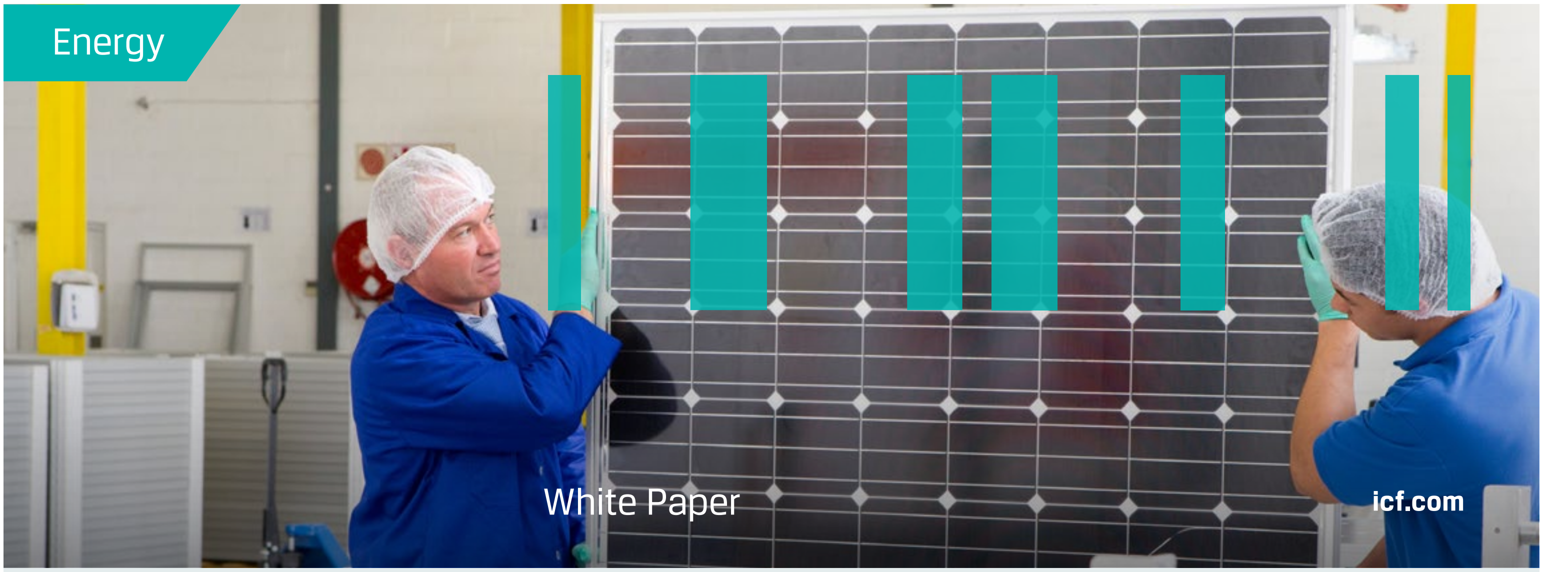


Bifacial Modules: **The Next Step in the Solar Revolution, Part 1 of 2**

By Dan Chawla, ICF

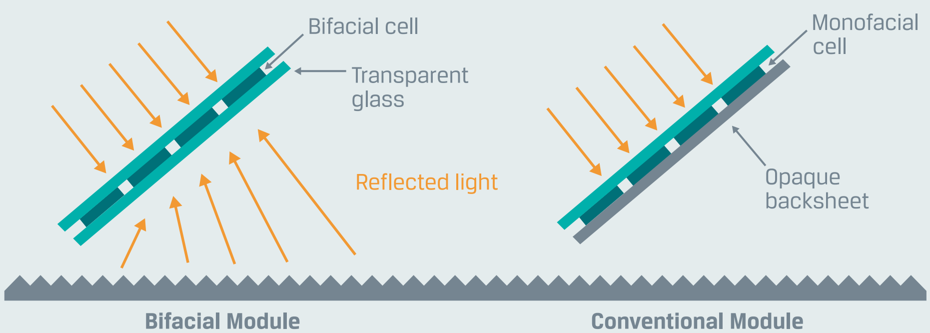
Part 2 of our series on bifacial modules will cover the current state of performance-modeling software capable of estimating the performance of solar projects that utilize bifacial modules. We will discuss the available modeling methodologies, validation with field performance, and potential sources of additional uncertainty in the modeling.

Executive Summary

"Bifacial modules"—one of the hottest topics in the solar industry today—is a generic term for photovoltaic devices that can absorb sunlight from both the front and rear surface. While a conventional monofacial solar module only absorbs the sunlight incident on the front surface, a bifacial module can absorb light that is reflected onto the rear surface as well. Additional energy gains of up to 30% have been reported by the use of bifacial modules in solar power projects, but these claims have yet to be proven.

At the end of 2017, more than half of the ten largest solar module manufacturers offered a bifacial module product. Despite the potential improvement in energy generation and the availability of products in the marketplace, there are still some risks limiting the adoption of bifacial solar modules, including: new module design and manufacturing practices; lack of standardized measurement of the rear-side performance of modules; lack of validated performance modeling software, and a lack of historical field performance data.

EXHIBIT 1: MODULE DESIGN COMPARISON



Module Design Changes

To allow absorption of light from the rear side of a solar module, both the rear backsheet of a conventional solar module and the rear surface of a conventional solar cell need to be replaced by transparent alternatives. While transparent backsheets are available, most module manufacturers are replacing the traditional opaque backsheet with glass to produce "glass-glass" or "double-glass" modules. This change in the module package can lead to additional risk if not appropriately managed.

Degradation

The glass-glass configuration has the potential to eliminate failure mechanisms specific to the backsheet and, according to some studies, can result in a more reliable module. Some module manufacturers are even offering lower warranted degradation rates and extended warranty coverage periods (as compared with their conventional module products). However, field data associated with glass-glass modules is limited, and the results from long-term field studies are inconsistent. The degradation rates observed in these studies can vary significantly depending on the materials and manufacturing practices utilized during construction of the module, which means there is still degradation risk that must be addressed when pursuing bifacial technologies.

Breakage

Adding a second pane of glass can increase the weight and cost of the module, so most manufacturers are utilizing thinner glass and a frameless design. While frameless glass-glass modules have been shown to be able to withstand the same mechanical load testing as framed modules, they have, historically, suffered from higher breakage rates during installation. Also, they can be more susceptible to breakage due to thermal cycling.

Thermal Performance

The thermal performance of glass-glass modules in the field is not well understood. The rear-side glass is significantly thicker than a conventional backsheet. Some studies have shown that it can limit the heat dissipation from within the module, leading to higher operating temperatures. In general, modules that operate at higher temperatures perform less efficiently. However, it is still unclear how this effect will manifest in the field and if there will be any impact on overall energy generation or degradation.

While these risks may seem daunting, appropriate technical diligence can mitigate them. It is important to ensure that any module warranty provided by the manufacturer is based on reliable field data; that the installation personnel is trained for glass-glass modules; and that the energy generation modeling of the modules accounts for the thermal performance. Additionally, we recommend conducting a detailed review of the module design, materials, and manufacturing practices (specific to the module manufacturer) to further minimize risk.

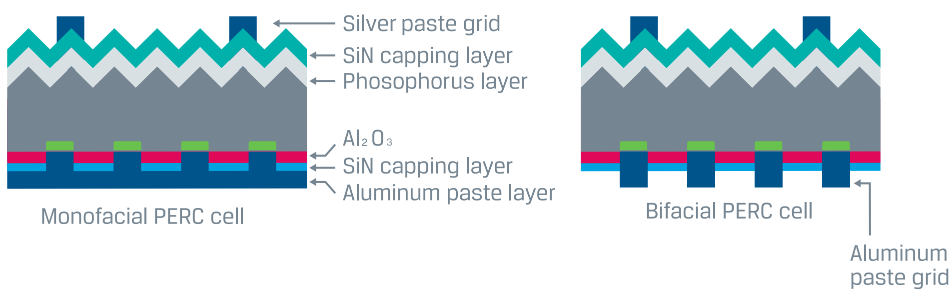
Cell Design Changes

The most common cell technology being used for bifacial modules is Passivated Emitter and Rear Contact ("PERC"). By some estimates, PERC makes up more than 30% of the worldwide module manufacturing capacity. At the end of 2017, ten largest module manufacturers all offered a monofacial PERC module product. There are some additional risks associated with monofacial PERC cells as compared with conventional Aluminum Back Surface Field ("Al-BSF") solar cells that have been discussed in a previous paper.

The bifacial PERC cell design is very similar to the monofacial design; the majority of materials and manufacturing processes are the same. The key change is on the rear side of the cell, where an aluminum grid (similar to the silver grid on the front) replaces the screen-printed aluminum layer. This change allows the cell to absorb light from front and rear sides.

Screen printing a grid instead of a layer requires changes to the aluminum paste and to the screen printer. The aluminum paste must be reformulated for printing as a grid rather than a layer. The precision of the screen printer must be improved such that it can print the grid in the exact location required to make contact with the rear side of the cell. Both the aluminum paste and high accuracy screen printers are available from multiple reputable equipment manufacturers. However, these changes could impact the interconnection of the cells, so we recommend evaluating quality controls and reliability testing practices of the module manufacturer to minimize this risk.

EXHIBIT 2: PERC CELL DESIGN COMPARISON



Module Performance Measurement

The first step in estimating the energy generation of a solar project (and meeting safety guidelines) is reliable measurement of the performance of the module in the laboratory. There are international standards available for the laboratory measurement of monofacial modules. The electrical performance of the module is measured under different levels of light and temperature to capture the range of operating conditions a module will likely experience in the field. Furthermore, the uncertainty associated with these measurements has been well studied and can be evaluated for any given testing apparatus. The results of these measurements and corresponding uncertainties are integral to the accurate assessment of solar energy generation.

In general, bifacial modules are measured by separately exposing each side of the module to similar levels of light and recording the "bifaciality." Bifaciality, the ratio of the rear side performance of a bifacial module to the front side performance, generally ranges from 70-80% for PERC modules. As of mid-2018, the standard for measurement of bifacial modules (IEC 60904-1-2) is still in draft format. As a result, manufacturers' approaches to measuring bifacial modules and presenting that information on datasheets are inconsistent. Additionally, the uncertainty associated with the bifaciality of a module is often not presented clearly.

Until a standard is established, we recommend an in-depth review of the bifacial measurement methodology of each module. It is imperative to understand how the laboratory measurement was conducted, how it will translate into field performance, and any additional uncertainty.

Final Thoughts

Bifacial modules may spur significant gains in energy generated from a solar project. Gains as high as 30%—a jump that would significantly change the financial calculus of any solar project—have been reported. The actual gains realized depend significantly on how the modules are installed, including the reflective characteristics of the underlying surface. The current cell and module technology utilized to manufacture bifacial modules is beginning to reach maturity; multiple manufacturers have introduced products to the market.

However, new module design and manufacturing practices also introduce risk; lack of standardized measurement of the rear side performance of modules; lack of validated performance modeling software; and lack of historical field performance data. To capture the value generated by bifacial modules, it is important to mitigate these risks with additional diligence.

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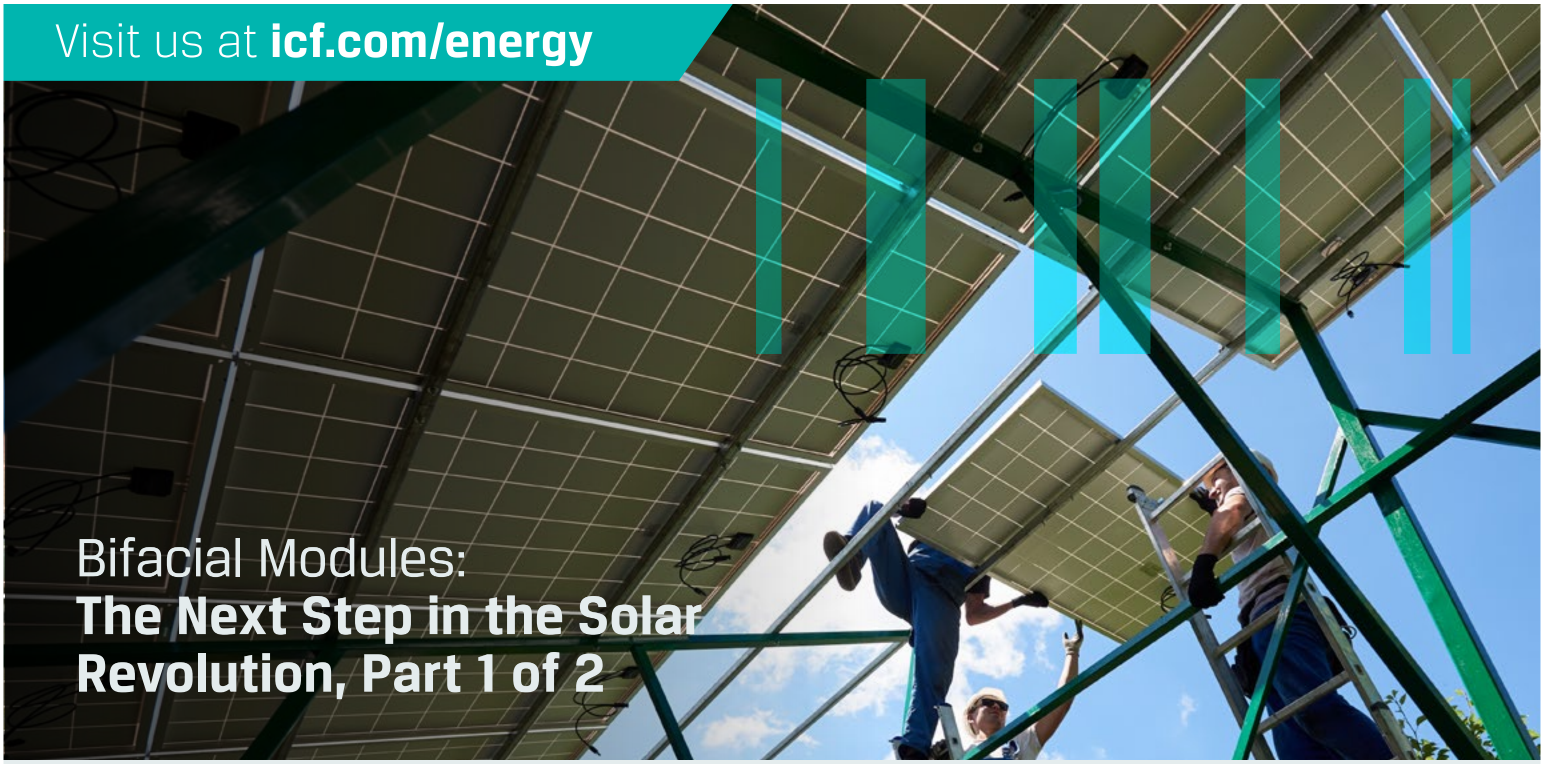

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About the Author

Dan Chawla Specializes in solar photovoltaic technology with almost a decade of experience in R&D, manufacturing and product management. He has served as an independent engineering representative for multiple solar energy projects and as the technical expert for due diligence associated with large investments in solar manufacturing ($3-5B) and solar company acquisitions ($400-$500M). He has extensive experience working with solar manufacturers in the US, China, Korea, Malaysia and India. Dr. Chawla developed his expertise in technology by working in early stage R&D, with manufacturing sites in multiple countries, conducting due diligence on investments, and supporting independent engineering reviews of solar projects. He specializes in solar technology, manufacturer audits and evaluation of quality/reliability of solar products.

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