

Unit 2

Energy Resources:

- Types of Energy-Renewable, Non renewable & sustainable energy & their advantages and disadvantages
- Renewable energy sources- Solar energy, Wind energy, Tidal energy, Ocean thermal energy. Geothermal energy, Hydroelectric power, Biomass energy, Hydrogen energy, Thermal power- environmental impacts
- Conservation of energy

Numerical problems on Solar energy and Wind power

Energy Resources

Definition and importance of energy: Energy is defined as the ability to do work. It is measured by multiplying the force applied on an object (measured in Newton) with the distance measured by that object (measured in meter). The unit of energy therefore is **Newton-meter** (N-m) called **Joule** (J). Its higher units are kilo joule (kJ), Mega joule (MJ), Giga joule (GJ) and Exa joule (EJ).

When energy is converted into electricity, it is called **power**. The unit of measurement of power is J/s (Joule per second), known as **watt** (W). 1000 watt is known as **one kilowatt** (kW), 10^6 watt is one mega watt (M.W), and 10^9 watt is one Giga watt (G.W). The electricity consumed in our homes is measured in kilowatt hour (kWh); i.e., one kilowatt load used for one hour.

Energy is required for doing any type of work in life.

- It is required for cooking, heating, cooling, lighting, etc in our homes.
- It is required to run machines and other mechanical equipment in industries.
- It is required to run locomotives for transportation.

The amount consumption of energy by a nation is usually considered as an index of its development. This is because of the fact that almost all our developmental activities are directly or indirectly dependent upon the energy consumption. That is why, there exists wide disparities between the energy consumption of the developed and non-developed countries.

Sources of energy: An energy source may be defined as the one that can provide us with adequate amount of energy in a usable form over long periods of time. These sources can be divided into the following major types:

1. **Renewable energy sources**
2. **Non-renewable energy sources**
3. **Sustainable energy sources**

Renewable energy sources: These are those energy sources which are either **perpetually available in nature** (such as the heat of the sun, power of winds, power of tidal sea waves, thermal energy of the oceans, heat persistent under the earth's crust etc) or are generated continuously in nature (such as the potential energy of the stored water).

Non-renewable energy sources: These are those energy sources which have accumulated in nature over a long span of time (millions of years) and cannot be replenished in hundreds of years. These sources are, thus, finite in quantity and cannot be reproduced. They are, thus, sure to be exhausted after some years. These energy sources include fossil fuels such as coal, petroleum and natural gas and nuclear fuels like Uranium-235.

Sustainable energy source: Sustainable energy is a term sometimes applied to nuclear power. The supplies are not exactly renewable but they will last for a very long time because a great deal of electricity is produced from a small amount of radioactive material

Advantages and disadvantages of various energy types are listed in table.

Energy type	Advantages	Disadvantages
Renewable	Wide availability. Lower running cost. Decentralized power production. Low pollution. Available for foreseeable future.	Unreliable supply. Usually produced in small quantities. Often very difficult to store. Currently per unit cost of energy is more compared to other type.
Non-renewable	Available in highly concentrated form. Easy to store. Reliable supply. Lower cost per unit of energy produced as the technology is advanced.	Highly polluting. Available only in few places. High running cost. Limited supply and will one day get exhausted.
Sustainable (Nuclear power)	Highly reliable. Produces large amounts of energy with very little carbon dioxide emission. Uses small amount of raw material per unit energy production.	Risk of radioactivity. High waste disposal cost. High capital investment and maintenance cost.

Accordingly we have the following types of energies:

Renewable energies:

1. Solar energy
2. Wind energy
3. Tidal energy
4. Ocean thermal energy
5. Geothermal energy
6. Hydro-power

Non-renewable energies:

1. Biomass energy
2. Thermal power
3. Nuclear power.

Solar energy

The solar energy is the direct heat and light energy released continuously by the sun, as sun is perpetual source of energy. The nuclear fusion reactions occurring inside the sun are understood to be releasing enormous quantities of energy in the form of heat and light. The solar energy, received by the near space surrounding the earth is estimated to be about $1.4 \text{ kJ/second/m}^2$. This is known as solar constant.

Solar energy holds a tremendous potential for the future, since the total energy we receive each year from the sun is around 35,000 times the total energy being used presently by man. However, about $1/3^{\text{rd}}$ of this total energy is either absorbed by the outer atmosphere, or reflected back into the space, through a process called albedo. In spite of such a huge amount of solar energy being received on earth, its present utilization is on a very small scale in homes and to heat up waters of swimming pools. In homes, it is being used for cooking food in solar cookers, but on a very small scale. Its use in solar water heaters to supply hot water in houses and hotels, however, is more popular.

There is an urgent need to increase their use in hotels, hospitals and individual homes to replace the usual electric geysers, for obtaining hot waters for bathing and washing purposes. In future, solar energy can possibly be used to run cars, power plants and spaceships. Solar energy is freely available, but the necessary equipment and installations are not free. The initial cost of setting up a solar energy harnessing system, including a standby heating unit (to be used when the sunlight is not available), can be substantial.

Nevertheless, over the long term, solar energy will become economical, and may even become cost effective, as the prices of fossil fuels increase with their dwindling stocks, in future.

Wind energy

Wind has been used for centuries, as almost a free and a non-polluting source of energy. Sailing ships and wind powered grind mills are the early examples of the use of wind energy. The high-speed winds, in fact, do possess a lot of kinetic energy due to their velocity, although the driving force of the wind is sun. The wind energy was subsequently harnessed by making use of the windmills. In a windmill, the blades of the windmill are kept rotating continuously by the force of the striking wind. The rotational motion of the blades can drive a number of machines, like water pumps, flourmills and electric generators. A large number of windmills are installed in clusters of hundreds of units, called wind farms, which generate power and feed it to the nearest power grid for distribution. These farms are ideally located in coastal areas, open grasslands, or hilly regions, particularly mountain passes and ridges, where the winds are usually strong and steady. The minimum wind speed required for satisfactory working of a wind generator is 15 km/hr.

Wind is an intermittent source, and the intermittency of wind depends on the geographic distribution of wind. Wind, therefore, generally cannot be used as the sole source of electricity in an area, and requires some other backup or standby source of electricity.

Wind power is a function of wind speed and therefore, the average wind speed of an area is an important determinant of economically feasible power. Wind speed increases with height. At a given turbine site, the power available 30 m above ground is typically 60 % greater than at 10 m height. That is why windmills need to be located at enough heights. The wind energy could also be used to produce hydrogen by the electrolysis of water. This combustible gas could then be piped to land and used as a fuel.

The future for this non-polluting wind energy appears to be promising, but it has its own problems and obstacles. There are many technical problems to overcome in building large efficient turbines. In addition, noise pollution and the cost of large tracts of land in populated areas, present significant obstacles to its development. Besides noise pollution, wind mills may have some other environmental impacts like bird kills, interference with TV

reception and aesthetic objections to the sheer number of wind turbines that are required to meet the large scale needs of electricity in modern days.

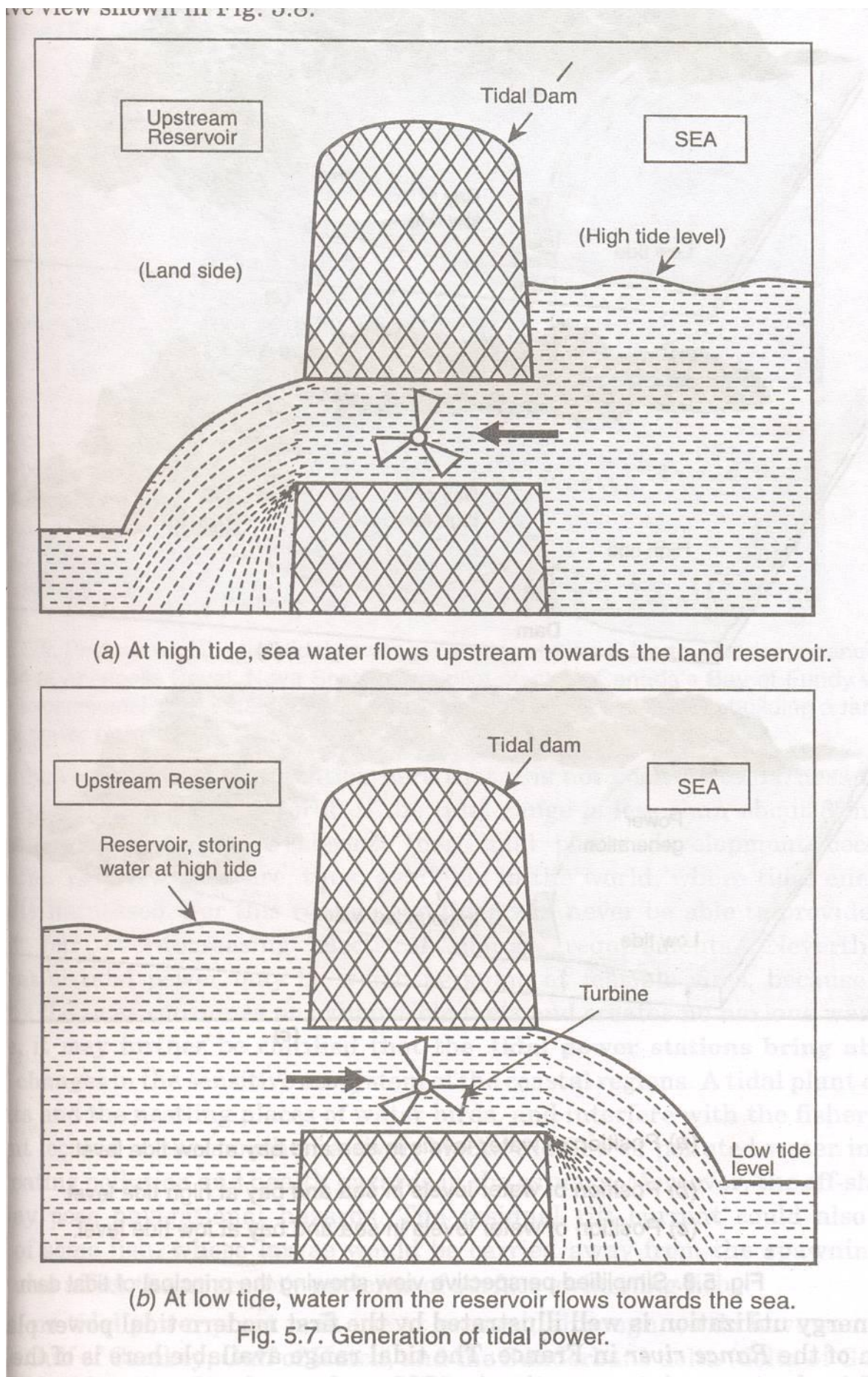
Tidal energy

The water level in a sea rises and falls during tides, caused by the attraction of moon and to a lesser extent of the sun. The rise of sea water level is known as the high tide while the fall of sea water level is known as the low tide. The difference in water level during high tide and low tide is known as the tidal range. The potential energy developed by the water head created during high tide can be used to run turbines, to generate electricity.

Tidal power is harnessed by constructing a dam or a barrage across the mouth of a bay or an estuary in a coastal area having a large tidal range. The narrow opening between the bay and the open sea magnifies the variations in the water levels that occur as the tide rise and fall. During high tide, the seawater flows upstream towards the land reservoir through the openings in the dam or barge, and turns the turbines, generating electricity (Fig. a). During the low tide, as the sea water level falls, the water from the upstream reservoir flows towards the downstream in seaward direction, again turning the turbine blades, to generate electricity (Fig.b).

The development of tidal power may be worth pursuing at feasible sites, because electricity produced by the tides consumes no exhaustible fuels and creates no noxious wastes.

At the same time, the tidal power stations bring about major ecological changes in the sensitive ecosystem of the coastal regions. A tidal plant can destroy the habitats and the nestling places of water birds and interfere with the fisheries. A tidal power plant located at the mouth of bay, blocks the flow of polluted water into the sea, thereby creating pollution and health hazards in the estuary. The offshore energy devices may pose navigational hazards. The residual rift current could also affect the spawning of some fish, whose larvae would be carried away from the spawning grounds. They may also affect the migratory patterns of surface swimming fish.



Ocean thermal energy

The ocean covers a little more than 70 % of the Earth's surface. This makes them the largest solar energy collector and energy storage system. On an average daily basis, 6000Mha(60Mkm²) of tropical seas absorb an amount of solar radiation equal in heat content of about 250 Billion barrels of crude oil. If less than 1/1000th part of this solar energy could be converted into electrical energy, it would be 20 times the total amount of electricity consumed in the United States on any given day.

The technology that is used to convert this heat energy contained in the upper layers of the ocean into electrical energy is known as OTEC (Ocean Thermal Energy Conversion). This technology makes use of the ocean's natural thermal gradient, caused due to warm upper layers and cold lower layers of water. As long as the temperature difference between the warm surface water and the cold deeper water of an ocean differs by about 20⁰ c, an OTEC system can produce significant amount of power. The ocean can, thus, prove to be vast resources of renewable power. The potential is estimated to be of the order of 10000 GW of base load power generation.

The cold deep-sea water in the OTEC plant is also rich in nutrients and can be used to culture both marine organism and plant life near the shore or on the land. An OTEC system may, in fact, have many applications and uses.

For example, OTEC can be used to

- Generate electricity,
- Desalinate sea water,
- Support deep water marine culture,
- Provide refrigeration and air conditioning,
- Aid in crop growth and mineral extraction from sea water.

These complimentary products may make the OTEC system quite attractive to the industry and island communities, even if the prices of fossil fuel remain low. OTEC can also be used to produce methanol, ammonia, hydrogen, aluminum, chlorine and other chemicals. In spite of such multipurpose benefits, installations of OTEC plants have not attracted much financing, primarily because, it involves high-tech installations, and electricity generation is

not found economical at present, in comparison to other modes of power like thermal, hydro, nuclear and geothermal powers. In any case, OTEC is highly promising as an alternative energy resource, especially for tropical communities that rely heavily on imported fossil fuels (like oil, etc) for generation of thermal power.

Basically, two types of OTEC system designs have been demonstrated to generate electricity;

- (i) Closed cycle type
- (ii) Open cycle type

(i) Closed cycle type:

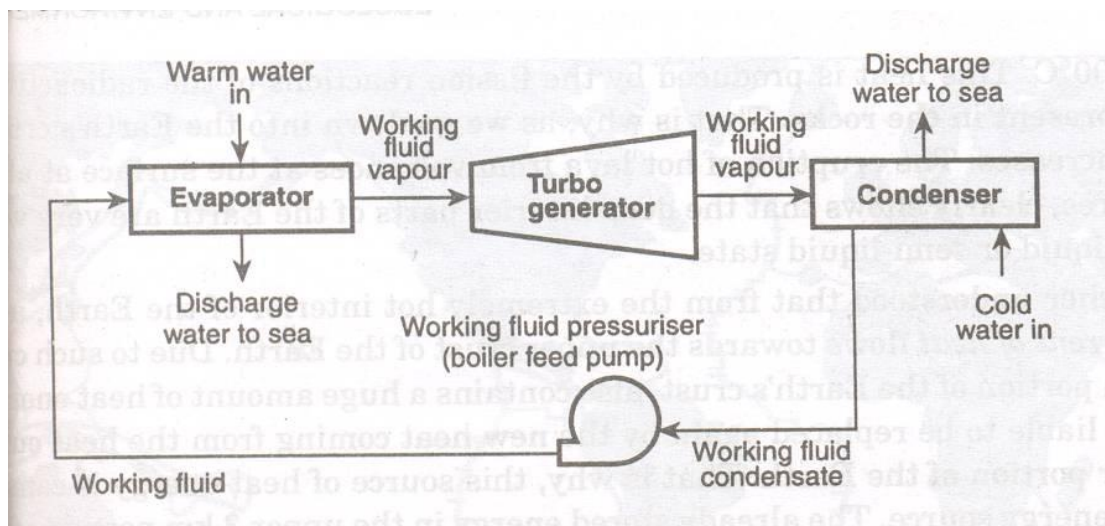
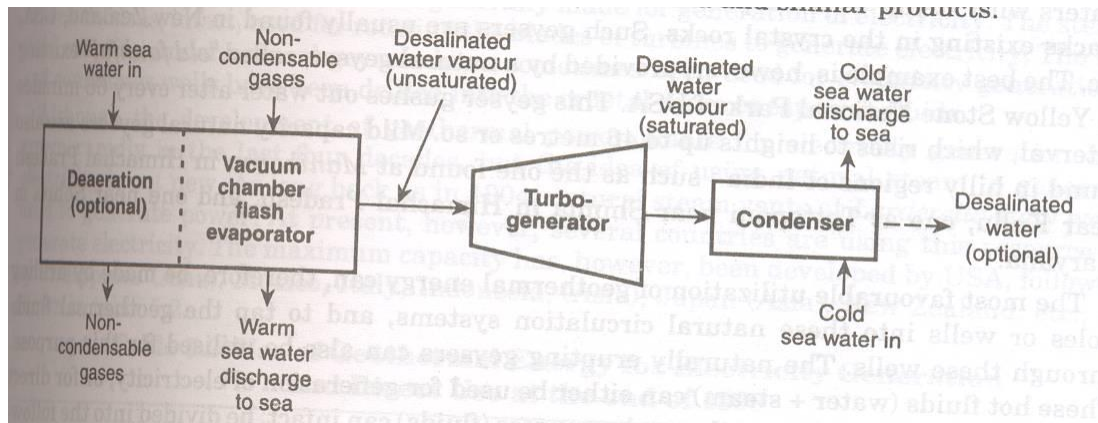


Fig: Closed cycle OTEC system

In closed cycle OTEC system, warm sea water vaporizes a working fluid (such as ammonia) flowing through a heat exchanger (evaporator). This fluid vaporizes at lower temperatures (warm temperatures) and expands at lower pressures to run the turbines coupled to a generator that produces electricity. The vapour of the working fluid, after coming out from the turbine, is then condensed in another heat exchanger (condenser) using cold seawater pumped from the ocean's depths through a cold water pipe. The condensed working fluid is repumped to the evaporator to repeat the cycle. The working fluid remains in a closed system and circulates continuously. The working of such a plant is illustrated in fig.

(ii) Open cycle type:**Fig: Open cycle OTEC system**

In open cycle OTEC system, warm seawater is used as the working fluid. The warm seawater is flash evaporated in a vacuum chamber to produce steam at an absolute pressure of 2.4 kilopascal (kpa). The steam expands through a low-pressure turbine coupled to a generator, producing electricity. The steam coming out of the turbine is condensed by cold seawater, pumped from deeper ocean through a cold water pipe. The liquid water is again discharged to the ocean or can be recycled and used in stages, in multistage systems. If a surface condenser is used for cooling the steam coming-out of the turbine, then the condensed steam provides desalinated water, as it will be kept separated from the seawater. The electricity produced by the system can be delivered to a utility grid or used to manufacture methanol, hydrogen, refined metals, ammonia and similar products.

Geothermal energy

The heat energy available in abundance inside the Earth in the form of very high temperatures. So much so that the inner core of the Earth may have as high a temperature as 4000°C . This heat is produced by the fission reactions of the radioactive materials naturally present in the rocks. That is why, as we go down into the Earth's crust, the temperature increases. The eruption of hot lava from volcanoes at the surface at about 1200°C temperatures, clearly shows that the deep interior part of the Earth are very very hot and may be in liquid or semi liquid state.

It is further understood that from the extremely hot interior of the Earth, a continuous upward current of heat flows towards the upper crust of the Earth. Due to such currents,

the upper 3 km portion of the Earth's crust, also contains a huge amount of heat energy, which if removed is liable to be replaced again by the new heat coming from the heat currents from the interior portion of the Earth. That is why, this source heat energy is considered as a renewable energy source. The already stored energy in the upper 3 km portion of the Earth's crust has been estimated to be of the order of 43×10^{24} Joules. Theoretically, this amount of energy would be enough to meet the energy demand of the world's population in the coming 1-lakh years. Such calculations are fictitious, but they certainly indicate that very large quantities of heat energy can be extracted from the stored component of the geothermal energy from the permeable rocks of the upper 3 km portion of the Earth's crust.

Water is transporting the Geothermal heat from the depth (inside the Earth) to the surface, where it is utilized for human needs. In the natural geothermal areas, water-circulating systems are continuously transporting the heat energy to the surface and this is observed as natural hot springs, called natural geysers or fumaroles. These natural eruptions of hot waters with temperatures reaching up to 350°C , may occur through the cracks existing in the crystal rocks. Such geysers are usually found in New Zealand, USA, etc. The best example is, however, provided by a natural geyser, called 'old faithful' existing in Yellowstone National Park of USA. This geyser gushes out water after every 66 minutes interval, which rises to heights up to 46 meters or so. Mild capacity natural geysers are also found in hilly regions of India such as the one found at Manikaran in Himachal Pradesh near Kullu, one at Tattapani near Shimla in Himachal Pradesh and one near Sohna in Haryana.

The most favorable utilization of geothermal energy can, therefore, be made by drilling holes or wells into these natural circulation systems and to tap the geothermal fluids through these wells. The naturally erupting geysers can also be utilized for these purposes. These hot fluids (water + steam) can either be used for generation of electricity, or for direct heating purposes. The hot geothermal resources (fluids) can, in fact, be divided into the following two types:

- (i) High temperature resources with temperatures of geothermal fluids above 150°C : They are mainly used for generation of electricity. The high temperature resources are generally restricted to the volcanic and geothermal zones of the Earth.

- (ii) Low temperature resources with temperatures of geothermal fluids below 150°C : They are mainly used for direct heating purposes. The low temperature resources are found in almost every country of the world.

Biomass energy:

Biomass is the organic matter produced by the plants or animals and includes wood, cattle dung, agricultural wastes such as crop residues, organic municipal solid waste like paper, food wastes and other non fossil fuel derived materials like textiles, natural rubber, leather etc.

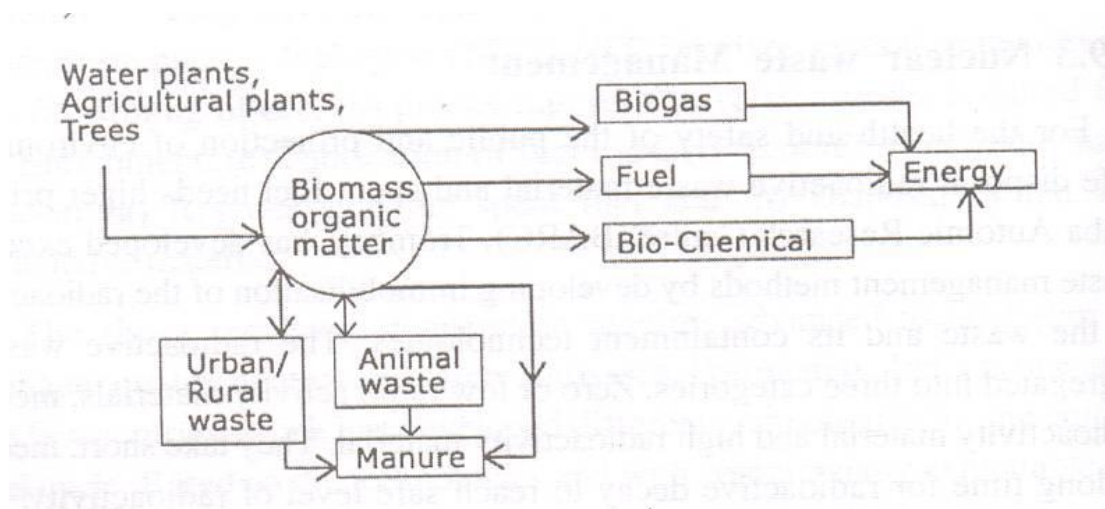


Fig: Origin of Biomass Energy

Biomass is used on a large scale to obtain energy either by directly burning the same or by converting it into more convenient form of solid fuels like manure, dung cakes etc or into liquid fuels like ethanol, biodiesel etc or into gas fuels like biogas etc.

Biomass has infact, provided a major source of energy to human beings, since the early days of human civilization. The firewood is the best known and most widely used biomass fuel in the world. Wood alone is being used as a primary source of energy, even in those modern days. In India dung cakes are made from cattle dung and burnt for cooking.

The vegetation matter (biomass), besides being used as a fuel for direct burning to produce heat or electricity, can also be converted into liquid fuels, called biofuels. These biofuels can some day replace the fossil fuels (i.e. diesel and petrol) to run our locomotives. The two most common types of biofuels produced from biomass are ethanol and biodiesel.

Ethanol is an alcohol made by fermenting any biomass high in carbohydrates (i.e. sugars, starches, cellulose etc). Ethanol is at present, is mostly used as a fuel additive to cut down a

vehicle's carbon monoxide and other smog causing emissions. But flexible fuel vehicles, which would run on mixtures of gasoline and up to 85% ethanol, have been developed in Japan. Thus, technology is already underway to replace diesel and petrol with such biofuels. Biodiesels is made by combining alcohol (usually methanol) with vegetable oil, animal fat etc. Biodiesel can be used as an additive to reduce vehicle's emissions (typically by 20%) or in pure form, as a renewable alternative fuel for diesel engines. Researchers are also developing algae that produce oils, which can be converted to biodiesel. New ways have also been found to produce ethanol from grasses, trees, barks, sawdust, paper and farming wastes.

The fibrous waste of sugar industry is world's largest potential source of biomass energy. Ethanol produced from sugarcane molasses is a good automobile fuel.

Another liquid fuel, called the pyrolysis oil, can also be produced from the biomass, through a process called pyrolysis. Pyrolysis occurs when biomass, is heated in absence of oxygen. The biomass then turns into liquid, called pyrolysis oil, which can be burnt like petroleum to generate electricity.

The vegetation matter, cow dung and other organic municipal wastes (biomass) can also be converted into gas fuels, like biogas, which can be used as a clean source of energy, for cooking or for producing electricity on a small scale to light the individual homes or group housing flats or even street lights. Since the direct burning of biomass produces air pollutants like CO_2 , SO_2 , NO_x etc, it is always preferable to convert the biomass into a cleaner gas fuel (biogas).

Production of Biogas and gobar gas from biomass:

Biogas is produced from animal dung, kitchen wastes, plants like hyacinth, etc and organic wastes from households and industries like fish processing, dairies etc. In India, the biogas is primarily being produced from cattle dung (gobar), and hence this biogas is called the 'Gobar gas'.

Biogas primarily contains methane- CH_4 (60-79%) and carbon dioxide- CO_2 (30-35%), along with small quantities of nitrogen- N_2 (5%) and oxygen- O_2 (0 - 0.1%). The hydrogen sulphide- H_2S gas may also sometimes be present, though rarely. In this mixture of gases, methane burns easily and hence this biogas can be easily used for cooking, heating and for producing electricity. It has been estimated that from 1 tonne (1000 kg) of food waste, one can

produce 85 m³ of biogas. Once the biogas is produced from the waste biomass, some residue is left, which can be used as an agricultural fertilizers (manure).

Environmental impacts of biomass energy:

1. There is the potential for biomass to be taken from unsustainable, non-certified, forest sources.
2. There are some negative impacts of forest management and farming of biomass crops on ecosystems and habitats. Therefore, an environmental impact assessment for forestry and cropping is required.
3. Transporting biomass has noise and emissions implications.
4. There is air quality implications depending on the type of biomass used.
5. There are high levels of water use for biomass cropping which can be problematic in areas where access to water is limited.

Hydroelectric energy:

In hydroelectric power generation, water is stored up to a certain height and then allowed to flow to a lower level. The potential energy of the stored water will thus be converted to kinetic energy and the velocity of flow at the lower level will be governed by the head difference between the two water levels. This flow velocity is used to rotate the blades of the turbines.

The electric power so produced is hence, called hydroelectric power.

Advantages:

1. It is clean and renewable source of energy.
2. The water (natural energy) is stored in the high level reservoir and used when necessary.
3. Transportation of raw energy is natural by gravity.
4. The operating cost of hydroelectric power plants is low.
5. The energy resource occurs free of cost
6. Hydroelectric power plants have operational flexibility
7. Hydro reservoirs are multipurpose, provides water for irrigation facilities, drinking water, industries etc.

Disadvantages:

1. The dam sites submerge large forest and agricultural areas.
2. Storages of water cause water logging and siltation.
3. It causes loss of biodiversity and aquatic organisms.
4. Submergence displaces local people and creates problems of rehabilitation and socio economic problems.
5. Large volume of water storage increases the **seismicity** of the area.
6. Initial capital cost is high and construction periods are long
7. Additional investments are necessary for transmission of bulk power from large remote hydroelectric power plants.

Hydrogen as an alternate source of energy:

The fossil fuels (coal, petroleum and natural gas) based energy sources are getting depleted rapidly and their availability is not promising. At present petroleum fuels are contributing to the 80% of energy requirement.

Hydrogen has been identified as alternative promising energy source. Hydrogen can be produced in unlimited quantities from abundant, universally distributed and inexhaustible energy sources.

The primary energy sources may be water, coal, biomass, natural gas, petroleum etc. Hydrogen is an intermediate secondary energy source. Using Hydrogen fuel in transportation sector is presently in planning and development stage only. Hydrogen can be used economically and commercially around 2020. It has been established that hydrogen can meet all the energy needs of world in the coming years.

The merits of hydrogen as an alternative future fuel are

1. It can be produced by several alternative methods.
2. It can be produced from fossil fuels, water, biomass etc.
3. Hydrogen is a renewable energy source.
4. Hydrogen has high energy density as compared to fossil fuels.
5. Hydrogen is an environmentally friendly and clean fuel. The end product is water
6. Hydrogen can be transported by pipeline, just like natural gas.

The limitation is that hydrogen is a gas at normal temperature and pressure, hence it is difficult to store and transport. Hydrogen is an explosive gas and care is necessary against leakage and explosion.

Hydrogen is used in synthesis of ammonia (NH_3), methanol (CH_3OH), urea and as reducing agent in metallurgy etc. It is used as high thrust fuel in rockets. In future, hydrogen will be an intermediate fuel for transportation.

Hydrogen can be produced commercially by electrolysis of water, steam reforming of hydrocarbons, liquefaction of natural gas, cracking of ammonia, by reaction of coal at high temperatures. Hydrogen can be produced without pollution by electrolysis of water, water electrolysis would be a major hydrogen production of the future.

Thermal power: Thermal power plants develop electricity by using the heat energy produced by burning of the fossil fuels like coal, oil and natural gas. The heat produced by burning of such a fuel is used to heat up and boil water to produce steam, which in turn, is moved in pipes to turn the turbines, coupled with generators to produce electricity. These fuels are non-renewable and their supply shall last only for a finite period. The power generated from the use of these fuels is, hence known as non-renewable energy.

Environmental impacts of thermal power plants:

1. Use of coal in thermal power production causes generation of huge quantities of flyash waste.
2. The burning of coal emits air pollutants like particulate matter and gases like sulphur dioxide, oxides of nitrogen carbon dioxide etc.
3. Drilling and extraction of oil may cause leaks and accidental fires causing severe pollution of the land, sea and air.
4. During refining of crude oil, several solid wastes like grease are produced which damages the environment.
5. The high-ash fuels used makes flue-gas dust control a difficult problem.
6. The hot water disposed into the river cause an increase in the temperature of a river which leads to Oxygen depletion of the river water. Oxygen deficiency can be seriously detrimental to aquatic life.
7. Thermal power plants can have impacts on soil and groundwater. The soil quality, can be adversely affected by dust sediment, particularly in the near vicinity of the plant. The seriousness of ground-level pollution depends on the heavy-metal content of the dust.

The chemistry of the soil can be altered by acidic precipitation (acid rain) characterized mainly by the acid formers SO_2 and NO_x . Under unfavorable conditions, acidification can pass from the soil to both the groundwater and surface waters.

8. Adverse effects of thermal power plants on human health can derive from the direct impact of noxious gases on the organism and/or their indirect impact via the food chain and changes in the environment. Especially in connection with high levels of fine particulates, noxious gases like S_2 and NO_x can lead to respiratory diseases.
9. The personnel working in power plants are exposed to substantial noise nuisance.
10. The landscape is affected by construction of the roads needed for delivering operating media and disposing of residues.

Energy conservation: Energy conservation means to reduce the quantity of energy that is used for different purposes. This practice may result in increase of financial capital, environmental value, national and personal security, and human comfort.

Individuals and organizations that are direct consumers of energy may want to conserve energy in order to reduce energy costs and promote economic, political and environmental sustainability. Industrial and commercial users may want to increase efficiency and thus maximize profit.

On a larger scale, energy conservation is an important element of energy policy. In general, energy conservation reduces the energy consumption and energy demand per capita. This reduces the rise in energy costs, and can reduce the need for new power plants, and energy imports. The reduced energy demand can provide more flexibility in choosing the most preferred methods of energy production.

By reducing emissions, energy conservation is an important method to prevent climate change. Energy conservation makes it easier to replace non-renewable resources with renewable energy. Energy conservation is often the most economical solution to energy shortages.

Tips to save energy:

1. Turning the lights off whenever you leave a room.
2. Using energy saving light bulbs in rooms.
3. Turning the heating down or off in rooms that are not being used regularly.
4. Ensuring the window and door seals are in good condition in air conditioned rooms.
5. Using sun light to dry clothes in the summer rather than mechanical cloth drier.

6. Choosing low energy rating appliances for cooking, washing and refrigerating.
7. Making sure that hot water boilers and pipes are well insulated.

Problems on Solar Energy

The global formula to estimate the electricity generated in output of a photovoltaic system is:

$$E = A \times r \times H \times PR$$

E = Energy (kWh)

A = Total solar panel Area (m²)

r = Solar panel yield (%) = Electrical power (in kWp) of one solar panel divided by the Area of one panel

H = Annual average solar radiation on tilted panels (200 kWh/m² to 2600 kWh/m².)

PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75)

The unit of the nominal power of the photovoltaic panel is called "Watt-peak" (Wp or kWp = 1000 Wp or MWp=1000000 Wp).

Problem-1: Calculate the solar energy output of a photovoltaic system per year and day for the following data:

- i) Electric power of one solar panel: 250 Wp
- ii) Area of one panel: 1.6 m²
- iii) No. of panel: 1
- iv) Annual average solar radiation on tilted panel: 2000 kWh/m².
- v) Performance ratio: 0.75

Solution:

A = Total solar panel Area = 1.6 m²

H = Annual average solar radiation on tilted panels = 2000 kWh/m².

PR = Performance ratio = 0.75

r = Solar panel yield (%) = Electrical power (in kWp) of one solar panel/ Area of one panel

Electrical power of one solar panel = 250 Wp = (250/1000) = 0.25 kWp

$$r = (0.25/1.6) \times 100 = 15.6 \%$$

$$E = A \times r \times H \times PR = 1.6 \times 15.6 \times 2000 \times 0.75 = 37440 \text{ kwh/year}$$

$$\text{Per day} = 37440/365 = 102.57 \text{ kwh/day}$$

(**Note:** As the No. of panels increases Total solar panel Area increases.)

Problem-2: Calculate the solar energy output of a photo voltaic system for the following data:

- i) Electric power of one solar panel: 280 Wp
- ii) Area of one panel: 1.8 m²
- iii) No. of panel: 10
- iv) Annual average solar radiation on tilted panel: 2080 kWh/m².
- v) Performance ratio: 0.80

Solution:

$$A = \text{Total solar panel Area} = 1.8 \text{ m}^2$$

$$H = \text{Annual average solar radiation on tilted panels} = 2080 \text{ kWh/m}^2.$$

$$PR = \text{Performance ratio} = 0.80$$

$$r = \text{Solar panel yield (\%)} = \text{Electrical power (in kWp) of one solar panel} / \text{Area of one panel}$$

$$\text{Electrical power of one solar panel} = 280 \text{ Wp} = (280/1000) = 0.28 \text{ kWp}$$

$$r = (0.28/1.8) \times 100 = 15.5 \%$$

$$E = A \times r \times H \times PR = 1.8 \times 10 \times 15.5 \times 2080 \times 0.8 = 464256 \text{ kWh}$$

Problems on Wind Energy:

Calculation of Wind Power hitting wind turbine

Wind is made up of moving air molecules which have mass - though not a lot. Any moving object with mass carries **kinetic energy** in an amount which is given by the equation:

$$\text{Kinetic Energy} = 0.5 \times \text{Mass} \times \text{Velocity}^2$$

Where the mass is measured in **kg**, the velocity in **m/s**, and the energy is given in **joules**.

Air has a known density (around 1.23 kg/m³ at sea level), so the mass of air hitting our wind turbine (which sweeps a known area) each second is given by the following equation:

$$\text{Mass/sec (kg/s)} = \text{Velocity (m/s)} \times \text{Area (m}^2\text{)} \times \text{Density (kg/m}^3\text{)}$$

And therefore, the **power** (i.e. energy per second) in the wind hitting a **wind turbine** with a certain swept area is given by simply inserting the *mass per second* calculation into the standard kinetic energy equation given above resulting in the following **vital** equation:

$$\text{Power} = 0.5 \times \text{Swept Area} \times \text{Air Density} \times \text{Velocity}^3$$

Where **Power** is given in Watts (i.e. joules/second), the **Swept area** in m^2 , the **Air density** in kg/m^3 , and the **Velocity** in m/s .

Swept area $A = \pi r^2$, where r is radius or length of the blade

$$A = (\pi d^2/4), \text{ where } d \text{ is diameter of the blade}$$

Problem-3: Calculate the wind power hitting the wind turbine with a rotor blade diameter of 126 m. Air density is 1.23 kg/m^3 and Air velocity is 14 m/s .

Solution:

$$\text{Swept area } A = (\pi d^2/4) = (\pi 126^2/4) = 12470 \text{ m}^2$$

$$\text{Wind Power} = 0.5 \times \text{Swept Area} \times \text{Air Density} \times \text{Velocity}^3$$

$$\text{Wind Power} = 0.5 \times 12,470 \times 1.23 \times (14)^3$$

$$= 21,000,000 \text{ Watts}$$

$$= 21 \text{ MW}$$

Problem-4: Calculate the size of wind mill to meet the annual energy requirement of an industry with the following data:

- i) Annual energy requirement of industry = 20,000 kwh
- ii) Annual average wind velocity = 18 km/hr.
- iii) Coefficient of performance of turbine = 0.4
- iv) Efficiency of rotor = 0.9
- v) Efficiency of generator = 0.9
- vi) Assume density of air = 1.0 kg/m^3

Solution:

$$\text{Velocity} = (18 \times 1000) / 3600 = 5 \text{ m/s}$$

Consider one unit area of turbine

$$\text{Wind power} = 0.5 \times \text{Swept Area} \times \text{Air Density} \times \text{Velocity}^3$$

$$= 0.5 \times 1 \times 1 \times 5^3 = 62.5 \text{ Watts}$$

$$\text{Wind power that is converted in to useful power} = 0.4 \times 0.9 \times 0.9 \times 62.5$$

$$= 20.25 \text{ Watts}$$

$$\text{Power consumption is expressed in wh or kwh} = (20.25 \times 1\text{h}) = 20.25 \text{ wh}$$

Annual power density produced by turbine per unit area

$$= \text{Power density} \times \text{no. of hours in the year}$$

$$= 20.25 \times 365 \times 24$$

$$= 177390 \text{ wh/m}^2 \text{ /year}$$

$$= 177.39 \text{ kwh/m}^2 \text{ /year}$$

$$\text{Total energy required per year} = 20,000 \text{ kwh}$$

$$\text{Energy of turbine per unit area} = 177.39 \text{ kwh/m}^2$$

$$\text{Area of turbine required, } A = 20,000 / 177.39 = 112.75 \text{ m}^2$$

$$(\pi \times D^2) / 4 = 112.75$$

$$D = \sqrt{\frac{112.75 \times 4}{\pi}} = 11.98 \text{ m} = 12 \text{ m or Radius, } R = 6 \text{ m}$$

Problem 5: The annual power requirement of an industry is 30,000 kwh. The management has decided to meet this energy requirement through wind energy. Calculate the size (diameter) of wind mill to meet the annual energy requirement. The following data:

- i) Annual average wind velocity at the site = 20 km/hr.
- ii) Coefficient of performance of turbine = 0.4
- iii) Coefficient of transmission = 0.85
- iv) Coefficient of generator = 0.89
- v) Density of air = 1.0 kg/m³

Solution:

$$\text{Velocity} = (20 \times 1000) / 3600 = 5.55 \text{ m/s}$$

Consider 1 m² area of turbine

$$\text{Wind power} = 0.5 \times \text{Swept Area} \times \text{Air Density} \times \text{Velocity}^3$$

$$= 0.5 \times 1 \times 1 \times 5.55^3 = 85.5 \text{ Watts}$$

$$\begin{aligned}\text{Wind power that is converted into turbine power} &= 0.4 \times 0.85 \times 0.89 \times 85.5 \\ &= 25.87 \text{ Watts}\end{aligned}$$

$$\text{Power consumption expressed in wh or kwh} = (25.87 \times 1\text{h}) = 25.87\text{wh}$$

Annual power density produced by turbine per unit area

$$\begin{aligned}&= \text{Power density} \times \text{no. of hours in the year} \\ &= 25.87 \times 365 \times 24 \\ &= 226621\text{wh/m}^2 / \text{year} \\ &= 226.621 \text{ kwh/m}^2 / \text{year}\end{aligned}$$

$$\text{Total energy required per year} = 30,000 \text{ kwh}$$

$$\text{Energy of turbine per unit area} = 226.621 \text{ kwh/m}^2$$

$$\text{Area of turbine required, } A = 30,000 / 226.621 = 132.38\text{m}^2$$

$$(\pi \times D^2) / 4 = 132.38$$

$$D = \sqrt{\frac{132.38 \times 4}{\pi}} = 12.98\text{m} = 13\text{m or Radius, } R = 6\text{m}$$

UNIT – II (Examination Problems)

Problems on Solar Energy

Problem 1: Calculate the solar energy output of a photo voltaic system for the following data:

Electric power of one solar panel: 280 Wp

Area of one panel: 1.8 m²

No. of panel: 1

Annual average solar radiation on tilted panel: 2080 kWh/m².

Performance ratio: 0.80

Solution:

$$A = \text{Total solar panel Area} = 1.8 \text{ m}^2$$

$$H = \text{Annual average solar radiation on tilted panels} = 2080 \text{ kWh/m}^2.$$

$$PR = \text{Performance ratio} = 0.80$$

$$r = \text{Solar panel yield (\%)} = \text{Electrical power (in kWp) of one solar panel} / \text{Area of one panel}$$

$$\text{Electrical power of one solar panel} = 280 \text{ Wp} = (280/1000) = 0.28 \text{ kWp}$$

$$r = (0.28/1.8) \times 100 = 15.5 \%$$

$$E = A \times r \times H \times PR = 1.8 \times 15.5 \times 2080 \times 0.8 = 46425.6 \text{ kWh}$$

Note: As the No. of panels increases Total solar panel Area increases.

Problems on Wind Energy:

Problem 2: Calculate the size of wind mill to meet the annual energy requirement of an industry with the following data:

- i) Annual energy requirement of industry = 20,000 kwh
- ii) Annual average wind velocity = 18 km/hr.
- iii) Coefficient of performance of turbine = 0.4
- iv) Efficiency of rotor = 0.9
- v) Efficiency of generator = 0.9
- vi) Assume density of air = 1.0 kg/m^3

Solution:

$$\text{Velocity} = (18 \times 1000) / 3600 = 5 \text{ m/s}$$

Consider one unit area of turbine

$$\begin{aligned} \text{Wind power} &= 0.5 \times \text{Swept Area} \times \text{Air Density} \times \text{Velocity}^3 \\ &= 0.5 \times 1 \times 1 \times 5^3 = 62.5 \text{ Watts} \end{aligned}$$

$$\begin{aligned} \text{Wind power that is converted in to useful power} &= 0.4 \times 0.9 \times 0.9 \times 62.5 \\ &= 20.25 \text{ Watts} \end{aligned}$$

$$\text{Power consumption is expressed in wh or kwh} = (20.25 \times 1\text{h}) = 20.25 \text{ wh}$$

Annual power density produced by turbine per unit area

$$\begin{aligned} &= \text{Power density} \times \text{no. of hours in the year} \\ &= 20.25 \times 365 \times 24 \\ &= 177390 \text{ wh/m}^2 / \text{year} \\ &= 177.39 \text{ kwh/m}^2 / \text{year} \end{aligned}$$

$$\text{Total energy required per year} = 20,000 \text{ kwh}$$

$$\text{Energy of turbine per unit area} = 177.39 \text{ kwh/m}^2$$

$$\text{Area of turbine required, } A = 20,000 / 177.39 = 112.75 \text{ m}^2$$

$$(\pi \times D^2) / 4 = 112.75$$

$$D = \sqrt{\frac{112.75 \times 4}{\pi}} = 11.98 \text{ m} \approx 12 \text{ m}$$

Problem 3: The annual power requirement of an industry is 30,000 kwh. The management has decided to meet this energy requirement through wind energy. Calculate the size (diameter) of wind mill to meet the annual energy requirement. The following data:

- i) Annual average wind velocity at the site = 20 km/hr.
- ii) Coefficient of performance of turbine = 0.4
- iii) Coefficient of transmission = 0.85
- iv) Coefficient of generator = 0.89
- v) Density of air = 1.0 kg/m^3

Solution:

$$\text{Velocity} = (20 \times 1000) / 3600 = 5.55 \text{ m/s}$$

Consider 1 m^2 area of turbine

$$\begin{aligned} \text{Wind power} &= 0.5 \times \text{Swept Area} \times \text{Air Density} \times \text{Velocity}^3 \\ &= 0.5 \times 1 \times 1 \times 5.55^3 = 85.5 \text{ Watts} \end{aligned}$$

$$\begin{aligned} \text{Wind power that is converted into turbine power} &= 0.4 \times 0.85 \times 0.89 \times 85.5 \\ &= 25.87 \text{ Watts} \end{aligned}$$

$$\text{Power consumption expressed in wh or kwh} = (25.87 \times 1\text{h}) = 25.87 \text{ wh}$$

Annual power density produced by turbine per unit area

$$\begin{aligned} &= \text{Power density} \times \text{no. of hours in the year} \\ &= 25.87 \times 365 \times 24 \\ &= 226621 \text{ wh/m}^2 \text{ /year} \\ &= 226.621 \text{ kwh/m}^2 \text{ /year} \end{aligned}$$

$$\text{Total energy required per year} = 30,000 \text{ kwh}$$

$$\text{Energy of turbine per unit area} = 226.621 \text{ kwh/m}^2$$

$$\text{Area of turbine required, } A = 30,000 / 226.621 = 132.38 \text{ m}^2$$

$$(\pi \times D^2) / 4 = 132.38$$

$$D = \sqrt{\frac{132.38 \times 4}{\pi}} = 12.98 \text{ m} = 13 \text{ m}$$