ESE 2024

UPSC ENGINEERING SERVICES EXAMINATION

Preliminary Examination

General Studies and Engineering Aptitude

Basics of Energy and Environment

Comprehensive Theory *with* Practice Questions
and ESE Solved Questions

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ESE 2024 Preliminary Examination : Basics of Energy and Environment

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Preface

B. Singh (Ex. IES)

The compilation of this book **Basics of Energy and Environment** was motivated by the desire to provide a concise book which can benefit students to understand the concepts of this specific topic of General Studies and Engineering Aptitude section.

This textbook provides all the requirements of the students, i.e. comprehensive coverage of theory, fundamental concepts and objective type questions articulated in a lucid language. The concise presentation will help the readers grasp the theory of this subject with clarity and apply them with ease to solve objective questions quickly. This book not only covers the syllabus of ESE in a holistic manner but is also useful for many other competitive examinations. All the topics are given the emphasis they deserve so that mere reading of the book clarifies all the concepts.

We have put in our sincere efforts to present detailed theory and MCQs without compromising the accuracy of answers. For the interest of the readers, some notes, do you know and interesting facts are given in the comprehensive manner. At the end of each chapter, sets of practice question are given with their keys and detailed explanations, that will allow the readers to evaluate their understanding of the topics and sharpen their question solving skills.

Our team has made their best efforts to remove all possible errors of any kind. Nonetheless, we would highly appreciate and acknowledge if you find and share with us any printing and conceptual errors.

It is impossible to thank all the individuals who helped us, but we would like to sincerely thank all the authors, editors and reviewers for putting in their efforts to publish this book.

With Best Wishes

B. Singh

CMD, MADE EASY Group

Basics of Energy and Environment

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■■■■

1 Energy Resources : Conservation & Utilisation

1.1 Introduction

- The word 'energy' is derived from the Greek word "*en-ergon*" which means "*in-work*" or "*work content*". Therefore, energy may be defined as the capacity of doing work.
- All living things possess some form of energy and simultaneously witness the flow of energy from one form to another form, i.e. mechanical to electrical, thermal to chemical, tidal to electrical, etc. These forms of energy differ from one another, but constitute the physical reality of the universe.
- Energy is an important input for the overall development and is, therefore, vital for improvement in quality of life. Its use in sectors such as industries, commerce, transports, telecommunications, and wide range of agriculture and household activities has compelled to meet ever increasing demands which can not be fulfilled by conventional sources of energy alone, like coal, petroleum, gas, etc. Hence, there is need to explore the possibilities of harnessing energy from renewable sources of energy like solar energy, wind energy, tidal energy, geothermal energy, etc.
- The phrase 'conservation of energy' was coined and made popular by German physicists Helmholtz and Joule. They demonstrated that energy could not be annihilated but only be transformed.

The different types of energy and their conversion from one form to another are given below:

- **Heat Energy :** Heat is an intrinsic energy of all the combustible substances. It is basically the kinetic energy of molecules.
- **Chemical Energy :** Chemical energy is trapped in fossil fuels such as coal, oil and natural gas. Fossil fuels are used to generate electricity, power vehicles and railway engines.
- **Nuclear Energy :** Matter can be changed into energy when larger atoms are split into smaller ones (Atomic Fission) or when smaller ones combine to form larger atoms (Atomic Fusion).
- **Radiant Energy :** Solar radiation is the manifestation of radiant energy that is received on the earth. Radio waves, X-rays, infrared and ultraviolet electromagnetic radiations contain radiant energy.
- **Electrical Energy :** Electrical energy arises out of the movement of electrons to produce heat, magnetic field and electromagnetic radiations. It is a highly versatile form of energy, and can be easily converted to other forms for utilization.
- **Kinetic Energy :** The energy of an object in motion is called kinetic energy. If the mass of an object is m and the object is moving with a velocity v, then its kinetic energy is expressed in Joules as :

  $$KE = (1/2)mv^2$$, where m is in kg and v is in m/s.
- **Potential Energy :** The energy which a body possesses as a result of its position in the earth's gravitational field is called 'potential energy' and is expressed in Joules as:

  $$PE = mgh$$

  Where the mass m is in kg, g is the acceleration due to gravity in m/s^2, and h is the height in metre.

1.2 Types of Energy Resources

- Energy resources can be classified into two types:
  (i) Renewable energy resources
  (ii) Non-renewable energy resources

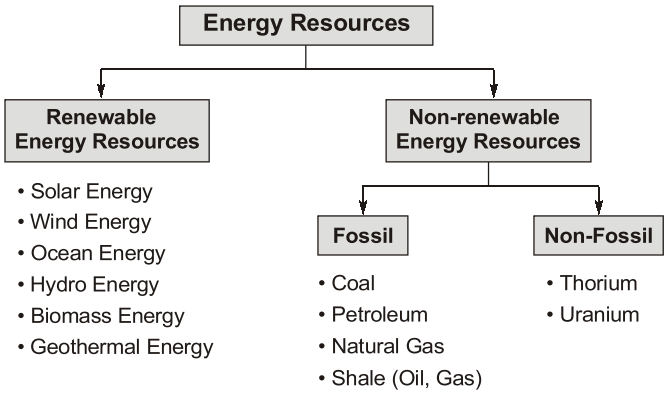


Fig: 1.1 Types of Energy Resources

- The renewable energy resources, such as wind, water, solar, geothermal, etc., come from sources that regenerate as fast as they are consumed and are continuously available.
- The non-renewable energy resources, such as fossil fuels and nuclear materials, are extracted from the earth and can be depleted in near future. These resources have been the most used type of energy in the modern era.
- In the early part of the 21st century, renewable energy resources have become more popular as non-renewable energy resources have begun to be depleted.
- Thermal plants (coal, oil, gas), nuclear and hydropower stations are the major conventional methods of generating electrical energy. Rise in the cost of fossil fuels has created an urgency to conserve these fuels, and engineers across the world are looking for alternative renewable sources of energy.

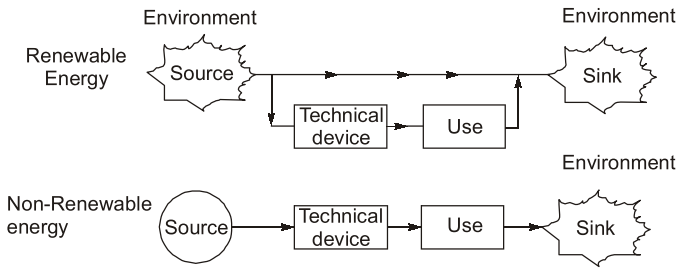


Fig: 1.2 Energy Conversion

1.3 Renewable Energy Resources

- The energy sources which can be renewed by nature again and again, and their supply is not affected by the rate of their consumption are called renewable energy resources. These are environment friendly and have potential to replace non-renewable energy resources. These are also known as inexhaustible sources of energy. The examples of renewable energy resources are solar, wind, ocean, hydro, biomass, geothermal, etc.
- Renewable energy resources are available in unlimited amount in nature and can be renewed over relatively shorter period of time. Most of the renewable sources of energy are fairly non-polluting and considered as clean.

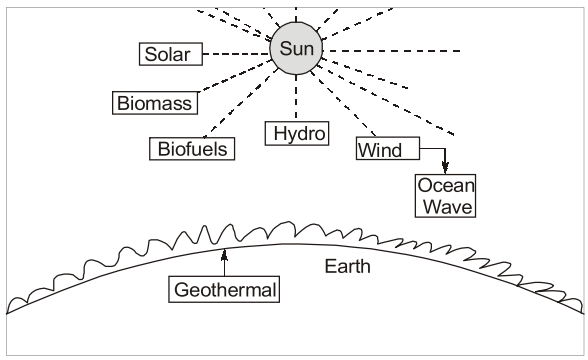


Fig: 1.3 Renewable Energy Resources

- India is implementing one of the world's largest programmes in renewable energy sector. The Government of India is on its way to achieving 175 GW target for installed renewable energy capacity by 2022.

- Large hydropower is also renewable in nature, but has been utilized all over the world for many decades and hence not included in the term 'renewable'. However, small hydropower comes under renewable source category.
- Municipal and industrial waste is also a useful source of energy, but these are different forms of biomass.
- The Ministry of New and Renewable Energy (MNRE) has made efforts during the past few decades to develop and utilize various renewable energy resources in the country. Consequently, wind electric generators, solar water heaters, solar lanterns, street lights, biogas plants, biomass gasifiers and small hydroelectric generators have become commercially available.

Table 1.1: Renewable energy installed capacity in India (As on February 28, 2023)

Renewable Energy Source	Installed Capacity (MW)
Solar Power	64,381
Wind power	42,015
Biomass power	10,218
Small Hydro Power (up to 25 MW)	4,943
Waste to energy (Urban & Industrial)	523
Total	**122,080**

1.3.1 International Energy Agency (IEA)

- International Energy Agency is an inter-governmental organization established in 1974 as per framework of the Organisation for Economic Co-operation and Development (OECD).
- Its prime focus is on the "3Es" of effectual energy policy: energy security, economic development and environmental protection.
- It also seeks to promote alternate energy sources (including renewable energy), rational energy policies and multinational energy technology co-operation.
- It acts as energy policy advisor to 30 member countries. India has become Associate Member of IAE.
- It publishes World Energy Outlook report.

  Headquarters: Paris, France.

1.3.2 The Energy and Resources Institute (TERI)

- TERI is a leading think tank dedicated to conducting research for sustainable development in India.
- It was established in 1974 as an information centre on energy issues.
- TERI's key focus lies in promoting:
  (i) Clean Energy
  (ii) Water Management
  (iii) Pollution Management
  (iv) Sustainable Agriculture
  (v) Climate Resilience

  Headquarters: New Delhi, India.

1.3.3 International Renewable Energy Agency (IRENA)

- The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation on renewable energy.

- IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean energy, solar and wind energy in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.
- It encourages governments to adopt enabling policies for renewable energy investments, provides practical tools and policy advice to accelerate renewable energy deployment, and facilitates knowledge sharing and technology transfer to provide clean, sustainable energy for the world's growing population.
- It has 160 Member States actively engaged, IRENA promotes renewable resources and technologies as the key to a sustainable future and helps countries achieve their renewable energy potential.

Headquarters: Abu Dhabi, United Arab Emirates.

1.3.4 Renewable Energy and Energy Efficiency Partnership (REEEP)

- REEEP is an international multilateral partnership that works to accelerate market-based deployment of renewable energy and energy efficient systems in low- and middle-income countries.
- It invests in clean energy markets in low and middle income countries to reduce CO_2 emissions and build prosperity.
- It creates, adapts and shares knowledge to build sustainable markets for renewable energy and energy efficient solutions; advance energy access, improve lives and economic opportunities; and reduce climate and environmental damage.

Headquarters: Vienna, Austria.

1.3.5 REN21 (Renewable Energy Policy Network for the 21st Century)

- REN21, an international non-profit association, is the global renewable energy policy multi-stakeholder network that connects a wide range of key actors from including Governments, International organisations, Industry associations, science and academia and civil society to facilitate knowledge exchange, policy development and joint action towards a rapid global transition to renewable energy.
- It promotes renewable energy to meet the needs of both industrialized and developing countries that are driven by climate change, energy security, development and poverty alleviation.

Objectives of REN21:

- Providing policy-relevant information and research based analysis on renewable energy to decision makers, multipliers and the public to catalyse policy change.
- Offering a platform for interconnection between multi-stakeholder actors working in the renewable energy field worldwide and identifying barriers as well as working to bridge existing gaps to increase the large-scale deployment of renewable energy worldwide.

Headquarters: Paris, France.

1.4 Solar Energy

- Solar energy is a primary source of energy which directly obtained from the sun by capturing the solar radiation and converting it into another form of energy to perform various useful activities.
- For receiving the solar radiation, it is necessary for the collectors to be able to track the sun to ensure a maximum and continuous reception.

Terrestrial Solar Radiation

- Solar radiations that pass through the earth's atmosphere and are subjected to scattering and atmospheric absorption, are known as Terrestrial Solar Radiation.
- Short wave ultraviolet rays are absorbed by ozone and long wave infrared rays are absorbed by CO_2 and water vapour. A part of scattered radiation is reflected back into space. This scattering is due to air molecules, dust particles and water droplets that cause attenuation of radiation.

- There are two ways of solar energy utilization:
  1. Conversion of solar energy into thermal energy
  2. Photovoltaic cells
- The conversion of solar energy into thermal energy can be done by using solar collectors, whereas in photovoltaic cells the direct sunlight is used to generate electricity.
  The given schematic diagram of solar power plant depicts four processes:
  (i) Photovoltaic (PV) cells convert sunlight to Direct Current (DC) electricity.
  (ii) The inverter converts Direct Current (DC) into Alternating Current (AC) electricity.
  (iii) The electrical panel sends power to be consumed within property as lights and in other appliances.
  (iv) The distribution board supplies electricity to grid.

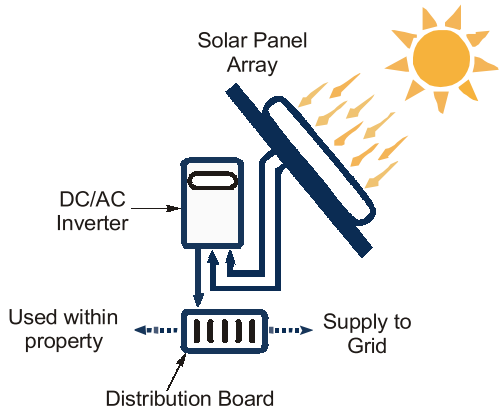


Fig. 1.4: Working of Solar Power Plant

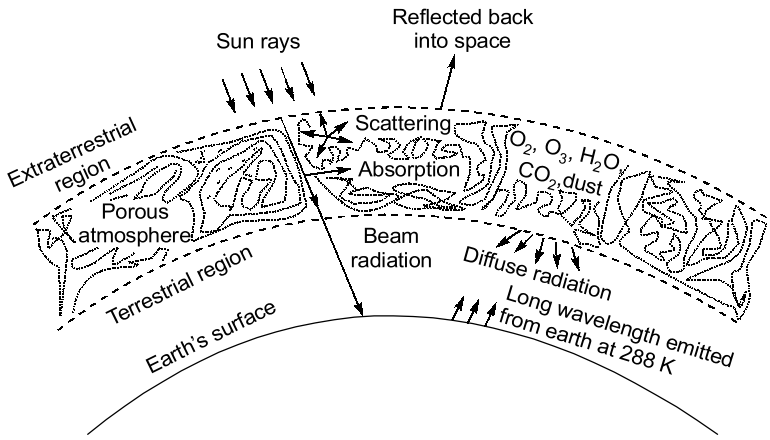


Fig: 1.5 Solar Radiation Atmospheric Mechanisms

1.4.1 Types of Radiation

- **Beam radiation (I_b):** Solar radiation received on the earth's surface without change in direction, is called beam or direct radiation.
- **Diffuse radiation (I_d):** The radiation received on a terrestrial surface (scattered by aerosols and dust) from all parts of the sky, is known as diffuse radiation.
- **Total radiation (I_T):** The sum of beam and diffuse radiations is referred as total radiation. When measured at a location on the earth's surface, it is called solar insolation at that place. When measured on a horizontal surface, it is called global radiation (I_g).
- **Irradiance:** The rate of incident energy per unit area of a surface is termed as irradiance. It is also known as Solar Constant. Based on the experimental measurements, the standard value of the Solar Constant is 1.367 kW/m^2.
- **Albedo:** The earth reflects back nearly 30% of the total solar radiant energy to the space by reflection from clouds, scattering and reflection at the earth's surface. This is called the albedo of the earth's atmosphere system.
- **Insolation:** Insolation is the solar radiation that reaches the earth's surface. It is measured by the amount of solar energy received per square centimeter per minute. Insolation is directly proportional to

the temperature i.e., more the insolation; higher the temperature. Factors that affect insolation are angle of the sun, distance between sun and the earth and duration of daylight.

NOTE

The sun is a hydrodynamic spherical body of extremely hot ionized gases (plasma) which generates energy by the process of thermonuclear fusion. The energy radiated from the sun is electromagnetic waves reaching the Earth in three spectral regions namely, ultraviolet 6.4% ($\lambda < 0.38\ \mu m$), visible 48% ($0.38\ \mu m < \lambda < 0.78\ \mu m$) and infrared 45.6% ($\lambda > 0.78\ \mu m$) of total energy.

COUNTRIES LOCATIONS ON EQUATOR AND SUB-TROPICS	
Countries lies on Tropic of Cancer	
North America	Mexico, Bahamas (Archipelago)
Africa	Niger, Algeria, Mauritania, Egypt, Libya, Mali, Western Sahara
Asia	Myanmar, Omen, Bangladesh, India, Saudi Arabia, China, United Arab Emirates, Taiwan
Countries lies on Equator	
South America	Ecuador, Columbia, Brazil
Africa	Gabon, Congo, Democratic Republic of Congo, Uganda, Kenya, Sao Tome and Principe, Somalia
Asia	Maldives, Indonesia and Kiribati (Oceania)
Countries lies on Tropic of Capricorn	
South America	Argentina, Brazil, Chile Paraguay
Africa	Namibia, Botswana, South Africa, Mozambique, Madagascar
Australia	Australia

1.4.2 Light

Sun is the ultimate source of energy for most of the organisms on the earth. It emits light as a electromagnetic radiation which is visible within the certain portion of the electromagnetic spectrum.

Electromagnetic Spectrum

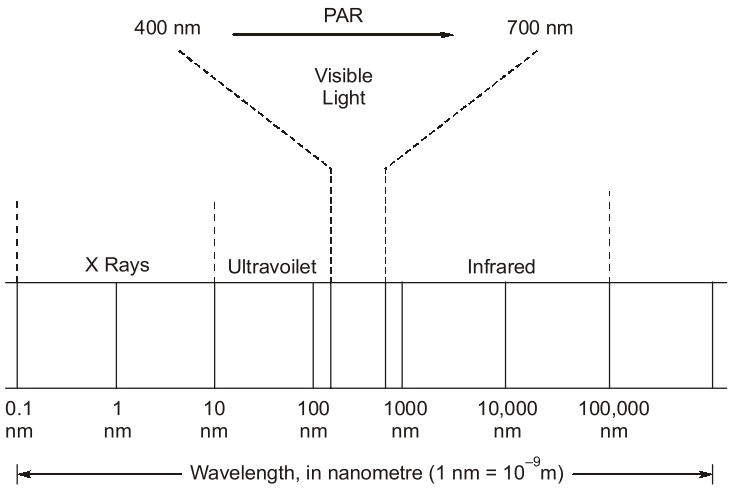


Fig: 1.6 Electromagnetic Spectrum of Solar Radiation

- Electromagnetic spectrum consists of short wave radiation, light and long wave radiation.
- The short wave radiation includes cosmic rays, X-rays and ultraviolet (UV) rays which have wavelengths shorter than 0.4 μm or 400 nm. Light or visible spectrum having wavelengths of 400-700 nm is also called Photo-synthetically Active Radiation (PAR).
- Depending upon the wavelength, three types of ultraviolet radiations are distinguished. These are UV-A (320 nm – 400 nm), UV-B (280 nm-320 nm) and UV-C (100 nm-280 nm). Out of these three, UV-C radiation is lethal.
- The ultraviolet radiation (wavelength 100 nm-400 nm) is mostly absorbed by ozone layer present in the stratosphere and a small fraction of it reaches the earth's surface.

1.4.3 Solar Radiation Measuring Instruments

- **Pyranometer:** The pyranometer measures global or diffuse radiation on a horizontal surface. It covers total hemispherical solar radiation with a view angle of 2π steradians. It operates on the principle of thermopile. Pyranometer consists of a black surface which heats up when exposed to solar radiation.
- **Pyrheliometer:** A pyrheliometer is an instrument which measures beam radiation on a surface normal to the sun's rays. It is often used in the same setup with pyranometer.
- **Sunshine recorder:** A sunshine recorder is a device that records the amount of sunshine at the given location. The results provide information about the weather and climate of a geographical area.

1.4.4 Solar Photovoltaic System

- Photovoltaic power generation is a method of producing electricity using solar cells. A solar cell converts solar optical energy directly into electrical energy. A solar cell is essentially a semiconductor device fabricated in a manner which generates a voltage when solar radiation falls on it.
- Solar cells are fixed on a board and connected in series and parallel combinations to provide the required voltage and power to form a PV module.

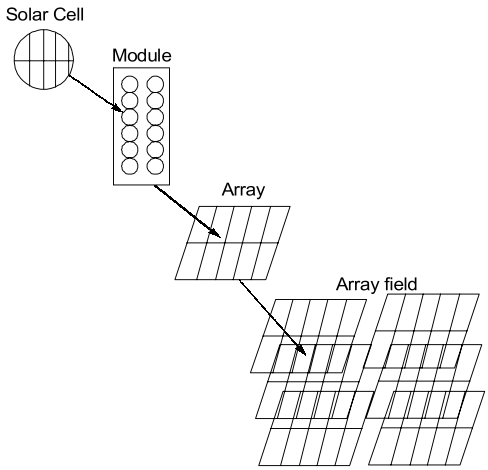


Fig: 1.7 (a) Components of PV Array

Working of Solar Photovoltaic System

- Solar photovoltaic system consists of photovoltaic cells in which each cell is made up of at least two semiconductor layers–one positively charged and the other negatively charged.
- As a PV cell is exposed to sunlight, photons are absorbed by the cell. When enough photons are absorbed by the negative layer of the photovoltaic cell, electrons are freed from the negatively charged semiconductor material. These freed electrons migrate to the positive layer creating a voltage difference. When these two layers are connected to an external load, the electricity produced.

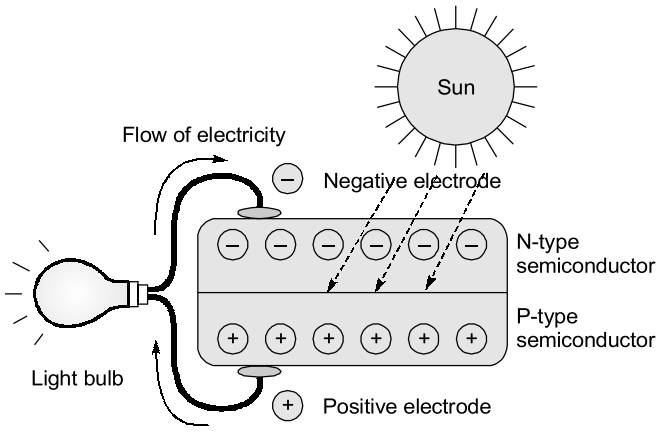


Fig: 1.7 (b) Working of a PV Cell

- To operate electrical appliances used in households, the inverters are used to convert DC power into 220 V, 50 Hz AC power.

- Components other than PV module are collectively known as Balance of System (BOS) which includes storage batteries, an electronic charge controller, and an inverter. Storage batteries with charge regulators are provided for back-up power supply during periods of cloudy day and during nights. Batteries are charged during the day and supply power to loads.

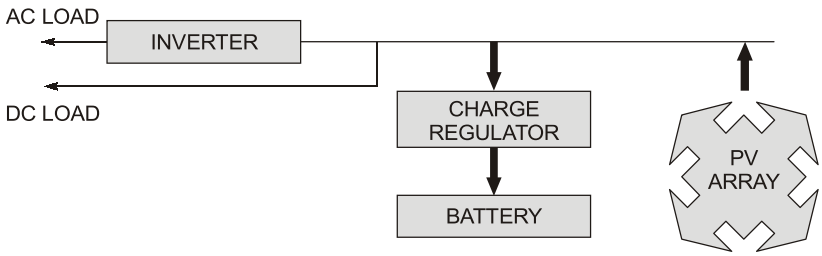
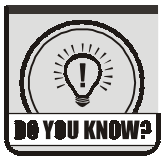


Fig: 1.7 (c) Block Diagram of Solar Photovoltaic System

- The major uses of photovoltaic system have been in space satellites, remote radio-communication booster stations and marine warning lights. Besides, these are also used in water pumping, medical refrigeration and for lighting in remote areas.

1.4.5 Solar Thermal Collector

- A solar thermal energy collector is an equipment in which solar energy is collected by absorbing radiation in an absorber and then transferring to a fluid.
- In general, there are two types of solar collectors:
  - (i) Flat-plate solar collector : In flat-plate solar collector, the collector area and the absorber area are numerically the same. The efficiency of this type of collector is low, and temperature of the working fluid can be raised only up to 100°C. It has no optical concentrator.
  - (ii) Concentrating-type solar collector : In concentrating-type solar collector, the area receiving the solar radiation is several times greater than the absorber area and the efficiency is high. Mirrors and lenses are used to concentrate the sun's rays on the absorber, and the fluid temperature can be raised up to 500°C.



The capacity of a battery is usually expressed in ampere-hours (Ah). It is defined as the number of hours for which a battery can provide current equal to the discharge rate at the nominal voltage of the battery.

Advantages of Solar Energy

- Solar energy is a clean, noise free and renewable energy source which causes no pollution.
- Very little maintenance is required to keep solar cell running as there are no moving parts in it.
- In the long term, there can be a high return on investment due to the amount of free energy a solar panel can produce.

Limitations of Solar Energy

- Electricity generation depends entirely on the exposure to sunlight; this could be limited by climate.
- Solar power stations do not match the power output of similar sized conventional power stations; they can also be very expensive to build.
- Solar power is used for charging batteries so that solar powered devices can be used at night. The batteries can often be large and heavy, taking up space and need to be replaced from time to time.

Applications of Solar Energy

(i) Photovoltaic cell (ii) Solar thermal power generation (iii) Solar drying system
(iv) Solar cooker (v) Solar water and air heater (vi) Cooling and refrigeration

- The establishment of a Bureau of Energy Efficiency (BEE) in place of the existing Energy Management Centre (EMC) to implement the provisions of the Act. BEE to act as a facilitator for the evolution of a self-regulatory system and organizations to regulate on their own with a view to save energy and thereby bring the commercial concept in the organization.

Previous ESE Prelims Questions

Q.1 Consider the following statements regarding solar energy:

1. To encourage the adoption of solar energy production, many State Governments and the Centre have announced plans by way of buy back as well as subsidies for installation.
2. Land acquisition of several hectares is a bottleneck in implementing this programme.
3. Considerable *R* & *D* effort is needed to bring down the cost of P-V cells.

Which of the above statements are correct?

(a) 1 and 2 only (b) 1 and 3 only
(c) 1, 2 and 3 (d) 2 and 3 only

[ESE Prelims : 2017]

Ans. (c)

Q.2 Which one of the following statements is correct?

(a) The end product of fossil fuels is in the form of electrical energy.
(b) Watershed protection increases the rate of surface runoff of water.
(c) If timber is overharvested, the ecological functions of the forest are improved.
(d) Rivers change their course during floods and lots of fertile soils are lost to the sea.

[ESE Prelims : 2017]

Ans. (d)

Directions: Each of the next items consists of two statements, one labelled as '**Statement (I)**' and the other as '**Statement (II)**'. You are to examine these two statements carefully and select the answers to these items using the code given below:

Code:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

Q.3 **Statement (I):** Increased cloud cover will lead to warmer winters due to clouds reflecting more intense solar energy.
Statement (II): Overcast cloud conditions result in decrease in the day-night temperature difference.

[ESE Prelims : 2017]

Ans. (d)

Q.4 **Statement (I):** Green energy refers to one which does not harm the ecosystem of planet Earth.
Statement (II): All renewable energy is green energy.

[ESE Prelims : 2018]

Ans. (c)

Q.5 Consider the following statements regarding Insolation:

1. It is the solar radiation that reaches the Earth's surface.
2. It is measured by the amount of solar energy received per square centimeter per minute.
3. It is the amount of solar energy absorbed by the stratosphere.

Which of the above statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE Prelims : 2018]

Ans. (b)

Q.6 What are the limitations of solar energy?

1. Collecting solar energy over large areas and converting it to other forms that can be conveniently transported, stored and used in existing equipment is not economical.
2. Low density of solar energy as compared to coal, oil and gas.
3. Its major applications are photothermal conversion, solar water heating, green housing technology and photo voltaic conversion.

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE Prelims : 2019]

Ans. (b)

Third statement is advantage regarding solar energy rather than limitation. Therefore third statement is wrong and 1 and 2 are correct.

Q.7 What are the advantages of Biomass as a source of energy?

1. Its storage and transportation is possible
2. It is ecologically safe and is inoffensive
3. Can be developed with present man and material abilities
4. Low capital input required

Select the correct answer using the codes given below:

(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 1, 3 and 4 only (d) 2, 3 and 4 only

[ESE Prelims : 2019]

Ans. (a)

Q.8 Energy used by man does NOT originate from which one of the following sources ?

(a) Radiant energy (b) Geothermal power
(c) Frictional energy (d) Gravitational energy

[ESE Prelims : 2022]

Ans. (c)

Q.9 The largest tidal range in the world is

(a) Bay of Fundy (b) Ungava Bay
(c) Bristol Channel (d) Turnagain Arm of Cook Inlet

[ESE Prelims : 2022]

Ans. (a)