A T M E
College of Engineering

Technologies of Renewable Energy Sources

Module-1

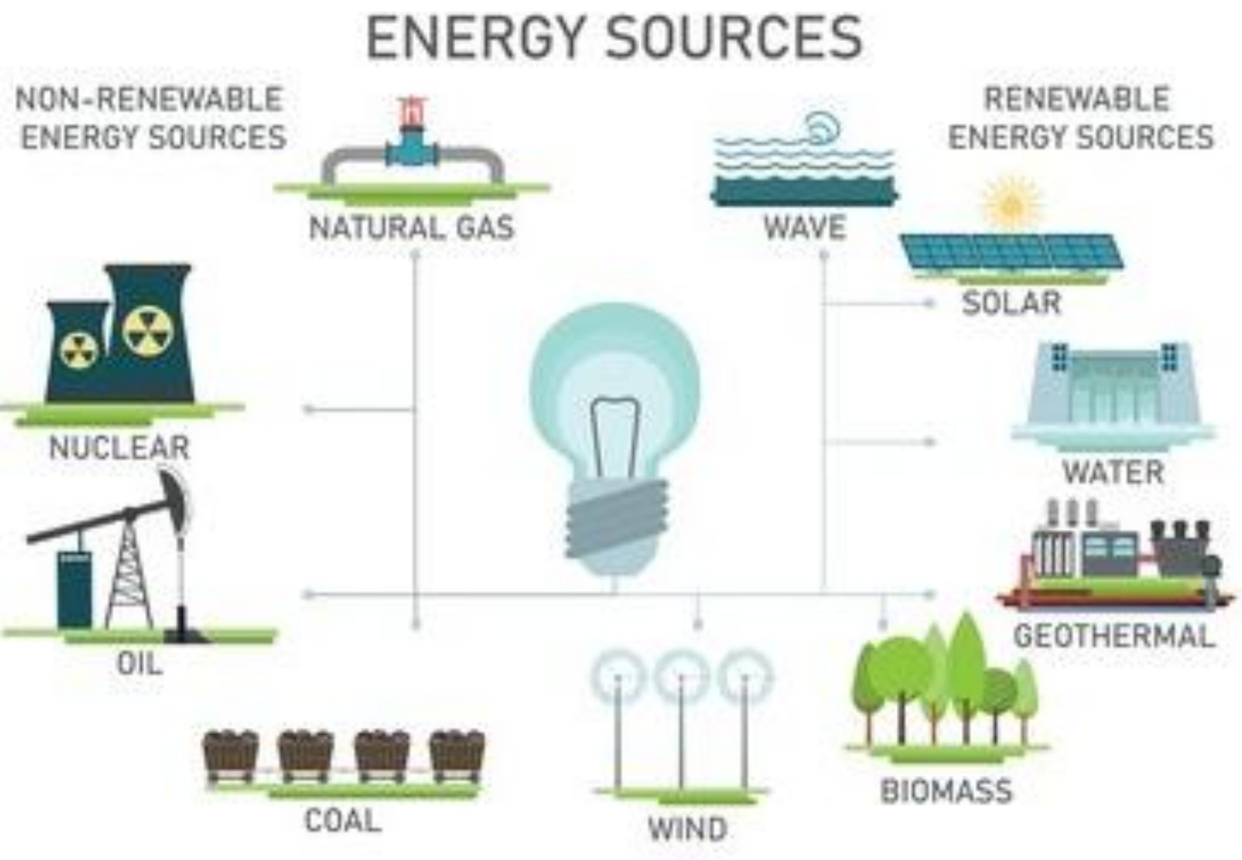
Module-1

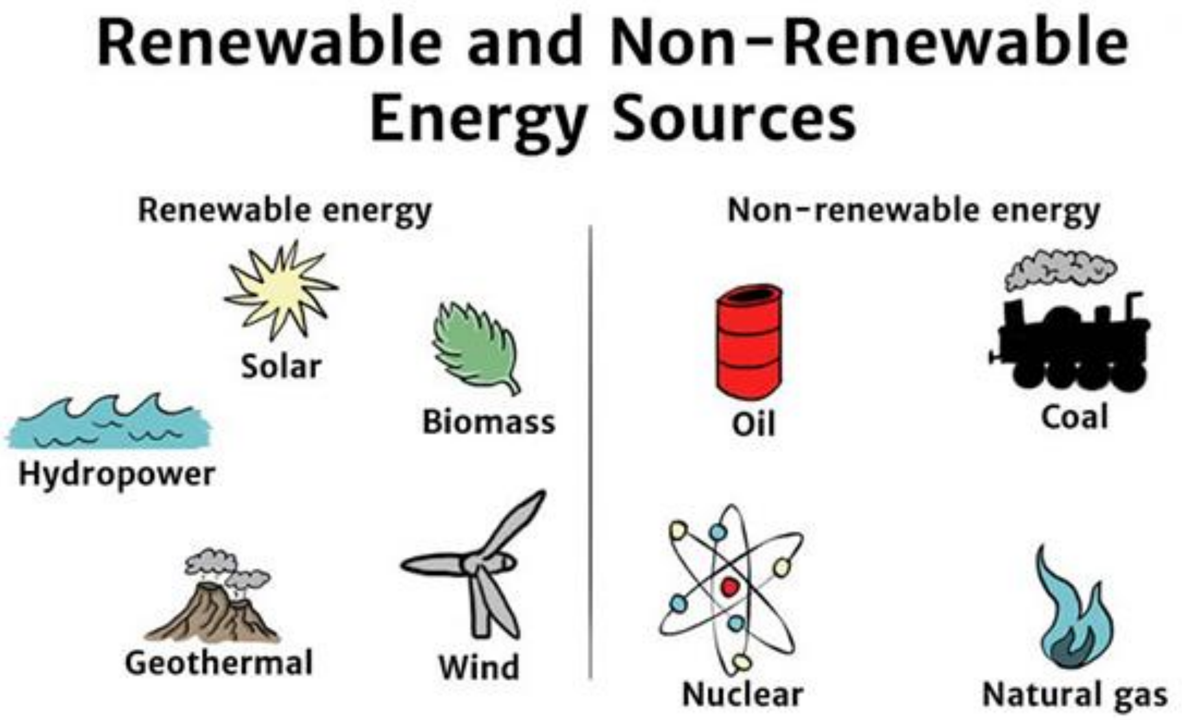
Introduction: Causes of Energy Scarcity, Solution to Energy Scarcity, Factors Affecting Energy Resource Development, Energy Resources and Classification, Renewable Energy – Worldwide Renewable Energy Availability, Renewable Energy in India.

Energy from Sun: Sun- earth Geometric Relationship, Layer of the Sun, Earth – Sun Angles and their Relationships, Solar Energy Reaching the Earth's Surface, Solar Thermal Energy Applications.

Text Books:

1. Nonconventional Energy sources, Shobh Nath Singh, Pearson Publication, First Edition 2015
2. Energy Technology, S.Rao and Dr. B.B. Parulekar, Khanna Publication, 2nd Edition, 1996.


ENERGY SOURCES
NON-RENEWABLE ENERGY SOURCES
RENEWABLE ENERGY SOURCES
NATURAL GAS
WAVE
SOLAR
NUCLEAR
WATER
OIL
GEOTHERMAL
COAL
WIND
BIOMASS


Renewable and Non-Renewable Energy Sources
Renewable energy
Non-renewable energy
Solar
Biomass
Hydropower
Geothermal
Wind
Oil
Coal
Nuclear
Natural gas

- Solar energy is referred to as renewable or sustainable energy because it will be available as long as the sun continues to shine. Estimates for the remaining life of the main stage of the sun are another 4 to 5 billion years.
- The energy from the sun, electromagnetic radiation, is referred to as insolation.
- The other main renewable energies are wind, bioenergy, geothermal, hydro, tides, and waves.
- Wind energy is derived from the uneven heating of the surface of the Earth due to more heat input at the equator with the accompanying transfer of water and thermal energy by evaporation and precipitation.
- In this sense, rivers and dams for hydro energy are stored solar energy.
- The third major aspect of solar energy is the conversion of solar energy into biomass by photosynthesis. Animal products such as oil from fat and biogas from manure are derived from solar energy.

- Another renewable energy is geothermal energy due to heat from the Earth from decay of radioactive particles and residual heat from gravitation during formation of the Earth. Volcanoes are fiery examples of geothermal energy reaching the surface from the interior, which is hotter than the surface.
- Tidal energy is primarily due to the gravitational interaction of the Earth and the moon.
- Overall 14% of the world’s energy comes from bioenergy, primarily wood and charcoal but also crop residue and even animal dung for cooking and some heating. This contributes to deforestation and the loss of topsoil in developing countries.
- Production of ethanol from biomass is now a contributor to liquid fuels for transportation, especially in Brazil and the United States
- In contrast, fossil fuels are stored solar energy from past geological ages. Even though the quantities of oil, natural gas, and coal are large, they are finite, and for the long term of hundreds of years, they are not sustainable

ADVANTAGES/DISADVANTAGES

- **The advantages** of renewable energy are that they are sustainable (nondepletable), ubiquitous (found everywhere across the world, in contrast to fossil fuels and minerals), and essentially nonpolluting.
- Note that wind turbines and photovoltaic panels do not need water for the generation of electricity, in contrast to steam plants fired by fossil fuels and nuclear power.

- **The disadvantages** of renewable energy are variability and low density, which in general results in higher initial cost.
- For different forms of renewable energy, other disadvantages or perceived problems are visual pollution, odor from biomass, avian(birds) and bat mortality with wind turbines, and brine(Water containing salts) from geothermal energy.

ADVANTAGES/DISADVANTAGES

- Wherever a large renewable facility is to be located, there will be perceived and real problems to the local people.
- For conventional power plants using fossil fuels, for nuclear energy, and even for renewable energy, there is the problem of "not in my backyard."

GLOBAL WARMING

- Global warming is a good example that physical phenomena do not react to political or economic statements. Global warming is primarily due to human activity.
- "Global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years

GLOBAL WARMING

- The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture”
- Concentrations of carbon dioxide in the atmosphere (Figure 1.2) are projected to double with future energy use based on today’s trend
- The Kyoto Protocol of 1996 to reduce greenhouse gas emissions became effective in 2005 as Russia became the 55th country to ratify the agreement. The goal was for the participants collectively to reduce emissions of greenhouse gases by 5.2% below the emission levels of 1990 by 2012.

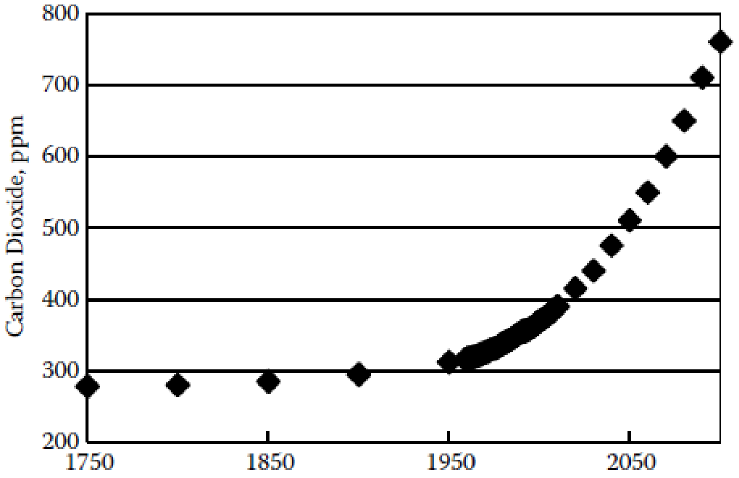


FIGURE 1.2 Carbon dioxide in the atmosphere and projected growth with no emission reductions.

GLOBAL WARMING

- If participant countries continue with emissions above the targets, then they are required to engage in emissions trading.
- Notably, participating countries in Europe are using different methods for carbon dioxide trading, including wind farms and planting forests in other countries.
- Carbon dioxide emissions will still increase, even if nations reduce their emissions to 1990 levels, because of population growth and increase in
- energy use in the underdeveloped world. As the Arctic thaws, then methane, a more potent greenhouse gas than CO_2, would further increase global warming.

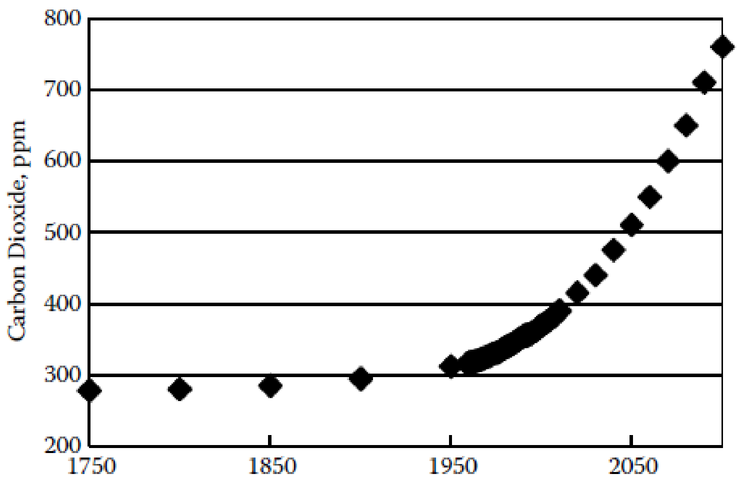


FIGURE 1.2 Carbon dioxide in the atmosphere and projected growth with no emission reductions.

GLOBAL WARMING

- Increased temperatures and the effect on weather and sea-level rise are the major consequences.
- Overall, the increased temperature will have negative effects compared to the climate of 1900–2000.
- By 2100, sea levels are projected to increase by 0.2 to 1 m, with an increase of 2 m unlikely but physically possible
- With positive feedback due to less sea ice and continued increase in carbon dioxide emissions, then melting of the Greenland ice sheets would increase the sea level by over 7 m, and the West Antarctic Ice Sheet would add another 5 m.

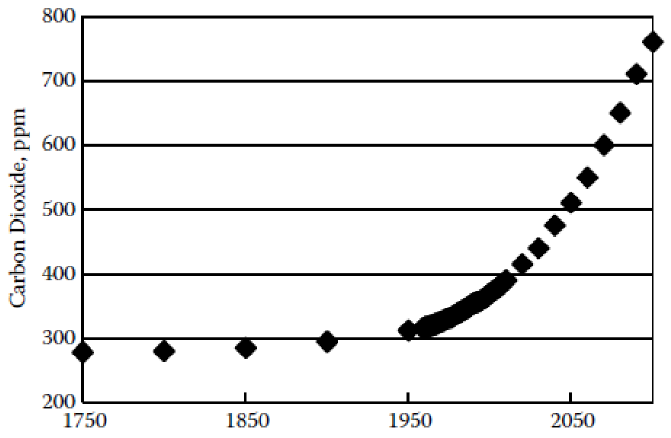


FIGURE 1.2 Carbon dioxide in the atmosphere and projected growth with no emission reductions.

- The large cities on the oceans will have to be relocated or build massive infrastructures to keep out the ocean. Who will pay for this, national or local governments?

ENERGY AND SOCIETY

Industrialized societies run on energy, Population, gross domestic product (GDP), consumption and production of energy and production of pollution for the world and the United States are inter related.

The United States has less than 5% of the population of the world; however, in the world, the United States generates around 25% of the gross production and 22% of the carbon dioxide emissions and is at 22% for energy consumption (Figure 1.1). Notice that the countries listed in Figure 1.1 consume around 75% of the energy and produce 75% of the world GDP and carbon dioxide emissions.

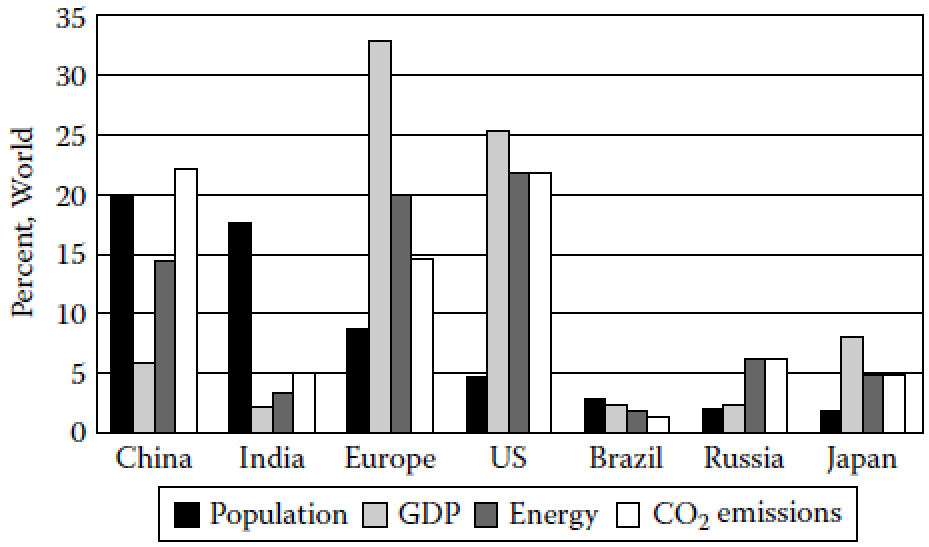
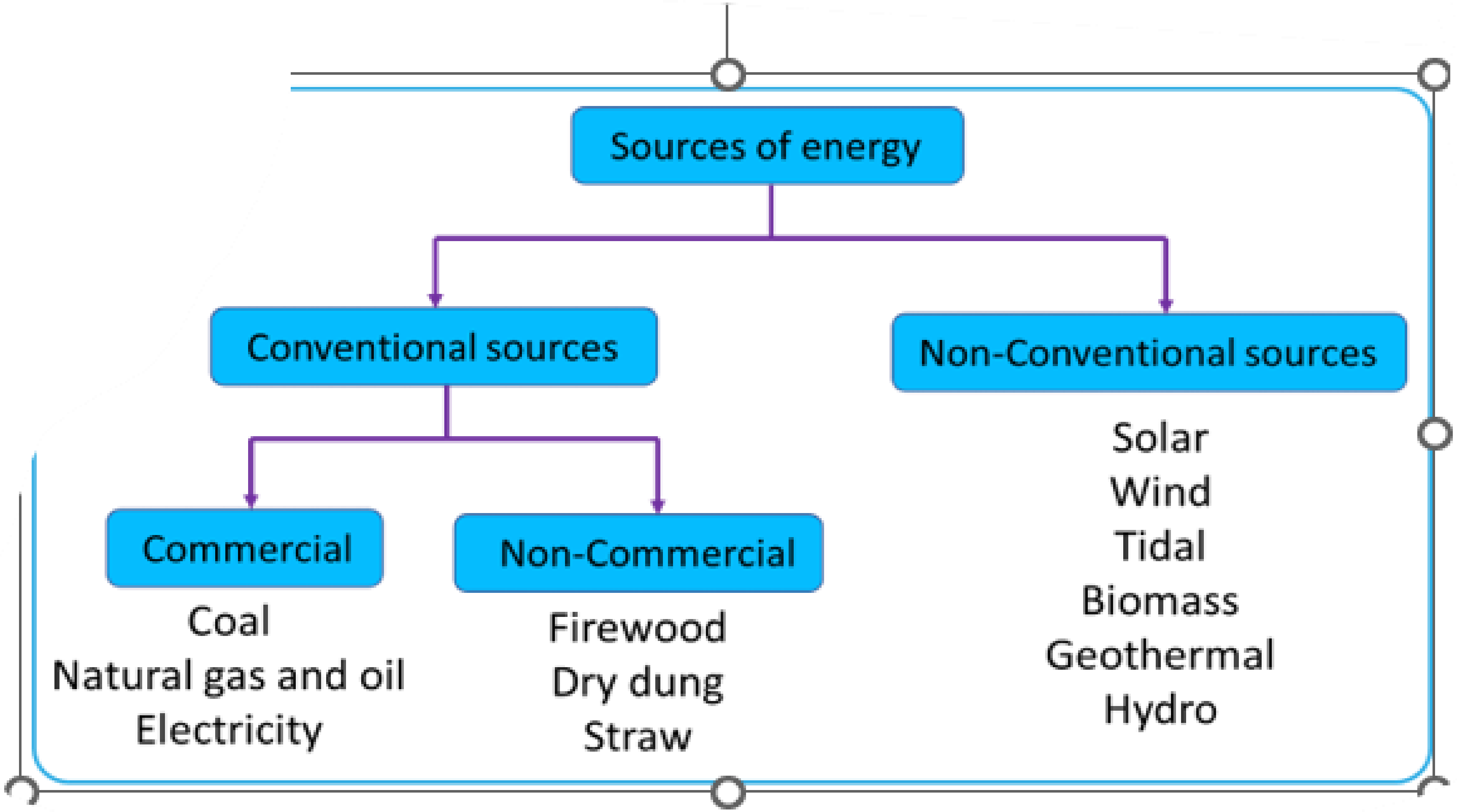
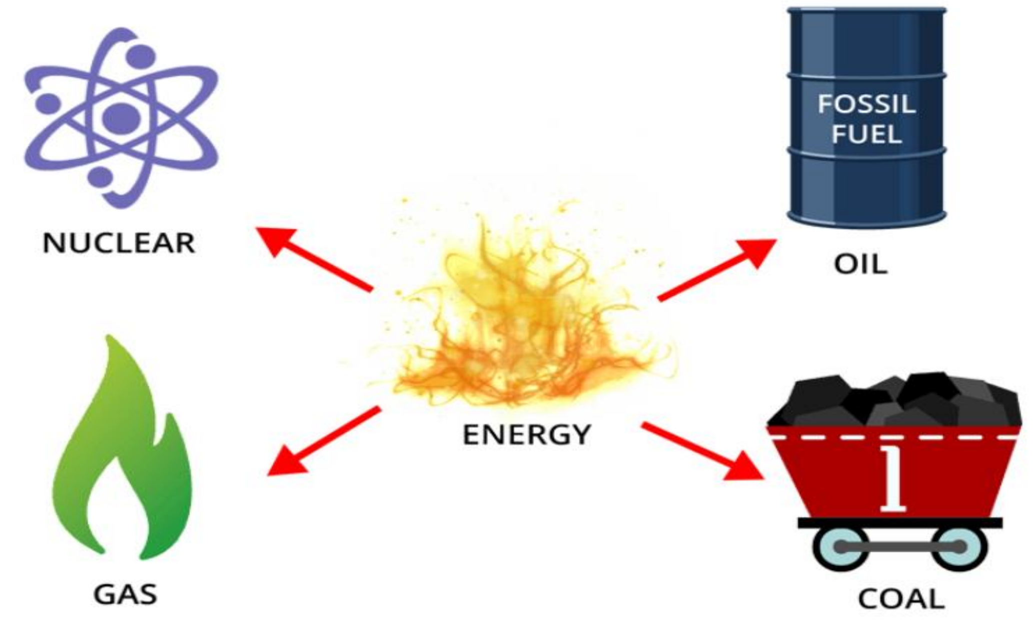


FIGURE 1.1 Comparisons, percentage of world, for population (rank in world), gross domestic product, energy consumption, and carbon dioxide emission.

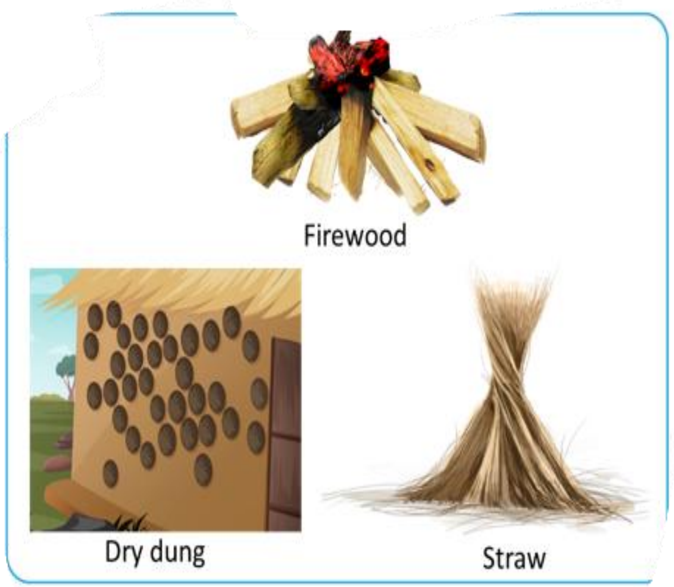

Sources of energy
Conventional sources
Non-Conventional sources
Commercial
Non-Commercial
Coal
Natural gas and oil
Electricity
Firewood
Dry dung
Straw
Solar
Wind
Tidal
Biomass
Geothermal
Hydro

Conventional Sources of Energy: The energy sources that are present for a long time found naturally on or beneath the Earth and take a long time to produce or replenish are known as conventional sources of energy. Generally, these are also non-renewable energy sources.

Commercial energy sources



Non-commercial energy sources

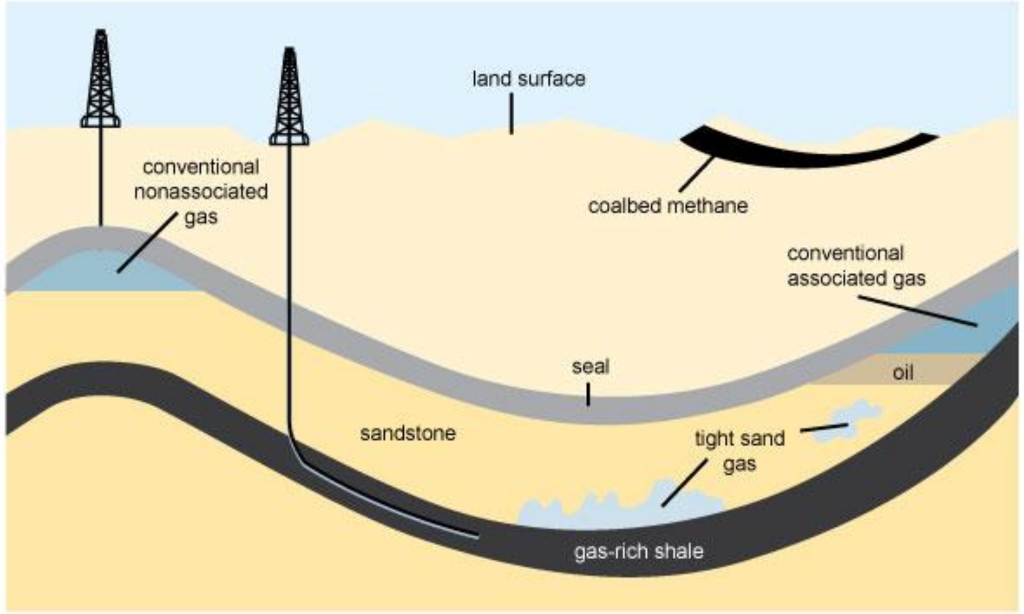


Commercial energy sources: To get energy from these kinds of sources, we need to pay for it. The consumption price depends on various factors like demand and supply, availability, feasibility etc.

Coal: It is a type of fossil fuel that is present beneath the surface of the Earth and was formed by decomposed organic materials due to the high compression and temperature due to Earth's layers. It takes millions of years to form coal which we use. Therefore it is a non-renewable energy resource.

Natural gas and oil: These are also obtained from fossil fuels and are present beneath the surface of the Earth and formed from decomposed organic materials. They are in such form because of the high compression and temperature of the Earth's layers. Natural gas and oil also take a very long time to produce but can be used instantly therefore these are also known as non-renewable energy resources.

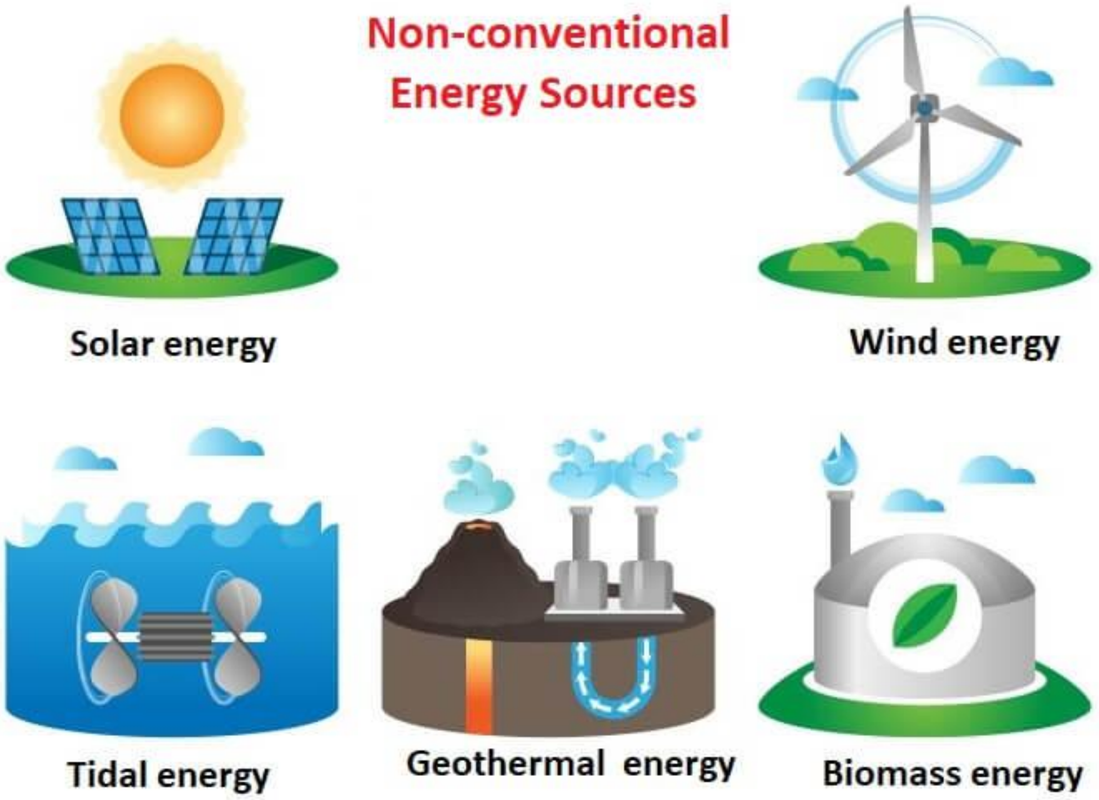
Schematic geology of natural gas resources

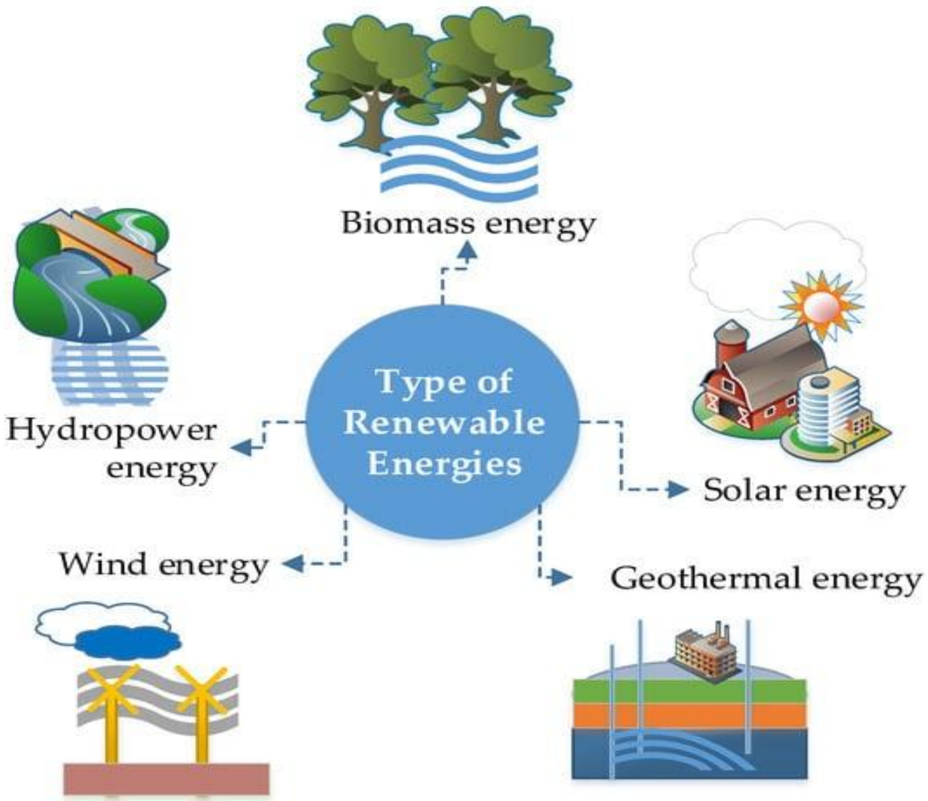


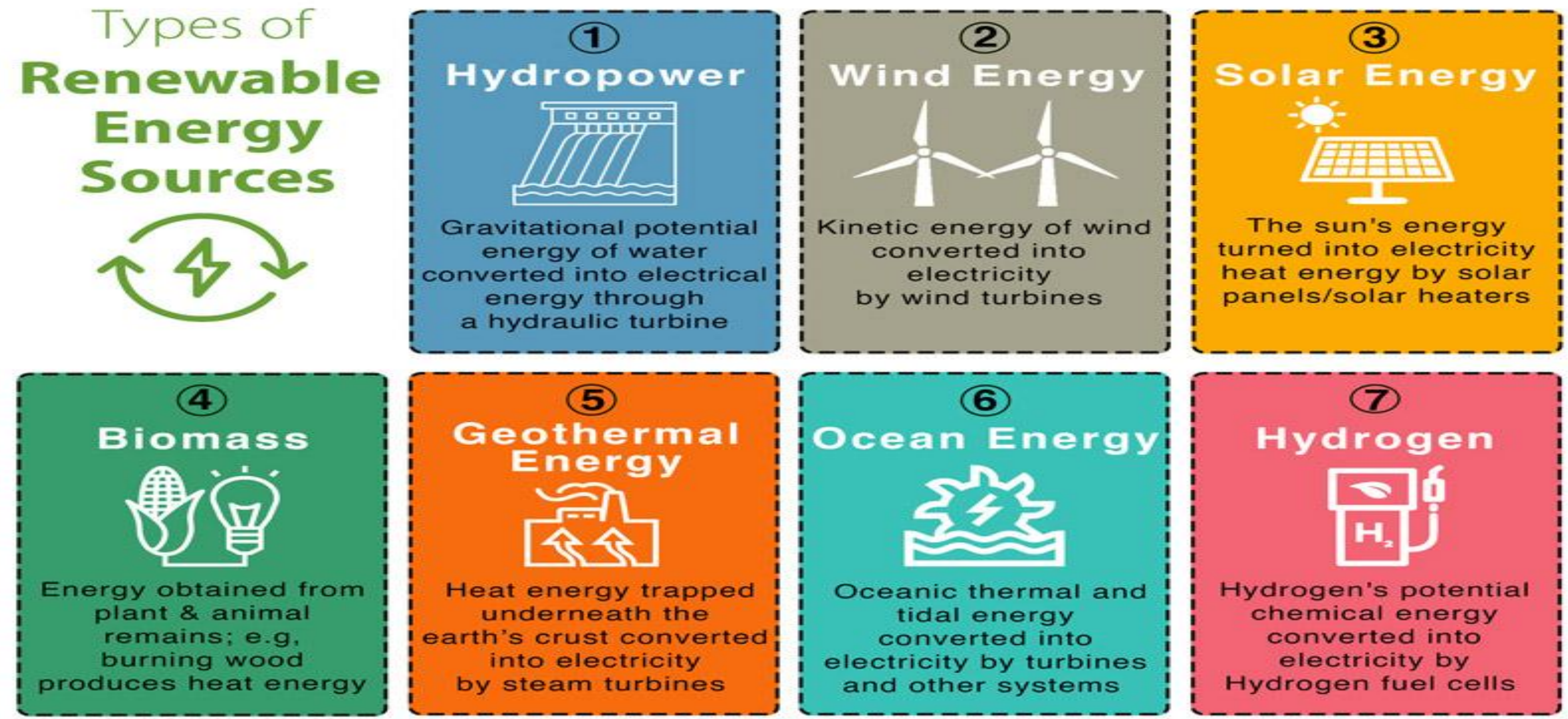
Source: Adapted from *United States Geological Survey factsheet 0113-01* (public domain)

Today oil is considered to be liquid gold and one of the crucial sources of energy in India and the world. Oil is mostly used in planes, automobiles, trains and ships. It is mainly found in Assam, Gujarat, and Mumbai.

Non-Conventional Sources of Energy: The natural resources that can produce useful energy continuously for a long period of time and are available again and again for use even after it is exhausted are known as non-conventional sources of energy or renewable resources of energy.






Types of
Renewable Energy Sources
1 Hydropower
Gravitational potential energy of water converted into electrical energy through a hydraulic turbine
2 Wind Energy
Kinetic energy of wind converted into electricity by wind turbines
3 Solar Energy
The sun's energy turned into electricity heat energy by solar panels/solar heaters
4 Biomass
Energy obtained from plant & animal remains; e.g, burning wood produces heat energy
5 Geothermal Energy
Heat energy trapped underneath the earth's crust converted into electricity by steam turbines
6 Ocean Energy
Oceanic thermal and tidal energy converted into electricity by turbines and other systems
7 Hydrogen
Hydrogen's potential chemical energy converted into electricity by Hydrogen fuel cells

Classification of Renewable Energy

Renewable energy can be classified into several types based on the source of energy. The main types of renewable energy include:

Solar Energy: Solar energy is obtained from the sun and can be harnessed using solar panels or concentrated solar power (CSP) systems.

Wind Energy: Wind energy is obtained from the kinetic energy of wind and can be harnessed using wind turbines.

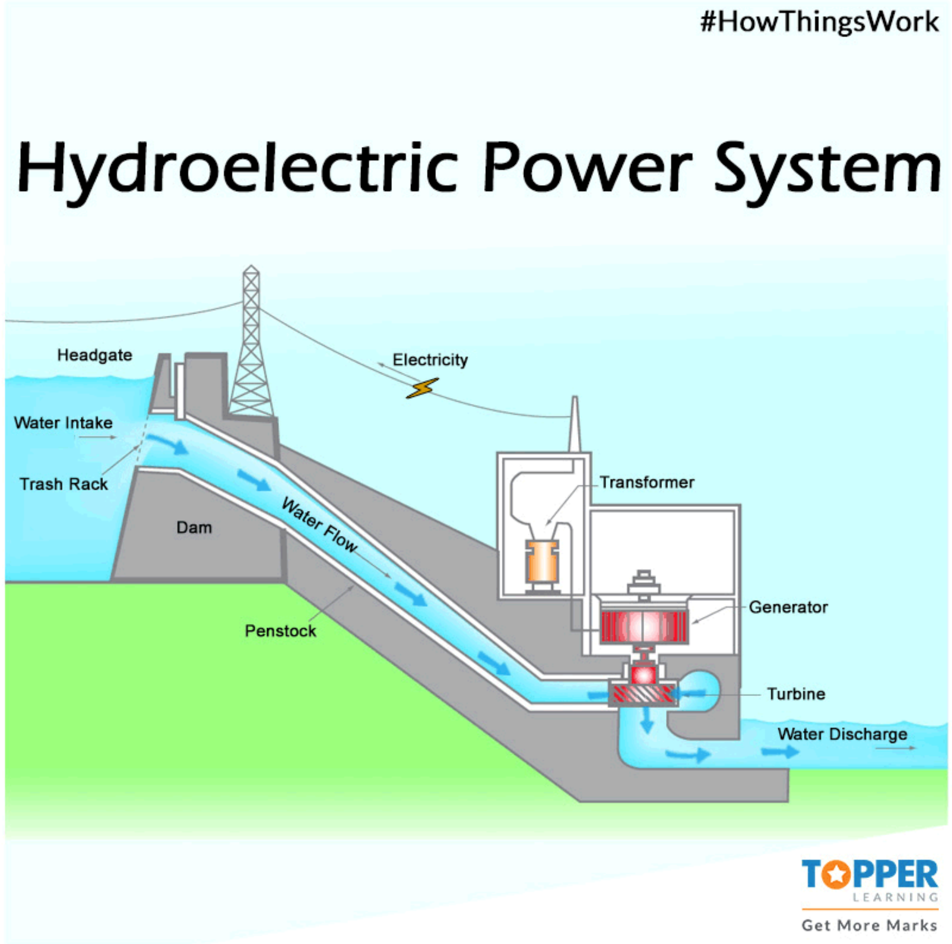
Hydro Energy: Hydro energy is obtained from the kinetic energy of water and can be harnessed using hydropower plants.

Geothermal Energy: Geothermal energy is obtained from the heat generated within the Earth and can be harnessed using geothermal power plants

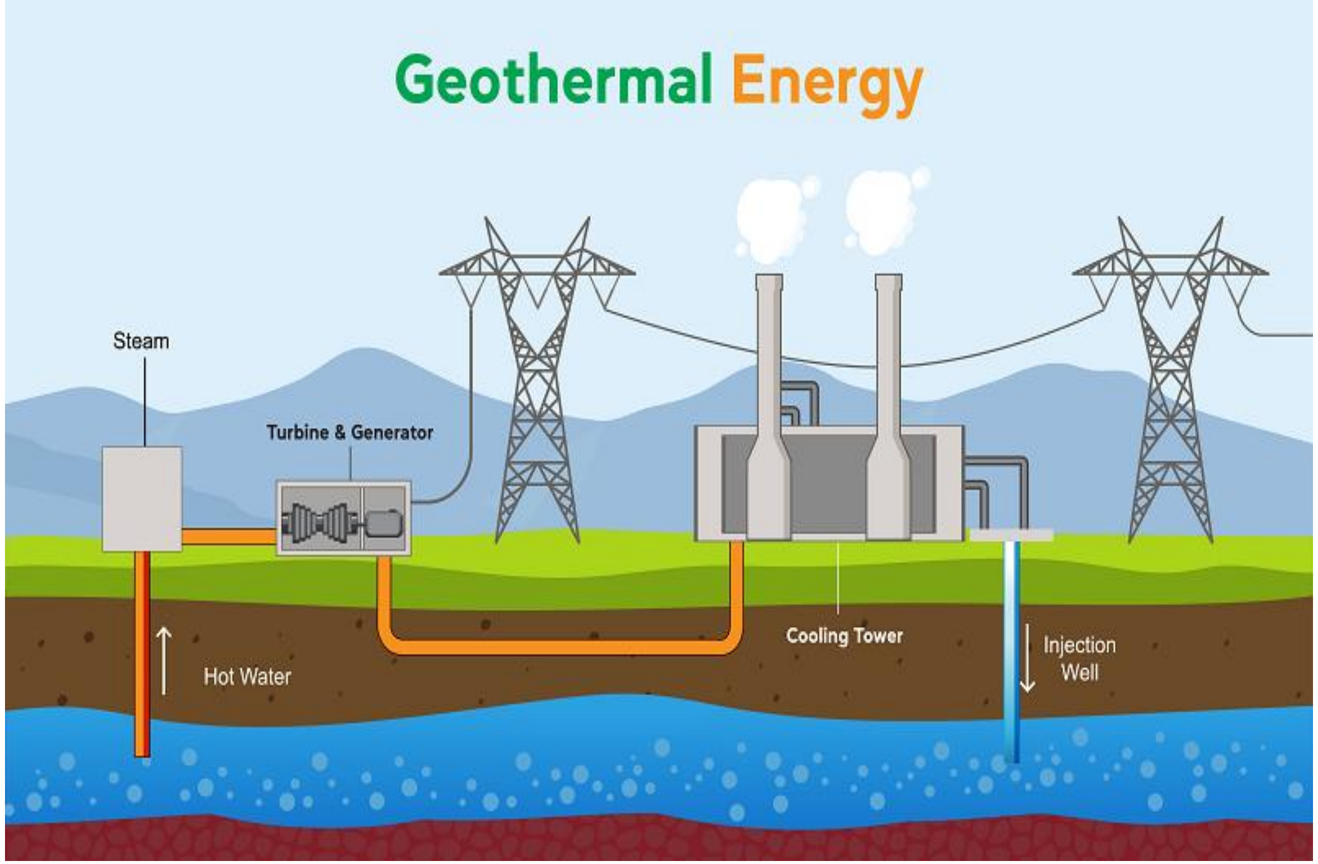
Solar:

Wind:

Hydro:



Geothermal :



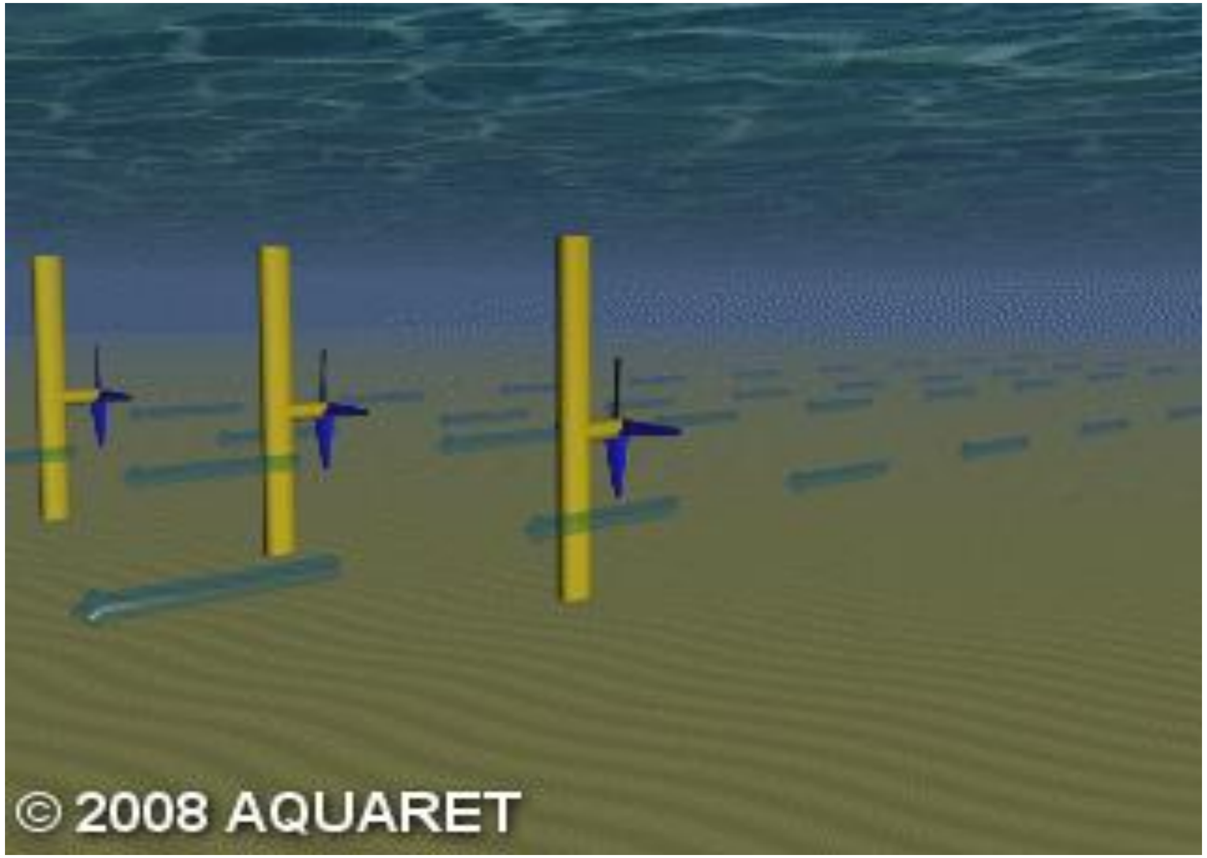
Classification of Renewable Energy

Biomass Energy: Biomass energy is obtained from organic matter such as wood, crops, and waste materials, and can be harnessed using various technologies such as combustion, gasification, and anaerobic digestion.

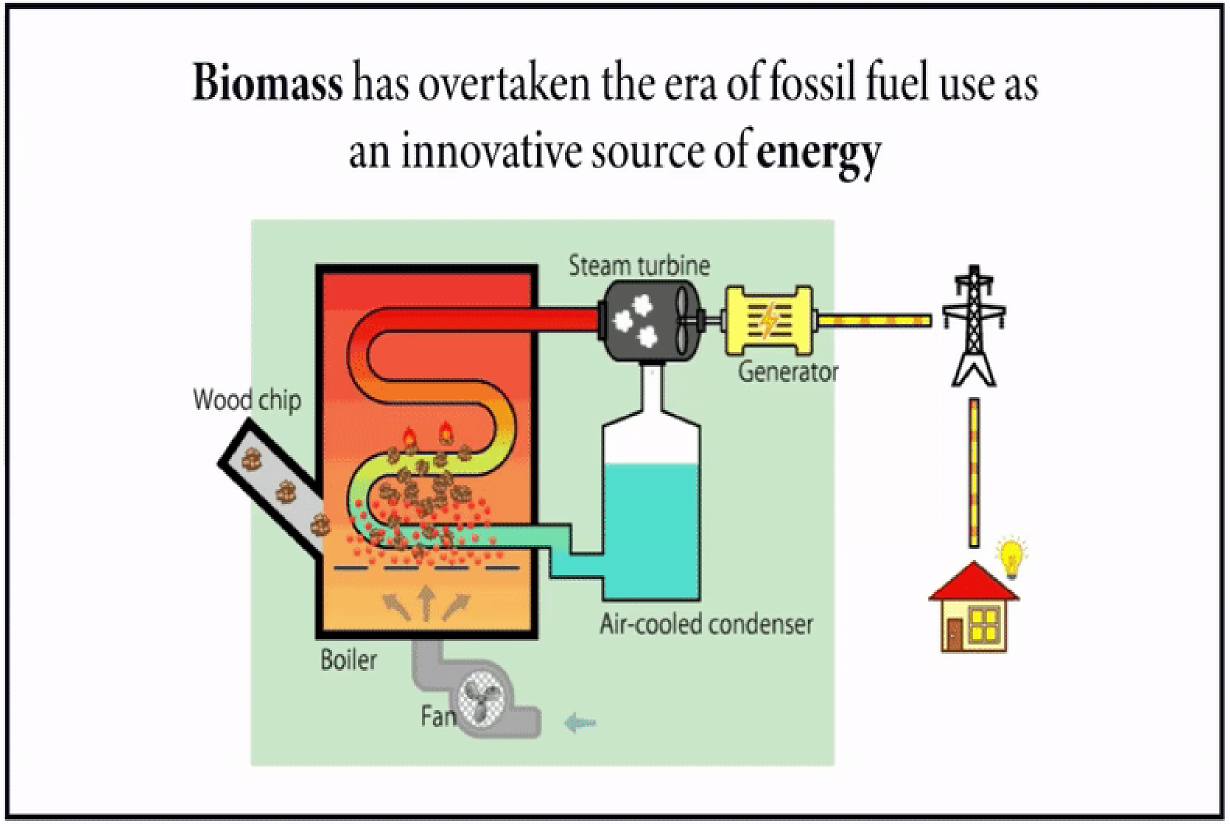
Ocean Energy: Ocean energy is obtained from the kinetic energy of waves, tides, and currents, and can be harnessed using various technologies such as tidal turbines and wave energy converters.

Each type of renewable energy has its unique advantages and challenges, and their suitability varies depending on factors such as location, availability of resources, and technology.

Tidal:



Biomass:



Causes of Energy Scarcity

- Energy scarcity can be caused by several factors:

1. Population growth: The world's population continues to grow, and with it, the demand for energy increases. This increase in energy demand can lead to energy scarcity, especially in developing countries with inadequate infrastructure to meet the energy demand.
2. Limited fossil fuel resources: Fossil fuels like coal, oil, and gas are finite resources and will eventually be depleted. As these resources become scarcer, the cost of extracting them increases, making them less affordable and leading to energy scarcity.
3. Political instability: Political instability and conflicts in regions that produce or transport energy resources can disrupt the supply of energy, leading to energy scarcity. This is especially true for countries heavily reliant on imports of energy resources.

Causes of Energy Scarcity

- Natural disasters: Natural disasters such as hurricanes, earthquakes, and floods can damage energy infrastructure, leading to energy scarcity. This was evident during Hurricane Katrina in the United States, where a significant portion of the country's oil and gas production was affected.
- Inadequate infrastructure: Inadequate infrastructure, such as outdated power grids, can lead to energy scarcity. Power outages and brownouts can occur when the power grid is unable to meet the energy demand, leading to energy scarcity.
- Climate change: Climate change can also contribute to energy scarcity, especially in regions that rely heavily on hydropower. Changes in precipitation patterns and temperatures can affect water availability, reducing the amount of energy that can be generated from hydropower.

Solution to Energy Scarcity

There are several solutions to address energy scarcity:

- Increase the use of renewable energy sources: Renewable energy sources such as solar, wind, hydro, geothermal, and biomass can play a significant role in reducing energy scarcity. Governments and private sector organizations can invest in the development of renewable energy infrastructure, making it a more accessible and cost-effective alternative to traditional fossil fuels.

- Implement energy efficiency measures: Energy efficiency measures, such as improving building insulation and upgrading to energy-efficient appliances, can reduce the demand for energy and decrease the strain on energy infrastructure, ultimately reducing energy scarcity.

Solution to Energy Scarcity

- Develop energy storage technologies: Advances in energy storage technologies can allow renewable energy sources to be stored more efficiently and effectively, reducing energy scarcity during periods of high demand.
- Implement demand-side management: Demand-side management involves managing energy consumption during peak periods to reduce the strain on the energy grid. This can be achieved through the use of smart grids and the implementation of pricing policies that encourage consumers to reduce energy consumption during peak periods.
- Improve energy infrastructure: Upgrading energy infrastructure, such as power grids and transmission lines, can increase the capacity of the energy system and reduce the risk of energy scarcity.

Factors Affecting Energy Resource Development

- Factors affecting energy resource development include:

1. Resource Availability: The availability of energy resources is a crucial factor that affects energy resource development. Regions with abundant energy resources are more likely to have developed energy industries. For example, countries with significant oil reserves are more likely to have developed oil industries.
2. Infrastructure: Adequate infrastructure is essential for energy resource development. Infrastructure includes transportation, communication, and energy infrastructure. For example, the development of pipelines, transmission lines, and roads are essential for the transportation of energy resources.

Factors Affecting Energy Resource Development

3. Technological Advancements: Advancements in technology can significantly impact energy resource development. New technologies can improve the efficiency and effectiveness of energy production, making it more accessible and cost-effective. For example, advancements in solar panel technology have made solar energy more accessible and cost-effective.

4. Government Policies: Government policies can impact energy resource development. Policies that provide incentives for renewable energy production and limit the use of fossil fuels can promote sustainable energy development. For example, government policies that provide tax incentives for the production of renewable energy can encourage investment in renewable energy.

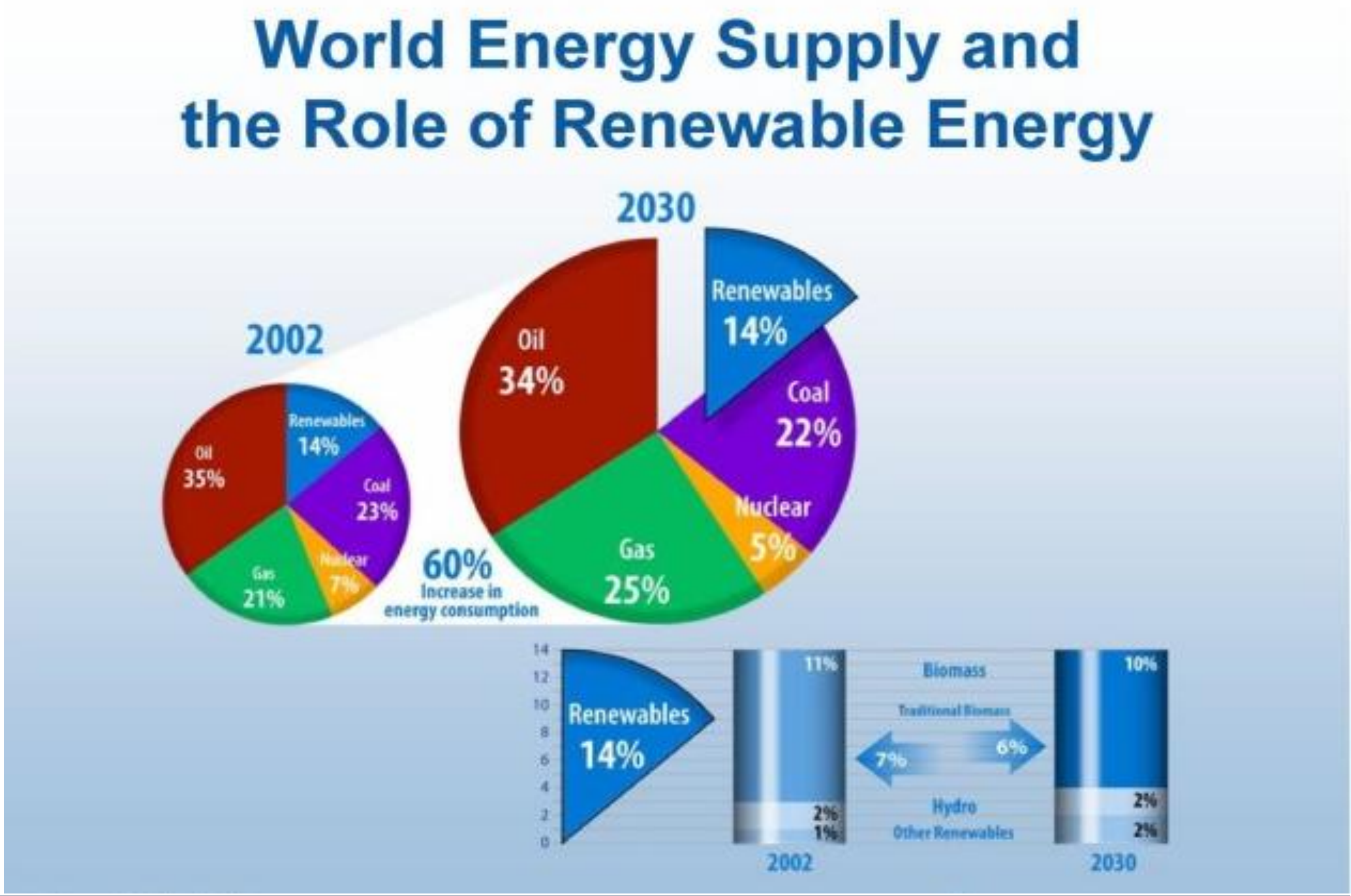
Factors Affecting Energy Resource Development

1. Economic Factors: Economic factors such as investment capital and energy prices can impact energy resource development. For example, high energy prices can encourage investment in renewable energy, while low energy prices can discourage investment.

2. Environmental Concerns: Environmental concerns such as air and water pollution and climate change can impact energy resource development. The production and use of fossil fuels can result in air and water pollution, while the use of renewable energy can reduce greenhouse gas emissions and promote environmental sustainability.

Worldwide Renewable Energy Availability

Renewable energy sources are available all around the world, although their availability and potential vary depending on several factors such as geographical location, climate conditions, and natural resources. Here are some general facts about renewable energy availability worldwide:



Solar Energy: The sun is a source of abundant and free energy, and solar power is one of the fastest-growing sources of renewable energy worldwide. The areas with the highest solar energy potential are deserts and other arid regions, as they receive more sunlight and have less cloud cover.

Wind Energy: Wind power is another rapidly growing source of renewable energy, and its potential is highest in areas with consistent and strong winds. Coastal regions, high-altitude areas, and plains are some of the places where wind energy potential is high

Hydropower: Hydropower is generated by the force of falling water, and its potential depends on factors such as the height of the waterfalls and the volume of the water flow. Areas with high rainfall and mountainous terrain tend to have high hydropower potential.

Geothermal Energy: Geothermal energy is generated by the heat from the Earth's core, and its potential is highest in areas with active tectonic activity or hotspots. Some of the areas with high geothermal energy potential include Iceland, the western United States, and parts of East Africa.

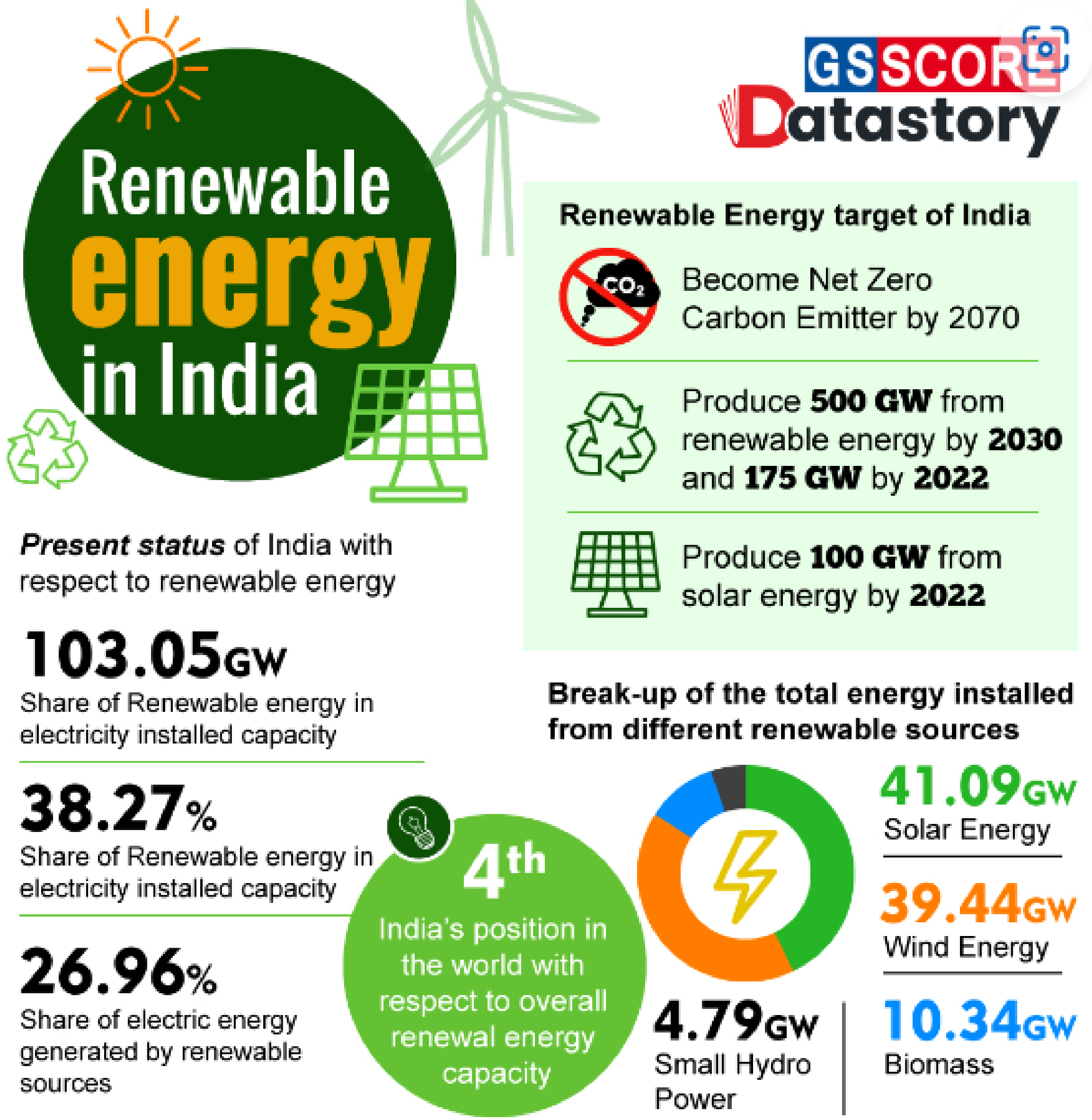
Overall, renewable energy sources have the potential to meet a significant portion of the world's energy demand and reduce our reliance on fossil fuels. However, the deployment and adoption of renewable energy technologies require significant investments and policy support to overcome technical and economic barriers.

Renewable Energy in India

India has set ambitious targets for renewable energy deployment as part of its efforts to address energy security, climate change, and sustainable development. Here are some facts about renewable energy in India:

Solar Energy: India is one of the largest solar power markets in the world, with a total installed capacity of over 40 GW as of 2021.

The Indian government has launched several programs and policies to promote solar energy deployment, including the Jawaharlal Nehru National Solar Mission and the Kisan Urja Suraksha evam Utthaan Mahabhiyan (KUSUM) scheme.



- Wind Energy: India has a total installed wind power capacity of over 39 GW as of 2021, making it the fourth-largest wind power market in the world. The Indian government has implemented several policies and incentives to support wind energy deployment, such as the National Wind-Solar Hybrid Policy and the Generation-Based Incentive (GBI) scheme.

- Hydropower: India has significant hydropower potential, with an estimated total potential of over 145 GW. However, the development of hydropower projects in India faces several challenges, including environmental concerns and social issues.

- Other renewable energy sources: India has also been exploring other renewable energy sources such as biomass, biogas, and small hydropower projects. The Indian government has launched several programs and initiatives to promote these sources, such as the National Bio-Energy Mission and the Small Hydro Power Programme.

- Overall, renewable energy is a key component of India's energy strategy, and the country has set a target of achieving 450 GW of renewable energy capacity by 2030. The deployment of renewable energy technologies in India is expected to provide significant economic, social, and environmental benefits, including job creation, rural development, and greenhouse gas emissions reduction.

SOLAR POWER

The sun is a big ball of plasma(a hot, ionized gas) composed primarily of hydrogen (92%), helium (8%), and small amounts of other atoms or elements. A plasma is where the electrons are separated from the nuclei because the temperature is so high (kinetic energy of nuclei and electrons is large). By the process of fusion, protons are converted into helium nuclei plus energy. The sun is a stable main sequence star with an estimated age of 4.5 * 10+9 years and will continue for another 4 to 5 *10+9 years before starting the next phase of evolution, the burning of helium. At that point, the sun will expand and be larger than the orbit of the Earth.

TABLE 3.1
Characteristics of Sun and Earth

	Sun	Earth
Diameter, km	1,392,000	12,740
Mass, kg	$1.99 * 10^{30}$	$5.98 * 10^{24}$
Surface temperature, K	5,800	300

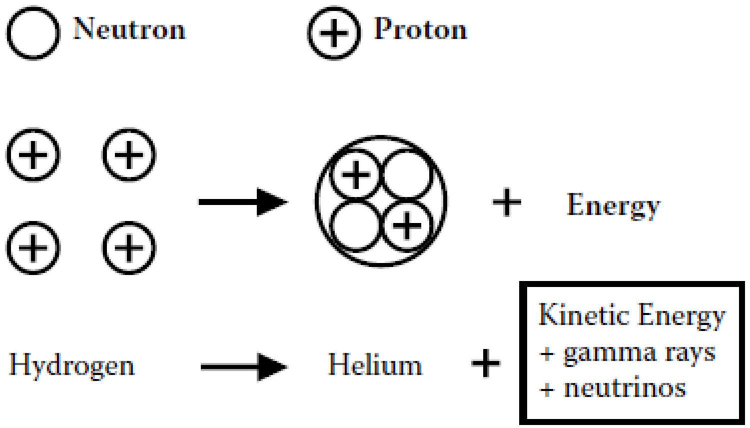


FIGURE 3.1 In the center of the sun, protons are converted into helium nuclei plus energy.

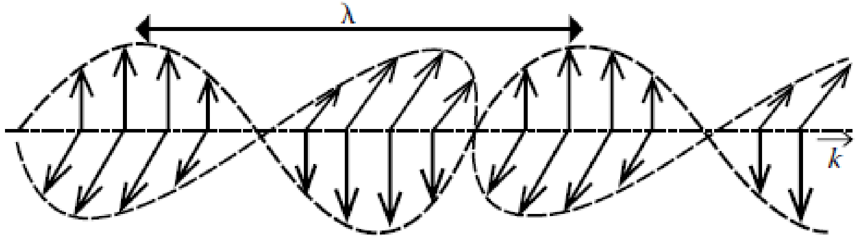


FIGURE 3.3 Diagram of electromagnetic wave showing components of electric and magnetic fields; the wave is traveling to the right.

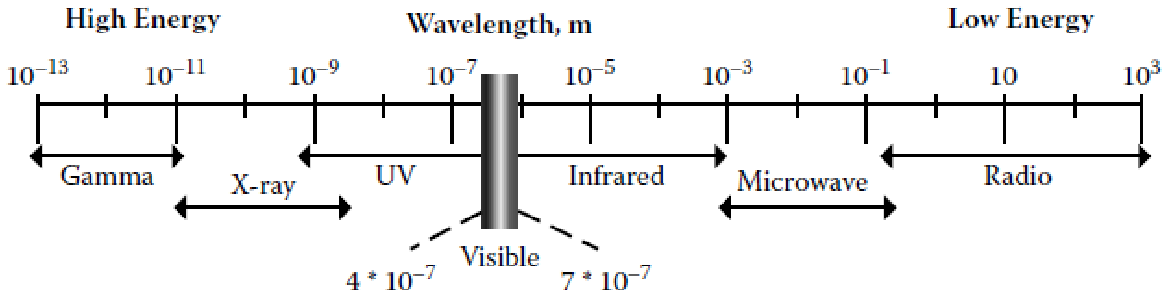


FIGURE 3.4 Electromagnetic spectrum from gamma radiation to long-wavelength radio waves.

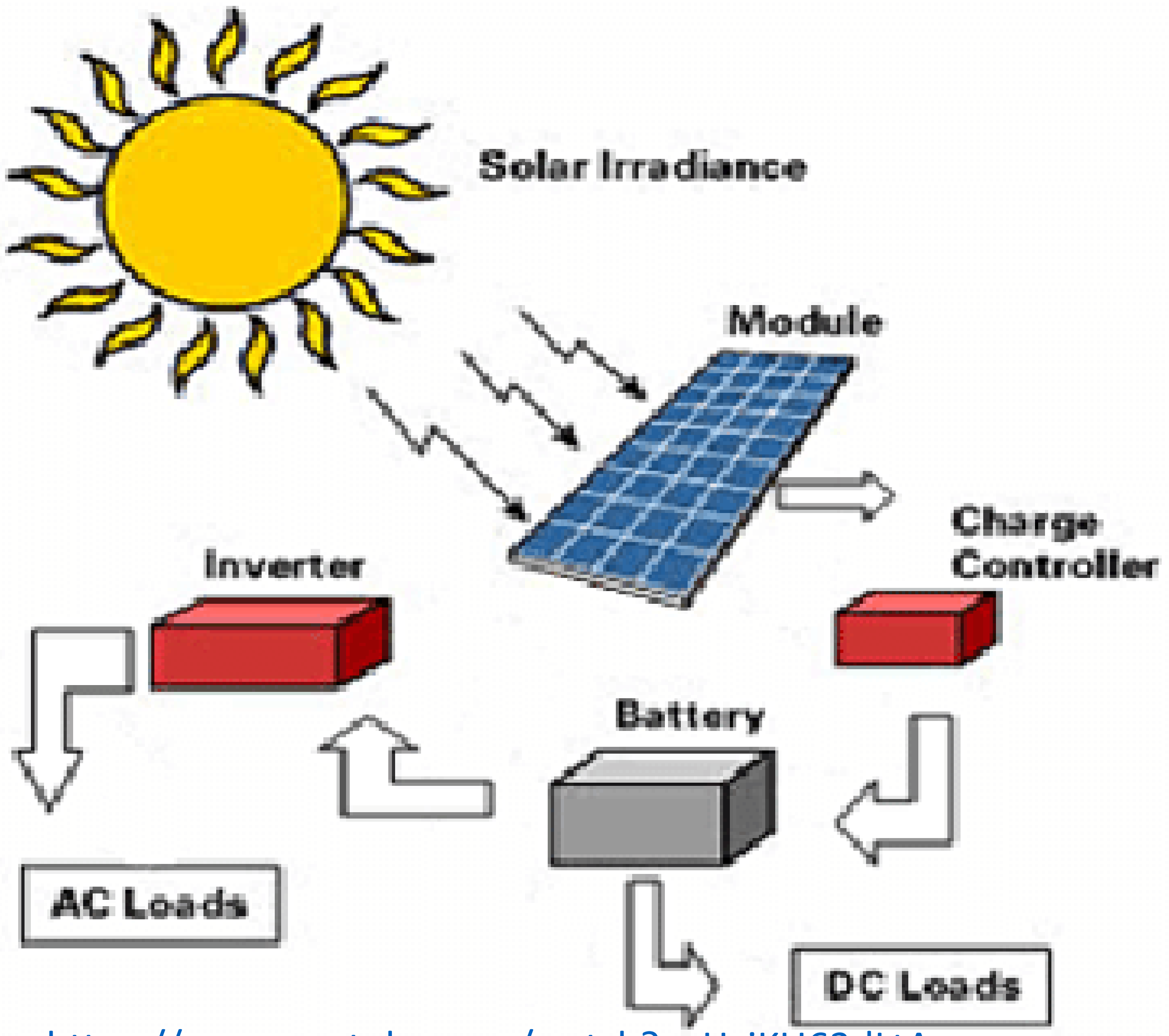
Solar Power Generation:

The amount of energy supplied to the earth in one day by the sun is sufficient to power the total energy needs of the earth for one year.

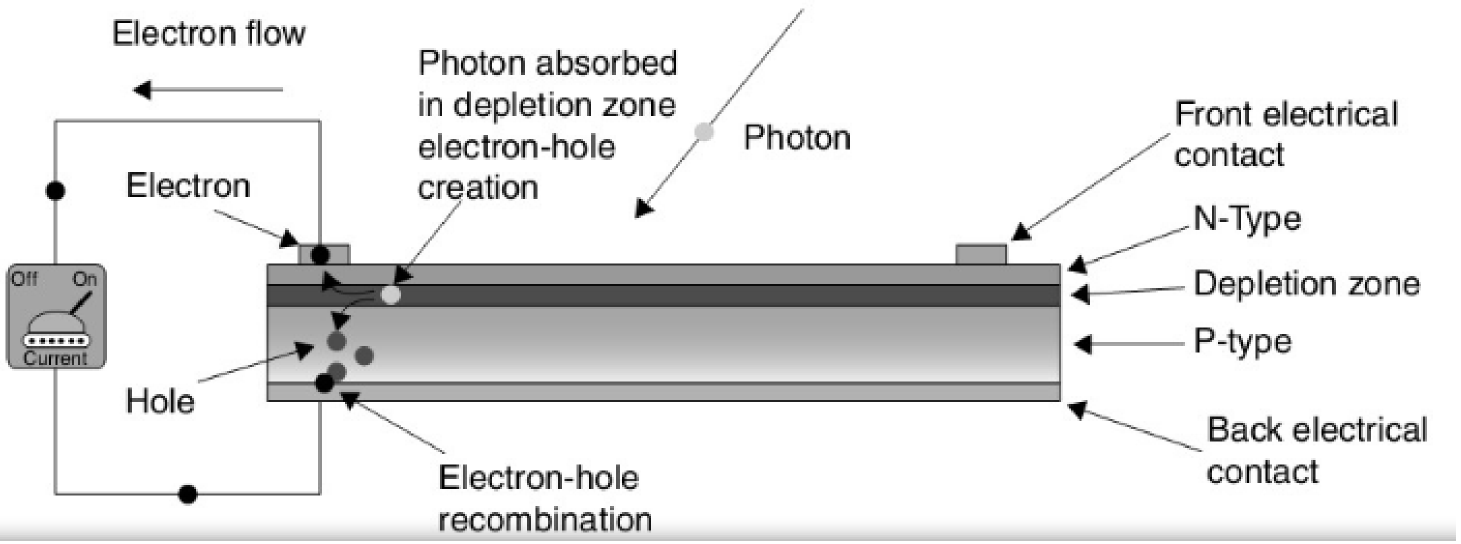
Solar energy is clean and free of emissions, since it does not produce pollutants or by-products harmful to nature.

The conversion of solar energy into electrical energy has many application fields. Residential, vehicular, space and aircraft, and naval applications are the main fields of solar energy

The essential component in solar energy system is photovoltaic or solar cell, by which sunlight energy is converted into electric current upon the principle of the photoelectric effect



https://www.youtube.com/watch?v=HciKU63dLtA



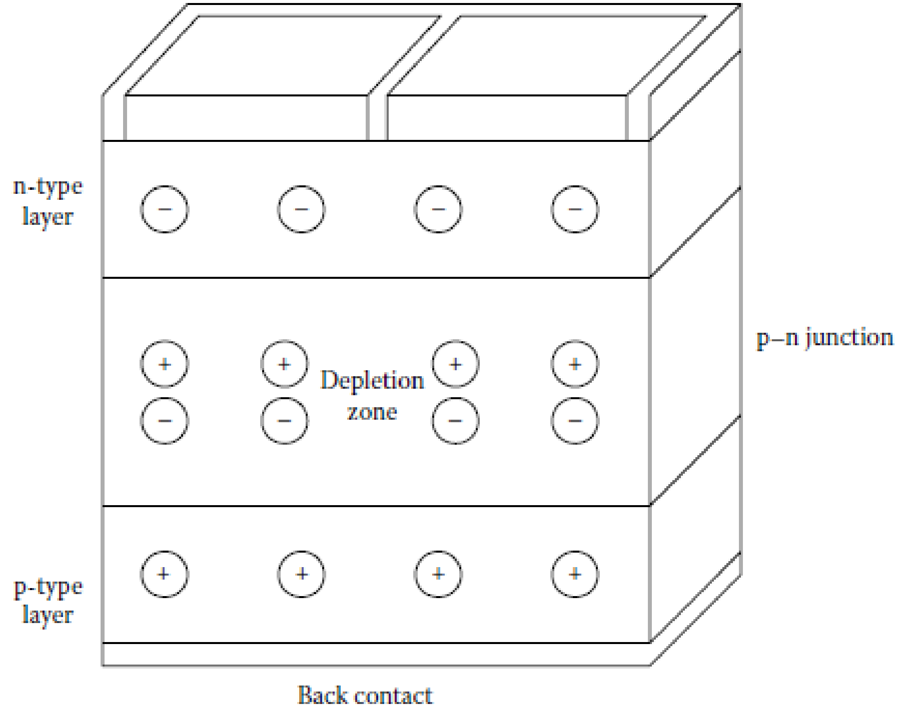


FIGURE 1.1 p–n junction of the PV cell.

More than 80% of solar cells currently produced are crystalline silicon solar cells. Nearly all of the other 20% are developed as amorphous silicon solar cells.

A Solar PV cell has a P-type silicon layer placed in contact with a N-type silicon layer. The P-type material consists of holes to accept the electrons and the N-type material has ample electrons, thus forms the P-N junction as like diode component.

Under the influence of the solar energy, electrons passes from an N- type material combines with holes. This creates an electric charge on either side of the p-n junction to create an electric field. This field develops a potential difference across the junction. If an external load is connected to the solar panel, this charge difference drives the load current. As a long as the sunlight is present on the panel, current will drive the load.

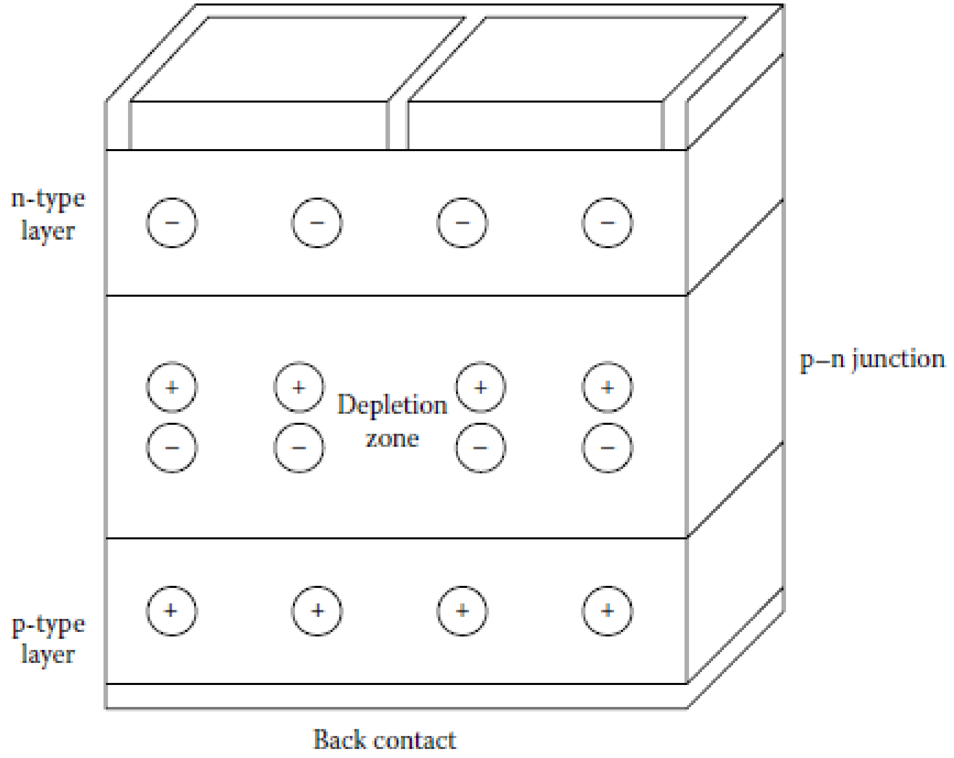


FIGURE 1.1 p–n junction of the PV cell.

A PV or solar cell is the basic building block of a PV(or solar electric) system. An individual PV cell is usually quite small, typically producing about 1 or 2W of power. To boost the power output of PV cells, they have to be connected together to form larger units called modules. The modules, in turn, can be connected to form larger units called arrays, which can be interconnected to produce more power. By connecting the cells or modules in series, the output voltage can be increased. On the other hand, the output current can reach higher values by connecting the cells or modules in parallel

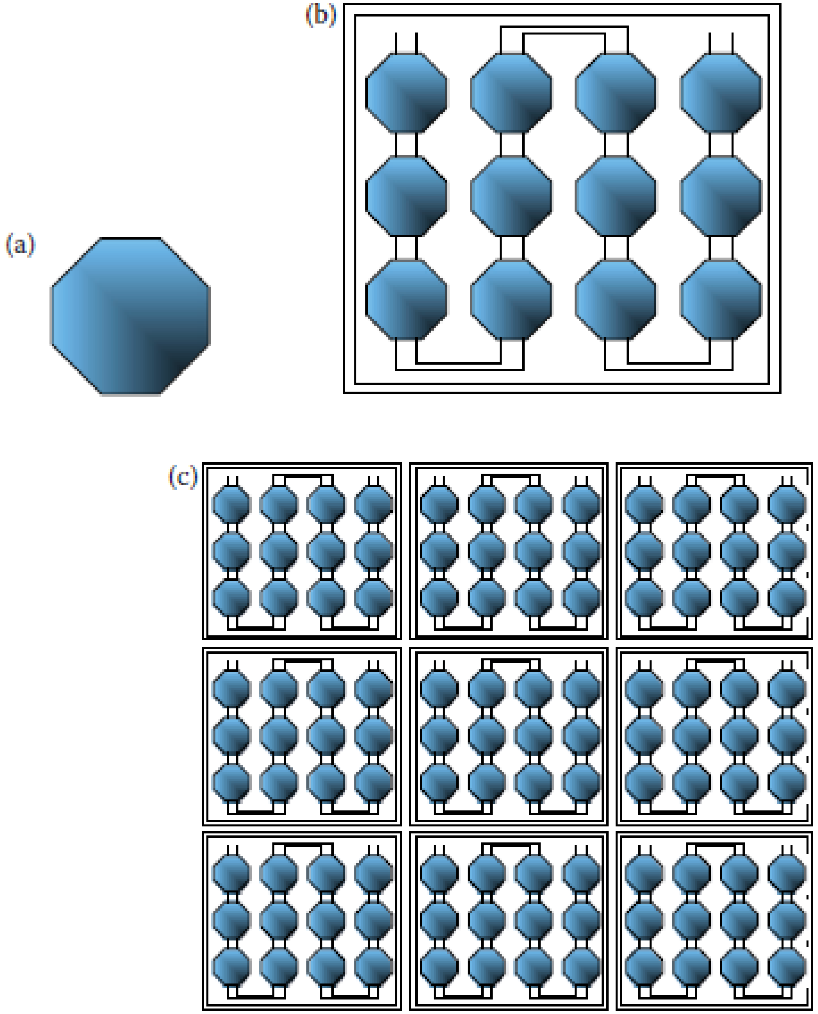


FIGURE 1.2 (a) PV cell, (b) module, and (c) array.

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A solar cell (see Fig. 1.9) is essentially a PN junction with a large surface area .The P-type material is thick (about 200–300 μm). The N-type material is kept thin (of the order of 0.2–0.3 μm) to allow light to pass through to the PN junction. Light travels in packets of energy called photons. The energy (E) of photon is given by

$$E = hc/\lambda \qquad (1.6)$$

where

h = Planck's constant, 6.62×10^{-27} erg/s

c = velocity of light, 3×10^{8} m/s

λ = wavelength of light, μm

From which, we get

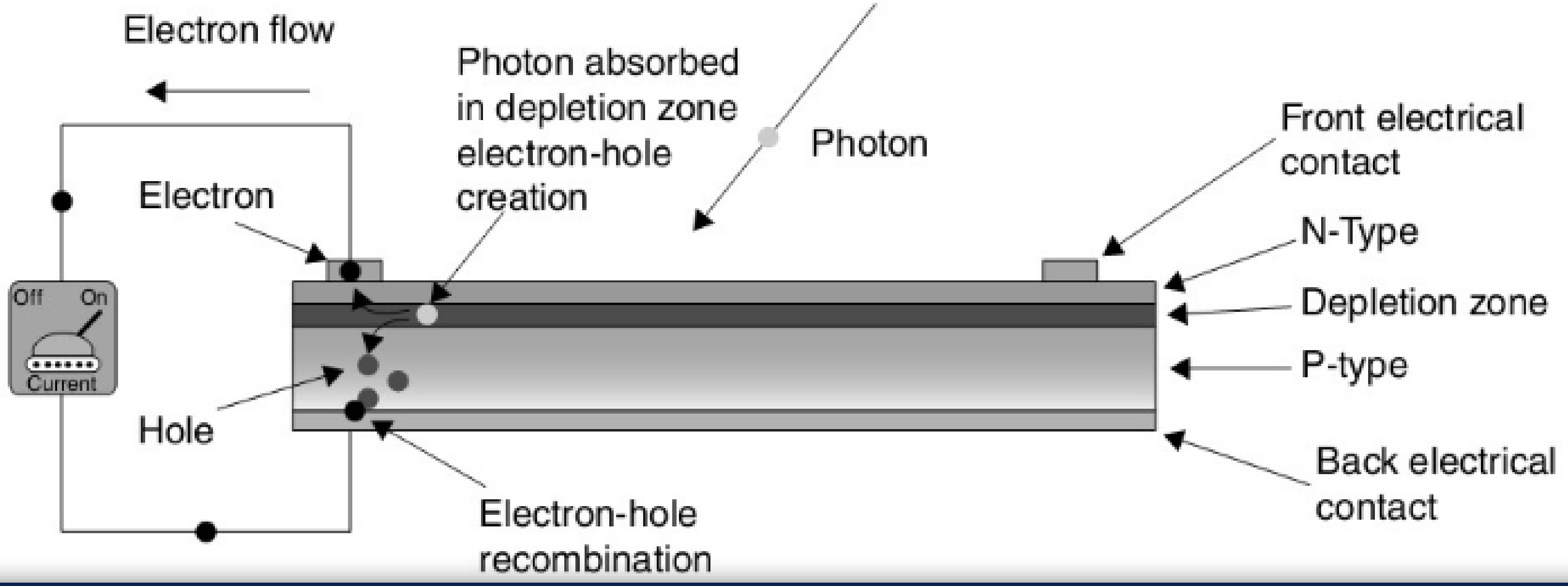
$$E = 1.24/\lambda \qquad (1.7)$$

The energy of a photon must be larger than the bandgap energy of a semiconductor material to free an electron

The bandgap Energy often symbolized by 'Eg'

for Semiconductor
3eV > Eg > 1eV,

for Silicon Eg = 1.1eV



- A photovoltaic (PV) cell converts sunlight into electricity, which is the physical process known as photoelectric effect. Light, which shines on a PV cell, may be reflected, absorbed, or passed through; however, only absorbed light generates electricity. The energy of absorbed light is transferred to electrons in the atoms of the PV cell. With their newfound energy, these electrons escape from their normal positions in the atoms of semiconductor PV material and become part of the electrical flow, or current, in an electrical circuit.
- A special electrical property of the PV cell, called "built-in electric field," provides the force or voltage required to drive the current through an external "load" such as a light bulb..
- To induce the built-in electric field within a PV cell, two layers of different semiconductor materials are placed in contact with each other. One layer is an "n-type" semiconductor with an abundance of electrons (Kept thin of the order 0.2-0.3µm to allow light to pass through to the PN Junction) , which have a negative electrical charge. The other layer is a "p-type" semiconductor material is thick about 200-300µm with an abundance of "holes," which have a positive electrical charge.

- Although both materials are electrically neutral, n-type silicon has excess electrons and p-type silicon has excess holes. Sandwiching these together creates a p/n junction at their interface, thereby creating an electric field. Figure shows the p–n junction of a PV cell.
- When n-type and p-type silicon come into contact, excess electrons move from the n-type side to the p-type side. The result is the buildup of positive charge along the n-type side of the interface and of negative charge along the p-type side.
- The two semiconductors behave like a battery, creating an electric field at the surface where they meet, called the p/n junction. This is a result of the flow of electrons and holes. The electrical field forces the electrons to move from the semiconductor toward the negative surface to carry current .At the same time, the holes move in the opposite direction, toward the positive surface, where they wait for incoming electrons.

Based on the sunlight collection method, PV systems can be classified into two general categories: flat-plate systems and concentrator systems.

Flat panel PV systems directly capture the sunlight or they use the diffused sunlight from the environment. They can be fixed or combined with sun tracking systems. On the other hand, concentrator systems collect a large amount of sunlight and concentrate and focus the sunlight to target PV panels using lenses and reflectors. These systems reduce the size and required number of cells while the power output is increased. Moreover, by concentrating the solar light, the efficiency of the PV cell is increased.

Components of a Solar Energy System

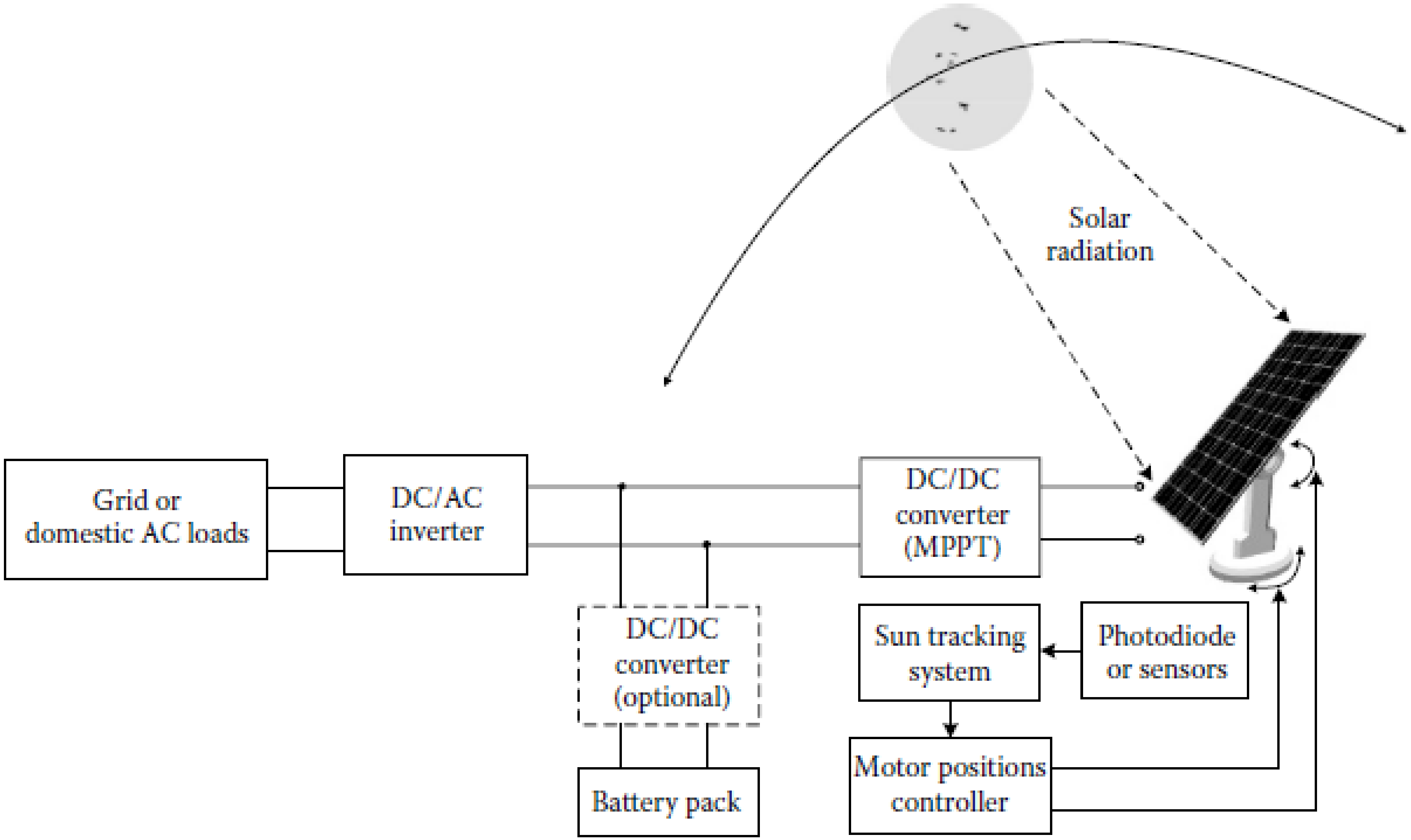


FIGURE 1.3 Solar energy system.

Components of a Solar Energy System

Figure demonstrates the block diagram of a solar energy system. In this system, sunlight is captured by the PV array. The sun tracking system takes the photodiode or photosensor signals and determines the sun tracking motor positions. Therefore, daily and seasonal solar position changes are followed in order to face the sun directly and capture the most available sunlight. The output of the PV panel is connected to a DC/DC converter to operate at the desired current or voltage to match the maximum available power from the PV module. This MPPT DC/DC converter is followed by a DC/AC inverter for grid connection or to supply power to the AC loads. Abattery pack can be connected to the DC bus of the system to provide extra power that might not be available from the PV module during night and cloudy periods. The battery pack can also store energy when the PV module generates more power than that demanded.

Usually the output voltage of a solar panel when it is open circuited is higher than rated voltage. Suppose if the solar panel is rated at 12V, it gives approximately 20V in an open circuit condition, but if it is connected to battery then it will give 14-15V. The output of the solar panel is measured in terms of watts or kilowatts, some of these ratings are 5 watts, 10 watts, 20 watts, 100 watts, etc. Hence it is necessary to find out the power requirement of the load before selecting the solar panel. The main consideration of solar panel is the generation of output power when it is installed in optimal position. Some of the Factors to be considered for getting high power from solar panels are panel orientation, panel pitch, roof, shade, etc.

Ohm's law describes mathematically how voltage, current, and resistance in a circuit are related

Ohm's law states that current is directly proportional to voltage and inversely proportional to resistance

$$I = \frac{V}{R}$$

The Linear Relationship of Current and Voltage

In resistive circuits, current and voltage are linearly proportional. **Linear** means that if one is increased or decreased by a certain percentage, the other will increase or decrease by the same percentage, assuming that the resistance is constant in value. For example, if the voltage across a resistor is tripled, the current will triple. If the voltage is reduced by half, the current will decrease by half

Sun- earth Geometric Relationship

- The Sun-Earth geometric relationship refers to the way that the Earth and the Sun are positioned relative to each other
- Some key facts about the Sun-Earth geometric relationship:

❖Earth's orbit

❖Rotation and revolution

❖Seasons

❖Solstices and equinoxes

Sun- Earth Geometric Relationship

- Earth's orbit:

❖Earth orbits around the Sun in an elliptical path

❖365.24 days

❖Tilted at an angle of about 23.5 degrees

- Rotation and revolution

❖Earth rotates on its own axis once every 24 hours

❖Earth revolves around the Sun, which gives rise to the different seasons that occur throughout the year.

Sun- Earth Geometric Relationship

- Seasons

❖The tilt of the Earth's axis means that different parts of the planet receive different amounts of sunlight throughout the year, which causes the seasons

❖When the northern hemisphere is tilted towards the Sun, it receives more direct sunlight and experiences summer, while the southern hemisphere experiences winter

❖This effect is reversed when the northern hemisphere is tilted away from the Sun.

- Solstices and equinoxes

❖The summer solstice occurs around June 21st in the northern hemisphere

❖The winter solstice occurs around December 21st in the northern hemisphere

Sun- earth Geometric Relationship

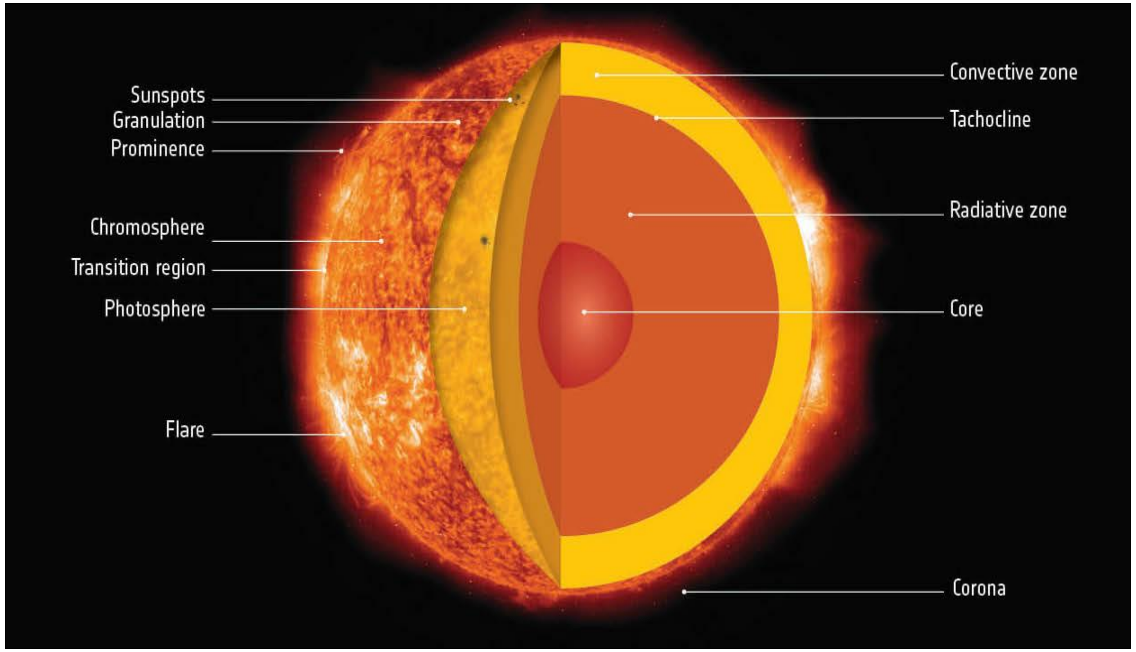
- The equinoxes occur around March 20th and September 22nd, when the Sun is directly overhead at the equator, and day and night are of equal length all over the planet

Layers of Sun

Layers of the Sun, starting from the center and moving outwards:

Core: The core is the central region of the Sun where nuclear fusion takes place. This is where hydrogen atoms are fused together to form helium, releasing a huge amount of energy in the process.

Radiative zone: Surrounding the core is the radiative zone, which is a thick layer of plasma where energy is transferred by radiation. This is where the energy generated in the core gradually moves outward, in the form of electromagnetic radiation



Layers of Sun

Convection zone: Beyond the radiative zone is the convection zone, which is a layer of hot plasma where energy is transferred by convection. This is where the hot plasma rises, cools off, and sinks back down, creating a circulation pattern that helps to transport energy to the Sun's surface.

Photosphere: The photosphere is the visible surface of the Sun, where most of the light and heat that we receive on Earth originates.

Chromosphere: The chromosphere is a thin layer of hot plasma that lies just above the photosphere.

Corona: The corona is the outermost layer of the Sun, extending millions of kilometers into space.

Earth – Sun Angles and their Relationships

Solar altitude angle (h): The solar altitude angle is the angle between the Sun's rays and the Earth's horizon.

It varies throughout the day as the Sun rises and sets.

At solar noon, when the Sun is directly overhead, the solar altitude angle is 90 degrees minus the latitude of the observer.

The solar altitude angle can be calculated using the following equation:

- $h = \sin^{-1}(\sin(\delta)\sin(\varphi) + \cos(\delta)\cos(\varphi)\cos(ha))$
- where δ is the declination angle of the Sun, φ is the latitude of the observer, and ha is the hour angle of the Sun.

Earth – Sun Angles and their Relationships

Solar azimuth angle (A): The solar azimuth angle is the angle between the Sun's rays and due south.

It varies throughout the day as the Sun moves across the sky.

The solar azimuth angle can be calculated using the following equation:

- $\cos(A) = \sin(\delta)\cos(\varphi) - \cos(\delta)\sin(\varphi)\cos(ha) / \cos(h)$
- where δ is the declination angle of the Sun, φ is the latitude of the observer, and ha is the hour angle of the Sun.

Earth – Sun Angles and their Relationships

Solar declination angle (δ): The solar declination angle is the angle between the plane of the Earth's equator and the line connecting the Earth to the Sun.

It varies throughout the year as the Earth orbits the Sun.

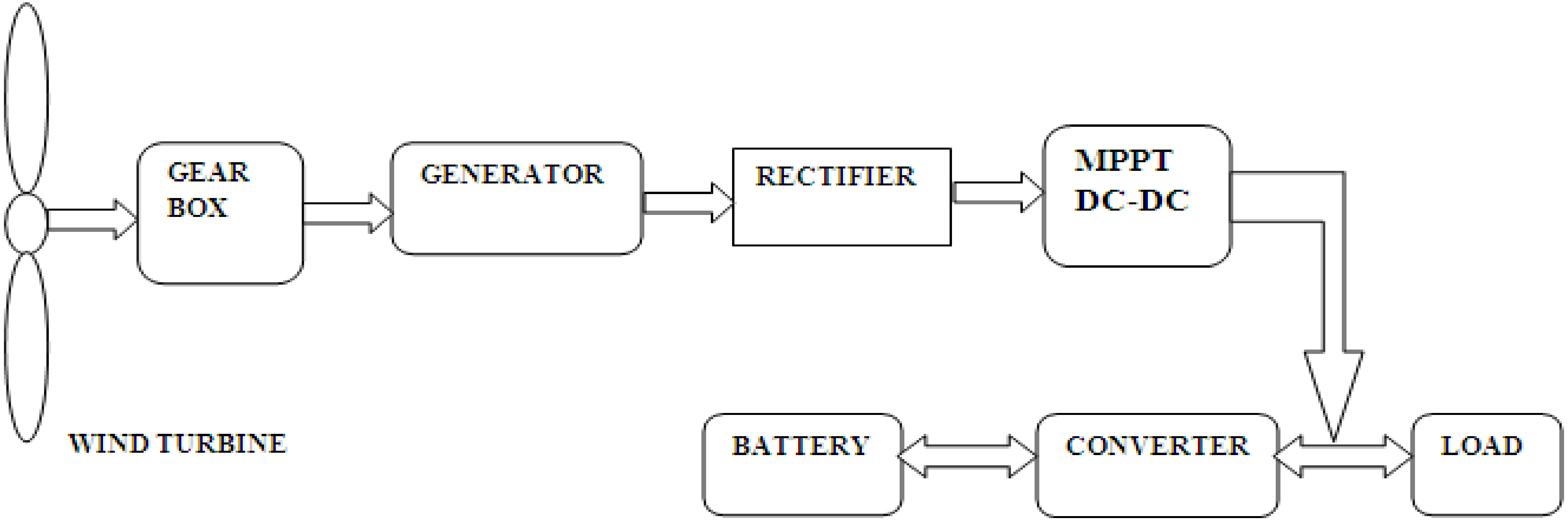
The solar declination angle can be calculated using the following equation:

- $\delta = 23.45° \sin(360/365(d-81))$
- where d is the day of the year, with January 1st being day 1.

Earth – Sun Angles and their Relationships

- Hour angle is the angular distance measured westward along the celestial equator from the observer's meridian to the hour circle of a celestial body. It is usually denoted by the symbol "H".
- The formula for calculating the hour angle of a celestial body is:
- H = LST - RA
- Where:
- LST - Local Sidereal Time (the hour angle of the vernal equinox measured from the observer's meridian)
- RA - Right Ascension (the celestial equivalent of longitude, measured in hours, minutes, and seconds)

Wind Power Generation:



There is an air turbine of large blades attached on the top of a supporting tower of sufficient height. When wind strikes on the turbine blades, the turbine rotates due to the design and alignment of rotor blades. The shaft of the turbine is coupled with an electrical generator. The output of the generator is collected through electric power cables. https://www.youtube.com/watch?v=DILJJwsFl3w

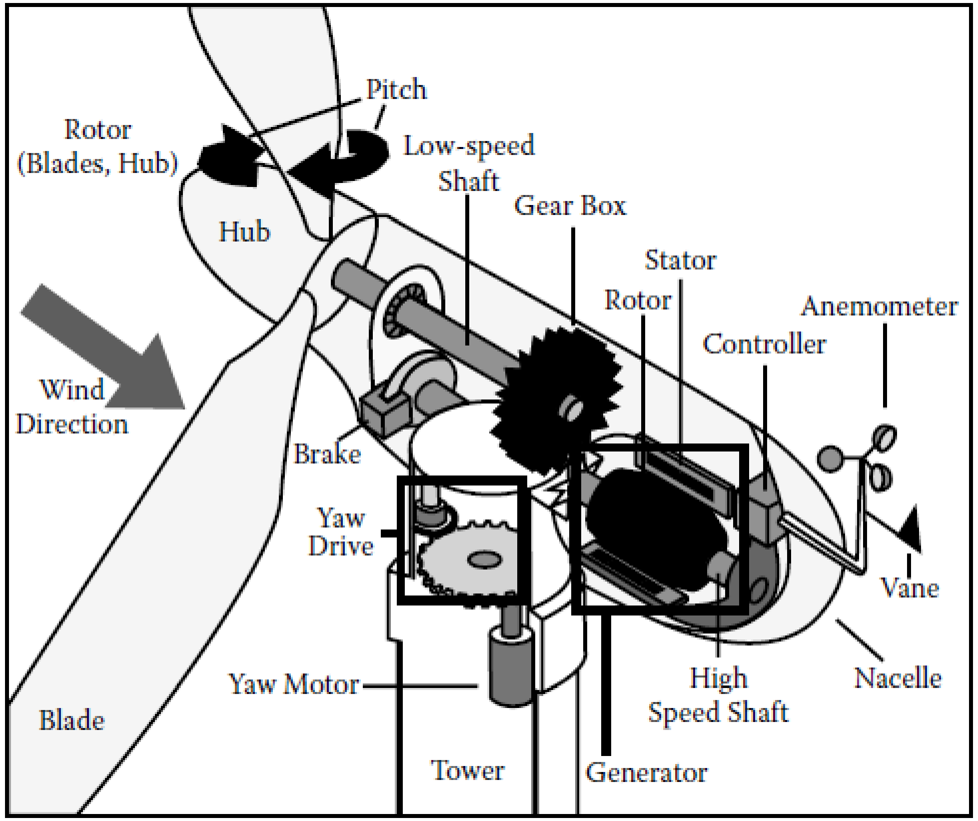


FIGURE 9.10 Diagram of main components of large wind turbine.

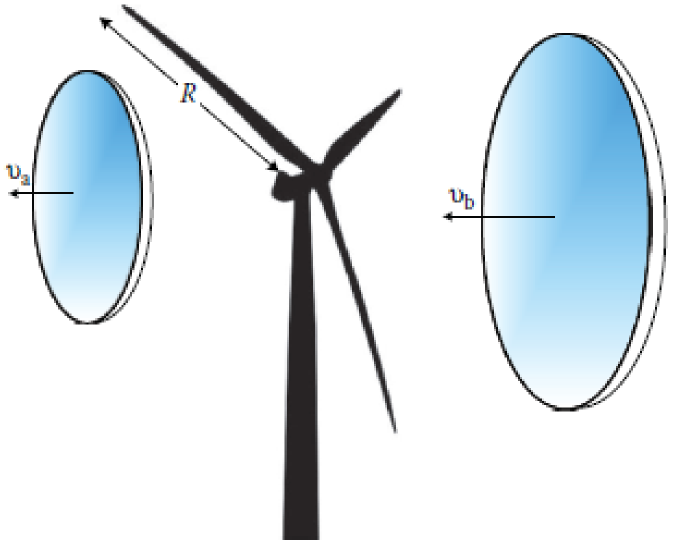


FIGURE 2.4 Wind speed before and after the turbine.

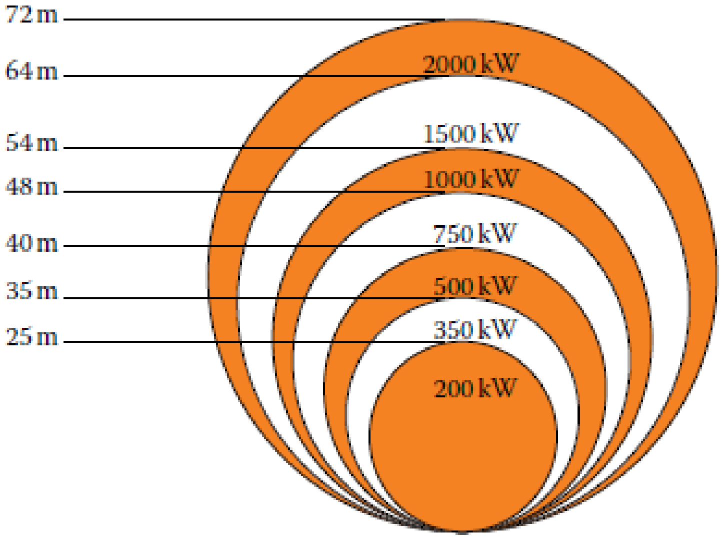


FIGURE 2.10 Turbine output power for different wind turbine diameters.

When the wind strikes the rotor blades, blades start rotating. The turbine rotor is connected to a high-speed gearbox. Gearbox transforms the rotor rotation from low speed to high speed. The high-speed shaft from the gearbox is coupled with the rotor of the generator and hence the electrical generator runs at a higher speed. An exciter is needed to give the required excitation to the magnetic coil of the generator field system so that it can generate the required electricity.

The generated voltage at output terminals of the alternator is proportional to both the speed and field flux of the alternator. The speed is governed by wind power which is out of control. Hence to maintain uniformity of the output power from the alternator, excitation must be controlled according to the availability of natural wind power.

The exciter current is controlled by a turbine controller which senses the wind speed. Then output voltage of electrical generator(alternator) is given to a rectifier where the alternator output gets rectified to DC. Then this rectified DC output is given to line converter unit to convert it into stabilized AC output which is ultimately fed to either electrical transmission network or transmission grid with the help of step up transformer.

An extra units is used to give the power to internal auxiliaries of **wind turbine** (like motor, battery etc.), this is called Internal Supply Unit.

There are other two control mechanisms attached to a modern big wind turbine.

- Controlling the orientation of the turbine blade.
- Controlling the orientation of the turbine face.

The orientation of turbine blades is governed from the base hub of the blades. The blades are attached to the central hub with the help of a rotating arrangement through gears and small electric motor or hydraulic rotary system. The system can be electrically or mechanically controlled depending on its design. The blades are swiveled depending upon the speed of the wind. The technique is called pitch control. It provides the best possible orientation of the turbine blades along the direction of the wind to obtain optimized wind power.

The orientation of the nacelle or the entire body of the turbine can follow the direction of changing wind direction to maximize mechanical energy harvesting from the wind. The direction of the wind along with its speed is sensed by an anemometer (automatic speed measuring devices) with wind vanes attached to the back top of the nacelle.

The signal is fed back to an electronic microprocessor-based controlling system which governs the yaw motor which rotates the entire nacelle with gearing arrangement to face the air turbine along the direction of the wind.

THANK YOU