

Value Added Course

Solar Energy & Applications

Introduction to Renewable energy

Sustainability: Renewable energy sources are sustainable because they are naturally replenished on a human timescale. Examples include solar energy, wind energy, hydropower, biomass, and geothermal energy.

Environmental Benefits: Unlike conventional fossil fuels, renewable energy sources produce fewer greenhouse gas emissions, reducing air pollution and mitigating climate change. They also have lower environmental impacts in terms of land use and water consumption.

Diversity of Sources:

Solar Energy: Capturing energy from the sun using solar panels or solar thermal systems.

Wind Energy: Harnessing the kinetic energy of the wind using wind turbines.

Hydropower: Generating electricity from flowing water in rivers or dams.

Biomass: Using organic materials, such as wood or agricultural residues, for energy.

Geothermal Energy: Tapping into the Earth's internal heat for heating or electricity generation.

Global Energy Transition: The shift from fossil fuel-dominated energy systems to renewable energy is a global initiative aimed at reducing dependence on finite resources and decreasing the environmental impact of energy production.

Technological Advancements: Ongoing advancements in renewable energy technologies, such as improvements in solar panels, wind turbine efficiency, and energy storage systems, contribute to increased affordability and accessibility.

Economic Opportunities: The renewable energy sector creates job opportunities, fosters innovation, and stimulates economic growth. Investments in clean energy contribute to a more sustainable and resilient economy.

Challenges and Solutions: Despite its benefits, the transition to renewable energy faces challenges such as intermittency, energy storage, and infrastructure development. Ongoing research and policy initiatives are addressing these challenges to make renewable energy more reliable and widespread.

Sun as an energy source:

Solar Radiation:

The Sun emits vast amounts of energy in the form of electromagnetic radiation, including visible light, ultraviolet (UV) light, and infrared (IR) radiation.

Solar radiation is the energy that reaches the Earth from the Sun and is the foundation of various renewable energy technologies.

Solar Energy Harvesting:

Technologies like solar panels, also known as photovoltaic (PV) cells, convert sunlight directly into electricity through the photovoltaic effect.

Solar thermal systems use mirrors or lenses to concentrate sunlight onto a small area, generating heat for electricity production or heating applications.

Importance in Earth's Climate:

The Sun plays a fundamental role in Earth's climate by driving atmospheric and oceanic circulation through the uneven heating of the planet's surface.

Solar energy is a key factor in weather patterns, seasons, and the water cycle.

Solar Constant:

The solar constant is the amount of solar radiation received per unit area at a distance of one astronomical unit (AU) from the Sun. It is approximately 1361 watts per square meter.

Sun-Earth Distance:

The Earth's distance from the Sun varies slightly due to its elliptical orbit. On average, it is about 93 million miles (150 million kilometers).

Solar Spectrum:

Solar radiation consists of a spectrum of wavelengths, ranging from short-wavelength ultraviolet to long-wavelength infrared.

Different solar technologies are designed to capture specific portions of the solar spectrum.

Renewable and Inexhaustible:

Solar energy is a renewable resource as long as the Sun continues to shine, which is expected for billions of years.

Unlike finite fossil fuels, solar energy is inexhaustible and has the potential to meet global energy demands sustainably.

Applications:

Solar energy is utilized for various applications, including residential and commercial electricity generation, water heating, space heating, and powering remote areas through off-grid systems.

Challenges and Opportunities:

Challenges in harnessing solar energy include intermittency (day-night cycles and weather dependence) and the need for efficient energy storage solutions.

Advances in solar technologies, energy storage, and grid integration present opportunities for overcoming challenges and expanding the use of solar power.

Structure and composition

Structure of the Earth:

Crust:

The outermost layer, composed of solid rock and soil.

Divided into the continental crust (thicker, less dense) and oceanic crust (thinner, denser).

Mantle:

Beneath the crust, extending to about 2,900 kilometers below the Earth's surface.

Composed of solid rock that can flow over long periods, generating geological processes.

Outer Core:

Located beneath the mantle, extending from about 2,900 to 5,150 kilometers deep.

Composed of liquid iron and nickel, generating the Earth's magnetic field through the dynamo effect.

Inner Core:

The Earth's central region, extending from about 5,150 kilometers to the center at 6,371 kilometers.

Composed of solid iron and nickel due to high pressure, despite extremely high temperatures.

Composition of the Earth:

Atmosphere:

The gaseous envelope surrounding the Earth.

Main components include nitrogen (78%), oxygen (21%), and trace amounts of other gases.

Hydrosphere:

The Earth's water component, including oceans, seas, lakes, rivers, groundwater, and atmospheric water vapor.

Lithosphere:

The rigid outer layer, consisting of the crust and the upper part of the mantle. Divided into tectonic plates that float on the semi-fluid asthenosphere.

Asthenosphere:

A semi-fluid layer beneath the lithosphere, allowing for the movement of tectonic plates.

Biosphere: The zone where living organisms exist, including the interactions between living organisms and their environment.

Earth's Interior:

Core Composition:

The core is primarily composed of iron and nickel, with smaller amounts of other elements.

Minerals in the Crust:

The Earth's crust is made up of various minerals, including silicate minerals like quartz, feldspar, and mica.

Volcanic and Tectonic Processes:

The composition of rocks and minerals varies based on the geological processes that form them, such as volcanic eruptions and tectonic movements.

Magnetic Field:

The Earth's magnetic field is generated by the movement of molten iron in the outer core.

SOLAR ENERGY, ITS IMPORTANCE:

Solar Energy:

Definition: Solar energy is the radiant light and heat from the Sun that is harnessed using various technologies to generate electricity, provide heating, and power numerous applications.

Components of Solar Energy:

1. **Photons:** Solar energy consists of tiny packets of energy called photons. Photons are particles of light that carry energy.
2. **Electromagnetic Spectrum:** Solar radiation spans a broad range of wavelengths, forming the electromagnetic spectrum. It includes ultraviolet (UV), visible, and infrared (IR) light.

Importance of Solar Energy:

1. Renewable and Sustainable:

- Solar energy is a renewable resource, meaning it is virtually limitless and can be replenished naturally. It provides a sustainable alternative to finite fossil fuels.

2. Clean and Environmentally Friendly:

- Solar power generation produces little to no air or water pollution, and it doesn't emit greenhouse gases. It contributes to cleaner air and mitigates climate change.

3. Reduced Greenhouse Gas Emissions:

- By utilizing solar energy, societies can decrease their reliance on fossil fuels, leading to a significant reduction in greenhouse gas emissions that contribute to global warming.

4. Lower Electricity Bills:

- Solar panels on residential and commercial buildings can generate electricity, reducing dependency on the grid and lowering electricity bills over time.

5. Off-Grid Power Generation:

- Solar energy allows for off-grid power generation, particularly in remote or rural areas where traditional power infrastructure is lacking. It provides a reliable source of electricity for various applications.

6. Job Creation and Economic Growth:

- The solar industry creates jobs in manufacturing, installation, maintenance, and research. Its growth contributes to economic development and innovation.

7. Energy Independence:

- Solar energy can contribute to reducing dependence on imported fossil fuels, promoting energy independence for countries.

8. Decentralized Power Generation:

- Solar power systems can be deployed at various scales, promoting decentralized power generation. This enhances grid resilience and reduces transmission losses.

9. Technological Advancements:

- Ongoing advancements in solar technologies, such as increased efficiency and decreased costs, make solar energy more accessible and competitive in the energy market.

10. Addressing Energy Poverty:

- Solar energy can play a vital role in addressing energy poverty by providing affordable and sustainable power solutions in underserved regions.

11. Educational Opportunities:

- The solar industry offers opportunities for education and research in science, technology, engineering, and mathematics (STEM) fields.

Solar Radiation:

Definition: Solar radiation refers to the energy emitted by the Sun in the form of electromagnetic waves. This energy, primarily in the form of light and heat, is a crucial factor in understanding and harnessing solar power.

Key Points:

1. Electromagnetic Spectrum:

- Solar radiation encompasses a spectrum of wavelengths, including ultraviolet (UV), visible light, and infrared (IR) radiation.

2. Intensity Variation:

- Solar radiation intensity varies based on factors such as time of day, season, and geographical location.

3. Direct and Diffuse Radiation:

- **Direct Radiation:** Solar energy that reaches the Earth's surface without scattering, often in a straight line from the Sun.

- **Diffuse Radiation:** Solar energy that reaches the Earth's surface after being scattered by the atmosphere.

4. **Absorption and Reflection:**

- Earth's surface absorbs a portion of incoming solar radiation, while some is reflected back into space.

5. **Solar Constant:**

- The solar constant is the average amount of solar radiation received per unit area at one astronomical unit (AU) from the Sun. It is approximately 1361 watts per square meter.

Sun-Earth Angles:

1. Tilted Axis and Seasons:

- The Earth's axis is tilted relative to its orbital plane, leading to variations in sunlight received during different times of the year, causing seasons.

2. Solar Declination:

- The solar declination is the angle between the rays of the Sun and the plane of the Earth's equator. It varies throughout the year, affecting the Sun's position in the sky.

3. Latitude and Sun Angle:

- Solar angles at different latitudes influence the intensity of sunlight. Near the equator, sunlight is more direct, leading to higher solar angles.

4. Sun Path Diagrams:

- Sun path diagrams illustrate the Sun's position in the sky at different times of the day and throughout the year, providing insights into solar availability.

Solar Radiation Data Calculation:

1. Solar Irradiance:

- Solar irradiance is the power per unit area received from the Sun in the form of electromagnetic radiation. It is measured in watts per square meter (W/m^2).

2. Factors Influencing Solar Radiation:

- **Sun-Earth Distance:** Solar radiation varies based on the Earth's elliptical orbit, known as the solar constant.
- **Latitude:** Solar angles are influenced by latitude, affecting the intensity of solar radiation.
- **Cloud Cover:** Clouds can attenuate solar radiation reaching the Earth's surface.

3. Solar Radiation Measurement Devices:

- Pyranometers and pyrheliometers are instruments used to measure global and direct solar irradiance, respectively.

4. Solar Radiation Data Analysis:

- Analyzing solar radiation data involves interpreting measurements, understanding variations, and predicting solar availability for different applications.

ELECTRICITY FROM SOLAR ENERGY, SOLAR COLLECTORS AND TYPES

Electricity from Solar Energy:

Photovoltaic (PV) Technology:

1. **Photovoltaic Cells (PV Cells):**
 - PV cells, commonly known as solar cells, convert sunlight directly into electricity using the photovoltaic effect.
2. **Solar Panels:**
 - Multiple PV cells are connected to form solar panels or modules. These panels are the building blocks of solar arrays.
3. **Inverters:**
 - Inverters are used to convert the direct current (DC) generated by solar panels into alternating current (AC), which is suitable for most electrical appliances and the grid.
4. **Battery Storage:**
 - In some systems, electricity generated by solar panels can be stored in batteries for later use, providing a continuous power supply during periods of low sunlight.
5. **Grid-Connected Systems:**
 - Grid-connected solar systems allow excess electricity to be fed back into the grid, and users may receive credits or compensation for the surplus energy.
6. **Net Metering:**
 - Net metering enables users to receive credits or compensation for the excess electricity they generate and feed into the grid.

Solar Collectors and Types:

Solar Thermal Technology:

1. **Flat Plate Collectors:**

- Flat plate collectors are the most common type and consist of a flat, insulated metal plate covered with a transparent glass or plastic cover. They absorb sunlight and transfer heat to a fluid circulating through the collector.

2. **Evacuated Tube Collectors:**

- Evacuated tube collectors consist of parallel rows of transparent glass tubes containing an absorber that absorbs sunlight and converts it into heat. The vacuum between the tubes reduces heat loss.

3. **Parabolic Trough Collectors:**

- Parabolic trough collectors use parabolic mirrors to concentrate sunlight onto a receiver tube running along the focal line. The concentrated sunlight heats a fluid within the tube.

4. **Solar Dish Collectors:**

- Solar dish collectors use parabolic dishes to concentrate sunlight onto a receiver at the focal point. The concentrated energy is typically used for electricity generation or high-temperature industrial processes.

5. **Concentrated Solar Power (CSP) Systems:**

- CSP systems use mirrors or lenses to concentrate sunlight onto a small area. The concentrated heat is used to produce steam, which drives a turbine to generate electricity.

6. **Solar Water Heaters:**

- Solar water heaters use collectors to absorb sunlight and heat water for residential or commercial purposes. Two main types are passive and active solar water heaters.

Importance of Solar Electricity and Collectors:

1. **Clean Energy Generation:**

- Solar electricity is generated without emitting greenhouse gases or air pollutants, contributing to clean and sustainable energy production.

2. **Reduced Dependence on Fossil Fuels:**

- Solar power reduces reliance on finite fossil fuels, promoting energy independence and mitigating the environmental impact of conventional energy sources.

3. **Grid Stability and Decentralization:**

- Solar electricity contributes to grid stability and decentralization by allowing distributed power generation, reducing transmission losses.

4. **Renewable Heating Solutions:**

- Solar collectors, especially in solar water heaters, provide renewable heating solutions for residential and commercial applications, reducing the reliance on electric or gas-based heating systems.

5. **Economic Benefits:**

- Solar technology deployment stimulates economic growth, job creation, and innovation in the renewable energy sector.

6. **Resilience in Remote Areas:**

- Solar collectors, particularly in off-grid systems, provide a reliable source of electricity and heat in remote areas where traditional power infrastructure is limited.

Unit II:

Storage of Solar Energy:

1. Battery Storage:

- **Purpose:** To store excess electricity generated during peak sunlight hours for later use during periods of low sunlight or at night.
- **Technology:** Rechargeable batteries, such as lithium-ion batteries, store the electricity generated by solar panels.

2. Pumped Hydro Storage:

- **Purpose:** To store excess energy by pumping water uphill to a reservoir during surplus electricity generation and releasing it to generate electricity during high demand.
- **Technology:** Involves two water reservoirs at different elevations and a reversible hydroelectric turbine.

3. Thermal Energy Storage:

- **Purpose:** To store heat energy generated by solar collectors for later use in heating applications or electricity generation.
- **Technology:** Includes molten salt storage, phase-change materials, and other thermal storage methods.

Passive and Active Thermal Applications of Solar Energy:

Passive Solar Energy Applications:

1. Solar Architecture:

- **Purpose:** Designing buildings to optimize natural sunlight and heat for lighting, heating, and cooling without mechanical systems.
- **Features:** South-facing windows, thermal mass, and shading elements.

2. Solar Water Heating Systems:

- **Purpose:** To heat water for domestic or industrial use using passive methods, often without the need for pumps or controls.
- **Features:** Batch collectors, thermosiphon systems, and integral collector-storage systems.

3. Solar Greenhouses:

- **Purpose:** Utilizing passive solar design to create a warm environment for growing plants.
- **Features:** South-facing orientation, thermal mass, and insulation.

Active Solar Energy Applications:

1. Solar Water Heaters:

- **Purpose:** Using solar collectors to actively capture and transfer heat to water for domestic or industrial use.
- **Features:** Evacuated tube collectors, flat plate collectors, and active circulation systems.

2. Solar Air Heating Systems:

- **Purpose:** Collecting and distributing solar heat for space heating or industrial processes.
- **Features:** Air collectors, fans, and ductwork.

3. Solar Cooling Systems:

- **Purpose:** Using solar energy to power absorption or adsorption cooling systems for air conditioning.
- **Features:** Absorption chillers or desiccant systems.

Solar Pond:

1. Definition:

- A solar pond is a large, shallow body of saltwater that acts as a solar collector, absorbing and storing solar energy for various applications.

2. Working Principle:

- The pond has three layers – a top layer with low salt concentration, a middle layer acting as a non-convecting insulating layer, and a bottom layer with high salt concentration. Solar radiation heats the bottom layer, and the insulating middle layer prevents heat loss.

3. Applications:

- **Warm Water Supply:** Solar ponds can provide warm water for industrial processes or space heating.
- **Electricity Generation:** The stored heat in solar ponds can be used to generate electricity using a Rankine cycle.

Solar Water Heater:

1. Definition:

- A solar water heater is a device that uses sunlight to heat water for domestic, industrial, or commercial purposes.

2. Types:

- **Batch Collectors:** Also known as integral collector-storage systems, they consist of a tank integrated with solar collectors, often installed on rooftops.
- **Flat Plate Collectors:** These are flat, box-like collectors with a transparent cover, absorbing sunlight to heat a fluid (usually water or antifreeze).
- **Evacuated Tube Collectors:** These collectors use parallel rows of transparent glass tubes, each containing an absorber to heat the fluid inside.

3. Working Principle:

- Solar collectors absorb sunlight and convert it into heat, which is transferred to water or another fluid. The heated fluid is then stored in a tank for later use.

4. Applications:

- Residential hot water supply
- Commercial and industrial process heating
- Swimming pool heating

Flat Plate Collector:

1. Definition:

- A flat plate collector is a type of solar thermal collector used to capture sunlight and convert it into heat energy for various applications, such as water heating and space heating.

2. Components:

- Flat plate collectors typically consist of a flat, insulated box with a transparent cover (glass or plastic) on top. Inside the box, there is a dark-colored absorber plate that absorbs sunlight and transfers the heat to a fluid (air or liquid) circulating through the collector.

3. Working Principle:

- Sunlight passes through the transparent cover and strikes the absorber plate, where it is converted into heat. The heated fluid is then circulated to transfer the thermal energy for specific uses.

4. Applications:

- Domestic water heating
- Space heating
- Preheating of industrial process water

Solar Distillation:

1. Definition:

- Solar distillation is a process that uses solar energy to purify water by evaporating it and then condensing the vapor back into liquid form.

2. Components:

- A solar still typically consists of a transparent cover, a basin to hold the impure water, and a condensation surface where water vapor collects and is then collected as distilled water.

3. Working Principle:

- Solar radiation heats the impure water in the basin, causing it to evaporate. The vapor rises, condenses on the transparent cover, and drips down to the collection point as distilled water.

4. Applications:

- Purification of drinking water in remote or arid areas
- Desalination of brackish water

Solar Cooker:

1. Definition:

- A solar cooker, also known as a solar oven, is a device that uses sunlight to cook or heat food.

2. Types:

- **Box Cookers:** Consist of an insulated box with a transparent cover and reflective panels to focus sunlight on the cooking pot.
- **Parabolic Cookers:** Use parabolic mirrors to concentrate sunlight onto a cooking vessel.
- **Panel Cookers:** Reflect sunlight onto a cooking pot using reflectors made of flat panels.

3. Working Principle:

- Solar cookers use reflective surfaces or concentrators to focus sunlight onto a cooking vessel. The absorbed heat cooks or heats the food inside the vessel.

4. Applications:

- Cooking in areas with limited access to conventional energy sources

- Promoting energy-efficient and sustainable cooking practices

Solar Greenhouses:

1. Definition:

- Solar greenhouses are structures designed to capture and utilize solar energy for plant growth and climate control.

2. Features:

- **Orientation:** Greenhouses are oriented to maximize exposure to sunlight.
- **Thermal Mass:** Use of thermal mass materials to store and release heat.
- **Ventilation:** Controlled ventilation systems to regulate temperature.

3. Working Principle:

- Solar greenhouses capture sunlight, creating a warm environment for plants. Thermal mass materials help maintain optimal temperatures during the night.

4. Applications:

- Year-round cultivation of crops
- Experimentation in controlled environments for research

Solar Cell (Photovoltaic Cell):

1. Definition:

- A solar cell, or photovoltaic cell, is a device that converts sunlight directly into electricity through the photovoltaic effect.

2. Composition:

- Solar cells are typically made of semiconductor materials, such as silicon. When exposed to sunlight, electrons in the semiconductor material are excited, generating an electric current.

3. Working Principle:

- Sunlight hits the solar cell, and photons are absorbed, releasing electrons. The flow of these electrons creates an electric current.

4. Applications:

- Residential and commercial solar power systems
- Portable solar chargers
- Space applications, such as solar panels on satellites

Absorption Air Conditioning:

1. Definition:

- Absorption air conditioning is a cooling technology that uses a heat source, typically provided by solar energy or waste heat, to drive the absorption refrigeration cycle.

2. Components:

- Absorption chillers consist of an absorber, generator, condenser, and evaporator. Heat is supplied to the generator, and the refrigerant is absorbed in the absorber.

3. Working Principle:

- A heat source, often solar energy, provides the energy needed to separate the refrigerant from the absorbent in the generator. The refrigerant is then condensed, evaporated, and absorbed in a cyclical process that produces cooling.

4. Applications:

- Air conditioning in buildings
- Cooling systems for industrial processes

Success Stories of Solar Energy Application in India:

1. Kurnool Ultra Mega Solar Park:

- Located in Andhra Pradesh, it is one of the largest solar parks in the world.
- With a capacity of over 1,000 MW, it significantly contributes to India's solar power generation.

2. Diu Smart City:

- Diu, a small island, is the first city in India to run entirely on solar energy.
- Solar power generation has led to reduced electricity costs and improved sustainability.

3. Kolkata Airport's Solar Power Plant:

- Kolkata's Netaji Subhas Chandra Bose International Airport has a 15 MW solar power plant.
- It reduces the airport's carbon footprint and demonstrates the viability of solar energy in large infrastructure projects.

4. Gujarat Solar Park:

- Gujarat is a pioneer in solar energy projects, with the Charanka Solar Park being one of the largest.
- It showcases the state's commitment to renewable energy and contributes significantly to India's solar capacity.

5. Solar-Powered Health Centers in Chhattisgarh:

- Remote health centers in Chhattisgarh have adopted solar power for electricity needs.
- Solar energy ensures continuous power supply for medical equipment, improving healthcare services in rural areas.

6. Solar Street Lighting in Varanasi:

- Varanasi has implemented solar street lighting projects to enhance public safety and reduce energy consumption.
- Solar streetlights contribute to sustainable urban development.

7. Rooftop Solar Installations at Railway Stations:

- Indian Railways has implemented rooftop solar installations at various stations.
- This initiative demonstrates the potential for large-scale adoption of solar energy in public infrastructure.

Present Scenario of Solar Energy in India:

1. Ambitious Targets:

- India has set ambitious renewable energy targets, including a goal to achieve 175 GW of renewable energy capacity by 2022, with a significant portion from solar power.

2. Grid-Connected Capacity:

- India has made substantial progress in grid-connected solar capacity, reaching over 40 GW as of 2022.
- Large-scale solar parks contribute significantly to this capacity.

3. Rooftop Solar Growth:

- There is a growing emphasis on rooftop solar installations, both in residential and commercial sectors, supported by government incentives and policies.

4. Government Initiatives:

- Various government initiatives, such as the Jawaharlal Nehru National Solar Mission (JNNSM) and Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM-KUSUM), aim to promote solar energy adoption.

5. Investment and International Collaboration:

- India has attracted significant investments in the solar sector, and collaborations with international organizations contribute to technology transfer and capacity building.

6. **Off-Grid Solar Applications:**

- Solar energy is increasingly being used in off-grid applications, including decentralized power generation in remote areas and solar water pumping for agriculture.

7. **Policy Support:**

- Supportive policies, feed-in tariffs, and incentives from both central and state governments encourage the growth of solar energy in India.

8. **Job Creation:**

- The solar industry has become a significant source of job creation, fostering employment opportunities in manufacturing, installation, and maintenance.