Competing PV cell technologies set to co-exist out to 2020

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ABSTRACT
The solar industry is going through the final stages of correcting its supply–demand imbalance, with the decision-making on technology choice for the next generation of GW-scale factory expansions becoming a key strategic issue for leading manufacturers. In contrast to previous capacity expansion phases – where new entrants largely copied known process flows and technology types – the next round of technology additions is seeing a broader range of influences, indicative of a new type of technology roadmap unfolding for the industry as a whole.

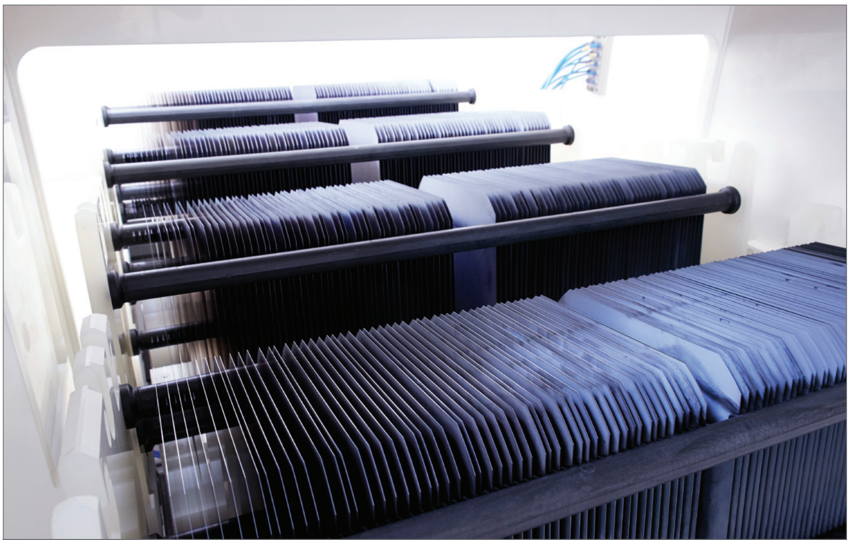
Introduction

This paper provides a detailed overview of current crystalline silicon (c-Si) cell solar photovoltaic (PV) manufacturing technologies, and the factors that are influencing decision-making for new capital expenditure (capex) and capacity expansions.

A discussion is provided first that will help in understanding the current segmentation of c-Si cell technologies, across n-type and p-type substrates, and their different processing methods. Reference is also made here to the legacy solar PV cell roadmaps that have been promoted heavily by academic research institutes in the last five to ten years.

The results of new market research undertaken by PV-Tech are then presented, including conclusions from interviews undertaken with leading cell manufacturers and materials and equipment suppliers, backed up by data from a detailed analysis of the forecast top-20 cell producers by MW-volume in 2015.

The conclusions highlight a more complex blend of factors that are creating a broader mix of options for c-Si cell manufacturing going forward, and suggest that the industry's previous desire to choose a winning technology type (n-type or p-type, mono or multi, standard or advanced process flows) may be somewhat misleading, and that different technology options are likely to continue to co-exist in the short to mid term (three- to five-year time frame).



Credit: MegaCell

Figure 1. BiSon solar cell production: low-cost manufacture of high-efficiency n-type bifacial monocrystalline silicon solar cells.

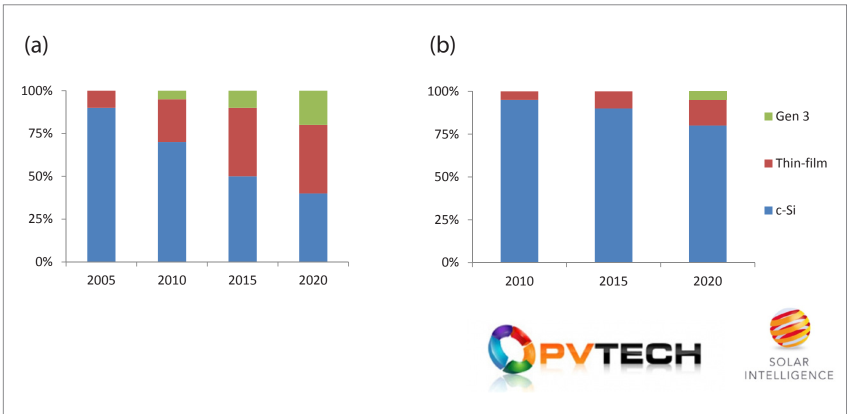


Figure 2. Early versions of PV technology roadmaps: (a) circa 2005; (b) circa 2010.

Understanding legacy PV cell technology roadmaps

During the early growth phase of the solar industry (from annual end-market demand levels of around 10GW to the 30–50GW level of 2012–2014), the industry went through two stages of technology roadmap consensus. The first, illustrated in Fig. 2(a), was based on an assumption that thin-film technologies (covering each of a-Si, CIGS and CdTe) would see gradual market-share gains, with many of the roadmaps projecting that thin-film modules would be the dominant technology type by 2020. In fact, most of these roadmaps also factored in the adoption of so-called generation 3 (Gen 3) cell technologies based on dye-sensitized and organic-based technologies.

The failure of a-Si technologies to move beyond 10% efficiency levels – coupled with the challenges in transferring large-area deposition equipment originally conceived for flat-panel displays to solar PV – effectively eliminated a-Si from any credible technology roadmap from 2011 onwards.

> "Solar technology roadmaps by 2010 sought to focus more on c-Si."

Fast forward to 2015, and thin-film activity in the solar industry is all but confined to the strategies, and technology excellence, of two companies: First Solar for CdTe, and Solar Frontier for CIGS. Consequently, solar technology roadmaps by 2010 (see

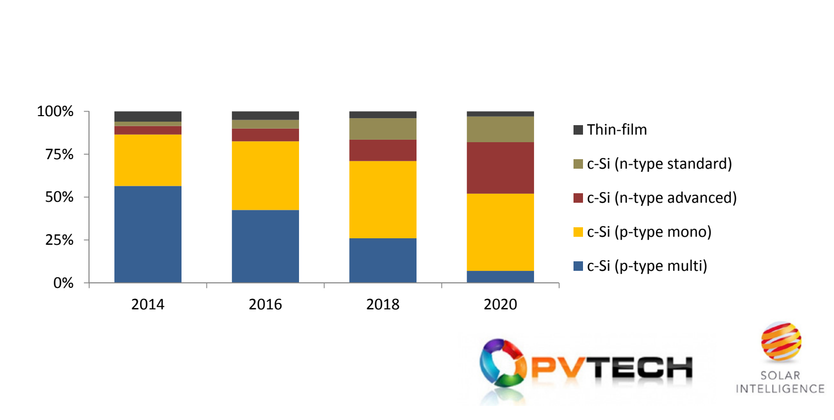


Figure 3. PV technology roadmap circa 2014, which neglects to factor in the advances made by leading p-type multi c-Si manufacturers.

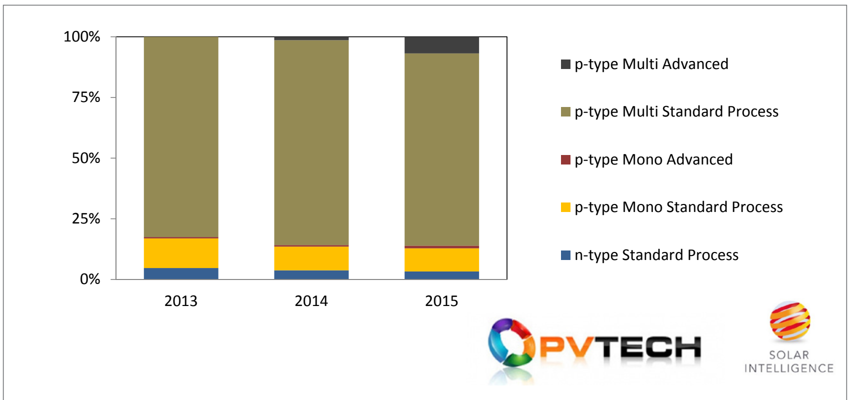


Figure 4. Cell capacity preferences of the big-six c-Si module suppliers in 2015, indicating a strong bias towards p-type multi technology, in contrast to many of the industry roadmaps in the past.

Fig. 2(b)) sought to focus more on c-Si, largely confining thin-film market shares to the production capacity and shipments driven by the two above-mentioned thin-film specialists, and assigning new entrants, such as Hanergy, to the thin-film sector. Gen 3 activity was by this time getting squeezed into a smaller wildcard contribution by 2020.

The c-Si roadmap consensus at the start of 2015

Concentrating on c-Si cell manufacturing as the leading indicator for module shipment trends, PV roadmaps from 2012 became heavily influenced by dedicated research laboratories again, and not directly by the leading c-Si cell producers, many of whom by then had accumulated manufacturing capacities at the GW level.

The fundamental assumption for most of these roadmaps was that p-type substrates, and corresponding cell processing using this wafer type, would ultimately be superseded by the higher efficiencies that were inherent in using better-quality n-type silicon material. Furthermore, p-type multi c-Si manufacturing was largely regarded as something of a passing phase in the industry, and in use across much of Asia simply because of its lower barriers-to-entry for manufacturing.

As a result, c-Si roadmaps until recently were strongly biased towards market-share gains for p-type mono over p-type multi, and ultimately moving to an industry using n-type cells that would largely comprise thin silicon wafers and either back-junction or heterojunction cell types (see Fig. 3). Intrinsic to these assumptions was a perceived limit to p-type multi c-Si efficiency pegged below the 20% level.

While forecasting efficiency and cost at the multi-GW level over a three- to five-year period is fraught with challenges and always difficult, a major drawback of these roadmaps was the assumption that technologies had to compete directly with one another, ultimately leading to a single technology type (or small subset) that would reign supreme in the solar industry.

The reality of c-Si cell manufacturing going into the 60GW-plus end-market landscape of 2016 indicates that this concept of head-to-head competition is largely misplaced, as will be explained in more detail in the next section.

Technology production reality in 2015

Putting aside previous forecasts and legacy roadmaps for the solar industry, the starting point for technology over the next three to five years should be what is actually happening in manufacturing today. While there is no immediate need to over-complicate the rationale for the breakdown of n-type and p-type, and mono and multi, a quick overview now will help to set the stage for the later discussion on roadmaps.

During 2015 it is likely that approximately 60GW of solar cells will be manufactured (note that here, for accurate methodology, thin-film manufacturing is classed as both cell and module production). This 60GW will probably end up including about 5% from thin-film manufacturing (dominated by CdTe from First Solar) and about 5% from n-type c-Si variants; therefore 90% is most likely to come from p-type solar cell production, of which about 80% comes from p-type multi. The final split could then end up being approximately 70% p-type multi, 20% p-type mono, 5% thin-film and 5% n-type. This is similar to the split seen during 2014, but with p-type multi seeing increased use at the expense of p-type mono.

At this point, it is useful to look at the cell manufacturing capacities of the leading c-Si module suppliers of 2015: this group includes Canadian Solar, Hanwha Q CELLS, JA Solar, JinkoSolar, Trina Solar and Yingli Green. Collectively, these six leading module suppliers – grouped by PV-Tech under the banner of Silicon Module Super League – are expected to ship approximately 24GW of modules during 2015, or about 40% of the entire industry requirements for 2015.

> "The strong preference for p-type multi is at the heart of why the industry urgently needs a rethink on technology forecasts going into 2016."

Fig. 4 shows the cell capacity breakdown for the Silicon Module Super League between 2013 and 2015; this helps to explain the differences between the legacy PV technology roadmaps and what is happening in the industry at the end of 2015. The strong preference of this leading module-supplier grouping for p-type multi is clear to see, and is at the heart of why the industry urgently needs a rethink on technology forecasts going into 2016.

Within the p-type options, the main difference in the past 12 months has been the increase in the use of passivated layers on the rear surfaces, with a move away from the industry-standard full aluminium back-surface field (Al-BSF) architectures employed in the past. More commonly referred to by the acronym PERC (passivated emitter and rear contact cell), coined by the University of New South

Wales, the technology has seen upgraded line activity for both p-type mono- and multi-based production.

The default way of forecasting the market-share trends of the different cell technologies (p-type, n-type, mono, multi) is simply to estimate which will win market share against the others, and to continue to do a side-by-side comparison. This also leads to conclusions about technologies 'winning' against the others, and as a consequence, it is all too easy to piece this together and call it the roadmap of the industry.

This somewhat naïve process has not, however, worked in the past, and there is also no evidence at all that it will work – or indeed provide any great help to manufacturers – going forward. Instead, we are now seeing that a different type of research methodology is needed, which will next be explained in more detail.

Shifting from technology competition to co-existing competitive alternatives

As background research undertaken by PV-Tech ahead of its inaugural solar cell manufacturing conference in Malaysia in March 2016 (PV CellTech [1]), an exhaustive series of interviews has just been completed with the leading cell manufacturers, as well as with the main materials and equipment suppliers to the industry. The study was initially geared towards scoping out the optimum session topics and issues for presentation and discussion at the conference; the findings, however, uncovered more than was originally targeted, in particular key inputs relating to the solar cell roadmap of 2016 and beyond.

At the p-type and n-type levels, there was broad consensus not to pitch these as competitive cell manufacturing approaches, but to separate out n-type activity more as an overall business approach by the companies with know-how and intellectual property regarding manufacturing.

In fact, despite many leading p-type manufacturers having had n-type on corporate technology roadmaps on show to the outside world, there now appears to be a more pragmatic assessment of in-house skill sets. Basically, most p-type producers – even those at the multi-GW level – seem to be coming to the conclusion that the transition from p-type to n-type is not only an extremely difficult proposition, but also not necessary in order to have a market-competitive offering as a business. While to many this may seem rather obvious, plenty of cell manufacturers had got bought into the assumption that p-type was just a passing phase and that within five years, n-type would be essential; therefore, for the outside world, they were almost forced to include this in technology roadmaps when talking about in-house R&D activities.

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Looking at n-type against p-type is not entirely dissimilar to comparing c-Si and thin-film technologies. Thin-film works for the two leading manufacturers because they have manufacturing excellence coupled with a downstream business model that is adaptive and works, and each company has the ability to supply a quality brand offering, either in-house or via third parties.

Furthermore, even when purely p-type was looked at in isolation, there were similar conclusions emerging from just comparing p-type mono and multi options. While flipping cell and module lines between mono and multi is an easy transition, the strategies of p-type cell makers still seem to be firmly dedicated to one of the two substrate types on offer; there are actually very few cell makers with balanced mono and multi cell production levels today. If any member of the Silicon Module Super League needs to increase short-term mono module supply, the easiest route is to simply increase the mono portion of outsourced cells.

With this in mind, some of the key c-Si manufacturers at the start of 2016 will be looked at in the next section, which will be a useful way of illustrating the concept of co-existence over competition for cell manufacturing going forward three to five years.

Grouping the leading players by strategy

To provide some colour to the above summary, the top-20 (approximately) cell producers in the industry will be examined, along with some of the new

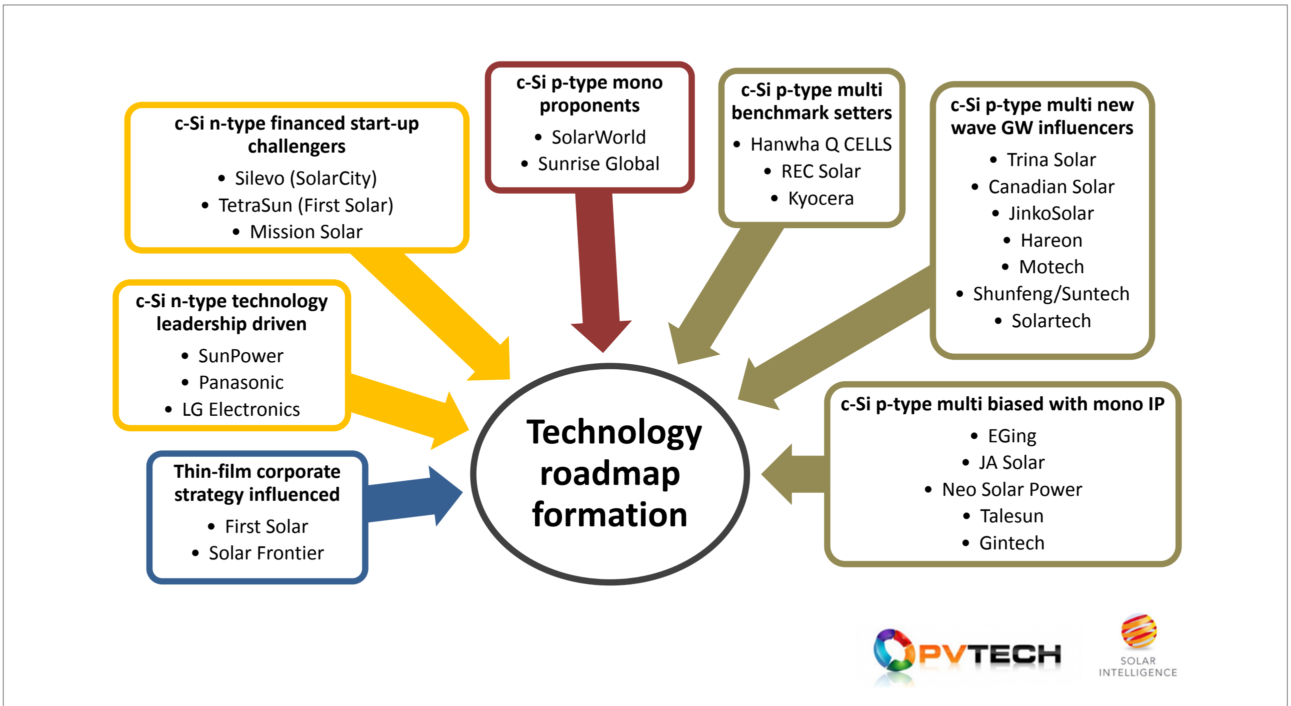

Figure 5. Co-existing cell technology groupings for 2016–2020. It is likely that each of the seven different categories will shape the overall make-up of PV cell production in the short term.

start-ups looking to disrupt the current technology mix. Ultimately, the top-20 cell producers shape the current segmentation of solar cell manufacturing; they do not follow a predestined path set out by any external think-tank seeking to offer guidance on how they should change their technologies to remain competitive.

Additionally, the disruptive approaches (most notably being championed by SolarCity through its Silevo operations, and First Solar with TetraSun) are not seeking to gain market share against p-type suppliers per se, but instead to open up new opportunities as part of company-specific downstream deployment growth. In this context, it has to be remembered that strong year-on-year growth of the solar industry is forecast to continue in the next three to five years, effectively creating the space for various technologies to expand and co-exist, rather than competing within a finite and static end-market space.

First, the thin-film activities are filtered out, leaving only c-Si technologies. Direct competition between First Solar or Solar Frontier and mainstream p-type c-Si producers is becoming less of an issue within the industry today, with the business deals being won and lost on the project side, within which the blend of module price, efficiency and levelized cost of energy (LCOE) is just one of a complex set of variables dictating the final choice.

Similarly, n-type activity can be largely segmented, especially in the case of SunPower. The other leading n-type producers (Panasonic and LG Electronics) are less influential in the downstream channels but still have a very different company approach to solar panel distribution when compared with today's mainstream p-type solar cell suppliers. It is entirely reasonable, therefore, to pull out SunPower and Panasonic as having a dedicated n-type strategy that operates largely decoupled from the issues affecting GW-scale p-type cell producers. Although LG Electronics are not yet fully aligned to an n-type strategy, it was decided to group the company within this category too, assuming that LG's solar business is based on differentiation from Chinese and Taiwanese manufacturing, and heavily driven by long-term R&D and technology development investments.

Sitting on the periphery of this n-type grouping are Silevo and TetraSun. While each has its own set of risks and challenges ahead before any volume production can be shown, it could be argued that if these two companies were running at the GW level today, the overall technology/end-market penetration strategy would look not entirely dissimilar to that of SunPower today.

The more interesting outcome of PV-Tech's new research relates to p-type mono and multi approaches, and the clear preference from one company to another, each with an internal roadmap that has been carefully and strategically selected.

Given these findings, it could be strongly argued that the current dominance and share gains for p-type multi are largely coming from the sheer volume of capacity and number of companies in China that made technology decisions based on having the easiest market-entry route some years ago, coupled with the very tangible impact that GCL Poly has had on the solar industry through its polysilicon/wafer capacity and supply. Further impacting this equation is the fact that many of the Chinese p-type multi c-Si cell makers have been somewhat gifted a captive domestic end-market that has one of the lowest global price points and is easily receptive of p-type multi modules for ground-mount installations.

When the remaining (p-type) subset of cell makers that comprise the top-20 (approximately) producers this year is inspected, a clear divide can be seen between those shifting to mono-based approaches (SolarWorld, Sunrise Global), those historically attached to p-type multi (REC Solar, Hanwha Q CELLS), and those that entered the industry post-European manufacturing and are now dominated by p-type multi (Trina Solar, Canadian Solar, JinkoSolar, Yingli Green, Hareon, Motech, Shunfeng/Suntech and Solartech).

Currently sitting somewhat on its own is Kyocera, a company that has its own lineage, comparable to SunPower, Panasonic, REC Solar and Q CELLS, but is now the only Japanese c-Si cell maker of note with domestic production capacity, and is best grouped together with REC Solar and Hanwha Q CELLS.

Completing the technology categorization is a group of cell makers that are historically p-type multi producers but have significant mono activities (Gintech, JA Solar, Neo Solar Power, Talesun). Also included in this category is EGing, but coming from the opposite starting point (mono dominant to multi dominant). The overall grouping is shown in Fig. 5.

In terms of forecasting solar cell technology into 2016, it is useful to look at these groups and how their efforts to improve efficiency and yield, and reduce manufacturing costs, will unfold. In many cases, the approaches to maintaining competitive cell production will probably include a unique subset of variables, from wafer supply to processing tools and material supply. However, for most there is an overlap of issues (wafer quality, handling, PERC, inspection, metallization) that will ultimately help to drive the entire segment forward, and for most of the equipment and materials suppliers, these are potentially the most important issues to understand.

Setting the scene for 2016

Perhaps the main takeaway from the analysis outlined above is that it is simply not possible to decouple the upstream and downstream parts of the solar industry, which precludes any head-to-head comparison between chosen production approaches.

> "It is simply not possible to decouple the upstream and downstream parts of the solar industry."

Of course, each of the categories shown in Fig. 5 has to be market competitive in terms of cost and efficiency, but the boundaries here are certainly blurred and are clearly different for a downstream-focused, domestically entrenched, vertically integrated, US-centric thin-film producer and a China-based, state-favoured c-Si cell/module maker targeting domestic EPCs as part of its own government-driven end-market installation targets.

When the mix of technologies and approaches co-existing in the PV industry is examined, another conclusion is that all manufacturers have been forced to move efficiencies higher and costs lower, simply to justify sustaining a manufacturing presence. And in this respect, one is left to contemplate what could really be achieved by the solar industry if a common approach to implementing technology and reducing cost was followed, notwithstanding making the best use of locations that would ultimately favour the lowest-cost labour market at the time.

Reference

[1] PV CellTech Conference, 16–17 March 2016, Kuala Lumpur, Malaysia [http://celltech.solarenergyevents.com/]

About the Author

Finlay Colville joined Solar Media as head of the new Solar Intelligence activities in June 2015, before which he was vice president and head of solar at NPD Solarbuzz until October 2014. Widely recognized as a leading authority on the solar PV industry, he has presented at almost every solar conference and event worldwide, and has authored hundreds of technical blogs and articles in the past few years. He holds a B.Sc. in physics and a Ph.D. in nonlinear photonics.

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