RENEWABLE ENERGY SYSTEMS

UNIT I

SOLAR ENERGY

Energy:

Energy is the primary and most universal measures of all kinds of work done by human being and nature

(or)

Energy means the capacity of something a person, an animal to do work and produce change

Sources of energy:

Based upon the availability in nature there are two main sources of energy

1) Conventional source of energy
2) Non Conventional source of energy.

Conventional source of energy:

Conventional source of energy are wood, flowing water, fossil fuels (coal, petroleum, natural gas)

Fossil fuels: these are coal, petroleum, natural gas.

These fuels are formed inside the earth from the remains of plants and animals after millions of years.

Coal, oil, gas are commonly known as commercial or Non Renewable energy sources

Non conventional sources of energy:

Solar energy,

Wind energy,

Biomass energy,

Ocean energy,

Tidal energy,

Geothermal energy,

Nuclear energy

Sources of energy

Conventional sources

Commercial

- Coal
- Oil & natural gas
- Thermal power

Non-commercial

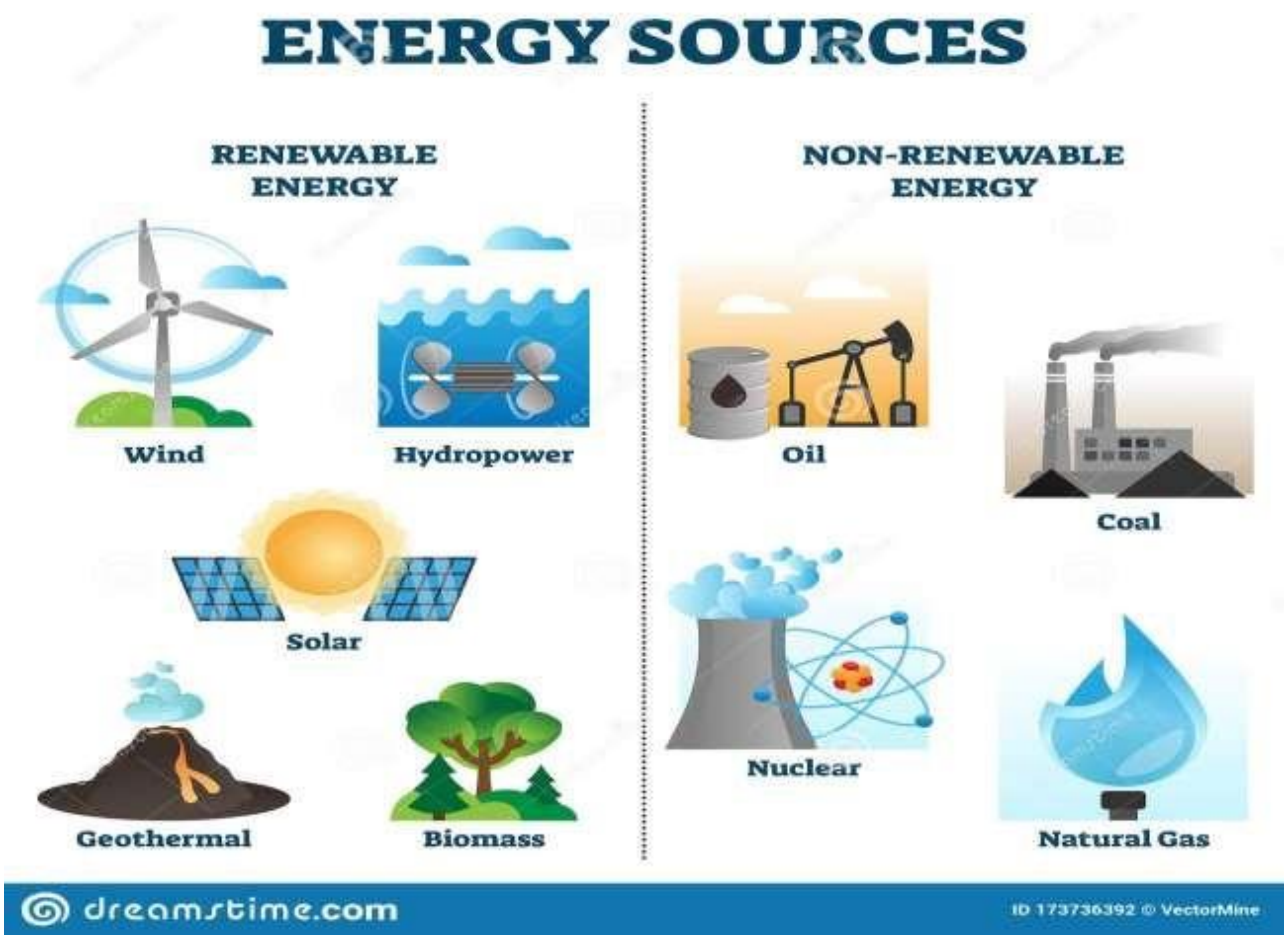
- Firewood (Fuel wood)
- Hydro power
- Nuclear power

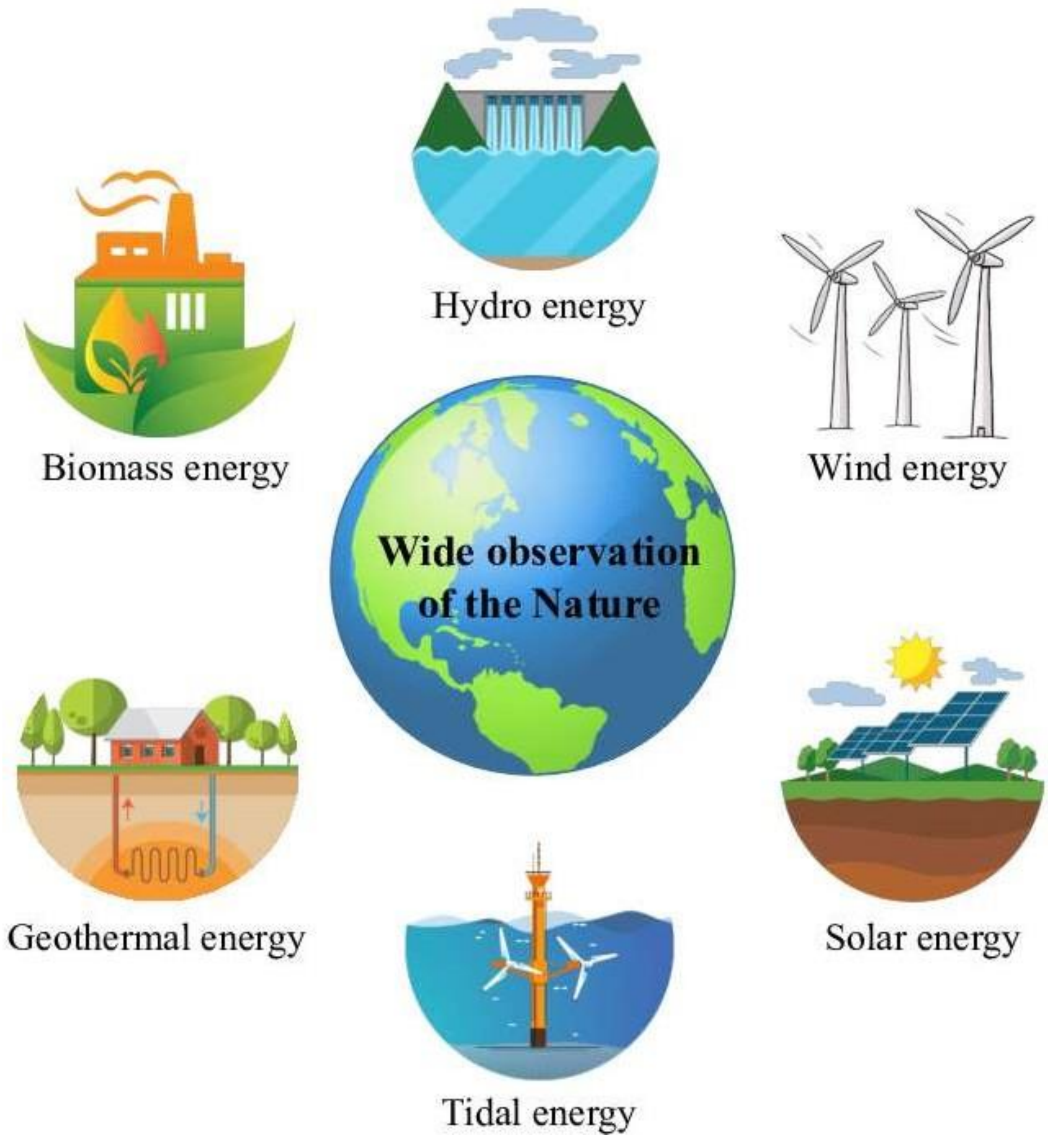
Non-conventional sources

- Solar energy
- Wind energy
- Tidal energy
- Geothermal energy
- Biomass - based energy

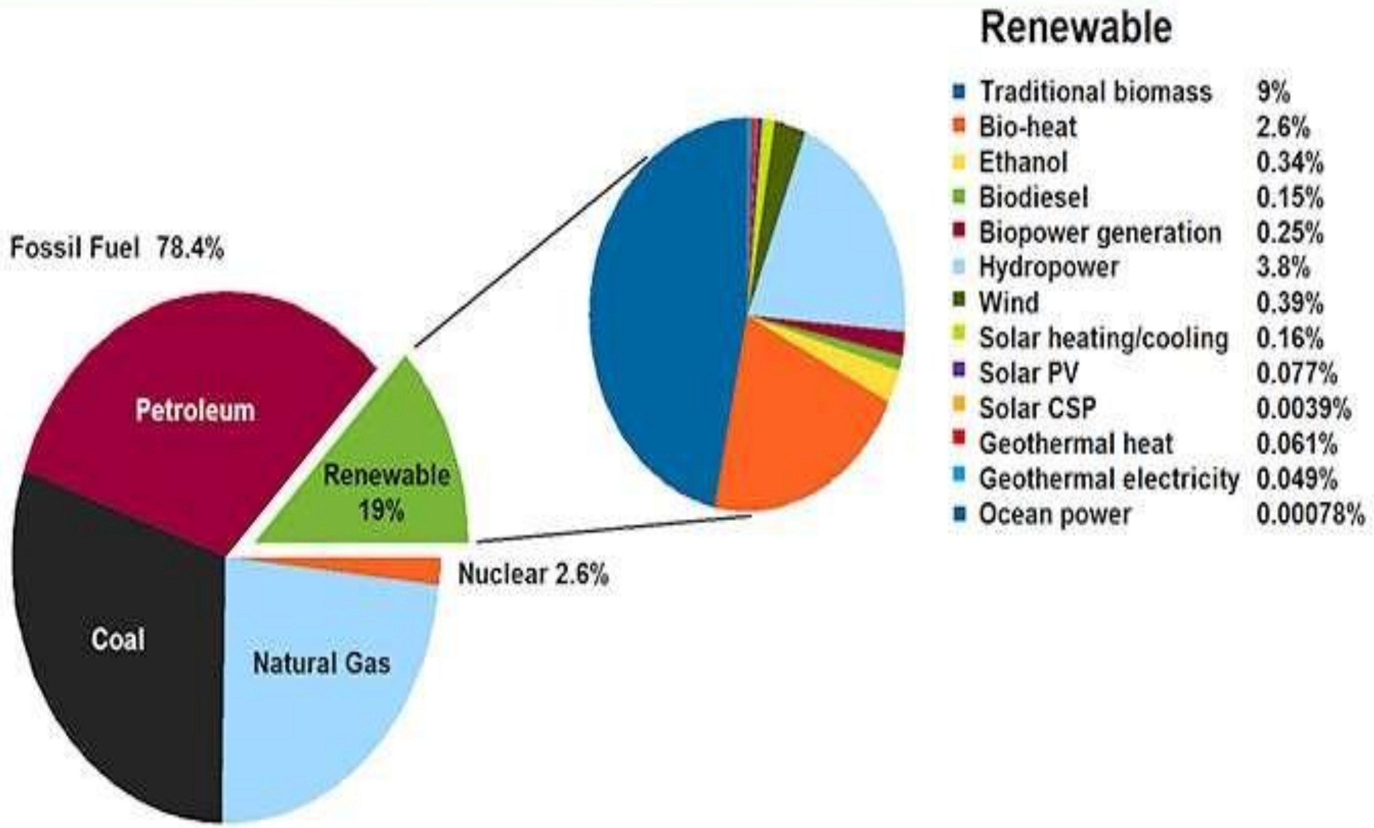
Renewable energy:

It is the energy that is collected from renewable sources




Hydro energy
Biomass energy
Wind energy
Wide observation of the Nature
Geothermal energy
Solar energy
Tidal energy

TOTAL WORLD ENERGY CONSUMPTION BY SOURCE

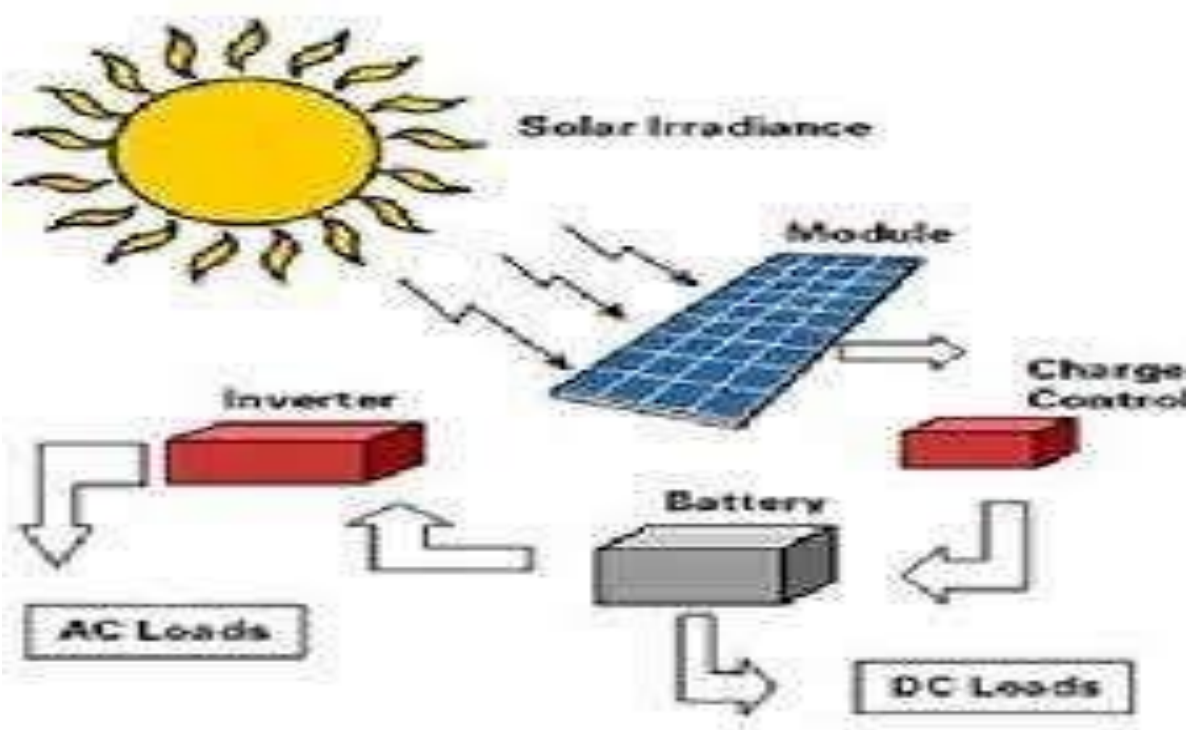


Solar energy:

- Energy obtained from the sun in the form of heat and light
- Energy derived in the solar radiation

-Solar energy reaching the top of the earth's atmosphere consists of about 8 percent ultraviolet radiation (short wave length) , 46 percent visible light, and 46 percent infrared radiation(long wave length)

- The heat energy is used in solar heating devices like solar cooker, solar water heater, solar furnaces.


Solar Irradiance
Module
Charge Control
Inverter
Battery
AC Loads
DC Loads

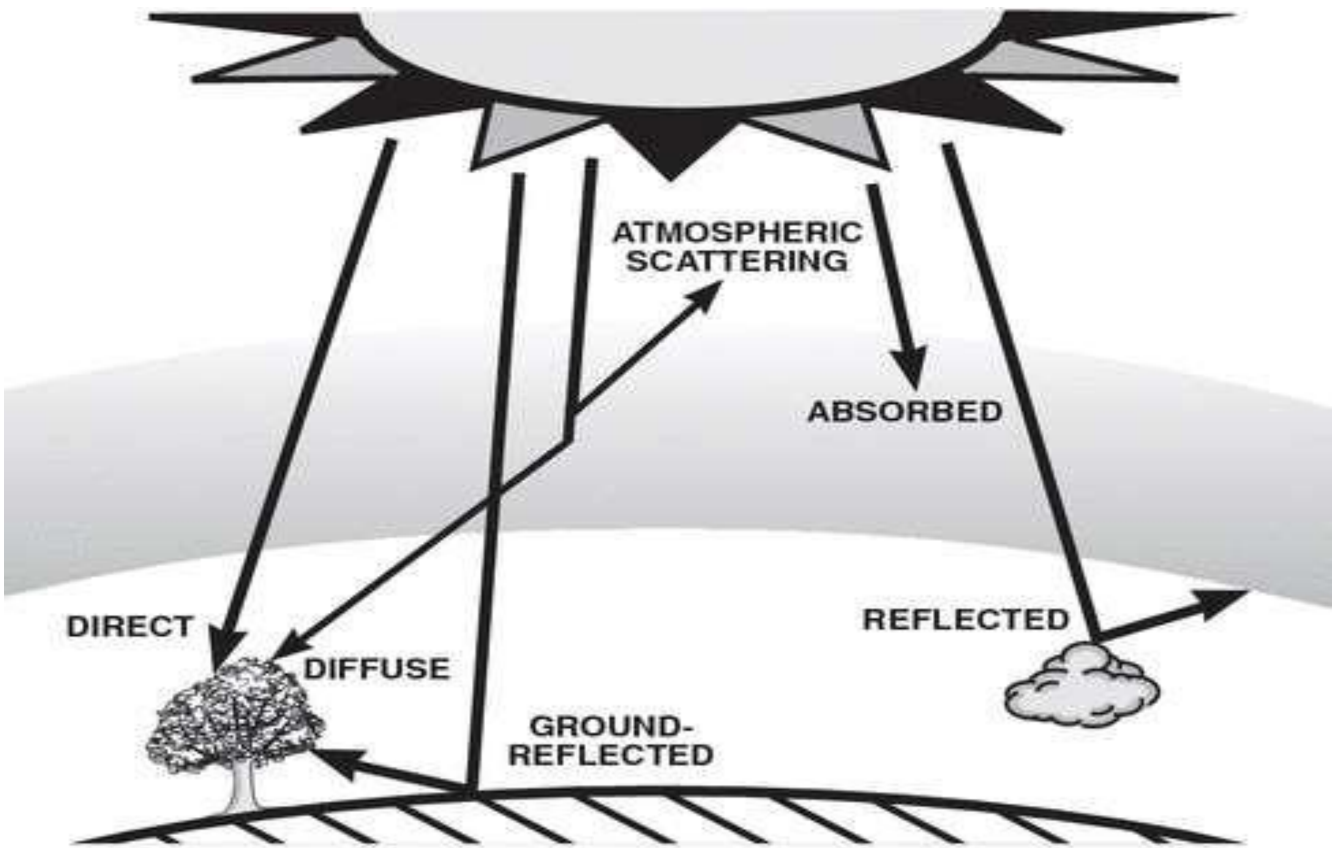
Applications of solar energy:

- Heating and cooling residential buildings
- Solar water heating
- Solar drying of agricultural and chemical products.
- Solar distillation of a small community scale
- Salt production by evaporation of sea water
- Solar cookers
- Solar engines for water pumping
- Food refrigeration
- Bio conversion and wind energy and which are indirect source of solar energy
- Solar furnaces
- Solar electric power generation by
  - Solar ponds
  - Steam generators heated by rotating reflectors
  - reflectors with lenses and pipes for fluid circulation

Solar radiation:

- Solar energy, received in the form of radiation can be converted directly or indirectly in to other forms of energy, such as heat and electricity.

Solar radiation on earth' surface: beam and diffuse solar radiation



Solar constant:

-The sun is a large sphere of very hot gases, the heat being generated by various kinds of fusion reactions. Its diameter is 1.39 X 10^6 km while that of earth is 1.27 X 10^4 km. the mean distance between the two is 1.5 X 10^8 km.

-The total radiation from the sun is 5762 degrees K

The rate at which solar energy arrives at the top of the atmosphere is called solar constant Isc. This is the amount of energy received in unit time on a unit area perpendicular to the sun's direction

The solar energy received by near earth space is approximately 1.4 kilo joules/ second known as solar constant.

$$I/I_{sc} = 1+0.033 \cos(360n/365)$$

where n is the day of the year

And I is the intensity of solar radiation that reaches the earth.

UNIT II

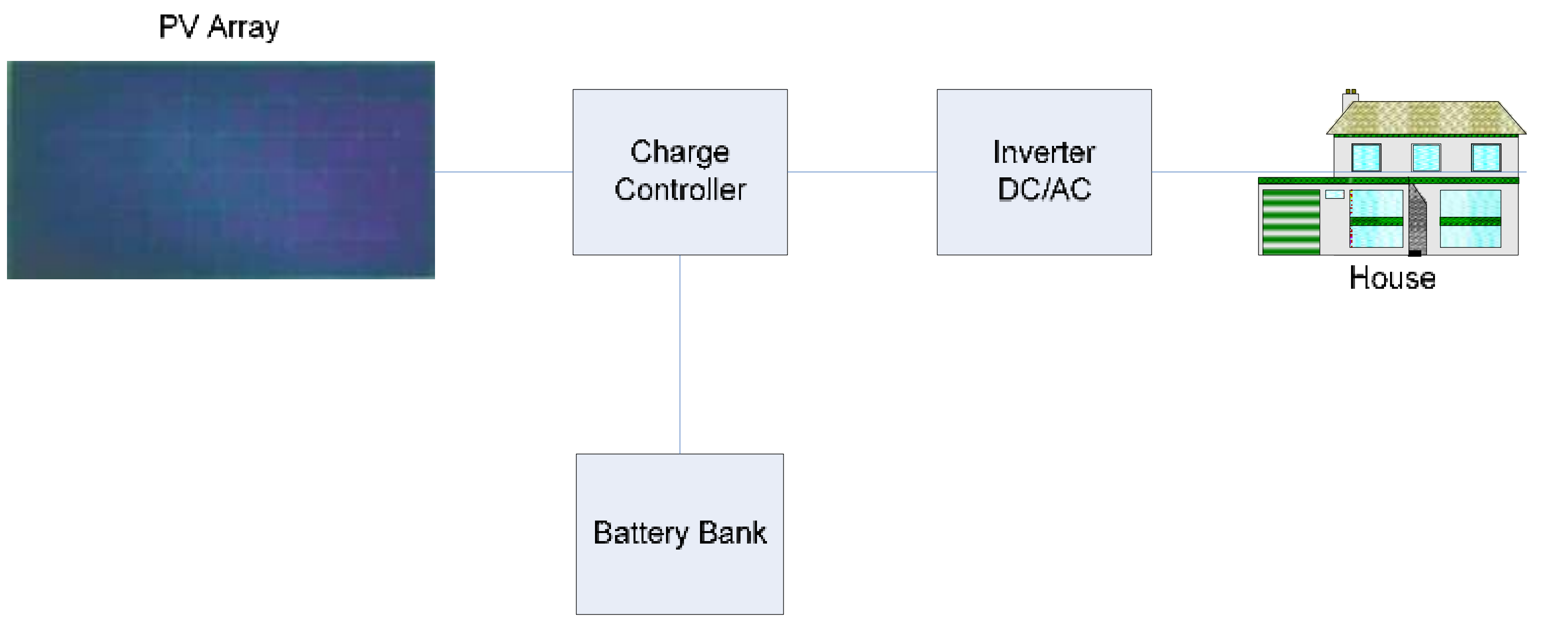
PV system

A photovoltaic (PV) system is able to supply electric energy to a given load by directly converting solar energy through the photovoltaic effect.

PV systems can be broadly classified in two major groups:

1) **Stand-Alone**
2) **Grid-Tied:**

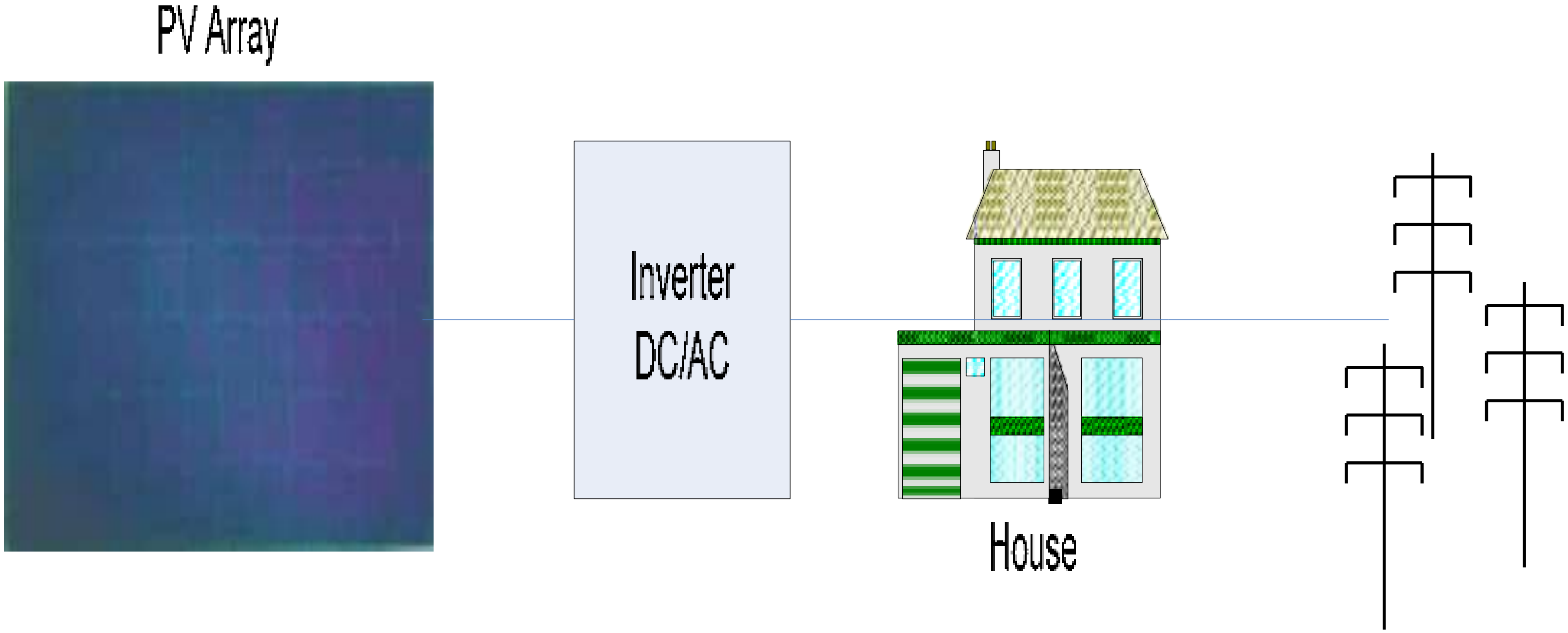
Stand alone:



Stand alone photo voltaic system

- includes all the elements necessary to serve AC appliances in a common household or commercial application.
- The inverter could be eliminated or replaced by a DC to DC converter if only DC loads are to be fed by the PV modules.
- Ex: water pumping applications were a PV module is directly coupled to a DC pump, water is stored in a tank through the day whenever energy is available.

Grid-Tied:



- These systems are directly coupled to the electric distribution network and do not require battery storage.
- Electric energy is either sold or bought from the local electric utility depending on the local energy load patterns and the solar resource variation during the day,
- This operation mode requires an inverter to convert DC currents to AC currents.
- There are many benefits that could be obtained from using grid-tied PV systems instead of the traditional stand-alone schemes

Benefits of grid type:

1) Smaller PV arrays can supply the same load reliably.
2) Less balance of system components are needed.
3) Eliminates the need for energy storage and the costs associated to substituting and recycling batteries for individual clients.
4) Efficient use of available energy. Contributes to the required electrical grid generation while the client's demand is below PV output.

There are three types of cell technologies:

1) **Monocrystalline**:

- These are cells that are grown from a single crystal.
- The production methods are difficult and expensive. These tend to be more efficient (more power in less area) and more expensive.

2) **Multicrystalline:**

- The production process allows multiple crystalline structures to develop within the cell.
- It is relatively cheaper than mono- crystalline at the expense of lower efficiency.

Thin-film:

- Uses less silicon to develop the cell) allowing for cheaper production costs (silicon is in high demand).
- It tends to be less expensive but has also lower efficiency.

PV Module:

Def:

A photovoltaic module is an array of photovoltaic cells pre-arranged in a single mounting mold.

or

A number of solar cells electrically connected to each other and mounted in a support structure are called a photovoltaic module

- The basic building block of a photovoltaic module is the photovoltaic cell; these convert solar energy into electricity.
- The power output will depend on the amount of energy incident on the surface of the cell and the operating temperature of the photovoltaic cell.
- The power output of a single cell can supply small loads like calculators or watches, but in order to be useful for high energy demand projects these cells must be arranged in series and parallel connections.

Characteristics of various PV cell technologies:

- Polarity of output terminals or leads
- Maximum series fuse for module protection
- Rated open-circuit voltage
- Rated operating voltage
- Rated operating current
- Rated short-circuit current
- Rated maximum power
- Maximum permissible system voltage

Types of silicon cell technologies:

1) Single Crystal Silicon
2) Polycrystalline Silicon
3) Ribbon Silicon
4) Amorphous Silicon

1) Single Crystal Silicon:

is a silicon material in which the crystal lattice of the entire sample is continuous and unbroken to the edges of the sample, with no grain boundaries.

Advantages:

- Well established and tested technology
- Stable
- Relatively efficient

Disadvantages:

- Uses a lot of expensive material
- Lots of waste in slicing wafers
- Costly to manufacture
- Round cells can’t be spaced in modules efficiently

2) Polycrystalline Silicon:

Made up by polycrystalline having small crystals

Advantages

- Well established and tested technology
- Stable
- Relatively efficient
- Less expensive than single Crystalline Si
- Square cells for more efficient spacing

Disadvantages:

- Uses a lot of expensive material
- Lots of waste in slicing wafers
- Fairly costly to manufacture
- Slightly less efficient than Single Crystalline Si

3) Ribbon Silicon:

Is a thin sheet type made up of silica

Advantages:

- Does not require slicing
- Less material waste than single and polycrystalline
- Potential for high speed manufacturing
- Relatively efficient

Disadvantages:

- Has not been scaled up to large-volume production
- Complex manufacturing process

4) Amorphous Silicon:

Amorphous silicon solar cells are **the most well-developed thin-film solar cell**. The structure usually has the p-i-n (or n-i-p) type of duality, where p-layer and n-layer are mainly used for establishing an internal electric field (i-layer) comprising amorphous silicon. It is alloy of silicon and carbon

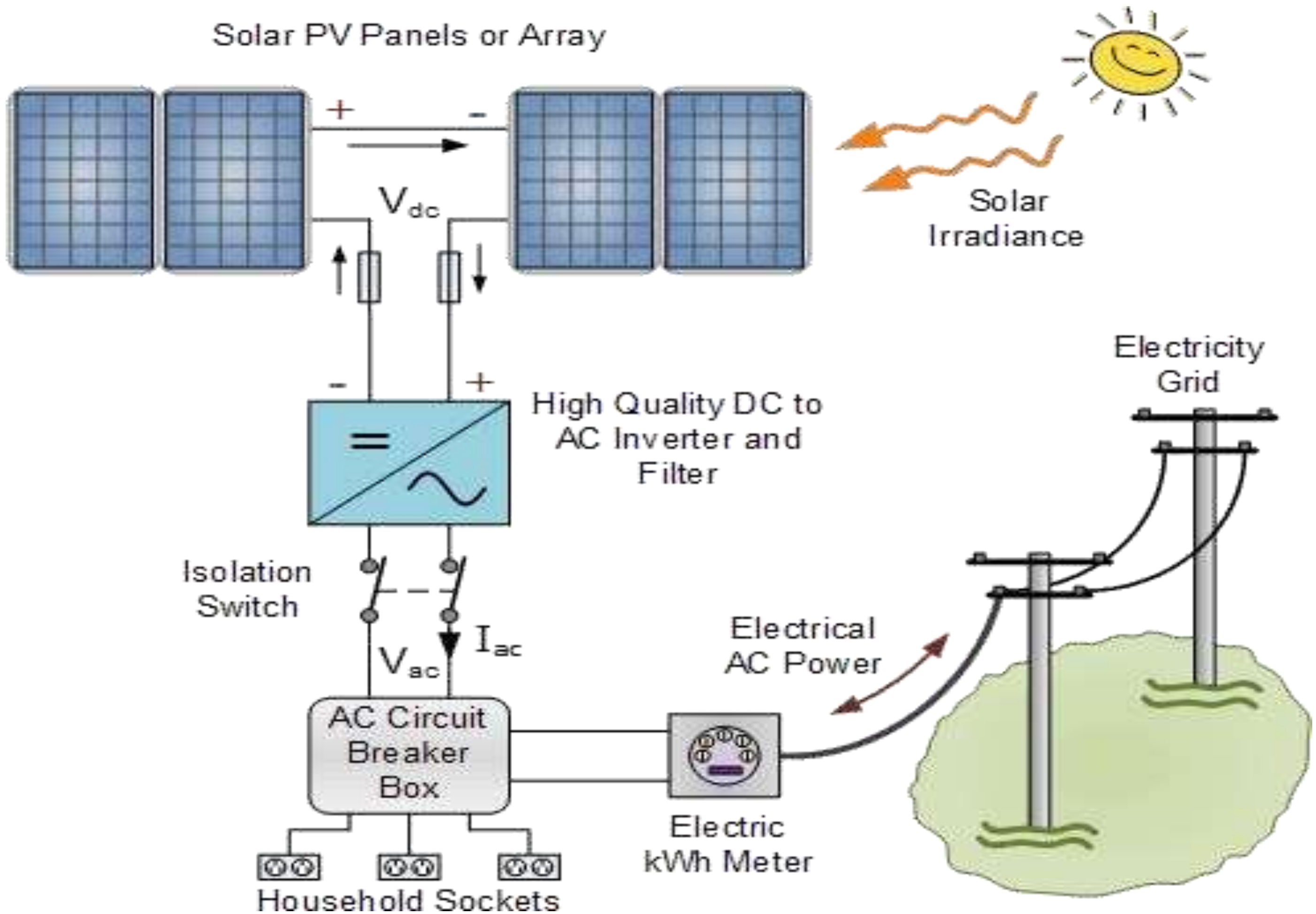
Advantages:

- Very low material use
- Potential for highly automated and very rapid production
- Potential for very low cost

Disadvantages:

- Pronounced degradation in power output
- Low efficiency

Grid connected PV systems



Inverter:

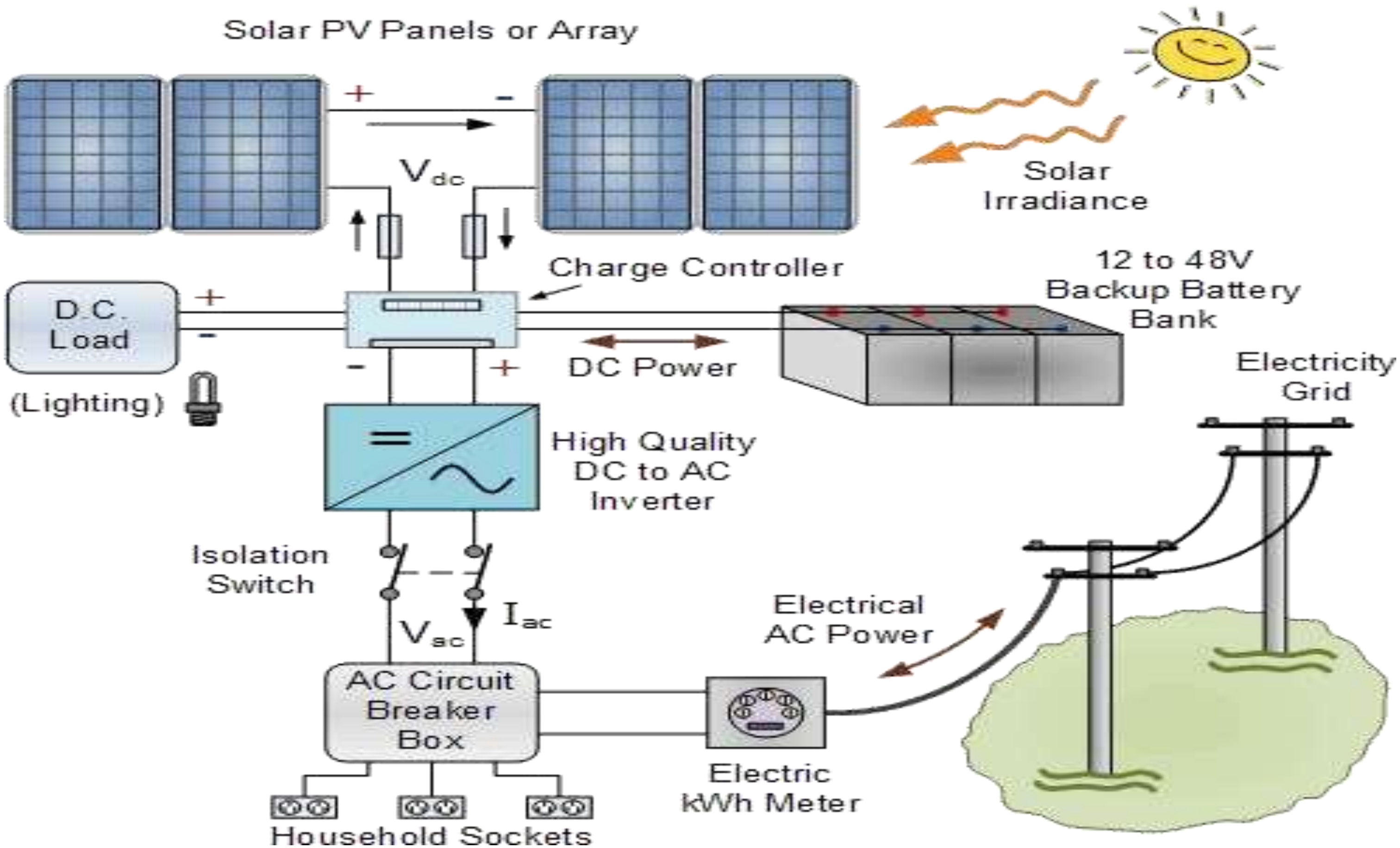
-The inverter is the most important part of any grid connected system.

- The inverter extracts as much DC (direct current) electricity as possible from the PV array and converts it into clean mains AC (alternating current) electricity at the right voltage and frequency for feeding into the grid or for supplying domestic loads.

Electricity Meter:

- The electricity meter also called a Kilowatt hour (kWh) meter is used to record the flow of electricity to and from the grid.

Grid connected system with battery



- The battery charge controller, determines whether the power generated by the solar panels is needed for home use,

UNIT III

Wind Energy

- Wind power or wind energy is the use of wind to provide the mechanical power through wind turbines to operate electric generators.
- Wind power is a sustainable and renewable energy.
- Wind possesses energy by virtue of its motion.

Wind Energy Basics:

- Wind is caused by the uneven heating of the atmosphere by the sun, variations in the earth's surface, and rotation of the earth.
- Wind power is the conversion of wind energy into electricity or mechanical energy using wind turbines. Wind turbines convert the kinetic energy in the wind into mechanical power.

The mechanism used to convert air motion into electricity is referred to as a turbine. The power in the wind is extracted by allowing it to blow past moving blades that exert torque on a rotor. The rotor turns the drive shaft, which turns an electric generator. The amount of power transferred is dependent on the rotor size and the wind speed.

- **Classification of Wind Energy Conversion Systems**

1) Based on axis
   - Horizontal axis machines
   - Vertical axis machines

2) According to size
   - Small size machines (upto 2k W)
   - Medium size machines (2 to 100k W)
   - Large size machines (100k W and above)
     - Single generator at single site
     - Multiple generators

3) Types of output

- DC output
  - DC generator
  - Alternator rectifier
- AC output
  - Variable frequency, variable or constant voltage AC.
  - Constant frequency, variable or constant voltage AC

4) According to the rotational speed of the area turbines

-Constant speed and variable pitch blades

-Nearly constant speed with fixed pitch blades

-Variable speed with fixed pitch blades

-Variable speed constant frequency generating system.

5) As per utilization of output

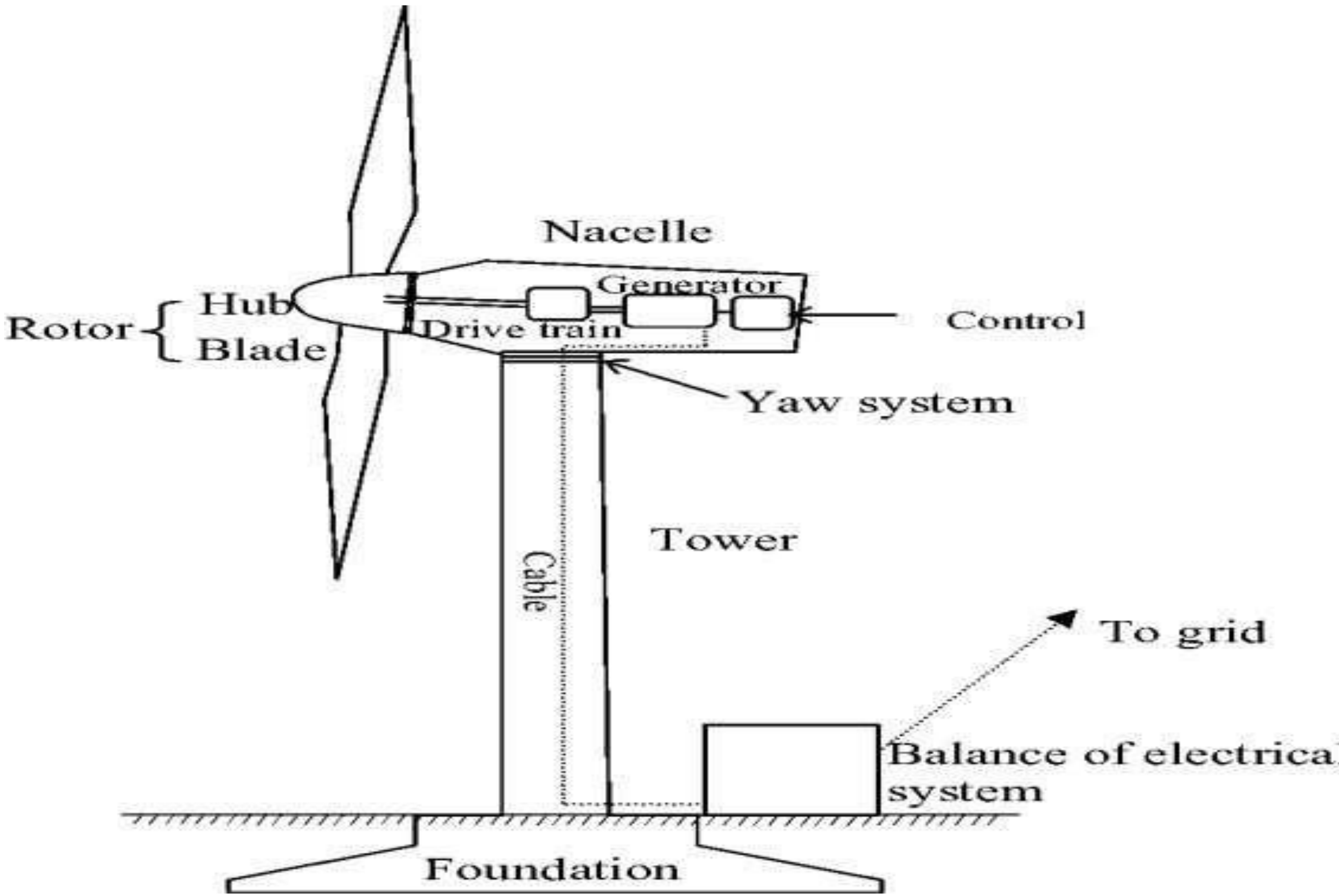
- Battery storage
- Direct conversion to an electro magnetic energy converter
- Thermal potential
- Inter convention with conventional electric utility guides

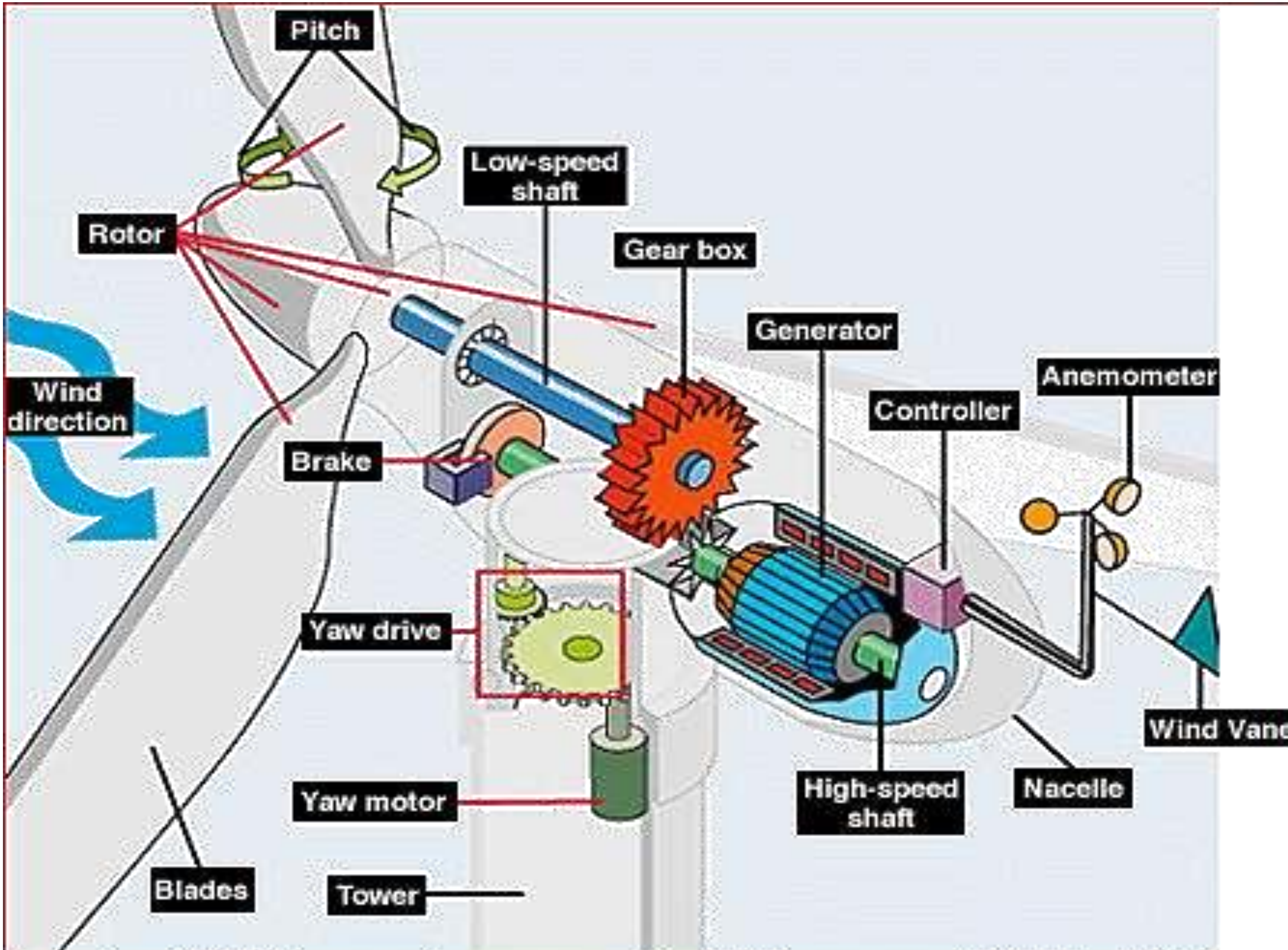
- **Types of wind turbines**

Wind turbines can be separated into two basic types determined by which way the turbine spins.

1) Horizontal Axis Wind Turbines (HAWT)
2) Vertical axis wind turbines (Savonius and Darrieus are the most common)

1) Horizontal Axis Wind Turbines (HAWT)




Pitch
Low-speed shaft
Rotor
Gear box
Generator
Anemometer
Wind direction
Controller
Brake
Yaw drive
Wind Vane
High-speed shaft
Nacelle
Yaw motor
Blades
Tower

Components of HAWT:

-The tower is the physical structure that holds the wind turbine. It supports the rotor, nacelle, blades, and other wind turbine equipment. Typical commercial wind towers are usually 50–120 m long and they are constructed from concrete or reinforced steel.

Blades are physical structures, which are aerodynamically optimized to help capture the maximum power from the wind in normal operation with a wind speed in the range of about 3–15 m/s. Each blade is usually 20m or more in length, depending on the power level.

-The nacelle is the enclosure of the wind turbine generator, gearbox and internal equipment. It protects the turbine‘s internal components from the surrounding environment.

-**The rotor** is the rotating part of the wind turbine. It transfers the energy in the wind to the shaft. The rotor hub holds the wind turbine blades while connected to the gearbox via the low-speed shaft.

The shaft is divided into two types: low and high speed. The low-speed shaft transfers mechanical energy from the rotor to the gearbox, while the high-speed shaft transfers mechanical energy from gearbox to generator

-**Yaw** is the horizontal moving part of the turbine. It is used to control high speed rotor. It turns clockwise or anticlockwise to face the wind. The yaw has two main parts: the yaw motor and the yaw drive. The yaw drive keeps the rotor facing the wind when the wind direction varies. The yaw motor is used to move the yaw.

The brake is a mechanical part connected to the high-speed shaft in order to reduce the rotational speed or stop the wind turbine over speeding or during emergency conditions.

Gearbox is a mechanical component that is used to increase or decrease the rotational speed. In wind turbines, the gearbox is used to control the rotational speed of the generator.

The generator is the component that converts the mechanical energy from the rotor to electrical energy. The most common electrical generators used in wind turbines are induction generators (IGs), doubly fed induction generators (DFIGs), and permanent magnet synchronous generators (PMSGs).

The wind vane is a type of sensor that is used to measure the wind direction. The wind direction information is important for the yaw control system to operate.

- Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind.
- Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.

Working of HAWT:

1) Wind (moving air that contains kinetic energy) blows toward the turbine's rotor blades.
2) The rotors spin around, capturing some of the kinetic energy from the wind, and turning the central drive shaft that supports them.
3) In most large modern turbines, the rotor blades can swivel on the hub at the front so they meet the wind at the best angle (or "pitch") for harvesting energy. This is called the pitch control mechanism.
4) Inside the nacelle (the main body of the turbine sitting on top of the tower and behind the blades), the gearbox converts the low-speed rotation of the drive shaft (16rpm) into high-speed (1600 rpm) rotation

5)The generator, immediately behind the gearbox, takes kinetic energy from the spinning drive shaft and turns it into electrical energy. Running at maximum capacity, a typical 2MW turbine generator will produce 2 million watts of power at about 700 volts.

6)Anemometers (automatic speed measuring devices) and wind vanes on the back of the nacelle provide measurements of the wind speed and direction.

7)The electric current produced by the generator flows through a cable running down through the inside of the turbine tower.

Advantages:

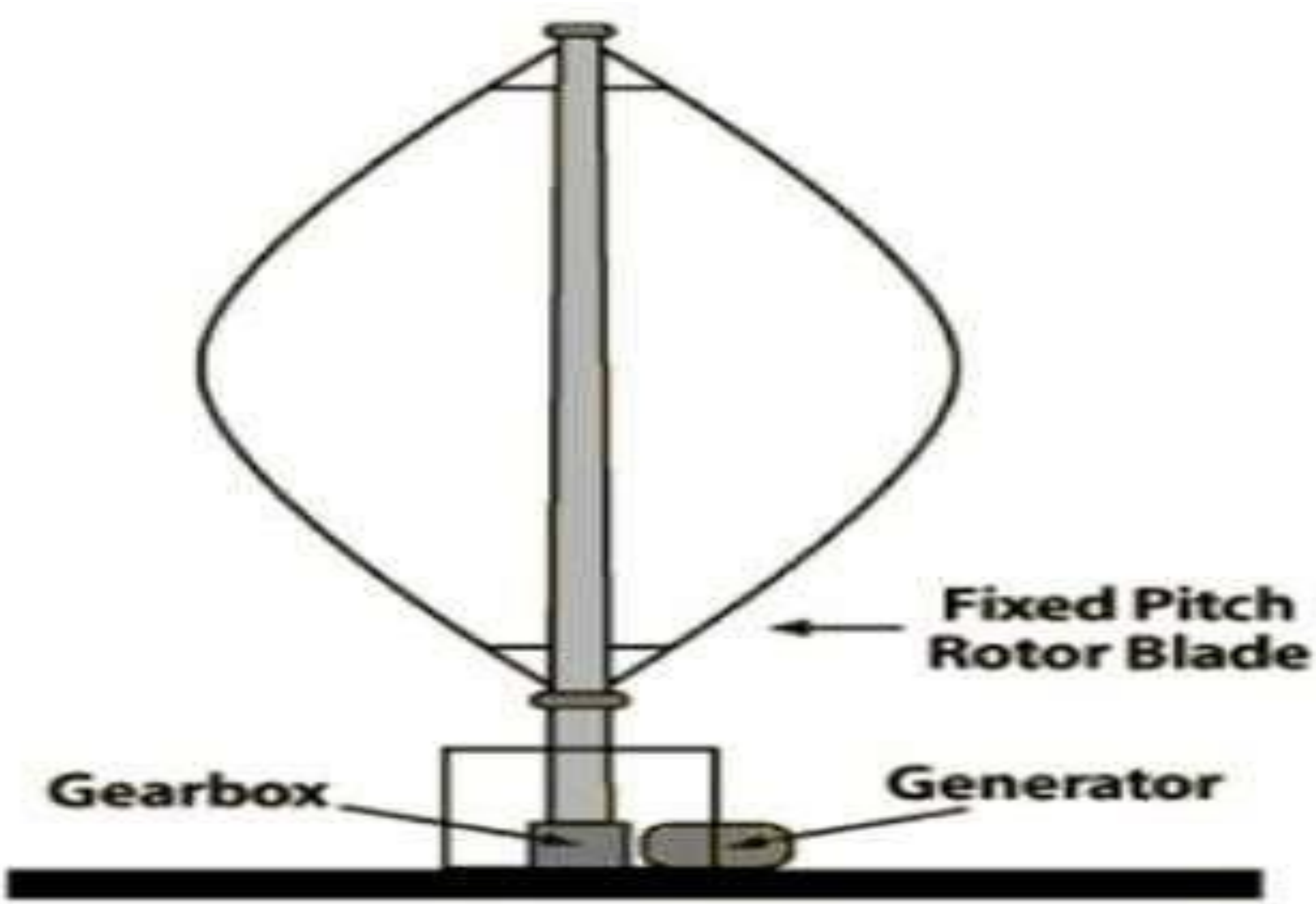
- The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up the wind speed can increase by 20% and the power output by 34%.
- High efficiency, since the blades always move perpendicular to the wind, receiving power through the whole rotation.

Disadvantages:

-Massive tower construction is required to support the heavy blades, gearbox, and generator.

- generally require a braking or yawing device in high winds to stop the turbine from spinning and destroying or damaging itself.
- Components of horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position.

Vertical Axis Wind Turbine (VAWT): Darrieus type:



Vertical axis

-Vertical wind turbines (VAWTs), have the main rotor shaft arranged vertically

- The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind.
- a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier.

Advantages:

-can be located nearer the ground, making it easier to maintain the moving parts.

- have lower wind startup speeds than the typical HAWTs.

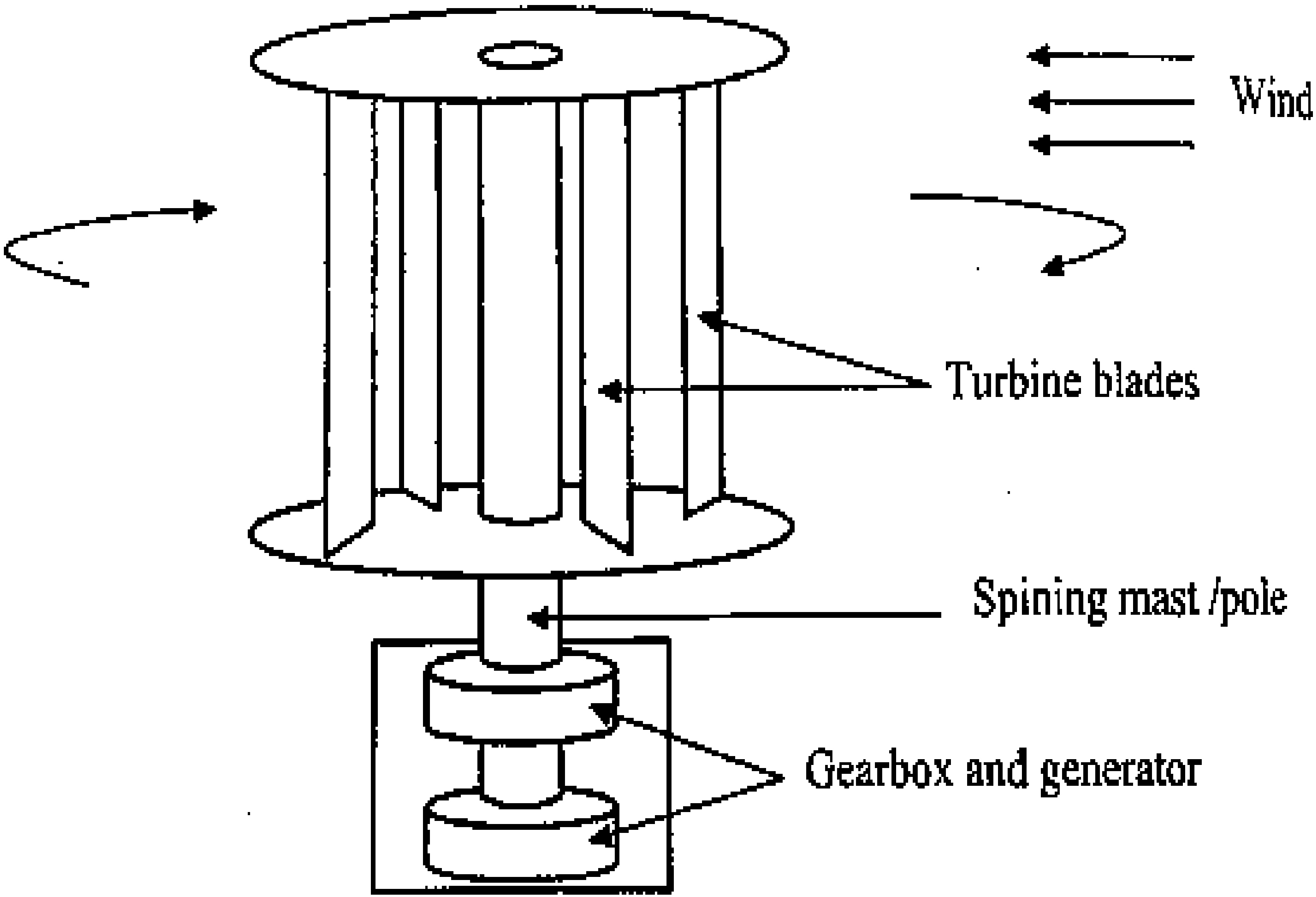
-may be built at locations where taller structures are prohibited.

- No yaw mechanisms is needed.
- The rotor can take wind from every direction.

Disadvantages:

- Most VAWTs have an average decreased efficiency from a common HAWT.
- Having rotors located close to the ground where wind speeds are lower and do not take advantage of higher wind speeds above.

Savonius wind turbine:



-The Savonius wind turbine is a type of vertical-axis wind turbine. It is one of the simplest wind turbine designs. It consists of two to three—scoops||that employ a drag action to convert wind energy into torque to drive a turbine.

- Savonius are excellent in areas of turbulent wind and self starting.

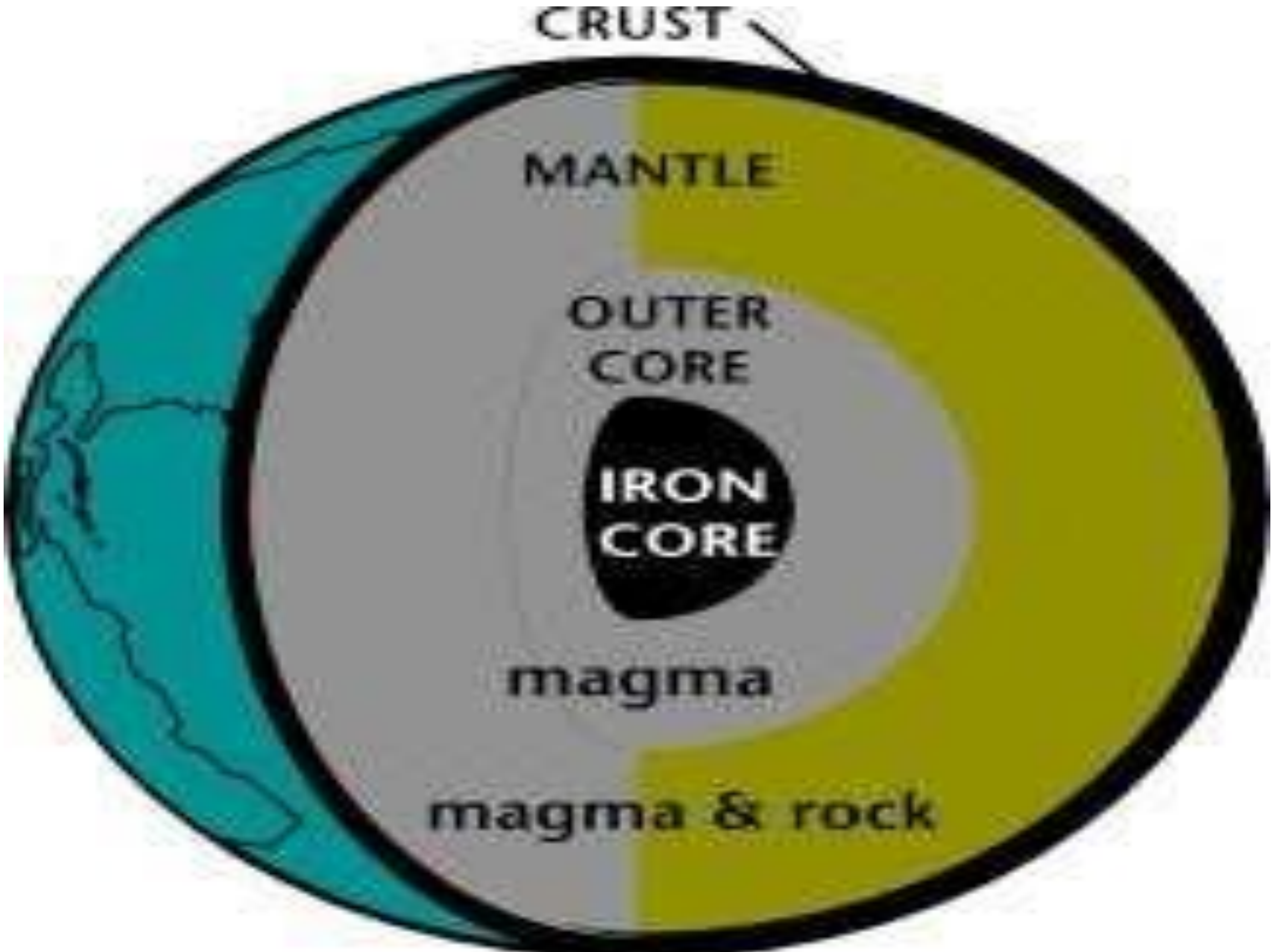
Advantages:

- Having a vertical axis, the Savonius turbine continues to work effectively even if the wind changes direction.
- Because the Savonius design works well even at low wind speeds,there‘s no need for a tower or other expensive structure to hold it in place, greatly reducing the initial setup cost.
- The deviceis quiet, easy to build, and relatively small.
- Because the turbine is close to the ground, maintenance is easy.
- The scoop system used to capture the wind‘s energy is half as efficient as a conventional turbine, resulting in less power generation.

UNIT IV

GEOTHERMAL ENERGY

- The word geothermal comes from greek words geo means earth, and thermal means heat.
- Geothermal energy is heat from with in the earth.
- We can use the steam and hot water produced inside the earth to heat buildings or generate electricity.



THE EARTH'S INTERIOR

Energy inside the earth:

-Geothermal energy is generated in the earth's core, about 4,000 miles below the surface.

The earth has a number of different layers:

- The core itself has two layers: a **solid iron core** and an outer core made of very hot melted rock, called **magma**.
- The **mantle** which surrounds the core and is about 1,800 miles thick. It is made up of magma and rock.

- The **crust** is the outermost layer of the earth, the land that forms the continents and ocean floors. It can be three to five miles thick under the oceans and 15 to 35 miles thick on the continents.
- The earth's crust is broken into pieces called **plates**. Magma comes close to the earth's surface near the edges of these plates. This is where volcanoes occur.
- Deep underground, the rocks and water absorb the heat from this magma.

-People around the world use geothermal energy to heat their homes and to produce electricity by digging deep wells and pumping the heated underground water or steam to the surface.

Classification of Geothermal fields:

Based on the classifying earth's surface divided into three broad groups.

- Non thermal area- having temperature of 10° C to 40° C per km depth
- Semi thermal area- having temperature of 70° C per km depth
- Hyper thermal area- temperature more than non thermal

- Geothermal sources:

General kinds of geothermal sources are

1) Hydrothermal Convective system

   - Vapour dominated or dry steam fields

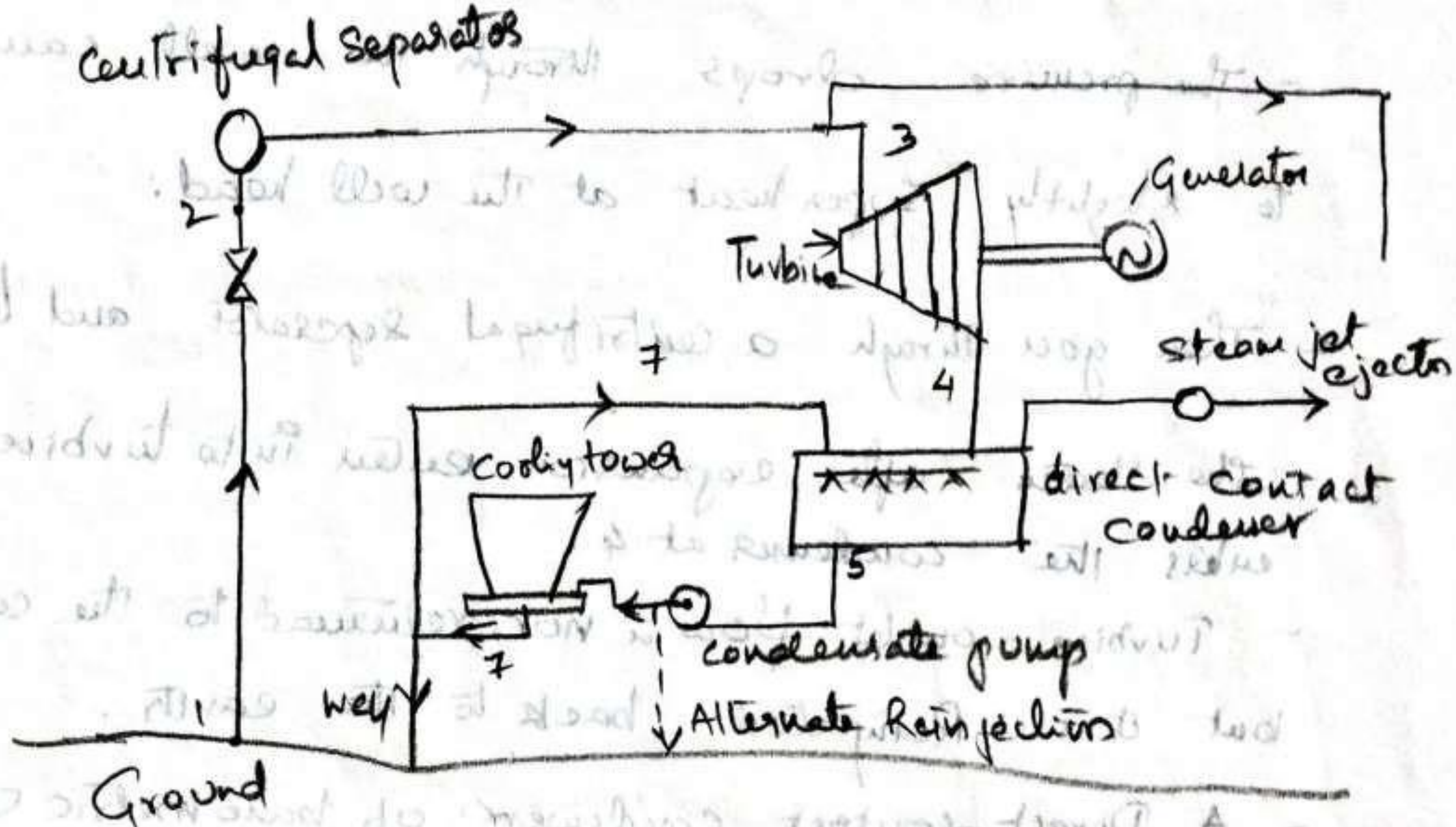
   - Liquid dominated system or wet steam

2) Geo pressure resources

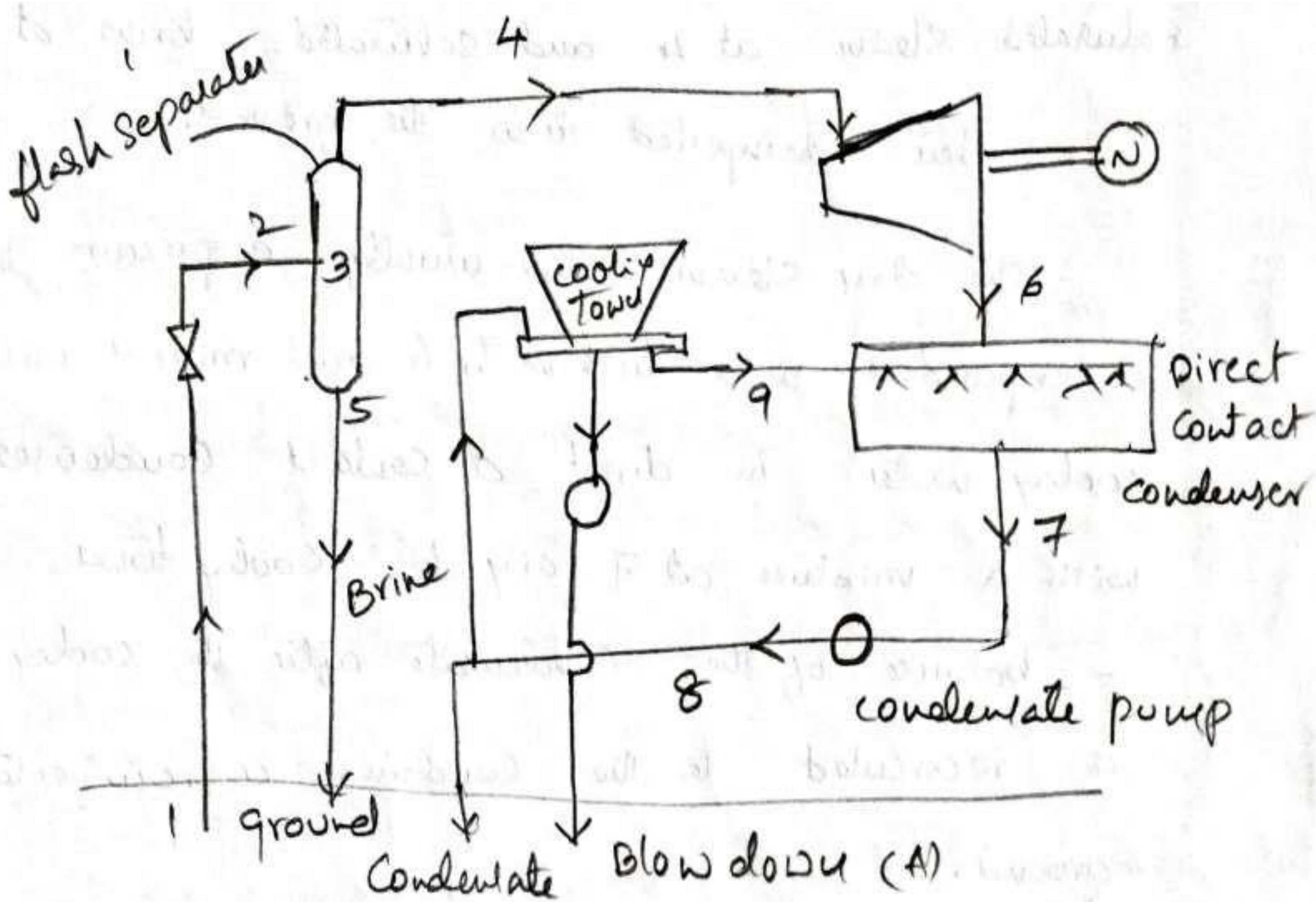
3) Magma resources

4) valconoes

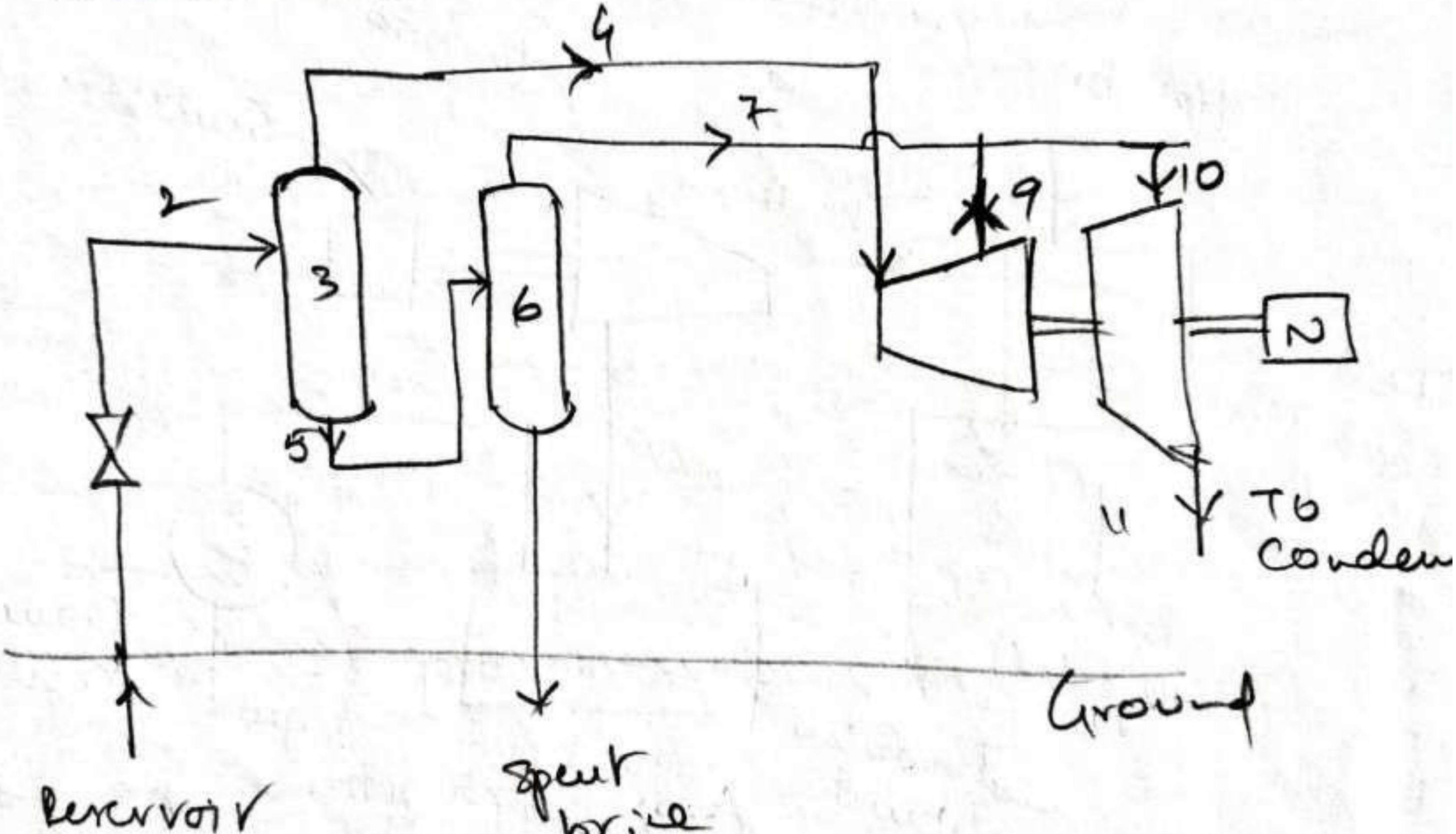
Vapour dominated system:



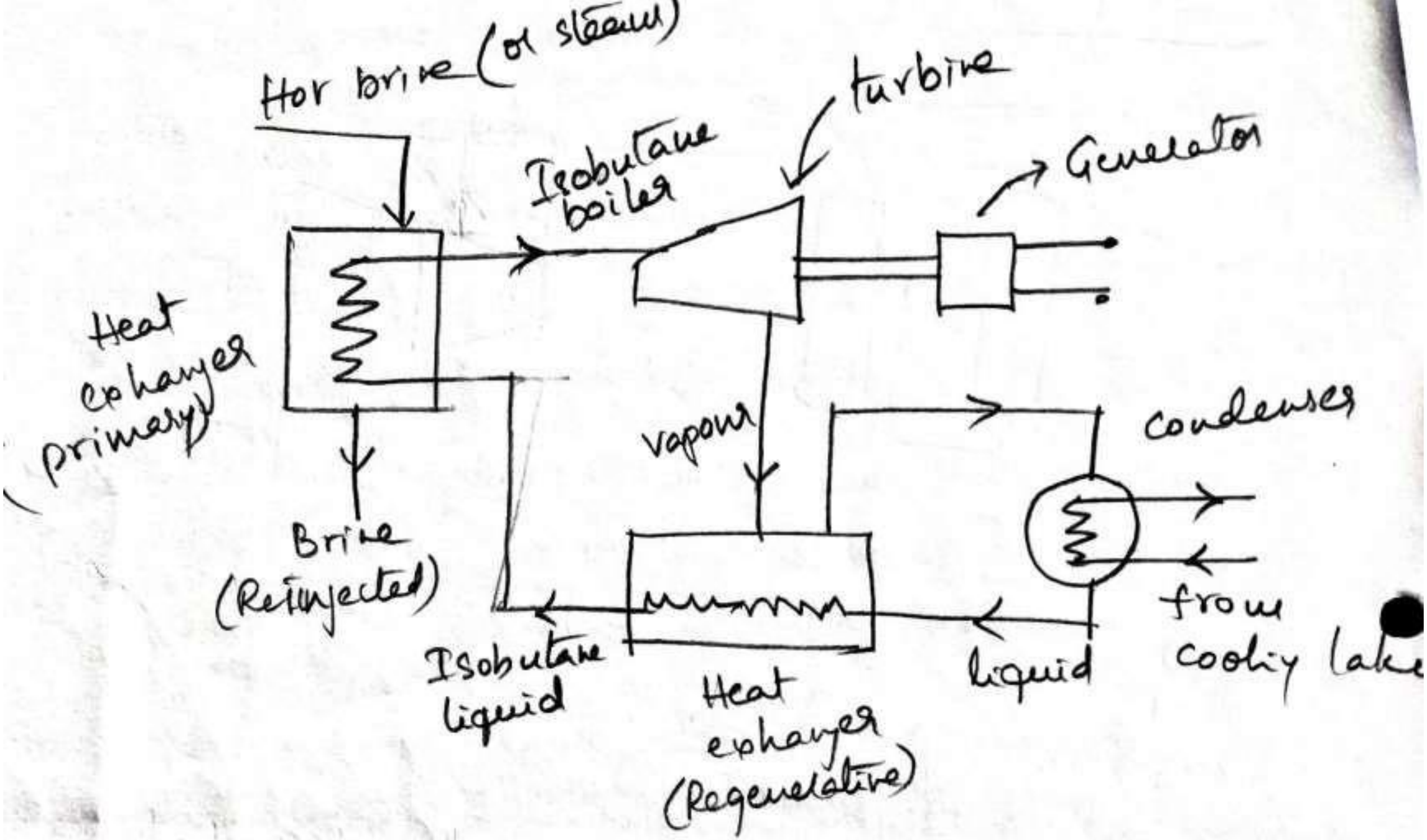
Liquid dominated system: (wet steam fields)



Double flash system



Liquid dominated System (Binary cycle)



UNIT V

Ocean Energy

Introduction:

- The sources of energy from ocean are Ocean Thermal Energy Conversion(OTEC).
- The conversion of solar energy stored as heat in the ocean in to electrical energy by making use of the temperature difference between warm surface water and the colder deep water.

Types of Ocean thermal electric conversion (OTEC).

- Open cycle OTEC system or Claude cycle
- The closed or Anderson OTEC cycle

Open cycle OTEC cycle:

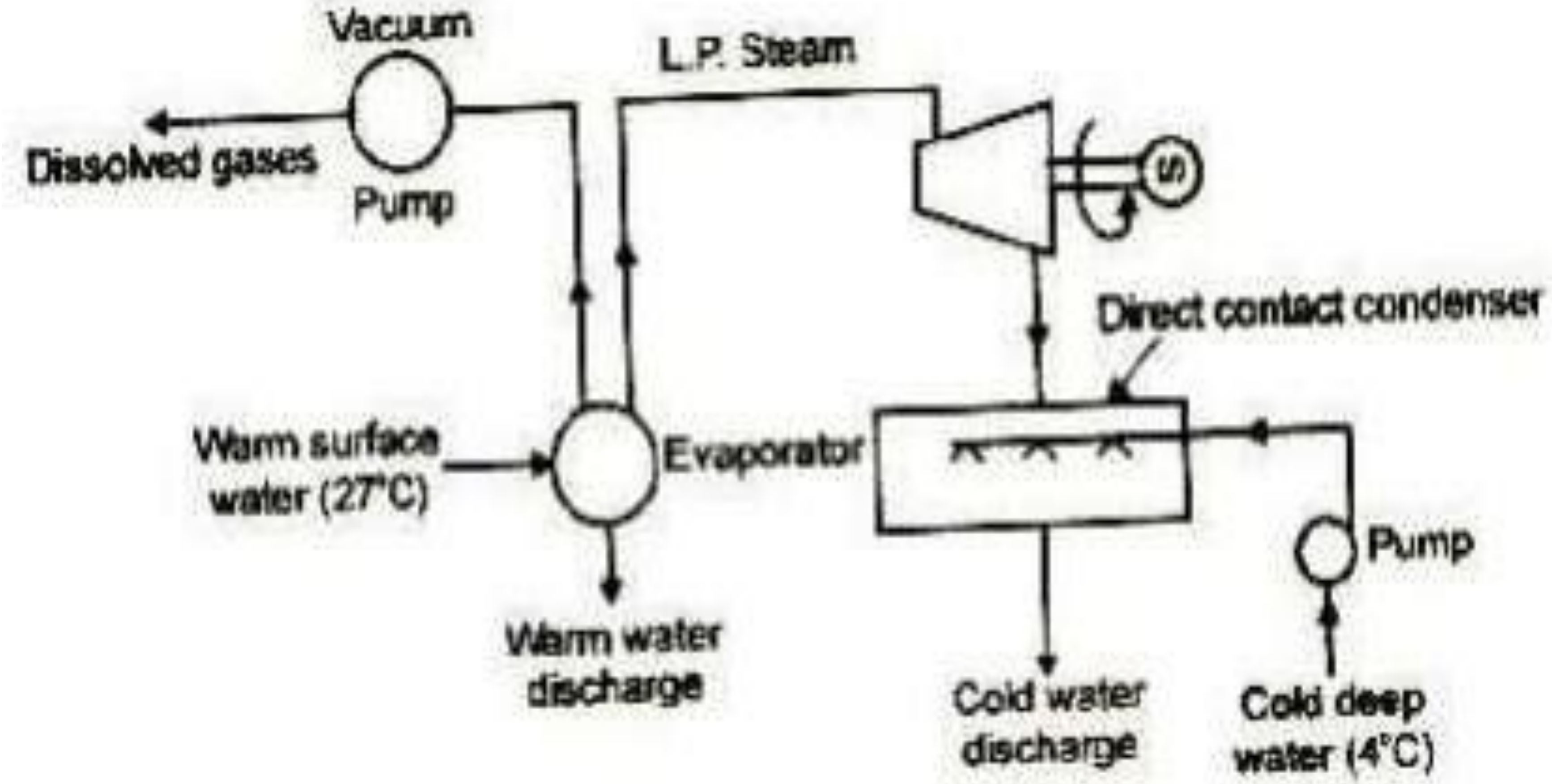


Figure: OTEC – open cycle.

Open cycle OTEC directly uses the warm water from the surface to make electricity. The warm seawater is first pumped into a low-pressure chamber, where it undergoes a drop in boiling point due to the pressure drop. This causes the water to boil. This steam drives a low-pressure turbine which is attached to an electrical generator.

The advantage this system has over a closed system is that, in the open cycle, desalinated water is obtained in the form of steam. Since it is steam, it is free from all impurities

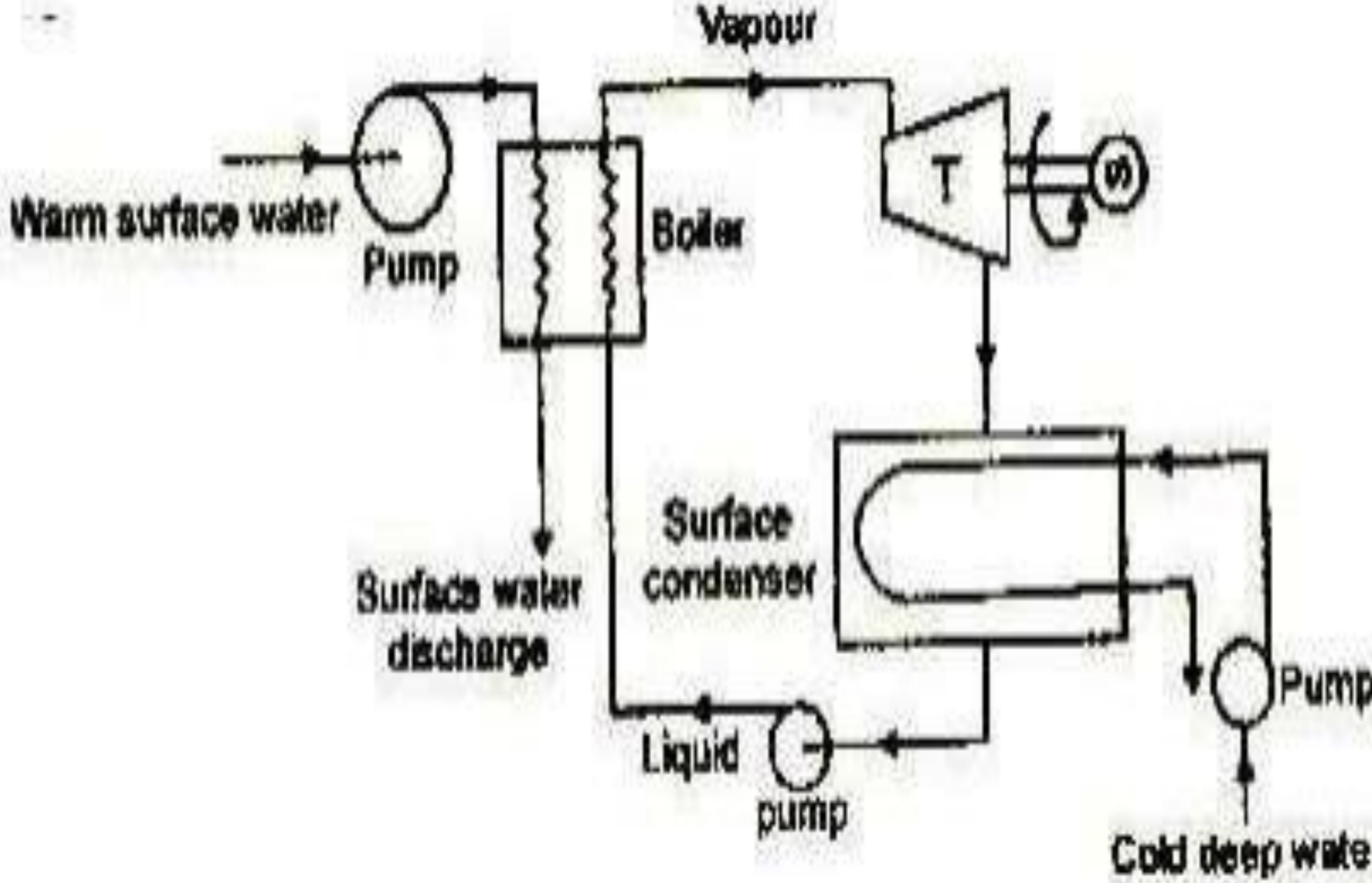


Figure: OTEC – closed cycle

- Closed cycle Ocean Thermal Energy Conversion systems use a working fluid with a low boiling point, Ammonia, for example, and use it to power a turbine to generate electricity. Warm seawater is taken in from the surface of the oceans and cold water from the deep at 5o. The warm seawater vaporises the fluid in the heat exchanger, turning the generator’s turbines.
- The fluid now in the vapour state is brought in contact with cold water, which turns it back into a liquid. The fluid is recycled in the system, which is why it is called a closed system.

BIOMASS

Introduction:

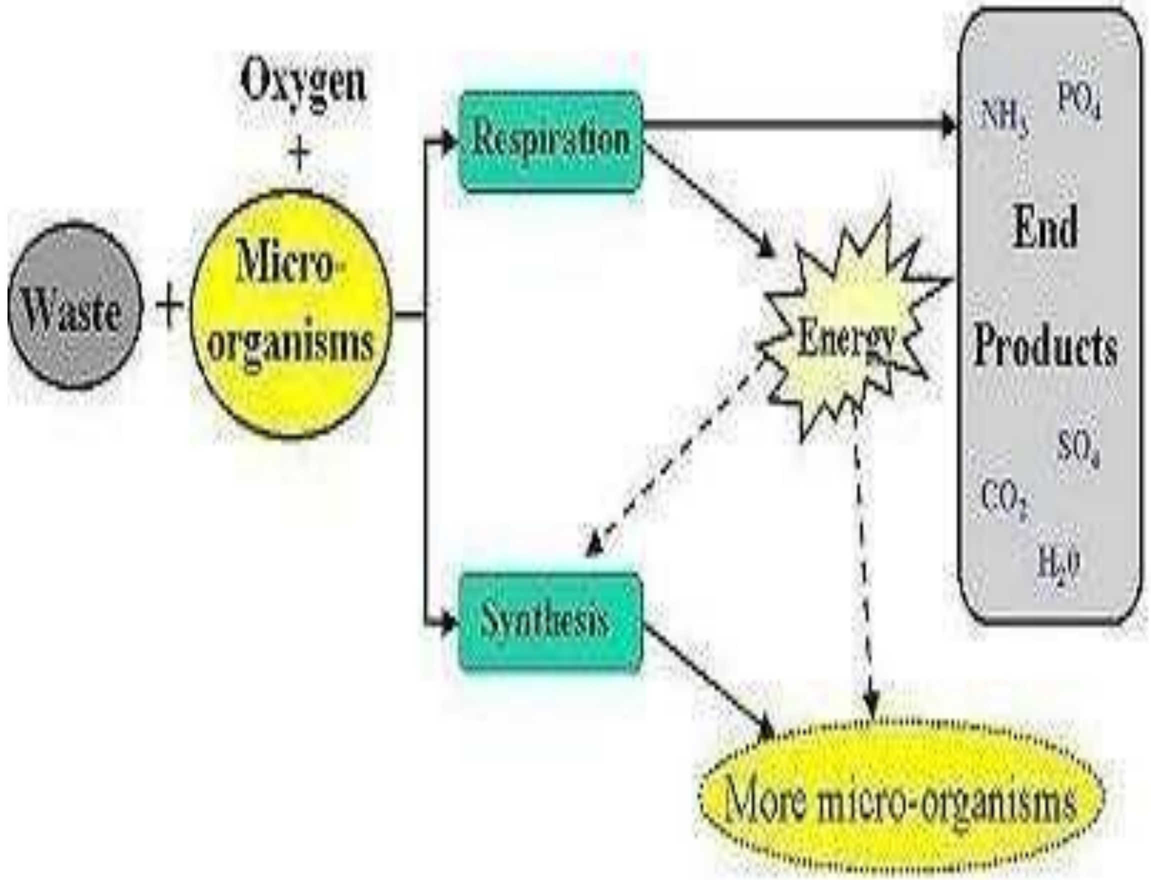
- Biomass energy is organic matter produced by plants which growth both on land and in water. The source of all energy in biomass is the sun, the biomass acting as a kind of chemical energy store. Biomass is constantly undergoing a complex series of physical and chemical transformations and being regenerated while giving off energy in the form of heat to the atmosphere.
- Solar energy--> photo synthesis--> Biomas--> energy generation

Aerobic Digestion:

- Aerobic digestion of waste is the natural biological degradation and purification process in which bacteria that thrive in oxygen-rich environments break down and digest the waste.
- During oxidation process, pollutants are broken down into carbon dioxide (CO_2), water (H_2O), nitrates, sulphates and biomass (microorganisms). By operating the oxygen supply with aerators, the process can be significantly accelerated. Of all the biological treatment methods, aerobic digestion is the most widespread process that is used throughout the world.

- Advantages :

Aerobic bacteria are very efficient in breaking down waste products. The result of this is; aerobic treatment usually yields better effluent quality that that obtained in anaerobic processes. The aerobic pathway also releases a substantial amount of energy. A portion is used by the microorganisms for synthesis and growth of new microorganisms.



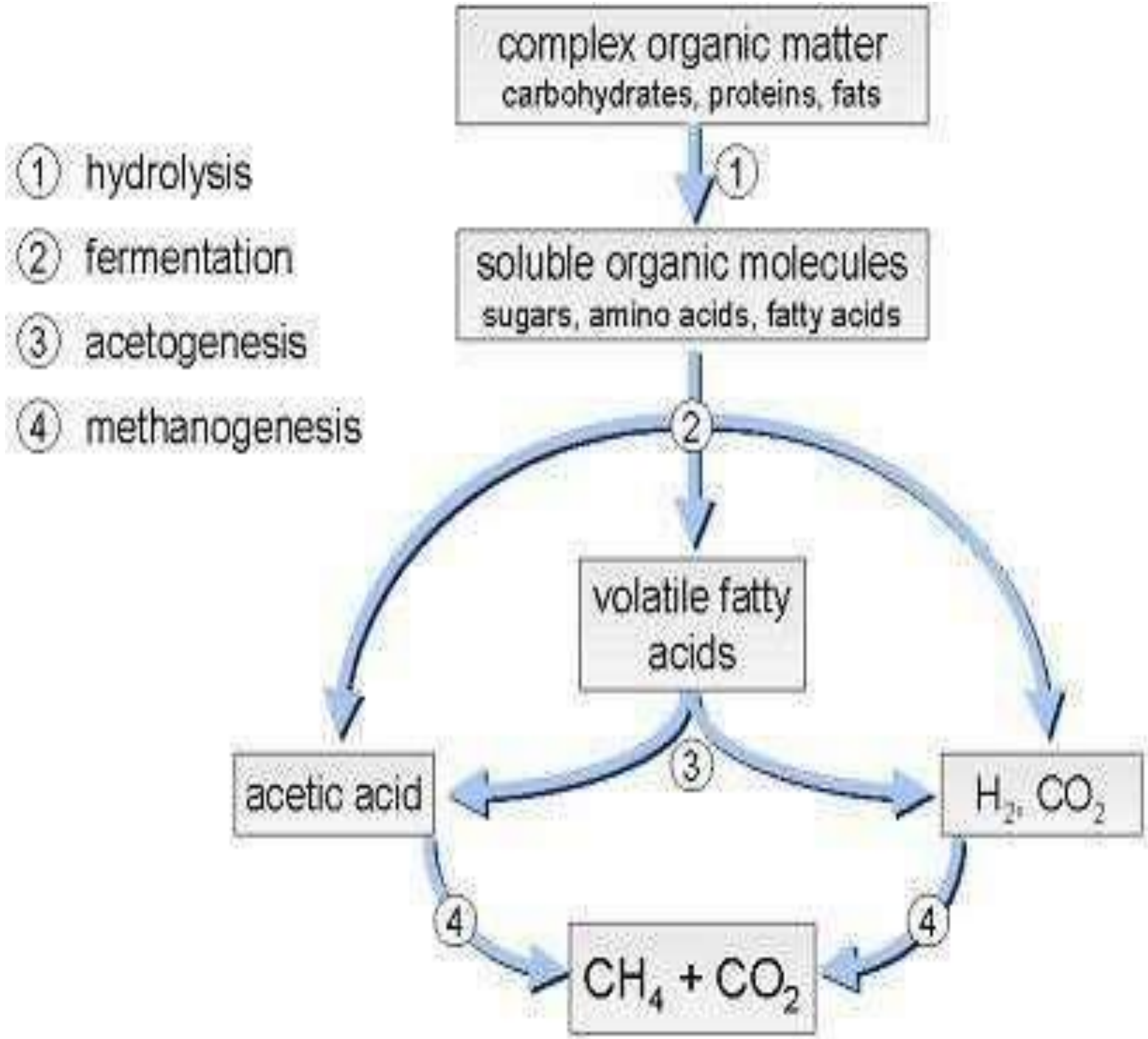
Oxygen
+
Waste
+
Micro-
organisms
Respiration
Synthesis
Energy
End
Products
NH3
PO4
SO4
CO2
H2O
More micro-organisms

- Anaerobic Digestion:

Anaerobic digestion is a complex biochemical reaction carried out in a number of steps by several types of microorganisms that require little or no oxygen to live. During this process, a gas that is mainly composed of methane and carbon dioxide, also referred to as biogas, is produced. The amount of gas produced varies with the amount of organic waste fed to the digester and temperature influences the rate of decomposition and gas production.

Anaerobic digestion occurs in four steps:

- Hydrolysis : Complex organic matter is decomposed into simple soluble organic molecules using water to split the chemical bonds between the substances.
- Fermentation or Acidogenesis: The chemical decomposition of carbohydrates by enzymes, bacteria, yeasts, or molds in the absence of oxygen.
- Acetogenesis: The fermentation products are converted into acetate, hydrogen and carbon dioxide by what are known as acetogenic bacteria.
- Methanogenesis: Is formed from acetate and hydrogen/carbon dioxide by methanogenic bacteria.



① hydrolysis
② fermentation
③ acetogenesis
④ methanogenesis
complex organic matter
carbohydrates, proteins, fats
soluble organic molecules
sugars, amino acids, fatty acids
volatile fatty acids
acetic acid
H_2, CO_2
$CH_4 + CO_2$

Classification of biogas plants:

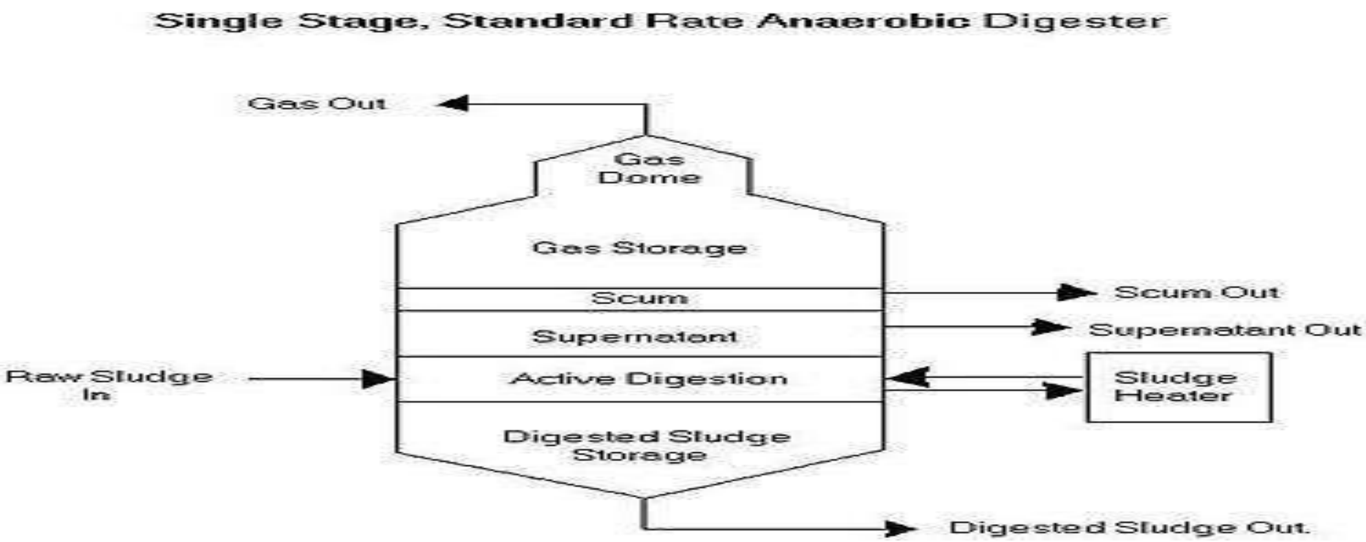
1) Continuous and batch type

- Single stage
- Double stage

2) Dome and drum type

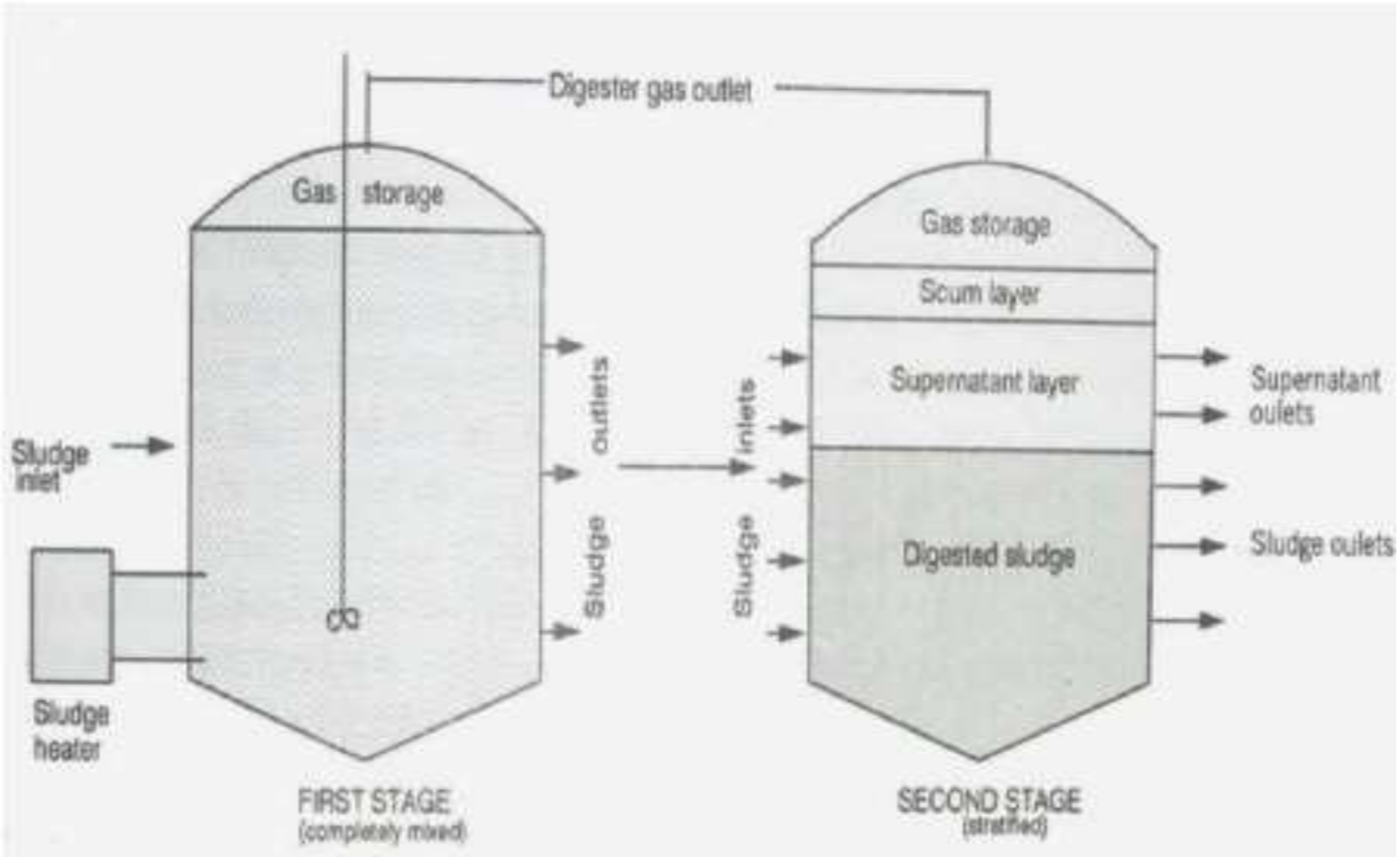
- The floating gas holder digester
- Fixed dome digester

Single stage:



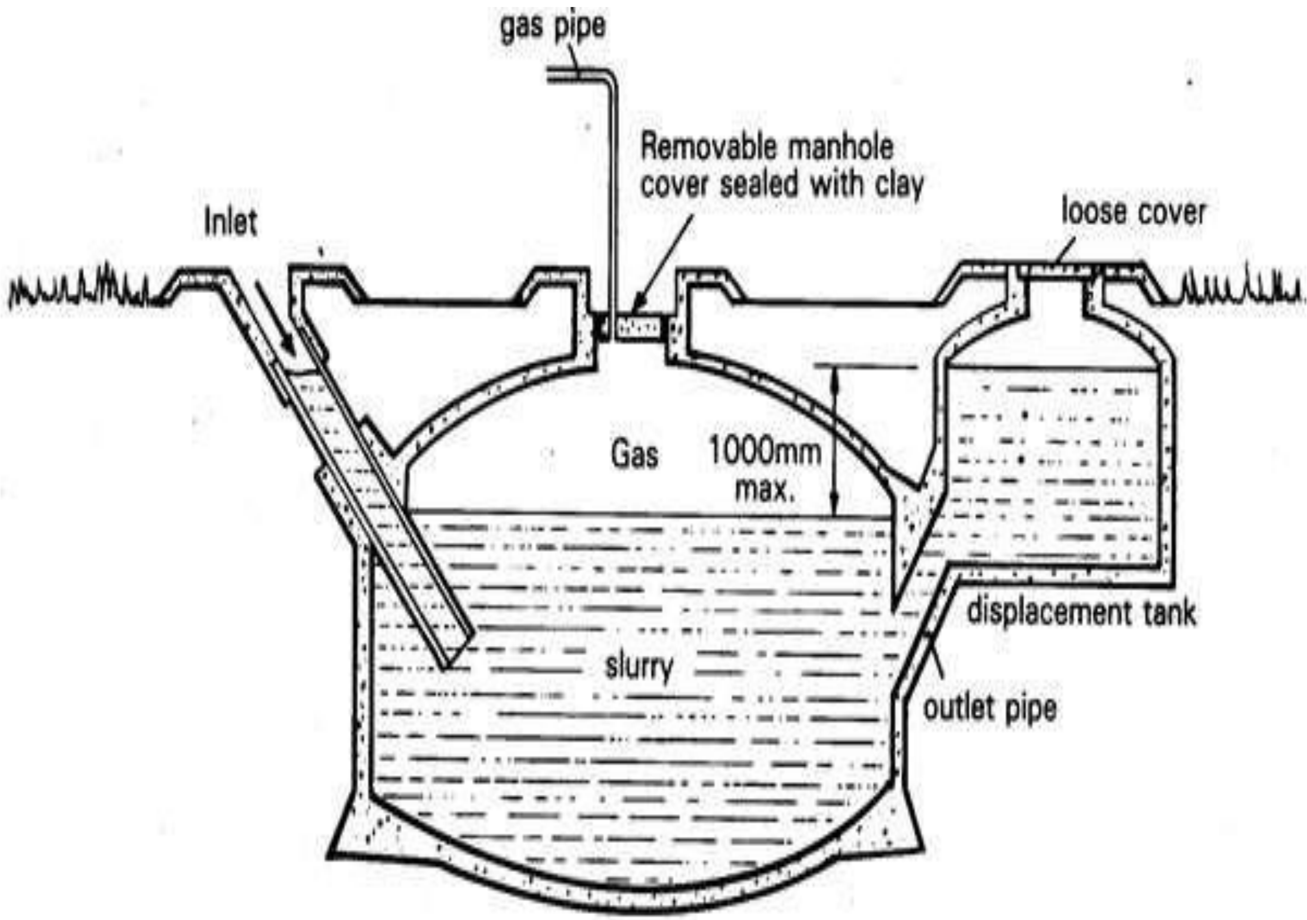
This refers to mixed fermentation with only one biogas digester (or fermentation device), and its fermentation process is only carried out in one fermentation digester. The equipment for single-stage fermentation is simple, but its condition control is difficult.

Double stage:



In order to improve the digestibility and removal rate of organic matter, a two-stage or multistage biogas fermentation process has been developed. This type of fermentation is characterized by fermentation in two or more connected fermentation ponds. The raw materials are decomposed and gas is produced in the first fermentation pool over a certain period of time, then the feed liquid is transferred from the first fermentation pool to the second or other fermentation pools for further fermentation. The fermentation process has a long detention period and decomposes organic matter completely, but the investment cost is higher.

Fixed dome type:



- A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gas- holder and a displacement pit, also named ’compensation tank’. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gasholder, the gas pressure is low.
- Digester:

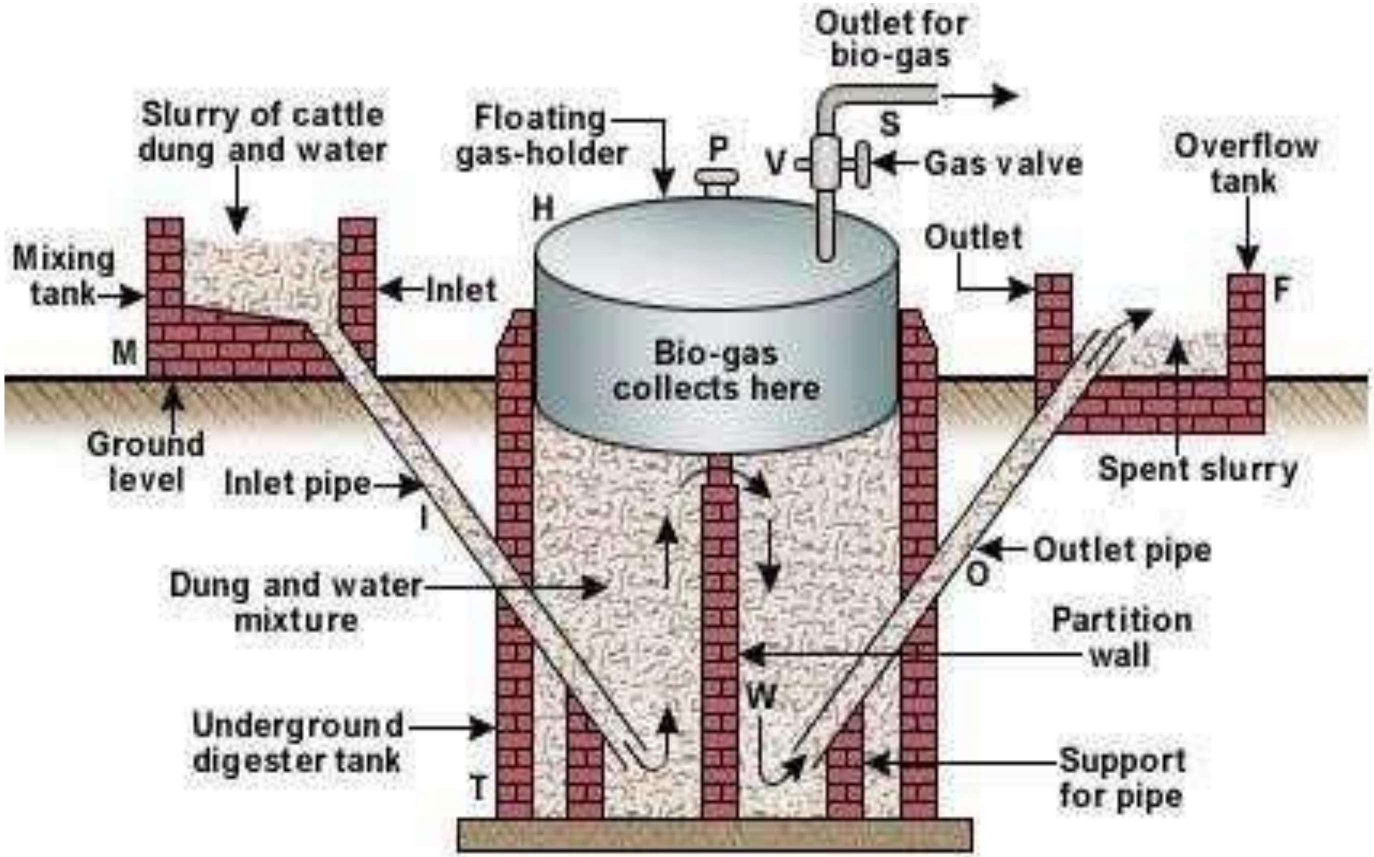
  The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferro-cement exist. Main parameters for the choice of material are:

  Technical suitability (stability, gas- and liquid tightness);

  cost-effectiveness;

- **Advantages:** Low initial costs and long useful life-span; no moving or rusting parts involved; basic design is compact, saves space and is well insulated; construction creates local employment.
- **Disadvantages:** Masonry gas-holders require special sealants and high technical skills for gas-tight construction; gas leaks occur quite frequently; fluctuating gas pressure complicates gas utilization; amount of gas produced is not immediately visible, plant operation not readily understandable; fixed dome plants need exact planning of levels; excavation can be difficult and expensive in bedrock.

Floating gas holder type:



Floating gas-holder type bio-gas plant.

In the past, floating-drum plants were mainly built in India. A floating-drum plant consists of a cylindrical or dome shaped digester and a moving, floating gas-holder, or drum. The gas-holder floats either directly in the fermenting slurry or in a separate water jacket. The drum in which the biogas collects has an internal and/or external guide frame that provides stability and keeps the drum upright. If biogas is produced, the drum moves up, if gas is consumed, the gas holder sinks back.

Advantages: Floating-drum plants are easy to understand and operate. They provide gas at a constant pressure, and the stored gas-volume is immediately recognizable by the position of the drum. Gas- tightness is no problem, provided the gasholder is de-rusted and painted regularly.

Disadvantages: The steel drum is relatively expensive and maintenance-intensive. Removing rust and painting has to be carried out regularly. The life-time of the drum is short (up to 15 years; in tropical coastal regions about five years). If fibrous substrates are used, the gas-holder shows a tendency to get "stuck" in the resultant floating scum.