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Materials and advanced cell concepts under the microscope in latest PV roadmap

Ben Willis, Head of Content, *Photovoltaics International*

ABSTRACT
As the upstream PV industry enters a new phase of growth, manufacturers are seeking new strategies and technologies to enable them to continue to cut costs and remain competitive. The sixth edition of the annual International Technology Roadmap for Photovoltaic describes the key trends likely to shape the PV sector in the coming year. This paper analyses some of the most promising areas for development.

Introduction

After several difficult years for the upstream PV industry, recent months have seen positive momentum building as supply and demand have returned to some sort of equilibrium. ASPs have begun to stabilize, or at least have not declined as quickly as they had been doing, prompting market research firm IHS to predict four-year record high profits for the module manufacturers this year of US$5bn – double last year's total (see Table 1).

The extent to which manufacturers are now investing in new production capacity certainly bears this forecast out. It is equally clear, however, that not all parts of the supply chain are yet feeling the effects. The latest analysis by SEMI of PV equipment manufacturer performance, for example, shows a year-on-year decrease in both order bookings and billings, and the ratio between the two – the number of orders fulfilled – remaining below parity. This is an indicator that the headline figures do not tell the full story.

"Recent months have seen positive momentum building as supply and demand have returned to some sort of equilibrium."

That message – of a tentative upturn – is at the heart of the latest edition of the International Technology Roadmap for Photovoltaic (ITRPV) [1]. Launched at the SNEC expo in Shanghai at the end of April, the ITRPV, now in its sixth iteration, is published annually with the aim of informing the industry about anticipated technology trends in the field of crystalline silicon PV.

The roadmap acknowledges the industry's ongoing efforts to cut costs and remain competitive through ongoing innovation, highlighting the fact that in 2014 several manufacturers reported a return to profitability as a reward for their efforts.

As in previous editions, however, the roadmap is clear on the need for industry

Source: GT Advanced Technologies.

Figure 1. Polysilicon is one of the areas identified by the ITRPV as offering the most potential for further cost reductions in PV manufacturing.

to maintain its historical 'learning rate' – the rate at which ASPs decline relative to module shipments – of around 20% (Fig. 2). This will be achieved through the introduction of advanced cell concepts, improved module technologies and new production processes that significantly reduce manufacturing costs. Such ongoing innovation will be an intrinsic factor in PV's ongoing competitiveness and therefore sustainability.

Materials

Recent analysis of polysilicon prices on PV Tech, Photovoltaics International's sister website, has revealed the delicate nature of the interplay between polysilicon supply, PV module capacity expansions, and downstream demand in the coming year. The rebalancing of supply with growing demand for modules, and the consequential uptick in capacity expansions, would suggest a parallel growth demand for polysilicon. In early May, however, REC Silicon reported a sharp drop in sales as a number of factors, including weaker than expected demand from China, coincided.

This indication that business for polysilicon producers remains unpredictable is reflected in recent erratic polysilicon pricing. In 2014 a mid-year peak of US$23/kg was predicted, followed by a drop back in pricing to US$18–20/kg by the end of the year and possibly beyond. This seems borne out by the REC Silicon case, with the company revealing it had seen a 7.9% fall in prices in the first quarter of 2015.

With polysilicon remaining the most expensive individual material in a module, according to the roadmap, cutting costs in this part of the value chain would seem to be an ongoing necessity, regardless of the peaks and troughs in demand and pricing; the ITRPV acknowledges this fact, citing it as an area with significant potential for cost reductions.

With this in mind the roadmap says it expects fluidized-bed reactor (FBR) technology to increase its share in relation to silicon made using the Siemens process (Fig. 3). Other processes, such as upgraded metallurgical-grade silicon (umg-Si), are not expected to gain any significant market share at the expense of the other two processes, as they are unlikely to demonstrate any major cost advantages. Nevertheless, they will remain available on the market; for example, one US-based firm, Silicor Materials (formerly Calisolar) is pursuing plans to develop a umg-Si plant in Iceland, which it claims will offer significant cost advantages over conventionally produced polysilicon.

The roadmap cites the ongoing roll-out of diamond wire sawing in wafer production as a significant development, offering the potential to cut wafering process costs.

	PV modules 2014	2015	Y/Y change
Shipments	48GW	61GW	+27%
Revenues	$31bn	$38bn	+20%
Gross margins	7%	13%	+6%
Gross profit	$2.3bn	$5bn	+117%

Table 1. Estimate of module manufacturers' profits in 2015.

Source: IHS PV Market Integrated Tracker.

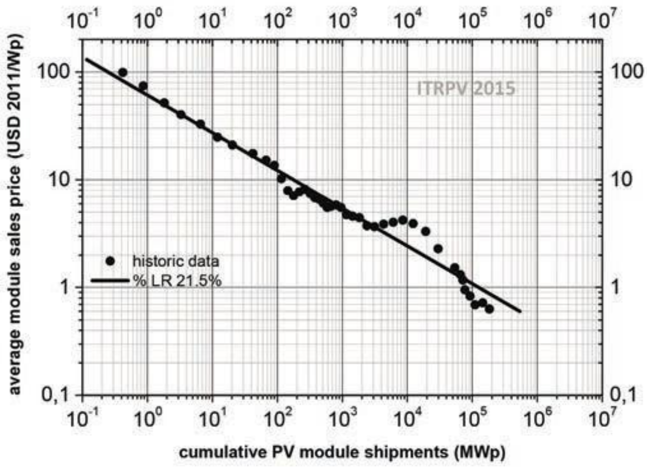


Figure 2. Learning curve for module price as a function of cumulative PV module shipments.

Source: ITRPV.

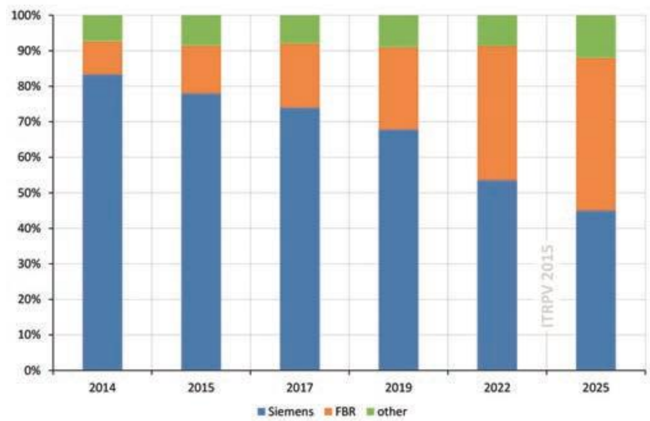


Figure 3. Expected change in the distribution of poly-Si production techniques.

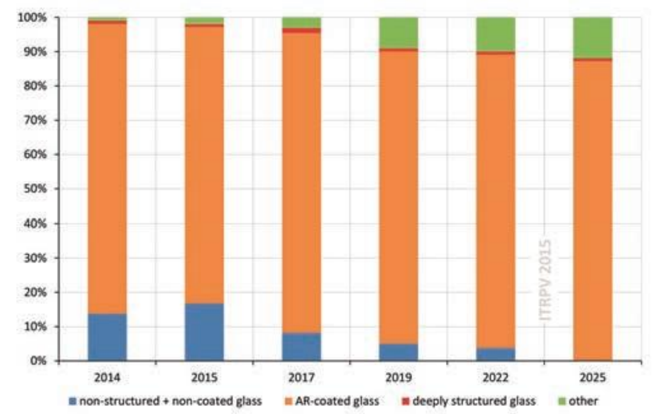
Source: ITRPV.

Slurry-based wafer sawing is currently the dominant technology, but diamond wire sawing is maturing in mono-Si wafering and thus becoming more widespread.

The same is expected in multicrystalline wafering, with the roadmap predicting significant market share gains for diamond wire use at the expense of slurry-based techniques over the next 10 years. Other new manufacturing technologies, particularly kerfless, are not expected to get above 5% in market share terms.

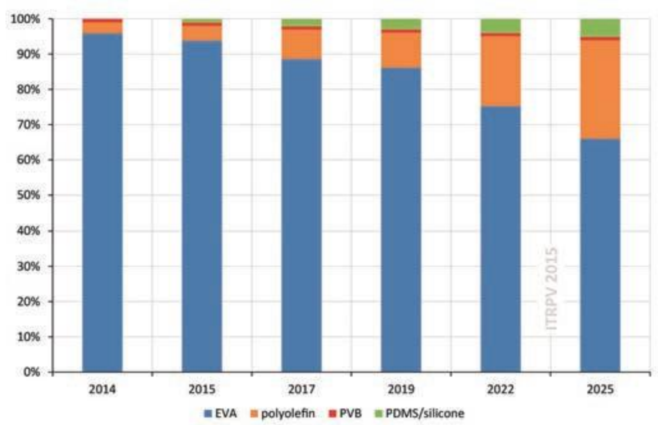
Material costs are also a consideration in the final production of modules. One of the principal materials used in module production is the glass that covers the front of a panel. The roadmap points out that anti-reflection coatings have become commonplace on the front cover glass as a means of improving optical performance. Consequently, AR-coated glass is set to remain the dominant force in c-Si modules for the next 10 years, with an expected market share of over 80% by 2025 (Fig. 4).

One issue highlighted by the roadmap is that not all coatings on the market



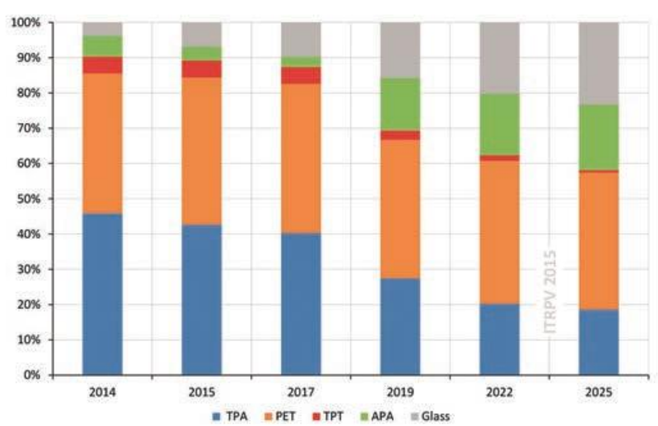
Source: ITRPV.

Figure 4. Expected relative market share of different front cover materials.



Source: ITRPV.

Figure 5. Expected market shares for different encapsulation materials.



Source: ITRPV.

Figure 6. Expected market shares for different module backsheet materials.

perform equally well under various outdoor conditions over a module's life cycle, raising questions over their stability. However, the ITRPV suggests there is a clear trend towards improved service lifetimes among coating brands, indicating that most products should be in line with expected module service lifetimes within the next five years.

Two other key components of a module – the encapsulant and backsheet materials – are also explored by the ITRPV. Encapsulants have been the subject of intensive development work aimed at reducing costs. The roadmap predicts that, although EVA will remain the dominant encapsulant type for the foreseeable future, these efforts will see polyolefin-based materials grow from a market share of 2% in 2014 to around 30% in 2025 (Fig. 5).

This trend towards alternative materials is even more pronounced where backsheets are concerned, with the market share of TPA expected to decline and that of both APA and glass to increase, reaching 25% and 20% respectively by 2025. PET backsheets are expected to retain their current share of around 40% (Fig. 6).

Processes

Another key area for reducing costs is in the development of new and more-productive manufacturing processes.

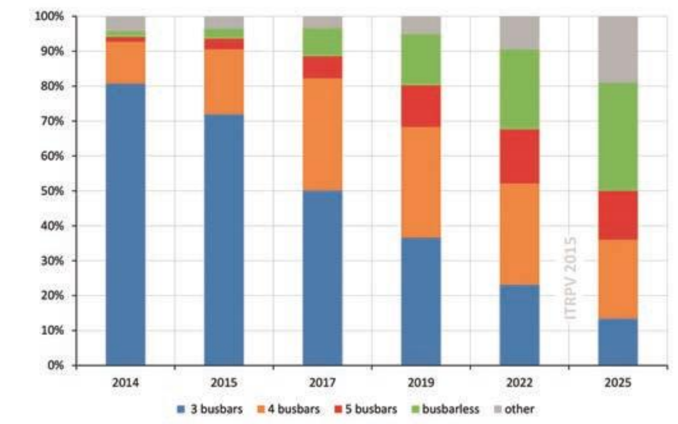
The ITRPV confirms a trend identified in previous issues towards larger ingot mass as a method for increasing throughput: 'Gen 6' and 'Gen7' ingots of 1,000kg are now being commonly manufactured on production lines today, with greater masses anticipated for casted silicon and Czochralski/Continuous Czochralski (Cz/CCz) mono-Si ingots alike. Casted silicon ingots are expected to reach 1,200kg within four years with the transition to 'Gen8' production, while the mass of mono ingots, driven by CCz technology, will double over the next 10 years, to 300kg.

Aside from the greater throughput made possible by increased ingot size, two other important manufacturing advances are the increased throughput and yield from sawing. As regards throughput, the roadmap predicts an increase of 20–25% over the next 10 years for both slurry-based and diamond wire sawing.

Where yield enhancement is concerned, the optimization of kerf loss during sawing is a key consideration, as it allows an improvement in productivity – as opposed to just throughput – in wafering. As things stand, kerf loss in diamond wire is around 20 microns less than the 150 microns lost through slurry-based sawing; for both technologies the roadmap predicts that kerf loss will decline by around 25 microns in the next decade.

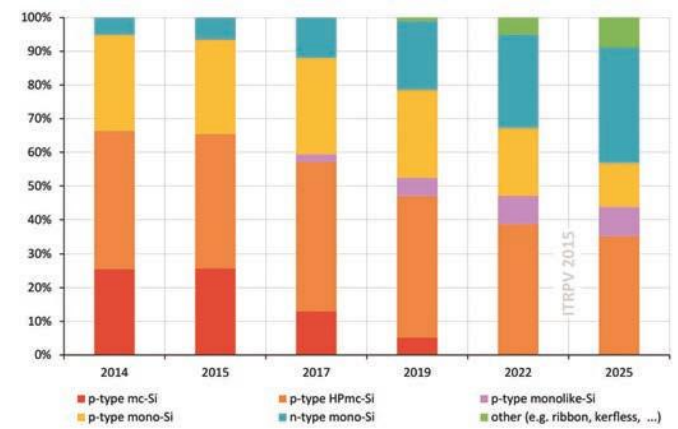
Beyond ingot and wafer production processes, the ITRPV also focuses on emerging trends in metallization. Within this area, one key development highlighted in the latest roadmap edition is the number of busbars used in cell layout. The three-busbar layout currently dominates the industry, but the roadmap envisages that this will be replaced in the next few years by four- or even five-busbar designs (Fig. 7).

That trend is already well in evidence. Prior to SNEC in April, Chinese firm Suntech said it was upgrading all its cell manufacturing capacity from three- to four-busbar layout, then during the show unveiled a new module line – dubbed 'HyPro' – incorporating the new four-busbar cells. Hanwha Q CELLS revealed a similar progression to four-busbar design during SNEC in its HSL S series modules, while shortly after SNEC, SolarWorld disclosed that some of its US production would be upgraded to five-busbar technology alongside a previously announced shift to PERC (passivated emitter rear cell) cell technology.



Source: ITRPV.

Figure 7. Worldwide market share for different busbar technologies.



Source: ITRPV.

Figure 8. Worldwide market share for different wafer types.

Products

Since the emergence of the first signs of an upturn for the battered PV manufacturing industry last year, debate has been focused on which of the cell and module technologies that have been under development will emerge as the industry's workhorses as it enters a new phase of growth.

Until now that title has arguably been held by mc-Si cell-based modules, which make up for generally lower efficiencies with cheaper production processes. This year mc-Si cells are expected to achieve a market share of over 60%. However, that is set to change.

> "By 2025, according to the ITRPV, mono-Si cell technology will have developed from a minority player to one with a 47% market share."

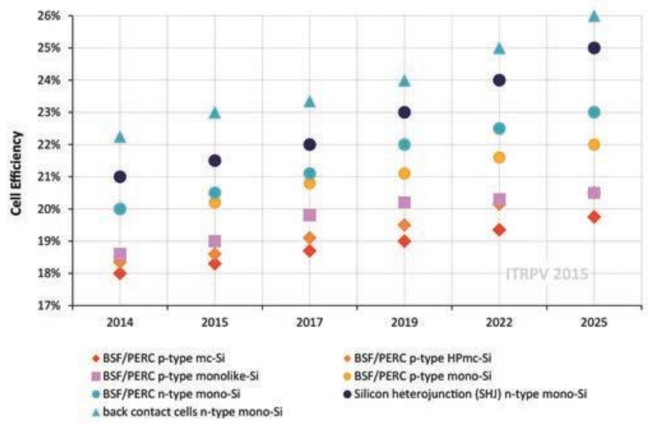
By 2025, according to the ITRPV, mono-Si cell technology will have developed from a minority player to one with a 47% market share. Within this, n-type mono, with its offer of higher efficiencies, will become the main player at the expense of p-type mono-Si, whose share will roughly halve within the next 10 years.

On the mc-Si side, while cells using this material will lose out in absolute terms, high-performance p-type mc-Si will grow in importance and replace 'conventional' mc-Si altogether by 2022. Mono-like, or quasi-mono, which has all but disappeared, is expected to make a limited comeback, with an 8% market share by 2025 (Fig. 8). ReneSola is currently the main exponent of quasi-mono technology.

Regardless of wafer material, the roadmap reveals plenty of room for improved efficiencies in most of the main crystalline silicon technologies. Perhaps unsurprisingly, the greatest scope for efficiency improvements is in the advanced n-type mono-Si family of cells; this has been extensively explored in a previous issue of this journal [2]. Broadly speaking, n-type cells offer a host of benefits, including greater resistance to degradation, not to mention the previously discussed performance advantages. The only barrier has been cost, but that has mainly been a function of economies of scale rather than any fundamental technology-related expense. Parity between p- and n-type technologies is therefore expected by around 2018, after which n-type will start to grow in dominance (Fig. 9).

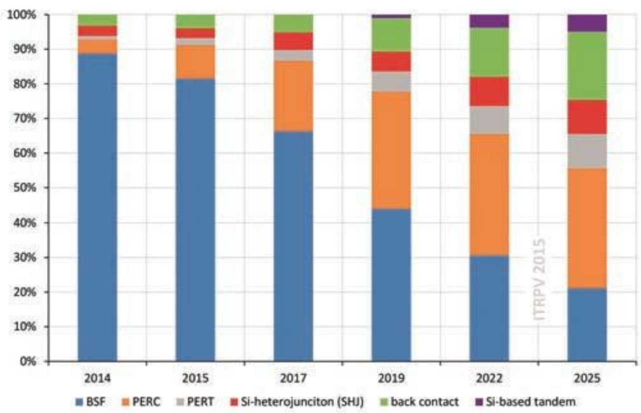
Another landmark identified in the roadmap is in the improvement in mc-Si cell efficiencies. Some of these, having loitered in the upper teens, are predicted by the ITRPV to exceed the 20% mark in mass production within the next few years, led by high-performance p-type PERC variants. The first glimpse of this came earlier this year, when China's Trina Solar revealed it had achieved a 19.14% conversion efficiency in a prototype mc-Si module using its p-type PERC technology.

On the subject of PERC, this would seem to be a cell technology whose time has well and truly come. In the first quarter and a bit of 2015, production line upgrades announced by several leading manufacturers – Suntech, SolarWorld and JinkoSolar to name a few – have included PERC technology. This is underlined by the roadmap's predictions, which foresee PERC's market share eating into that of back-surface field (BSF) cells, the current dominant player (Fig. 10).



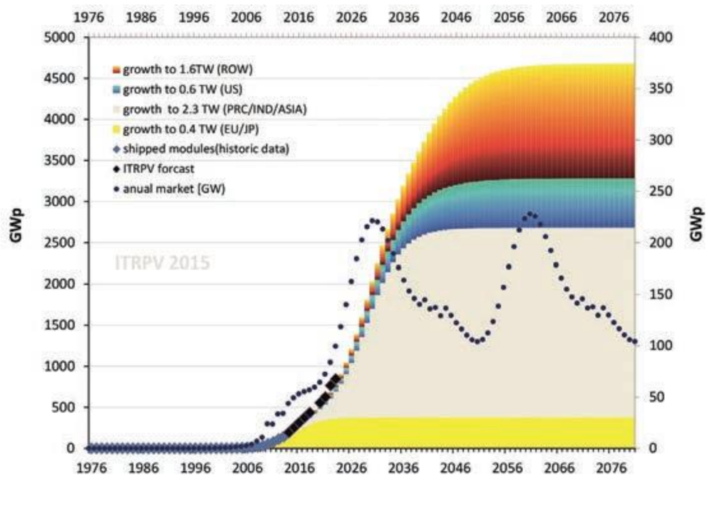
Source: ITRPV.

Figure 9. Average stabilized efficiency values for Si solar cells (156mm × 156mm).



Source: ITRPV.

Figure 10. Worldwide market shares for different cell technologies.



Source: ITRPV.

Figure 11. Cumulative installed module power calculated with a logistic growth approximation for different regions based on the IEA predictions of approximately 4.7TWp installed PV module power in 2050.

Heterojunction cells too are expected to see wider take-up, with a market share of 10% by 2025. The roadmap also predicts that an increasing number of cells will be bifacial – sensitive to light on both sides. Beginning in 2014, the ITRPV estimates that bifacial cell take-up will steadily increase to around a 20% share by 2025. This trend will not necessarily be reflected in bifacial modules, as not all bifacial cells will be integrated into bifacial modules with transparent backsheets or glass–glass construction, according to the roadmap.

> “ITRPV anticipates PV production demand peaking in 2030 at 220GW, then declining to around 100GW by 2050.”

Outlook

On the basis of simple modelling of demand over the coming decades, the ITRPV anticipates PV production demand peaking in 2030 at 220GW, then declining to around 100GW by 2050. This up-and-down cycle will repeat itself as old systems are replaced (Fig. 11).

This modelling is based on International Energy Agency (IEA) figures, which are recognized for being conservative where solar and other renewables are concerned, and so should be treated with some caution. However, the ITRPV message is that there will be no ‘endless’ market for PV modules and that ‘endless’ capacity expansions will not therefore be needed.

Nevertheless, the roadmap describes the opportunities for PV manufacturing as ‘considerable,’ with ongoing technology upgrades, the replacement of worn-out equipment, and ‘modest’ capacity expansions combining to constitute a considerable business segment in the coming years.

The roadmap concludes: “Current activities for increasing module power and cell efficiency, ensuring more efficient wafering and poly-Si usage, and achieving a higher utilization of production capacities as discussed in this ITRPV edition will help manufacturers with their efforts to supply the market with highly competitive and reliable c-Si PV power generation products in the years to come.”

References

[1] SEMI PV Group Europe 2015, “International technology roadmap for photovoltaic (ITRPV): 2014 results”, 6th edn (Apr.) [http://www.itrpv.net/Reports/Downloads/].

[2] Kearns, J. & Li, B. 2013, “Progress in n-type monocrystalline silicon for high efficiency solar cells”, *Photovoltaics International*, 21st edn, pp. 34–37.