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Challenges and Opportunities in Widespread Bifacial PV Adoption

Utility-scale solar development in 2020

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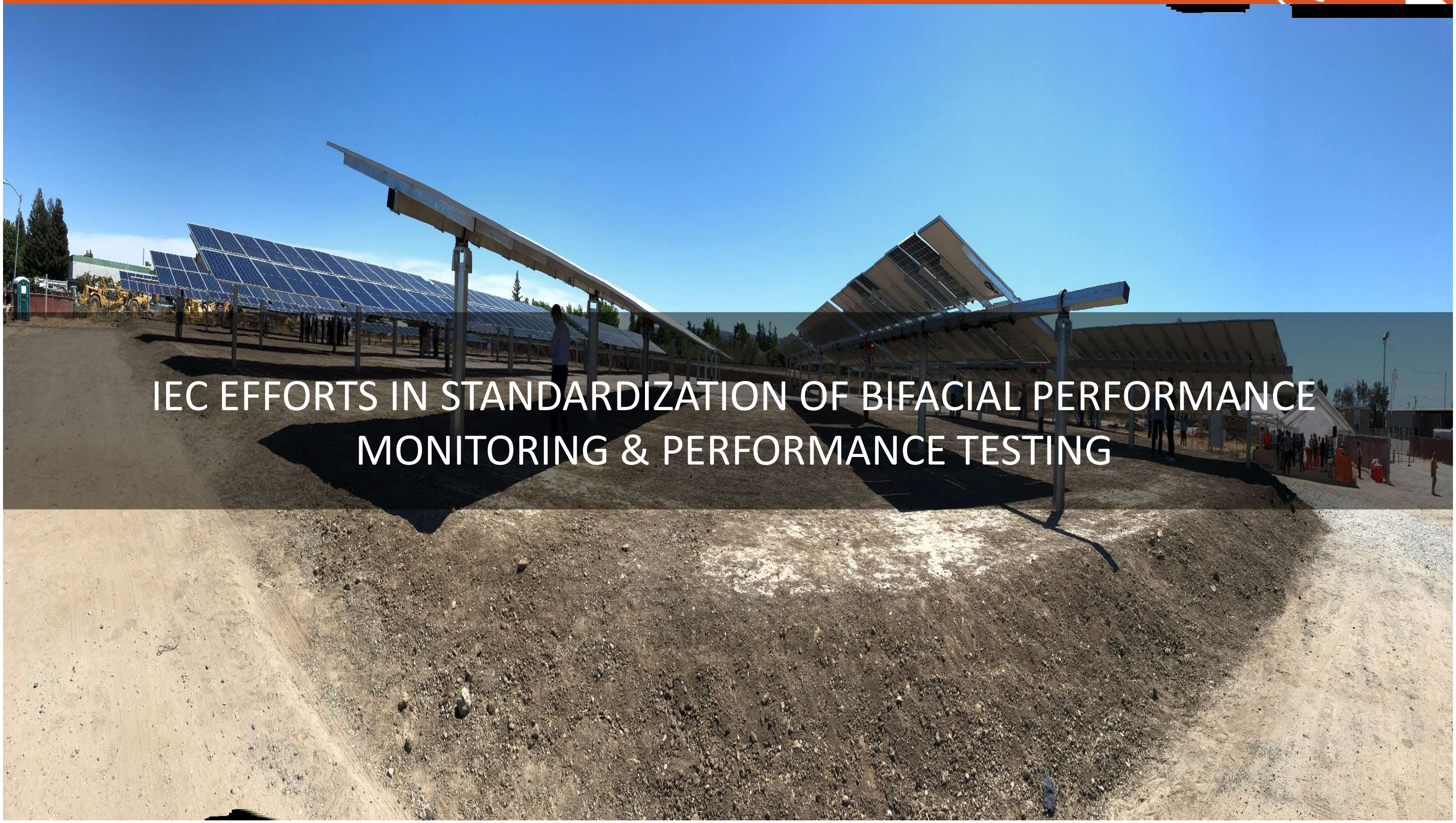
BiFi 2019 Worksop, Amsterdam NL

AGENDA: OVERVIEW

- **A** IEC efforts in standardization of bifacial performance monitoring & performance testing
- **B** Bifacial performance models and parametric sensitivities
- **C** Project economics and optimization of system design



IEC EFFORTS IN STANDARDIZATION OF BIFACIAL PERFORMANCE MONITORING & PERFORMANCE TESTING

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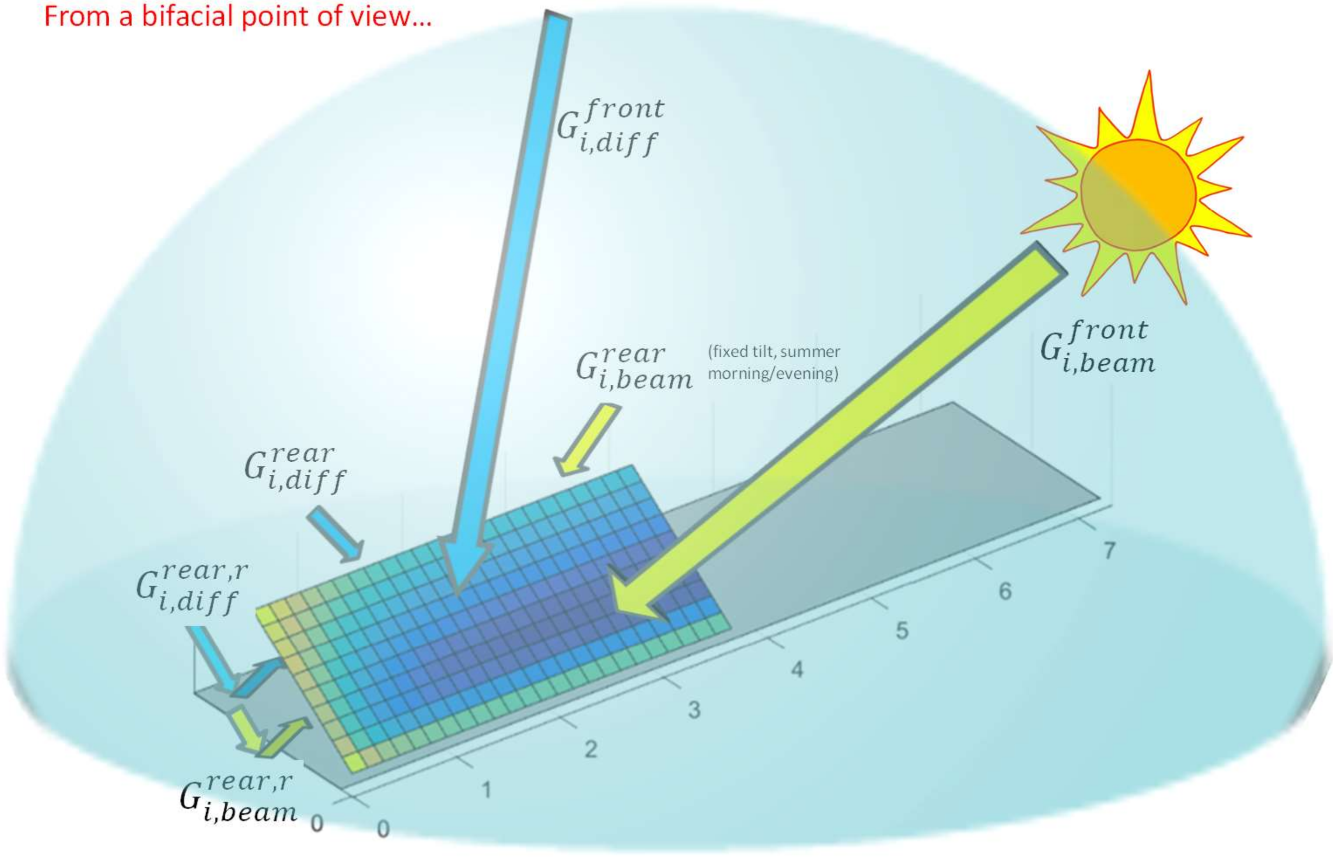
AN OVERVIEW OF THE SOLAR RESOURCE

From a bifacial point of view…



IEC TS 60904-1-2 (WG2, TC82)

first Bifacial related technical specification, published 01/2019

$$G_{E_i} = 1\,000\ Wm^{-2} + \varphi \cdot G_{R_i} \quad \textbf{(6)}$$

$$\varphi = Min(\varphi_{Isc}, \varphi_{Pmax}) \quad \textbf{(7)}$$

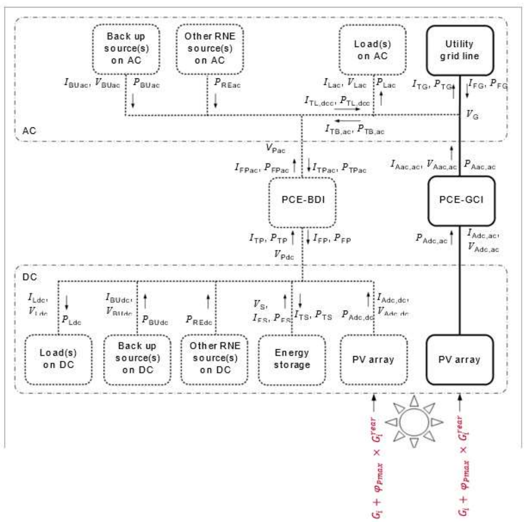
G_{E_i} [=] Equivalent Irradiance

φ [=] Bifaciality Coeff

PV Devices, Part 1-2 Measurement of I-V characteristics of Bifacial PV Devices

IEC 61724-1 (WG3, TC82)

PV System performance, Part 1 - Monitoring



A Project Team formed and tasked with defining Bifacial PV performance standard following TC82 Plenary Meeting in Busan, S. Korea (Oct. 2019)

B Final draft edits to IEC 61724-1 complete.
Project team is seeking comments by no later than 10/31/2019

C Major overhaul to defined terms were necessary (rear-side plane-of-array irradiance, spectrally-corrected albedo, etc)

D Expect to have IEC 61724-1 revision with bifacial system consideration committee draft (CD) submitted within the 2019 calendar year

$$PR^{i}_{annual-eq,bi} = \left(\sum_k P_{out,k} \times \tau_k\right) \Big/ \left(\sum_k \frac{C_k \times P_0 \times G_{i,k} \times BIF \times \tau_k}{G_{i,ref}}\right)$$

IEC 61724-1 (WG3, TC82)

PV System performance, Part 1 - Monitoring

3.10
bifacial PV device
in a bifacial PV device, both surfaces (front and back sides) of the PV module are used for power generation.

3.11
bifaciality
bifaciality refers to the ratios between the main I-V characteristics of the back side and the front side of a bifacial device, typically at Standard Test Conditions (STC) unless otherwise specified. It is quantified with reference to bifaciality coefficients, namely the short-circuit current bifaciality coefficient φ_{Isc}, the open-circuit voltage bifaciality coefficient φ_{Voc} and the maximum power bifaciality coefficient φ_{Pmax}.

3.15
in-plane rearside irradiance ratio
ρ_i
the ratio of the irradiance incident on the rear side of the modules in the PV array to the irradiance incident on the front side of an inclined surface parallel to the plane of array. It is a dimensionless quantity but can exceed a value of 1 since, in addition to reflected light, diffuse

3.16
spectrally-corrected in-plane rearside irradiance ratio
ρ_i^{SP}

the in-plane rearside irradiance ratio per 3.16 when both irradiance quantities are measured with a spectrally matched reference device or with the application of spectral correction factors per IEC 60904-7

3.17
spectrally matched reference device
a reference device (such as a PV cell or module) with spectral response characteristics sufficiently close to those of the PV modules in the PV array such that spectral errors are acceptably small under the typical range of incident spectra

3.18
in-plane rearside irradiance
$\mathrm{G_i^{rear}}$ *or* $\mathrm{POA^{rear}}$
is the sum of direct, diffuse, and ground-reflected irradiance incident on the rear side of the modules in the PV array, also known as rearside plane-of-array ($\mathrm{POA^{rear}}$) irradiance.

Note 1 to entry: Expressed in units of W·m^{-2}.

Note 2 to entry (if measured via in-plane rearside irradiance ratio): $G_i^{rear} = \rho_i \times G_i$ OR $G_{i,SP}^{rear} = \rho_i^{SP} \times G_i$

Table 2 – Measured parameters and requirements for each monitoring system class

Parameter	Symbol	Units	Monitoring purpose	Class A system		Class B system	
				Required?	Minimum number of sensors	Required?	Minimum number of sensors
Irradiance (see section 8)							
Global horizontal irradiance	GHI	W·m^{-2}	Solar resource, connection to historical and satellite data	√	1 × Table 3	√ or E	
in-plane irradiance (POA)	G_i	W·m^{-2}	Solar resource	√	1 × Table 3	√	
Horizontal albedo	ρ_H	Unitless	Solar resource, rearside	√ Option 1 for bifacial	1 × Table 3		
In-plane rearside irradiance (POA)	$\mathrm{G_i^{rear}}$	W·m^{-2}	Solar resource, rearside	√ Option 2 for bifacial	3 × Table 3		
Spectrally-corrected in-plane rearside irradiance	$\mathrm{G_{i,sp}^{rear}}$	W·m^{-2}	Solar resource, rearside	Optional, for bifacial			
Direct normal irradiance	DNI	W·m^{-2}	Solar resource, concentrator	√ for CPV	1 × Table 3		
Diffuse irradiance	G_d	W·m^{-2}		√ for CPV with < 20× concentration	1 × Table 3		

3.19
bifacial irradiance factor
BIF
is a dimensionless variable that can be directly multiplied by the frontside in-plane irradiance ($\mathrm{G_i}$) to calculate the "effective" irradiance reaching a bifacial device from both the front and rear side collectively.

Note 1 to entry: $BIF = (1 + \varphi_{Pmax} \times \rho_i)$ OR $BIF^{sp} = (1 + \varphi_{Pmax} \times \rho_i^{SP})$

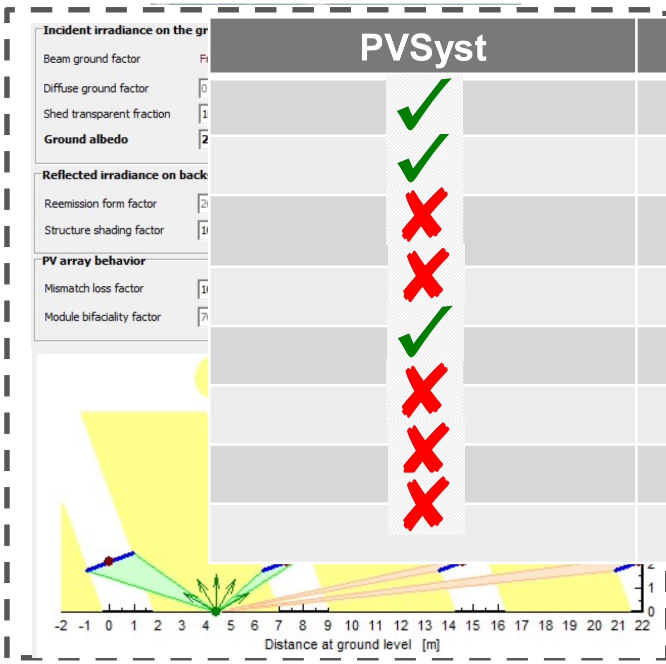
Note 2 to entry: rearside POA irradiance can be measured simultaneously with frontside POA irradiance using a bifacial reference cell. In that case, $BIF = G_i^{BiFi\ Ref\ Cell} \div G_i$ provided that frontside POA irradiance is measured with same type of device as the bifacial reference cell for consistency of the BIF calculation.

BIFACIAL PERFORMANCE MODELS AND PARAMETRIC SENSITIVITIES

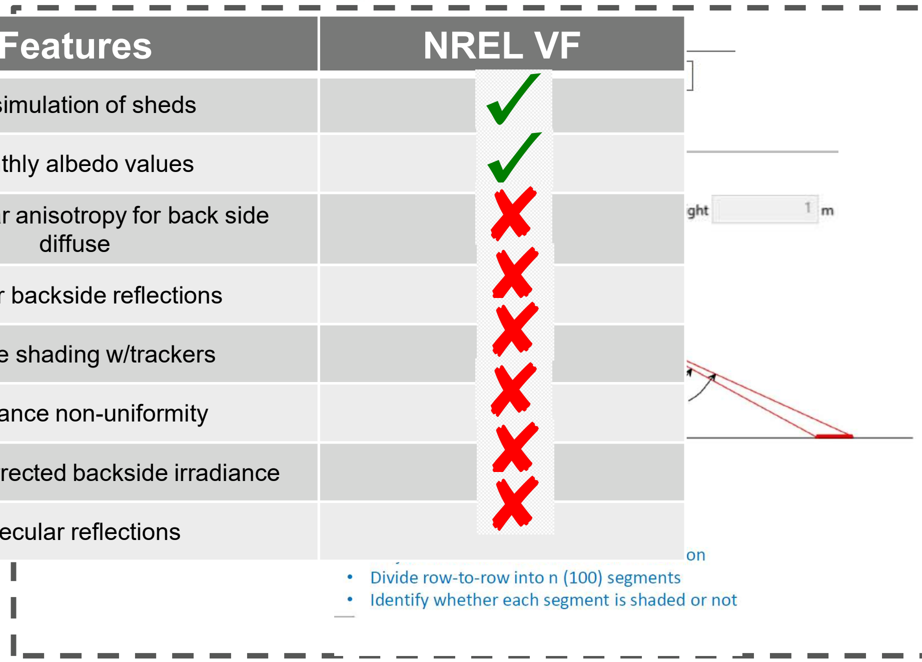
Commercial Bifacial PV simulation software

Modeling assumptions in currently released versions

System Advisor Model 2018



PVSyst	Features	NREL VF
✓	2D simulation of sheds	✓
✓	Monthly albedo values	✓
✗	Circumsolar anisotropy for back side diffuse	✗
✗	IAM for backside reflections	✗
✓	Diffuse shading w/trackers	✗
✗	Irradiance non-uniformity	✗
✗	Spectral-corrected backside irradiance	✗
✗	Specular reflections	✗

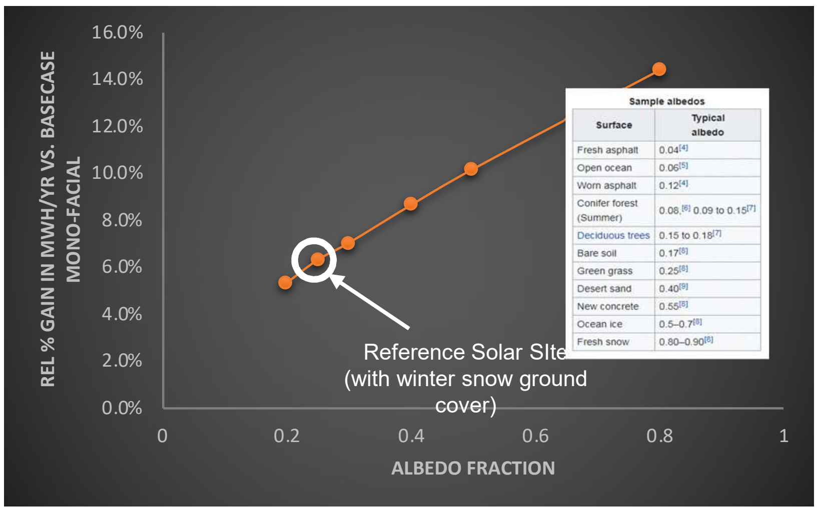


Commercially available PV sim software | **Modeling Assumptions**

- IMEC, EnergyVille, PVCase releasing performance simulation model in 1H 2020
- PVLighthouse develops bifacial simulation using raytracing software with SPICE electrical PV model (*Mismatch loss in bifacial modules due to non-uniform illumination in 1D tracking systems.* McIntosh, K.R., Abbott, M.D., Sudbury, B.A., Meydbrey, J., 46th IEEE PVSC 2019)

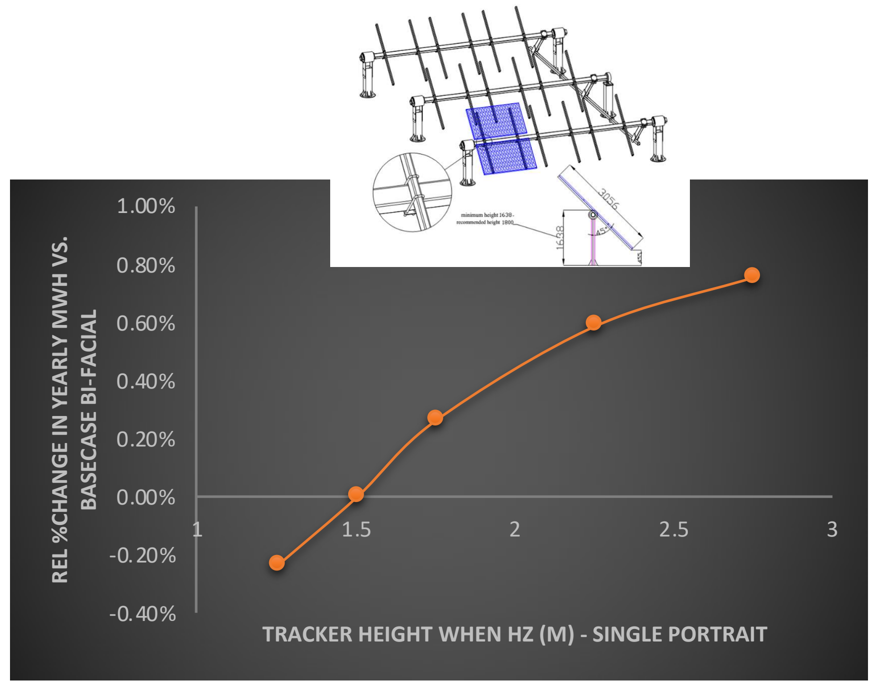
Parametric sensitivities

Albedo, racking height (tracker)



Sample albedos

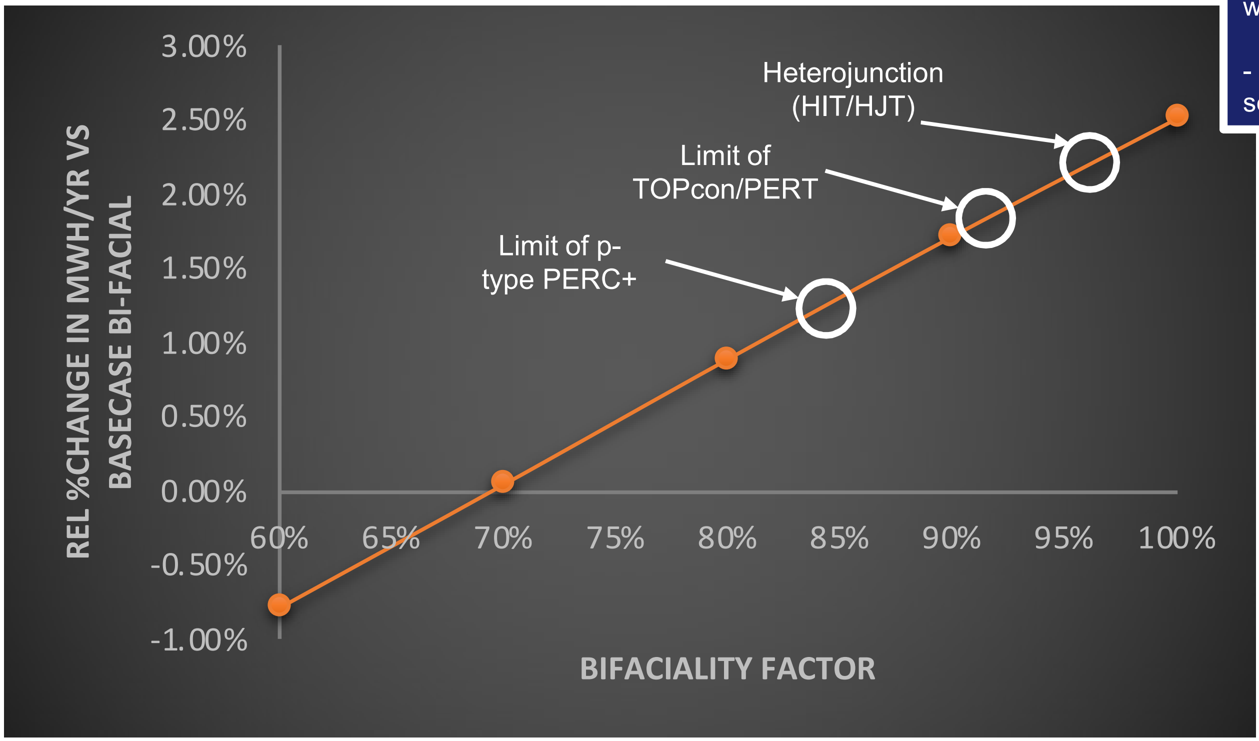
Surface	Typical albedo
Fresh asphalt	0.04[4]
Open ocean	0.06[5]
Worn asphalt	0.12[4]
Conifer forest (Summer)	0.08,[6] 0.09 to 0.15[7]
Deciduous trees	0.15 to 0.18[7]
Bare soil	0.17[8]
Green grass	0.25[8]
Desert sand	0.40[9]
New concrete	0.55[8]
Ocean ice	0.5–0.7[8]
Fresh snow	0.80–0.90[8]



Albedo | **Racking height**

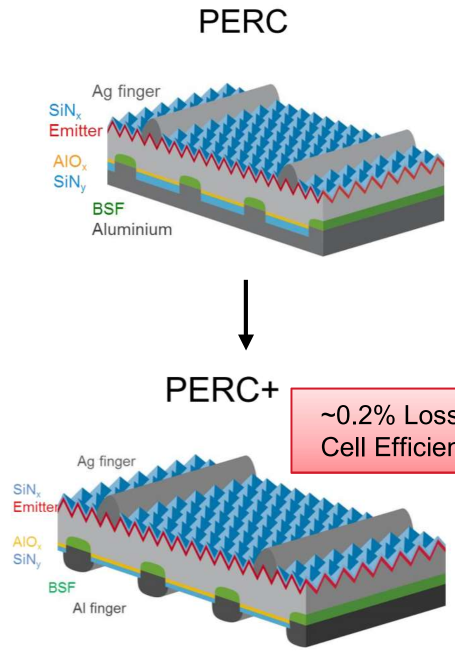
Parametric sensitivities

Bifaciality Factor



PERC's bifacial capability is perhaps the key feature that will make the technology spread wider and reign longer than many anticipate…

- Shravan K. Chunduri, Michael Schmela "PERC solar cell technology 2018", Taiyang News.



~0.2% Loss in Cell Efficiency

T. Dullweber et al., 31st EUPVSEC (2015), p. 341
T. Dullweber et al., Prog. Photovolt.: Res. Appl., **24** (2016), p. 1487

PVsyst PHOTOVOLTAIC SOFTWARE

Parametric sensitivity | **Bifaciality Factor**

Every 1% increase in Annual Energy Production ~1.5¢/Wp in NPV

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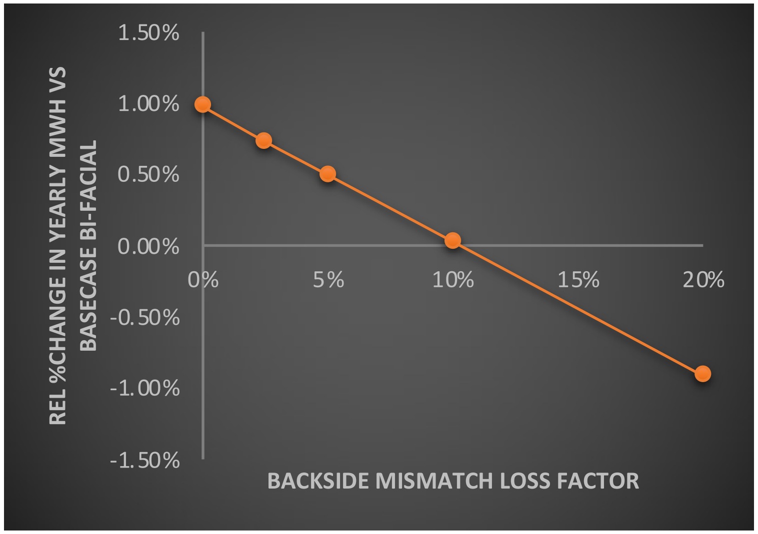
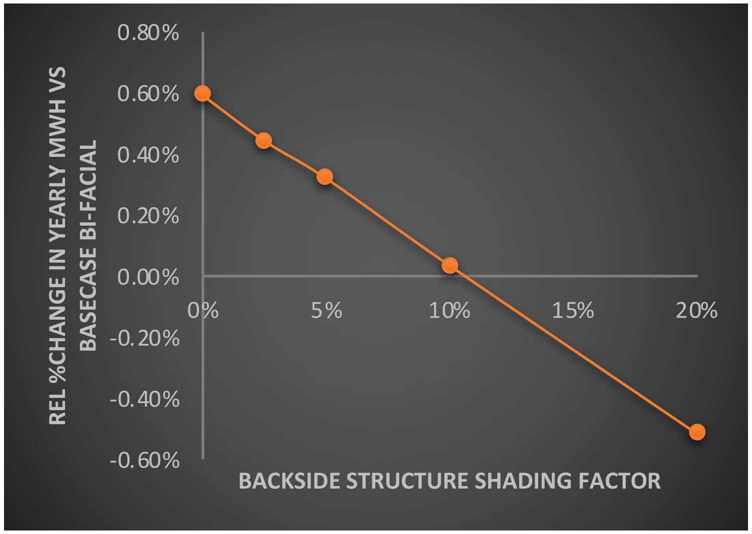
"Economic Factors of Production Affecting Current and Future Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing" by M Woodhouse, et al.
Presented at BiFi Workshop 2018

Parametric sensitivities

Structure shading, backside mismatch loss



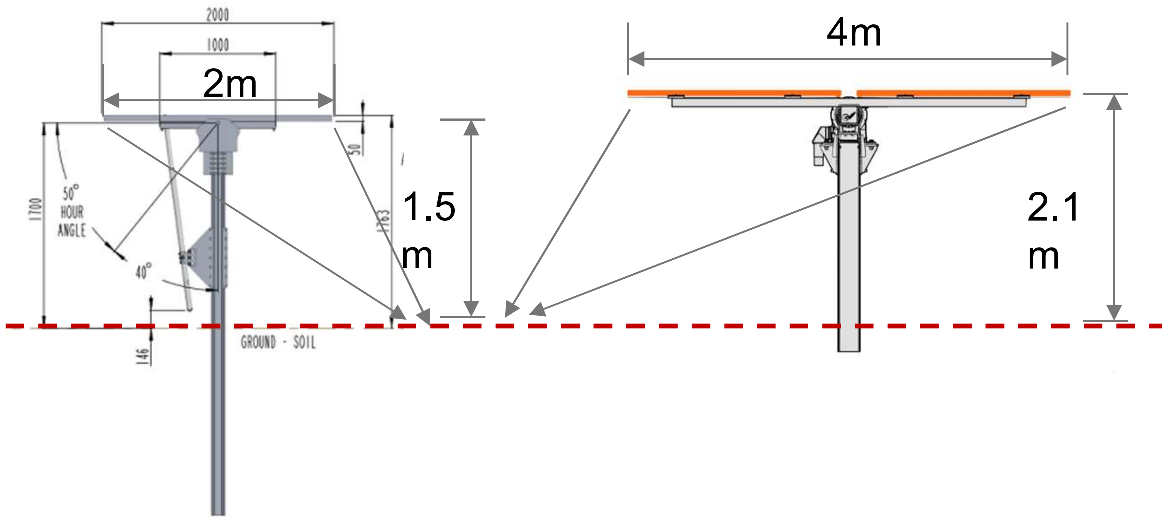


- Initial Estimates (not based on field data):
    1. 2P Tracker = 5% Mismatch/2.5% Structure Shading
    2. 1P Tracker = 10% Mismatch/10% Structure Shading

- TOTAL IMPACT OF SHADING/MISMATCH ~1.5% on MWh/yr per 10% increase

Racking type (Tracker)

1P vs. 2P (single portrait/dual portrait)



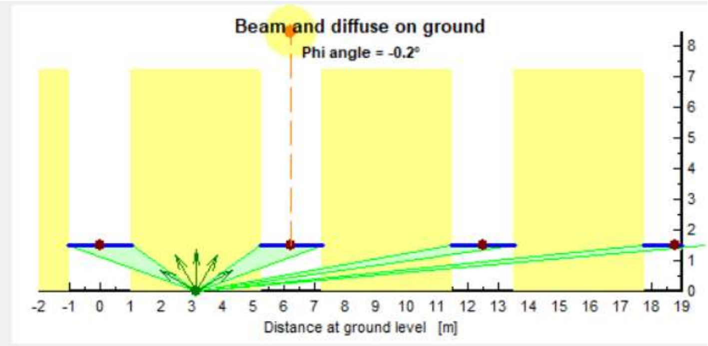
Single-Portrait

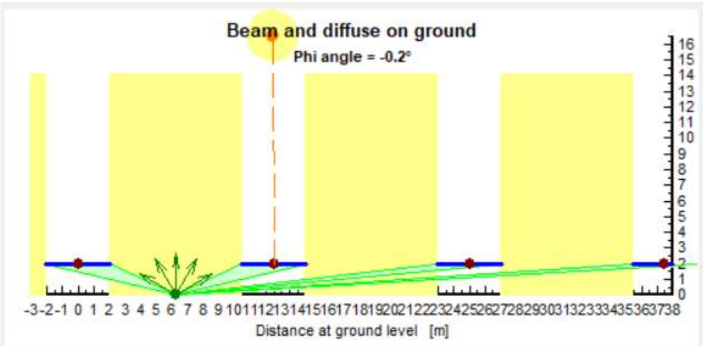
Dual Portrait

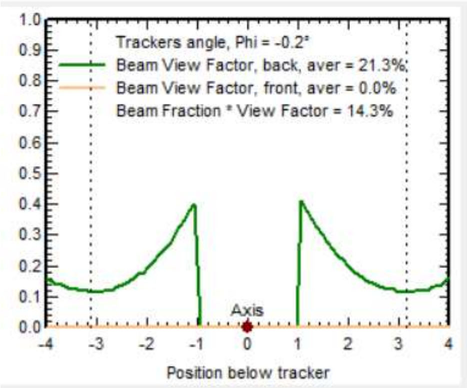
- Lower Aspect Ratio of Module Width to Tracker height produces better "ViewFactor"
- Single Portrait vs. Dual Portrait = 2% Gain in performance (fixing all other variables)

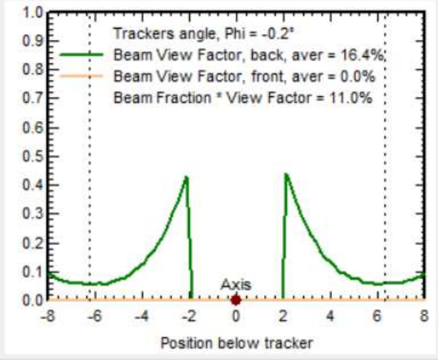
Racking type (Tracker) – Horizontal (noon)

1P vs. 2P (single portrait/dual portrait)







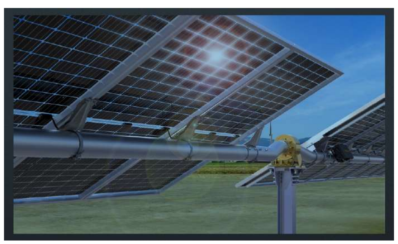


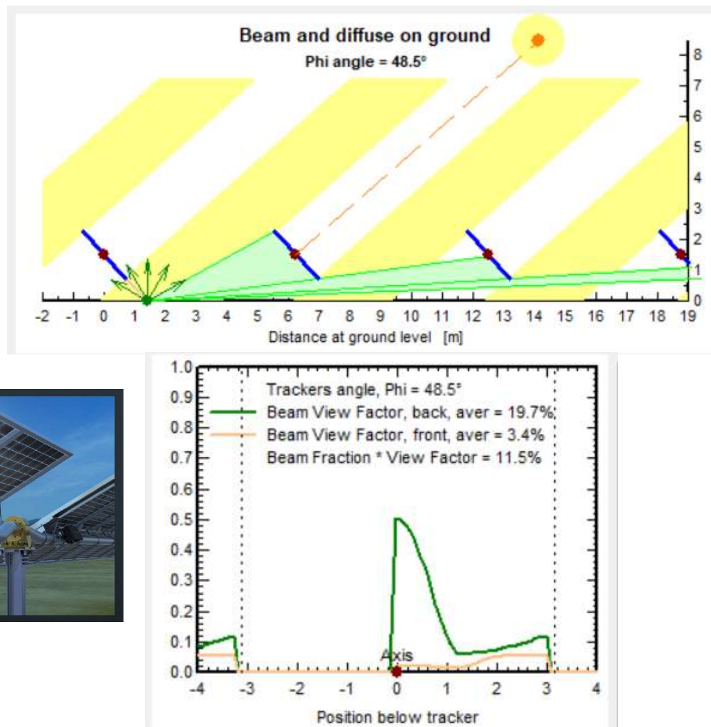
Single-
Portrait

Dual
Portrait

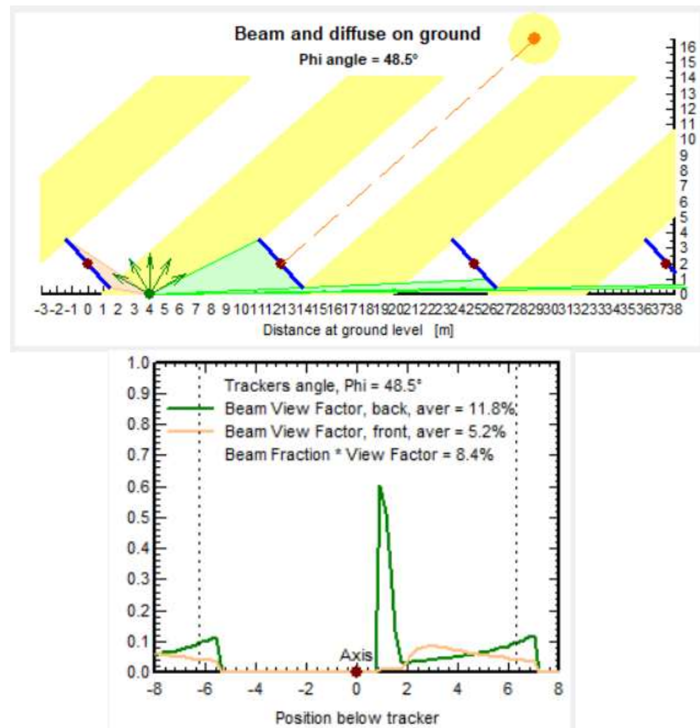
Racking type (Tracker) – Angled, morning/evening

1P vs. 2P (single portrait/dual portrait)





Single-Portrait



Dual Portrait

PVSYST PHOTOVOLTAIC SOFTWARE

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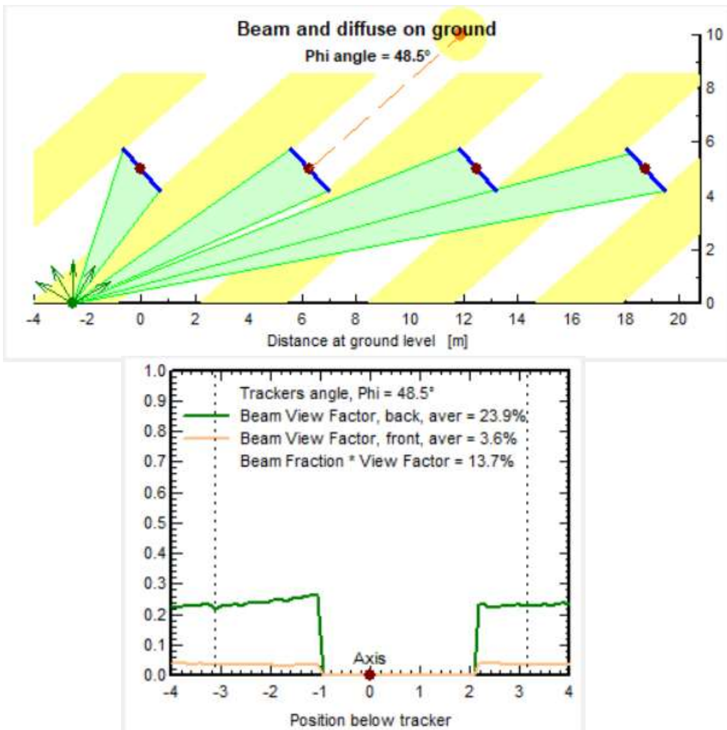
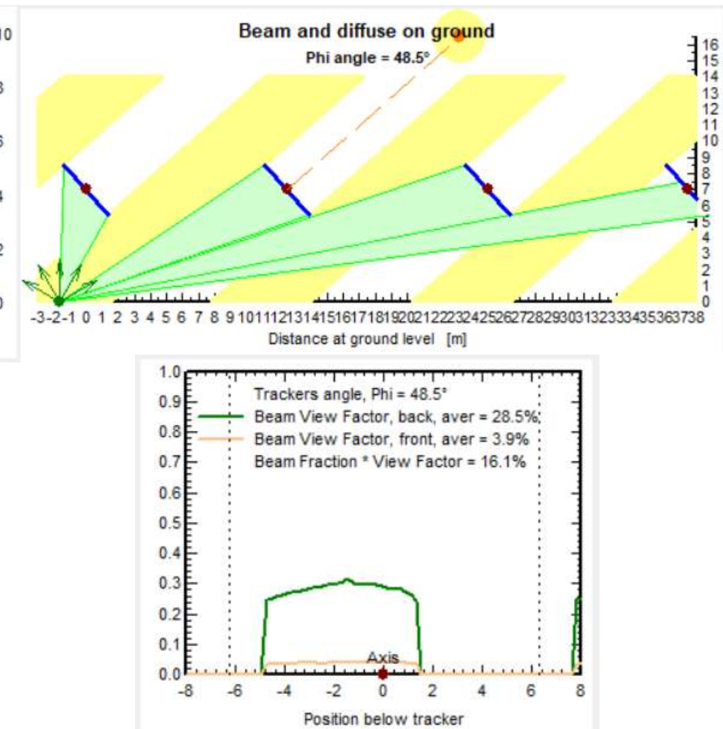
Racking type (Tracker) – Unconstrained Height
1P vs. 2P (single portrait/dual portrait)



Single-
Portrait



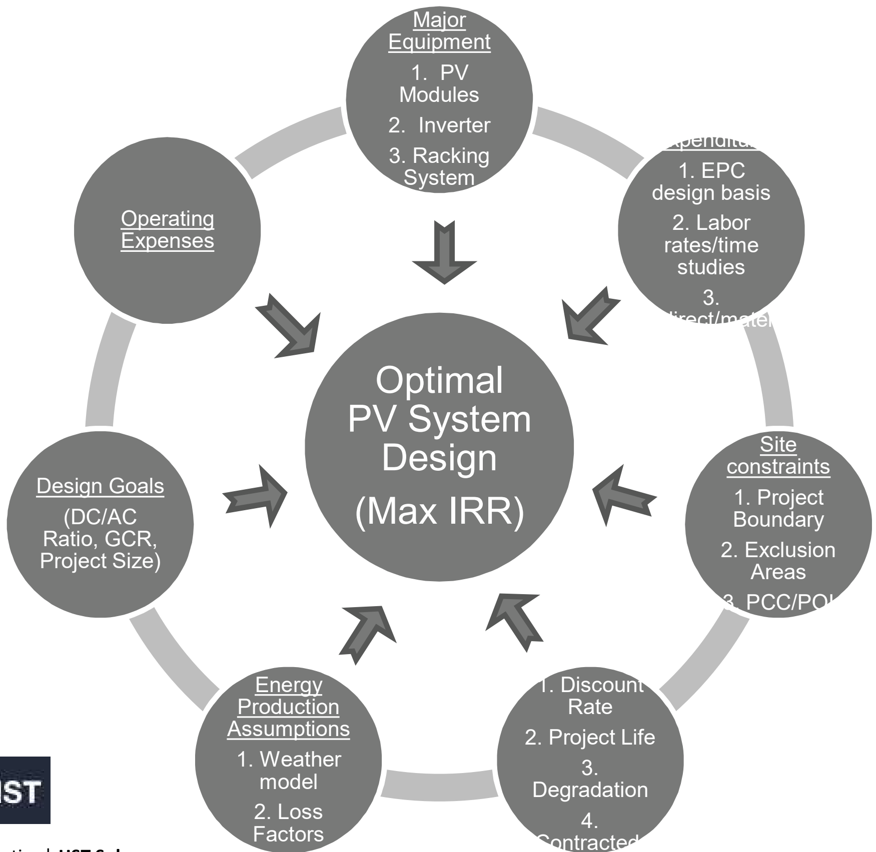
Dual
Portrait

PROJECT ECONOMICS AND OPTIMIZATION OF SYSTEM DESIGN

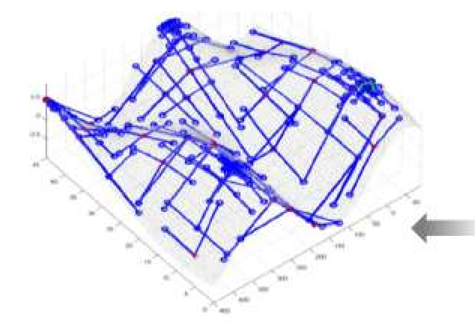
Bifacial – The disruptive technology of our time

PV Plant Optimization Software

Multivariable optimization of design based on financial output

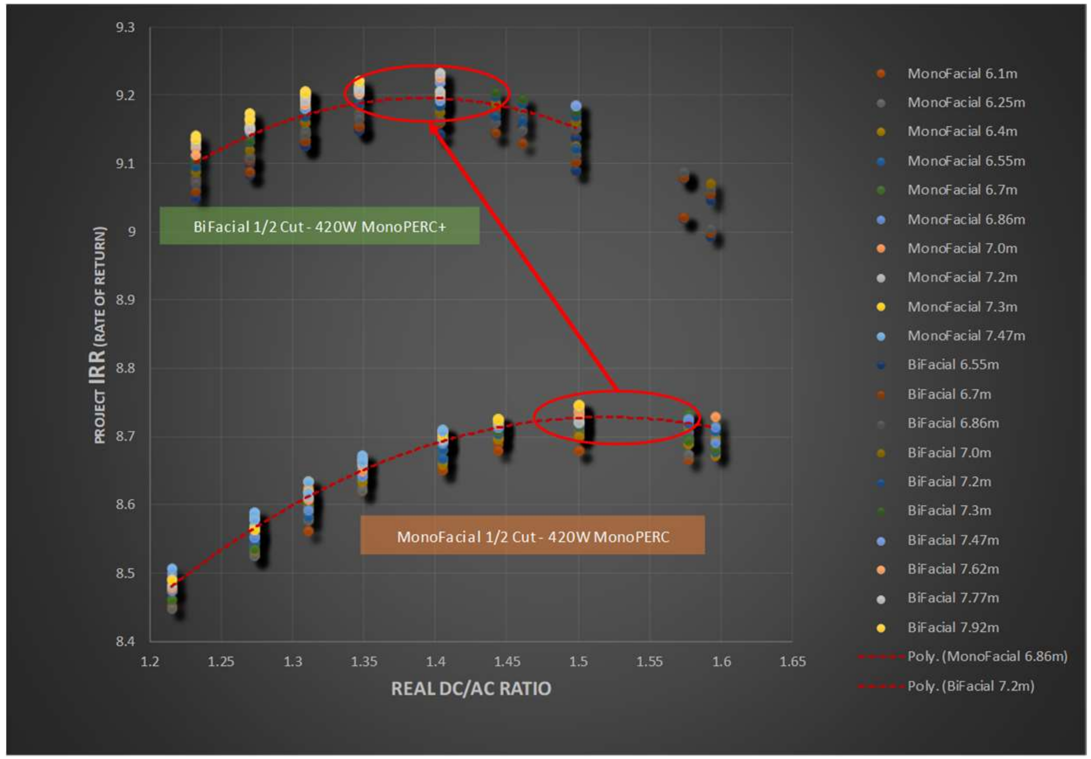


- Potential for 1000's of combinations
- All possible designs must be constrained by project boundaries & various exclusion areas
- Manual approach to design optimization is inherently limited…



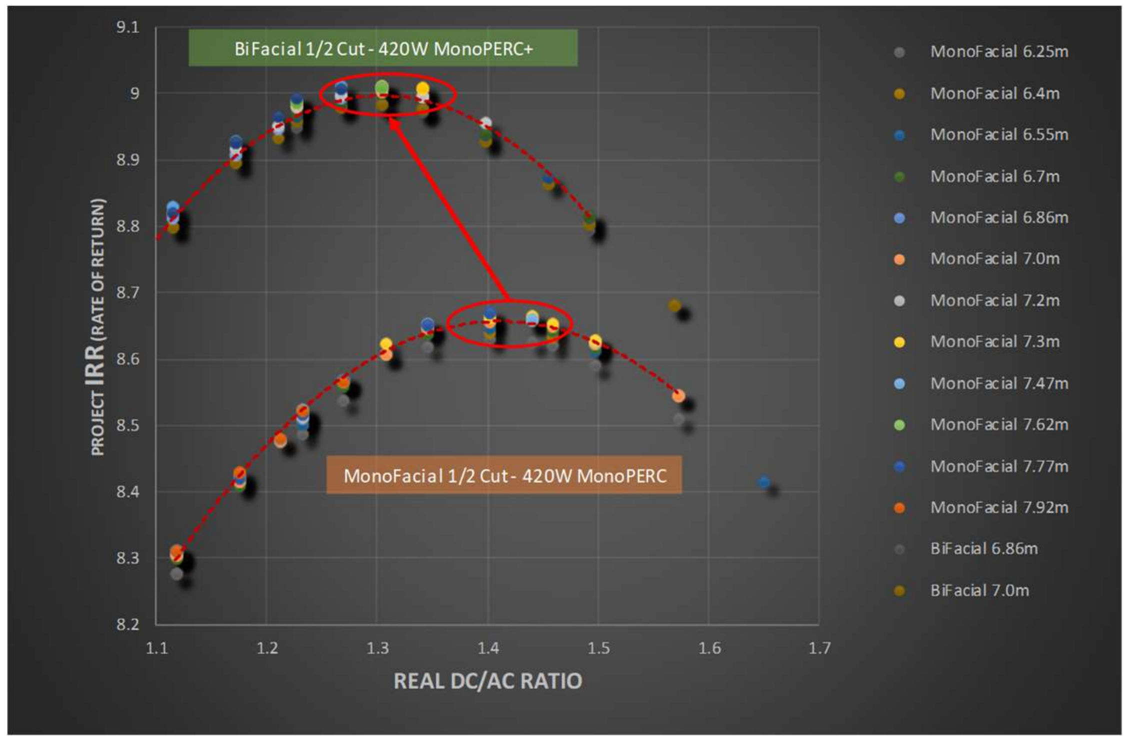
BIFACIAL VS. MONOFACIAL SYSTEM DESIGN OPTIMIZATIONS

Project site in Georgia (higher DHI/GHI)



BIFACIAL VS. MONOFACIAL SYSTEM DESIGN OPTIMIZATIONS

Project site in California (lower DHI/GHI)



Modeled Bifacial gains around the U.S.

All horizontal SAT systems (relative gains, same GCR+DC/AC ratio)

Indiana	S. California	Georgia	Alabama	Colorado	Wisconsin	Washington
BiFacial Gain = **6.3%**	BiFacial Gain = **3.2%**	BiFacial Gain = **5.2%**	BiFacial Gain = **2.6%**	BiFacial Gain = **4.8%**	BiFacial Gain = **6.0%**	BiFacial Gain = **6.3%**
Bifacial yield (1,529 kWh/kWp)	Bifacial yield (2,078 kWh/kWp)	Bifacial yield (1,808 kWh/kWp)	Bifacial yield (1,712 kWh/kWp)	Bifacial yield (1,968 kWh/kWp)	Bifacial yield (1,448 kWh/kWp)	Bifacial yield (1,647 kWh/kWp)

Summary and Conclusions

- **A** Bifacial adoption is happening much faster than anticipated
- **B** Performance guarantees will be challenging, but international standards will be necessary to pave the way
- **C** Modeling energy production of bifacial systems is in very early stages, but likely on the conservative side
- **D** Project economics are overwhelmingly favorable, but design and optimization require new ways of thinking

THANK YOU

FOR

YOUR ATTENTION