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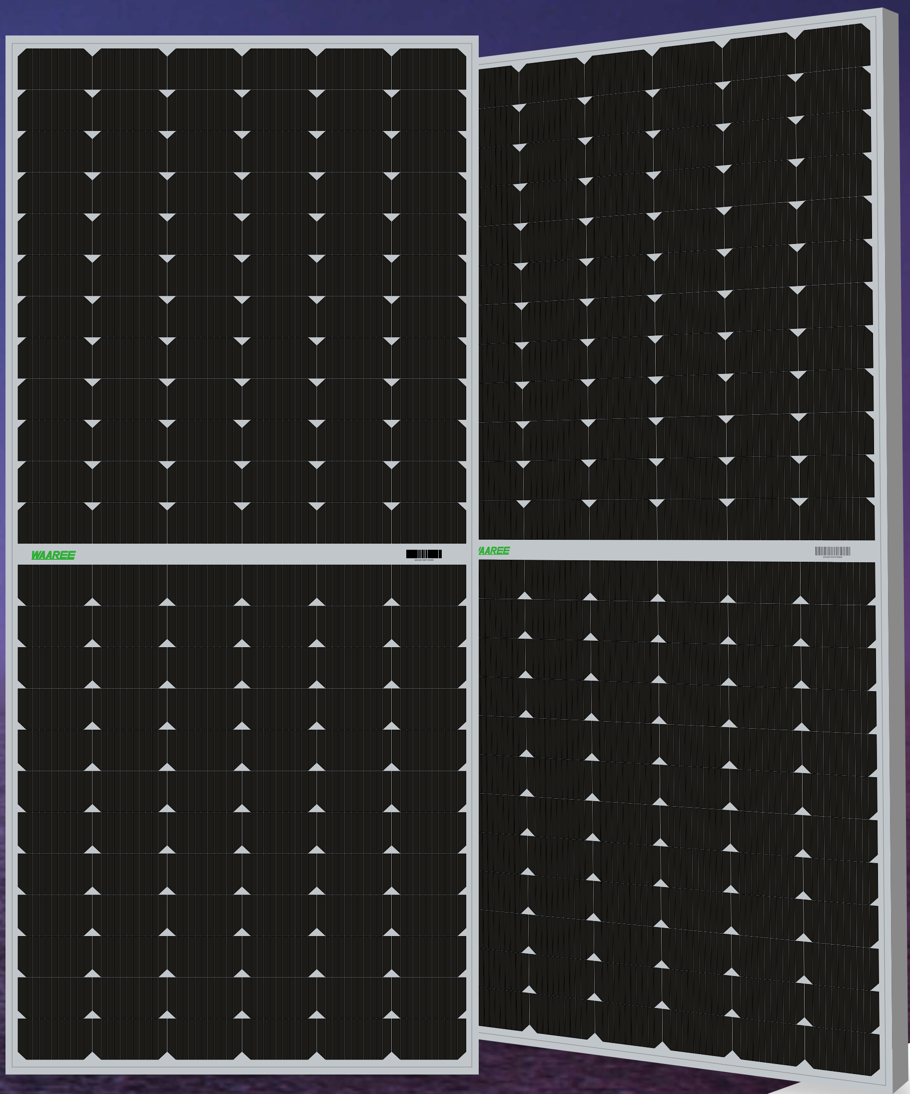
HETEROJUNCTION

THE TECHNOLOGICAL WAY AHEAD FOR SOLAR PV!



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ABSTRACT

With the wafer size increasing from the traditional 156.75 mm/157 mm to the more advanced 182 mm/ 210 mm, the levelized cost of electricity (LCOE) has come down to an extent. However, now with the customer demanding enhanced efficiency & superior reliability from the solar photovoltaic (PV) modules, it's time to shift to newer technologies. All the current developments now are towards developing cells with N-type structure. This paper focuses on the heterojunction technology (HJT) detailing its structure, technical and commercial advantages. It would also educate it end readers on why is it the best time to switch to HJT technology and how would their on-field performance outclass the currently available commercial PV technologies.

Heterojunction
The technological way ahead for solar PV!

Solar cell for almost a decade had been stable with its size as M2 which was also the choice of the end customer. However, with the drive for enhanced power output alongside reduction in solar PV's levelized cost of electricity (LCOE), the need for change was inevitable. The industry started taking cue from the semiconductor industry i.e, to increase the wafer size (refer Figure 1) which would result in direct increase in power output. The size of the wafer quickly jumped from 156.75 mm / 157 mm to an intermediate size of 161.75 mm / 166 mm and then to 182 mm / 210 mm within a span of around five years. With the current standard cell sizes, the PV module may have reached its size limits which currently spans between 2.2 ~ 2.4 m in length to 1.1 ~ 1.3m in width. With higher power output still being the demand from end customer, any further increase in wafer size would lead to proportional increase in module size. Such increase in module size have limitations like MMS cost, self-weight, handling limitation, etc. which would nullify the commercial gain from such enhancement. Further with PERC cell reaching its efficiency limits, the need to focus on alternative technologies is the need of the hour.

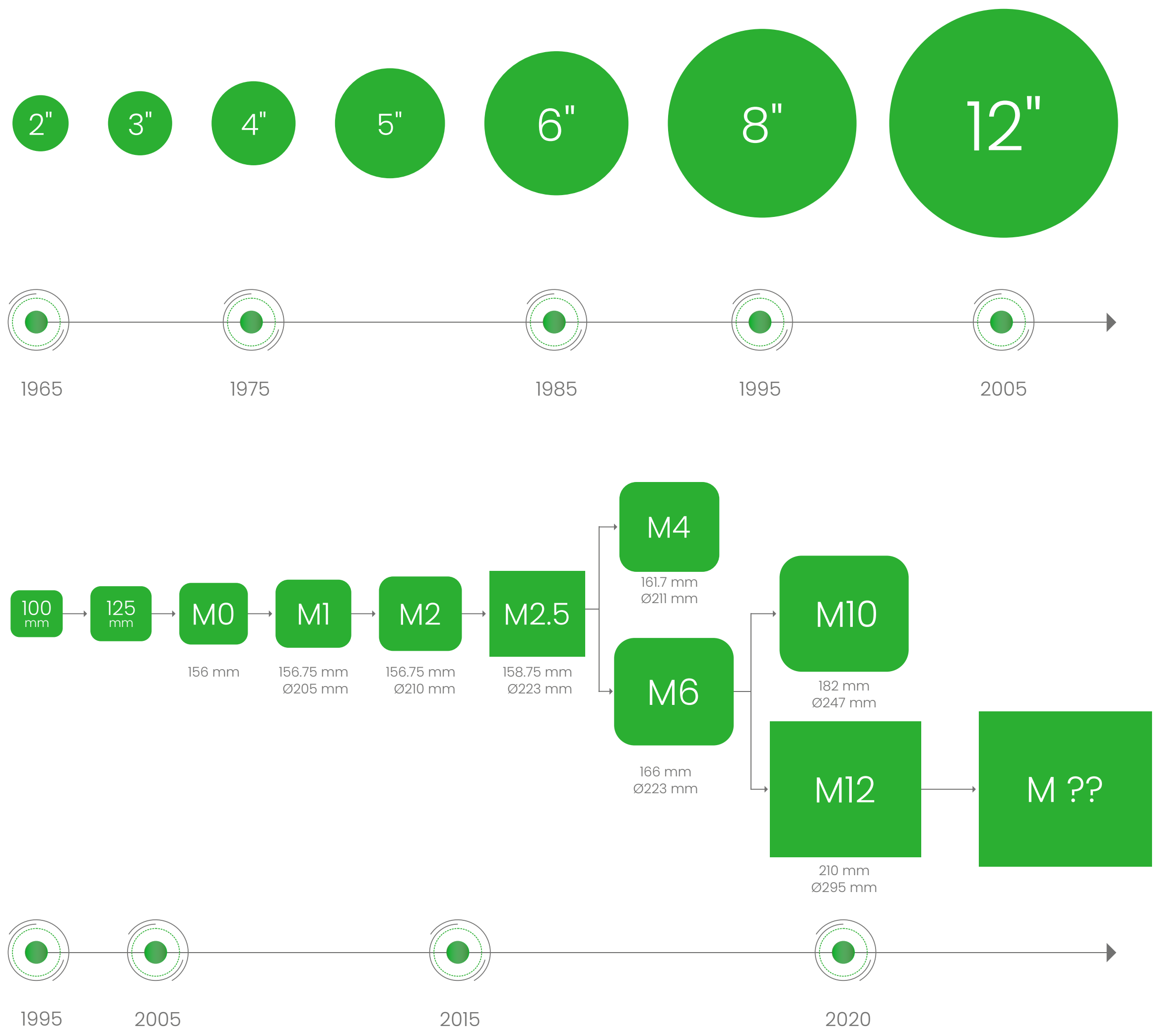


Figure 1: The evolution of semiconductor market (on top) & PV market (on bottom) over years.

All the commercially available solar cells and the developments have only taken place on P type solar cells (depends on type of dopant use while manufacturing). This was contradictory to the fact that the first ever developed solar cell was N type but it couldn't make it as the first used solar modules were in the space. The initially developed N type solar cell were obviously not stable under UV exposures and hence P type became the only choice. However with the current N type solar cells having better reliability & higher efficiency, they are finding their way back from highly advanced solar labs to the manufacturing facilities. The current offering in N type module is based on PERL, PERT, Topcon & heterojunction (HJT) solar cell. We would however focus more on HJT explaining you its construction, features, its advantages and compare it to other traditional technologies at the later stage.

Construction of HJT cell

The HJT solar cell, as the name suggest are made up of different layers combined into one. The cell is made up of crystalline silicon cell sandwiched between (thin film) amorphous silicon on both the sides. This means that the cell combines the advantage of better absorption of light (from the crystalline layer) alongside better passivation properties (from the amorphous layer) thus creating a superior cell. The current light conversion efficiency record for HJT cells stands at greater than 26.5% which clearly means that the cell has the potential to unlock the next generation of modules. However, efficiency improvement is only one of its many advantages. Before we jump in to all its advantages, let us understand the construction of HJT cell and then we would discuss its advantages in detail.

The HJT cells (refer Figure 2) contains n-type crystalline silicon absorber at the centre. It has both intrinsic (neutral) and doped layers of amorphous silicon on its either sides thus forming a p/i/n/i/n+ stacking. As we mentioned earlier, the crystalline silicon has the property of better light absorption meaning that it can absorb almost all the light which falls on it thus generating more free carriers. Immediately around the n type crystalline silicon are the intrinsic hydrogenated amorphous silicon (a-si:H(i)). Bare amorphous silicon while is easy to deposit on the crystalline silicon but has lot of surface defects, which means that there will be loss of carriers due to high resistance. Hydrogenating the bare amorphous silicon decreases the defect density drastically while also increasing their band-gap (when compared to the crystalline silicon).

The intrinsic (or un-doped) layer of a-si(H)(I) enables better surface passivation which means that the exited electrons and holes would not recombine before being collected. Moving on, further to the intrinsic layers are the p-type and n-type doped hydrogenated amorphous silicon layers which forms the P-N junction in the solar cells. The top p-type layer collects part of the light falling onto it both, directly and from inter-layer reflection. Similarly the bottom layer captures the remaining amount of light which may have passed through the first two layers while also providing surface passivation. Generally, the conductivity of a-Si:H layer is poor and may not be sufficient to provide a good carrier (charge) collection via the metal contacts. This is when the transparent conductive oxide (TCO) comes in play.

The TCO layer are deposited on both the sides of a-Si:H layer. They work by promoting a good ohmic-contact, facilitating lateral carrier transportation and also working as anti-reflective coating (ARC) similar to the SiNx coatings in crystalline solar cells. There are many industry standard TCO's but indium tin oxide (ITO) is the most common of them. The thickness of the top and the bottom TCO may be different. The thickness of the top layer of the TCO and its oxygen content are optimized for a suitable sheet resistance for carrier transportation, good transparency to avoid unusual light absorption and to further enhance light trapping. The rear TCO may be optimized for absorption in the infrared (IR) region.

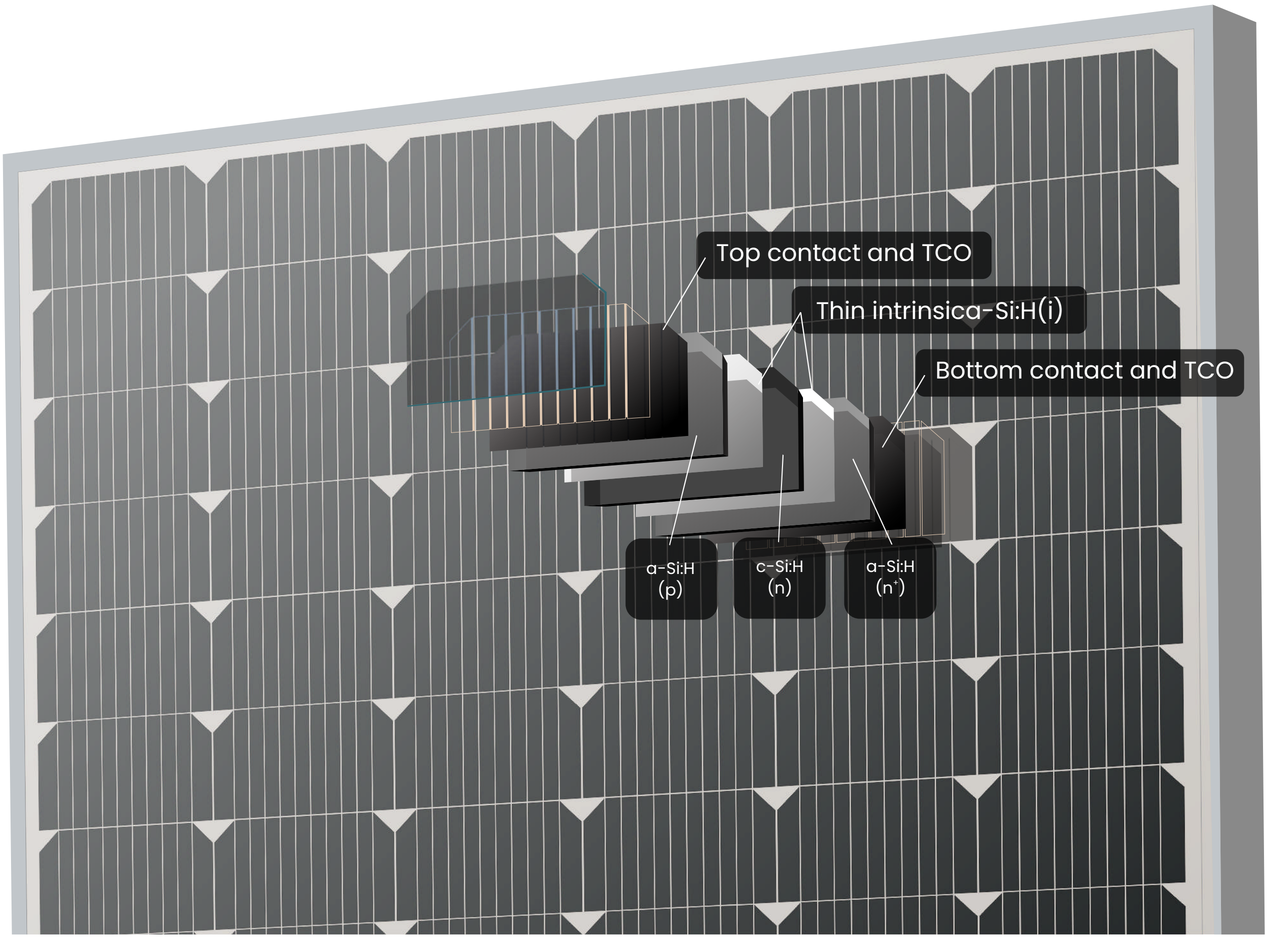


Figure 2: A typical Heterojunction solar cell.

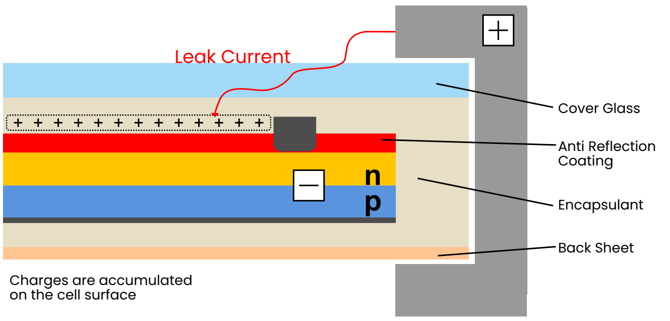
Advantages of HJT

With the construction being clear, it's time to understand what advantages HJT has to offer:

Manufacturing advantages: The first and foremost advantage of HJT is that it is a less energy intensive process, thanks to the thin film depositions on its either sides. The HJT cells are processed at < 250 °C which saves a lot of energy during manufacturing cells. The number of steps required to manufacture these cells are halved compared to the industry standard PERC. Further at module level, they are again processed at around same temperature when stringing the HJT cells onto a module

PID free technology: Potential Induced Degradation or better known as PID is known to affect almost all the type of solar modules. In a PID affected module, there is either a current leakage from the cell to the ground via the frame (better known as PID-polarization or PID-p) or there is a shift of positive ions (usually Na+) from the glass to the solar cell which leads to recombination loss (better known as PID-shunting or PID-s). This PID mechanism usually attacks the insulating layer of the solar cell which if polar in nature accumulates electric charges under high potential difference. While this happens in case of crystalline cells where the SiNx coating is polar in nature, the TCO used over the HJT cells in non-polar. This means that there would not be any charge built up in these cells and hence there would practically be no PID in them (refer Figure 3).

Conventional c-Si PV module structure



HIT PV module structure

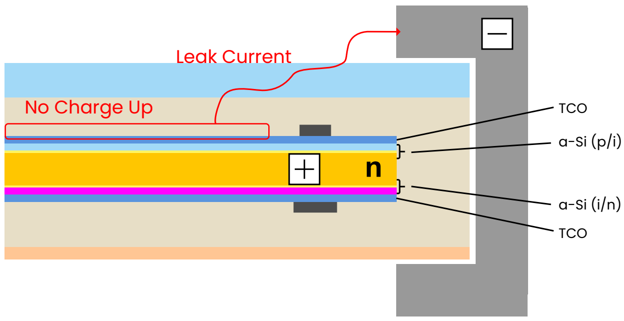


Figure 3 : Comparing crystalline & HJT cells for PID (Source: NREL)

No LID / LeTID effect: Light Induced Degradation (LID) is known to effect almost all the silicon crystalline based solar modules. LID causes initial power degradation of more than or equal to 1% in these modules. The two main reasons for LID are either Boron Oxygen (B-O) complexities or Dissociation of Iron-Boron (Fe-B) pairs. In B-O based LID, the oxygen during the wafer manufacturing reacts with the dopant (boron) forming a complex compound. This complex forms intermediate energy levels where the exited electrons recombine which leads to efficiency loss in solar cell. In Fe-B based LID, the iron present during manufacturing reacts with the boron in the dark due to coulomb interaction. When the solar cell is illuminated, the iron ions break apart and thus recombining with electrons causing efficiency loss. Light and elevated Temperature Induced Degradation (LeTID) is known to affect PERC cells, where in both light & elevated temperatures (as high as 50 °C to 95 °C) affect the efficiency of these cells. HJT cells based on their construction do not involve Boron which eradicates the chances of LID in them. Further, no such reported incidents at labs or at field confirms the effect of LeTID in these cells (refer) meaning that they are LID & LeTID free.

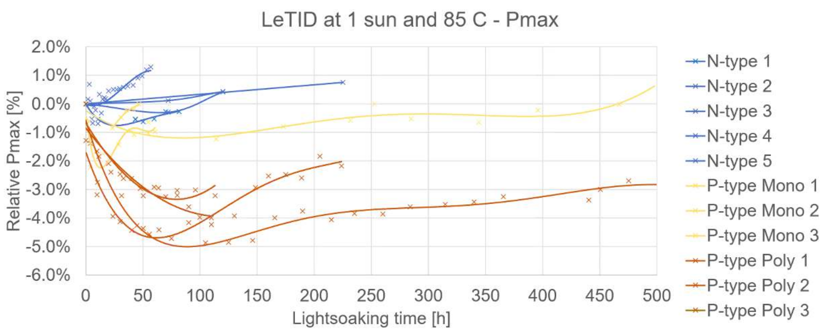


Figure 4 : LeTID results of different modules (Source: Eternal Spire)

Lowest temperature coefficient: Temperature coefficient is one of the most crucial parameter of a solar module. It determines the amount of power drop that the cell or module would face if there is a rise in temperature. Temperature coefficient depends on a lot of factors namely series & shunt resistance, quality of surface passivation, number of interstitial defects, etc. With each interlayer of the HJT cell taking care of better light absorption, enhanced surface passivation at low series and higher shunt resistances, the cell has the lowest thermal coefficients amongst all the known technologies in solar PV.

Lowest degradation: With almost no known mechanism effectively affecting the HJT modules, they are known to have lowest power degradation rates. Further, they are also known to have better reliability compared to its peer technologies.

Figure 5: An overview of all the advantages HJT has to offer.

Technical comparison between HJT & other cell technology

As we discussed earlier, the HJT technology is by default bifacial in nature. And with the technology having symmetric structure and alike-manufacturing methodology, the technology has one of the best bifaciality. Theoretically, its bifaciality is above 90% and the recorded bifaciality of the technology on field goes around 93% which is highest amongst all the competing technology. Most prevalent commercial cells are crystalline in nature which means they may not be able to resist micro crack effectively. Comparing HJT to it, the technology has amorphous layers on both the sides which gives it much needed flexibility which improves its resistance to micro cracks. Further, as we described earlier, the technology has no initial LID which makes it the leading contender for lowest initial degradation. Additionally, with no PID/ LeTID/ other degradation mechanism known affecting the HJT module in general, they also have one of the lowest year-on-year degradation rates. Finally comparing the temperature coefficients of all available technologies, the Δ is 0.10%abs between HJT & mono PERC which means that in a country like India, implementing HJT module would lead to reduced energy loss due to higher temperature.

Sl. No.	Module properties	p-Perc	n-Perc	n-TopCon	n-HJT
1	Bifaciality	70%	80%	80%	>90%
2	Micro crack resistant	No	No	Yes	Yes
3	Initial power degradation	High	High	Medium	Low
4	Long term power degradation rate	High	High	Medium	Low
5	LID/ LeTID/ PID	Yes	Yes	Yes	No
6	Low light performance	Good	Good	Good	Better

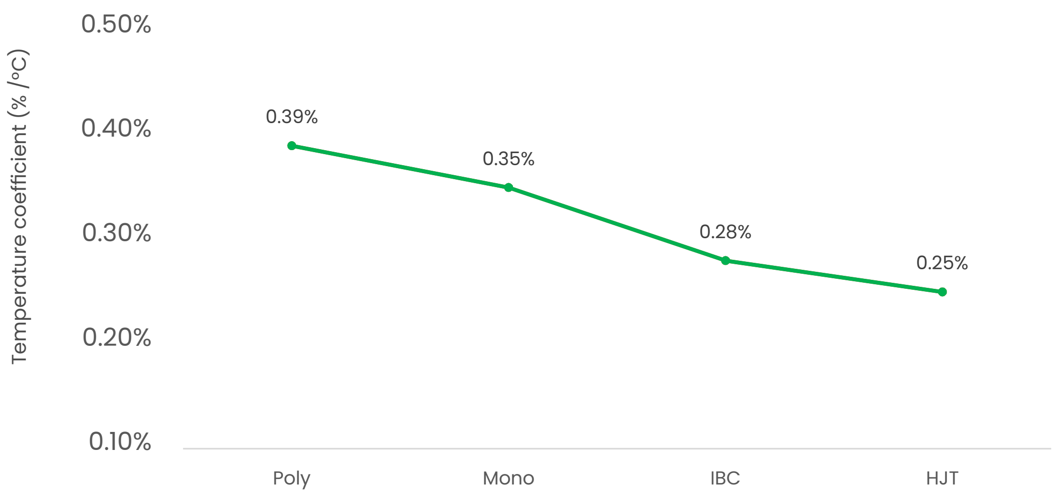


Figure 6: Technical comparision of HJT vs other technologies.

Commercial comparison between HJT & PERC

We understood that HJT is technically superior amongst all the available technologies. However, it is also important to compare HJT to the on-going passivated emitter and rear contact (PERC) technology. We simulated a 1 MW power plant in the state of Gujarat (refer Figure 7). We kept all the other factors like tilt angle, module arrangement, inverter loading ratio, etc. constant in order to have a comparative analysis. We know from the graph above (Figure 6) that the Δ of temperature coefficient between HJT & mono PERC is 0.10%abs. While this number seem small, when we look at the power plant output the temperature losses in a mono PERC module based plant are around 50% higher. The quantum of this energy loss is huge when we consider (ultra) mega power plants and with further in temperate zones like India where ambient temperatures always stays above 35 degrees. Next, with HJT having better surface passivation & low light performance along with lowest initial degradation, we find that the specific energy output of HJT based power plant stands at 1922 kWh/kWp/year which is around 6% higher than PERC based power plants. Finally, talking about performance ratio (PR) which indicates the how good or bad a plant is performing. The PR of HJT based plant is 4.7%abs greater than the PERC based plant which clearly shows the advantages of utilizing HJT technology. With such advantages, HJT stands out tall when compared to its competitors in almost all the fields.

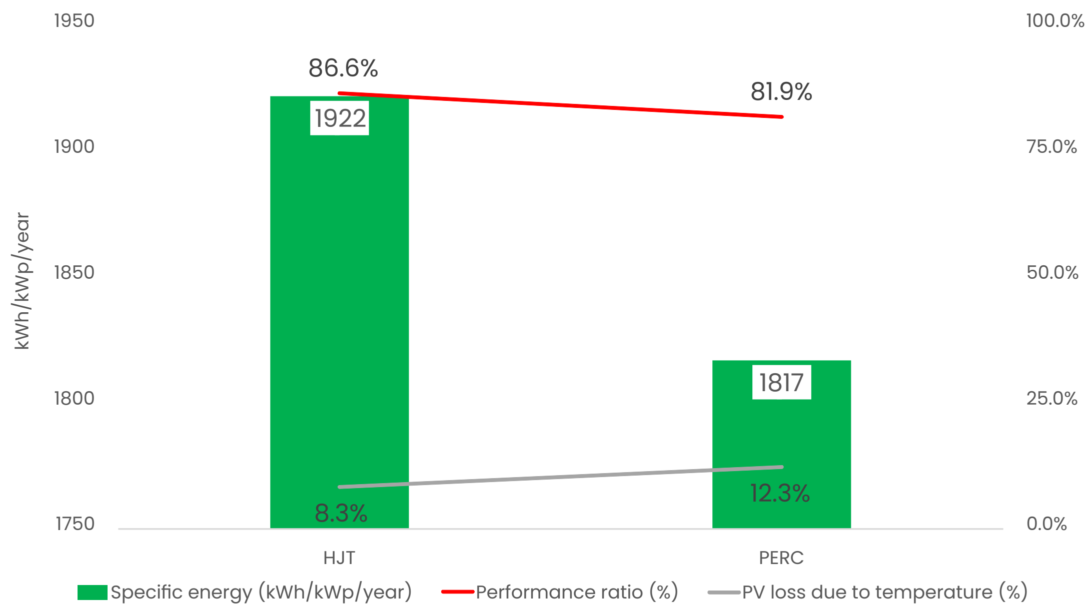


Figure 7: Comparison between HJT & PERC.

Where is the world going ahead with HJT?

With the advantages being clear on the technology, we know that HJT is definitely the thing to look forward in years to come. The solar PV community has been voicing the same idea with majority manufacturers having already announced plans of the shift. Let us understand first what the future holds for HJT. Three technologies i.e. PERx, TopCon & HJT are compared in terms of their power output & Bifaciality (refer Figure 8). For simplification, we have normalized the power output to M6 144 cell based solar module. The current power output of all the three technologies are 450 Wp+ with the delta being 10 Watts between PERx & TopCon and TopCon & HJT respectively. However, with the PERx technology reaching efficiency limits, the maximum enhancement in power output would only be around 20 Wp per module. Comparing this to TopCon & HJT, the maximum enhancement currently stands at 25 Wp per module with this number going up to as much as ~40 Wp for HJT based module. Further, even in terms of Bifaciality, the PERx technology has almost reached upper limit at around 75%. Compare that to HJT, where maximum Bifaciality of around 95% is expected making it a strong contender for all the future modules.

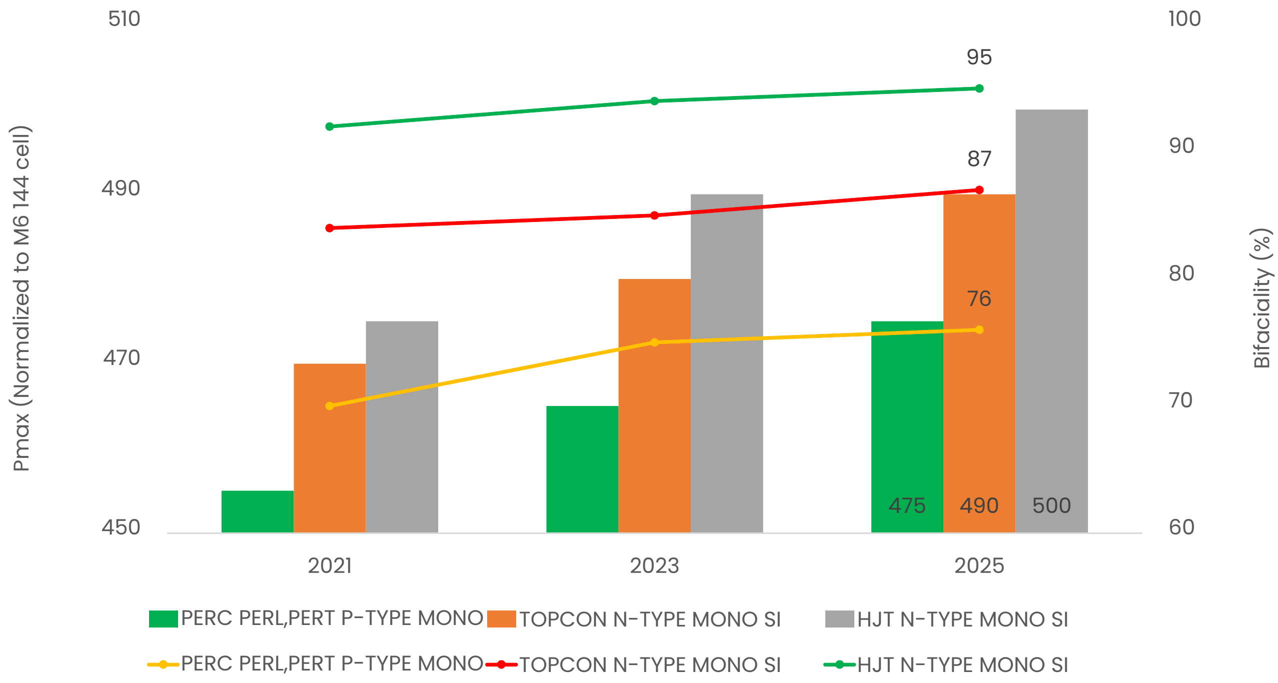
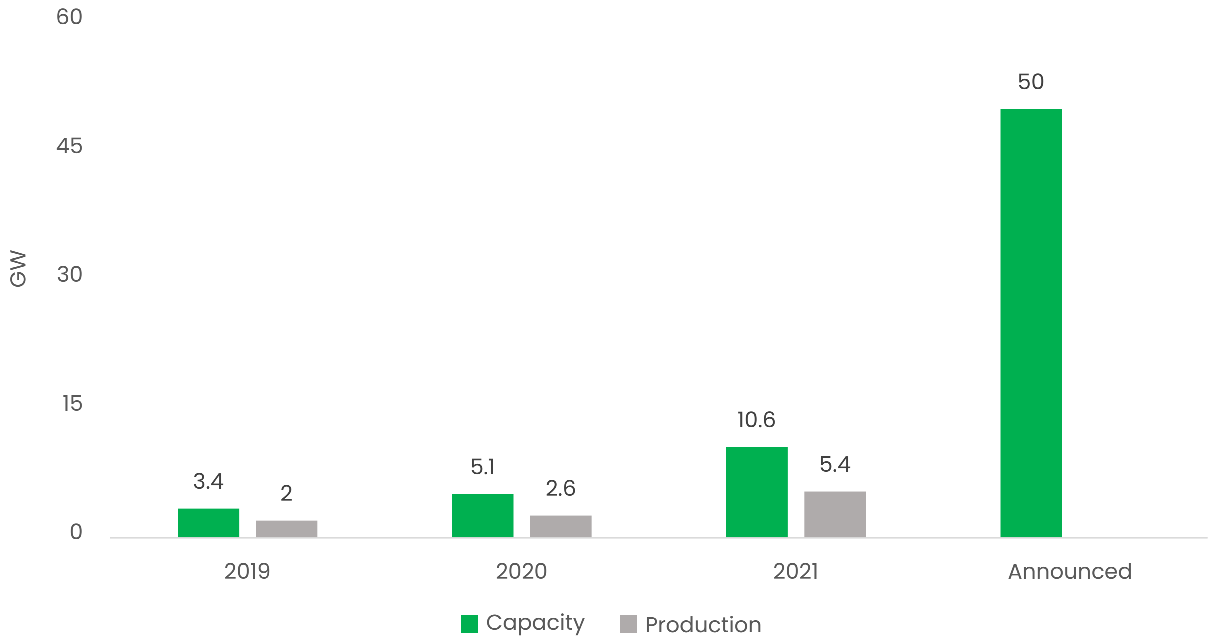


Figure 8: Normalized power output & bifaciality for M6 module from different technologies (Source: ITRPV)

The current nameplate capacity vs actual production of HJT modules is expected to stay somewhere at 50% in 2021. However with many manufacturers jumping in, the total announced HJT capacity cumulates to 50+ GW. Further with the capacity expansion spread out almost equally around the world, we expect that HJT technology would pick up pace by the mid of this decade with more than 70% of the world's PV capacity turning to HJT.



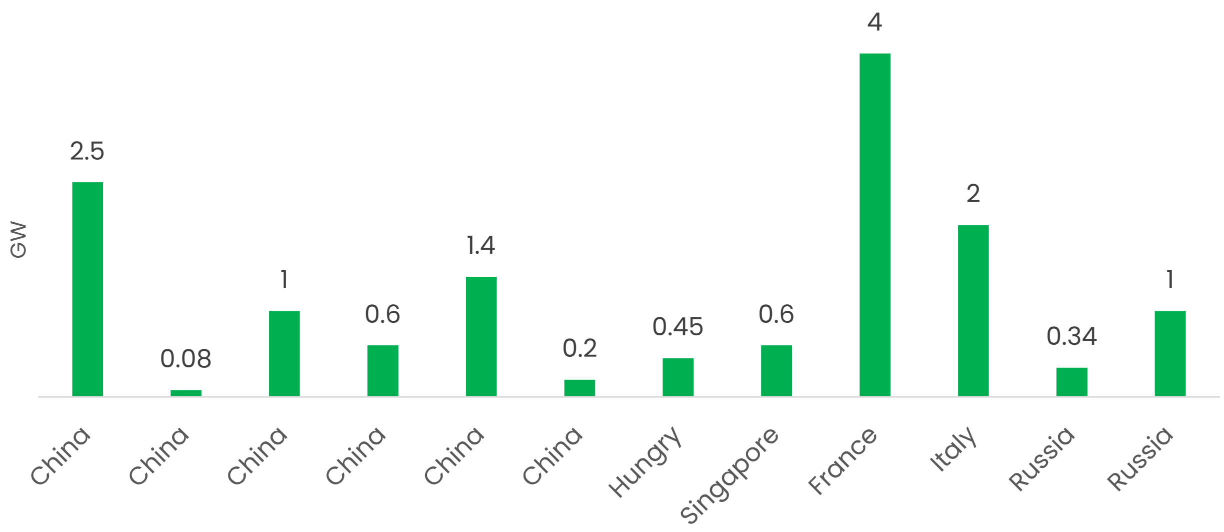


Figure 9: Capacity vs actual production & country wise production capacity announced for HJT (Source: Taiyang news)

With all the given technical and commercial advantages, HJT definitely seems to be the technology of the future. And with further new cell architecture almost utilizing HJT in them, we strongly believe that the future of solar PV is HJT.

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