MIT Art Design and Technology University

MIT School of Computing, Pune

Department of Applied Sciences and Humanities

First Year Engineering

23ASH1105-Engineering Physics

Class – F.Y. (SEM-II)

Unit – V Physics for Sustainable Energy

Dr. Bhavik Kodrani

AY 2024-2025 SEM-II

Unit V - Syllabus

Physics for Sustainable Energy

- Broad overview of renewable energy and its need
- Solar energy, Solar cells, efficiency of Solar cell
- Wind energy: Basic components and principle of wind energy conversion
- Ocean energy: Tidal energy
- Geothermal energy
- Biomass: Biomass and bio-fuels

Physics for Sustainable Energy

- Humans require energy for various activities such as heating, cooling, transportation.
- Conventional sources of energy are wood, coal, biomass, fossil fuels.
- Fossil fuels (or Non-Renewable energy) are things like oil, gas, coal formed over hundreds of millions of years when plants and sea creatures rot away, fossilize, and get buried under the ground, then squeezed and cooked by Earth's inner pressure and heat.
- As the population is increasing and living standards are improving, the demand for energy is increasing day by day.
- The reserve for fossil fuels are limited and are expected get depleted soon.
- Therefore it has become necessary to find the alternative sources of energy.

- Green energy also called Renewable energy is a term used to refer to forms of energy that are naturally obtained from the environment and from sources that can be replenished naturally.
    - Solar energy
    - Wind energy
    - Tidal Energy
    - Geothermal energy
    - Biomass

Solar Energy

Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, artificial photosynthesis.

Solar thermal power (sometimes called passive-solar energy or passive-solar gain) means absorbing the Sun's heat into solar hot water systems or using it to heat buildings with large glass windows.

Solar cell

- A solar cell, or photovoltaic cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect.
- Solar cells are the building blocks of photovoltaic modules, which are known as solar panels.
- The most commonly known solar cell is configured as a large-area p-n junction made from silicon by diffusing an n-type dopant into one side of a p-type wafer (or vice versa).

- A proper metal contacts are made on the n-type and p-type side of the semiconductor for electrical connection.
- The surface is coated with anti-refection coating to avoid the loss of incident light energy due to reflection.

- **Basic working Principle**

- Solar cells are based on the photo voltaic effect, in which a potential difference is generated by the separation of electrons and holes in the built-in electric field of a p-n junction.

- When light reaches the p-n junction, the light photons which have energy higher than 'eV$_{oc}$' or band gap (E$_g$) can easily enter in the junction, through very thin p-type layer.

- The incident light, breaks the thermal equilibrium condition of the junction and create pair of holes and electrons. The free electrons in the depletion region can quickly come to the n-type side of the junction.

- Similarly, the holes in the depletion can quickly come to the p-type side of the junction. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs.

- In order for an electron to make the leap from the valence band to the conduction band, it requires a boost of "band gap" energy. Electrons can gain enough energy to jump to the conduction band by absorbing either a "phonon" (heat) or a "photon" (light) with at least band gap energy.

- Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction. Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction.

- As the concentration of electrons becomes higher in one side i.e. n-type side of the junction and concentration of holes becomes more in another side i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell.

- A voltage is set up which is known as photo voltage.

- The built-in voltage is created which is approximately 0.6 to 0.7 volts. This voltage is the significant factor in the operation of the pn juction and the solar cell.

- The voltage provides the driving force to the electron flow (current) created by sunlight photons striking the semiconductor and freeing up electrons to do "work".

- If an external conductive path is provided, electrons will flow through that path to unite with holes on the other side of the junction.

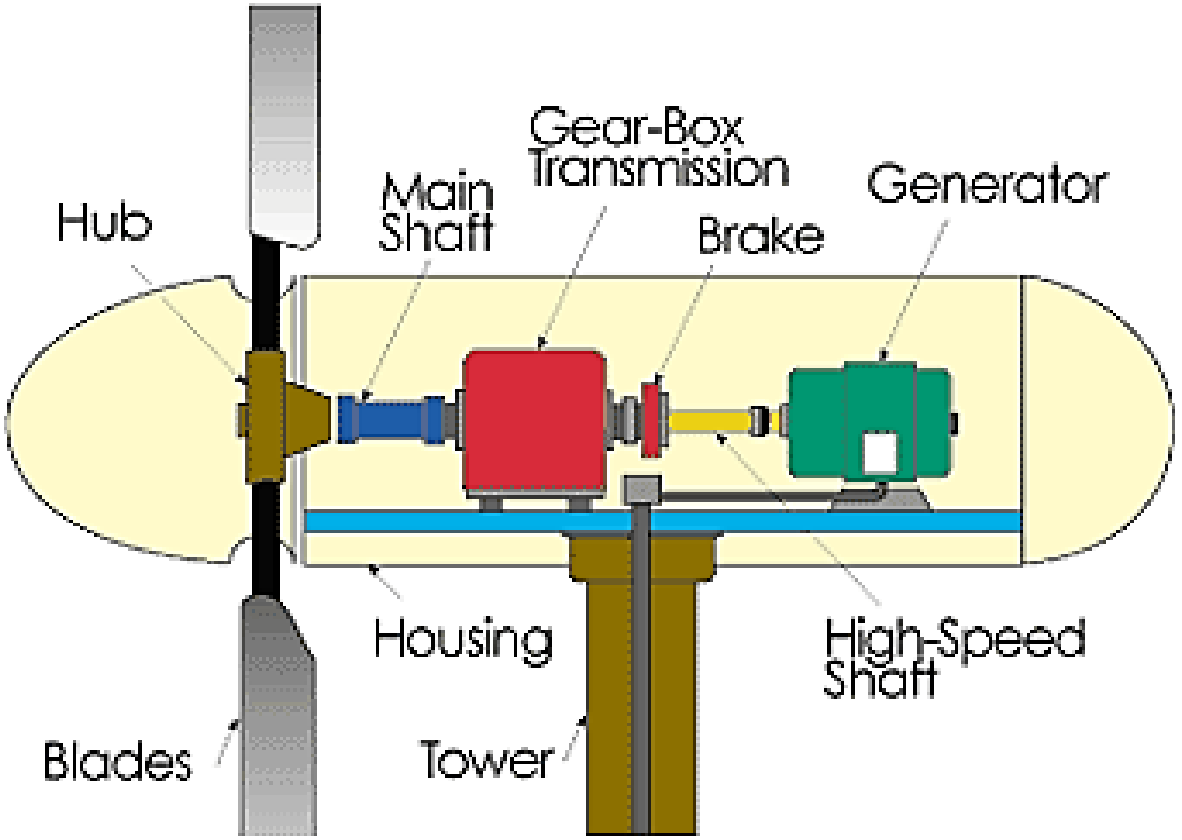
Advantages

- It is clean and non-polluting
- It is a renewable energy
- Solar cells do not produce noise and they are totally silent.
- They require very little maintenance
- They are long lasting sources of energy which can be used almost anywhere
- There are no fuel costs or fuel supply problems

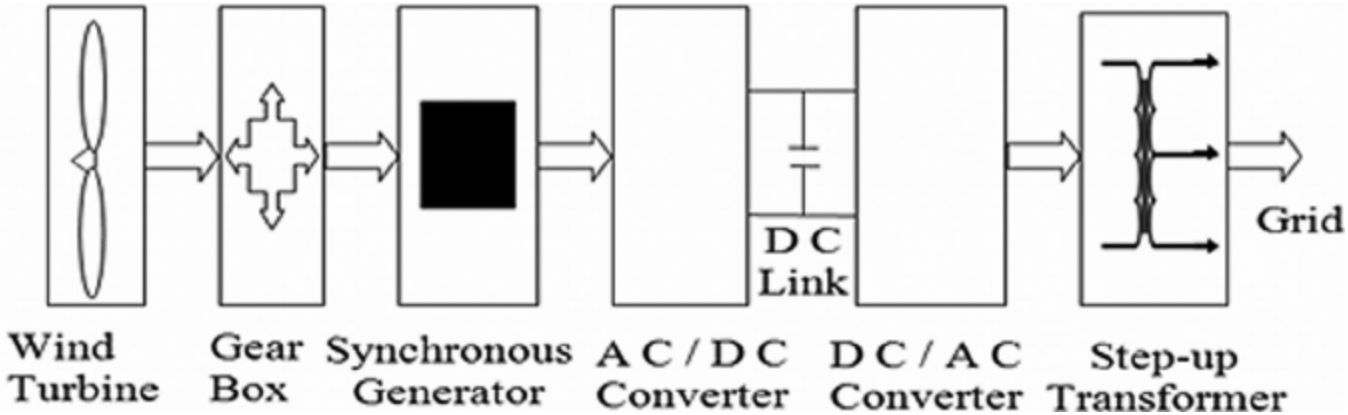
Disadvantages

- Solar power cannot be obtained in night time
- Solar panels are expensive
- Energy has to be stored in batteries
- Air pollution and whether can affect the production of electricity
- They need large area of land to produce more efficient power supply

Wind energy



Source: Iowa Energy Center



Basic principle and Working of wind turbines

- Wind energy is conversion of kinetic energy (i.e. energy of motion of the wind) into mechanical energy that can be utilized to generate electricity.
- The wind blows against the blades and they rotate about the axis. The rotational motion is converted to energy by wind turbines because wind turbines produce rotational motion.
- Wind-energy is readily converted into electrical energy by converting the turbine into an electrical generator.
- Wind turbines are used to produce electricity. The windmills that generate electricity are conventional in their propeller design, which employs 2 or 3 tapered blades.
- The axle of the windmill is connected to the shaft of an armature in the generator. When the fast moving wind rotates the blades of the windmill, the armature inside the generator rotates and produces electricity.

Major components of the comercial wind turbine

- **Tower**- Tower supports the rotor and wind turbine at the desired height.
- **Rotor** - Rotor is the most important part in the wind energy turbine. It receives kinetic energy of the wind stream and transform into machanical shaft power. It connected to the blades hub.
- **Blades** - The blades are basically the sails of the system; in their simplest form, they act as barriers to the wind. When the wind forces the blades to move, it has transferred some of its energy to the rotor.
- **Shafts** - The wind-turbine shaft is connected to the center of the rotor. When the rotor spins, the shaft spins as well. In this way, the rotor transfers its mechanical, rotational energy to the shaft, which enters an electrical generator on the other end.

- **Generator** - It uses the properties of electromagnetic induction to produce electrical voltage A simple generator consists of magnets and a conductor. The conductor is typically a coiled wire. Inside the generator, the shaft connects to an assembly of permanent magnets that surrounds the coil of wire.

- **Pitch Control system**- The turbine's electronic controller monitors the turbine's power output. At wind speeds over 45 miles per hour (mph) the power output will be too high, at which point the controller tells the blades to alter their pitch so that they become unaligned with the wind. This slows the blades' rotation. Pitch-controlled systems require the blades' mounting angle (on the rotor) to be adjustable.

- **Active stall control** - The blades in this type of power-control system are pitchable, like the blades in a pitch-controlled system. An active stall system reads the power output the way a pitch-controlled system does, but instead of pitching the blades out of alignment with the wind, it pitches them to produce stall.

- **Passive stall control** - The blades are mounted to the rotor at a fixed angle but are designed so that the twists in the blades themselves will apply the brakes once the wind becomes too fast.

Advantages

- Wind power is clean, and it's renewable.
- It doesn't release harmful gases like CO_2 and nitrogen oxides into the atmosphere.
- A wind turbine can bring electricity to remote areas not served by the central power grid.

Disadvantages

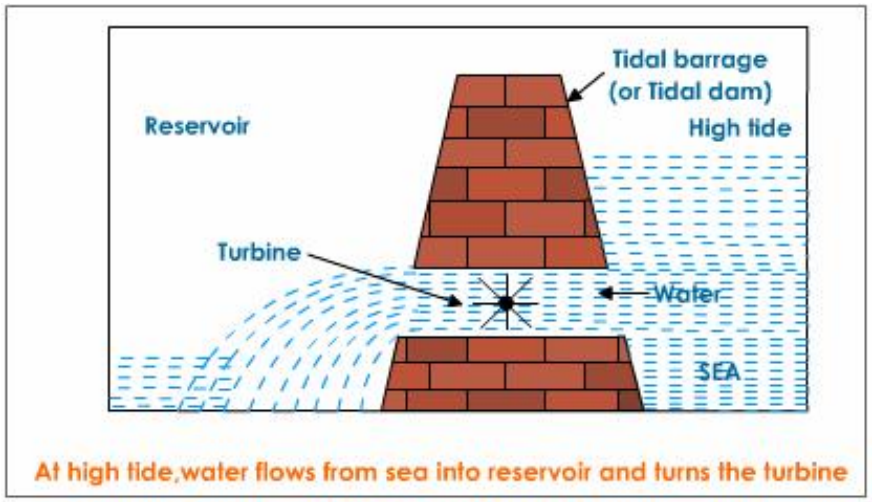
- Wind turbines can't always run at 100 percent power like many other types of power plants, since wind speeds fluctuate.
- Wind turbines can be noisy if you live close to a wind plant.
- Wind turbines can be hazardous to birds and bats.
- Wind is a relatively unreliable source of energy, operators of wind-power plants have to back up the system with a small amount of reliable, non-renewable energy for times when wind speeds die down.

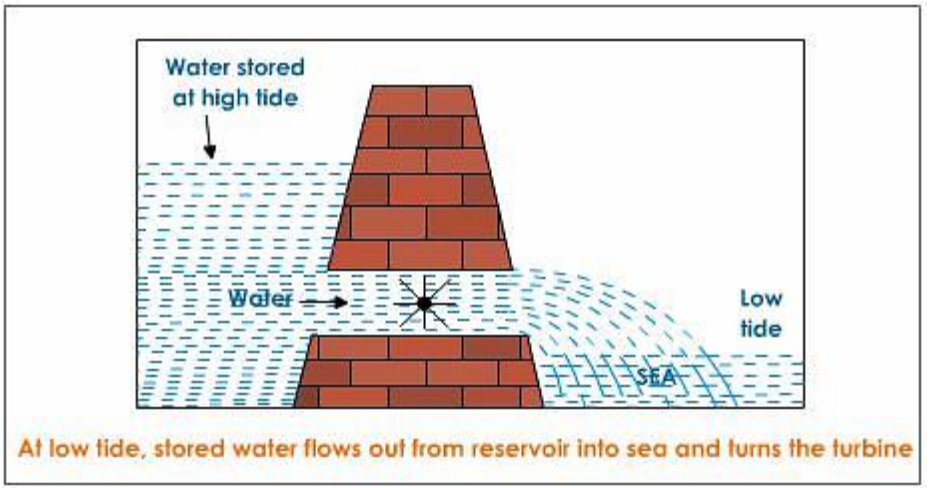
Ocean energy

- Oceans cover more than 70 percent of Earth's surface, so clearly they represent an enormous energy resource. Ocean power is a never-ending resource.

Tidal energy

- Tidal stream generators (or TSGs) make use of the kinetic energy of moving water to power turbines, in a similar way to wind turbines that use wind to power turbines.





- During high tide, when the level of water in the sea is high, sea-water flows into the reservoir of the barrage and turns the turbines. The turbines then turn the generator shaft to produce electricity.
- During low tide, the sea-water stored in the barrage reservoir is allowed to flow out into the sea. This flowing water also turns the turbines and generates electricity. Thus, as the sea-water flows in and out of the tidal barrage during high and low tides, the turbines rotate continuously to generate electricity.
- The energy conversion involved in a tidal power plant is given below:

Advantages

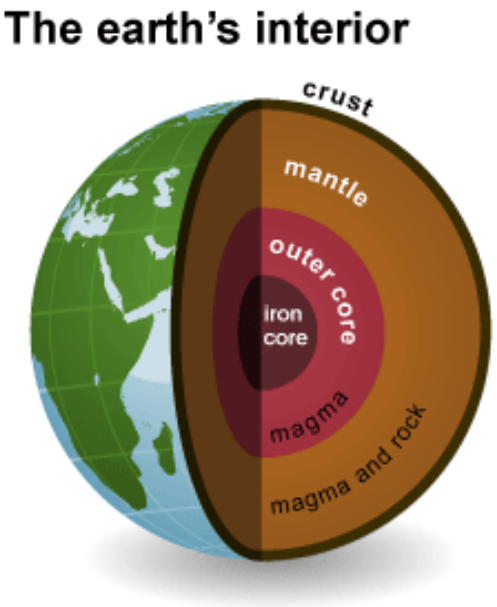
- Ocean power systems require less space and far fewer units than wind farms or solar arrays.
- The equipment used to deliver ocean power is located offshore, either on the surface or below the surface, so the systems don't block views or interfere with aviation or radar.
- They also run silently, unlike wind turbines, which can produce aerodynamic noise

Disadvantages

- Disturbance or destruction of marine life.
- Possible threat to navigation from collisions due to the low profile of the wave energy devices above the water, making them undetectable either by direct sighting or by radar. Also possible is the interference of mooring and anchorage lines with commercial and sport-fishing.
- Degradation of scenic ocean front views from wave energy devices located near or on the shore, and from onshore overhead electric transmission lines
- Salt water causes corrosion in metal parts. It can be difficult to maintain tidal stream generators due to their size and depth in the water.

Geothermal energy

- Deep inside the Earth lies hot water and steam that can be used to heat our homes and businesses and generate electricity cleanly and efficiently. It's called geothermal energy.



- There is plenty of heat in the center of the Earth. The deeper you dig, the hotter it gets. Part of that heat is left over from the Earth's formation, about 4 billion years ago. The rest comes from the constant decay of radioactive isotopes inside the Earth.

- The heat inside the Earth is intense enough to melt rocks. Those molten rocks are known as **magma**. Because magma is less dense than the rocks surrounding it, it rises to the surface.
- Sometimes magma escapes through cracks in the Earth's crust, erupting out of volcanoes as part of lava.
- But most of the time magma stays beneath the surface, heating surrounding rocks and the water that has become trapped within those rocks.
- Sometimes that water escapes through cracks in the Earth to form pools of hot water (hot springs) or bursts of hot water and steam (geysers).
- The rest of the heated water remains in pools under the Earth's surface, called geothermal reservoirs. Most geothermal resources are near tectonic plate boundaries

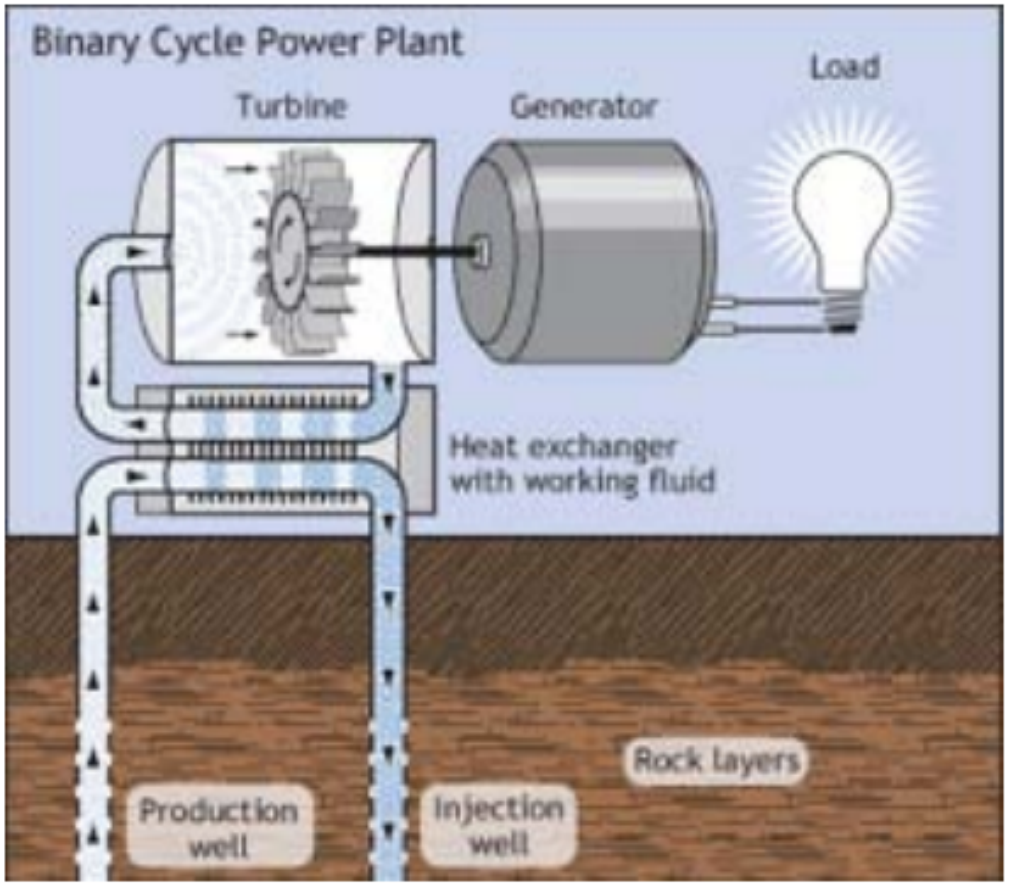
Geothermal power plant.

- Hot water and steam from deep underground can be piped up through underground wells and used to generate electricity in a power plant. Some geothermal wells are up to two miles deep. Three different types of geothermal power plants exist:

- **Dry steam plants.** Hot steam is piped directly from geothermal reservoirs into generators in the power plant. The steam spins turbines, which generate electricity.

- **Flash steam plants.** Water that's between 300 and 700 degrees Fahrenheit (148 and 371 degrees Celsius) is brought up through a well. Some of the water turns to steam, which drives the turbines. When the steam cools it condenses back into water and is returned to the ground.

- **Binary cycle plants.** Moderately hot geothermal water is passed through a heat exchanger, where its heat is transferred to a liquid (such as isobutene) that boils at a lower temperature than water. When that fluid is heated it turns to steam, which spins the turbines.



Advantages

- It is more cost-effective than burning fossil fuels, and it can reduce our dependence on foreign oil.
- Geothermal plants release a fraction of the carbon dioxide produced by fossil fuel plants, and they create very little nitrous oxide or sulfur gases.
- The energy is generated right near the plant, it saves on processing and transportation costs compared to other types of fuel.
- Geothermal plants are also considered to be more reliable than coal or nuclear plants because they can run consistently, 24 hours a day, 365 days a year.
- Geothermal energy is considered renewable because the heat is continually replaced. The water that is removed is put right back into the ground after its heat is used.

Disadvantages

- The initial costs of drilling and installation of geothermal system are high.
- Geographic availability of geothermal energy is limited, and the difficulty and expense of drilling down far enough to reach that energy.

Biomass

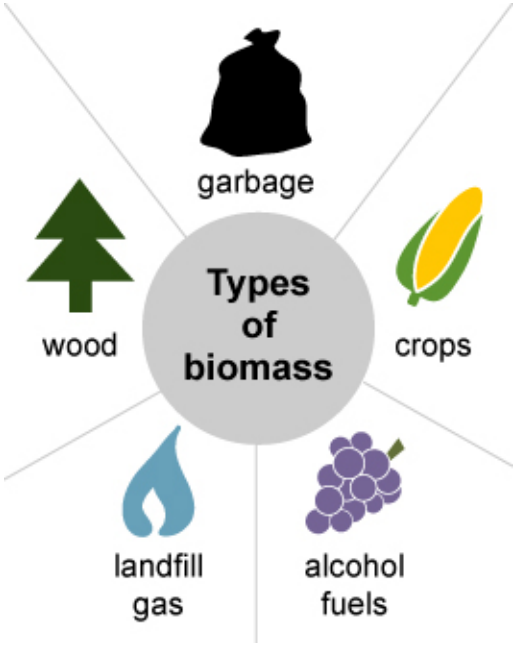
- Biomass is organic material that comes from plants and animals, and it is a renewable source of energy. Biomass contains energy stored from the sun.
- Plants absorb the sun's energy in a process called photosynthesis. When biomass is burned, the chemical energy in biomass is released as heat.

Photosynthesis

In the process of photosynthesis, plants convert radiant energy from the sun into chemical energy in the form of glucose—or sugar.

(water)	(carbon dioxide)	(sunlight)	(glucose)	(oxygen)
$6H_2O$	+ $6CO_2$	+ radiant energy →	$C_6H_{12}O_6$	+ $6O_2$

- Biomass can be burned directly or converted to liquid biofuels or biogas that can be burned as fuels.



- Examples of biomass and their uses for energy:
- wood and wood processing wastes—burned to heat buildings, to produce process heat in industry, and to generate electricity
- agricultural crops and waste materials—burned as a fuel or converted to liquid biofuels
- food, yard, and wood waste in garbage—burned to generate electricity in power plants or converted to biogas in landfills
- animal manure and human sewage—converted to biogas, which can be burned as a fuel

- Biomass requires combustion to release its energy and therefore does release harmful emissions, many types of biofuels pollute less than fossil fuels, and they're unquestionably a more sustainable sources of power.
- Plus, "trash" derived biofuels that recycle substances like fast-food-fryer grease and decaying landfill mass have the added bonus of reducing waste.

Converting biomass to other forms of energy

- Burning is only one way to release the energy in biomass. Biomass can be converted to other usable forms of energy such as methane gas or transportation fuels such as ethanol and biodiesel.
- Methane gas is a component of landfill gas or biogas that forms when garbage, agricultural waste, and human waste decompose in landfills or in special containers called digesters.
- Crops such as corn and sugar cane are fermented to produce fuel ethanol for use in vehicles.
- Biodiesel, another transportation fuel, is produced from vegetable oils and animal fats.

- **Biogas:** Biogas is a mixture of various gases formed when the animal dung/waste mixed with water is allowed to decompose by anaerobic micro organisms. Biogas is a clean and efficient fuel. It is a mixture of methane (CH_4), carbon dioxide (CO_2), hydrogen (H_2) and hydrogen sulphide (H_2S).

- The conditions necessary for the formation of biogas.

- 1) A fairly large amount of water should be added to the animal dung/ waste to make the slurry.
  2) This slurry should be made to ferment only in the absence of air (anaerobic fermentation)
  3) The temperature of the slurry should be maintained around 35° C

Biogas plant.

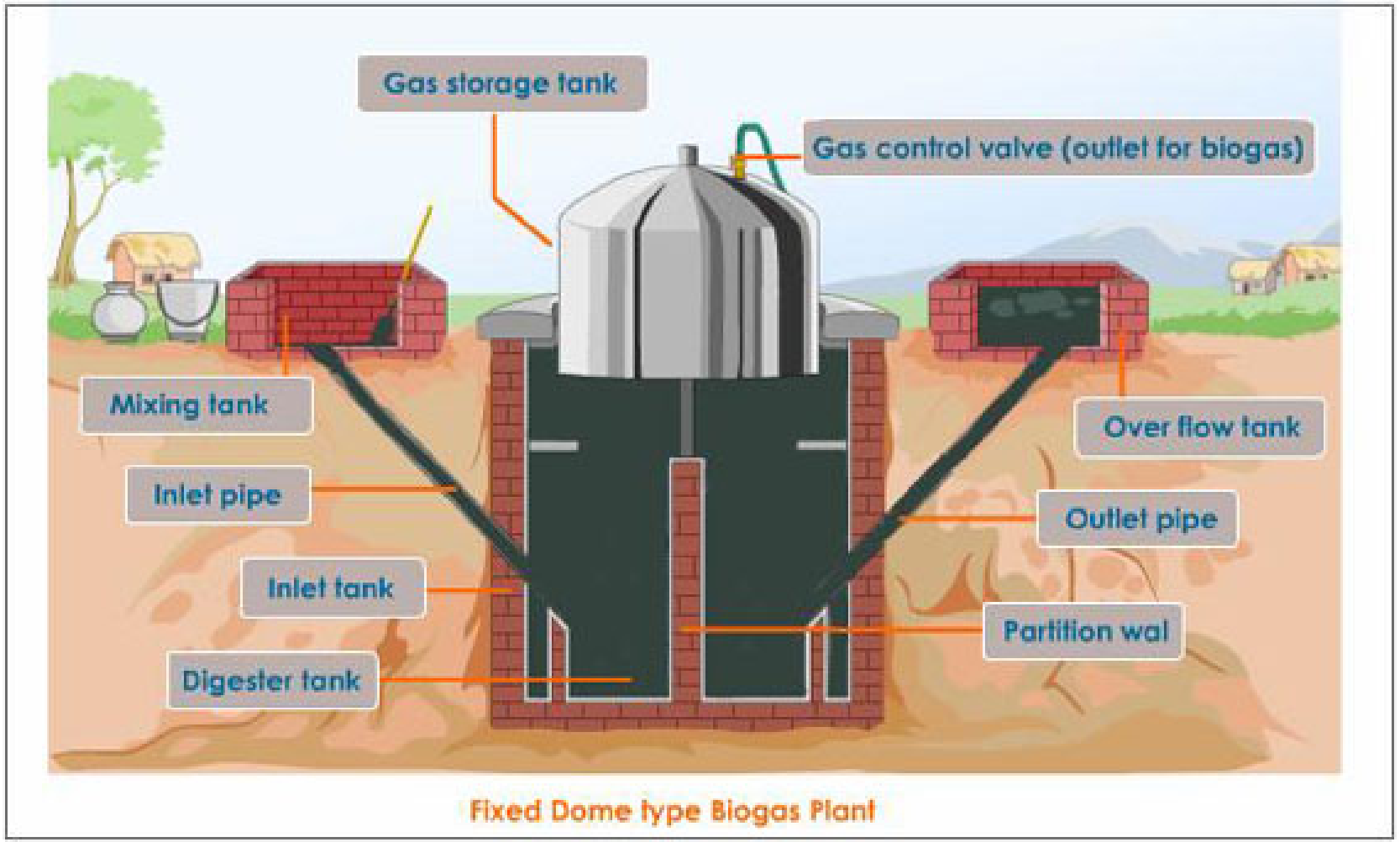
Forms of biomass listed below may be used along with water:

1) Animal dung
2) Poultry wastes
3) Plant wastes (Husk, grass, weeds etc.)
4) Human excreta
5) Industrial wastes(Saw dust, wastes from food processing industries)
6) Domestic wastes (Vegetable peels, waste food materials)

- **Principle**

- Biogas is produced as a result of anaerobic fermentation of biomass in the presence of water.

Construction of Biogas plant



The biogas plant is a brick and cement structure having the following five sections:

1) Mixing tank present above the ground level

2) Inlet chamber: The mixing tank opens underground into a sloping inlet chamber

3) Digester: The inlet chamber opens from below into the digester which is a huge tank with a dome like ceiling. The ceiling of the digester has an outlet with a valve for the supply of biogas

4) Outlet chamber: The digester opens from below into an outlet chamber

5) Overflow tank: The outlet chamber opens from the top into a small over flow tank

Working

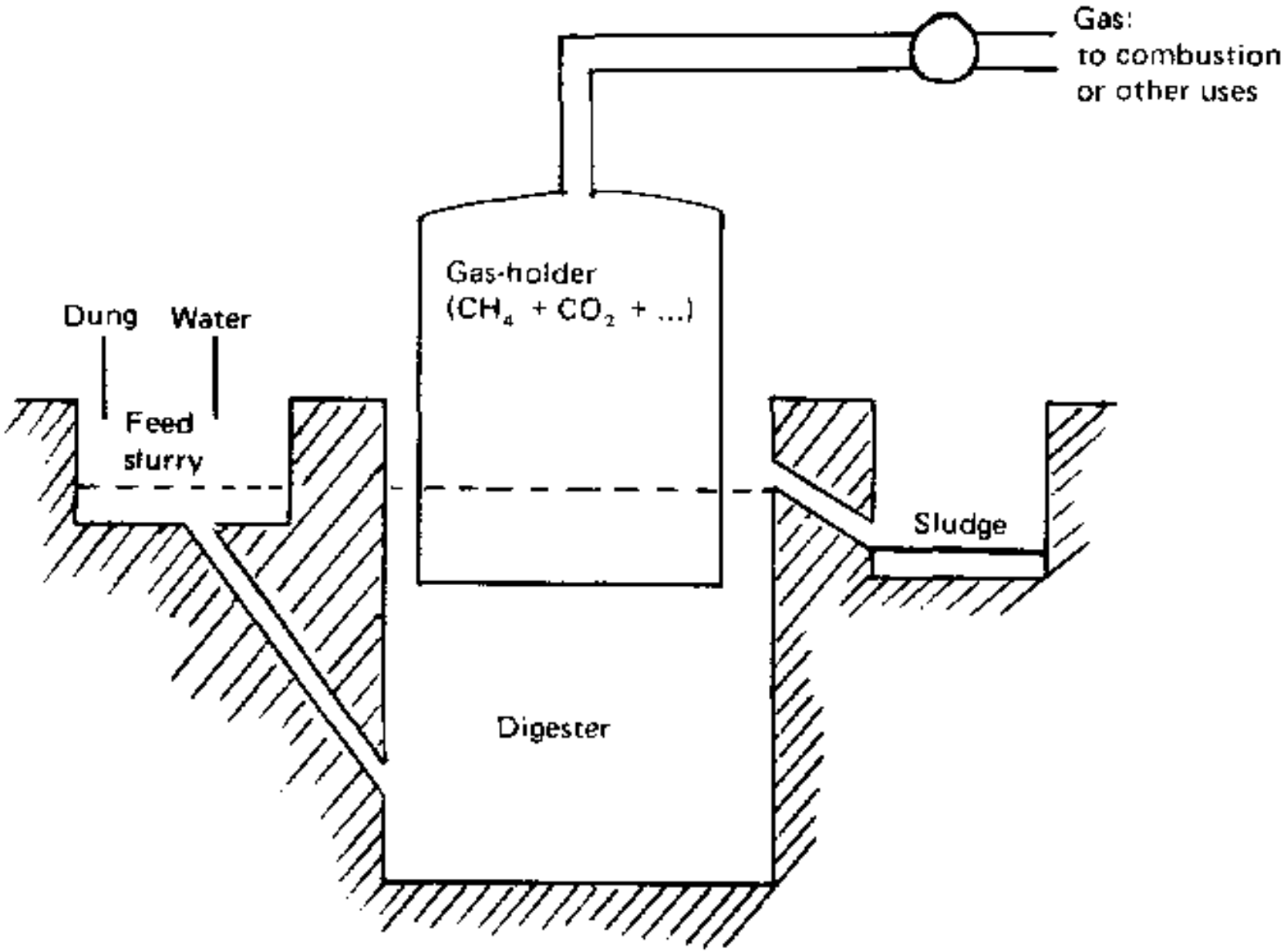
1) The various forms of biomass are mixed with an equal quantity of water in the mixing tank. This forms the slurry

2) The slurry is fed into the digester through the inlet chamber. The temperature of the slurry must be maintained around 35° C. Any drop in temperature will reduce the anaerobic activity and hence the yield of biogas

3) When the digester is partially filled with the slurry, the introduction of slurry is stopped and the plant is left unused for about two months

4) During these two months, anaerobic bacteria present in the slurry decompose or ferment the biomass in the presence of water
5) As a result of anaerobic fermentation, biogas is formed, which starts collecting in the dome of the digester
6) As more and more biogas starts collecting, the pressure exerted by the biogas forces the spent slurry into the outlet chamber
7) From the outlet chamber, the spent slurry overflows into the overflow tank
8) The spent slurry is manually removed from the overflow tank and used as natural fertilizer for plants
9) The gas valve connected to a system of pipelines is opened when a supply of biogas is required
10) To obtain a continuous supply of biogas, a functioning plant can be fed continuously with the prepared slurry

Schematic of Bio-gas plant



Questions

1. Write short notes:
(i) Geothermal energy
(ii) Biomass and bio-fuels

2. Describe the basic principle and working of Solar cells

3. What are the renewable energy sources? Give some examples

4. Explain the basic components and working principle of wind turbines.

5. What is tidal energy? Explain the basic principle its conversion to Electrical energy.