

INNOVATIONS IN SOLAR ENERGY TECHNOLOGIES: FROM PHOTOVOLTAICS TO SOLAR THERMAL SYSTEMS

Abstract

In the quest for sustainable energy solutions amidst the looming threat of climate change, solar energy emerges as a beacon of hope. This chapter explores the dynamic landscape of solar energy innovation, driven by the imperative to mitigate climate change and reduce dependence on fossil fuels. From photovoltaic (PV) to solar thermal systems, the evolution of solar technologies holds transformative potential for global energy supply. Solar energy, harnessed from the sun's radiant energy, has garnered significant attention as a cleaner and more efficient energy source. Notable progress has been achieved in recent decades across various applications of solar energy. Photovoltaic and solar thermal systems stand out as primary drivers of this transformative journey.

The remarkable strides in PV technology have propelled it to the forefront of solar energy solutions. PV cells, embedded in solar panels, directly convert sunlight into electricity, with advancements yielding enhanced efficiency, reduced production costs, and increased design flexibility. Innovations such as bifacial panels, perovskite cells, and transparent solar windows are expanding the horizons of solar electricity generation, making it more accessible and aesthetically appealing. The ongoing advancements in solar energy technology hold promise for a sustainable energy future. By leveraging innovations in PV and solar thermal systems, humanity can transition towards cleaner, more resilient energy systems, thereby mitigating the impacts of climate change and fostering global energy security.

Keywords: Solar energy, Photovoltaic cell, Global energy, Thermal systems

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I. INTRODUCTION

Solar energy stands out as a ray of hope for a sustainable future in the dynamic world of renewable energy. Innovations in solar energy technology have attracted a lot of interest and investment globally due to the urgent need to prevent climate change and lessen our reliance on fossil fuels. Solar energy developments, ranging from photovoltaics to solar thermal systems have game-changing potential to change the face of the world's energy supply.

Solar energy, which derives from the sun's radiant energy, has become a front-runner in the search for cleaner and more effective energy sources. Significant advancements have been made in the past several decades in the use of solar energy for a wide range of purposes. Photovoltaic (PV) and solar thermal systems are the two main solar technologies that will drive this revolution.

The extraordinary advancements in PV technology have made it the most well-known expression of solar energy. Photovoltaic cells found in solar panels convert sunlight directly into electricity. Increased efficiency, lower production costs, and more design and integration flexibility are all results of advances in PV technology. The possibilities for solar electricity generation are being expanded by new ideas like bifacial solar panels, perovskite solar cells, and transparent solar windows. These innovations make solar panels more aesthetically pleasing and more affordable for a wider range of uses.

Solar thermal systems concentrate on utilizing heat for a variety of applications, whereas photovoltaics focus on capturing the sun's energy in the form of electricity. Concentrated solar power (CSP) has been at the forefront of these systems' own set of advances. Through the use of mirrors or lenses, CSP technology concentrates sunlight onto a single spot, producing high-temperature heat that can be used for energy storage, industrial activities, and even the production of electricity. Advanced heat storage techniques, fresh heat transfer fluids, and improved receiver designs are all examples of CSP innovations that promote efficiency and scalability.

II. NEXT GENERATION PHOTOVOLTAIC

Solar PV cell technology has become more widely used as a sustainable energy source as a result of growing concerns about how conventional energy affects climate change and global warming. There are different generations of solar cells that can be used to categorise recent technological advancements. Among other things, the first two-generation (GEN) solar cell discusses how generation and the current market interact with one another. For the first generation of silicon cells (mono or polycrystalline), low-cost and medium-cost methods produce moderate commercial yields. Thin-film technologies, often known as GEN II, are based on more effective but less expensive manufacturing techniques. The 3GEN showcases new materials and a variety of fresh designs that all make use of the most effective but expensive cells. This idea, known as the 4GEN, includes hybrid materials, including innovative, more stable inorganic nanostructures like metal oxides and flexible, affordable polymer films. All of these materials are now being studied. It is vital to investigate the numerous facets of solar cell technology in terms of materials, efficiency, and technological

manufacturing costs in order to achieve the main goal of this review. Device architectures are discussed in the paper along with fabrication, stability, and limits (1).

Some of the latest developments of solar cells technologies are:

- 1. Perovskite Solar Cells:** The mineral perovskite, which bears the name of the Russian mineralogist L.A. Perovski, has a particular crystal structure with the notation ABX_3 (X = oxygen, halogen). While the smaller B cation is stabilised in an octahedral position shared with six X anions, the bigger A cation resides in a cubo-octahedral site shared with twelve X anions. Due to their electrical characteristics of ferroelectricity or superconductivity, oxides are the perovskites that have been the subject of the most research. Prior to the discovery that stacked organometal halide perovskites showed a semiconductor-to-metal transition with increasing dimensionality, halide perovskites got little attention. A developing photovoltaic technology is represented by perovskite solar cells based on organometal halides. Dyesensitized solar cells are the ancestors of perovskite solar cells. As first observed in 2009, methylammonium lead halide perovskite adsorption on a nanocrystalline TiO_2 surface results in a photocurrent with a power conversion efficiency (PCE) of about 3-4% in a liquid-based dye-sensitized solar cell configuration. By improving the perovskite coating conditions, the PCE was doubled after two years. Due to stability problems, such as the perovskite's instantaneous breakdown in a liquid electrolyte, the liquid-based perovskite solar cell isn't given much attention. In 2012, a solid hole conductor was switched out for a liquid electrolyte to create a long-lasting, stable, and high efficiency (10%) perovskite solar cell. In just two years, efficiencies have quickly increased to 18%. Perovskite solar cells are a potential photovoltaic technology since PCE values exceeding 20% are reasonably anticipated with the usage of inexpensive organometal halide perovskite materials (2).
- 2. Tandem Solar Cells:** Splitting the spectrum into several parts and using solar cells that are suited for each part of the spectrum is one way to boost the efficiency of a solar cell. Solar panels made of tandem cells can be joined in series or used as separate cells. Although it is easier to manufacture series connected cells, the band gaps that can be employed are limited because the current flows through each cell at the same rate. The most typical setup for tandem cells is to grow them monolithically, in which case all the cells are grown as layers on a single substrate, and tunnel junctions link the different cells (3). The effectiveness of the stack could potentially rise as the number of bandgaps does. In practice, there aren't enough high-quality, arbitrary materials with a certain bandgap to go around. Utilising a tandem structure can significantly increase the efficiency of polymer solar cells since it allows for the use of a wider range of solar radiation and reduces photon energy loss due to thermalization. High-performance tandem solar cells have historically been difficult to produce due to a shortage of high-performance low-bandgap polymers. Here, we describe the creation of a poly[2,7-(5,5-bis-(3,7-dimethyloctyl)-5H-dithieno[3,2-b:2',3'-d]pyran)-alt-4,7-(5,6-difluoro-2,1,3-benzothia diazole) with a bandgap of 1.38 eV, strong mobility, and deep highest occupied molecular orbital. A single-junction device as a result exhibits high external quantum efficiency of >60% and spectrum responsiveness that extends to 900 nm, with a power conversion efficiency of 7.9%. The polymer allows for a solution-processed tandem solar cell with a verified 10.6% power conversion efficiency under standard reporting conditions (25 °C,

1,000 Wm², and IEC 60904-3 worldwide), making it the first polymer sun cell efficiency to surpass 10% (4).

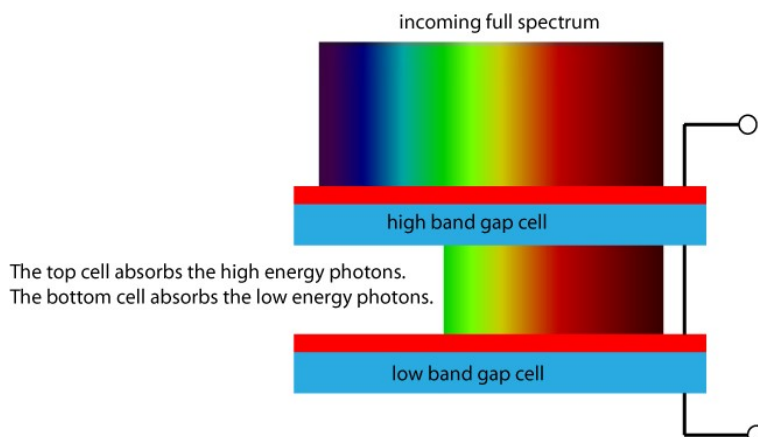


Figure 1: Series connected Tandem Solar Cell
<https://www.pveducation.org/pvcdrom/tandem-cells>

- 3. Organic Photovoltaics:** For prospective uses in consumer electronics, organic photovoltaics (OPVs) are flexible enough to fit to the human body, light enough to have tandem architectures, and fabricable on plastic substrates. The OPVs can be used as building components for a range of applications because they can also be transparent or color tunable. The development of organic solar cells' single- and multi-junction record efficiencies. At the moment, the maximum efficiency is close to 11%. Despite the benefits and advancements made in the development of OPVs, there are still a number of technical challenges that need to be cleared before this exciting new technology can be successfully introduced to the market. The maximum OPV efficiency has increased from 2.5 to 11% during the past ten years, thanks to technologies like bulk heterojunction polymer, fullerene solar cells. This quick development suggests that the commercialization of OPVs should happen shortly. The improvements in the development of OPVs can be attributed to four areas: (i) a deeper comprehension of the mechanism of photon-to-electron conversion; (ii) new materials with tailored energy levels and solubility; (iii) new processing approaches to induce the best microstructures in the active layer; and (iv) new device architectures with novel interfacial layers (5).

A cradle-to-grave system model was used to examine the effects of multi-crystalline silicon (m-Si), organic thin-film (OTF), and perovskite thin-film (PSC) panels over the course of each product's lifetime. To take into account efficiency, functional lifetime, and deterioration, the rate of panel installation each year was modelled. Comparing the end-of-life effects of recycling and landfilling was done while applying LCIA (Life Cycle Impact Assessment) at the midpoint and endpoint levels to determine the overall environmental effects. The use and production of m-Si panels were shown to have the worst effects across all categories, according to impact estimations. PSC designs performed at the middle of the spectrum, while OTF panels delivered noticeably lower impacts. All module types had their impacts reduced by recycling, although m-Si panels had the most drop. The data can be used to compare different panel types in various regions even though they are only slightly sensitive to the energy production mix. Due to

their superior optoelectronic qualities and broad visible light absorption, large bandgap inorganic perovskites make excellent front cell candidates (6, 7).

III. ENERGY STORAGE SOLUTIONS

In addition to the fact that solar energy integration into non-renewable sources is important as it reduces the rates of consuming of non-renewable resources thus reduce dependence of fossil fuels, the world's energy requirements have imposed significant need for different methods by which energy can be produced or integrated. This has led to an increase in the importance of integration technology. By converting solar energy from DC to AC, photovoltaic systems are at the forefront of this transformation. Due to the current energy demand, the depletion of fossil fuel reserves, and environmental effects, integrating renewable energy from this source into grids has gained popularity among academics and scientists (8).

The inherent erratic nature of the solar resource presents one of the biggest problems to those who would develop and execute the next generation smart grid as solar photovoltaic power generation becomes more widespread. With a lot of deployed photovoltaic devices, grid-tied solar power generation is a dispersed resource whose output can change very quickly and cause a lot of problems for the distribution system operator. Systems for battery energy storage are being employed more frequently to aid in the grid integration of solar electricity. These devices have response times of less than a second and are capable of absorbing and delivering both actual and reactive power. With these features, battery energy storage devices can reduce the ramp rate, frequency, and voltage problems associated with solar power generation. Energy storage control systems can be connected with energy markets in addition to these applications that concentrate on system stability to increase the economics of solar energy. This paper provides a high-level introduction to this application area by presenting an overview of the difficulties in integrating solar power into the electrical grid, a technical overview of battery energy storage systems, and an illustration of a number of operational modes for battery energy storage systems in grid-tied solar applications. The real-time control modes covered include output levelling, ramp rate control, frequency droop response, power factor correction, and solar time-shifting (9).

The energy storage sector is being revolutionized by advances in battery technology, which also have the potential to have an impact on many other industries. Some of the major issues with conventional lithium-ion batteries are being addressed through the development of solid-state, Li-S, and flow batteries.

1. Lithium-Ion Battery: Lithium-ion is a crucial part of the electrochemistry of a typical lithium-ion battery. Ionization and electron separation of lithium atoms occur in the anode. In order to achieve higher energy densities and cheaper costs, the next generation of lithium-ion batteries will focus on technological advancements in the cathode. Electric vehicles use three different types of lithium-ion batteries: lithium ferro phosphate, also known as lithium iron phosphate, lithium nickel manganese cobalt oxide, and lithium nickel cobalt aluminum oxide. Even while typical graphite anodes in lithium batteries are more environmentally friendly and have a lower operating potential, they still have trouble meeting the demands of new trends in electric and hybrid vehicles. Novel anode materials are used in higher density next-generation lithium-ion batteries. In comparison

to ordinary graphite batteries, these ones could offer higher energy capacities and longer cycling lives (10,11).

- 2. Solid-State Battery:** Solid-state batteries use solid electrodes and a solid electrolyte made of ceramics like oxides, glass, and sulphides, in contrast to typical lithium batteries, which use liquid and polymer gel electrolytes. In comparison to lithium-ion batteries, these batteries are more energy dense and have a ten-year lifespan. They can also be recharged up to seven times.

The carbon footprint of an electric vehicle can be reduced by 24% by solid-state batteries. An EV's carbon footprint can be further reduced by 39% by using these additional materials in the batteries, according to research. Aside from wearable technology, they are also utilised in pacemakers and RFID tags.

The company with the most solid-state battery patents is thought to be Toyota Motor. Although solid-state batteries for EVs are not yet commercially available, they are anticipated to do so starting in 2025. Additionally, Ford and BMW are testing solid states in electric vehicles. Robert Bosch, Cymbet, Bright Volt, Samsung SDI, Quantum Scape, Solid Energy Systems, Toyota Motor Corporation, and others are significant players in the solid-state market (10, 11).

- 3. Flow Batteries:** With a focus on large-scale energy storage applications, flow batteries are a newcomer to the battery storage market. The study and development of this storage technology dates back many years, but it is only recently that it is beginning to see some practical application.

Its distinctive shape makes flow battery technology interesting. Instead of having a single enclosed battery cell, where the electrolyte and conductors mix easily, the fluid is divided into two tanks, where electrons travel through electrochemical cells and a membrane that separates them (12).

The Improved flexibility and stability the power system receives because of integrating solar and energy storage is one of the most important advancements. Sunlight is a variable resource that affects solar energy production throughout the day. Excess solar energy can be gathered and stored for later use by integrating energy storage systems with solar panels. This makes it possible to have an energy supply that is more reliable and consistent, less affected by solar variability, and offering a steady source of electricity. This breakthrough promotes greater penetration of renewable energy sources, mitigates the need for additional backup power sources, and ensures grid stability.

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be optimally consumed by itself when solar and energy storage are integrated. In the past, extra solar energy that wasn't immediately used was put back into the grid. The need for grid-supplied electricity can be greatly reduced by storing extra energy with the use of energy storage systems for later usage. Solar energy generation, energy storage, and energy consumption may all be seamlessly integrated thanks to cutting-edge energy management systems. By prioritising self-consumption, managing energy usage effectively, and lowering electricity costs, customers are now more empowered. Consumers can maximise the return on their solar investment and optimise their energy usage by using smart controls and predictive algorithms (13).

IV. BIFACIAL SOLAR PANELS

Solar cells are the cornerstone of solar panels. While silicon is the material that is most frequently used to create solar panels, other materials can also be utilised to create solar cells. Silicon is also used to make bifacial solar cells. Simply put, a bifacial solar cell is a stack of two silicon cells with the faces facing in opposite directions. When numerous bifacial cells are stacked on top of one another, a bifacial solar panel is produced. Bifacial solar panels have solar cells on both sides, thus both sides generate electricity. Given that they can be made of either monocrystalline or polycrystalline cells, bifacial panels are an intriguing variant. Since bifacial panels can absorb solar energy from both the front and back sides, they have the potential to produce more electricity than traditional (monofacial) photovoltaic panels. Bifacial PV cells and PV panels (PV modules, PV collectors) have also been designed with this goal in mind. Bifacial solar photovoltaics (PV) is a promising, established technology that uses light absorption from the albedo to enhance the amount of power produced per square metre of PV module.

The most effective solar panel is a bifacial panel. To simplify matters, let's go through the process step by step:

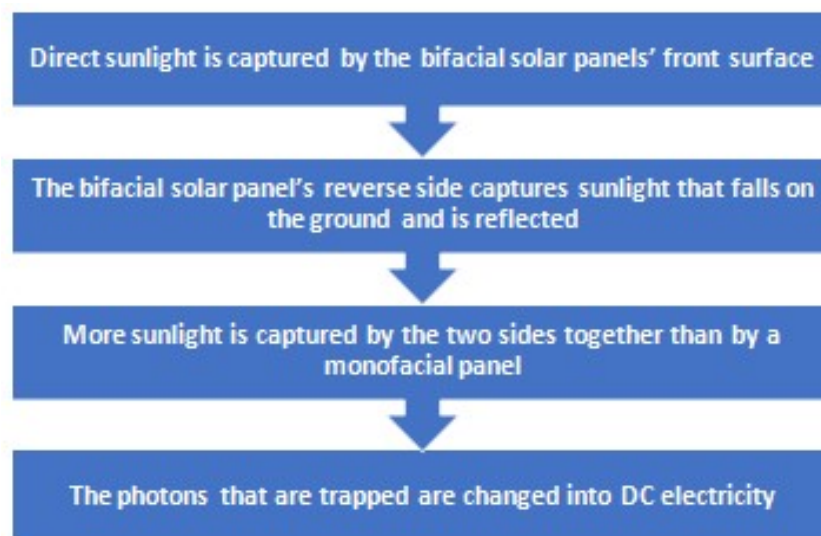


Figure 2: Process of Bifacial Panel

This methodically described operation can give the impression that bifacial solar panels produce twice as much as monofacial panels. That's not the case, though. A bifacial panel produces an output that is 4-5% higher than one-sided (conventional) panels (14). When solar trackers are deployed, bifacial panels begin to serve their true purpose. Bifacial solar panel types are undoubtedly more advantageous in commercial and industrial settings. The method for installing monofacial and bifacial solar panels is the same. To allow light to reach the rear of the panels, homeowners are encouraged to mount them on higher racking systems due to their distinctive shape. With bifacial modules, some installations are conceivable that have an impact on the generation. Setups for the chosen utility scale employing bifacial modules are displayed in the left column with setups for fixed tilt, vertical, and tracking. While integrated systems are shown in the right column with fixed tilt, vertical, and tracking positions, fixed tilt, vertical, and tracking installations for flat roof surfaces are listed in the middle column. Bifacial modules have a front surface that directly faces the sun and a back surface that collects dispersed energy. In bifacial installations, the reflector is crucial. Bifacial solar panels have two absorption surfaces, which increases their electrical energy output over monofacial solar panels, particularly in gloomy weather. The amount of electrical energy that bifacial solar panels with external reflectors produce will depend on the reflector's placement and the reflector's characteristics. The slope, distance, and reflection efficiency are a few crucial reflector factors. The surface's colour and roughness both affect reflection. With a 75% average reflectivity, white is the ideal diffuse painted reflector colour. With 61 to 32% variance in reflection, yellow is rated as the second-best reflector, followed by orange, red, blue, brown, purple, grey, and dark blue and dark green. A non-luminous surface's reflectivity is described by its albedo. The proportion of incident radiation to light reflected from the surface controls it. Reflected light minus incident light equals the surface's albedo. The standard way to express albedo is as a percentage. A surface has a higher albedo value the more reflective it is. According to various surface types and installation heights, the bifacial module's increased energy yield is shown in the table below. The findings show that when laid at a height of 0.5 metres, dazzling white roofing foil with an 80% albedo yields the most additional energy (15).

For flat commercial rooftops and ground-mounted installations, this technique is useful. Because they are more effective at producing solar energy, bifacial solar panels are becoming more and more common in industrial and utility-scale applications, according to Edie. These include solar panel installations on large, open fields and flat, business rooftops. They are especially helpful in utility-scale solar projects since the ground-mounted panels allow for a lot of light reflection. Sand and snowy surfaces will reflect more light than asphalt, which is darker (16).

V. SOLAR TRACKING SYSTEM

The direction of a solar panel is always adjusted by the solar tracking system to match the position of the sun. Surprisingly, the amount of light that enters increases when the angle at which the panels face the sun is increased. The panels trap more solar energy since this method of light reflection reflects less light. The amount of energy that a solar PV panel can produce increases with the smaller the angle of incidence. The best choice to improve the performance of the photovoltaic panel is a solar tracking system. The payload is continuously moved towards the sun by solar trackers. A practical solution to the majority of the world's energy issues is the conversion of solar energy into electricity (17).

The azimuth and tilt angle of concentrated solar power systems in relation to the sun are among the factors influencing both of these technologies' performance. The best devices for increasing efficiency are solar trackers (ST). Benefits include increased productivity, improved tracking accuracy, simple installation, and cost effectiveness.

The two primary types of ST are single axis and double axis ST. These devices must be optimised according to complex standards in order to prevent tracking errors, which frequently result in poor performance. Due to various sources of tracking errors, including the tracking fixture's alignment, the area's level of pollution, the shading of the sensors, the different types of control schemes involved, the system's auxiliary units, a lack of maintenance, and the imperfection and power mismatch of connecting grids, these specifications cannot be satisfied by simple tracking methods. The most efficient double axis STs typically outperform fixed PV panels by more than 40% and come in the form of polar-axis and azimuth/elevation, featuring solar movement models and dynamic closed loop feedback control. Large systems also save on materials and save prices dramatically. The majority of the time, moving fixtures use very little energy. The energy used by the moving fixtures is typically minimal (between 2 and 5 percent of the energy collected), but if no optimisation is done, this could increase. Last but not least, all hardware and software energy-saving settings must be optimised from the very beginning of the system's construction to avoid wasting materials and having the tracking devices consume too much energy.

Based on axis there are two types of solar tracking system:

- 1. Single Axis Solar Tracker:** With one degree of freedom serving as an axis of rotation, single axis trackers have one degree of freedom. Single axis trackers frequently have their axis of rotation aligned with true north. Rizk and Chaiko created a solar tracking system that uses solar panels more effectively. This paper examined the possible system advantages of a straightforward solar tracking system with a single axis tracker that uses a stepper motor and light sensor. By using a system that tracks the sun to keep the panel at a correct angle to the sun's beams, this technique improved the efficiency of electricity collecting. Compared to a fixed horizontal array, the power gain was 30% higher.
 - **Horizontal Single Axis Tracker:** With regard to the ground, the horizontal single axis tracker's (HSAT) rotational axis is horizontal. One of the problems with calculating the distribution of panels and the optical performance of HSAT solar panels is backtracking. From the data, it was evident that the east-west HSAT was the worst for boosting energy whereas the north-south HSAT significantly boosted efficiency by about 36%.
 - **Vertical Single Axis Tracker:** Vertical single axis trackers (VSATs) have a vertical rotating axis in relation to the earth. Throughout the day, these trackers move in a clockwise direction from east to west. Lorenzo created a single vertical axis for the tracking of photovoltaic installations. When compared to inclined static panels, vertical single axis tracking, also known as azimuth tracking, can provide up to 40% higher energy gain. The design of the VSAT solar facility is the topic of this research project. The causes of shadowing in the E-W and N-S directions, as well as the solutions, were thoroughly addressed. The findings made it quite evident that VSAT increased energy gain by almost 40% annually.

- **Tilted Single Axis Tracker:** The term “tilted single axis tracker” refers to a tracker with rotational axes that are both horizontal and vertical. In order to lower the wind profile and lower the elevated end height, tracker tilt angles are frequently restricted. A module sweeps a rotationally symmetric cylinder around the axis of rotations as it tracks.
 - **Polar Aligned Single Axis Tracker:** The typical technique for erecting a telescope support structure is well recognised in science. The polar star is aligned with the one axis that is inclined. Consequently, it is known as a polar aligned single axis tracker (18).
2. **Dual Axis Tracker:** In dual axis trackers, each of the two degrees of freedom serves as an axis of rotation. A main axis is an axis that is fixed with regard to the earth. The secondary axis is the axis that refers to the primary axis.
- **Tip – Tilt Dual Axis Tracker:** The panel array of a tip-tilt dual axis tracker is positioned on the top of a pole, hence the name. Typically, the array is rotated around the pole’s top to produce the east-west movement. The azimuth vertical axis is permanent, preventing the cabling from being twisted around the pole, which gives the payload connection to ground-mounted equipment a significant deal of flexibility. By minimizing up-sun shading, tip-tilt trackers can increase the amount of electricity being captured overall.
 - **Alzimuth Dual Axis Tracker:** With its secondary axis (elevation axis) normal to the primary axis and its primary axis (azimuth axis) vertical to the ground, an azimuth-altitude dual axis tracker can measure both azimuth and altitude. While the system’s operation is comparable to tip-tilt systems, the manner the array is rotated for daily tracking is different. As opposed to spinning the array around the top of the pole, they employ a sizable ring that is anchored to the ground and has the array mounted on a series of rollers.

The benefit of this design is the improved resolution of the solar sensor due to the closer arrangement of photosensitive arrays. According to the results, the system followed the sun’s focal point with a location precision of less than 0.3 mm and a tracking angle precision of 0.1°. There is a refinement of a nanowatt-powered dual-axis solar tracking device on a small scale. The solar module was positioned first in any given direction, and the PV array had to look for and halt at the solar cell's highest current gain. Every 30 minutes from 6:00 am to 8:00 pm, the process was repeated. For current, voltage, and power, the data were measured in these positions. The motors are managed by an open loop control. To investigate how voltage-through systems respond to inputs such as temperature, power output, and energy yield, a theoretical model was put into practice. The gadget, known as double sun technology, was built by fusing a dual axis system with a typical crystalline Si-module. According to the findings, twin sun technology improved efficiency by almost 86% when compared to fixed panels. A parabolic solar cooker that automatically tracks the sun on two axes. Standing in the sun for hours to gain frequent tracking and facing the concentrated solar cooker was eliminated by the solar cooker with automatic two

axes. The findings of the continuous test, which was conducted over three days from 8:30 to 16:30 h in the year 2008, revealed that on normal summer days, the water temperature within the cooker's tube reached 90 °C while the highest ambient temperature recorded was 36 °C. a review of the position control for a dual-axis sun tracker for a photovoltaic system. Without the use of solar sensors, a sun tracker was presented in this work. Two motors were used to adjust the orientation of the solar panels in both the horizontal and vertical orientations in order to monitor the sun. A microprocessor was in charge of controlling these motors. The nonlinear equations were solved by sliding mode control. According to the simulation's findings, tracking increases efficiency by about 40% compared to fixed panels. A bi-directional solar tracking device that can rotate in both azimuth and altitude directions was designed and built. Intensity and wavelength of solar light were discussed in detail as the two elements that affect power output. The results showed that the tracker's efficiency is significantly higher than that of a fixed panel and that its overall cost is relatively small. An improvement in the efficiency of parabolic trough collectors using a two-axis sun tracking technology. Two axes of rotation towards the sun are employed with a parabolic trough. According to the findings, parabolic collectors increase energy more than flat collectors. The best angle for the single axis tracker to provide maximum energy output for the full year was predicted using sophisticated software models that calculated the sun's shift in path throughout the year. The best angle was predicted using two modelling programmes. Five panels were employed in a single axis to track azimuthally during the experiment at tilt angles of 20, 25, 32, 40, and 50 degrees (latitude). A fixed control panel with its latitude tilted to the south made up the final panel. A higher inclined panel (50°) will produce more electricity throughout the year compared to PV Watts' modelling, which proposes a 32° tilt, according to the results of the one-year study (19).

VI. FLOATING SOLAR FARMS

Utilising both marine and renewable energy technologies, it is an eco-friendly method of producing electricity. In a dam or reservoir, for example, solar panels are made to float on the water's surface. Wires beneath the water carry electricity to a transmission tower. A floating solar power plant is made up of a solar module, a buoyancy body, and anti-rust material. These components also include the vertical and horizontal frames, the inspection footrest, and the module mount assembly. The solar panel must to have passed the drinking water test and be resistant to humidity, lead, dust, and the effects of brief water jets. Polyethylene, which can support 2.5 times its weight, is used to build the buoyancy body. Electricity is being captured by floating solar farms, sometimes known as floating photovoltaics or "floatovoltaics," in locations where no other power plants have gone. The sole difference between a solar farm on land and a floating solar array is that the latter is located in water.

Solar farms are significantly advancing clean energy access. Land has historically made the most logistical sense. However, there is a counterargument: why limit solar's potential by enclosing it on land? For a certain solar farm, water might be a superior option for a number of reasons. To start, getting land for a project isn't always feasible. Floating photovoltaics can provide a solution in areas where land is scarce and needs to be set aside for residences and other constructions. Because solar development may prevent the land from

being used for more practical purposes, such as agriculture, construction, or simply adding to the natural scenery, people aren't always excited about solar development, even in locations where there are plenty of available lands. The construction of a solar farm so near to homes is not always well received by the neighborhood. Almost all floating solar farms right now are situated on man-made bodies of water such reservoirs, ponds for storing wastewater, and ponds used for agricultural irrigation. Although man-made reservoirs offer benefits, natural bodies of water also have potential for floatovoltaic growth. Because they were formed by humans, man-made bodies of water are more likely to be governed, have already been built, and have roads. As a result, installation and maintenance are more practical and economical.



Figure 3: Floating PV System
Source: Google Images

Because they don't need any ground space, floating solar panels have one of the biggest advantages. The bulk of these solar panel installations can be installed on bodies of water, including hydropower dam reservoirs, sewage treatment ponds, or drinking water reservoirs, where there is currently an open space. Instead of erecting solar panels on sunny property that might later be used for something else, this will enable landowners to utilize a location that might otherwise go unused. The removal of trees and clearing of forests, which is a regular practice for larger solar panel installations, is also avoided when installing solar panels over open water. Additionally, the necessity for tree removal and forest clearing, which is a usual practice for larger solar panel installations, is eliminated when installing solar panels on open water. Solar panels are durable and resistant to high temperatures. Lower power outputs are the result of increased temperatures, just like with other devices. For property owners who want to install solar panels in a hot, sunny area, the efficiency of a solar panel declines as the temperature rises. The installation of floating solar panels will likely boost efficiency in hot climates since the bodies of water where they are housed will help to cool the solar-powered devices (20).

VII. SPACE BASED SOLAR ENERGY

The idea of gathering solar energy in space using solar power satellites and transferring it to Earth is known as space-based solar power. Its benefits include the potential for very little night, a higher collection of energy due to a lack of reflection and absorption by the environment, and a better ability to orient toward the Sun. Microwaves, for example, can be sent through the atmosphere to receivers on the Earth's surface via space-based solar power systems, which transform sunlight into another type of energy.

Satellite-based solar panels would be able to gather and transmit significantly more energy than terrestrial solar panels because there are no clouds, atmosphere, or nights in space. Energy-transmitting satellites with solar panels gather continuous, high-intensity solar radiation by reflecting massive amounts of it onto smaller solar collectors using enormous mirrors. Then, in a safe and controlled manner, this radiation is wirelessly delivered to Earth as either a microwave or laser beam (21).

VIII. ADVANCEMENTS IN SOLAR MANUFACTURING

Significant improvements had been made in several areas of solar production. The effectiveness of solar cells has been a focus of research. To do this, new materials must be created, such as dye-sensitized solar cells, perovskite solar cells, and organic solar cells. They have demonstrated considerable promise for increasing efficiency levels above those of conventional silicon-based cells.

Due to their high efficiency and low cost, perovskite solar cells are poised to be a game-changing element in next-generation photovoltaic technology. According to published studies, the shape and crystalline quality of the perovskite layers have a significant impact on how well they convert energy. Rapid production of perovskite solar modules on a wide scale is the goal of recent advancements. These most recent developments may increase PSCs' competitiveness in photovoltaics and open the door to their commercialization (22).

Organic solar cells (OSCs) have the potential to replace current solar cells in various applications because of their low price, light weight, semitransparency, outstanding adaptability, and vast manufacturing area. The OSC device's efficiency has increased by more than 20% thus far. An significant aspect impacting the device's performance is the optical band gap between the lowest unoccupied molecular orbital (LUMO) level and the highest occupied molecular orbital (HOMO) level. Because selenophene, an aromatic pentacyclic thiophene derivative, is easily polarized and has a very low LUMO energy level, the optical band gap can be narrowed. Additionally, an intermolecular bond can be created between the selenium atoms in selenophene and additional oxygen or sulfur atoms (23).

An effective photovoltaic technique for powering electronic devices like wireless sensors with indoor light is dye-sensitized solar cells (DSSCs). Their potential for affordable interior photovoltaics is highlighted by their low cost and abundant supply of materials, as well as their ability to be produced as thin and lightweight flexible solar modules. Their production processes, however, need to be scaled up to industrial manufacture with high photovoltaic efficiency and performance stability in normal interior environments. The solar sector is dynamic, and new developments and discoveries keep happening (24).

IX. HYBRID SOLAR SYSTEMS

When your solar panels are part of a hybrid system, they are still hooked up to the grid's power cables and have a backup battery system to store extra energy. Solar panels use an inverter to convert the solar energy they absorb into useful electricity. Electricity either travels to your house, your batteries, or the grid from that point.

You will always have power with a hybrid solar system, which is an advantage. The extra energy that your solar panels produce but that your home does not utilize will be saved in the backup battery. Then, when the sun is not shining, you will have power from this battery during the night, power outages, or bad weather. If you use a hybrid solar system (25)



Figure 4: Hybrid Solar System Powering our Home
<https://www.solarreviews.com/blog/hybrid-solar-systems>

X. SOLAR MATERIALS AND COATINGS

We already know that the irradiance and spectral composition of the Sun, as well as component performances, are essential to photovoltaic (PV) systems. However, the installation location and environmental factors also have a significant impact on the output power, which can change system performance. One of the problems is dust buildup on PV panels, which is underestimated yet can negatively impact PV facilities by reducing output power. It becomes critically vital to provide a coating with appropriate qualities to reliably and persistently remove dust from surfaces.

The best anti-dust coating must fulfill few criteria before a full launch such as being highly transparent in the visible range, having a longer lifespan, lower costs for mass production, and being non-toxic and feasible for large-scale fabrication.

- 1. Anti-Dust Coating:** The output power of PV glass modules is dramatically decreased by dust buildup. Determining anti-soiling and anti-reflection coatings has thus been a focus of the PV industry. However, relatively few experimental studies have documented these layers over longer testing periods that took into account natural sandstorms and other cleaning techniques.
- 2. Methods of Using Hydrophobic and Hydrophilic Coatings to Stop Soiling:** In contrast to a hydrophilic surface, which allows water molecules to spread out and wash away dust particles, a hydrophobic surface allows water to collect on the module glass surface and use kinetic energy to clear up the accumulated dust particles. The best surface to prevent soiling must be chosen based only on environmental considerations. Due to its capacity to reject

both dust particles and organic molecules in drier environments, hydrophobic surfaces have drawn a lot of interest, whereas hydrophilic surfaces have been used in places with significant rainfall.

In this method, the solvent evaporates to leave a coating of porous silica on the glass panel. Numerous hydroxyl groups found in this silica layer aid in the adsorption of water molecules on the surface.

- 3. Adhesion Force Reduction in the SHP Coating:** For both super-hydrophilic and super-hydrophobic surfaces, the van der Waals force between the dust particle and surface diminishes as surface roughness increases. While experimental measurement verifies that the force is somewhat less than that of SP surfaces, theoretical computation indicates that SPH surface adhesion is 30% higher than that of SP surfaces. Surface roughness is crucial in determining the relationship between adhesion force and the coated substrate, as shown by both approaches (26).

XI. SYNERGY AND INTEGRATION

The synergistic fusion of PV and solar thermal technology is one of the solar energy industry's most promising trends. The benefits of both strategies are combined in hybrid solar systems, which concurrently produce power and heat. By improving system efficiency, such integration expands the utility and economic viability of solar energy. Ground breaking ideas like solar-powered desalination, effective space heating and cooling, and grid stabilization through combined energy and heat generation are the result of innovations in hybrid systems.

XII. CHALLENGES AND FUTURE PROSPECTS

While solar energy technology is developing, there are still obstacles to overcome. To ensure a smooth transition to a solar-powered future, concerns including intermittency, energy storage, and scalability must be addressed. However, it cannot be denied that advances in solar energy technologies hold great promise. Solar energy has the potential to become the mainstay of a sustainable energy ecosystem, lowering greenhouse gas emissions and decreasing the effects of climate change, with continued study and development.

A monument to human creativity and the pressing need for sustainable energy solutions, solar energy's development from its modest origins to its present degree of innovation. In our drive to capture the sun's limitless energy and open the door to a greener, more sustainable future, advancements like photovoltaics and solar thermal systems, as well as the synergistic integration of both, provide a glimmer of hope.

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