

Solar PV technologies what's next?

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Executive Summary

The rapidly declining of silicon-based photovoltaic (PV) solar cells price over the past two decades, has facilitated the advent of PV as a commercially viable energy source. However, solar still only accounts for approximately 3% of the world's electricity generation capacity. While, the solar PV electricity is projected to contribute up to 13% and 30% of the total electricity demand by 2030 and 2050, respectively. However, there are many challenges along the way, achieving this vision would represent a transformation in the way we generate, store, and utilize solar energy.

The report surveys the current solar photovoltaic technologies status and trends. It also introduces the most potential technologies expected to disrupt the PV market in the coming decade. To break the Ogier ceiling of 29.2%, aside of the tandem solar cells, we identify three potential disruptors as: perovskite, quantum-dot photovoltaics, and concentrated photovoltaics.

These emerging PV technologies currently under development show the potential to disrupt and replace the dominant market incumbent crystalline silicon (c-Si) technology in the future. These technologies have been used to record cell efficiencies more than three times that of typical commercial c-Si PV, and have growing academic and financial sponsorship and the prospect of value-creating cross-applicability and complementarity between materials and technology. The question now is whether the long term viability of c-Si as the market leader has a time limit in the face of these emerging challengers ?

The list of the technologies presented in this report is not exhaustive. It's rather, an exploration of the most promising emerging technologies capable to disrupt the c-Si dominance. Through innovation that will allow the solar PV energy not only to compete against the other form of energy but also without any kind or form of subsidies.

However, to compete in the PV market a focus on a new paradigm shifting from cost/W to cost/kWh (reducing LCOE) integrating with energy company which direct sells energy.

The grid parity has already been reached in many countries around the glob. But there is more to do before the solar PV become the world mainstream energy.

**We are at the dawn of the age of solar energy, the future is bright ...
Innovations are on the way.**

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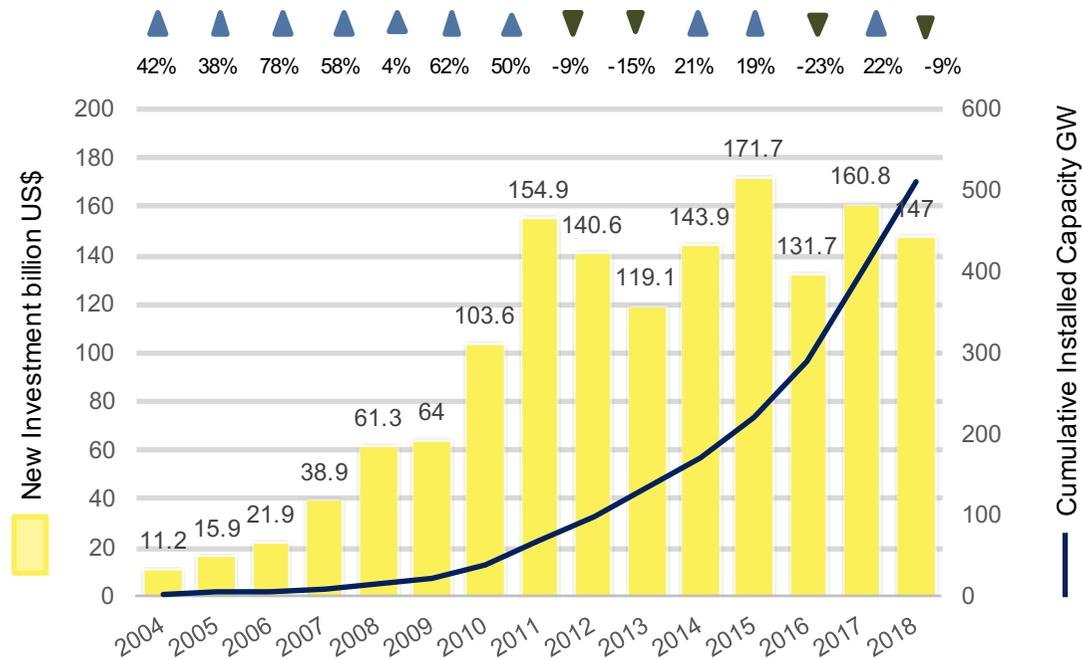
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Global solar power investments vs cumulative installed capacity

Markets for solar energy are maturing rapidly around the globe, and solar electricity is now economically competitive with traditional energy sources in several countries. According to market forecasts, the installed PV power capacity of 504 GW at the end of 2018 could triple by 2023. At the end of 2018, the PV installed capacity was able to produce roughly 2.6 percent of the worldwide electricity demand. The real installed capacity exceeded the predictions as it is the case since 2000.

The global PV market has experienced vibrant growth since the early 2000 as it shown in the chart below.



Source: Bloomberg, NCH, IEA-PVPS

- The investments in Solar PV declined by 9% to 147 billion USD in 2018. The lower investments compared to other years reflects the effect costs reductions. The investment expected to reach \$2 trillion USD by 2030.
- Despite the 531 New Deal for solar in China, BNEF noted that China was again the leader in overall clean energy investments in 2018.
- The global cumulative installed capacity for photovoltaic power had reached an estimated 504 GW, indicating nearly 50 times the growth in cumulative installed capacity within a decade

PV Market Status #1

At the end of the year 2018, more than 500 GWp of PV system had been installed globally, with at least 100 GWp installed (and commissioned) during the year 2018. This establishes the PV market in 2018 at a similar level to the 99 GW installed in 2017. While final numbers are not known yet with certainty, a market around 100 GW represents already a major growth compared to the previous year, with a 9 GW market decline in China that was compensated in emerging markets. With non-China PV markets growing from 46 GW in 2017 to 55 GW in 2018, this could be considered a major achievement while China was driving the market for some years.

The growth is spread amongst continents, with the European market growing for the first time in years to 8.5 GW, the US, India and Japanese markets remaining stable at respectively 10.8, 10.6 and 6.5 GW; but the growth was high in Australia, Korea, Mexico, the UAE and Egypt (with commissioning in 2019 on both cases). Turkey also installed more than 1 GW for the second year in a row, to the extent that all top 10 countries in 2018 installed at least 1 GW, a completely new situation. Activity was important in Vietnam, Pakistan, Brazil, Chile, Morocco, Jordan and more.

Plans for large-scale PV development have also popped-up in 2018, and the newly created International Solar Alliance envisages 1000 GW of PV in emerging countries at the horizon 2030.

A key driver of the rapid development of PV has been and continues to be the ability of some countries to implement the right measures to ease its development. With prices of PV electricity going down to the point of being naturally competitive with the cheapest sources of conventional electricity, the need for adequate policies remain in order to adapt the electricity systems to the specific needs of renewable electricity produced by variable sources such as PV or Wind.

While the development was initially supported by countries such as Germany, Italy or in the last years China, that wanted to develop either the market or the industry, the current PV development remains concentrated in some dozens of countries due often to the lack of adequate policies, especially for distributed PV.

In 2018, the share of utility-scale continued to remain high, with most market developments in new and emerging markets being driven by tenders. The growing markets in 2018, especially in Europe, the Middle-East and Latin America were all driven by tenders for utility-scale or pure competitive PV installations in the same segment.

PV Market Status #2

The developments in China are linked to the political will to keep electricity prices low and have led the government to impose a limitation on PV development unless it could compete with coal prices. This limited the market in 2018 but opens a possibility for growth for competitive PV in China in the coming years.

India, the second largest market in 2018, with around 10.8 GW is expected to develop further, due to a massive need for electricity, and important government plans. There is little reason not to envisage India installing as much as China once policies will be in place.

Third market is the US, despite a federal administration largely opposed to renewable energy development. With more than 10.6 GW, the PV market in the US could continue to grow, pushed by the declining cost of PV electricity especially in southern states and the willingness from dozens of states to promote solar.

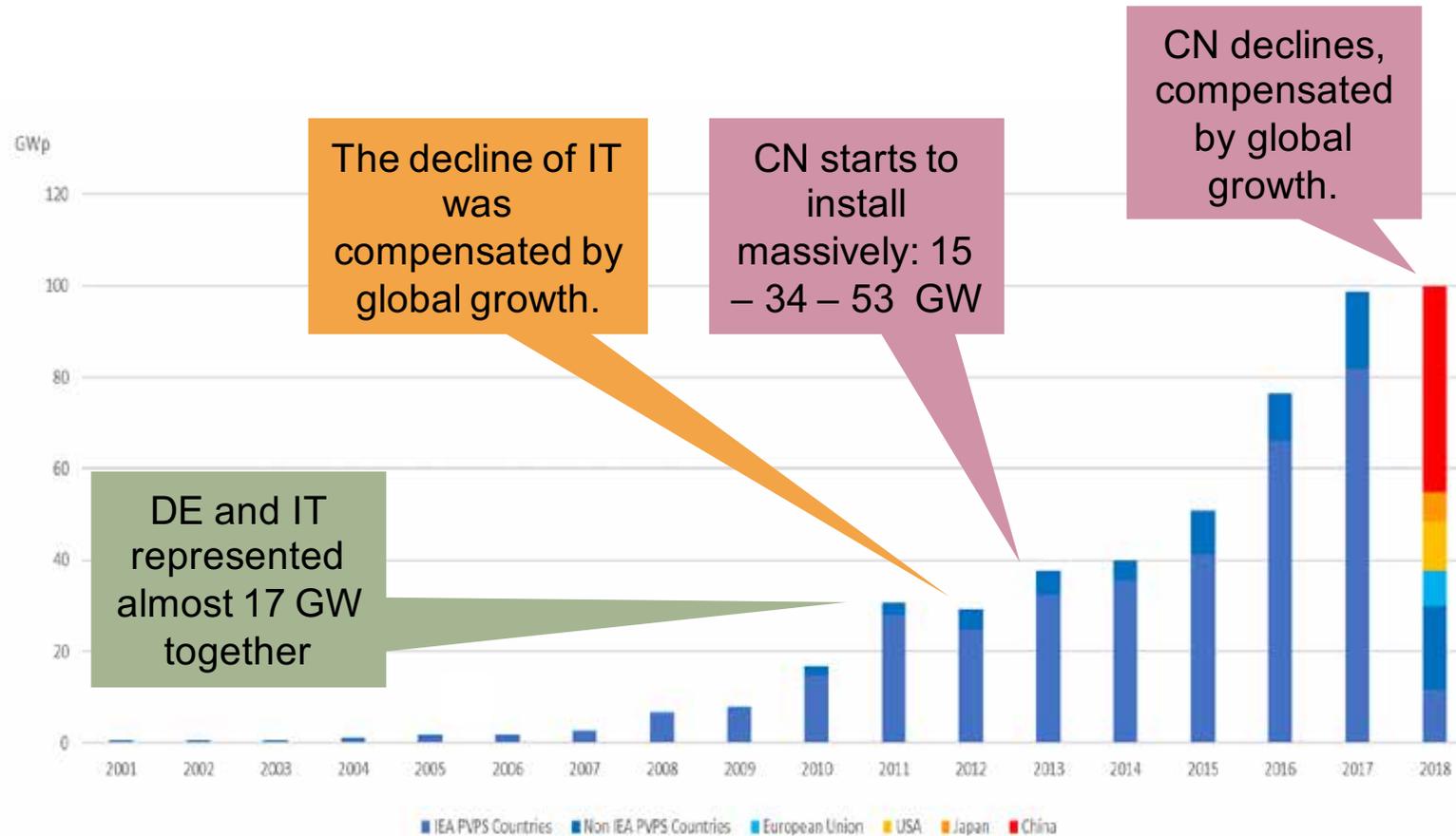
The European Union is fourth with more than 8 GW in 2018 and is expected to grow in the coming years after years of market stagnation. European policies have changed and will support the regrowth of PV in Europe. Moderately ambitious targets for 2030 will drive the market up, together with competitive prices for PV electricity.

With Japan is in 5th place with close to 7 GW in 2018 and the list continues with almost 4 GW in Australia, 3 GW in Mexico, 2 GW in Korea, and more currently planned installations in many countries around the world, from Turkey, to the UAE, Jordan, Egypt, Chile, Brazil, Taiwan, the Philippines, Morocco.

The number of countries installing at least 1 GW a year has reached more than 10 for the first time and the number of countries where PV is developing is now higher than 100. The prospects are driven by the low and declining cost of PV electricity, which allows to imagine a short-term future with a growing PV market, possibly above 200 GW in 4 years from now. The reasons are numerous to imagine that it could go even further, with some industry leaders announcing 1000 GW a year in 2030.

However, the road is still complex to such massive market development and a doubling on the short term is a reasonable prospect.

History of the PV market until 2018



**In a decade, the market was multiplied by a factor 15.
From 6,6 GW in 2008 to 100 GW in 2018.**

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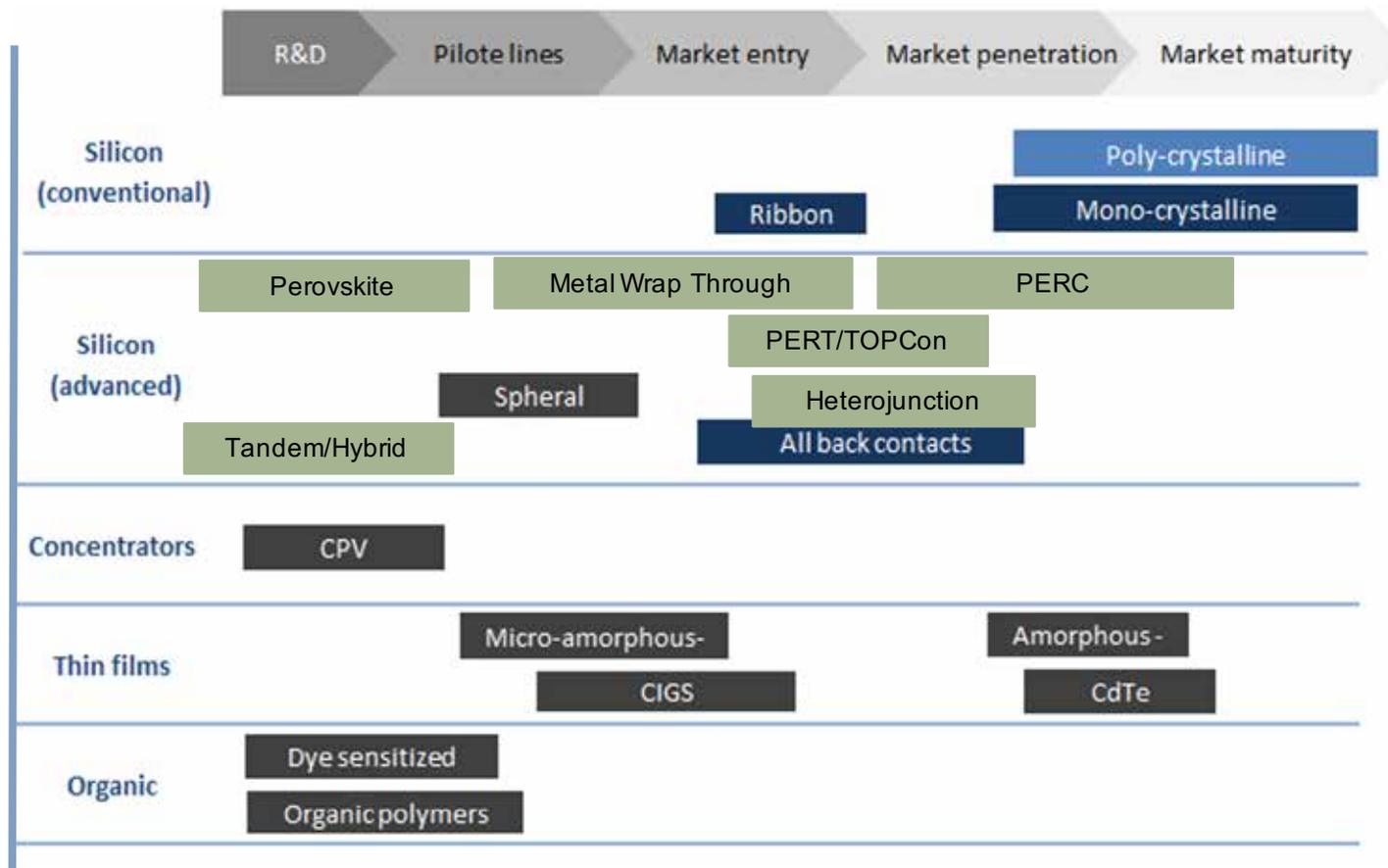
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Solar Photovoltaic Technologies Status

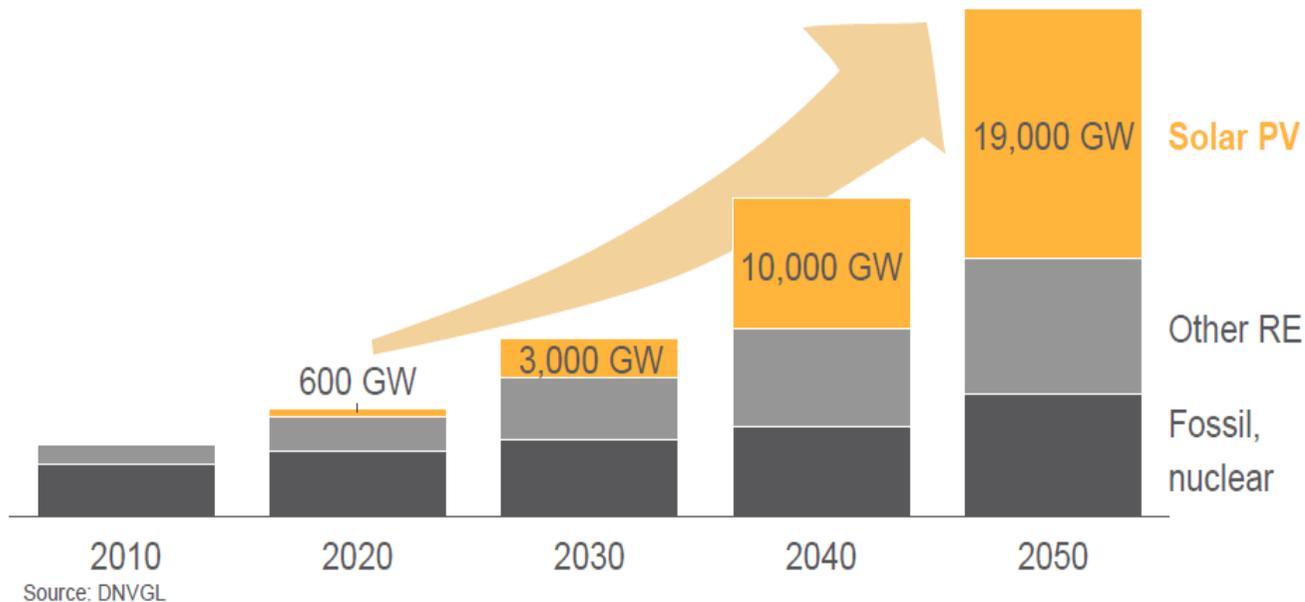


With the aim of achieving further significant cost reductions and efficiency improvements, R&D is predicted to continuously progress in improving existing technologies and developing new technologies. It is expected that a broad variety of technologies will continue to characterize the PV technology portfolio, depending on the specific requirements and economics of the various applications. The table gives an overview of the different PV technologies and concepts under development.

Any good scientific book will tell you how to make a solar cell. What is complex is the know-how required to make it efficient, at a lower price, in higher quantities, and with a better quality while keep improving the technology. This is the challenge!

Explosive growth in sight ... Opportunities for newcomers

World electricity generation capacity



Assuming at least 600 MW will be reached at the end of 2019, the projected market demand between 2020 and 2030 could reach 2400 GW. This means a yearly installation average of 240 GW. The overall supply capacity is estimated at 150 GW at the beginning of 2019, including the obsolete lines, for an annual market around 100 GW. The need for the industry is to rapidly double its production capacities in the coming years.

Forecasting the PV market in 2030 is a difficult task that depends on multiple parameters. However the fact that PV has reached « grid parity » or at least a level of competitiveness compatible with massive development, indicates that its development has been rather low so far and could significantly increase in the coming years. With electricity competitive in emerging countries with almost all other electricity sources, PV has a path to develop massively, which will lead to a market significantly higher than today.

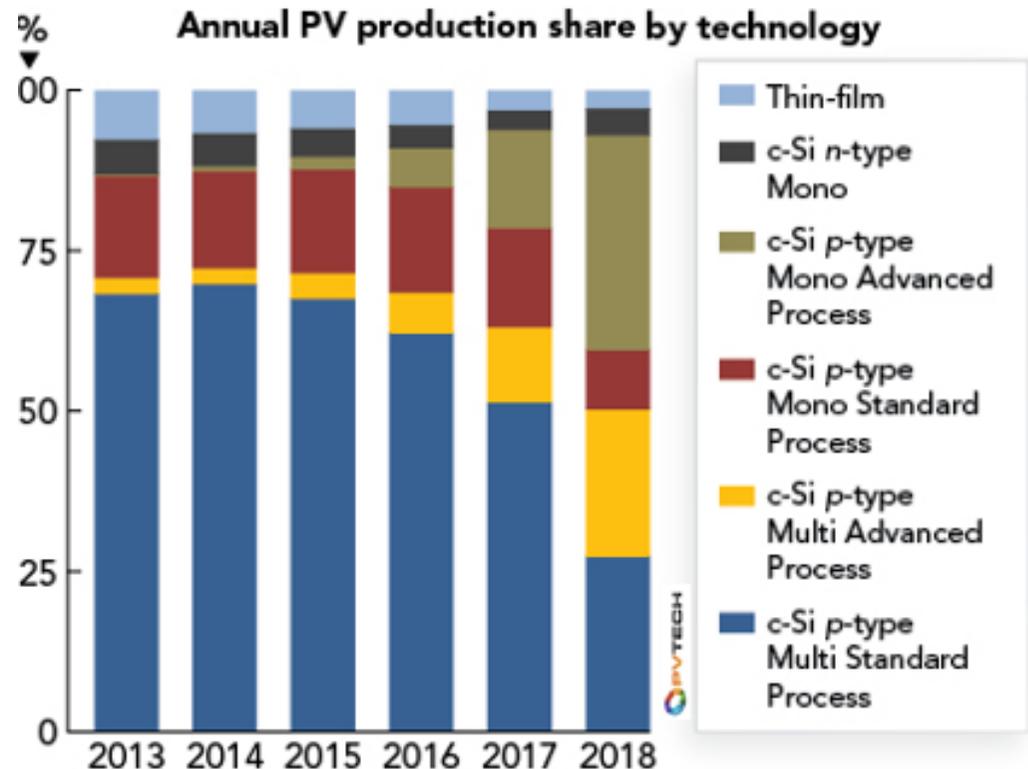
The growth of the electricity demand, together with the expected shift for transport and industry, but also buildings (cooling/heating), will lead to additional electricity demand, which PV can now cover at competitive prices. Thus, there is little doubt that PV development will continue growing, despite short term setbacks in some geographies.

The rise and dominance of c-Si photovoltaics

The rapid increase in overall photovoltaic electricity production has been facilitated by one key factor – the declining unit cost of silicon-based solar cells. The cost in dollars per watt of crystalline silicon PV has declined from a peak of over \$76 in 1977, to \$5 in 2000, to just \$0.30 in 2015 and reach around \$0.22 today. This has enabled the commercial viability of PV electricity. PV electricity production has already reached “grid parity” in several countries cross the glob.

Representing over 95% of worldwide installed PV capacity, c-Si have been the vanguard to date. The affordability of c-Si is driven by the economies of scale of its main ingredient, silicon, generated in the booming semi-conductor industry and the fast technology improvement: less materials and high efficiency. The strong competitive position of c-Si in the market drove other promising PV technologies out to the margins. The continually falling cost of c-Si has made it incredibly difficult for other technologies to compete. This is despite the fact that, theoretically, silicon is not particularly well suited for photovoltaic uses because it is an indirect bandgap semi-conductor and has a low absorption coefficient. One such promising technology that suffered from competition with c-Si is copper indium gallium selenide (CIGS). Although exhibiting promise to ultimately be more cost competitive than c-Si, it was driven to near extinction due to its lesser technological maturity and yet-unproven cost advantage. Thus, CIGS fell prey to one of the two lab-to-fab “valleys of death” in which funding is not sustained at a sufficient level to bring the technology to commercial fruition on the precipitous road to the consumer.

The chart below, shows market share contributions from c-Si variants and thin-film production. Only two prominent companies left pursuing thin-film based technologies—First Solar, using CdTe and Solar Frontier using CIGS.



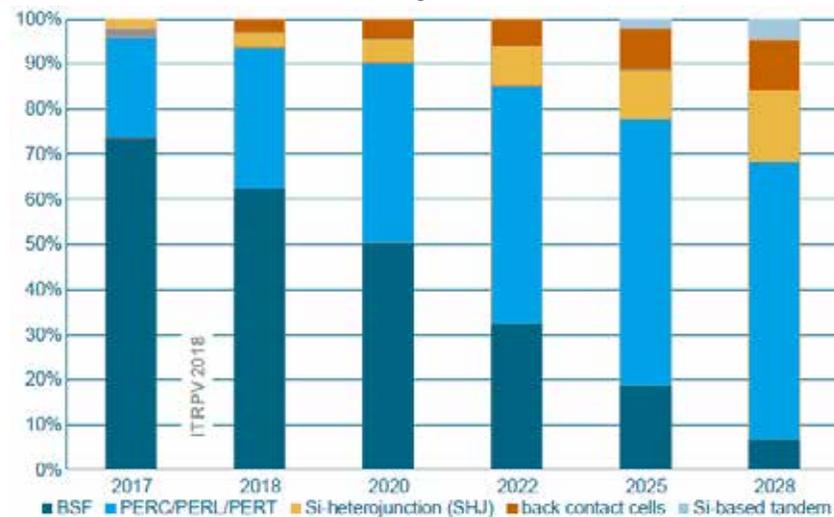
Expected technologies market trends

The prime drive to move n-type c-Si cell is, its high minority carrier lifetime, no light-induced attenuation (LID), good low-light effect, low temperature coefficient, is expecting towards the theoretical highest efficiency of c-Si solar cells. Moreover, another drive is the decreasing price gap between n-type and p-type wafers.

In order to keep the race for efficiency improvement, the existing back Surface Field (BSF) technology manufacturers started since 2015 upgrading their existing lines to PERC by adding two new equipment parts in the process (cheap solution). PERC structure is a natural progression from the standard BSF cell architecture, which suffers from some inherent limitations. However, this has also a limitation in terms of cell efficiency, which can get to around 23-24% maximum on the industrial level.

Meanwhile, manufacturers will have to consider upgrading again n-PERC to TOPCon. As for IBC, it has many production processes, and thus the difficulties and costs are far higher than other technologies. Consequently, HJT and TOPCon are expected to be the two major n-type technologies in the coming years.

Technologies market share



Capacity forecast of N type technology



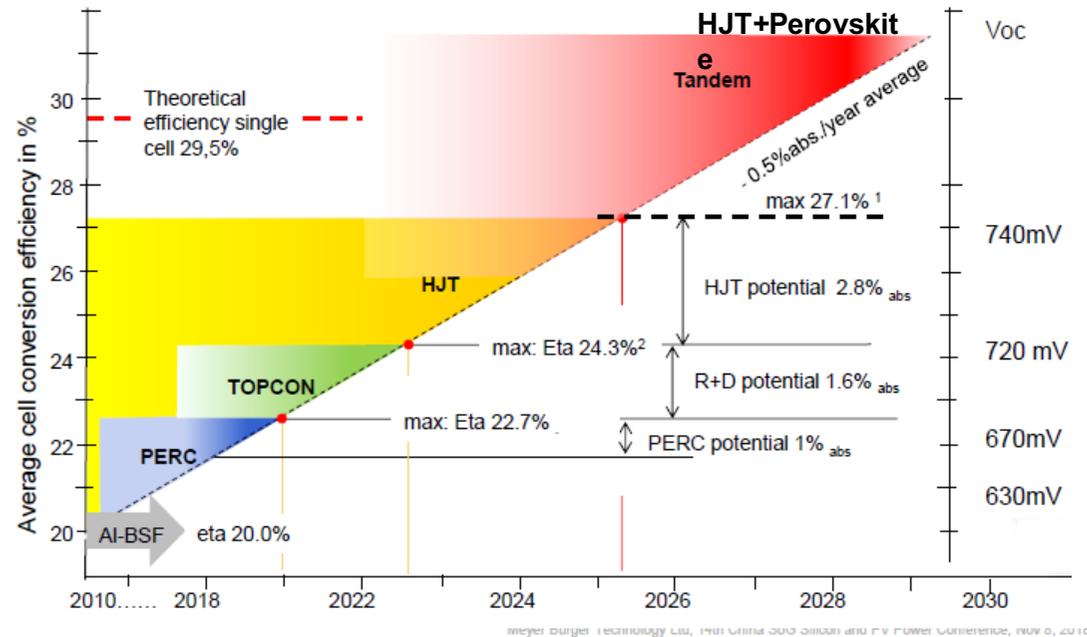
Source: PV InfoLink

Cell Efficiency Trend in Mass Production, current and roadmap

Among crystalline silicon technologies, p-type wafers have dominated the market for a long time due to their ability to be produced at a reasonable cost. n-type wafers are progressing now due to lower production costs but p-type remain dominant. Multi is only now about to be surpassed by mono, for the same cost reason.

The bulk of the market continues to develop technologies that are improvements of the existing ones to avoid changing production lines completely, which implies to work with limited changes. In that respect AL-BSF is moving rapidly towards PERC, with some possible new changes with TOPCON and more.

- Al-BSF being phased out
- p-PERC is mainstream and « Work horse »
- 22.5% CE likely to be the limit for mass production
- n-type technology industrially ready
- n-PERT unlikely to break through because of complex process sequence and limitations of surface passivation
- N-TOPCon/monoPoly likely to be the next evolutionary upgrade technology for existing PERC lines
- HJT likely to be the green field technology of choice because of higher CE and lower complexity
- 3rd generation solar cell technologies such as perovskite-on Si and III/V-on-Si



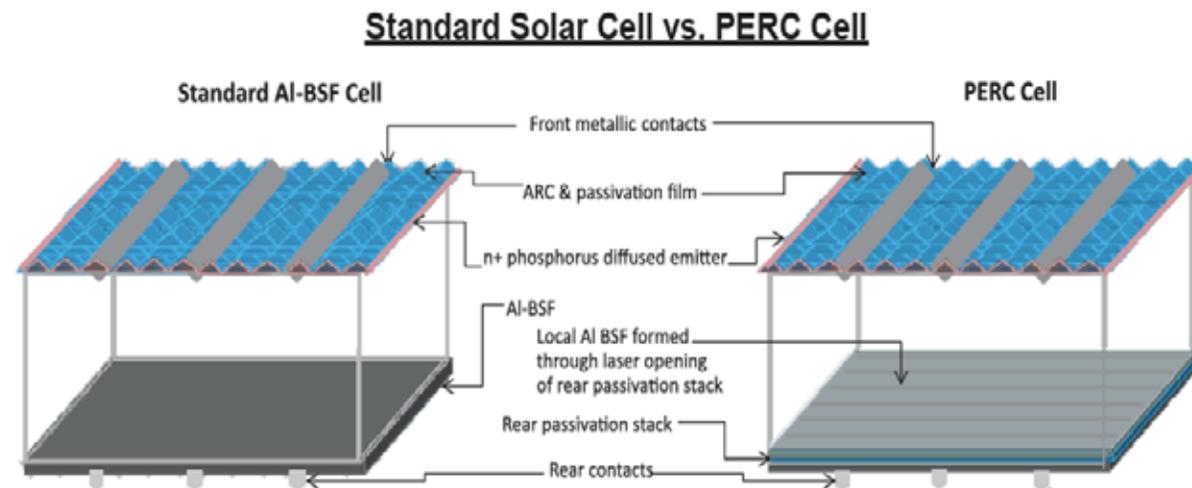
The bulk of the market : Al-BSF vs PERC

Back Surface Field (BSF) vs Passivated Emitter Rear Contact (PERC) technology

In a conventional solar cell BSF, there is an aluminum metallization layer which makes contact across the full area of the back of the cell. PERC technology first coats the backside of the cell with a special dielectric layer that has tiny holes made by a laser. The aluminum metallization is then applied on top of the dielectric layer and contacts the silicon wafer only through the microscopic holes.

The cell efficiency increases through the dielectric layer that reflects back into the cell any light that has passed through to the rear without generating electrons. Through this reflection, the photons are essentially given a second chance to generate current.

PERC allows to increase efficiencies while maintaining the same equipment for cells and modules production. At the beginning of 2019, it was estimated that at least 60 GW of PERC lines were in operation and more was expected in 2019. Roughly 50% was dedicated to multi (with key actors: GCL, Canadian Solar) while the rest was about mono (LONGI, and more).

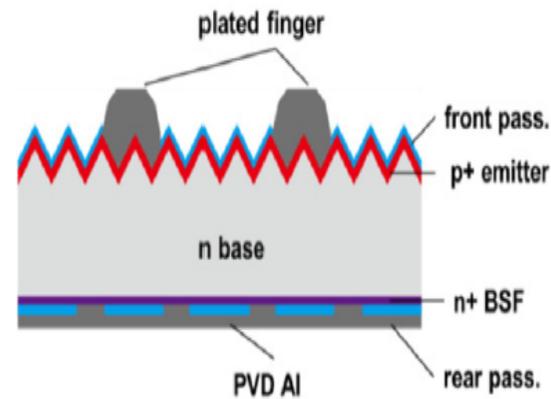


Adding rear passivation: Passivating the rear surface is the major change that turns a standard crystalline solar cell into a PERC cell.

Next steps : Passivated Emitter Rear Totally diffused - nPERT

n-type PERT (passivated emitter rear totally diffused) silicon solar cells promise high and stabilized conversion efficiencies. As relative big contact recombination and shading losses were introduced by traditional front screen-printed metallization, this technology applied Ni/Cu/Ag plating to form the front metallization grid, and PVD (physical vapor deposited) aluminum for the rear side contacts for better optical reflection. With help of laser ablation, the front and rear metallization fraction can be reduced to less than 1%, which benefits both V_{oc} and J_{sc} . The result was efficiencies of up to 22.2% on 5 inch, commercial grade Cz n-type wafers.

n-PERT is seen as an option to develop efficiencies with n-type wafers

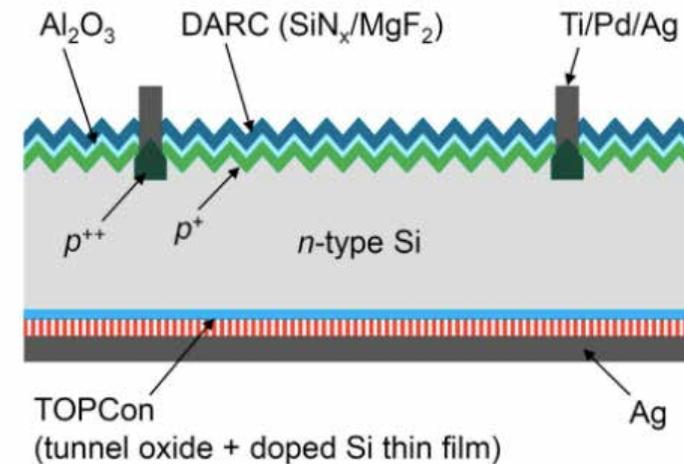


Further step : Tunnel Oxide Passivated Contact - TOPCon

In 2014, Fraunhofer ISE proposed a full-area, carrier-selective, passivated contact as an appealing alternative to a partial rear contact (PERC), and named it Tunnel Oxide Passivated Contact (TOPCon). For the concept, in order to reduce recombination losses from the metal contacts and the silicon surface of cells, a thin oxide layer is introduced, in addition to heavily doped polycrystalline silicon between metal contacts and wafer.

The carriers, i.e. electrons and holes, can tunnel through, due to a quantum-physical phenomena. This establishes the contact, while the wafer is better passivated, and recombination losses are significantly reduced compared to standard technology.

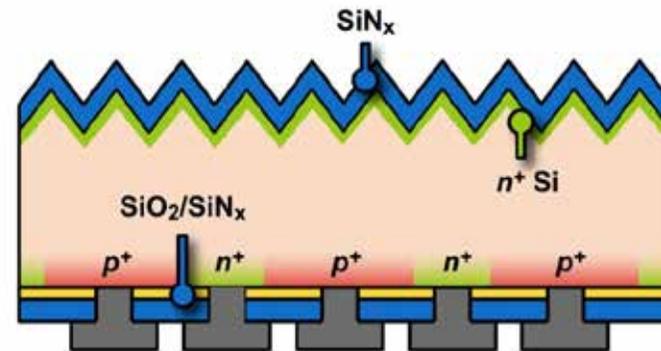
The efficiency of a cell is always related to the balance of establishing a good contact with low contact resistance, and avoiding recombination losses, which occur on all metal contacted areas.



Interdigitated Back Contact Solar Cells - IBC

The interdigitated back contact (IBC) cell can be understood as a rear junction solar cell. The concept of (IBC) silicon solar cells was originally introduced in 1975 for concentrator photovoltaic (CPV) applications as it would allow silicon solar cells to be used in several hundred times concentrated sunlight, an application that was out of reach of conventional solar cells. CPV was the only application for IBC cells until around 2004 when the SunPower Corporation introduced the first commercial flat plate IBC module. Due to cost constraints, IBC solar cells for one sun flat plate modules cannot be fabricated with very fine patterning technique such as photolithography. Therefore, the process must be simplified and low cost patterning limits the minimum pitch to about 800 1500 μm . The best results with IBC solar cells have been presented by SunPower, and Panasonic.

IBC cell's P-N junction and electrodes are all on the back, completely eliminating the gate line shading of front surface, the average mass production efficiency is up to 23%. But IBC cell requires high quality wafer, and production processes are complicated, so the cost is high. Using industrial technologies in the production line, such as screen printing, tube diffusion or ion implantation, is the key to achieving low cost IBC cell. And the use of passivated contact technology can improve the efficiency of IBC cells. At the beginning of 2018, Trina Solar's 6-inch IBC cell achieved a full-area efficiency of 25.04%.



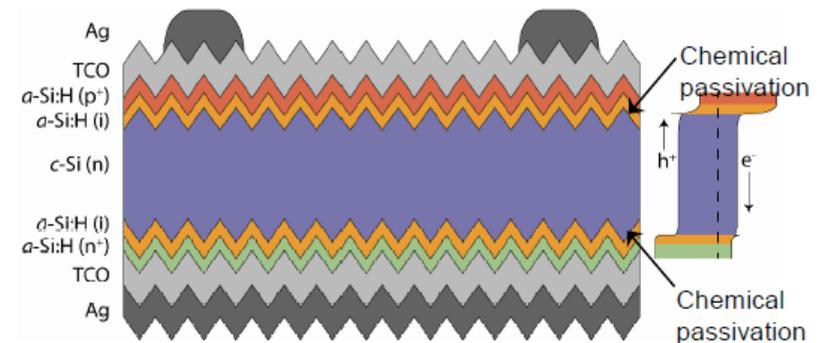
In Aug. 2018, Huanghe Hydropower and Jolywood officially started construction of 200MW IBC cell and module project. In February 2019, Valoe (FI) officially announce its 60 MW IBC line.

Heterojunction – HJT

Since the 1980s, Sanyo Corporation, which was subsequently acquired by Panasonic Corporation, has been in the leading position in the SHJ solar cell industry. The first a-Si:H/c-Si heterojunction solar cell was fabricated in 1983. The potential of heterojunction technology was demonstrated by Sanyo in 1992. HJT cell technology combines the advantages of monocrystalline silicon (c-Si) solar cells with the good absorption and superior passivation characteristics of amorphous silicon (a-Si), which have been observed in a-Si thin film technology using readily available materials

The silicon heterojunction solar cell is based on a device structure that combines thin film and bulk silicon technology. Of particular interest is the heterojunction cell with an intrinsic thin layer (HIT) with which Sanyo had achieved a very high efficiency of 23% in 2009, and of 25.6% efficiency most recently. This strongly challenges the standard high efficiency c-Si homojunction cell. Surface passivation of the c-Si wafer is a key requirement to optimize the performance of HJT solar cells. Generally, surface passivation is ascribed to two different phenomena, namely, chemical passivation and field effect passivation.

From the cell fabrication process perspective, a-Si:H/c-Si heterojunctions have the following advantages over a conventional diffused homojunction: (1) Excellent passivation properties, which achieve a high V_{oc} and therefore a high efficiency; (2) low processing temperatures, which prevent bulk quality degradation in low-quality c-Si wafers; (3) a better temperature coefficient, compared to diffused-homojunction cells; and (4) a low-cost fabrication process, with a high potential for reducing production costs.

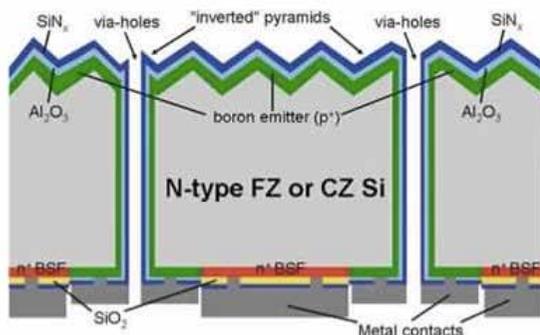


Heterojunction (HJT) solar cell has the advantages of high conversion efficiency, simple manufacturing process, low temperature coefficient, no LID and PID, and bifacial power generation. It is regarded as the next generation ultra-efficient cell technology with the most industrial potential. At present, the highest efficiency of HJT cell has reached 26.7%, and the mass production efficiency has exceeded 24%.

Emitter Wrap Through / Metal Wrap Through

The simplest solar cells have contacts on the front and rear surfaces to collect the negative and positive charge carriers. But the screen-printed metal comprising the front-side contacts blocks a significant area from receiving sunlight. Two newer high-value device architectures address this. In metal wrap through (MWT) devices, the thin metal “fingers” are moved to the rear surface. In emitter wrap through (EWT) devices, power-conveying busbars are moved to the rear surface as well, leaving the front free of metal. This is made possible by drilling tiny vias to connect the front surface with rear-surface contacts. The drilling is made by means of Laser.

Wetal Wrap Through (EWT)

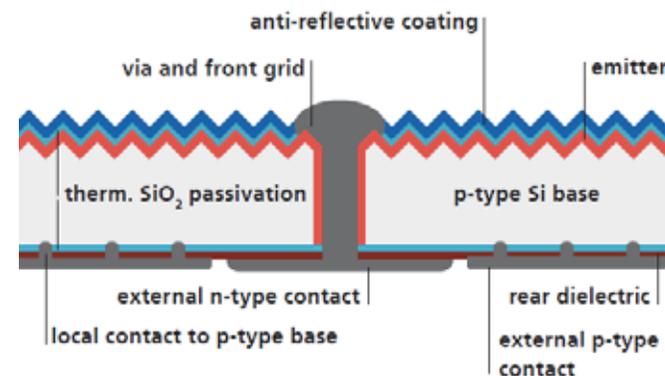


A representative cross-sectional scheme of the n-type FZ or CZ Si EWT solar cells with passivation schemes covering all the Si surfaces: the front side, the rear side and the via-holes. In general, the passivation schemes usually cover only the front and rear surfaces for most Si EWT solar cells.

- The advantages of the EWT solar cell are comparable to the ones of IBC cells.
- The efficiency reaches 23% at Lab level.
- Interesting point: efficiency of an EWT cell degrades less as the diffusion length degrades with light induced degradation

Metal Wrap Through (MWT)

In an MWT technique there are three main stages, which partially shift the front side contacts over to the rear side, thus reducing the front side metallization almost by 50%. During the first stage a laser is used to drill holes into the cells. The through-connection of the cells is simultaneously achieved through the subsequent silkscreen printing process for the production of rear side contacts. After this a silk-screen printing paste is used to cover the holes, which completes the electrical connection to the front side. This isolation of the contacts reduces additional costs.



Cadmium Telluride (CdTe), The First Solar case

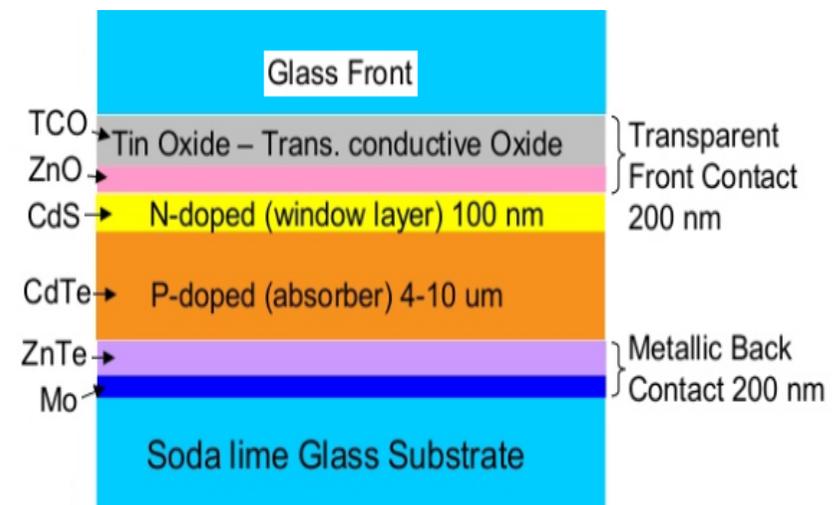
At 22.1%, CdTe has achieved similar efficiencies to CIGS. It also has a band gap close to ideal at 1.43eV, with advantages including good absorption and low energy losses. CdTe solar cells can be made through low-temperature processes, allowing flexible and affordable production (as with OPVs) - which is preferable to expensive and time-consuming high-temperature processes. CdTe currently has the largest market share of all thin-film technologies. However, cadmium is toxic, and tellurium is particularly rare. These factors may point to potential issues with long-term, large-scale production in future. However, there has been some introduction of CdTe PV recycling by manufacturers. In terms of component toxicity and natural abundance, OPVs are advantageous compared to CdTe.

The choice of First Solar (FS) to invest massively in its CdTe technology is the result of a decision to follow the cost decline on the market. By increasing the size of panels, and increasing their efficiency in the 18% range, the company has shifted its business model. Such a decision was probably taken to counter the Chinese massive development and low production costs of c-Si technology. That decision is expected to allow shipments to grow significantly, from below 3 GW in 2018 to more than 5 GW in 2019 and up to 10 GW in the next three years.

First Solar changes scale and could move rapidly into the top producers again, with a technology that remains proprietary:

This strategy choice to continue with their own technology, allows FS to position themselves outside of the standard competitors using c-Si, and allows the company to promote the technology with some key advantages, such as a better temperature coefficient, better degradation of performances etc.

FS, also leads the thin-film industry, with the mid-efficiency, low-cost profile, and a huge pipeline of projects. However, it is unsure the residential, commercial and industrial rooftop markets could really use that technology, due to possible (and hardly verifiable) fears about the health impacts (real or feared). In that perspective, this technology has been mostly used for utility-scale plants, and rarely for buildings until now, which could limit its development in the coming years.



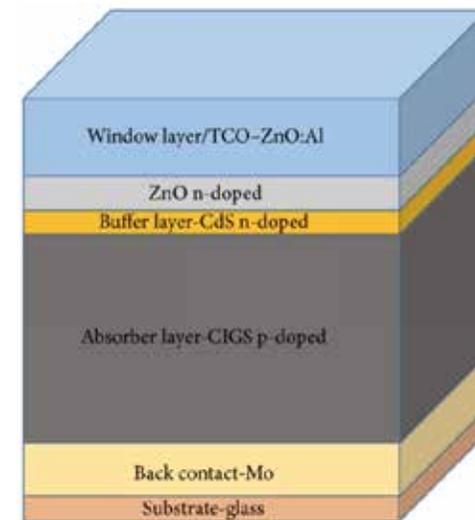
Copper Indium Gallium Selenide (CIGS)

CIGS cells have achieved the highest efficiency for a true thin-film solar cell. At 22.6%,⁶ they are comparable to commercial crystalline silicon, and far exceed the current efficiencies of OPVs. An advantage they share with OPVs over other second-generation cells is that they allow the band gap of the semiconductor to be tuned. In this case, by varying the In:Ga and Se:S ratios to obtain around 1.0 to 2.4eV, allowing targeting of an ideal band gap and applications in tandem solar cells.

However, CIGS are expensive (due to the rarity of indium), and manufacturing can be difficult. The complex stoichiometry and multiple phases means that it is a challenging process to optimise CIGS cells, and this may restrict large-scale production in the near term. The main advantages of OPVs compared to these are low-cost materials, and easy manufacture and optimization.

CIGS production capacity is expected to reach 7 GWp by 2020

- These production facilities are part of an ambition national plan to reach 5 GW of CIGS production capacity and establish China as a technological leader, as it already is for crystalline silicon.
- Most major Chinese companies, such as CNBM, relies on European equipment manufacturers, e.g. Singulus, Midsummer, Von Ardenne and Manz.
- Hanergy relies on its own expertise to develop its production lines, as well as technology transfer from acquired companies. It is supplying local governments and Chinese industrial actors based on a new business model, where lines are established within industrial parks to increase their technological attractiveness while reducing their environmental footprint. Hence, planned expansion capacity listed above might not actually be owned by Hanergy once commissioned.



Dye-Sensitized Solar Cell

A dye-sensitized solar cell is a low-cost solar cell belonging to the group of thin film solar cells. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a photo electrochemical system.

The dye sensitized solar cells (DSSC) provides a technically and economically credible alternative concept to present day p-n junction photovoltaic devices.

In contrast to the conventional systems where the semiconductor assume both the task of light absorption and charge carrier transport the two functions are separated here. Light is absorbed by a sensitizer, which is anchored to the surface of a wide band semiconductor.

Charge separation takes place at the interface via photo induced electron injection from the dye into the conduction band of the solid.

The phenomenal progress realized recently in the fabrication and characterization of nanocrystalline materials has opened up vast new opportunities for these systems.

Unlike other thin-film cells, dye-sensitized solar cells do not degrade in sunlight over time. This characteristic makes the cells last long. They will not require frequent replacements.

Besides, the DSSC have several other advantages:

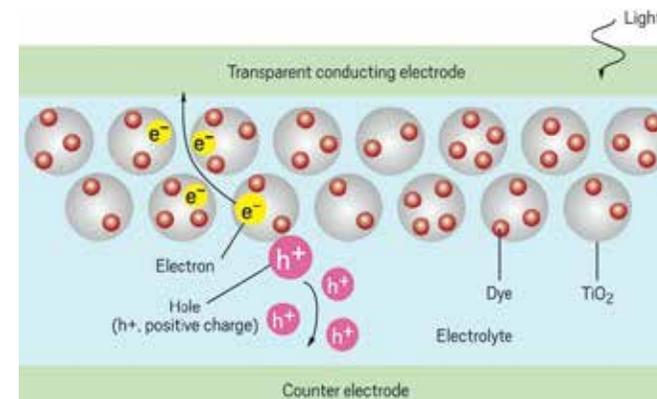
Low cost

Ability to work at wider angles and in low light

Ability to Operate at Lower Internal Temperatures

Mechanical robustness, is the fact that they have higher efficiencies at higher temperatures than traditional solar cells

Despite these myriad advantages, DSCs do have a disadvantage. The major disadvantage is that the liquid electrolyte used in DSCs is temperature-sensitive. At low temperatures, the electrolyte can freeze, thus rendering the solar cell completely unusable. At high temperatures, the liquid electrolyte expands, making sealing the solar panels a major problem. The use of a liquid electrolyte causes some serious additional problems such as potential potential instability, limitation of maximum operation temperature, danger of evaporation, and extra cost for forming an electrical series connection



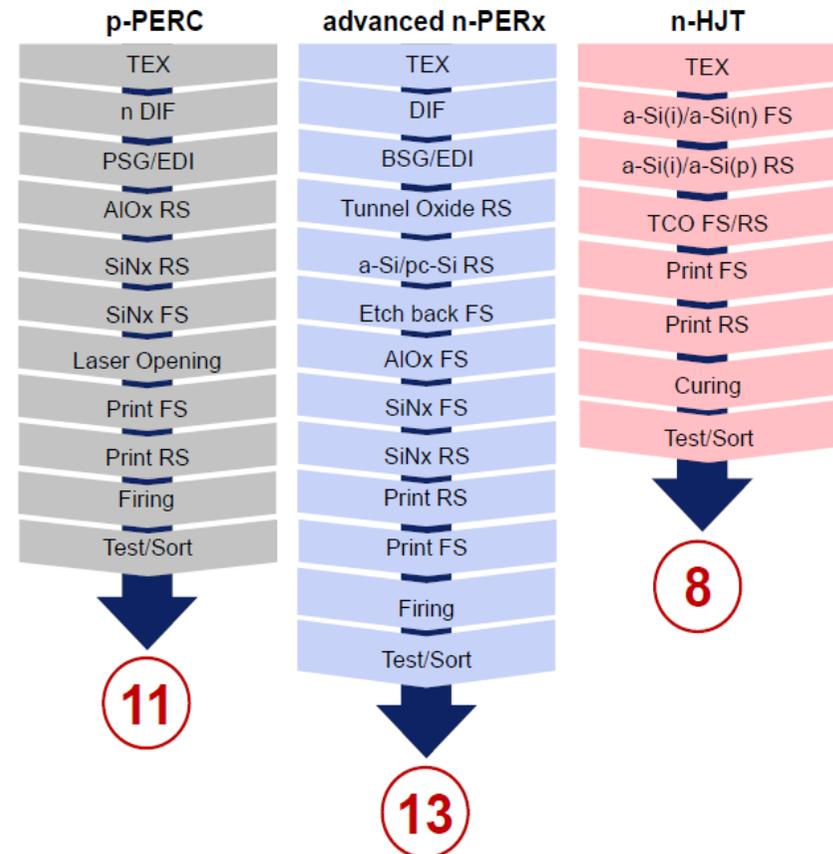
With conversion efficiencies of over 13% having already been obtained, DSSCs, the efficiencies can only improve. Future research will focus on improving the short circuit current density by extending the light response of the sensitizers in the near-infrared spectral region, and substantial gains are expected from introducing ordered oxide mesostructures and controlling the interfacial charge recombination by manipulating the cell on the molecular level.

Process & manufacturing benchmark

Various process steps including texturing, diffusion, passivation and metallization are used to convert a silicon wafer into a solar cell. The leading commercial solar cell technology over the past four decades uses screen printing of the metallic contacts onto p type single or multi crystalline silicon wafers. Passivated emitter and rear cells (PERC) were developed in 1988 to address several shortcomings of conventional screen printed solar cells, primarily related to the rear surface. Passivated emitter and rear local diffusion (PERL) solar cells have a similar design to PERC solar cells with the addition of boron diffusions at the rear contact points to reduce recombination and resistive losses. The performance of the n type rear emitter silicon solar cell can be improved to above 20% by incorporating a passivation dielectric over most of the rear surface, which reduces rear surface recombination and optical absorption, increasing the cell efficiency to exceed 20%.

Process-wise, HJT has both advantages and quite some limitations. The cell process involves only 8 steps which will need less footprint and manpower. This is considerably lower than for PERC/PERT cells, which have around 11 and 13 steps respectively. Furthermore, the symmetrical design of the HJT cells, allow bifacial design with higher backside efficiency. The low temperature process is favorable of the use of thin wafer helping further cost reduction and VOC increase. This will generate a low temperature coefficient.

On the flip side, except for the wet-chemistry, the process sequences are based on completely new steps, strongly deviating from standard processes that will necessitate new equipment.



Cells technologies production benchmarking

As the efficiency represents a large contributor for cost reduction, more and more manufacturers have started mass production mono PERC, forcing n-PERC with much higher cost to begin upgrade.

If n-type cells cannot achieve an efficiency of 23.5%, or over 24%, its difficult to widen the wattage gap. Meanwhile, the difficulty and costs are too high for IBC. As a result, the coming years will be the years of TOPCon and HJT to compete with each other. The two technologies equipment maturity and possibility to reduce cost and further increase the efficiency are obvious.

It's likely that new entrants, or manufacturers that plan to expand capacities will go with HJT, while the existing PERT and vertically integrated companies will prefer to adopt TOP-Con. The two technologies will coexist in the market. However, the HJT technology already has several mass production experiences seems to have more advantages.

		P-Mono PERC	N-PERC	N-TOPCon	HJT	IBC
Cell Efficiency		21.5 - 22%	21.5 - 21.7%	22.5 - 23.5%	22.5 - 23.5%	23.5 - 24.5%
Current Capacity		63 GW	2.1 GW	2 GW	3.8 GW	1.5 GW
Advantage		High cost effectiveness	Upgrade from the existing production lines	Upgrade from the existing production lines	Few processes	High efficiency
Current Status Comparison	Mass production	Highly mature	ready to go MP	Only LG went into MP	Ready to go MP	Only SunPower went MP
	Technology Difficulty	Easy	Quite easy	Quite difficult	Difficult	Very Difficult
	Production Process	11	13	15	8	19
	Bifacial cells	Possible	Possible	Possible	Easy	Not possible
	CAPEX	Few	Quite few	Expensive	Expensive	Very expensive
	Compatibility with existing production lines	Easy and cheap upgrade	Easy and cheap upgrade	Could be upgraded	No compatible	No compatibility
Current Issues		Efficiency limit	No cost effectiveness compared to P-PERC	Difficult to go into MP efficiency may be slightly lower than HJT	No compatible with the existing lines will need a new investment	High difficulty, high cost investment

Cells technologies cost benchmarking

Comparing the efficiency and the cost between mono PERC and n-PERC, the cost effectiveness is lower for n-PERC. Therefore, the manufacturers of the n-PERC will continually upgrade their production lines to TOPCon.

Comparing the TOPCon and HJT, because the rapid decline in mono PERC prices have drove down the overall high-efficiency market price, with prices of TOPCON and HJT remaining flat or slightly higher than cost, its difficult for these technologies to gain many profit.

Despite the higher profits of IBC, it can only aim at the niche market because the power output is much higher than conventional products.

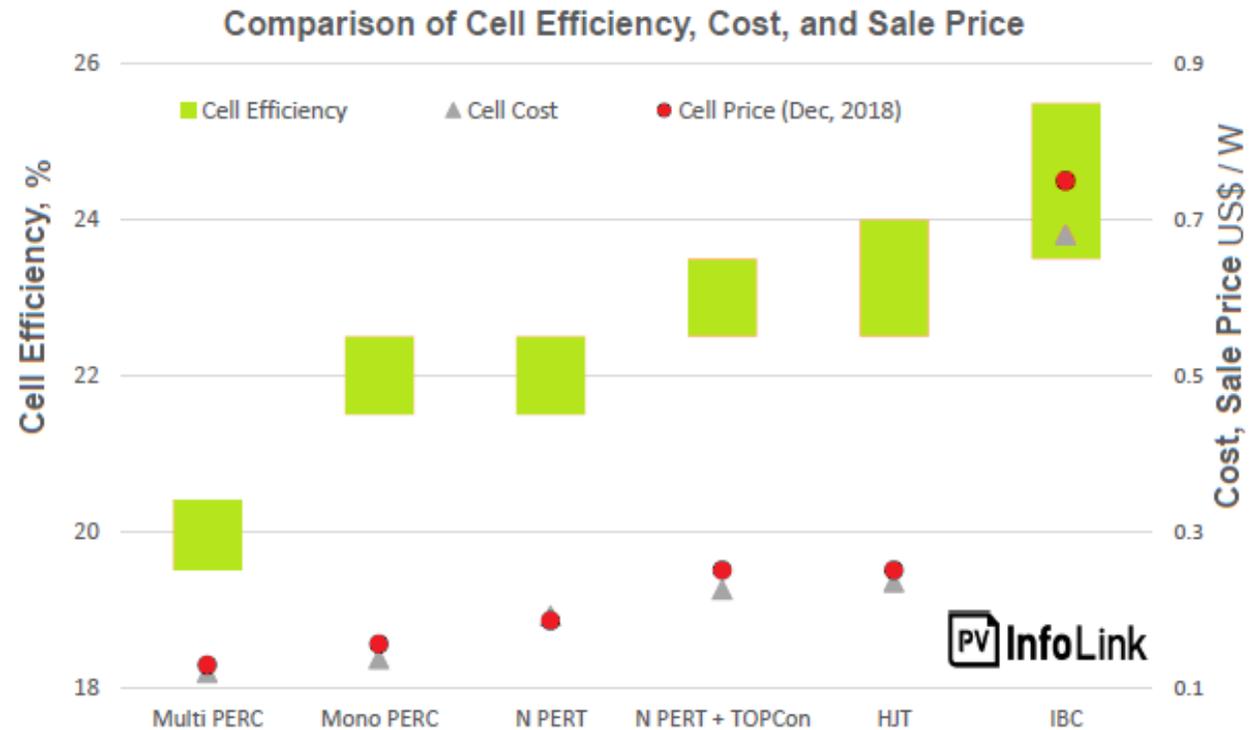


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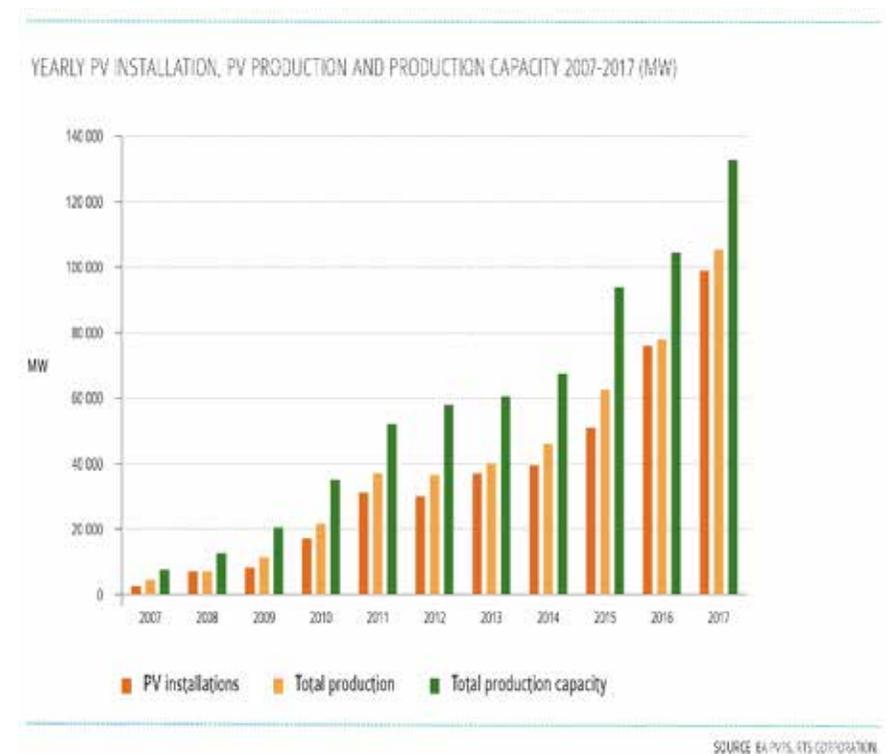
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Industry status

The PV industry has always anticipated the market growth by putting new production lines in operation before the market was really growing. One can also see the imbalance between supply and demand that is driving the prices down. This imbalance differs depending on the technology and the segment of the value chain considered.

The key event of 2018 was the Chinese decision on May 31 to constraint its market. Being the largest in the world by far, this triggered a fear of massive overcapacities in the market which drove the prices down rapidly, faster than the usual price decline observed in the quarters before the decision. This decision finally produced a 9 GW market decline, significantly less than foreseen, and the final 2018 market results were in the same range as in 2017, but with additional capacities, this led to a massive price decline as we will see in the coming slides.

The other key trends of the year are first the move towards mono, pushed mainly by the massive expansion of Longi in China. With a stable market, mono could be considered as competitive as multi, and developed fast, up to 50% of the market in 2018. Additional demand would have resulted in a higher share of multi, since mono was not expected to be able to cover more demand in 2018. The second trend is the generalisation of PERC, with most cell lines being adapted. It can be estimated that PERC represents at least 63 GW of capacity at the end of 2018, out of a 90 GW of conventional crystalline silicon PV market.



Trade measures continue to shape the market in some countries. While the European Union has decided to phase out its trade duties, this is not the case of the USA. Since January 2018, a quota and decreasing tariff has been enacted in the USA on cells & modules for a four-year period. Since August 2018, safeguard duties of 25% are imposed in India on solar cells imported from China & Malaysia. In general, the willingness to develop PV with a local production of components and local workers becomes a trend in all places of the world. Even in Europe, some voices are becoming stronger to ask for some measures to avoid flooding the market with low-cost Chinese production.

Such measures reflect the political willingness to control a part of the value chain, as well as creating industrial jobs and local actors that could compete on the international level.

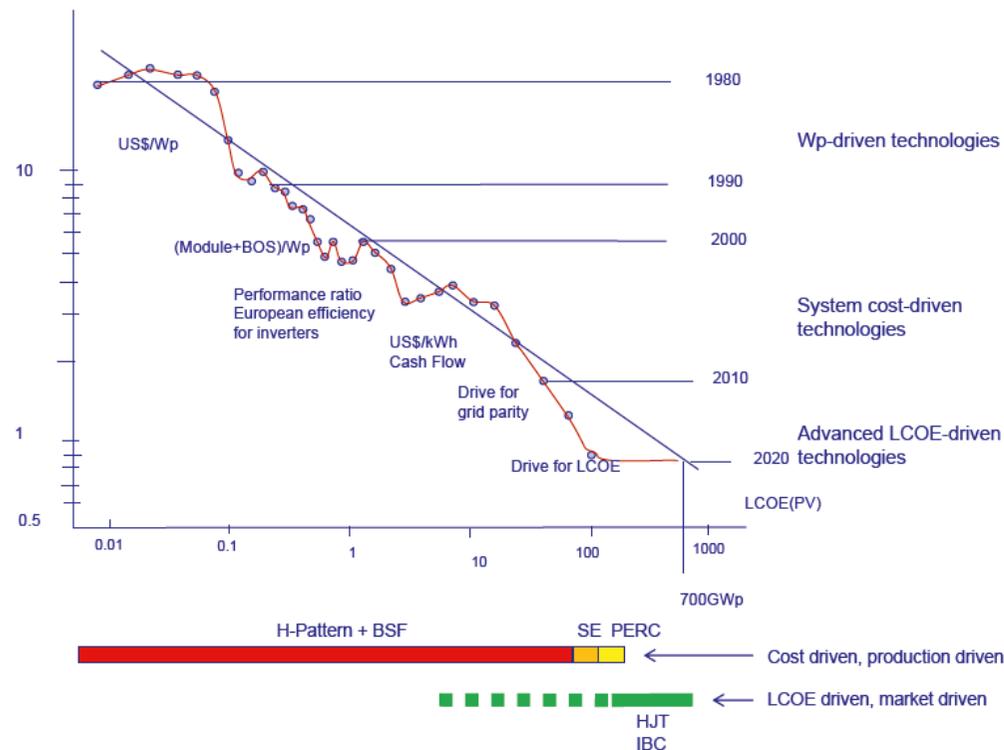
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Findings from the PV learning curve

The 'standard' cells on mc or cz wafers have the largest market share and are the most technically mature. However, these technologies are almost at the limit of their efficiency, and they offer few criteria for long-term reductions in LCOE costs, with the result that the only opportunities for improvement lie in production cost reduction. To achieve higher efficiencies, various upgrades have been introduced, but some – such as selective emitters or MWT (metallization wrap-through) – have almost reached the end of their product life cycles. The use of selective emitters lasted approximately four years and became obsolete when appropriate pastes were made available. MWT technology lost its advantage of a reduction in silver usage on the front when smart wire technology was introduced. Another upgrade – the co-diffusion cell – is costly to produce and expensive in use, with limited cell efficiency, and it offers less potential in terms of temperature coefficient. The remaining upgrade for existing systems is the conversion to PERC (passivated emitter and rear cell), which will allow existing systems to continue operating for a number of years.



This is associated with a strategy that is based purely on cost, because in the mainstream area it is crucial to remain the cost leader. For this reason, new investments are being directed at new technologies which meet the requirements outlined by the LCOE calculation. Cell concepts of this type are based on HJT cell technology: one such example is heterojunction with intrinsic thin layer HJT, developed by Sanyo. HJT modules began line production in 1997 and have since repeatedly broken the world efficiency record for modules.

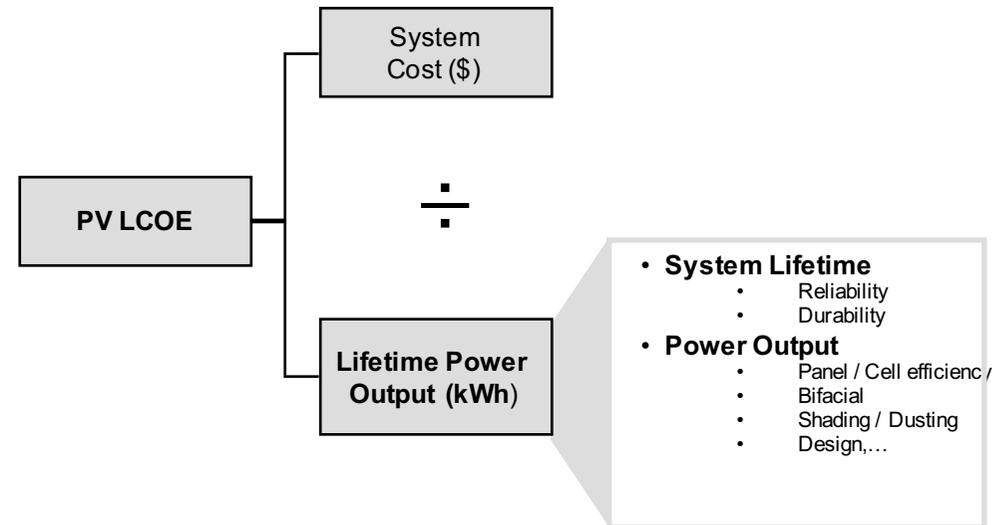
The economy of scale potential for HJT is not yet exhausted, because it is at the beginning of its product life cycle. Upscaling from 500MWp to 2GWp, for example, would bring cost benefits of 20% , and HJT can also benefit from this potential. The upper level, however, has not been included in the present consideration of LCOE. According to the learning curve, the hundreds of GW of production have to be produced at the same price level as today, which does not allow a reasonable profit margin with today's mature technology. In contrast, today's manufacturing costs for HJT modules are lower than market module prices, and profits are realistic.

Levelized Cost of Energy (LCOE)

Rather than considering the Wp cost as a comparison parameter between the solar technologies, the key solar energy indicator should be the cost per kWh translated by the Levelized Cost Of Energy (LCOE).

The LCOE, is the prevalent metric used in the energy sector for cost comparison purposes indeed. Conceptually, the LCOE is the ratio of all costs incurred throughout the lifetime of the power plant to overall energy generated. It is easy to understand and also relatively easy to calculate. Most importantly, it enables comparison of different generation technologies by capturing fundamental cost components including capital costs, operation and maintenance costs and discount rates.

In its simplest form, the expression of the LCOE can be written as:



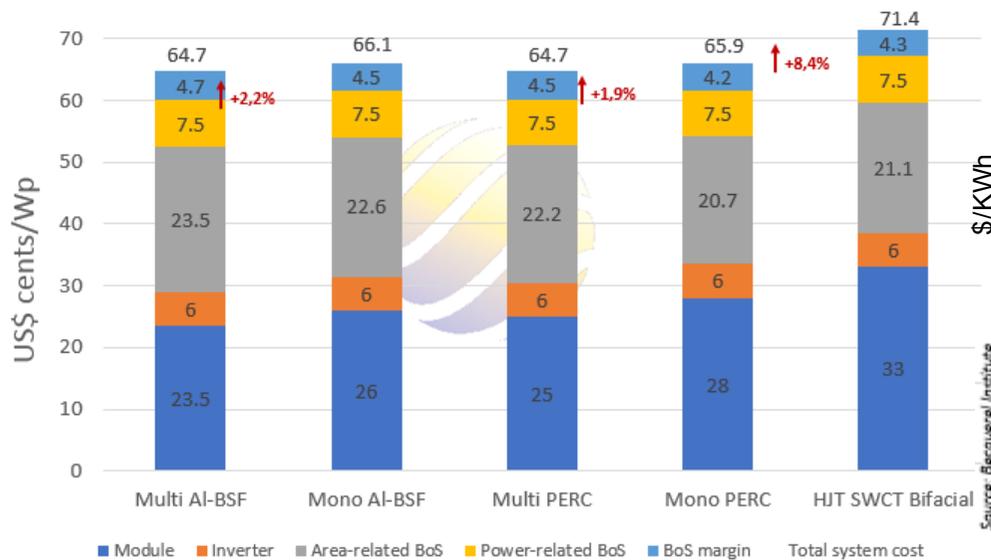
- I_t : investment expenditures in the year t
- M_t : operations and maintenance expenditures in the year t
- F_t : fuel expenditures in the year t
- E_t : electrical energy generated in the year t
- r : discount rate
- n : expected lifetime of system or power station

$$\text{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

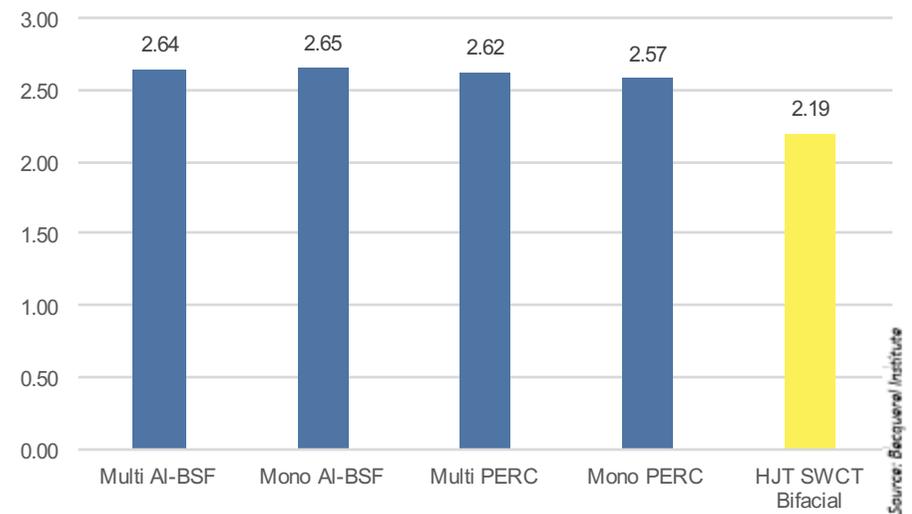
System cost Vs. LCOE

The LCOE is the de facto measure of cost competitiveness and comparison across technologies for power generation.

Total system cost of different technologies



LCOE of competing technologies



Source: Becquerel Institute 2019

Production costs are higher for HJT, for the time being. Due to lower economies of scale. However, the potential for cost reduction is much higher than in the competing technologies.

LCOE is the lowest compared to the competing technologies

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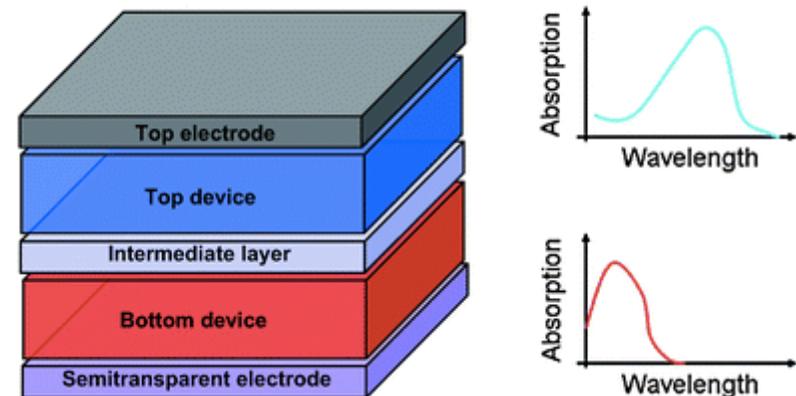
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Emerging technologies and novel concepts for high efficiency

The push to ever increasing energy conversion efficiency is providing the opportunity for advanced silicon cell technologies to make their mark, commercially. The increased efficiency is likely to significantly reduce costs per Watt, particularly as a mature technology. In the near term, the traditional aluminum back surface field (Al BSF) approach is being replaced by higher efficiency passivated emitter and rear cell (PERC) sequences, with the transition expected to be largely completed by 2020. In the longer term, more disruptive technology may influence the way the industry evolves. At present, silicon has a clear energy conversion efficiency advantage over these alternatives. A potentially disruptive development would be the reversal of this situation. The trend towards a high-efficiency device design that combines old and new technologies for greatly enhanced performance, called a tandem solar cell.

Tandem solar cells are stacks of individual cells, one on top of the other, that each selectively convert a specific band of light into electrical energy, leaving the remaining light to be absorbed and converted to electricity in the cell below. By doing so, tandem cells can surpass the theoretical energy conversion efficiency (Augier cap 29.2%) of any single cell acting on its own.

This tandem cell approach has been used to fabricate the world's most efficient solar cells that are capable of converting 46% of sunlight into electricity. Unfortunately, these devices use very expensive materials and fabrication processes, and so are priced out the market.



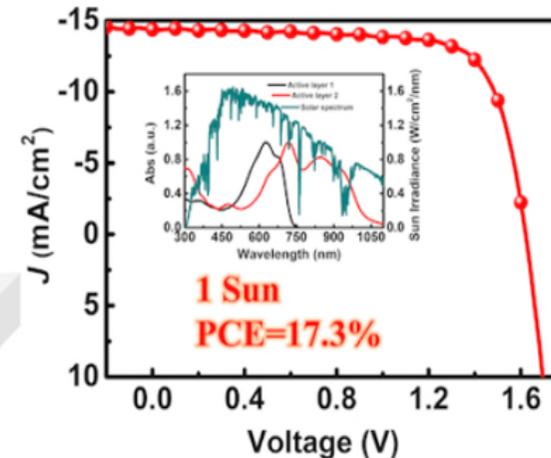
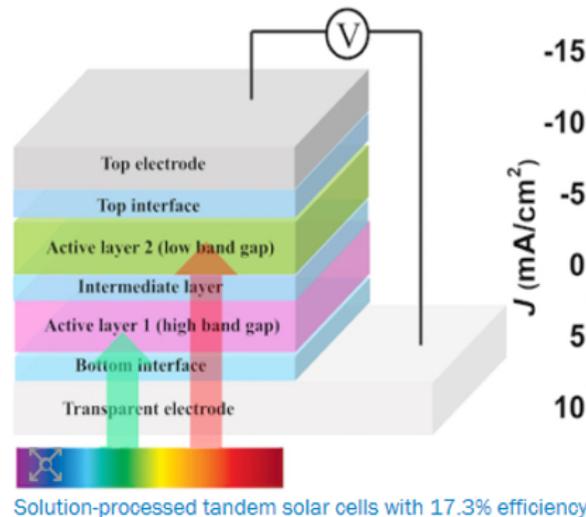
Schematic representation of an organic tandem device comprised of two sub-cells having different, complementary absorption spectra

Tandem solar cells, a new design for high efficiency I

Emerging PV technologies comprise several types of tandem cells that can be grouped mainly depending on materials used – whether it is organic, inorganic, hybrid and then classification goes deeper of what kind of connection type is used for sub-cells – stacked, monolithic or optical splitting. Compounds of tandem module with silicon here are separated as to show their perspective and high results.

Organic tandem cells

Organic photovoltaics goes straight in making cheap cells, with small or medium efficiencies. Tandem cells with only polymer materials have power conversion efficiencies of less than 10%. This kind of solar cells are expected to reach around 15%. These tandem cells are mostly favorable due to cheap production and semi-transparency. However, such pros give you one important con – low efficiency.

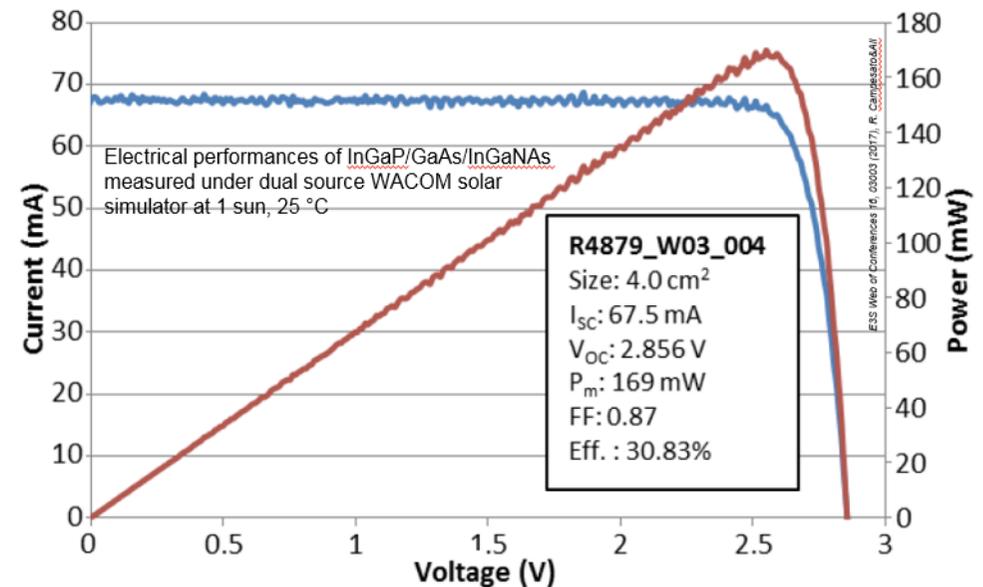


Source: [Yongsheng Chen of Nankai University in Tianjin](#)

Tandem solar cells, a new design for high efficiency II

Inorganic tandem cells

The only commercial tandem cells to our knowledge are made from III-V group materials, that are sometimes called mother and father of the technology. Mainly because III-V semiconductor compound solar cells have been leading in conversion efficiencies since the start of single junction solar cells and tandem cells made from these materials were steadily increasing too. The world-record efficiency of 3 junction cell comprises of GaInP/InGaAs/InGaAs, which reach 44.4% efficiency under 302 suns, whereas a four-junction GaInP/GaAs; GaInAsP/GaInAs reach 46.0% at 508. These type of cells (little less effective than these laboratory world records) are used mainly in space applications, like satellites or with difficult and expensive concentrator systems, because of very high price yet highest efficiencies.



The benefits of inorganic tandem cells: Very high efficiencies, Bandgap tunability by elemental compositions in alloys (bandgap is a semiconductor property showing what minimum energy is needed to move electron from valence band to conduction band), Good range of lattice parameters (lattice is a network of atoms in crystalline material) and bandgaps to choose from, higher photon absorption (because they have direct bandgap, simply meaning, that it is easier to absorb light than in indirect semiconductor like silicon), higher resistance against high-energy rays in space, smaller efficiency degradation by heat than Si solar cells. Quite a lot, huh!!! However, there are minuses too: very expensive and these structures are complex to manufacture.

Hybrid tandem cells

Hybrid is the third type of tandem cells. It is where the solar industry perspective – perovskite - steps in. Perovskite tandem has already proven to be quite efficient and low cost, mostly because of cheap materials that are being used. This combination also has strong optical absorption and long diffusion length and ability to be printed by roll-to-roll technology. On the other hand, as perovskite is still developing, its stability is questionable, which degrades in humid air. Thus perovskite tandems also suffers from this issue as well as recombination losses, bandgap optimization and transparent conductive oxide reflections and parasitic absorbance.

This new generation solar cells are built up like a sandwich and perovskite is used as the solar power harvesting layer. The material is also semi-transparent, thus it can be installed in building windows, house windows or even car windows.

In the light of hybrid type of tandem, it is also worth mentioning DSSC – dye sensitized solar cells – which has promising future. It is an example of different view to solar cells, with a quite interesting structure, partial transparency and low price. These cells are being used for semi transparent and flexible modules, but still are in an early commercialization stage, mostly due to lack of efficiency.

Using them in tandems has many perspectives, because it also has a big potential to reduce price of solar industry, can be flexible and semi-transparent.

Efficiencies of these tandems here range from 8 to more than 17%:

7.1 % efficiency DSSC/DSSC (different dyes of each of sub cells) – DSSC/DSSC (different dyes of each of sub cells)

12.35 % efficiency – DSSC/CIGS (CIGS is a member of thin film solar cell family)

7.63 % efficiency – DSSC/GaAs (GaAs is a III-V group alloy)

Hybrid tandem cells: Tandem cells with silicon I

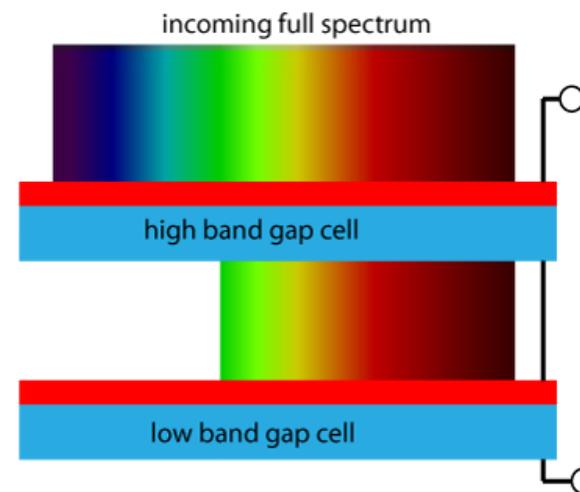
Perovskite solar cells PSC are rapidly emerging as a high-efficiency photovoltaic technology. Owing to their fairly large bandgap, PSCs are particularly attractive for building tandem solar cells, combined with well-established silicon bottom cells. In such a configuration the PSC harvests the blue part of the solar spectrum while letting red and near-infrared (NIR) light pass through to be absorbed in the silicon bottom cell. In this way, such a combination is expected to overcome the single-junction power conversion efficiencies PCE limit of silicon solar cells 29.2%. In this context, thanks to its tunable band gap of 1.7–1.8 eV, and high PCE >20% perovskite solar cells are indeed very promising as top cells. The most attractive bottom cell technology is that of silicon heterojunction HJT solar cells which offer the highest operating voltages >750 mV and efficiencies, thanks to their passivating contacts and the best red response of all silicon solar cells. The most attractive way to combine these two technologies is in a monolithic tandem concept by employing textured HJT solar cells as the bottom cell and semitransparent perovskite solar cells PSC as the top cell.

Integrate both technologies into monolithic perovskite/silicon tandem solar cells remains challenging. Specific points of attention for this are:

1/ The fabrication of semitransparent PSCs, requiring the deposition of transparent contact stacks onto the perovskite films. The manufacturing process requires the compatibility of all layers.

2/ Low-temperature PSC fabrication. This is required for monolithic tandem fabrication, as the SHJ bottom cell, featuring a-Si:H contact layers cannot withstand temperatures above 200 °C.

3/ Vacuum deposited PSCs. In order to reduce any reflection losses, and to be close as current industrial standards, the tandems ultimately will need to use so-called random-pyramid textured bottom cells (feature size of several micron), which makes PSC solution processing a challenge.



Hybrid tandem cells: Tandem cells with silicon II

Even if DSSC has an interesting prospects, it is still the product of future. On the other hand we have tandem with silicon which brings interesting results today. It was found, that silicon mixed in tandems with III-V group materials, CZTS, CIGS, perovskites, polymers produces promising outcomes.

Records:

17.23% efficiency – DSSC/c-Si

12.31% efficiency – a-Si/DSSC

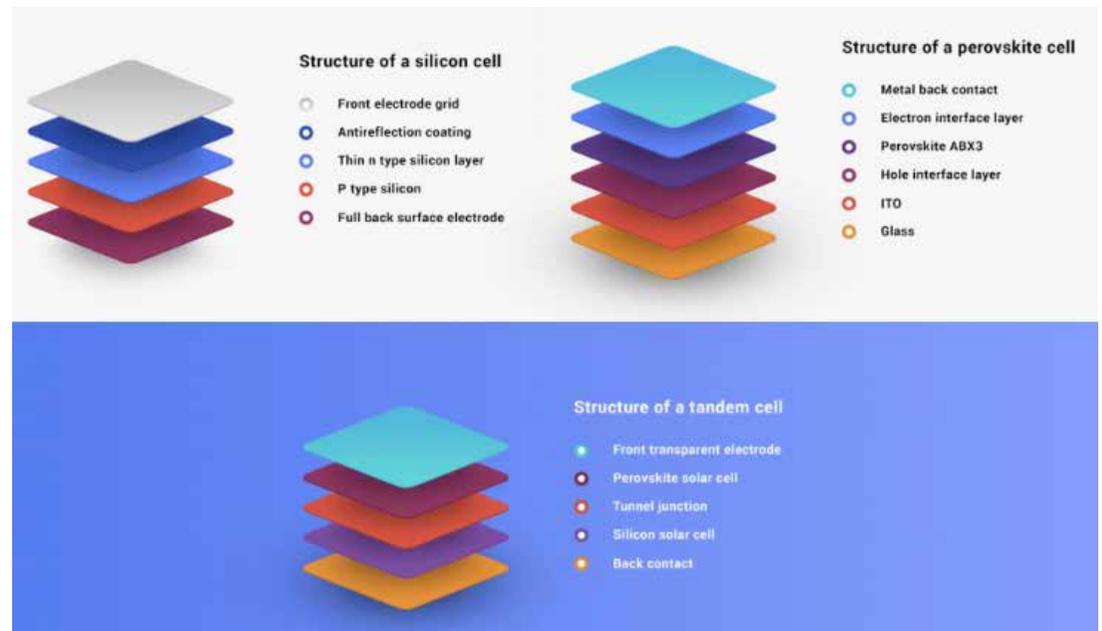
26.4% efficiency – Perovskite/c-Si (mechanically stacked tandem)

23.6% efficiency – Perovskite/c-Si (monolithic tandem)

16.8% efficiency – CZT/c-Si (CdZnTe is a member of thin film solar cell family)

Can we expect tandem cells in the market any time soon?

Although tandem cell technology is a promising technology, yet it is clear that we will not see them as commodity products on the market in the near future due to number of issues to be solved before this technology will mature to the level of commercial product. Today Si based devices are becoming the cheapest energy generation option – therefore it will be really difficult to beat them in the nearest future.

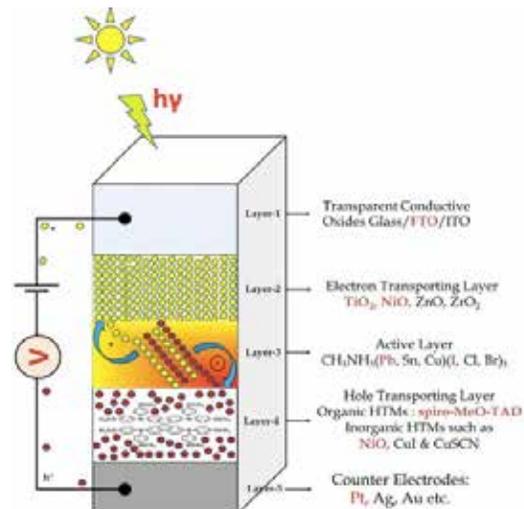
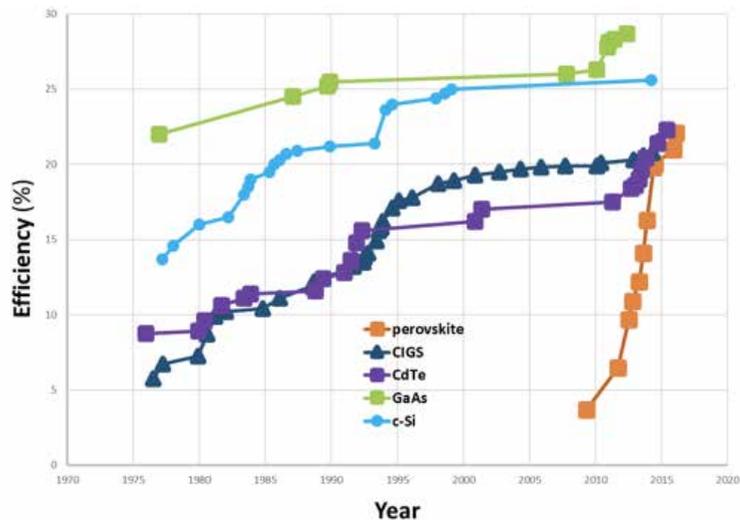


Perovskite solar cells

Perovskite cells, which are primarily lead-halide based, lend their name to the class of compounds which have the same type of crystal structure as calcium titanate, known as the “perovskite structure”.

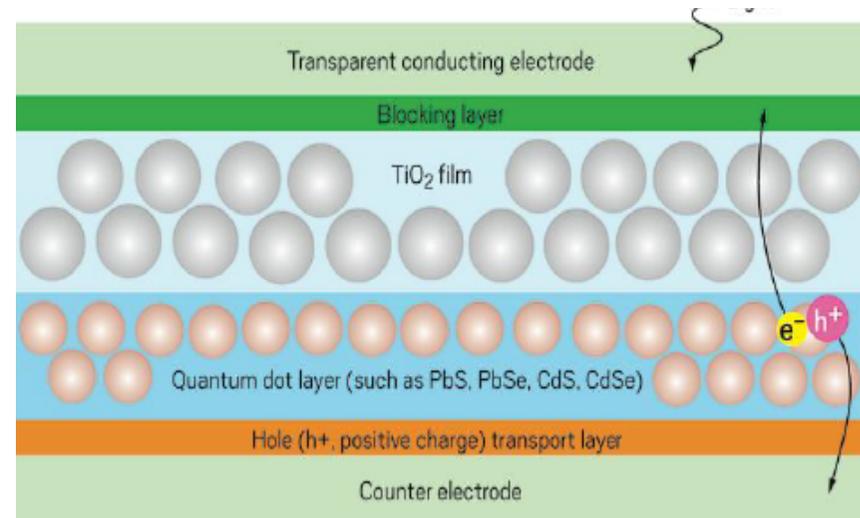
The organic-inorganic halide perovskite solar cells (PSCs) have attracted a great deal of attention of solar cell research community. Having been in very early stages of development throughout the 2000s, from 2009 this highly exotic material has achieved incredible device efficiency improvement from 3.8% to 22.1%. This is a faster rate-of-efficiency increase than any of the other emerging PV technologies, The perovskite already gained much attention as a potential replacement of the silicon photovoltaic (PV) devices.

The perovskite materials show various advantages such as long carrier diffusion lengths, widely-tunable band gap with great light absorption potential. The low-cost fabrication techniques together with the high efficiency makes PSCs comparable with Si-based solar cells. But the drawbacks such as device instability Because, it degrades quickly due to its high sensitivity to moisture, J-V hysteresis and lead toxicity reduce the further improvement and the future commercialization of PSCs.



Quantum Dot Solar Cell

Novel PV concepts aim at achieving ultra-high efficiency solar cells by developing active layers which best match the solar spectrum or which modify the incoming solar spectrum. Both approaches build on progress in nanotechnology and nano-materials. Quantum-dot cells have what is called a “tunable bandgap”. In lay terms, by varying the size of the quantum dots used, the type of solar energy that can be absorbed can be altered or “tuned”. This is useful since by including quantum-dot technology as one junction in a multi-junction cell, solar energy that is usually lost as heat can be captured. This cutting-edge technique has been dubbed “multiple exciton generation” (MEG) by the NREL. These novel concepts are currently the subject of basic research. Their market relevance will depend on whether they can be combined with existing technologies or whether they lead to entirely new cell structures and processes. Large market deployment of such concepts – if proven successful – is expected in the medium to long term. Considerable basic and applied R&D efforts aimed at the mid- to long-term are required in order to further develop these approaches and to ultimately bring them to market in end use applications.

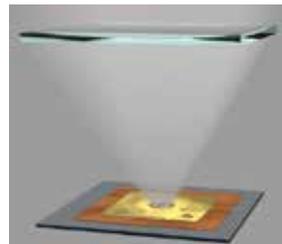


The maximum certified efficiency 13%

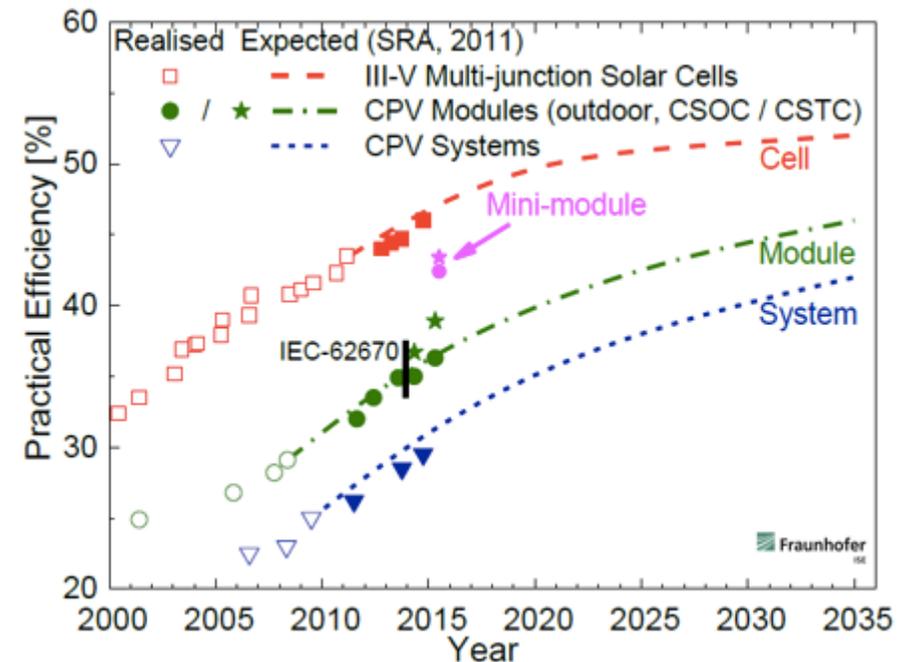
Concentrator solar photovoltaic technologies (CPV)

All PV technologies described so far are so-called flat-plate technologies which use the naturally available sunlight. As an alternative, direct solar radiation can be concentrated by optical means and used in concentrator solar cell technologies.

Differing from conventional non concentrated PV systems, concentrated PV (CPV) systems use lenses and curved mirrors to focus sunlight onto small but highly efficient solar cells.



Considerable research has been undertaken in this high-efficiency approach because of the attractive feature of the much smaller solar cell area required. Low and medium concentration systems (up to 100 suns) work with high-efficiency silicon solar cells. For the highest concentration levels beyond 500 suns, III-V compound semiconductors are being used for the CPV solar cells and efficiencies beyond 40% have been achieved in the laboratory. The CPV technology is presently moving from pilot facilities to commercial-scale applications. Further R&D efforts are required in optical systems, module assembly, tracking systems, high-efficiency devices, manufacturing and installation.



Graphene as a Material for Solar Cells Applications

Graphene is a highly exotic material at the cutting edge of development. It is made of a single layer of carbon atoms that are bonded together in a repeating pattern of hexagons.

Graphene is a two-dimensional material with honeycomb structure. Its unique mechanical, physical electrical and optical properties makes it an important industrially and economically material in the coming years. One of the application areas for graphene is the photovoltaic industry. Studies have shown that doped graphene can change one absorbed photon of a few electrons, which in practice means an increase in efficiency of solar panels. In addition, graphene has a low coefficient of light absorption 2.3% which indicates that is an almost completely transparent material. In fact, it means that solar cells based on graphene can significantly expand the absorbed spectrum wavelengths of electromagnetic radiation. Graphene, additionally is a material with a very high tensile strength so it can be successfully used on the silicon, flexible and organic substrates as well. So far, significant effort has been devoted to using graphene for improving the overall performance of photovoltaic devices. It has been reported that graphene can play diverse, but positive roles such as an electrode, an active layer, an interfacial layer and an electron acceptor in photovoltaic cells. Research on solar cells containing in its structure graphene however, are still at laboratory scale. This is due to both lack the ability to produce large-sized graphene and reproducibility of its parameters



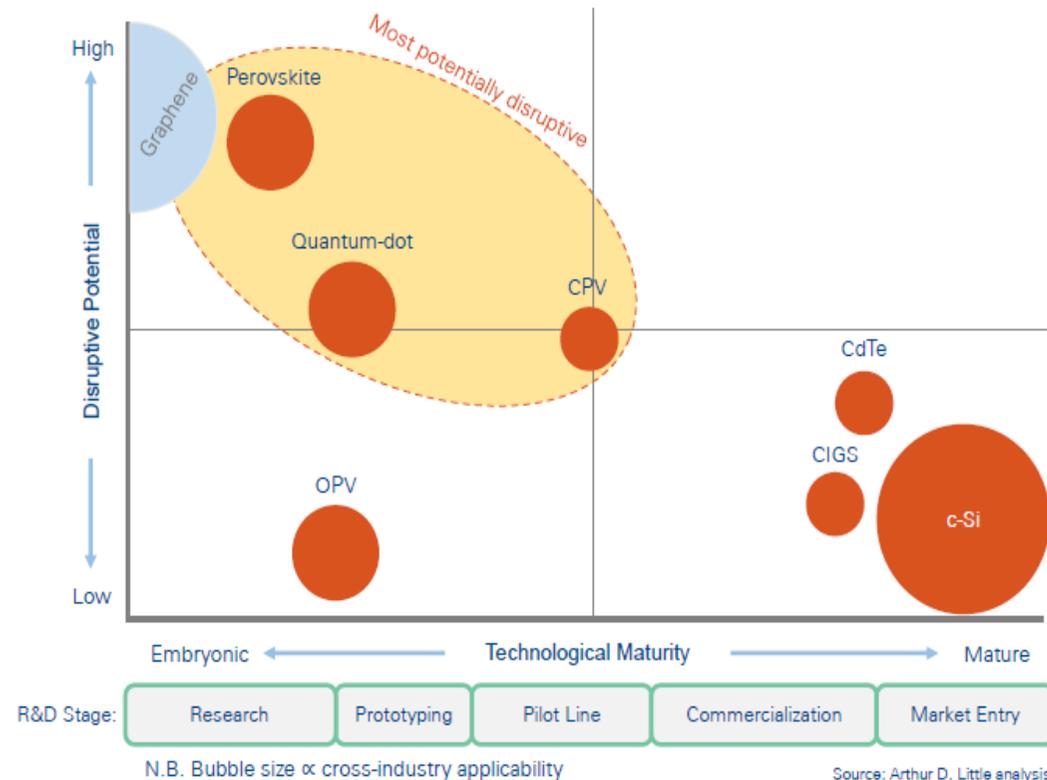
A new flexible graphene solar cell developed at MIT is seen in the transparent...

As a material with the potential of extremely high cross-industry applicability, graphene naturally invites comparison with silicon and its functional and industrial revolution over the past 40 years.

Disruptive potential vs. technological maturity of candidate disruptors

Based on their ability to Compete with c-Si within PV applications ; Venture successfully into new applications outside of the reach of c-Si. The perovskite, the quantum dot photovoltaics and concentrated photovoltaics are the most potentially disruptive

PV technologies in the coming 10–15 years. This is neither to undermine the daunting challenge of beating c-Si as it continues to break new records for higher efficiencies, nor to say that these technologies are the ones that we expect to see rising rapidly up the PV installed capacity rankings in the next decade or so. Rather, these three, if given sufficient R&D attention, have the highest potential to change the PV game in the long term. They are all still in relatively early lab stages. Perovskite and quantum-dot more so than concentrated photovoltaics, and require further dedicated attention to bring them to mass production.



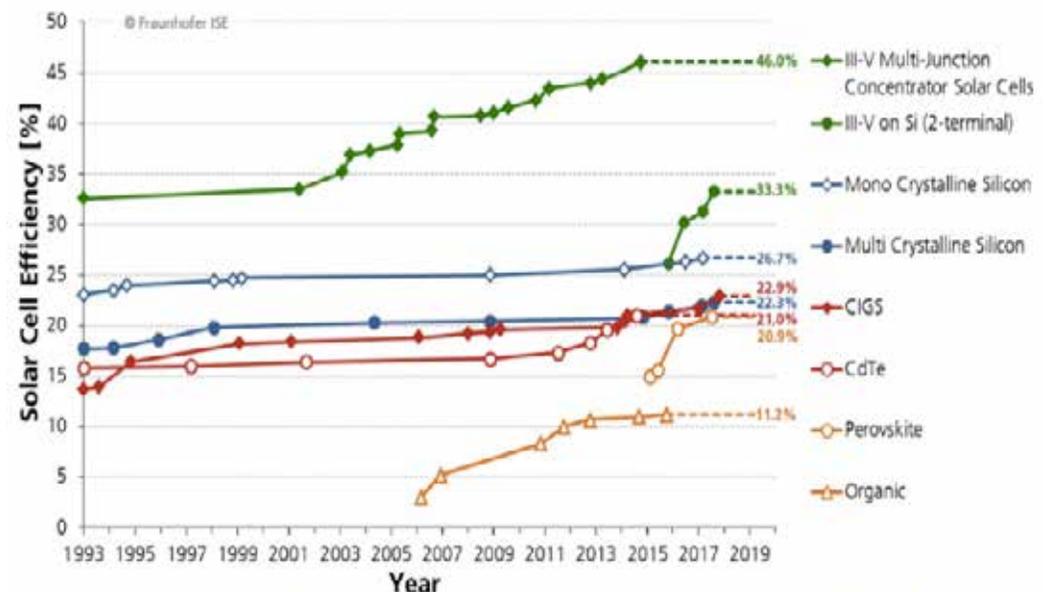
Defining the credentials of potentially disruptive PV technologies

In the last 15 years, cutting-edge PV concepts including concentrated photovoltaics (CPV), multi-junction cells, organic photovoltaics (OPV), quantum-dot cells, perovskite, and (to some extent, the exotic and not-yet fully-understood) graphene, have all been receiving attention from both academic and financial arenas. These emerging technologies have the potential to disrupt c-Si because of their dual abilities to:

1. Beat c-Si directly in PV applications due to lower long-term \$/W potential.
2. Venture into new applications outside of PV; we call this “cross-industry applicability”.

Qualifications in these two abilities, in addition to other relevant dynamics, particularly synergies and complementarities with important existing technology, are the prerequisites that certify a PV technology as potentially disruptive.

Development of Laboratory Solar Cell Efficiencies



Data: Solar Cell Efficiency Tables (Versions 1 to 53), Progress in Photovoltaics: Research and Applications, 1993-2018. Graph: Fraunhofer ISE 2019

From the Lab to the Fab, it's never smooth path way

A graphic put out by the US Department of Energy's SunShot Initiative demonstrates the implications of the belief that PV technologies with high disruptive potential have been identified. The graphic shows the typical path that PV technologies take from laboratory to fabrication, from high to low technological risks, and the magnitude of related necessary financial investments. Two zones of danger, or "valleys of death", are highlighted. The first is the prototyping valley of death. The second, and much more foreboding, valley of death comes after the technology has been through the pilot line but has yet to hit the production line. This is the commercialization valley of death.

In order to traverse this chasm and to ensure that promising technologies make it from "lab to fab", governments and other potential financial donors must exert more support to bring the technological potential to market and convert pipeline dreams into mainline reality.

Besides, providing financial muscle to develop the technologies, an enlightened, patient, long-term view is required in which concerned actors do not cave in to external demands for short-term returns. Doing so would result in the abandonment of fledgling, but potentially game-changing, emerging PV technologies. Scientific advancements of this scale often happen incrementally, so a time horizon of five years or greater is necessary.

Until now, developed countries such as the US, Germany and Japan have carried the bulk of the burden in developing emerging PV technologies. That said, the current situation offers a unique opportunity to emerging countries such as China, India and the Gulf Co-operation Council region, among others, to share efforts towards the development of these promising technologies.

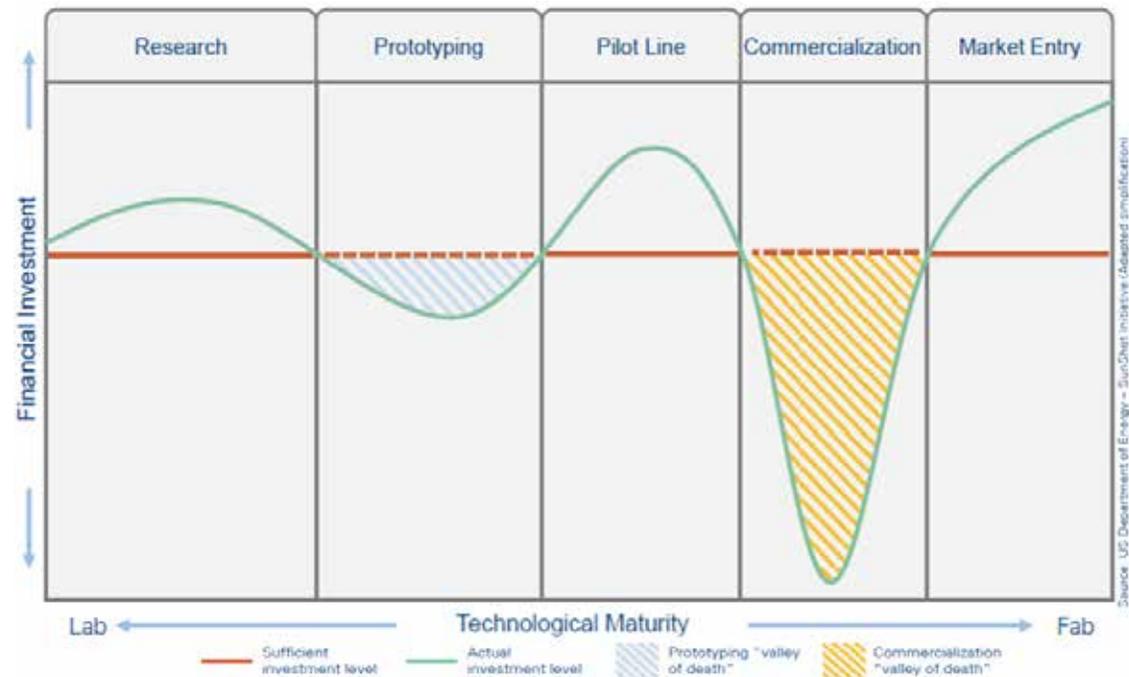
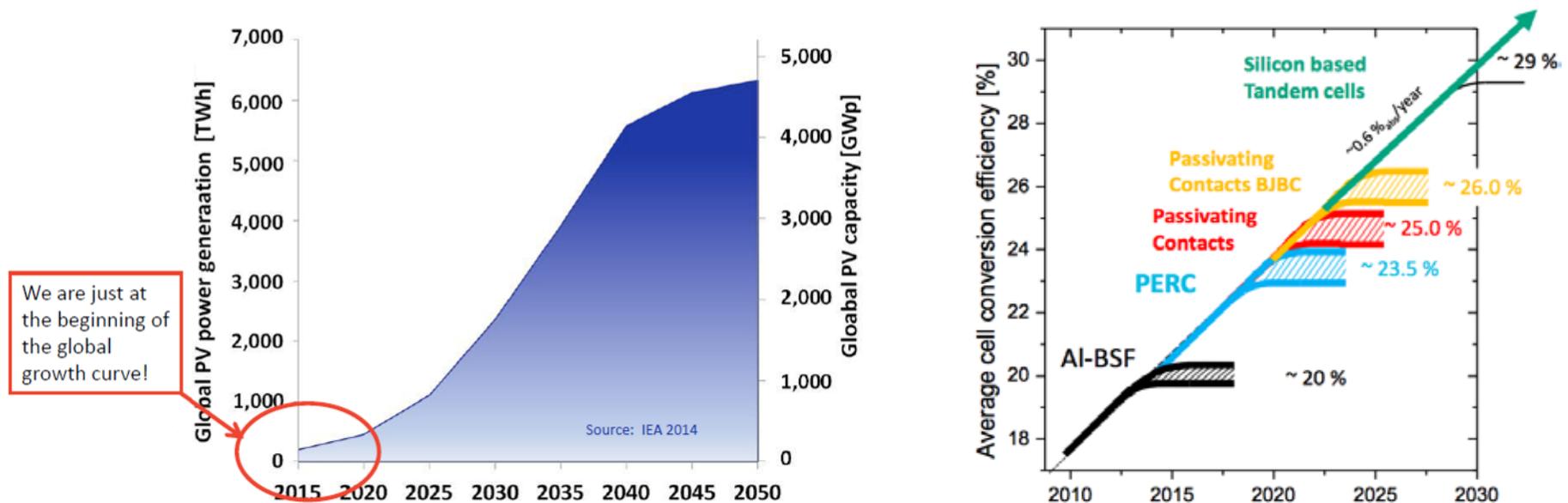


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Executive Summary

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We are at the dawn of the age of solar energy, and the future is bright. Innovation is on the way.



Remarkable progress made in synthesis, processing and characterization leads to major improvement in PV efficiency. Although, c-Si is the dominant Solar PV technology today, it may not remain so forever. Instead, the emerging PV technologies surveyed in this report could potentially disrupt and replace c-Si in the long term, depending on their ability to beat c-Si within PV applications and their cross-industry applicability. Nevertheless, we can't expect a breakthrough technology sometimes soon. Currently, mono PERC is the mainstream, thanks to the small investment needed to convert the existing lines. The next step is expected to be n-PERT and TOPCon. However, the HJT will be considered as the first step in game change as it offers the way to the tandem cells. Regarding the most promising emerging technologies are Perovskite, Quantum Dot and Concentrated photovoltaics.

Technology report, 2019

The solar PV is a fast moving developing technologies. The information provided in this report is very concise by its nature. The purpose of this report was to provide a rough overview of the technology status and its potential for further development and thus cost reduction.

The technologies listed in the this report as well and the trends are not exhaustive. The report was specifically designed this way to highlight the potential for solar PV to significantly impact the electricity generation portfolio and explore the challenges likely to be encountered as the market growth and diversifies. Its rather a description of technologies that are revalorizing the solar PV sector. The given information in these report is a result of divers investigations, compilation of information and data.

My thanks goes to all the institutes, organizations, intelligence firms, magazines etc.. Active in the sector providing valuable information and data.

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Disclaimer:

This report has been written based on compilation of information from divers reports, articles and data intelligence. All have been referenced.