



Bifacial Trackers, the Real Deal

Bifacial Gain and production analysis at BiTEC

The BiTEC data indicates that individual bifacial modules on an **SF7 Bifacial Solar Tracker** have up to **19.2%** Bifacial Gain under high albedo.

Authors:

Javier Guerrero-Perez holds a Ph.D. in Renewable Energy. His professional activity spans over ten years in the solar industry within multinational EPC operations. He has published several papers on modelling electrical behavior of both PV modules and inverters, oriented to large scale simulation. Since 2015, when he was part of the team of La Silla PV plant (2015), current research lines are focused on modelling the bifacial PV modules behavior while he is managing Soltec's Bifacial Tracker Evaluation Center in Livermore, California.

Samir Chaouki-Almagro holds a B.S. degree in Automatic and Industrial Electronics Engineering, M.S. degree in Electrical Engineering and M.S. degree in Renewable Energies and he is currently working toward the Ph.D. degree. His research interests are isolated communications for power multistage converters, photovoltaic grid connected inverters and since 2015 working on PV tracker control systems



Initial BiTEC data shows that individual bifacial PV modules on a SF7 bifacial tracker have 2.4% higher Bifacial Gain than that of the same bifacial modules on trackers with modules in one-in-portrait configuration.

The BiTEC data indicates that individual bifacial modules on a SF7 bifacial solar tracker have up to 19.2% of Bifacial Gain in conditions of high albedo. With medium albedo, the Bifacial Gain of an individual module on a SF7 bifacial solar tracker reached 11.9%.

In a hypothetical project scenario we estimate that the use of SF7 bifacial solar trackers results in an 11.9% increase in energy output compared to the same project using monofacial modules in two-in-portrait configuration trackers. The increase in project net present value, is estimated to be around 8%.

ABSTRACT

This white paper presents a summary of the results obtained from September to November 2018 at Soltec's Bifacial Tracker Evaluation Center (BiTEC) in Livermore, California, USA. BiTEC studied the Bifacial Gain of PV modules deployed in the two most common tracker configurations in the market today: 1-in-Portrait (1P) and 2-in-Portrait (2P). Initial results show that individual modules deployed in SF7 Bifacial tracker in 2P configuration exhibit a Bifacial Gain that is 2.4% higher than that of the same modules in 1P configuration.

This white paper discusses the data gathered by BiTEC to substantiate the higher Bifacial Gain. The increased Bifacial Gain is applied to a hypothetical 65 MWp solar project of and yields an improvement in project net present value of 1 US\$ Million.

Black & Veatch Management Consulting LLC (Black & Veatch) reviewed the data and measurement techniques used to produce Technical Tables (1 to 6) and believes that the methodology is consistent with accepted industry practice*.

INTRODUCTION

The high energy output of bifacial modules has revolutionized the solar power arena. However, not all revolutions imply big events that alter and shake foundations. Some revolutions are subtle, apparently small and, at times, difficult to perceive and slow in their implementation. However, their effects can be overwhelming.

That is exactly how bifacial technology is impacting the design of PV fixed tilt and tracker structures as well as the design of PV power plants. Features that are considered negligible in the design of PV power plants that use monofacial modules are relevant when using bifacial modules. The appropriate consideration of such features in plant design can translate into millions of dollars.

Solar tracker systems for monofacial modules are designed to maximize solar irradiance on the modules' front side and thus the modules' energy output. However, bifacial plant designs strive to optimize the energy output from both the front and rear sides of a module. This requires the use of tracker structures that are optimized for bifacial modules.

Bifacial technology

Bifacial module technology is not new. The first bifacial cells at a laboratory scale date back to the 1960s. The technology was first commercialized by Isofotón, a Spanish company, in 1981. In the 1990s the Swiss city of Zurich installed noise barriers comprised of bifacial modules in a vertical array (90 degrees).

Widespread deployment of bifacial modules did not begin until the 2010s. The giant Italian utility Enel Green Power commissioned in 2016 one of the first large-scale PV plants using bifacial technology. This plant supplies power to La Silla Observatory (Chile) and uses SF Utility trackers specifically designed by Soltec to maximize the energy output from the rear side of the modules. The trackers are situated on limestone and measurements showed a module Bifacial Gain of 13% [1].

BIFACIAL GAIN

The power output of a bifacial module may be expressed as the sum of the energy generated by the module's front and rear sides:

$$E_{bifacial} = E_{front} + E_{rear}$$

This apparently simple formula has puzzled the PV industry for years. The reason is simple. In traditional monofacial modules the front side of the module accounts for all its energy output. This energy output can be accurately modeled. In bifacial modules the energy output also depends on the irradiance that impinges on the rear side of the module. Today's energy forecasting models may not provide accurate results for the energy generated for the rear side of a module.

Some energy forecasting tools estimate the module rear side energy output as a percentage of the module front side energy output. These tools utilize the concept of “Bifacial Gain” to indicate the energy generated by the rear side of the module (E_{rear}) as a fraction of the energy produced by the front side of the module (E_{front}).

To understand the Bifacial Gain, we need to consider that (1) the sunlight that reaches the rear side of a module behaves differently from the sunlight that reaches the front side and that (2) the rear side power conversion efficiency differs from that of the front side. Thus, two new concepts are introduced:

- Bifacial ratio, defined as the ratio of the irradiation that reaches the rear side of a module (G_{rear}) to the irradiation that reaches the front-side (G_{front}).
- Module Bifaciality, which is the ratio of the energy conversion efficiencies of the rear and front sides of a module.

$$Bifacial\ Gain = E_{rear} / E_{front} \quad Bifacial\ Ratio = G_{rear} / G_{front}$$

$$Bifaciality = Bifacial\ Gain / Bifacial\ Ratio$$

Using these definitions, the energy generated by both sides of a module ($E_{bifacial}$), is related to the energy generated by the front side of a module ($E_{monofacial}$), as follows:

$$E_{bifacial} = E_{monofacial} \times (1 + Bifacial\ Gain)$$

$$E_{bifacial} = E_{monofacial} \times (1 + Bifacial\ Ratio \times Bifaciality)$$

It is important to consider that Bifaciality is an inherent module property, whereas the bifacial ratio depends directly on the irradiation on the rear and front sides of a module. This means that a module’s Bifacial Gain could increase by positioning the module in a way that maximizes the irradiation on the rear side of module. Table 1 shows how the previous formula can be used to estimate the Bifacial Gain for modules with different Bifacialities. Table 1 uses the bifacial ratio values measured at BiTEC for two different albedos.

Albedo	Bifacial Ratio	Module Bifaciality (p.u.)	Bifacial Gain (Estimate, %)
19%	10%	0.75	7.5
		0.80	8.0
		0.85	8.5
63%	24%	0.75	18.0
		0.80	19.2
		0.85	20.4

Table 1. Estimated Bifacial Gain for modules with different Bifaciality as a function of measured bifacial ratio. Source: BiTEC

OPTIMIZING POWER GENERATED BY THE REAR SIDE: BIFACIAL TRACKER

To maximize the energy output of the rear side of a module located in a PV power plant we need to understand the factors that can increase the irradiation that reaches the rear of the module. As figure 1 shows, G_{rear} is comprised of (1) diffuse irradiation, which is present in the atmosphere, and (2) irradiation reflected from the ground or other surfaces.

$$G_{rear} = G_{diffuse} + G_{reflected}$$

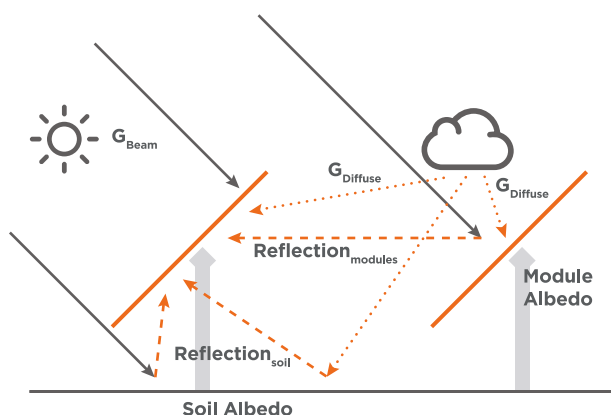


Figure 1. Graphic representation of irradiation in a bifacial plant. Source: Soltec

The proportion of incident irradiation that is reflected by a surface is known as the surface’s albedo.

The problem is that the energy forecasting tools that are used for power plants with monofacial modules do not adequately forecast the output energy of a power plant that uses bifacial modules. Actual plant measurements must be used to estimate the energy output and identify which elements affect module rear-side power generation.

During the design of the bifacial module tracker system for the European Southern Observatory La Silla PV power plant in 2015 Soltec performed a comprehensive analysis of the factors that impacted the irradiation that reached the rear of the modules.

The key factors were: (1) albedo, (2) distance between module rows (pitch), (3) module height and (4) the shading created by the torque-tube and other elements of the tracker structure on the rear side of the module. Figure 2 illustrates the positive and negative influence of these factors on Bifacial Gain, associated to the installation elements.



Figure 4. Parameters influencing Bifacial Gain. Source: in-house

With the goal of analyzing these factors and creating models that can forecast the energy output of any bifacial power plant, Soltec created in 2018 the Bifacial Tracker Evaluation Center (BiTEC) located in Livermore, California (USA) which is shown in Figure 3.



Figure 3. Bifacial Tracker Evaluation Center, BiTEC. Source: Soltec

This research center is equipped with 18 solar trackers capable of deploying around 300 kWp of modules. The trackers are located in areas with different albedo, pitch, and height. Soltec's goals are to expand the bifacial tracker performance knowledge base, refine bifacial energy forecasting and further bifacial solar tracker technological development. In this endeavor Soltec is working with the National Renewable Energy Laboratory (NREL), Black & Veatch Corporation, Renewable Energy Test Center (RETC), and leading PV module manufacturers, such as, Canadian Solar, Hanwha Q CELLS, Jinko Solar, LG, LONGi and REC.

Black & Veatch Management Consulting LLC (Black & Veatch) reviewed the data and measurement techniques used to produce Technical Tables (1 to 6) and believes that the methodology is consistent with accepted industry practice*.

BIFACIAL PARAMETERS

Albedo

The albedo varies with the color and characteristics of the surfaces that reflect light on to the rear of a module. Light colored, smooth surfaces have high albedos which can lead to high energy output from the rear of a module.

During September, October and November 2018 BiTEC measured the albedo for the three types of surfaces: seasonal ground, gravel and a controlled white ground cover. BiTEC also measured the energy output of two Jolywood JW-D72N-355 bifacial modules located on a 2P SF7 bifacial tracker for each albedo condition with a 10-meter pitch between trackers.

BiTEC calculated the ratio of the energy output of each module to the peak module power and refers to this ratio as that normalized energy output. The normalized energy output of the Jolywood modules for each albedo condition was divided by the normalized energy output of a Jinko JKM320PP-72 monofacial module that was also located on a 2P SF7 bifacial tracker. The Bifacial Gain of the Jolywood modules for each albedo condition was estimated by dividing the normalized energy output of the Jolywood modules by those measured for the

Jinko JKM320PP-72 monofacial module. The results for the different combinations of pitch and albedo which appear in Table 2, suggest that for an albedo of 38% the estimated Bifacial Gain may be about 13%.

Types of ground	Albedo (%)	Pitch (m)	Estimated Bifacial Gain (%)
Scenario A: Seasonal	19	10	7.9
Scenario B: Gravel	32	10	11.9
Scenario C: White	63	10	19.2
Interpolation	38	10	13.3

Table 2. Estimated Bifacial Gain of Jolywood modules on a SF7 bifacial solar tracker with a 10-meter pitch between trackers measured between September and November 2018 for different types of ground. Source: BiTEC

Soltec followed the same procedure to estimate the Bifacial Gain, in the same scenarios shown in Table 2, of two other commercial bifacial modules installed on the same tracker.

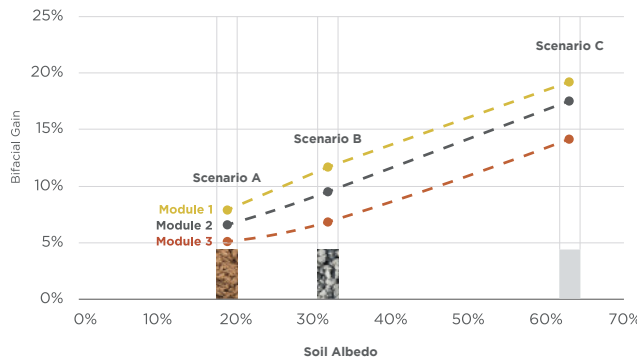


Figure 4. Relationship between albedo and module Bifacial Gain. Source: BiTEC

All three bifacial module types had different Bifaciality. The estimated Bifacial Gain for the three bifacial module types are plotted in Figure 4 as a function of albedo. Figure 4 confirms that there is a strong relationship between the estimated Bifacial Gain and albedo. Albedo values may change with the season [2] and are an important factor in determining the output of a bifacial PV system.

BiTEC estimated the Bifacial Gain of four individual bifacial modules using the method discussed in the albedo section of this white paper. Each bifacial module was from a different manufacturer. The bifacial modules were located on SF7 bifacial trackers with three different albedo values and the same GCR¹. The results appear in Table 3.

Module	Surface Albedo					
	White		Gravel		Seasonal	
	GCR	Albedo	GCR	Albedo	GCR	Albedo
Module 1	0.4	63%	0.4	32%	0.4	19%
Module 2		19.2%		11.9%		7.9%
Module 3		17.5%		9.5%		6.5%
		14.1%		6.8%		5.1%

Table 3. Estimated Bifacial Gain for four different modules and three albedo values. Source: BiTEC

Figure 5 illustrates the change in normalized module power during the day for two different albedos. As can be seen the difference in power output for the modules in each case are significant during the hours of highest energy output.

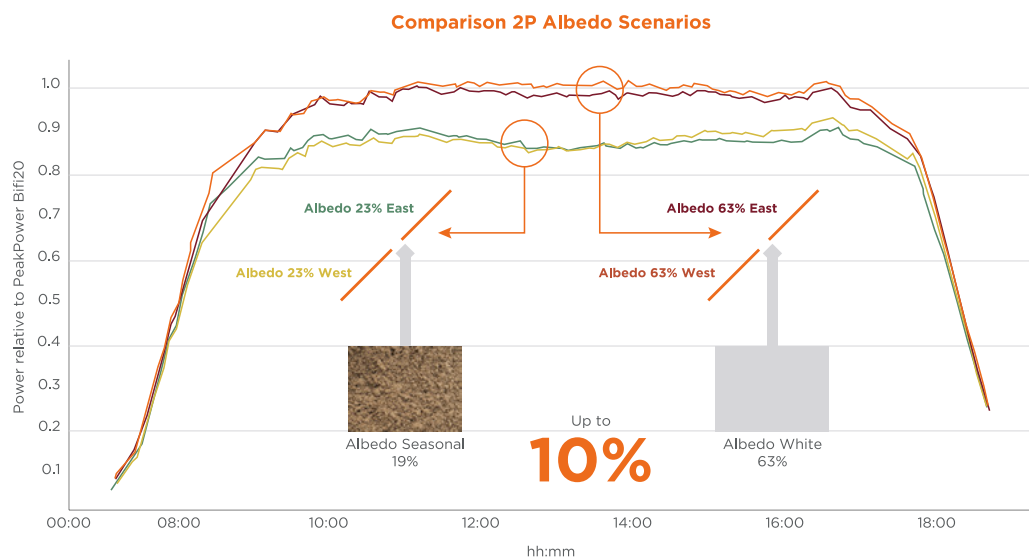


Figure 5. Comparison of daily power curves for bifacial modules on a 2P SF7 bifacial solar tracker for two albedo scenarios. Source: BiTEC. Measured on Sept-9 2018. Jolywood JW-D72N-355 modules mounted on SF7 bifacial tracker. Pitch 10m

¹GCR is defined as the area covered by modules in stow position divided by the total system area

Shading, hot spots and power losses

Shading has a negative impact on the performance of monofacial and bifacial PV modules. Shading can decrease module energy output and reduce the revenue of a PV project. Studies suggest that shading from the module fastening system could result in over 20% rear irradiation loss [3]. Thus, the structures used to support PV modules should be designed to minimize the presence of objects that can cast shadows on the modules.

6a.



6b.



Figure 6- Example of rear shading on 1P and 2P. 6a) 1-in-Portrait 6b) 2-in-Portrait SF7 bifacial Source: BiTEC

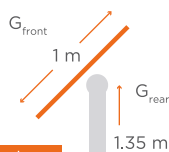
In the case of solar trackers, the torque tube is a major source of module shading, as can be observed in Figure 6.a. However, PV power plant performance simulation software such as PVsyst® does not model the specific features of a particular tracker. PVsyst® assumes that the PV modules are a continuous plane suspended in the air (Figure 7.a) with no other shading elements and estimates the irradiance on the rear of the modules by using a rear shading factor. PVsyst® defines the rear shading factor as the percentage of irradiance on the rear of a module lost due to rear shading. In this paper we estimate the rear shading factors by running simulations using NREL Bifacial Radiance 0.2.3 software [4] which allows us to calculate shading factors for different tracker designs by comparing the rear irradiance output of comprehensive modelling (Figure 7.b) and simplified modelling (Figure 7.a). Figure 7 shows detail-level modelling of 1P and 2P trackers performed by NREL for Soltec and the results. As shown, the rear shading factor for 1P is 4.5%, whereas for the 2P SF7 bifacial tracker optimized for bifacial modules (Figure 6.b), the shading factor is 0.7%.

7a. Simplified Modeling

PV syst / SAM / bifacial radiance

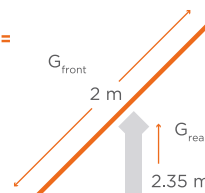
No shading

Module 1 = continuous plane
No torque tube



Shading factor:
4.5%

Module 1 + Module 2=
continuous plane
No torque tube



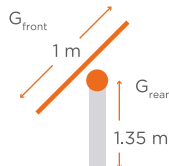
Shading factor:
0.7%

7b. Comprehensive Modeling

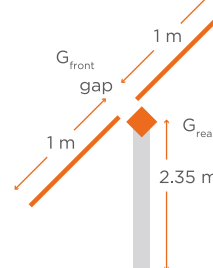
bifacial radiance

Real module location
torque tube shading

Module 1 = continuous plane
With torque tube



Module 1 + Gap
+ Module 2
With torque tube



Example of central row. Simulations count with my rows.

Figure 7. Shading factor assessment as detailed modeling comparison for a sunny day. 7.a) **Simplified** modelling. 7.b) **Comprehensive** modelling. Percentages of rear side irradiation are relative to front-side irradiation for a sunny day. Soil Albedo 28%, GCR=0.33 Source: NREL

The bifacial module production loss due to shading by the tube in 1P trackers in high albedo scenarios can reach 0.8% of total energy (both front and rear sides). The bifacial production loss in a SF7 Bifacial tracker is 0.1%.

Furthermore, module shading caused by the torque-tube in the case of 1P trackers, lead to different irradiance across the module surface. The literature reports that the non-uniform irradiance can lead to non-uniform heating of the module [5]. Non-uniform heating is known to contribute to module power loss.

To illustrate the areas of different irradiance on a bifacial module mounted on a 1P tracker, we short-circuited the module to highlight the temperature differences between the areas with different irradiance and observed the infrared (IR) image of the module. Figure 8 shows that the warmest areas, which are the areas with the lowest irradiance, are located over the tracker torque tube.

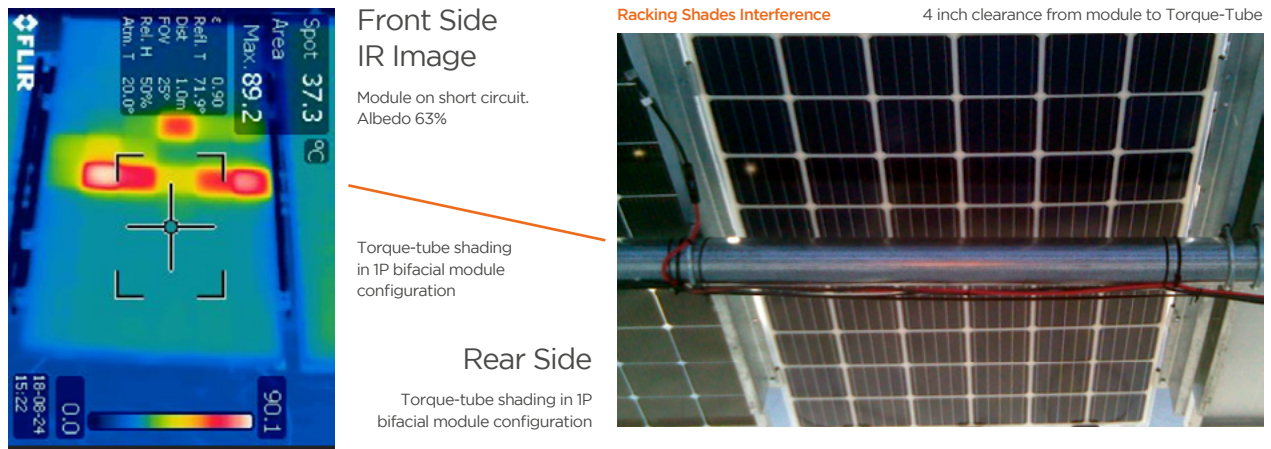


Figure 8. Infrared image of a short-circuited module in a 1P tracker. Source: BiTEC

Tracker piles or module cabling are other elements that can shade the rear side of the modules on a tracker. A tracker designed to optimize bifacial module energy layout should use as few piles as possible and cabling layouts that do not shade the rear of the modules. Figure 9 illustrates the cabling in Soltec’s SF7 Bifacial tracker StringRunner that enables the insertion of cables inside the tracker torque tube thus reducing the shading from the cables.

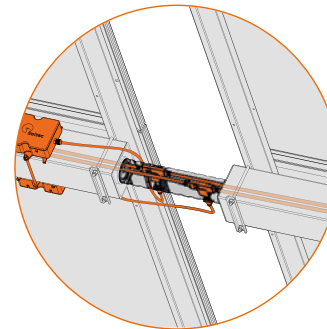


Figure 9. The StringRunner™ of Soltec’s SF7 solar tracker enables the insertion of cables inside the torque tube. Source: Soltec

Module Temperature

The energy output of a PV cell decreases at higher operating temperature. Bifacial modules have a higher operating current than monofacial modules and are prone to operate at higher temperatures. System designs that reduce module temperature can result in increased system energy output. Measurements performed at BiTEC show that the temperatures of modules on a 2P tracker tend to be lower than those on a 1P tracker.

The SF7 Bifacial tracker design allows for airflow through the tracker and the modules are generally higher off the ground than those in a 1P tracker as indicated in Figure 10. The lower module operating temperatures result in higher module energy output.

As seen in the thermographies, the upper 2P module operates at a temperature 6 degrees Celsius lower, whereas the lower module has a 2-degree difference compared to the 1P module. This temperature difference is mainly due to (1) higher unit height and (2) a design favoring airflow through the tracker and optimized module cooling compared to 1P trackers. This temperature difference translates into a 1.6% production increase.

2P Vs. 1P tracker cooling

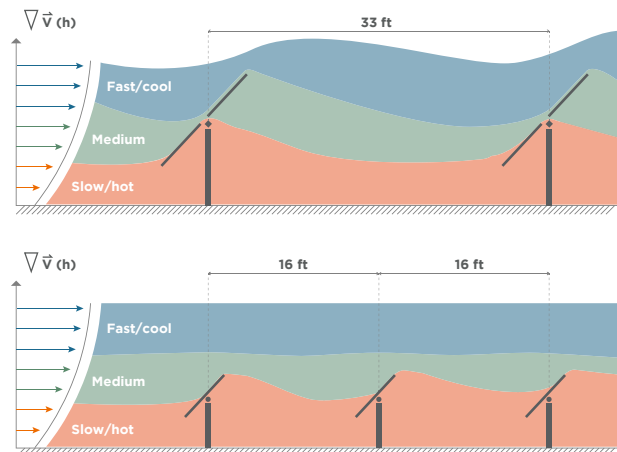


Figure 10. Graphic representation of 1P & 2P SF7 bifacial tracker cooling. Source: Soltec

IR images were taken of two modules mounted on a 2P SF7 Bifacial tracker and one module mounted in a 1P tracker. Both trackers were deployed with a GCR of 0.4 and albedo of 63%. The surface temperature for the module on the 1P tracker and both modules on the 2P tracker for five different dates and times are shown in Table 4. The analysis of the IR images showed that the module located in the upper 2P position was always cooler than the module in the lower 2P position by an average 6.4°C.

The average temperature of the modules on the 2P SF7 Bifacial tracker was also lower than the temperature of the module on the 1P tracker. We estimated the impact of the lower average module temperature on the module power output by using the modules' power temperature coefficients. The results show that for the module operating temperatures shown in Table 3 the modules on the 2P SF7 bifacial tracker should produce 1.3% more power than the module on the 1P tracker.

Date (2018)	Time	1P Tracker		2P SF7 Bifacial		2P Vs. 1P	
		Single Module T(°C)	Module down T (°C)	Module up T (°C)	2P \bar{T}	ΔT (°C)	ΔP %
oct 18	11:01	33.0	30.8	22.0	26.4	6.6	2.4
oct 22	15:23	36.3	34.6	30.3	32.5	3.8	1.4
oct 23	10:23	27.3	29.4	24.4	26.9	0.4	0.1
oct 24	10:53	33.0	30.5	23.7	27.1	5.9	2.2
oct 25	15:23	40.2	41.3	37.4	39.4	0.9	0.3
Average		33.96	33.32	27.56	30.44	3.5	1.3

Table 4. IR-measured temperatures of the front side of modules on 2P SF7 tracker and on a 1P tracker. Source: BiTEC

Module height

Module height can affect the irradiance on the rear of a module in three different ways.

- The modules higher off the ground see more diffuse radiation than those closer to the ground. This effect can be easily understood by looking at the shadow of an object as it moves farther from the ground. As shown in Figure 11 the shadow becomes lighter as the object moves higher.
- The modules higher off the ground receive more radiation reflected from the ground than those in lower positions as illustrated in Figure 12.
- Higher modules tend to operate at lower temperatures as discussed above.
- These three effects can lead to higher module power output for modules located higher off the ground than for modules closer to the ground.

Several studies [5,6] have pointed out that as the modules are higher off the ground the irradiance distribution on the rear side of the module is more uniform. This effect can be seen in Figure 13. More uniform irradiance contributes to reducing the mismatch power losses between cells.

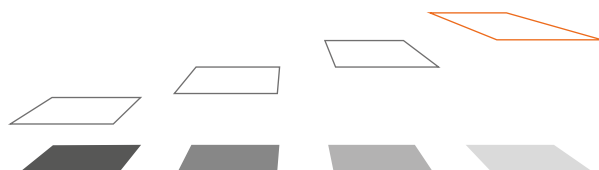


Figure 11. The shadow of an object becomes clearer as the object moves higher. Source: Soltec

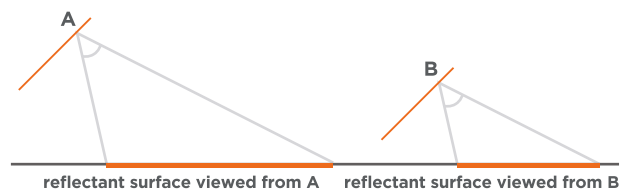
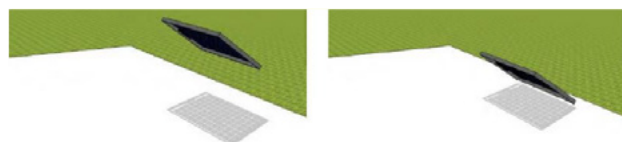
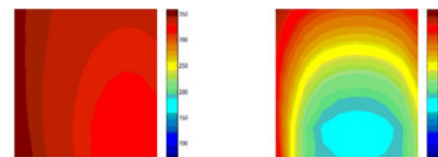


Figure 12. Irradiance on the rear of modules in high and low positions. Source: Soltec



Module elevation: 2 m | $\alpha = 0.5$

Module elevation: 1 m | $\alpha = 0.5$



Irradiance at the module rear side [W/m²] on an exemplary summer day in Cairo

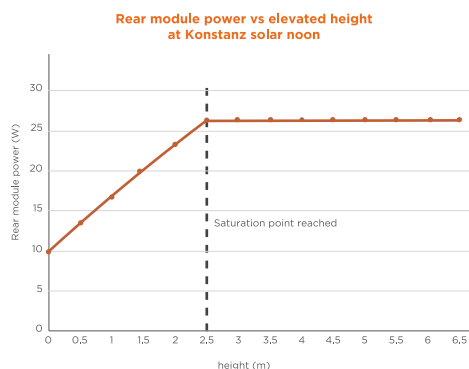


Figure 13. No homogeneity irradiation in the rear module plane at low clearance. Source: Source: RWTH Aachen University - ISC [7]

Figure 14. Power output of the rear of a bifacial module in a fixed tilt structure as a function of module height off the ground. Source: REC Solar - UNSW [6]

A third party study on fixed tilt PV structures reported that the Bifacial Gain of a bifacial module reached its highest value when the module was located 2.5 meters above the ground [5]. The same study indicated that the Bifacial Gain of the module did not increase further as the module moved higher off the ground. This is illustrated in Figure 14.

Distance between trackers or pitch (GCR)

The irradiance seen by the rear of a module is directly linked to the surface area that is reflecting light onto the module. As the distance between adjacent tracker rows increases, so does the surface area that is reflecting light onto the rear of the module and the module Bifacial Gain. Module level measurements performed by Soltec indicated that for an albedo of 63% and a pitch of 8.7 meters, the bifacial module energy output was 8.55% lower than for modules on trackers with a 10-meter pitch. When the pitch increased to 12-meters the module energy output increased by 2.47%.

The pitch of the module determines the GCR of a PV plant. As can be seen in Figure 15 as the pitch increases, so does area that reflects light on to the rear of the module.

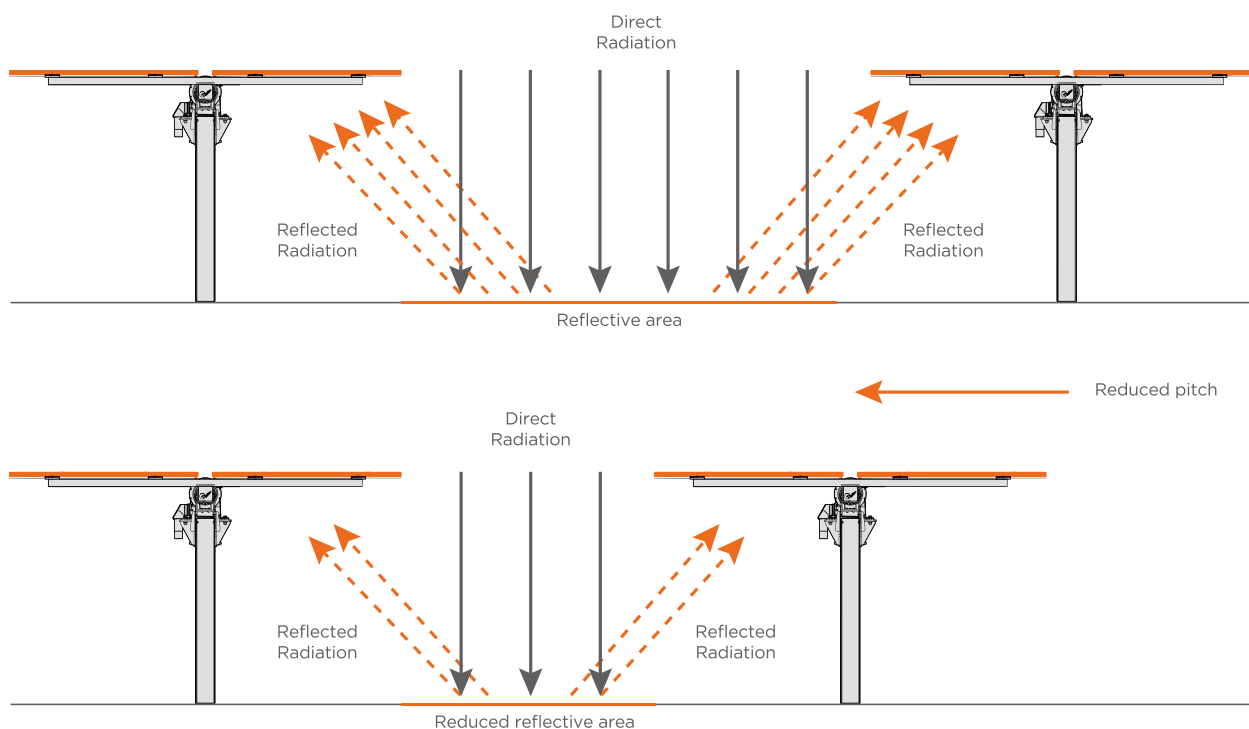


Figure 15. Graphic representation of the change in radiation reflection with pitch. Source: Soltec

BiTEC: UNDERSTANDING AND COMPARING THE ENERGY OUTPUT OF BIFACIAL MODULES ON TRACKERS

BiTEC, Soltec's bifacial tracker research plant which opened on July 2018, is designed to study the output of bifacial modules under various conditions of albedo, height, distance between modules and module temperature, among others. BiTEC's other key focus is to determine the best tracker design for bifacial module deployment.

1P Solar Trackers vs. 2P Solar Trackers

In today's solar tracker market there are two trends regarding the positioning of bifacial modules on a tracker: individual modules are placed on the tracker in a vertical position and are aligned in either one or two rows. When the modules are aligned in one row the tracker is referred to as a "one-in-portrait" or 1P tracker. When the modules are aligned in two rows, the tracker is referred to as "two-in-portrait" or 2P tracker. Figure 6 shows examples of modules in 1P and 2P configurations.

BiTEC has studied the Bifacial Gain of individual modules in both 1P and 2P tracker configurations. Two Jolywood JW-D72N-355 bifacial modules were mounted in 2P configuration on a SF-7 bifacial tracker (module height in stow position 2.35 m) and one module of the same type was mounted on a 1P tracker (module height in stow position 1.35m). The surface where the trackers were deployed had the same albedo value and the trackers had the same GCR.

Table 5 shows the results of module level Bifacial Gain calculations performed on data collected at BiTEC. The Bifacial Gain was calculated using the methodology discussed in the albedo section of this paper. The Bifacial Gain was estimated relative to the normalized output of a Jinko JKM320PP-72 monofacial module that was located on the 1P tracker.

The estimated Bifacial Gain of the modules placed in the SF7 bifacial in 2P configuration was 2.4% higher than that of the module in the 1P tracker configuration.

Configuration	Module Height (with the modules parallel to the ground)	Albedo	GCR	Calculated Bifacial Gain
1P	1.35 meters	63%	40% (5 m pitch)	16.8%
2P (SF7 Bifacial)	2.35 meters	63%	40% (10 m pitch)	19.2%

Table 5. Bifacial Gain calculation for modules on trackers in 1P & 2P configurations. Source: BiTEC

The calculated 2.4% higher Bifacial Gain for the modules in 2P configuration is consistent with the different module height, distance between module rows, module temperature and shading in the 1P and 2P SF7 bifacial trackers.

Table 6 breaks down the 2.4% higher Bifacial Gain for the modules on the 2P SF7 Bifacial tracker according to its components. As discussed previously, 1.3% is due to the lower average module operating temperature, 0.7% is due to the absence of module shading by the torque tube, and 0.4% is attributable to the higher average module height and pitch.

Parameters	Calculated Bifacial Gain
Lower average module temperature (better cooling)	+1.3%
No torque tube shading	+0.7%
Higher module height and pitch, and other design details.	+0.4%
Total	+2.4%

Table 6. Higher calculated Bifacial Gain of SF7 bifacial solar trackers compared to 1P tracker. Source: BiTEC

BiTEC SIMULATIONS: BIFACIAL GAIN AND FINANCIAL GAIN

A key question in the industry today is when does it make economic sense to use bifacial modules instead of monofacial modules. Although every project is unique, the data gathered at BiTEC from September through November 2018 provides useful input for modeling the performance of PV systems using bifacial and monofacial modules.

Bifacial Gain in gravel ground (albedo: 32%)

As discussed earlier, modules located over a white high albedo surface generated more energy than the modules over gravel or seasonal ground coverage. Similarly, the energy output of a PV power plant located in an area of high albedo will be greater than that of the same power plant in an area of lower albedo.

The 32% albedo value measured at BiTEC for a gravel surface may be closer to the actual albedo values seen in PV projects than the 63% albedo value measured for the white ground cover. We will use module level data obtained at BiTEC from September to November 2018 to estimate the energy outputs of monofacial and bifacial systems in a hypothetical 65 MW DC power plant located in Sonora, Mexico. We assume that the monofacial system in this plant would have a yearly energy yield of 2 200 kWh/kWp. We also assume that the 11.9% module level Bifacial Gain measured at BiTEC for a 2P SF7 bifacial tracker on Albedo 32% is applicable to the bifacial system.

Consequently, the yearly energy yield of the hypothetical bifacial version of the project is estimated at 2462 kWh/kWp.

We then compare the economics of the bifacial and monofacial versions of the project to illustrate how the increased output of the bifacial modules translates into revenue. The assumptions used in our calculations appear in Table 7. These assumptions were provided by Powertis S.A. a developer of large-scale PV projects in Europe and Latin America [8].

The monofacial version of the project uses Jinko JKM 350M-72-V monofacial modules and the bifacial version uses Jolywood JW-D72N-360 bifacial modules. The Jolywood modules are US\$0.03/Wp costlier than the Jinko modules, but fewer modules are required and the system pitch is higher. The area of both versions of the project is the same. We also assume that the cost of inverters in the bifacial version of the project is higher than in the monofacial version by US\$0.005/Wp in order to handle the higher power output of the bifacial modules. We consider the electrical substation the same in both versions of the project because the system voltage level is not changing.

Project Details

Location	Ciudad Obregón, Sonora, Mexico		
Project Assumptions		Monofacial	Bifacial
Scenario	Tracker:	+/- 60°	+/- 60°
	Installation:	2P	2P SF7 Bifacial
	Equipment:	Huawei	Huawei
	Module:	Jinko Monofacial	Jolywood Bifacial
Size	MW-AC:	54.2	59.1
	MW-DC:	65.0	65.0
Capital Expenditure (CAPEX)	Panel (US\$/Wp):	0.230	0.260
	BOS (US\$/Wp):	0.300	0.350
	BOS (US\$/Wp):	0.100	0.100
	Sum	0.630	0.665
Generation	Bifacial Gain:		11.9%
	kWh/kWp:	2.200	2.462
	MWh:	142 978	159 992
Energy Price	US\$/MWh):	25	25
	Escalation:	2.0%	2.0%
Operational Expenditure (OPEX, all-in)	% of Revenue:	10.0%	11.0%
Module Degredation	Year 1:	2.000%	1.000%
	Year 2-5:	0.500%	0.400%
	Year 6-12:	0.714%	0.400%
	Year 13+:	0.769%	0.400%
Weighted Average Cost of Capital (WACC)		6.00%	6.50%

Table 7. Project assumptions including installation costs, PV module prices, plant generation, energy prices, operational costs, degradation and weighted average capital cost. Source: Powertis

Table 8 shows the estimated energy output of the 65 MW-DC monofacial plant that using monofacial modules on 2P trackers and the estimated energy output of the same plant using bifacial modules on 2P SF7 bifacial tracker. The estimate assumes an 11.9% Bifacial Gain for the bifacial plant and a 32% albedo.

Albedo 32% Bifacial Gain SF7 Bifacial: +11.9%				
Monofacial		SF7 Bifacial		Difference
Energy output over 30 years	3 843 844 kWh	Energy output over 30 years	4 505 169 kWh	+661 325 kWh

Table 8. Power generation comparison between a monofacial plant and a bifacial plant equipped with SF7 trackers. Operation: 30 years. Source: Soltec

Considering an energy price average of US\$25 /MWh and a CAPEX of US\$0.63/Wp for the monofacial plant and US\$0.665/Wp for the bifacial plant (due to the higher bifacial module costs), it is possible to estimate the plant's gross and net revenues over the life of the plant (30 years) and its net present value (NPV). The NPV is the sum of the present values of incoming and outgoing cash flows over the life of the plant.

Other aspects that are considered in the estimate are the plant Operational Expenses (OPEX). We assume that the OPEX of the bifacial version of the plant is US\$ 0.015 /Wp more expensive than that of the monofacial version. This is due to a 30% increase in module cleaning costs to account for the cleaning of the rear side of the bifacial module. The more intensive soil maintenance in order to maintain the albedo values in the bifacial version is assumed to add 70% to the required soil maintenance for the monofacial system. The year-over-year decrease in plant power (degradation) is assumed to be driven by the degradation of individual modules. We use the module manufacturers' degradation guidance, i.e. the degradation of the bifacial modules is lower than that of the monofacial modules. Finally, we assume a 0.5% higher Weighted Average Capital Cost (WACC) for the bifacial technology. This assumption is based on the fact that bifacial technology is new and carries a higher risk.

The estimated energy outputs and financials of the monofacial and bifacial project versions appear in Table 9.

Albedo 32%	Bifacial Gain SF7 Bifacial		+11.9%
	Monofacial Module	Bifacial Module	
	Tracker 2P	Tracker 2P SF7 Bifacial	
30 year estimate			Difference
Energy Output (kWh)	3 843 844	4 505 169	661 325
Gross Revenue (US\$)	\$97 946 524	\$114 801 802	\$16 855 277
Net Revenue (US\$)	\$88 151 872	\$101 599 595	\$13 447 723
NPV Revenue (US\$)	\$41 661 683	\$44 993 955	\$3 332 272
CAPEX (US\$)	\$40 943 700	\$43 188 809	\$2 245 109
NPV Project (US\$)	\$717 983	\$1 805 146	\$1 087 163

Table 9. Comparison of energy output and financials for a plant with monofacial modules on a 2P tracker and bifacial modules and a SF7 Bifacial trackers Source: Powertis

Table 9 indicates that the estimated NPV of the bifacial version of the plant is 8% higher than that of the monofacial version.

TRACKER OPTIMIZATION FOR BIFACIAL MODULES

Factors such as module height, rear interference and others aspects that influence tracker Bifacial Gain also have an economic impact on the project finances. As was presented in Table 5, for 63% albedo the estimated Bifacial Gain of modules on a 1P tracker is 2.4% lower than that of modules on a tracker 2P SF7 bifacial tracker which is optimized for bifacial modules. If we assume that the difference in module level Bifacial Gain does not change with the value of the albedo, Bifacial Gain for 1P in Albedo 32% is estimated in Table 10.

Case	Bifacial Gain
Measured on modules in 2P SF7 bifacial tracker at BiTEC (Albedo 32%)	+11.9%
Estimated Difference in Bifacial Gain between individual modules in 1P and 2P SF7 Bifacial tracker (Albedo 63%)	-2.4%
1P tracker Albedo 32% (Estimated) ²	+9.5%

Table 10. Estimated Bifacial Gain for a module in 1P configuration and 32% albedo Source: BiTEC

Table 11 shows the estimated NPV for a plant where the bifacial modules are located on 1P trackers with a 9.5% Bifacial Gain and for the same modules located on SF7 bifacial trackers which have an 11.9% Bifacial Gain under the same conditions. According to this estimate an improvement of almost US\$1 million can be obtained by choosing an optimized structure for bifacial modules.

Tracker	Albedo	Bifacial Gain	30-year Energy Output	NPV
2P SF7 bifacial	32%	11.9%	4 505 169 kWh	US\$ 1.805.146
1P bifacial	32%	9,5%	4.408.543 kWh	US\$ 840.128
		-2.4%	-96.626 kWh	US\$ -965.018

Table 11. Comparison of the 30-year energy output and net present value for a bifacial plant using SF7 bifacial and 1P trackers. Source: Soltec

CONCLUSIONS AND UPCOMING CHALLENGES

Measurements taken at BiTEC between September and November 2018 show Bifacial Gains of over 19% for individual bifacial modules on a SF7 Bifacial tracker over a white ground cover with an albedo of 63%. We have estimated that even with lower Bifacial Gains and albedo values the economics of a hypothetical project using bifacial modules on SF7 bifacial trackers are better than those of the same project using bifacial or monofacial modules on 1P trackers. The Bifacial Gain of individual bifacial modules on a SF7 Bifacial tracker is 2.4% higher than that of the same modules on a 1P solar tracker, according to data collected at BiTEC. The higher Bifacial Gain on the SF7 Bifacial tracker is because the rear of the modules are free from shadows and the modules operate at a lower temperature.

Our estimates, based on results obtained at BiTEC, indicate that the use of bifacial modules instead of monofacial modules in PV plants may be economically advantageous thus improving investment profitability.

An increasing number of projects are using modules capable of generating energy from both sides. Structures designed specifically to optimize bifacial generation are must-have for tracker manufacturers. The replacement of monofacial modules with a bifacial modules brings about new challenges and the need for improved system designs in order to maximize energy output.

Additional challenges such as updating tracker algorithms lay ahead. Maximizing the energy output of a bifacial system requires maximizing the irradiation on the front and back sides of the modules. This also requires a particular focus on the type of irradiation, i.e. direct, diffuse or reflected that hits the modules. A new technological race in the PV energy arena has begun.

²Assumes that the difference in Bifacial Gain between individual modules in 2P and 1P configurations does not depend on the albedo value.

REFERENCES

[1] A.Di Stefano, G. Leotta, F. Bizzarri. "La Silla PV plant as a utility-scale side-by-side test for innovative modules technologies". 33rd European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC2017 September 2017 Amsterdam. Proc 6CO.14.1 p.p 1978 – 1982, online reference:

<https://www.eupvsec-proceedings.com/proceedings?paper=44211>

[2] M. Chiodetti, A. Lindsay, P. Dupeyrat, D. Binesti, E. Lutun, K. Radouane, S. Mousel. "PV Bifacial Yield Simulation with a Variable Albedo Model". 32nd European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC2016 June 2016 Germany Proc. 5DP.1.4 p.p 1449 - 1455, online reference:

<https://www.eupvsec-proceedings.com/proceedings?paper=37431>

[3] Pelaez, S.A., C. Deline, P. Greenberg, J. Stein, and R.K. Kostuk. 2018.

"Model and Validation of Single-Axis Tracker with Bifacial Photovoltaics:

Preprint." Golden, CO: National Renewable Energy Laboratory.

NREL/CP-5K00-72039. on-line link:

<https://www.nrel.gov/docs/fy19osti/72039.pdf>.

[4] NREL, Bifacial_Radiance 0.2.3 , bifacial irradiance simulation software, online reference:

https://github.com/NREL/bifacial_radiance

[5] C. Monokroussos, X. Y. Zhang, M. Li, S. Chen, A. Zhou, S. Liu, J. Zhu, N. Wang, E. Lee, J. Bonilla Castro, W. Herrmann, M. Schweiger, V. Feng, Y. Zhang and C. Zou. 'Additional Requirements for Supplementary Rating and Qualification of Bifacial PV-Modules', Conference at 12th International Photovoltaic Power Generation and Smart Energy Exhibition & Conference, SNEC 2018, Shanghai May 29,2018 on-line link:

<http://www.snec.org.cn/Download.aspx?dir=SNEC2018-Presentation+Slides%5CS8+PV+Module+Quality+Assurance&file=6-ADDITIONAL+REQUIREMENTS+FOR+SUPPELEMNTARY+RATING+AND+QUALIFICATION+OF+BIFACIAL+PV-MODULES.pdf>

[6] S. Wang, O. Wilkie, J. Lam, R. Steeman, W. Zhang, K.S ingKhoo, S. Chun Siong, H. Rostan. 'Bifacial photovoltaic systems energy yield modelling'. 5th International Conference on Silicon Photovoltaics, SiliconPV. March 2015, Konstanz. Elsevier, Science Direct Energy Procedia 77 p.p 428 – 433, online reference:

<https://www.sciencedirect.com/science/article/pii/S1876610215008280>

[7] U. Yusufoglu T. Lee, T. Pletzer, H.Kurz, A. Halm, L.J. Koduvelikulathu C. Comparotto, R. Kopecek. "Modeling and simulation of annual energy yields of bifacial modules at different climate zones" 2014 Bifacial PV Workshop, Chambery, May 27, 2014, online reference:

<https://www.slideshare.net/sandiaecis/3-yusufoglu-ok>

[8] "Powertis to develop 2 GW of solar by 2022", PV Magazine, February 5, 2019, online reference:

<https://www.pv-magazine.com/press-releases/powertis-to-develop-2-gw-of-solar-by-2022/>



Black & Veatch Management Consulting LLC (Black & Veatch) reviewed the data and measurement techniques used by Soltec Energia Renovables S.L. (Soltec) to produce tables one through six of this white paper (the "Technical Tables"). Black & Veatch reviewed the methodology used by Soltec to generate the Technical Tables and believes that the methodology is consistent with accepted industry practice.

Black & Veatch understands that Tables seven through eleven of this white paper (the "Economic Tables") are based upon information provided by Powertis S.A., a developer of large-scale PV projects in Europe and Latin America. Black & Veatch did not independently verify this information and cannot verify its accuracy. If the data is accurate, Black & Veatch believes the Economic Tables are consistent with accepted engineering practice.

Legal Notice: This statement is qualified in its entirety by the full Black & Veatch Report. The statements contained in this document are for general information purposes only. Black & Veatch makes no representations or warranties of any kind about the accuracy or suitability of such statements for any purpose. B&V shall not be responsible or held liable for any losses or damages related to your reliance on this document and you hereby waive and release B&V from any such losses or damages of any kind or nature, including any consequential, indirect, special, or incidental damages.