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Solar Energy: Our Future for Sustainable Energy

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Abstract

Due to both population growth and technical developments, the global need for energy is rapidly increasing. The key to meeting future energy demands is selecting a sustainable energy source that is reliable, cost-effective, and long-term. Among other renewable energy sources (RESs), solar power offers great promise as a long-term solution to the energy dilemma because it is both affordable and environmentally friendly. Because of the huge need for energy, the scarcity of fossil fuels, and the exorbitant prices of alternative energy sources, the solar business is progressively expanding worldwide. Research into its rapid expansion was so intense and aggressive that it has now transformed into a tool to improve emerging nations' economic standing and provide for the lives of many poor people. When compared to other RESs, solar power clearly stands head and shoulders above the competition in terms of future global energy supply due to its superior accessibility, affordability, capacity, and efficiency.

Keywords: Concentrating solar thermal, photovoltaic, solar heating and cooling

1. Introduction

Rising populations and more advanced manufacturing processes are driving up global energy demand. There has been a two-billion-person increase in the world's population in the span of a single generation, and the emerging world is mostly to blame. One of the least pressing global concerns in the 21st century is preventing an energy disaster. Consequently, the need for energy is growing at a rapid pace to accommodate the expanding global population. When it comes to expanding their influence over the world, many nations have different plans, objectives, programs, and hierarchies in place. Due to population growth and development activities, resources across the world are becoming scarcer [1]–[3]. People lack access to enough energy for a variety of reasons, such as a nation's growth profile, its residents' economic standing, and the nature of its technical developments. The burning of readily available fossil fuels results in the production of several gases that severely harm the environment. Due to their rapid population growth and need for economic development to become economically viable, developing countries are currently under pressure to hunt for energy sources [4]–[6].

Since there is a proportionate relationship between the two, rising economic growth leads to an increase in energy consumption. Even though several strategies for increasing the amount of energy that can be produced have been proposed, a significant number of people in developing nations continue to live in areas that do not have access to power. The introduction of non-renewable energy sources, which are limited in quantity and eventually run out, would not guarantee that current levels of energy demand will be met [7]. It should be possible for all countries to make use of the energy-recovery resources available to them in order to build ecosystems that will sustain human life on the planet for an extremely extended period of time. It is not currently practiced correctly to carry out a task of this nature due to the fact that many nations depend more heavily on non-renewable energy sources than on renewable energy sources (RES). It is a well-known fact that many contentious disputes between nations frequently result in serious catastrophe. This is due to the fact that powerful parties frequently travel to places that contain substantial amounts of fossil fuels. In addition, prolonged reliance on energy sources that do not replenish themselves has the potential to induce climate change, which in turn may result in major natural disasters that inflict damage to the ecosystems found around the earth. Therefore, choose energy sources that are less harmful to the environment is of the utmost importance for the sake of the planet of the future [8].

According to this point of view, it is essential to take into account environmentally friendly RES such as solar energy, wind energy, hydropower, and geothermal energy [9]. Solar power, on the other hand, has a number of advantages that make it a strong contender for the role of energy source of the future. To begin, the sun is responsible for the emission of solar energy at a rate of 3.8 x 10^{23} kW, of which the earth absorbs around 1.8 x 10^{14} kW. Solar power is by far the most accessible and abundant form of renewable energy [10]. The sun provides the world with a multitude of forms of energy, including light and heat, which are absorbed by the globe. The vast majority of this energy is dissipated as it travels across space due to the cloud's ability to absorb, reflect, and disperse light. Studies indicate that solar energy, which is a source of energy that is naturally abundant and does not incur any costs, has the potential to adequately satisfy the energy requirements of the entire planet [11]. It is a feasible source of energy in the globe due to the facts that it cannot run out and that it has a better production efficiency than other energy sources [12]. The dispersion and intensity of solar radiation are two key factors that have a significant impact on the efficiency of the photovoltaic (PV) solar sector. Both of these factors are very different between countries. The global horizontal irradiation is presented in a clear and concise manner in Fig. 1. Because of the extensive amount of time that the sun shines each year in Asia, the continent's countries have a greater potential than those of other temperate regions to absorb solar radiation [13]. Solar radiation is a naturally occurring resource that is plentiful in many countries, particularly in developing countries [14]. For instance, the average daily solar radiation in Sri Lanka is about 15-20 $MJ/m^2/day$ (4.2–5.6 $kWh/m^2/day$) [15]. Third, the utilization of solar energy and the monitoring of its impacts have no adverse consequences on ecosystems. Ecosystems are places where the natural balance is preserved for the benefit of living things. The mining and extraction of fossil fuels causes the destruction of ecosystems, which in turn disrupts the natural order [16].

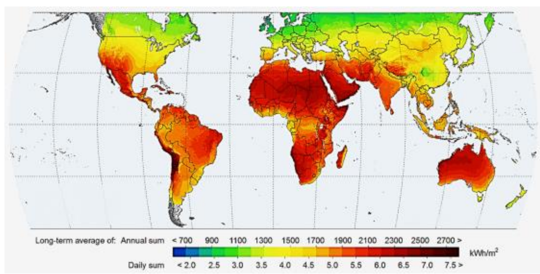


Fig. 1 Maps of global horizontal irradiation [17]

Solar energy can be successfully utilized in homes, businesses, and even village systems due to the fact that it is easily available and can be implemented with relative ease. In addition, the growing dependence of the world's population on fossil fuels for the recovery of energy in order to carry out a wide variety of activities has generated an international quest for solar energy. Utilizing this technology in an appropriate manner would be the most effective course of action for the future world to take in order to avert unforeseen ramifications that would emerge from the energy problem. At this time, a great number of research are being carried out with the purpose of enhancing the effectiveness of the solar industry in order to make the world a more energy-productive place in the future [18]. It has been suggested that these reserves will exhaust in 2300 as a result of rising energy demand. However, because to a rise in energy consumption from 1980 to 2010, its use has already led to large CO_2 emissions, as seen in Fig. 2. Fig. 3 shows that fuel energy is developing substantially. In order to meet the rising demand, RES are therefore required. The evolution of solar energy is evident. Due of its potential for energy recovery. As shown in Fig. 4, solar PV, concentrating solar panels (CSP), and solar heaters were reported to have the highest yearly growth rates in 2013 when compared to other RES. Solar PV has the best growth rate of all solar technologies in 2013. Ever since extensive development in the production of solar cells was first noted. As a result, this essay aims to present a comprehensive, fundamental understanding of solar energy for the future world with logical justification. The use of solar energy, the world's energy situation, as well as obstacles to such an industry, have all been comprehensively explored [19], [20]. The solar industry and its importance for a future world that is energy-wise, sustainable, and low in emissions are easily understood by readers of this study.

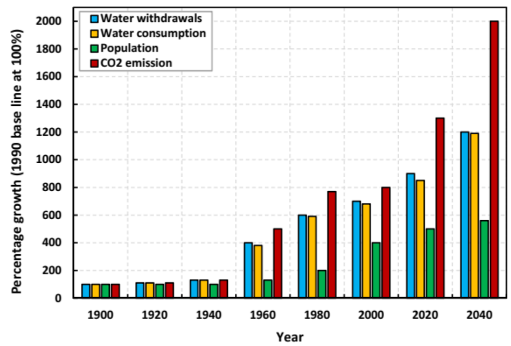


Fig. 2 Rate of increase, from 1900 (baseline at 100%), in water, population, and carbon dioxide emissions [21]

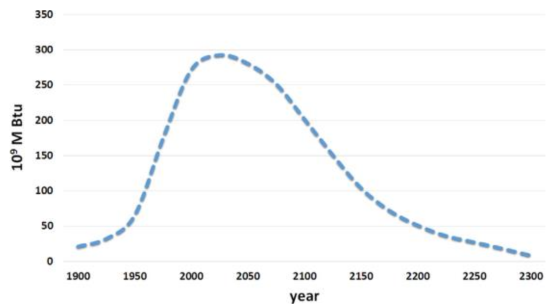


Fig. 3 World fossil fuel energy [22]

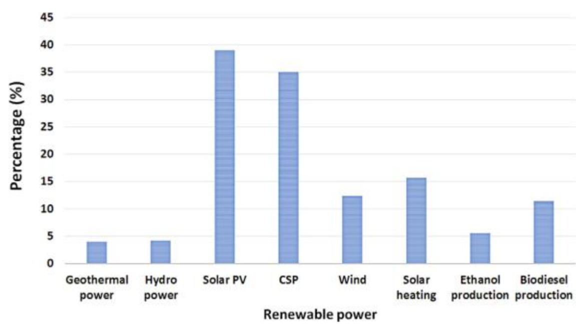


Fig. 4 Annual growth rate of renewable energy capacity in 2013 [23]

2. Highlights of research works done to upgrade solar industry

The three main types of solar energy systems are PV, CSP, and solar heating and cooling (SHC). PV systems directly convert light into electricity, while CSP and SHC systems use the sun's heat to power large electric turbines. These are the three main methods for converting solar radiation into usable energy.

2.1 Photovoltaic (PV) systems

Devices known as photovoltaic, or PV, transform the light from the sun directly into electrical energy [24], [25]. The amount of sunlight that is available has a direct bearing on the total amount of energy that can be generated. In this way, for instance, PV systems are able to generate electricity even in the winter and even when the weather is gloomy, albeit at a lower rate. In the context of PV systems, natural cycles therefore have three aspects. Although PV devices working along the equator have, in principle, a nearly constant exploitable potential throughout the year, the potential for PV power production varies seasonally, with a peak in the summer, much as it does with a great number of other forms of renewable energy technology. Second, the generation of energy is subject to diurnal fluctuations, with its highest point being in the middle of the day. Last but not least, variations in the immediate weather conditions, like as cloud cover and the amount of precipitation, have an effect on the total amount of electricity that may be gathered from the interior [26]–[31]. Table 1 outlines both the benefits and drawbacks of using this technology.

Table 1 Strengths and weakness of PV energy systems

Strengths	Weaknesses
The state of technology is at a mature stage. The power output warranties from PV panels now routinely last 25 years, demonstrating their extended lifespan and good reliability.	Storage and backup are usually needed because the amount of sunlight changes and power production stops at night.
Fully autonomous operation requiring minimal human intervention	Because sunlight levels change and power production stops at night, storage and backup are generally needed.
Gasoline is not necessary (there will be no extra expenses for gasoline or delivery logistics).	High costs of capital or beginning investment
Due to its modular design, PV systems can be customized to suit a wide range of sizes.	A certain amount of silicon for PV solar cells
Minimal harm to the environment as compared to more traditional energy sources	How much energy is used to make silicon for PV solar cells?
The solar system is a visible symbol of great care, concern, and dedication to the environment.	It is important to have places to recycle batteries and ways to collect them.
The consumer feels less of a pinch as the cost of alternative energy sources goes up.	Some photovoltaic panels use harmful ingredients.

Australia and South Korea have a slightly higher prevalence of off-grid solar power installations [32]. Connected to the electrical grid, almost 90% of U.S. solar power systems and 99% of European systems generate electricity. Solar photovoltaic systems seldom make use of battery storage. When investments in storage solutions become financially feasible for small systems and the government starts to incentivize distributed energy storage, this might change [33]. Most residential solar arrays are rack-mounted on rooftops rather than integrated into the structure's exterior or roof, the latter of which is a far more costly choice. Rather than investing in costly tracking technology, utility-scale solar power plants often use ground-mounted solar panels angled at a set angle. While thin film has witnessed a decline in its market share, crystalline silicon remains the primary material utilized in the fabrication of 90% of the world's solar modules [33], [34]. Nearly 70% of the world's solar cells and modules are made in China and Taiwan, whereas only 5% are made in Europe and the US [33]. While large-scale solar power stations are becoming increasingly popular, investors are placing more emphasis on cost-effectiveness and smaller rooftop systems are also experiencing rapid growth. This is due to the fact that new installations are moving away from Europe and towards sunnier regions, like the Sunbelt in the US, where investors are less against ground-mounted solar farms [32]. Despite a clear tendency towards utility-scale systems, this remains the case.

The price of photovoltaics has been steadily going down over the past few years [28]–[30], driven by technological advancements as well as increases in manufacturing scale and sophistication. Several million PV systems may be found all over the world, the majority of which are located in Europe (there are 1.4 million PV systems in Germany alone) and North America (440,000 PV systems in the United States alone) [32]. Since 2004, the energy conversion efficiency of a standard solar module has grown from 15 to 20 percent [32], and the amount of energy that is required for the production of a photovoltaic system is recouped in around two years. The so-called energy payback time can be reduced to one year or less in places that receive an extraordinarily high amount of sunlight, or when thin-film technology is utilized [32]. In many countries, the installation of PV systems has been considerably boosted by net metering and other financial incentives, such as preferential feed-in prices for solar-generated electricity [38], [39].

As of the year 2015, the rapidly expanding global PV market is swiftly reaching the record of 200 GW, which is approximately 40 times the capacity that was installed in 2006. At the moment, these systems are responsible for approximately one percent of the total electricity generation worldwide. United States, China, and Japan are now the leading installers of PV systems in terms of capacity; however, Europe is home to installations accounting for fifty percent of the world's total PV capacity. Germany and Italy both meet between seven and eight percent of their household electricity needs with PV solar panels. According to projections made by the International Energy Agency (IEA), solar energy would overtake all other forms of generation of electricity by the year 2050, with solar photovoltaics and concentrated solar thermal accounting for 16% and 11% of the worldwide demand for power, respectively [7].

During the 1980s and 1990s, when photovoltaic technology was still very expensive and a pure niche market of small-scale applications, these types of systems were the most popular type of installation [40], [41]. They were only economically viable in areas where there was no access to an existing electrical grid. While new stand-alone systems are still being constructed in various parts of the world, the contribution that these systems provide to the total solar capacity that has been installed is declining. Off-grid installations currently constitute one percent of Europe's total installed capacity. They make up approximately 10 percent of the population in the United States. Off-grid systems are still widely used in Australia and South Korea, in addition to a great number of developing nations.

2.1.1. Concentrator photovoltaics (CPV)

Concentrator photovoltaics (CPV) and high concentrator photovoltaics (HCPV) systems utilize optical lenses or curved mirrors to focus the sun's rays onto solar cells that are very small yet have a high conversion rate. CPV systems typically make use of sun trackers and cooling systems in addition to concentrating optics, making them significantly more expensive. HCPV systems, in particular, are optimized for use in areas with high solar irradiation. These systems may concentrate sunlight by up to 400 times or more, and their efficiencies of 24–28 percent are higher than that of standard systems. Several other configurations of systems are commercially available, but their use is not very widespread. On the other hand, there is continual research and development being done [32].

CPV is frequently mistaken with CSP, which does not utilize photovoltaics. Both technologies are most effective in areas that get a lot of sunlight, which puts them in direct competition with one another.

2.1.2. Hybrid

In a hybrid system, photovoltaic cells are combined with different types of generators, most commonly a diesel generator as shown in Fig. 5. The other type of generation may be one that is capable of modulating the amount of power produced in response to changes in demand. Nevertheless, the utilization of more than one kind of renewable energy, such as wind, is possible. The generation of electricity by photovoltaics helps to cut down on the use of fuels that aren't renewable. Islands are the most common places to find hybrid energy systems. Notable instances include the island of Pellworm in Germany and the island of Kythnos in Greece (both of which are combined with wind) [42]. The fuel that was used in the Kythnos plant has been cut back by 11.2% [42].

A case study that was carried out in seven different nations in 2015 came to the conclusion that hybridizing mini-grids and isolated grids is the most effective way to lower the costs of generating electricity. Nevertheless, the costs of financing such hybrids are of the utmost importance and are largely determined by the ownership structure of the power plant. According to the findings of the study, the economic benefits of cost reductions for non-public utilities, such as independent power producers, were found to be minor or even negative [42]. Cost reductions for publicly held utilities could have a major impact.

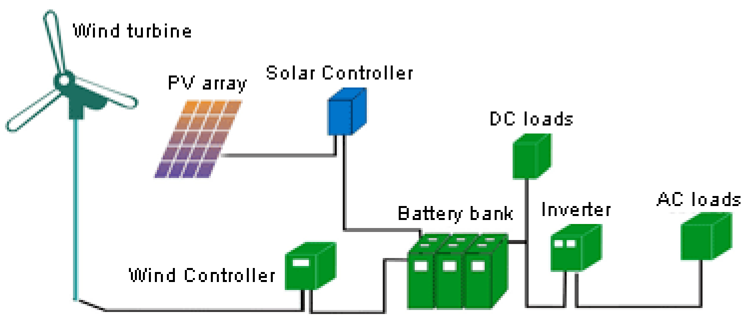


Fig. 5 A wind-solar PV hybrid system

Work has also been done indicating that the PV penetration limit in the United States can be raised by establishing a distributed network of PV and combined heat and power (CHP) hybrid systems. This work has been presented at conferences and presented in academic journals [42]. The temporal distribution of solar flux, electrical and heating requirements for representative single-family homes in the United States were analysed, and the results make it abundantly clear that hybridizing CHP with PV can enable additional PV deployment over and above what is possible with a conventional centralized electric generation system. This hypothesis was validated by numerical simulations that made use of solar flux data collected on a per-second basis. The results of these simulations determined that the necessary battery backup for such a hybrid system could be provided by relatively compact and cost-effective battery systems [43]. In addition, big PV and CHP systems are feasible for use in academic buildings. These systems, which again offer backup for intermittent PV and reduce the amount of time that CHP is required to run, can be installed.

- Photovoltaic thermal hybrid solar collectors' systems (PVT) are able to convert solar radiation into both thermal and electrical energy. These systems are hybrids of photovoltaics and thermovoltaics. A solar PV module and a solar thermal collector are combined in this system in a manner that is complementary to one another.
- A concentrated photovoltaic thermal hybrid system, also known as a PVT system, functions in a similar manner. It utilizes concentrator photovoltaics rather than the more common photovoltaic technology and combines that with a solar thermal collector.
- The CPV/CSP system is a proposed unique solar hybrid system that combines the non-PV technology of CSP with the photovoltaic technology of concentrator photovoltaics.

• A photovoltaic diesel system is one that integrates a diesel generator with a solar system. Combinations with other forms of renewable energy are feasible, and one example of this is the use of wind turbines.

2.1.3. Floating solar arrays

Floating solar, also known as floating photovoltaics (FPV) and floatovoltaics, are solar panels that are mounted on a structure that floats on a body of water as shown in Fig. 6. This body of water is often a reservoir or a lake, such as drinking water reservoirs, quarry lakes, irrigation canals, or cleanup and tailing ponds. Floating solar can also be termed floatovoltaics [44], [45].

Fig. 6 Floating photovoltaic on an irrigation pond

In comparison to PV, these systems offer a number of benefits. It is possible that the cost of water surfaces is lower than the cost of land, and there may be less laws and regulations for buildings constructed on bodies of water that are not used for recreational purposes.

Unlike many solar plants that are located on land, floating arrays are typically hidden from public view, which makes them less of an eyesore. Because the water helps to cool the panels, they are able to attain higher efficiency than PV panels that are placed on land. It is possible for the panels to have a specific coating that will protect them against rust and corrosion.

Since 2016, there has been a significant expansion in the market for this renewable energy technology. Between the years 2007 and 2013, the first twenty plants, each with capacity of a few dozen kWp, were constructed [46]. The amount of power that was installed increased from 3 GW in 2020 to 13 GW in 2022, which was greater than the projection of 10 GW by 2025 [47]. The World Bank calculated that there are 6,600 major bodies of water that are appropriate for floating solar, and that these bodies of water have the potential to produce more than 4,000 GW of electricity if 10% of their surfaces were covered with solar panels [47]. When compared to ground-mounted systems, the costs of a floating system are around 10–20 percent greater [48].

2.2 Concentrated solar power (CSP) systems

Concentrated solar power systems create solar power by utilizing mirrors or lenses to concentrate a wide area of sunlight into a receiver [1]. Other names for these systems include concentrated solar power and concentrated solar thermal. The concentrated light is turned into heat (solar thermal energy), which then drives a heat engine (often a steam turbine) connected to an electrical power generator [49] or powers a thermochemical reaction [50]. This results in the generation of electricity. As of the year 2021, the total installed capacity of concentrated solar power around the globe had reached 6.8 gigawatts [51]. The United States National Renewable Energy Laboratory (NREL) has a comprehensive database of the current status of all CSP facilities across the world, including those that are in the process of being built, have been decommissioned, and are in operation. These details include the capacity of the power block, the kind of components that make up the power block, the number of hours that can be used to store thermal energy, and the sizes of the turbines. CSP is utilized in the production of electricity (sometimes referred to as solar thermoelectricity, which is typically produced through the use of steam). Mirrors or lenses along with tracking systems are used in concentrated solar technology systems. This focuses sunlight from a wider region onto a more contained space. After that, the focused light is converted into heat or used as a source of heat for a traditional power plant (solar thermoelectricity). The solar concentrators that are utilized in CSP systems are frequently put to work in the provision of industrial heating or cooling processes as well, such as in solar air conditioning.

There are four different optical types of concentrating technologies, and they are as follows: the parabolic trough, the dish, the concentrating linear Fresnel reflector, and the solar power tower. Dish and solar tower are examples of collector types that fall into the category of point focus, while linear focus collectors include the parabolic trough and concentrated linear Fresnel reflectors. Collectors with a linear focus can achieve concentration factors of up to 50 suns or higher, while collectors with a point focus can achieve concentration factors of up to 500 suns or higher. These solar concentrators, despite their ease of construction, fall significantly short of the maximal concentration that can be achieved theoretically. For instance, the concentration obtained by using a parabolic trough yields approximately one-third of the theoretical maximum for the design acceptance angle. This is the case even though the overall tolerances for the system remain the same. Getting closer to the theoretical maximum is possible through the utilization of more complex concentrators that are based on nonimaging optics.

Because of the unique ways in which each variety of concentrator tracks the sun and focuses light, the peak temperatures they achieve and the related thermodynamic efficiencies they achieve are each unique to that particular concentrator. New developments in CSP technology are causing systems to become increasingly efficient, and this trend is expected to continue [52].

2.2.1 Parabolic trough

A parabolic trough is a type of reflector that is constructed in the shape of a linear paraboloid and is used to focus light onto a receiver that is positioned along the focal line of the reflector as shown in **Fig. 7**. The receiver is a tube that is filled with a working fluid and is positioned such that it is parallel to the longitudinal focal line of the parabolic mirror. During the daylight hours, the reflector will move along a single axis in order to follow the path of the sun. After passing through the receiver, a working fluid, such as molten salt [53], is heated to temperatures ranging from 150 to 350 degrees Celsius (302 to 662 degrees Fahrenheit) and is then put to use as a heat source for a power production system [53]. The most advanced kind of CSP technology is now trough systems. Representative examples include the Solar Energy Generating Systems (SEGS) plants in California, which were the first commercial parabolic trough plants anywhere in the world; Acciona's Nevada Solar One, which is located near Boulder City, Nevada; Andasol, which was the first commercial parabolic trough plant in Europe; and the SSPS-DCS test facilities in Spain, which are operated by Plataforma Solar de Almera.

Fig. 7 Parabolic trough at a plant in Harper Lake, California

2.2.2 Enclosed trough

The design creates a glasshouse that functions like a greenhouse and encloses the solar thermal system within it. The glasshouse provides a protected environment that is capable of withstanding the factors that have the potential to negatively impair the solar thermal system's dependability and performance [54]. Mirrors that are bent to reflect the sun's rays and are lightweight are strung from the ceiling of the glasshouse using wires. A tracking mechanism on a single axis positions the mirrors so that they capture the maximum amount of available sunlight. The mirrors direct the sun's rays onto a stationary system of steel pipes [54]. These pipes are hanging from the construction of the glasshouse. When powerful solar radiation is directed into the pipe, water is transported along its entirety, where it is then heated to a boiling point to produce steam. By protecting the mirrors from the wind, not only are they able to reach higher temperature rates, but the dust that would otherwise accumulate on the mirrors is also prevented [54].

GlassPoint Solar, the business that developed the Enclosed Trough design, claims that its technology can produce heat for Enhanced Oil Recovery (EOR) for under $5 per 290 kWh (1,000,000 BTU) in sunny places, whereas other conventional solar thermal solutions cost between $10 and $12 per unit of energy [55].

2.2.3 Solar power tower

An array of dual-axis tracking reflectors, also known as heliostats, is what makes up a solar power tower. These reflectors direct the sun's rays toward a central receiver that sits atop the tower. The receiver holds a heat-transfer fluid, which may be made up of water-steam or molten salt. A solar power tower is identical to a circular Fresnel reflector from an optical point of view. The working fluid in the receiver is heated to temperatures ranging from 500 to 1000 degrees Celsius (773 to 1,273 kelvin or 932 to 1,832 degrees Fahrenheit), and it is then employed as a heat source for a system that generates electricity or stores energy [56]. One of the benefits of the solar tower is that individual reflectors can be modified rather than the entire structure. Although the development of power towers is not as far along as that of trough systems, power towers offer more efficiency and a more robust capacity for energy storage. There is also the possibility of using heliostats in a beam down tower application in order to heat the working fluid.

The Solar Two facility, located in Daggett, California, and the CESA-1 plant, located in Plataforma Solar de Almeria, Almeria, Spain, are the demonstration plants that are the most emblematic of their kind. Planta Solar 10 (PS10), located in Sanlucar la Mayor, Spain, holds the distinction of being the world's first commercial utility-scale solar power tower. There are three power towers at the 377 MW Ivanpah Solar Power Facility, which is located in the Mojave Desert. This facility was the largest CSP project in the world when it was built. Ivanpah was only able to produce 0.652 TWh (63%) of its energy from solar sources, while the remaining 0.388 TWh (37%) was accomplished by the combustion of natural gas [56].

In order to improve the effectiveness of the generation of electricity, supercritical carbon dioxide may be substituted for steam in the role of heat-transfer fluid. It is not possible to bring the temperature of the carbon dioxide in the compressor inlet down below its critical temperature due to the high temperatures that prevail in arid regions, which are often where solar power plants are situated. As a result, mixtures of supercritical carbon dioxide with higher critical temperatures are currently undergoing research.

2.2.4 Fresnel reflectors

Fresnel reflectors are constructed out of a large number of thin, flat mirror strips. Their primary use is to concentrate solar radiation onto tubes that contain working fluid [57]. It is possible to fit more reflective surface into the same amount of space occupied by a flat mirror than it is possible for a parabolic reflector, so that more of the available solar radiation may be collected using flat mirrors. Additionally, flat mirrors are far less expensive than parabolic reflectors. Fresnel reflectors are adaptable and can be utilized in CSPs of varying sizes.

Fresnel reflectors are sometimes considered to be an outdated technology that produces a lower quality output compared to other technologies. The fact that this model is more cost-effective than others with higher output ratings is the primary reason why some people choose to utilize it. Initial testing of several new types of Fresnel Reflectors with Ray Tracing capabilities has begun, and these reflectors have already demonstrated that they are capable of producing a higher output than the conventional model.

2.2.5 Dish Stirling

A Stirling or dish engine system is made up of a freestanding parabolic reflector that focuses light onto a receiver located at the focal point of the reflector. Along two axes, the reflector follows the path of the sun as shown in Fig. 8. In order to generate electricity, a Stirling engine first heats the working fluid in the receiver to temperatures between 250 and 700 degrees Celsius (482 and 1,292 degrees Fahrenheit). Systems using parabolic dishes have a high efficiency of converting sunlight into electricity (between 31% and 32%), and their modular design allows for easy expansion. These technologies are exemplified by the Stirling Energy Systems (SES), United Sun Systems (USS), and Science Applications International Corporation (SAIC) dishes located at the University of Nevada, Las Vegas, as well as the Big Dish located at the Australian National University in Canberra, Australia. On the chilly and sunny day of the 31st of January in 2008 at the National Solar Thermal Test Facility (NSTTF) in New Mexico, SES dishes at the facility achieved a world record for solar to electric efficiency by achieving a rate of 31.25%. Ripasso Energy, a Swedish company and the system's creator, reported that in 2015, their Dish Sterling system was being tested in the Kalahari Desert in South Africa, and the results revealed that the system had an efficiency of 34% [58]. Before it was purchased by United Sun Systems, the Stirling Dish power facility that was owned by SES and located in Maricopa, Arizona, was the largest of its kind anywhere in the globe. As a direct result of this, greater components of the project have been relocated to China in order to meet the enormous demand for electricity.

Fig. 8 A dish Stirling

The village of Adrano in Sicily was the site of an early plant. The United States saw the launch of its first solar electric generating system (SEGS) plants in 1984. In 1990, building of the last SEGS facility was completed. Between 1991 and 2005, no new concentrated solar power facilities were built anywhere in the globe. Among 2004 and 2013, the world's installed capacity of CSP expanded by about a factor of 10, with the past five years seeing annual increases of fifty percent or more. The expansion in the number of countries using CSP is largely responsible for this upsurge. Around 0.9 GW, or 36 percent, of the world's installed capacity was added in 2013. The overall capacity was therefore increased to almost 3.4 GW. In 2014, 925 MW of capacity was added, which was a record. However, this was then followed by a decline due to policy shifts, the worldwide economic downturn, and the rapid decline in solar cell prices. Regardless, by 2021 the total capacity had increased to 6,800 MW [51].

The potential and possible applications of concentrated solar power were explored in a study that was carried out by Greenpeace International, the European Solar Thermal Electricity Association, and the SolarPACES group of the International Energy Agency. According to the findings of the study, by 2050, concentrated solar power might meet as much as 25 percent of the world's need for energy. During that time span, the amount of money invested would rise from 2 billion euros all over the world to 92.5 billion euros. With more than 50 government-approved projects currently in the works, Spain is the undisputed leader in the field of concentrated solar power technology. In addition to this, it sells its technology on the international market, which helps to increase the sector's overall market share. Experts anticipate the most rapid expansion in regions such as Africa, Mexico, and the southwest of the United States. This is due to the fact that the technology functions most well in countries that receive a high amount of insolation (solar radiation). It is a sign that the thermal storage technologies that are based on nitrates (calcium, potassium, sodium, etc.) will make CSP plants more lucrative over time. Last but not least, the research pointed out that the technology behind CSP was getting better and that this would lead to a significant drop in price by the year 2050. It forecasted a reduction in cost to the range of 0.14–0.10 $/kWh, down from the current range of 0.23–0.15 $/kWh.

2.2.6 Solar water heating

Solar water heating systems can be utilized in rural healthcare facilities, hospitals, and even educational institutions (see Fig. 9). The water is heated, most of the time in a specialized collector, and then stored in a tank until it is needed. This is the basic function of the system. The heat is often collected into a heat transfer fluid, which subsequently transmits its heat to the water that is stored in the tank. Collectors are designed to collect heat in the most efficient and cost-effective manner possible. The flat plate and the evacuated tube collectors are the two most common types of collectors. For instance, using a straightforward flat plate solar collector to bring the temperature of 100 liters of water up by 40 degrees Celsius uses only around 2.5 square meters of collector space, but it saves approximately 10 kilograms of the wood fuel that would ordinarily be used to bring this quantity of water up to the desired temperature. The thermosiphon system, which makes use of the natural propensity of warm water to rise and cooled water to sink, is the most affordable technology that is now available. It is also the technology that can be installed with the least amount of difficulty. When the sun shines on the collector, it warms up the water that is contained within the flow tubes of the collector. This water will become lighter than the cold water that is stored in the solar storage tank that is positioned above the collector as it warms since it will expand slightly as it heats. After then, gravity is responsible for drawing the denser, colder water down from the tank and into the collector inlet. Because the cold water forces the heated water through the collector outlet and into the top of the tank, the water that is contained within the tank is heated as a result.

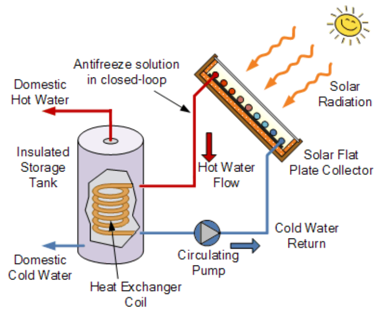


Fig. 9 flat plate solar collectors

2.2.7 Solar air heating

A solar air collector consists of two main parts: an absorber material that takes in radiation from the sun (which could or might not have a selective surface) and a conduction heat transfer mechanism that transfers this heat to the air as shown in Fig. 10. Air is heated and then directed into the building or the process area via ducts, depending on which one is needed to suit the heating demands of the space or the process. Similar to a standard forced-air furnace, solar thermal air systems distribute heat. In order for these systems to function, air is directed into ducts after passing over a surface that collects energy, allowing it to absorb the thermal energy from the sun. Streamlined and efficient collectors have several potential uses in HVAC and other industrial settings [59], [60].

There are many different ways to put solar air heating technologies to use, but one of them is finding a greener approach to generate thermal energy while simultaneously decreasing our reliance on traditional heat sources like fossil fuels. A few examples of the many uses for solar air heat systems include heating rooms, making greenhouse growth seasons last longer, preheating makeup air for ventilation, and supplying process heat. Solar co-generation involves combining solar thermal technology with P to increase system efficiency. This is achieved by drawing heat away from the PV collectors, which in turn cools the PV panels to increase their electrical output, while at the same time warming the air to heat the area. Improving the system's overall efficiency is the goal of all these actions.

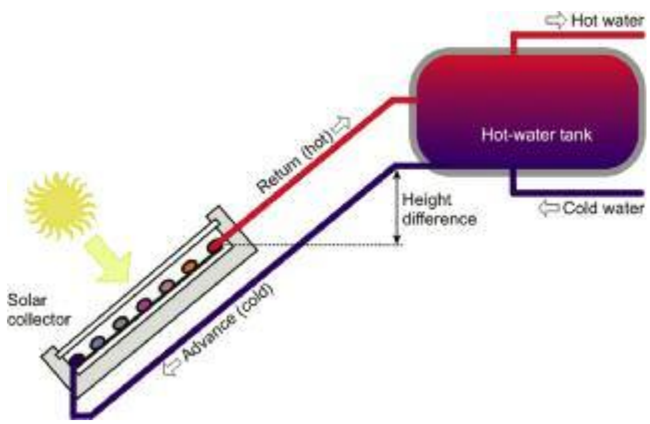


Fig. 10 A thermosiphon solar water heating system

2.2.8 Solar drying

Drying wood for use in building and wood fuels such as wood chips for burning can both benefit from the utilization of solar thermal energy. Solar energy is also put to use in the production of food. The drying of crops using solar energy is not only better for the environment, but also more cost effective and improves product quality. When it costs less money to create a product, that product may be offered for less money, which is to the benefit of both the customers and the sellers. In the field of solar drying, there are technologies such as ultra-low cost pumped transpired plate air collectors that are based on black textiles. using increasing the temperature while still enabling air to circulate and rid the product of moisture, solar thermal energy can be of assistance in the drying process of products such as wood chips and other forms of biomass as shown in Fig. 11. This can be accomplished using the procedure described above [61]. Table 2 and 3 provides an illustration of a comparison of several drying procedures.

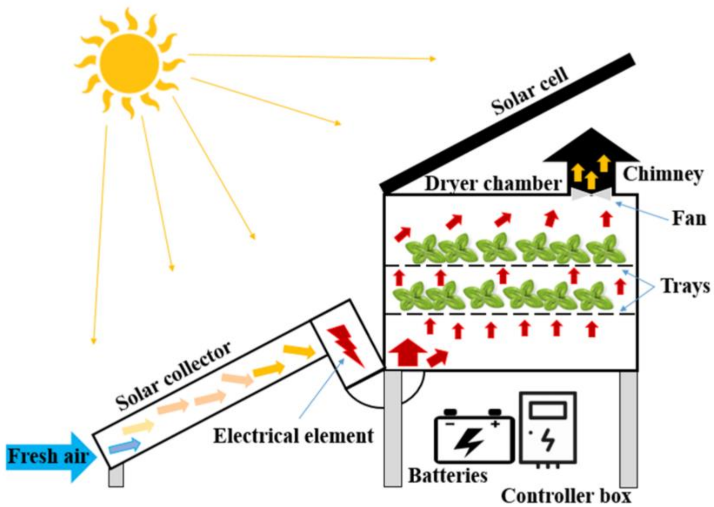
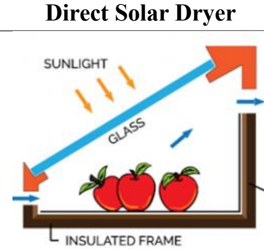
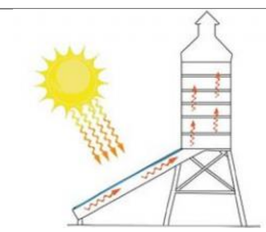


Fig. 11 A solar drying system

Table 2 Comparison of drying technologies

	Sun drying	Solar drying	Fuelled drying
Initial cost	None	Low	High
Operating cost	Low	Low	Medium
Temperature control	None	Poor	Good
Continuous operation	No	No	Yes
Speed of drying	Slow	Medium	Fast
Protection from pests	No	Yes	Yes

Table 3 Comparison of between direct and indirect drying technologies

	Direct Solar Dryer	Indirect
		
Operating Temperature	Medium temp. usage (45-78 C)	Medium temp. (45-75 C)
Scale of operation	Applicable in small to industrial scale	Better in small scale usage
Need of solar collector	No solar collector	Solar collector must
Types of commodities	Can also be used for products where direct solar contact is mandatory	Can also be used for products where direct solar contact is not mandatory
Performance in unfavourable weather	Operating even in unfavourable weather	Poor performance in unfavourable weather

2.2.9 Solar cookers

Cooking, drying, and pasteurizing can all be accomplished with the use of solar cookers. Cooking with the sun can save money on fuel costs, cut down on the need for fuel or firewood, and improve air quality by removing or minimizing a source of smoke in the kitchen.

The box cooker is the most basic form of solar cooker and was first constructed by Horace de Saussure in the year 1767. A box cooker is a simple type of slow cooker that consists of an insulated container with a see-through lid as shown in Fig. 12. These cookers may be used successfully even when the sky is partially cloudy and will normally attain temperatures between 50 and 100 degrees Celsius [62]–[64].

Concentrating solar cookers utilize reflectors to focus the sun's rays on a cooking vessel, which speeds up the cooking process. The flat plate, disc, and parabolic trough types are the reflector geometries that are used the most frequently. However, in order for these designs to perform correctly, they need to be exposed to direct light. The maximum temperature that they can reach is 350 degrees Celsius.

The solar bowl is a one-of-a-kind form of concentrating technology that is implemented at the Solar Kitchen in Auroville, India. The solar bowl is an alternative to the traditional tracking reflector and fixed receiver systems. Instead, it combines a spherical reflector that is fixed in place with a receiver that follows the focus of light as the Sun travels across the sky. The receiver of the solar bowl can reach temperatures of up to 150 degrees Celsius, which can be used to produce steam that assists in the preparation of 2,000 meals every day [62].

Scheffler reflectors are used in a number of different solar kitchens around India. This is yet another innovative form of concentration technology. In the year 1986, Wolfgang Scheffler was the first person to invent this technology. A parabolic dish with a single axis of tracking is called a Scheffler reflector. This type of reflector follows the daily path of the Sun. These reflectors have a flexible reflective surface that can change its curvature to accommodate seasonal shifts in the angle at which sunlight strikes it. This allows the reflectors to better reflect light. Scheffler reflectors have the advantage of having a fixed focal point which improves the ease of cooking and are able to reach temperatures of 450-650 °C [62]. The world's largest Scheffler reflector system is located in Abu Road, Rajasthan, India. It was constructed in 1999 by the Brahma Kumaris, and it has the capacity to prepare up to 35,000 meals each day. As of the beginning of 2008, over 2000 large cookers based on the Scheffler design had been constructed all over the world.

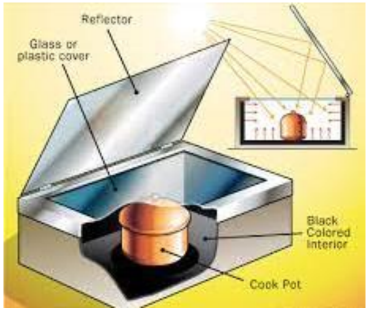


Fig. 12 A solar cooker system

2.2.10 Solar distillation

The method of producing drinkable water from a salty source through the use of sun distillation is known as solar enhanced distillation. It is possible to put it to use in regions where, for example, potable water is in short supply but brackish water, which refers to water that contains dissolved salts, is readily available. Stills that use solar energy to distill liquids typically offer a better return on investment for operations with lower production rates as shown in Fig. 13. In comparison to other technologies that have huge economies of scale, the costs rise significantly along with the amount of output that is produced [65].

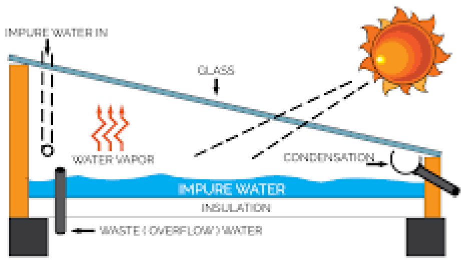


Fig. 13 A solar distillation system

2.3 Space application

The technology involved in spacecraft has recently gained a lot of popularity all around the world. In order to advance in such a sector, a lot of study is being done right now. The process of refuelling spacecraft is the most important factor to consider while developing space systems. The simulation process makes use of a wide variety of computer models. For instance, NASCAP-2K has the capability to model spacecraft charging for a wide variety of complex geometries and orbits [66]. Solar energy is employed to create an electrostatic discharge, which is the most significant consequence in the process of spacecraft altering. This discharge can take the shape of a bulk discharge or a surface discharge, depending on how it is created [54-65]. Because of the difficult nature of the technology and the environmental problems surrounding nuclear power sources in space craft technology, photovoltaic power sources have been successfully integrated into earth-orbiting space spacecraft that are in low earth geo synchronous orbits. Even for its trips in deep space, NASA plans to incorporate solar panels into its infrastructure.

3. Conclusion

This article provides a concise overview of solar energy for the future, covering topics such as the basics of photovoltaic technology, the global energy scenario, the driving forces and development trends, the most outstanding research in the field of solar power generation, photovoltaic thermal collectors, solar heaters, design improvements and sizing, materials for efficient light absorption to enhance the solar industry, and the industry's potential applications and obstacles. In order to make a substantial contribution to this field and ensure the world's energy efficiency in the future, this concise depiction is extremely helpful for decision makers, academics, researchers, and producers of solar systems.

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