July 2015 Research Sample

Silicon Solar Cell and Module Roadmap

PERC and PERL cell architectures have become significantly more common among tier-one x-Si solar players in the past two years; meanwhile, companies like First Solar and SolarCity are investing in n-type, bifacial cell technologies to target distributed generation markets. In this report, we will lay out the possibilities for continued cell evolution as manufacturers continue to increase investments in R&D, with a focus on higher efficiencies and lower production costs to drive the next wave of solar deployment.

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Executive Summary

Following several years of dramatic cost reductions of crystalline-silicon (x-Si) solar technologies and consolidation efforts throughout the industry, the next wave of solar deployment will utilize innovations focusing on higher-efficiency cells and modules. The performance improvements will continue to drive down the cost of solar modules on a dollars per watt basis, but perhaps more importantly, these improved cell architectures will introduce greater opportunity for differentiation in the marketplace. Solar companies will greatly benefit from their research and development efforts by offering more diverse products that are able to better meet the wide range of customer requirements – especially for distributed generation applications. While technology differentiation will drive higher margins throughout the industry, some technologies are better suited for large-scale success due to the associated costs, technical value, and commercial readiness.

Modules Utilizing Passivated Emitter Rear-contact (PERC) and Metal Wrap-through (MWT) Cells Will Supplant Incumbent Technology Like Aluminum Back-surface Field (AL BSF)

Due to higher efficiencies and relatively lower capex expenses for production upgrades, major solar manufacturers are already commercializing PERC technologies. Like many other high-efficiency technologies, PERC cells reduce electron recombination within the active material. However, the production of PERC cells is similar to traditional AL BSF cells, and so compared to other cell architectures – such as interdigitated back contact (IBC) – upgrading to PERC processing lines is relatively inexpensive and straightforward. MWT cells are less commercially ready; however, the expected efficiency gains by 2020 will drive down the costs of modules using that technology and thus offer another alternative to AL BSF and PERC architectures. While we expect PERC and MWT products to reach large-scale deployment by the end of the decade, other high-efficiency technologies like heterojunction and IBC will continue to meet the needs of customers seeking modules with even higher efficiencies. Beyond 2020, these and other cell architectures could supplant PERC and MWT, and thus solar companies should pursue development of high-performance technologies in parallel to address the market needs of multiple time scales.

Other Next-generation Cell Architectures May Not Consistently Offer the Lowest Module Cost, but They Will Be the Best Solution to Address Specific Customer Needs in Niche Markets

Similar to PERC cells, passivated emitter, rear locally-diffused (PERL) and passivated emitter, rear totally diffused (PERT) architectures utilize additional processing steps to reduce electron recombination. While these technologies increase efficiency, the added costs will limit their potential in the market. However, these technology options will be suitable for space-limited projects where efficiency drives the decision-making process. Similarly, other technologies, such as bifacial modules, offer a differentiated solution for certain markets and applications that can utilize both the front- and back-side electricity generation capabilities – for example, snowy locations, building-applied and building-integrated photovoltaics (BAPV, BIPV), and vertically-mounted applications.

Landscape

High-efficiency silicon cell and modules types are the next wave of solar innovation.

Manufacturers Are Ramping Up Production of High-efficiency Cells and Modules

As the solar market continues to mature, near-term innovations will focus on squeezing more efficiency out of the trusted silicon photovoltaic (PV) cell. Cell and module manufacturers are ramping up high-efficiency silicon PV production, and those who fail to stay on top of the trend risk falling behind. Tier-one solar manufacturers have started producing high-efficiency structures – such as passivated emitter, rear contact (PERC) – since mid-2014, and other manufacturers are pursuing even higher-efficiency structures, such as passivated emitter, rear locally-diffused (PERL) and heterojunction technology (HJT). At the module level, companies are pursuing bifacial technologies, busbar changes, and half-cells to increase efficiencies. To maintain a competitive edge, we see leading manufacturers pursuing these technologies aggressively.

- **High-efficiency cells are the key to capturing the distributed generation market.** Distributed generation (DG) markets require higher efficiency for a multitude of reasons. First, these markets have to maximize space economy, unlike utility PV plants that are typically located in remote and low-cost sites, forcing DG users to use more efficient modules to reach the same harvesting potential. In addition, energy policies like net metering and feed-in tariffs (FIT) provide economic benefits for DG users to produce a larger surplus, since such policies require utilities to purchase surplus at regulated prices or offer electricity credits to the user. Currently, there are 44 U.S. states with net-metering policies in place, and six states with FIT policies.[1] Other countries with these policies include Denmark, Germany, and France.[2] The largest DG markets are in U.S., Europe, and Japan.

- **The current standard cell type is reaching its efficiency apex.** Current high-efficiency (c-Si) cell structure has an aluminum or boron back surface field (BSF) structure (see Figure 1). There are points of deficiency in the current standard cell type that limit the maximum efficiency of the cell. One issue is recombination, where defects or other processes prevent the generated charges from contributing to the energy harvesting. Other points of efficiency loss include shading from the front-side metal contacts, electrical resistance (series resistance) from contacts between the different materials, and resistance from the emitter to the base and other parts of the cell structure. In addition, n-type wafers are becoming more popular over p-type, due to longer carrier lifespan and less sensitivity to metal impurities, which leads to higher efficiencies. To improve efficiencies of the standard cells, use of higher efficiency materials like silicon and paste is feasible, but this option can be more expensive (see the report "High-performance Crystalline Silicon Ingots and Wafers").

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Figure 6: Cross-section of an IBC Cell

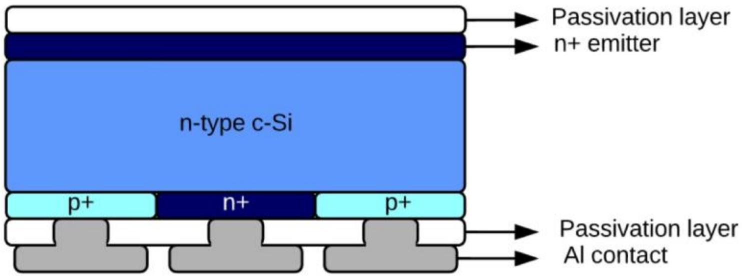


Figure 7: Cross-section of PERL and PERT Cells

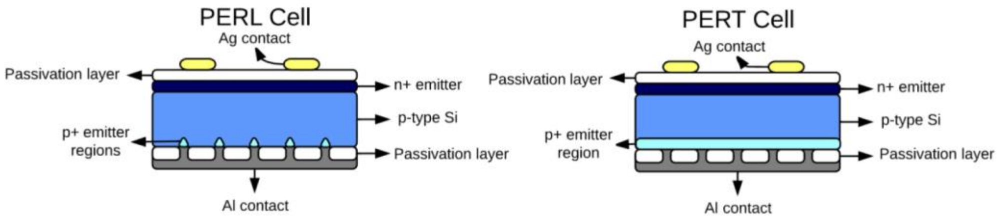
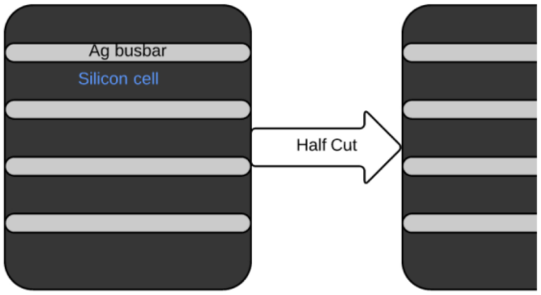


Figure 8: Half-cut Si Cells Decrease Resistive Losses and Increase Module Output



- **As these technologies become more widespread, hybrid structures will emerge to increase efficiency further.** Universities, as well as research and development (R&D) labs from cell and module manufacturers, are already looking at the next generation of technology that combine aspects of the various cell architectures, including HJT-IBC and HJT-MWT, which take the best features of both structures to increase efficiency to new heights. For instance, tier-one manufacturer Trina Solar is developing HJT-IBC in its labs. While these structures are still in labs and small pilot lines, the adoption of PERC, MWT, HJT, and IBC will give cell and module manufacturers equipment to produce not only these cells, but the new hybrid structures in development. Companies are also integrating half-cells and busbar changes into high-efficiency structures, with companies like REC Group manufacturing PERC half-cell modules.

PERC Will Reach Market First, Followed by IBC and HJT, but Firm Cost Estimates and Timelines Remain Unclear

High-efficiency cell and module structures are promising, and the dollar per watt cost will largely determine when each technology will find success in the market. Many cell and module manufacturers are seeking to commercialize more than one high-efficiency product to remain relevant in both the near- and longer-term future.

- **Production of new structures is ramping up, with PERC leading the way.** PERC is becoming more prevalent due to the relative ease of equipment installation compared to other high-efficiency cell structures, which has helped its capacity expansion and growth in the market. Cell and module manufacturers started ramping up production in 2014, with large producers like Hanwha Q-cells, Trina, JA Solar, and Sun Edison commercializing PERC.

  IBC and HJT show promise, but the timeline is murky. Both technologies have one company dominating the space (SunPower for IBCs and Panasonic for HJT), and competitors are just starting to get on board. Both technologies push cell efficiency to 25% but the high cost has been a deterrent for some time. Equipment manufacturers are starting to address this growing market (Meyer Burger now has HJT equipment), and it will reduce capex for cell and module manufacturers, which will make it more attractive for competitors. Companies like Trina are now pursuing IBC techologies, while Sunpreme is starting HJT production in the near future.

With uncertainty around cost and the timeline by which these technologies will roll out, the entire value chain must recognize the realistic projections for cost and adoption in the five-year and 10-year timeframe. In the Analysis section, we'll attack this problem, both by looking at cost projections for different iterations of these technologies and the expected timeframe for adoption.

Landscape Conclusions

High-efficiency cell and module designs are gaining popularity, and we conclude:

- Distributed generation markets drive high-efficiency adoption due to application requirements – namely, space limitations and diverse environments.
- More and more equipment manufacturers are coming out with equipment specifically for high-efficiency that will invariably lead to lower capex for the equipment and streamline high-efficiency production processes.
- Cell and module manufacturers are in various states of commercialization, with large tier-ones ramping up PERC production, and smaller players introducing bifacials and HJT structures.

Figure 9: Select Companies Currently Active in High-efficiency c-Si Cells and Module Structures

Company	Product	Current Capacity	Production Efficiency	Cost ($/Wp)
Sunpreme	HJT Bifacial modules	40 MW	22.2%	*0.90 to 1.20*
Prism Solar	Co-diffused bifacial n-type modules	40 MW	21%	1.00
Silfab Solar	Co-diffused bifacial n-type cells	100 MW	25.5%	*0.90 to 1.20*
Neo Solar Power	Co-diffused bifacial n-type cells	30 MW	24.5%	*0.70 to 0.80*
Panasonic	HJT bifacial cells and modules	*>800 MW*	25.6%	Not available
Nusola	HJT Bifacial cells	0	*23% to 25%*	*0.15*
Hanwha Q-cells	PERC (multi-crystalline) cells	600 MW	*19.5%*	0.28 to 0.29
SolarWorld	PERC cells	*530 MW**	*20%*	*0.80 to 0.90*
Hareon Solar	PERC cell/module	*300 MW*	*19.9%/17.2%*	0.70 to 0.76 (modules)

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Partial View of Chart Offered as Part of Research Sample

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Figure 10: Distributed Generation Will Drive Innovation and Adoption of High-efficiency Cells and Modules

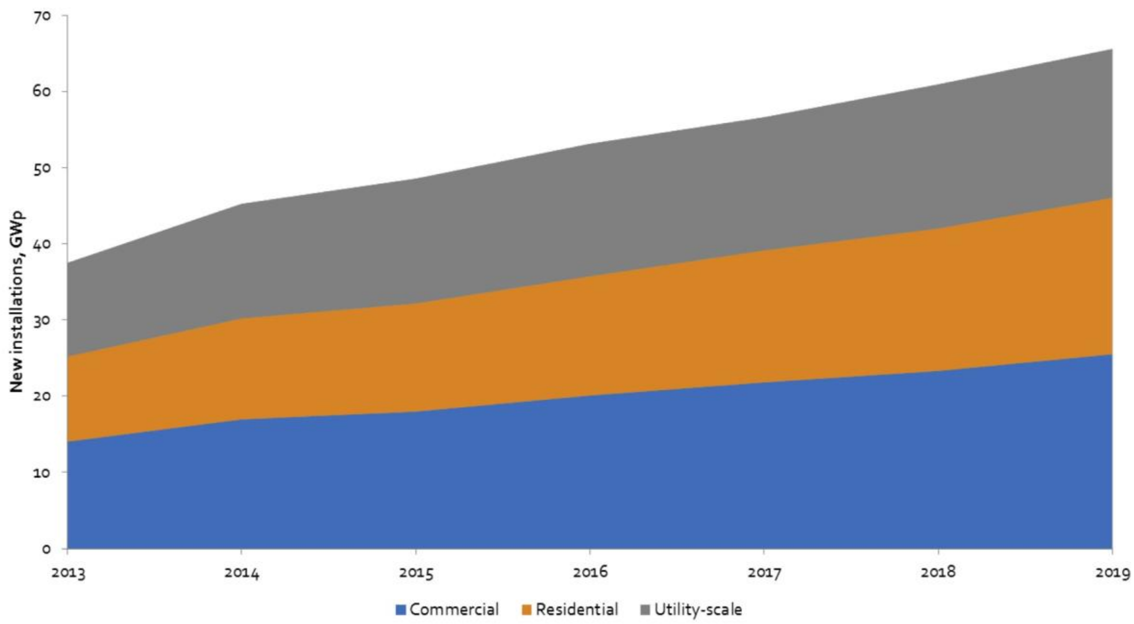
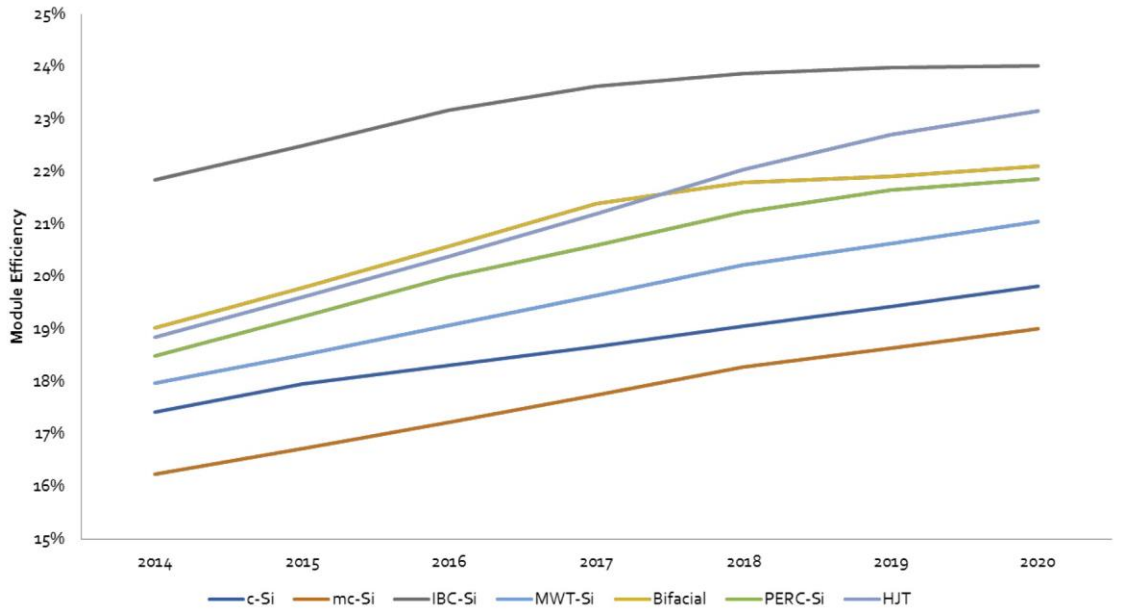


Figure 11: Module Efficiency for Each Technology over Time



Improvements in patterning processing equipment will lead to a decrease in costs for PERL and IBC. Currently, the utilization of patterning for PERL, IBC, and HJT cell architectures render these technologies cost prohibitive to most potential customers. SunPower relies on photolithography technology from the semiconductor industry to manufacture its IBC products, which causes costs to skyrocket, making them approximately three times more expensive than Al BSF today, and 2.5 times more expensive in 2020. Companies like Trina, Yingli, and Suntech are developing less expensive patterning processes to reduce costs.

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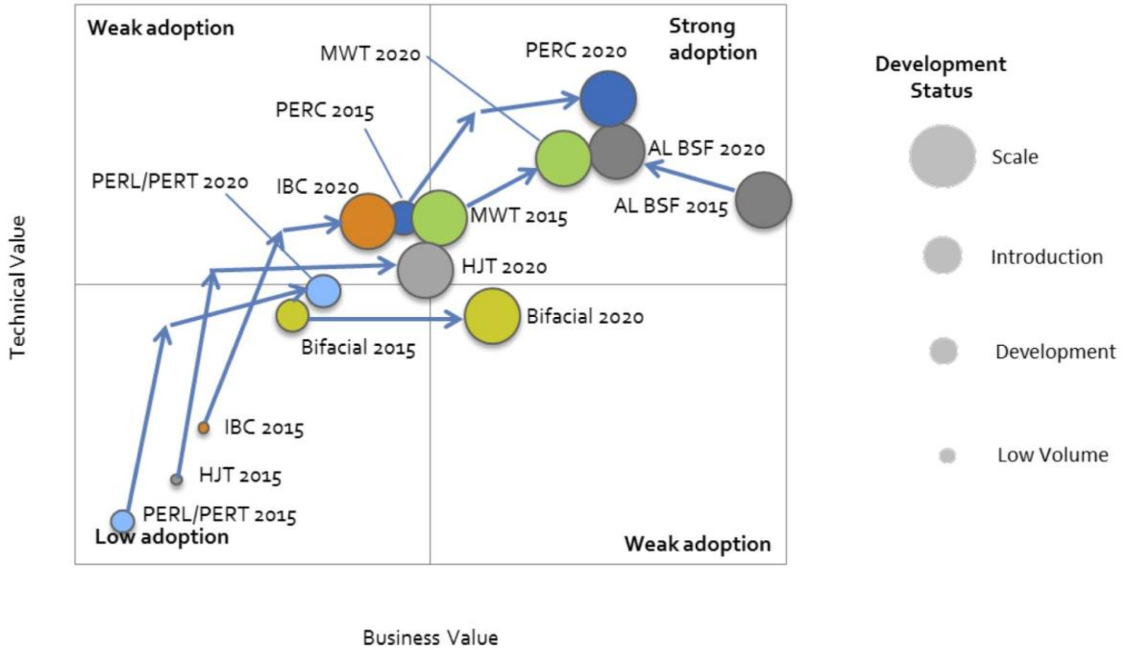
Figure 14: Cost and Commercial Readiness Drive Utility Adoption of AL BSF, PERC, and MWT modules



- **Module level improvements will vary by different manufacturers; additional busbars are the most likely to be adopted.** Module manufacturers using three busbars are likely to move towards implementing five busbars due to increase in efficiency at only a $0.02/$W_p$ increase. Module manufacturers who utilize four busbars, such as Suntech, see little efficiency improvement in moving from four to five busbars, and will skip the movement towards five busbar modules. Busbar additions will occur in 2015 and 2016. Half-cut cell adoption will be limited to champion modules and a handful of companies (like Mitsubishi Electric and REC group) in the near future, but expect some tier-one manufacturers to start developing half-cut cells for commercial use.

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Endnotes

1 http://www.ncsl.org/research/energy/net-metering-policy-overview-and-state-legislative-updates.aspx

2 http://www.epia.org/fileadmin/user_upload/Policies/OSS-Q4_2014_short_version.pdf

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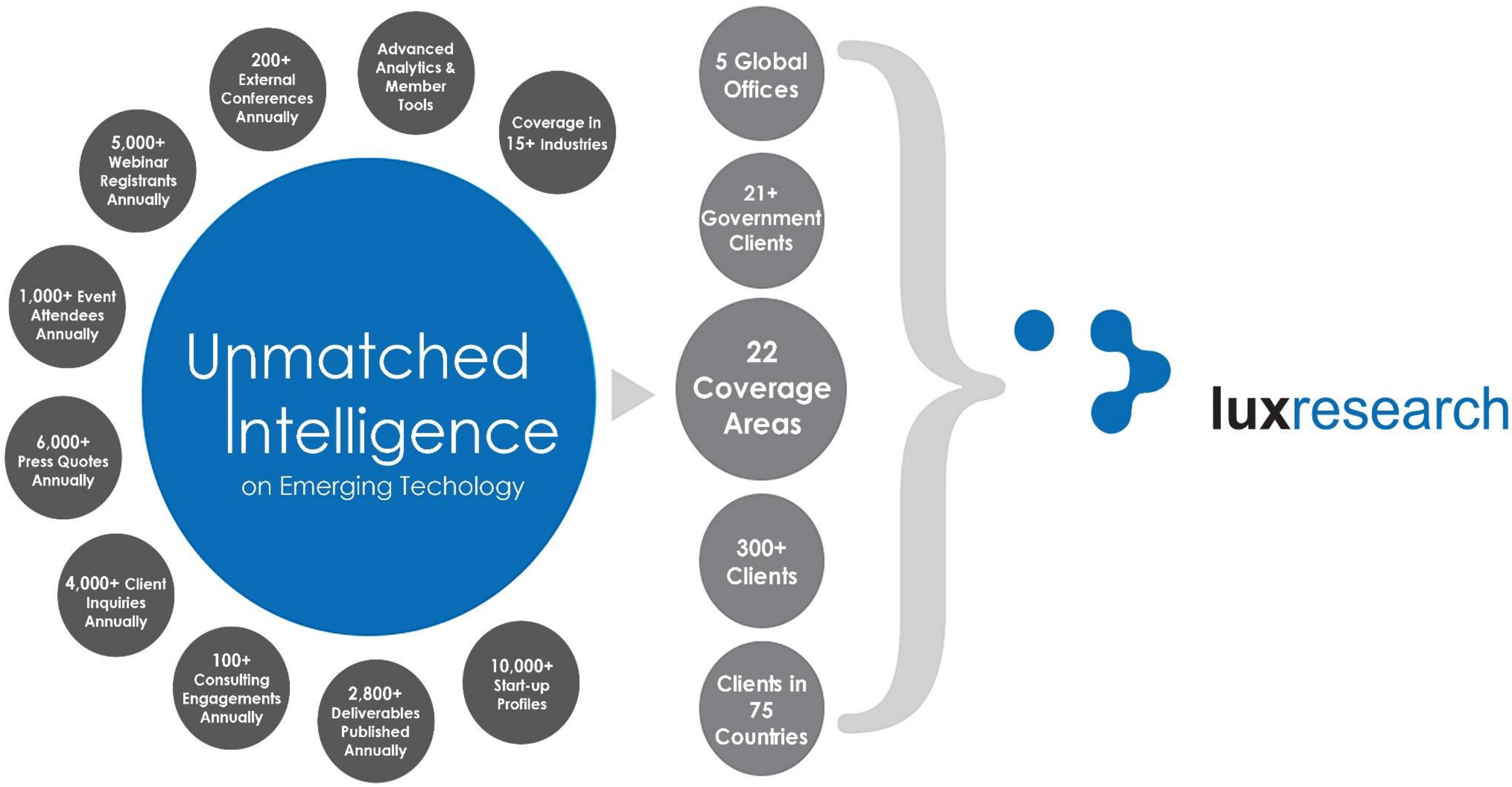

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