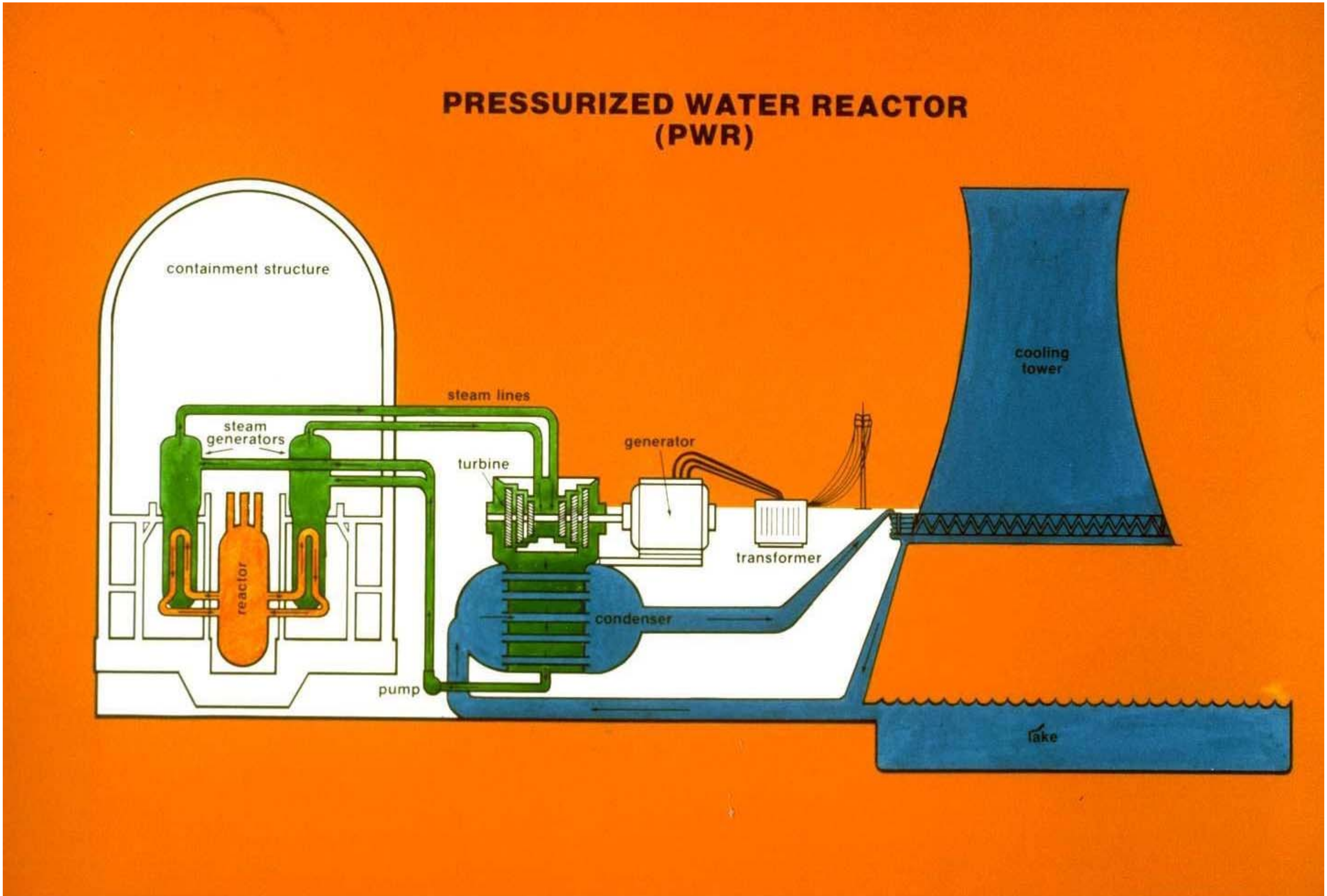




Basic view of how electricity is produced.
(Courtesy of Carolina Power and Light Company)



Overview of a coal fired generating plant.

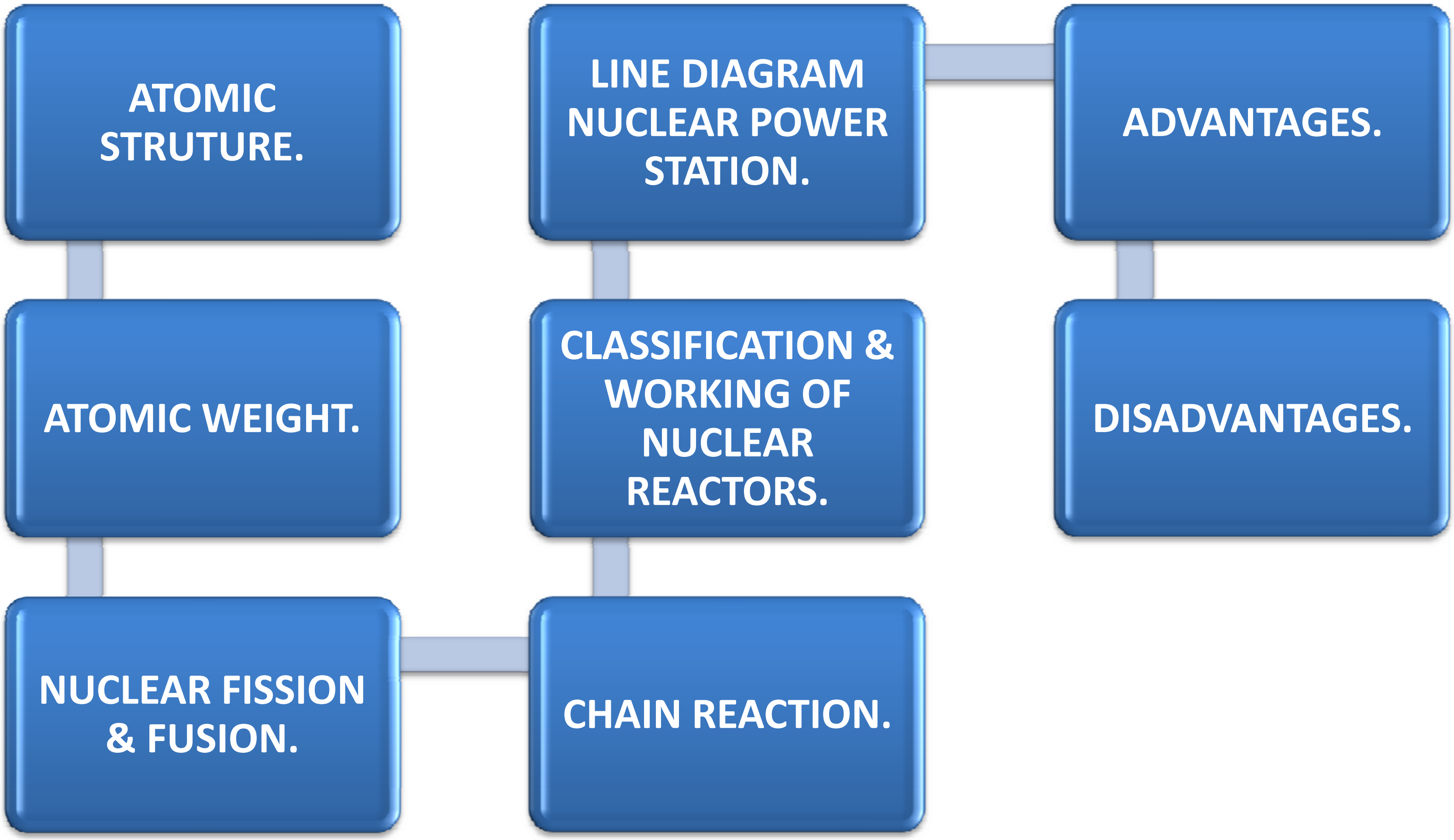


Pressurized water reactor power plant.

Unit V

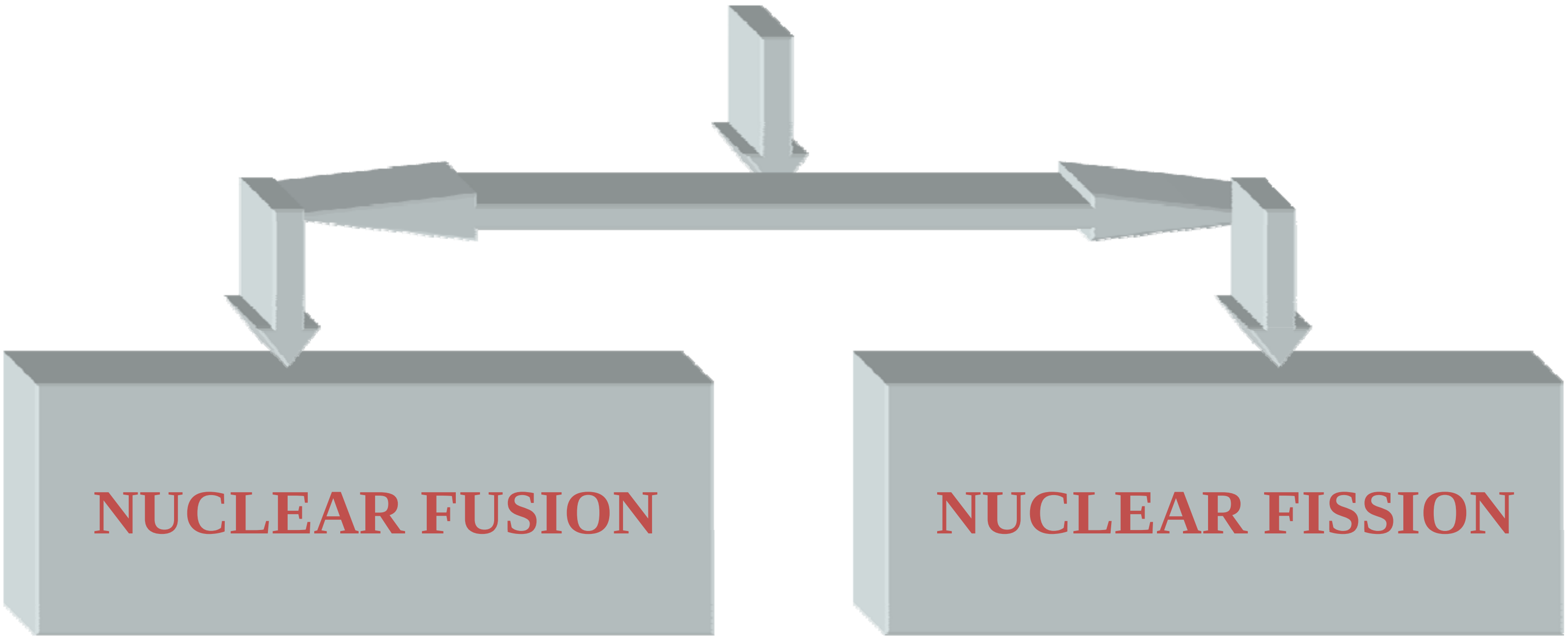
Nuclear Power Plants

Nuclear power station.`



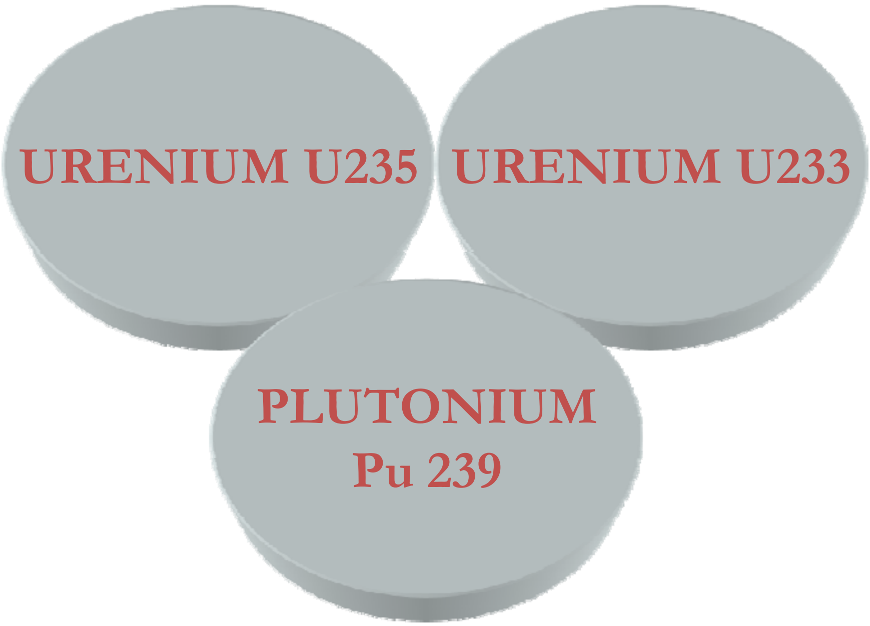
Nuclear power station.`

Generation of heat in nuclear power reactor.



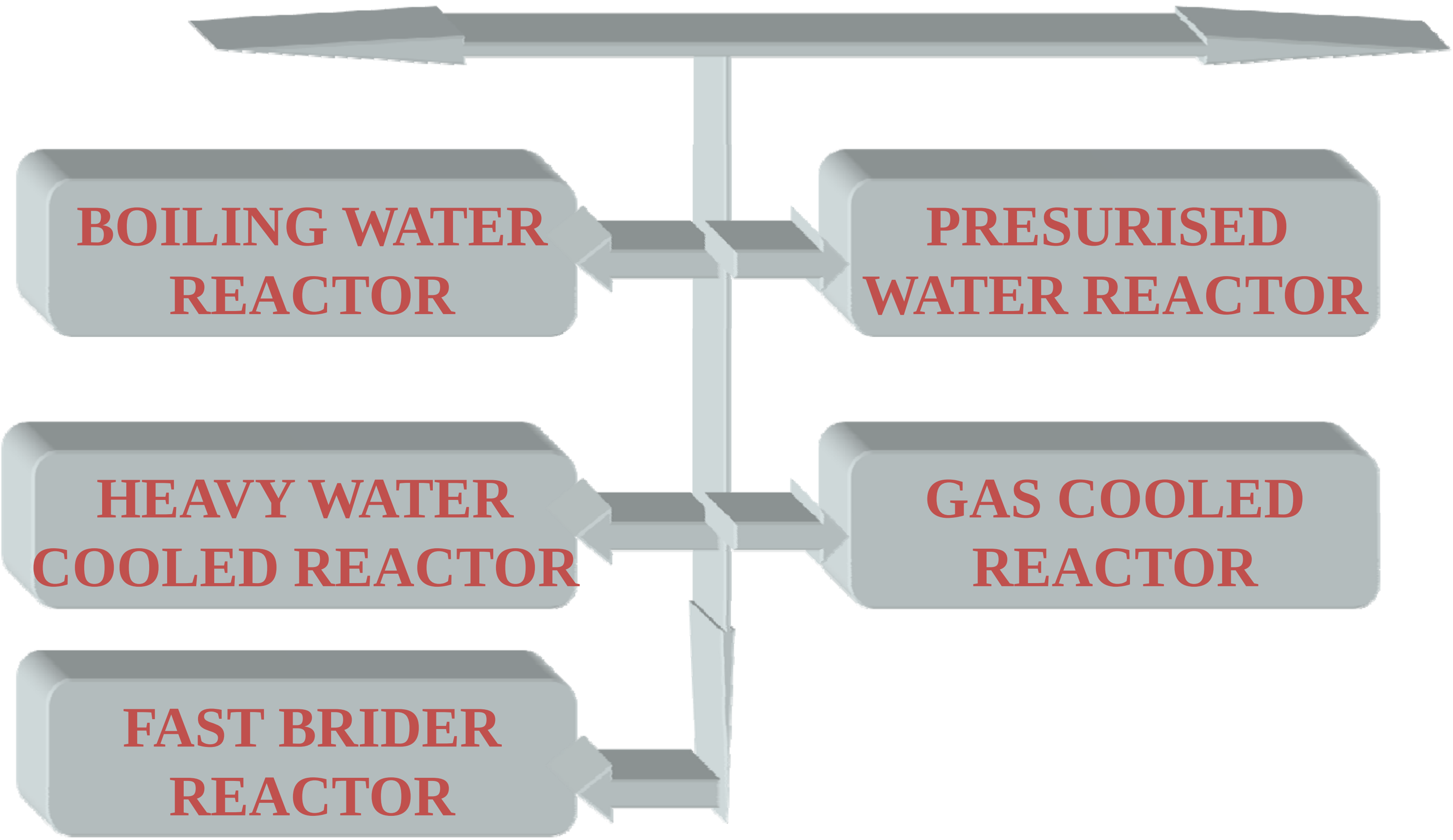
Nuclear power station.`

Fuels used in Reactor.



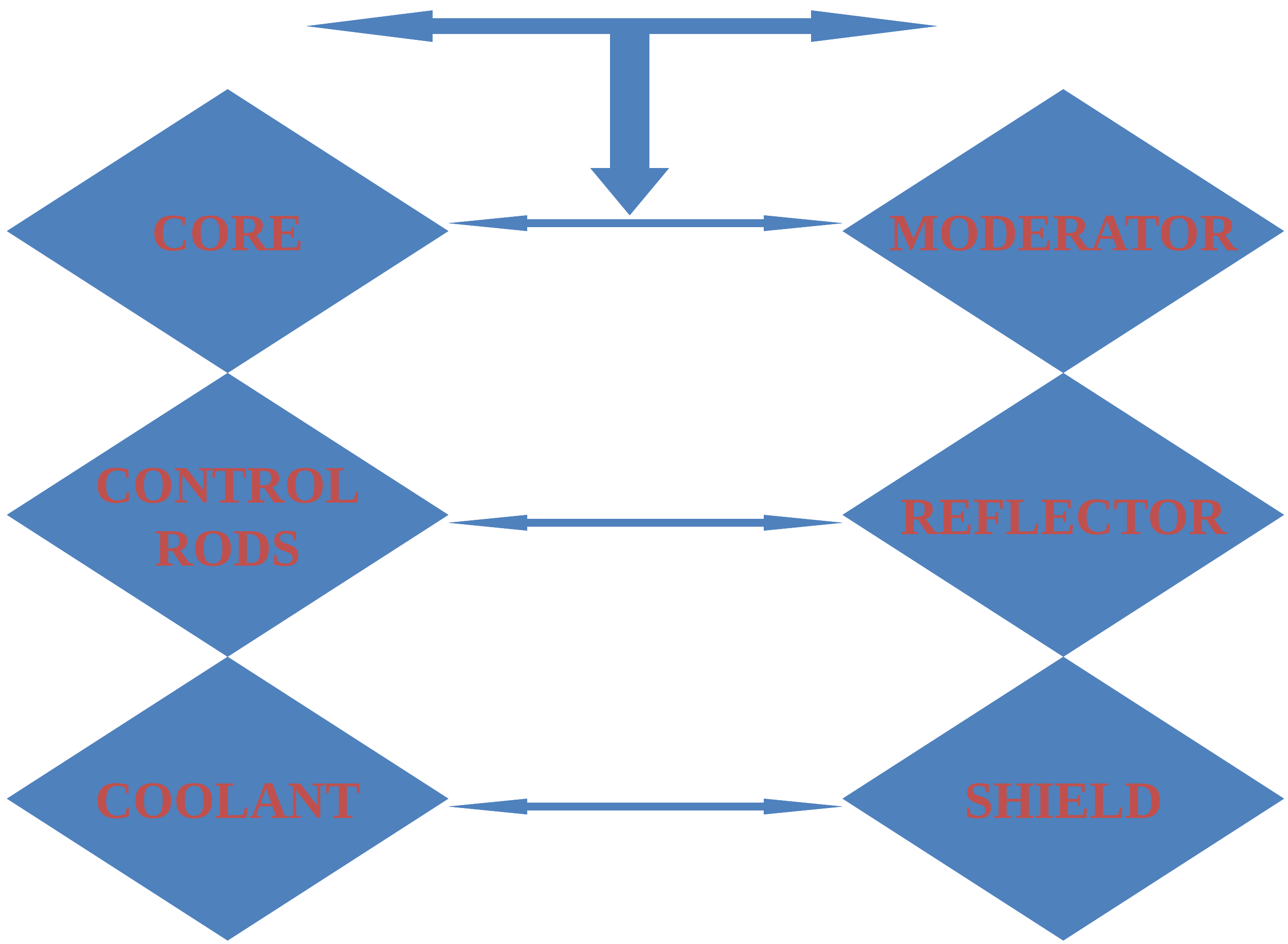
Nuclear power station.`

- Types of nuclear reactor.



Nuclear power station.`

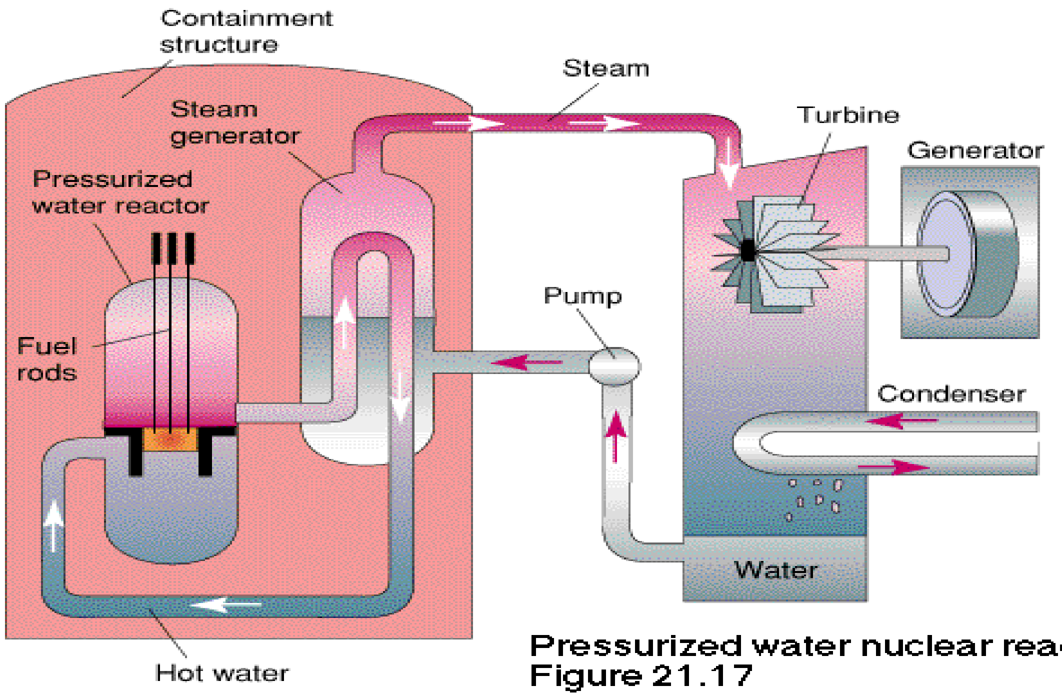
Main element of nuclear reactor.



Nuclear power station.`

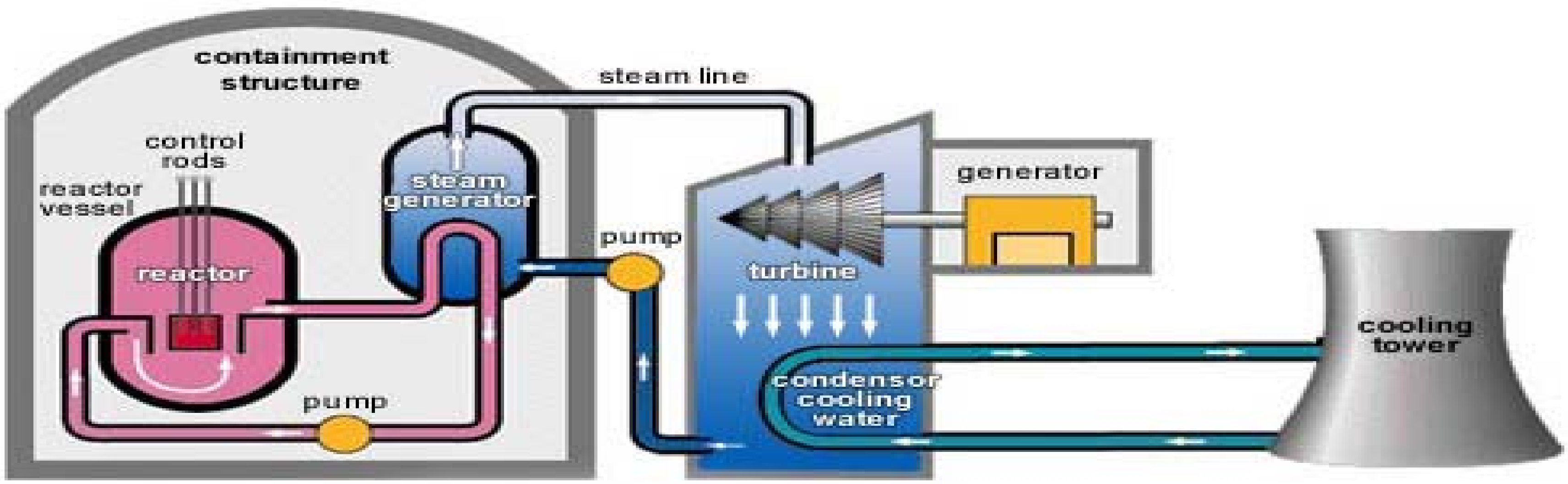
Pressurized water nuclear reactor.

Cunningham & Saigo, Environmental Science, 3d ed. © 1995 TM Higher Education Group, Inc.

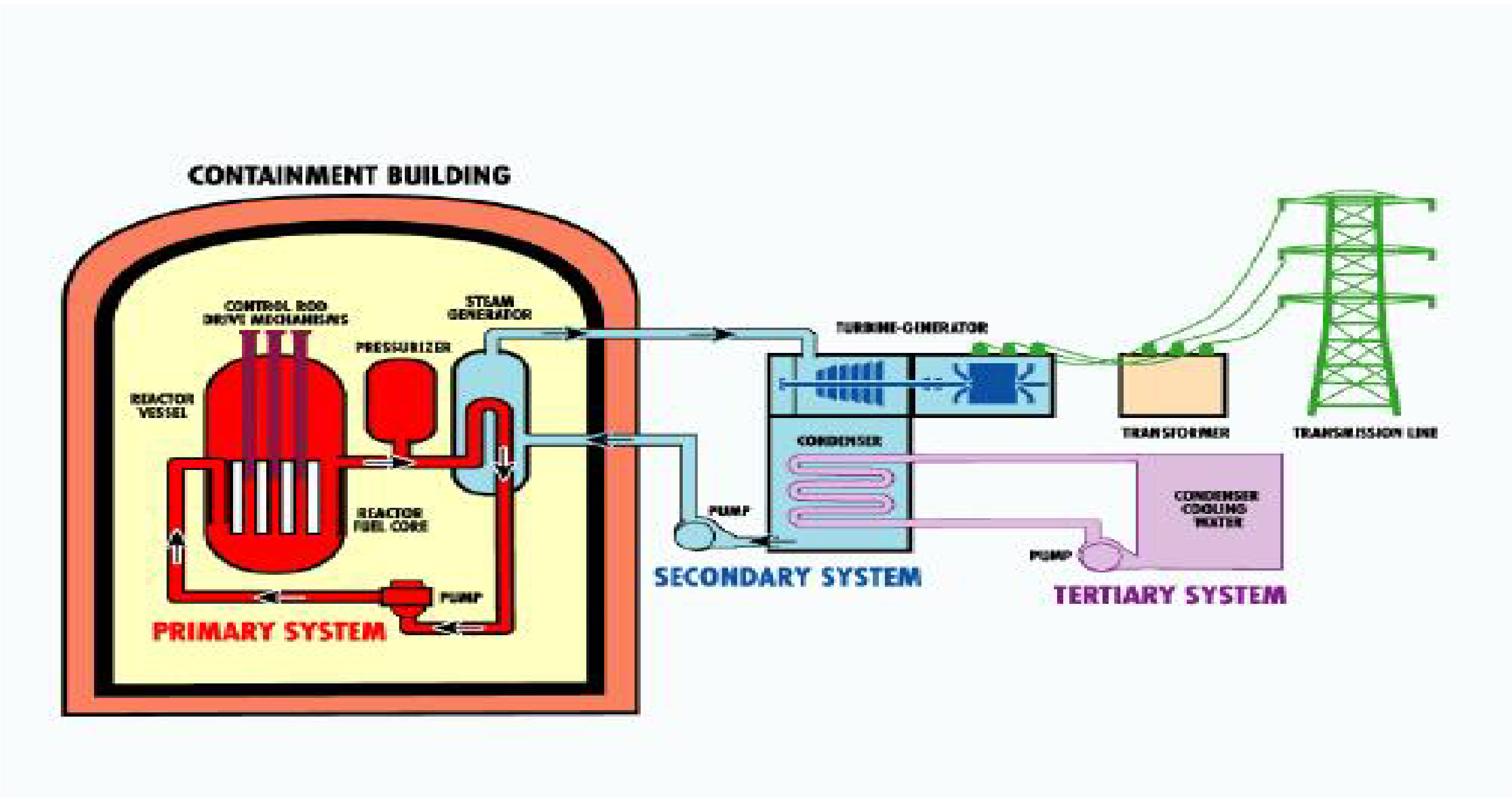


Pressurized water nuclear reactor.
Figure 21.17

Working diagram of Nuclear power station.`



Working diagram of Nuclear power station.`



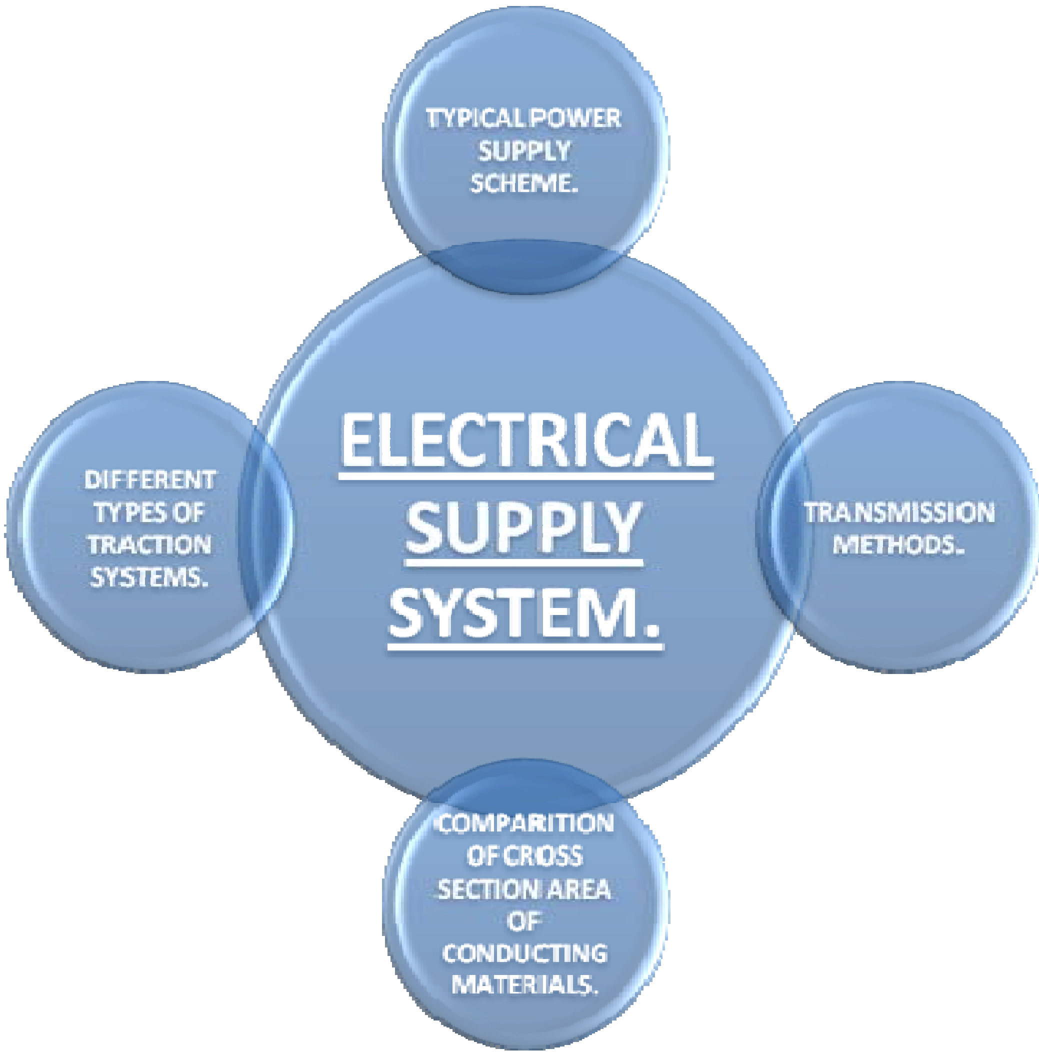
View of Kakrapar Nuclear power station.`

Top view Nuclear power station.`

Unit VI

Power Plant Economics

Electrical supply system.



Element of transmission system.

A.C. TRANSMISSION

D.C. TRANSMISSION

Types of transmission line

- **A.C. transmission line.**

i. A.C. three phase three wire system.

ii. A.C. three phase four wire system.

iii. A.C. single phase two wire system.

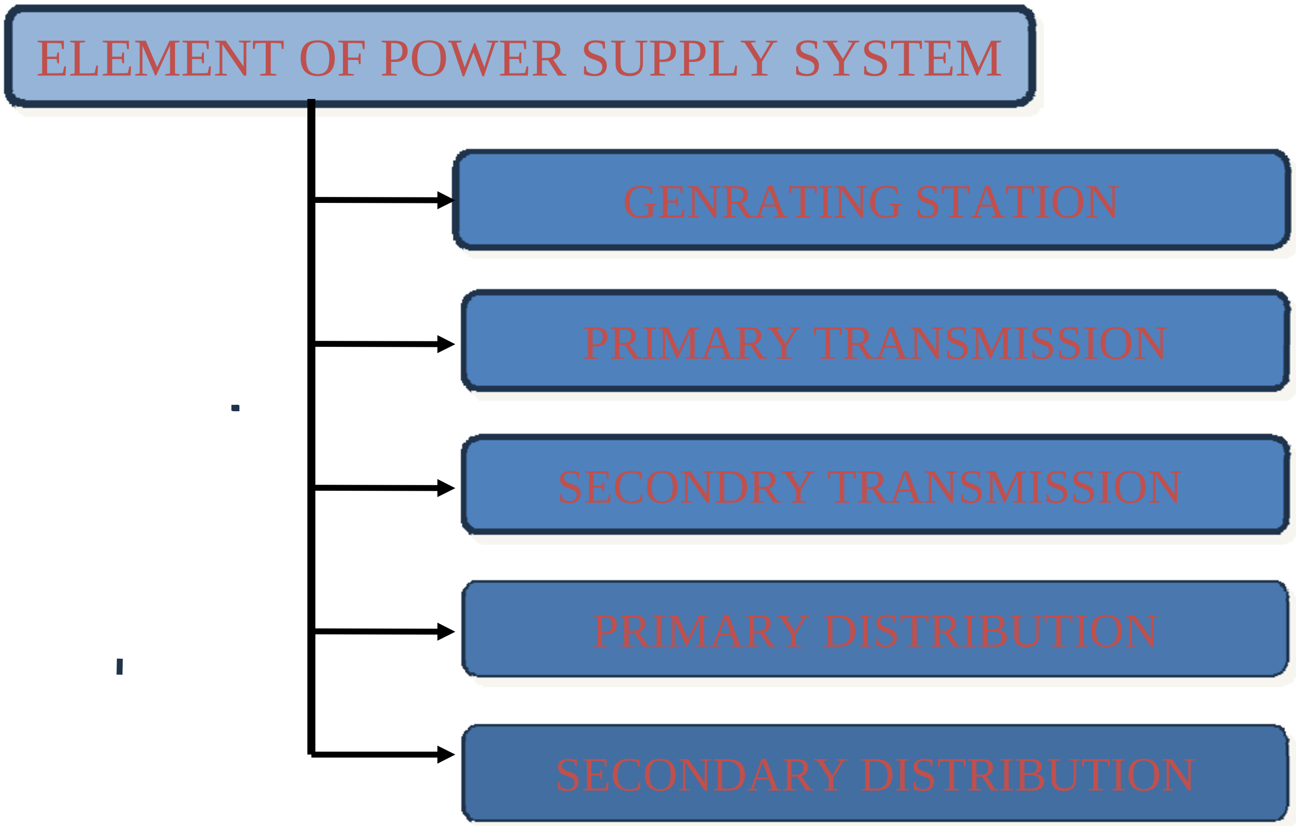
iv. Mid point earth type A.C.single phase two wire system.

- **D.C. transmission line.**

i. D.C. two wire system.

ii. Mid point earth type D.C. two wire system.

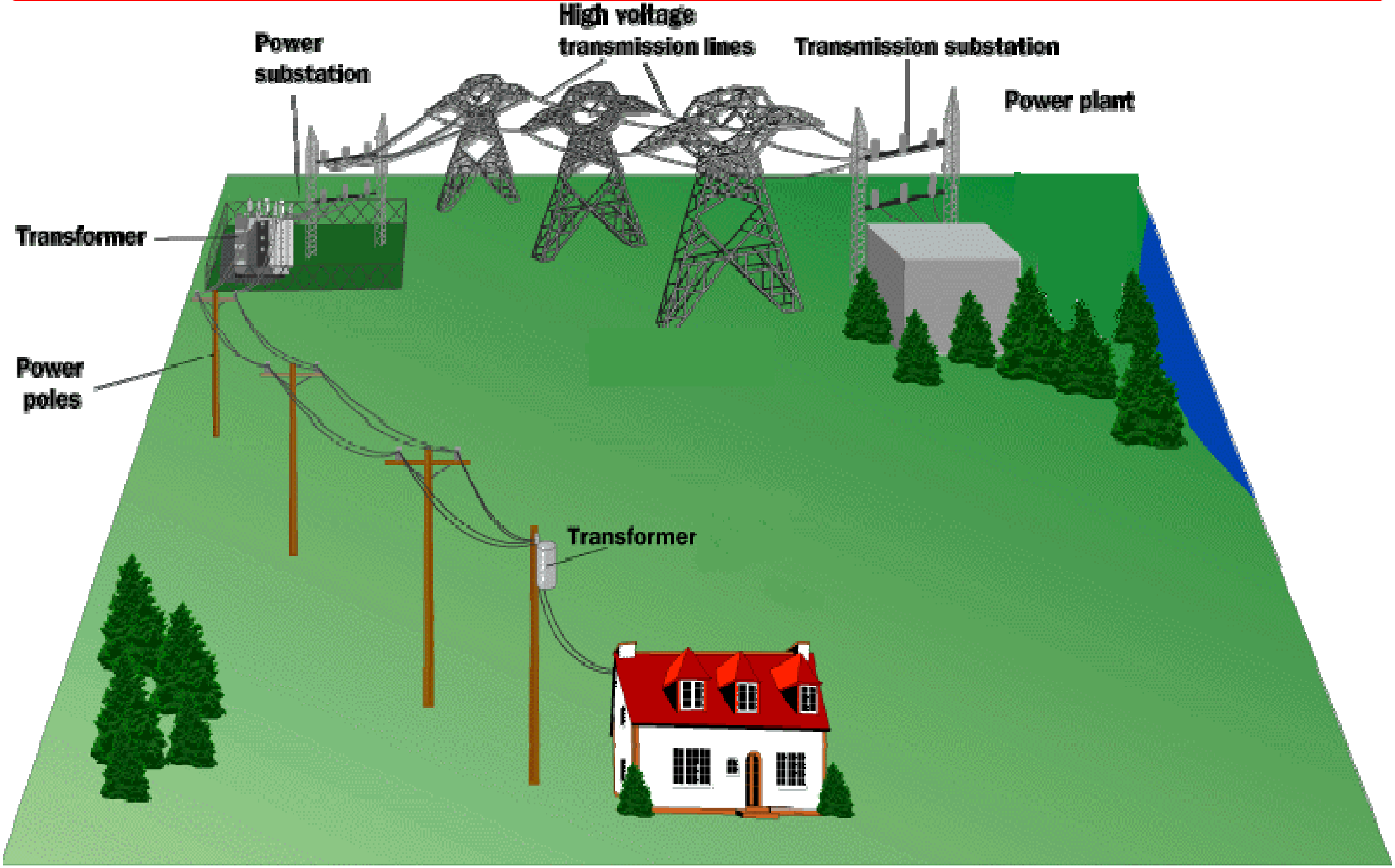
Electrical energy supply system.



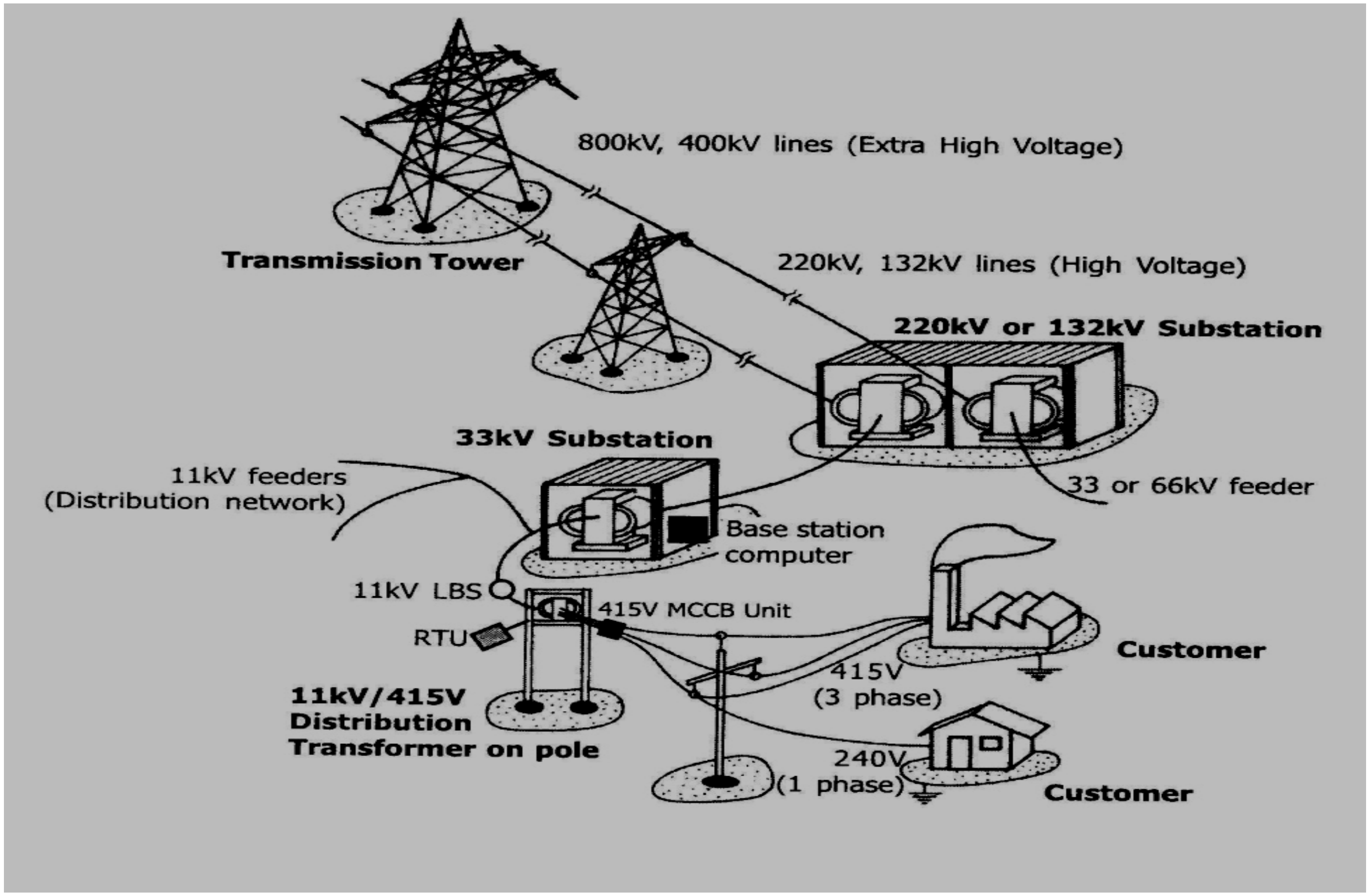
Element of transmission system.

i. Step –up transformer.
ii. Line support.
iii. Line insulator.
iv. Conductor.
v. Step-down transformer.
vi. Protective device.
vii. Regulator.

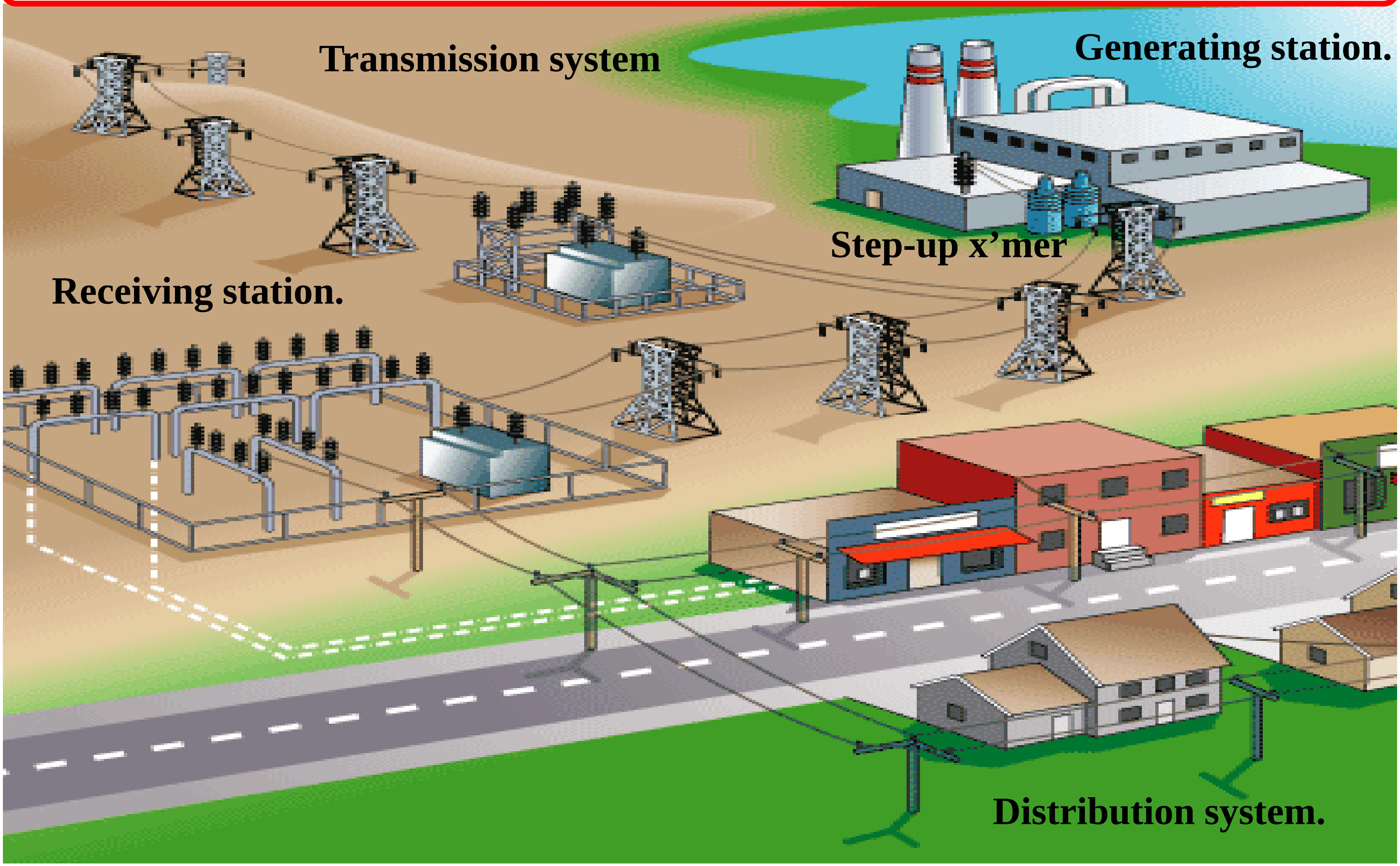
Transmission and Distribution supply system.



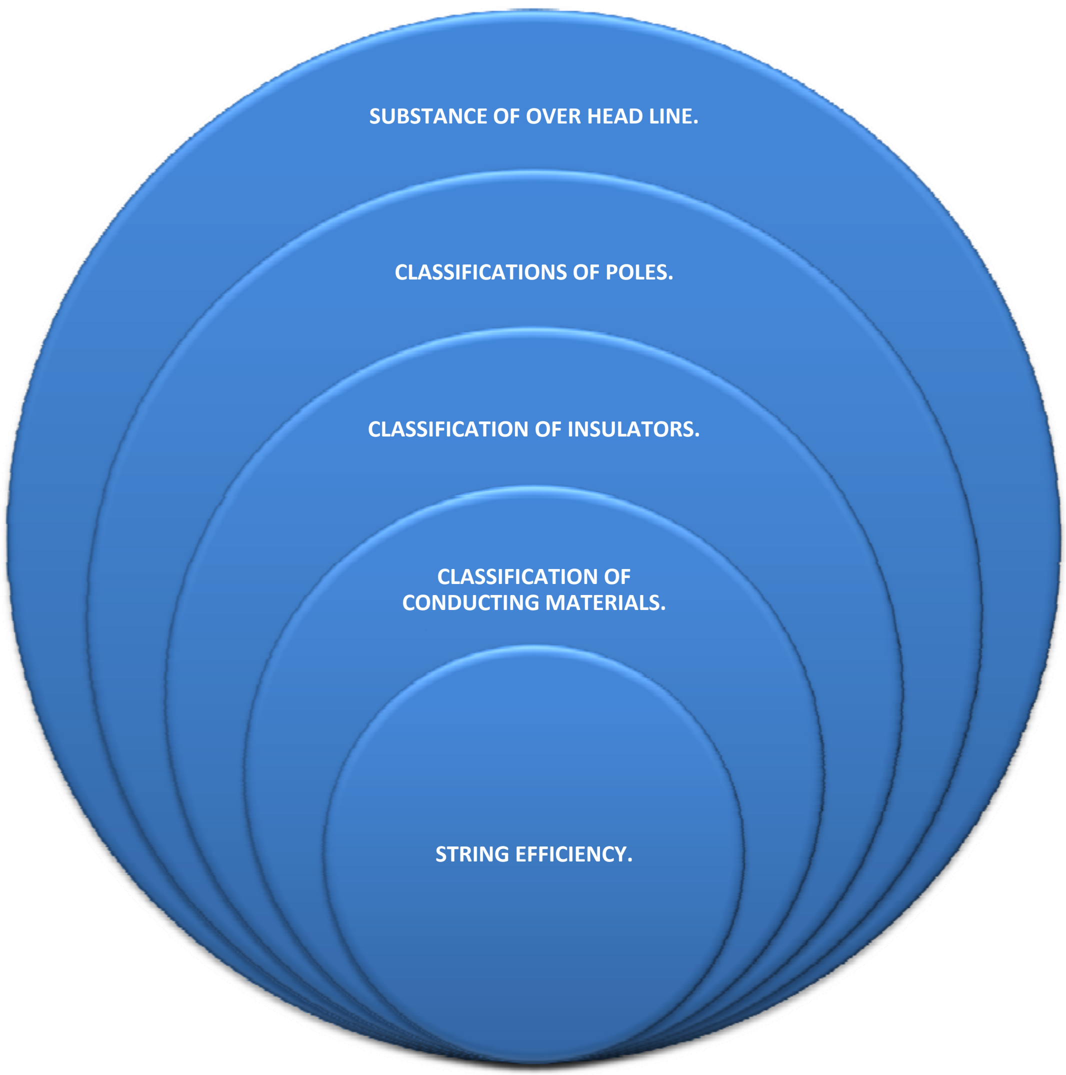
Transmission and Distribution supply system.



Transmission and Distribution supply system.



Over Head line.



Main components of over head line.

A. Conductor.

B. Line support.

C. Line insulator.

D. Earth wire.

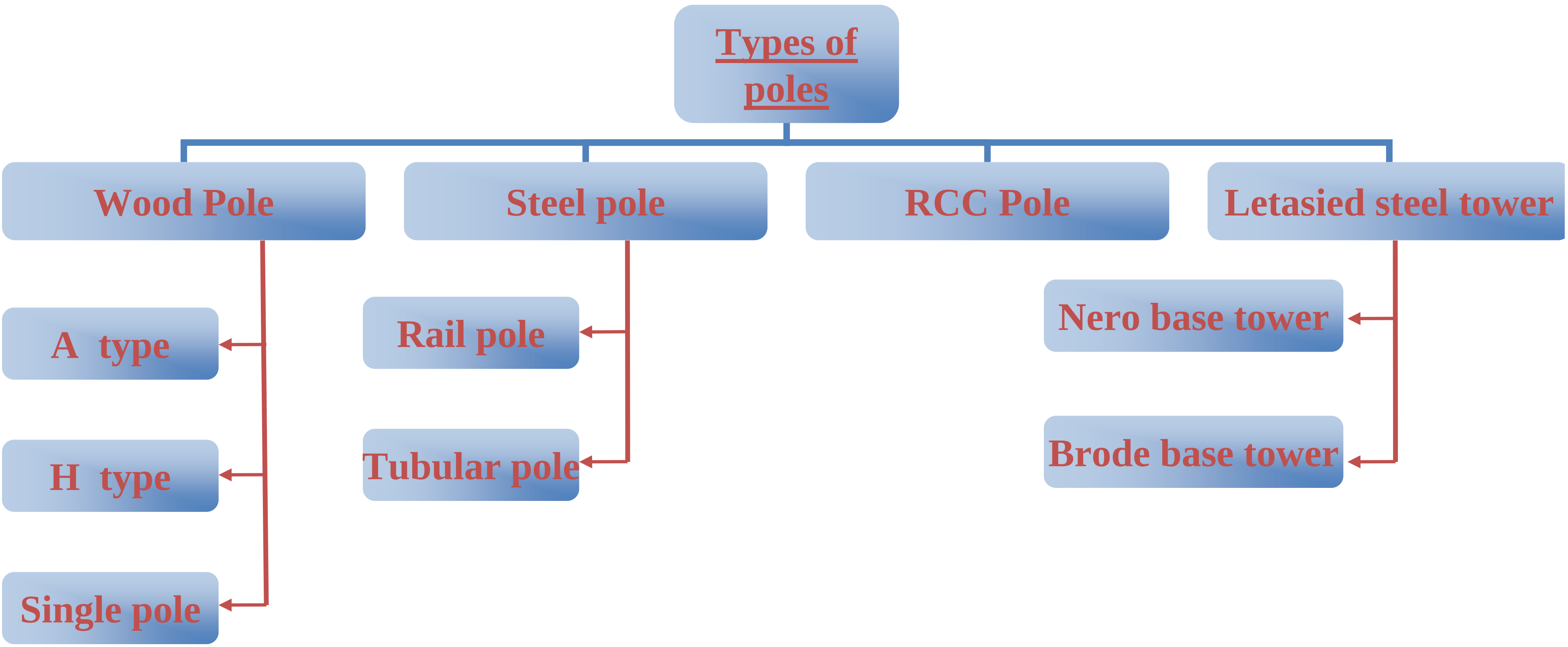
Characteristic of conductor materials.

- High conductivity.
- High tensile strength.
- Low specific gravity.
- Low cost.
- Long working life.
- Should not be brittle.

Characteristic of line support .

- **Low weight.**
- **High mechanical strength.**
- **High accessibility.**
- **Low cost.**
- **Long working life.**

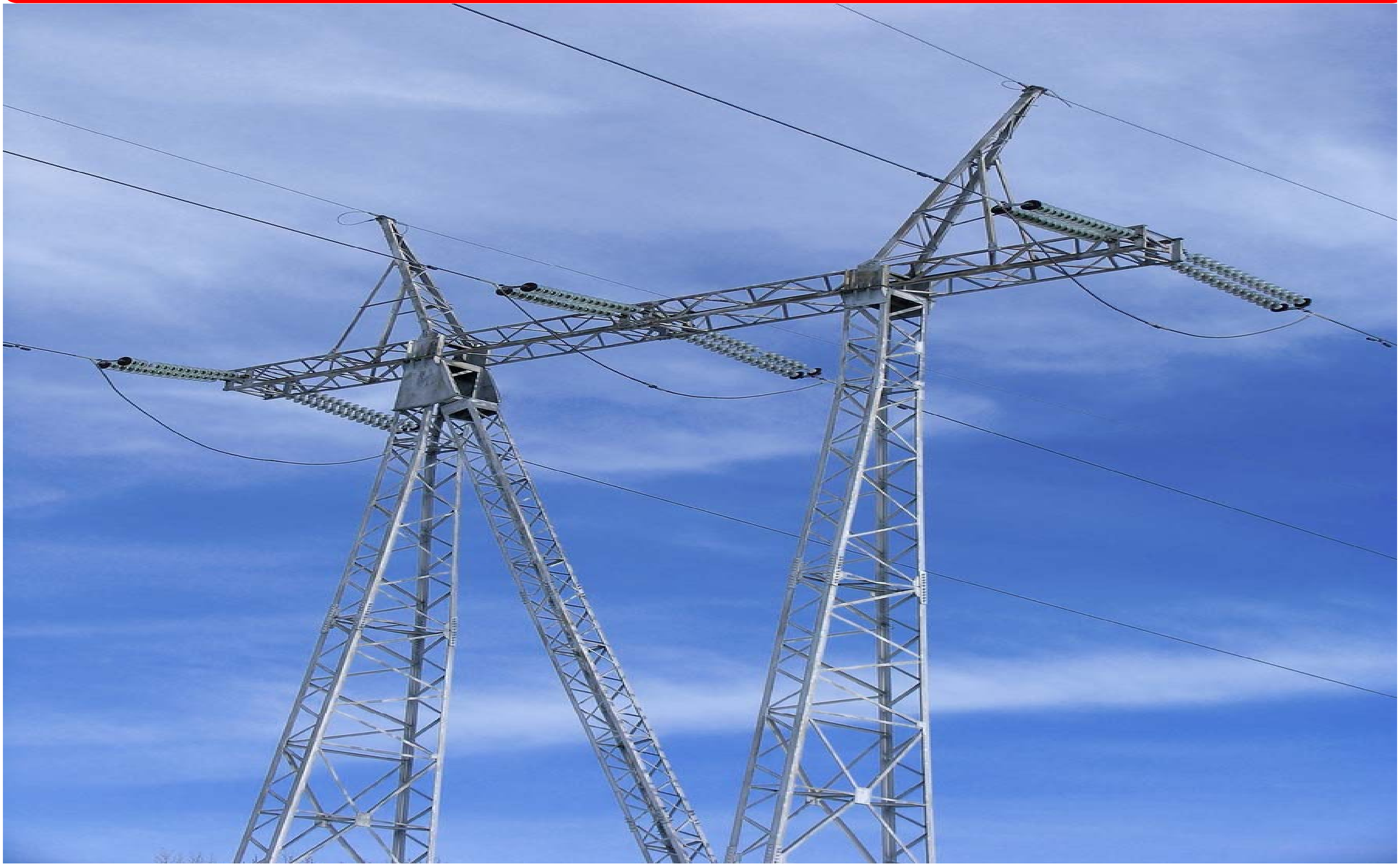
Classification of Poles.



View of tubular Poles.

Different type mounting arrangement of pole.

Steel tower use in transmission line.

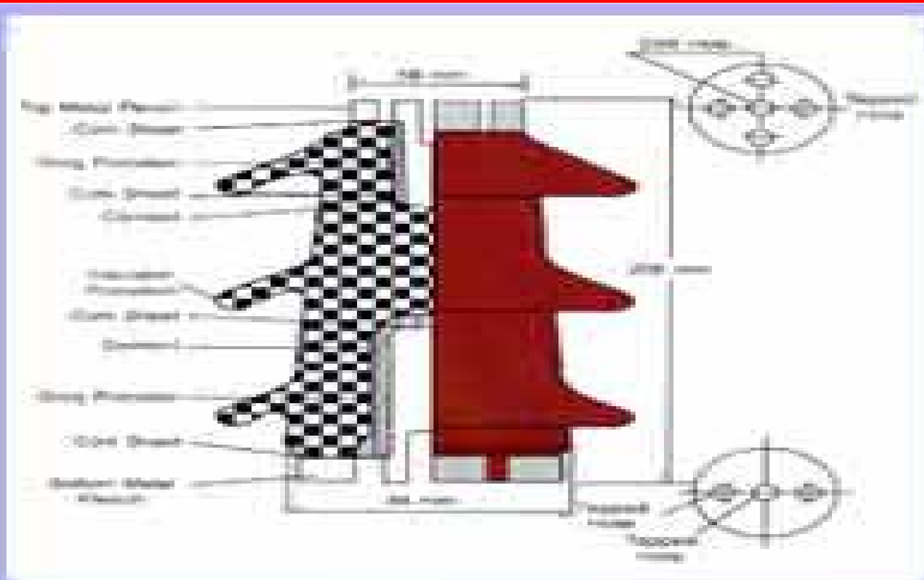


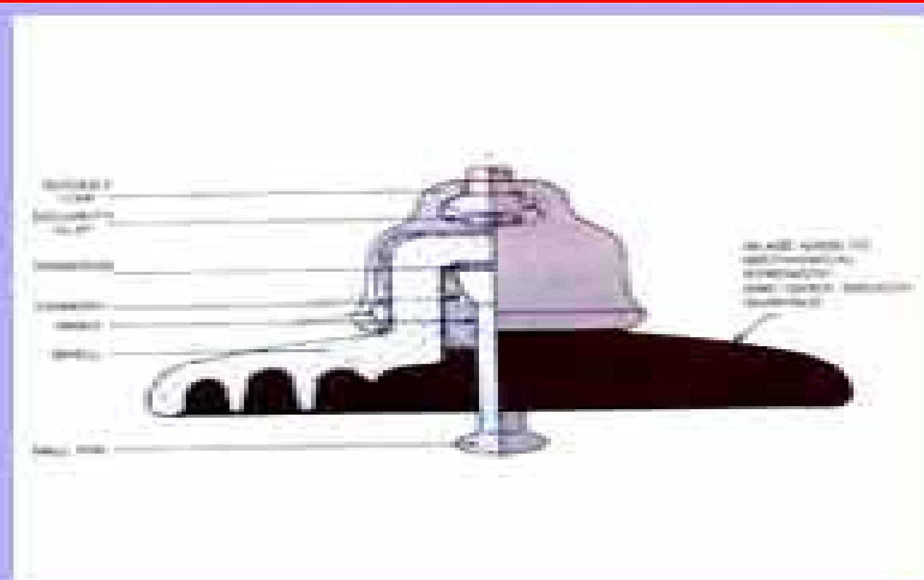
Steel tower use in transmission line.

Type of insulator use in power system.

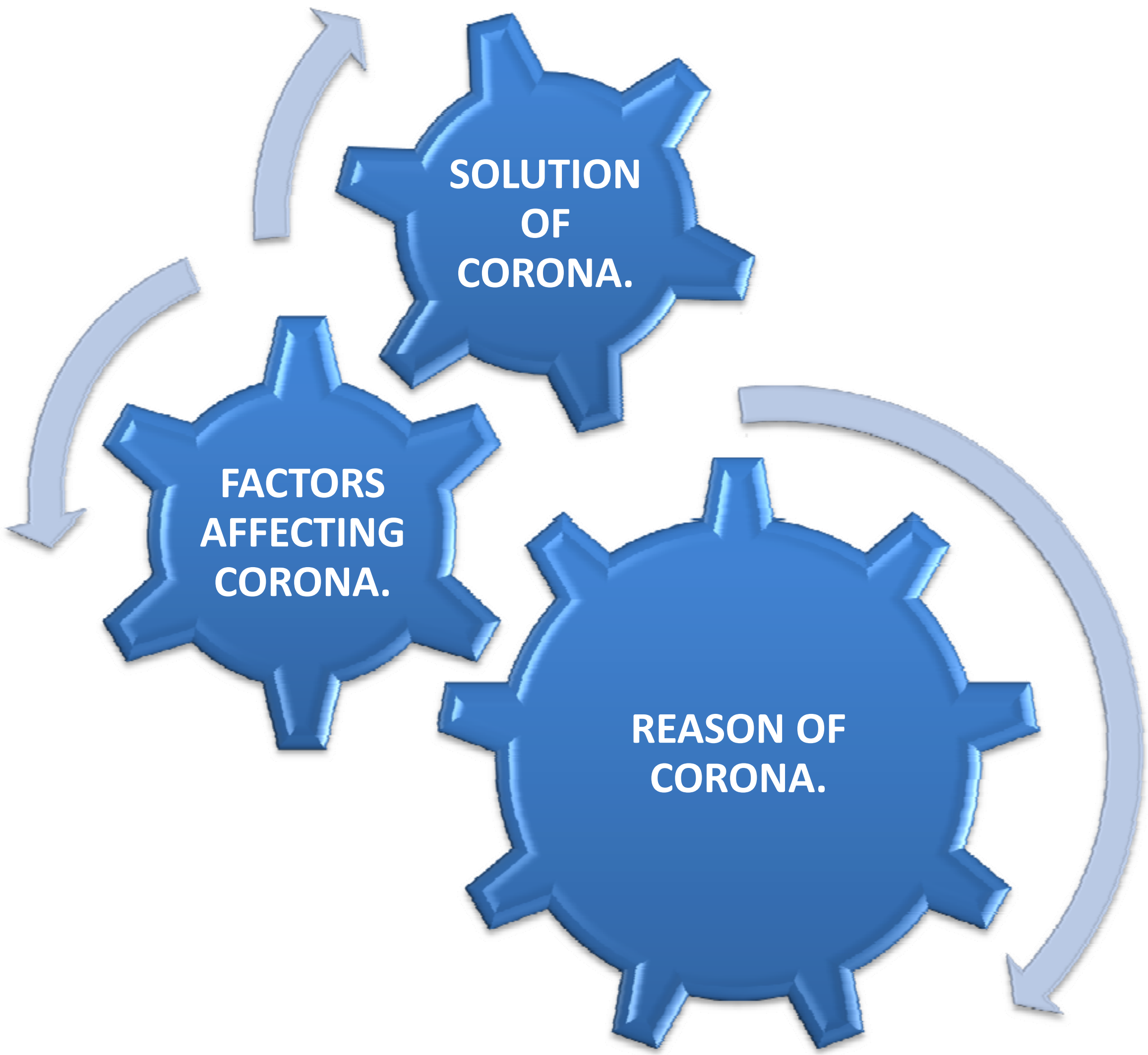
a. Pin type insulator.
b. Suspension type insulator.
c. Strain type insulator.
d. Shackle type insulator.
e. Egg or Stay insulator.

Different type insulator use in power system.





Corona effect in power transmission system.



Factor affecting in corona losses.

- **Condition of the corona effect.**
- **Potential difference is two conductor.**

Method use in reducing corona losses.

*Use of bundle Conductor.

*Increase of conductor Diameter.

Factor affecting sag.

i. Weight of conductor.

ii. Span between two poles.

iii. Working tensile strength.

iv. Ice- coating.

v. Wind pressure.

vi. Tem pressure.

Performance of transmission line.

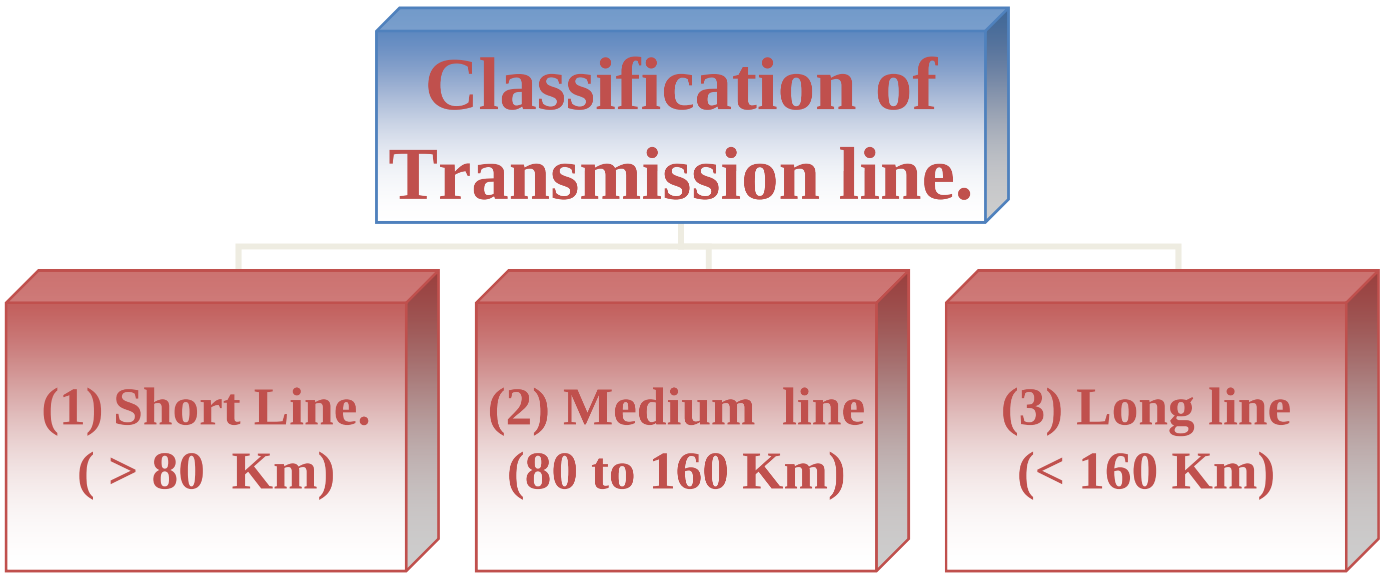
Parameters/constants of transmission line.

Resistance.

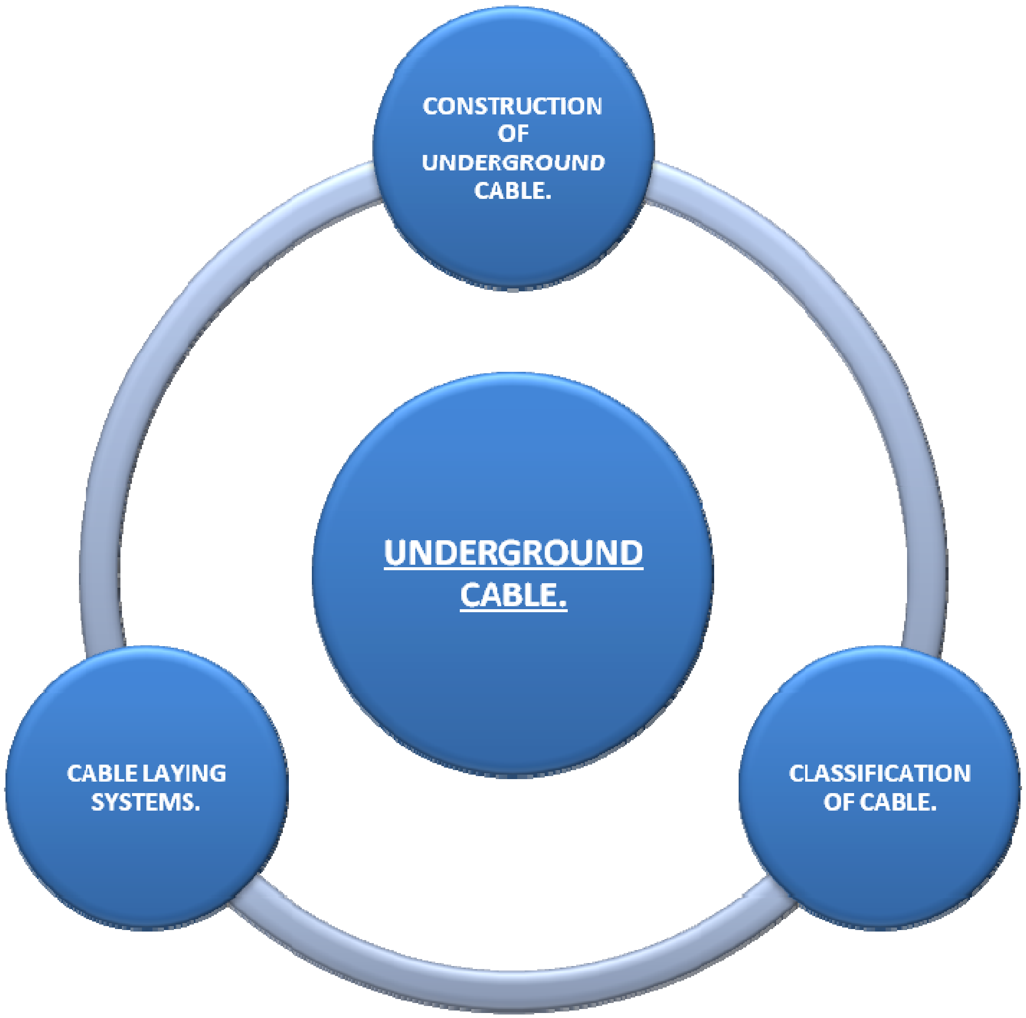
Inductance.

Capacitance.

Classification of transmission line.



Underground Cable.

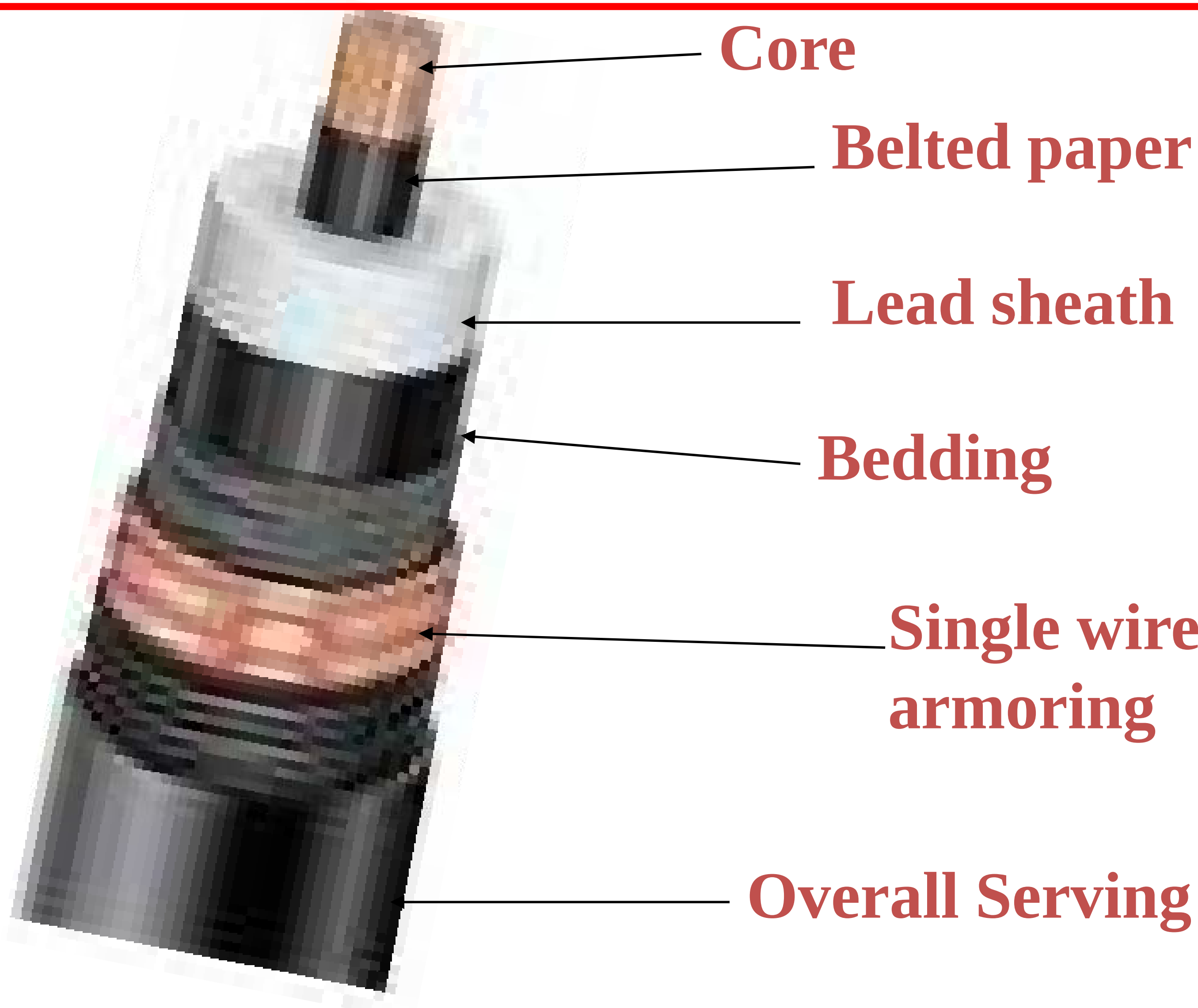


Classification cable.

1. Low voltage (L.T) cable. Operating voltage up to 1 KV.
2. High voltage (H.T.) cable. operating voltage up to 11 KV.
3. Super tension (S.T.) cable. Operating voltage up to 33 KV.
   i. H-type cable.
   ii. S.L. type cable.
   iii. H.S.L. type cable.
4. Extra high tension (E.H.T.) cable.opertaing voltage up to 66 KV.
5. Extra super tension voltage cable. Operting voltage up to 132 KV.

View of cable.

UNDER GROUND CABLE



Types of Cable.

- Oil filled cables.
  - (A) Single core oil filled cables used up to 132 KV.
  - (B) Three core oil filled cables used up to 66 KV.

- Gas pressure cables.
  - (A) External pressure cables.
  - (B) Internal pressure cable.
    - (a) High pressure gas filled cable.
    - (b) Gas cushion cable.
    - (c) Impregnated pressure cable

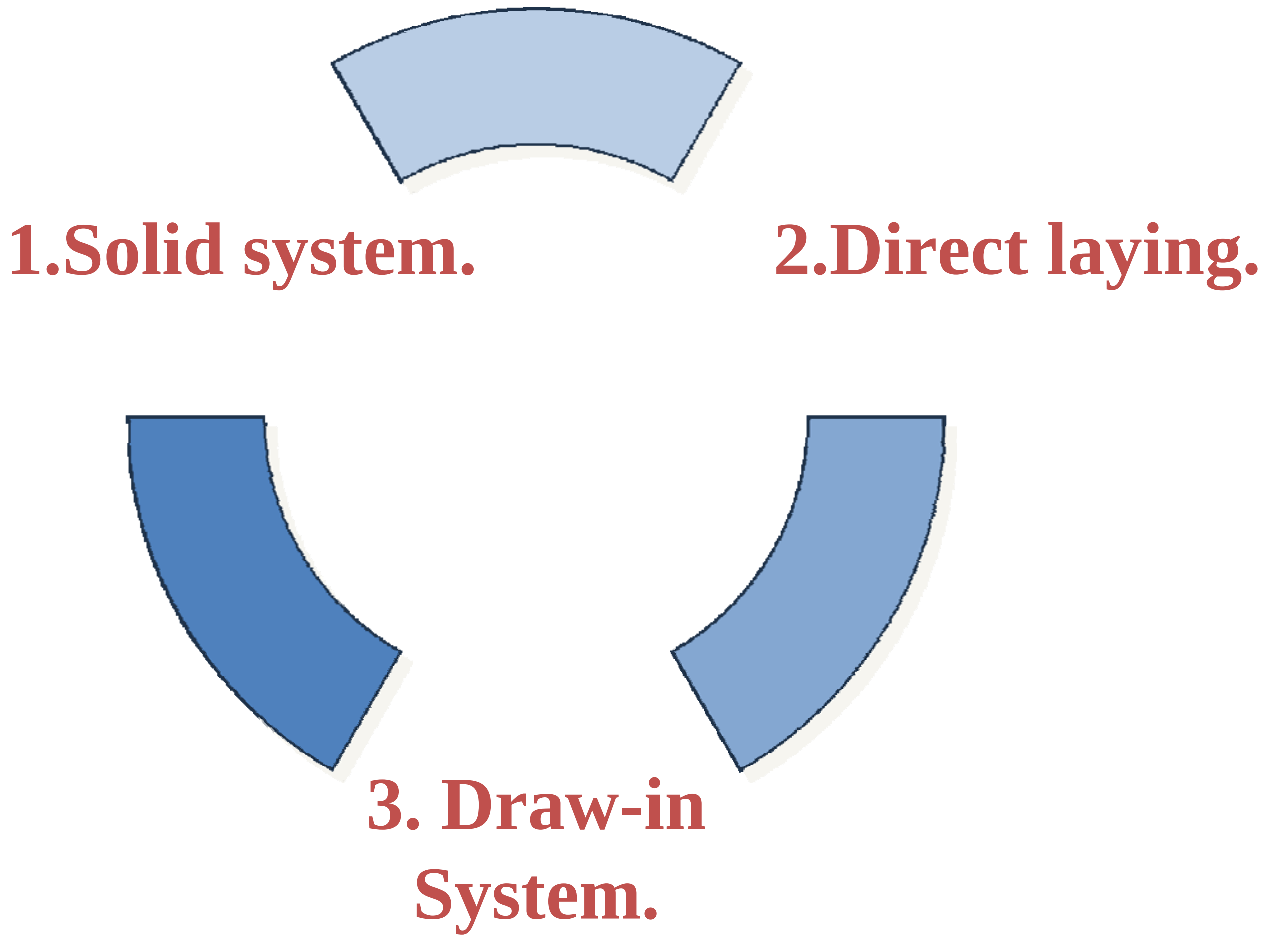
Various type insulating materials in used in cable.

1. Rubber.
2. Vulcanized India rubber. (V.I.R.).
3. Impregnated paper.
4. Varnished cambric.
5. Polyvinyl chloride.
6. Silk and cotton.
7. Enamel insulation.

Properties of insulating materials for cable.

- High resitivity.
- High dielectric strength.
- Low thermal co-efficient.
- Low water absorption.
- Low permittivity.
- Non – inflammable.
- Chemical stability.
- High mechanical strength.
- High viscosity at impregnation temperature.
- Capability to with stand high rupturing voltage.
- High tensile strength and plasticity.

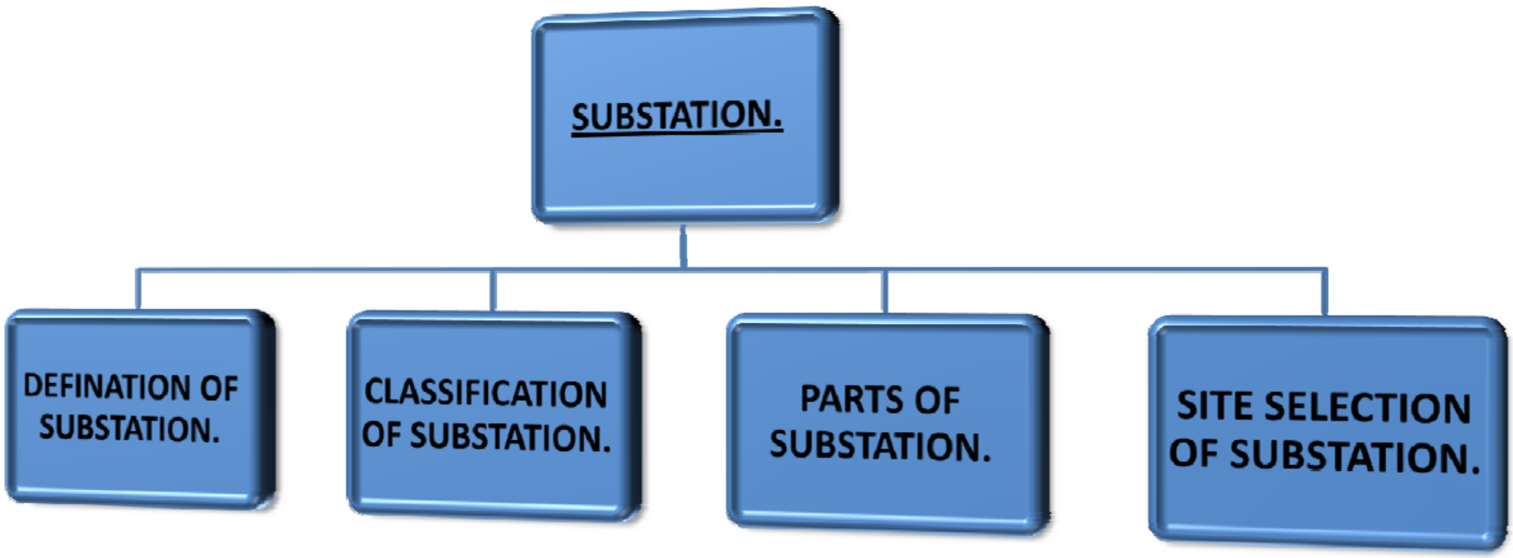
Method laying of Under ground system.



Fault which are likely to occurs in cable.

A. Insulating fail between line and earth.
B. Insulating fail between two core.
C. Open circuit fault.

Substation.


SUBSTATION.
DEFINATION OF SUBSTATION.
CLASSIFICATION OF SUBSTATION.
PARTS OF SUBSTATION.
SITE SELECTION OF SUBSTATION.

Function of Substation.

- The main functions of sub-station are to receive energy transmitted at high voltage from the generating station, reduce to a value appropriate for local distribution and provide facilities for switching.

Classification Substation.

According to Service

1. Transformer sub-station
2. Industrial sub-station
3. Switching sub-station
4. Synchronous sub-station
5. Frequency sub-station
6. Converting sub-station.

Classification Substation.

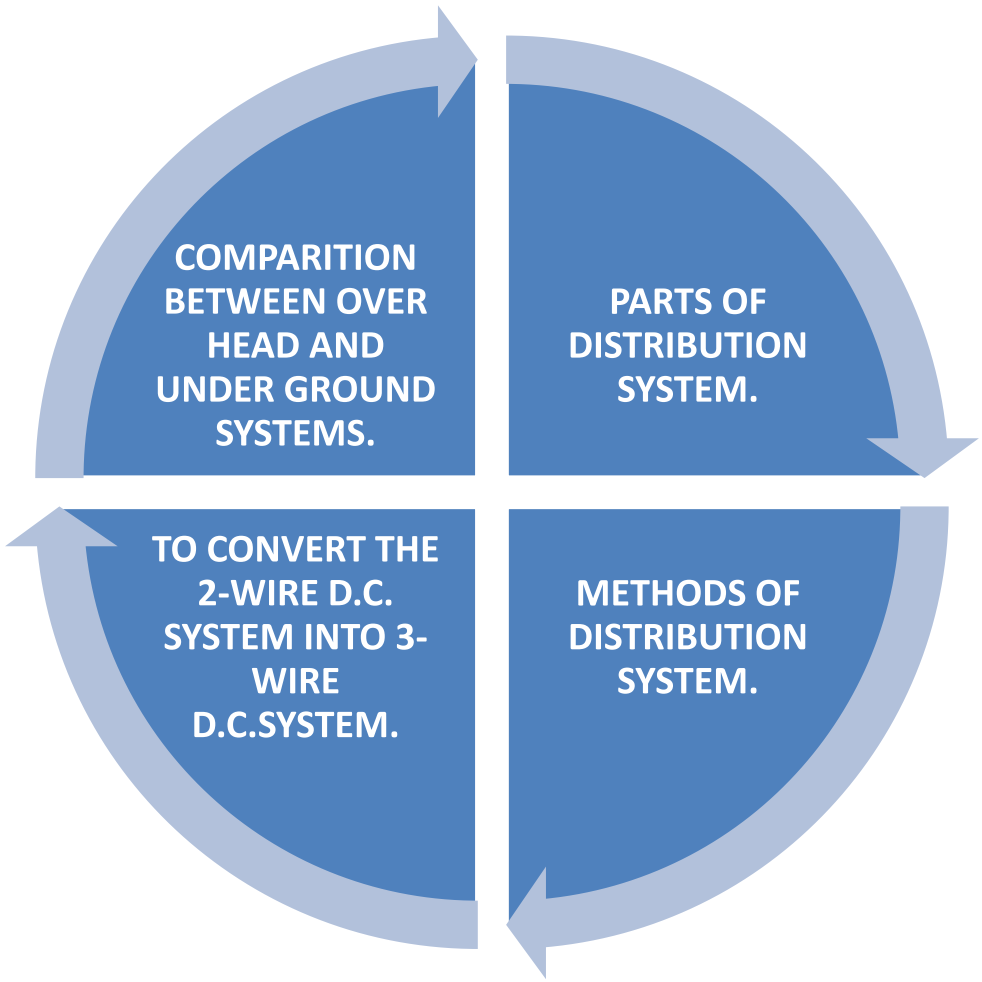
According to Design.

- 1.Indoor type Sub-station.
  - (a) Pole mounted Sub-station.
  - (b) Foundation mounted Sub-station.
- 2.Out door type Sub-station.

The main equipment for Substation.

1. Main bus-bar.
2. Isolator.
3. Insulator.
4. Circuit breaker.
5. Load interrupter switches.
6. Fuses.
7. Power transformer.
8. Current transformer and potential transformer.
9. Control cable.

Distribution system.

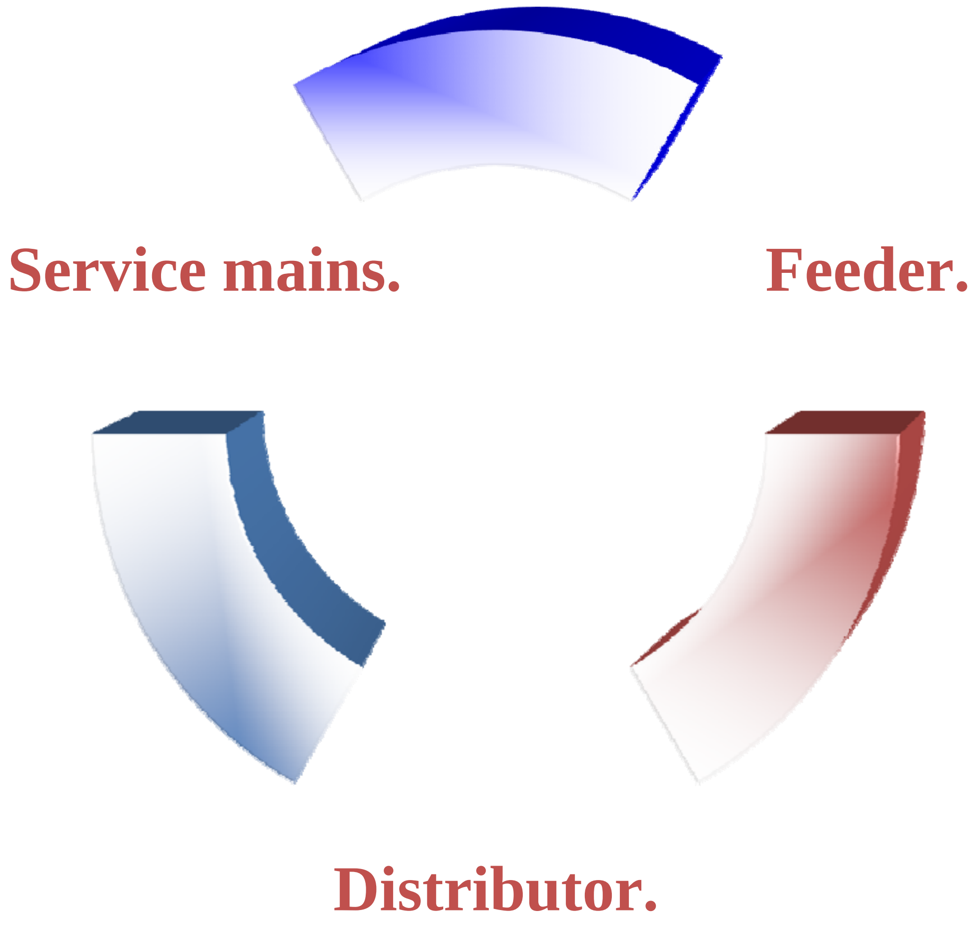


Distribution system.

1.Primary distribution.

2.Secondary distribution.

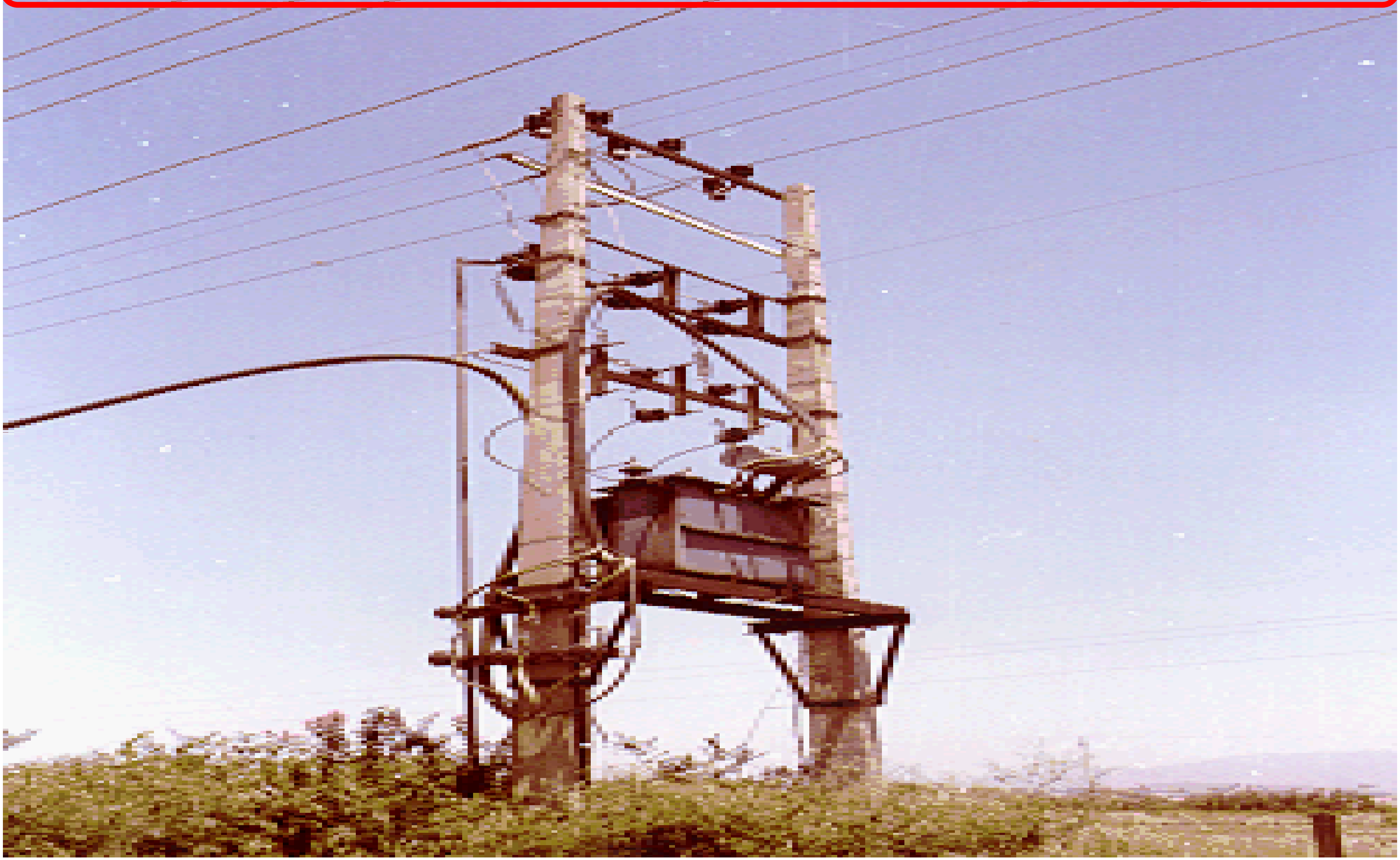
Main parts Distribution system.



View of distribution system.

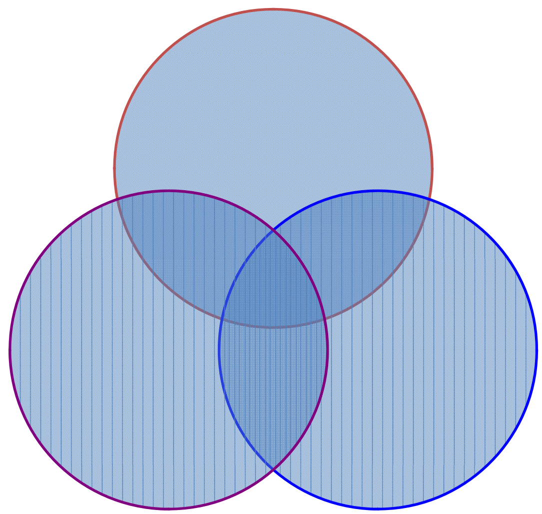
View of L.T. distribution system.

View of L.T. distribution Distribution transformer.



Method of feeding a distributor.

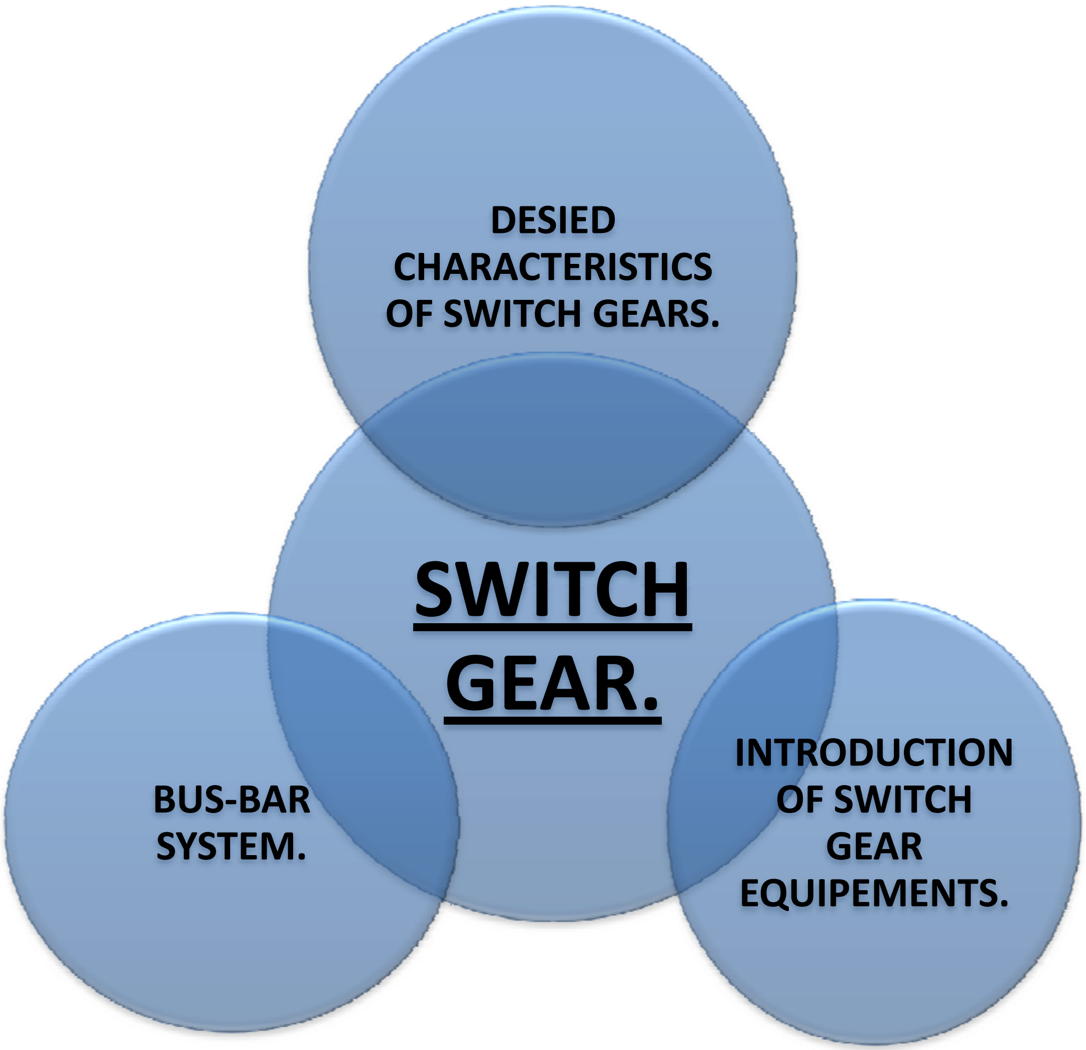
1.Redial system.



2.Ring mains system.

3.Inter connected grid
Type system .

Introduction of switch gear.



Types of switch gear equipment.

I. Circuit breaker.

II. Bus-bar.

III. Fuses.

IV. Protective relay.

Various type of bus-bar arrangement.

I. Single bus bar system used in D.C. and A.C. power station.

II. Single bus bar system with sectionalisation.

III. Ring bus bar system.

IV. Duplicate bus bar system.

Types of faults in distribution power system.

- Over current.
- Under voltage.
- Unbalance voltage.
- Reversed power.
- Surges.

Types of faults in distribution power system.

Characteristics of protection system.

1.Reliability
2.Sensitivity.
3.Selectivity.
4.Descrimination.
5.Speed.
6.Simplicity.
7.Economy.

Function of protective relay.

- **The relay are used to cut off the power supply, promptly to any element of power system which undergoes short –circuit it starts operating abnormally.**

Main feature of a good protective Relays.

- Selectivity.
- Sensitivity.
- Reliability.
- Quickness.
- Non- interference with future extension.

Types of relays.

I. Solenoid relay.

II. Attracted armature type relay.

III. Electrodynamics type.

IV. Moving type relay.

V. Induction type relay.

VI. Thermal relay.

VII. Over current relay.

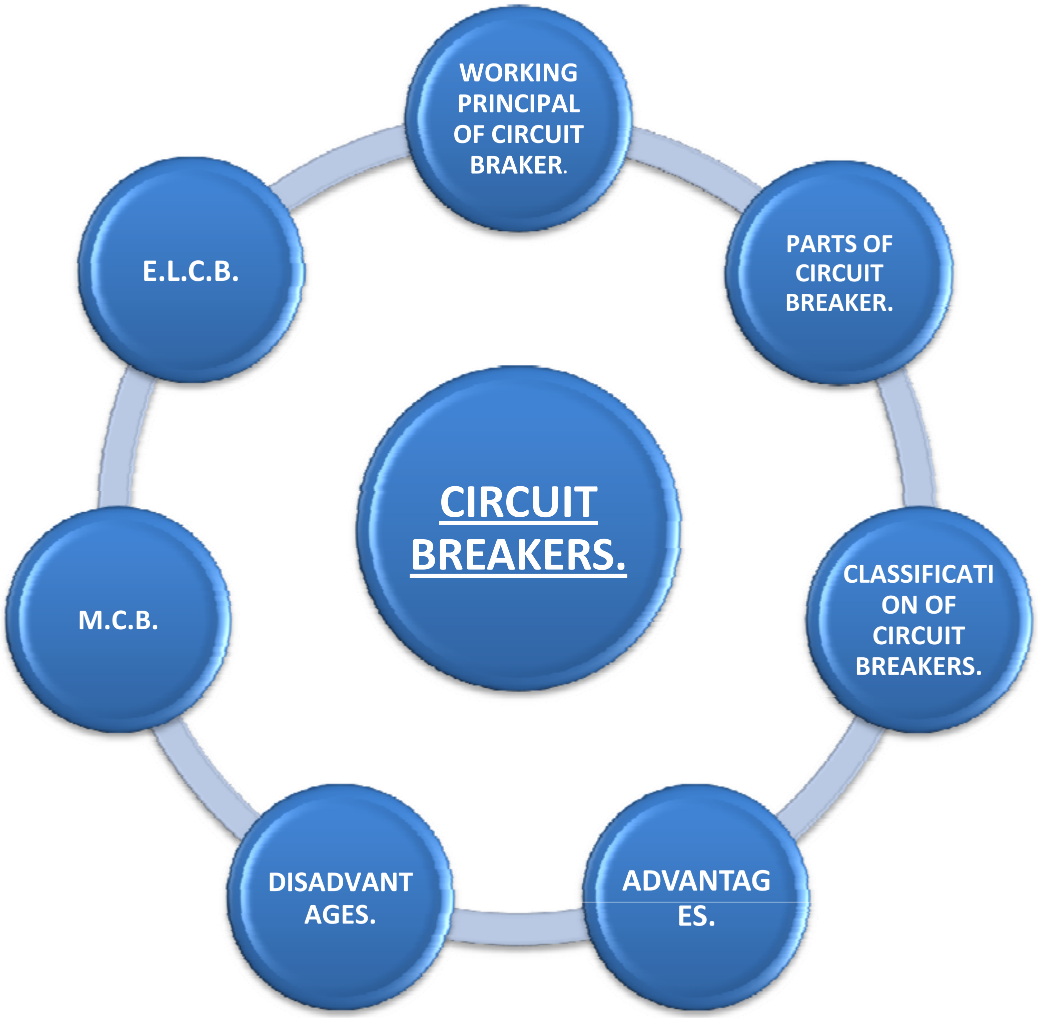
VIII. Over voltage relay.

Following relay are used in protection of transformer.

Types of relay.

1. Over current Relay.
2. Buchhoelz 's Relay.
3. Earth fault Relay.

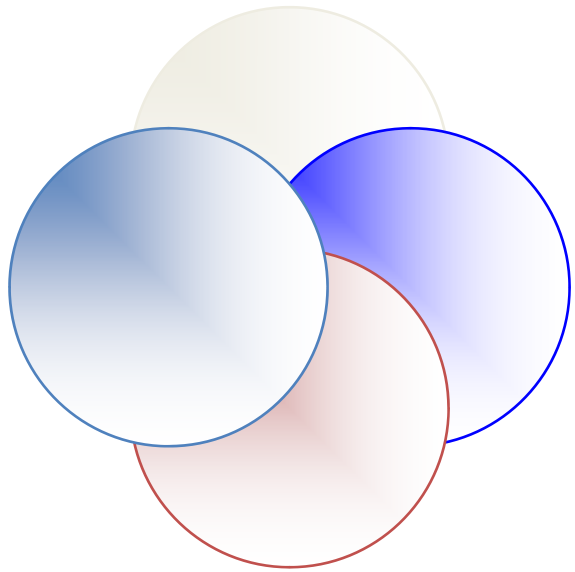
Circuit breaker.



Basic element of circuit breaker.

1.Contect.

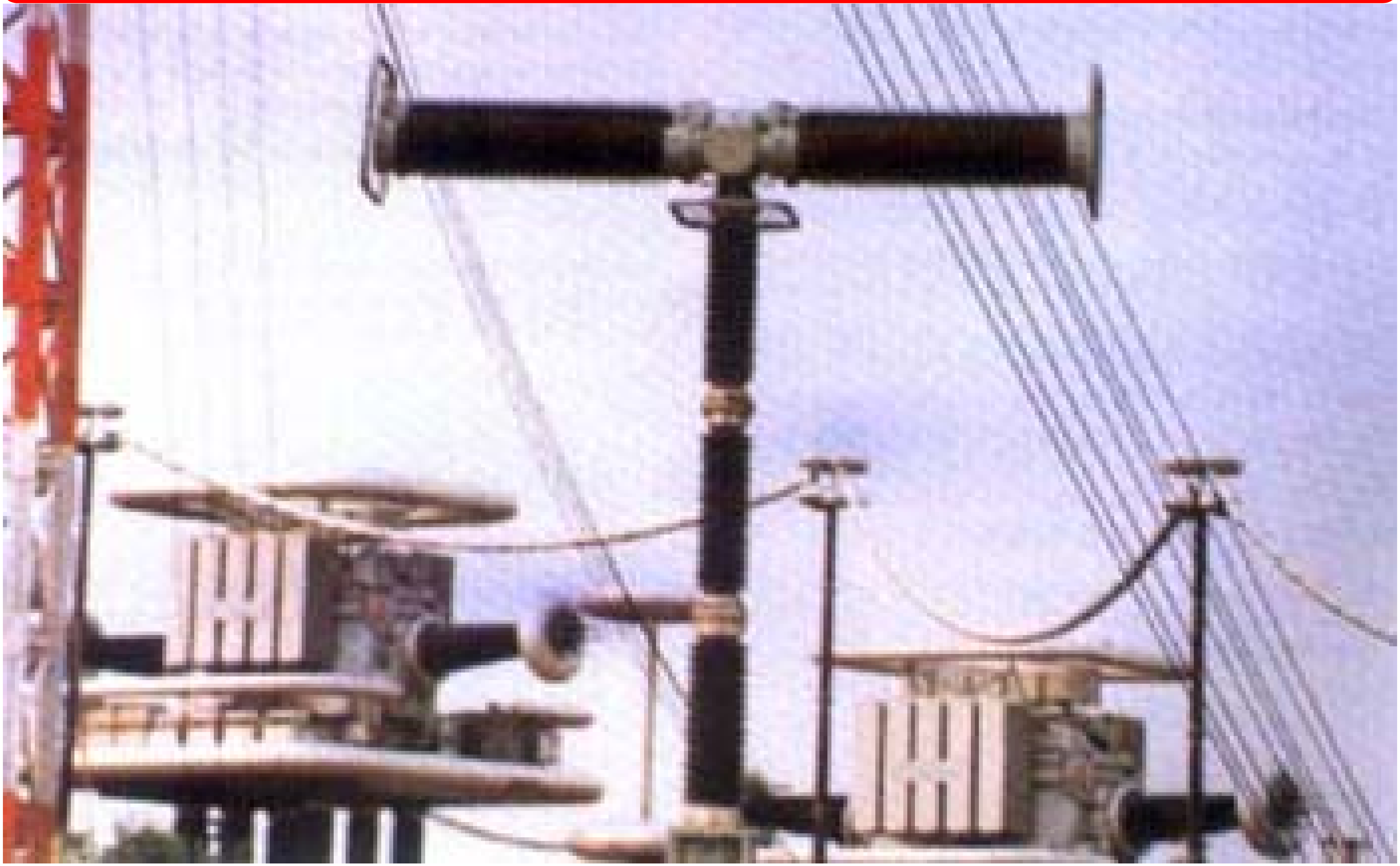
2.Insulation.



3.Operating Mechanism.

4.Arc quenches medium.

View of SF6 circuit breaker.



Construction of circuit breaker.

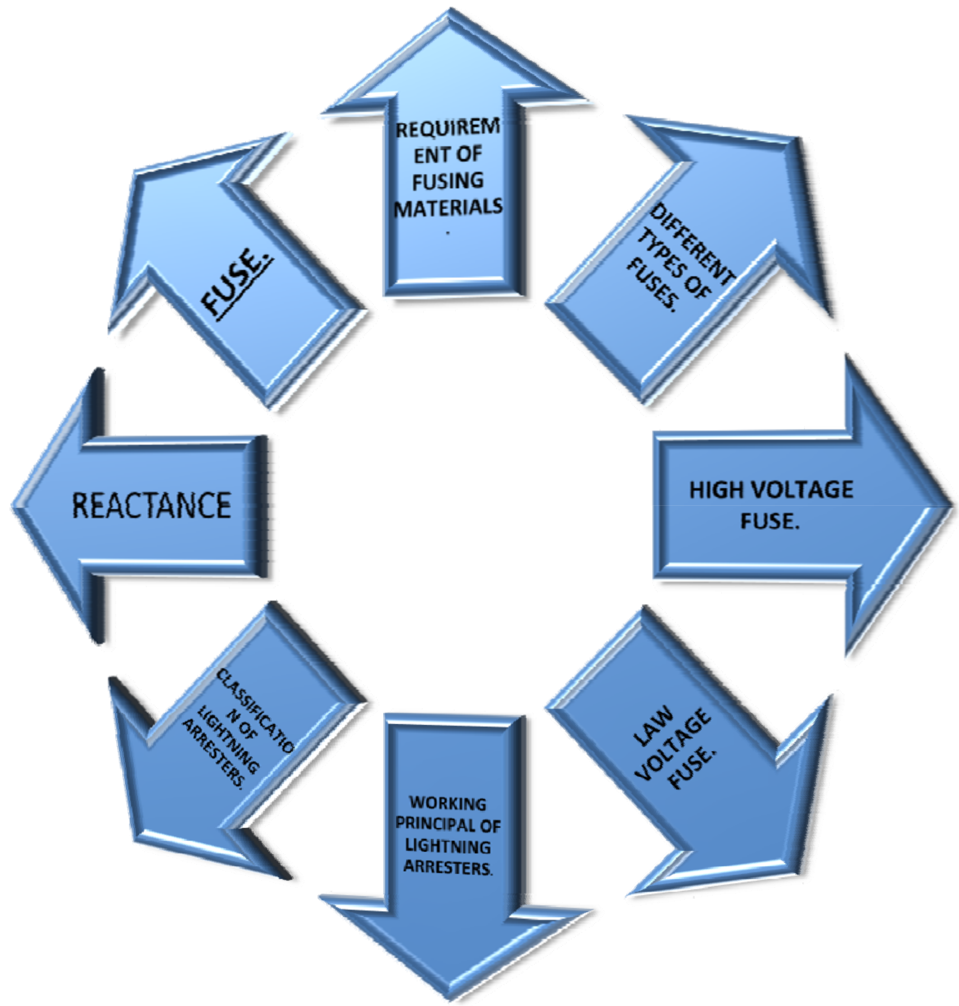
Method of arc extinction in circuit breaker.

- **High resistance interruption.**
  (1) Arc lengthening.
  (2) Arc cooling.
  (3) Arc splitting.
  (4) Arc constraining.
- **Low resistance interruption.**
  (1) Cooling.
  (2) Gap lengthening.
  (3) Blast effect.

Types of circuit breaker.

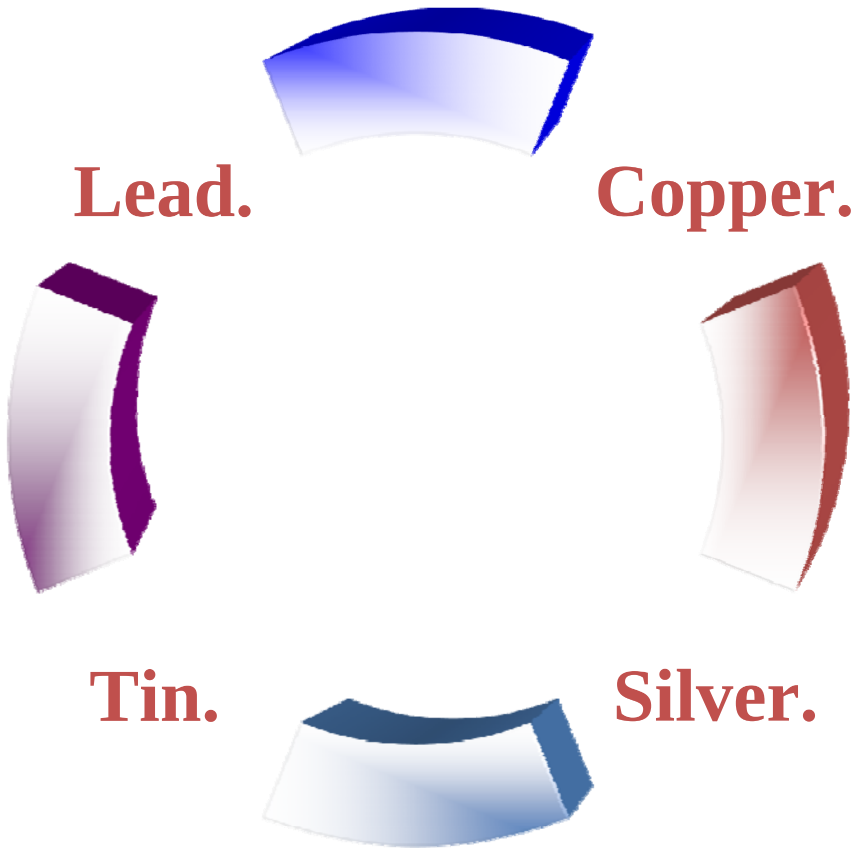
- Low voltage air circuit breaker.
- Oil circuit breaker.
- Air blast circuit breaker.
- SF6 circuit breaker.
- Vacuum circuit breaker.

Fuse.



REQUIREMENT OF FUSING MATERIALS.
DIFFERENT TYPES OF FUSES.
HIGH VOLTAGE FUSE.
LAW VOLTAGE FUSE.
WORKING PRINCIPAL OF LIGHTNING ARRESTERS.
CLASSIFICATION OF LIGHTNING ARRESTERS.
REACTANCE
FUSE.

Types of material used in Fuse element.



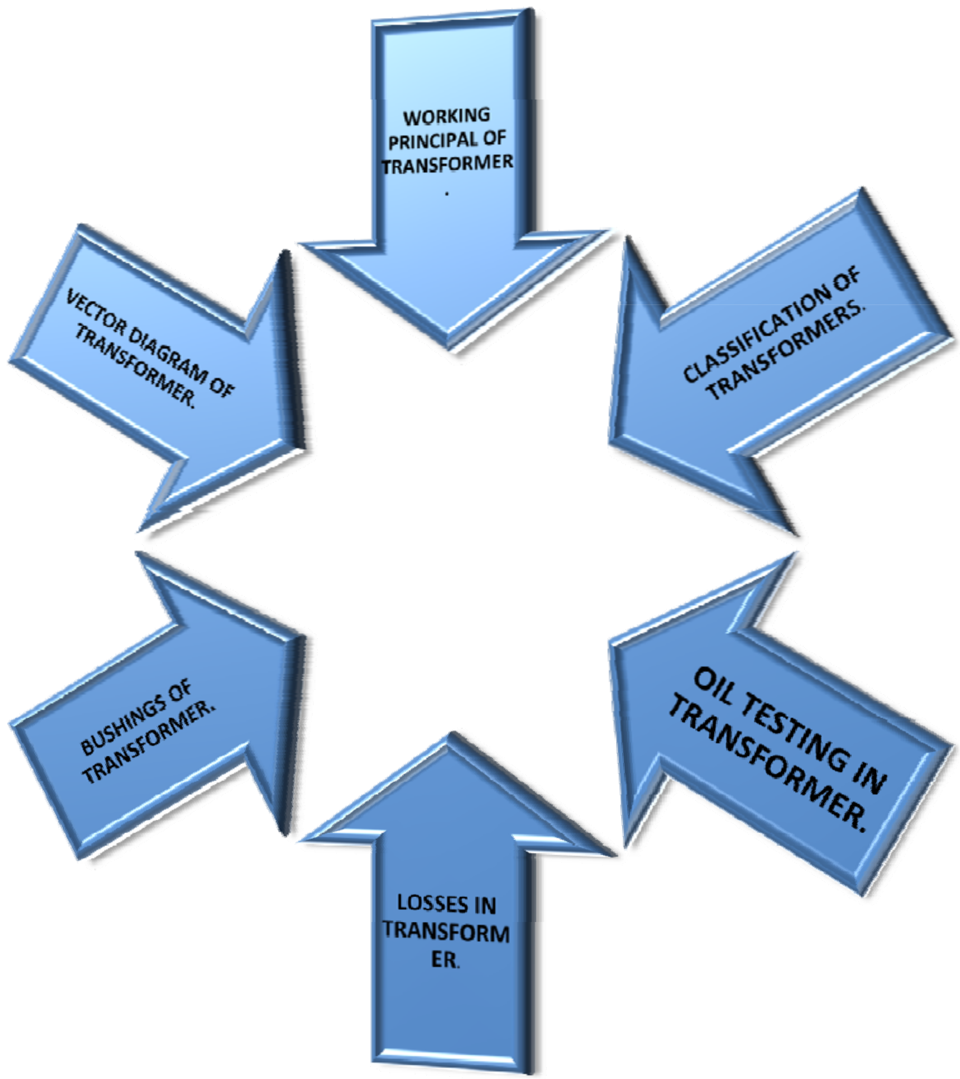
Types of material used in Fuse element.

- Rewireable fuse.
- Cartridge type fuse.
- Drop out fuse.
- High capacity H.R.C. fuse.
- High voltage H.R.C. fuse.

Different type of Fuses.

Type of M.C.B.

Transformer.



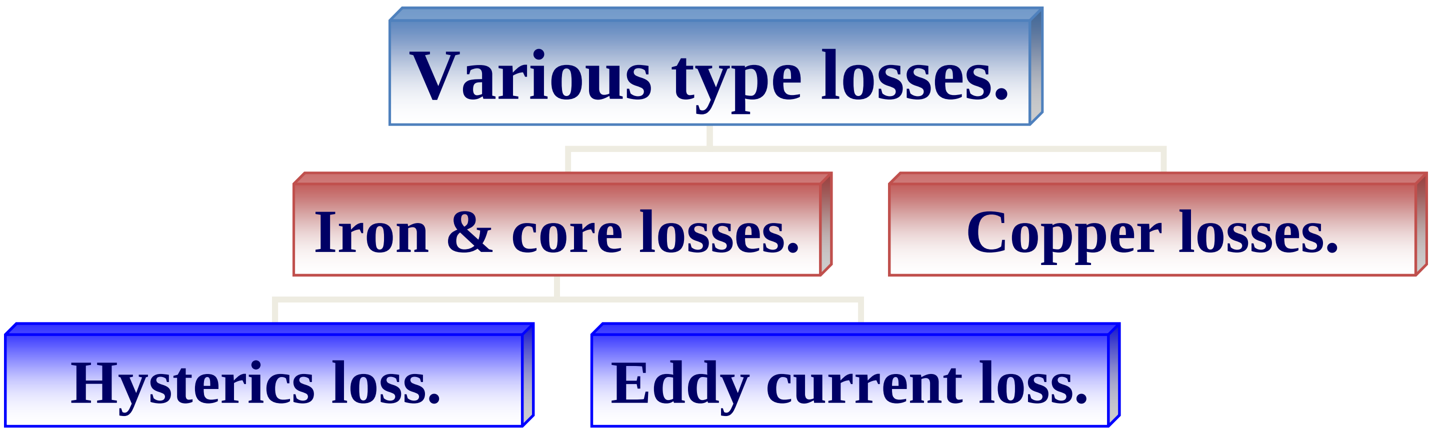
Types of Transformer.

- Power transformer.
- Auto transformer.
- Transformer for Feeding installation with static converters.
- Testing transformer.
- Power transformer for special application.

View of Transformer.

View of Transformer.

Various type losses in Transformer



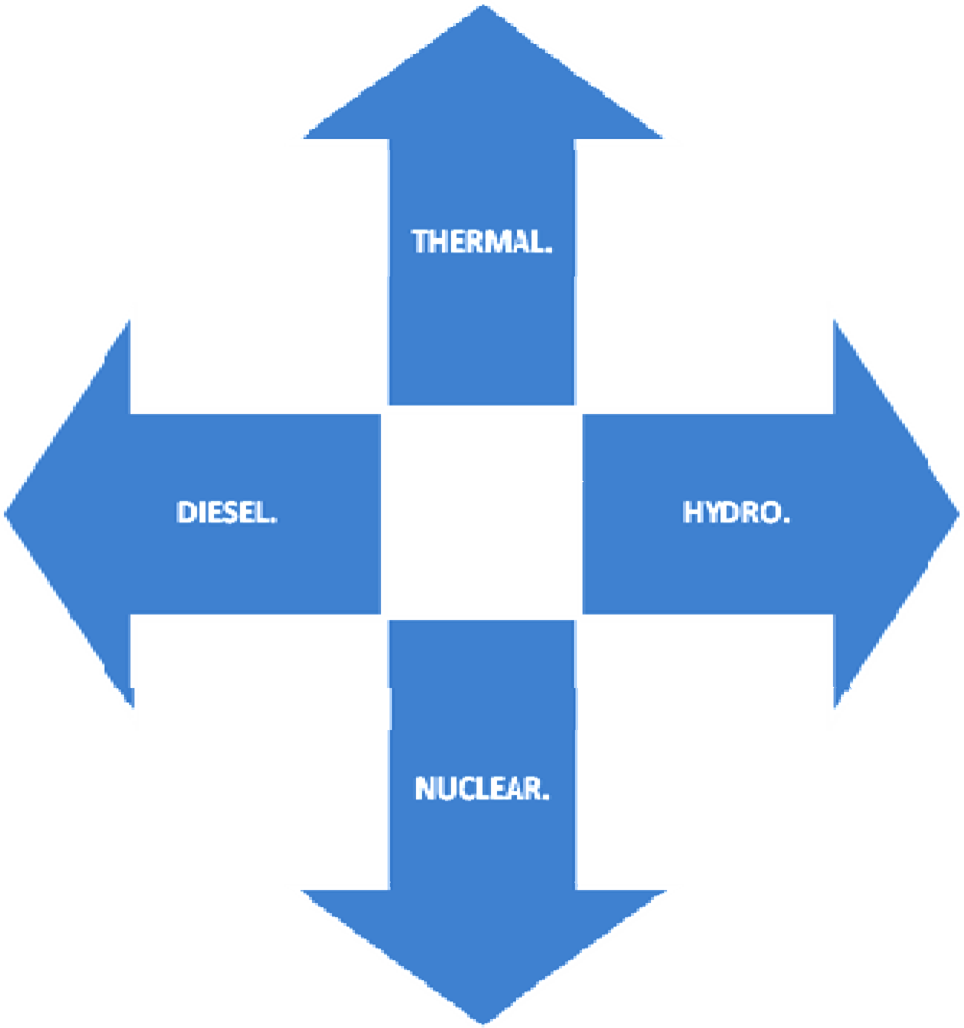
Various type losses in Transformer

- It’s a mineral oil obtained by refine crude petroleum. It serves the following purpose.
- Provide additional insulation.
- Carries away the heat generated in the core & coils .
- Protects the paper from dirt & moisture.

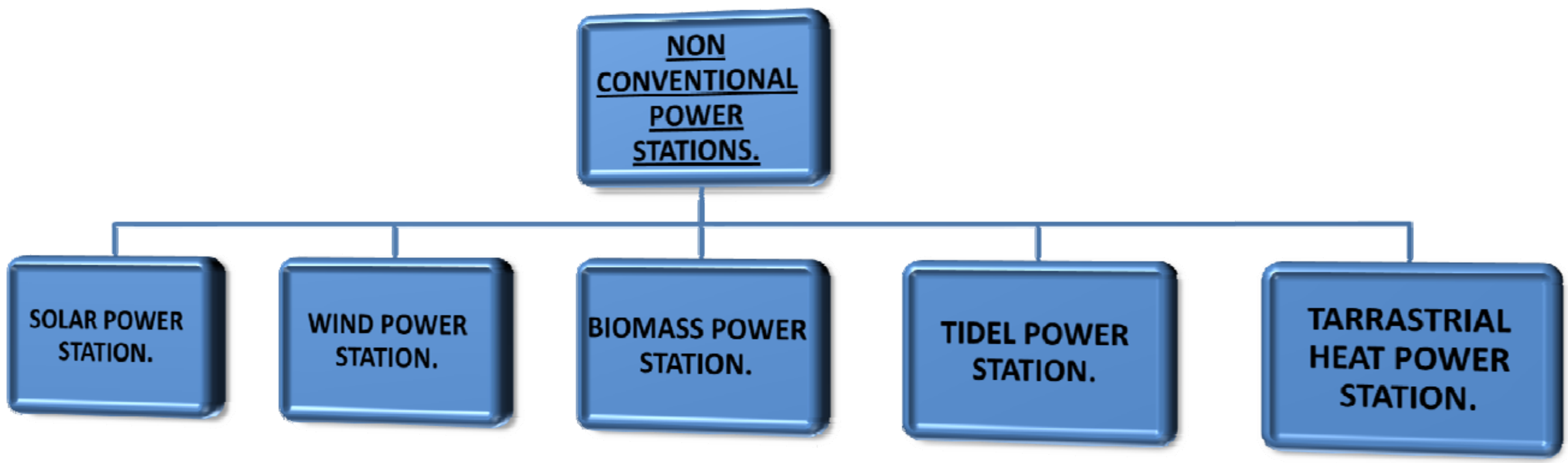
Unit VII

Non Conventional Power Generation

comparison between types of power station.`



comparison between types of power station.`



Use of Solar energy .

Photovoltaic conservation system.

- SOLARCOLLECTOR & WATCHES
- BATTERY CHARGING
- COMMUNICATIN
- NAVIGATION,RAIL WAY, SIGNAL, ETC.
- SOLAR TUBE LIGHT TV,ETC.
- DOMESTIC ELCT, APPLIANCES.
- FOR SPACE CRAFT ELECTRICITY.

Use of solar energy.

- **Direct method.**

❖ **Photovoltaic conservation.**

❖ **Thermal conservation.**

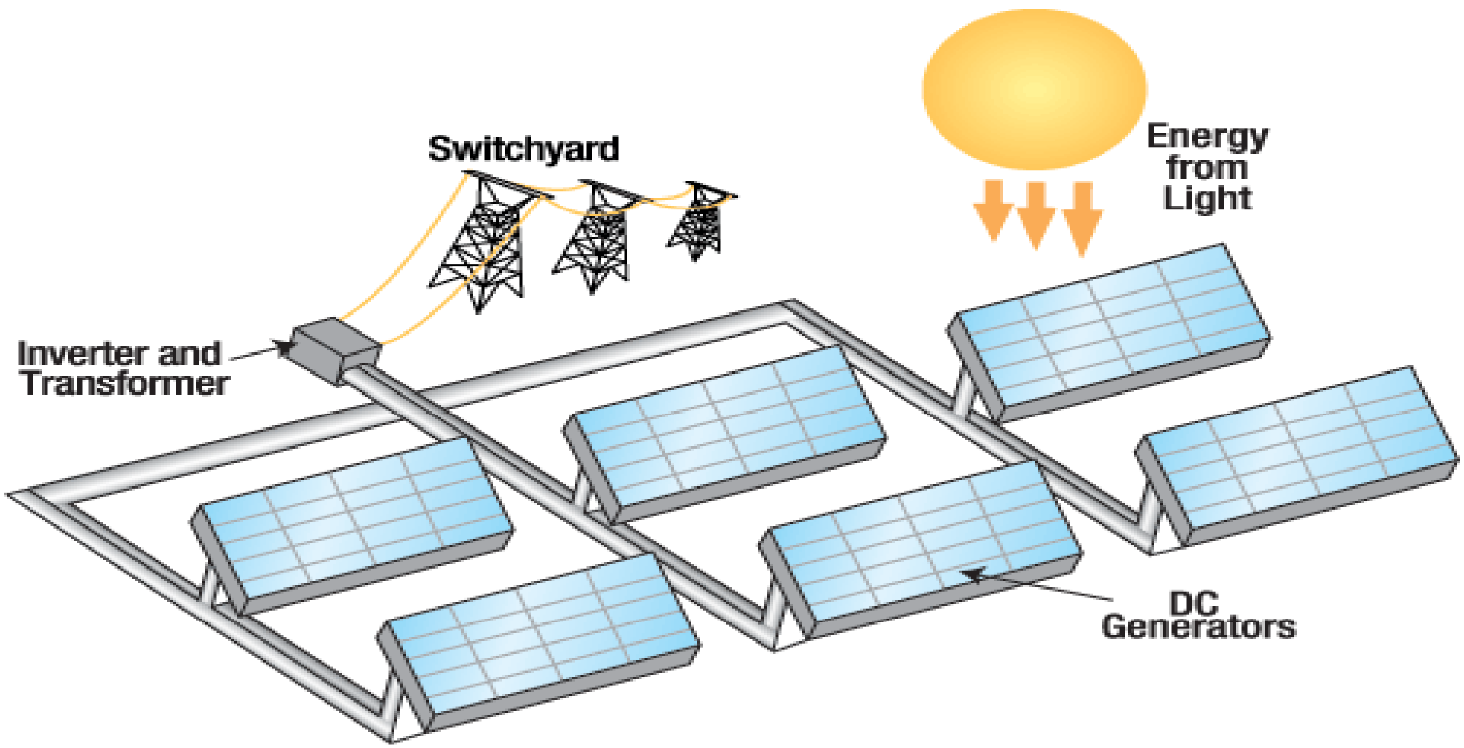
a) **Solar water heating.**
b) **Solar air heating.**
c) **Solar drying.**
d) **Solar pumping.**
e) **Solar furnace.**
f) **Solar space heating.**

Use of solar energy.

- **Indirect method.**

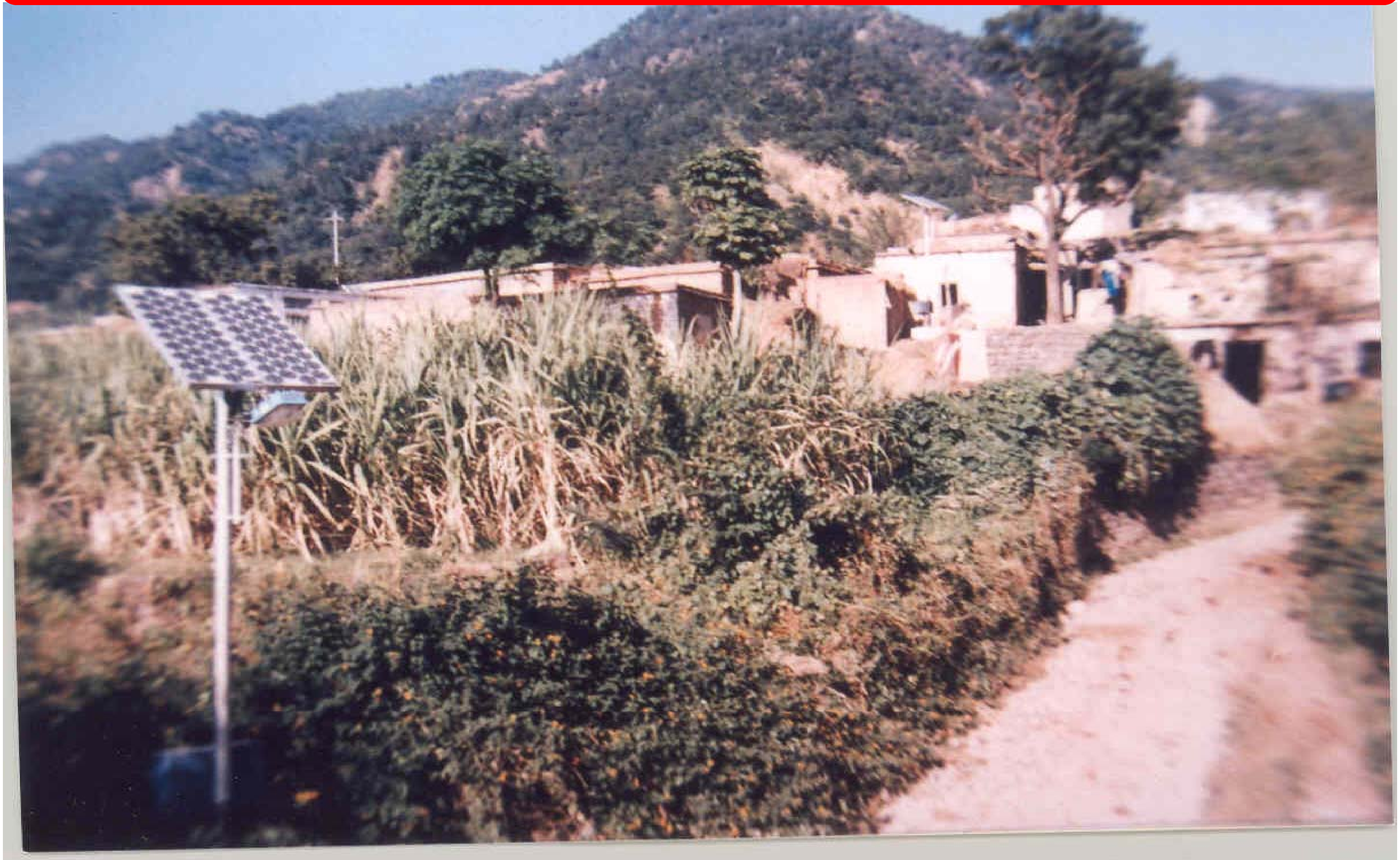
a) **Wind energy.**
b) **Tidal energy.**
c) **Biomass energy.**
d) **Geothermal energy.**
e) **Photosynthesis energy.**
f) **Hydraulic energy.**

Use of Solar energy system.



Photovoltaic Solar energy system.

Solar street light system.



Wind power energy.

- **Application of wind mill.**

i. **For water pumping.**

ii. **For producing electric power.**

iii. **For running flour mill.**

iv. **As stand by energy source.**

v. **For running domestic appliances & lighting.**

vi. **For battery charging.**

vii. **Combining with solar generation system to supply additional power.**

View of wind power station.

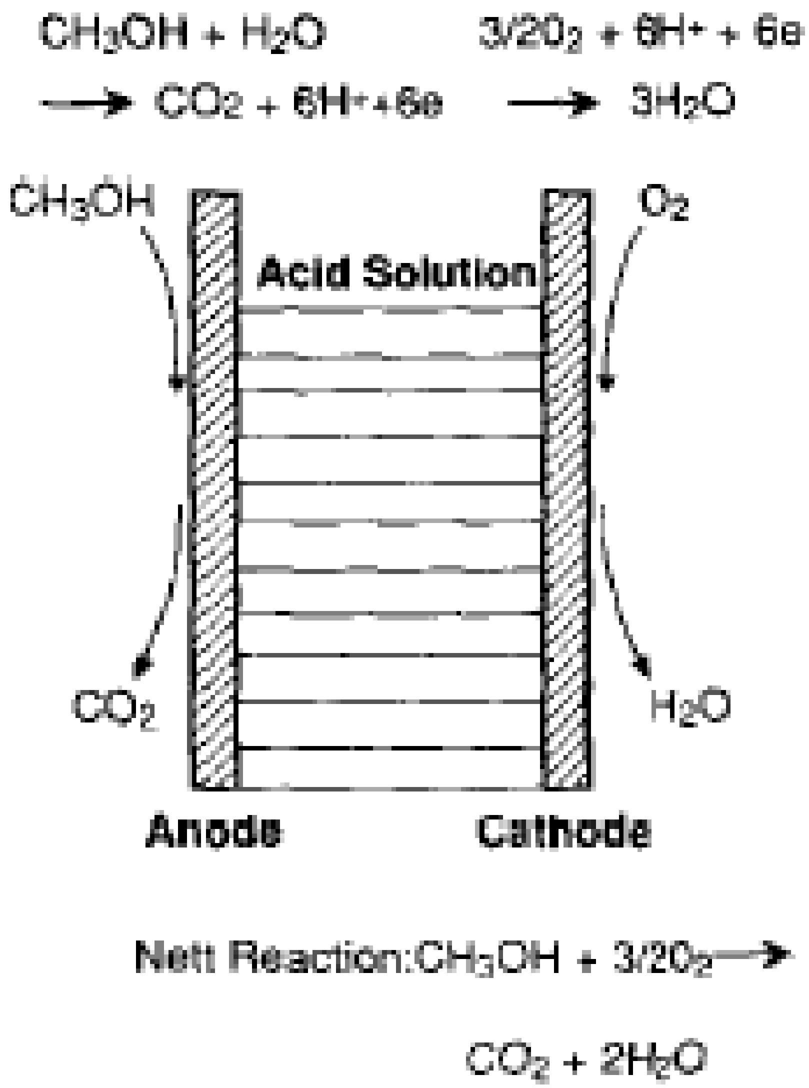
View of wind power station.

View of wind power station.

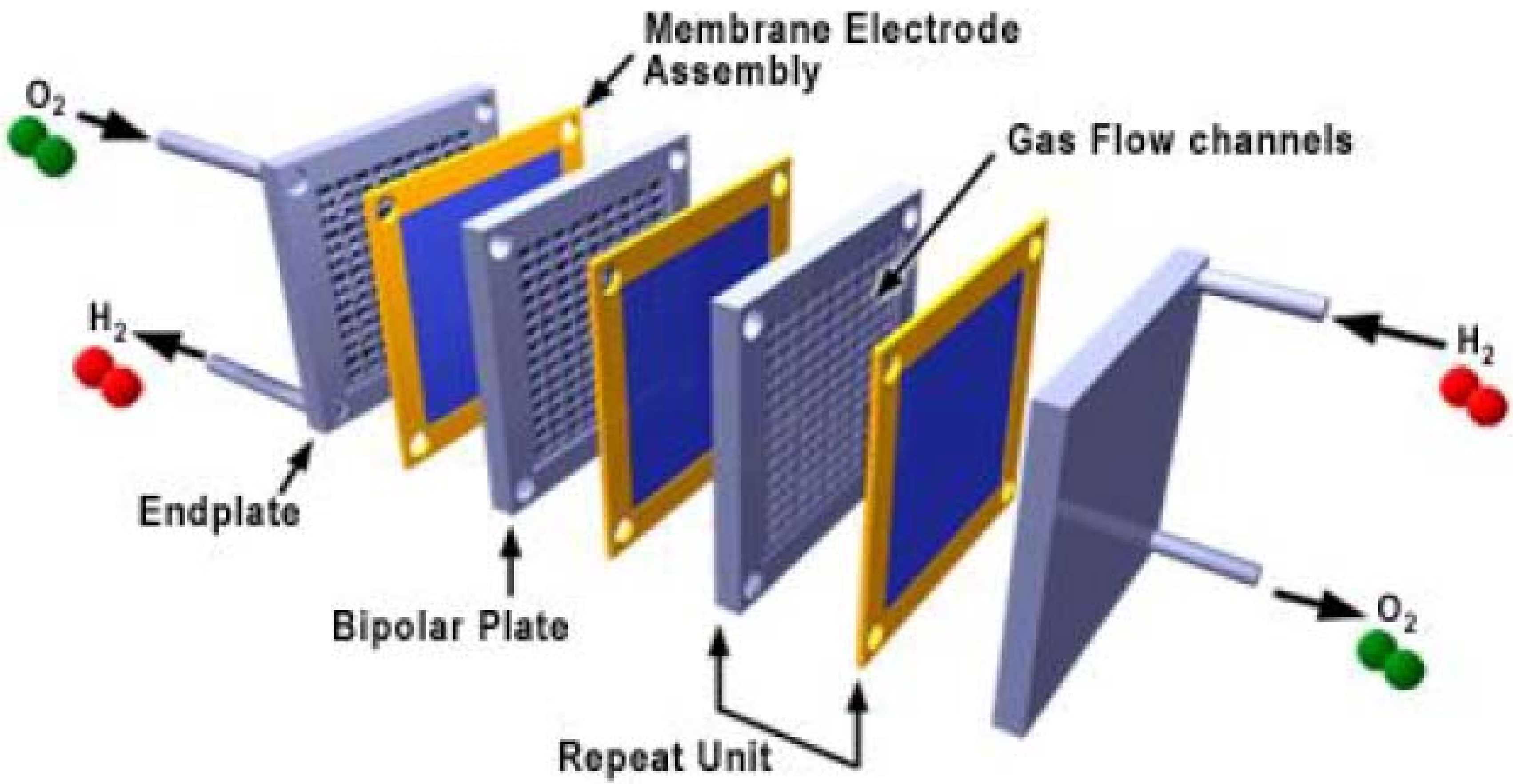
Unit VIII

Direct Energy Conversion Systems

Schematic Diagram of a Fuel Cell



Fuel Cell Stack

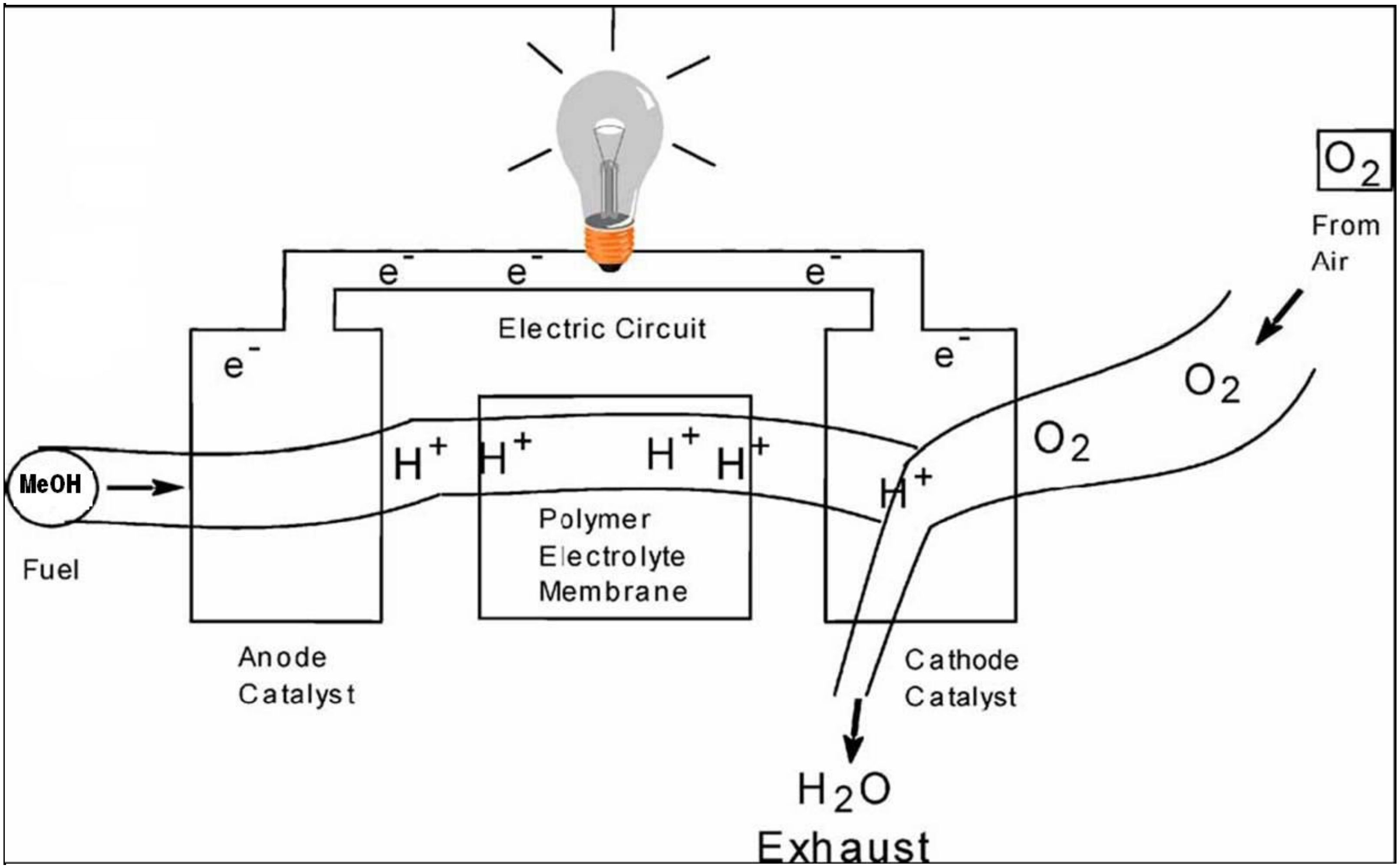


Mechanism for Methanol Oxidation

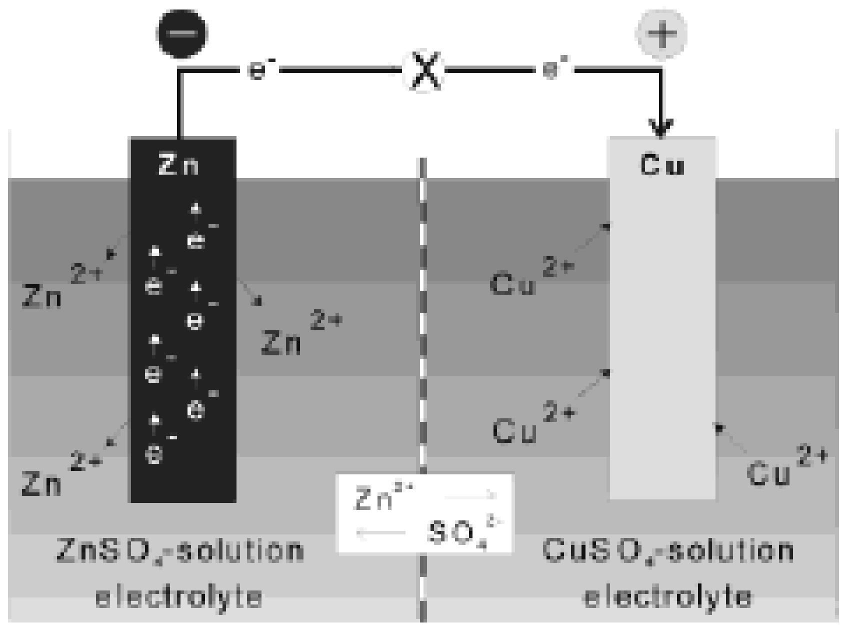
- Electrosorption (forming Pt-CH_2OH, Pt_2-CHOH species) of methanol onto Platinum layer deposited on MEA

- Addition of oxygen to adsorbed carbon containing intermediates generating CO_2

Operation of Fuel Cell

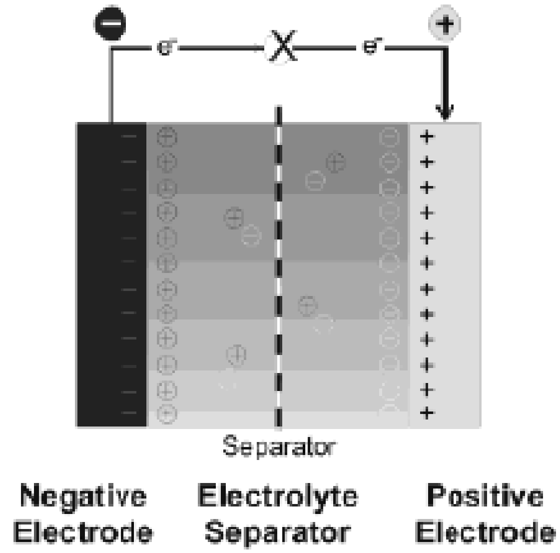


Battery

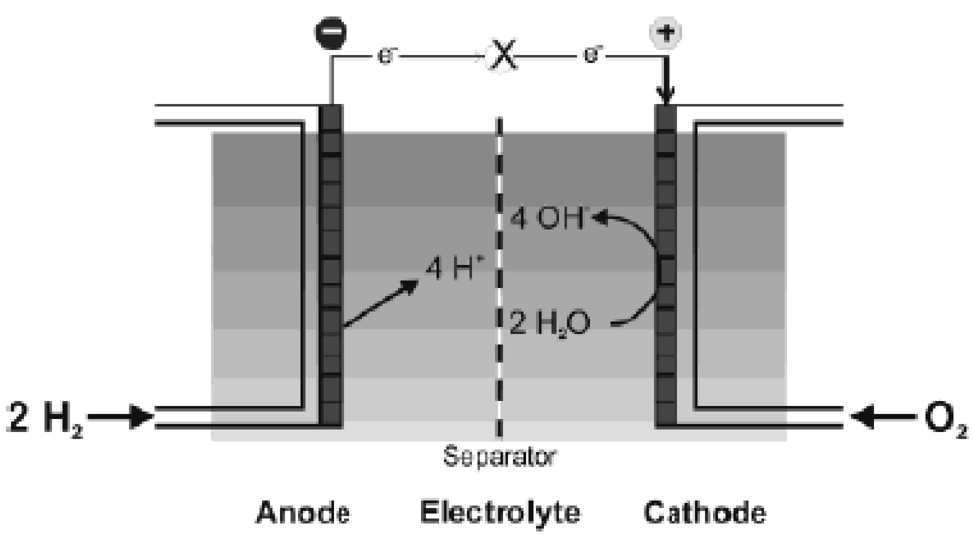


	Anode	Electrolyte Separator	Cathode
Requirements on electron conduction:	**must**	**no**	**must**
ion conduction:	**can**	**must**	**can**

Supercap



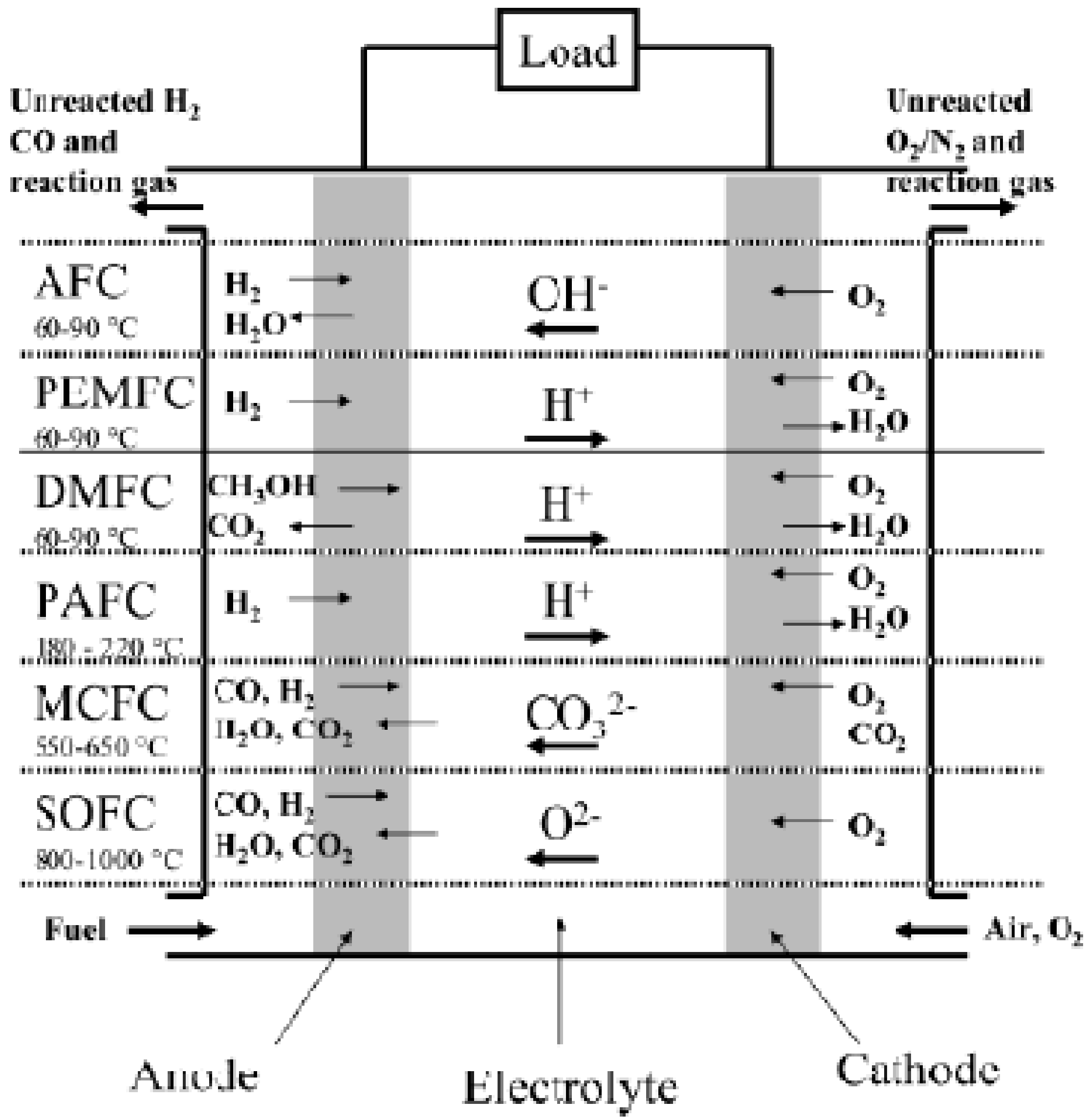
Fuel Cell



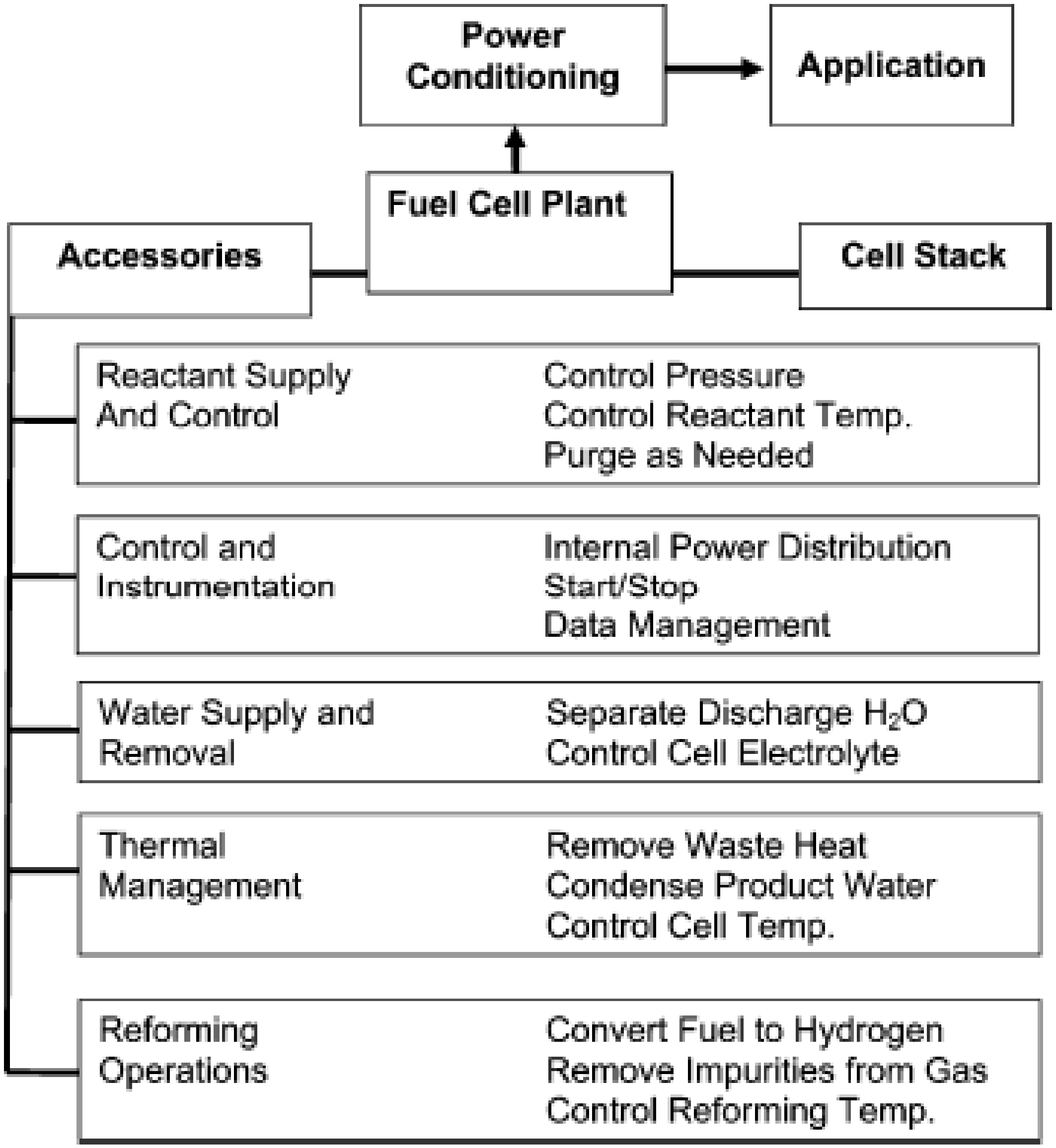
Types of Fuel Cells

Fuel Cell	Operating Conditions
Alkaline FC (AFC)	Operates at room temp. to 80 ^{0}C Apollo fuel cell
Proton Exchange Membrane FC (PEMFC)	Operates best at 60-90 ^{0}C Hydrogen fuel Originally developed by GE for space
Phosphoric Acid FC (PAFC)	Operates best at ~200 ^{0}C Hydrogen fuel Stationary energy storage device
Molten Carbonate FC (MCFC)	Operates best at 550 ^{0}C Nickel catalysts, ceramic separator membrane Hydrocarbon fuels reformed in situ
Solid Oxide FC (SOFC)	Operates at 900 ^{0}C Conducting ceramic oxide electrodes Hydrocarbon fuels reformed in situ
Direct Methanol Fuel Cell (DMFC)	**Operates best at 60-90 ^{0}C** **Methanol Fuel** **For portable electronic devices**

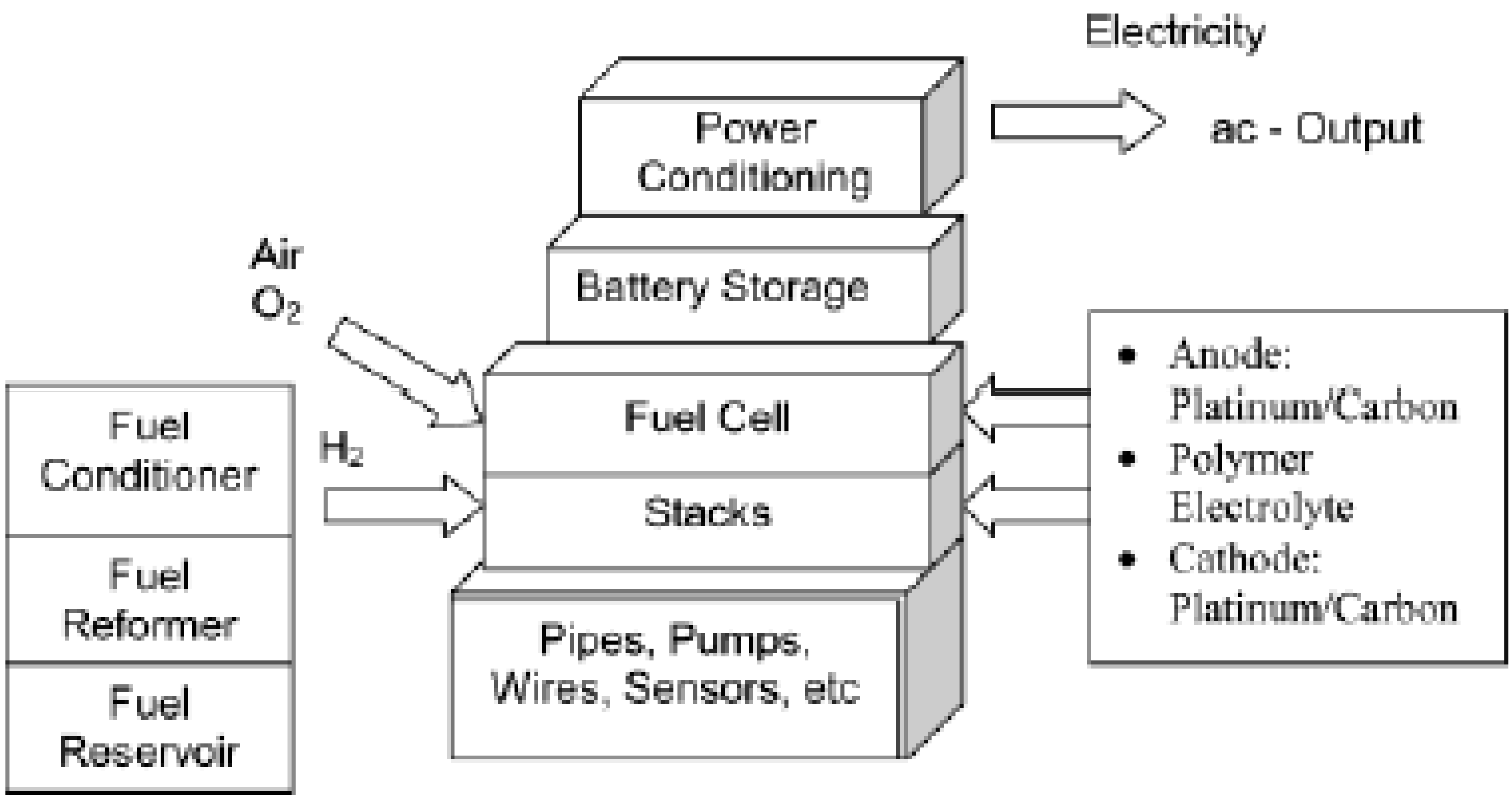
Summary of Reactions and Processes in Various Fuel Cells



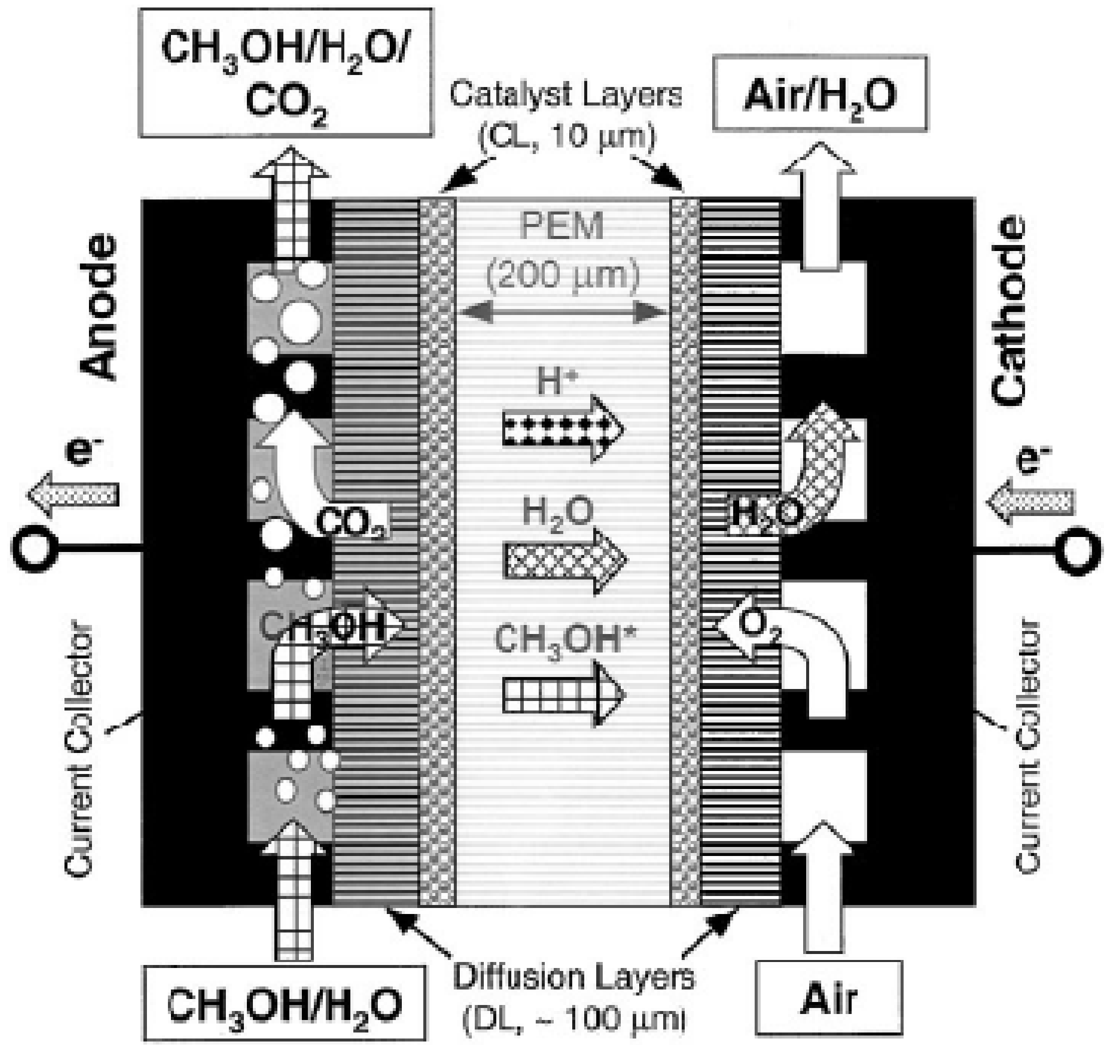
Block Diagram of the Component Parts of a Fuel Cell



Depiction of Components of Complete Fuel Cell System



Polyelectrolyte Membrane Fuel Cell (PEMFC)



Technology Limitations with DMFC

Poor Electrode Kinetics

↓

Large activation work potential

↓

200-300 mV Cell Voltage Loss

↓

Catalyst Development

Mass Transport

↓

CO_2 Rejection | Low MeOH concentration

↓

Electrode Structure

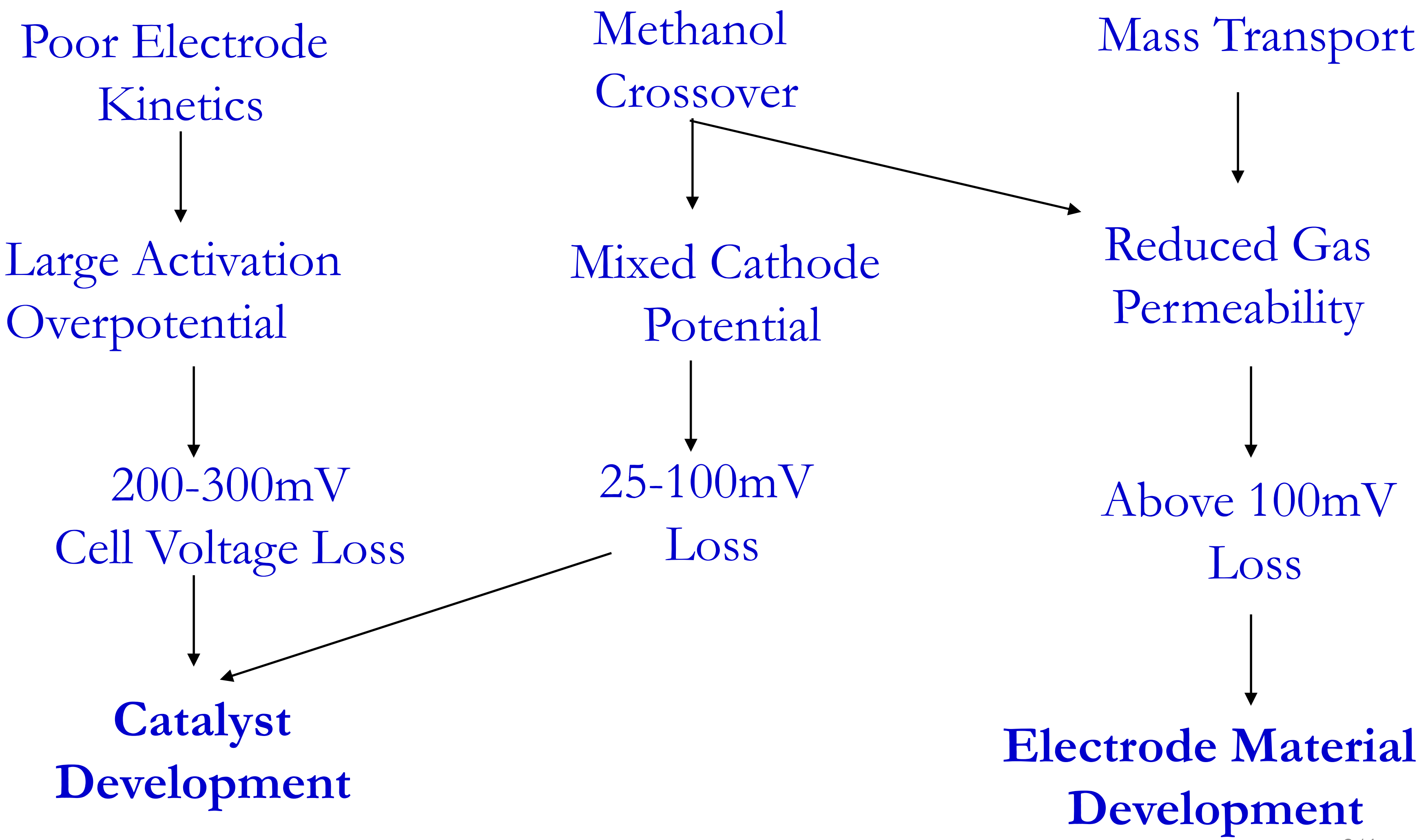
↓

25-150mV Cell Voltage Loss

↓

Electrode Material Development

Technology Limitations with DMFC Cathode



Three components of the Fuel Cells

• Electrode Material: Special conducting carbon Vulcan XE-72 available with Cabot Corporation, USA.

•Anodic Catalyst: Platinum-Ruthenium adsorbed on conducting carbon. Procedure of making it is well documented.

•Cathodic Catalyst: Platinum adsorbed on conducting carbon. Procedure of making it is well documented.

•Membrane: Nafion Membrane available with DuPont USA. They create lot of problems before supplying.

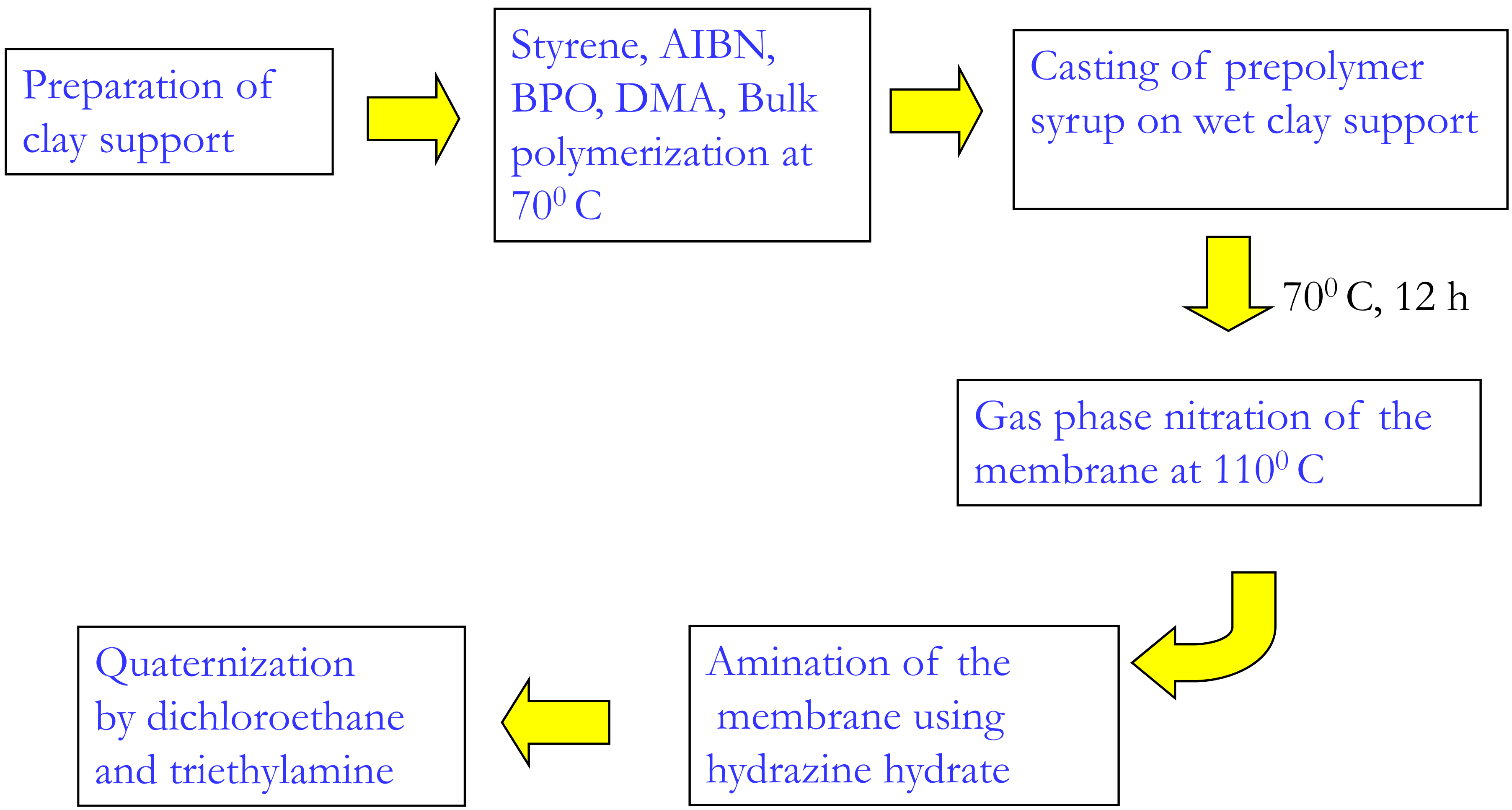
Ion Exchange Membranes

Polystyrene (PS) Membranes

- Dense membranes used for gas separation and pervaporation
- Sulfonated PS membrane used in methanol based fuel cells
- Sulfonated PS blended with Nafion® membrane
- High impact PS blended with polyaniline
- Anion exchange membranes prepared by chloromethylation of polystyrene

Experimental Section

Membrane Preparation



Preparation of Clay Support

Steps of Preparation

I Casting

Clay mixture casted on a gypsum surface

II Drying

Ambient Temp : 24 h

100 ^{0}C : 12 h

250 ^{0}C : 12 h

III Sintering

900 ^{0}C : 6 - 8 h

IV Dip Coating

Dip coated in polymerized TEOS (tetraethyl orthosilicate)

Drying, 100 ^{0}C : 24 h

Sintering, 1000 ^{0}C : 5 h

Composition

Clay raw material	Composition (wt. %)
Kaolin	10.15
Ball clay	12.90
Feldspar	4.08
Quartz	18.85
Calcium carbonate	22.52
Pyrophyllite	11.50
Water	20.00

Solid Oxide Electrolyte Ceramics

Overpotential $\eta_{OP} = \eta_{AOP} - \eta_{COP} - IR_{internal}$

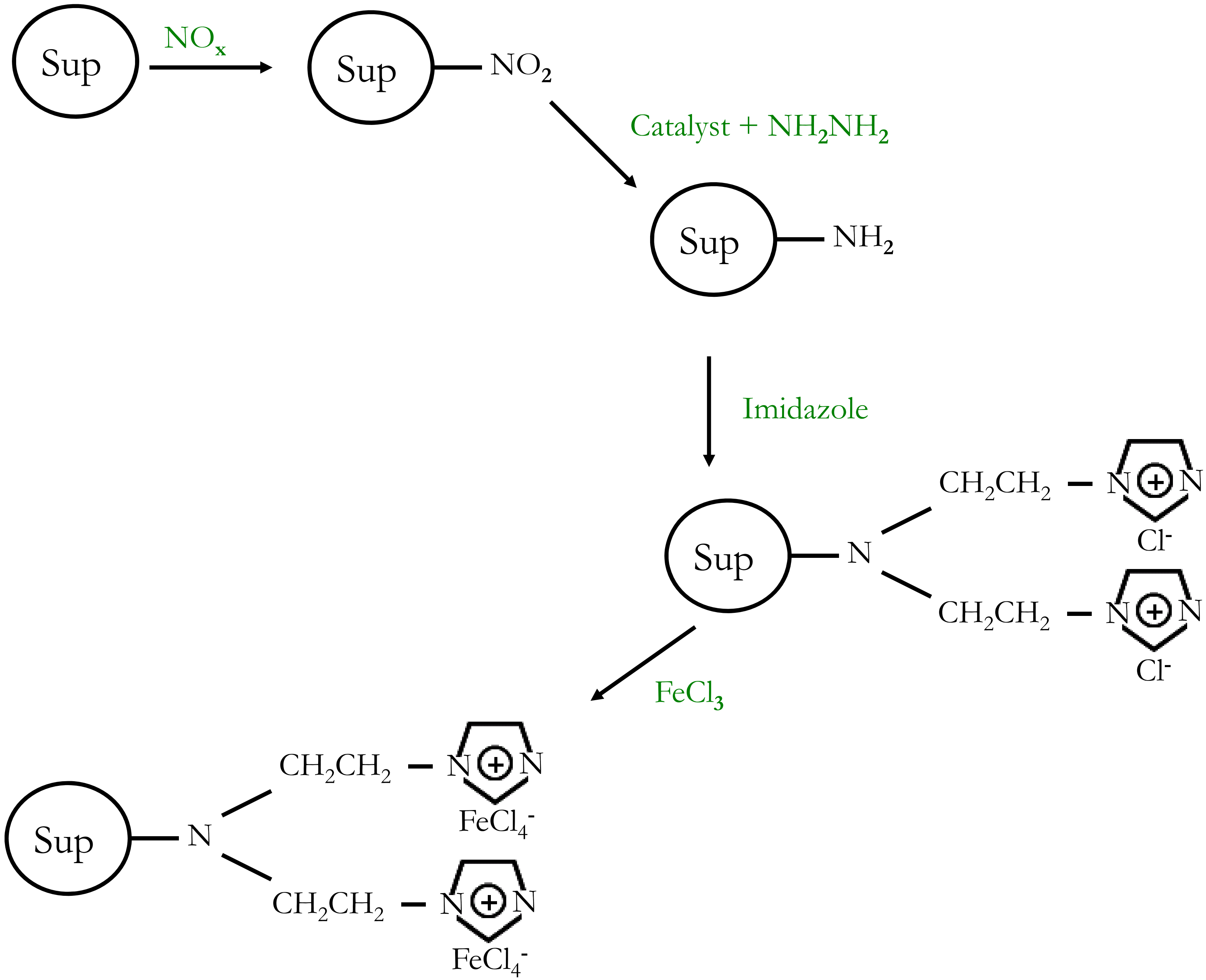
Perovskite Oxides: $La_{1-a}A_aM_{1-b}B_bO_{3-x}$

$A = Sr^{2+}, Ln^{3+}, Ce^{4+}$
M=Fe, Co, Ga a=0.1 to 1mol
B=Co, Fe, Mg b=0.1 to 0.5 mol

High Temperature Superconductors	$YBa_2Cu_3O_{7-x}$
Piezoelectric material	$BaTiO_3$
Semiconductor sensors	$SrTiO_3$
Oxygen Ion Conductors	$LaGaO_{3-x}$
Proton Conductor doped	$BaCeO_{3-x}$
Cathode Material	$La_{0.8}Sr_{0.2}CoO_{3-x}$

Working Temperature range: $100\text{-}2000^0C$

Modification of the Support

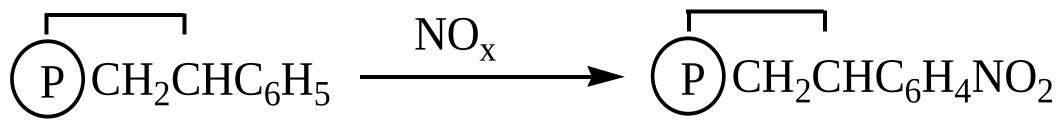


Experimental Section

Modification Reactions

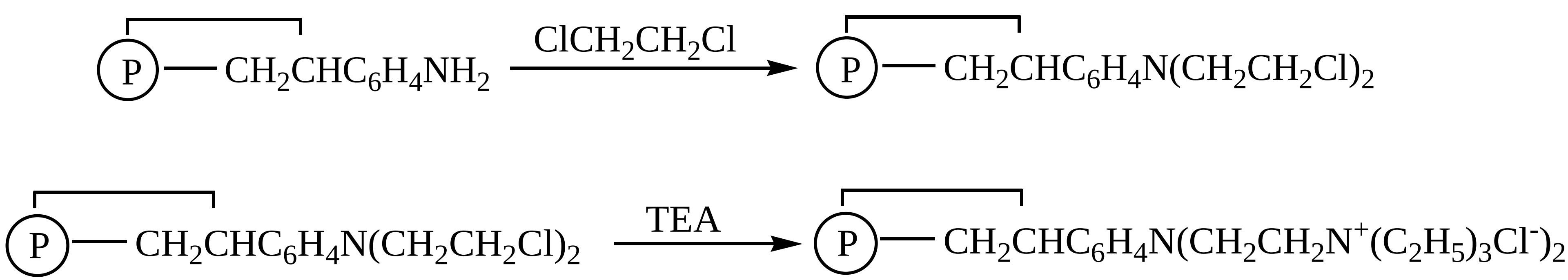
Nitration:

$$2NaNO_2 + H_2SO_4 \rightarrow NO + NO_2 + H_2O + Na_2SO_4$$



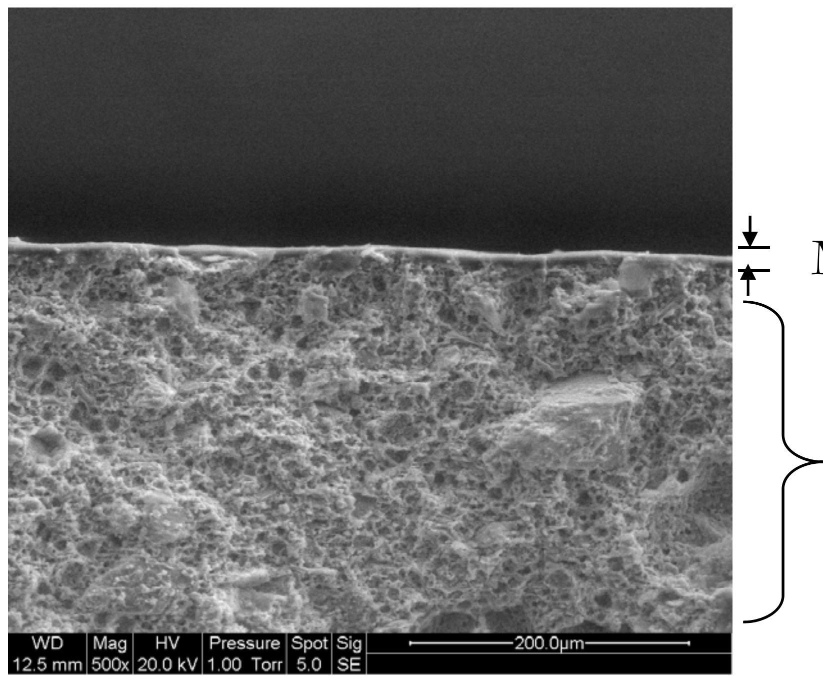
Amination:

Quaternization:



Membrane Characterization

Scanning electron microscopy (SEM)



Crossectional view of the membrane

Experimental Setup for Electrodialysis