

# A literature analysis of the mechanism, application, and future potentials of PV solar cells

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**Abstract.** With the exacerbated environmental issues and energy shortage, renewable energy is progressively accentuated for sustainable development. Solar energy is casted a striking light for electricity supply in human use. Accordingly, PV solar cells, devices storing and supplying electricity, are applied more extensively in multiple areas including residential usage, production, and facilities. Due to their renewable nature and multifaced applicability, humans are committed to invoke their potentials to more ameliorate reliance on fossil fuels. Through literature review, this article analyzes the essential operational mechanism of solar cells, compares attributes of different types of commonly used solar cells, including silicon-based types, thin-film types, organic types, among others, and discusses their application in various industries regarding future potential trend. Finding that P-N junction is indispensable for energy conversion within solar cells, traditional silicon-based solar cells are evolving through incorporating with organic materials, obviating inefficiency and vulnerability of solely used organic solar cells. Moreover, through cooperating with other energy types, PV solar cells supplement electricity necessary to diverse industries, considerably augmenting energy efficiency. However, future commitments requiring interdisciplinary human capitals and technologies are equally significant to increasing public awareness to further optimize solar cells usage. This article is instrumental in deepening comprehension of basic function of solar cells with their distinctive traits, serving as reference contributing to proper practices in future implementation sustainably.

**Keywords:** PV solar cells; mechanism; application; prospection.

## 1. Introduction

Humans have already exploited traditional energy sources such fossil fuels (e.g. coals, tars, and petroleum) extensively after industrialization for electricity supply and factors of production such as power plants continually providing heats for daily usage for residential areas. While taking advantage of such conventional non-renewable energy sources, we humans, starting from developed countries and spreading subsequently to a pervasive global range, gradually realized a multitude of shortcomings of these non-renewable energy sources: that is, pollutants such as sulfur dioxides and nitrogen dioxides contributing to acid rain, heavy metals discharged from mining spots causing abnormal agricultural outputs and bioaccumulation leading to diseases in humans and animals along with food web, and frequent carbon emission aggravating Greenhouse Effect, etc. Along with these environmental concerns are health issues constantly inflicted by various emissions, limited nature of such non-renewable resources that raises international concern of sustainability, and long-term cost to remediate those ecological, medical, and economic damages incurred by these established energy sources.

To address these problems, humans must turn to another pathway to develop energy use sustainably for a long-term benefit, and thus renewable energy sources drew attention around the world these years, with the most prevalently used one-solar energy. Solar cells are essential components responsible for energy storage and output, effectively responsible to converting, storing, and supplying electrical energy to human lives. The most defining characteristics of solar cells are their renewability and pollution-free attribute: they directly convert light energy continuously and sufficiently supplied by the sun into electrical energy through the Photoelectric effect, avoiding a series of chemical reactions related to the conversion of traditional energy sources into electricity,



thereby eliminating pollution and cost caused by these reactions while capitalizing on the permanent energy source for it-that is, the sun-to power disparate fields [1]. Moreover, their wide temperature adaptability, long lifespan, and environmental tolerance enable these batteries to operate in the most inhospitable desert and plateau environments within a broad temperature range of -40 to 85 degrees Celsius, making them a model application that ensures applicability while maintaining power generation efficiency. After 2020, with the iteration of technology, as seen in the accelerated industrialization, innovative types such as perovskite and thin-film batteries, as well as the strong market demand for solar cell assemblies, a large number of scientific research efforts can be more widely promoted to the applicational level for the innovative research and development of solar cells, achieving broader market promotion of energy as a commodity and production technology in economic trade, and pushing innovative solar cells to the large-scaled applications as a new benchmark for global sustainable development relying on these new energy sources [2]. However, public awareness and coordinate scientific efforts of solar cells are still needed in order to spread such technological achievements to a broader scope of people in the future.

Accordingly, this article will primarily focus on the functional mechanism of PV solar cells and their categorization predicated on their intrinsic and instrumental properties, and then explore the potential application for current and future use. Therefore, through reviewing the operational basis and attributes of these prevalent solar cells' usage driven by PN-junction, this article will provide pragmatic suggestions for marketized, broadly applicable utilization, forming the solid foundation of renewable, efficient, and sustainable development of the field of solar cells.

## **2. Operational mechanism of PV solar cells**

The operational mechanism of PV solar cells is predicated on the Photoelectric Effect [3], converting the energy source from the sun into electric energy directly through semiconducting materials, obviating the/ need of complex chemical reactions emitting greenhouse gasses or air pollutants. The functioning basis can be elucidated for following procedures.

### **2.1. Reception**

Photon absorption is the first step serving as the onset of the operation of solar cells, similar to raw materials for the whole functioning. Silicon crystal lattice-a common type of semiconductor-is prepared to receive the photons from the sunlight. When the photons reach the surface of silicon crystal lattice, providing that their energy can exceed the Band Gap of silicon [4], which refers to the minimum energy for the electronic transition from Valence Band to Conduction Band, thereby allowing for conduction, they are absorbed by silicon atoms.

### **2.2. Activation**

Activating the valence electrons is the consequence of the energy supplied by the absorption process, prompting valence electrons to get through the Band Gap into the conduction band and then leave the holes in their original orbits, thereby forming electron-hole pairs, charge carriers, imagining people pushed from the bus while leaving the seats. The upper side of the silicon crystal lattice will be doped with N-type loading dock while the lower side of it will be doped with P-type loading dock correspondingly for separation the freely-wandered electrons and holes left by them due to activation [5]: that is, the negative electrons from N-side activated will flow into P side while the positive holes from P-sides will flow into N-side.

### **2.3. Separation and Sorting**

During this process, a central sorting hub for the separating process is formed, called depletion region, as a result of the equilibrium of the flowing process activated. In fact, in this depletion region, owing to the difference of concentrations of N and P doped docks, no carriers present in this depletion region while fixed positive and negative ions in N and P sides respectively are immobile, untouched the

insulating depletion region-the balanced region. Then, as the positive ions-the holes-and the negative ions-the valences electrons already photoelectrically activated exert reactive forces on each other, an inner electric field in the depletion region-the region between congregations of positive and negative ions result, from N-side to P-side, which exerts forces accelerating the movement of electrons and holes.

#### **2.4. Current Formation**

As the accelerating process proceeds, the N-side will accumulate separated electrons while the P-side will correspondingly accumulate holes. Accordingly, the N-side will serve as a cathode producing a positive charge and the P-side will play a role as anode creating a negative charge, which consequently forms a voltage across the N-P junction. Under this circumstance, when connecting the N docks and the P docks, due to the voltage, an external circuit result. Through it, electrons from the cathode-the N-side-will be directly driven by the voltage to the anode-the P-side-in which they recombine with the holes, forming the current in which electrons flow [6].

#### **2.5. Continuous Operation**

As the sunlight providing photons with sufficient energy is absorbed by silicon atoms continually, energy supply of solar cells is ensured. Next, as the P-N junction proceeds sorting or separating work, accumulation of electrons and holes would be driven. Then, the voltage brought by the sorted cathodes and anodes prompts the external circuit, directly proffering electricity in an enduring way. When connected or incorporated to set solar panel collectively, such solar cells generally produce greater power [7].

Through photoelectrically formed current, PV solar cells are functionally operated, storing and supplying electricity without emitting pollutants, benefiting residential and industrial usage of electricity.

### **3. Common Categories of Solar Cells**

Disparate types of PV solar cells are meeting demands in different fields, utilized by engineers based on their respective characteristics and evolved by weighing their own advantages and disadvantages. There are several extant technologies of common types of solar cells, aligned with their traits attributed to their own properties behind. Noted, the following discussion will not cover all current usages of solar cells. Instead, it will proceed with representative solar cells showcasing common utilization of solar technologies and their evolving patterns from first generation-primarily silicon-based cells-to further advancements incorporating efficient, novel, and modernized technologies with the orientation of sustainability. Predicated on their respectively distinctive properties and the renewable and efficient energy outputs of PV solar cells, practices of solar cells are pervasive in diverse and increasingly extensive industries, generating electricity indispensable for human usage, strongly relevant to industrial production process, agricultural yields, residential power, transportation, even space. Indeed, multiple industries powered by solar cells are interconnected with the intrinsic energy conversion from solar energy to electrical energy, therefore heat, to transform energy sources into heterogeneous energy forms conforming to demands in different fields, supplementing, cogenerating, or superseding original energy use patterns among devices belonging to these industries. Nowadays, industries embodying solar cells are undergoing increasing innovations, aiming at fully exploiting solar energy for productive and sustainable energy usage, showcased in varied wise and efficient role in people's demanding production and living requirements played by these cells. Following typical cells promote people's living standards through making the use of their advantages while eschewing or diminishing their drawbacks.

### **3.1. Monocrystalline Solar cell (Mono-Si)**

Monocrystalline solar cells are of the most commonly used electricity supply among extensively electric equipment usages [8]. One monocrystalline solar cell consists of a continuous large solid plate sliced from large single crystal silicon rods without crystalized edges grain boundaries [9]. In most cases, monocrystalline cells are made of pure silicon, with purity more than 99.9%. However, apart from the necessary doping, which refers to the P-N doping, doped monocrystalline cells can be reached by adding materials such as copper, gallium, and selenium taking up the absolute minority of the concentration for an intact cell.

Monocrystalline solar cells are well-established for their high efficiency, and this type of solar cell has a performance ratio-a measurement of the efficiency of cells-of 0.63. This means that such cells can be practiced in a wide range of realm owing to its adequate power supply. Moreover, monocrystalline can resist to temperature changes, reported as only 2.3% output loss compared to 10.12% output loss of polycrystalline cells when exposing to ambient temperature approximately 33 degree Celsius, while the temperature reported for the monocrystalline cells is 2.4 degree Celsius below ambient temperature and for polycrystalline cells is 14.5 above ambient temperature, considerable showcasing the thermally resistible nature of single crystal structure for such cells. Additionally, as most monocrystalline cells consist of highly pure silicon, their structure tend to be extremely stable, allowing for stable electricity supply and longevity, thereby simultaneously lowering cost for maintaining relevant implementations and attrition. For their disadvantages, material losses present when producing monocrystalline cells as slicing single crystal rods would cause leftover materials cut from square sheets. Another productional cost is the crystal pulling process, which likely cost extra energy.

### **3.2. Polycrystalline Solar cells**

Polycrystalline solar cells are essentially made possible by Siemens process-a process involving distilling silicon compounds, decomposing them into trichlorosilane further combining with hydrogen gas in temperature approximately 1100 degree Celsius, and purifying them-and fluidized and metallurgical purifications are adopted in some cases, too. Implementing multilayer doped silicon technology and pouring methods for direct ingot casting, the selectivity of electrons is enhanced and the cost for production set polycrystalline solar cells apart from monocrystalline ones. For the grain boundary, the polycrystalline cells consist of multiple grains without a fixed orientation separated by grain boundaries, which account for the transitional and recombinational regions in the silicon lattices, regions distinctive for polycrystalline cells. Both the polycrystalline and monocrystalline solar cells are doped with P-N junctions, demonstrating their utility as the central component for solar electric formation.

For the polycrystalline cells, they indeed can save the energy input for their production through the pouring method, and less internal electricity is dissipated for polycrystalline solar cells [10]. Thus, the lower cost of production makes polycrystalline solar cells to be more extensively manufactured and implemented. Nonetheless, as mentioned in 2.1, the weaker resistibility towards temperature means that polycrystalline should be set up in areas without erratic temperature fluctuations. Moreover, polycrystalline cells are more prone to attrition due to their lesser pure nature. According an experiment comparing the mechanical efficiency of monocrystalline and polycrystalline cells, the best efficiency is 14.95% for the former one while 13.07% for the latter one, indicating the relatively modest position of polycrystalline cells regarding their efficiency of electricity production.

### **3.3. Thin-film solar cells**

Thin film solar cells are actually representative of second-generation solar-driven devices [11]. A thin-film solar cell has substrate generally made by plastic, glass, and metallic materials, which are capable of photovoltaic activation, and depositing one or several thin layers onto these substrates. Still adopting P-N junction, thin-film solar cells also employ transparent conducting coating and

antireflecting coating on their top to reduce losses of solar energy received and augment the efficiency of solar absorption and therefore conversion in the P-N junction. Most prominent as thin-film cells, the thickness of films can vary in a technologically noticeable range-from a few nanometers to tens of micrometers-but still remains its collective strength-traditional silicon solar cells typically have wafers up to approximately 200 nanometers that are representative of first-generation solar cells.

Accordingly, the trait brought by the thinness of such thin-film cells involving lower weight, fewer special occupations, and lower received resistance (drags) enable the flexible application in various fields whereby portable, light, and adaptable solar devices can be installed, remarkably practicable in transportation or portable mobile devices [12]. Flexible structure indeed corresponds to expeditious application, but thin-film solar cells generally have comparable unassuming efficiency than those first-generation pioneers. Hence. The trade-off between adjustability and efficiency is still under hot debate even though modernized technologies are elevating the potential of thin-film cells.

### **3.4. Organic solar cells**

Organic solar cells are among the third-generation solar cells that hold a relatively new status in the history of solar-driven electricity generation. For an organic solar cell, it consists of a top electrode made of metallic materials, and it contains a transparent conducting electrode, which constitute the electronically conducting layer. Moreover, a layer consisting of conjugated polymers made by organic materials plays a role as semiconductor. Through the bandgap characteristics of these organic materials, light with different wavelength can be absorbed on this layer, covering the range of 300-1100 nanometers. In addition, the functional layer is also a crucial component for organic cells, whereby the anodes and cathodes interlayers are present, responsible for the transmission of electrons and holes driven by organic polymers in this case, functionally analogical to the P-N junction extensively used in silicon-based cells. For the external coating, organic solar cells generally adopt glass or PET coatings to serve as protection of external temperature changes and guarantee the transparency for light to get through [13].

For the organic solar cells, they indeed have their unique advantages: Firstly, the pliability brought by solution method make them highly adjustable in multiple scenarios, with their intrinsic pliable nature offered by the polymers used and the instrumental conditions of lower temperature during production. Secondly, the reasonable cost of manufacturing of organic solar cells is also conspicuous since organic materials can be processed in a few steps chemically with artificial synthesis, precluding the need for thousands of procedures involving extreme temperature and pressure to process silicon-based cells. Consequently, the time saved, consumption of raw materials, input of human capitals and labors ensure the position exclusively unique to organic matters. Also, compared with toxicity intrinsically existing in perovskite [14] and heavy metals, organic solar cells can be biological decomposed in natural environment without pollutants emitted or released when disposing organic wastes, conforming to the notion of sustainable development that ecological footprints of production in this case can be considerably ameliorated. For the disadvantages of organic solar cells, precisely because their organic nature, these materials are more susceptible to erosion caused by intensive sunlight, humidity, and oxygen, and the acidic matters in their coatings and photo-receptive layers compromise their longevity when functioning in long term, burdened with costs for maintenance. Furthermore, compared to orthodox silicon-based solar devices, organic cells have limited scope of light absorption, leading to a comparable lower efficiency of energy conversion. Lastly, due to their environmental sensitivity, large-scale commercialized application would frequently serve as an obstacle: when implementing organic solar cells in plateaus where intensive sunlight is prevalent and humid areas suffering from intensive precipitation leading to fraught moisture corroding the sunlight reception layer, undermining the range to which organic solar cells can be applied.

### 3.5. Other types

Apart from these representative typical solar cells, diverse other categories of solar cells are developing as well, supplementing the realm of solar-driven technologies in various applicable scenarios.

Dye-sensitized solar cells, belonging to thin film solar cells and third generation of solar-driven devices, are driven by the energy conversion between anodes and electrolytes in a semiconducting way, mimicking natural light absorption to perform work. Through absorbing photons, dyed molecules activate electrons while the electrolytes are responsible for transmission of holes, generally equipped with conducting glasses to catalyze the transmission. Low in producing cost, rolling-print technique offers an expeditious method to manufacture such solar cells. Nonetheless, the majority of light they absorb is visible light, undermining their efficiency of energy utilization, and therefore energy conversion and generation. Moreover, liquid electrolytes are easily volatile, making such cells challenging to be applied under every weather condition [15].

Hybrid solar cells, incorporating organic and inorganic materials, as the organic materials absorbing photons transport holes and donate electrons while the inorganic components transport electrons and accept holes. Such solar cells tend to yield higher efficiency than respectively application of organic and inorganic solar cells. For their drawbacks, as they incorporate both organic and inorganic materials, maintaining both would cost an increasing amount of money, while simultaneously the organic (donor) portion of the cells exposed to acidic or humid environments would cause abrasion on the surface, leading to compromised energy conversion rate.

Perovskite solar cells are also a mass component in the family of solar devices. They consist of the pad generally made by glass to allow for light going through and base supported for cells, transparent conducting layer typically made by ITO or FTO [16], electron transmission layer and hole transmission layer for the external current formation, the essential light absorbing region where perovskite materials are installed, and the metallic electrons incorporating metallic coating to form the circuit with the transparent layer. Perovskite solar cells are also representative of the third generation for solar cell advancement. In fact, perovskite cells reach both the standards of high efficiency and low cost, standing out among other newly emerging devices like organic cells discussed before. Moreover, their resistible nature towards nearly every environment with disparate light intensity and low energy consumption when produced enable fast manufacturing of such cells. However, the toxicity of lead is able to result in nervous disorder, posing a potential of nervous diseases for labors working closely with their production and their babies' malformation. Economically, the easily decomposed trait of the organic materials for holes' transmission region and the aggravated decomposition of perovskite when exposed to intense sunlight would undermine their efficacy in long term.

Apart from these discussed types, there are also many differently functional or made PV solar cells serving as their unique roles in heterogeneous niches among diverse fields, including easily tuned quantum dot solar cells superseding silicon with copper-based pliable materials, nanocrystal solar cells with substrates made primarily by silicon or organic matters to convert sunlight fully, or biohybrid solar cells mimicking natural photosynthesis for green, renewable, and efficient generation of electricity. From the relatively premier silicon-based cells to incorporation of organic or biological traits to broadly applicable commercialized ones, the evolution of solar cells demonstrates not only the ever-changing trend from pure output towards sparked creative electricity generation with sustainability but also people's increasing reliance on solar generated electricity, corresponding to their augmented share of total electricity and power generation.

## 4. Application

Predicated on their respectively advantages, PV solar cells are implementing pragmatically in various realms, functioning well to cater to demands of people versatily.

#### **4.1. Production**

Silicon-based solar cells, as one of the most orthodox solar devices, are extensively used in industrial production by implementing large-scale solar panel on the roofs of workplaces, connecting solar cells storing electrical energy converted by P-N junction built-in with inverters transforming direct current prompted by the external circuit to alternating current with 220V/50Hz. Then, electricity inverted can serve as monitoring device instantly reporting streamline working as well as temperature, humidity, and pressure to avoid malfunction or even accidents in factories. Apart from monitoring, spinning machines in textile industry, processing and packaging machines in food industry, heating machines for mining processing...all these industrial practices demonstrate the usefulness empowered by renewable solar energy.

#### **4.2. Agriculture**

In agriculture, solar cells enable multifaced agricultural benefits. Firstly, 3-dimensional agriculture is enabled with the function of ecological preservation since solar panel would provide scaffold supporting species adapting to different sunlight intensity to thrive while reserving water, namely humidity and water needed for plant species to grow, under the panel. Simultaneously, the electricity collected by solar panel can power farmers in distant regions from central urban areas where comprehensive powering station is built, saving cost of transporting electricity from such areas, thereby reaching a dual effect on energy utilization and agricultural possibility. Moreover, greenhouse relying on solar energy can be primarily applied in zones where sunlight intensity is sufficient while other factors such as stable heat or water abundance are uncertain such as plateaus. In these greenhouses, solar energy absorbed during daytime is stored on cells beneath, used subsequently for natural light simulation and thermal control deployed both by the light and water to satisfy crops' growing environments. The seasonal broad applicability of greenhouses eschews the unwanted low yields during temperature drops, especially in winter, ensuring continuous cultivational growth regardless of seasonal changes. However, during winter times, if solar radiation poses a lower-than-required intensity, other energy sources should be cooperated with solar panel to allow for crops growth, renewably wind energy during winter, which generally synchronizes with intense, high-speed winds able to supplement energy lacked by solar sources.

#### **4.3. Architecture**

In architecture, solar panel would be installed on the outer and top surface of residential buildings, or incorporated with glass transparent enough to absorb solar radiation laterally, thereby supplementing extra energy supply in these buildings, serving as auxiliary energy storage when natural gas system malfunctions. Furthermore, with solar panel serving as coating, the durability of buildings would be enhanced through reduced exposure to sunlight and wind, maintaining the stability of constructions while proffering an enriched energy budget. Given that solar cells suffer from shortages during nighttime, alternating pattern of electricity supply can be practiced for residential areas where overall demand for electricity is not extremely overwhelming for such patterns. Namely, during daytime, electricity from grids guarantees abundant electricity supply for daytime work, while during nighttime, stored electricity in solar cells can be invoked from power box, reaching the maximum utility of multiple energy sources. Solar energy is also a contributing component of alternating electricity transmitted in grids, and thus residential areas adopting both electricity from national grids and installed solar panel would take a full advantage of solar energy sources, weakening reliance on traditional powering supply bestowed by combustion of fossil fuels.

#### **4.4. Transportation**

Transportation may seem have nothing to do with solar cells, but with the notion of sustainable development, possibility of commuting powered by them is sparked. Solar-powered vehicles installing panel on their car roof are being innovated and applied commercially. A typical solar-powered car includes solar roof connected with batteries and then chargers connected in series or

parallel with converter in the front and the generator behind, which respectively connect with motor and reservoir, and the reservoir is connected with the engine. Thus, the source of energy supplied to the motor and the engine is attributed to and transmitted from the sun, obviating carbon footprint and air pollutants emitted during energy collection and powering process. Concurrently with the advancement of solar-powered vehicle, facilities encouraging its usage are being constructed, predominantly built as solar charging stations. Nevertheless, frequent charging when driving such vehicles means that drivers are burdened with concerns with electricity shortages and time consumed on searching for charging stations, posing a complexity in comparison with established traditional cars powered by fossil fuels.

These applications illustrate the broad applicability of PV solar cells, ubiquitous in nearly industries requiring electricity supply to function.

## **5. Future developmental prospects of PV solar cells**

According to disparate mechanical and applicable traits of solar cells aligned with human's intense urge to sustainably develop, innovative promising potentials for solar energy usage is imminent.

Departing from conventional notion of electricity generation for residential areas exclusively, generalist among heterogeneous domains is what solar cells are playing. Considerably, electric vehicles powered by solar cells are attached greater attention, shown as increasing construction of charging stations. Monitors powered by solar cells are applied in manufacturing and mining regardless of their specific categories of production. Moreover, solar panel incorporating both organic and inorganic materials guarantee both efficiency and pliability, easily installed in industries that have not been thought with solar cells, including telephone watch conferred with the portability from soft and easily bent coatings. Thus, extensivity and cross-industry orientation are the growing accentuated trend of solar cells use. This, in turn, required human capitals from interconnected disciplines to cooperate to take the advantage of different academic domains to benefit a widened range of solar energy users.

Innovation is also an essential component of future prospect of solar cells. Sustainability offers both opportunity and obligation of innovative solar devices since its environmentally friendly standards guide the broad direction of utilize renewable energy sources while refining the specific requirement gradually weakening the reliance of traditional-in other words, orthodoxly reliable-energy sources. Titanium-selenium photovoltaic material innovated as hardened building use of solar cells bestows both generativity and durability, researched by University of Tokyo. Flexible laminated solar cells explore the way portability and adaptability confer solar devices that can consequently be implemented on each side of commercial or residential buildings, precluding the conventional notion limiting solar cells to roofs or large, even plains. Therefore, innovation is what makes convenient experiences applied indeed in multiple aspects in people's living. Different from silicon-based heavy, inflexible, and costly electricity, light, adjustable, and multifunctional materials delved sincerely by scientists are trying to refine the expeditious practice of solar energy, thereby promoting the future innovative orientation for human energy needs.

Coordination is also indispensable for potent system based on solar cells. In fact, we cannot discount issues distinctive for solar devices such as nighttime energy shortages and organic device attrition. Therefore, coordinating solar cells with other types of electricity supplies makes a difference aiming at circumventing these sticky troubles. For example, in regions where winds are sufficient blowing with adequate exposures to sun, wind turbines and solar panel can be constructed in an interlaced way, while sunlight can be absorbed with enough wide spaces by solar panel and wind in the air can propel blades generating electricity within the windmill. Underneath the ground are the solar cells storing both energy input converted from solar panel and turbines, fully exploiting the geographical advantage (climate, evenness, and soil condition). Hence, when cloudy, energy stored from windmill can temporarily supplement the void suffered by solar panel to power local towns and villages, and during days winds are intense or sunlight is abundant, extra energy is stored on extensively

implemented solar cells, coordinately forming a system proffering stable electricity benefiting nearby regions. From this coordinate application, solar energy is utilized aligned with advantages of different energy types, demonstrating the future significance of coordination of energy interconnected usage.

Ultimately, marketization and generalization would serve as obstacle but obligatory mission ought to be shouldered by current solar cells researchers and human capitals in marketing areas, aiming at spreading progressively advancing solar devices to equip regions with a robust population base. The dearth of specialized agencies promoting selling of solar devices makes them disadvantaged in competition with other energy sources, especially in developing countries primarily relying on fossil fuels. During production, the intermittent nature of solar devices and cost involved often burden people in most nations without enough technologies to expediently sustainably produce commodities and equipment in various industries with tough trade-off between short-term economic growth and concerns and sustainability, and therefore how would large-scale commercialization to be realized without sturdy economic base? From an educational perspective, in fact, subjects in university curricula are also in an experimental stage to straddle the boundary among energy use and orthodox marketing majors, expected to be more interdisciplinary. Equivalently relevant, people in rural regions without high-level educational background are suffering from dearth of knowledge relevant to apposite energy usage and essential disciplinary knowhow about science. Accordingly, people in these poorly educative conditions are unlikely to embrace innovative transition and construction of solar cells among other renewable energy types. Concurrently, these groups of people tend to overlook long-term and sustainable developmental standards, shown as deep-rooted reliance on traditional cars driven by fossil fuel combustion that retards the popularization of EVs and the destruction of wind turbines to enlarge their cultivational fields even though these wind-driven devices would not block sunlight necessary to crop growth. Thus, the lack of education is a considerable barrier for the generalization of solar cells and other renewable energy types. While generalizing solar cells may seem ideally the next step in the near future, an increasing accentuation of breaking economic and educational obstruction should be established: in other words, raising public awareness and strengthening industries championing solar cells usage would be the absolute prerequisite for healthy future developmental trend of PV solar cells.

## **6. Conclusion**

Along with the extended realm of energy usage, sustainability is increasingly playing a tremendous role considering extant energy crisis faced by people all over the world. Through this analysis, finding that, PV solar cells are therefore attached significant mission to transform from traditional unsustainable banality of energy use to sustainable reliable energy storage, efficiently converting solar energy directly into electrical energy through separating process conferred by P-N junctions. That is, the external current formed within solar cells is driven by electrical potential to obviate chemical reactions casing pollutants. The sun providing continuous energy sources is increasingly attracting passionate scientists to appreciate and gain the value of sustainable energy supply of it. General types of solar cells have their own traits. Specifically, silicon-based monocrystalline and polycrystalline solar cells are facing the trade-off between efficiency and high costs during production while the intermittent energy conversion is also annoyingly inflicted by thick clouds. Organic solar cells having minimum environmental concerns due to its biological decomposability while the acidic humid conditions often pose risks of attrition and compromised efficiency to them. Thin-film solar cells indeed abate the costs burdened by producers and offer pliable, flexible, adjustable nature to be installed in complex constructions, but their efficiency is also in an experimental stage, waiting for breakthrough. Other solar cells encompassing dye-sensitized and hybrid solar cells are also constrained by either limited absorbing wavelength of light or dual vulnerability incurred by embodied organic and inorganic materials. In comparison, perovskite solar cells, also having potential of toxicity due to lead in their components, are leading the balance between high-efficiency and large-scale affordable cost, and scrupulous use of them seems promising as long as the toxic nature of them could be inhibited from exposing humans frequently. These solar cells are strikingly performing in

diverse realms, pervasive in productional monitoring and massive electricity supply, flexibly installed to power residential areas with nimbly adjusted solar panel, providing greenhouses and cooperative energy use in agriculture for attuning conditions mimicking natural growing environments, empowering vehicles through solar energy collection to drive the motor and engine, among other ranges of basic human production and living. Taking advantage of their respective attributes, solar cells are gradually serving as societal driver that benefit the public while retaining sustainable feature. Thus, to fully utilize solar cells, people still need to coordinately recognize the interrelation among different energy types, innovatively incorporate solar cells with other powers, and spread public consensus and commercialized propagation of solar cells, with committed scientists and human capitals from relevant disciplines to coherently reach a further sustainable future.

This literature review is meaningful in construct the basic comprehension of operational and applicational extant situations of solar cells for people aspiring to major in or work in relevant fields, sparking their ideas when considering future accomplishments powered by incorporated, hybrid, and productive solar cells. For engineers and scientists, this article can provide references for further developmental orientation for solar cells, aiming at optimally advancing the forte of disparate solar cells types. Currently, insights into mechanism and operation of solar cells can help to publicize more human capitals to start from the basics, and to lay the solid foundation of public educational resources of solar energy. In the future, the instrumental developmental possibility can propel interdisciplinary forces pushing this relatively newly established energy source to a higher stage, progressively lessening the reliance of orthodox unsustainable energy use, conducive to reaching low footprints and modernized sustainable ushered by solar-powered devices.

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