Bifacial beats Trump’s tariffs

Federal trade authorities have ruled that bifacial solar modules are no longer subject to the Section 201 ruling, which currently apply a 25% tariff to most solar modules imported to the United States.

JUNE 12, 2019 JOHN WEAVER

Canadian Solar Secures Its Largest Order as Bifacial Modules Gain Traction

EDF Renewable Energy will buy 1.8 gigawatts of modules from Canadian Solar as the Investment Tax Credit phases down, in a sign that developers are growing more comfortable with two-sided solar technology.

KARL-ERIK STROMSTA | MAY 29, 2019

Scatec Solar’s first bifacial project goes live in Egypt

By José Rojo Martín | Apr 12, 2019 10:44 AM BST | 0

February 25, 2019

By Renewable Energy World Editors
Historic & projected PV market

Different cell technology

<table>
<thead>
<tr>
<th>Year</th>
<th>AI-BSF</th>
<th>PERC</th>
<th>SHJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>20%</td>
<td>60%</td>
<td>20%</td>
</tr>
<tr>
<td>2019</td>
<td>30%</td>
<td>50%</td>
<td>20%</td>
</tr>
<tr>
<td>2021</td>
<td>40%</td>
<td>40%</td>
<td>20%</td>
</tr>
<tr>
<td>2023</td>
<td>50%</td>
<td>30%</td>
<td>20%</td>
</tr>
<tr>
<td>2026</td>
<td>60%</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>2029</td>
<td>70%</td>
<td>10%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Bifacial cell in world market

<table>
<thead>
<tr>
<th>Year</th>
<th>Monofacial c-Si</th>
<th>Bifacial c-Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>50%</td>
<td>10%</td>
</tr>
<tr>
<td>2019</td>
<td>40%</td>
<td>20%</td>
</tr>
<tr>
<td>2021</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>2023</td>
<td>20%</td>
<td>40%</td>
</tr>
<tr>
<td>2026</td>
<td>10%</td>
<td>50%</td>
</tr>
<tr>
<td>2029</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>
PERC cell technology – easily bifacial

Module bifaciality $\phi = \frac{P_{\text{Rear}}}{P_{\text{Front}}} = \begin{align*} \text{0.65-0.80} & \quad \text{(p-PERC)} \\ \text{0.75-0.90} & \quad \text{(n-PERT)} \\ \text{0.85 – 0.95} & \quad \text{(Si Heterojunction)} \end{align*}$

Monofacial vs Bifacial module manuf. cost

Bifacial Performance Modeling
Bifacial total irradiance

\[ G_{Total} = G_{Front} + (G_{Rear} \times \text{bifaciality}) \times (1 - \eta_{Loss}) \]
Modeling Rear Irradiance

\[ G_{\text{rear}} = G_{\text{diffuse},r} + G_{\text{reflected},r} + G_{\text{beam},r} \]
Modeling Rear Irradiance

\[ G_{\text{rear}} = G_{\text{diffuse},r} + G_{\text{reflected},r} + G_{\text{beam},r} \]
Bifacial Plus Tracking Boosts Solar Energy Yield by 27 Percent

Recent testing shows bifacial PERC modules can significantly increase energy yields.

Bifacial energy gain $BG_E$

$$= \frac{E_{Bifacial}}{E_{Mono}} - 1$$

What bifacial gain can be expected?
Surface Albedo has a big effect

Rear irradiance, single module at STC (1kWm⁻² frontside)

- White EPDM
- Built-up roof
- Soil
- Concrete
- Asphalt

Surface Albedo has a big effect

R. Kopecek and J. Libal, Bifacial Photovoltaics: Technology, applications and economics, IET publishing, 2019
System $G_{\text{Rear}}$ experiences self-shading

$G_{\text{rear}}$ (Wm^-2)

Modules per row

Single row

Front row

Interior row

$G_{\text{rear}}$: -50%

C. Deline et al., Assessment of Bifacial Photovoltaic Module Power Rating Methodologies – Inside and Out, J. Photovoltaics 7, 2017
Bifacial Performance

Models
Complicated geometries possible, including racking and terrain. Radiance uses **backward ray-trace** to evaluate the irradiance (W/m²) at the modules.


Field validation shows good agreement with close-mount rooftop mockup
View Factor Model for Rear Irradiance

- Simple: basic geometry
- Fast: computationally inexpensive
- Common: Behind SAM, Pvsyst, and others

PVSyst v6.75
View Factor Model for Rear Irradiance

$G_{\text{rear}}$ is summed over 180° field-of-view:

$$G_{\text{rear}} = G_{DNI,\text{rear}} + \sum_{i=1^\circ}^{180^\circ} VF_i \cdot F_i \cdot G_i ;$$

$$VF_i = \frac{1}{2} \cdot [\cos(i - 1) - \cos(i)] ;$$

$$F_i = \text{Incidence angle modifier(}\Theta\text{)}$$

$$G_i = \text{Irradiance } [G_{\text{sky}}, G_{\text{hor}}, \rho \cdot G_{\text{ground}}] ;$$

Irradiance sources: sky, ground (shaded or unshaded)
NREL SAM Model

Bifacial trackers, 75 kW
5 bifacial technologies
Bifacial system configuration

20 modules (7.5 kW) / row

- 4 PERC, 1 SHJ Bifacial strings
- 3 PERC monofacial strings
- Module electronics / monitoring
- String kWh$_{DC}$ monitoring
- Front, rear POA irradiance
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- String kWh\textsubscript{DC} monitoring

#### Front, rear POA irradiance

- = Front POA
- = Rear POA
Initial field results – bifacial trackers

Bifacial gain: 5%
Bifacial gain: 15%

\[ \text{BGE} = \frac{E_{\text{bifacial}}}{E_{\text{mono}}} - 1 \]
Initial field results – bifacial trackers

1-axis tracker - cloudy & sunny day

Bifacial gain: 15%
Bifacial gain: 5%

\[ \text{BGE} = \frac{E_{\text{bifacial}}}{E_{\text{mono}}} - 1 \]
Initial field results – bifacial trackers

More diffuse = higher $BGE$

\[ BGE = \frac{E_{bifacial}}{E_{mono}} - 1 \]
Initial field results – bifacial trackers

\[ \text{BG}_E = \frac{E_{bifacial}}{E_{mono}} - 1 \]

Annual power histogram

50% energy production

Front POA Irradiance [Wm\(^{-2}\)]
Modeled vs Measured $P_{DC}$ Power

Monofacial PERC
Mean model error: 1.88%. RMSE: 18.0%

Bifacial PERC
Mean model error: 1.75%. RMSE: 19.9%

*SAM v2018.11 using 15-minute measured DNI, DHI, albedo from SRRL BMS. Andreas, A.; Stoffel, T.; (1981). NREL Solar Radiation Research Laboratory (SRRL): Baseline Measurement System (BMS); Golden, Colorado (Data); NREL Report No. DA-5500-56488. Bifacial systems assume 5% shading loss, 5% mismatch loss, 0% transmission factor
Bifacial modeling sensitivity

### 3 sensitivity cases:

<table>
<thead>
<tr>
<th></th>
<th>Ground albedo</th>
<th>PERC $\phi_{Bifi}$</th>
<th>Si-HJT $\phi_{Bifi}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High case</strong></td>
<td>0.30</td>
<td>0.75</td>
<td>0.95</td>
</tr>
<tr>
<td><strong>Average case</strong></td>
<td>0.20</td>
<td>0.7</td>
<td>0.90</td>
</tr>
<tr>
<td><strong>Low case</strong></td>
<td>0.15</td>
<td>0.65</td>
<td>0.85</td>
</tr>
</tbody>
</table>

$BGE = \frac{E_{bifacial}}{E_{mono}} - 1$

**PERC bifacial gain 4-8%**

**Si-HJT bifacial gain 6.5-11%**

Field test results to date

Market Analysis
LCOE Analysis for Monofacial and Bifacial PV Systems


Assumptions: 100MW system, 1.2 DC-AC ratio, 0.35 GCR
LCOE Analysis for Monofacial and Bifacial PV Systems

POST-TARIFF Bifacial vs Monofacial LCOE at various US sites
6% Nominal Discount Rate. Single Owner and Unlevered Pro Forma with 30% ITC

Monofacial LCOE

- PERC Bifacial
- SHJ Bifacial

Seattle, WA
Kansas City, MO
Miami, FL
Daggett, CA

$1.05/W $1.05/W $1.09/W


Assumptions: 100MW system, 1.2 DC-AC ratio, 0.35 GCR
Conclusions:

• Bifacial PV is becoming mainstream with GW’s of installed projects

• Energy gain depends on the site configuration and surface albedo. Models like SAM, PVSyst and Bifacial_Radiance can assist with system design and power estimation.

• 1-axis tracker validation is underway at NREL, showing good initial match with model, and energy gain of 6% and 9% annually for PERC and Si-HJT.

• LCOE of bifacial systems is competitive with monofacial systems now, even with initial cost adder of 5-6 ¢/W. Post-tariff, bifacial is a clear winner.
WEDNESDAY, 10:30A: (Sheraton 4-5)
• B. Lee, J. Wu: Bifacial PERC cells. 11A & 11:30A

THURSDAY, 8:30A: (Chicago 8)
• A. Asgharzadeh: Benchmarking models. 8:30A
• M. Waters: Bifacial Capacity Testing. 8:45A
• K. McIntosh: Bifacial mismatch loss 9:00A

THURSDAY 10:30A: (Sheraton 1)
• M. Patel, R. Bailey: Albedo. 10:30 & 10:45A
• S. Ayala: Shading effects on bifacial trackers. 11A

36th EU PVSEC (Marseille)
6th Bifi PV Workshop (Amsterdam)
• S. Ayala: Electrical mismatch and shading
• B. Marion: Ground albedo measurements
• J. Stein: HPC Optimization of Bifacial Systems

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08-G028308 with the National Renewable Energy Laboratory (NREL). Funding provided by the U.S. Department of Energy’s Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 34910. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.
Backup Slides
Modeling Rear Irradiance

- Albedo
- Row-to-row spacing
- Tilt
- Clearance
- Others:
  - Spacing between cells
  - #rows, #panels
  - Mounting Structure
  - Other scene elements

Irradiance Model
Location
Weather
Sky Diffuse Model

LCOE Analysis for Monofacial and Bifacial PV Systems


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LCOE Analysis for Monofacial and Bifacial PV Systems


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