

Module Outline

GENERAL ASPECTS OF SOLAR ENERGY





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Relevance and Background

There has been tremendous growth in the use of solar energy in the last few years all over the world. The advantages of solar energy are now well appreciated by many countries and due to the higher demand for applications there have been strong research and development in this area. Solar energy either used in the form of solar heat for thermal applications or solar light in the form of radiation used for generating electricity is becoming prominent in the overall energy mix of many communities. Numerous countries are trying to increase the portion of solar energy in the national energy mix.

The development in many countries has been from simple off-grid solar products to grid-interactive and then to grid-feeding products and systems. As the complexities increase in such applications, the basic principle remains the same and it can be understood by one and all. Presently, in many areas simple solar energy utilization alone has not remained an optimum solution and therefore there have been developments in deploying hybrid solar systems in combination with either storage or other energy sources.



Figure 1: Solar generation and agriculture or Agrivoltaics, a new concept (Image source: Getty Images)

The speed at which the governments wish to grow the adoption of solar energy in the overall energy mix still certainly requires government interventions in different forms like direct support, rebates, specially designed programs and so on. Such programs would enable speedy solar energy adoption thereby addressing the climate change challenges in a timely manner.

Theme – Foundation

Competency – General

Code of the Module – T01Co1Mo1

Learning Outcomes

The participants shall be conversant with:

- Different forms of renewable energy sources and their features
- Advantages and limitations

An overview of RE sources would give them an idea of the suitability of different sources at various places and emphasize the prominent role of solar energy among all these RE sources.

Through this module, the participants also will:

- Learn detailed aspects of solar energy.
- Understand all the possible applications, covering off-grid, on-grid, standard products, and systems.
- Become aware of the new hybrid technologies that could be used favourably along with solar.
- Finally, the participants will understand the need for special promotional policies and programs along with some possible features, learning from some current examples.

Method of Delivery

Duration	Resource Code	Resource Delivery
10 min.	Mo1 Vo1	General introduction to solar energy
35 min.	Mo1 Lo1	Lecture on general aspects of solar energy
15 min.	Mo1 Co1	Case Study

M01 V01: Video

Solar Energy Video



M01 L01: Lecture Presentation

The MS PowerPoint presentation will begin by introducing renewable energy and provide an overview of solar energy, its increasing prominence and its positive impacts on the environment and carbon emissions.

The presentation will then cover the two broad aspects of solar energy, i.e., solar thermal and solar electrical and their comparison with conventional power. It will then cover various of solar thermal and solar electrical applications and

other upcoming technologies that are being integrated with solar energy. Finally, the lecture will touch upon the need for designing special policies, programs, and schemes to promote solar energy.

M01 C01:

A case study on Planning and developing large solar power plants A case study of 750 MW Rewa Solar Park in India

What it Talks About

The video explains the power of solar energy and describes how it may fit into our diversified energy future.

What Will Be Done?

The planning for Rewa Ultra Mega Solar (RUMS) Park began in 2014 and the full commercial generation started in 2020. At a levelized tariff of Rs 3.30 (~USD 0.04) per unit for 25 years, it is one of the cheapest solar power-producing plants in the world.

Insights from the case are useful for designing policies and planning for large solar projects in India and elsewhere.

Key Topics to be Covered

1. Renewable Energy Overview
2. Overview of Solar Energy
3. Solar in Comparison with Conventional Power
4. Thermal Applications of Solar Energy

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5. Electrical Applications of Solar Energy
 6. Other New Technologies in Sync with Solar
 7. Need for Policies and Programs for Upscaling Solar Deployment

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General Aspects of Solar Energy

1 Renewable Energy Overview

Renewable sources of energy are those which are inexhaustible in nature, unlike conventional sources like coal, gas and oil which are limited sources and are estimated to be exhausted within decades in this century itself. Also, such conventional sources while generating power also emit various gases that are hazardous to mother earth and to all the living organisms on the Earth. Their consumption of other resources like water is too high and they pollute air, land and water. Renewable energy (RE) sources are cleaner and greener with minimal negative impact on the environment.

To focus on utilizing such RE sources to a larger extent many governments have classified these RE sources and defined what will be categorized as RE power generation. In these RE sources, there are two types, somewhere we need to arrange manually for fuel like biomass or flowing and streamlined water and others where fuel arrangement is not required as these are naturally available to us, like solar heat or radiation and naturally flowing wind. In the first type, the fuel like biomass can be regenerated so that this is available in the required quantity and is never exhausted. The naturally available sources like Sun and wind are not envisaged to be ever exhausted, at least not in the visible future.

2 Overview of Solar Energy

Solar energy is the radiant light and heat from the Sun that is harnessed using a range of technologies to generate electricity and heat. It is an essential source of renewable energy, and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar technologies include the use of photovoltaic systems, concentrated solar power, and solar water heating to harness the energy. Passive solar technologies include orienting a building to the south, using light-colored materials, and incorporating thermal mass (Kannan and Vakeesan 2016).

2.1 Solar Energy - Electrical

Solar energy from sunlight can be converted into electricity directly using photovoltaic (PV) cells which convert light into electric current using the photoelectric effect. The thermal component of solar energy can also be concentrated using lenses or mirrors to generate heat, which can be used to generate electricity. In both systems, tracking systems to focus a large area of sunlight on a hot spot, are often used to increase the efficiency of collection of solar energy.

2.2 Solar Energy - Thermal

Solar thermal energy is the use of the sun's energy to heat water for domestic, commercial, or industrial use. Solar water heating systems use solar collectors to absorb the sun's heat and transfer it to a fluid, which then heats water in a tank. In some cases, there is no additional fluid and the water is directly heated. Passive solar technologies use architecture and design of buildings which tap solar energy to reduce energy consumption of buildings. Such buildings can be designed to be comfortable and energy-efficient without the need for active solar systems.

2.3 Key benefits and limitations of solar energy

Solar energy is a clean, renewable, and abundant source of energy. It has the potential to meet a significant portion of the world's energy needs and help to reduce greenhouse gas emissions. Some of the advantages of solar energy are as follows:

- It is a clean and renewable source of energy.
- It does not produce greenhouse gases or other pollutants.
- It is a domestic source of energy that is not subject to foreign price fluctuations.
- It can be used to generate electricity, heat water, and even power vehicles.



- It is a cost-effective way to reduce energy costs.

There are, however, certain shortcomings, like:

- The cost of solar panels and other equipment can be high as compared to conventional energy producing technologies.
- Solar energy is not always available, such as at night or on cloudy days.
- Solar energy systems may not be suitable for all locations.
- Solar energy systems may require regular maintenance.

Overall, solar energy is a promising renewable energy source with many advantages. The cost of solar panels and other equipment has been declining in recent years, making solar energy more affordable. As technology continues to improve and the cost of solar energy continues to decline, solar energy is likely to become a more widespread source of energy in the future.

3 Solar in Comparison with Conventional Power

Solar energy is a clean and renewable source of energy that has the potential to meet a significant share of the world's energy needs. Although solar energy is not available throughout the day or during cloudy days, falling costs of solar panels and other equipment in recent years is making solar energy more and more affordable. As technology continues to improve and the cost of solar energy continues to decline, solar energy is likely to become a more widespread source of energy in the future.

Conventional energy sources, on the other hand, are not renewable and their use can have negative impacts on the environment. Burning of fossil fuels, for example, releases greenhouse gases (GHGs) into the atmosphere, which contribute to climate change. Nuclear energy can also be dangerous, as evidenced by the Chornobyl and Fukushima Daiichi disasters. A comparison of the two forms of energy is given in the following table (Chenchireddy et al. 2022).

Feature	Solar Energy	Conventional Energy
Source	Sun	Fossil fuels, nuclear
Renewable	Yes	No
Clean	Yes	No
Efficiency	Depends on location and Technology	Varies by source
Cost	Decreasing	Increasing
Environmental impact	Low	High

Overall, solar energy is a more sustainable and environmentally friendly option than conventional energy sources. With its hybridization with other RE technologies and use of energy storage systems (ESS), energy supply throughout the day can be achieved. As the cost of solar energy continues to decline, it is likely to become a more popular choice for meeting our energy needs in future.

4 Thermal Applications of Solar Energy

Solar thermal applications like solar cooking, water heating or steam generation can be used for meeting various needs like cooking food, heating water at low temperature for bathing purposes, heating water or fluid at medium temperature for industrial applications or heating at high temperatures to generate steam to run turbines and generate electrical power. These technologies and products are available in different capacities and sizes and can be tailored to meet the end-use requirements. Overall solar thermal technologies can be categorized into the following:

- **Space Heating and Cooling:** Solar thermal systems can be used to heat and cool buildings. In the heating mode, solar collectors absorb sunlight and transfer the heat to a fluid, which then circulates through a heating system. In the cooling mode, solar collectors can be used to evaporate water, which absorbs heat from the air, thereby making the space cool.
- **Water Heating:** Solar water heaters can be used to heat water for domestic, commercial, or industrial use. Solar collectors absorb sunlight and transfer the heat to water, which is then stored in a tank and used as per requirements.
- **Process Heat:** Solar thermal systems can be used to provide heat for industrial processes, such as food processing, chemical production, and metalworking.
- **Drying:** In rural contexts, solar thermal systems can be used to dry agricultural products, such as fruits, vegetables, and grains. In industries, they can also be used to dry industrial products, such as timber products and textiles.
- **Cooking:** Solar cookers can be used to cook food using the sun's heat. Solar cookers can be simple devices made from cardboard and plastic, or they can be more complex, with features such as reflectors and insulation.
- **Desalination:** Solar thermal systems can be used to desalinate seawater, which is the process of removing salt from water. Desalination can be used to produce drinking water or to produce water for industrial use.

Solar thermal systems are becoming more efficient and affordable, making them a viable option for a variety of applications where heating is a key need.



5 Electrical Applications of Solar Energy

Solar energy can be used to generate electricity in a variety of ways, including:

- **Photovoltaics (PV):** PV cells convert sunlight directly into electricity. PV cells are made from semiconductor materials, such as silicon, that generate an electric current when exposed to sunlight. PV cells are used in solar panels, which can be used to generate electricity for homes, businesses, and other applications.
- **Concentrated solar power (CSP):** CSP systems use mirrors or lenses to concentrate the incident sunlight onto a small area, where it is converted into heat. The heat can then be used to generate steam, which drives a turbine to generate electricity. CSP systems are typically used to generate electricity on a large scale, such as for utility-scale power plants.
Solar thermal power generation is deployed in different parts of the world, though in a very limited manner due to the costs and unavailability of practically deployable standard equipment.
- **Hybrid Systems:** Hybrid systems combine PV cells and CSP systems to generate electricity. Hybrid systems can provide a more reliable and consistent source of electricity than either PV cells or CSP systems alone.
Hybridization can also be of different RE technologies like solar plus wind; ESS systems can be included too. Hybridization enables generating a consistent power output, which is always desirable for consumers, especially the large ones like power distribution companies (DISCOMs) and large industrial consumers and process industries.

Some of the electrical applications of solar energy are as follows:

- **Residential:** Solar panels can be installed on homes to generate electricity for use in the home. This can help to reduce the homeowner's electricity bill and make their home more environmentally sustainable.
- **Commercial:** Solar panels can be installed on businesses to generate electricity for use in business. This can help reduce the business's electricity bill and make their business more sustainable.
- **Utility-Scale:** Solar power plants can be built to generate electricity for use by a DISCOM or a large industrial consumer. This can help to reduce the consumer's reliance on fossil fuels and make the grid more sustainable.
- **Off-Grid:** Solar panels can be used to generate electricity in remote areas where there is no access to the electrical grid. This can help provide electricity for homes, businesses, and other facilities in these areas.
- **Transportation:** Solar panels can be used to power electric vehicles. This can help to reduce the emissions of greenhouse gases from the transportation sector.

- **Space:** Solar panels have been used to power spacecraft since the early days of the space program. They are a reliable and efficient way to generate electricity in space, where there is no other source of energy.


Solar energy is a versatile and powerful source of energy that can be used to generate electricity for a variety of applications.

5.1 Utility-Scale Solar Projects

Utility-scale solar projects are large-scale solar power plants that generate electricity for the electrical grid. Although there is no standard definition of utility-scale solar, some classify those projects that are typically larger than 1 MW in capacity as utility-scale solar. Lawrence Berkeley National Laboratory (LBNL) define utility-scale as any ground-mounted project that is larger than 5 MW (Bolinger et al. 2002).

Utility-scale solar projects' main distinguishing feature is that they sell the electricity they produce directly into the electrical grid. Utility-scale solar projects are frequently referred to as being "in front of the meter" as opposed to distributed generation systems, which are "behind the meter" — that is, a system that is matched with a facility's energy load and provides that facility with electricity directly. Beyond these essential characteristics, the definition of utility-scale solar is quite complex and depends on a range of variables, such as size, location, interconnection type and voltage, state laws, and the final sale location and method of solar electricity production.





Utility-scale solar projects can be built using a variety of technologies, including PV and CSP systems. When it comes to technological competitiveness, CSP stands head and shoulders above PV due to its capacity to reach large levels of long-lasting energy storage, which makes the goal of continuous solar energy a reality. CSP facilities have demonstrated their ability to store thermal energy for up to 16 hours using molten salt storage, a feat that PV has not yet been demonstrated to be able to accomplish. The long-term viability of one technology over another could be determined by the dispatch ability that CSP plus energy storage offers. In the context of India, various issues have restricted the development of CSP. Lack of a trustworthy direct normal irradiance database, domestic production of components, reliance on local engineering and execution and competition from PV are the major obstacles for the large-scale development of CSP. Finally, the capital cost per MW of installed capacity is higher than the benchmark costs even with domestic manufacturing and taking economies of scale into account limiting the growth of this technology.

PV on the other hand has been the dominant technology tapping solar as a resource, across the world. For utility-scale projects, there are a few reasons why PV has led against CSP:

- **Cost:** PV is generally less expensive to install and operate than CSP. This is due to several factors, including the lower cost of PV cells and the fact that PV systems do not require tracking systems to follow the sun. Tracking systems, though, are now increasingly being used in large-scale PV projects as it increases the electric output.
- **Efficiency:** PV systems are more efficient than CSP systems. This means that they can generate more electricity from the same amount of sunlight.
- **Modularity:** PV systems are modular, which means that they can be easily scaled up or down to meet the needs of a particular project. CSP systems are less modular, which makes them more difficult to scale up or down.
- **Versatility:** PV systems can be used in a wider variety of locations than CSP systems. PV systems can be installed on rooftops, in parking lots, and in other areas where there is not a lot of space. CSP systems require more space and are therefore more limited in their applications.

As a result of these factors, PV has become the dominant technology for utility-scale solar power generation. CSP is still a viable option for some applications, but PV is the better choice for most projects.

5.2 Distributed Solar Projects

Distributed solar generation is an approach to generate solar electricity by deploying tools and technologies in proximity to the end users of the electricity. Distributed solar systems can be installed in homes, businesses, schools, and other buildings. They can also be installed on farms, ranches, and other land.

Distributed solar has several advantages over utility-scale solar power plants. First, distributed solar systems are closer to the point of consumption, which means that the electricity they generate does not have to travel as far. This can reduce transmission and distribution losses. Second, distributed solar systems can help to improve the reliability of the electrical grid. When there is a power outage, distributed solar systems can continue to generate electricity, which can help to keep homes and businesses running. Third, distributed solar systems can help to reduce greenhouse gas emissions and reduce local pollution. Local pollution is a major concern in areas where diesel generator sets are used.

Commercial and industrial systems continue to be the fastest-growing market for distributed solutions because, depending on the legislative framework in place, they are typically more affordable and have a daytime load profile that is reasonably steady, allowing for greater power bill savings. Distributed solar is becoming increasingly popular. The cost of solar panels has been declining in recent years, making solar power more affordable. In addition, many governments are offering incentives to encourage the installation of distributed solar systems. As a result, the amount of distributed solar power being generated is growing rapidly.

Depending on whether they are connected to the grid or not, the end use and compensation mechanism if electricity generated is being fed into the grid, distributed solar projects can broadly be categorized into:

- Off-grid systems
- Grid-tied systems
- Hybrid systems

The following sections describe each of the above.

5.2.1 Off-Grid Systems

An off-grid solar energy system is not connected to the DISCOM's grid as opposed to an on-grid system, which is connected to the grid. They are especially suited to areas that do not have the grid like remote locations, rural areas, and even disaster zones. What equipment is required for surplus production, what happens when the grid goes down, and how one gets invoiced for electricity depends on whether one uses an off-grid or an on-grid system.

Off-grid solar systems typically consist of solar panels, a battery, and an inverter. The solar panels convert sunlight into electricity, which is then stored in the battery. The inverter converts the stored

electricity into alternating current (AC), which is the type of electricity used in homes and businesses. These systems can be used to power a variety of devices, including lights, fans, televisions, and even computers. They can also be used to pump water, charge cell phones, and run small appliances. These systems offer several advantages over traditional fossil fuel-powered systems. They are clean, renewable, and quiet. They also require little maintenance and have a long lifespan, if maintained and run properly. Off-grid solar systems are becoming increasingly popular as the cost of solar panels continues to decline. There are, however, some challenges/ limitations of such applications. They can be expensive to install and require a sunny location. Such systems may not be able to provide enough power for all the devices that one needs to run. As solar generation happens only during the day, for night-time supply, one needs to install a battery to store the solar energy and provide supply during non-solar hours and batteries are expensive and need to be replaced every five to six years. Some examples of off-grid solar applications are:

- **Electrification of Rural and Remote Areas:** Off-grid solar systems can be used to provide electricity to homes and businesses in rural and remote areas that do not have access to the electrical grid. This can help to improve the quality of life for people in these areas and can also help to reduce their reliance on fossil fuels.
- **Emergency Power Supply:** Off-grid solar systems can be used to provide emergency power during power outages. This can be especially important for hospitals, schools, and other critical infrastructure.
- **Mobile Solar Systems:** Off-grid solar systems can be used to power mobile devices and appliances in remote areas. This can be useful for campers, hikers, and other people who spend time outdoors.
- **Power Backup:** Off-grid solar systems can be used as a backup power source for homes and businesses that are connected to the electrical grid. This can help to protect against power outages.
- **Solar Water Pumping:** Off-grid solar systems can be used to power solar water pumps. This can be used to irrigate crops, provide drinking water, and for other water-related applications.



Figure 2: Installation of solar panels

5.2.2 Grid-Tied Systems

Grid-tied systems are solar power setups that are connected to the electricity grid — and work without any battery backup equipment. This type of solar panel system is known by many names, such as ‘on-grid,’ ‘grid-connect(ed),’ ‘grid-intertied’ and ‘grid-direct.’ Grid-tied systems are different from other off-grid solar systems with respect to:

- **Use of Grid-Tie Inverters:** Grid-tied solar systems require an inverter that can communicate with the grid, known as grid-tie inverters. These inverters can intelligently manage the solar panels so that their power is first sent to supply the load before exporting the excess to the grid.
- **No Use of Batteries:** Grid-tied systems do not include batteries for supplying electricity during non-generation hours. Instead, they enable the loads to be powered by the grid when solar generation is not available.

Solar rooftops and grid-connected solar pumping are examples of grid-tied solar systems. Grid-tied solar systems are connected to the electrical grid, which means that they can use electricity from the grid when the solar panels are not producing electricity. This makes grid-tied solar systems a very reliable option for homeowners and businesses.

Solar rooftops are a type of grid-tied solar system that uses solar panels to generate electricity on the roof of a building. The electricity generated by the solar panels is then used to power the building's appliances and lights. Solar rooftops help homeowners and businesses to reduce their electricity bills and save money on their energy costs.

Grid-connected solar pumping is a type of grid-tied solar system that uses solar panels to power water pumps. Solar water pumps are used to irrigate crops, provide drinking water, and for other water-related applications. Connecting these solar pumps to the grid enables feeding of electricity back to the grid when the pump is not running; farmers can get paid for such a mechanism (Ministry of New and Renewable Energy 2019).

Both solar rooftops and grid-connected solar pumping are examples of grid-tied solar systems that can help homeowners, businesses, and farmers to save money on their energy costs and earn additional revenue.

5.2.3 Hybrid Systems

A solar energy system that is both connected to the grid and equipped with a battery bank to store any extra energy is known as a hybrid system. Hybrid systems enable their owners to run their equipment even when the grid goes down and may even assist businesses with lower demand charges. They are, however, more expensive due to the additional cost of batteries.

Solar panels generate DC current which can be directly stored in batteries, through a charge controller, but because appliances and equipment use AC current the current must be converted via inverters for it to be used by the appliances/ equipment. This is where coupling to the batteries is important. There are two ways for grid-tied solar systems to be connected to batteries: DC Coupling and AC Coupling. DC-coupled systems typically use solar charge controllers, or regulators, to charge the battery from the solar panels, along with a battery inverter to convert the electricity flow to AC. Separate inverters are used in AC-coupled systems to power the batteries and solar panels. There is flexibility in the system's operation because both the solar panels and the battery module can be dispatched at full power and either jointly or independently. The grid connector for the solar panels and batteries can either be shared or used separately. It is worth noting that because both the solar panels and the batteries are DC-current compatible, the current will need to be converted three times in an AC-coupled system. AC coupled is the preferred battery configuration for larger solar installations while DC coupling works very well for smaller systems (Marsh 2019).

5.2.4 Metering Mechanisms for Grid-Tied and Hybrid Systems

Whenever electricity is generated and fed into the grid, a metering and payment mechanism needs to be put in place. In the case of distributed systems, the owners of such projects consume electricity from the grid as well as supply electricity to the grid; they become prosumers. There are broadly two types of metering mechanisms for grid-tied (and hybrid) systems.

- **Net Metering:** In this mechanism, the system owner who is producing more power than they are using is allowed to export that extra energy to the grid and receive a credit in kWh. The credit can be used to offset electricity use during the current billing cycle (for example, one month), as well as frequently during subsequent billing cycles. During a billing cycle, the system owner is billed for the net energy used. When the system is producing more energy than the system owner is using, the consumption meter for the system is permitted to spin backwards, which reduces the meter's measurement of the system owner's net kWh use. A single bidirectional meter or two unidirectional meters are needed for net metering.
- **Gross Metering:** A gross metering mechanism offers a standard sell rate to a system owner for all the solar electricity they generate and sell to the grid. This mechanism commonly offers a fixed long-term contract price for energy exports. Unlike net metering, gross metering customers do not physically consume the electricity of their solar systems. These customers continue to be billed for all the electricity they consume from the grid at the applicable retail rate, independent of electricity generated by their solar system. The system exports all electricity directly to the grid, and the system owner is compensated at a predetermined and typically fixed tariff either through utility bill credits or in cash. In other words, in a gross metering mechanism, the system owner continues to buy all electricity from the utility and sell all electricity produced by the solar system to the grid.

- **Net Billing:** A solar system owner who uses net billing can use the electricity produced by their system in real time and export any extra production to the grid. Net metering and net billing are similar in this regard. However, with net billing, it is not permitted to bank kWhs throughout a billing cycle to offset future use, and credits are not given in kWh terms at all. Instead, as soon as energy is pumped into the grid, it is metered and credited at a predetermined rate. This rate is generally different from the grid electricity tariff.



6 Other New Technologies in Sync with Solar

6.1 Energy Storage System (ESS)

ESS, in its various forms, is one of the emerging areas of development that has the potential to enable large-scale adoption of renewable energy into the power system. Almost every component of a power system, including generation, transmission, and demand flexibility, can be replaced, or enhanced by energy storage. Storage needs to be co-optimized with sustainable energy production, transmission infrastructure, and consumer incentive programs for flexible electricity consumption.

Energy storage is the capture of energy produced at one time for use later to reduce imbalances between energy demand and energy production. Energy storage involves converting energy from forms that are difficult to store to more convenient or economically storable forms. ESS comes in multiple forms including chemical, gravitational potential, electrical potential, electricity, elevated temperature, latent heat and kinetic.

Common examples of energy storage are the rechargeable battery, which stores chemical energy readily convertible to electricity to operate a mobile phone; the hydroelectric dam, which stores energy in a reservoir as gravitational potential energy; and ice storage tanks, which store ice frozen by cheaper energy at night to meet peak daytime demand for cooling. Green hydrogen, from the electrolysis of water, is a more economical means of long-term renewable energy storage in terms of capital expenditures than pumped-storage hydroelectricity or batteries.

Energy storage has several benefits, including:

- **Increased Reliability of the Electrical Grid:** Energy storage can help to smooth out fluctuations in energy demand and supply, which can help to prevent blackouts and brownouts.
- **Reduced Reliance on Fossil Fuels:** Energy storage can help to store renewable energy, such as solar and wind, which can help to reduce our reliance on fossil fuels.
- **Lower Energy Costs:** Energy storage can help to reduce energy costs by shifting energy consumption to times when energy is cheaper.
- **Improved Grid Resilience:** Energy storage can help to make the grid more resilient to disruptions, such as natural disasters and cyberattacks.

There are a number of different ESS technologies, each with its own advantages and disadvantages. Some of the most common ESS technologies include:

- **Batteries:** Batteries are the most common type of energy storage. They are relatively inexpensive and easy to install, but they have a limited lifespan and can be expensive to replace.

- **Pumped-Storage Projects:** Pumped-storage projects is a type of energy storage that uses the potential energy of water to store energy. It is a very efficient form of energy storage, but it requires a large amount of land and water. These projects need to be executed at a minimum scale, which means high capital investments. They are also not very responsive like batteries.

- **Compressed Air Energy Storage:**

Compressed air energy storage is a type of energy storage that uses compressed air to store energy. It is a very efficient form of energy storage, but it requires a large amount of energy to compress the air.

- **Flywheel Energy Storage:** Flywheel energy storage is a type of energy storage that uses the kinetic energy of a spinning flywheel to store energy. It is an efficient form of energy storage, but it has a limited lifespan and can be expensive to maintain.

- **Thermal Energy Storage:** Thermal energy storage is a type of energy storage that uses the heat of a material to store energy. It is a very efficient form of energy storage, but it can be difficult to find materials that can store large amounts of heat. Insulation is an essential component of thermal ESS.

The best energy storage technology for a particular application depends on a number of factors, including the amount of energy that needs to be stored, the cost of the technology, and the environmental impact of the technology.

Energy storage is a rapidly developing field, and new technologies are being developed all the time. As these technologies continue to develop, energy storage is likely to play an increasingly important role in our energy future.



6.2 Green hydrogen

Hydrogen is the most abundant element in the universe, but it is not found in its pure form on Earth. It is typically found in water, which is made up of two hydrogen atoms and one oxygen atom. Hydrogen can be extracted from water through a process called electrolysis, which uses electricity to split the water molecules into hydrogen and oxygen gas. Hydrogen can be used as a fuel to generate electricity, power vehicles, and heat homes and businesses. It is a clean-burning fuel that produces no emissions, making it a potential solution to climate change. However, hydrogen production can be energy-intensive and can produce greenhouse gases if fossil fuels are used as an energy source.



Green hydrogen is hydrogen that is produced using renewable energy sources, such as solar or wind power. This type of hydrogen production does not produce greenhouse gases, making it a more sustainable option than hydrogen produced using fossil fuels. Green hydrogen is still in its early stages of development, but it has the potential to play a major role in the future of energy. As the cost of renewable energy sources continues to decline, green hydrogen is expected to become more affordable and accessible. This could make it a viable option for a wide range of applications, from generating electricity to powering vehicles. The following table summarizes the key benefits and challenges of green hydrogen.

Benefits	Challenges
Clean-burning fuel that produces no emissions	More expensive than hydrogen produced using fossil fuels
Can be used to generate electricity, power vehicles, and heat homes and businesses.	Not yet widely available
Can be produced using solar or wind power	Best ways to produce and store green hydrogen
Potential to create jobs and boost the economy	Transport network needs to be created

Despite these challenges, green hydrogen has the potential to be a major player in the future of energy. As the cost of renewable energy sources continues to decline and the demand for clean energy grows, green hydrogen is expected to become more affordable and accessible. This could make it a viable option for a wide range of applications, from generating electricity to powering vehicles.

7 Need for Policies and Programs for Upscaling Solar Deployment

Solar energy is a clean, renewable, and abundant source of energy that has the potential to meet a significant portion of our global energy needs. In recent years, solar energy has become increasingly affordable and accessible, and it is now one of the fastest-growing energy sources in the world.

However, there are still several challenges that need to be addressed in order to upscale solar deployment. These challenges include:

- **High Upfront Costs:** The upfront cost of installing solar panels can be a barrier for many businesses and homeowners.
- **Lack of Awareness:** Not everyone is aware of the benefits of solar energy or how to install it.
- **Regulatory Hurdles:** In some countries, there are regulatory hurdles that make it difficult to install solar projects.

To overcome these challenges, there is a need for policies and programs that support the up scaling of solar deployment. These policies and programs could include:

- **Financial Incentives:** Financial incentives, such as tax breaks and rebates, can help to reduce the upfront cost of solar panels.
- **Education and Awareness Campaigns:** Education and awareness campaigns can help to raise awareness of the benefits of solar energy and how to install it.
- **Regulatory Reforms:** regulatory reforms can help to remove barriers to solar deployment.

By implementing policies and programs that support the up scaling of solar deployment, we can help to make solar energy more affordable, accessible, and widespread. This will help us to reduce our reliance on fossil fuels, improve air quality, and combat climate change.

Here are some specific examples of policies and programs that can be used to upscale solar deployment:

- **Feed-In Tariffs:** Feed-in tariffs are a type of government subsidy that pays solar power producers a fixed price for the electricity they generate. This can help to make solar energy more affordable for businesses and homeowners.
- **Net Metering:** Net metering is a policy that allows solar power producers to sell excess electricity back to the grid. This can help to offset the cost of solar panels and make them more affordable.

- **Solar Tax Credits:** Solar tax credits are a type of government subsidy that reduces the amount of taxes that solar power producers owe. This can help to make solar energy more affordable and accessible.
- **Solar Rebates:** Solar rebates are a type of government subsidy that provides a one-time payment to solar power producers. This can help to reduce the upfront cost of solar panels.
- **Solar Financing Programs:** Solar financing programs provide loans and other forms of financing to help businesses and homeowners install solar panels. This can help to make solar energy more affordable and accessible.
- **Education and Awareness Campaigns:** Education and awareness campaigns can help to raise awareness of the benefits of solar energy and how to install it. This can help to drive demand for solar panels and make solar energy more widespread.

By implementing these policies and programs, we can help to upscale solar deployment and make solar energy a more affordable, accessible, and widespread source of energy. This will help us to reduce our reliance on fossil fuels, improve air quality, and combat climate change.

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For Further Reading

Reading Material

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The Future of Energy Storage, Energy Initiative, Massachusetts Institute of Technology (<https://energy.mit.edu/wp-content/uploads/2022/05/The-Future-of-Energy-Storage.pdf>)

Grid-Connected Distributed Generation: Compensation Mechanism Basics, National Renewable Energy Laboratory (<https://www.nrel.gov/docs/fy18osti/68469.pdf>)

Case Study

Case study: Planning and developing large solar power plants: A case study of 750 MW Rewa Solar Park in India (<https://doi.org/10.1016/j.clet.2022.100396>)