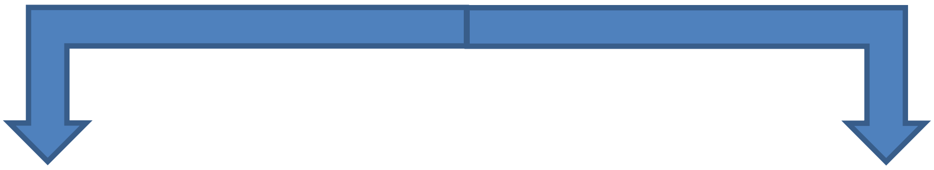
2.6.1 PV panel:-

In this block, we shall focus on the central character of the PV system - the PV modules. Before I start, I want to touch upon briefly on the subtle difference between the terms solar modules and solar panels. You must have observed that a lot of people use these terms interchangeably, but what is exact the difference? A module is an interconnection of solar cells, as you had seen before. It is the generic name given to any kind of packaging for an interconnection of solar cells. That is, irrespective of technology or packaging, an interconnection of solar cells will be called a module. However, the term solar panel is a bit more exclusive for the rectangular, rigid packaging with typical encapsulations. For example, most standard crystalline modules are called solar panels. All solar panels are solar modules but the converse is not true. For instance, a thin-film silicon solar cell that is packaged as a flexible laminate is a solar module. But it is not entirely accurate to call it a panel. Note that in most cases, the commercial modules being used are panels, and therefore modules are synonymously called as panels in common usage. Henceforth, I might use the terms solar panels and modules interchangeably as well. But I hope you understand the exact difference between the two. So let us move onto the module level concepts.

Let's start with the different types of solar panels currently on the market, list their benefits and downsides, and then look at a few typical scenarios where certain types would be the better than others (hopefully one of them resonates with you).

PV panel



Thin-Film Solar Cells (TFSC)

Crystalline Silicon (c-Si)

Crystalline silicon forms the basis of mono- and polycrystalline silicon solar cells:

Crystalline Silicon (c-Si)

Almost 90% of the World's photovoltaics today are based on some variation of silicon. In 2011, about 95% of all shipments by U.S. manufacturers to the residential sector were crystalline silicon solar panels.

The silicon used in PV takes many forms. The main difference is the purity of the silicon. But what does silicon purity really mean? The more perfectly aligned the silicon molecules are, the better the solar cell will be at converting solar energy (sunlight) into electricity (the photoelectric effect).

The efficiency of solar panels goes hand in hand with purity, but the processes used to enhance the purity of silicon are expensive. Efficiency should not be your primary concern. As you will later discover, cost-and space-efficiency are the determining factors for most people.

Monocrystalline Silicon Solar Cells

Solar cells made of monocrystalline silicon (mono-Si), also called single-crystalline silicon (single-crystal-Si), are quite easily recognizable by an external even coloring and uniform look, indicating high-purity silicon, as you can see on the picture below:

Monocrystalline solar cells are made out of silicon ingots, which are cylindrical in shape. To optimize performance and lower costs of a single monocrystalline solar cell, four sides are cut out of the cylindrical ingots to make silicon wafers, which is what gives monocrystalline solar panels their characteristic look.

A good way to separate mono- and polycrystalline solar panels is that polycrystalline solar cells look perfectly rectangular with no rounded edges.

Advantages

- Monocrystalline solar panels have the highest efficiency rates since they are made out of the highest-grade silicon. The efficiency rates of monocrystalline solar panels are typically 15-20%. SunPower produces the highest efficiency solar panels on the U.S. market today. Their E20 series provide panel conversion efficiencies of up to 20.1%.[3]Update (April, 2013): SunPower has now released the X-series at a record-breaking efficiency of 21.5%.
- Monocrystalline silicon solar panels are space-efficient. Since these solar panels yield the highest power outputs, they also require the least amount of space compared to any other types. Monocrystalline solar panels produce up to four times the amount of electricity as thin-film solar panels.
- Monocrystalline solar panels live the longest. Most solar panel manufacturers put a 25-year warranty on their monocrystalline solar panels.
- Tend to perform better than similarly rated polycrystalline solar panels at low-light conditions.

Disadvantages

- Monocrystalline solar panels are the most expensive. From a financial standpoint, a solar panel that is made of polycrystalline silicon (and in some cases thin-film) can be a better choice for some homeowners.
- If the solar panel is partially covered with shade, dirt or snow, the entire circuit can break down. Consider getting micro-inverters instead of central string inverters if you think coverage will be a problem. Micro-inverters will make sure that not the entire solar array is affected by shading issues with only one of the solar panels.
- The Czochralski process is used to produce monocrystalline silicon. It results in large cylindrical ingots. Four sides are cut out of the ingots to make silicon wafers. A significant amount of the original silicon ends up as waste.
- Monocrystalline solar panels tend to be more efficient in warm weather. Performance suffers as temperature goes up, but less so than polycrystalline solar panels. For most homeowners temperature is not a concern.

Polycrystalline Silicon Solar Cells

The first solar panels based on polycrystalline silicon, which also is known as polysilicon (p-Si) and multi-crystalline silicon (mc-Si), were introduced to the market in 1981. Unlike monocrystalline-based solar panels, polycrystalline solar panels do not require the Czochralski process. Raw silicon is melted and poured into a square mold, which is cooled and cut into perfectly square wafers.

Advantages

- **The process used to make polycrystalline silicon is simpler and cost less.** The amount of waste silicon is less compared to monocrystalline.
- **Polycrystalline solar panels tend to have slightly lower heat tolerance than monocrystalline solar panels.** This technically means that they perform slightly worse than monocrystalline solar panels in high temperatures. Heat can affect the performance of solar panels and shorten their lifespans. However, this effect is minor, and most homeowners do not need to take it into account.

Disadvantages

- **The efficiency of polycrystalline-based solar panels is typically 13-16%.** Because of lower silicon purity, polycrystalline solar panels are not quite as efficient as monocrystalline solar panels.
- **Lower space-efficiency.** You generally need to cover a larger surface to output the same electrical power as you would with a solar panel made of monocrystalline silicon. However, this does not mean every monocrystalline solar panel perform better than those based on polycrystalline silicon.
- Monocrystalline and thin-film solar panels tend to be more aesthetically pleasing since they have a more uniform look compared to the speckled blue color of polycrystalline silicon.

Thin-Film Solar Cells (TFSC)

Depositing one or several thin layers of photovoltaic material onto a substrate is the basic gist of how thin-film solar cells are manufactured. They are also known as thin-film photovoltaic cells (TFPV). The different types of thin-film solar cells can be categorized by which photovoltaic material is deposited onto the substrate:

- Amorphous silicon (a-Si)
- Cadmium telluride (CdTe)
- Copper indium gallium selenide (CIS/CIGS)
- Organic photovoltaic cells (OPC)

Depending on the technology, thin-film module prototypes have reached efficiencies between 7–13% and production modules operate at about 9%. Future module efficiencies are expected to climb close to the about 10–16%.

The market for thin-film PV grew at a 60% annual rate from 2002 to 2007. In 2011, close to 5% of U.S. photovoltaic module shipments to the residential sector were based on thin-film.

Advantages

- Mass-production is simple. This makes them and potentially cheaper to manufacture than crystalline-based solar cells.
- Their homogenous appearance makes them look more appealing.
- Can be made flexible, which opens up many new potential applications.
- High temperatures and shading have less impact on solar panel performance.
- In situations where space is not an issue, thin-film solar panels can make sense.

Disadvantages

- Thin-film solar panels are in general not very useful for in most residential situations. They are cheap, but they also require a lot of space. Sun Power`s monocrystalline solar panels produce up to four times the amount of electricity as thin-film solar panels for the same amount of space.
- Low space-efficiency also means that the costs of PV-equipment (e.g. support structures and cables) will increase.
- Thin-film solar panels tend to degrade faster than mono- and polycrystalline solar panels, which is why they typically come with a shorter warranty.

Solar panels based on amorphous silicon, cadmium telluride and copper indium gallium selenide are currently the only thin-film technologies that are commercially available on the market:

Amorphous Silicon (a-Si) Solar Cells

Because the output of electrical power is low, solar cells based on amorphous silicon have traditionally only been used for small-scale applications such as in pocket calculators. However, recent innovations have made them more attractive for some large-scale applications too.

With a manufacturing technique called “stacking”, several layers of amorphous silicon solar cells can be combined, which results in higher efficiency rates (typically around 6-8%).

Only 1% of the silicon used in crystalline silicon solar cells is required in amorphous silicon solar cells. On the other hand, stacking is expensive.

Cadmium Telluride (CdTe) Solar Cells

Cadmium telluride is the only thin-film solar panel technology that has surpassed the cost-efficiency of crystalline silicon solar panels in a significant portion of the market (multi-kilowatt systems).

The efficiency of solar panels based on cadmium telluride usually operates in the range 9-11%.

First Solar has installed over 5 gigawatts (GW) of cadmium telluride thin-film solar panels worldwide. The same company holds the world record for CdTe PV module efficiency of 14.4%.

Copper Indium Gallium Selenide (CIS/CIGS) Solar Cells

Compared to the other thin-film technologies above, CIGS solar cells have showed the most potential in terms of efficiency. These solar cells contain less amounts of the toxic material cadmium that is found in CdTe solar cells. Commercial production of flexible CIGS solar panels was started in Germany in 2011.

The efficiency rates for CIGS solar panels typically operate in the range 10-12 %.

Many thin-film solar cell types are still early in the research and testing stages. Some of them have enormous potential, and we will likely see more of them in the future.

Cell Technology	**Crystalline Silicon**	**Thin Film**
Types of Technology	Mono-crystalline silicon (c-Si) Poly-crystalline silicon (pc-Si/ mc-Si) String Ribbon	Amorphous silicon (a-Si) Cadmium Telluride (CdTe) Copper Indium Gallium Selenide (CIG/ CIGS) Organic photovoltaic (OPV/ DSC/ DYSC)
Voltage Rating (Vmp/ Voc) (Higher is better as there is less gap in Voc and Vmp)	80%-85%	72%-78%
Temperature Coefficients	Higher	Lower **(Lower is beneficial at high ambient temperatures)**
I-V Curve Fill Factor (Idealized PV cell is 100%)	73%-82%	60%-68%
Module construction	With Anodized Aluminum	Frameless, sandwiched between glass; lower cost, lower weight
Module efficiency	13%-19%	4%- 12%