**Open Access Research Journal of**
**Multidisciplinary Studies**
Journals home page: https://oarjpublication/journals/oarjms/
ISSN: 2783-0268 (Online)

OARJ OPEN ACCESS RESEARCH JOURNALS

(RESEARCH ARTICLE)

Check for updates

# TECHNOLOGICAL APPLICATIONS OF SOLAR CELLS

Zainab Amer Hefzi *

Department of physics, faculty of science, University of Babylon.
* Corresponding Author

Open Access Research Journal of Multidisciplinary Studies, 2026, 12(02), 032–043

Publication history: Received on 25 September 2026; revised on 02 November 2026; accepted on 04 November 2026

Article DOI: https://doi.org/10.53022/oarjms.2026.12.2.0045

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

## ABSTRACT

Solar cell, also known as photovoltaic (PV) cell, is a semiconductor device which transforms the solar energy into electrical energy based on photovoltaic effect. This work introduces an in-depth discussion of solar cell technology including working principles, constructional design, material types, efficiency considerations and various applications. It also investigates the importance of solar energy in meet the global energy needs and reduce greenhouse gas (GHG) emissions and contribute to sustainable development. The work has reviewed on technology advances which enable to enhance solar cell performance, cost decrease, and applications expansion into various areas including home, industrial, transport, agriculture and aerospace sectors. However, limitations of solar cell are its efficiency limit, dependent on the environment and storage problem. It also addresses these limitations of solar cell and prospects of future development of solar technology.

**Keywords:** P-N Junction, Photovoltaic (PV) Cell, Semiconductor Material, Thin-Film

## 1 INTRODUCTION

Solar energy is one of the most abundant and sustainable sources of energy available on Earth. With increasing concerns about climate change, fossil fuel depletion, and environmental degradation, renewable energy technologies have become essential. Among these, solar cells play a crucial role due to their ability to directly convert sunlight into electricity without producing harmful emissions.

Solar cells work on principles of semiconductor physics, where they convert photons into electricity using materials such as silicon. Over the past few years, significant advancements in material science and engineering have led to a decrease in cost and an increase in the efficiency of solar cells, and as a result, this technology has gone from a purely scientific endeavor to a widespread energy solution, used by people in both the developed and developing worlds [4–6].

The range of applications is varied, including large scale solar power stations, individual house roof-tops, small electronics, vehicles and satellites, all of which are testimony to the role that solar power now plays.

### 1.1 Research Problem

Even though there has been exponential development in solar cell technology with mass acceptance, there are certain inherent challenges restricting the technology. The efficiency of energy conversion is comparatively low compared to

conventional energy resources. Environmental factors like cloud cover, temperature fluctuations and dust accumulation significantly impact the efficiency [7].

High setup cost for the installation of solar panels and setting up the entire system and its infrastructure is also one of the critical issues that can be faced. Low operational cost may benefit but, at the same time, the initial setup cost will pose a challenge to many users. Solar energy cannot be produced during the night time and the same energy need to be stored and to cater to the demand of power [6, 8].

Long-term sustainability is of a great concern due to material degradation during time, as well as recycling problems. In this respect there is need for ongoing investigation for increasing the efficiency, decrease the price and making more durable and eco-friendly solar technologies [9, 10].

### 1.2 Objectives

The objectives of this work are:

- To illustrate the underlying principle of the operation of solar cells and of photovoltaic effect
- To study the structure and components of the solar cells
- To compare the different types of solar cell technologies
- To discuss the various application domains of the solar cells in the different sectors
- To discuss efficiency parameters and limitations of the performances of the solar cells
- To discuss advantages and disadvantages of solar power systems
- To research environmental and economic aspects associated with solar power systems
- To examine future prospects and advancements of solar power technology

This study endeavors to offer a comprehensive perspective on solar cell technology and its place in our current society.

## 2 METHODOLOGY

The work undertaken used a qualitative and analytical approach and was conducted following thorough examination of literature from both the scientific and technological communities. It was the aim of this work to produce an in-depth examination of solar cell technology and the work drawn from the scientific papers, renewable energy communities and industry journals provided valuable information regarding many aspects of solar cell technology.

This method consisted of:

- Literature Review - Comparison of previous and current research into the topic of solar cells including efficiency, technology and applications
- Comparative Analysis - Comparing the variety of types of solar cells available with their suitability to current technologies
- Data Interpretation - Looking at the efficiency of the devices and analyzing trends of development within the solar cell industry

The methods used were deemed to be the most efficient and appropriate to obtain accurate and reliable research results.

## 3 PHOTOVOLTAIC EFFECT

The photoelectric effect is the basis for this generation of electricity by solar cells. When light shines on a semiconductor, photons transfer energy to electrons, which are released to generate an electric current.

The operation of a typical solar cell is due to the presence of a p-n junction which results from the joining of a p-type and an n-type semiconductor material. An electric field at the p-n junction allows the separation of charge carriers (electrons and holes) which are driven toward the external circuit and contribute to electricity generation (Figure 1).

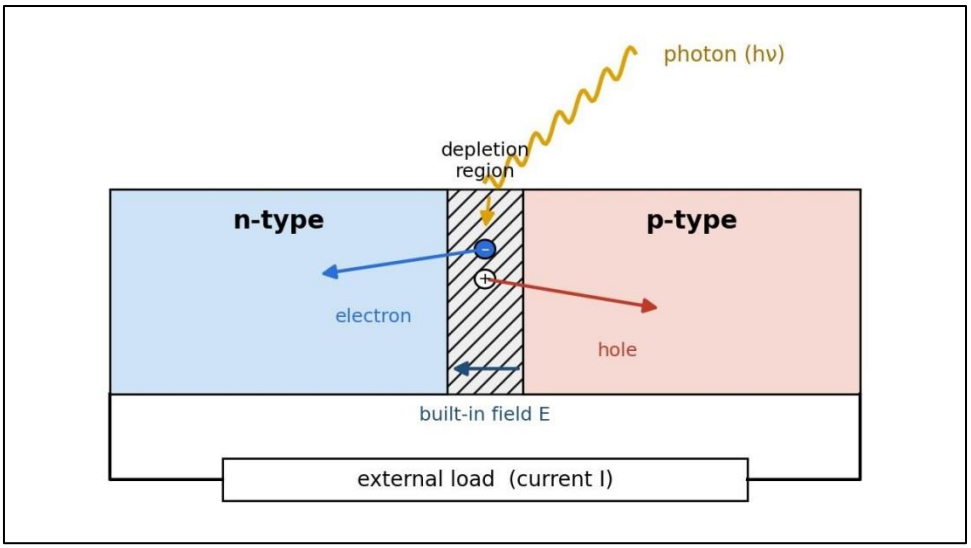



**Figure 1: Schematic of the photovoltaic effect in a p–n junction solar cell: photon absorption, electron–hole generation, charge separation by the built-in field and current through the external circuit.**

The nature of the solar cell makes it an extremely reliable and maintenance free energy device because it operates without moving parts. Material properties, light intensity and cell structure all affect the efficiency of the effect [1, 2, 11]

## 4 STRUCTURE OF SOLAR CELLS:

A solar cell is a semiconductor multi layer device that absorbs sunlight to produce electrical energy efficiently. The structure of solar cell is so designed as to maximize light absorption and minimize energy loss and enable electron-hole charge movement. Figure 2 shows the cross-section of a silicon cell and Figure 3 shows the layers of a complete module.

### 4.1 Main Components

Semiconductor Layer (p-n Junction) This semiconductor material is the essential component of a solar cell. A typical semiconductor material, like silicon, is made up of:

- p-type layer: the region where holes (positive charge carriers) are concentrated [11].
- n-type layer: the region where electrons (negative charge carriers) are concentrated [11].

When a p-type and n-type layer are joined together, the p-n junction creates an internal electric field that separates the charge carriers [1, 11].

Anti-Reflective Coating: The function of this layer is to minimize sunlight reflected by the surface of the solar cell and allows more photons to penetrate into the solar cell. If there is no such coating, a large portion of the energy provided by the sun would be wasted [12].

Metal Contacts (Front and Back Contacts):

- Front contacts: This element gathers up the electrons released by the sunlight.
- Back contact: This part completes the electric circuit.

It should achieve an optimum of conduction and shading [3].

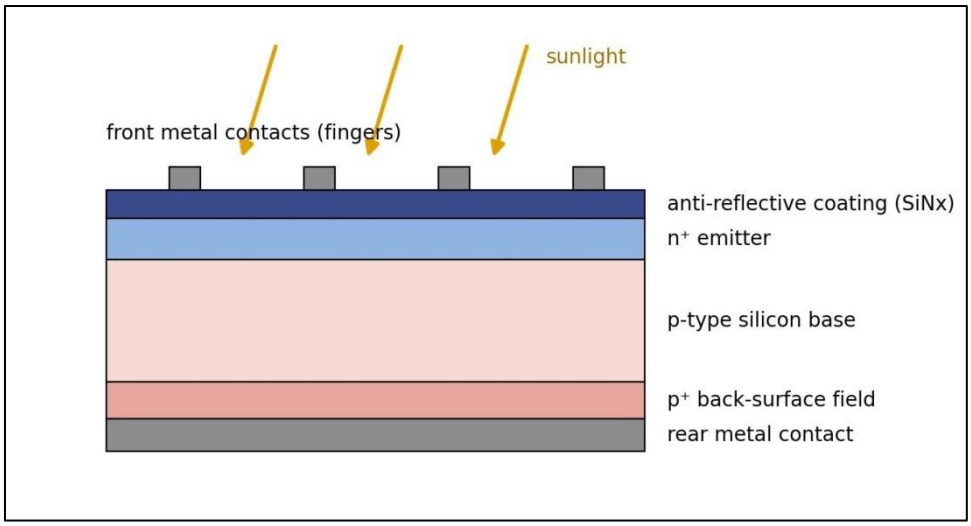



**Figure 2: Cross-section of a crystalline silicon solar cell: front contacts, anti-reflective coating, $n^+$ emitter, p-type base, $p^+$ back-surface field and rear contact.**

Protective Glass Layer: A transparent glass cover protects the solar cell from environmental damage such as dust, moisture, and mechanical stress while allowing sunlight to pass through [3].

Encapsulation Layer: A transparent polymer layer (commonly EVA) bonds the cells to the glass and the back sheet and seals them against moisture, dirt and mechanical stress [3].

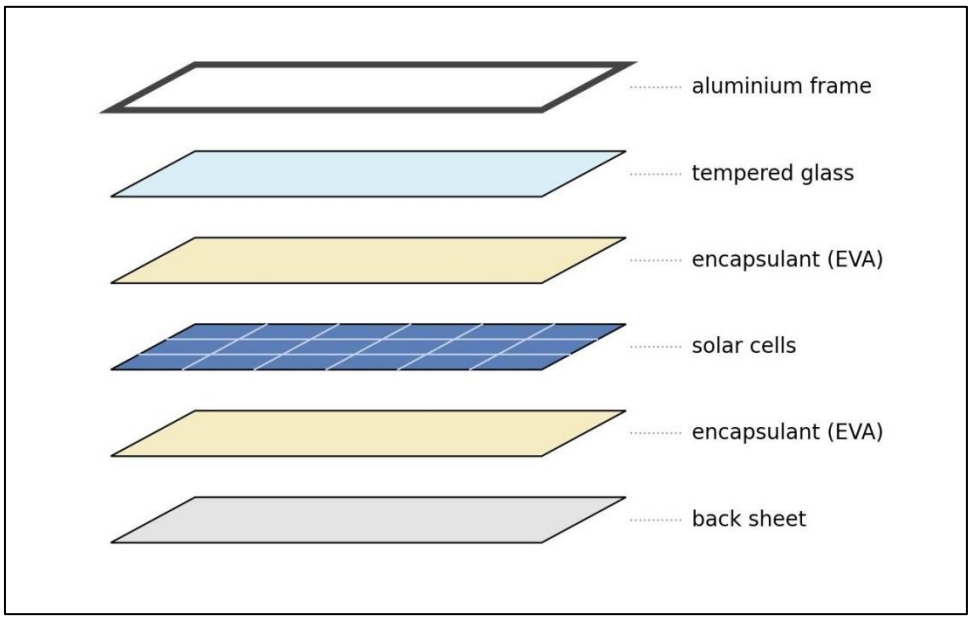



**Figure 3: Layer structure of a PV module: frame, tempered glass, encapsulant, solar cells, encapsulant and back sheet.**

### 4.2 Working Mechanism within the Structure

When sunlight incident on solar cell:

- Photons will reach and transmit through the anti-reflective coating layer.
- The energy of the photons will be absorbed by the semiconductor.
- Electron-hole pairs will be generated.
- Charges are separated by electric field at the p-n junction.
- Electrons are collected through external circuit for producing the electrical power. This structure is all integrated in order to enable energy convert and last in a long time [1, 2].

## 5 TYPES OF SOLAR CELLS

Solar cells can be classified in two ways: based on material used to fabricate them, and based on their manufacturing technique. Each category is beneficial on its own due to efficiency, cost, flexibility or intended usage.

### 5.1 Main Types

- Monocrystalline Silicon Solar Cells: As the name implies, these are built from one crystal of silicon, hence they have high efficiency and life-time, and are widely used for homes and businesses [3].
- Polycrystalline Silicon Solar Cells: These cells consist of multiple crystals of silicon; they are cheaper than mono crystalline but slightly less efficient [3].
- Thin-Film Solar Cells: These cells are manufactured by depositing thin films of photovoltaic material on substrates like glass, or plastic. They are light and flexible but less efficient than crystalline cells [13].
- Perovskite Solar Cells: These cells are newly developed technology and they are highly improving efficiency at low manufacturing cost. Still their stability and durability is issue [14, 15].
- Organic Solar Cells: Made from carbon based materials, cells are flexible and light but development is at low level since its efficiency is lower [16]. The layered architecture shared by perovskite and organic devices is shown in Figure 4.

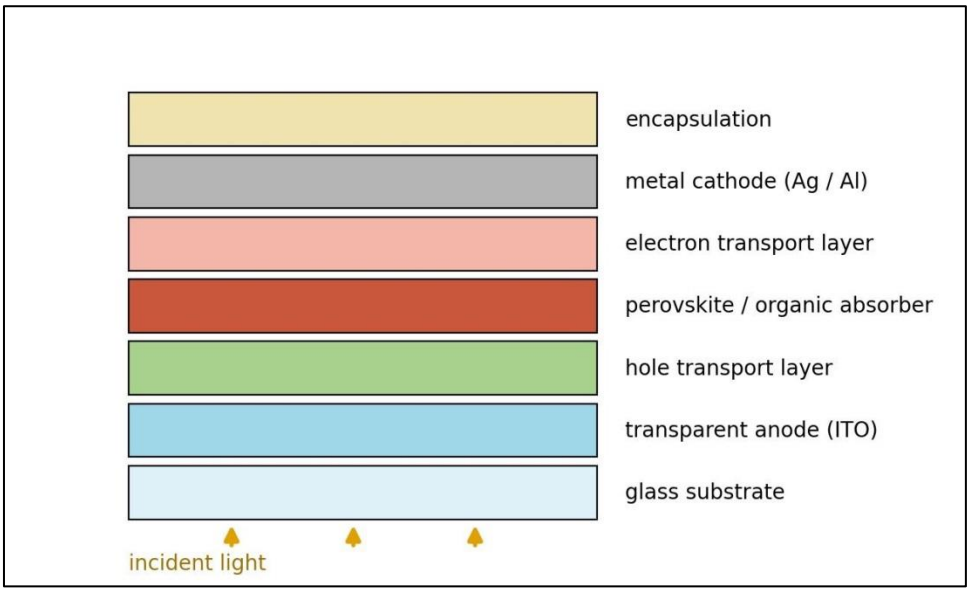



**Figure 4: Layered architecture of a perovskite/organic solar cell, from the glass substrate and transparent anode to the metal cathode and encapsulation.**

**Table 1: Comparison of Solar Cell Types [17]**

| Type | Efficiency Range | Cost Level | Lifespan | Key Advantages | Key Limitations |
|---|---|---|---|---|---|
| Monocrystalline | 18–24% | High | 25–30 years | Highest efficiency, durable | Expensive |
| Polycrystalline | 15–20% | Medium | 20–25 years | Lower cost, reliable | Lower efficiency |
| Thin-Film | 10–19% | Low | 10–20 years | Flexible, lightweight | Lower lifespan |
| Perovskite | 20–27% (lab) | Low | Developing | High potential, low cost | Stability issues |
| Organic | 8–12% | Low | Short | Flexible, eco-friendly | Low efficiency |

### 5.2 Discussion of Types

Type of solar cell to be selected relies on the application:

- Applications where high efficiency is essential (e.g., rooftop arrays): monocrystalline
- Cost critical application: polycrystalline

- Applications needing portability and flexibility (e.g., handheld devices, clothing): thin film or organic
- Next generation of solar cells: Perovskite
- The research into hybrid cells and multi-junction cells is emerging which combines materials and is designed to provide efficiencies higher than conventional limits [5, 17].

### 5.3 Technological Trends

- Improvement of bifacial cells, which capture light on both sides
- Integration of nanotechnology into solar cells, for enhanced absorption
- Use of artificial intelligence in optimizing the solar cells' performance
- Development of building integrated photovoltaics (BIPV)
- These areas are pushing the progression of solar cell development [18–20]

Applications of Solar Cells:

Overall the solar cell can be considered one of the most flexible forms of energy generation as it can be incorporated into many different applications, from large-scale power production to small handheld gadgets, due to the absence of moving parts. Figure 5 summarises the main application sectors.

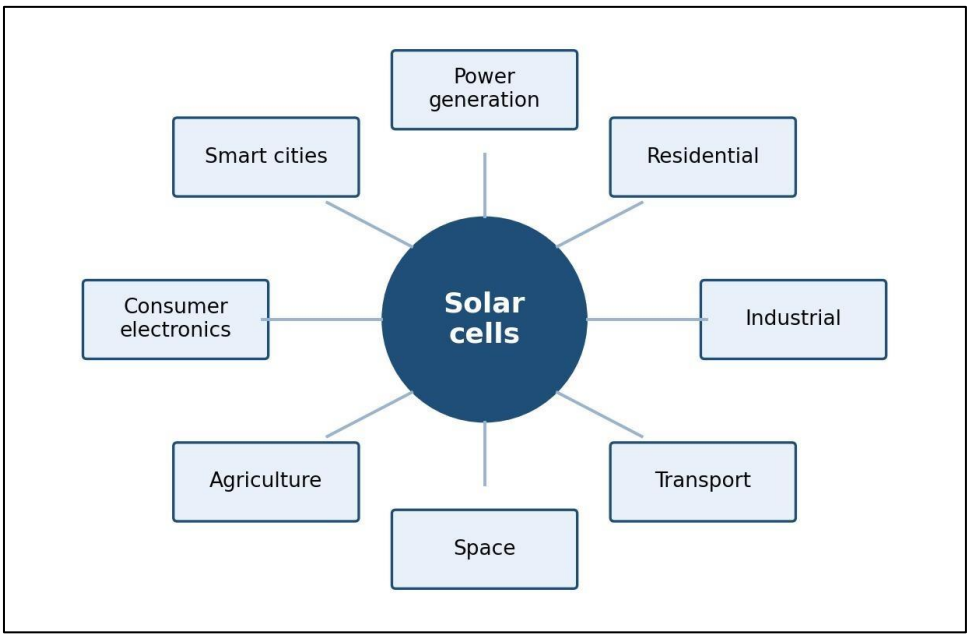



**Figure 5: Main application sectors of solar cells.**

### 5.4 Power Generation Applications

One of the largest uses for solar cells is for producing electricity in bulk for electrical grids. In such uses solar farms, also known as photovoltaic (PV) farms, utilize thousands of panels connected together in an electrical array to transform solar radiation into electrical power and feed it into national grids (Figure 6). The main reason these systems have become so widely utilized is that they:

- Allow nations to reduce reliance on fossil fuel dependence
- Reduce greenhouse gas emissions
- Offer sustainable energy options for an expanding global population

In many modern instances, the system includes energy storage capabilities so that it will also provide electricity when the sun is not present [4, 8].

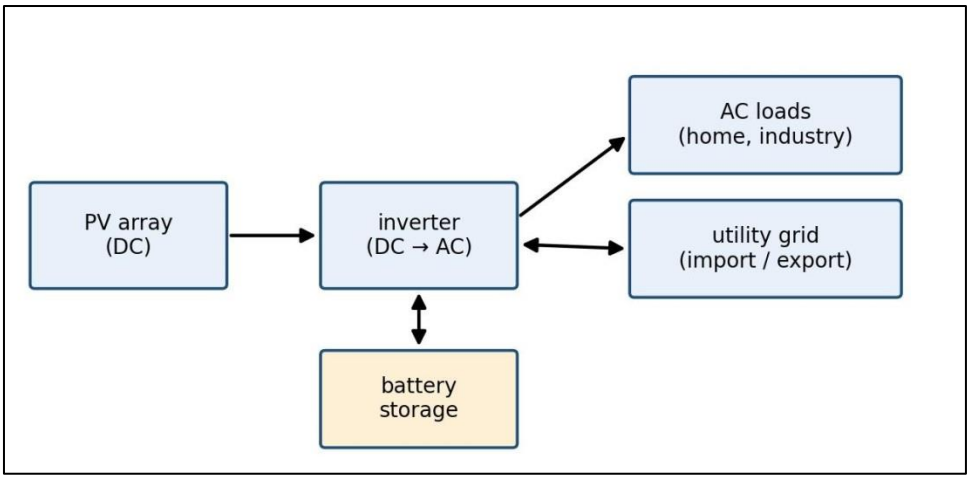



**Figure 6: Block diagram of a grid-connected PV system with battery storage.**

### 5.5 Residential Applications

Another common use for solar cells that has seen increasing adoption is within residences by having solar panels installed on rooftops. This method allows residents to have the power being produced be used by the household, so that their reliance on electrical utility providers decreases. This application of solar power provides its main benefits through:

- A reduction in the electricity bills that the home is receiving
- Enabling energy independence for the house
- An increase in the property value of the home
- In some areas excess power can be sent back into the grid via net metering. In recent years improvements in battery systems, especially Li-ion systems, have made this use more feasible [6, 8].

### 5.6 Industrial Applications

Factories need vast amounts of energy which makes solar power a desirable renewable alternative in order to reduce cost and emissions. Solar applications in industry use is demonstrated through:

- Electricity consumption in manufacturing and factories
- The requirements of warehouses and data centers
- Supply of energy in isolated sites in the industry sector.

Using solar technology helps industries achieve sustainability goals and comply with environmental legislation while at the same time reducing cost of energy in the long run [6].

### 5.7 Transportation Applications

Solar technology is more and more adopted by the transportation sector. Although there are still some prototype solar-powered vehicles under design and test, solar panels have been installed and utilized in electric transportation to complement it. Applications include:

- Powering electric vehicle charging stations with solar energy
- Supporting systems in electric vehicles and buses.
- Prototypes of solar powered cars and planes.

These developments help in the reduction of emission of carbon gas in the transportation sector [4].

### 5.8 Space Technology Applications

Solar cells are vital in space missions, which provide a long lasting and stable supply of power for various space applications:

Satellites powering, space stations operation, space exploration missions in the depth space, etc... In addition to this, the panels can generate power very efficiently due to no atmospheric obstruction which occurs in space. A multi-junction solar cell is often adopted in the space missions [3].

### 5.9 Agriculture Applications

Solar energy plays a great impact on agriculture especially in rural areas, such as solar energy powered irrigation, greenhouse supplied with power and drying and storage of crops. The solar-powered irrigation systems not only promote the crop productivity but also can replace the diesel generator for the supply of power in rural and remote areas [21].

### 5.10 Consumer Electronics

The solar cells are very often used in small electronic gadgets as portable power supplies that don't need to be plugged into mains power, for example:

- Solar-powered calculators
- Solar mobile phone chargers
- Solar powered outdoor lighting

These applications represent how easily adaptable the technology is for modern applications and it is easily integrated into a vast number of items, for many years, and is not limited by size [3].

### 5.11 Smart Cities and Infrastructure

The solar cells are essential in smart cities where sustainability is the priority. These applications can be split into different categories for example:

- Solar-powered street lighting
- Building integrated photovoltaics (BIPV)
- Smart grids and energy management systems

These systems increase energy saving in cities and decrease their impact on the environment [4, 19].

### 5.12 Integrated Application Analysis

This diversity in the application of solar cells throughout various sectors illustrates a couple of significant aspects of this technology. The three most commonly referenced points being:Scalability (applications range from small to grid-size applications),Decentralization (power is generated locally where it is used), andSustainability (less environmentally impactful than current energy technologies), all these positive points can be enhanced when issues of intermittency and energy storage are resolved [4, 8].

## 6 EFFICIENCY AND PERFORMANCE OF SOLAR CELLS

The solar cell efficiency (the fraction of incident solar power that is converted to electrical power) is another critical parameter that is widely used to gauge the performance of solar cells. The efficiency of a solar cell depends on the following intrinsic (material and structural) as well as extrinsic factors (environmental factors).

### 6.1 Key Factors Affecting Efficiency

Quality of Materials. High-purity semiconductor materials provide better charge carrier mobility and recombination loss is decreased [1, 7]. Temperature. Temperature does not favour higher efficiencies due to increased energy loss of the electrons. Sunlight Intensity. Higher irradiance increases power, but could cause additional heat losses. Angle of Incidence. Angle at which light is hitting the panel affects the efficiency of absorption. Shading and Dust. Even a small percentage of shading would result in large loss because of series circuits. Recombination Loss. Electron meeting hole instead of moving to external circuit causes the efficiency to be lower.

**Table 2: Factors Influencing Solar Cell Performance**

| Factor | Effect on Efficiency | Description |
|---|---|---|
| Temperature | Negative | High temperatures reduce voltage output |
| Sunlight Intensity | Positive | More photons increase current generation |
| Material Purity | Positive | Fewer defects improve charge flow |
| Surface Reflection | Negative | Reduces absorbed light |

| | | |
|---|---|---|
| Dust/Shading | Negative | Blocks sunlight and reduces output |
| Electrical Resistance | Negative | Causes energy loss in circuits |

### 6.2 Efficiency Limits

The Shockley-Queisser limit, or the theoretical maximum efficiency for a single junction solar cell, is about 33%. However, other types of solar cells, such as multi junction cells, are capable of going over this limit and can exploit different parts of the solar spectrum [22, 23].

### 6.3 Performance Optimization Techniques

Using anti-reflective coatings solar tracking systems cooling the system Advanced materials such as perovskites or tandem solar cells All these factors are implemented in the solar cells so that they produce more energy and more efficient.

## 7 ADVANTAGES OF SOLAR CELLS

Some reasons why solar cells are seen to be a suitable source of energy are the advantages that are listed below:Renewable source of energy: Solar energy is readily available and will not run out.Environmental friendly: There are no green-house emissions during operation of a solar system.Cheap operating cost: Once a solar system is installed, it doesn't cost much to operate or maintain it.Scalable: It can be implemented on anything from small electronic device to a power plant.Independence of energy: The world is less dependent on a grid, it depends on solar panels for energy.Silent operation: There are no noises produced by a solar system because there are no moving parts.

The above points show why solar cells are gaining such popularity and recognition worldwide [4, 6].

## 8 DISADVANTAGES OF SOLAR CELLS

In addition to the advantages of solar cells are disadvantages:

- High initial cost
- High initial cost for installation and the grid.
- Weather dependent
- Less efficient during cloudy/rainy weather.
- Need for storage
- Need of batteries for nighttime/insufficient sunlight.
- Space requirements
- Large scale deployment would require large land area.
- Issues with materials and recycling
- Recycling and waste disposal of solar panels is an issue.
- Efforts to overcome such problems is vital for development of solar energy systems [8–10].

## 9 ENVIRONMENTAL IMPACT

Environmental consequences for solar energy are much smaller when compared to fossil fuels. Solar power decreases carbon emissions, air pollution, and the need for finite resources.

- Positive Impacts
- Reduced greenhouse gas emissions
- Reduced air and water pollution
- Reduced consumption of natural resources
- Negative Impacts
- Land used to build large solar farms
- Use of resources in production (silicon, metals, etc.)
- Disposal/recycling of solar panels
- Overall the environmental advantages of solar power much outweigh its negative effects, this making it a central aspect of a sustainable future [24, 25].

## 10 ECONOMIC IMPACT

The Solar Energy Sector also benefits the global economy in many other ways:

- Job Creation-Jobs are created through manufacturing, installation and maintenance of the system.
- Cost Reduction-Through advancements in technology the cost of solar panels have been decreased over time.
- Energy Saving-Electricity bills of consumers and industries have reduced.
- Energy Security-The country can be independent from importing fuels.

In this way, the solar energy sector helps the country to be economically stable and develop an everlasting energy sector [4, 6].

## 11 FUTURE DEVELOPMENTS IN SOLAR CELL TECHNOLOGY

The solar cell industry is in constant evolution, striving for ever higher efficiency, lower costs, and wider implementation. It's likely the following technologies will play key roles in determining its future:

### 11.1 Perovskite Solar Cells

Perovskites are a class of materials that offer high efficiency at an affordable cost. They are manufacturable using inexpensive processes making them competitive alternatives to silicon, but issues with stability and long term reliability are yet to be resolved.

### 11.2 Multi-Junction Solar Cells

Multi-junction cells are constructed of layers of various semiconductors, each absorbing different light spectra and leading to significantly higher efficiency than conventional cells, especially in space.

### 11.3 Flexible and Wearable Solar Cells

Developments in thin film and organic materials have allowed for the construction of flexible solar panels, capable of being embedded into clothes and portable electronics, and shaped onto any surface.

### 11.4 Floating Solar Farms

By setting up floating photovoltaic (PV) systems on water bodies, less land is consumed and performance can be better due to the cooling effect of water [26].

### 11.5 Smart Solar Systems

By integrating AI and IoT in to these PV systems, it enables the real time monitoring, performance optimization and the predictive maintenance of solar systems. These trends are bringing the solar energy to a more convenient and better performing future [20].

## 12 RESULTS AND DISCUSSION

The findings of this review are organised according to the eight objectives stated in Section 3. Because the study is a qualitative literature review, the results are a synthesis of published evidence rather than of new experimental or simulation data.

Operating principle (Objective 1). Photovoltaic conversion rests on three steps: absorption of photons in a semiconductor, generation of electron–hole pairs, and separation of these carriers by the built-in field of a p–n junction (Section 5, Figure 1). The performance of any cell is therefore set by how well it absorbs light, how few carriers are lost to recombination, and how efficiently the remaining carriers are collected [1, 2].

Structure and components (Objective 2). A solar cell is a stack of functional layers: the p–n junction, an anti-reflective coating, front and rear contacts and, at module level, protective glass and an encapsulant (Section 6, Figures 2 and 3). Each layer addresses a specific loss or failure mechanism, namely reflection, resistive loss and environmental degradation [3, 12].

Types of solar cells (Objective 3). The comparison in Table 1 shows a clear trade-off between efficiency, cost and maturity. Crystalline silicon offers the best combination of efficiency and lifetime, thin-film and organic cells offer

flexibility at lower efficiency, and perovskite cells show the fastest efficiency gains but are still limited by stability [5, 15, 17].

Application domains (Objective 4). Solar cells are used from grid-scale power plants to rooftops, industry, transport, space, agriculture, consumer electronics and smart-city infrastructure (Section 8, Figures 5 and 6). Three features recur in all of these sectors: scalability, decentralised generation and sustainability. Their full benefit depends on solving intermittency through energy storage and grid integration [4, 8].

Efficiency and performance limits (Objective 5). Efficiency depends on intrinsic factors (material quality, recombination) and extrinsic factors (temperature, irradiance, angle of incidence, shading and dust), as summarised in Table 2. Single-junction cells are bounded by the Shockley–Queisser limit of about 33 %, which tandem and multi-junction designs can exceed [7, 22, 23].

Advantages and disadvantages (Objective 6). The advantages (renewable resource, no emissions during operation, low running cost, scalability and silent operation) have to be weighed against high initial cost, weather dependence, the need for storage, land requirements and end-of-life waste. Two of these drawbacks, cost and storage, are already being reduced: the cost of solar electricity has fallen by roughly 90 % since 2010 [6]. Degradation and recycling remain open problems [9, 10].

Environmental and economic aspects (Objective 7). Operating a PV system avoids the emissions and air pollution of fossil-fuel generation, while manufacturing, land use and panel recycling are the main environmental concerns [24, 25]. Economically, falling costs, job creation and reduced fuel imports support wider adoption [6].

Future prospects (Objective 8). Perovskite and multi-junction cells, flexible and wearable devices, floating PV and AI/IoT-based monitoring are the most promising directions. Their main open issues are long-term stability, cost and deployment at scale [5, 20, 26].

Limitations of the study. This is a qualitative review based on published literature; no new data were produced. The efficiency and cost values in Tables 1 and 2 are indicative ranges that change quickly as the technology develops, and should be checked against the latest efficiency tables when the review is updated [17].

Taken together, the results show that solar cells are a mature, versatile and increasingly affordable technology, and that their wider adoption now depends mainly on improving efficiency, stability, storage and recycling.

## 13 CONCLUSION

One of the crucial technology in developing renewable energy. The characteristic of solar cell (converting sunlight directly to electrical energy) provide a green, renewable and available energy.

From this study, it can be seen that solar cell are not only a very useful technology, but they are also very flexible and widely applied to houses power, power plants, spacecraft and other system. Although issues of efficiency, cost and storage of solar cells have yet to overcome, the materials and design of the solar cell are still continuing developed in the future.

Overall, solar cell is a key component for the clean and sustainable energy system. More research and investment is necessary in order to fully utilize its benefits [4, 5].

### 13.1 Recommendations

Based on the results of this study, the following recommendations are provided:

Increase Research & Development Investment from governments and organizations for the solar technology must be enhanced. Enhance Energy Storage systems R&D should be put on the affordable and high-efficient battery technology. Enhance Policy and Incentives for Solar PV installation Incentive from governments (i.e. Subsidies, tax reductions) to provide better benefits to install solar PV system can improve people's interest. Public Awareness Provide public education programs on the advantages and the application of solar PV systems. Enhance Solar panel Recycling Technology Sustainable practices are necessary to eliminate adverse environmental impacts during solar panel disposal and recycling processes. Promote Smart grid integration Smart grid could make use of solar PV electricity more efficiently and reliably.

## REFERENCES


[1] Nelson, J. *The Physics of Solar Cells*; Imperial College Press: London, 2003.

[2] Würfel, P.; Würfel, U. *Physics of Solar Cells: From Basic Principles to Advanced Concepts*, 2nd ed.; Wiley-VCH: Weinheim, 2009.

[3] Luque, A.; Hegedus, S., Eds. *Handbook of Photovoltaic Science and Engineering*, 2nd ed.; Wiley: Chichester, 2011.

[4] Haegel, N. M.; Atwater, H., Jr.; Barnes, T.; et al. Terawatt-scale photovoltaics: Transform global energy. *Science* 2019, 364 (6443), 836–838. https://doi.org/10.1126/science.aaw1845

[5] Polman, A.; Knight, M.; Garnett, E. C.; Ehrler, B.; Sinke, W. C. Photovoltaic materials: Present efficiencies and future challenges. *Science* 2016, 352 (6283), aad4424.

[6] International Renewable Energy Agency (IRENA). *Renewable Power Generation Costs in 2024*; IRENA: Abu Dhabi, 2025.

[7] Skoplaki, E.; Palyvos, J. A. On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations. *Sol. Energy* 2009, 83 (5), 614–624.

[8] Dunn, B.; Kamath, H.; Tarascon, J.-M. Electrical energy storage for the grid: A battery of choices. *Science* 2011, 334 (6058), 928–935.

[9] Jordan, D. C.; Kurtz, S. R. Photovoltaic degradation rates—an analytical review. *Prog. Photovolt.: Res. Appl.* 2013, 21 (1), 12–29.

[10] Xu, Y.; Li, J.; Tan, Q.; Peters, A. L.; Yang, C. Global status of recycling waste solar panels: A review. *Waste Manag.* 2018, 75, 450–458.

[11] Sze, S. M.; Ng, K. K. *Physics of Semiconductor Devices*, 3rd ed.; Wiley-Interscience: Hoboken, NJ, 2007.

[12] Raut, H. K.; Ganesh, V. A.; Nair, A. S.; Ramakrishna, S. Anti-reflective coatings: A critical, in-depth review. *Energy Environ. Sci.* 2011, 4, 3779–3804.

[13] Poortmans, J.; Arkhipov, V., Eds. *Thin Film Solar Cells: Fabrication, Characterization and Applications*; Wiley: Chichester, 2006.

[14] Kojima, A.; Teshima, K.; Shirai, Y.; Miyasaka, T. Organometal halide perovskites as visible-light sensitizers for photovoltaic cells. *J. Am. Chem. Soc.* 2009, 131 (17), 6050–6051.

[15] Park, N.-G. Perovskite solar cells: An emerging photovoltaic technology. *Mater. Today* 2015, 18 (2), 65–72.

[16] Hoppe, H.; Sariciftci, N. S. Organic solar cells: An overview. *J. Mater. Res.* 2004, 19 (7), 1924–1945.

[17] Green, M. A.; Dunlop, E. D.; Yoshita, M.; Kopidakis, N.; Bothe, K.; Siefer, G.; Hao, X.; Jiang, J. Y. Solar cell efficiency tables (Version 66). *Prog. Photovolt.: Res. Appl.* 2025, 33 (7), 795–810. https://doi.org/10.1002/pip.3919

[18] Guerrero-Lemus, R.; Vega, R.; Kim, T.; Kimm, A.; Shephard, L. E. Bifacial solar photovoltaics – A technology review. *Renew. Sustain. Energy Rev.* 2016, 60, 1533–1549.

[19] Heinstein, P.; Ballif, C.; Perret-Aebi, L.-E. Building integrated photovoltaics (BIPV): Review, potentials, barriers and myths. *Green* 2013, 3 (2), 125–156.

[20] Mellit, A.; Kalogirou, S. Artificial intelligence and internet of things to improve efficacy of diagnosis and remote sensing of solar photovoltaic systems: Challenges, recommendations and future directions. *Renew. Sustain. Energy Rev.* 2021, 143, 110889.

[21] Chandel, S. S.; Naik, M. N.; Chandel, R. Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. *Renew. Sustain. Energy Rev.* 2015, 49, 1084–1099. https://doi.org/10.1016/j.rser.2015.04.083

[22] Shockley, W.; Queisser, H. J. Detailed balance limit of efficiency of p–n junction solar cells. *J. Appl. Phys.* 1961, 32 (3), 510–519.

[23] Rühle, S. Tabulated values of the Shockley–Queisser limit for single junction solar cells. *Sol. Energy* 2016, 130, 139–147.

[24] Fthenakis, V. M.; Kim, H. C. Photovoltaics: Life-cycle analyses. *Sol. Energy* 2011, 85 (8), 1609–1628.

[25] Edenhofer, O.; Pichs-Madruga, R.; Sokona, Y.; et al., Eds. *Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, 2011.

[26] Sahu, A.; Yadav, N.; Sudhakar, K. Floating photovoltaic power plant: A review. *Renew. Sustain. Energy Rev.* 2016, 66, 815–824. https://doi.org/10.1016/j.rser.2016.08.051