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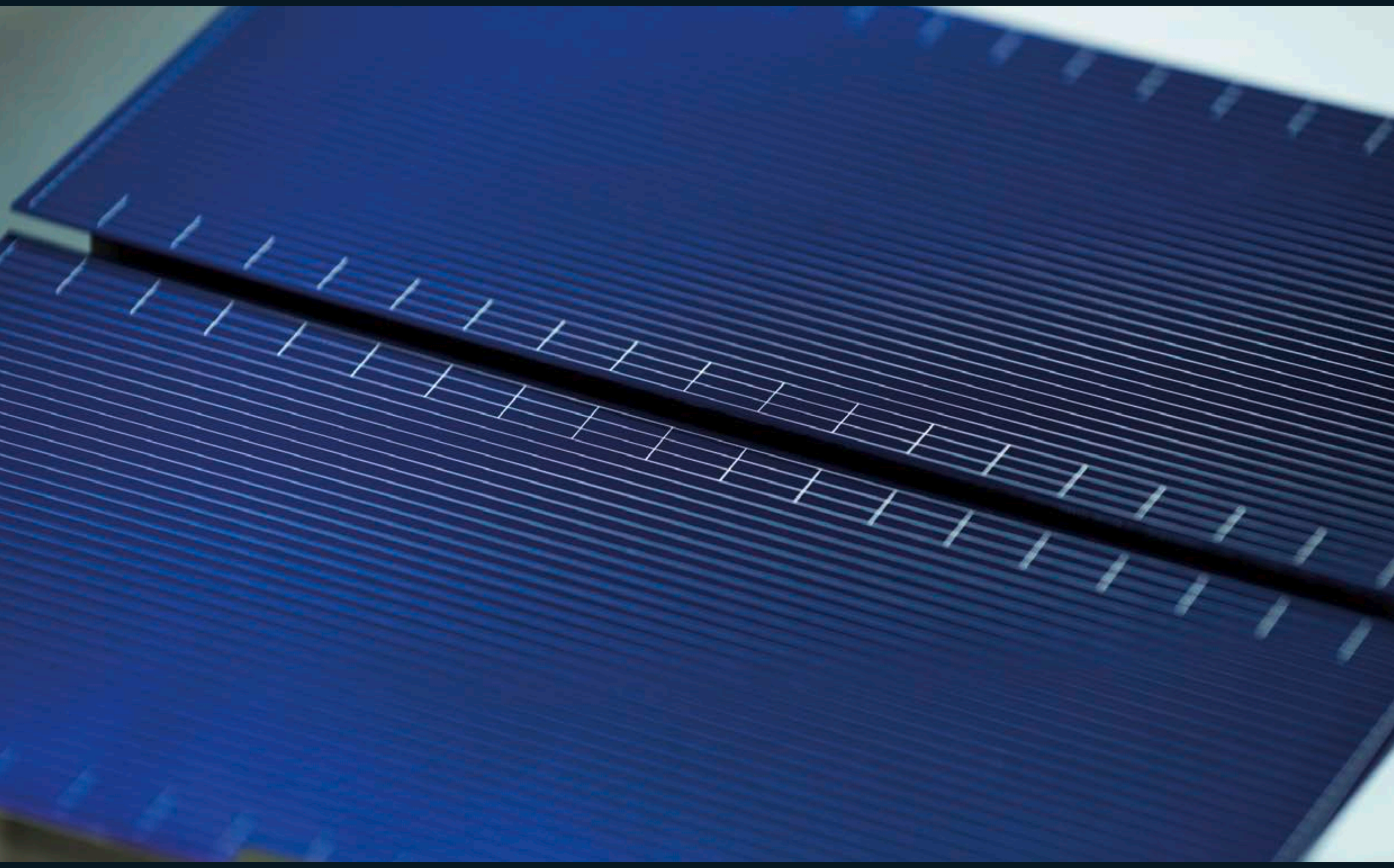

Why Solar Modules Are Starting To Look Different Now

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Executive Summary

Module making is becoming increasingly interesting. Unlike in the past, when module manufacturers were solely relying on innovations at the cell level in order to improve performance, they are now very active employing innovative approaches to improve PV panel output power independent from cell efficiency. It is not only about power output, module makers are commercializing concepts that improve reliability and durability. This report provides an overview on solar module technology with an emphasis on developments in the field of advanced technologies

Module efficiencies and power ratings continue to go up with PV manufacturers working on several advanced module concepts of which 5 are basically on everyone's radar.

Glass glass modules – with a fundamental difference of replacing the backsheet with glass – is one of the up and coming module concepts. This concept not only results in more durable product, it also enables the adoption of another important technology - bifacial modules.

Bifacial technology uncovers the rear side of the PV module for sunlight absorption. The gain varies between 5 and 30%, depending on various aspects, such as device design, site albedo, mounting conditions.

Half cut cells is a simple but effective way to improve the module power. By cutting a fully processed cell into two pieces, resistance losses can be reduced, providing a power boost of about 5 to 6 W. Today, a 60 cell equivalent module reaches a power rating of around 330 W with 120 half cells.

Shingle modules are also based on cell slicing – not into two pieces but several strips. The process completely changes cell interconnection by eliminating ribbon. Here, cell strips are connected in as shingle manner, similar to roof tiles. On the heels of two US pioneers, several companies have recently launched shingled modules as well. A shingled module with 19.1% efficiency and a very high power rating of 405 W, equivalent to a 72 cell module in size, is available in the market.

One of the most simple ways to reduce resistance losses is to increase the number of busbars. While 4 busbars are today's standard and 5-busbar products are increasingly launched, the first companies are introducing 6-busbar cell panels. More sophisticated is **multi busbars** technology, which is built on the same template as 'more busbars' and with the same goal of reducing resistance losses in fingers. But the magnitude is higher - it employs at least a dozen thin wires instead of flat ribbons and needs different equipment. Multi busbar technology, which also saves on silver paste, has a product in the market that comes with a 400 W power rating.

The very good thing about these advanced module technologies is that they can be implemented separately but mostly also together, thus offering the possibility to add up the different benefits. For example, half cut bifacial cells interconnected in multi busbar fashion in dual glass configuration is possible.

Please enjoy reading our Advanced Module Technology Report 2017

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1. Introduction

The design of solar modules basically hasn't changed for decades, but these days are over. Unlike in the past, when module manufacturers were solely relying on innovations at the cell level to improve performance, they are now more and more contributing their part to improve power and yield of a panel.

The improvements on the module level are mirrored in the high cell-to-module power ratios (CTM), that continue to go up. Employing innovative cell interconnection methods play an important part in the effort to increase module power ratings. This started with a quickly increasing number of busbars, is now reaching the **'multi busbar'** level, while pioneers have already begun to do without ribbon by mass producing **shingle** type cells. An interim step are **half cells**, which are also gaining in popularity among module producers.

Power is just one characteristic, reliability is equally important. While module manufacturers take responsibility for their products for 25 years and more, they have to manage the huge cost pressure that requires innovations in order not to compromise on quality. There is interesting developments in the encapsulation and backsheet field as well as choosing glass on both sides for packaging the module. The dual glass configuration is also supported by the growing interest in bifacial solar modules.

While we've looked into different equipment and materials used for solar cell and module manufacturing in several market surveys this year, the TaiyangNews Advanced Module Technology 2017 Report provides an overview on the latest trends in solar panels, the heart and most expensive part of any PV system.

2. Overview

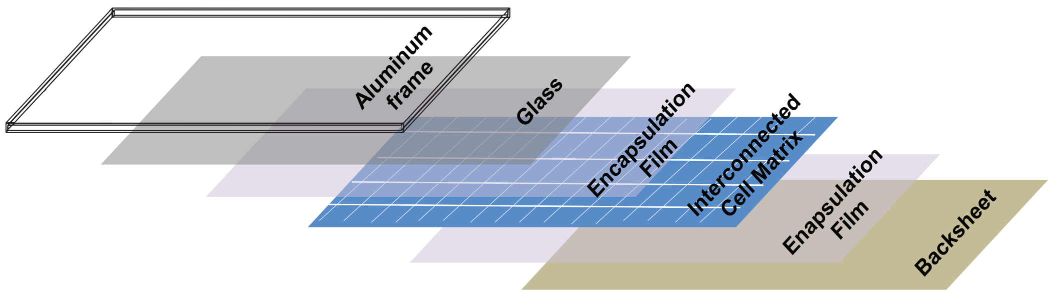
A solar cell is the basic unit of a fully functional PV system. Since the output power of one cell is low, several cells are interconnected electrically in series to form a matrix in order to reach a meaningful output power level. This interconnected matrix is encapsulated to protect the electrical circuit from physical damage and weather. The laminate is usually framed and provided with a junction box to collect the power from the cell strings. There are a number of different types of solar module technologies, but the predominant technology is crystalline silicon-based, which is also the focus of this study.

2.1 Basics of Module Manufacturing

Module manufacturing starts with connecting cells in series to add up voltage. The number of series-interconnected cells depends on the particular module design. However, the majority of PV panels are built with either 60 or 72 square-shaped cells. The cells are electrically connected in stringers with copper strips running from the front side of the cell to the rear of the adjacent cells. The interconnection process is very important as it governs the electrical properties of the module. The power rating is one thing; reliability is yet another important aspect of a PV panel, which is still the most expensive part of a solar system. A solar module is a rare commodity product that comes with a warranty of 25 years and more – for that reason, it contains many protective layers. After the stringing process, the cell string matrix is placed in a lay-up station – together with the encapsulation layers and the front and rear-side cover. The front layer is typically glass, which has to fulfill several criteria – one is protection from the weather, serving as a barrier to moisture and water ingression into the cell circuit and providing mechanical stability. Moreover, the glass has to exhibit a very high transparency so that a maximum of the incoming sunlight reaches solar cells embedded in the module.

The glass is attached to the cell matrix by means of an encapsulant, which similar to glass must be optically transparent. It provides cushion to the brittle silicon cells from any mechanical stress. The encapsulant also serves as additional moisture barrier to cells and circuitry. EVA is still the most common encapsulant today, while other materials, like polyolefins, are also being used. For most modules, a backsheets serves as a rear protection layer. It mimics the role of glass on the rear side with no requirement of any optical features. The backsheet provides electrical insulation and offers protection from moisture ingression and UV stability.

Main Components of Standard Solar Modules



Source: © TaiyangNews 2017

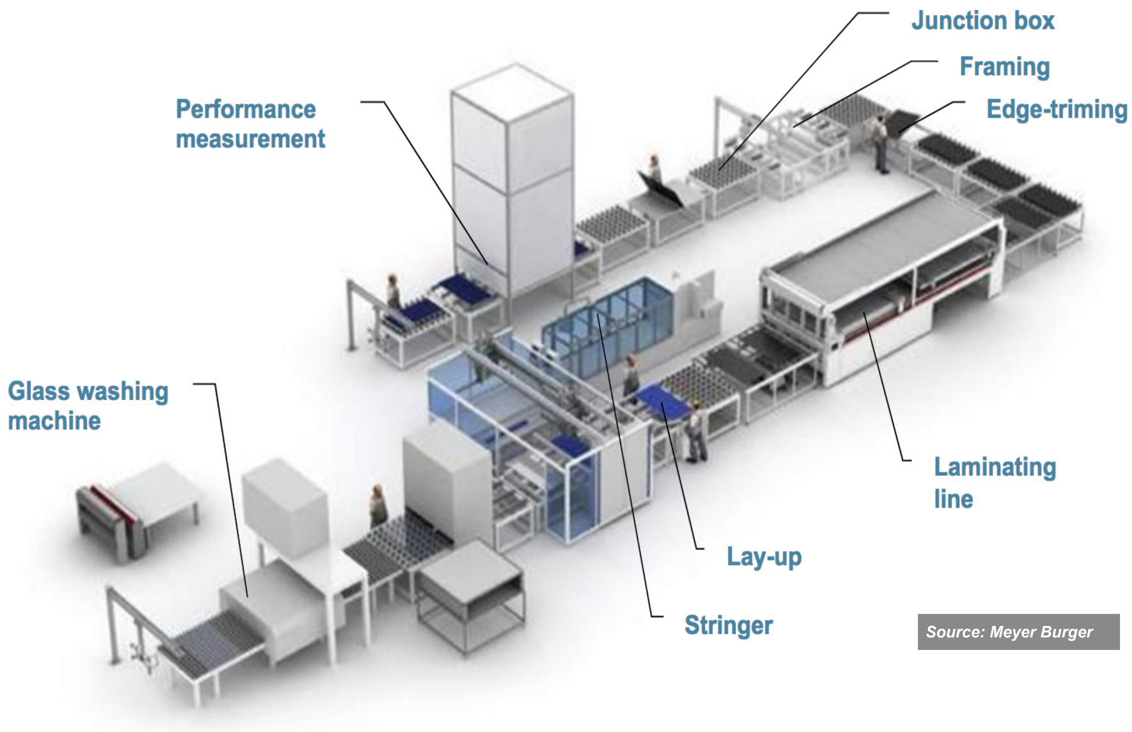
Solar module assembly is all about tightly packing the interconnected cell matrix with several protective layers

The cell matrix with glass, EVA and backsheet is 'baked' together in a laminator. Finally, an aluminum frame is added in a framing station to protect the module from mechanical damages during transportation, handling and installation. The rear of the module is fixed with a junction box to extract the power generated by the solar modules. The last production step takes place in a solar simulator that measures the power rating of the PV module.

2.2 Module Technology Shares

While there are many differences between crystalline silicon-based module products in the market, they can be broadly classified into multicrystalline and monocrystalline panels. There is an ongoing tough competition between these two varieties of the same species. The year-long incumbent – multicrystalline module technology - is still dominating the market, but all analysts see monocrystalline to catch up. The 8th International Technology Roadmap for Photovoltaic (ITRPV), released in March 2017, estimates that mono (including n-type) had a share of 35% in 2016 and around 40% in 2017 – and slowly increases by 3-4% every 2 years until it reaches 45% in 2021. In the following 3 years, mono is supposed to take over multi and reach about 50% in 2024. By 2027, mono is expected to exceed 60%, getting into the spheres multi is hovering today.

Standard Module Production Line

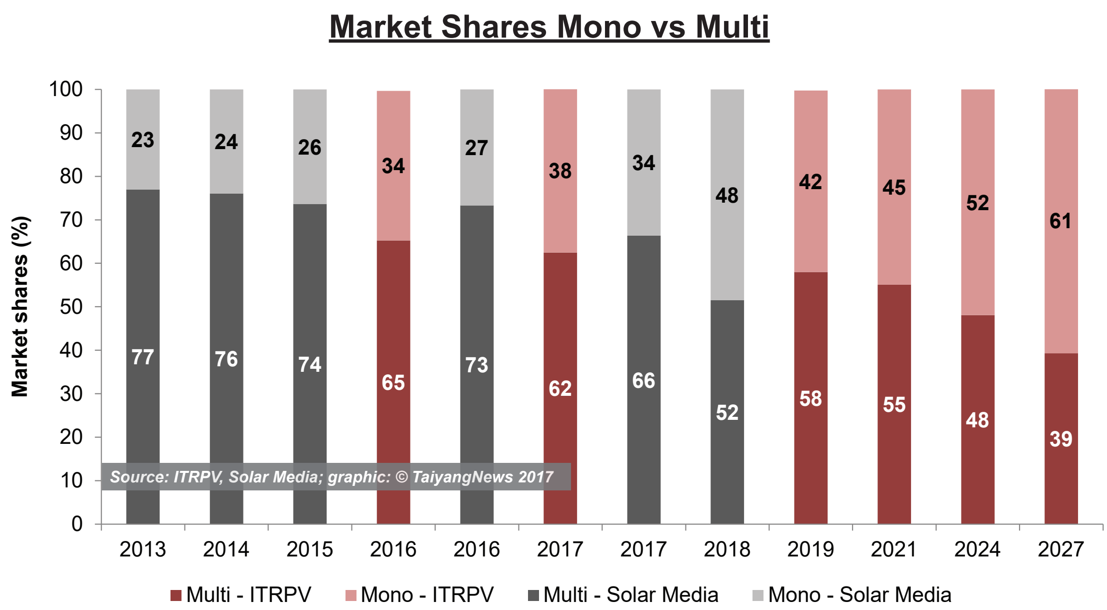


Connection & protection: Module manufacturing involves first interconnecting the cells, then this circuited matrix is encapsulated with polymer films and glass for protection from environmental assaults.

Finlay Colville, head of market intelligence at Solar Media, for example, is much more upbeat about mono. After he saw mono shares hovering around 25% between 2013 and 2016, he expects the share to increase to around 30% this year, and jump to nearly 50% already in 2018.

The high flight of monocrystalline has two reasons. Mono wafer manufacturers were successful in basically fully implementing diamond wire based sawing, which cut costs significantly over traditional slurry-based wafer slicing. Moreover, monocrystalline silicon - which enables anyway higher efficiencies than its multicrystalline peer - is better compatible with high-efficiency cell concepts. Take PERC for example - a technology shift nearly every cell producer is participating in. The majority of PERC cells are based on mono – and even the two main proponents of multi PERC, Hanwha Q CELLS from Korea and REC from Norway, have expanded into mono PERC cells. The efficiency gain of implementing PERC architecture for monocrystalline cells is about 0.8% to 1% absolute, while the boost for multicrystalline cells is a bit lower, from 0.4% to 0.8% (for more info on PERC, see the TaiyangNews PERC Technology 2017 Report).

PERC is just one of several advanced cell concepts. The world's largest mono wafer manufacturer LONGi, which plans to have 20 GW capacity by 2019, is developing n-type wafers. In an interview with TaiyangNews in May, Archie Flores, LONGi Solar's VP for Corporate Strategy and GM of Longi Solar US said that p-type PERC will remain its mainstream product for the next 12-24 months. ITRPV, however, forecasts n-type to grow only slowly from less than 5% in 2016 to about 10% in 2019, before it jumps to slightly less than 30% in 2027.



Mono is the future: While there is a clear trend towards a shift from longtime dominating multicrystalline silicon to monocrystalline wafer based solar cells, the most optimist analyst forecasts an equal share already by the end of 2018.

3. Key Metrics of Solar Modules

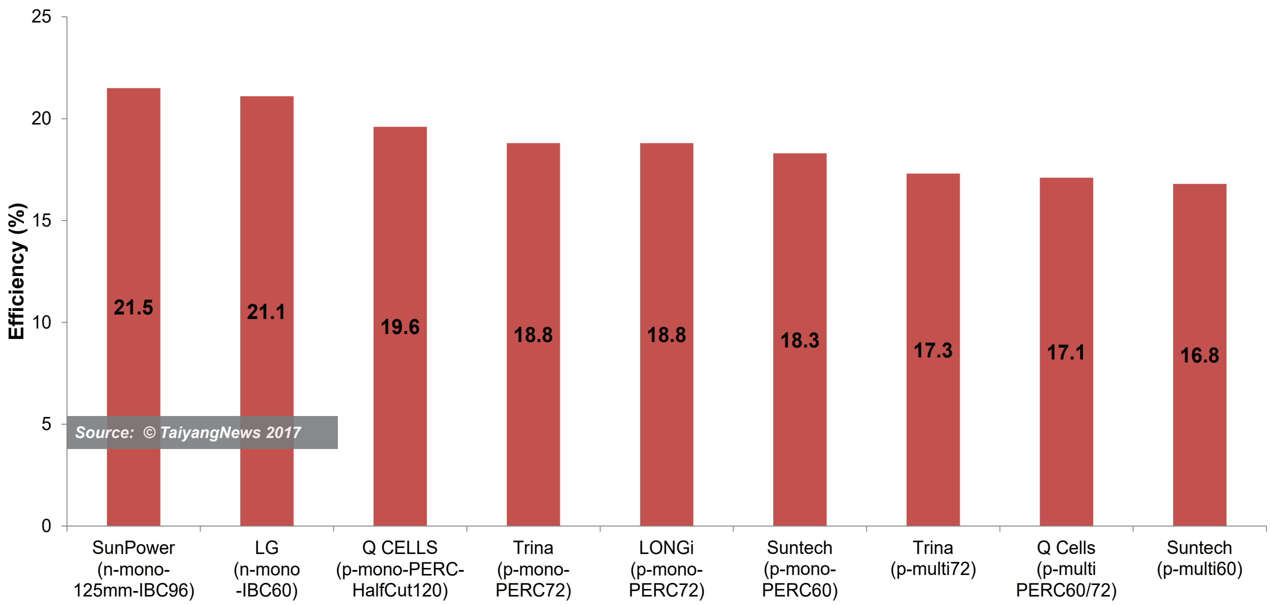
3.1 Efficiency

In the end, efficiency is the key metric for a solar module. The higher the efficiency, the higher the power rating – and that's what EPCs pay for - dollars per watt. According to ITRPV, the average module efficiency in 2016 was about 17.5%, consistently improving from the 2010 level of around 14.7%. For traditional monocrystalline modules, LONGi's current commercial modules reach top efficiencies of 18% to 18.1%, in case of PERC modules the best commercial module efficiencies are between 18.7% to 18.8%. The world record for a monocrystalline PERC module is 20.2%, held by Institute for Solar Energy Research Hamelin (ISFH) since January 2016. This 60 cell equivalent cell module is built with 120 half-cut PERC cells with an average efficiency of 20.8% has a rated output power of 303.2 W

Trina Solar holds the world record for multicrystalline module aperture efficiency of 19.86% since October 2016. This very high-efficiency, though non-commercial, module was realized by combining advanced approaches, including half cut PERC cells. Trina's commercial monocrystalline panels (mostly PERC) have up to 18.8% efficiency, while its multicrystalline technology products have conversion efficiencies up to 17.3% today.

With advanced module technologies (see chapter 4) and backed by continuous improvements in cell efficiencies, crystalline module efficiencies will only know one way in the coming years – and that is up. Regarding average cell efficiencies, ITRPV foresees p-type mono to reach around 23% by 2027 from less than 21% in 2016, n-type heterojunction to increase to 24% from less than 22%, and n-type back-contact cells touch 26% from 23% in the same period of time.

Top Solar Module Efficiencies of Leading Manufacturers



Here comes PERC: A selection of commercial modules from leading suppliers shows back contact cell technology (IBC) at the top with the highest efficiencies. But quickly expanding lower-cost PERC is not far distant, in particular when using half cut cells.

3.2 Power Rating

Module manufacturers do like to highlight their module efficiencies but the power rating is the main differentiator for the products. Standard modules still come mostly with 60 or 72 cells, whereas the larger variant is increasingly preferred for ground mount installations, except for Europe and China, where customers continue to prefer using 60-cell modules. “That’s due to philosophy and tradition, rather than any technical advantage,” said LONGi’s Director of Technical Marketing Hongbin Fang. According to ITRPV, 60-cell panels dominate the market, but the 72-cell configuration is expected to get more popular – increasing its share from 30% in 2016 to 35% in 2017, and about 60% in 2027. The roadmap further notes that 96-cell modules are appearing in special markets. Last year, GCL, for example, presented a 96-cell 440 W module as part of its ‘Super’ 2.5 MW Solar Block turnkey system product for utility-scale solar projects.

Then there is also half-cell modules, that come in standard sizes but have up to 120 monocrystalline cells, like the Q.PEAK DUO model from Hanwha Q Cells or the shingle-based panels from SunPower, which consists of a non-disclosed number of cell strips.

When looking at a 60-cell configuration, ITRPV estimates that power ratings are improving 1.3% in average over the next 10 years across all technologies, except for back-contact cells, which are supposed to improve by 1.6%. While multi BSF modules will continue to have the lowest nominal power at around 275 W in 2017, they are anticipated to increase to about 300 W by 2027. PERC multi should grow from 280 W to around 325 W, and p-PERC mono from 305 W to about 340 W. Back-contact modules are expected to remain the top scorer, improving from around 335 W in 2017 to close to 380 W by 2027.

While the top power ratings of several module suppliers are already a few years ahead of ITRPV’s roadmap, the average fits basically well for 2017. The top product range of LONGi has a 310 W power tag for 60 cells and 370 W for 72 cells today. “The average is between 302 W and 303 W,” said Fang. “We have 90% of distribution above 300 W,” he added. Q CELLS’ best mono 60-cell panels come at 305 W, while the multicrystalline variant reaches a top power of 285 W and 340 W for 72-cell modules.


Source: Hanwha Q CELLS

Quality is Priority: Higher module power ratings is one thing PV system operators are thriving for, the other is long-term durability. Pictured is a module undergoing a quality check at the Hanwha Q CELLS’ facility in Korea.

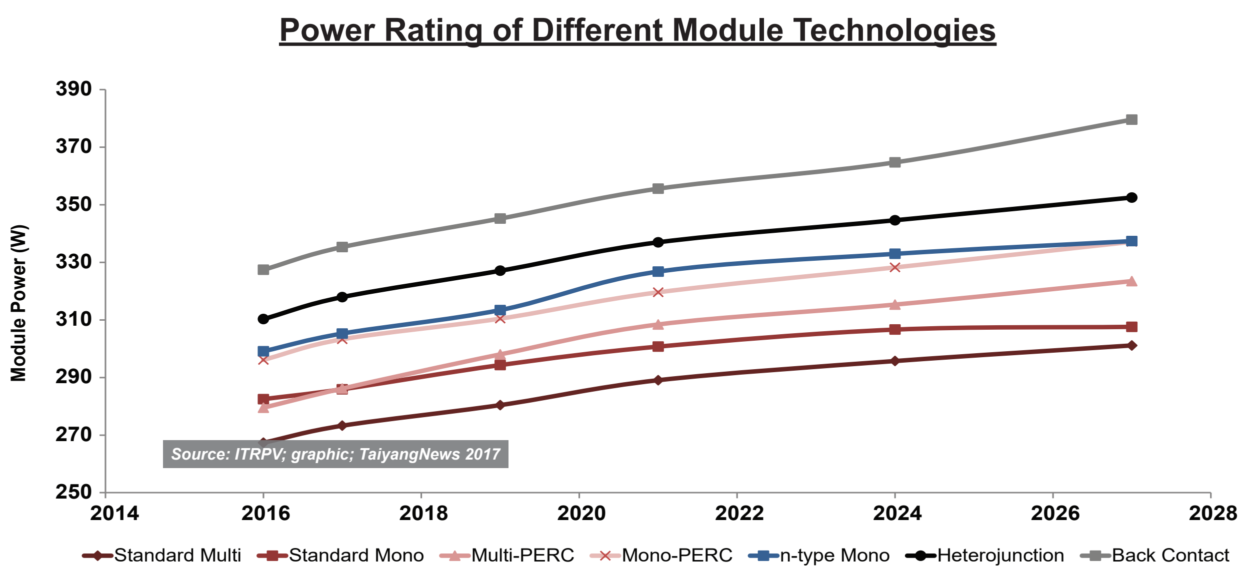
Power Ratings of Commercial Standard Solar Modules with 72 Cells (or Equivalents*) from Selected Manufacturers

Company	Model	Cell Type	Module Technology	Efficiency (%)	Power Rating (W)
Solaria	PowerXT	n-type mono	Shingles	19.3	405
LG	NeON 2	n-type mono	Multi Busbar	19.3	400
Canadian Solar	KuMax	p-type mono PERC	Half Cells*	18.65	370
LONGI	Hi-MO 1	p-type mono PERC	**	18.8	365
Trina	TALLMAX PLUS	p-type mono PERC	**	18.8	365
LG	MonoX Plus	p-type mono	**	17.4	360
SunPower	P-Series	p-type multi	Shingles	17.2	355
LONGI	LR6-72	p-type mono BSF	**	18.1	350
Suntech	STP345S	p-type mono	5 Busbars	17.7	345
Q CELLS	Q.PRIME	p-type mono BSF	**	17.7	345
Q CELLS	Q.PLUS	p-type multi PERC	**	17.1	340
Trina	TALLMAX	p-type multi BSF	**	17.3	335
Suntech	STP325	p-type mulit	5-busbars	16.7	325

Source: Companies module specs; graphic: © TaiyangNews 2017

Note: * Half cells but same module size; ** Number of busbars no included in module data specs

Worth the effort: Though complicated over standard, Shingling technology results very high power rating – a shingled module from Solaria has highest rated power of 405 W in our listing of modules with 72 cells, followed by LG employing multi busbar technology enabling to bear a power tag of 400 W.



Power gain potential: The power ratings of solar modules are expected to increase by an average of about 1.3% per year over the next 10 years, back contact modules and multi-PERC are expected to gain highest - close to 1.6% per year.

3.3 Cell-to-Module (CTM) Losses

One way of improving module power is to simply employ cells with higher efficiencies. However, improving the module power independent from the cell level is also possible. The so-called cell-to-module (CTM) power ratio is a good metric to assess developments at the module level. It is nothing but the ratio of total module output power to the sum of each of the cells embedded in the module.

Several module processing steps, such as interconnection, stringing and lamination, lead to optical gains. But module manufacturing also induces various loss mechanisms – such as resistive, mismatch and optical losses, which offset the optical gains and result in a net power loss. The optical losses are mainly due to reflection losses that occur at various interfaces of the module layers – "air-glass - encapsulant – cell". Undesired absorption of light from the front cover glass and EVA add up to this. Resistive losses are mainly contributed by the interconnection of cells and strings. Encapsulation gains are due to direct optical coupling as a result of higher refractive indices of the encapsulation layers. In addition, the light scatter from the cell gaps in the module and the metal contacts covered with ribbons also contribute to the plus side. Light scattered at an angle greater than the total internal reflection angle for the glass-air interface, which is about 42°C, undergoes total internal reflection at the front glass-air interface and is redirected back to the solar cell offering a second chance for absorption.

Power Ratings of Commercial Standard Solar Modules with 60 Cells (or Equivalents*) from Selected Manufacturers

Company	Model	Cell Type	Module Technology	Efficiency (%)	Power Rating (W)
LG	NeON R	n-type mono IBC	Back Contact	21.1	365
SunPower	X-series	n-type mono IBC**	Back Contact	21.5	345
LG	NeON 2	n-type mono	Multi Busbar	19.6	335
Q CELLS	Q.ANTUM DUO	p-type mono PERC	Half Cells*	19.6	330
Solaria	PowerXT	p-type mono	Shingle	19.3	330
LONGI	Hi-MO 1	p-type mono PERC	***	18.7	305
Trina	ALLMAX PLUS	p-type mono PERC	***	18.6	305
Q CELLS	Q.ANTUM	p-type mono PERC	***	18.3	305
SUNTECH	HyPro	p-type mono PERC	5 Busbars	18.3	300
LONGI	LR6-60	p-type mono	***	18	295
Q CELLS	Q.ANTUM	p-type multi PERC	***	17.1	285
SUNTECH	STP285S	p-type mono	5 Busbars	17.4	285
Trina	ALLMAX	p-type multi	***	17.1	280
SUNTECH	STP275	p-type multi	5 Busbars	16.8	275

Note: * Half cells but same module size, ** SunPower uses 5-inch cells; *** No. of busbars no included in module data specs

Source: © TaiyangNews 2017

Module technology matters: The most powerful modules built with 60 cells rely on advanced but complex back contact cell technologies. Still, rather 'simple' technologies, like half cut mono p-PERC from Q CELLS are not too far distant, reaching impressive 330 W.

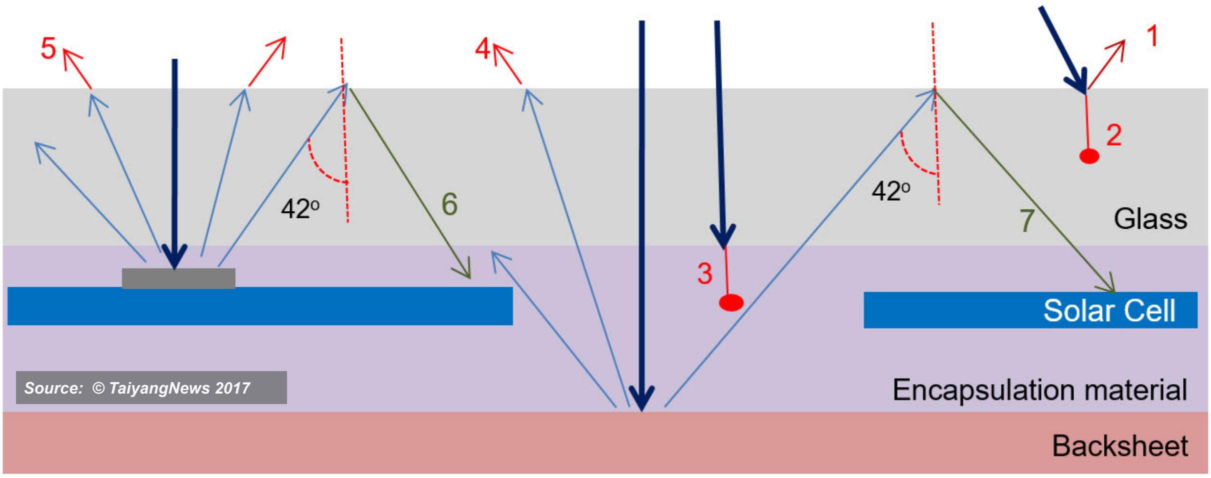
A 2012 research paper from Fraunhofer ISE provides a split of cell-to-module gains and losses in terms of absolute efficiency. According to the paper, the electrical losses account for 0.61% of which almost everything (0.57%) originates from cell interconnection and small fraction (0.04%) from the string. As for the light management, glass reflection and absorption pull down efficiency by 0.72% points and encapsulation absorption costs further 0.33% points. On the other hand, the coupling gain due to reflection from the cell surface, fingers, backsheet are given as 0.54%, 0.16% and 0.27% absolute, respectively. (Though module technology has changed considerably since then, which means it is not completely applicable to today's state of the art, the data provides a good indication on gains and losses of modules.)

Despite the various loss mechanisms, today's PV modules have the capability to reach a CTM power gain of more than 100%. In simple terms, this can be achieved with the proper choice and mix of complementing materials that result in higher optical gains than combined optical and electrical losses. In parallel, advanced interconnection approaches such as half cells and multi busbars help in reducing the resistance losses, pushing CTM power ratios to further heights.

The CTM power ratio varies for mono- and multicrystalline modules. That's because the cell output power is measured in air, while cells in modules gain from encapsulation. From this perspective, a careful selection of cells makes a lot of sense. Cells with higher UV spectral response and better texturing properties are less sensitive to encapsulation gains as they tend to considerably reduce reflection, which is the basis for the encapsulation gain. In other words, the lower the reflection, the smaller the encapsulation gain. This results in multicrystalline modules having a higher CTM power ratio compared to monocrystalline.

The latest ITRPV anticipates multicrystalline modules to reach a CTM power ratio of 100% in 2017, which would progressively increase to 103% by 2027. The monocrystalline CTM is expected to reach the 100% benchmark in 2021, improving from 98% in 2016 and close to 98.5% in 2017, and finally reaching 101% in 2027.

Optical Gains and Losses Mechanism



Losses: *1 - Glass reflection losses; 2 - Glass absorption losses; 3 - Encapsulation absorption losses; 4 - Encapsulation reflection losses; 5 - Cell related reflection losses*

Gains: *6 - Cell related total internal reflection gain; 7 - Encapsulation reflection gains*

Nearly no net optical losses: Though the module manufacturing induces the optical losses due to absorption of light in various layers and reflection from glass, most of this is compensated with reflection gains from cell and module components.

Developments to improve the CTM power ratio can be divided into two complementing streams – **light management and reducing resistance losses.**

Improving Light Management:

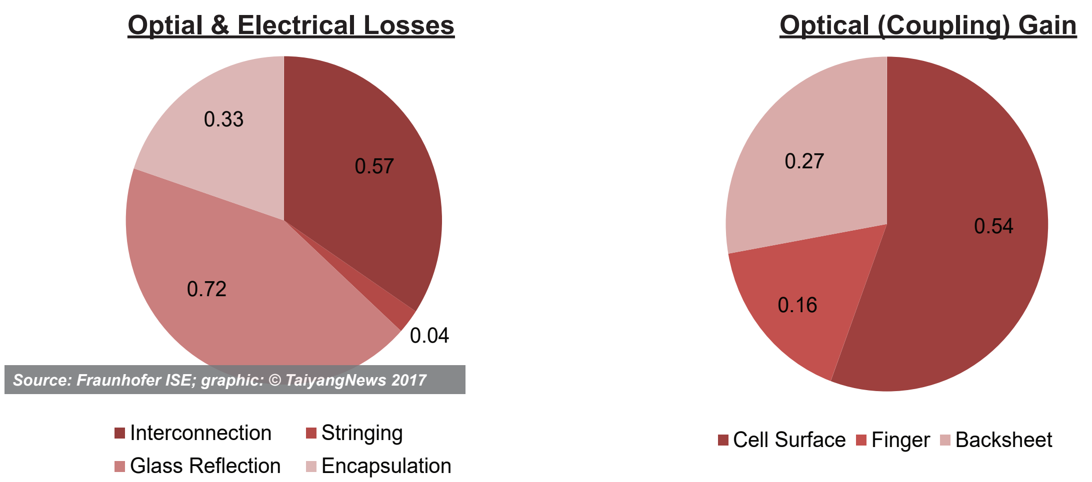
- Optimization of space between the cells in a module, namely increasing the reflectance of inactive areas by employing reflective backsheets.
- Using white EVA and reflective ribbons. Employing a reflective film fixed onto the ribbons is an approach that is under consideration by many module makers.

Reducing Resistance Losses:

- Optimizing ribbon thickness and width. Especially increasing ribbon cross section without increasing width is one example of keeping resistance losses low.
- Increasing number of busbars (and multi busbars)
- Using half cut cells or strip cells for shingling

While optimizing ribbon thickness and width is one way to reduce resistance losses, this issue is primarily governed by the interconnection process. Two fundamental approaches are applied – increasing the number of busbars and employing sliced cells instead of full cells for interconnection. Adding more busbars has been high on the agenda of cell and module suppliers for the last few years. Most companies use 4-busbars cells for their modules today, many have started to sell products with 5 busbars, and even panels with 6-busbar cells have been introduced by the first companies this year. The multi-busbar approach develops this concept even further, replacing cell busbars with many thin copper wires that are directly connected to the cell contact grid. Modules based on half cut cells is yet another approach that has been becoming very popular in recent months, especially in China. Shingling is an extrapolated version of half cells that involves dividing cells into several pieces, thus reducing resistance losses considerably.

Losses & Gain Factors in Solar Modules



Losses & gains: There are several loss and gain factors in solar modules, which determine the so-called cell-to-module power gain, whereas glass reflection contributes most to losses and reflection from cell surface most to gains.

4. Advanced Module Concepts

Advanced solar module interconnection approaches mostly require some fine-tuning of the process; the changes in the manufacturing vary from no changes at all to significant modifications, such as replacing the interconnection technology completely.

In this chapter, we look at different advanced module concepts – that are all commercially available – though in different market penetration stages. When it comes to double glass modules, basically every module manufacturer has already a model in its portfolio for a while; half cells are just seeing increasing attention these days; while multi busbar technology is the next evolution step, at the time when adding more busbars won't make sense anymore, which will be reached soon. Shingled module technology is still in its infancy, lead by few pioneers, but on the to-do list of many others. And then there are bifacial modules, which probably have the highest potential to increase power density and yield.

The good thing about these advanced module technologies is that – although many of them are well-known concepts for years –, only recent advancements and inter-compatibility is now making them commercially viable (see below table). The way for bifacial modules has now been finally paved by the success of mono PERC and other high-efficiency cells in combination with cost improvements of glass-glass modules

4.1 Glass-Glass Modules

Glass-glass modules were already produced decades ago. But heavy weight and cost opened the door for lighter and lower-cost glass-polymer products, which still dominate the market. For a few years now, more and more module manufacturers have been trying to push glass-glass modules. BYD from China, for example, advertises a longer operation time of up to 40 years – a sales argument most glass-glass suppliers have been using, though with limited success so far. According to ITRPV, the share of glass-glass modules has been about 3% in 2016, and is expected to reach only 6% this year.

Still, the durability argument is important – and together with a number of technology advancements, glass-glass modules will see quite soon some momentum. ITRPV expects glass-glass modules to reach a 35% share in 10 years.

Glass-glass modules are ideal products for utility-scale systems as they provide a heavy duty solution for harsh environments with high temperatures, high humidity or high UV conditions that usually impact the reliability of standard modules with backsheet. The extra layer of glass on the backside improves

Compatibility of Advanced Module Technologies

Technology	Bifacial	Double Glass	Shingles	Half Cells	More Busbars	Multi-Busbars
Bifacial		✓	✗	✓	✓	✓
Double Glass	✓		✓	✓	✓	✓
Shingles	✓	✓		✗	✗	✗
Half Cells	✓	✓	✗		✓	✓
More Busbars	✓	✓	✗	✓		✗
Multi-Busbars	✓	✓	✗	✓	✗	

Legend: Yes: ✓ Not applicable: ✗

Source: © TaiyangNews 2017

Highly compatible: A benefit of today's advanced module technologies is that they are highly compatible with each other. Most can be implemented collectively to add up individual benefits.

mechanical stability, reduces the chances of forming microcracks during installation and operation. Double-glass modules are also PID free, which is especially beneficial for p-type modules.

While standard modules have a degradation rate of about 0.7% per year, LONGi's Fang says that the degradation of his company's glass-glass modules is reduced to 0.45%, which results in 85% power output at the end of 30 years. LONGi and many other dual glass module suppliers offer power warranties of 30 years, which is 20% higher than the typical 25 years offered for glass-backsheet panels. Although double glass modules can be offered without aluminum frame, which saves on cost, many products come with a frame for stability reasons.

In order to reduce weight for a dual-glass module, the glass used is thinner than for glass-backsheet panels. While a typical glass-backsheet panel using 3.2 mm glass for the front weighs about 18 kg, a dual glass module using 2.5 mm glass on both sides weighs about 23 kg - so it is about 20% heavier.

The typical glass thickness in the dual glass configuration is usually 2.5 mm. Some companies have already started using 2.2 or 2 mm thin glass, and a few are even evaluating 1.8 or 1.5 mm. But producing low amounts of thinner solar glass is expensive compared to the regular size. With increasing volumes prices drop and glass-glass module technology is becoming more and more mature and affordable.

Except for the replacement of the backsheet, the configuration of a double glass module is the same as for a standard module. Interestingly, module companies often use polyolefins for encapsulation rather than EVA, which clearly dominates standard modules. But EVA poses some limitations as it releases free radicals during the cross-linking process which may negatively affect module reliability. Acetic acid is also produced during the standard module manufacturing process, but the polymer backsheet on the rear side is to a certain extent permeable for these free radicals – unlike in a glass-glass module. On top, polyolefins have higher water vapor barrier properties than EVA.

BOM Changes with Advanced Module Technologies

Technology	BOM						Remarks
	Ribbon	Encapsulation	Backsheet	Front Cover Glass	Frame	Junction Box	
Bifacial	✗	✗ / ✓✓	✓✓ / ✓✓✓	✗ / ✓✓	✗ / ✓✓✓	✗ / ✓✓✓	Back cover has to be transparent for both – glass or backsheet; advanced junction box is optional
Double Glass	✗	✗ / ✓✓	✓✓✓	✓✓	✗ / ✓✓✓	✗	Glass replaces backsheet for rear cover; thinner front glass is used
Shingles	✓✓✓	✗	✗	✗	✗	✗	Eliminates ribbon
Half Cells	✗	✗	✗	✗	✗	✗	Slightly more ribbon
Multi-Bus-bars	✓	✗	✗	✗	✗	✗	Ribbon replaced with thin wires
More bus-bars	✓	✗	✗	✗	✗	✗	Slightly more ribbon

Source: © TaiyangNews 2017

Legend: ✗ No impact; ✓ Minimum positive impact; ✓✓ medium positive impact; ✓✓✓ High positive impact; ✓ Low negative effect; ✓✓ Medium negative effect; ✓✓✓ High negative effect.

Higher or lower bills for materials: Different advanced module concepts have different impacts on the bill of materials. Double glass requires the largest BOM changes - shifting from backsheet to glass and switching to thinner front cover glass (which is also true for bifacial when opting for a dual glass structure). The move to half cells has almost no impact at all.

4.2 Bifacial Modules

Glass-glass panels are the key enabler for the hottest advanced solar module technology today – bifacial modules. This simple but excellent technology opens the usually covered back side of a photovoltaic device for sunlight absorption. Even diffused or reflected light, to which the solar cell's rear side is normally exposed, can generate charge carriers. The gain varies between 5 and 30% and depends on various aspects, such as device design, site albedo, mounting conditions.

While bifacial technology was invented in 1960, it took over half a decade before the time arrived for mass production. This year, the first companies have started bifacial module production lines, with one manufacturer, Linyang from Shanghai, fully betting on this promising technology.

Next to glass-glass modules, there is an even more important driver that pushes bifacial development. Cell manufacturers are quickly moving to high-efficiency solutions, which are bifacial by nature, unlike traditional aluminum-BSF solutions.

Besides cells, bifacial modules also require a few changes at the module level. Obviously, the module design first needs to switch to a transparent rear cover. Then the junction box design has to be moved away from the back to the side. On top, it is recommended to look at alternative encapsulation materials and implement more suitable interconnection technology to maximize the benefit of bifacial architecture.

As module manufacturers are trying to push glass-glass configuration because of its longer lifetime anyway, the bifacial option to increase output is a very welcome supporting sales argument. The market leader for frontside antireflection coating, DSM from the Netherlands, has already developed a tailored solution for rear glass of bifacial modules. The company says that this light trapping technology, which is applied using a roll-to-sheet process, results in 2.5% gain in power production.

While nearly every bifacial module maker is employing glass for the rear cover, Jolywood is an exception. The Chinese company is promoting

Source: TaiyangNews 2017

Back boosting: Bifacial PV is a very interesting technology that opens the rear side of the solar module for sunlight absorption, like this glass-glass panel from Trina, which was on display at the SNEC 2017 trade show and was advertised to generate up to 25% more power in addition to the power output from the front.

transparent backsheets, which is due to its major business - being a world leading manufacturer of solar backsheets. The plus side of transparent backsheet is that the traditional module process does not change and the module remains lighter to handle due to lower weight. Backsheets also have advantages in hot regions as heat dissipation is higher compared to glass, positively affecting the normal operating cell temperature in the field. On the backsheets' downside are lower transparency, durability and the need for a frame.

Bifacial modules not only can be used with any of the commercial high-efficiency cell architectures –PERC, PERT, IBC and Heterojunction –, they also work very well with half cut cells. Since current is getting high, so do losses, which makes the half cell configuration a very good fit for interconnecting bifacial cells. Linyang's entire bifacial module production is based on half cells. According to Linyang's CTO Xu, not only the output power increases by 5 W minimum per module, the CTM power ratio improves as well, now reaching 98.5%.

Despite its old age, there is still interesting R&D developments in the bifacial area. German research center ISFH has developed an interesting interconnection called Flip-Flop, which is based on front-to-front and rear-to-rear interconnection of cells with alternating orientation (n+ or p+ side facing up). That means, instead of running the ribbon from the cell front to the rear of the adjacent cell, every alternate cell is turned around so that the ribbons can move straight. According to a technical paper presented at EU PVSEC 2016, the Flip-Flop interconnection scheme has the potential for a module efficiency improvement of 0.5 % on aperture area (as compared to a conventional "all cells emitter up" configuration) despite a 3 % current mismatch (Flip-Flop Cell Interconnection Enabled by an Extremely High Bifacial Factor of Screen-Printed Ion Implanted n-PERT Si Solar Cells; Author: Henning Schulte-Huxel).

The replacement of the junction box is one more specific change that should be considered for a better design of a bifacial module - in particular as it doesn't require big efforts. However, the possible current mismatch when using traditional back-side J-boxes is not significant, as the photocurrent generated from the rear side is mainly based on low level diffused light. New junction box designs enabling to be placed in the corners are available from several vendors.

Solar module manufacturers are now quickly expanding into the bifacial field. You can see such products increasingly on display at trade shows, even though production capacities are still rather small.

With high-efficiency cells like PERC taking over, so will glass-glass and bifacial technology. The most notable company in this field is Linyang, which fully focuses on bifacial technology and operates a 400 MW n-type cell and module production, which will be increased to 800 MW by the end of the year. Another bifacial proponent is LONGi, which has 300 MW of its capacities dedicated to bifacial technology, but using p-type PERC cells. “Output so far is fully allocated,” said Archie Flores, LONGi Solar VP for Corporate Strategy, adding, “We will scale it up as the market allows.”

As the output gain of bifacial technology depends among others on the cell technology, it remains to be seen if this will push certain high-efficiency technologies. The so-called “bifaciality” of p-PERC cells is much lower than for n-type cells – the ratio is around 75% versus over 90% for n-type. However, the bifacial effect for all high-efficiency cells comes for free – and there is still a lot of optimization potential for p-PERC, but that wasn’t the focus so far, according to LONGi.

Many in one: Bifacial modules combine with several advanced technologies. This 72-cell model LONGi introduced at the SPI 2017 trade show in Las Vegas comes with a 5-busbar PERC cell design, resulting in a high power output of 370 W. The 1,500 V dual glass product is advertised to have a lifetime of 30 years.

In April, LONGi, for example, launched its bifacial module series with a rated power of 360 to 365 W, the 60-cell module reaches 300 to 305 W. While this is similar to the monofacial products of the company, depending on location of the system the output will be higher. These bifacial module have a bifaciality of above 75%. TaiyangNews has published a detailed report on Bifacial Solar Module Technology 2017 in June covering all aspects of this promising solar technology. We estimated that bifacial technology would have an installed base of 4 GW in 2017 and would double to about 8 GW in 2018. However, actual production will be only about 300 to 400 MW this year. ITRPV’s 8th edition estimates that the bifacial concept will rapidly expand - from almost negligible presence in 2017, to 10% market share in 2019 and 20% in 2021, before reaching 35% in 2027.

In the meantime, bifacial technology has to overcome a number of teething problems. This includes missing bankability, questions how to rate and price the products. But the major issue is the lack of standardization. An IEC standard is in the final stages and expected to be ready for publication in 2018.

4.3 Half Cut Cells

One reason why half cut cells were not used more frequently earlier is probably aesthetics v they simply looked very different, a little bit like broken cells were recycled in a module. But using half cut cells in solar modules makes a lot of sense – it is about physics. Two half cut pieces have the same voltage as the full cell, but the current – which is a function of the surface area – gets divided accordingly by half. Consequently, the internal electrical losses – which are in the second order of the flowing current – are reduced to 1/4th for a half cell compared to full square solar cells.

There is also a flip side of the half cell concept beyond aesthetics - and that is an additional process step to slice the cells. This is a mechanical process, which might induce additional breakage losses and micro-cracks. On top, half cells also reduce the throughput of interconnection tools by half. A 100

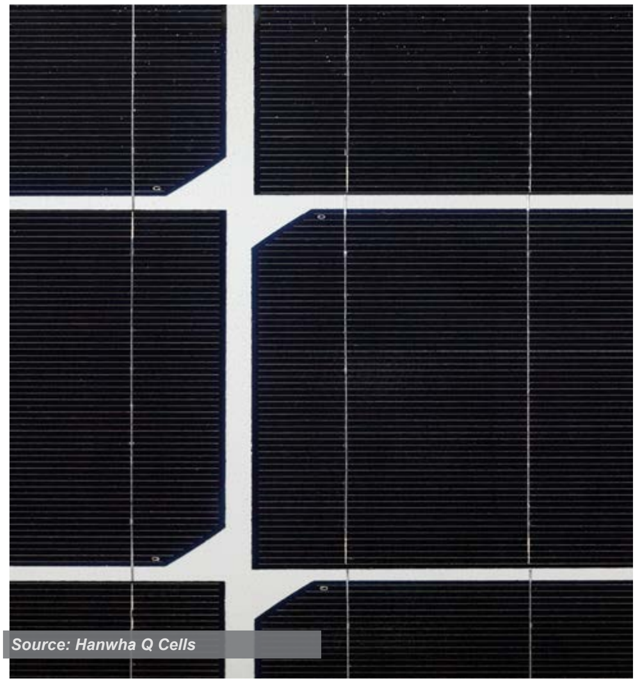
MW stringer can only process about 50 MW half cut cells per year, because the machine considers both a half cell and a full cell as one unit. Overall, the approach adds more complexity to module making. For all these reasons, the share of half cell technology – although known for years – basically has not increased as much as anticipated in the last few years. This is now quickly changing.

REC Solar was the first bigger module maker that has taken half cell technology very seriously and implemented it in mass production at its Singapore 1 GW facility already in 2013/14. As of this year, basically every Chinese module manufacturer is producing half cell modules as well. Linyang not only produces 100% bifacial modules, it relies even exclusively on the half cut approach. According to a top executive of a leading module manufacturer, who requested anonymity, hundreds of new stringers have been ordered by Chinese module makers.

The reason of this sudden demand surge for half cells is the high bench mark set up by the Chinese government sponsored Top Runner Program, which is a scheme auctioning 8 to 10 GW this year. The Top Runner Program's goal is to push commercialization of high-tech solar modules. The 3rd phase of the program requires at least 280 W for 60-cell multicrystalline modules and 295 W for mono. Half cut cells help module manufacturers to circumvent any shortage in high-efficiency cells as they provide an instant boost in module power by about 5 to 6 W. "It is the most economic and fastest way to realize a power gain," said Linyang CTO Xu.

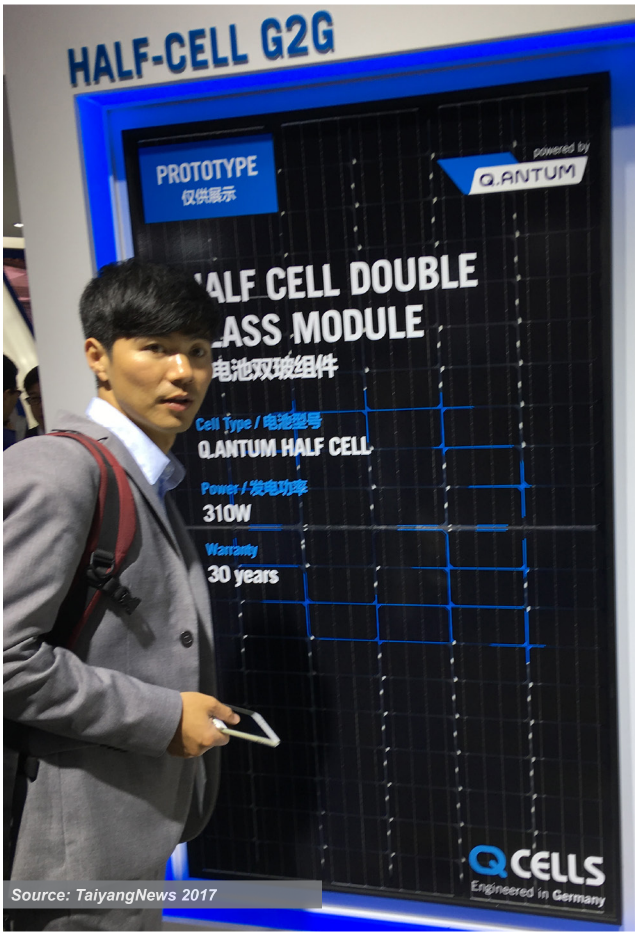
Q CELLS, for example, has a 330 W half-cell panel in its product portfolio. With a size equivalent to a 60-cell module, this Q.ANTUM Duo is based on 120 p-type PERC half cells and comes with a higher output than any other panel with traditional square p-type PERC cells.

It is possible to cut nearly any cell technology in half – the higher the original cell efficiency, the better for the module power rating. All it needs to produce half cut cells is a laser and additional stringing and



Source: Hanwha Q Cells

Full benefits with half cells: Half cell technology in combination with a double glass structure leads to high power ratings. This 120 half-cell prototype module Q CELLS presented at SNEC 2017 in Shanghai reaches 310 W and will be offered with 30 years warranty.



Source: TaiyangNews 2017

tabbing tools in order to maintain production capacity at the same level. According to the **TaiyangNews Market Survey on Interconnection Equipment**, the prime stringing tool suppliers are already offering interconnection equipment with throughputs exceeding 3,000 cells per hour.

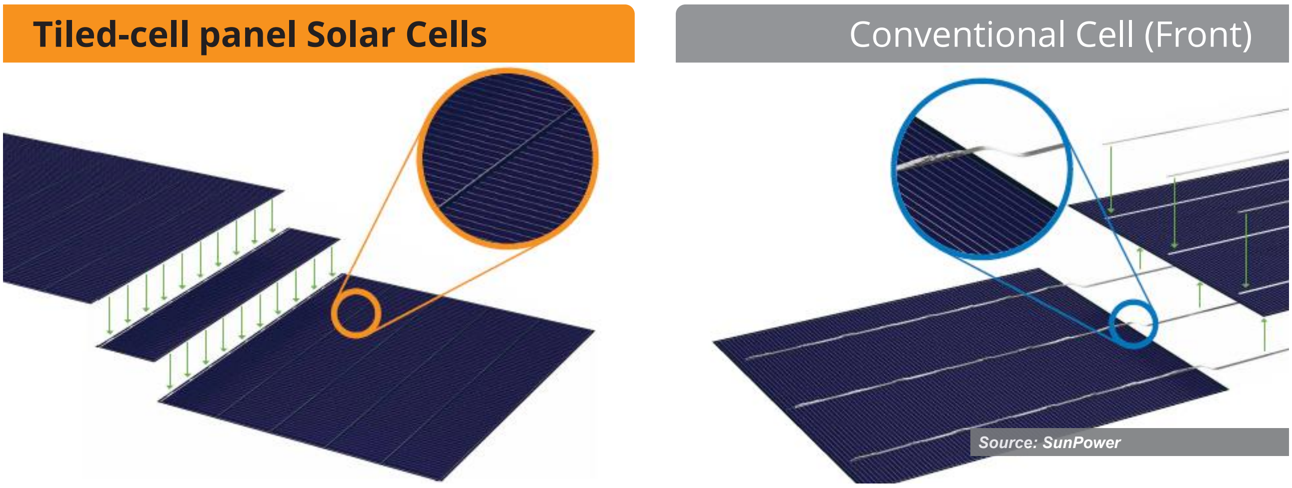
As module manufacturers can combine half cells not only with any traditional high-efficiency cell technology as well as with any other advanced module concept, except shingles (which is one evolutionary step ahead), it is likely that this technology will see a huge uptick in the near future from the less than 3% market share in 2016 – and probably beyond the around 14% ITRPV is forecasting for 2021. According to LONGi's Fang, the cost per piece for producing half cell modules is probable higher compared to the standard, but turns out to be equivalent at a per watt basis. Except for aesthetics, nothing speaks against a fast development towards half-cut cells.

4.4 Shingles

Another interesting module concept is the so-called shingles or tiles based interconnection. The beauty of the technology is that it eliminates ribbons completely. Here the cells are connected to each other in a similar fashion to a shingle structure of tiles placed on roofs. That means the cells are interconnected directly by placing them on each other. However, standard size cells cannot be used. Instead, the cells are sliced into a number of strips along the busbars. These busbars are used to interconnect two adjacent cells, which means the busbars are covered in the overlap area (see infograph).

The method of interconnection is the challenge of shingled modules as the interconnection material used must be able to compensate the thermo-mechanical stress due to the mismatch of the thermal expansion coefficient of glass and silicon during operations. In standard modules, ribbon provides a cushion for this issue. In any case, the interconnection medium must be flexible enough to avoid failure of the connection. Companies like Dow Corning are offering electrical conductive adhesives for this application.

Regarding changes at the cell level, a special metallization design is required. Unlike a standard cell, in which the front and rear busbars are aligned to each other, cells for shingled modules should have busbars at opposites ends of the strip that is sliced from a cell. That means if a strip has busbars on the top left, then the rear busbars should be on the right side for that particular strip. Slicing a cell into several strips reduces the current, and thus reduces the load on fingers. This enables reducing the number of fingers as well as the finger thickness on the cells, which results in less shading and improved output power of the cell. In addition to power gain, the shingled module approach results in less silver paste consumption.



Solar shingles: Shingle or tile modules are based on solar cells that were sliced into several strips and are interconnected similar to roof tiles. Two American companies – SunPower and Solaria – are pioneers in the shingled module technology field, but the first Chinese companies have introduced such products as well.

Last but not least, the technology results in a higher module aesthetics - homogeneously colored shingled panels look simply beautiful. The reason for this homogenous appearance is that the concept eliminates ribbons. There are busbars, but they are hidden in the cell overlap zone.

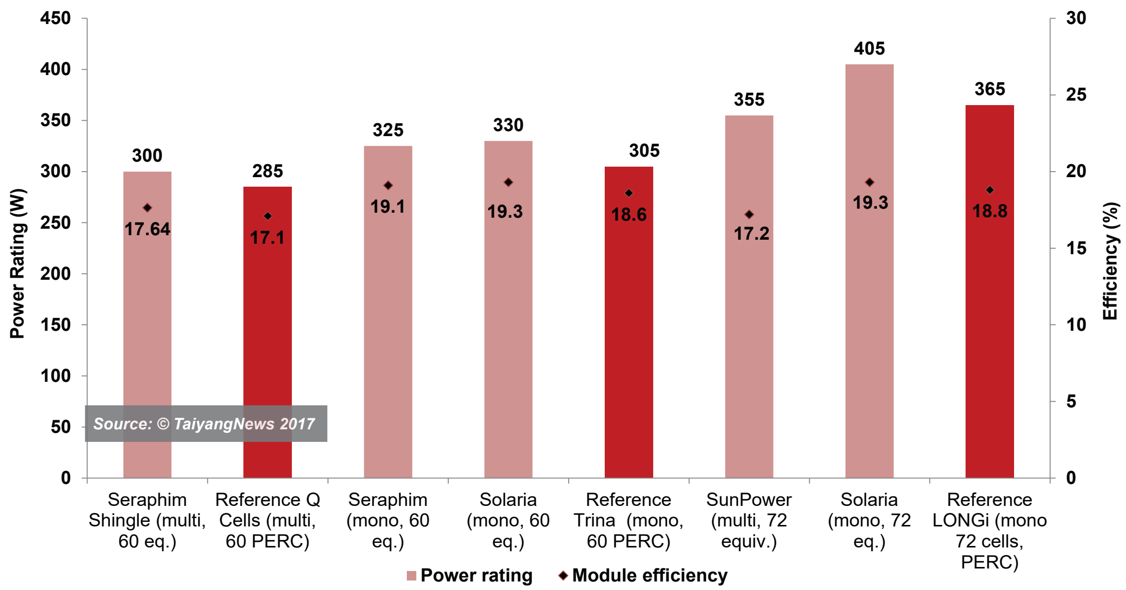
Beauty is on thing, but in the end it's usually about the power output gain of a technology, which largely depends on several process variables – number of strips sliced from the cell, overlap area, metallization layout. A Fraunhofer ISE research paper (Cell-to-Module (CTM) Analysis for Photovoltaic Modules with Shingled Solar Cells; Author: Max Mittag) that was published at this year's 43rd IEEE conference in June in Washington DC provides a fair estimation of the gain. It emphasizes that shingle interconnection technology following a specific design improves the power output power by 38 W and improves the module efficiency by 1.86% absolute compared to standard ribbon based interconnection.

Cogenera belongs to the pioneers of shingled modules. In March 2015, the US company showed that a 72-cell panel based on shingle technology can produce 400 W, while a module based on standard design using the same cells reached a maximum of 350 W, which equals a gain of about 17%. SunPower acquired Cogenra in mid-2015 and commercialized the technology in its Performance series (P-Series). As SunPower's core product – back contact cells – is not well suited for shingle-style interconnection, it started to use p-type multicrystalline cells, which it has sourced externally. In February, SunPower announced a joint venture with Chinese partners TZS and Dongfang for 5 GW cell and module manufacturing capacity for its P-Series panels based on shingling technology. A P-Series panel's size is comparable to that of a 72 cell standard module; today's maximum power rating reaches 355 W.

Another US-based pioneer of shingled solar modules is Solaria. Bankrupt company SunEdison had licensed Solaria's technology for its 'Zero White Space' modules. Solaria also offers the product directly – its Power XT model comes with a power rating of 330 W and 19.3% efficiency.

The attractiveness of shingle module technology has been recognized by many other manufacturers.

Commercial Shingle Modules of Selected Companies



Power boost: Shingling, though a bit more complicated in production than standard panels, results in very high module output power. One model from Solaria comes with a labeled wattage of 405 W, which is about 40W more than a comparable 72 cell module.

BOX Lasers for Cleaving

There are two critical aspects in the production of shingle modules – the interconnection medium and lasers. Generally, lasers are used for cutting cells into several pieces during the production of shingle modules. This is mainly accomplished with laser scribing – first a groove is cut with a depth of about 1/3rd of the wafer thickness; then mechanical force is applied to break the silicon slice exactly along the scribed line. One issue with this method is creation of dust during the scribing process, which is nothing but laser ablation. Moreover, mechanical separation requires some kind of automation.

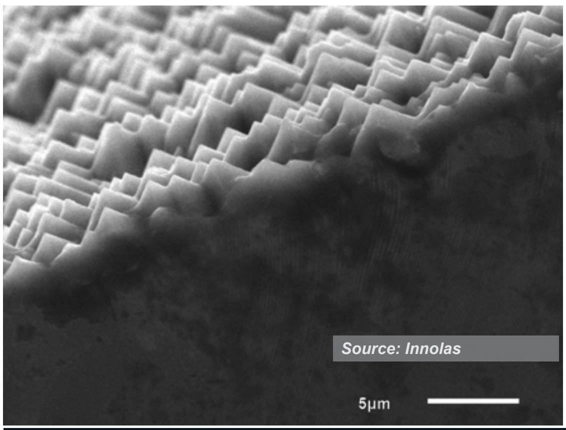
Innolas from Germany has developed a technology called Laser Direct Cleaving (LDC), which, as the name indicates, is a direct cleaving method. This process directly results in two separate work pieces. Ernst Hartmannsgruber, sales director at Innolas, says that in addition to saving on automation for mechanical separation, the process does not create any dust as no material is ablated from the surface. Cleaving separates the silicon slices through tension created by the laser. First, a well defined micro crack is created at the edge of the wafer, then the heat of the laser guides the crack to the other edge. The process does not induce any damage to the cleaved edges of silicon, says Innolas.

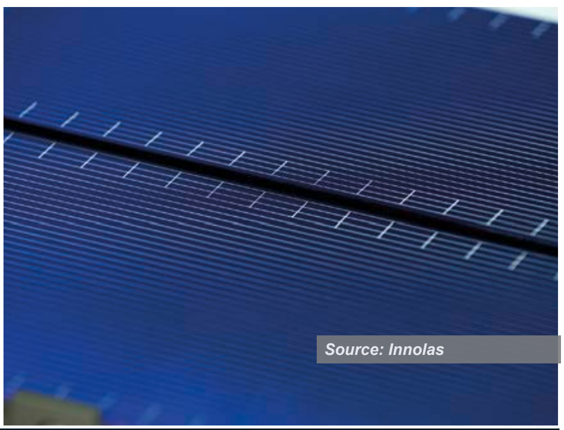
"The purpose itself is to keep the wafer free from damaged molten areas," said Hartmannsgruber. Since there is no dust formation, the costs associated with filtration can be eliminated completely. Another advantage of the LCD technology is that the cell pieces produced with the 'scribe and break' method have lower mechanical strength compared to cleaved pieces.

Innolas has integrated the technology into its ILS-TT machine platform. The standard configuration has a throughput of 4,000 half cells per hour, the ILS-TTnx comes with an hourly throughput of 6,000 half cells per hour.

While applicable for half cut cells, Innolas is promoting the tool mainly for shingle modules. As several strips need to be cut from a cell, not only the breaking mechanism becomes difficult but dust from grooving becomes a big concern as well, said Hartmannsgruber.

During the shingling process, typically 5 strips are produced with 4 cuts. Interestingly, the throughput of ILS-TTnx does not decrease accordingly to 1,500 cells, but can still process 4,000 cells per hour. Innolas would not provide details. Hartmannsgruber only said that, "For half cell cutting we are comparable, with shingling we have a real cutting edge." This is also reflected in projected costs of ownership values – 0.18 USc per cut for shingling and 0.5 USc per per cut for half cells.





Clear cut: Shingle technology needs lasers to cut the cells into several strips; the same is true for half cell technology, where lasers are used to slice cell into two pieces. The new LDC process from Innolas slits the wafer without inducing any damage at the sliced edge of the wafer.

Seraphim from China, for example, is offering shingled mono modules (equivalent to a 60-cell panel) with an efficiency of 19.11% and a power rating of 325 W, as well as a multicrystalline 290 W model with 17.6% efficiency. And there are many others that have been presenting prototypes at recent trade shows.

Shingled module pioneers are apparently not too happy about competitors tending towards shingles. In September 2016, Solaria filed an IP lawsuit against GCL over shingled module production technology infringement. In the same month, Cogenera accused SolarCity of IP theft related to its shingle technology. In April 2017, Solaria filed also a lawsuit on the same topic, this time against Seraphim and leading Chinese cell connection equipment supplier Autowell. When looking at these lawsuits one could get the impression shingling is a new invention. However, as with many PV technologies, shingling is an age old approach – we tracked it back to 1973, when a patent on "Shingled Array of Solar Cells (US 3769091 A) was issued. So it remains to be seen if the patent lawsuits can really stop or slow down shingle module technology.

4.5 More Busbars

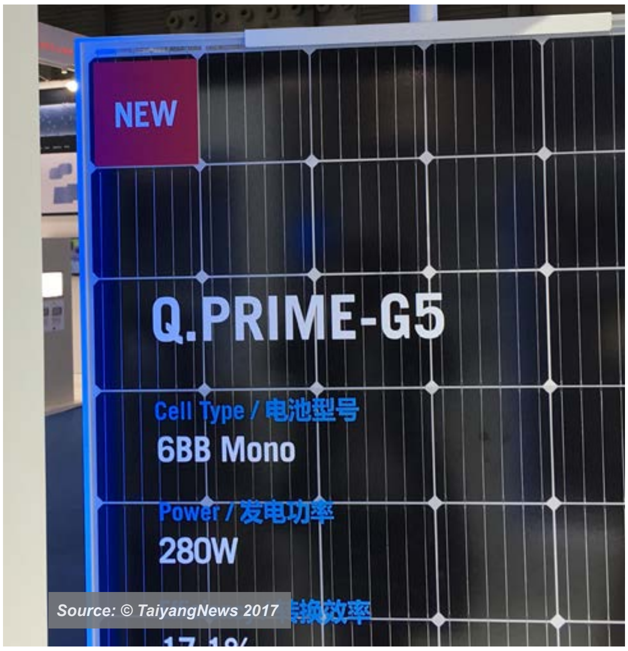
Not really an advanced module technology, but one of the most simple ways to reduce resistance losses is to increase the number of busbars. While using 3-busbar cells was a standard in module assembly about 2 years ago, the industry has now shifted more or less completely to 4-busbar cells. Many of the leading PV manufacturers are already selling a significant amount of their module products with 5 busbars. And the first companies have even started to offer 6-busbar cells. Moving to more busbars requires suitable stringing machines. The interconnection tools from leading equipment suppliers are coming with the ability to process cells with up to 5 busbars, the first can even handle 6-busbar cells (see TaiyangNews Market Survey on Cell Interconnection Equipment 2017).

4.6 Multi Busbars

The multi busbar approach is aimed at reducing resistance losses. In fact, it is nothing but an

Source: © TaiyangNews 2017

More busbars: While modules with 4-busbar cells have become a standard in the industry, many module makers, like LONGi, have moved beyond, offering solar panels based on 5 busbars.



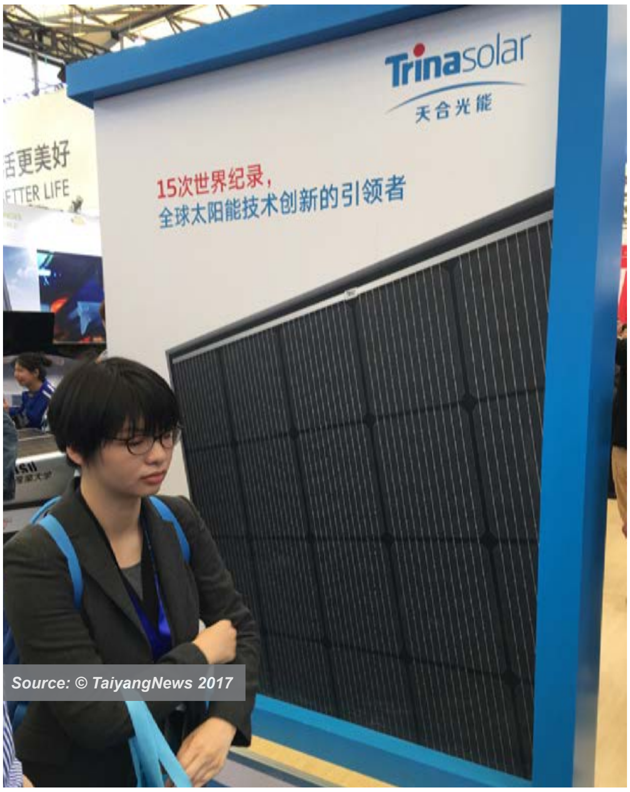
Source: © TaiyangNews 2017

Six cells?: While experts still argue if the benefit of moving to 6-busbar cells in modules is mostly marketing rather than power gain, the first suppliers have already designed the products, like Q CELLS.

extrapolation of the idea of increasing the number of busbars. But instead of employing 4, 5 or even 6 ribbons for interconnection between cells, several thin wires are used. While the concept is similar, the magnitude is higher.

Increasing the number of busbars or employing thin wires reduces the gap between busbars, which also shortens the finger length. Thus the current load carried by the section of fingers between the busbars lessens with an increasing count of busbars or wires. More busbars or wires decrease the internal electrical resistance of a solar cell to a great extent, because the fingers have the highest impact on resistance losses. It also enables reducing the finger width, in particular in the case of the multi busbar approach. Reducing the finger width has a dual impact – it not only cuts shading losses, but also lowers paste consumption. The exact details vary depending on the technology used.

Meyer Burger and Schmid are the pioneers in multi busbar technology, although the method employed by each of these European equipment makers



More and more leads to multi: The multi busbar approach is nothing but increasing the number of busbars, though with different interconnection machines using thin wires instead of ribbons. Pioneered by equipment manufacturers Meyer Burger & Schmid, and commercially introduced first by LG, several module makers are now following the trendsetters. Pictured is the Trina booth at SNEC 2017.

Saving silver: Multi busbar technology, in addition to power gain, enables reducing finger width (as shown top right), which reduces silver paste consumption in cell production.

Interconnection Process Changes with Advanced Module Technologies

Technology	Fundamentals	Cell Level Changes	Process Comlexity Increase in:			Additional Equipment
			Pre-Interconnection	Interconnection	Lamination	
Bifacial	Enables absorption of sunlight from both PV modules sides increases power	✓✓✓	✗	✓	✓	Most changes at cell level; no special equipment required at module level
Double Glass	Replaces the back sheet with a sheet of glass on rear side	✗	✗	✗	✓	Basically standard module production
Shingles	Eliminates ribbon and connect cells like roof tiles	✓	✓✓✓	✓✓✓	✓	Lasers to slice cells into pieces; special interconnection equipment
Half Cells	Reduces series resistance losses to 1/4 by slicing cells into 2 pieces	✗	✓✓	✓✓	✗	Laser system for cutting cells
Multi-Busbars	Reduce series resistance losses by employing thin wires instead of regular ribbon	✓✓	✗	✓	✗	Requires special interconnection tools designed to handle thin wires
More Busbars	Adding busbars to reduce series resistance losses	✓	✗	✗	✗	Most stringers can process up to 5-busbar cells; standard for 6-bsubars is often optional

Source: © TaiyangNews 2017

Legend: ✗ No impact; ✓ Minimum positive impact; ✓✓ medium positive impact; ✓✓✓ High positive impact; ✓ Low negative effect; ✓✓ Medium negative effect; ✓✓✓ High negative effect.

Processing impacts: All ‘real’ advanced module concepts require some changes in processing – either in the cell production, interconnection or lamination step. While all remains the same for adding just more busbars, from multi busbars to shingles there are more or less considerable changes needed.

is fairly different when looking at the details. However, based on Schmid's approach, several other equipment makers from Asia have started developing multi busbar systems. A change specific to the multi busbar approach is that it eliminates busbars at the cell level. Thin copper wires take over the role of busbars, though at the module level.

Meyer Burger

Meyer Burger calls its advanced interconnection approach Smart Wire Connection Technology (SWCT). The technology was initially developed by Day4 Energy, which was acquired by Meyer Burger. The process, which employs thin wires coated with low melting point alloy embedded into a polymer foil, is used as interconnection media instead of solar ribbons. This foil is placed onto the cell and the stack is laminated, after which the wires are bonded to the cell's metallization.

While this sound very different from standard module assembly, SWCT follows the typical process sequence - it only employs some customized equipment. The process also uses a stringer, called Cell Connection system, for putting wires on top and bottom of the cell, and connects the positive side to the negative side.

The advantages of SWCT are similar to any multi wire connection technology. Moving away from busbars increases the power of the module, due to lower resistivity losses and reduced shading. Even more important is reduction in silver consumption. With SWCT, every finger is contacted with wire, which is not the case with rival approaches. And Meyer Burger's approach does not need high alignment. While the company has evaluated several configurations with different number of wires, 18 is currently the standard.

Meyer Burger attained an output power of 330 W with 22.8% efficient 60 heterojunction cells. As a general note, the company says it can attain 6% higher power compared to a 3-busbar layout and reach a silver reduction of 83% at the cell level.

Schmid & Others

Schmid's multi busbar solution is built on a soldering platform that stays closer to traditional interconnection. Like a typical interconnection tool, it routes the connection media from the top of the first cell to the bottom of the next cell; the only difference is that thin wires are employed instead of flat copper strips. Similar to many other interconnection machines, Schmid's tool relies on an IR heat source for soldering process. But there is one big difference at the cell level, where the cells need to be processed with a special print layout, resulting in soldering pads attached to each wire. Schmid has designed the concept for 22 pads as a reference, but it can vary if customers prefer more or less pads. As for the number of wires, the standard is 12 wires, though customers can opt for between 8 and 15 wires. Thus, busbar spacing varies accordingly. Chinese module production equipment suppliers XN Automation and Autowell are among other companies that are offering multi busbar technology inspired by Schmid's approach.

One advantage of the multi busbar approach is that it fits very well with power boosting of half cut cell technology. LONGi, for example, is working on combining half cells with multi busbar cells, while bifacial module manufacturer Linyang is also very closely looking at combining its half cell technology with multi busbar for its current capacity expansion step.

5. Advanced Process Materials

Progress in today's module manufacturing is mainly governed by processes. But there are also incremental developments in consumables that are worth taking note of. We briefly summarize the progress in process materials for advanced module technologies in this chapter – detailed background can be found in market surveys we have already published on this subject (or will do in the coming months).

5.1 Ribbon

Solar ribbons are the process consumables of the traditional interconnection process. Composition and cross-sectional dimension are the most important parameters of this connecting medium. For a 4-busbar layout, 1.1 to 1.2 mm wide ribbons with a thickness of about 0.2 to 0.22 mm are used. As module manufacturers move to more busbars, the ribbon width is decreased while the thickness is increased to maintain the cross-section. The exact dimensions, however, depend on the module producer. In addition to these standard copper strips coated with solder, there are also special ribbon types available, such as grooved ribbons and colored ribbons. These ribbons direct the sunlight back to the module by means of total internal reflection to increase the optical gain. As an alternative, 3M is promoting a solution called Light Redirecting Film, which is a micro structured mirror film that comes with integrated EVA adhesives. When placed over the cell tabbing ribbon, it reflects the light back onto the modules, much like silver grooved ribbon. 3M claims a power increase of about 0.5 to 2% with its solution.

5.2 Encapsulants

When it comes to encapsulation, EVA has been the predominant material of choice for many years, while polyolefins and silicones are the other well known alternatives. However, EVA is expected to maintain its leadership in the near future, which is currently about 95% and supposed to be at close to 60% in 2027, according to ITRPV. Today's EVA market is segmented into two parts, according to Daniel Zhou, CTO of Hangzhou First, the global solar market leader for EVA. One is transparent EVA, the other is white EVA. The white variant is used on the cell's rear side to increase reflectivity. The power gain varies depending on the rear cover – glass or backsheet. According to Zhou, in double glass modules it is about 7 to 8 W per module of 270 W, which is about 3%. With glass-backsheet modules, the white EVA increases the power only by 0.5 to 0.8% as backsheets come with good reflectivity.

However, in double glass modules, polyolefins are increasingly preferred as encapsulation material. Hangzhou First, which is also the biggest supplier of polyolefins, is offering both the cross linking type as well as thermoplastic type polyolefins. The latter is originally from Dow Chemical, whose polyolefin production plant was acquired by Hangzhou First last year. “In China, market demand is mainly for the cross linking type, especially for high humid operational conditions, said Zhou. In the double glass segment, polyolefins have a share of about 50%, while EVA still covers 40%, according to Zhou.

5.3 Backsheets

Backsheets are an important process consumable in module manufacturing that influence both cost and quality of the final product. The current solar backsheets market offers a large variety of products with different configurations using different polymers. They can be divided into two groups – fluoropolymer and non-fluoropolymer products. In the fluoro polymer backsheet either one or both of the protective films are fluorine based. The options here are to use Tedlar from DuPont, Kynar from Arkema, PVDF or coatings. PET is the main non-fluoro configuration. TaiyangNews has published a Market Survey on Solar Backsheets in April). While nothing groundbreaking has happened since then, we now see that Tedlar-based backsheets are regaining popularity, especially in China.

5.4 Glass

When it comes to front cover glass, in addition to taking the responsibility of protecting the cell circuit, glass also has to meet optical requirements in a solar modules. Two glass parameters are important in module manufacturing – transparency and thickness. Glass with antireflection coatings to increase the transmission is dominating the market with a share of more than 90%. When it comes to thickness, 3.2 mm glass is still the state of the art in the glass-backsheet module configuration, while slightly thinner glass of 2.5 mm is mainly considered for dual glass module configurations.

6. Conclusions

An advanced module to a large extent still looks like a traditional solar panel, even if the dimensions are usually the same. But indeed many changes have been taking place. And we are here not talking about the solar cell – although a lot is happening there as well, as high-efficiency cell concepts are quickly evolving.

There are currently 5 commercial advanced module technologies - double glass, bifacial, half cells, shingles and multi busbars. So what's the most promising one? There is no straight answer – as every concept has its advantages but also requires a different degree of changes in the production process. The table below summarizes the impact of the different advanced module technologies on various aspects of the module production process. In general, one thing is clear – the greater the degree of deviation from the standard (at cell and module level), the bigger are the benefits.

It is obvious that the effort to go to '**more busbars**' is very low, and so is the improvement potential over the standard process. With the first companies having launched 6-busbar cell modules, the power optimization limit seems to be reached for this option. Following this path means moving to **multi busbars**. In addition to a higher power gain, the technology also saves silver paste at the cell level, an attractive option to cut on cost. Multi busbar technology needs different interconnection tools, but these are available commercially. Replacing traditional ribbon with wires requires also some learning and optimization.

When looking at improving durability and little process changes, **double glass** is the right method of choice, even if is has no positive impact on output power. But it brings one big benefit, because it is an enabling technology for **bifacial modules** (even though it could be also used with transparent backsheets). In fact, bifacial technology coupled with dual glass configuration scores high in most of the important module attributes. The flip side is, it requires a change from traditional BSF cells to high-efficiency concepts. However, as almost any cell producer is moving to PERC anyway, this barrier is basically being crossed. You can argue that bifaciality of PERC is low, but at 70%+ the gain is good enough, and there is still upside potential. Alternatively, one can use other high-efficiency cells. The nice thing is that glass-glass, bifacial and multi-busbar technology can be combined, although that means that quite a bit of changes are needed – from cells to module production equipment.

New equipment is also needed for one concept that is very different from modules with traditional cells – and that is **shingle** or tile based solar modules. It also requires efforts in preparing the PV substrates for interconnection as the cells need to be cut into several strips. However, the power gain potential is impressive – a 405 W module with dimensions of a typical 72-cell standard panel is available.

When aiming to keep efforts and rewards somewhat balanced the most attractive option is half cells. The technology scores high in almost any aspect. The only change required is in the pre-process preparation, where the cells needs to be cut into half with lasers, a well-known slicing application in the PV industry. A main caveat is the negative impact on the throughput of stringing machines, actually reducing it by half. However, interconnection equipment has improved a lot – the machines got a lot faster and a lot cheaper. That means using half cell technology enables a 5 to 6 W gain in module power with relatively very less effort and rather low capex. And if you want more, you can combine it with any other technology, except for the shingled approach.

While there will be for sure different module concepts used for different applications and needs, all of these panels will increasingly combine several of the advanced module technologies in one – whatever suits best.

Pros & Cons of Changing to Advanced Module Technologies

Technology	Advantages	Cell Level Changes	Module Process	BOM	Weight	Durability	Aesthetics	Power Rating	Commercial Status	Capex	Opex	Limitations
Bifacial	Making rear cover transparent is the only change at module level; increases power output by 10 to 30% depending installation site; module life extends when using double glass protection	✓✓✓ (red)	✓ (red)	✓✓✓ (red)	✗ / ✓✓✓ (red)	✗ / ✓✓✓ (green)	✓ (green)	✓✓✓ (green)	✓✓ (green)	✗	✓ (red)	Glass-glass configuration increases weight; difficult to determine exact power gain & design system
Double Glass	Improves mechanical strength, reliability and increase in module life time; can be frameless, thus eliminates material cost	✗	✓ (red)	✓✓✓ (red)	✓✓✓ (red)	✓✓✓ (green)	✓ (green)	✗	✓✓✓ (green)	✗	✓ (red)	Increases weight
Shingles	Increases active cell area; reduces silver consumption at cell level; eliminates need for solar ribbon; reduces inactive areas from module	✓ (red)	✓✓✓ (red)	✓✓✓ (red)	✗	✓✓ (green)	✓✓✓ (green)	✓✓✓ (green)	✓ (green)	✓✓✓ (red)	✓✓✓ (red)	Intense use of laser slicing might induce cracks; new interconnection equipment needed
Half Cells	Ssimple upgrade resuls in higher module power; one additional process step over standard (cell cutting)	✗	✓✓ (red)	✗	✗	✗	✓ (red)	✓✓ (green)	✓✓✓ (green)	✓ (red)	✗	Reduces interconnection throughput by half; cell cutting might induce cracks
Multi-Busbars	Eliminates busbars at cells level (shading); reduces silver consumption at cell level	✓✓ (red)	✓✓ (red)	✓ (red)	✗	✗	✓✓ (green)	✓✓ (green)	✓✓ (green)	✓✓ (red)	✗	Increase criticality of interconnection process; requires special tools
More busbars	Most simplest upgrade, fully based on standard process	✓ (red)	✓ (red)	✓ (red)	✗	✗	✗	✓ (green)	✓✓✓ (green)	✓ (red)	✓ (red)	Power gain diminishes with move to higher number of busbars

Source: © TaiyangNews 2017

Legend: ✗ No impact; ✓ (green) Minimum positive impact; ✓✓ (green) medium positive impact; ✓✓✓ (green) High positive impact; ✓ (red) Low negative effect; ✓✓ (red) Medium negative effect; ✓✓✓ (red) High negative effect.

The higher the effort, the better the output: When comparing various advanced module technologies, it is clear that more helps more. If the process – at both cell and module level – is changed considerably, power output improves considerably, such as with shingled module technology.

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Product	Publication Date*	Launch Event	Language	Topic
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Market Survey	30-Aug-17		EN	Aluminum Oxide Deposition Systems
Market Survey	12-Sep-17		EN	Cell Interconnection Equipment
Report	20-Sep-17	REI Expo Delhi	EN & CN	Advanced Module Technologies
Report	26-Sep-17	EU PVSEC Amsterdam	EN & CN	Solar Wafer Technologies
Market Survey	1-Oct-17		EN	Luminescence Imaging Systems
Report	18-Oct-17	PVCEC Beijing	EN & CN	Heterojunction Cell Technology
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*Exact publication dates might change within a month.