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Solar Energy Technologies: A Complete review of the Solar system technologies

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Abstract: Due to the rapid rise in the need for energy, the use of fossil fuels is also increasing. It impacts the environment. The world is now searching for alternatives. Solar energy is one of the most promising, renewable, eco-friendly, green, and alternative energy sources. However, to supply enough energy, the technologies should be improved, and we have to find new technologies to increase solar energy production to fulfil the global energy demand. This study mainly focuses on the solar energy technologies that are now available worldwide and discusses the improvements and future views of those technologies: concentrated solar power technology and photovoltaic solar energy technology.

Keywords: Concentrated solar power, Solar energy, Solar photovoltaic energy, Renewable energy

1 INTRODUCTION

Renewable energy sources have been important for humans since the beginning of civilization. For centuries and in many ways, biomass has been used for heating, cooking, steam raising, power generation, hydropower, and wind energy for movement and later for electricity production. Renewable energy sources generally depend on energy flows through the Earth’s ecosystem from the insolation of the sun and the Earth's geothermal energy [1]. Renewable energy sources can often meet the present world energy demand, so their potential is enormous. They can enhance diversity in energy supply markets, secure long-term sustainable energy supplies, and reduce local and global atmospheric emissions. They can also provide commercially attractive options to meet specific needs for energy services (particularly in developing countries and rural areas), create new employment opportunities, and offer possibilities for local equipment manufacturing.

There are many renewable technologies. Although often commercially available, most are still at an early stage of development and not technically mature. They demand continuing research, development, and demonstration efforts. In addition, few renewable energy technologies can compete with conventional fuels on cost, except in some niche markets. However, substantial cost reductions can be achieved for most renewables, closing gaps and making them more competitive. That will require further technology development and market deployment—and boosting production capacities to mass production [1,2].

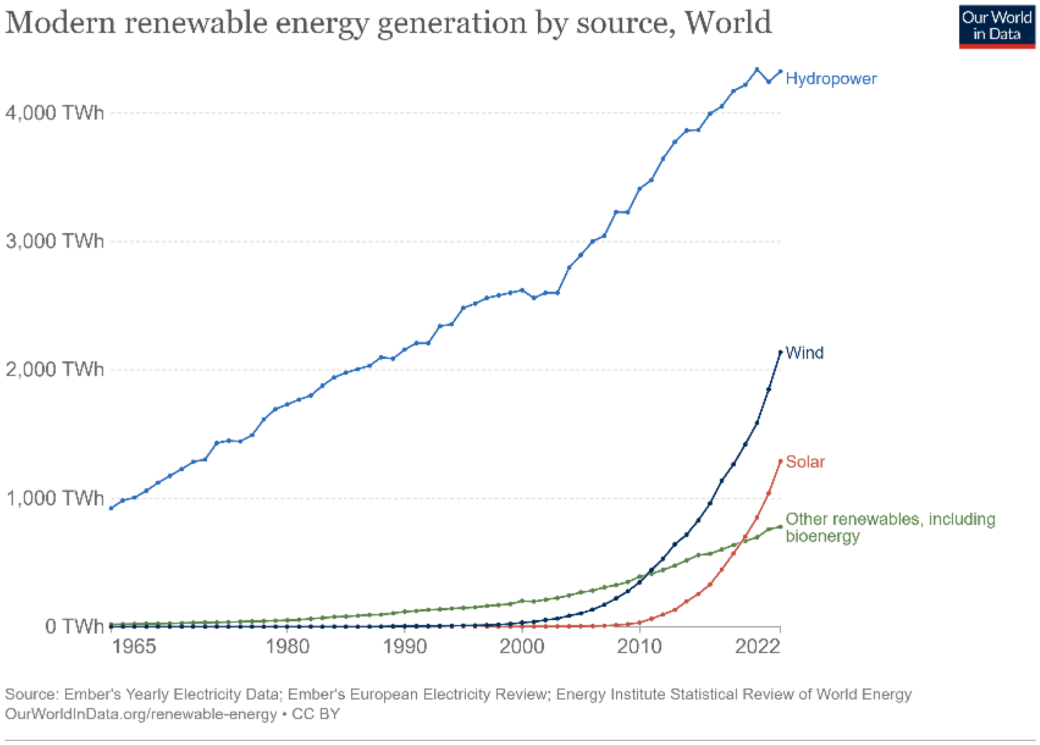


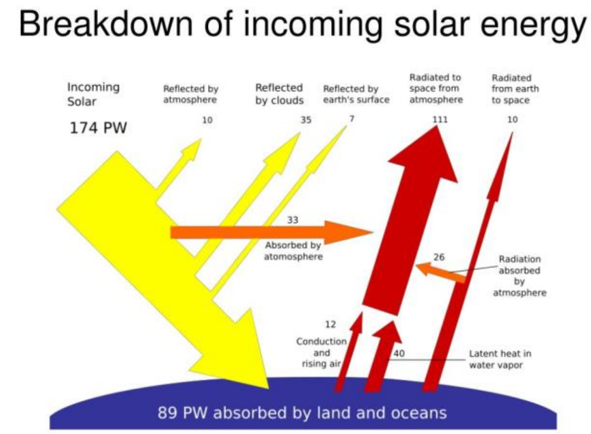
Fig 1: Modern renewable energy generation by source, World [67]

1.1 SOLAR ENERGY

Solar energy is the cleanest, most abundant renewable energy source available. The U.S. has some of the world's richest solar resources. Today's technology allows us to harness this resource in several ways, giving the public and commercial entities flexible ways to employ both the light and heat of the sun [3].

Solar energy is produced directly by the sun and collected elsewhere, usually the Earth. The sun creates its energy through a thermonuclear process that converts about 650,000,000 tons of hydrogen to helium every second. The process creates heat and electromagnetic radiation. The heat remains in the sun and maintains the thermonuclear reaction. Electromagnetic radiation (including visible, infrared, and ultraviolet) streams into space in all directions [4].

Only a tiny fraction of the total radiation produced reaches the Earth. The radiation that does reach the Earth is the indirect source of nearly every type of energy used today. The exceptions are geothermal energy, and nuclear fission and fusion. Even fossil fuels owe their origins to the sun; they were once living plants and animals dependent on the sun [4]. The quantity and fate of solar radiation striking the top of the Earth's atmosphere. 52 PW (1015 W) is reflected in space (or 30% of the total). Thus, in outer space, there is more solar energy available to be collected, which has prompted potential schemes to launch photovoltaic arrays into space as satellites, with which to capture the Sun's energy, which is then beamed back to Earth in the form of microwaves for terrestrial applications. With the Sun directly overhead at the top of the atmosphere, the radiation flux provides around 1.4 kW/m^2 energy, the ‘‘solar constant’’. Since the total amount of energy (oil, gas, coal, nuclear, hydro, everything) used on Earth by humans amounts to a power of 18 TW, at 174 PW, the amount of radiation striking the exposed hemisphere of the Earth amounts to around 10,000 times that. So, if we could capture even a tiny amount of that, the imminent energy crunch would thus be averted [5].



http://en.wikipedia.org/wiki/File:Breakdown_of_the_incoming_solar_energy.svg

Fig 2: Breakdown of the incoming solar energy [4]

Sunlight is composed of two parts - direct sunlight and diffuse sunlight. Solar radiation goes through the atmosphere and reaches the ground due to the atmosphere’s air molecules, water vapor, and dust. Solar radiation absorption, reflection, and scattering reduce radiation intensity and change the direction of radiation and radiation's spectral distribution. Therefore, the actual solar radiation reaching the ground is usually caused by the direct diffusion of two parts. Direct sunlight is the radiation directly from the sun, and the direction of the radiation has not been changed; diffusion is the reflection and scattering by the atmosphere changed after the direction of the solar radiation, which consists of three parts: the sun around the scattering (surface of the sun around the skylight), horizon circle scattering (horizon circle around the skylight or dark light), and other sky diffuse radiation. In addition, the non-horizontal plane also receives the reflection of radiation from the ground. Direct sunlight, diffuse and reflected sunlight shall be the sum of the total radio or global sunlight. It can rely on the lens or reflector to focus on direct sunlight. If the condenser rate is high, you can get high energy density but loss of diffuse sunlight. If the condenser rate is low, it can also condense parts of the solar diffuse sunlight. Diffuse sunlight has an extensive range of variation; when cloudless, it is 10% of the total sunlight. However, when the sky is covered with dark clouds and the sun cannot be seen, the total sunlight equals the diffuse sunlight. Therefore, the poly-type collector collects energy usually far higher than the non-poly-type collector. Reflected sunlight is generally 7 weak, but when there is snow-covered ground, the vertical reflection sunlight can be up to 40% of the total sunlight [4]. Humans rely on solar energy to survive, including all other forms of renewable energy (except for geothermal resources). Although the total amount of solar energy resources is ten thousand times the energy used by humans, the solar energy density is low, and it is influenced by location and season, which is a significant problem in the development and utilization of solar energy [6].

2. SOLAR ELECTRICAL ENERGY TECHNOLOGIES

2.1 SOLAR PHOTOVOLTAIC ENERGY TECHNOLOGY

Solar photovoltaic energy is nothing but directly converts sunlight into electricity using a concept based on the photovoltaic effect [7]. The term ‘‘photovoltaic’’ derives from the Greek φώζ (phos), meaning ‘‘light’’, and ‘‘voltaic’’, meaning electric, to honor the name of the Italian physicist Volta, after whom the volt is named. The photovoltaic effect was first recognized in 1839 by French physicist A.E. Becquerel. In 1883, Charles Fritts coated selenium with a skinny layer of gold, thus creating a PV device that was only around 1% efficient. Russel Ohl patented the modern junction semiconductor solar cell in 1946, which was discovered while working on a series of advances that would eventually lead to the development of the transistor. In 1954, workers at Bell Laboratories accidentally found that silicon doped with certain impurities was very sensitive to light, and Daryl Chapin, along with Bell Labs colleagues Calvin Fuller and Gerald Pearson, invented the first practical device for converting sunlight into useful electrical power, with a sunlight energy conversion efficiency of around 6%. The first spacecraft to use solar panels was the US satellite Vanguard 1, launched in March 1958 and fitted with solar cells made by Hoffman Electronics. These milestone advances created interest in producing and launching a geostationary communications satellite, in which solar energy would provide a viable power supply. This crucial development stimulated funding from several governments into research for improved solar cells. Today, most photovoltaic modules are used for grid-connected power generation [5].

PV electricity output peaks mid-day when the sun is at its highest point in the sky and can offset the most expensive electricity when daily demand is most significant. Homeowners can install a few dozen PV panels to reduce or eliminate their monthly electricity bills, and utilities can build large “farms” of PV panels to provide pollution-free electricity to their customers [3].

2.1.1 Working Principle of Photovoltaic Cells

Photovoltaic systems (PV) are made of PV modules. The smallest unit in a PV module is the solar cell, which converts light into electricity. The direct electric current (DC) produced varies constantly depending on the intensity of the incoming solar light. Also, the current depends on incoming solar energy [8]. The solar-absorbed light is transferred to the electrons of the PV cell atoms, exiting them and producing the electrical current with the help of a “built-in electric field,” which provides the needed voltage. The “built-in electrical field” is created by two layers of semiconductor material: n-type with an excess of negative electrons and p-type with an excess of positive holes. The most commonly used semiconductor material is silicon. When n- and p-type silicon come into contact at the p-n junction, excess electrons move from the n-type side to the p-type side, resulting in a positive charge in the n-type side of the interface and a buildup of negative charge in the p-type side. Two types of semiconductors (n and p) are created by doping the silicon with an external element with either extra or a lack of electrons, respectively [9].

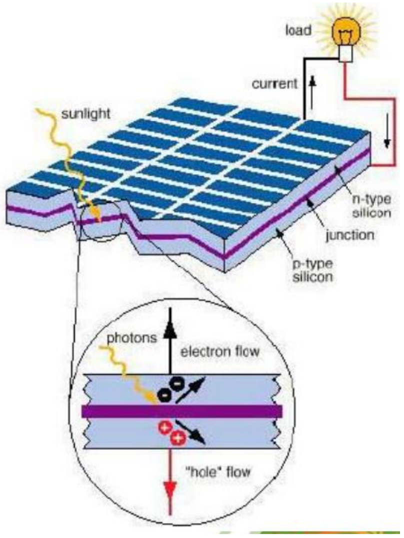


Fig 3: Photovoltaic Cell [9]

2.1.2: Classification of Photovoltaic Cells

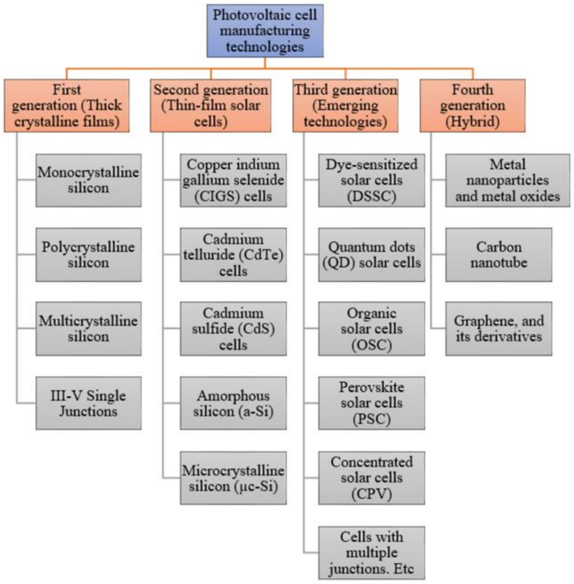


Fig 4: Various solar cell types and current developments within this field [10]

The generations of various photovoltaic cells essentially tell the story of the stages of their past evolution. Four main categories are described as the generations of photovoltaic technology for the last few decades since the invention of solar cells.

1. **First Generation**: This category includes photovoltaic cell technologies based on monocrystalline, polycrystalline silicon, and gallium arsenide (GaAs).

2. **Second Generation**: This generation includes the development of first-generation photovoltaic cell technology, as well as the development of thin film photovoltaic cell technology from "microcrystalline silicon (μc-Si) and amorphous silicon (a-Si), copper indium gallium selenide (CIGS) and cadmium telluride/cadmium sulfide (CdTe/CdS) photovoltaic cells.

3. **Third Generation**: This generation counts photovoltaic technologies based on more recent chemical compounds. In addition, this generation also belongs to technologies using nanocrystalline "films," quantum dots, dye-sensitized solar cells, solar cells based on organic polymers, etc.

4. **Fourth Generation**: This generation includes the low flexibility or low cost of thin film polymers along with the durability of "innovative inorganic nanostructures such as metal oxides and metal nanoparticles or organic-based nanomaterials such as graphene, carbon nanotubes, and graphene derivatives [10].

2.1.2.1: FIRST GENERATION OF PHOTOVOLTAIC CELLS

Silicon-based PV cells were the first sector of photovoltaics to enter the market, using processing information and raw materials supplied by the microelectronics industry. Solar cells based on silicon comprise over 80% of the world's installed capacity and have a 90% market share. Due to their relatively high efficiency, they are the most commonly used cells. The first generation of photovoltaic cells includes materials based on thick crystalline layers composed of Si silicon. This generation is based on mono-, poly-, and multicrystalline silicon and single III-V junctions (GaAs) [11,12]. Comparison of first-generation photovoltaic cells [12,13]:

- **Solar cells based on monocrystalline silicon (m-si)**

Efficiency: 15 ÷ 24%; Band gap: ~1.1 eV; Life span: 25 years; Advantages: Stability, high performance, long service life; Restrictions: High manufacturing cost, more temperature sensitivity, absorption problem, material loss.

- **Solar cells based on polycrystalline silicon (psi)**

Efficiency: 10 ÷ 18%; Band gap: ~1.7 eV; Life span: 14 years; Advantages: Manufacturing procedure is simple, profitable, decreases the waste of silicon, higher absorption compared to m-si; Restrictions: Lower efficiency, higher temperature sensitivity.

- **Solar cells based on GaAs**

Efficiency: 28 ÷ 30%; Band gap: ~1.43 eV; Life span: 18 years; Advantages: High stability, lower temperature sensitivity, better absorption than m-si, high efficiency; Restrictions: Extremely expensive [12].

2.1.2.2 SECOND GENERATION OF PHOTOVOLTAIC CELLS

The thin film photovoltaic cells based on CdTe, gallium selenide, and copper (CIGS) or amorphous silicon have been designed to be a lower-cost replacement for crystalline silicon cells. They offer improved mechanical properties ideal for flexible applications, but this comes with the risk of reduced efficiency. Whereas the first generation of solar cells was an example of microelectronics, the evolution of thin films required new growing methods. It opened the sector to other areas, including electrochemistry [14]. The second-generation photovoltaic cell comparison [12]:

- **Solar cells based on amorphous silicon (a-si)**

Efficiency: 5 ÷ 12%; Band gap: ~1.7 eV; Life span: 15 years; Advantages: Less expensive, available in large quantities, non-toxic, high absorption coefficient; Restrictions: Lower efficiency, difficulty in selecting dopant materials, poor minority carrier lifetime.

- **Solar cells based on cadmium telluride/cadmium sulfide (CdTe/CdS)**

Efficiency: 15 ÷ 16%; Band gap: ~1.45 eV; Life span: 20 years; Advantages: High absorption rate, less material required for production; Restrictions: Lower efficiency, Cd being extremely toxic, Te being limited, more temperature-sensitive.

- **Solar cells based on copper indium gallium selenide (CIGS)**

Efficiency: 20%; Band gap: ~1.7 eV; Life span: 12 years; Advantages: Less material required for production; Restrictions: Very high-priced, not stable, more temperature-sensitive, highly unreliable [12].

2.1.2.3 THIRD GENERATION OF PHOTOVOLTAIC CELLS

The third generation of solar cells (including tandem, perovskite, dye-sensitized, organic, and emerging concepts) represent a wide range of approaches, from inexpensive low-efficiency systems (dye-sensitized, organic solar cells) to expensive high-efficiency systems (III-V multi-junction cells) for applications that range from building integration to space applications.

Third-generation photovoltaic cells are sometimes called “emerging concepts” because of their poor market penetration, even though some have been studied for over 25 years [15]. The latest trends in silicon photovoltaic cell development are methods involving the generation of additional levels of energy in the semiconductor’s band structure. The most advanced studies of manufacturing technology and efficiency improvements are now concentrated on third-generation solar cells.

One of the current methods to increase the efficiency of PV cells is the introduction of additional energy levels in the semiconductor’s band gap (IBSC and IPV cells) and increasing ion implantation in the manufacturing process. Other innovative third-generation cells that are lesser-known commercial “emerging” technologies include [16,15]:

1. Organic materials (OSC) photovoltaic cells;
2. Perovskites (PSC) photovoltaic cells;
3. Dye-sensitized (DSSC) photovoltaic cells;
4. Quantum dots (QD) photovoltaic cells; and
5. Multi-junction photovoltaic cells

• Organic and Polymeric Materials Photovoltaic Cells (OSC)

Organic solar cells (OSCs) are beneficial in applications related to solar energy since they have the potential to be used in a variety of prospects based on the unique benefits of organic semiconductors, including their ability to be processed in solution, lightweight, low-cost, flexibility, semi-transparency, and applicability to large-scale roll-to-roll processing. Solution-processed organic solar cells (OSCs) that absorb near-infrared (NIR) radiation have been studied worldwide for their potential to be donor-acceptor bulk heterojunction (BHJ) compounds. In addition, NIR-absorbing OSCs have attracted attention as high-end equipment in next-generation optoelectronic devices, such as translucent solar cells and NIR photodetectors, because of their potential for industrial applications. With the introduction of non-fullerene acceptors (NFAs) that absorb light in the NIR range, the value of OSC is increasing. In contrast, organic donor materials capable of absorbing light in the NIR range have not yet been actively studied compared to acceptor materials that absorb light in the NIR range [17].

The most advanced BHJ structure, combining organic donor and acceptor materials, showed tremendous hope for low-cost, lightweight organic solar cells. Over the past decade, enormous progress was made, with power conversion efficiencies reaching more than 14% for a single-junction device and more than 17% for a tandem device by designing new NIR photoactive materials with low bandwidth. Compared to wide-band organic photovoltaic materials, low-band donor and non-fullerene acceptor materials with wide-range solar coverage extended to the NIR region typically exhibit more tightly superimposed electronic orbitals, easier delocalization of π electrons, higher dielectric constant, more vital dipole moment, and lower exciton binding energy. These properties make low-bandwidth photovoltaic materials essential in high-performance organic solar cells, including single-junction and tandem devices [18].

A clever strategy in active layer design could be summed up as optimizing the weight ratio of donor to acceptor materials, using ultra-low band gap materials as a third component to improve NIR light utilization efficiency, and adjusting the thickness of the active layer to achieve a compromise between photon collection and charge accumulation. Much effort has gone into optimizing the translucent top electrode: well-balanced conductivity and transmittance in the visible light range, increased reflectance in the NIR or ultraviolet (UV) light range, and better compatibility with active layers. In terms of device engineering, photon crystal, anti-reflection coating, optical microcavity, and dielectric/metal/dielectric (DMD) structures have been placed to realize selective transmission and reflection for simultaneous improvement of power conversion efficiency and average transmission of translucent OSC visible light [19].

• Dye-Sensitized Photovoltaic Cells (DSSC)

Conjugated polymers and organic semiconductors have been successful in flat panel displays and LEDs, so they are considered advanced materials in the current generation of photovoltaic cells. A schematic representation of dye-sensitized organic photovoltaic cells (DSSCs) is shown in **Fig 4**. Polymer/organic photovoltaic cells can also be divided into dye-sensitized organic photovoltaic cells (DSSCs), photoelectrochemical photovoltaic cells, and plastic (polymer) and organic photovoltaic devices (OPVDs), differing in mechanism of operation [20].

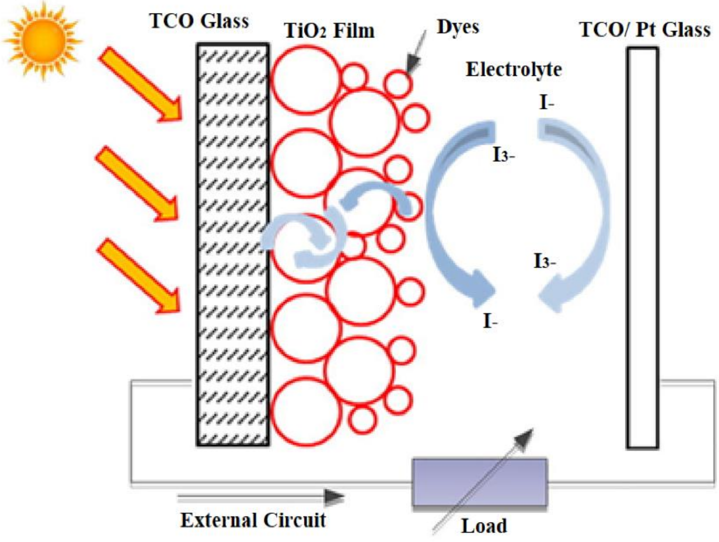


Fig 5. Schematic representation of DSSCs [21].

Dye-sensitized solar cells (DSSCs) represent one of the best nanotechnology materials for energy harvesting in photovoltaic technologies. It is a hybrid organic–inorganic structure where a highly porous, nanocrystalline layer of titanium dioxide (TiO_2) is used to conduct electrons in contact with an electrolyte solution containing organic dyes that absorb light near the interfaces. A charge transfer occurs at the interface, resulting in the transport of holes in the electrolyte. The power conversion efficiency is about 11%, and commercialization of dye-sensitized photovoltaic modules is underway. A novel feature in DSSC solar cells is the photosensitization of nanosized TiO_2 coatings in combination with optically active dyes, which increases their efficiency by more than 10% [22].

DSSCs hold promise as photovoltaic devices because of their simple fabrication, low material costs, transparency, color capability, and mechanical flexibility benefits. The main challenges in commercializing DSSCs are poor photoelectric conversion efficiency and cell stability. The highest attainable theoretical energy conversion efficiency was estimated at 32% for DSSCs; however, the highest efficiency reported to date is only 13%. Intensive work is underway to understand the parameters governing the DSSC to improve its efficiency. Numerous attempts have been made to optimize the redox pair and absorbance of the dye, modify a wide band gap semiconductor as a working electrode, and develop a counter electrode (CE). In addition to increasing the efficiency of DSSC, the cost of materials is another major issue that needs to be solved in future work [23].

• Perovskite Photovoltaic Cells

Perovskite solar cells (PSCs) are a revolutionary new photovoltaic cell concept that relies on metal halide perovskites (MHPs), e.g., methylammonium iodide as well as formamidine lead iodide ($MAPbI_3$ or $FAPbI_3$, respectively). MHPs integrate several features favoured in photovoltaic absorbers, including a direct band gap with a high absorption coefficient, long carrier lifetime and diffusion length, low defect density, and ease of tuning the composition and band gap. In the year 2009, MHP was first described as a sensitizer in a dye cell based on liquid electrolyte conducting holes. In 2012, MHP demonstrating ~10% efficiency of PSCs based on a solid-state hole conductor sparked an explosion of PSC studies. In about a decade of research, the efficiency of a single PSC junction increased to a certified level of 25.2% [24].

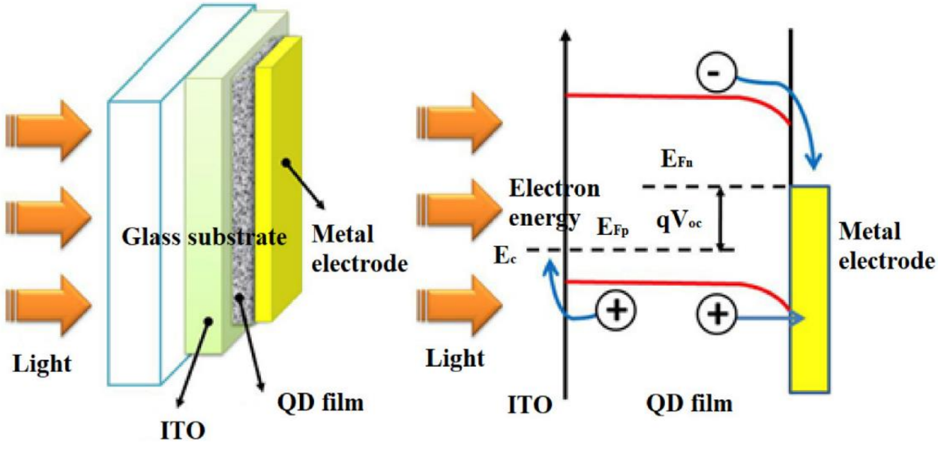
The development of PSCs has been heavily influenced by improving material quality through a broad range of synthetic methods designed under a fundamental understanding of MHP growth mechanisms. Comprehension of the complex and correlated processes of perovskite growth (e.g., nucleation, grain growth, as well as microstructure evolution) has aided in the development of a broad range of high-efficiency growth modes (for example, single-step growth, sequential growth, dissolution process, vapor process, post-deposition processing, non-stoichiometric growth, additive-assisted growth, and fine-tuning of structure dimensions). The latest efforts concentrated on interface engineering, reducing open-circuit voltage losses and improving stability, particularly by introducing a two-dimensional perovskite surface layer. With progress in synthetic control, the perovskite composition is becoming simpler, mainly toward $FAPbI_3$. This will undoubtedly contribute to the simplification of scale deposition methods and a basic understanding of the properties of these cells [25].

• Quantum Dots Photovoltaic Cells

Solar cells made from these materials are called quantum dots (QDs) or nanocrystalline solar cells. They are fabricated by epitaxial growth on a substrate crystal. Quantum dots are surrounded by high potential barriers in a three-dimensional shape, and the electrons and electron holes in a quantum dot become discrete energy because they are confined in a small space (**Fig 6).** Consequently, the ground state energy of electrons and electron holes in a quantum dot depends on the size of the quantum dot [26].

Nanocrystalline cells have relatively high absorption coefficients. Four consecutive processes occur in a solar cell: (1) light absorption and exciton formation, (2) exciton diffusion, (3) charge separation, and (4) charge transport. Due to the poor mobility and short lifetime of excitons in conducting polymers, organic compounds are characterized by small exciton diffusion lengths (10–20 nm). In other words, excitons that form far from the electrode or carrier transport layer recombine, and the conversion efficiency drops [27].

Developing thin film solar cells with metal halide perovskites has led to intensive attention to the corresponding nanocrystals (NCs) or quantum dots (QDs). Today, the record efficiency of QD solar cells has improved to 16.6% using mixed colloidal QDs with perovskites. The universality of these new nanomaterials regarding ease of fabrication and the ability to tune the band gap and control the surface chemistry allows a variety of possibilities for photovoltaics, such as single-junction, elastic, translucent, controlled cells with heterostructures and multi-junction tandem solar cells which would push the field even further. However, a narrower size distribution can potentially enhance the performance of QD solar cells in more ways than one. Firstly, electron transport might be better in smaller QDs, as larger QDs function as a band tail or shallow trap, making transport more difficult. Secondly, the open-circuit voltage (V_{OC}) of QD solar cells could be limited by the smallest band gap (largest size) QD near the contacts. Enhancing the homogeneity and uniformity of QD size would also improve PV performance by minimizing such losses. Although controlled experiments such as these have not yet been reported, more controlled synthesis might benefit QD cells [28].



(**a**) (**b**)

Fig 6**.** (**a**) A scheme of a solar cell based on quantum dots, (**b**) a solar cell band diagram [29].

- **Multi-Junction Photovoltaic Cells**

Multi-junction (MJ) solar cells consist of plural p-n junctions fabricated from various semiconductor materials, with each junction producing an electric current in response to light of a different wavelength, thereby improving the conversion of incident sunlight into electricity and the device's efficiency. Using various materials with different band gaps has been suggested to utilize the maximum possible number of photons and is known as a tandem solar cell. An entire cell could be fabricated from the same or different materials, giving a broad spectrum of possible designs [30].

Usually, the cells are integrated monolithically and connected in series through a tunnel junction, and current matching between cells is obtained by adjusting each cell's band gap and thickness. The theoretical feasibility of using multiple band gaps was examined and was found to be 44% for two-band gaps, 49% for three-band gaps, 54% for four-band gaps, and 66% for an infinite number of gaps. **Fig 7** illustrates an InGaP/(In)GaAs/Ge triple solar cell scheme and presents crucial technologies to enhance conversion efficiency [31].

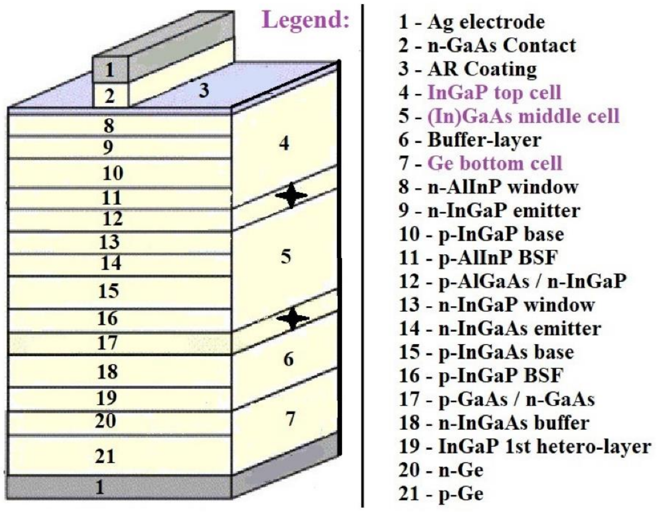


Fig 7**.** Schematic illustration of a triple-junction cell and approaches for improving the efficiency of the cell [30].

Grid-matched InGaP/(In)GaAs/Ge triple solar cells have been widely used in space photovoltaics and have achieved the highest actual efficiency of over 36%. Heavy radiation bombardment of various energetic particles in the space environment inevitably damages solar cells. It causes the formation of additional non-radiative recombination centers, which reduces the diffusion length of minority carriers and reduces solar cell efficiency. The sub-cells in multi-junction solar cells are connected in series; the sub-cell with the most significant radiation degradation degrades the efficiency of the multi-junction solar cell. To improve the radiation resistance of (In)GaAs sub-cells, measures such as reducing the dopant concentration, decreasing the thickness of the base region, etc., can be used [31].

• Photovoltaic Cells with Additional Intermediate Band

The National Renewable Energy Laboratory (NREL) estimates that multi-junction and IBSC photovoltaic cells have the highest efficiency under experimental conditions (47.1%). The main feature of these cells is precisely the additional intermediate band in the band gap of silicon. Currently, two types of these cells are specified in the world literature: IBSC (Intermediate et al.) and IPV (Impurity et al.) [32].

Impurity Photovoltaic Effect (IPV) is one of the solutions used to increase the infrared response of PV cells and thus increase the solar-to-electric energy conversion efficiency. The idea of the IPV effect is based on the introduction of deep radiation defects in the structure of the semiconductor crystal structure. These defects ensure a multi-step absorption mechanism for photons with energies below the band gap width. Under certain conditions, adding IPV dopants into silicon solar cell structure increases the spectral response, short circuit current density, and conversion efficiency [33].

A major direction of study with great potential for development is Intermediate Band Solar Cells (IBSCs). They represent a third-generation solar cell concept and involve silicon and other materials. The idea behind the intermediate band gap solar cell (IBSC) concept is to absorb photons with an energy corresponding to the sub-band width in the cell structure. These photons are absorbed by a semiconductor-like material that, in addition to the conduction and valence bands, has an intermediate band (IB) in the conventional semiconductor's band gap (**Fig 8**). In IBSCs, the silicon layers are implanted with very high doses of metal ions to create an additional energy level [34].

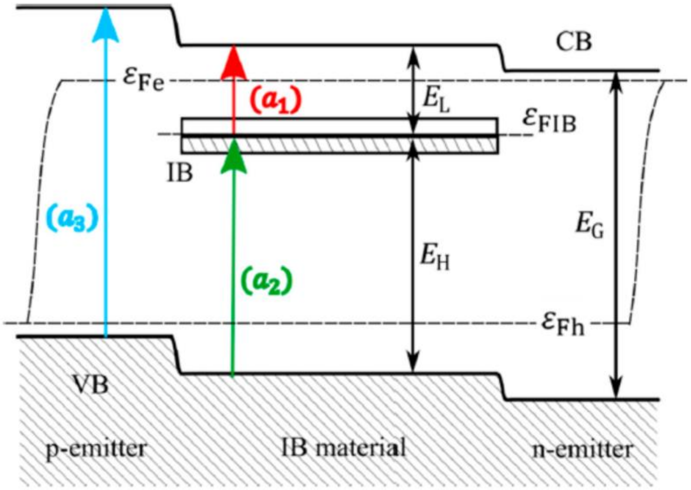


Fig 8. Energy band diagram of an intermediate band solar cell (IBSC) [34].

Based on the research conducted on the effect of defects introduced into the silicon structure, a model was developed. Introducing selected deep defects into the charge carrier capture region improves PV cell efficiency. Of particular interest are defects that facilitate the transport of majority carriers and defects that counteract the accumulation of minority carriers. This significantly reduces the recombination process at the charge carrier capture site. Finally, by introducing defects into the silicon structure underlying the solar cell, the researchers combine effective surface passivation with a simultaneous reduction in optical losses [35].

The introduction of intermediate bands in semiconductors, using ion implantation, can be executed using two methods: introducing dopants of very high concentration into the semiconductor substrate or implanting the silicon layer with high-dose metal ions. The increasing use of ion implantation in the photovoltaic cell manufacturing process can reduce the deployment cost and increase silicon cells' cost-effectiveness by increasing their efficiency. The use of ion implantation technology provides increased precision of silicon layer doping and generation of additional energy levels in the band gap, as well as shortening the individual stages of cell fabrication, which ultimately translates into improved quality and lower production costs [36].

The ion implantation technique has been gaining popularity in the solar industry, gradually displacing the diffusion technique used for many years. As shown in **Fig 8**, cell performance is expected to improve as the technology evolves toward higher efficiencies. In addition to local and reference doping, the significant benefits of this technology involve high precision control of the amount and distribution of dopant doses, which results in high uniformity, repeatability, and increased efficiency (above 19%), with a significantly narrower distribution of cell performance [37].

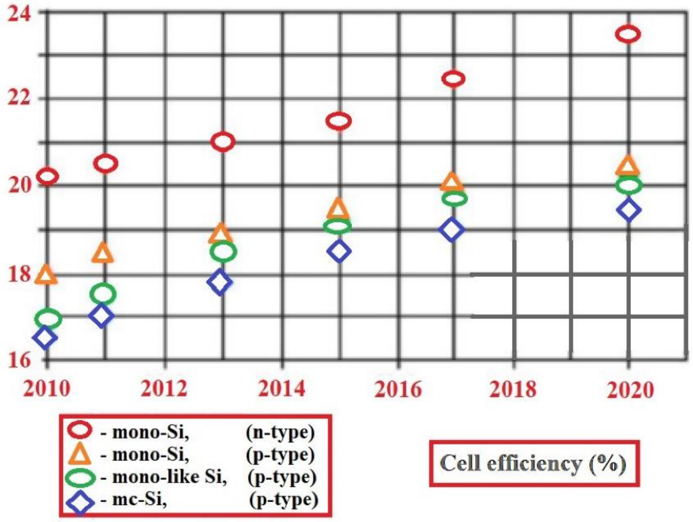


Fig 9**.** Stabilized cell efficiency trend curves [57].

In the ion implantation method, chosen ions with the required impurity are inserted into the semiconductor by accelerating the impurity ions to a high energy level and implanting the ions into the semiconductor. The energy given to the impurity ions defines the depth of ion implantation. Contrary to diffusion technology (where the impurity ion dose is introduced only at the surface), in the ion implantation technique, a controllable dose of impurity ions can be placed deeply into the semiconductor [38].
Third-generation photovoltaic cell comparison [12]:

- **Solar cells based on dye-sensitized photovoltaic cells**
  Efficiency: 5 ÷ 20%; Advantages: Lower cost, low light and wider-angle operation, lower internal temperature operation, robustness, and extended lifetime; Restrictions: Problems with temperature stability, poisonous and volatile substances.

- **Solar cells based on quantum dots**
  Efficiency: 11 ÷ 17%; Advantages: Low production cost, low energy consumption; Restrictions: High toxicity in nature, degradation.

- **Solar cells based on organic and polymeric photovoltaic cells**

Efficiency: 9 ÷ 11%; Advantages: Low processing cost, lighter weight, flexibility, thermal stability; Restrictions: Low efficiency.

• Solar cells based on perovskite
Efficiency: 21%; Advantages: Low-cost and simplified structure, light weight, flexibility, high efficiency, low manufacturing cost; Restrictions: Unstable.

• Multi-junction solar cells
Efficiency: 36% and higher; Advantages: High performance; Restrictions: Complex, expensive [12].

2.1.2.4 FOURTH GENERATION OF PHOTOVOLTAIC CELLS

Fourth-generation photovoltaic cells are also known as hybrid inorganic cells because they combine the low cost and flexibility of polymer thin films with the stability of organic nanostructures such as metal nanoparticles and metal oxides, carbon nanotubes, graphene, and their derivatives. These devices, often referred to as "**nano photovoltaics**," could become the promising future of photovoltaics [39].

- **Graphene-Based Photovoltaic Cells**

The fourth generation provides excellent affordability and flexibility by using thin polymer layers, metal nanoparticles, various metal oxides, carbon nanotubes, graphene, and their derivatives. Particular emphasis was placed on graphene because it is considered a future nanomaterial. Due to their unique properties, such as high carrier mobility, low resistivity and transmittance, and 2D lattice packing, graphene-based materials are being considered for use in PV devices instead of existing conventional materials. However, to achieve adequate device performance, the key to its practical applications is synthesizing graphene materials with appropriate structure and properties [40].

Since the properties of graphene are fundamentally related to its fabrication process, a judicious choice of methods is essential for targeted applications. In particular, highly conductive graphene is suitable for use in flexible photovoltaic devices, and its high compatibility with metal oxides, metallic compounds, and conductive polymers makes it suitable for use as a selective charge-taking element and electrode interlayer material [41].

In the past two decades, graphene has been combined with the concept of photovoltaic material. It shows a significant role as a transparent electrode, hole/electron transport material, and interfacial buffer layer in solar cell devices. The researchers can distinguish several types of graphene-based solar cells, including organic bulk heterojunction (BHJ) cells, dye-sensitized cells, and perovskite cells. The energy conversion efficiency exceeded 20.3% for graphene-based perovskite solar cells and 10% for BHJ organic solar cells. In addition to extracting and transporting charge to the electrodes, graphene plays another unique role—it protects the device from environmental degradation through its packed 2D lattice structure. It ensures the long-term environmental stability of photovoltaic devices [42].

Semi-metallic graphene having a zero-band gap creates Schottky junction solar cells with silicon semiconductors. Even though graphene was discovered for the first time in 2004, the first graphene–silicon solar cell was not characterized as an n-silicon cell until 2010. **Fig 10** schematically shows a graphene–silicon solar cell with a Schottky junction. Graphene sheets (GS), cultured by chemical vapor deposition (CVD) on nickel films, were wet deposited on pre-patterned Si/SiO_2 substrates with an effective area of

0.1–0.5 cm^2. The graphene sheet forms a coating on the exposed n-Si substrate, creating a Schottky junction. The graphene sheet was contacted using Au electrodes [43].

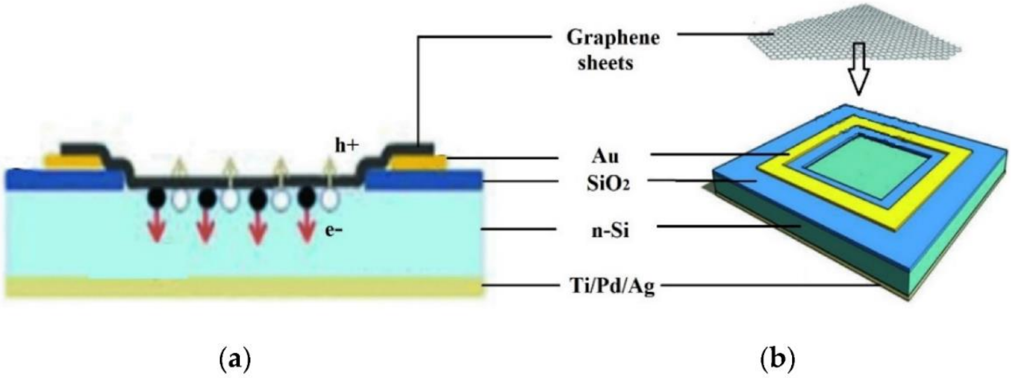


Fig 10**.** Graphene–silicon Schottky junction solar cell. (**a**) Cross-sectional view, (**b**) a schematic illustration of the device configuration [40].

Graphene synthesis uses mainly two methodologies, which are the bottom-up and top-down methods. In the top-down approach, graphite is the starting material, and the goal is to intercalate and exfoliate it into graphene sheets by solid, liquid, or electrochemical exfoliation. Another approach under this categorization is the exfoliation of graphite oxide into graphene oxide (GO), after which chemical or thermal reduction occurs. A bottom-up approach is to produce graphene from molecular precursors by chemical vapor deposition (CVD) or epitaxial growth. The resulting graphene's structure, morphology, and attributes, including the layer numbers, level of defects, electrical and thermal conductivity, solubility, and hydrophilicity or hydrophobicity, depend on the manufacturing process [43,44].

Graphene can absorb 2.3% of incident white light even though it is only one atom thick. Graphene in a silicon solar cell is a promising platform since graphene strongly interacts with light, fulfilling the optical (high transmittance) and electrical (low layer resistance) requirements of a typical transparent conductive electrode. It is important to note that the layer resistance and the transmittance of graphene change with the number of layers. As the layer resistance decreases as the number of graphene layers increases, the optical transparency decreases [45].

Graphene offers much more for PV technology because of its flexibility, environmental stability, low electrical resistivity, and photocatalytic features. It must be carefully designed for the targeted applications and specific requirements [43, 45].

One problem for graphene application is the absence of a more straightforward, more reliable way to deposit a well-ordered monolayer with low-cost flakes on target substrates having various surface properties. The other problem is the adhesion of the deposited graphene thin film, a subject that has not yet been studied adequately. CVD may fabricate large-area continuous graphene layers with high optical transparency and electrical conductivity. As an anode in organic photovoltaic devices, graphene holds great promise as a replacement for indium tin oxide (ITO) because of its inherently low-cost manufacturing process and excellent conductivity and transparency properties [46].

Graphene’s primary disadvantage is its poor hydrophilicity, which negatively affects the design of devices processed in solution. However, that fact may be overcome by modifying the surface by non-covalent chemical functionalization. Given graphene’s mechanical strength, flexibility, and excellent conductivity properties, it can be anticipated that new applications in plastic electronics and optoelectronics will soon emerge involving this new class of CVD graphene materials. The discovery paves the way for low-cost graphene layers to replace ITO in photovoltaic and electroluminescent devices [47].

2.2. CONCENTRATED SOLAR POWER TECHNOLOGY

CSP technologies utilize mirrors to concentrate sunlight onto a receiver, generating thermal energy that can be used to power turbines or generate electricity. Concentrating solar-thermal power systems are commonly used in utility-scale projects, with configurations including power towers and linear systems, which concentrate sunlight onto parallel tube receivers [48]. Basic concentrating solar power technologies concepts have been used: central receiver tower or solar power tower (SPT), parabolic trough collected system, parabolic dish collector system, and linear Fresnel reflector system [49].

2.2.1 Working Principle of Concentrated Solar Power Cells

In CSP technology, the sun's direct normal irradiation (DNI) is concentrated on HTF (Heat Transferred Fluid). which is then passed through a series of heat exchangers to produce super-heated steam. This steam is converted to electrical energy in a conventional steam turbine. A portion of heat is also stored in some liquid or solid media (such as molten salts), concentrated [50] for use at night or when there is no sunlight, thus continuing turbine operation [51].

The general working flow diagram of CSP is given in Fig. 11:

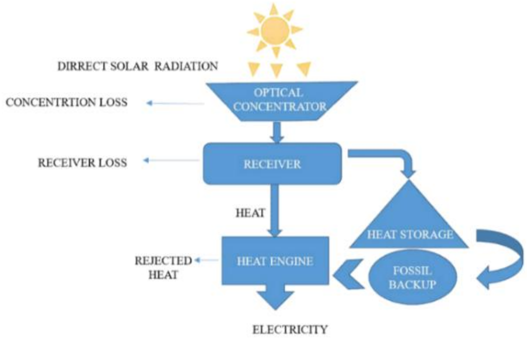


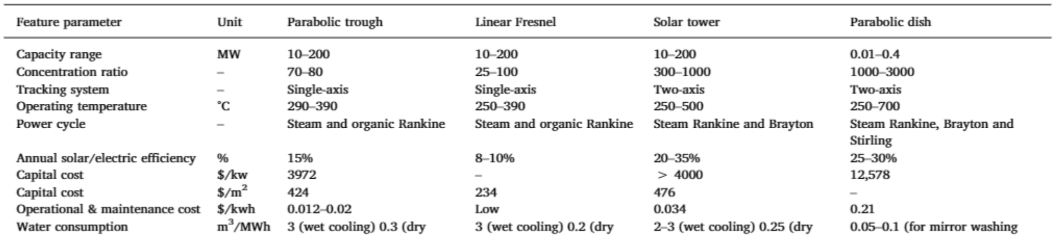
Fig 11: General Flow Diagram of CSP plant [52]

There are different CSP technologies, but their basic principle of generating electricity is the same. The structure and the focus of these systems are different, so they result in different temperature ranges that are generated [52].

2.2.2 Different CSP Technologies

Table 1 presents an analysis of several CSP systems in comparison. The concentration ratios of parabolic dish systems, linear Fresnel systems, and parabolic trough systems are higher than those of solar tower systems, which exhibit an intermediate concentration ratio between 300 and 1000. While parabolic dish systems are advised for smaller generation capacities between 0.01 and 0.4 MW, parabolic trough, linear Fresnel, and solar tower systems are appropriate for power generation capacities in the range of 10–200 MW [53].

Table 1: Different CSP Technologies [53]



Feature parameter	Unit	Parabolic trough	Linear Fresnel	Solar tower	Parabolic dish
Capacity range	MW	10–200	10–200	10–200	0.01–0.4
Concentration ratio	–	70–80	25–100	300–1000	1000–3000
Tracking system	–	Single-axis	Single-axis	Two-axis	Two-axis
Operating temperature	°C	290–390	250–390	250–500	250–700
Power cycle	–	Steam and organic Rankine	Steam and organic Rankine	Steam Rankine and Brayton	Steam Rankine, Brayton and Stirling
Annual solar/electric efficiency	%	15%	8–10%	20–35%	25–30%
Capital cost	$/kw	3972	–	> 4000	12,578
Capital cost	$/$m^2$	424	234	476	–
Operational & maintenance cost	$/kwh	0.012–0.02	Low	0.034	0.21
Water consumption	m^3/MWh	3 (wet cooling) 0.3 (dry	3 (wet cooling) 0.2 (dry	2–3 (wet cooling) 0.25 (dry	0.05–0.1 (for mirror washing

- **Parabolic Trough**

Large cylindrical parabolic mirrors called "trough" collectors focus sunlight on a specific line of focus, forming the solar field of a parabolic trough power plant (Fig 12). Several collectors are installed in rows about a hundred meters long, and the total solar field comprises many such parallel rows [54].

Every collector follows the direction of the sun's path along their longitudinal axes. More than 80 times as much light is focused on a metal absorber pipe in the line of focus by the mirrors. This pipe is inserted in an evacuated glass tube to minimize heat loss. A selective coating on the absorber tube surface reduces emission losses. The absorber tube is filled with either special thermal oil or water. It reaches around 400 °C due to the intense sunlight, which causes water to evaporate and turn into steam that powers a turbine and an electrical generator. (Fig 13) [54].

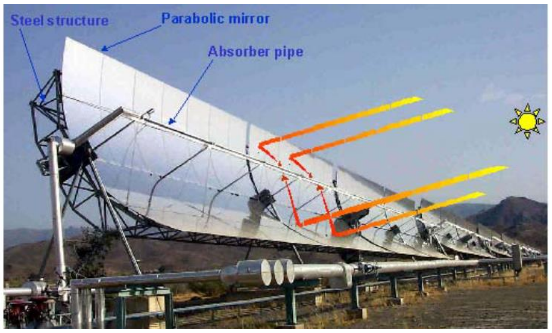


Fig 12: Principle of the parabolic trough solar collector [54]

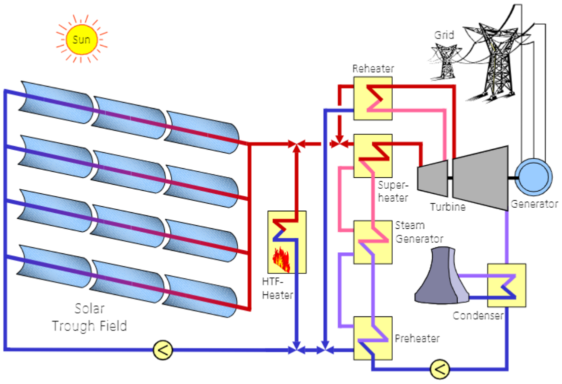


Fig 13: Principle of the parabolic trough solar power plant [54]

- **Central Receiver Tower**

The central receiver tower system (CRT) is a potential technology for large-scale energy utilization bases because of its outstanding efficiency, high solar concentration ratio, and energy cost reduction, as seen in Fig 14. The central receiver tower system (CRT) is regarded as a potential technology for large-scale energy utilization bases because of its outstanding efficiency with a very high solar concentration ratio, as seen in Fig 14, in addition to the energy cost reduction [49].

Fig 14. Gema solar power plant, heliostat field, Spain [49]

Heliostats (sun-tracking mirrors), which stand in for the solar field, reflect incident solar radiation onto the solar receiver's surface, which is positioned atop the central tower. Since the solar receiver functions as a heat exchanger, the received solar radiation elevates the heat transfer fluid inside the receiver above 500 ºC using a molten salt heat transfer fluid or other sufficient fluids. Traditional steam power cycle plants use this superheated steam to generate electrical power [49].

- **Linear Fresnel Reflector**

The first linear Fresnel reflector was developed in 1961 in Italy by Giorgio Francia and was further studied by companies like FMC (food machinery and chemical) corporation during the 1973 oil crisis. It follows the principles of parabolic trough technology but replaces curved mirrors with long parallel lines of thin, shallow curvature (or even flat) mirrors or reflectors. Mirrors track sunlight, directing it to a stationary linear receiver or absorber tube at a common focal point several meters above them. The mirrors can concentrate the sun’s energy to approximately 30 times its average intensity. On top of the receiver, a small parabolic mirror (called a secondary reflector) can be attached to focus the light further, as shown in Fig 15 [55].

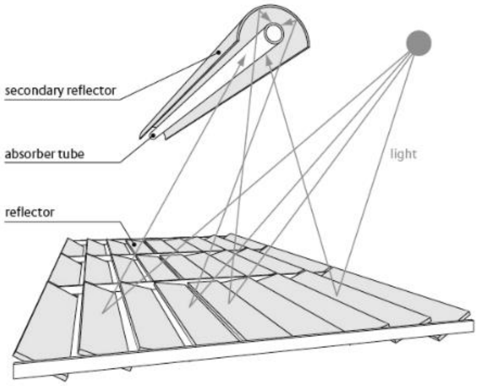


Fig 15. Principle of operation of linear Fresnel reflector solar system [55]

Linear Fresnel reflector systems are disadvantaged as the receiver row is shared among multiple mirrors, causing increased shading and blocking of incoming solar radiation. [55] However, the simplicity of the mirrors leads to low optical efficiency. This could be why a few large-scale LFR plants are installed worldwide [56].

- **Parabolic Dish**

The parabolic dish (PD) system is a two-axis point-focused system that concentrates the solar radiation on a focal point of the dish, as shown in Fig 16. The focal point/receiver is filled with Heat Transfer Fluid (HTF). Generally, fluid or gas is used as HTF in parabolic dish systems. HTF systems are heated to 1000°C due to the high concertation ratio in PD systems, then directed to Stirling engines or gas turbines to convert fluid thermal energy into electrical energy. PD systems' limited size and high capital cost make them less commercialized due to their off-grid nature and high installation costs [56]

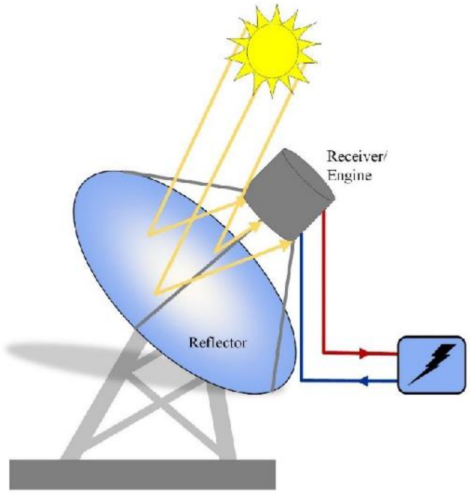


Fig 16: A schematic diagram of the Parabolic Dish system [56]

- **KSU Indigenous CSP**

Researchers at King Saud University (KSU) in the Kingdom of Saudi Arabia (KSA) have developed, engineered, and built an innovative and low-cost system of concentrating solar collectors currently being tested at the KSU campus in Riyadh before commercialization. Their Point Focus Fresnel Collector (PFFC) technology holds great potential as a highly effective and economical solution for various applications. It addresses particular needs in the area, like producing carbon-free electricity and power for district cooling, water desalination, process heat, and oil-free air conditioning in homes and businesses. The PFFC concentrates the sun’s rays using flat, square mirrors on a rotating surface. This surface and how each row of mirrors is constructed allow them to follow the sun as it moves through the sky and concentrate its heat on the same point throughout the day [57].

3. ENVIRONMENTAL IMPACTS

Solar cells offer a beacon of hope for the environment. While their manufacturing carries an upfront carbon footprint, they generate clean energy throughout their lifespan, offsetting this within a few years. However, land use, potential water, and materials concerns need careful consideration. Overall, Solar’s contribution to reducing greenhouse gases and air pollution makes it a crucial player in combating climate change, with ongoing research striving to mitigate its initial environmental impact.

3.1 Photovoltaic Cells

The environmental impacts of PV power generation systems from the manufacturing stage (Fthenakis et al., 2005) to installation and operation (Turney & Fthenakis, 2011), decommission and disposal or recycling of solar PV equipment (Fthenakis et al., 2008) have been reported in the literature. Like any power generation system, constructing a PV facility involves heavy machinery, which results in noise and visual disturbances, disturbing the natural habitat and the environment (Soliño et al., 2009; Guerin, 2017a). Several impacts are related primarily to human health (Aman et al., 2015), climate (Alsema, 2012), wildlife (Pimentel et al., 2018), land use (Denholm & Margolis, 2008), groundwater, and soil (Tammaro et al., 2016). Turney and Fthenakis (2011) identified up to 32 environmental impacts of utilizing solar instead of traditional energy sources.

There is a lack of knowledge about the effect of PV technology in reducing GHG emissions and the best practices in design and deployment to lower the PV carbon footprint. The impact of components of PV solar cells on the generation and emission of hazardous materials and the possible recycling approaches are other vital aspects that require further investigation [58].

- **Land Use**

Land patterns and proper distribution are essential to efficiently utilize it for PV systems and avoid competition with other vital activities such as agriculture. According to Dias et al. (2019), land prioritization for agricultural activities has decreased the amount of solar energy harvested to a great extent (from 2494 to 1116 MW).[58]

- **Air Pollution and Climate Change**

PV energy is a clean energy source whose impact on air quality and climate change is significantly lower than any other traditional power generation system. Hence, it can assist in eliminating numerous environmental issues that result from utilizing fossil fuels (Avril et al., 2012). PV systems have zero emissions of carbon dioxide, methane, sulfur oxides, and nitrogen oxides (CO_2, CH_4, SO_X, NO_X, respectively) during operation, with negligible effects on air pollution and global warming[58].

- **Hazardous Materials Emissions**

Manufacturing PV solar cells involves different kinds of hazardous materials during either the extraction of solar cells or semiconductors etching and surface cleaning (Marwede et al., 2013; Üçtuğ & Azapagic, 2018). Several raw materials are utilized during PV cells' manufacturing, such as silicon (Si), cadmium (Cd), tellurium (Te), copper (Cu), selenium (Se), and gallium (Ga) (Alami et al., 2020b; Stamford and Azapagic, 2019). The production of these raw materials involves mining [58].

- **Water Usage**

Water consumption is critical mainly for countries exposed to severe water shortage, such as Libya, Saudi Arabia, Jordan, and Singapore; therefore, sustainable and effective technologies for water consumption and treatment are critically required (Al-Bsoul et al., 2020; Al Bsoul et al., 2019; Al-Qodah et al., 2020; Elsaid et al., 2020). Meldrum et al. (2013) reviewed the life cycle of water use for electricity generation [58].

- **Noise And Visual Impacts**

According to the World Health Organization, noise is defined as unwanted sound (Gupta, 2006). Therefore, it is considered a type of pollution due to its impact on human health (Passchier-Vermeer & Passchier, 2000). The hearing range of healthy human beings ranges from 20 Hz to 20,000 Hz, and the effect on human health depends on the exposure time and the wavelength. Noise is an environmental factor that causes tension and possible harmful effects on human health [58].

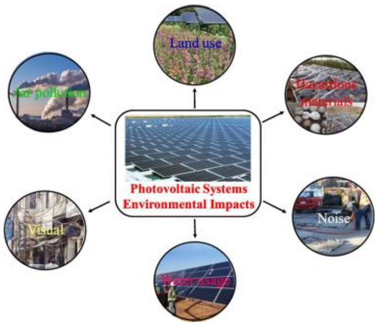


Fig 17: Graphical abstract of Environmental impacts of Photovoltaic Systems [59]

3.2. Concentrated Solar Power system

Studies usually evaluate the life-cycle environmental impacts of CSP plants. The life-cycle analysis (LCA) defines boundary conditions to include processes, such as manufacturing (extraction of raw materials, transport to the factory, component manufacturing processes, transportation to the regional warehouse), construction (land preparation, construction of auxiliary facilities, plant assembly), operation, and maintenance (production of spare parts and their transportation to the site, fuel consumption of maintenance vehicles, water consumption for mirror cleaning), dismantling (energy required to disassemble plant components) and disposal (energy required for transporting waste to landfills, recycling of components, incinerator or the energy required for final disposal) [59].

- **Land Used**

The land use of solar systems depend strongly on the insolation level. The land use for a given site decreases with higher insolation, which is why the same system may require up to three times more land for high latitudes than for sites closer to the equator.

CSP plants globally require a significant amount of land that must be relatively flat.

Land use is quantified based on capacity(area/MWel) and generation (area/GWh/yr). Capacity-based results help judge land use and new project costs because power plants are often rated in terms of capacity.

More recently, more solar power plants have a thermal energy reservoir. In this case, the required surface area increases with the reservoir's capacity. Generally, the land used is higher than for wind power, geothermal power plants, and nuclear power but lower than for coal, biomass, and hydropower [59].

- **Water Use and Consumption**

Like other power plants, solar thermal plants have a reasonably large water footprint to produce electricity. One part of the water is used to produce steam in the thermodynamic cycle, and most of the water (85% to 95%) is intended for cooling. The applied cooling technology largely determines the amount of water the plant has withdrawn. Most of the applied cooling water is returned to the environment, but the quality of that water differs from those taken from the environment, which can be a source of concern.

Water is also used to clean mirrors to maintain high surface reflectivity, although water consumption for this purpose is usually hundreds of times lower than for cooling (around 20 liters/ MWh) [59].

- **Solid and Non-Hazardous Waste**

Maintenance activities and waste disposal typical of electricity production will occur during the CSP plant's life cycle. Power plant waste includes oily rags, empty containers, broken and rusted metal and machine parts, waste electrical materials, and other various solid wastes, including the typical waste produced by workers. This waste is classified and managed by a local company authorized to do so. The collection and disposal of waste are carried out per the appropriate regulatory requirements to minimize the safety and health effects [59].

- **Hazardous Waste**

Different hazardous wastes can occur during the operation of a power plant. That waste includes waste HTF and solvents, waste oil and oil filters, cleaning rags, used or expired deadline chemicals from the water treatment system, expired deadline paints, etc. This hazardous waste is temporarily stored on-site in appropriate tanks and permanently disposed of in the prescribed manner by legal regulations. Workers will be trained to handle all hazardous waste generated in the place [59].

- **Gases Emitted into the Atmosphere**

The US National Renewable Energy Laboratory (NREL)has conducted a comprehensive LCA of renewable energy sources, including the CSP technology [9]. For this life-cycle assessment, 42 GHG emissions were identified in thirteen unique references for Fresnel, parabolic trough, power tower, and parabolic dish technologies. Although most published estimates of greenhouse gas emissions in the life-cycle range between 14 g and 32 CO2 eq./kWh [59].

- **Wasted Heat**

All heat energy-converting systems produce waste heat that can have a significant share. The waste heat fraction depends on the applied technology. The waste heat in the CSP plant is smaller than for geothermal plants and power plants on natural gas, but it is higher in coal-fired and oil-fired power plants [59].

- **Materials in CSP Plants**

CSP plants use many working materials inside their system, far more than the conventional fossil fuel power plants. The primary materials used are mostly steel, glass, and concrete, with a relatively high recycling rate, typically over 95%. Materials that cannot be recycled are primarily inert and can be used for road building or can be land-filled safely. However, several toxic materials (compounds) are found within the CSP system, most often synthetic organic compounds such as biphenyls and biphenyl ether used in the heat transfer system. These compounds can cause a fire and may, during leakage in the system, reach the ground through which they can reach other parts of the environment and need to be treated as hazardous waste. From the soil, poisonous compounds can be absorbed by plants, and by eating these plants, animals can also absorb them. They try to solve toxic materials by replacing them with water or molten salts [59].

4. ECONOMICAL ASPECTS

The economics of solar cells are on a bright path. While the initial installation cost can be daunting, it steadily decreases thanks to technological advancements and economies of scale. Plus, consider the long-term savings: solar cells generate free electricity from the sun, slashing your dependence on conventional, often volatile, energy sources. You will also likely benefit from government incentives like tax credits and net metering, where excess power you generate can be fed back to the grid for credits or cash. All things considered, solar cells are becoming an increasingly attractive investment, paying back over time while contributing to a cleaner planet.

4.1 Photovoltaic Solar Power System

The remarkable growth in deploying grid-connected photovoltaics (PV) in recent years has largely been driven by its rapidly improving economics. System costs have fallen almost fourfold in some markets over the past five years. However, the technology's future success will depend on the value it can contribute to delivering affordable, reliable, secure, and sustainable energy services to end users. PV has some precious characteristics in this regard. It can be deployed at almost any scale from household to utility plant, typically generates at times of higher demand and hence higher value, and has shallow adverse environmental impacts. However, its variable and somewhat unpredictable generation does raise some challenges within an industry aspiring to ensure that supply must meet demand at appropriate levels of quality at all times and locations across the electrical network. These challenges become more significant as the penetration of PV increases.

Energy storage is inherently valuable in a power system. However, direct storage of electrical energy and distributed small-scale storage have played only a limited role in most electricity industries. However, they have been widely used for off-grid applications. Growing penetrations of PV in grids will create a greater need for energy storage and new opportunities for distributed direct storage to play a valuable role in the industry. These opportunities include better managing end-user demand patterns and aggregated network flows, improving end-user reliability and power quality, and sharing the balance of system components between PV and storage equipment. This chapter explores these opportunities, highlighting the diverse range of potential value propositions from integrating PV and storage, identifying how these different values might be estimated for particular contexts, and providing suggestions on market arrangements to facilitate these economic opportunities' achievement [60].

4.2. **Concentrated Solar Power System**

- CSP systems offer significant economic advantages due to their unique capabilities and operational features: Cost Efficiency
- While the initial setup cost of CSP systems can be higher compared to traditional energy sources, their long-term economic benefits significantly outweigh the investment:
- Low operating costs: CSP systems require minimal ongoing expenses after installation, with lower maintenance and operational costs than conventional power plants.
- Stable energy prices: CSP systems provide stable and predictable electricity costs as fluctuating fuel prices do not influence them.
- Long lifespan: CSP plants have a projected lifespan of 25 to 30 years, providing a reliable energy source for several decades.
- Grid Reliability and Energy Storage
- CSP systems can enhance the reliability and stability of the electrical grid while enabling the storage of excess energy for later use, leading to:
- Renewable baseload power: CSP systems can provide continuous power supply through thermal energy storage, even during cloudy periods or at night.
- Grid stability and integration: The dispatchability and controllability of CSP systems help balance the grid and integrate other variable renewable energy sources, such as wind and photovoltaic solar power.
- Local Industry Development
- The implementation of CSP systems can foster local industry growth, create employment opportunities, and stimulate regional economies:
- Manufacturing and construction jobs: The installation and maintenance of CSP plants require skilled professionals to contribute to job creation and economic development.
- Supply chain development: The development of CSP projects spurs the growth of local supply chains for components and materials, supporting domestic industries.
- Technological innovation: CSP systems drive research, development, and innovation, leading to the creation of new technologies, patents, and expertise [61].

❖ ADVANTAGES OF PHOTOVOLTAIC SOLAR POWER SYSTEM

The photovoltaic cells are eco-friendly and provide clear green energy. At the time of electricity generation, photovoltaic cells do not affect greenhouse gas emissions. By this, it clears that non-hazardous to the environment.

- Availability
  Since solar energy is inexhaustible, it produces energy abundantly everywhere sunlight is. Smart energy network. The solar panels are handy for intelligent energy networks. Distributed power generation is the upcoming next-generation power network.
- Cost Effective
  Solar panels are cost-effective, and their cost may decrease significantly in the coming years. So, the future scope they are economically feasible, and sustainable growth [62].

❖ DISADVANTAGES OF PHOTOVOLTAIC SOLAR POWER SYSTEM

As we know, all renewable energy has intermittent problems except for wind energy because there is no sun at night and sometimes during the day due to cloudy skies or rain. So this makes solar panels less reliable in large areas. The installation of solar panels requires more space. So, selecting an area that occupies less space is not easy [62].

❖ ADVANTAGES OF CONCENTRATED SOLAR POWER SYSTEM

One of the main advantages of CSP is that it can generate electricity even when the sun is not shining, thanks to the thermal storage system. This makes CSP a more reliable renewable energy source than solar PV systems, which require sunlight to generate electricity. CSP also has a smaller environmental footprint than traditional fossil fuel power plants, as it produces no greenhouse gas emissions or air pollution. Additionally, CSP can be combined with other renewable energy sources, such as wind or hydropower, to create a more stable and reliable energy grid [63].

❖ DISADVANTAGES OF CONCENTRATED SOLAR POWER SYSTEM

While CSP has many advantages, it also has some disadvantages that must be considered. CSP systems can be expensive to build and maintain, requiring much land to accommodate the mirrors or lenses used to focus sunlight. CSP systems also require much water to generate steam, which can be challenging in areas with limited water resources. Finally, CSP systems can be less efficient than solar PV systems, as some sunlight is lost while concentrating it onto a small area [63].

❖ IMPLEMENTATION ISSUES OF PHOTOVOLTAIC SOLAR POWER SYSTEM

The higher panel temperature reduces the solar PV panel performance. The dust deposition on the PV panel reduces the power generation and increases the solar PV panel surface temperature, which may reduce the life of the solar PV panels [64].

❖ IMPLEMENTATION ISSUES OF CONCENTRATED SOLAR POWER SYSTEM

CSP is one of several new renewable electricity-generating technologies. However, CSP has high initial capital costs and complex technology deployment, a significant barrier to implementing CSP systems in many developing countries [65].

❖ FUTURE SCOPE OF PHOTOVOLTAIC SOLAR POWER SYSTEM

Research in photovoltaics is proceeding rapidly on many fronts. Some of these approaches are still in the early stages and far from being put into production, but they may become mainstream. Making a solar cell with several layers is possible since the band gap can be tuned by adjusting the doping. Each layer would have a band gap tuned to a particular wavelength of light. These “multi-junction” cells can attain 40% efficiency but remain expensive. As a result, they are more likely to be found on NASA spacecraft right now than on a terrestrial roof. The research behind solar energy is booming, too. Scientists are discovering new ways to decrease costs and increase the efficiency of solar panels and coming up with creative, impressive ways to generate power. Following are the futuristic developments in solar technology [66]
.

- Bionic leaf
- 3D printed solar-powered trees
- Perovskites
- Thin Film Solar
- Carbon-Based Solar Cells
- Colored solar panels
- Polymer Solar Cells
- Solar Concentration Technology
-

❖ FUTURE SCOPE OF CONCENTRATED SOLAR POWER SYSTEM

Despite its disadvantages, CSP has the potential to play a significant role in the future of renewable energy. As technology improves and costs decrease, CSP systems become more efficient and cost-effective. Additionally, CSP can help to address some of the challenges associated with other renewable energy sources, such as intermittent power generation and storage.

One promising development in the CSP field is using molten salt as a heat transfer fluid. Molten salt has several advantages over other fluids, including its ability to operate at higher temperatures and retain heat for extended periods. This means that CSP systems using molten salt can generate electricity for extended periods, even when the sun is not shining. Additionally, molten salt is more cost-effective and environmentally friendly than other fluids.

Another area of innovation in CSP is using hybrid systems, which combine CSP with other renewable energy sources such as wind or hydropower. These hybrid systems can help to overcome the challenges associated with each technology, creating a more stable and reliable energy grid. For example, wind power can generate electricity when the sun is not shining, while CSP can provide energy during periods of low wind [65].

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