QUANTIFYING YOUR BIFACIAL GAINS

Using Calibrated PVsyst Model Input Parameters to Accurately Predict In-Field Performance

By Greg Beardsworth & Amir Asgharzadeh Shishavan, Ph.D.
with Jenya Meydbray of PV Evolution Labs

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Executive Summary Testing at the Center for Solar Excellence, detailed here, indicates that industry-standard mono-PERC bifacial electrical strings fielded on one-in-portrait (1P) single-axis trackers provide additional DC-side gains as compared to equivalent monofacial strings. These additional bifacial gains are on the order of 5% to 7% under low-albedo conditions (≈20%) and 10% to 12% under high-albedo conditions (≈50%). These grid-connected test results are in good agreement with data from bifacial test sites that the National Renewable Energy Laboratory (NREL) and PV Evolution Labs (PVEL) operate. Side-by-side test results further indicate that NX Horizon provides an additional 1.02% to 1.67% of DC-side bifacial gains as compared to other 1P single-axis tracker designs. When using PVsyst to model bifacial gains with calibrated structure-specific inputs, we find a strong correlation between field-measured and PVsyst-modeled bifacial gains. Based on side-by-side test data comparing 1P to two-in-portrait (2P) tracker architectures, we are finding that bifacial modules mounted on a 1P tracker have an albedo-dependent gain advantage of 0.6% to 1.2%.

Capturing the Full Value of Bifacial Gains

Bifacial PV modules convert irradiance captured on both the front and back sides of PV cells into electrical power. From a manufacturing perspective, the evolution from monofacial passivated emitter and rear cell (PERC) to bifacial PERC PV modules is incremental, requiring only a modified solar cell back-side metallization pattern and certain module-packaging adjustments. In the field, this one small step for module companies is potentially one giant leap for the global energy transition.

A recent techno-economic assessment[1] evaluates yield potential and cost effectiveness based on levelized cost of energy (LCOE) for large-scale PV power plant architectures around the world and hints at the disruptive potential of tracker-mounted bifacial PV systems. The report concludes that "bifacial single-axis tracker installations achieved the lowest LCOE values for 93.1% of the total land area." Sensitivity analyses indicate that these results hold "over a wide range of parameter changes," emphasizing "the potential of bifacial one-axis tracking systems to transform the PV market."

The findings come as no surprise to Jenya Meydbray, CEO of PVEL. "Bifacial PV technology represents the single largest LCOE improvement opportunity since the introduction of trackers," Meydbray says. The challenge is to fully capture the value of bifacial PV power plants. "To realize this opportunity, investors need to be able to accurately and confidently predict bifacial performance," Meydbray continues. "For bifacial gains to be financeable, they must first be predictable."

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—Jenya Meydbray, CEO, PVEL

If stakeholders cannot model bifacial gains with confidence, the difference between monofacial and bifacial performance is interesting but not impactful. The industry's ability to precisely and consistently model monofacial PV system performance has reduced project risk, cost of debt, and barriers to adoption. To the extent that bifacial performance models carry comparatively more uncertainty and perceived risk, financiers may subject these projects to a higher debt-service coverage ratio, reducing profitability.

Accurately modeling bifacial gains using industry-standard software requires a combination of product-, design-, and location-specific model inputs. Bifaciality factor, for example, is a module-specific PVsyst input that quantifies the ratio of back-side power to frontside power under standard test conditions. Row-to-row spacing and tracker height are design-specific variables that influence irradiance on the ground and the rear side of the PV modules. Weather and ground albedo are fluctuating location-specific variables that significantly affect in-field performance. Missing from the above are tracker-specific inputs to the PVsyst model, a subject of considerable interest to Nextracker, its project partners, and other industry stakeholders.

To help eliminate barriers to the global energy transition, Nextracker operates a state-of-the-art testing laboratory in Fremont, California. At our Center for Solar Excellence, we have studied bifacial performance, in some capacity, since 2013. At this site, we commissioned a dedicated bifacial testbed in Q1 2019, which integrates commercially representative mono-PERC PV modules on the latest version of the NX Horizon single-axis tracker. High-level takeaways from this world-class bifacial testing laboratory are encouraging, both in terms of the magnitude of real-world bifacial gains as well as our ability to model these empirical gains in PVsyst.

Here, we present our test methodology and findings with the goal of providing actionable content for developers, financiers, independent engineering firms, and performance engineers struggling to characterize fielded bifacial system performance. Note that we use the term *bifacial gains* to specifically describe the additional DC-side energy yields in a bifacial PV array as compared to an equivalent monofacial array. For the basis of comparison, the modules in the monofacial and bifacial arrays are functionally equivalent insofar as they share the same manufacturer, cell technology, cell architecture, and cell stringing; the modules differ insofar as the bifacial product has double-glass packaging whereas the monofacial product has conventional single-glass packaging.

Real-World Bifacial Test Results

One high-level takeaway from our research and data analysis is that additional bifacial energy yields are not only measurable and meaningful, but also consistent across multiple test sites. Comparing field-measured bifacial gains from the Center for Solar Excellence to those from sites operated by PVEL and NREL, as shown in Figure 1, we see that monthly bifacial gains are on the order of 5% to 7% under low-albedo conditions and 10% to 12% under high-albedo conditions.

While these independently operated bifacial testbeds share some similarities—such as utilizing NX Horizon single-axis trackers—the sites are also different in meaningful ways. There are differences in ground cover, module design details, and location. Regardless of any site- or testbed-specific differences, field-measured bifacial gains are similar for high- and low-albedo cases, respectively.

Nextracker Test Center Results The bifacial testbed at the Center for Solar Excellence consists of five 1P tracker rows and four 2P tracker rows, which are located within the rows of a larger array. Test hardware includes bifacial modules from three different vendors. Flash-test results determine front-side power ratings for installed capacity (kWp) calculations. Additionally, rear-side flash test data determine the actual bifaciality coefficient. Researchers use these flash-test data to select the test modules for the best string-level power match. (See Appendix A, p. 18, for photos of the bifacial testbed at the Center for Solar Excellence.)

These equivalent PV source circuits feed 600-volt grid-interactive inverters. By evaluating full 600-volt strings, the test methodology is able to capture the impact of module-to-module mismatch resulting from manufacturing variations as well as non-uniform front- and rear-side irradiance. For reporting purposes, the test methodology normalizes all yield metrics (kWh/kWp) to the aggregate string-level flash-test capacity.

As detailed in Table 1, this bifacial test setup is highly instrumented with calibrated sensors selected for high accuracy. The collected data include global horizontal irradiance (GHI); diffuse horizontal irradiance (DHI); front-side plane-of-array irradiance; rear-side plane-of-array irradiance; representative back-of-module temperatures; and revenue-grade AC power for each string inverter. Consistent with experimental best practices, one-minute interval data are collected for analysis.

Since the goal is to understand DC-side energy generation for a bifacial PV system, the 600-volt test strings have a low DC-to-AC ratio that eliminates inverter power limiting and power curve clipping. The test methodology incorporates regular panel cleanings to minimize soiling effects. To exclude edge-of-row effects that tend to exaggerate system-level bifacial gains, only interior-of-row strings are used for testing purposes. To evaluate bifacial gains for high- versus low-albedo scenarios, the side-by-side test setup alternates between gravel ground cover (≈20% albedo) and a white-fabric ground cover (≈50% albedo).

The Nextracker column in Figure 1 (left) details the field-measured bifacial gains for a six-month period at the Center for Solar Excellence. In the low-albedo scenario (October–December 2019), the additional DC-side gains associated with back-of-module light capture range from 5.4% to 6.6%. In the high-albedo scenario (January–March 2020), the measured bifacial gains are higher due to the increased ground-surface reflectivity and range from 11.4% to 14.5%.

PVEL Bifacial Test Results PVEL operates an independent outdoor testing lab at PV-USA, one of the world's oldest, largest, and most sophisticated field-testing sites. Located in Davis, California, PV-USA is a 10-acre, grid-connected test center where PVEL does a variety of side-by-side technology testing to characterize real-world field performance. Its largest tracker-mounted bifacial study integrates nine different brands of bifacial PV modules mounted on ten NX Horizon rows. PVEL has four manufacturers participating with 1,500-volt test strings; the other five manufacturers are participating with shorter test strings. The bifacial testbed at PV-USA includes two different albedos running in parallel, representing high- and low-albedo groundcovers. The low-albedo case is natural grass, which varies seasonally from green grass, to dry grass, to dirt; the high-albedo case is a white fabric, which has an albedo of roughly 45%. (See Appendix B, p. 19, for photos of the bifacial testbed at PV-USA.)

Field Testing Comparison

Site Parameters	Nextracker	PVEL
PV Cell Technology	Mono PERC	
Backsheet	Transparent with white grid	Transparent
Bifaciality Coefficient	68%	77%
Bifaciality Testing	Flash measured	
Module Characterization	Pre-light soak flash test	
Tracker	NX Horizon Gen 2.4	
Ground Coverage Ratio	0.31	0.37
Rotation Axis Height	1.5m	1.2m
Low-Albedo Surface	Gravel (≈20%)	Dirt/Grass (≈23%)
High-Albedo Surface	White fabric (≈50%)	White fabric (≈45%)
Power Conversion	String Inverter	
Nominal System Voltage	600 V_{DC}	1,500 V_{DC}
Inverter Loading	Low DC-to-AC power ratio (no clipping)	
Power Measurement	Inverter revenue-grade meter	DC-side current & voltage
Data Collection	1-minute interval	
GHI Sensors	Hukseflux	
DHI or DNI Sensors	Hukseflux. Delta-T	
Rear-Side POA Sensors	Yes	
Washing Protocol	3 washes in 6 months	Weekly washes

TABLE 1 **The bifacial testbeds that Nextracker and PVEL used as the basis of this comparison are substantially similar in important ways, such as module technology, tracker model, and adherence to experimental best practice. Relevant site- and installation-specific differences between the two testbeds are also detailed here.**

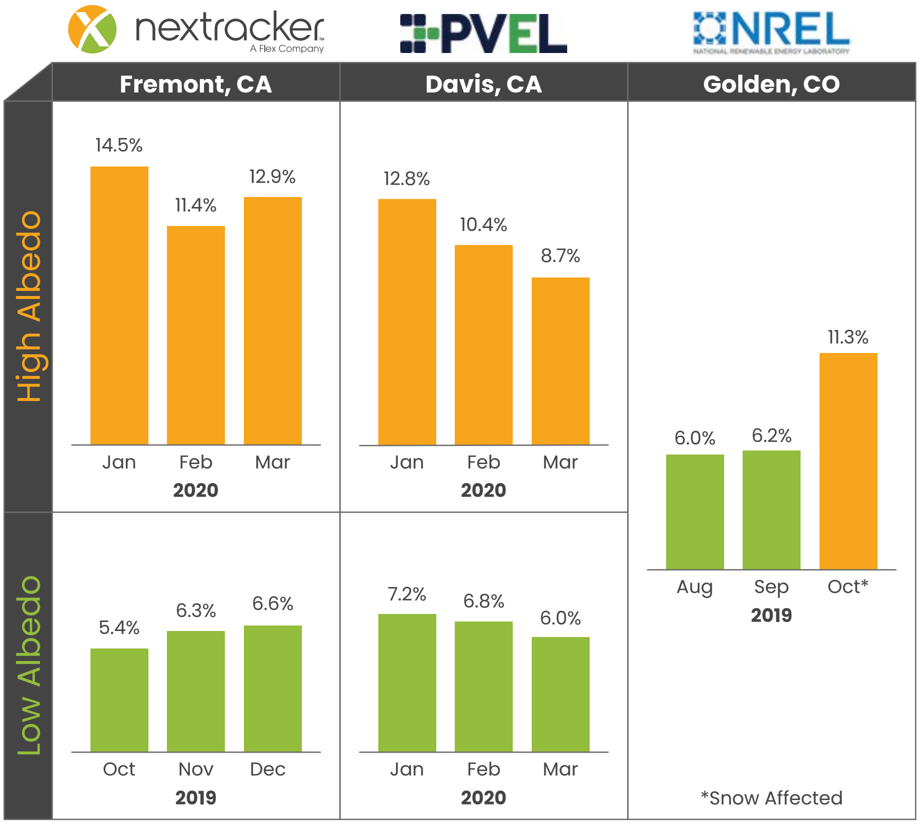

FIGURE 1 **Each of the columns summarizes field-measured bifacial gains on 1P single-axis trackers for three independently operated state-of-the-art testing centers. While the NREL site has native ground cover only, bifacial gains for snow-affected months in Golden, Colorado[2], show good agreement with the high-albedo test scenario results measured in Fremont and Davis, California.**

The PVEL column in Figure 1 (center) details the field-measured bifacial gains for tracker-mounted mono-PERC modules over a three-month period (January–March 2020) at the PV-USA test facility. In the low-albedo scenario, the additional DC-side gains associated with back-of-module light capture range from 6.0% to 7.2%. In the high-albedo scenario (January–March 2020), the measured bifacial gains are higher, due to the increased ground-surface reflectivity, and range from 8.7% to 12.8%.

Testbed Comparison Table 1 summarizes some of the similarities and differences between the bifacial testbeds that Nextracker and PVEL used here as the basis of comparision. In terms of similarities, both testbeds are heavily instrumented and integrate the same brand of mono-PERC bifacial PV modules on NX Horizon single-axis trackers. Frequent washings are common to both sites, as are low DC-to-AC ratios. Lastly, both test centers rely on direct measurement of DHI or direct normal irradiance (DNI), which is important for model calibration; transposing these values from GHI can introduce error, making measured versus modeled results less consistent.

In terms of notable differences, the modules at the Center for Solar Excellence have a white grid between the cells, whereas those at PV-USA have a transparent grid. As a result, PVEL's test modules have a relatively higher bifaciality factor due to more sunlight reaching the ground cover and getting reflected back to the module's backside. Ground-coverage ratio (GCR) and row height are slightly different between the sites. Nominal string voltage differs between the sites. Lastly, though both sites include high- and low-albedo test conditions, there are slight differences between surface albedo values. These different albedo values are meaningful, as ground reflection characteristics have a significant effect on bifacial system performance. Different ground materials have different albedo values and the value may vary by season, weather, and time. Type of materials also matters since the materials might have different spectral albedo, which is another variable that impacts bifacial system peformance.[3] These differences will influence field-test results.

To characterize performance in commercial power plants, the Nextracker and PVEL test facilities operate

NX Horizon-Specific PVsyst Model Inputs

PVsyst Parameter	Calibrated Bifacial Input Parameters
Structure Shading Factor	12.3%
Mismatch Loss Factor	3.5%
Shed Transparent Fraction	Module Transparency Factor + 2.1%
Uc (constant component)	25 W/m²k
Uv (wind velocity)	1.2 W/m²k/m/s
Module Height	1.35–1.50m (project-specific variable)

TABLE 2 **Use the model input parameters detailed here to account for the unique characteristics and geometry of the NX Horizon single-axis tracker—such as 90mm of torque tube-to-PV cell separation, 127mm-round torque tube, 400mm-long mounting rails, as well as bearing and motor gaps. Model-validation studies indicate that these manufacturer-recommended PVsyst inputs accurately and reliably model bifacial gains on the NX Horizon, with a slight bias toward underprediction.**

bifacial testbeds that study *interior* electrical strings, which mitigates edge-of-row effects. This is an important distinction. On the one hand, tests that study individual modules or end-of-row modules will result in higher field-measured bifacial gains at the module level. On the other hand, these enhanced results will tend to overstate system-level bifacial gains in the real world.

Comparing Gains Across Sites Despite site- and design-specific differences between the Nextracker and PVEL sites, field-measured bifacial gains at both testbeds are similar in magnitude. Moreover, the results from these California sites are similar in magnitude to measured bifacial gains at a testing facility in Colorado that NREL operates.

As is the case at the California sites, NREL's bifacial test facility integrates mono-PERC bifacial modules on NX Horizon trackers. The site has natural ground cover, similar to the low-albedo ground cover beneath the PVEL testbed. The NREL column in Figure 1 (right) summarizes field-measured bifacial gains for a three-month period (August–October 2019) in Golden, Colorado. The site's managing research engineer, Chris Deline, and his colleagues reported these results in December 2019.[2]

Comparing results across all three sites, the empirical bifacial gains at NREL generally track those for the low-albedo test cases in California. Similarly, NREL's snow-affected results in October generally track the high-albedo test case results. Insofar as consistency breeds confidence, the general agreement between these field-measured bifacial gains—under both high- and low-albedo conditions, as well as across multiple test facilities and states—is encouraging.

Calibrating PVsyst Inputs for NX Horizon

What follows here is a description of the comprehensive process that we used to derive and calibrate product-specific PVsyst inputs for the NX Horizon single-axis tracker. Outside of an idealized or virtual environment, there is no such thing as a hovering row of bifacial modules free of back-side structure shading. As long as the industry needs trackers to rotate bifacial arrays for optimal yield, structure shading and mismatch loss factors in PVsyst are inherently non-zero values.

With that in mind, we used a computationally intensive and iterative process to determine PVsyst model inputs that accurately and reliably describe bifacial gains on the NX Horizon single-axis tracker. The results of this comprehensive analysis are the calibrated structure shading and mismatch loss factors in Table 2.

Calculating Structure Shading Factor The *structure shading factor* in PVsyst accounts for the impacts of any obstacles between the ground and the back side of bifacial modules in fielded systems. These obstacles block reflected and diffuse light from reaching cells on the rear side of the panel and decrease the incident back-side irradiance. To determine this factor, we used an open-source three-dimensional (3D) ray tracing model developed by NREL. The bifacial_radiance computer software[4] can calculate cell-level front- and back-side irradiance based on a 3D structure model, accounting for rear-shading impacts of physical details such as module frame, torque tube, and mounting rail.

Determining an NX Horizon-specific structure shading factor requires a comparison of two model scenarios,

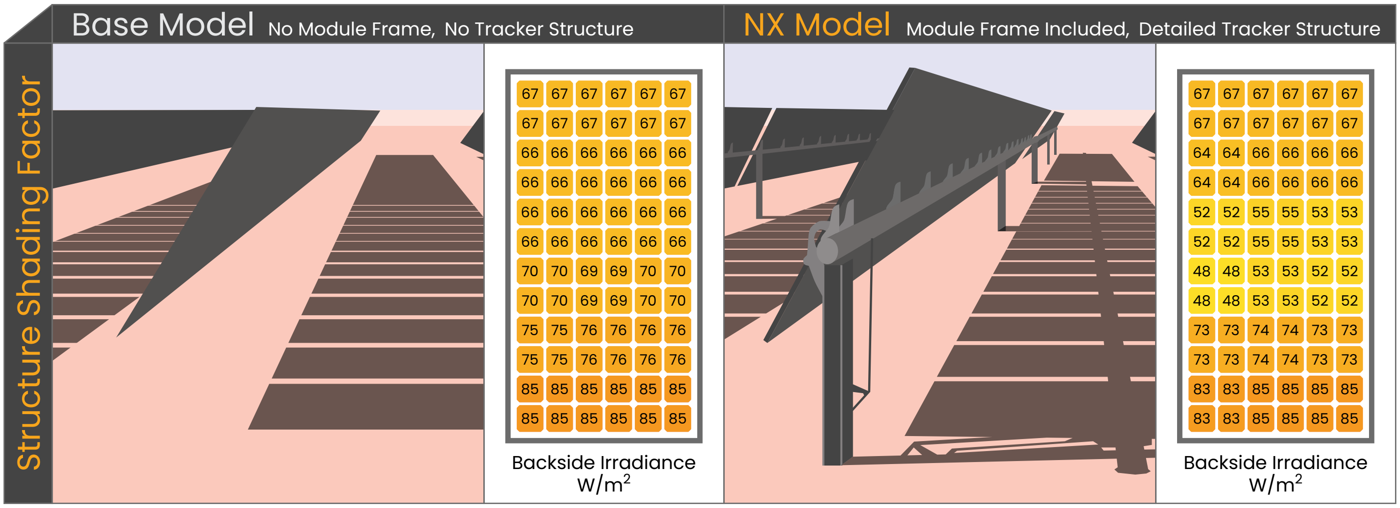

FIGURE 2 **Bifacial_radiance software can derive cell-level back-side irradiance heat maps based on an idealized array with no back-side shading (left) or based on a structure-specific 3D model (right). By comparing the idealized base model to the NX Horizon-specific model, we can determine the structure shading factor input parameter to PVsyst.**

summarized here in Figure 2. The first scenario, or base model, models a simple surface representing the modules only, with no back-side structure or module frames present to introduce rear-side shading. The second scenario is an NX Horizon-specific ray tracing model that accounts for the PV system with all of its physical details, such as module frames, mounting rails, torque tube, bearings, piers, and drive components. For this detailed model, we directly import the CAD model for the tracker into the ray tracing program.

The detail of this 3D simulation is exceptionally rigorous insofar as it is able to account for the impact of all elements of the backside structure. Whereas other published studies have used valid methods and software to calculate structure shading factor, most researchers are unable to model the structure in detail. Studies that model the impact of the torque tube only[5, 6]—ignoring the foundation and drive components—invariably underestimate structure shade factor values.

Based on these 3D models and scenarios, the bifacial_radiance software produces cell-level irradiance maps for the rear side of the bifacial modules, as illustrated in Figure 2. By comparing the back-side irradiance heat map for the detailed NX Horizon model against the base model, we are able to derive the structure shading factor. In this analysis, the base model represents the theoretical maximum back-side cell-level irradiance. As expected, the back-side irradiance for the detailed model is reduced, relative to the base model, due to the impacts of back-side obstacles.

In order to calculate the reduction in irradiance due to back-side obstacles for bifacial PV systems fielded using the NX Horizon single-axis tracker architecture, we ran annual simulations for both model scenarios using typical meteorological year (TMY) weather data. We then calculated the structure shading factor for NX Horizon as the total percentage of reduction in the annual accumulated back-side irradiance. In other words, the structure shading factor is the total reduction in kWh/m^2 caused by any obstructions between the module and the ground. The NX Horizon-specific structure shading factor derived using this methodology is 12.3%.

Note that structure shading factor only accounts for reductions in back-side irradiance. It does not account for the electrical effects of non-uniform back-side irradiance. Performance engineers must consider an additional loss factor to account for the electrical impacts due to irradiance mismatch.

Calculating Mismatch Loss Factor The *mismatch loss factor* in PVsyst accounts for the fact that irradiance is not distributed evenly on the back side of bifacial systems. Spatial nonuniformity of irradiance causes mismatch loss, which reduces system energy yield. Back-side mismatch loss is always present in tracker-mounted bifacial systems, even in a theoretical scenario with no physical support structure, because the intensity of ground-reflected irradiance across the back side of a module varies due to differences in the view factor and distance to the ground.

We used PVMismatch, a free open-source software program developed by SunPower, to determine the mismatch loss factor for NX Horizon. PVMismatch is a two-diode electrical model capable of assigning different irradiance values to each cell. Since the software can model cell-level irradiance variations, it is able to calculate mismatch caused by back-side nonuniformity.

To calculate the mismatch loss factor, we modeled two scenarios with PVMismatch, as illustrated in Figure 3. In one scenario, we ran the model using detailed cell-level irradiance values derived using the ray tracing model. In the other scenario, we calculated the average back-side irradiance and assigned this value uniformly to all of the cells. The difference between the generated energy of these two scenarios gives us the mismatch energy loss due to nonuniform back-side irradiance.

We ran annual simulations based on TMY weather data and calculated the back-side energy loss due to spatial nonuniformity. We accounted for the fact that the mismatch loss factor in PVsyst is not a measure of system-level energy loss but rather of back-side-contributed energy loss. We then calculated the back-side mismatch loss factor for bifacial systems mounted on NX Horizon to be 3.5%.

Modeled Versus Measured Bifacial Study We used PVsyst for model validation against the field-measured bifacial gains, as PVsyst is the industry standard modeling software for utility-scale power plants. The PVsyst inputs for this comparison include hourly measured weather data from our testing facility (DHI, GHI, ambient temperature, and wind speed) in combination with site-specific input parameters (GCR and albedo), module-specific parameters (PAN files plus measured bifaciality factor), and NX Horizon-specific bifacial input parameters (structure shading factor and mismatch loss factors described earlier). We then compared measured energy values from the field to the modeled energy values in PVsyst across different time scales, including hourly, monthly, and quarterly.

To analyze measured versus modeled results, we compared field-measured bifacial gains from the otherwise identical monofacial and bifacial strings, against PVsyst-modeled gains from simulating otherwise identical monofacial and bifacial strings. By using the real-world–measured weather data experienced at our test site, captured using calibrated on-site instrumentation, as the weather input to PVsyst rather than TMY data, we can assess the overall accuracy of PVsyst against reality in a controlled testing environment.

It is important to recognize that some deviation is inevitable between field-measured and

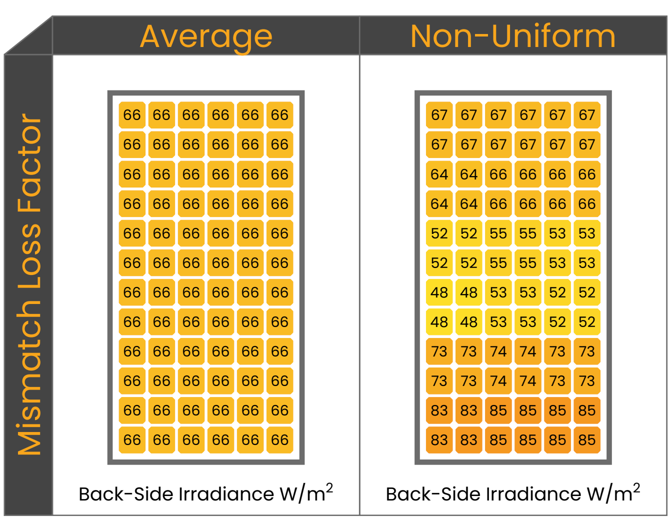

FIGURE 3 **The non-uniform cell-level back-side irradiance heat map shown here (right) is derived based on bifacial_radiance ray-tracing software simulations. To calculate the electrical effects of non-uniform irradiance, we use PVMIsmatch to compare the energy output of the system with non-uniform backside irradiance profile to a hypothetical scenario where the average irradiance value is uniform across the back side of the module (left), which determines the mismatch loss factor model input parameter for PVsyst.**

PVsyst-modeled performance. Each model input parameter caries some uncertainty, from the module characteristics in the PAN files to the inverter characteristics in the OND files to the weather characteristics in the TMY data. The overall accuracy of PVsyst reflects the methodologies of the model itself plus the uncertainties contributed by the data input to the model. Within this context, NX Horizon-specific bifacial loss factors are a relatively smaller contributor to overall model versus measured agreement. Therefore, we do not believe it is appropriate to "tune" the structure-specific shade and mismatch factors for the purpose of calibrating the overall PVsyst model results to perfectly match the measured results.

Modeled Versus Measured Results Analyzing the modeled versus measured results for both the Nextracker and PVEL testbeds, we see that PVsyst is reasonably good at predicting bifacial gains on NX Horizon based on manufacturer-recommended loss factors. While the data reveals a slight trend toward underprediction, this bias is preferable to overprediction.

Figure 4 details the results for the high-albedo (top) and low-albedo (bottom) test cases from both the Nextracker and PVEL test centers. For the high-albedo case, the PVsyst-modeled bifacial gains are 11.2% over three months, which compares favorably to the aggregated field-measured gains of 12.5%. For the low-albedo case, the PVsyst-modeled bifacial gains are 5.5%, which compares favorably to the aggregated field-measured gains of 5.9%. As a general rule, the offset between the measured and modeled results is consistent for individual months and the cumulative three-month data.

The December results are a notable exception to the rule. For this particular month, PVsyst-modeled results overpredict the measured results. To understand why this might be the case, we plotted daily modeled versus measured bifacial gains according to the *diffuse fraction index* (DFI), which describes the daily ratio of diffuse to global horizontal irradiance. These daily plots—found here in Appendix C (p. 20)—indicate that PVsyst will tend to underpredict bifacial gains for sunny months and overpredict bifacial gains for cloudy months, such as December 2019 in Fremont, California. This result is not alarming, since a PV power plant yields the bulk of its energy under sunny conditions.

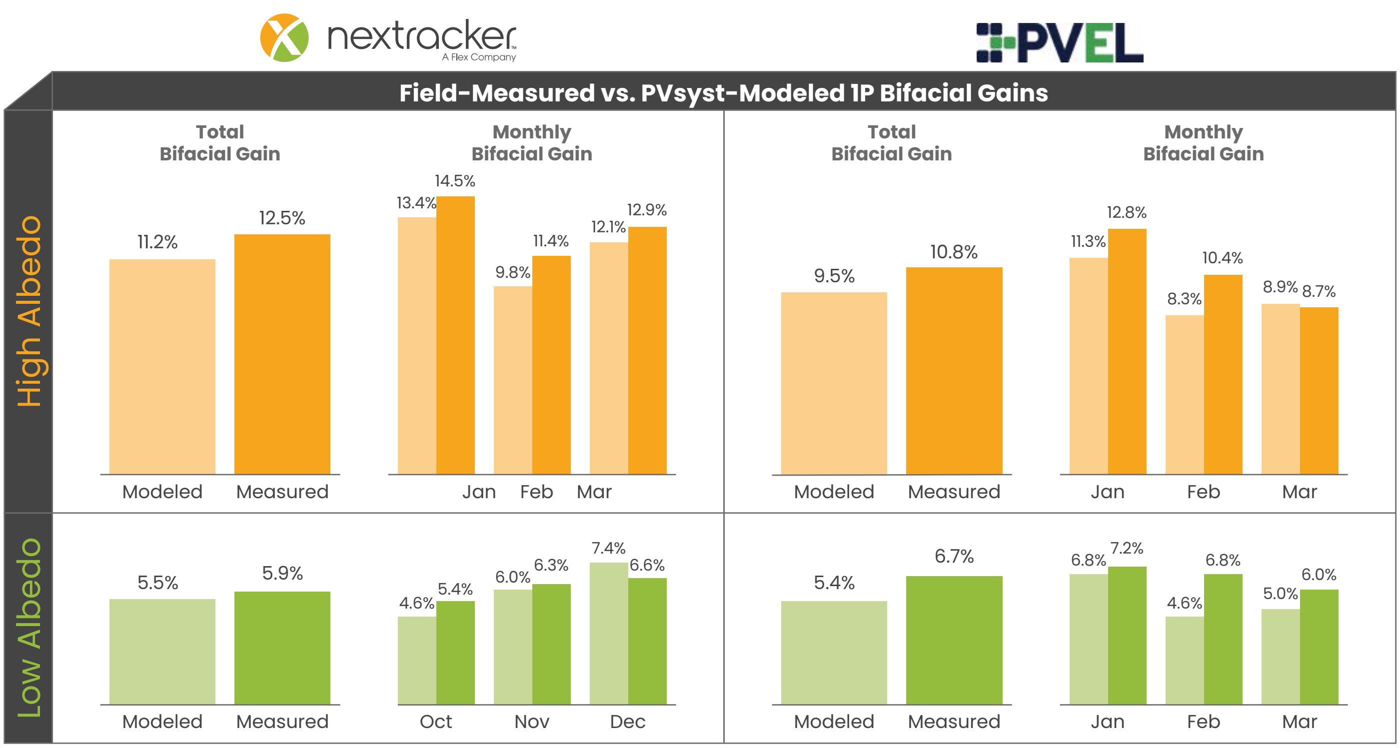

FIGURE 4 Comparing in-field measured bifacial gains to those modeled in PVsyst based on field-measured weather data and the NX Horizon-specific model input parameters from Table 2 (p. 6), we find good agreement between modeled and measured results. The trend toward underprediction appears to result from a slight bias in PVsyst, as shown in Appendix C (p. 20).

Optimizing Bifacial PV Power Plants

By Jenya Meydbray, CEO, PVEL

Designing and building a bifacial PV power plant is not much more difficult than building a monofacial power plant. Optimizing a bifacial solar plant, however, is far more complex. Bifacial energy gains are sensitive to many variables that do not impact monofacial plants, such as tracker height-to-width ratio, and obstructions below the module. Of course, albedo is the most critical parameter that uniquely impacts additional bifacial energy yields. These factors explain why there will always be some differences in bifacial gain across sites.

Ground Reflectance Albedo is a dimensionless quality that describes the ratio or percentage of surface-reflected light to the original incident irradiance. Part of the challenge of accounting for ground surface reflectivity in bifacial applications is that albedo is not a single value. Not only does the magnitude of the albedo change based on the time of day or year, but also the spectrum of the albedo changes based on the ground cover. The spectrum of the albedo is different for grass versus rocks versus snow. Since it is impractical for developers to artificially increase albedo in free-field applications, the relevant project optimization goal is to accurately characterize site-specific average or monthly albedo values.

Back-Side Shading Tracker design and orientation also have a significant impact on bifacial gains. These factors include: torque tube shape; torque tube distance from the back of the module; post and bearing orientation; tracker height-to-width ratio; row-to-row spacing; and view factor. Obstructions located between the modules and the ground will impact bifacial gains. These obstructions can include balance-of-system components, such as wire trays, PV wire, combiner boxes, and so forth. The support structure itself also contributes to back-side shading. Unlike albedo, project design engineers can influence back-side shading via strategic product selection and design decisions.

REAR-SIDE OBSTRUCTIONS **To optimize bifacial PV power plant performance, look for opportunities to reduce back-side shading via strategic product selection and deployment. In addition to structure shading, consider the impacts of combiner box placement, cable trays, home run conductors, and wire management. See Appendix D (p. 21) for an overview of the manufacturer-recommended wire management details for the NX Horizon.**

Module Mismatch In the field, strings of PV modules are wired in series so the same electrical current passes through each module. In a 1,500-volt system, 28-module strings are typical. Unfortunately, the optimal output current to achieve maximum output power may be slightly different for each PV module. The level of the optimal output current is influenced by multiple factors including manufacturing variations, degradation, and irradiance. Non-uniform degradation of mono- or bifacial PV modules can be caused by potential-induced degradation (PID), light and elevated temperature induced degradation (LeTID), encapsulant yellowing, and other factors.

For bifacial PV module technology, the relevant irradiance level for determining module mismatch is the combination of front-side irradiance and back-side irradiance. In the absence of shading from nearby objects, such as trees or adjacent module rows, the front-side irradiance level is typically consistent across modules. However, the irradiance on the rear side of the module is impacted by obstructions between the back of the module and the ground. Minimizing these obstructions will reduce mismatch losses.

Electrical Stringing In 2P-tracker designs, electrical stringing is also a potential source of module mismatch. Specifically, it is suboptimal to have modules from an upper row in the same electrical string as modules on a lower row. In this scenario, the intensity of the reflected sunlight on the back side of the modules varies between the rows based on distance to the ground. This irradiance nonuniformity will increase mismatch effects. Similarly, portrait versus landscape orientation could have an impact on mismatch based on whether the nonuniform back-side irradiance is perpendicular to or in parallel with the cell strings and bypass diodes.

Product Qualification PV module selection is one of the most dynamic and critical aspects of developing a solar project. Module technology is evolving quickly. Form factors and power ratings are increasing. Some manufacturers are increasing wafer size. Others are using half-cut or even third-cut cells. Internal circuit wiring methods differ. Bifacial modules may have glass-glass or glass-backsheet packaging. Bill-of-material (BOM) details will vary, based on manufacturer, factory, or even batch. Bifacial modules can exhibit different degradation on the front and the back, which will impact bifacial energy gains over time.

Selecting the right product for a given project will always depend on site-specific environmental conditions as well as project-specific financing requirements. PVEL's Product Qualification Programs (PQPs) are focused on evaluating the quality of PV modules, inverters, and energy-storage systems across a comprehensive set of reliability and performance tests. Developers and banks can access these PVEL reports at no cost to help with vendor selection. Learn more at pvel.com/pqps

This slight weather bias underscores why it would be inappropriate to use structure-specific bifacial model inputs in PVsyst for the purpose of globally aligning modeled to measured results. Based on the analysis detailed in Appendix C (p. 20), we believe that the key factors contributing to this modeled versus measured discrepancy are unrelated to the structure shade and mismatch factors that are the primary subject of our investigations. As the accuracy of the PVsyst model improves, we can likewise fine-tune and improve the accuracy of our structure-specific model input parameters. In the meanwhile, the general alignment between measured and modeled results indicates that the industry can use standard modeling tools, such as PVsyst, to estimate back-side POA irradiance, and bifacial gains by extension, with confidence.

NX Horizon Bifacial Gain Advantage

Four unique features, shown here in Figure 5, differentiate the NX Horizon from other single-axis tracker platforms. First, NX Horizon uses a round torque tube and high-rise mounting rails that result in a tube-to-cell height of 90mm. The increased standoff height, relative to other platforms, is intentional as it provides a performance advantage in bifacial applications. Second, NX Horizon is unique in that it has a small gap at each bearing assembly, which means the bearings and posts are not located directly below or in close proximity to bifacial cells. Third, NX Horizon has a gap at each foundation that installers can use as a wire chase. Routing DC source circuit conductors under the torque tube, as detailed in Appendix D (p. 21), can improve specific yield by 0.25% to 0.35%, depending on albedo. Lastly, the drive system components for NX Horizon are not located directly underneath the bifacial modules but rather in a larger gap at the center of each NX Horizon row. Because of these unique design features, NX Horizon has a distinct advantage in bifacial applications relative to other single-axis trackers.

NX Horizon Advantage in Side-by-Side Tests To quantify the NX Horizon bifacial gain advantage, we conducted controlled side-by-side tests using identical strings mounted on two different tracker designs. The goal of this study was to empirically calibrate the *difference* between the structure shading and mismatch loss factors for these two structures. Within the context of this controlled experiment, since all other factors are identical, it is valid to use the structure-related inputs to PVsyst as adjustment levers, so to speak, to develop calibrated structure-specific model input parameters. This means that the measured bifacial gain delta between NX Horizon and

NX Horizon Bifacial Enhancing Features

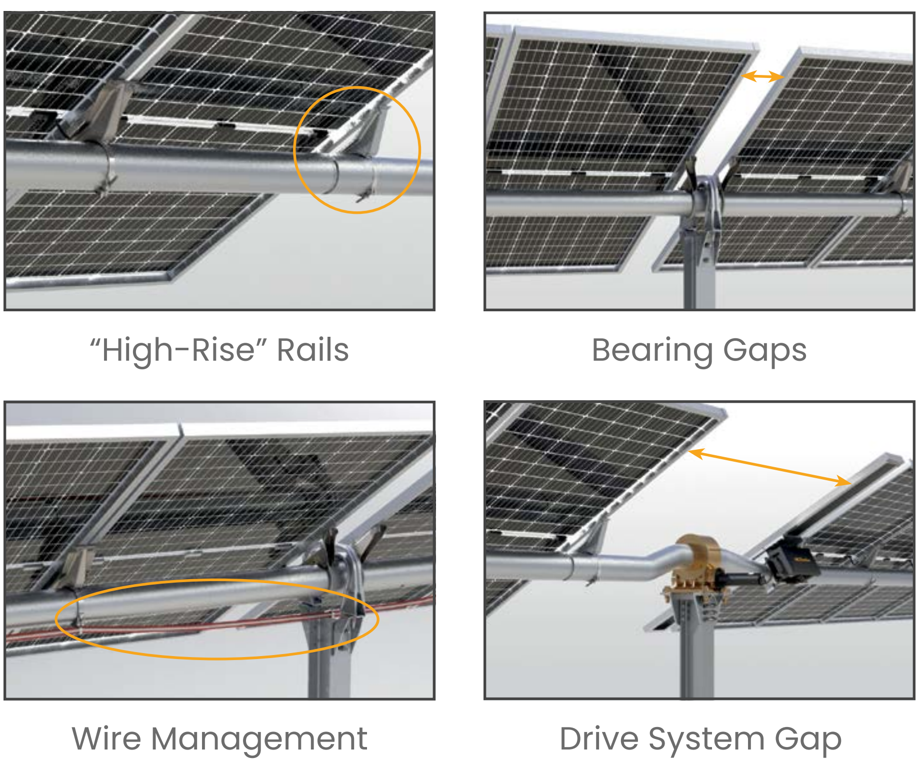

FIGURE 5 As compared to other single-axis tracker designs, NX Horizon features four unique bifacial enhancing features: 1.) high-rise mounting rails that provide 90mm of clearance between the round torque tube and the back side of the bifacial cells; 2.) a small bearing gap; 3.) shade-mitigating wire bundle accommodations; and, 4.) a large drive system gap. Note that the gaps in the tracker tables both increase back-side irradiance and reduce shading resulting from structural and drive components.

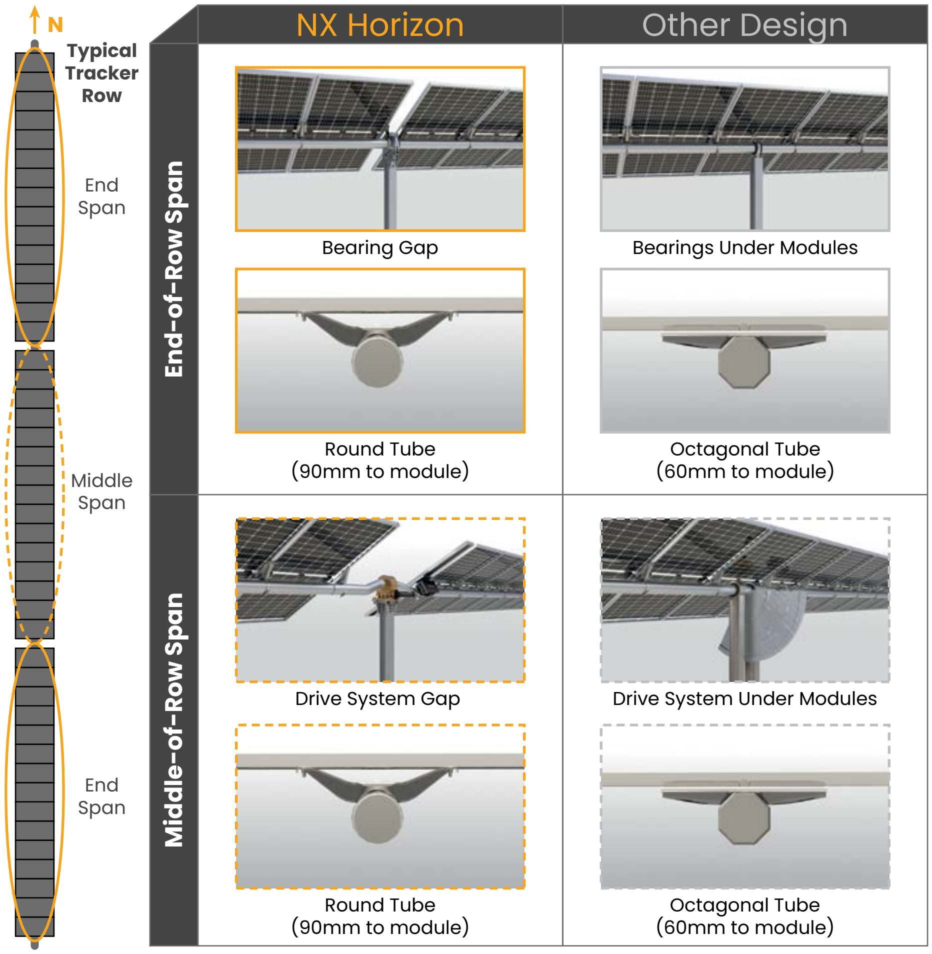

FIGURE 6 **This figure details the structure-specific characteristics of the NX Horizon (left) as compared to a common ganged-row tracker (right). In our side-by-side tests, the control string (NX Horizon) configuration remained constant while we alternated the mechanical configuration of the experimental string monthly to characterize the bifacial performance of the end-of-row (top) and middle-of-row (bottom) spans for the other tracker design.**

alternative tracker designs will align to the modeled bifacial gain delta, but the overall accuracy of the bifacial gains modeled versus measured will be the same for both systems.

The control, or baseline, for the side-by-side testing is a string of NX Horizon-mounted bifacial modules, spanning between two posts; this baseline represents the standard NX tracker unit. Directly adjacent to the control string is the experimental string, which integrates an equivalent 600-volt string of identical bifacial modules from the same manufacturer. Both strings are located in the interior of the array to eliminate edge-of-row bias. PV source circuit conductor lengths are identical for both strings. Tracker angle is identical for both strings, as both share the same support structure and are actuated by the same control system. Both the control and experimental PV source circuits are grid-connected via 600-volt string inverters. The only difference between the control string and the experimental string are the unique mechanical system details underneath the modules.

The mechanical structure for the experimental string is generally characterized by an octagonal torque tube with a tube-to-cell height of 60mm, as well as foundations and bearings located directly below the bifacial PV cells. On a monthly basis, we reconfigure the mechanical structure of the experimental row to represent structural configurations found in alternative one-in-portrait single-axis tracker designs. By reconfiguring the experimental row, we are able to analyze sub-string–level performance in a typical 1,500-volt system and capture the effects of different structural features.

In effect, we are breaking a typical tracker row into its constituent parts , as shown in Figure 6. On average, a typical tracker row has an eight-module span between foundation posts and three spans per source circuit. With an NX Horizon system, the basic structural shade profile under each of these three spans is more or less identical. In practice, the end-of-row and motor-gap spans will capture somewhat more ground-reflected light as compared to the middle-of-row span, due to the gap between rows and the motor

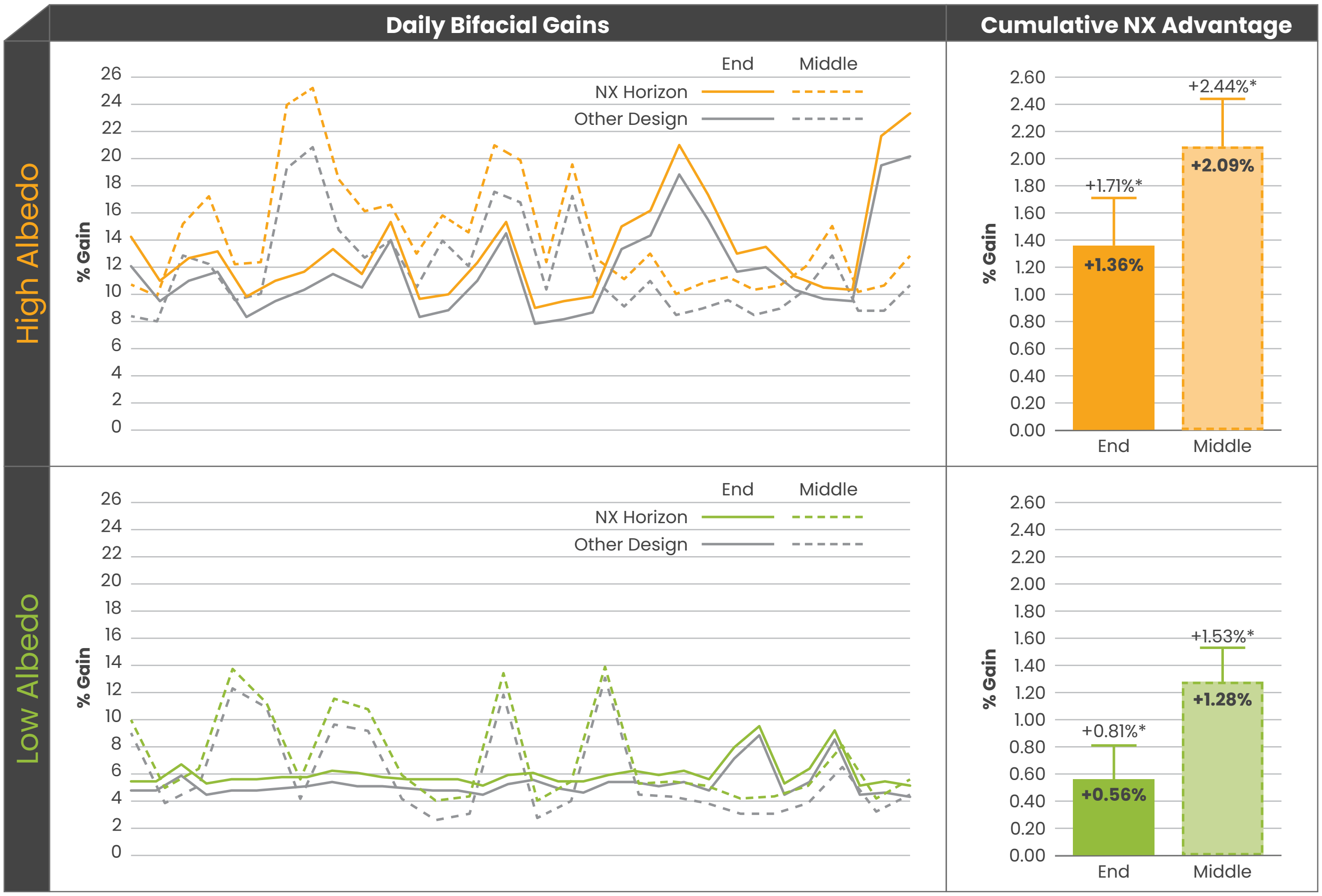

FIGURE 7 The daily data plots (left column) show the side-by-side bifacial gains for the NX Horizon and the other tracker design under high-albedo (top row) and low-albedo (bottom row) conditions. The bar charts (right column) aggregate the cumulative bifacial gain advantage of the NX Horizon relative to the other tracker design. Depending on ground albedo, an NX Horizon-mounted bifacial array will generate an additional 0.56% to 1.36% of bifacial gains as compared to the end-of-row spans (solid lines) and an additional 1.28% to 2.09% of gains as compared to the middle-of-row span (dotted lines). (*NX Horizon enables continuous DC cable management along the torque tube, including passing wiring through the bearing housings. Other 1P trackers do not allow for this and shade-free DC cable management may not be practically achievable. NX Horizon can thereby provide an additional albedo-dependent bifacial gain advantage of 0.25% to 0.35% annually, by avoidance of DC cable shading. See Appendix D, p. 21 for more detail.)

gap. Since the middle-of-row span characterizes the worst-case scenario, we used this as our experimental control to represent the basic in-field building block.

In the case of the experimental tracker design, detailed in Figure 6, two of the three eight-module spans have identical structure shade profiles, whereas the other eight-module span has a unique shade profile due to the drive-system components. In this case, two distinct structure profiles are required to characterize this system and calibrate the model inputs. To test the impacts of the drive-system components in the center of the other tracker row, for example, we installed mockups of these components at appropriate locations and accumulated one month's worth of data. Removing these drive-component mockups, we could then gather an additional one month's worth of data characterizing the performance of the other two-thirds of the experimental tracker row.

By varying the mechanical details of the experimental string and comparing its performance over time to the control string, we are able to isolate and quantify the impacts of specific structural design choices. The resulting time-series data indicate that the bifacial gains for the NX Horizon control string are larger than the gains measured in either of the experimental string configurations. Not surprisingly, the NX Horizon bifacial advantage is largest when compared to an experimental string with drive and actuation

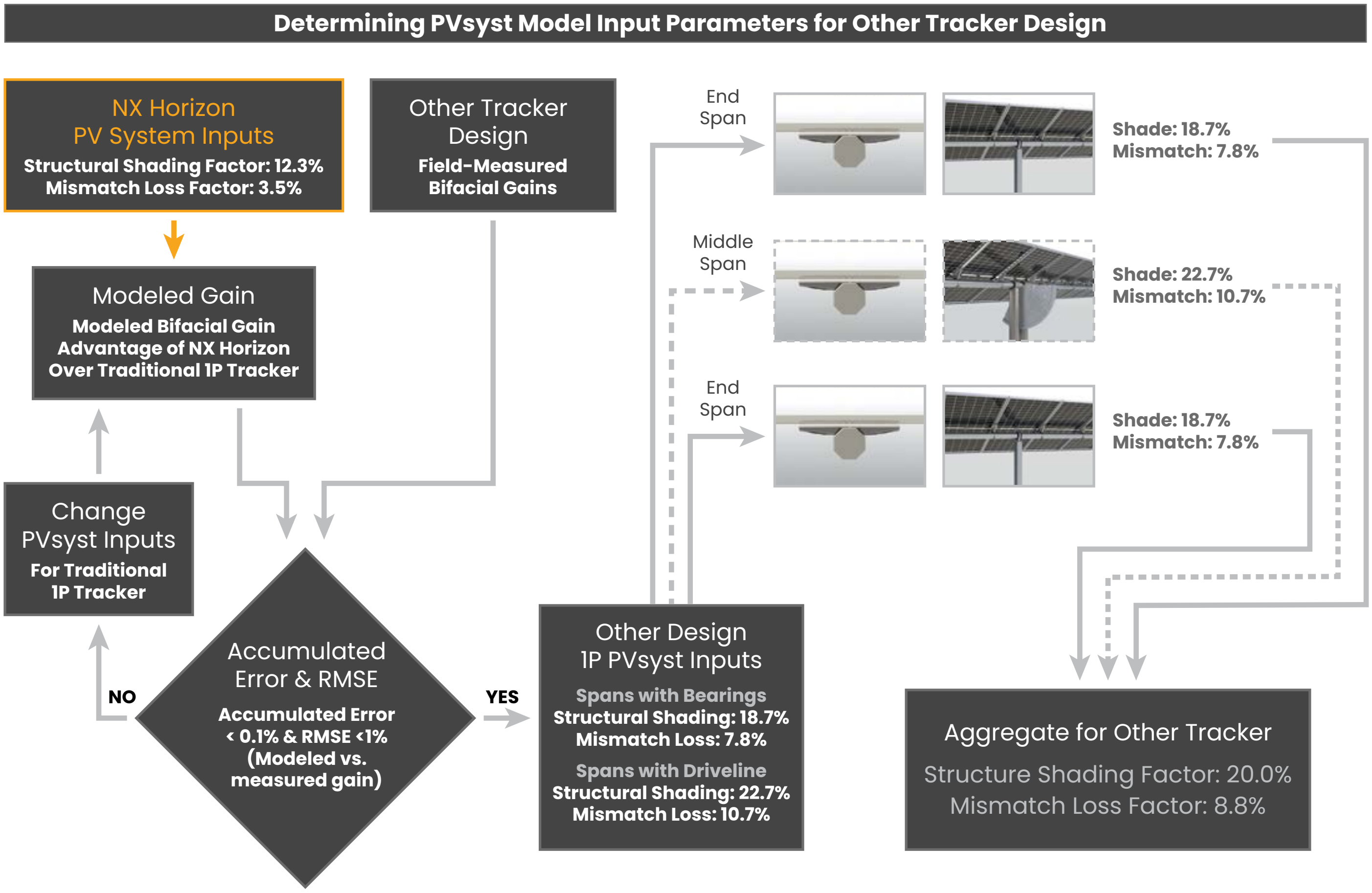

FIGURE 8 **The flow chart on the left details the iterative process used to determine the PVsyst model input parameters for the other tracker that best characterized the in-field performance on the end-of-row and middle-of-row spans. Weighted averaging accounts for the fact that each 1,500 V_{DC} string includes two end-of-row spans and one middle-of-row span. The resulting structure-specific PVsyst model input parameters for the other tracker design are: structure shading factor = 20.0%; mismatch loss factor = 8.8%.**

components located directly below the modules. This is logical since the introduction of obstacles between the back side of a bifacial array and the ground will increase structure shading and reduce bifacial gains.

Cumulating data over the test period for the low- and high-albedo scenarios, as shown in Figure 7, we find that the control string produces an additional 0.56% to 1.36% of bifacial gain versus the end-of-row experimental string configurations. As compared to the middle-of-row configuration with drive components, we find that the NX Horizon has a bifacial gain advantage of roughly 1.28% to 2.09%, depending on the ground-surface albedo.

These data clarify that the NX Horizon bifacial gain advantage is measurable, repeatable, and consistent across all test conditions. Moreover, our test methodology incorporated a control period—during which the underlying structure for both test strings was identical—to validate these results. The control period data confirms that no intrinsic bias exists between the two strings.

Modeling the NX Horizon Advantage Working backward from the side-by-side empirical test data, we use the iterative process outlined in Figure 8 to determine the appropriate delta in PVsyst model inputs for the two different experimental string configurations. The goal of this iterative process is to determine the structure shading and mismatch loss factors that best fit with the observed difference in bifacial gains. This process uses validated NX Horizon PVsyst inputs as a starting point and compares modeled bifacial gains for end-of-row and middle-of-row design configurations to field-measured gains. By constantly changing the model inputs and evaluating the accumulated error and root-mean-square error in the modeled versus measured results, it is possible to identify the specific structure shading and mismatch loss factors that best represent

Quantifying Your Bifacial Gains

PVsyst Input Parameters	NX Horizon	Other 1P Tracker	
	Good DC Wiring*	Good DC Wiring**	Poor DC Wiring
Structure Shading Factor	12.3%	20.0%	24.3%
Mismatch Loss Factor (rear)	3.5%	8.8%	9.0%
Shed Transparent Fraction* **	MT + 2.1%	MT + 1.0%	MT + 1.0%

PV Syst Annual Energy Impact

Low-Albedo Case	Baseline 1	-0.77%	**-1.02%**
High-Albedo Case	Baseline 2	-1.32%	**-1.67%**

*Easy to accomplish with DC wiring pass through at bearing
**More difficult to accomplish; no DC wiring pass through at bearing
***MT = Module transparency fraction

TABLE 3 **This table provides calibrated structure-specific PVsyst model input parameters (top) for the NX Horizon versus the other 1P tracker design, with and without good DC wire management. It also summarizes the estimated annual energy impact (bottom) associated with these different scenarios.**

"It is logical that structure shading factor will increase in magnitude with the addition of back-side structural components, such as bearings, piles, and drive mechanisms."

—Jenya Meydbray, CEO, PVEL

each of the experimental string configurations. This iterative process identified the PVsyst inputs for the other mechanical designs, detailed in Figure 8 (left side), as providing the best fit between measured and modeled results.

In a 1,500-volt system, both of these other mechanical design conditions will be present on individual strings. For the subject of this comparative analysis, two-thirds of the bifacial panels will be affected only by under-module bearings and foundations; one-third of the modules will be additionally affected by under-module drive components. To account for these blended effects, we used a weighted averaging approach to determine model-input factors that represent the other mechanical assembly in aggregate, which accounts for the fact that PVsyst does not easily model individual strings separately. The results of this analysis are summarized in Table 3. For the analyzed set of variables, PVsyst can model the aggregate effects of additional back-side shading in the other mechanical design using a structure shade factor of 20.0% and a mismatch loss factor of 8.8%.

PVEL's Jenya Meydbray notes that the results of this analysis are logically consistent with our understanding of fielded bifacial system performance. "On the one hand, structure shading factor is

FIGURE 9 **The close fit between the modeled versus measured NX Horixon bifacial gain advantage as compared to the other 1P single-axis tracker design validates the iteratively determined loss factors, detailed in Figure 8, for the end- and middle-of-row spans.**

intended to account for irradiance reductions due to obstructions between the ground and the back side of a bifacial module," he says. "It is logical, therefore, that structure shading factor will increase in magnitude with the addition of back-side structural components, such as bearings, piles, and drive mechanisms. On the other hand, mismatch loss factor is intended to account for the electrical impacts of non-uniform back-side irradiance. Since adding obstructions below a bifacial array increases irradiance distribution and non-uniformity—and structure shading factor does not account for these electrical effects—it is logical that mismatch loss factor will also increase in magnitude."

Using the PVsyst input parameters derived in the manner described above for model validation, we find a strong correlation between the modeled versus measured NX Horizon bifacial gain advantage, as shown in Figure 9. The modeled bifacial gain advantage is determined by running PVsyst simulations using the manufacturer-recommended NX Horizon-specific loss factors, on the one hand, and the iteratively determined loss factors for the other mechanical design, on the other. Comparing the PVsyst-modeled results with the field-measured results, we find good agreement—under both high- and low-albedo conditions and for both of the other mechanical design configurations. The resulting calibrated structure-specific PVsyst input parameters for both trackers are detailed in Table 3.

Bifacial Gains on 2P vs. 1P Trackers

Nextracker is the leading Tier 1 manufacturer to offer both 1P and 2P single-axis trackers. Released in Q3 2019, the NX Gemini is a 2P single-axis tracker platform that integrates four symmetrical strings per tracker. This symmetrical architecture—based on even rather than odd numbers of strings, as shown in Figure 10—reduces the mismatch losses associated with non-uniform irradiance. Especially in the morning and afternoon shoulder hours, irradiance non-uniformity increases in electrical rows shared between the east and west side of a 2P tracker. Nextracker intentionally designed NX Gemini to eliminate the additional mismatch losses associated with electrical strings split between the east and west panel rows as a way to optimize bifacial gains.

Based on five months of side-by-side test data, summarized here in Figure 11, we are finding that bifacial modules mounted on the 2P NX Gemini are generating slightly less bifacial gain than those on the 1P NX Horizon. These empirical data indicate an albedo-dependent bifacial gain advantage for the 1P NX Horizon of 0.6% to 1.2%. We believe the majority of this difference can be attributed to the favorable rear-side ground view factor for the 1P design, as shown in Figure 12. In other words, the ratio of the array height above grade to the array width, or wingspan, is significantly higher for the 1P tracker than for the 2P tracker.

NX Gemini Array Layout

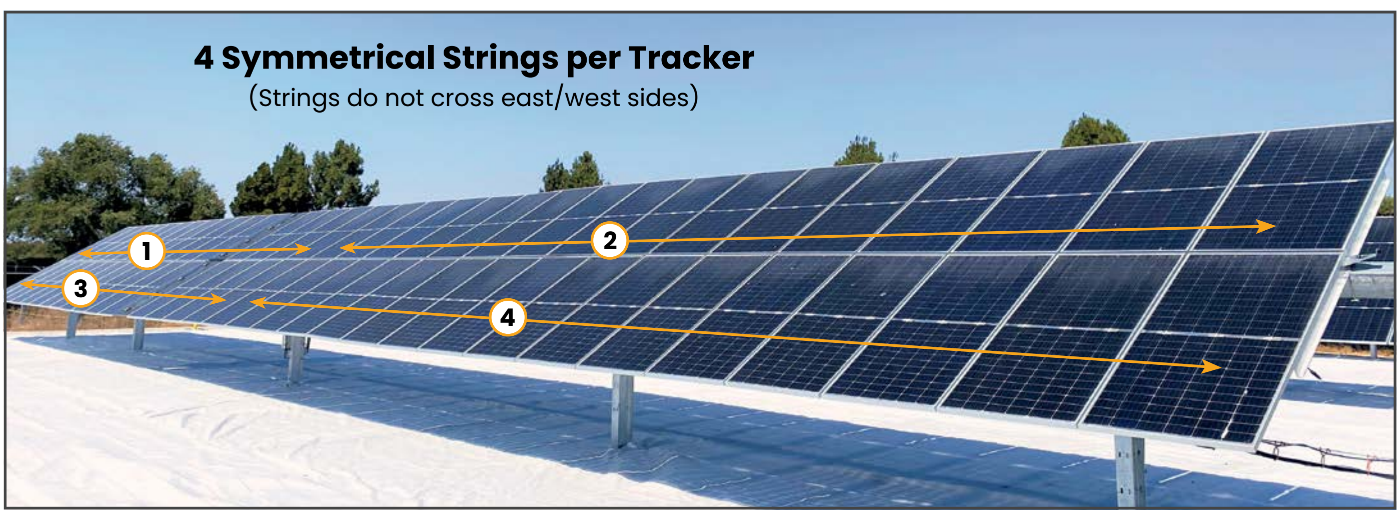

FIGURE 10 The 2P NX Gemini tracker integrates an even number of strings per tracker. This symmetrical design reduces mismatch losses associated with non-uniform back-side irradiance as compared to asymmetrical designs where modules on both the east and west side of a 2P tracker are electrically connected.

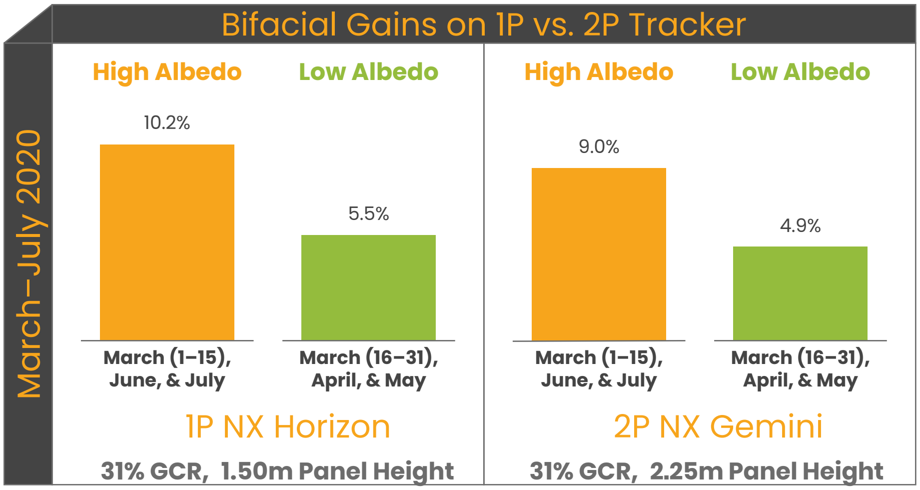

FIGURE 11 Side-by-side test data from the Center for Solar Excellence indicates that the 1P NX Horizon has an albedo dependent bifacial advantage of 0.6% to 1.2% as compared to the 2P NX Gemini. These empirical data support ray-tracing study results predicting a 1P bifacial gain advantage resulting from a favorable rear-side view factor.

The preliminary findings from Nextracker's side-by-side field comparison of 1P- versus 2P-tracker–mounted bifacial systems are consistent with reported results from a state-of-the-art 3D raytracing study by PV Lighthouse, an Australian PV performance engineering collaborative that seeks to assemble a Grand Unified Model of Photovoltaics. According to this report[5] on the results of a bifacial model validation study: "PV Lighthouse found a bifacial PV array mounted on 1MIP [1P] trackers to deliver more energy than the one mounted on 2MIP [2P] trackers within all reasonable ranges of pile spacing (post pitch), torque tube height, ground coverage ratio, albedo, and location."

Other industry white papers[6] report contradictory findings, indicating that both monofacial and bifacial panels perform better on a 2P tracker than on a 1P tracker. We believe that flawed testing methodologies can account for this apparent discrepancy. For example, non-representative array heights—such as a higher-than-typical 2P torque tube height or a lower-than-typical 1P torque tube height—can bias results. Test methodologies are also flawed if 2P testing rows are proportionally shorter than the 1P test rows in comparison to full-scale system deployments. In this scenario, the test results will be biased due to increased edge albedo brightening, decreased edge diffuse shading, and increased wind-cooling effects relative to a full-scale PV power plant.

Reconciling these conflicting claims is of keen interest to industry stakeholders. To that end, Nextracker is engaged in ongoing 1P versus 2P side-by-side performance studies at the Center for Solar Excellence, involving both monofacial and bifacial technologies. As a resource to performance engineers, project financiers, and IEs, Nextracker will publish these additional findings, including a detailed analysis comparing the modeled versus measured performance for the 1P NX Horizon and the 2P NX Gemini.

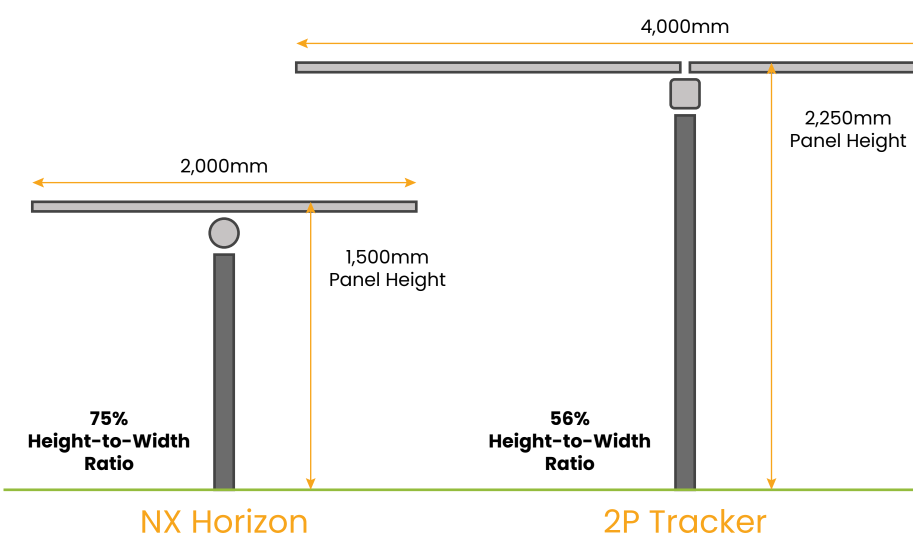

FIGURE 12 As compared to a 2P architecture, 1P trackers have a higher height-to-width ratio, allowing more light to be reflected to the back side of the panels. This results in a higher rear-side ground view factor for 1P designs, which increases bifacial gains. Because 2P tracker-mounted systems have a lower height-to-width ratio, they allow more ground-reflected light loss to the sky.

Appendix A

CENTER FOR SOLAR EXCELLENCE Nextracker's bifacial testbed in Fremont, California, consists of five 1P tracker rows and four 2P tracker rows. Test hardware includes bifacial modules from three different vendors.

LOW-ALBEDO CONDITION The gray gravel ground cover at the Center for Solar Excellence has an albedo of roughly 20%. To eliminate edge-of-row effects, researchers designed the experiment to study interior electrical strings only.

HIGH-ALBEDO CONDITION By installing a white fabric, researchers are able to characterize bifacial performance under high-albedo conditions. This white fabric—which is alternately installed or removed on a monthly basis—has an albedo of roughly 50%.

HALF-CUT CELLS The bifacial modules that Nextracker and PVEL used as the basis of this comparison, summarized in Table 1 (p. 4), have half-cut cells and mid-module junction boxes. Whereas the module backsheet material at the Nextracker site is transparent with a white grid between cells, the backsheet material at the PVEL site is fully transparent.

Appendix B

PV-USA PVEL's outdoor testing lab in Davis, California, is one of the world's oldest, largest, and most sophisticated field-testing sites. At the 10-acre site, PVEL conducts a variety of side-by-side technology testing to characterize real-world field performance.

LOW-ALBEDO CONDITION The low-albedo case at PV-USA is natural ground cover, which varies seasonally from green grass, to dry grass, to dirt. Averaged over time, this native ground cover has an albedo value of roughly 23%.

HIGH-ALBEDO CONDITION The white fabric at PV-USA is permanently installed to allow for parallel low- and high-albedo performance characterization. Due to soiling, the white fabric at the PVEL testbed has an estimated albedo of 45%.

HIGH-RISE RAILS Modules at both the Nextracker and PVEL test sites are integrated on NX Horizon Gen 4 single-axis trackers, which feature a bifacial-enhancing "high-rise" rail that provides 90mm of clearance between the torque tube and the back side of bifacial cells.

Appendix C

The apparent weather bias in PVsyst is a result that merits further investigation among the PV performance engineering community. As shown in Figure C1, our analysis of PVsyst-model data reveals a slight bias toward underprediction on sunny days and overprediction on cloudy days; moreover, this trend is consistent for both high- and low-albedo conditions. This slight weather bias explains why PVsyst will tend to underpredict bifacial gains for sunny months and overpredict bifacial gains for cloudy months, as seen in Figure 4 (p. 9).

To evaluate the model on a more granular basis, we have also plotted detailed irradiance profiles representative of cloudy versus sunny days. In these representative results, illustrated in Figure C2, the orange and green dotted lines represent field-measured plane-of-array (POA) irradiance values and the gray dotted lines represent POA irradiance values modeled in PVsyst. A comparison of the solid blue and dotted blue lines in Figure C2 indicates that there is good alignment between the measured and modeled POA irradiance values.

Note the measured back-side irradiance values for this analysis are based on the spatial average of multiple sensors across the back side of the module. The modeled values are from PVsyst, inclusive of the back-side shade factor described earlier. PVsyst only estimates a single back-side irradiance value for the entire string, for each hourly interval, not an irradiance distribution across the module back surface.

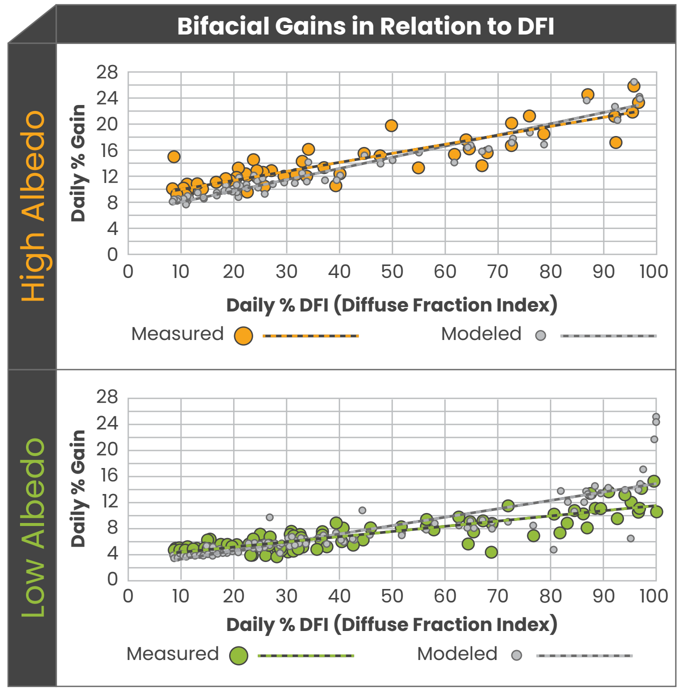

FIGURE C1 Plotting daily measured versus modeled bifacial gains, we find a slight bias toward underprediction on sunny days (low diffuse fraction index) and overprediction on cloudy days (high diffuse fraction index) under both high- and low-albedo conditions. Our analysis indicates this weather bias is intrinsic to the PVsyst model as of Q2 2020.

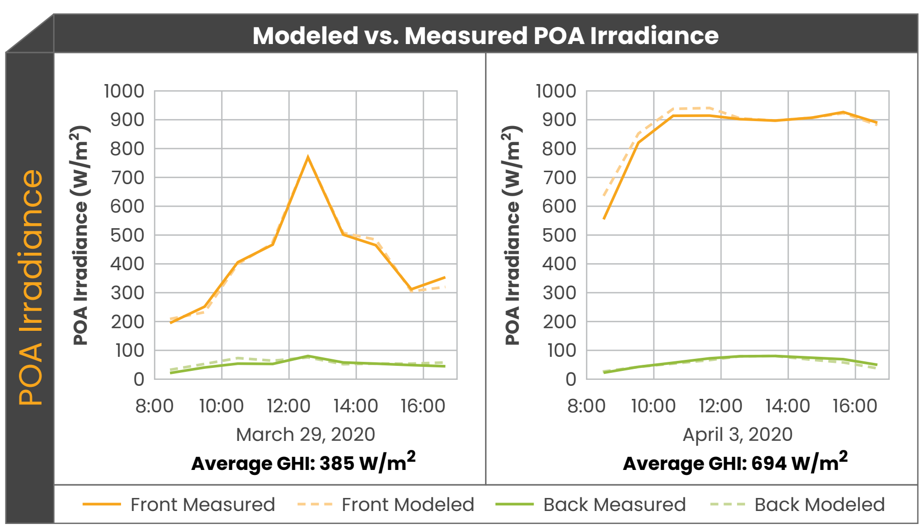

FIGURE C2 The plot on the left is a partly cloudy day in March, with an average GHI of 385 W/m²; the plot on the right is a sunny day in April with an average GHI of 694 W/m². The general alignment between these measured and modeled results indicates that the industry can use standard modeling tools, such as PVsyst, to estimate back-side POA irradiance, and bifacial gains by extension, with confidence.

Appendix D

Any obstructions located between the back side of a bifacial PV array—including source circuit conductors and wire-management hardware—will have an impact on in-field bifacial gains. To minimize the rear-side shading associated with PV wire homeruns, we recommend the wire management strategy detailed in Figure D1 for NX Horizon-mounted bifacial systems. This technique takes advantage of the intrinsic physical alignment between half-cell bifacial arrays and NX Horizon support structures.

Modules with half-cut rather than full-sized cells have several general benefits, such as lower resistive losses, higher shade tolerance, lower risk of microcracking, and improved durability. Within the specific context of single-axis tracker mounted bifacial PV systems, half-cell modules have an additional benefit of locating the decentralized mid-module junction boxes directly over the torque tube. To the extent that installers are able to aggregate and route DC source circuit and homerun conductors along the underside of this torque tube, it is possible to minimize back-side shading and optimize bifacial gains.

In many large-scale applications, PV plant designers effectively combine three or four tracker tables along a north-south axis in order to aggregate 12 to 16 source circuits before transitioning to direct burial conductor routing. NX Horizon is particularly well suited to this type of "super row" approach because installers are able to route these large conductor bundles directly below the torque tube, as shown in Figure D1.

A worst-case scenario for bifacial wire management is shown in Figure D2. Since this 1P single-axis tracker does not provide a wire chase at each foundation and bearing, installers in the field may revert to wire management and routing techniques commonly used in monofacial solar plants. Using the detailed 3D ray-tracing techniques described in this article, we would expect to see a 0.25% to 0.35% decrease in specific yield due to this suboptimal wire management approach.

FIGURE D1 For large wire bundles, installers can add wire hangers or harnesses at each short rail location, providing the necessary support at regular intervals along the torque tube. At each foundation and bearing, installers can use a beam clamp or similar to install wire management hardware that secures and protects the wire bundle while allowing for tracker rotation.

FIGURE D2 In a "super row" scenario, where DC homeruns are aggregated across multiple tracker tables, DC wire bundles are roughly two inches in diameter. The additional back-side shading in this scenario can decrease system-level specific yield by 0.25% to 0.35%.

Accurately Modeling the NX HORIZON BIFACIAL GAIN ADVANTAGE

NX Horizon incorporates unique bifacial-enhancing features that reduce structure shading and increase bifacial gains relative to a generic 1P single-axis tracker.

"High-Rise" Rails

Bearing Gaps

Wire Management

Drive System Gap

Accurately modeling bifacial gains using industry-standard software requires calibrated structure-specific model input parameters. To that end, Nextracker conducts rigorous side-by-side field tests at a state-of-the-art bifacial testing lab.

Empirical in-field test results indicate that NX Horizon has a 1.02% to 1.67% bifacial gain advantage relative to a generic 1P single-axis tracker. Using best-in-class ray tracing and PV mismatch modeling software, as well as computationally intensive means of data analysis and validation, we are able to determine calibrated structure-specific PVsyst input parameters that best characterize the measured in-field performance of NX Horizon-mounted bifacial PV systems. Additionally, we are able to determine calibrated input parameters that characterize the additional back-side shading impacts associated with the other 1P tracker design.

While other published studies have used valid methods and software to calculate structure shading factors, most researchers are unable to model a detailed 3D support structure. Our analysis is uniquely rigorous in this regard, insofar as it is able to account for all of the back-side structure shade elements. Studies that model the impact of the torque tube only—ignoring the impacts of the foundation and drive components—invariably underestimate structure shading and back-side mismatch loss factors.

As a leader in the global energy transition, Nextracker is committed to sharing information and best practices that enable stakeholders to capture the full value and maximize the efficiency of PV power plants. Over time, the industry's ability to precisely and consistently model bifacial system performance will reduce risk and uncertainty and improve investor confidence and project profitability.

Quantifying Your Bifacial Gains

PVsyst Input Parameters	NX Horizon	Other 1P Tracker	
	Good DC Wiring*	Good DC Wiring**	Poor DC Wiring
Structure Shading Factor	12.3%	20.0%	24.3%
Mismatch Loss Factor (rear)	3.5%	8.8%	9.0%
Shed Transparent Fraction* **	MT + 2.1%	MT + 1.0%	MT + 1.0%

PV Syst Annual Energy Impact

Low-Albedo Case	Baseline 1	-0.77%	**-1.02%**
High-Albedo Case	Baseline 2	-1.32%	**-1.67%**

*Easy to accomplish with DC wiring pass through at bearing
**More difficult to accomplish; no DC wiring pass through at bearing
***MT = Module transparency fraction

CALIBRATED MODEL INPUT PARAMETERS
These structure- and scenario-specific PVsyst model input parameters and annual energy impact estimates are calibrated to fit real world measured data.

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Acknowledgements

Jenya Meydbray is the CEO and cofounder of PV Evolution Labs (PVEL), the leading independent lab for solar project developers, financial institutions, and asset owners. Jenya developed among the first extended reliability and performance tests for the downstream PV industry as well as innovative risk assessment and mitigation methods for power plants. He has nearly 15 years of solar industry experience and holds two photovoltaic-related patents.

PVEL is a leading reliability and performance testing lab for downstream solar project developers, financiers, and asset owners and operators around the world. With over ten years of experience, PVEL conducts testing that demonstrates solar technology bankability. Its trusted, independent reports replace assumptions about solar equipment performance with data-driven, quantifiable metrics that enable efficient solar project development and financing.

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A Flex Company

Nextracker, a Flex company, is a leader in the energy transition, providing critical yield enhancing PV system technology, expertise and strategic services to capture the full value and maximize the efficiency of solar plants. Delivering the most comprehensive portfolio of intelligent solar tracker and control software solutions for solar power plants, Nextracker is transforming PV plant performance with smart technology, data monitoring and analysis services.

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