Soltec

Making Tracks,
Building Trust

View-Factor Vs. Ray Tracing

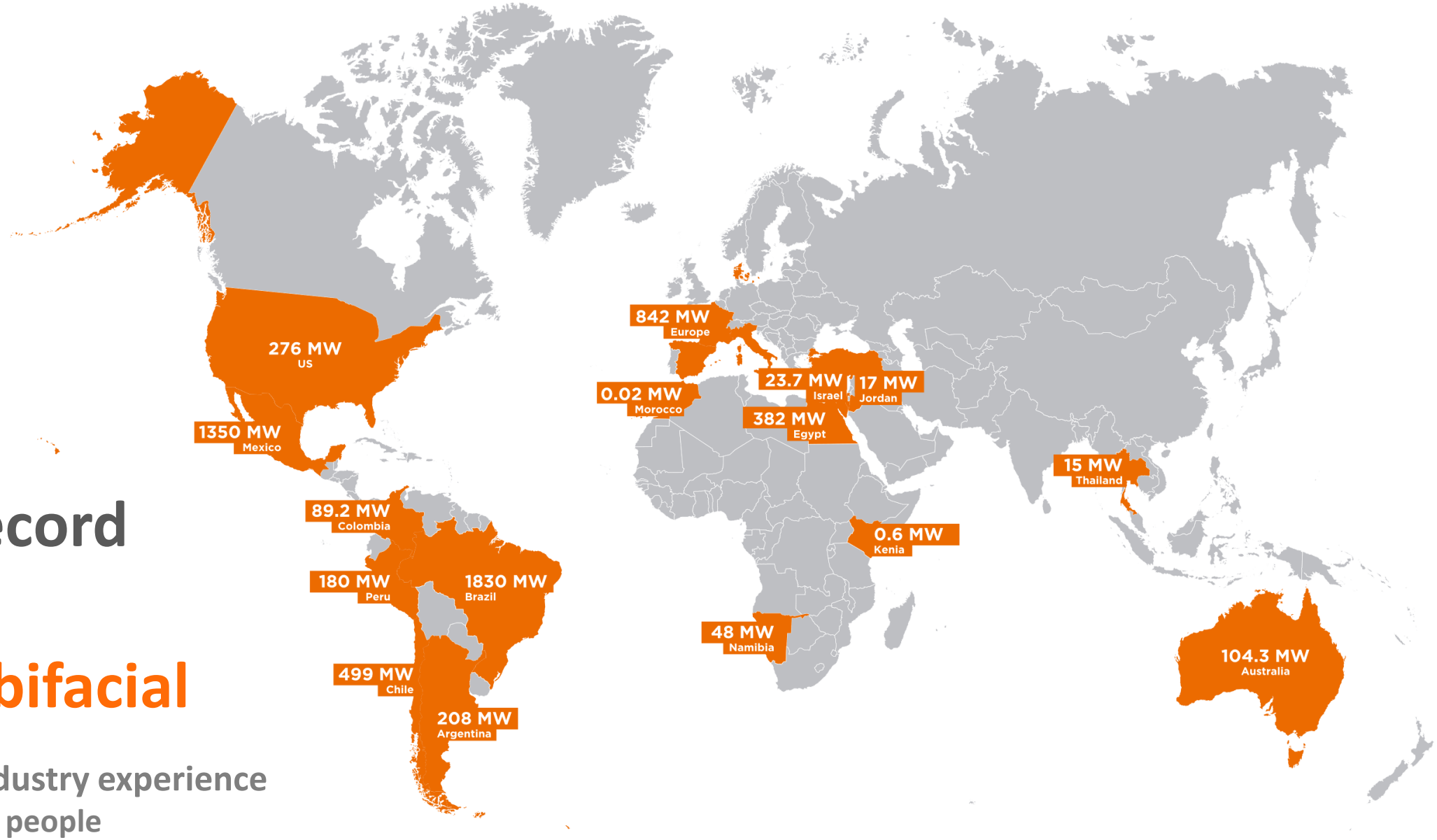
Jose Alfonso Teruel, CTO Soltec Innovations

18/12/2019

Soltec's track-record

8+ GW

2+ GW bifacial



15 years of industry experience

More tan 1,500 people

Our bifacial story

2015

'La Silla' solar plant (Chile), 2015. Soltec produced **the first solar tracker specifically designed for bifacial modules** installed in a utility scale solar plant.

2017

Soltec launchs SF7 Bifacial Single-Axis Tracker.

- Higher mounting height
- Shadow-free backside
- Wide-aisle reflecting surfaces

2018

Soltec Leads with the World's First Bifacial Tracking Evaluation Center

BiTEC (Bifacial Tracker Evaluation Center) measures bifacial performance and its effect on yield.

2019

2+ GW SF7 Bifacial in projects worldwide

Sao Gonçalo-Brazil (475 MW), Cluster MG-Brazil (118MW), Tlaxcala Mag II-Mexico (219,6 MW) among others.

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Bifacial Tracker Evaluation Center
Livermore - California

LA SILLA	2 YEAR	BG= 13%
BiTEC	1 YEAR	BG = 7 - 16%

Challenges:

1. **Acquiring long term bifacial tracking data**
2. **Obtaining real PV plant conditions**
3. **Characterizing variables influencing bifacial**
   - *Albedo*
   - GCR
   - Height
   - Shading and interferences

Determining Bifacial Gain = BG = f(Albedo, GCR, H)

Targets:

- **Optimizing the SF7 bifacial tracker**
- **Developing bifacial tracking algorithms**

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Bifacial Tracker Evaluation Center

Livermore - California

Test Features: --- 18 Trackers

- **Albedo:** White/Seasonal/Gravel
- **GCR:** 0.4, 0.33, 0.47
- **Height** 1P, 2P

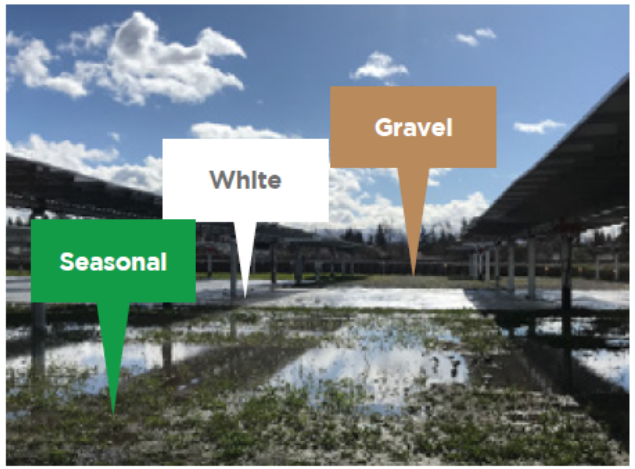


Figure 3. Trackers under different albedo conditions at BiTEC. Dirt test

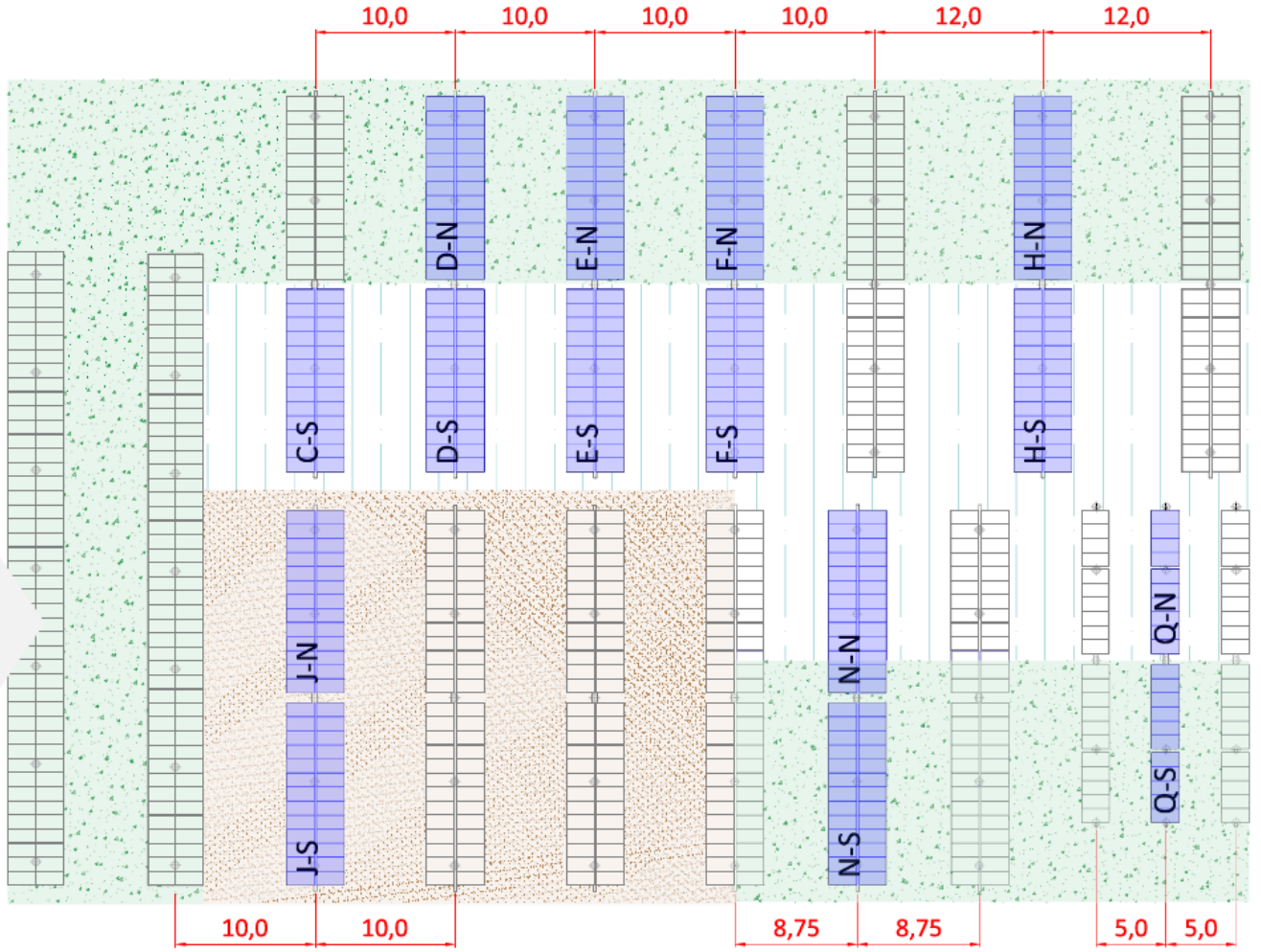
In Blue:
Modules used for measurements

In White, Brown and Green:
White, Gravel and Seasonal albedos respectively

In Red:
Aisle Pitch in meters:

2P - 12.0, 10.0 and 8.7 meters equivalent to a GCR of 0.33, 0.40 and 0.46 respectively

Albedo		Ground Coverage Ratio		
		0.46	0.40	0.33
White	49-65%	2P/1P		
Gravel	24-36%	2P	2P	2P
Seasonal	16-23%	2P/1P		



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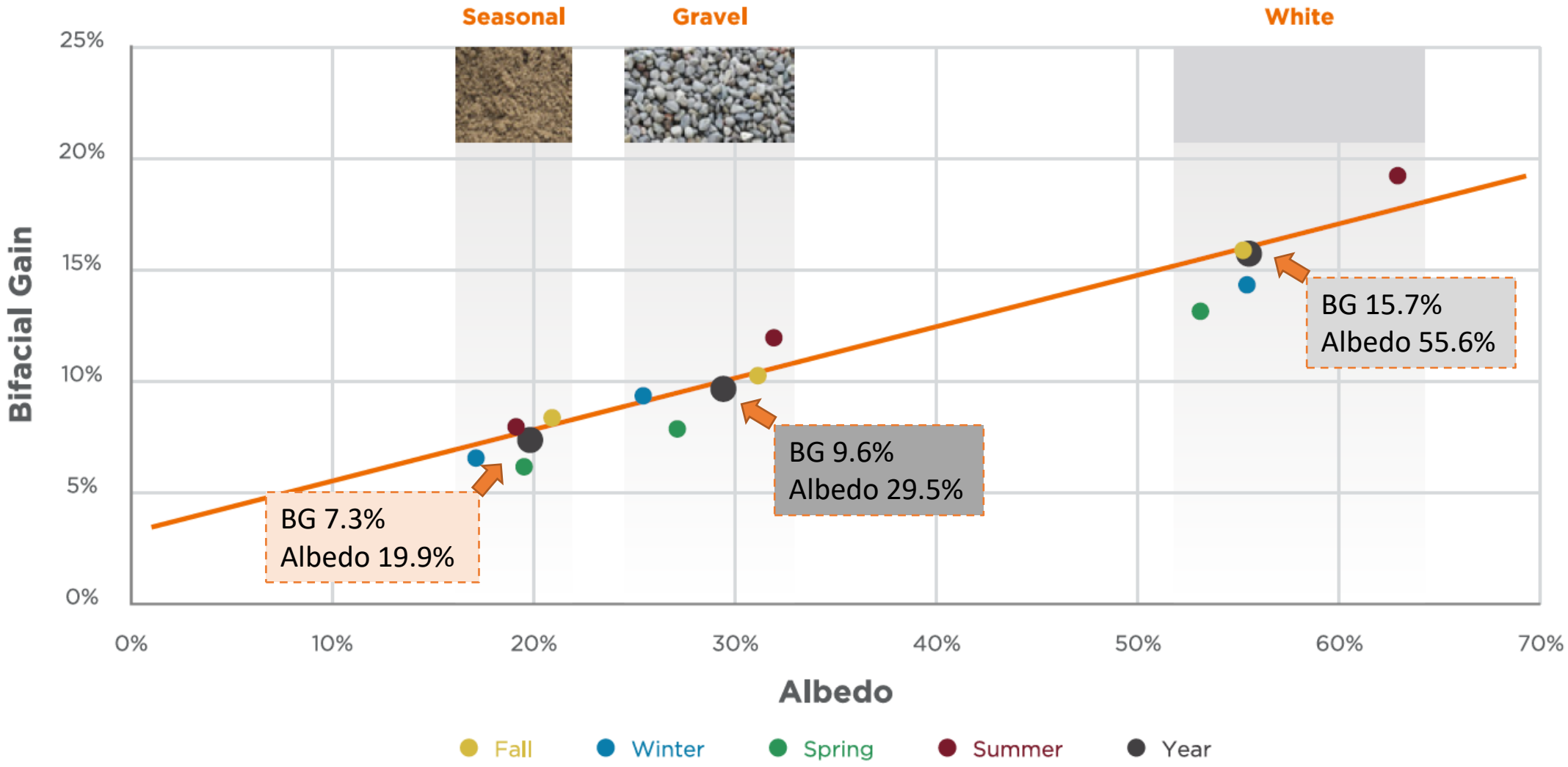
The Bifacial Year – Bifacial Gain



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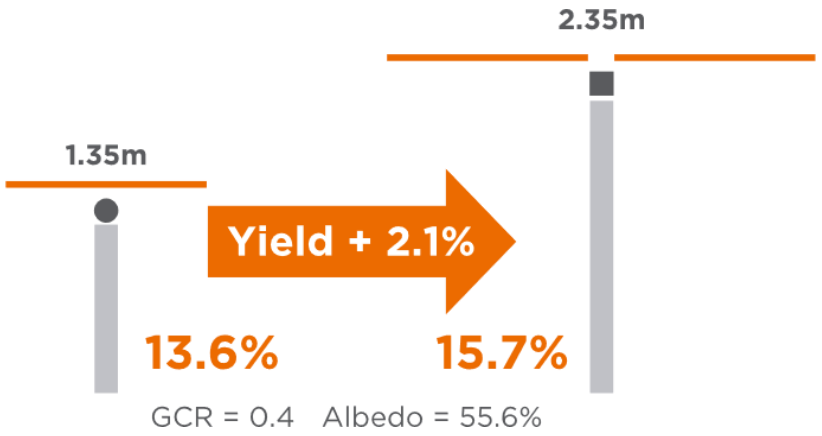
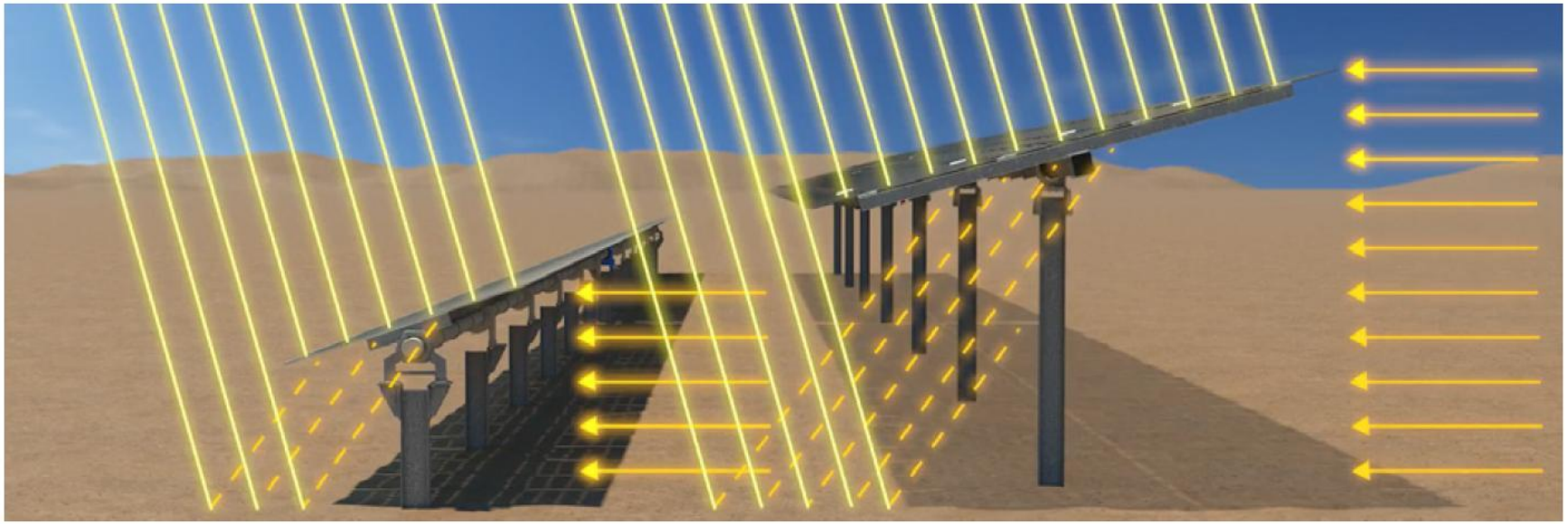
The Bifacial Year – 1P vs 2P



1P Standard tracker	Measured Bifacial Gain	2P SF7 Bifacial
16.8%	Fall	**19.2%**
12.6%	Winter	**14.3%**
11.2%	Spring	**13.1%**
13.7%	Summer	**15.8%**
13.6%	**Year**	**15.8%**



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The Bifacial Year – 1P vs 2P differences analysis

Variable	Factor	Respect Total Energy			
	Effect	**Δ**	**1P**	**SF7 2P Bifacial**	**Parameters**
Rear Irradiation -0.02%	View Factor Affection	**-1.00%**	9.20%	8.20%	Height
	Ground scattering	**0.74%**	0.09%	0.84%	Albedo-model
	Diffuse	**0.24%**	1.51%	1.75%	Height
Interferences / Design +0.89%	Torque Tube Shading	**0.56%**	-0.56%	0.00%	Shading Factor
	Radiation through Gap	**0.17%**	0.00%	0.17%	Module Transparency
	Mismatch	**0.16%**	-0.47%	-0.31%	Rear G Mismatch
Operation +1.2%	Temperature	**1.20%**	-5.10%	-3.90%	Uv & Uc
	TOTAL	**2.07%**			

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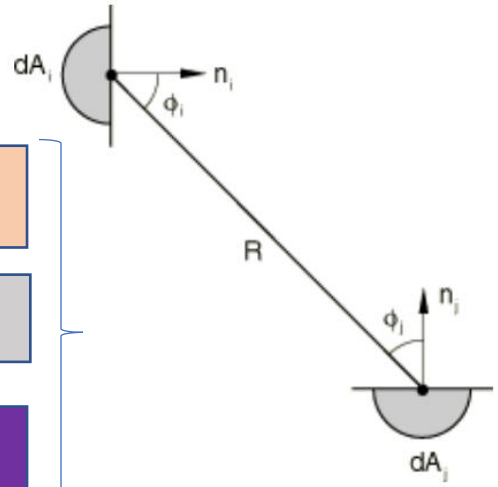
The Bifacial Year – Simulation Models
Raytracing vs View Factor

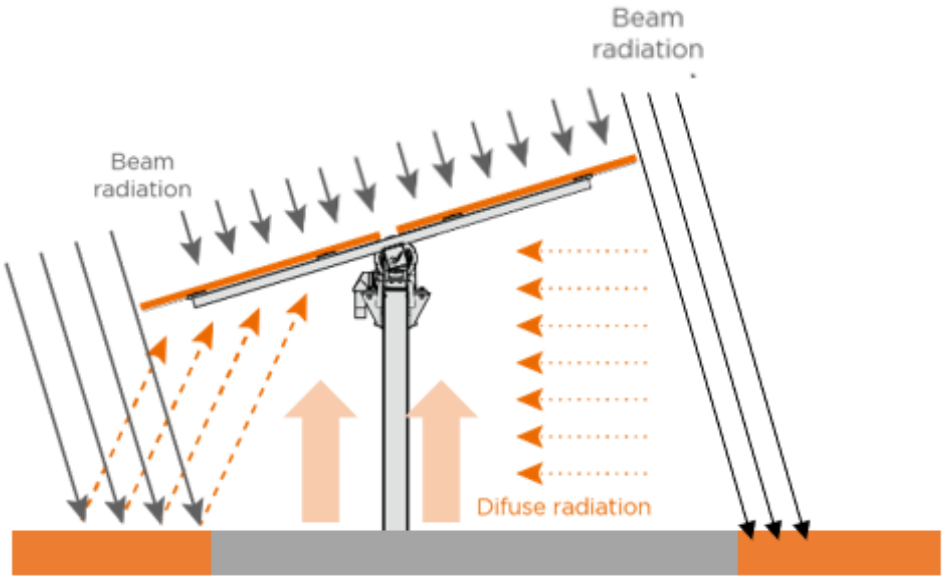
View Factor based software

$$\sum$$

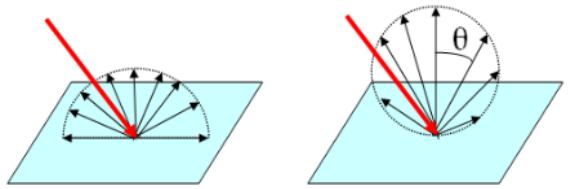
- Sky diffuse
- Beam
- Ground scattering
- Ground diffuse

Albedo → View factor

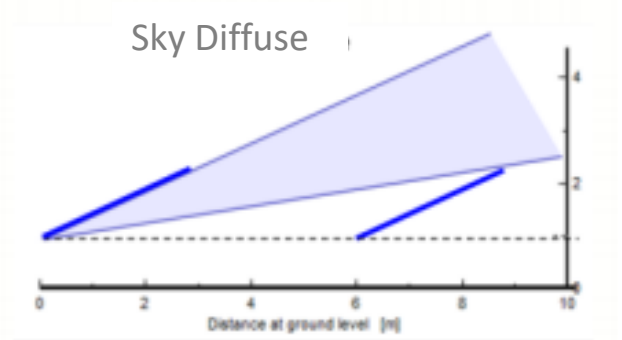




- Irradiation is estimated by adding components contribution
- 1-order reflections
- Simplified ground scattering (Lambertian surfaces)
- Surfaces geometrical relationship are critical
- Not considering non-uniform rear irradiance



Isotropic uniform scattering



A. Mermoud, B. Wittmer Bifacial shed simulations with PVsyst Bifacial Workshop 2017 25-26.10.2016 Konstanz, Germany
http://bifipv-workshop.com/fileadmin/layout/images/Konstanz-2017/2__B._Wittmer_PV_SYST_Bifacial_shed_simulations.pdf

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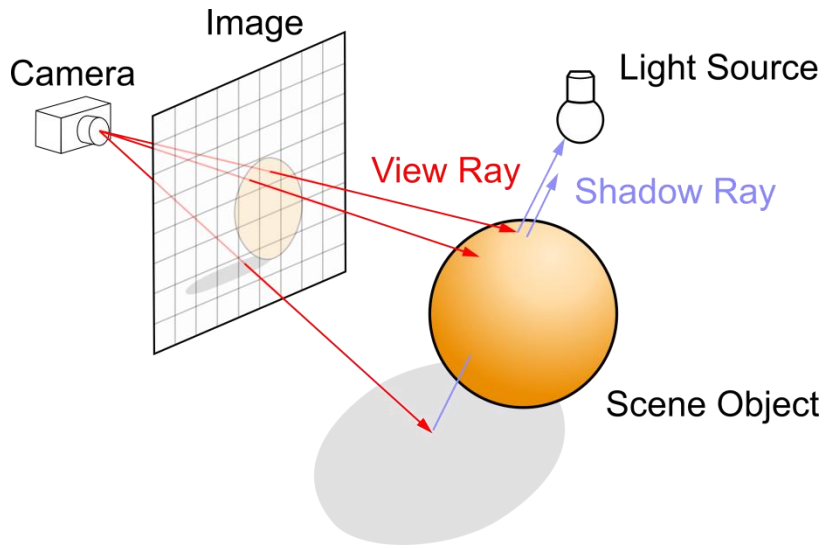
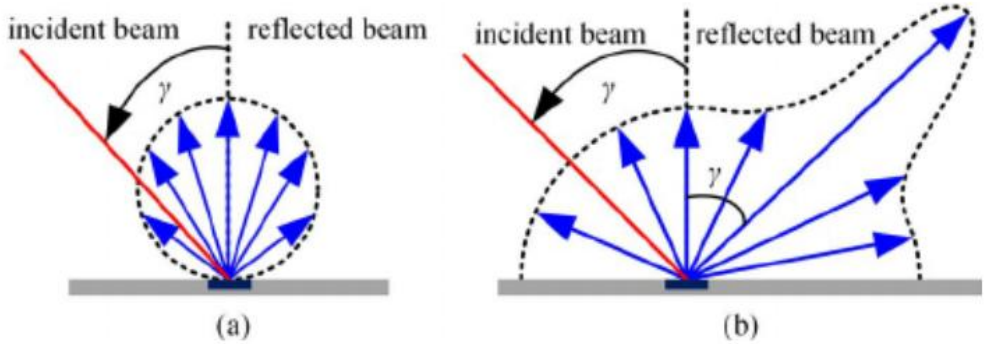
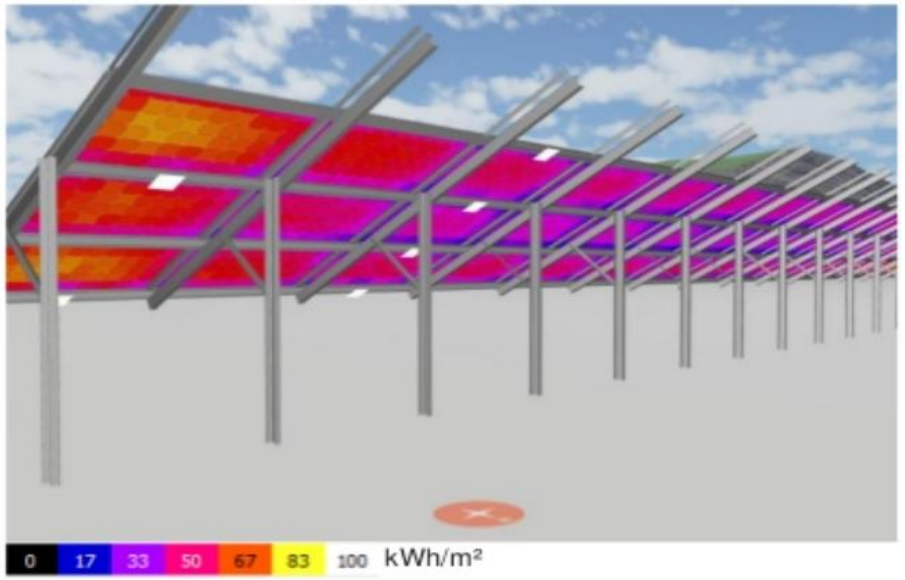
The Bifacial Year – Simulation Models
Raytracing vs View Factor

Ray Tracing based software





(a) Ideal Lambertian (diffuse) reflection. (b) Diffuse and specular combined reflection [25].



- Model traces rays reflecting in all surfaces
- n-order reflections
- Ground scattering with directional component (specular)
- Detailed geometry, contribution of shades is realistic
- Diffuse is estimated by the model

M. Roser and P. Lenz, “Camera-based bidirectional reflectance measurement for road surface reflectivity classification,”in Proceedings of IEEE Conference on Intelligent Vehicles Symposium (IEEE, 2010), pp. 340–347

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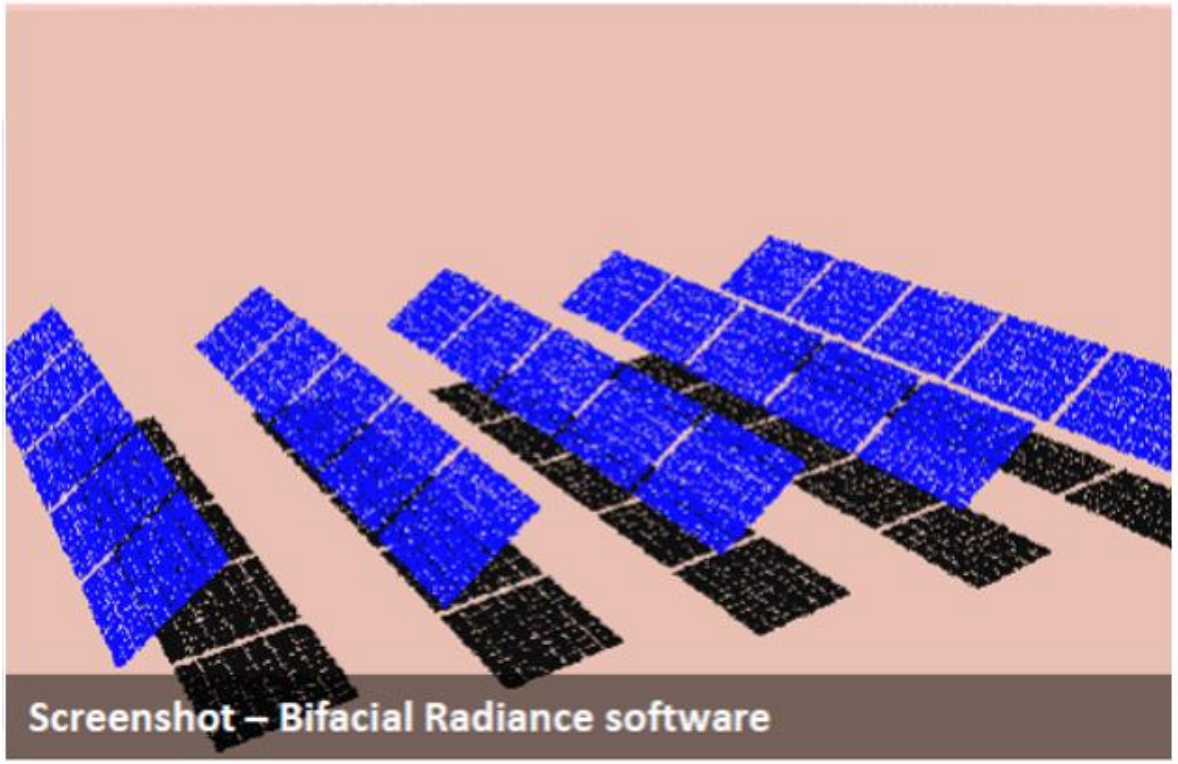
The Bifacial Year – Simulation Models
Raytracing vs View Factor



Ray Tracing is (vs View factor)[1] :

More complex modelling
Higher computing resources
More accurate

Ray Tracing is proper for[2] :

Irradiance with multiple angle
Multiple shades
Racking system
Torque tube
Non uniform irradiation
Detailing shades

Ray Tracing method is the most commonly used to simulate bifacial performance by key PV industry researchers, such as NREL, Canadian Solar, EDF, INES and DNV.

1-Marion B, MacAlpine S, Deline C, Asgharzadeh A, Toor F, Riley D, et al. A practical irradiance model for bifacial PV modules. In: *44th IEEE Photovoltaic Specialists Conference (PVSC), Washington, DC*. 2017.
2-S. Ayala Pelaez, C. Deline, P. Greenberg, J. S. Stein, and R. K. Kostuk, "Model and Validation of Single-Axis Tracking with Bifacial PV", IEEE J. Photovoltaics, vol. 9, no. 3, 2019. https://ieeexplore.ieee.org/abstract/document/8644027

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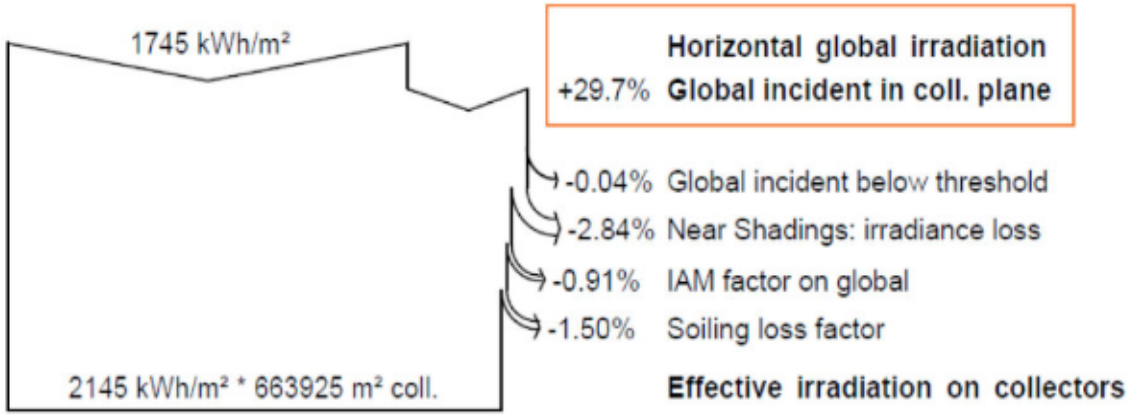
The Bifacial Year – Tracking angle

Larger tracking angle

Operate longer oriented directly facing sun → Higher Energy

Loss diagram over the whole year



Maximum tracking angle is important for Bifacials

Pitch (m)	Max Tracking Angle	kWh/kWp/year
SF 7 bifacial	60º	2046
Other trackers	50º	2038

Bifacial plants GCR tends to be lower

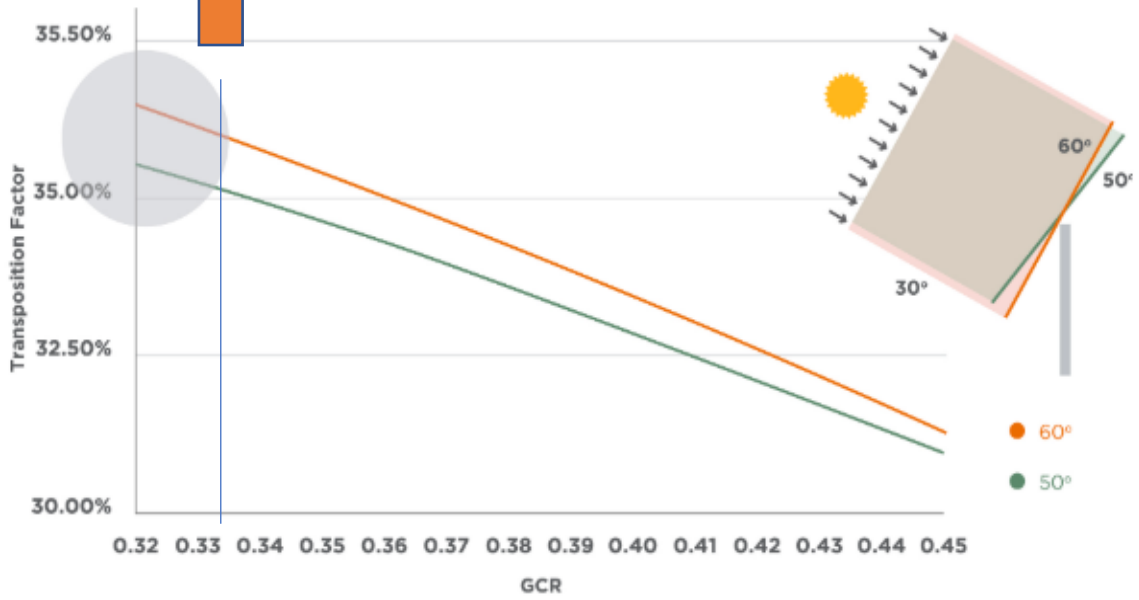


Figure 13. Transposition Factor for different GCR and Maximum Angles. Source: PVSyst

Comparison for 12 meters pitch

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The Bifacial Year – PVSyst Configuration

PVSyst bifacial key parameters should be set up for accuracy simulations

Parameters	Standard 1P trackers	SF7 Bifacial
Angle	–	-60º +60º
Height	1.35 meters	2.35 meters
Structure Shading Factor	5.6%	0%
Shed Transparent Fraction	MT%	(MT* + 3.75) x 1.017 (%)
Thermal Loss factor (Uc)	29 W/m2 k	31 W/m2 k
Thermal Loss Factor (Uv)	0 W/m2 k/m/s	1.6 W/m2 k/m/s
Mismatch Loss Factor	10 %	3.1 %

*MT: Module Transparency from module manufacturer

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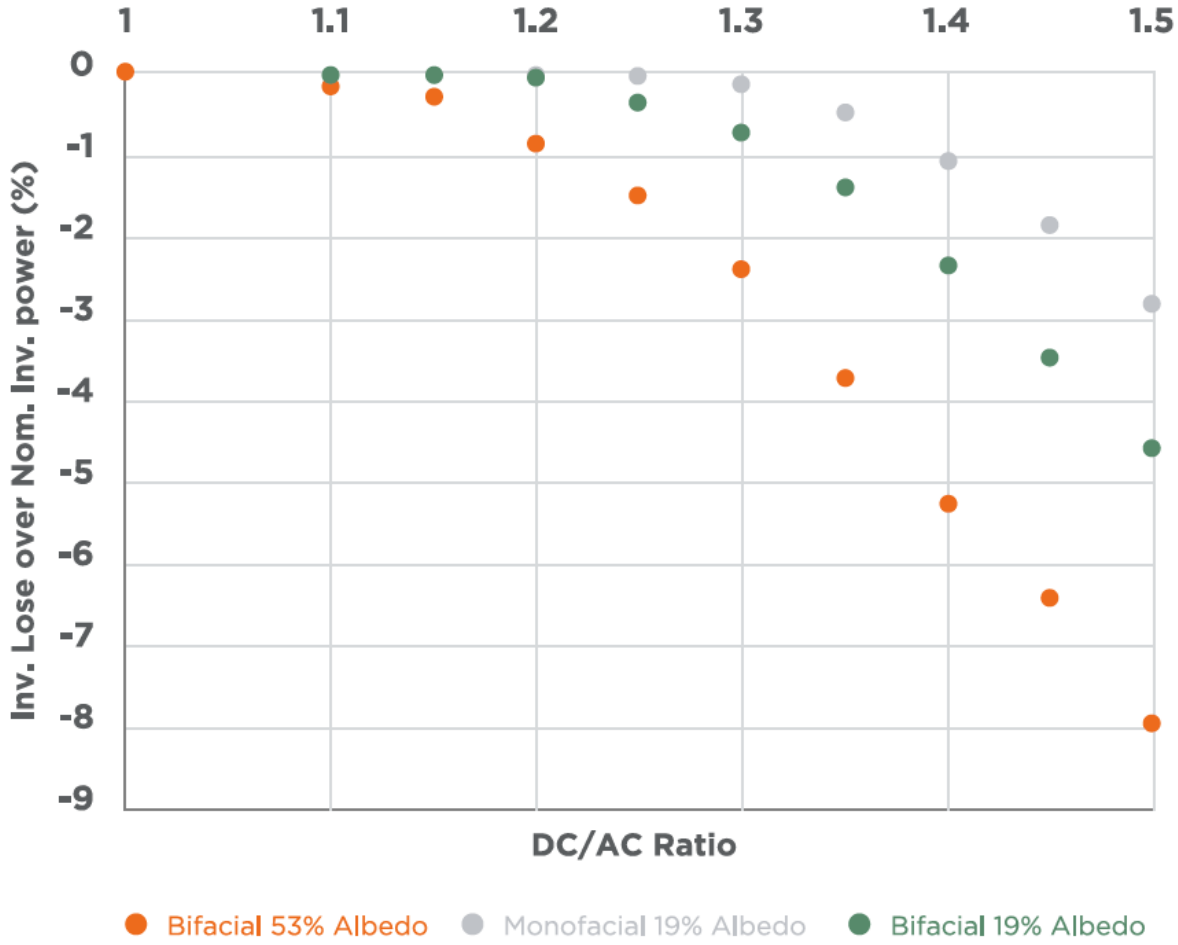
Electrical Dimensioning
AC/DC Ratio

Lower DC / AC Ratio is recommended for bifacials

Inv. Lose over Nom. Inv. Power			
	Bifacial		Monofacial
DC/AC Ratio	Albedo 53%	Albedo 19%	Albedo 19%
1	0	0	0
1.1	-0.14	0	0
1.15	-0.28	-0.01	0
1.20	-0.85	-0.07	0
1.25	-1.50	-0.33	-0.3
1.30	-2.40	-0.71	-0.11
1.35	-3.73	-1.39	-0.48
1.40	-5.25	-2.34	-1.06
1.45	-6.41	-3.47	-1.83
1.50	-7.93	-4.60	-2.81



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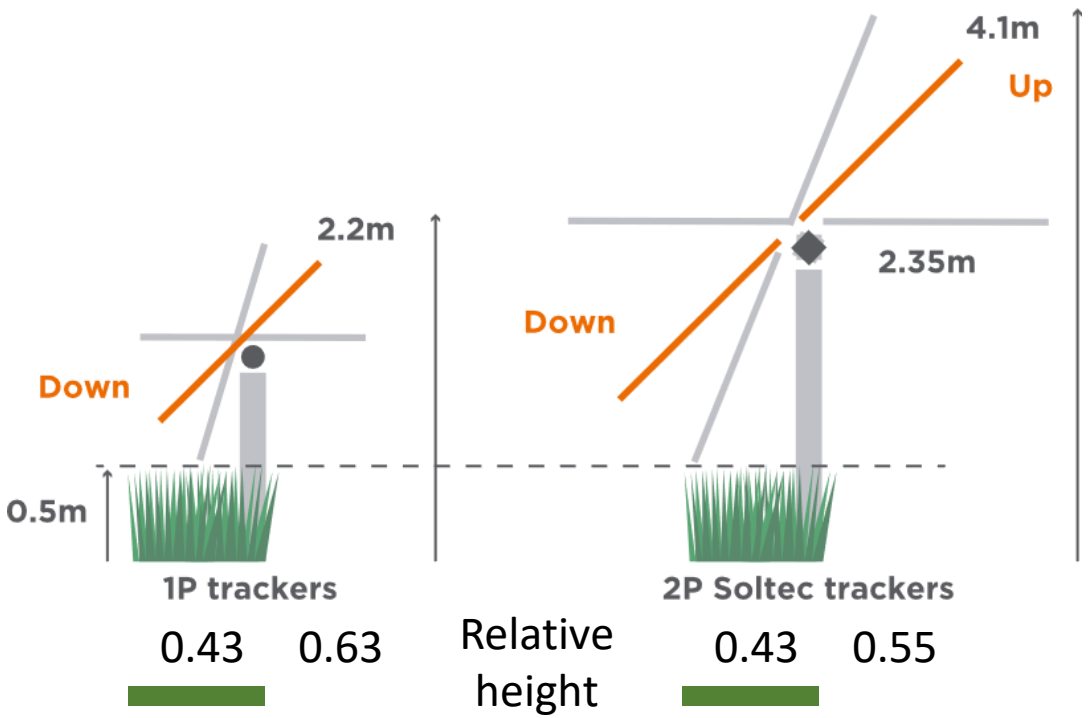
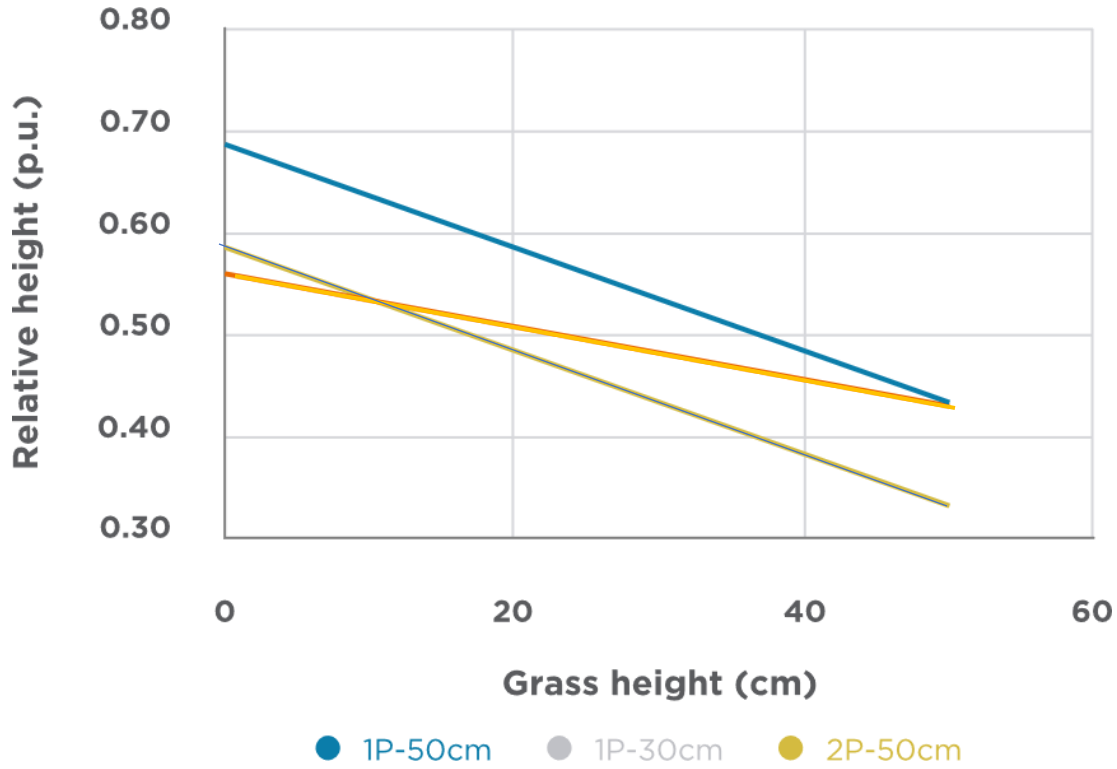
Operation and Maintenance
Effective relative height

Effective height useful for bifacial reflection depends on the gras level, so relative height does.



Efective relative height = $\frac{\text{Tracker height} - \text{grass height}}{\text{Tracker width}}$



Influence of useful tracker height in relation to vegetation growth 1P Vs. 2P. Source: Soltec

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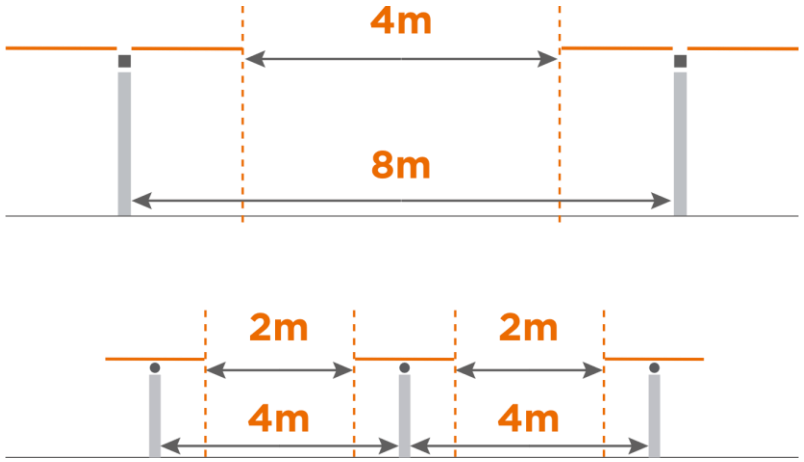
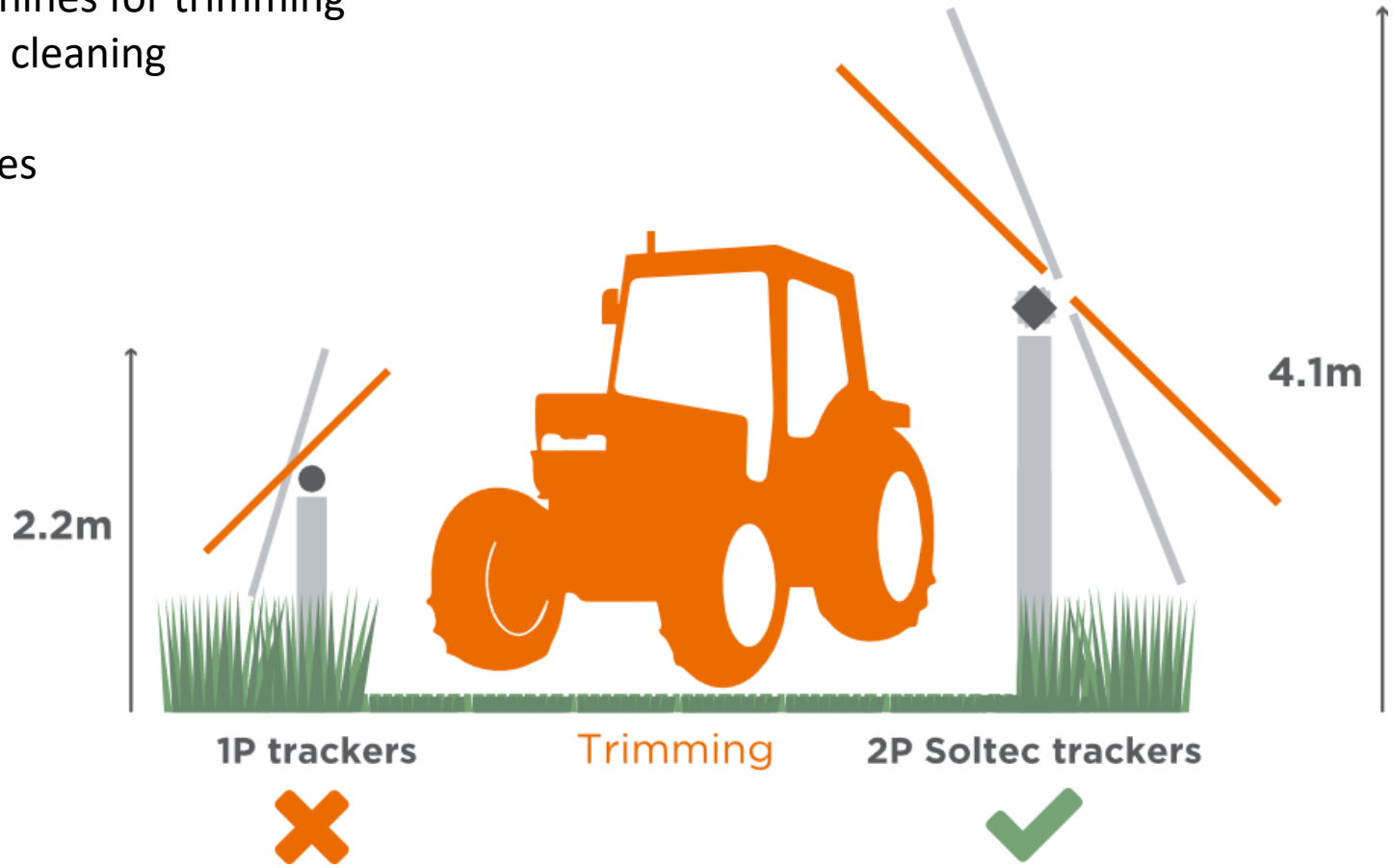
Operation and Maintenance

2P trackers implies easily maintenance for bifacials

- Higher clearance allows easily access of machines for trimming
- Double module surface = half movement for cleaning
- Higher modules = easily cleaning rear side
- Double pitch = double free space between iles





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Operation and Maintenance

Cutting Grass under the tracker and tracker height are important for bifacials

Beth Copanas, Bifacial Considerations from an Engineering, Procurement & Construction (EPC) Perspective
BifiPV worshop 2019. Amsterdam 16-19 September 2019. Poster season.
http://bifipv-workshop.com/fileadmin/layout/images/bifiPV/presentations2019/bifiPV2019-RES_Copanas.pdf]

Conclusions

- 1 YEAR : September 2018 - August 2019 of field measurement.
- Bifacial Gain of **15.7%** for SF7 bifacial with albedo of about 55%.
- Bifacial Gain of **7.3%** under seasonal albedo for northern California (ground conditions changes monthly)
- Bifacial Gain for 2P **SF7 Bifacial is 2.1% higher than 1P tracker**.
- This difference is mainly caused by:
  - **Lack of shading in the rear side** of the module
  - **Higher position of the solar panels** during operation
  - **Lower operating temperature**.
- The specific performance and advantages of bifacial modules can be simulated using PVsyst® setting properly bifacial key parameters
- Raytracing simulations have demonstrated to be more accurate than view factor
- Bifacial parameters are provided from BiTEC test:
  - **Structure Shading factor**
  - **Shed Transparent fraction**
  - **Thermal Loss factors**
  - **Mismatch Loss factor**
- Operation and maintence as cutting gras is relevant with Bifacials
- PV Plant design parameters like GCR, tracking range, AC/DC ratio are relevant with Bifacials

↑ ALBEDO:
- ↑ Main influence
- ↕ Seasonal variations

↓ GCR
- ↑ Tracking time
- ↑ Bifacial Ratio

↑ Height
- ↓ Rear irradiance
- ↓ Mismatch
- ↓ Temperature