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Bifacial Modules: The Next Step in the Solar Revolution

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Executive Summary

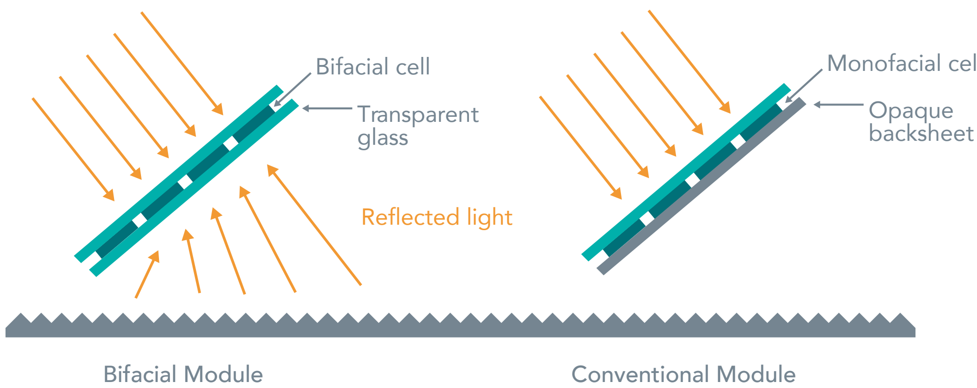
Bifacial modules—one of the hottest topics in the solar industry today—is a generic term for photovoltaic (PV) devices that can absorb sunlight from both the front and rear surface. While a conventional "monofacial" solar module only absorbs the sunlight incident on the front surface, a bifacial module 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.

As of mid-2019, more than half of the ten largest solar module suppliers offered a bifacial module product—with the remaining suppliers quickly adding bifacial capacity. Given the potential improvement in energy generation and the availability of products in the marketplace, bifacial modules are expected to quickly gain market share in 2020 and beyond.

However, there are some risks associated with bifacial modules: 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.

This white paper, which is divided into two sections, examines the technology behind bifacial modules and provides recommendations for accurately modeling their performance.

EXIHIBIT 1 : MODULE DESIGN COMPARISON



Section 1: Bifacial Module Technology

Bifacial modules use many of the same materials and manufacturing practices as conventional crystalline silicon modules, which have been widely used in the solar industry for the last decade. But, they do require cell and module level technology changes that present additional risks and must be managed with appropriate diligence.

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 requires different materials and manufacturing practices-leading to additional risks 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).

That said, 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 used during the construction of the module—meaning there is still degradation risk that must be addressed when pursuing bifacial technologies.

Mechanical Strength

Adding a second pane of glass can increase the weight and cost of the module. So, most manufacturers are using thinner glass and thinner module frames or, in extreme cases, no module frame. While glass-glass modules are typically certified to the same mechanical load testing standards as conventional modules, studies have shown that glass-glass modules can suffer from higher breakage rates during installation.

Module Performance Measurement

The first step in estimating the energy generation of a solar project (and meeting safety guidelines) is a reliable measurement of the performance of the module in the laboratory. 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 60-90% for Passivated Emitter and Rear Contact (PERC) modules, with a typical rate of 76% for most standard p-type modules.

The standard for measurement of bifacial modules (IEC 60904-1-2) was published in early 2019. Manufacturers are updating procedures for module measurement and datasheets to clearly present information on the bifacial aspects of the model.

Thermal Performance

In general, modules that operate at higher temperatures perform less efficiently. The thermal performance of bifacial modules in the field is not well understood. Some studies have shown that the rear side glass can limit heat dissipation from within the module, leading to higher operating temperatures.

Meanwhile, other studies have shown that—under nominal field conditions—bifacial modules exhibit temperatures similar to or lower than comparable monofacial modules. 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.

Cell Design Changes

The most common cell technology used for bifacial modules is PERC. By some estimates, PERC makes up more than 30% of the worldwide module manufacturing capacity. As of mid-2019, nine of the ten largest module manufacturers all offered a PERC module product. There are some additional risks associated with PERC cells as compared with conventional aluminum back surface field (Al-BSF) solar cells, as discussed in a previous paper.

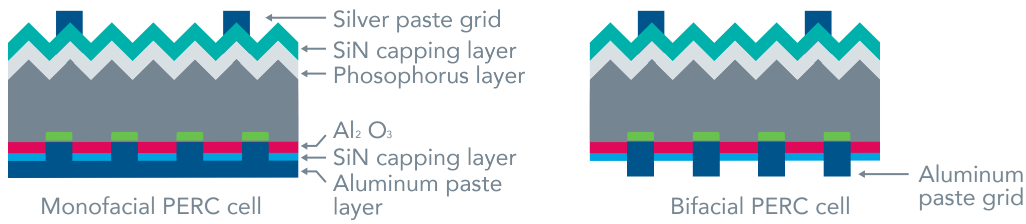
Summary

While the risks associated with bifacial modules 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, installation personnel is trained for glass-glass modules, and 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.

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.

Screen printing a grid instead of a layer requires changes to the aluminum paste material and to the manufacturing equipment, both of which are now available from multiple reputable equipment manufacturers. However, these changes could impact the interconnection of the cells. We recommend evaluating quality controls and reliability testing practices of the module manufacturer to minimize this risk.

EXHIBIT 2 - PERC CELL DESIGN COMPARISON



Section 2: A Guide to Modeling Bifacial

Although the idea for bifacial photovoltaic modules has existed since the 1950s, the technology only recently started to penetrate the market as mainstream. Now, it is gaining momentum—some have predicted bifacial modules to make up 5% of the market share by 2021.

A lack of broad industry acceptance and understanding of methodologies for estimating long-term energy generation continues to impact the use of bifacial PV modules. While several modeling platforms, such as PVsyst and NREL's System Advisor Model (SAM), include some bifacial modeling capabilities, the industry has not agreed on a detailed approach to modeling inputs or assessing the model uncertainty.

To move the industry and potential projects forward, we see three areas of modeling and measurement for bifacial modules to address:

- measuring resource availability,
- measuring performance, and
- understanding additional unknowns.

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Measuring Additional Resource on the Rear Side

Incident Irradiance

As with conventional mono-facial PV modules, the first step in modeling the generation is to determine the amount of irradiance that is incident on the surface of the module.

There are many algorithms and methods that have generally been accepted by the industry for modeling the expected irradiance on the front-side of a PV module, including impacts of shading, the accumulation of dirt and snow on the module surface (soiling), and several other factors that impact the incident irradiance.

These models are not appropriate for the estimation of the irradiance on the backside of PV modules. Therefore, models are now an area of significant attention and study.

Currently, the industry has adopted two general methodologies of modeling the irradiance incident on the rear side:

- **Ray-tracing algorithms:** These calculations estimate the trajectory of individual rays of light from the back of the module to the source, reflecting off nearby objects. This method is very computationally intensive and often considered impractical for annual generation estimates of large solar projects.
- **View factor method:** View factors quantify the fraction of irradiance "visible" to the backside of the modules based on the geometry of the array. The industry has generally accepted this method as appropriate for modeling utility-scale solar projects.

Once an approach is selected, several factors must be taken into account to accurately assess the available net irradiance.

Ground Albedo

A significant factor of backside irradiance is the ground albedo. The ground albedo depends strongly on surface properties. For example, green grass typically exhibits a ground albedo of approximately 23%, whereas white sand is approximately 65%.

Ground albedo can also vary seasonally—especially in places where it snows frequently—and daily, with higher albedo in mornings and evenings. Using a single annual albedo value, which is common in modeling mono-facial PV systems, may not be appropriate for bifacial systems.

Albedo is one of the key elements in modeling bifacial energy gains. Issues with the assumed albedo can result in up to 5% error in estimated annual energy gained from the backside of the module, also known as "bifacial gain."

Several publicly-available historic albedo datasets use satellite sensors deployed by NASA to better align analysis. When using historic datasets, the spatial resolution may not be detailed enough to capture a single project site. It may also include various geographic elements that impact the albedo, such as bodies of water, mountain ranges, forests, etc. Additionally, a project site is likely to change during construction efforts and new vegetation may alter the natural landscape used to determine the historic ground albedo.

For project financing, a ground campaign is encouraged to estimate ground albedo. An albedometer can measure the amount of irradiance reflected off the ground. This tool utilizes two pyranometers (devices used to measure the amount of irradiance from the sky above) oriented parallel to the ground, with one device directed towards the sky and the other facing the ground. It is recommended that a ground campaign is conducted for at least a year to get albedo data for every season when estimating bifacial gain for a new project.

Rear Side Shading

Unlike the front-side of a PV module, the backside has several shading elements that stop all potential irradiance from being used. The shadows from the array drastically impact the amount of irradiance that is reflected off the ground. The impact of the array's shadow directly correlates to the ground clearance of the modules.

As the modules are raised above the ground, the shadows on the ground become lighter and more irradiance is reflected off the ground. While more energy is yielded with higher ground clearance, there is generally an increase in construction costs.

Obstructions to the back of the modules, such as the purlins and wire management entities, can also shade the modules. The loss associated with rear side shading will depend on the project design, such as racking configuration and module orientation.

Typically, we would expect the rear side shading losses to be in the range of 3-5%. These physical barriers will not only limit the amount of irradiance captured by the module but can also lead to an increase in mismatch losses.

Shade obstructions are not the only cause for mismatch losses. The modules on the edges of rows experience higher rear side irradiance than a module in the middle of the row. This is due to fewer surrounding objects and shadows. So, not only are there mismatch losses due to the varying ground clearance of the cells but also due to edge effects. Similar to the rear side shading, this loss is highly dependent on the project design and array layout. But, typical ranges for mismatch losses is 3-7%.

Getting a Clearer Picture of Greater Production

Module Performance

Once the total effective irradiance incident on the rear side of the module is determined, the irradiance is then translated into power using the module-specific efficiency. This efficiency is also known as bifaciality.

A standard for measuring performance of a bifacial module is still in draft format. As a result, manufacturers' approaches to measuring and reporting the bifaciality is inconsistent. Until a standard is established, we recommend an in-depth review of the bifacial performance measurement methodology to understand how the laboratory measurement was conducted and how it will translate into field performance, along with any additional uncertainty.

Bifacial Model Uncertainty

While the steps and considerations required to model the energy gain of a bifacial system are known, there are additional uncertainties with modeling a bifacial system that need to be taken into account.

In our experience, weather-corrected estimates predict the generation of well-maintained, utility-scale monofacial PV systems within +/- 4% if modeled correctly. The additional design factors to consider with bifacial systems increases the overall uncertainty of energy modeling.

Resource uncertainty must be considered. A significant part of this is the ground albedo. As mentioned above, the uncertainty associated with ground albedo can be significantly reduced if a ground campaign is performed to get site-specific data.

There is further uncertainty around the other various loss assumptions described previously (rear side shading, mismatch, bifaciality, and so on). This is accounted for in the rear side irradiance model.

The uncertainty around the view factor model has been calculated to be about 22%. Contributors are shown in the table below. This should only be applied to the energy gained from the back of the module, i.e., the bifacial gain. Typically, this would result in about 2-4% additional uncertainty to the total energy generation estimates.

Table 1: Bifacial Uncertainty
Albedo
Bifaciality
Rear Side Shading
Rear Side Mismatch
Rear Side Irradiance Model
Total Bifacial Uncertainty

Source: National Renewable Energy Laboratory

Understanding and Overcoming Additional Unknowns

Bifacial modules are relatively new to the solar market, so there is a limited amount of empirical data available for the validation of performance modeling tools and methodology. Several unaccounted for elements still need to be addressed.

The first is soiling of the rear side, though this will not have the same effect as front-side soiling. The other is dynamic albedo—i.e., albedo on an hourly basis. While some modeling tools allows for inputs of hourly albedo values, models and datasets of hourly albedo need to be validated.

To help propel these modules to market, we need more publically-available validation studies and empirical data to improve the modeling methods. The industry has shifted so that manufacturers (solar module and racking) are leading the charge in conducting tests on bifacial systems to better understand their potential. This collaboration will greatly accelerate the acceptance of bifacial modules. However, as with any new technology, we need to understand where additional diligence is required to fully assess the long-term benefits.

Final Thoughts

Bifacial modules may spur significant growth 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 (4-9% for tracking systems and 7-12% for fixed-tilt systems), along with the reflective characteristics of the underlying surface.

Systems are still designed to optimize the front side irradiance since the direct sunlight greatly outweighs the reflected rear side irradiance. Nonetheless, the current cell and module technology utilized to manufacture bifacial modules is beginning to reach maturity. Multiple manufacturers have introduced products to the market. But, naturally, new module design and manufacturing practices also introduce risks—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 truly capture the value of bifacial modules, it is important to mitigate risks using the recommended diligence in this paper.

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About the Authors

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 U.S., China, Korea, Malaysia, and India. Dr. Chawla developed his expertise in technology by working in early-stage R&D, on 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 the quality and reliability of solar products.

Leah Holton is a Senior Energy Engineer and specializes in solar photovoltaics performance modeling. Her solar background began at Arizona State University, where she received a solar-based fellowship funded by the National Science Foundation. She then worked as a designer for a residential photovoltaics installation company. Ms. Holton has experience in programming using Python and is using her solar knowledge to develop more comprehensive generation models.

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