

Photovoltaic Technologies Perovskite Emerging Solar Cells

Deepak Choudhary

Research Scholar, D.J. College, Baraut, Uttar Pradesh, INDIA

Corresponding Author: choudharydeepak962@gmail.com

ABSTRACT

Photovoltaic solar cells are getting a lot of attention from all around the world because of their ability to produce electrical energy by harvesting photon energy, which is abundant and free on earth. However, the cost of electricity generation and the efficiency with which it is generated are critical factors. As a result, multiple solar cell generations have evolved in order to compete in the race for low cost and high efficiency. With the developing photovoltaic solar cell, Perovskite, it is possible to convert copious photon energy into electrical energy with high efficiency and low cost. The efficiency of perovskite solar cells, a new form of potential photovoltaic solar cell, increased rapidly from 3.8 in 2009 to 24.2 in 2019. Because of their high efficiencies, intrinsic flexibility, the variety of materials and synthetic processes that may be used to create them, and the different conceivable device topologies, PSCs have revolutionized photovoltaic research and development. Material compositions and device designs will be further optimized to improve efficiency and device stability. However, their stability is a key stumbling block to their commercialization.

Keywords-- Solar Cells, Perovskite, Photovoltaic Technologies, Challenges

future. As a result, humanity is forced to turn to renewable energy sources in order to avoid further degrading the environment and to find a replacement for non-renewable resources. The use of clean, renewable energy sources has become a requirement for human civilization's advancement. Solar power is unquestionably one of the most promising new energy technologies among a wide range of options. It is a well-known method of making solar energy useable. Recently, solar photovoltaic and concentrated solar power will provide 16 percent and 11 percent, respectively, of the world's greatest source of electricity by 2050. Solar cells use the photovoltaic effect to capture sunlight and transform it into electrical energy. Solar cells are divided into four generations based on the time they were developed and the types of materials they were made of. The first-generation solar cells, which are made up of single and multicrystalline silicon, are the most prevalent solar cells on the market. As a result of the high material usage and cost of silicon solar cells, second-generation solar cells were introduced. In this generation, the maximum film thickness was reduced from a few nanometers to tens of micrometers in order to reduce material utilization. In the meantime, many researchers have experimented with light management concepts such as dye-sensitized solar cells (DSSCs), perovskite, organic solar cells, photochemical cells, quantum dots, nanostructure, and Nano patterning using dye-sensitized solar cells (DSSCs), perovskite, organic solar cells, photochemical cells, quantum dots, nanostructure, and Nano patterning. Solar cells from the fourth generation are classified as composites of conjectural generation. Figure 1 depicts a schematic illustration of many solar cell generations.

I. INTRODUCTION

In today's civilization, adequate energy supply is a must. The global usage of energy has been rapidly increasing. Over time, society has been able to meet this need using traditional energy sources such as coal, petroleum products, and other fossil fuels, but at a significant cost to the planet's ecosystem. These energy resources are also expected to become extinct in the near

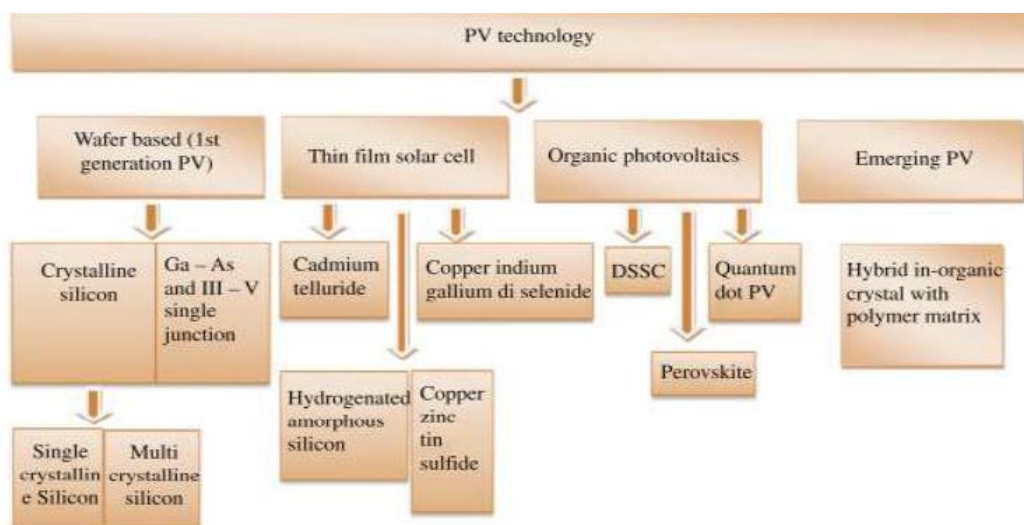


Figure 1: Solar cell generations

II. PEROVSKITE MATERIAL FOR SOLAR CELLS

The production and use of renewable and environmentally friendly new energy has become a big issue in the world since the total amount of non-renewable fossil resources such as oil, coal, and natural gas has gradually decreased. Si-based photovoltaic devices have made significant contributions in the field of photovoltaics, although their cost does not appear to be significantly lower than traditional energy. Perovskite solar cells are less expensive to manufacture than Si-based photovoltaic

devices. Meanwhile, perovskite solar cells' power conversion efficiency (PCE) has increased from 3.8 percent to 25.2 percent, indicating a promising future in the industry. (See Figure 2). Solar devices based on perovskite materials have been a hit in research institutes in recent years, with a steady increase in the number of publications and citations of linked scientific and technological papers. The number of publications on perovskite solar cells has been steadily increasing since 2013, and presently stands at around 3–4 thousand per year. We will primarily explore the benefits and drawbacks of perovskite solar cells, as well as their future prospects.

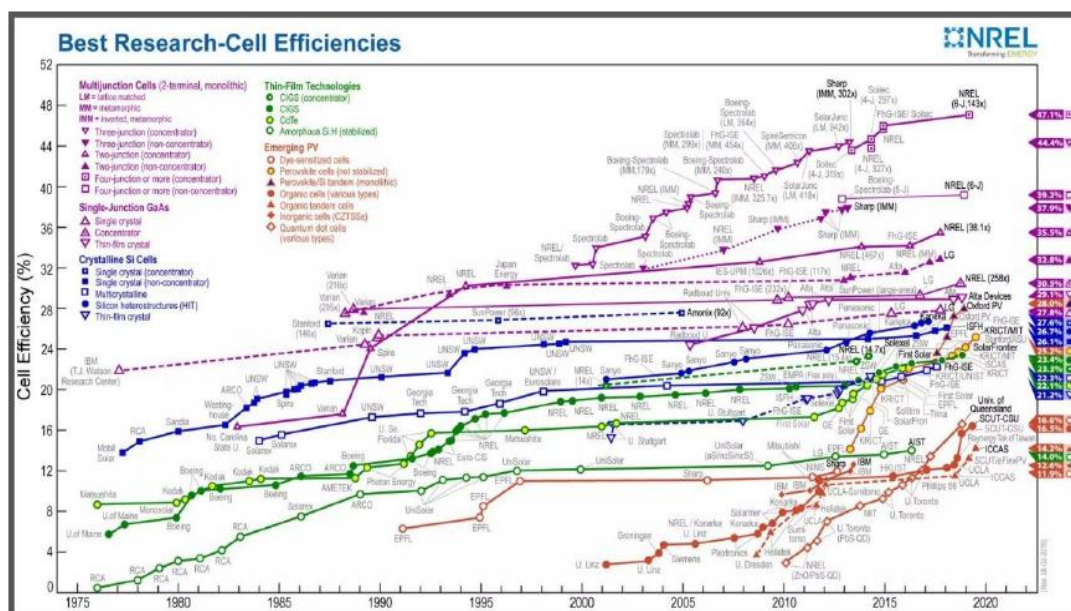


Figure 2: Shows the evolution of efficiency for a variety of solar cells over the last several decades

The name perovskite was first used in 1839 to denote materials with the same type of crystal structure as calcium titanium oxide (CaTiO_3), which was discovered by Lev Alexeievitch Perovskite. The perovskite compounds have the chemical formula ABX_3 , where A is a massive cation that is coordinated to 12 X anions and fills the octahedral holes, B is a metal that is connected to 6 X anions, and X is the anion that bonds to A and B. The B cation is in 6 fold coordination, surrounded by BX_6 octahedron anions, and the BX_6 octahedron is corner-connected to form a three-dimensional framework in the ideal cubic-symmetry perovskite structure. The cubic

lattice-nested octahedral layered structures and unusual optical, thermal, and electromagnetic properties of perovskite materials have drawn a lot of attention. Perovskite materials, which are used in solar cells, are organic-inorganic metal halide compounds with the perovskite structure, in which Group A (methyl ammonium, CH_3 , MA^+ , or formamidinium, FA^+) is located in the vertex of the face-centred cubic lattice, and metal cation B (Pb^{2+} , Sn^{2+} , etc.) and halogen anion X (Cl^- , Br^- or I^-). The metal-halogen octahedra are connected in three dimensions to produce a stable network structure. Figure 3 depicts the crystalline structure.

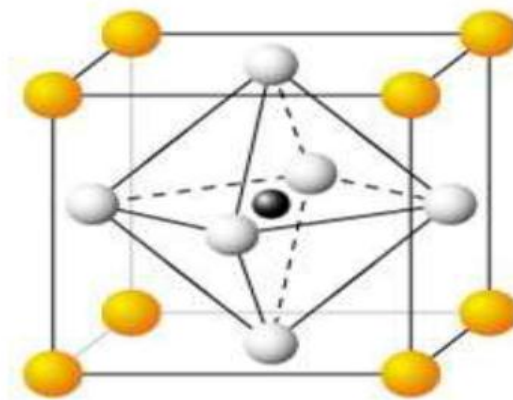


Figure 3: A typical cubic perovskite lattice structure

The materials with this structure have the four characteristics listed below. The materials have outstanding photoelectric characteristics, low exciton binding energy, and high optical absorption coefficients, for starters (up to 10^4 cm^{-1}). Second, perovskite, as a light-absorbing layer, can efficiently collect solar energy. Third, the materials have a high dielectric constant, allowing electrons and holes to be transferred and collected efficiently. Finally, electrons and holes can be transferred at the same time at a distance of up to $1 \mu\text{m}$. If the materials are used in solar cell devices, their properties result in a high open-circuit voltage and a high short-circuit current density. The perovskite layer absorbs photons to form excitons when exposed to sunshine. These excitons can form free carriers to generate a current or recombine into excitons due to differences in the exciton binding energy of the perovskite materials. The APbI_3 and $1 \mu\text{m}$ for Cl_x are due to the low carrier recombination probabilities of $\text{CH}_3\text{NH}_3\text{PbI}_3$ (MAPbI_3) and other perovskite materials, as well as the increased carrier mobility. The increased performance of perovskite solar cells is due to the greater diffusion distance and lifetime of carriers. After that, an electron transport material (ETM) and a hole transport material (HTM) capture the free electrons and holes (HTM). Electrons are transmitted from the perovskite

material to TiO_2 , which is used for the ETM layers, and then to FTO for collection. The holes are transmitted to the HTM layer and collected by the metal electrode at the same time. Finally, the photocurrent is generated in the outside circuit by connecting the FTO and metal electrode.

III. PEROVSKITE SOLAR CELLS' CHALLENGES

Despite the fact that perovskite solar cells have made incredible progress in terms of efficiency and manufacturing cost, many barriers remain in the way of perovskites' commercialization, one of which is the stability issue of perovskite materials, which is a major source of concern for researchers, especially when exposed to external conditions such as oxygen, water, and ultraviolet light. Furthermore, when contemplating future viable applications, lead toxicity is a concern that must be overcome.

3.1. Perovskite Solar Cells Becoming More Stable

The intrinsic chemical stability of perovskite solar cells, the stability of the solar energy device, and the influence of external environmental conditions are all aspects that can affect the stability of perovskite solar cells. Furthermore, perovskite materials are not only easy

to polarise when exposed to an electric field. Finally, the issue of instability becomes more acute when the perovskite absorption layer and additional functional layers are joined. In order to address these concerns, researchers primarily focus on improving the stability of the following two methodologies: The first is to improve perovskite crystals' intrinsic chemical stability, while the second is to avoid direct contact of the perovskite absorber with the aforementioned negative variables. We will mostly discuss four strategies for resolving these issues.

3.1.1 Compositional Engineering of Perovskite Materials

Compositional engineering is another useful way to improve the stability of perovskite-based electronics. Zhou et al. integrated the CsI into the inorganic skeleton based on the precursor chemistry, which could significantly alter the film nucleation dynamics during film production. The results showed that not only the efficiency but also the stability of the $\text{FA}_{0.9}\text{Cs}_{0.1}\text{PbI}_{3-x}\text{Cl}_x$ based device had substantially improved. Furthermore, all-inorganic perovskite devices would result from the complete replacement of fragile organic species with stable inorganic cations. Lyubov A. Frolova and colleagues examined the all-inorganic perovskite material $\text{Cs}_x\text{PbI}_2\text{Br}_x$, where x varied from 0.95 to 4. In comparison to CsPbI_3Br , which could generate CsPbBr_3 and CsPbI_3 via a disproportionation reaction under the stress of ultraviolet irradiation or high temperature, the $\text{Cs}_{1.2}\text{PbI}_2\text{Br}_{1.2}$ -based device had the best structural device performance (the PCE is over 10%), as well as optimised stability, when x equaled 1.2.

3.1.2 Additive Manufacturing

Ionic liquid additives were previously introduced into the precursor to increase the perovskite solar cells' long-term operational stability. Bai et al. used a straightforward, widely known approach in which they added ionic liquids 1-butyl-3-methylimidazolium tetrafluoroborate (BMIMBF_4) to the perovskite precursor ($\text{FA}_{0.83}\text{MA}_{0.17}$), $_{0.95}\text{Cs}_{0.05}\text{Pb}$ ($\text{I}_{0.9}\text{Br}_{0.1}$)₃. According to the results of the experiments, 0.3 percent mol done with a PCE of 19.8 percent under a light intensity of 105 mW/m² was able to get the optimal result with a PCE of 19.8 percent. Furthermore, after 1885 hours, the device could retain 85 percent of its initial efficiency. Wang et al. proposed the trivalent and divalent europium ion pairs, which could oxidise Pb and decrease I defects simultaneously. The redesigned solar cell may achieve significantly higher long-term durability with a PCE of 21.52 percent and a certified efficiency of 20.52 percent. The devices could retain 92 percent and 89 percent of the champion PCE after continuous illumination or 1500 hours of heating at 85 °C, respectively, and 91 percent of the initial PCE after 500 hours of ageing at maximum power point conditions.

3.1.3 Encapsulation Technology for Perovskite Solar Cells

Last but not least, encapsulation technology can improve the stability of perovskite solar cells while also protecting them from external variables such as moisture, oxygen, and light. Ashraf Uddin et al. described a variety of encapsulation materials and technologies, as well as a variety of scenarios in which different packaging materials are applicable. People have built many interface layers as barriers to safeguard perovskite layers up to this point, but they are insufficient. Capturing the devices using glass, on the other hand, is the most efficient and successful method so far, and it might be widely used in perovskite device manufacture. Many additional materials, such as ethylene methyl acrylate, ethylene vinyl acetate, polyvinyl butyral, thermoplastic polyurethane, and others, may also be used for device encapsulation.

3.1.4 Perovskite Solar Cell Interface Modification

Perovskite photovoltaic devices rely heavily on interfaces to perform properly. As a result, it's critical to pay close attention to the design and optimization of interfaces between functional layers in order to maximise device stability. Yang et al. created the PbSO_4 and $\text{Pb}_3(\text{PO}_4)_2$ passivation layers on the top interface of perovskite via a simple chemical reaction of the perovskite with SO_4^{2-} or PO_4^{3-} salts, followed by the formation of a thin and dense inorganic lead-oxygen layer. The strong chemical link between perovskite and passivation materials, in comparison to intermolecular forces, could improve the resistance to light and moisture. Furthermore, it has the potential to increase carrier lifetime and solar cell efficiency by up to 21.1 percent. The improved device may preserve 96.8% of its initial efficiency after ageing for 1200 hours at 65°C under maximum power point tracking. [24] Furthermore, Bu et al. observed that employing phenyl ethyl ammonium iodide reduced both iodide vacancy and superoxide formation. The results of the experiments showed that solar devices manufactured with it had higher stability and increased device PCE at the same time.

3.2 Lead's Potential to Pollute the Environment

Apart from the issue of solar cells made of perovskite materials' stability, the influence on the environment is also a major concern for perovskite solar cells' widespread use. When perovskite solar modules are used outside, for example, they may be corroded by natural elements such as rain, high winds, and fires, resulting in the discharge of toxic lead from the damaged modules, which could further harm the environment. In that situation, encapsulation technology and doping, i.e., partial substitution of harmful lead with Sn, are the two most effective strategies for reducing lead contamination. Furthermore, Douglas Fabini et al. attempted to calculate the probable upper limit of lead contamination during the

lifetime of perovskite solar cell modules. Based on the simulation results, it needed 38 g of lead to generate one kWh of power using perovskite solar cells, assuming a lifetime and efficiency of 25 years and 25%, respectively.

3.2.1 Doping Method

Another effective technique for reducing the potential pollution of perovskite solar cells is to partially replace lead with nontoxic tin. In this regard, Hao et al. set the bar high by using tin-based materials ($\text{CH}_3\text{NH}_3\text{SnI}_3$) to make perovskite solar cells. The tin-based MAPbI_3 had a bandgap of only 1.3 eV, which was better for sunlight harvesting than the typical MAPbI_3 's 1.5 eV bandgap. Furthermore, other qualities such as carrier mobility were superior to the old ones. Efat Jokar et al. also created Sn-based perovskite solar cells with the FASnI_3 crystal structure doped with various amounts of GA^+ . The resulting solar cell had an initial PCE of 8.5 percent when the ratio of FAI to GAI in the precursor was 8 to 2. After being stored in a glove box for two thousand hours, the efficiency continued to improve to 9.6 percent.

3.2.2 Technology for Encapsulation

Lead encapsulation, as previously stated, can aid in the prevention of lead leakage. Jiang et al. tested three packaging strategies for perovskite solar cells in various weather models and measured the amount of lead leakage. When compared to glass encapsulation, epoxy encapsulation reduced the lead leak rate by 375 times, which was attributed to the epoxy coating's self-healing capabilities and high mechanical strength.

IV. ARCHITECTURE OF PEROVSKITE SOLAR CELLS

One of the most important aspects in determining the overall performance of perovskite solar cells is the device configuration. Depending on whether transport (electron/hole) material is present on the outside portion of the cell and encountered by incident light first, perovskite solar cells can be classified as regular (n-i-p) or inverted (p-i-n) designs. These two types of structures can be further split into mesoscopic and planar structures. A mesoporous layer is present in the mesoscopic structure, whereas all the planar layers are present in the planar structure. There have also been tests on perovskite solar cells without electron and hole carrying layers. In summary, many researchers have explored six types of perovskite solar cell architectures so far: the mesoscopic n-i-p configuration, the planar n-i-p configuration, the planar p-i-n configuration, the mesoscopic p-i-n configuration,

the ETL-free configuration, and the HTL-free configuration.

4.1 Regular N-I-P Structure

The typical n-i-p mesoscopic structure, in which the light-harvesting dye was replaced with lead halide perovskite semiconductors in a traditional DSSC-type architecture, was the first arrangement of perovskite photovoltaics to be tested. When the liquid electrolyte was replaced with a solid-state hole-conducting substance in so-called mesoscopic device architectures (Fig. 4a), interest in perovskite solar cells grew even more. A transparent glass cathode is placed first, followed by the electron transportation medium (ETM). The structure is then coated with a perovskite-containing mesoporous metal oxide, followed by hole transport material (HTM), and finally capped with a metallic anode Figure-4a. This initial breakthrough in PSCs piqued the interest of photovoltaic researchers, leading to the development of additional PSC device designs Figure-4b, d. The perovskite light-harvesting layer is sandwiched between the ETM and HTM in the planar design, which is a development of the mesoscopic structure. The lack of a mesoporous metal oxide layer results in a simpler overall structure. By carefully managing the interfaces between the many layers that make up the PSC, it is possible to obtain high efficiency without the mesoporous layer (the perovskite light absorber layer, the electron-transporting layer, the hole-transporting layer, the electrodes, as well as the perovskite layer itself). A planar n-i-p PSC has a higher VOC (open-circuit voltage) and JSC (short-circuit current density) than a mesoscopic PSC device using the same materials and technique. However, the planar form also has more severe J-V hysteresis, calling the quoted efficiency into question.

4.2 P-I-N Structures Inverted

The organic solar cell inspired the p-i-n PSC structure. The HTM layer is deposited first in the p-i-n planar perovskite architecture, followed by the ETM layer. Perovskites have been revealed to be capable of transferring the holes themselves. The usage of oxide HTM allows for the construction of mesoscopic p-i-n device architecture, and the inverted p-i-n arrangement has widened the alternatives for selective layer from organic to inorganic materials. Low-temperature processing, little hysteresis behaviour, and excellent efficiency are all advantages of planar p-i-n PSC. Figure-4c, d shows the device configuration of the inverted p-i-n planar and mesoscopic PSC.

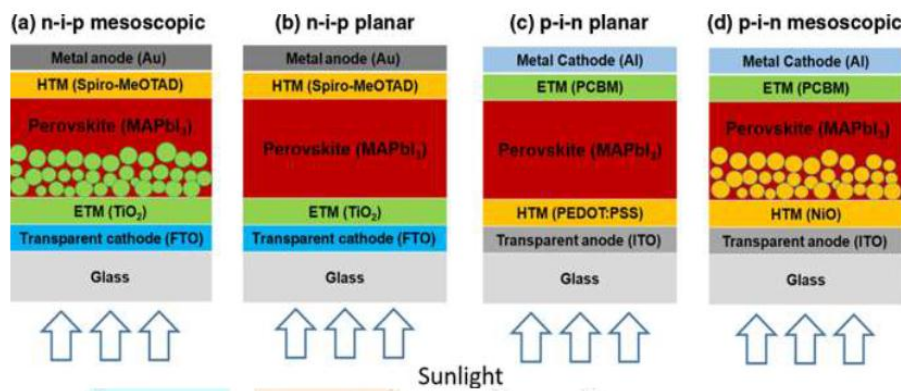


Figure 4: Layered structure of four perovskite solar cells (a) n-i-p mesoscopic, (b) n-i-p planar, (c) p-i-n planar, and (d) p-i-n mesoscopic)

V. PEROVSKITES IN THE FUTURE

Future perovskites research will likely focus on reducing recombination by passivation and defect reduction, as well as increasing efficiency through the use of 2D perovskites and better-optimized interface materials. To improve both efficiency and stability, charge-extraction layers are anticipated to shift from organic to inorganic materials. Improving lead stability and reducing lead's environmental impact are anticipated to be hot topics for the foreseeable future. While standalone perovskite solar cells have challenges in terms of manufacture and stability, their application in tandem c-Si/perovskite cells has advanced quickly (with efficiencies above 25%), and it is likely that perovskites will first hit the PV market as part of this structure. Perovskites have tremendous potential in other applications, including as light-emitting diodes and resistive memory, in addition to solar.

VI. CONCLUSION

Solar cells have received worldwide interest as one of the most efficient ways to utilise solar energy. On the other hand, many types of solar cells cannot provide sufficient device performance when critical criteria like cost, efficiency, and stability are taken into account. Within a few years, organic and inorganic hybrid perovskite solar cells surged to prominence, igniting a new wave of research in the field of photovoltaics with good performance and a wide variety of future possibilities. The efficiency of perovskite solar cells has reached 25.2 percent, and it is continually improving rapidly thanks to researchers' collaborative efforts. In this article, we briefly discussed the advantages and disadvantages of perovskite solar cells.

The benefits primarily include high solar performance efficiency, a simple film production

technique, amazing physical qualities, and inexpensive fabrication cost; however, the downsides include poor stability, short lifetime, and raw material toxicity, among others. Finally, perovskite solar cells have made incredible progress in terms of efficiency. The transition from traditional mesoscopic structures to planar structures, the shift from liquid sensitizers to all solid-state structures, and the simplicity and straightforward nature of new low-temperature fabrication methods will all undoubtedly aid in improving the PCE/stability of PSCs and speeding up progress toward commercialization. One of the biggest challenges to commercialization of perovskite solar cells is device instability, which must first be addressed in the laboratory. Although perovskite stability has improved from a few minutes to thousands of hours, it is still insufficient for practical applications; we need to increase the lifetime of perovskite solar cells to more than ten years in order to commercialise them. A number of aspects, including structural design, charge transport materials, electrode material preparation, and encapsulation procedures, must be taken into account for systematic engineering of perovskites in order to improve their stability. We recommend that certain novel materials and designs with great resilience in harsh environments be developed.

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