



# INSIGHTS FROM PVEL'S INDOOR AND OUTDOOR BIFACIAL TESTING

PV Evolution Labs (PVEL)

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# PVEL is the Independent Lab for the Downstream Solar Market

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**Our mission is to support the worldwide PV buyer community by generating data that accelerates adoption of solar technology.**

## **Global**

400+ downstream partners worldwide with 30+GW of annual buying power

## **Comprehensive**

Testing for every aspect of a PV project from procurement to O&M

## **Experienced**

Pioneered bankability testing for PV products nearly a decade ago

## **Market-driven**

Continuously refining test programs to meet partner needs



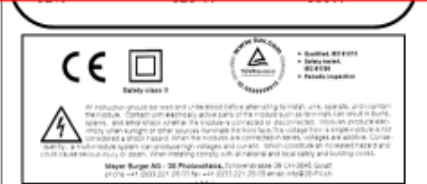
# PVEL's Module Product Qualification Program (PQP) Test Sequences

Factory Witness, Characterizations and Light-Induced Degradation Measurement							
Thermal Cycling	Damp Heat	Backsheet Durability Sequence	Mechanical Stress Sequence	Potential-Induced Degradation	LeTID Sensitivity	PAN File & IAM Profile	Field Exposure
TC 200	DH 1000	DH 1000	Static Mechanical Load	85°C, 85%RH MSV (+ and/or -) 96 hrs	LeTID 162 hrs (75°C, Isc-Imp)	PAN File	Field Exposure 6 Months
Characterization	Characterization	Characterization	Characterization	Characterization	Characterization	IAM Profile	Characterization
TC 200	DH 1000	UV 65 kWh/m²	Dynamic Mechanical Load	85°C, 85%RH MSV (+ and/or -) 96 hrs	LeTID 162 hrs (75°C, Isc-Imp)		Field Exposure 6 Months
Characterization	Characterization	Characterization	Characterization	Characterization	Characterization		Characterization
TC 200	Stabilization 85°C, Isc, 48 hrs	TC 50 + HF 10	Characterization	Characterization	LeTID 162 hrs (75°C, Isc-Imp)		Characterization
Characterization	Characterization	Characterization	TC 50		Characterization		
		UV 65 kWh/m²	Characterization				
		Characterization	HF 10				
		TC 50 + HF 10	Characterization				
		Characterization					
		UV 65 kWh/m²					
		Characterization					
		TC 50 + HF 10					
		UV 6.5 kWh/m²					
		Characterization					

# PQP Bifacial Considerations

- Measure and report STC bifaciality pre and post stress (including LID/LeTID)
- Full bifaciality characterization following IEC TS 60904-1-2 as part of PAN testing to determine *bifaciality*,  $P_{max_{BiFi100}}$  and  $P_{max_{BiFi200}}$
- Higher current will be used during TC as per draft 61215
- For Field Exposure: two modules on fixed tilt white albedo, two modules over grass (same POA)

Maximum Power point ( <b>P<sub>max</sub></b> ) 300 W		
Short-circuit current ( <b>I<sub>sc</sub></b> ) 8.6 A		
Open-circuit voltage ( <b>V<sub>oc</sub></b> ) 43.2 V		
Bifaciality ( $\phi$ ) 92%	<b>P<sub>max<sub>BiFi100</sub></sub></b> 328 W	<b>P<sub>max<sub>BiFi200</sub></sub></b> 356W



Source: Meyer Burger, 2018

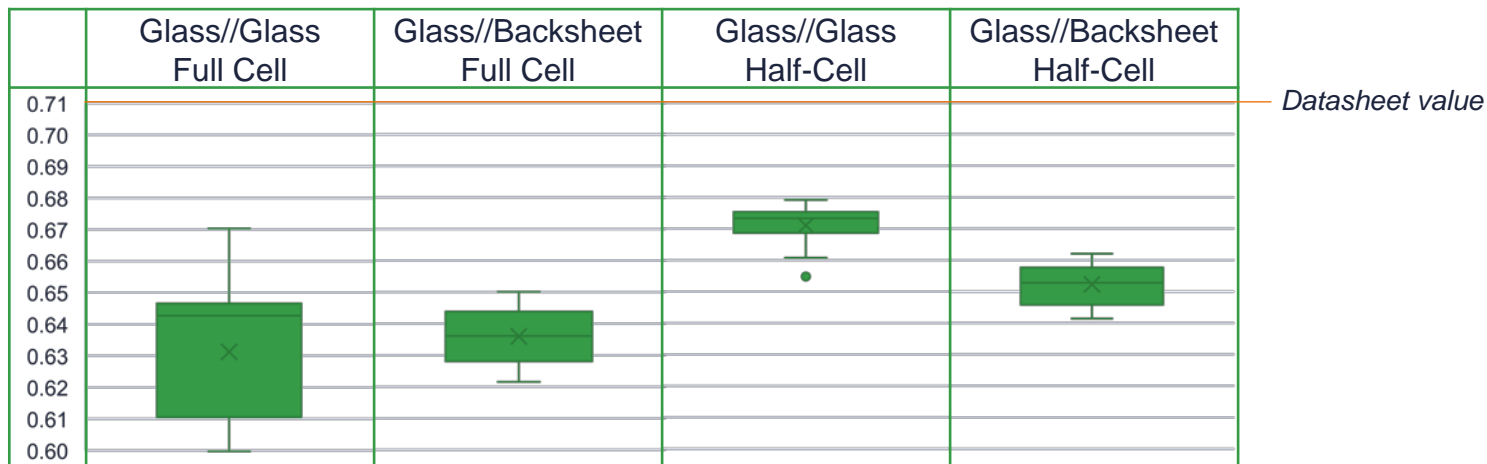
## Bifacial PQPs Currently Under Test at PVEL

PVEL leads the industry in bifacial extended reliability and performance data

- › Current PQP – 16 bifacial BOMs, from 8 manufacturers:
  - full cell, half-cut cells
  - 156.75, 158.75, 166mm cells
  - 5BB, 6BB, 9BB, interdigitated back contact (IBC)
  - p-type, n-type
  - glass//glass, glass//backsheet
  
- › Last year's PQP – 13 bifacial BOMs, from 5 manufacturers:
  - full cell, half-cut cells
  - 156.75, 158.75, 166mm cells
  - 5BB, 6BB
  - p-type
  - glass//glass, glass//backsheet

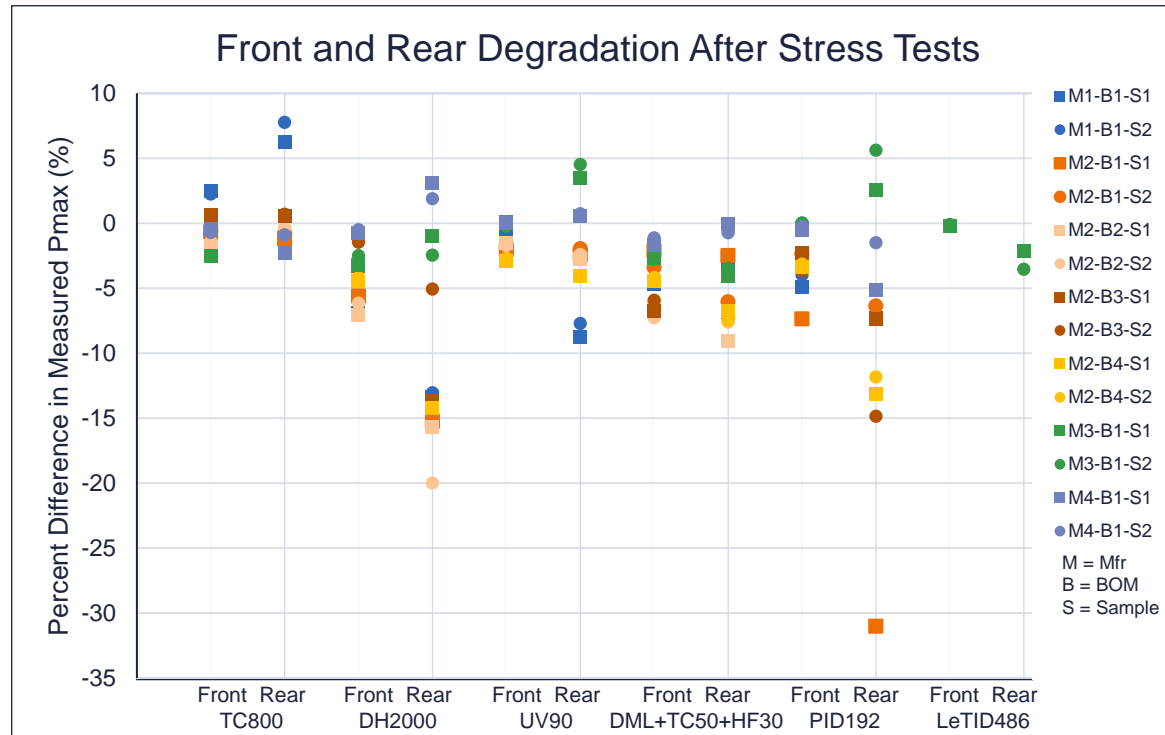
# Initial Results: Bifaciality Ranges

- › Bifaciality can differ based on module design
- › All BOMs shown below were produced by **the same manufacturer**
- › All BOMs shown below have **the same stated bifaciality of ~0.71** on their datasheet



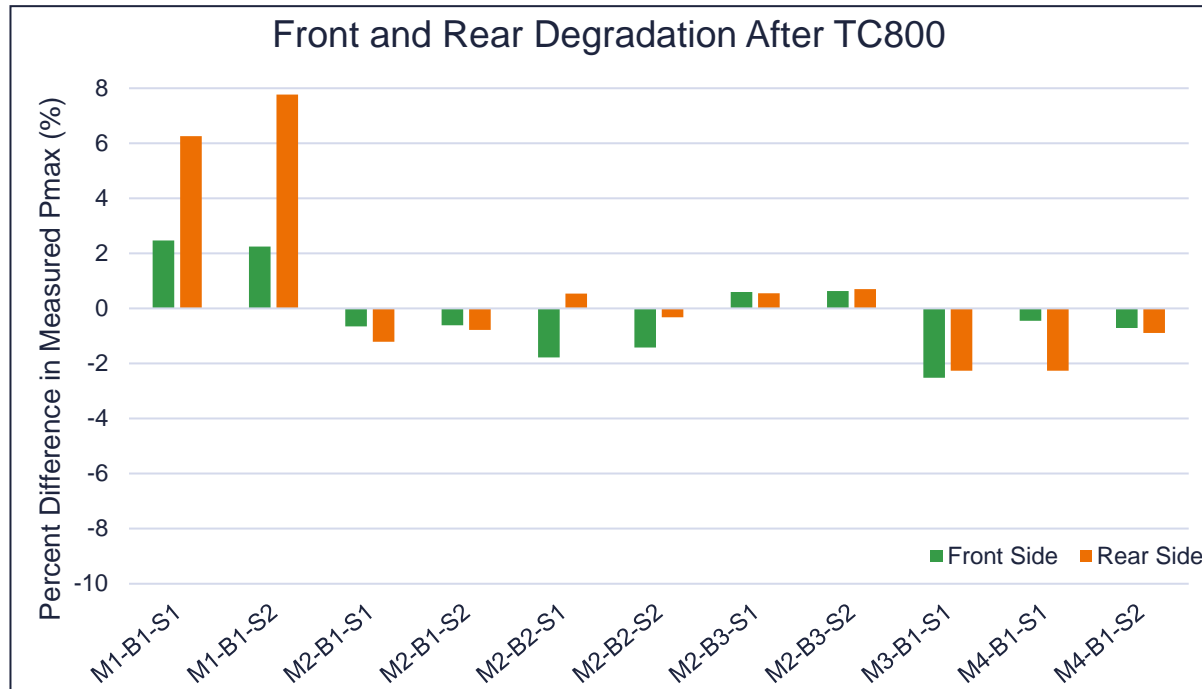
# Initial Results: Reliability Testing at a Glance

- Initial bifacial PQP results show a range of performance for both front and rear sides



# Initial Results: Thermal Cycling

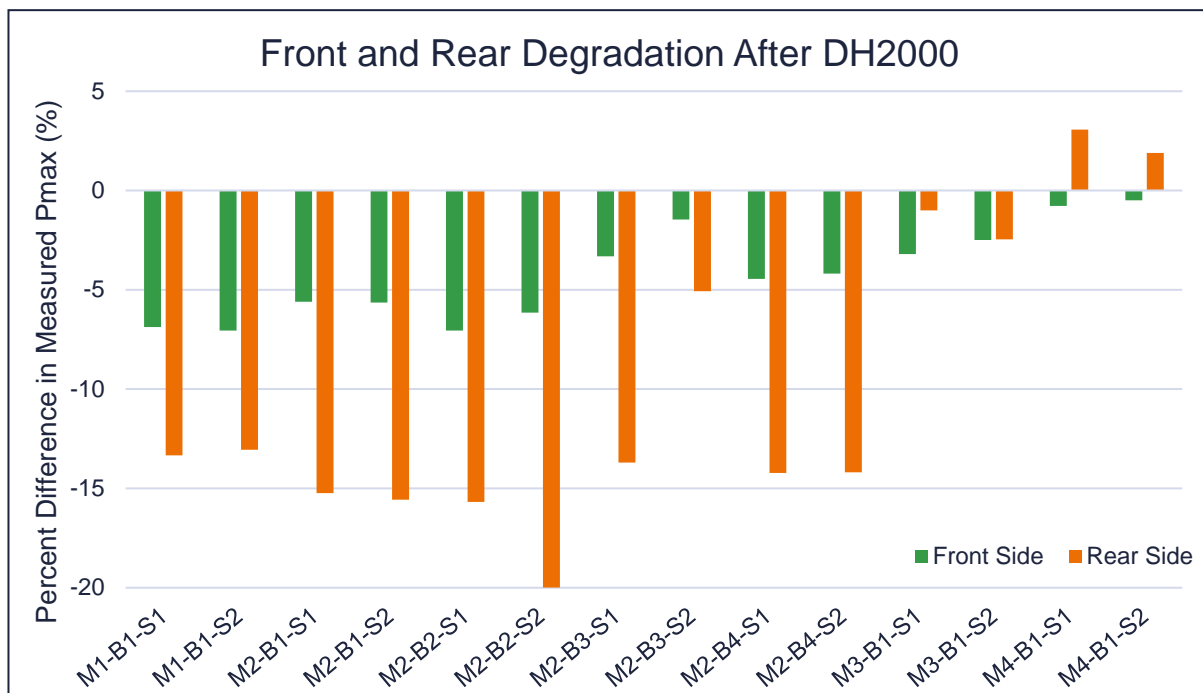
- Typically post-TC800 front and rear power degradation is relatively aligned
  - Reasons for Mfr. 1's increase in Pmax are under investigation





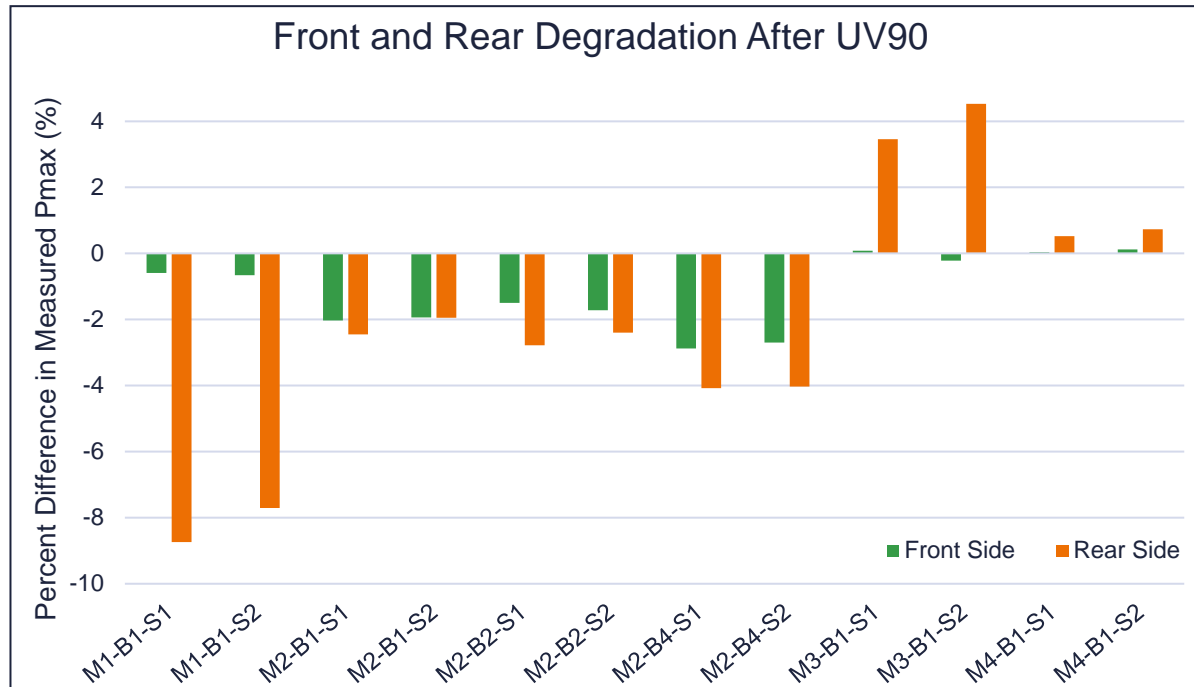
# Initial Results: Damp Heat

- Many PERC modules show signs of Boron-Oxygen destabilization following DH2000
  - The latest PQP (and draft IEC 61215) includes a post-DH stabilization process to mitigate BO impacts



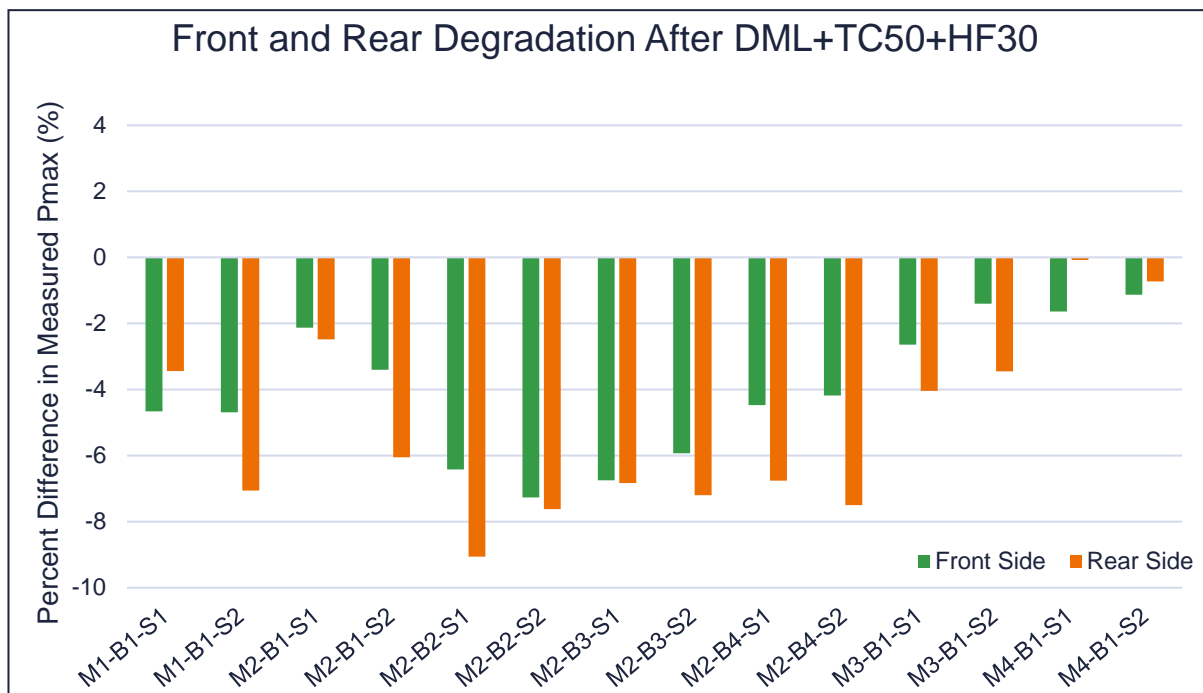
# Initial Results: Front-Side UV

- UV aging appears to cause a range of impacts on rear side power degradation
  - Reasons for Mfr. 1's substantial rear-side decrease in Pmax are under investigation



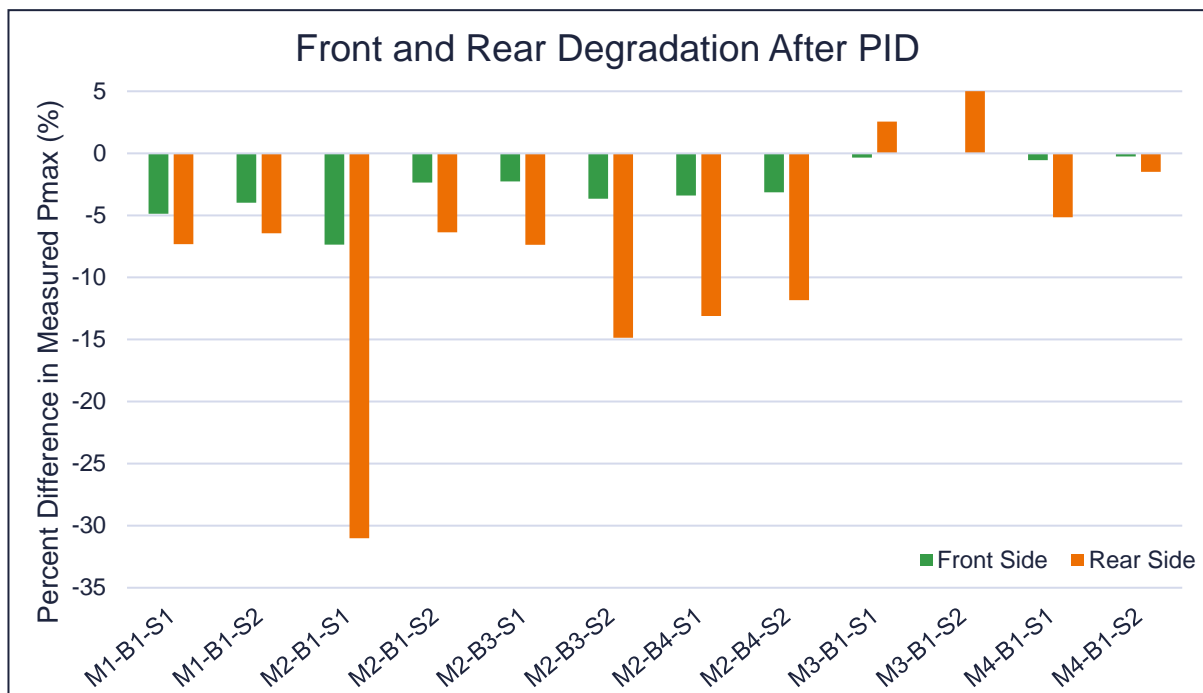
## Initial Results: DML+TC50+HF30

- DML+TC50+HF30 also causes a range of results, some of which may be attributed to Boron-Oxygen destabilization during HF's high temp + no current conditions



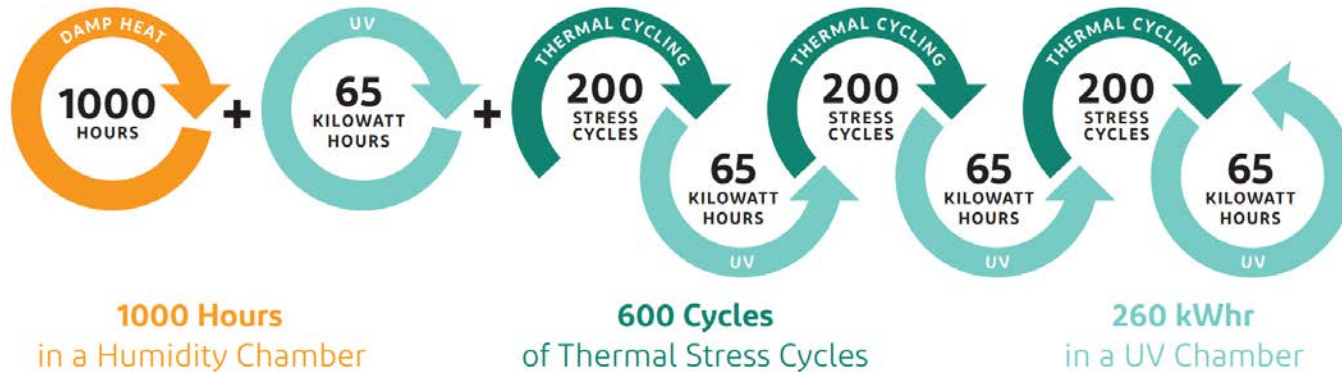
# Initial Results: Potential-Induced Degradation

- Rear-side polarization during PID testing can result in high degradation that is reversible in some cases – **but not all p-type bifacial modules are susceptible**



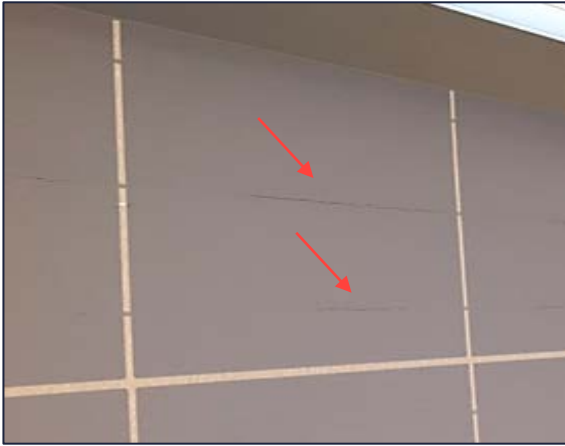
# Backsheet Testing

- › PVEL has completed a variety of backsheet tests with DuPont using their MAST test protocol
- › MAST submits modules to various stresses including extended UV exposure and thermal cycling to provide field-relevant backsheet durability results

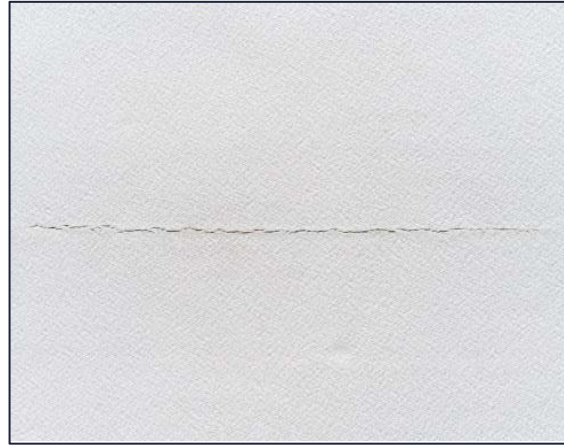


# PVEL's Backsheet Test Results

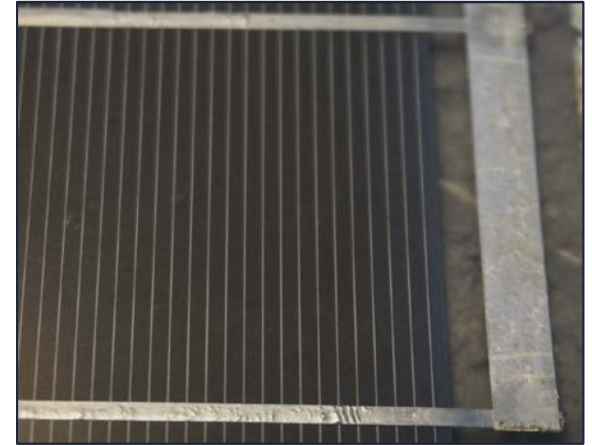
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Isovoltac 'AAA' Backsheet Field  
Failure  
(after 4 years)



Accelerated Lab Failure of  
PVDF (polyvinylidene fluoride)  
*Source: PVEL*



Clear Tedlar Shows No Cracking  
Following MAST  
*Source: PVEL*

# PVEL's 1500V Bifacial Testing in Davis, CA

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- › 4 module manufacturers
- › NEXTracker
- › 0.37 GCR
- › 1.2 meter height
- › 2 x albedos
  - Grass/Dirt
  - White Sheet
- › Monofacial vs. bifacial
- › 1500V strings

# PVEL's Outdoor Bifacial Study Participants

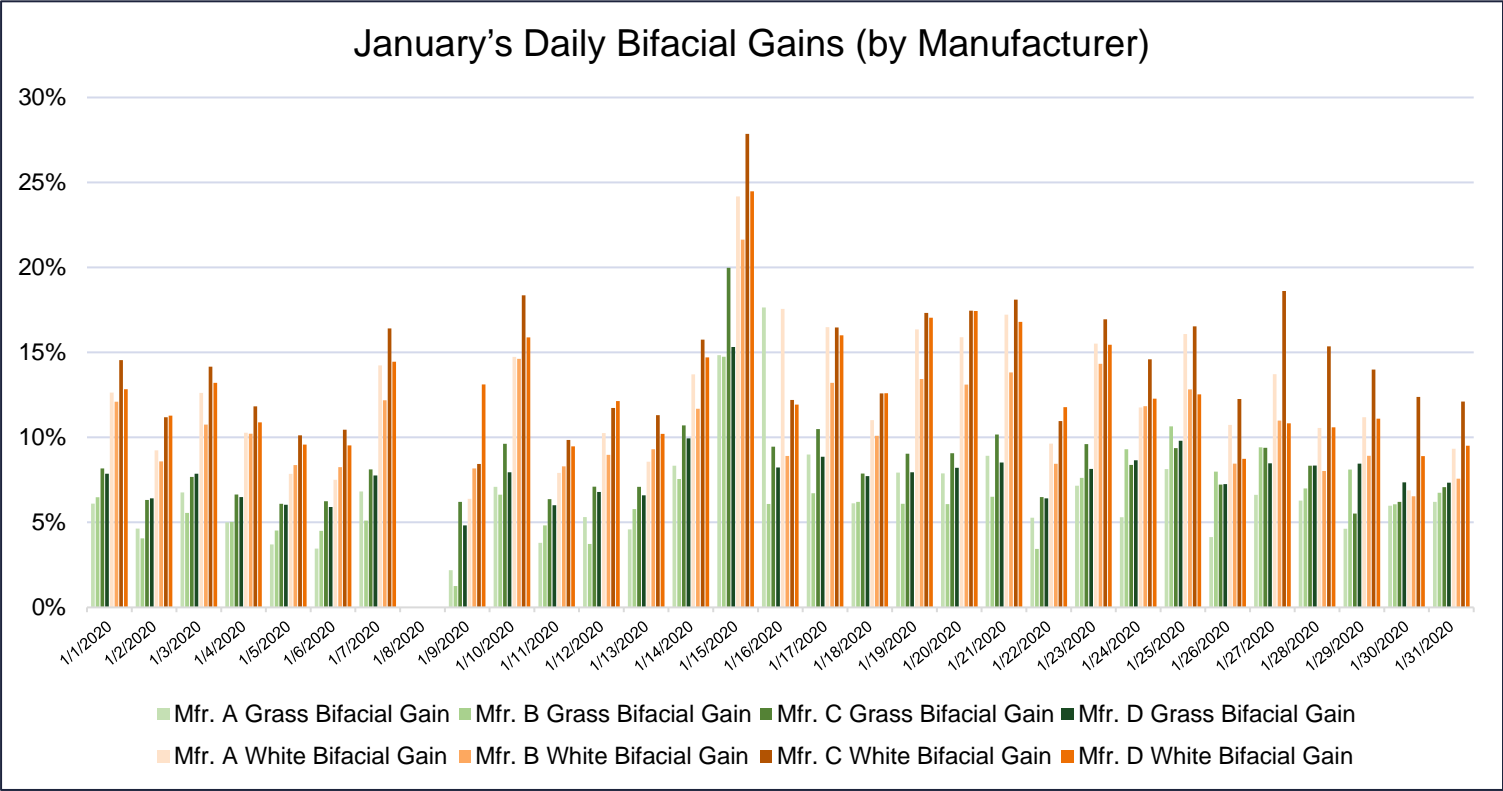
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- › Additional manufacturers are participating on the same trackers with smaller sample sets
- › Study participants:
  - Astronergy (including 1500V strings)
  - ET Solar
  - First Solar
  - GCL
  - Jinko
  - LONGi (including 1500V strings)
  - Morgan Solar
  - Q CELLS (including 1500V strings)
  - Trina (including 1500V strings)





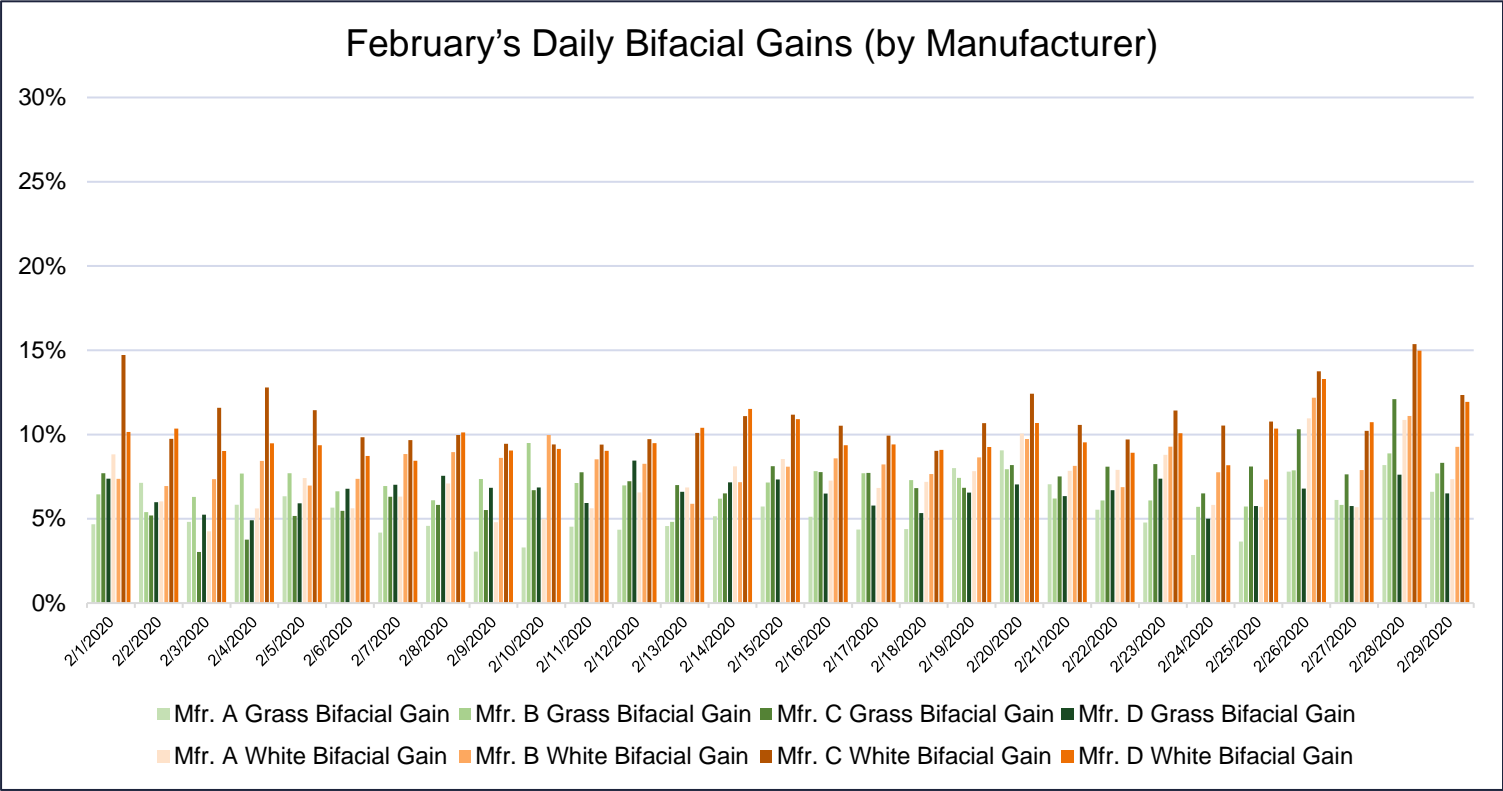
# Outdoor Performance Results: Bifacial Gains by Participant (January)



Data normalized to pre-light soak flash



# Outdoor Performance Results: Bifacial Gains by Participant (February)



Data normalized to pre-light soak flash



# Outdoor Performance Results: Summary (January and February)

- Weather data shows February had more than 2x the amount of insolation as January

	GHI (kWh/m <sup>2</sup> )	Albedo GHI (kWh/m <sup>2</sup> )	GHI Albedo Ratio (%)	POA (kWh/m <sup>2</sup> )	Albedo POA (kWh/m <sup>2</sup> )	POA Albedo Ratio (%)
Grass - January	56.9	11.4	20.0%	69.4	4.9	7.1%
White - January	56.2	25.7	45.8%	69.6	10.9	15.7%
Grass - February	109.5	27.2	24.8%	156.4	10.4	6.6%
White - February	116.5	54.8	47.0%	157.2	20.9	13.3%

- Total bifacial gains for each month, per manufacturer:

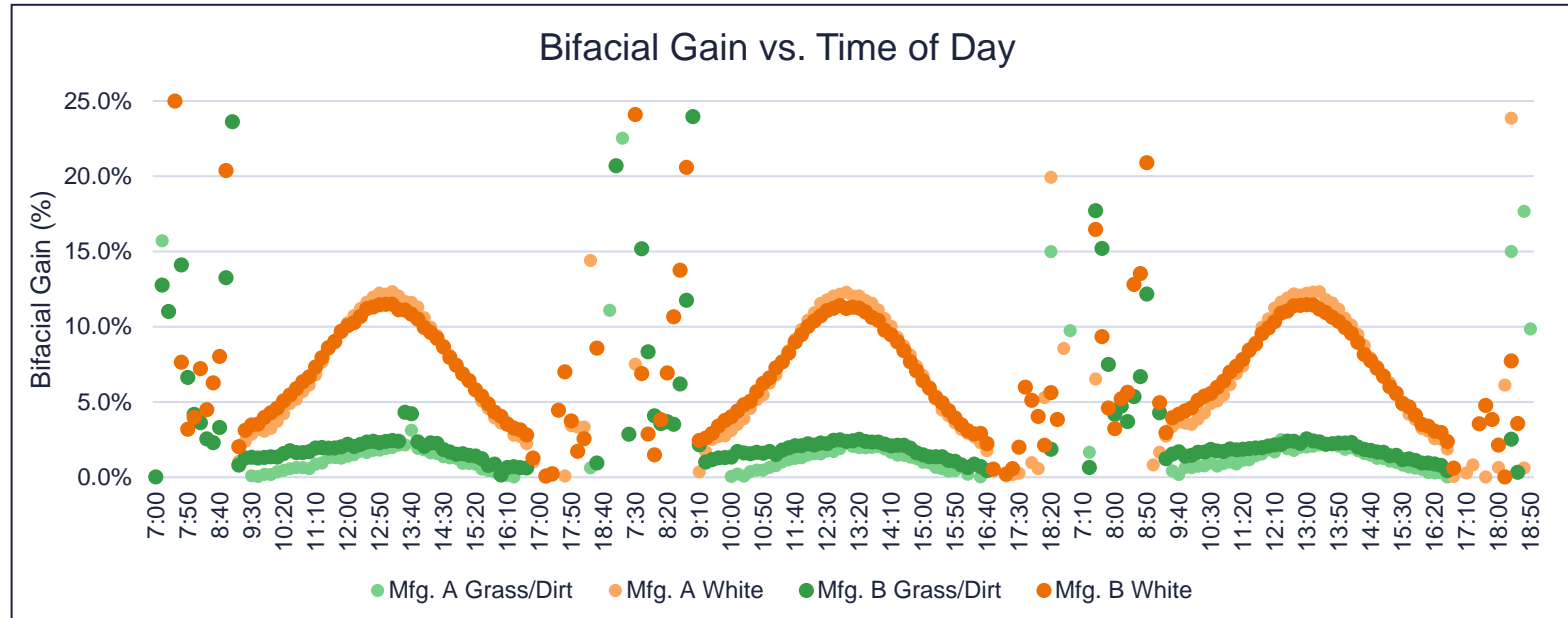
	Bifacial Gain Grass - January	Bifacial Gain White - January	Bifacial Gain Grass - February	Bifacial Gain White - February
Mfr. A	5.64%	11.04%	5.36%	7.02%
Mfr. B	6.41%	9.98%	6.89%	8.30%
Mfr. C	7.69%	13.37%	7.08%	10.84%
Mfr. D	7.53%	11.61%	6.48%	10.01%

Data normalized to pre-light soak flash



# Outdoor Performance Results: Bifacial Gains by Time of Day

- › Generally gains are highest mid-day, which could be lost to inverter clipping
- › Lots of noise at start and end of day

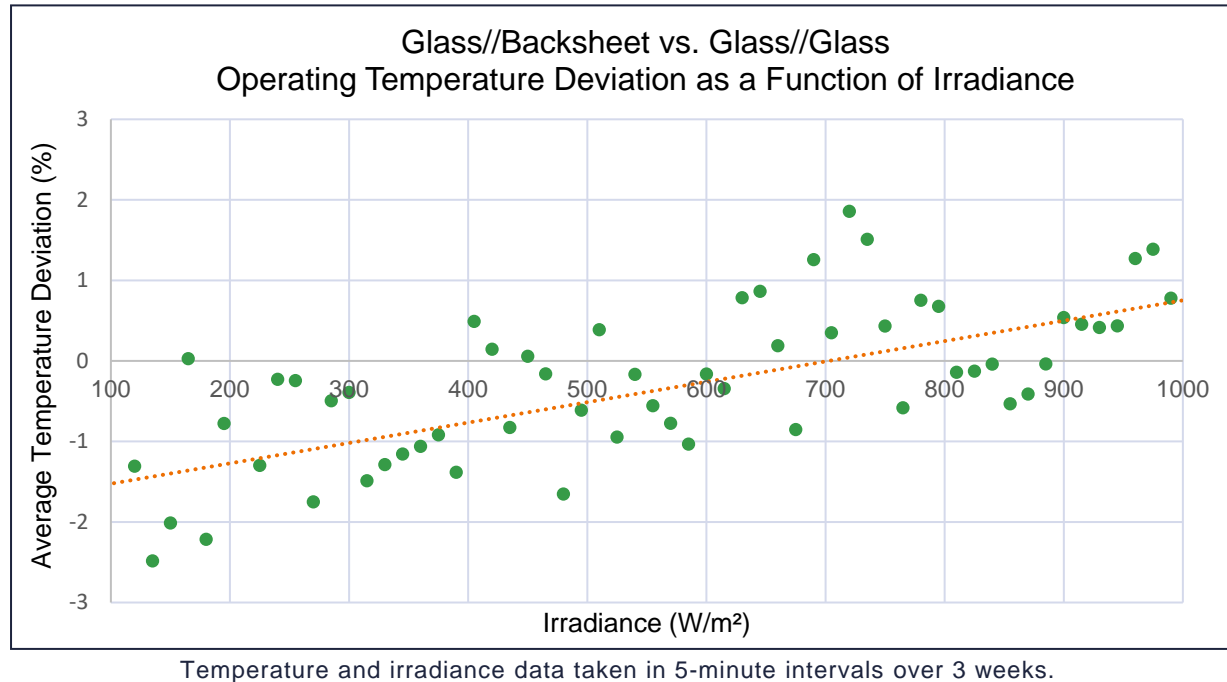


Data extracted over three sunny days; normalized to pre-light soak flash



# Outdoor Performance Results: Glass//Glass vs. Glass//Backsheet

- › With identical cells to glass//glass, glass//backsheet operates at a lower temperature during periods of higher irradiance





**THANK YOU!**

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 **PVEL**  
MAKE DATA MATTER.



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