

Hurdles to widespread bifacial PV adoption



Bifacial | Bifacial technology is seen by many as the shape of things to come for the solar industry. But how is it regarded by those on the frontline of choosing equipment that will result in the most profitable projects? Jenya Meydbray, VP of solar technology at Cypress Creek Renewables, offers an insider's view

Ten years ago, nobody batted an eye when the output of a photovoltaic (PV) system exceeded estimates from the best available performance modelling software by a healthy margin. Back then, overperformance gave project owners cause to praise the quality of their systems, while highlighting that they delivered all the energy expected by the end customer, and then some.

The rules of the game have changed.

Today, if a project developer proposes to build a PV system, all future energy generation must be captured in the third-party energy model to result in a profitable and financeable project. There's simply no more fat left in PV systems at power purchase agreement (PPA) rates

in the mid- to low-single digit USD cent range. That's because, in the past several years, yield estimates for systems with standard monofacial crystalline silicon (c-Si) modules have become very precise. Using the simulation software PVsyst, a popular tool for analysing system design configurations and evaluating results, investors and system owners have come to expect that actual output will be in a range of $\pm 1\%$ of what they expected, after normalising for weather. Why take the risk on a project or technology that may give you plus or minus 10% when many projects using standard technology minimise risk so effectively?

The predictable nature of c-Si technology has helped scale up project finance

Bifacial PV technology is generating great interest in the solar industry despite a paucity of data on its bankability

for the solar industry, where investors tend to apply a lower debt-service coverage ratio than in the wind industry. But by the same token, it presents challenges for the adoption of alternative PV design concepts, such as systems using bifacial modules.

A bifacial module uses glass or transparent backsheets behind the c-Si solar cells instead of an opaque white or black backsheet, allowing light to pass through it and onto the module's back side to generate more energy. Bifacial solar cells are also c-Si but are processed to allow light in from both sides. Everybody likes the idea of generating more energy, in principle. The problem is there's not enough data to tell investors how much

of a performance boost they can expect from replacing standard monofacial c-Si modules with bifacial modules. At this moment, yield estimates for systems with bifacial modules are too imprecise. Anytime we try to simulate their performance, it's like stepping into a time machine and going back 10 years to an age of low predictability in solar project output. Although there is reason to believe that bifacial modules will increase net present value for many solar projects, developers today are seeing increased risk in the performance model, which often leads to unnecessary conservatism.

With funding from the US Department of Energy, Cypress Creek Renewables is launching a project to generate data and analysis on the variables affecting bifacial solar output, accounting for obstructions on the module back side, tracking algorithms, module degradation, snow shedding and much more. The research will include the deployment of bifacial test stations, instrumenting of commercial systems in the field and computer modelling. The goal is to characterise bifacial technology behaviour and to further develop and validate performance models that investors and independent engineers can utilise to accurately quantify the performance boost from bifacial solar technology and ultimately to reduce the solar levelised cost of electricity (LCOE).

How bifacial technology impacts NPV

Investors develop their own criteria to measure a solar project against any other investment opportunity. As one important benchmark, many investors use net present value (NPV), a measure of profitability that combines cost of capital-adjusted payments and receipts. Whether an investor is seeking projects that yield NPV of 10 cents per watt or some other threshold, electricity sales are an important part of the projected cash inflows needed to show that a project should qualify for financing.

Bifacial PV technology has the potential to drive up NPV. According to researchers at the International Solar Energy Research Center in Konstanz, Germany, bifacial solar projects have reported energy gains of up to 20%. The best results thus far come from the 1.25MW Asahikawa Hokuto Solar Power Plant in Japan that has been operating since November 2013. Results vary at other sites, such as Yingli

Solar's 100MW Top Runner project, where an initial 50MW section of the project has reported about 17% energy gain, and a 2MW project in Saarland by the developer Ökostrom Saar that is reporting a 10% gain. Other industry players confidentially report 5-7% gains. However, the industry has not yet produced seminal research to establish how bifacial modules affect system yield in various system configurations and locations.

Projects can see a marginal upfront cost increase associated with bifacial modules. Module assembly isn't altogether different. Bifacial modules use the same cell technologies, front-side glass, encapsulant and wiring as c-Si modules. Module cost on a per-Watt basis may go up a little by replacing the backsheet with a second layer of glass, thereby potentially reducing front-side performance by a few watts. Mounting system costs could go up a little too, because they must be redesigned to avoid covering the module back side. Balance of system cost also could see a modest increase to account for a slightly higher series fuse rating. Altogether, expect to spend a couple cents more at the system level in the near term and less over time as the industry gains experience and production volume for bifacial-specific parts.

A wide variety of factors affect system output, for better or worse. This article is not intended to thoroughly cover all the factors but rather to briefly describe some

of the leading factors and demonstrate why the industry must understand their impacts on system output to accelerate bifacial solar deployment.

Albedo

This is the percentage of sunlight reflected by the ground back up onto the PV modules. The value depends heavily on what lies beneath the modules and can change hourly, daily and seasonally. Fresh snow provides a higher value than grass, for example. Albedo has the strongest impact of all bifacial-specific system design considerations that didn't impact standard monofacial c-Si PV modules.

Spectrum of albedo

As light passes through the atmosphere, certain colours (i.e., wavelengths) of light are absorbed more than others, thereby resulting in some spectrum of intensity as a function of wavelength. Different ground types can vary greatly in the spectrum they reflect. Solar cell efficiency is a function of wavelength, so this phenomenon will impact back-side efficiency. Light that hits the cell surface but fails to produce electricity is wasted as heat.

Incidence angle modifier (IAM) on back side

This refers to the amount of light that fails to reach the solar cell due to reflection off the glass and the encapsulant. When incident light hits the front glass at a sharp angle, the reflection is higher. When light comes in perpendicular to the module surface, reflection is lower. IAM describes the reflective losses at different angles. This is implemented in energy modelling of the front-side performance but will impact back-side performance as well.

Obstructions

Objects on the back side of the module—junction boxes, cables, mounting system components—that have no effect on traditional c-Si solar output can interfere with potential energy gain in a bifacial solar system. To optimise bifacial system output, modules should use a shallow junction box that does not obstruct solar cells on the back side, and systems should employ design configurations that keep balance of system components from blocking reflected light from below.

View factor

This describes the energy transfer from one surface (e.g., the sun) to another

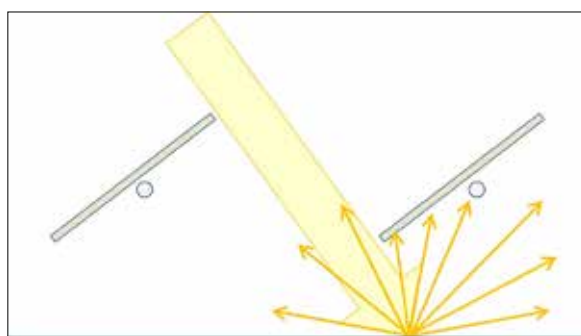


Figure 1. Light reflecting off of the ground (albedo) onto the back of PV modules

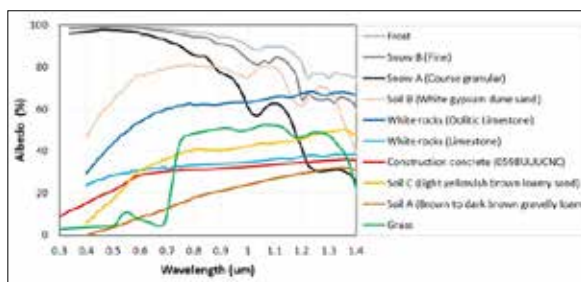


Figure 2. Spectral content of albedo for various ground types

Credit: PV Lighthouse

Credit: PV Lighthouse



Figure 3. PV module junction box installed directly over the back of two bifacial cells

(e.g., the back of the PV module). In solar, view factor is a function of the height and width of a module array. A tracker that is one module high lets more light around to the ground below the modules than a tracker that is two modules high. The diagram below from NEXTracker illustrates this effect for trackers that are the same height. It's important to note that trackers with two modules in portrait will be taller.

Mismatch

Like anything manufactured in volume, solar cells are not all identical. However, when wired in series they must have the same electrical current flowing through each one. Electrical current is approximately linear with light intensity. In other words, if you double the light intensity incident on the solar cell, you'll double the current. Non-uniform light intensity on the back side of the PV module and non-identical cells all contribute to mismatch losses.

Portrait versus landscape orientation

Bypass diodes, used to mitigate the effects of non-uniform shading on a solar module, operate based on module orientation relative to shade geometry. Neither configuration, portrait nor landscape, necessarily yields more energy in all cases. However, the non-uniformity of back-side illumination is typically in the dimension perpendicular to the ground or the tracker torque tube.

Snow shedding

Modelling for systems in locations that experience winter snowfall includes energy losses due to shading from snow. For standard monofacial c-Si systems, the range of loss estimates from various independent engineering (IE) firms can be 10% or more. To what extent does absorption of light on the back side cause the module to heat up faster and accelerate snow shedding? Does snow shedding cause soiling on the back side? Additional

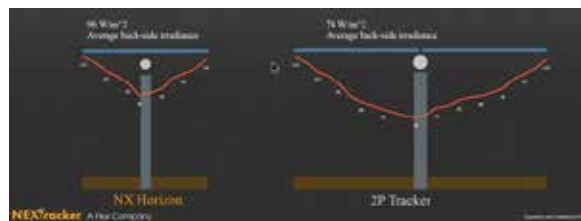


Figure 4. Diagram illustrating reduction of back side light intensity as the module table gets larger for the same height tracker. Source: NexTracker

testing is needed to introduce real-world behaviour into engineering estimates.

Module degradation

Due to a combination of factors, including prolonged exposure to temperature swings, moisture and ultraviolet light, c-Si modules tend to see a gradual decline in efficiency over time. With two layers of glass instead a glass-backsheet combination and with increased overall light absorption, degradation may occur at a different pace in bifacial

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modules. It's feasible that degradation can be lower if outgassing and delamination can be avoided.

Light-induced degradation (LID) / Light- and elevated temperature-induced degradation (LeTID)

All c-Si modules built with p-type wafers experience light-induced degradation (LID) caused by oxygen and other impurities in the silicon. Light- and elevated temperature-induced degradation (LeTID) can occur in passivated-emitter rear contact (PERC) cells. Depending on how the cells are processed, the magnitude of these behaviours can vary for a cell's front side and back side.

Tracking algorithms

Systems with single-axis or dual-axis trackers use algorithms to evaluate various tradeoffs to maximise overall

system output. According to discussions with two leading tracker manufacturers about how bifacial PV modules may affect tracking algorithms compared to standard monofacial c-Si modules, completely differing perspectives are present today.

Module-to-module spacing / Row-to-row spacing

Adding spacing between modules and between rows will allow more light to hit the ground under the modules and reflect onto the module back side. However, this adds potential cost to the land, racking, wiring and other electrical and mechanical balance of system.

Tilt angle for fixed-tilt systems

With standard c-Si modules, system designers tend to orient modules south facing at latitude tilt with a steeper tilt for systems located furthest from the Equator. With bifacial PV modules, maybe systems perform better at a slightly flatter angle. Maybe not.

Torque tube shape and size

When an opaque backsheet covers the back of a solar module, it makes no difference whether a tracker's torque tube, the part that controls module orientation, has a circle or a square cross-sectional shape. Shape doesn't affect monofacial system output, nor does torque tube size. In systems with bifacial modules, the torque tube shape and size can both introduce obstructions on the module's back side and impact reflection from the torque tube. Generally, you want the shape, size and placement of the torque tube to minimise back-side shading, if possible.

Electrical stringing

Details about the available land, such as shape, wetlands and waterways and topography, are just some considerations affecting the choice between going one module high or two modules high on a tracker. With bifacial PV modules one must also consider how electrical stringing affects module mismatch. In systems that go two modules high, one row is closer to the ground than the other, and the two rows capture different amounts of reflected light from the ground. Stringing the two rows together in series will increase mismatch losses.

In time, we may come to realise that impacts from some of the above-mentioned factors are trivial. That's ok. Incremental progress is the way that the

solar industry has driven down module costs by over 90% in less than a decade. Meanwhile, through the course of study, other as-yet-undiscovered considerations may materialise. Even if all the impacts from bifacial solar add up to a modest 2% energy gain at the system level, that would be the equivalent of a roughly 3 cents per Wp cost reduction, according to the National Renewable Energy Laboratory's (NREL) recent cost modelling presented at the 2018 Bifacial Conference in Colorado. If bifacial PV systems could increase output by 10% or more in a way that is predictable and widely adopted by the financial community, it would improve NPV and help many more projects get built.

How investors model bifacial technology today

Until the necessary research on bifacial PV modules is available, investors will most likely continue to associate the technology with a higher degree of risk and uncertainty relative to standard monofacial modules, particularly the cash investors who provide sponsor equity. Why? These are the people taking long-term risk, the ones who make money only after debts have been repaid and tax equity investors have cashed out. The financial community as a whole bases assumptions about a project's financial performance around the idea that cash flows are a known quantity. But since financiers are experts in risk management, not electrical engineering, they rely on IE firms to estimate energy output in one system design configuration or another.

IE analysis can be detailed at times and fairly high level at others. Sometimes the analysis is completed without a site visit, similar to a home appraisal in a real estate transaction. In addition, IEs don't provide a single firm number when predicting solar energy output. Instead, they provide figures based on the probability that output will exceed an estimate. If they say a project has a P50 value of 100,000 kilowatt-hours (kWh), for example, the investor understands that the project has a 50% chance of meeting or exceeding 100,000kWh. A P90 value says a project has a 90% chance of exceeding that estimate. If a project has a P50 value of 100,000kWh, the P90 will be lower than this. The more the uncertainty, the further apart the P90 is from the P50. The P75 or P90 values matter because often banks will lend on these lower-risk estimates. If

you ask three IEs to estimate the energy output for a system with bifacial modules, you're likely to get three different answers.

Years ago, there was enough margin in solar project development that nobody was bothered if a project could outperform its yield estimate by 5-6%. Everybody was making money. Today, leading developers are signing power purchase agreements in the US for 3c per kWh. Margins are thin and there's no room for uncertainty. This is how solar projects are competing with (and beating) fossil fuels. Higher confidence reduces the cost of

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capital and increases deployment. Lower confidence kills deals.

Department of Energy project and goals

In October 2018, the US Department of Energy's Solar Energy Technologies Office announced funding for 53 projects supporting research and development for PV and concentrating solar power, and workforce development initiatives. Among 12 projects aimed at increasing PV affordability and reliability, Cypress Creek Renewables has committed to a multiyear process that will help the solar industry capture the full benefit of bifacial PV technology.

To quantify yield under varying conditions, the project will include a combination of bifacial test stations and megawatt-scale commercially operating systems in different climate zones around the country. It aims to evaluate project yield sensitivity to a variety of design characteristics discussed earlier, including different cell technologies.

Using test results and commercial system output, the project will provide

the necessary input to improve (as needed) and validate modelling of leading simulation software programs, including PVsyst and NREL's System Advisory Model (SAM). Two to three years from now, when a bifacial project lands on an IE's desk, modelling tools and best practices should be able to provide a more accurate estimate of system output with higher confidence.

A central goal of the project is industry outreach and stakeholder engagement. Systems with bifacial modules can achieve a levelised cost below 3¢ per kWh. The only way to get there, however, is to increase investor and IE familiarity with bifacial technology.

Seeking project participants

For the past several years, industry analysts have been predicting that solar will become a primary source of electricity by 2040, outpacing coal and nuclear and, under the most optimistic scenarios, natural gas. Bloomberg New Energy Finance forecasts 6,700GW of solar capacity to be installed globally in 2050, up from about 500GW in 2018. The solar technologies that can reliably demonstrate improved project economics in the market today will be deployed in far greater volumes in the future. We're just getting started.

If you are an investor or an independent engineer with more than 200MWhs per year of solar project participation and have interest in bifacial technology, please contact me to become a project participant and contribute to the industry's adoption of bifacial PV technology. ■

Author

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