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Overview of Renewable Energy Power Generation and Conversion (2015-2023)

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ABSTRACT

This paper successfully reviewed the renewable energy trend from 2015 to 2023 based on investment, power conversion and future prospect. From the review it was observed that solar energy is progressively taking the lead as the cleanest energy generator followed by the wind turbine since 2019-2023. It also detailed the overview of solar photovoltaic technologies, photovoltaic conversion Efficiency Enhancement and the solar photovoltaic generations which showed that China is the most invested country in renewable energy followed by European union. From this paper it was clear that the renewable energy research trend has shifted to third generation solar photovoltaic (perovskites) and power conversion efficiency enhancement (Maximum Power Point Tracking). Perovskites as the third generational solar cell gives the best energy conversion due to its absorption coefficient, exceptional carrier mobility, high dielectric constant, tunable bandgap, materials abundance and as such recommended for solar installers and other PV designer.

Keywords: Solar Photovoltaics, Renewable Energy, Conversion Efficiency, Perovskites, MPPT

INTRODUCTION

The Covid-19 pandemic and its effect to the global energy crisis have provided a significant boost in clean energy sector. The 21st decade quest for clean and safe energy is increasing everyday with improvement in technology. The estimates for 2023 (2023e) with the data for 2021 annual clean energy showed that there are 9% increase in the renewable energy investment compared to fossil fuels. This showed that about 2.8 trillion USD will be approximately invested in energy in 2023 and more than 1.7 trillion USD will be invested in clean energy, including renewable power, nuclear, grids, storage, low-emission fuels, efficiency improvements and end-use renewables and electrification. Hence, the remaining 1 trillion USD will be invested in unabated fossil fuel supply and power, of which around 15% is to coal and the rest to oil and gas. Five years ago this ratio of fossil fuel to clean energy was 1:1 but in 2023 the ratio will be 1:1.7 which showed that Clean energy investments have been boosted by a variety of factors. These include improved economics at a time of high and volatile fossil fuel prices and as well as enhanced government policy support [1], [2] One of the major causes of shift from conversional sources of energy generation to renewable is the problem of the depletion of the ozone layer caused by the excess concentration of CO_2 in the atmosphere [3] [4]. Therefore, humankind is looking for an alternative energy sources like solar and wind for effective and reliable energy that is harmless.

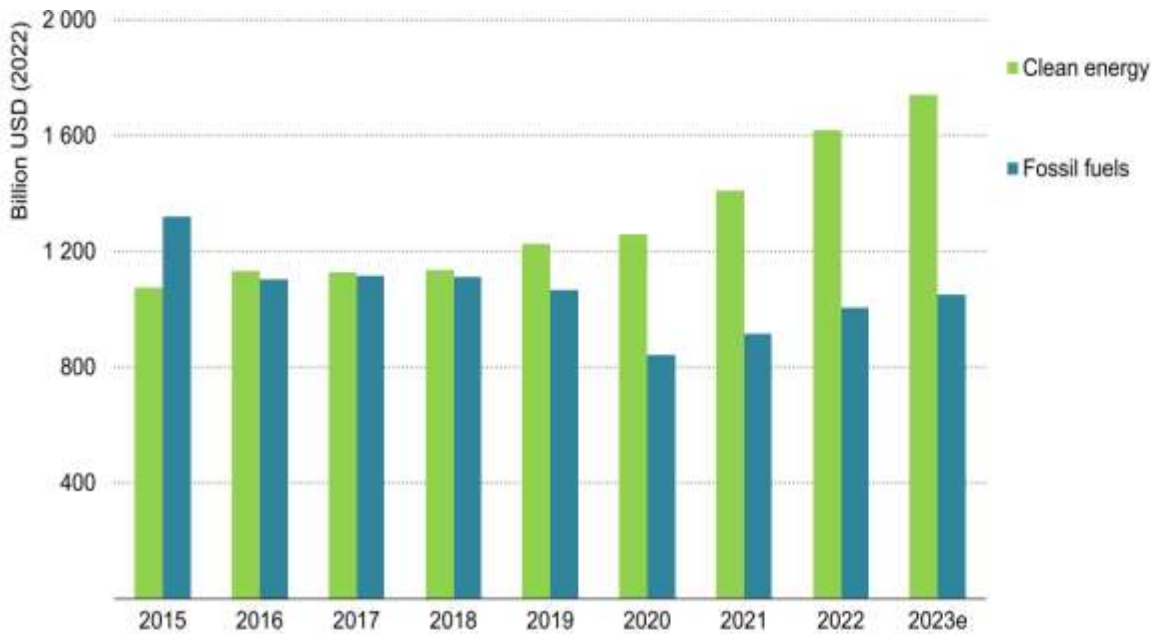
Types of Renewable Energy

- ✓ **Wind energy:** The type of energy harnessed from the wind.
- ✓ **Solar energy:** The type of energy harnessed from the sun. The main technologies here are solar photovoltaic (using the light from the sun) and solar thermal (using the sun's heat)
- ✓ **Hydroelectric energy**: The type of energy harnessed from rivers and other freshwater currents.
- ✓ **Biomass and biogas**: The type of energy extracted from organic materials.
- ✓ **Geothermal energy:** The type of energy harnessed from the heat inside the Earth.
- ✓ **Tidal energy:** The type of energy harnessed from the tides.
- ✓ **Wave energy:** The type of energy harnessed from ocean waves.
- ✓ **Bioethanol:** The type of energy harnessed from the fermentation of vegetation which results in the organic fuel suitable for vehicles.
- ✓ **Biodiesel:** The type of energy harnessed from vegetable oils which among other applications, also results in the organic fuel suitable for the vehicles [5] [3].

Renewable Energy Trend

This section will compare the renewables (clean) and none-renewable (fossil fuels) sources of energy based on world financial investment, performance and the one that will likely have the best future potential.

Figure 1: Global Energy Investment in Renewable and None-Renewable (2015-2023) [1]From figure 1 it



was observed that there is more investment in the none renewable energy in 2015 and in the year 2016-2019 there are slightly an increase in the renewable energy investment. From the year 2020- July 2023, the investment in renewable energy is about two-third of the investment in none renewable energy. From figure1, one can easily conclude that there is serious shift from the none renewable sources of energy to renewable sources of energy.

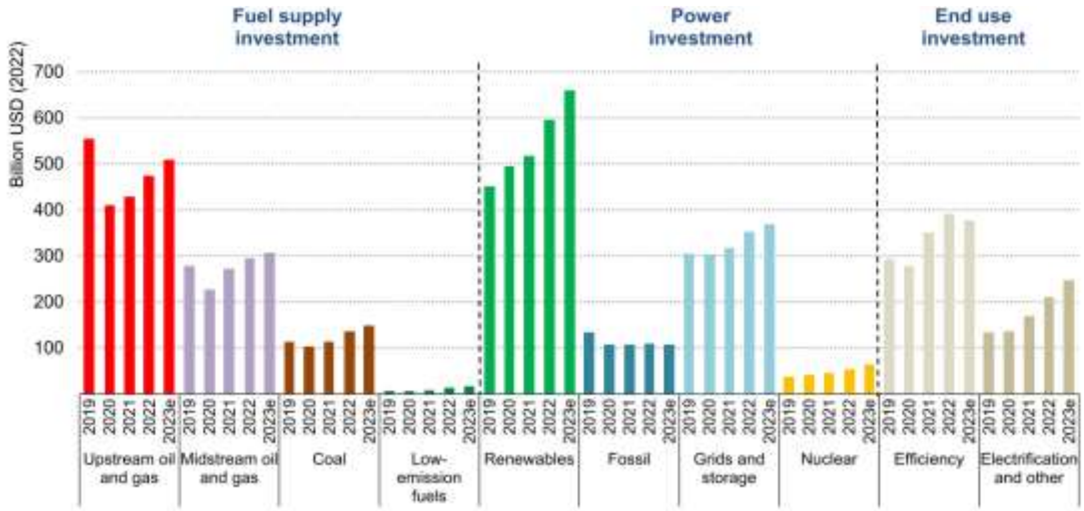
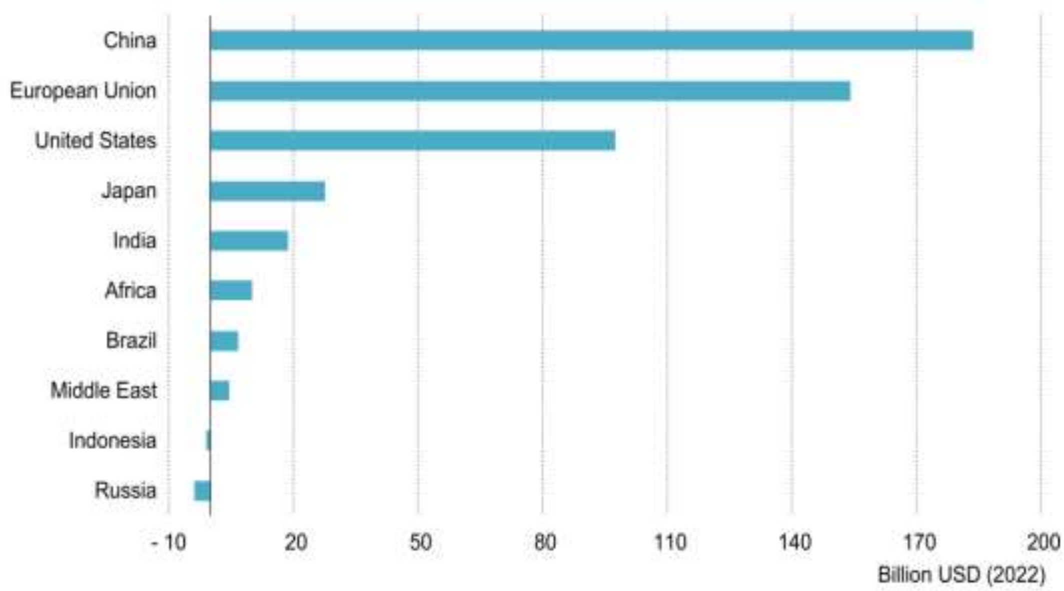


Figure 2: global energy sector investments (2019-2023)

Low-emission fuels" include modern liquid and gaseous bioenergy, low-emission hydrogen and low-emission hydrogen-based fuels; "Other end use" refers to renewables for end use and electrification in the buildings, transport and industrial sectors. The terms grids and networks are used interchangeably in this paper and do not distinguish between transmission and distribution and e in 2023 means estimated values for 2023 [1][3]. From figure 2, it was observed that renewable energy is still taking the lead in the global energy sector from 2019-2023 followed by the upstream oil and gas.

Figure 3: Annual clean Energy Investment in some countries (2019-2023e) [1]

From figure 3, it was observed that china is investing so acidulously in renewable energy more than every other



country in the world. the second largest investors in renewable energy is the European Union (EU) followed by United State of America (USA). Russia and Indonesia has the least investment among the selected countries as of 2023 records obtained from [1]

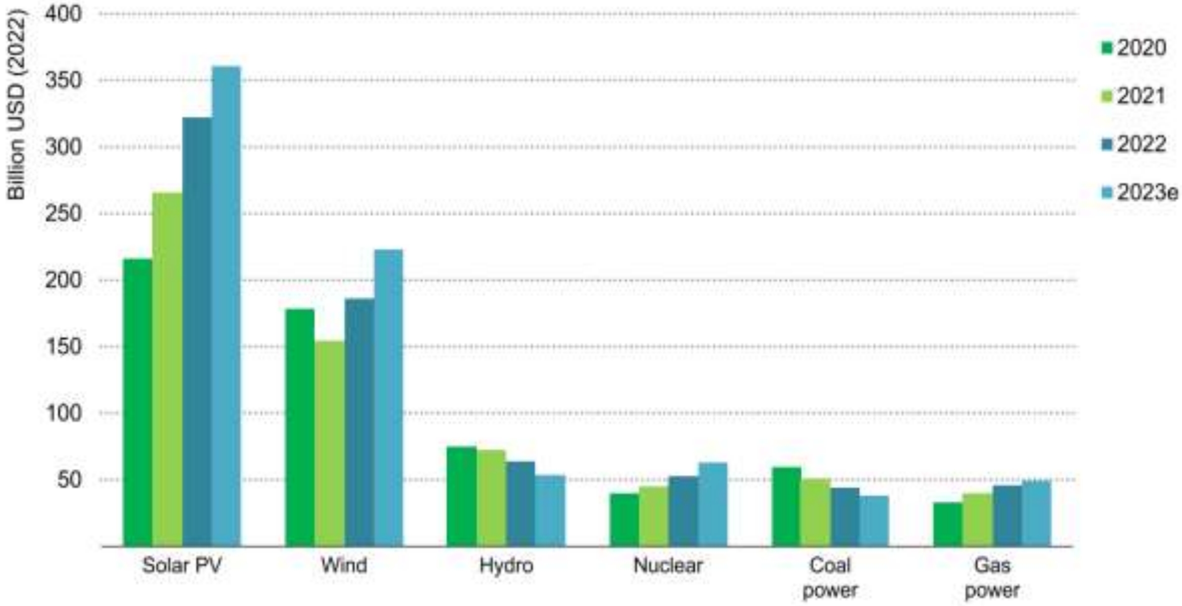


Figure 4: Renewable Sources of Energy and their Generated Power from 2020-2023 [5]

Figure 4 showed the energy generated by difference renewable energy sources, it was clearly observed that solar has the leading trend. The most leading renewable energies in 2023 are solar, wind, nuclear and gas whereas hydro and coal are diminishing with respect to the years. Solar photovoltaic has the brightest prospect among all the renewable sources of energy and with this rapid increase will make a very great history in energy sector before 2050. The second is wind which is still in the performance level of solar in the year 2020 and with this it may still be among the trending one as it decreased in 2021 and picked up in 2022 and 2023 [5].

Overview of Solar Energy

The major component of a solar photovoltaic (PV) system is the PV module which is made up of solar cells. A solar cell converts the energy in the photons of sunlight into electricity by the means of the PV phenomenon found in certain types of semiconductor materials such as selenium (Se) germanium (Ge) and silicon (Si). In isolated operation, Photovoltaic cell produces a negligible amount of power. To produce substantial electrical output power, solar cells are connected in series and parallel to form a PV module. PV cells are connected in series to increase voltage output and connected in parallel to increase the current output [6] [7].

Methods of conversions of solar Energy

The two major ways solar energy can be converted to electrical energy are through concentrating solar power and solar photovoltaics

Concentrating solar power (CSP): CSP is a system that produce heat or electricity by hundreds of mirrors that concentrate the sunlight to a temperature commonly between 400 and 1000 °C. Figure 5 is the conversion process of the concentrated solar power plant.

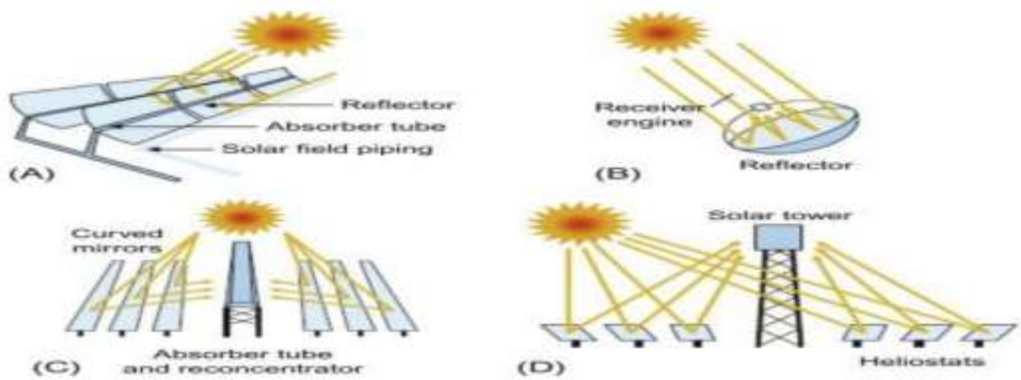
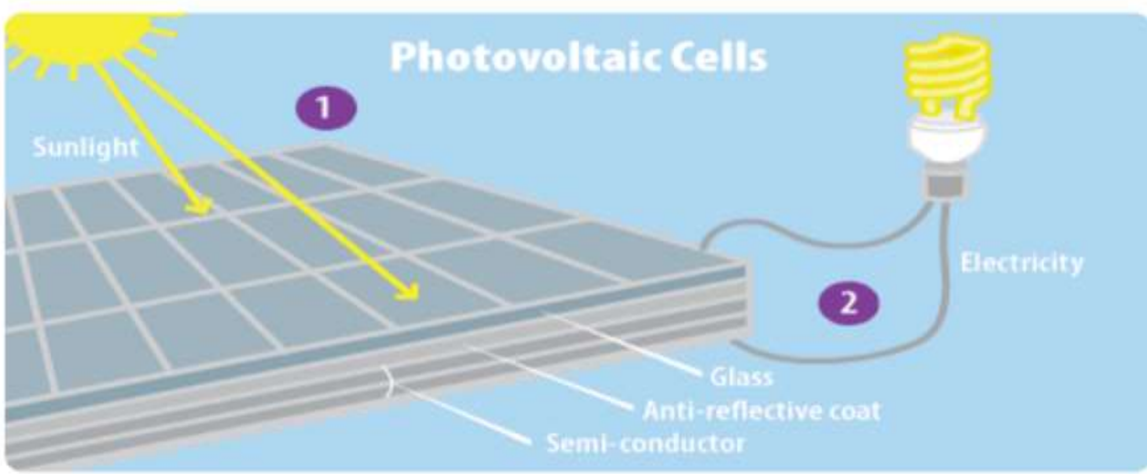


Figure 5: Concentrated Solar Power Plant [3]

Solar Photovoltaic Powers: Electricity can be produced through the photovoltaic solar energy system. PV cells convert radiant energy from the sun directly into electricity through a solar photovoltaic phenomenon. The most common solar photovoltaic panels are; monocrystalline silicon solar cells, polycrystalline silicon solar cells, microcrystalline silicon solar cells as well as the cadmium telluride and copper-indium-gallium-diselenide (CIGS) solar cells. Figure 6 is the solar photovoltaic cells and the bulb that was lighted from the conversion processes.

Figure 6: Solar Photovoltaic Cells [3]



Photovoltaic (PV) systems are rated in terms of maximum power which is the highest power that can be generated by PV system under Standard Test Condition (STC). The power output efficiency of the solar module depends on many factors such as temperature, irradiance and spectral characteristics of sunlight. At STC the temperature is 25°C, solar irradiance is 1,000 W/ m2, air mass is 1.5, wind speed is 2 m/s and solar panels tilt angle when it faces south is 30°. Under normal operating conditions, maximum power generation from PV is not possible because the PV panel cannot always be operating at optimum power. PV systems generate the highest amount of power when the incident sun beam is perpendicular to the panel. The effective utilization of power from the sun using PV systems is improved by adding PV Efficiency Enhancement (EE) systems such as solar tracking system and fabrications [4], [6]–[11]. Solar Photovoltaic efficiency optimization techniques are maximum power point tracking (MPPT) and Fabrication methods.

PV modules transfer the highest percentage of power generated to the load at MPP. MPP is a point along the P-V characteristic of a PV panel where the photovoltaic impedance is equal to the load impedance. It is also a point where there is negligible energy loss in the transmission of the generated power to the load. MPP along the P-V curve is detected using MPPT techniques. MPPT is the method of operating the photovoltaic system in a manner that allows the modules to transfer most of the power generated to the load. It is implemented in charge controllers alongside battery charge level monitoring system [12]. MPPT varies the electrical operating point of the PV system so that the module will deliver nearly all the generated power to the load. It ensures that maximum power is transferred from the photovoltaic (PV) panel to the load [7].

PV efficiency enhancement can be improved through fabrication by the process of selecting elements with high absorption coefficient, exceptional carrier mobility, high dielectric constant, tunable bandgap, materials abundance [5], [7], [11], [13], [14].

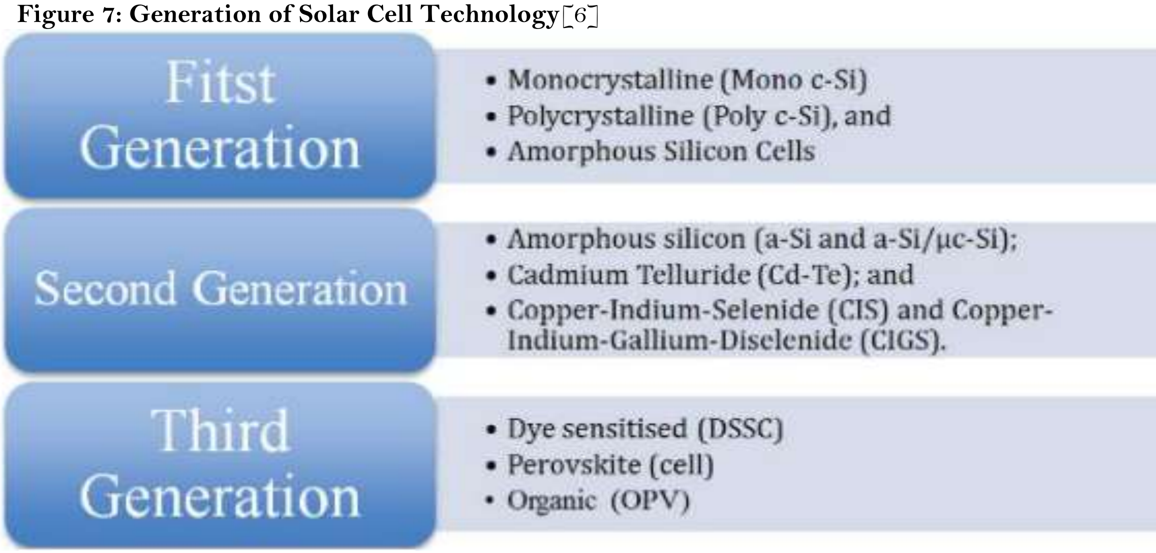
Classifications of Solar Photovoltaic Technology

The Solar PV cell technologies are generally classified into thin-film solar PV cell technology, Wafer-based crystalline solar PV cell technology and other recently emerging technologies. The two major commercial photovoltaic technologies invoke that are being used by the Photovoltaic designers due to their trending availability in the renewable energy market are:

(i) Wafer-based Solar cells made from crystalline silicon either as single or polycrystalline wafers
(ii) (ii) Thin-film products typically incorporate thin layers of PV active material placed on a glass/metal substrate using vacuum deposition [6].

Figure 7 is the solar generation cell technology and its made up of different first, second and third generations.

Figure 7: Generation of Solar Cell Technology[6]



1. **First Generation Solar Photovoltaic**

Crystalline Silicon (c-Si)

Crystalline silicon (c-Si) is a type of solar cell with efficiency of around 12–20% and a life span of almost 30 years. The main applications of single crystal solar cells are in space, or as modules for roofs and on facades. It is the most used semiconductor material for the manufacturing of photovoltaic solar cells. Electronically, a monocrystalline silicon is used in the production of microchips. The c-Si known as wafer based silicon solar cells are made from wafers with characteristics such as thickness of 160/190µm, efficiency of 25.6± 0.5%, areas of 143.7cm^2 and open circuit voltage of 0.740V [14]–[21].

Polycrystalline Solar Cell (Multi-Si)

Another name for polycrystalline silicon is Polysilicon (Poly-Si) and it is a highly purified type of silicon used by solar PV companies as raw material. This process is directly cast into multi-crystalline ingots to grow single boule of silicon crystals. The crystals are then sliced into wafers, assembled for the production of solar PV cells. The advantage of Polysilicon cells use is that it is less expensive and its disadvantage is that it is less efficient.

Amorphous Silicon Solar Cells (a-Si)

Amorphous silicon is one of the most well-developed of the thin-film technologies that comprise of microcrystalline form of silicon. The high bandgap of 1.7eV of amorphous silicon materials made it an outstanding type of silicon technology. The visible light spectrum was absorbed by top cells of the amorphous silicon while the infrared spectrum of the bottom cells will be taken care of by Nc-Si. An a-Si is widely used in the production of pocket calculators and also to power some private homes and thin-film transistor in LCDs.

2. Second Generation Solar Photovoltaic

Multi-Junction Solar Cell (M-J)

Multi junction solar cell consists of different semiconductor materials that were made of multiple p-n junctions. The type of p-n junction material and the wavelengths of light absorbed by the cell will determine the quantity of electric current to be generated. The use of multiple semi-conducting materials improves the efficiency and rate of conversion of sunlight by the cell to electrical energy. Furthermore, each layer of the junction has different band gap which allows it to absorb electromagnetic radiation over different portions of the spectrum. The Advantage of M-J cells is that it is used in special application such as space exploration and satellite. It is also used in Concentrator Photovoltaics (CPV) to focus sunlight on a small highly efficient M-J solar cells.

Quantum Dot Solar Cells (QDSC)

A QDSC was designed to make use of quantum dots as a PV absorbing material. With the rapid growth of QDSC, if no characteristic defect is detected in nearest feature it will replace other bulky materials such as Copper Indium Gallium Selenide (CIGS) or CdTe and Silicon. The excellent characteristics of changing the dots' size of QDSC due to its tunable band gap makes it attractive for multi junction solar cells. This is because varieties of materials are used to improve the efficiency of QDSC by effectively harnessing M-J portions of the solar.

3. Third Generation of Solar Photovoltaic

Dye-Sensitized Solar Cells (DSSC)

Dye-sensitized solar cell (DSSC) is a third generational PV solar cell that converts visible light into electrical energy. DSSC is a disruptive technology that is very sensitive to light that it produces electricity at indoors and outdoors. Its high sensitivity to light enables it to rapidly converts both natural and artificial light to a reasonable quantity of electrical energy. A DSSC is a thin-film PV formed between electrolyte and photo-sensitized anode to yield photo-electrochemical system. The advantage of DSSC is that it is less expensive compare to conventional solid state electronic solar cell designs. Second advantage is that it converts artificial light into electrical energy even at indoor state.

Perovskite Solar Cells (PSC)

Perovskite cells are lead-halide based with crystal structures. A perovskites material is a hybrid solar cell material known as organic-inorganic solar cell material[5], [7], [11], [13], [14]. The general chemical formula for perovskite material is given by ABX_3 where A is organic or inorganic Cation (Na+, $CH_3NH_3^+$ etc), B is inorganic Cation (Pb^{2+}, Sn^{2+}, Fe^{2+} etc) and X is inorganic Anion (Cl^-, I^-, O^{2-}). It is produced from the by-products of crude oil (methyl ammonium and ethyl ammonium) and inorganic compounds (lead iodide, tin iodide). The advantages of Perovskite materials are (a) direct optical band gap (b) broad light absorption (c) bipolar transport (d) long carrier diffusion length and finally its flexibility which makes it a good material for solar photovoltaic fabrications.

Advantages of Renewable Energy Sources Over Non-Renewable Sources

1. Renewable energy is a reliable source of power because its sources are non-depletable. It is replenishable in nature and costs little or nothing to harness it.
2. Renewable energy reduces the pollution and therefore reduces threats to our own health. Solar, wind and hydroelectric systems create negligible air pollution emissions and geothermal and biomass energy systems emissions are much lower than other non- renewable sources.
3. Renewable energy sources can combat climate change as it creates no direct greenhouse gas emissions. The only emissions that the renewable energy sources produce are indirect, meaning those that result from the manufacturing parts installation or operation and maintenance but even those emissions are little.
4. Renewable energy is less harmful to human nature, cheaper to operate and more user friendly compared to non-renewable sources of energy.

CONCLUSION

Solar photovoltaic is the invoke and trending renewable energy sources as it has the leading market since 2019 to 2023. Hence, as of 2023 solar Photovoltaic is leading the renewable energy power generation/conversion followed by wind turbine. China is the most invested country in renewable energy followed by European union. The renewable energy research trend has shifted from other sources to third generation solar photovoltaic known as perovskites. Perovskites gives the best energy conversion due to its absorption coefficient, exceptional carrier mobility, high dielectric constant, tunable bandgap, materials abundance.

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