“Solar Energy a New Era of High Tech Opportunities”

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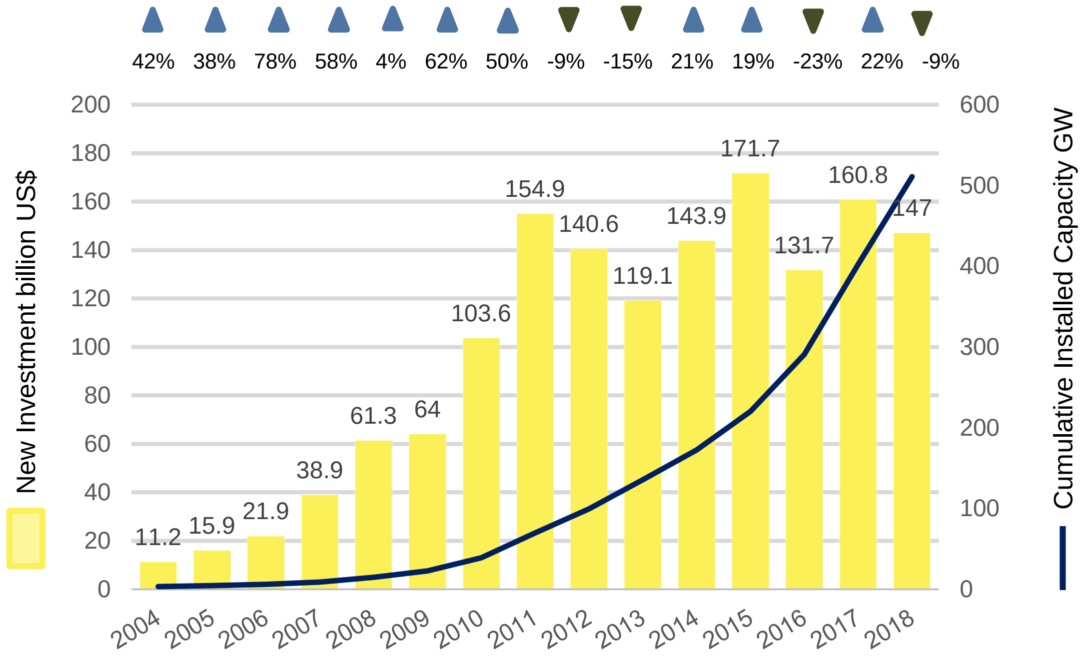
تكنولوجيات الصحراء

desert technologies

Global solar power investments vs cumulative installed capacity

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



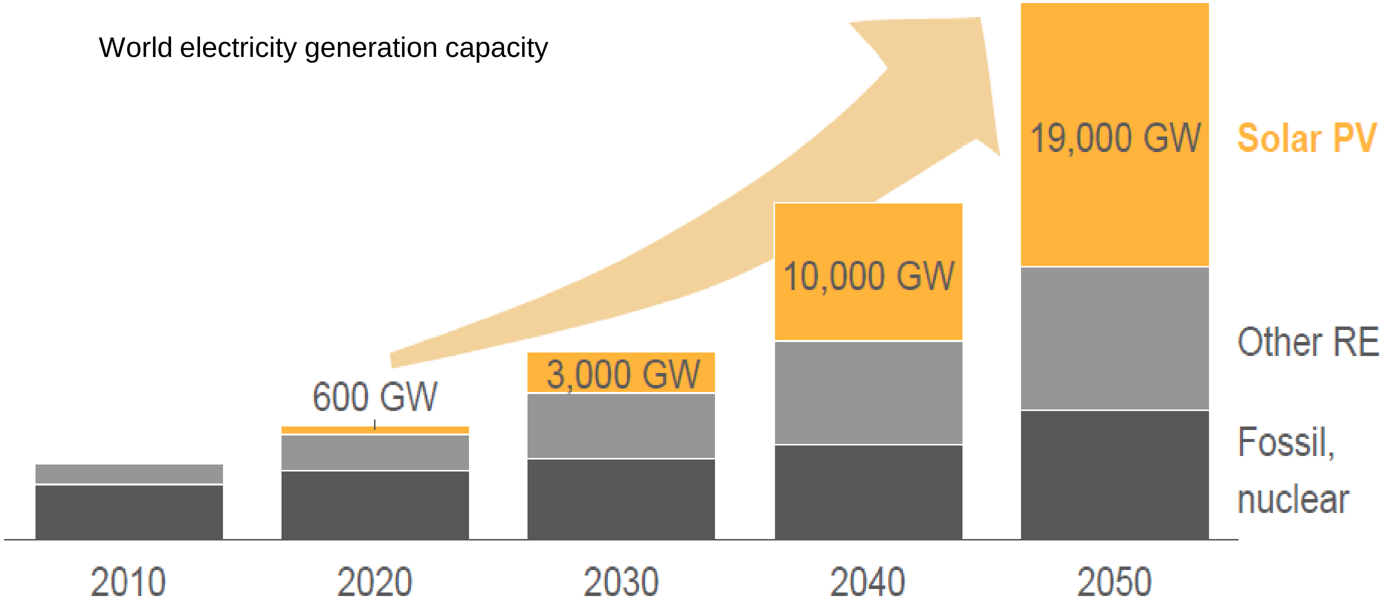
Soure: Bloomberg, NCH, IEA-PVPS

- 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

Explosive growth in sight…. Opportunities for newcomers

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.

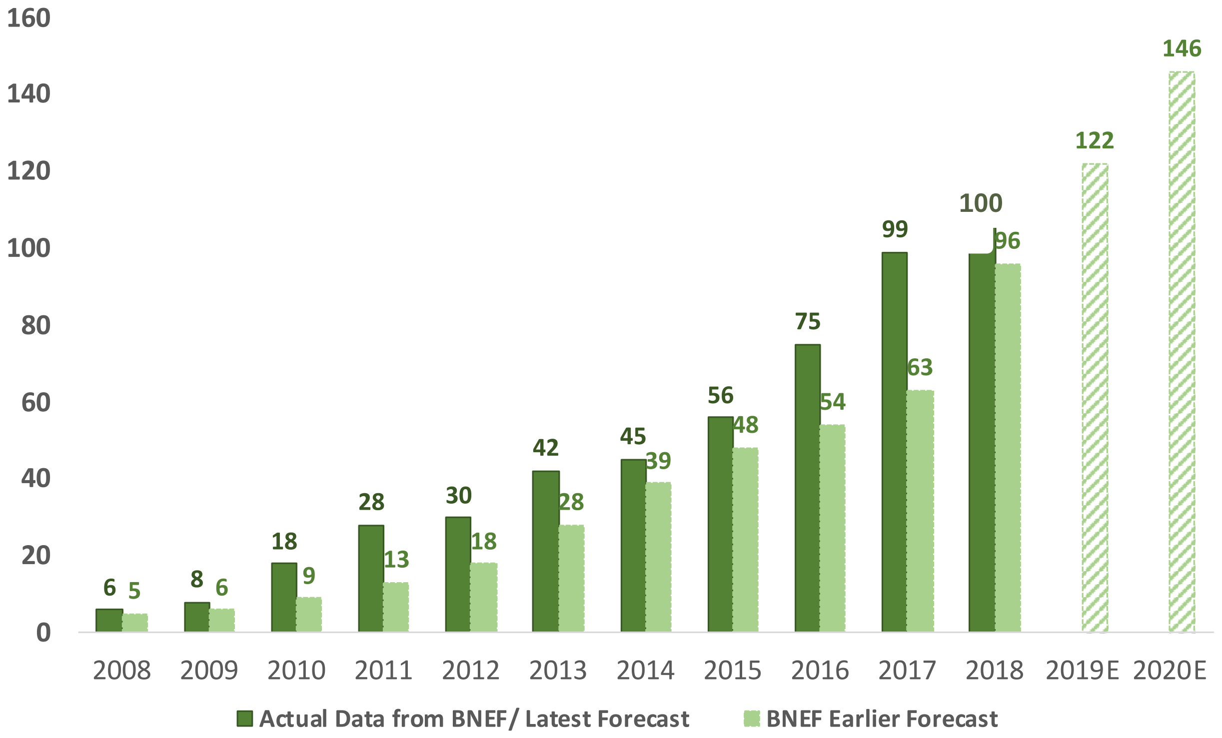
World electricity generation capacity



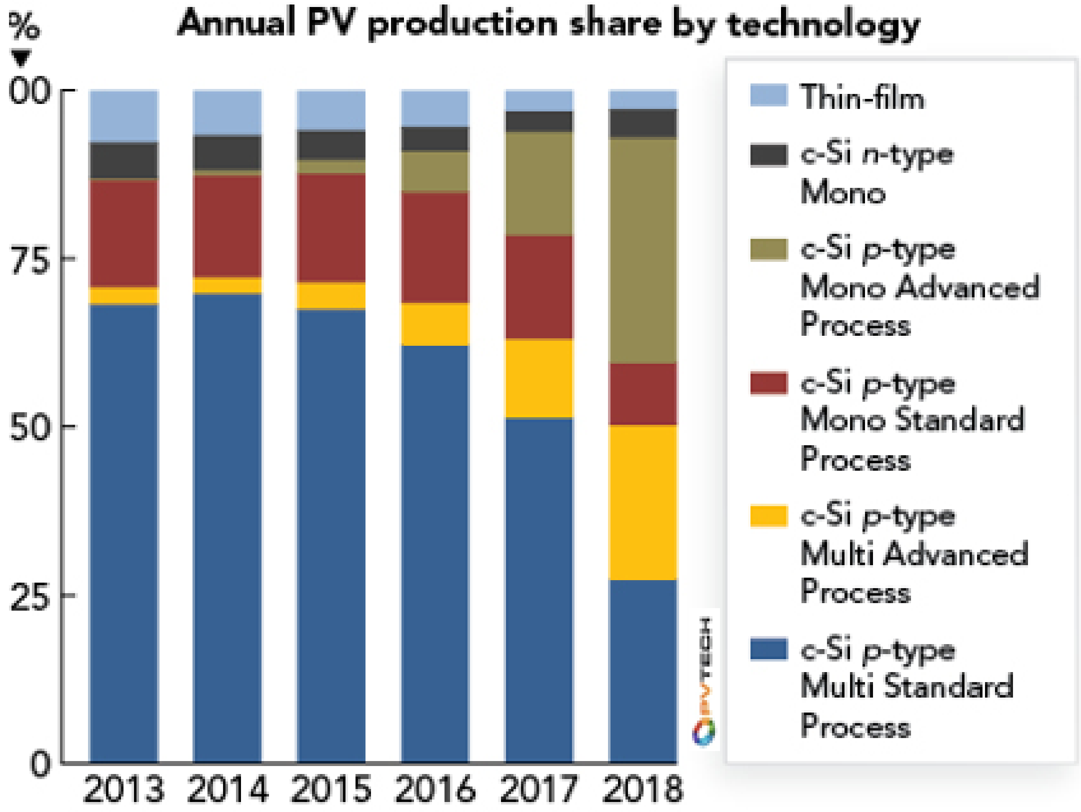
Source: DNVGL

The reality, always overpasses the projections

Comparison of Earlier Forecast with Actual Global Demand by Research Institute



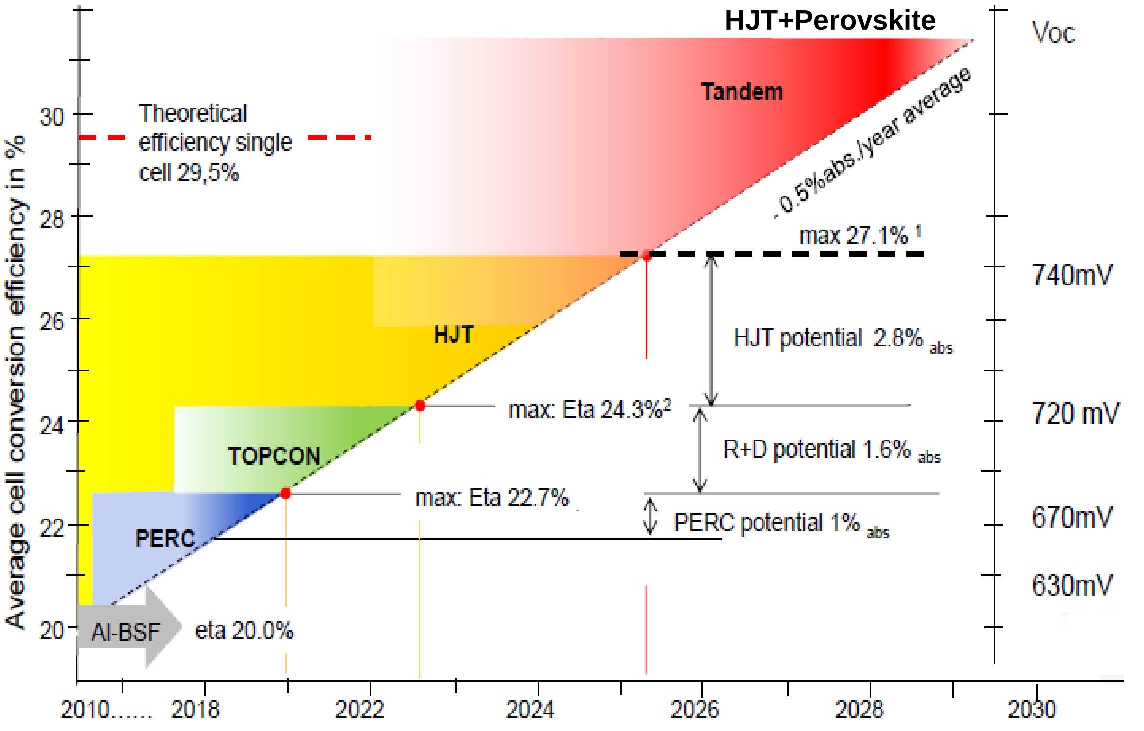
The rise and dominance of c-Si photovoltaics



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.

Cell Efficiency Trend in Mass Production, current and roadmap

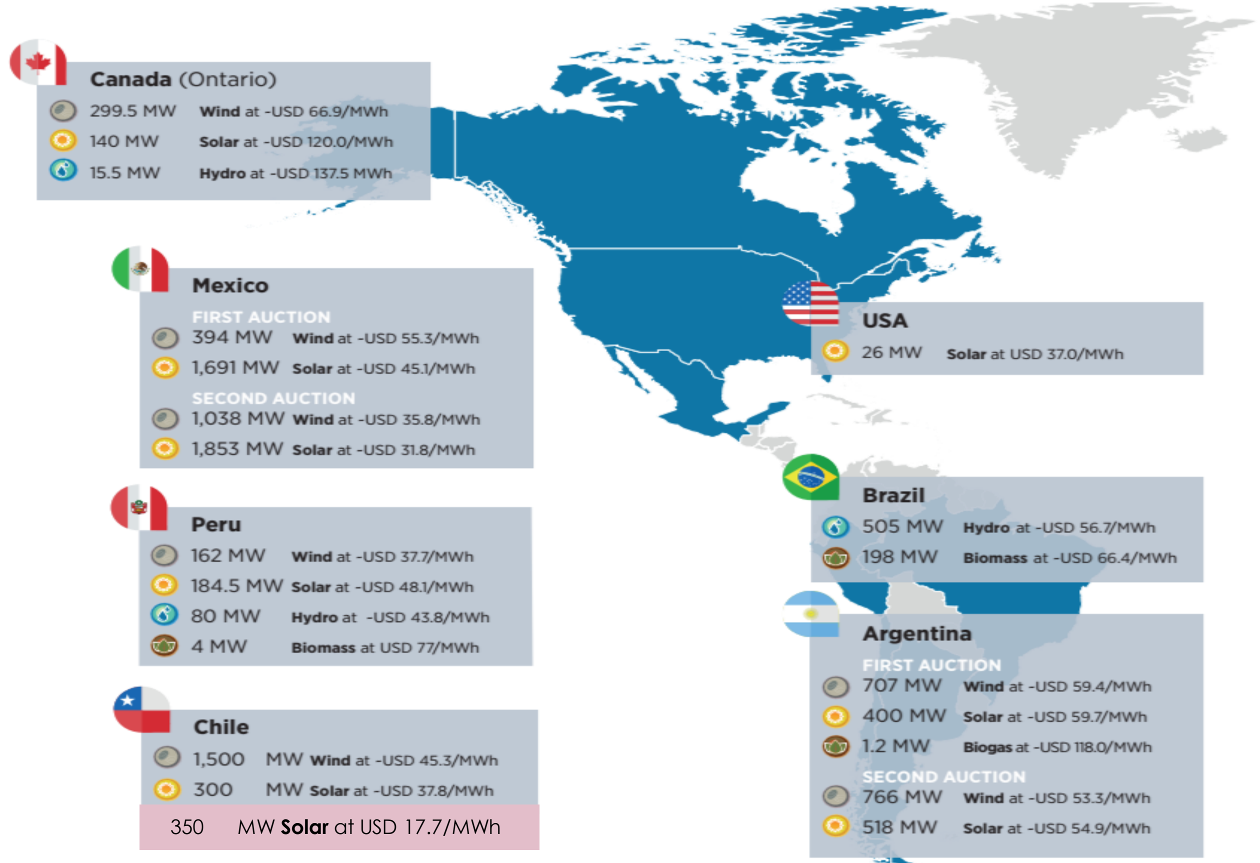
- Al-BSF being phased out
- p-PERC is mainstream and « Work horse »
- 22.5% CE likely to be the limit for mass production
- n-type technology industrially ready
- n-PERT unlikely to break through because of complex process sequence and limitations of surface passivation
- N-TOPCon/monoPoly likely to 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

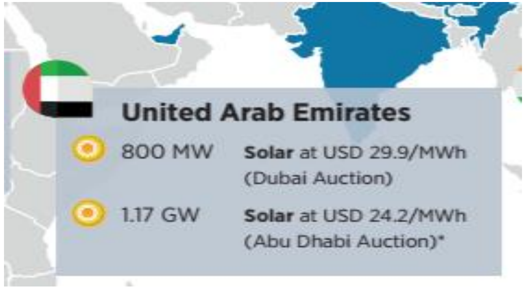


Meyer Burger Technology Ltd, 14th China SoG Silicon and PV Power Conference, Nov 8, 2018

Continuous record solar PV prices

Besides of the governments ambitions implementing renewables in their energy mix. The development of RE sector remain mainly driven by the LCOE reduction





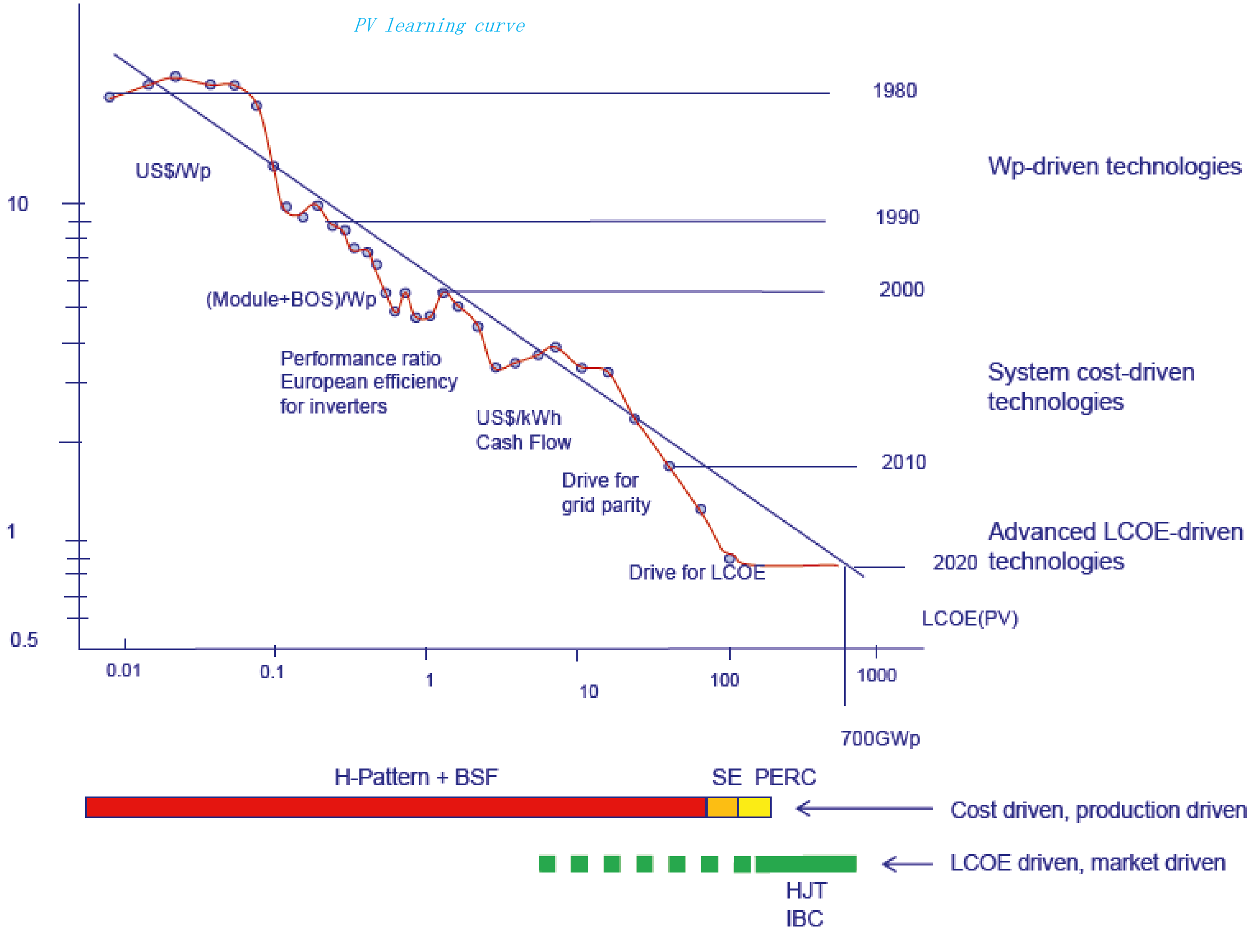
Saudi Arabia
300 MW **Solar** at USD 23.4/MWh

What would be the limit for a profitable and suistanable industry

…. USD 10/MWh ?

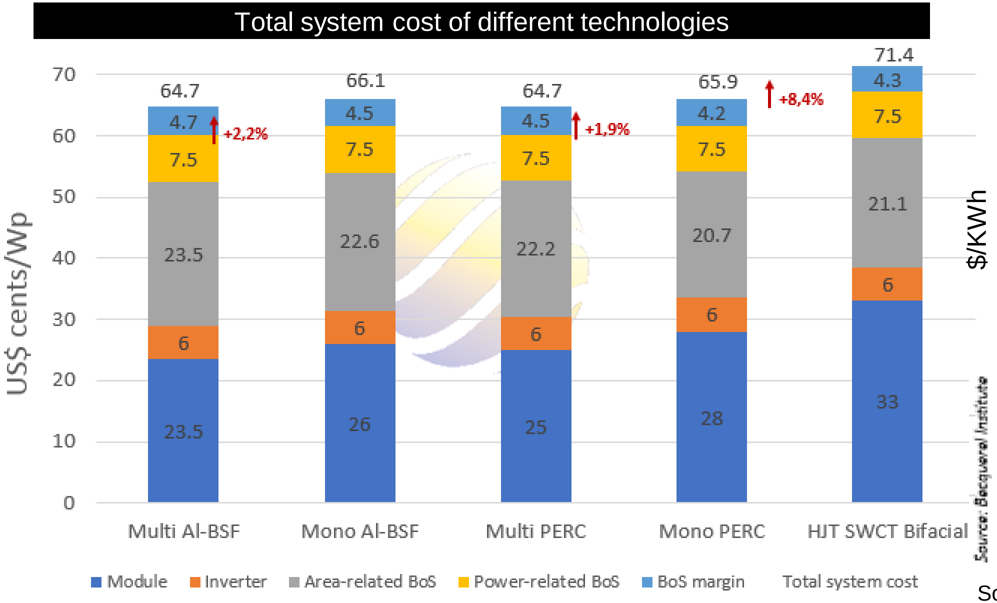
Source: IRENA (2017) Renewable Energy Auctions: Analyzing 2016

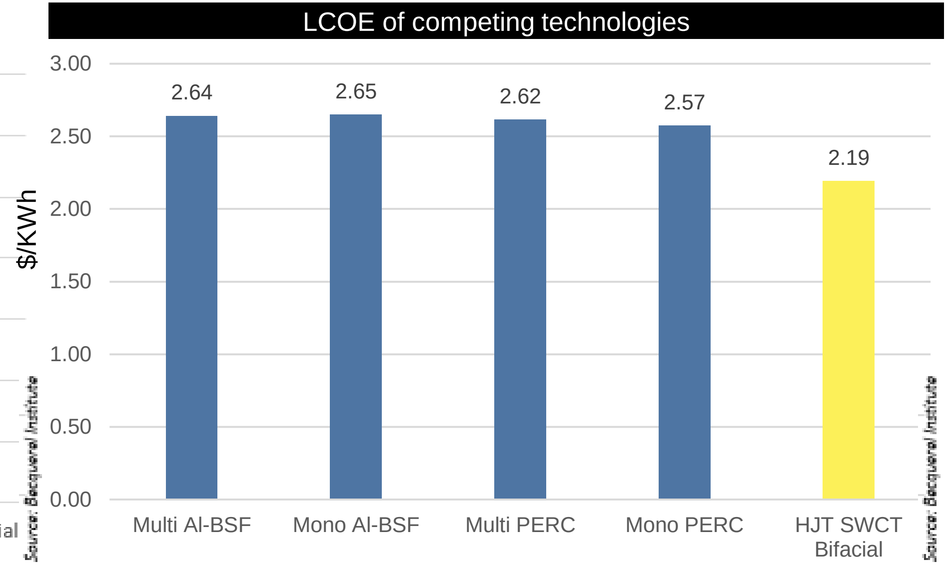
What the learning curve says about the future technology



System cost Vs. LCOE

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





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.

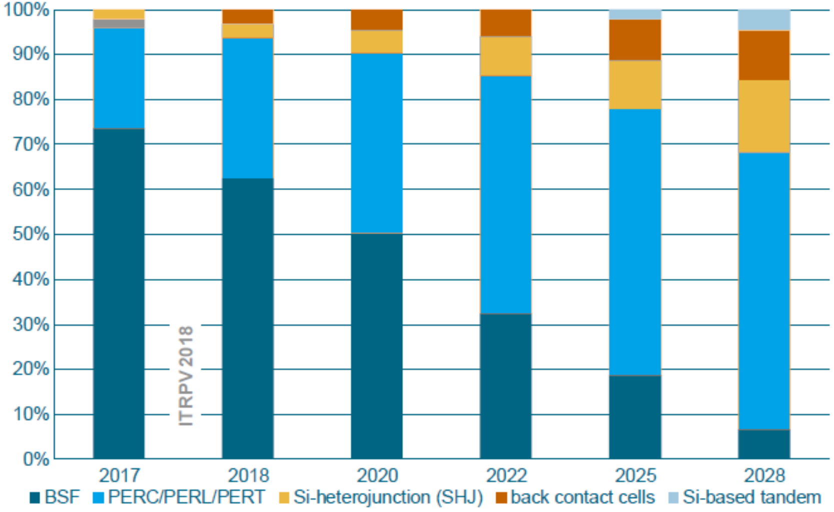
LCOE is the lowest compared to the competing technologies

Expected technologies market trends

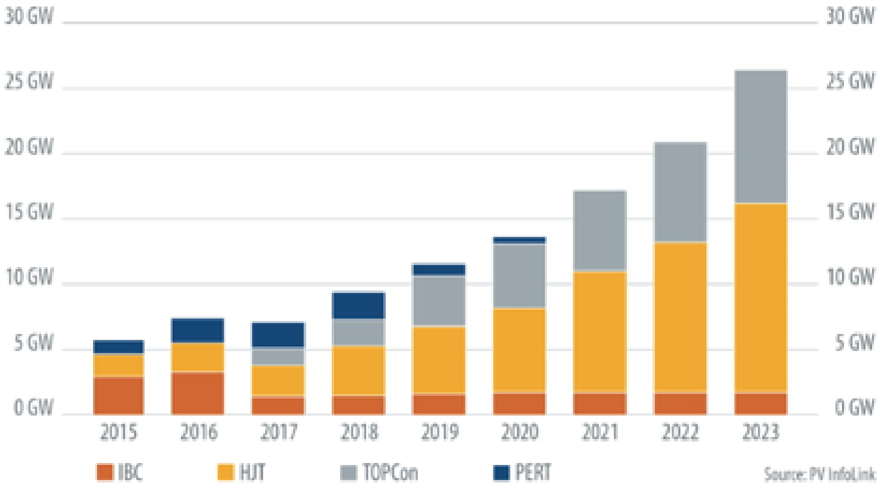
In order to keep the race for efficiency improvement, the existing back Surface Field (BSF) technology manufacturers started since 2015 upgrading their existing lines to PERC by adding two new equipment parts in the process (cheap solution). PERC structure is a natural progression from the standard BSF 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

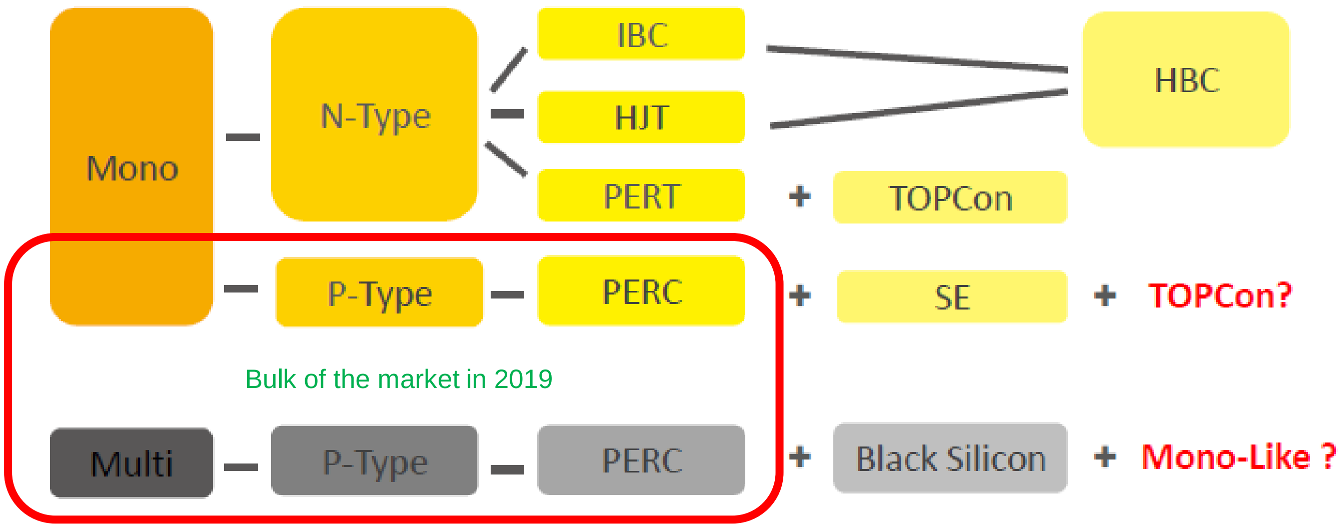


High-efficiency battlefield with efficiencies more than 22%

The mainstream efficiency has increased to 21.5 - 22% for mono-Si PERC and 19.5-20% for multi-Si PERC in late-2018. After implementing Selective Emitter on the production lines next year, the technology and efficiency improvement will be limited for p-type mono-Si cells. Top-tier manufacturers and new capacities will have to evaluate the development of next-generation n-type technology.

Although P-type mono-Si PERC efficiency can no longer increase after reaching 22%, cost effectiveness is t the key factor of the PV market. Consequently, PERC is expecting to be the mainstream product in the next two years, the market share of n-type products will be difficult to increase before 2020.

Due to the high technology difficulties and costs of IBC, the market will firstly focus on n-PERT, TOPCon, and HJT.



Cells technologies production benchmarking

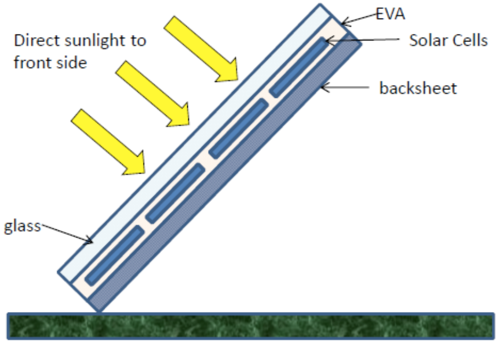
As the efficiency represents a large contributor for cost reduction, more and more manufacturers have started mass production mono PERC, forcing n-PERT with much higher cost to begin upgrade.

		P-Mono PERC	N-PERT	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 Dificulty	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

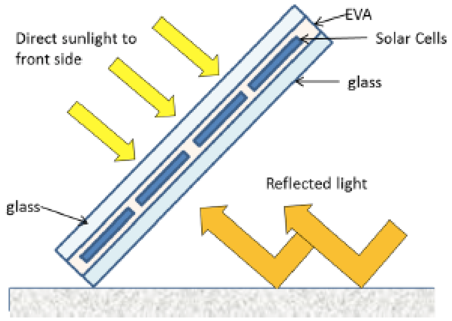
PV InfoLink

Cell technologies: Bifacial cells

Standard module

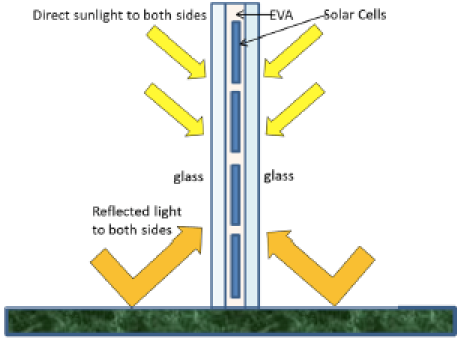


Bifacial module



Installation with high reflection:

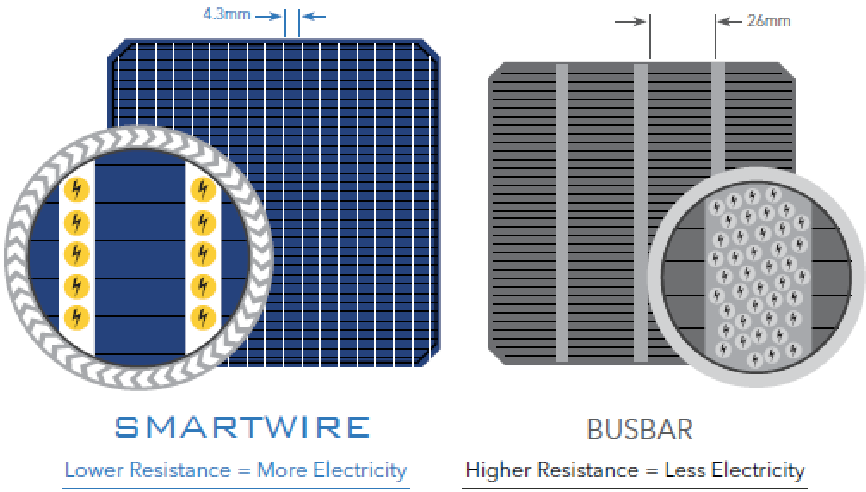
- More albedo → higher yield
- +10…... + >30% [kWh/kWp]
- Solar farms, white rooftop, …



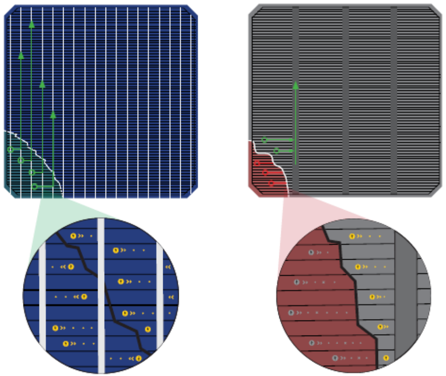
Vertical installation:

- ~100% yield compared to south-facing
- Noon peak shaving
- "rectangle" solar power generation
- Noise barriers, fences, ….

Multi Busbar evolutions:



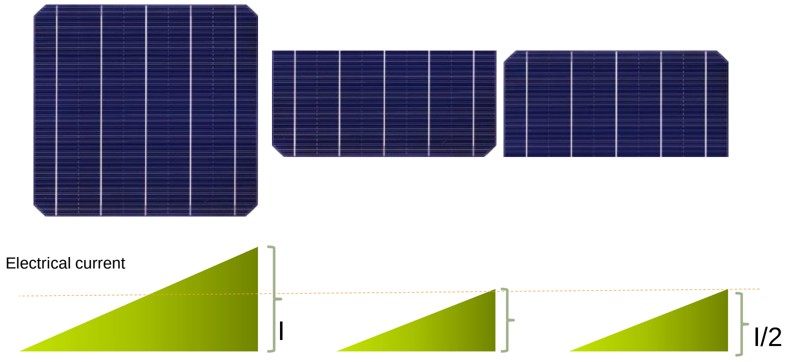
Micro-cracks have a minimum effect on modules with Smart Wire since the Foil Wire Assembly acts as a protective layer for the solar cell with the dense grid of up to 2,660 contact points.



The round shape of the micro-wire introduces a light trapping effect which reduces the shading by 25% compared to busbar technology.

Modules technologies: Half Cell

$$P_{loss} = I^2 * R_s$$



Electrical current I flowing on busbar is halved

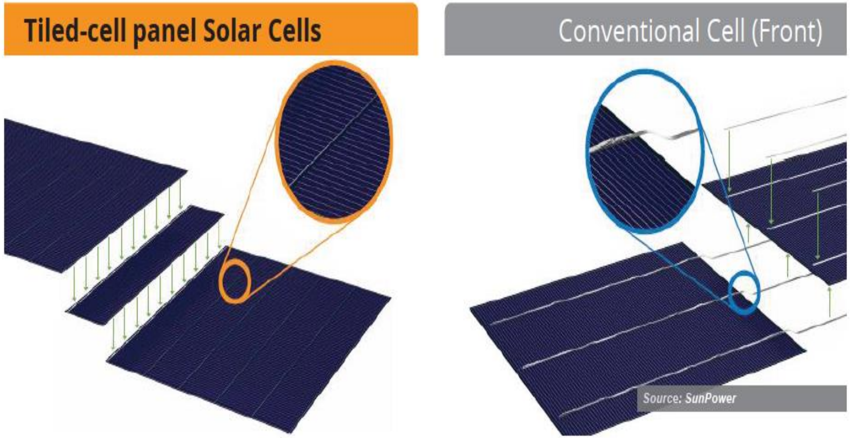
Resistive losses in a HC module is ¼ of a full-sized cell

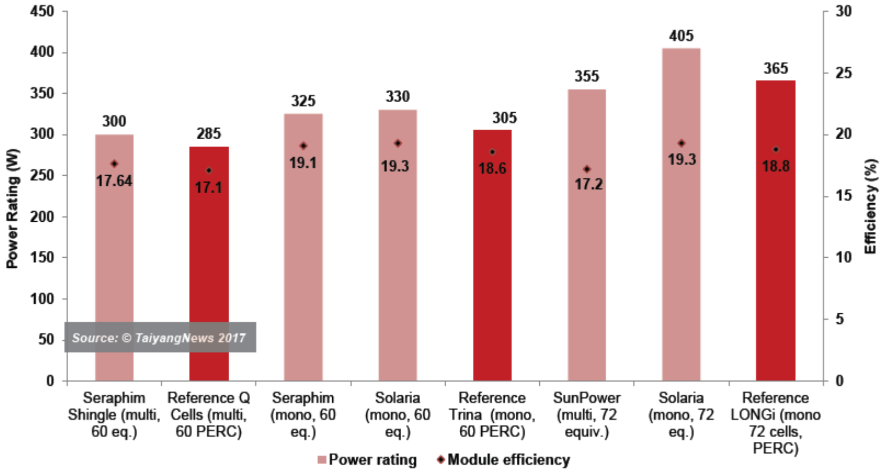
- Lower losses → *higher power*
- Lower operating temperature → *higher yield*
- Lower hot-spot temperature → *more reliable in operation*
- Symmetrical module design → *better shadow management*

Modules technologies: Shingle Cells

New merging modules concept shingles or tiles based interconnection maximizing direct sunlight exposure and raising the module efficiency up to 15%.

Shingling, though a bit more complicated in production than standard panels, results in very high module output power.



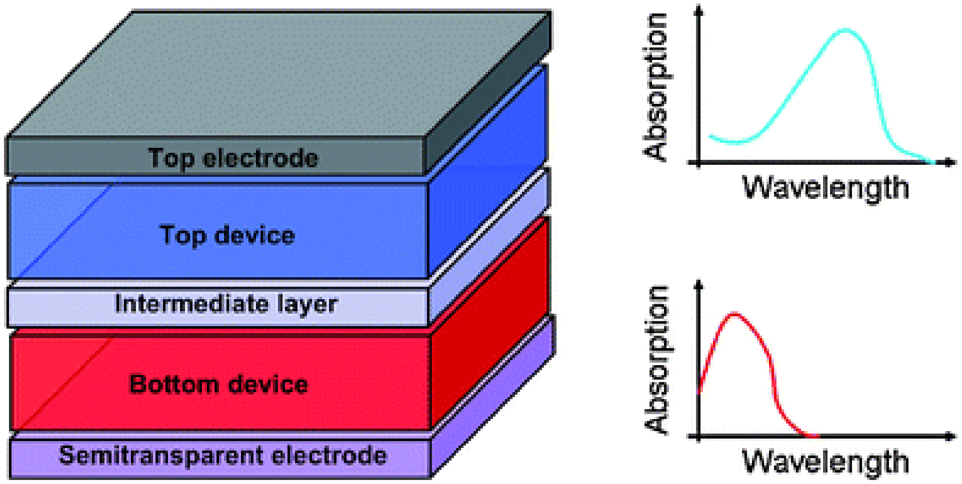


Emerging technologies and novel concepts

Tandem solar cells, a new design for high efficiency

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.

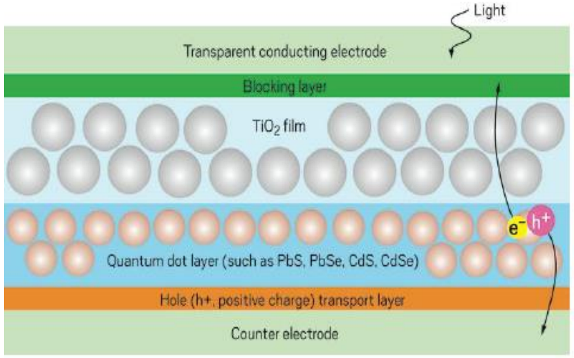
This tandem cell approach has been used to fabricate the world's most efficient solar cells that are capable of converting 46% of sunlight into electricity. Unfortunately, these devices use very expensive materials and fabrication processes, and so are priced out the market.



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

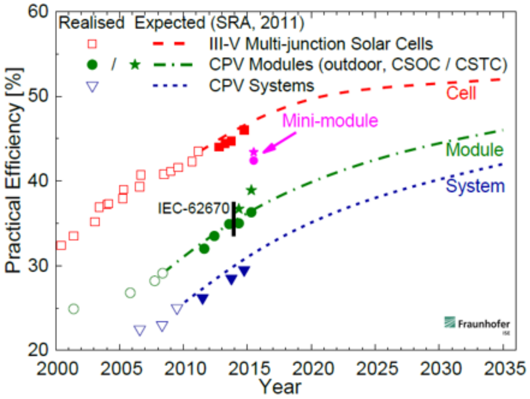
Emerging technologies and novel concepts

Quantum Dot Solar Cell



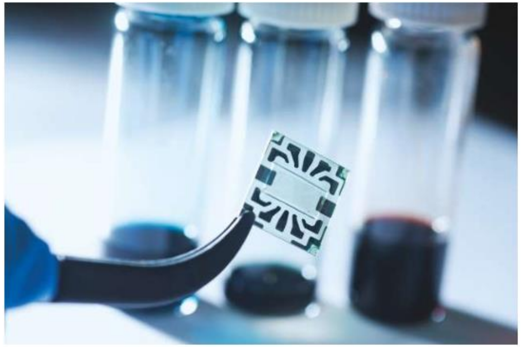
Quantum-dot cells have what is called a "tunable bandgap". In lay terms, by varying the size of the quantum dots used, the type of solar energy that can be absorbed can be altered or "tuned". The maximum certified efficiency 13%

Concentrator solar photovoltaic technologies (CPV)



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.

Graphene as a Material for Solar Cells Applications

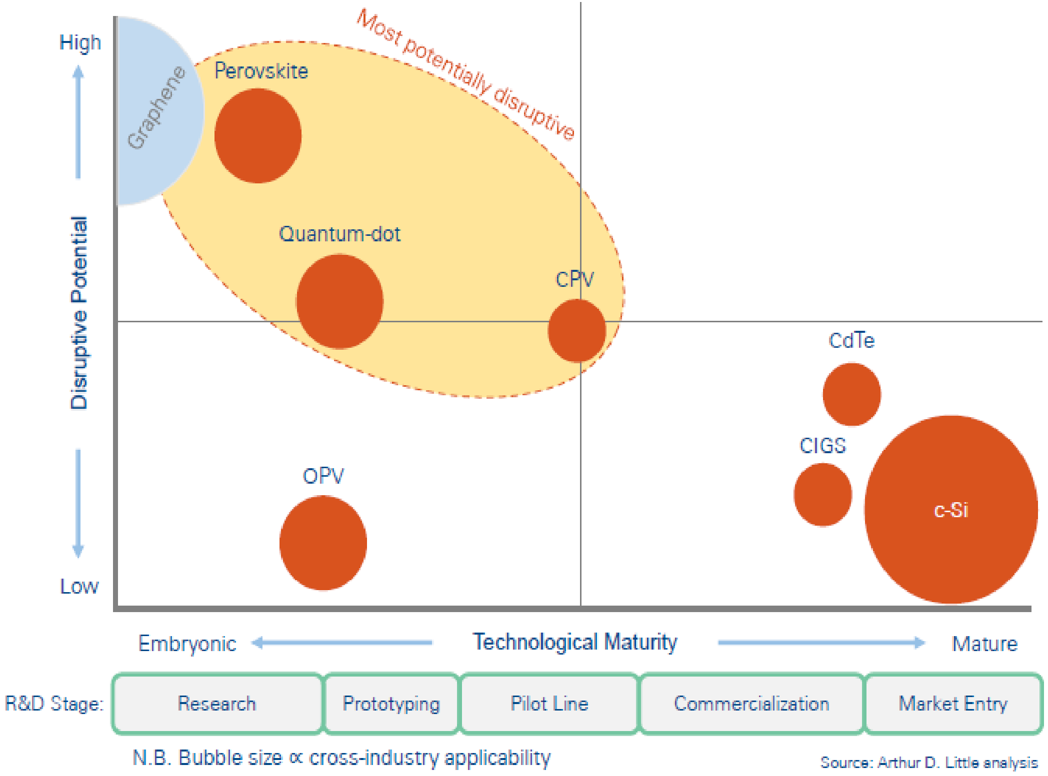


A new flexible graphene solar cell developed at MIT is seen in the transparent...

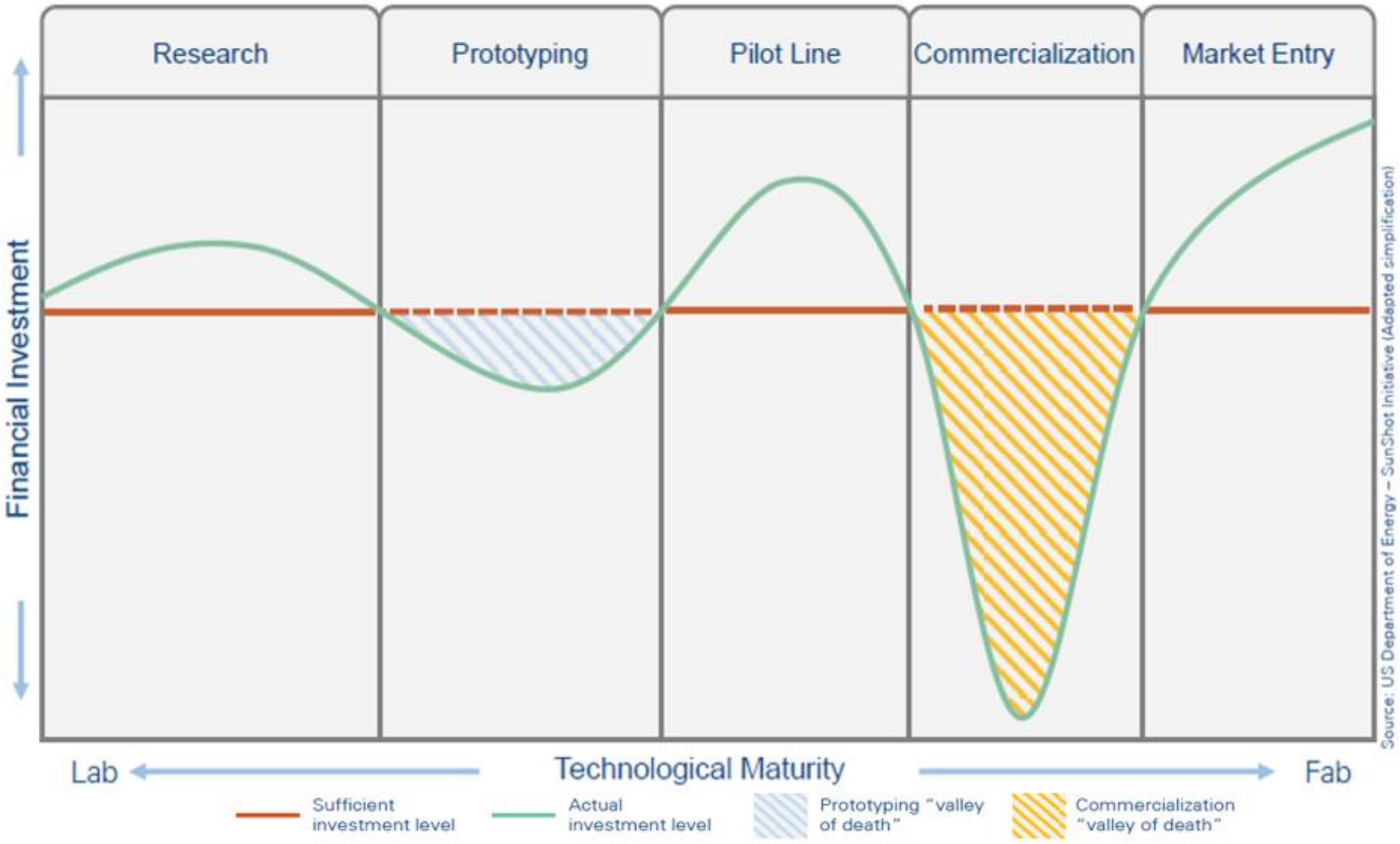
Studies have shown that doped graphene can change one absorbed photon of a few electrons, which in practice means an increase in efficiency of solar panels. In addition, graphene has a low coefficient of light absorption 2.3% which indicates that is an almost completely transparent material-

Disruptive potential vs. technological maturity of candidate disruptors

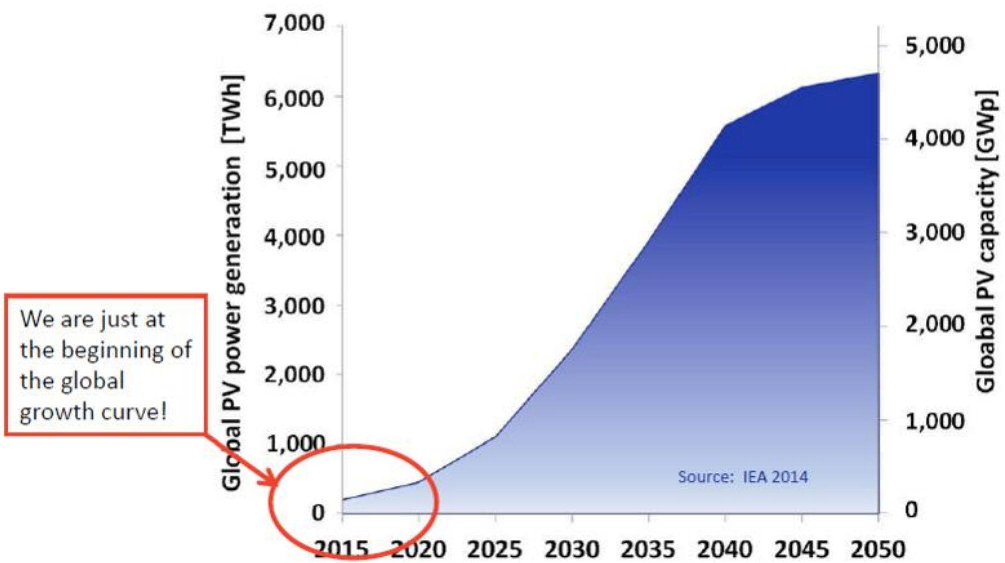
Based on their ability to Compete with c-Si within PV applications ; Venture successfully into new applications outside of the reach of c-Si. The perovskite, the quantum dot photovoltaics and concentrated photovoltaics are the most potentially disruptive PV technologies in the coming 10–15 years. This 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.

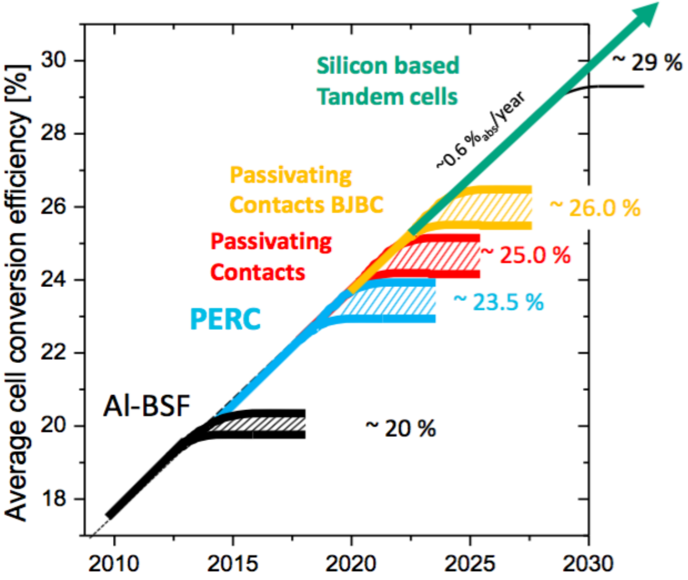


From the Lab to the Fab, it’s never smooth path way



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 cant 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.