PVEL

MAKE DATA MATTER.

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

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

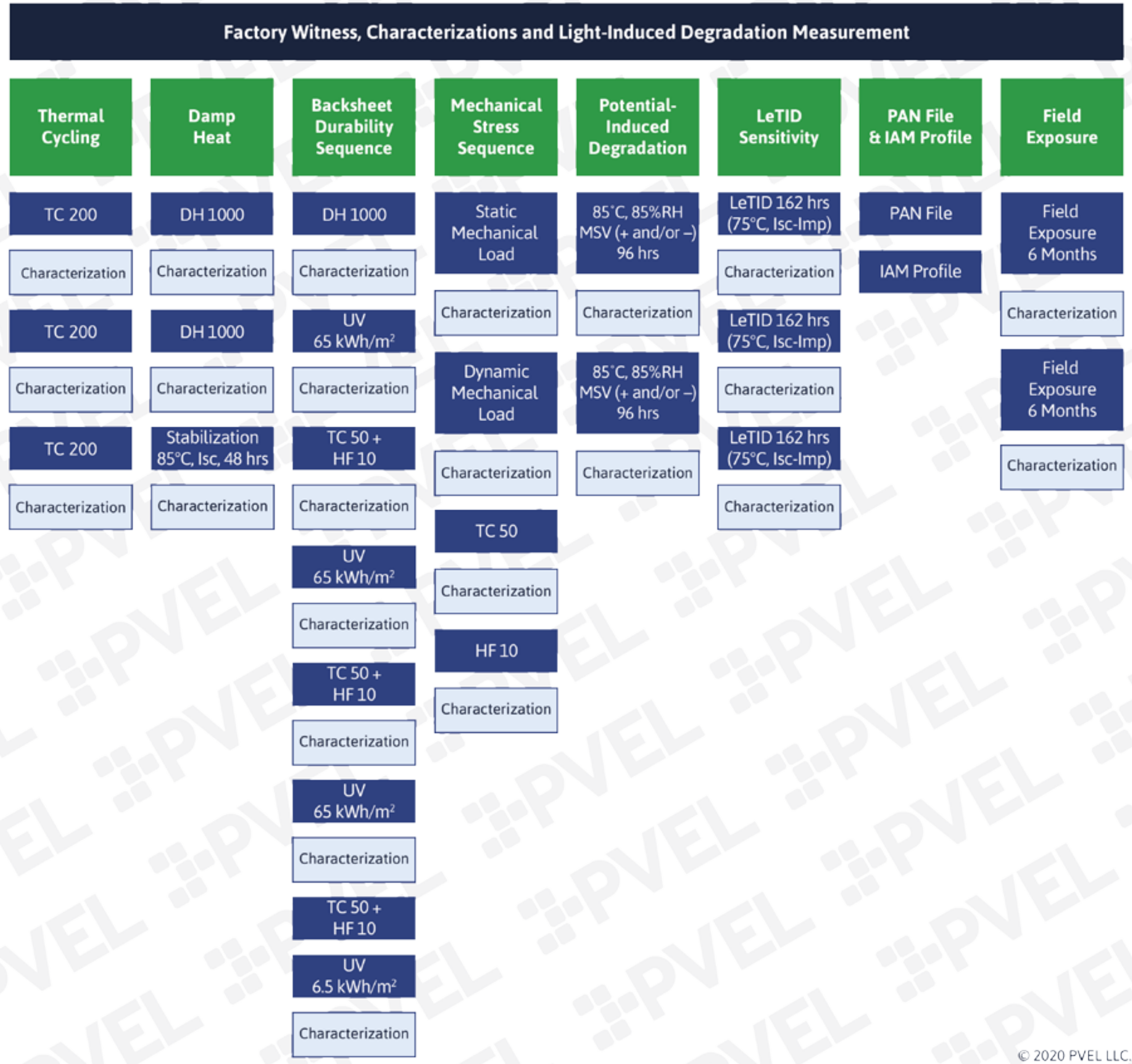
Experienced

Pioneered bankability testing for PV products nearly a decade ago

Market-driven

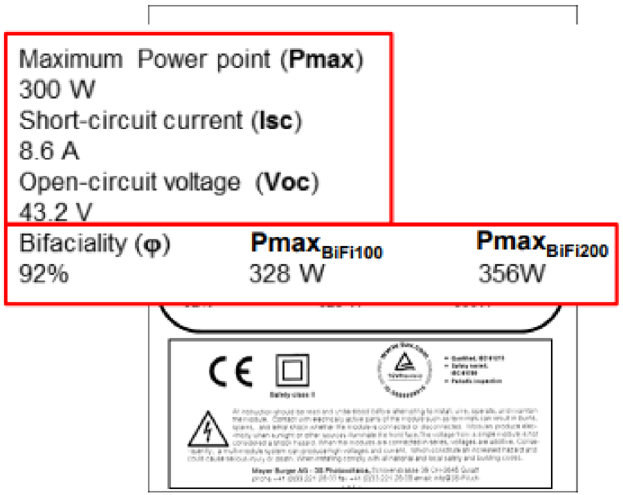
Continuously refining test programs to meet partner needs

PVEL’s Module Product Qualification Program (PQP) Test Sequences



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*, $Pmax_{BiFi100}$ and $Pmax_{BiFi200}$
- 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)



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

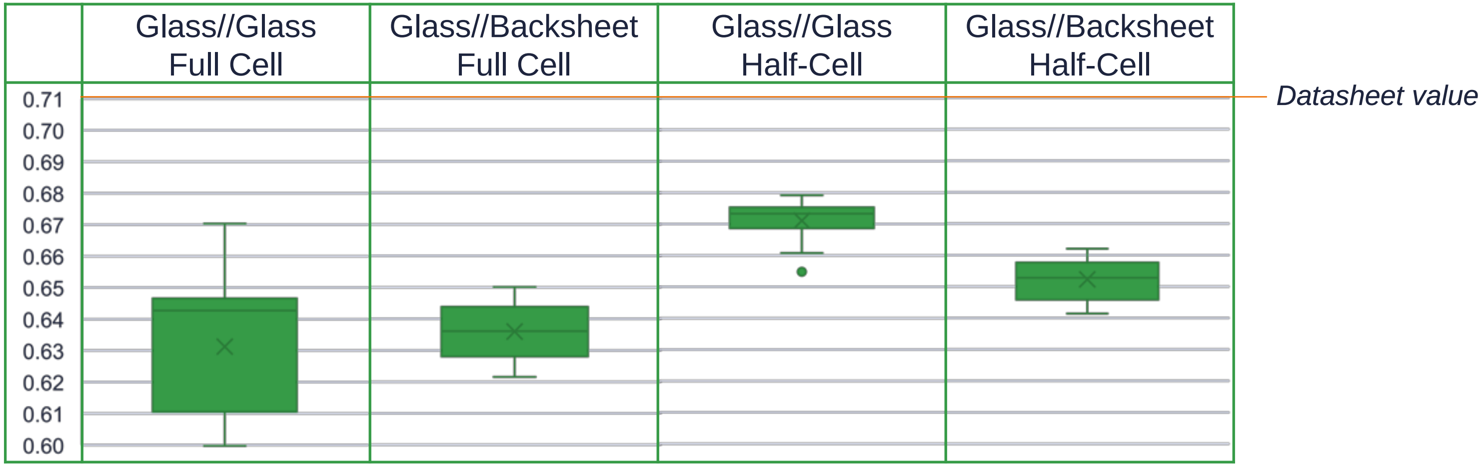
- Last year's PQP – 13 bifacial BOMs, from 5 manufacturers:
  - full cell, half-cut cells
  - 156.75, 158.75, 166mm cells
  - 5BB, 6BB
  - p-type
  - glass//glass, glass//backsheet

Initial Results: Bifaciality Ranges

› Bifaciality can differ based on module design

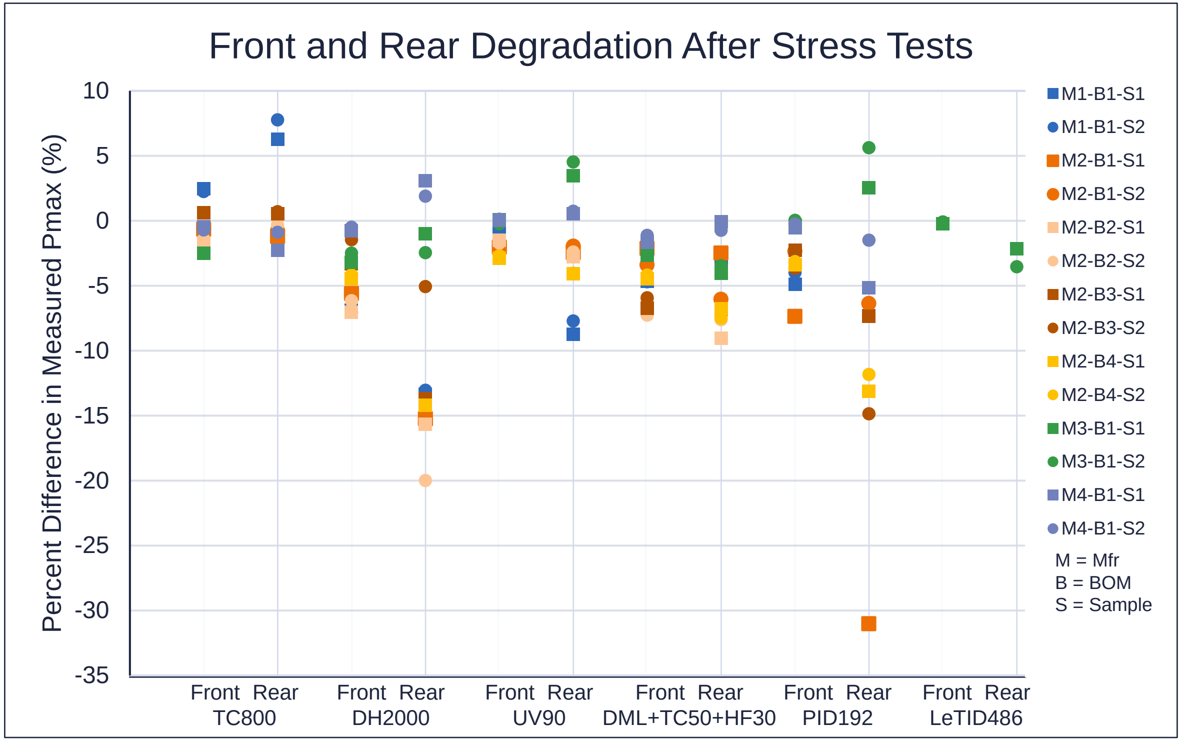
› All BOMs shown below were produced by **the same manufacturer**

› All BOMs shown below have **the same stated bifaciality of ~0.71** on their datasheet



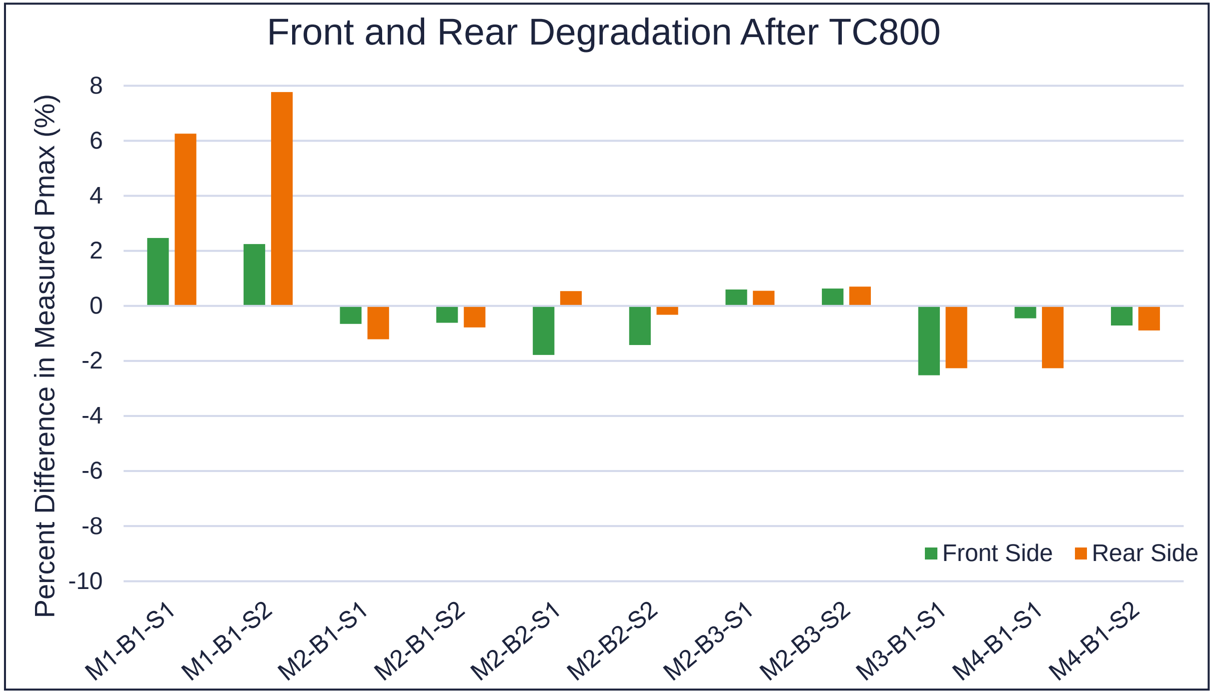
Initial Results: Reliability Testing at a Glance

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



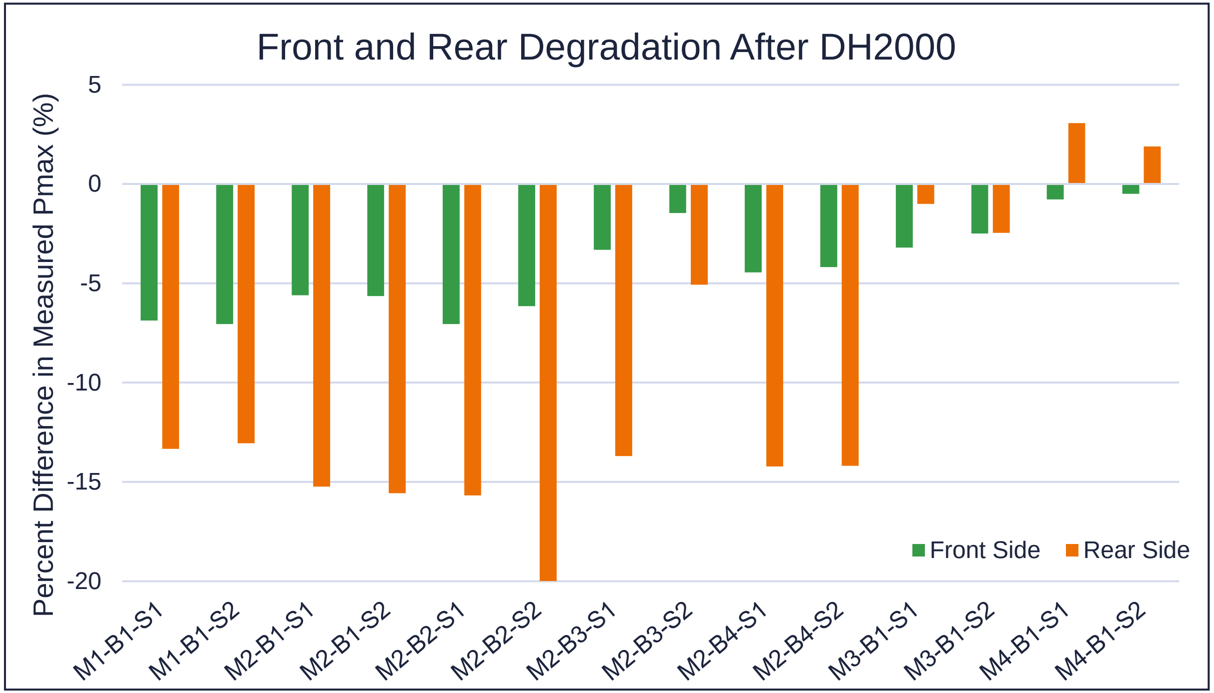
Initial Results: Thermal Cycling

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



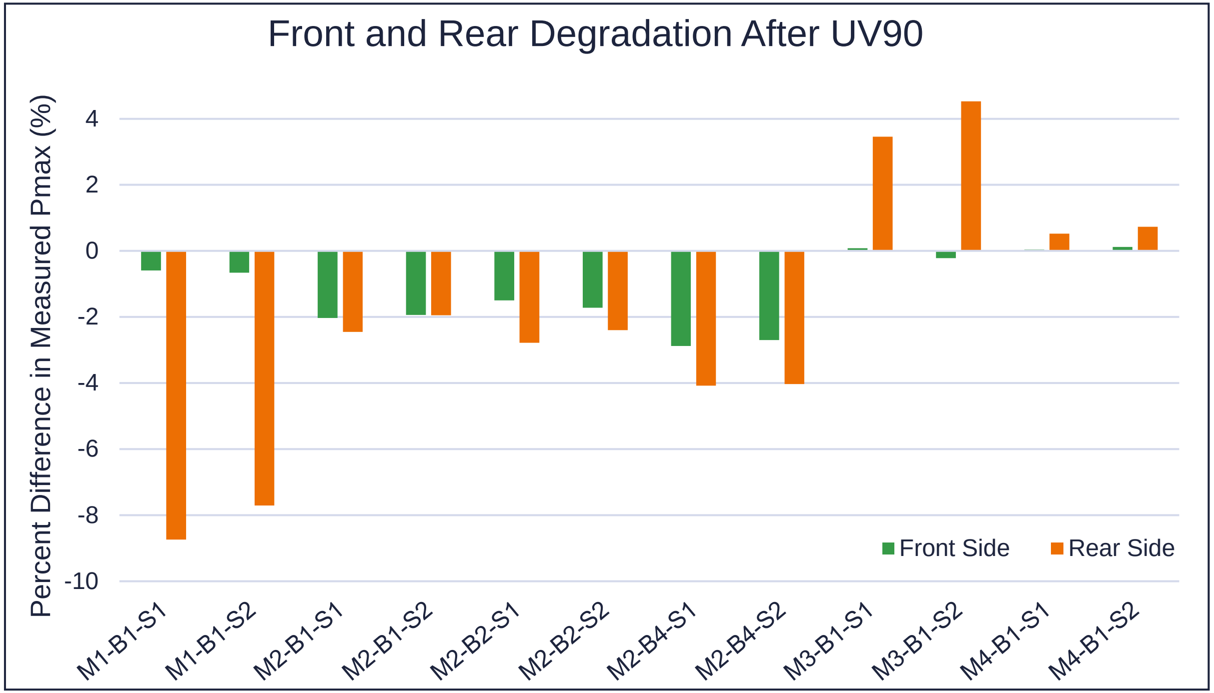
Initial Results: Damp Heat

- 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



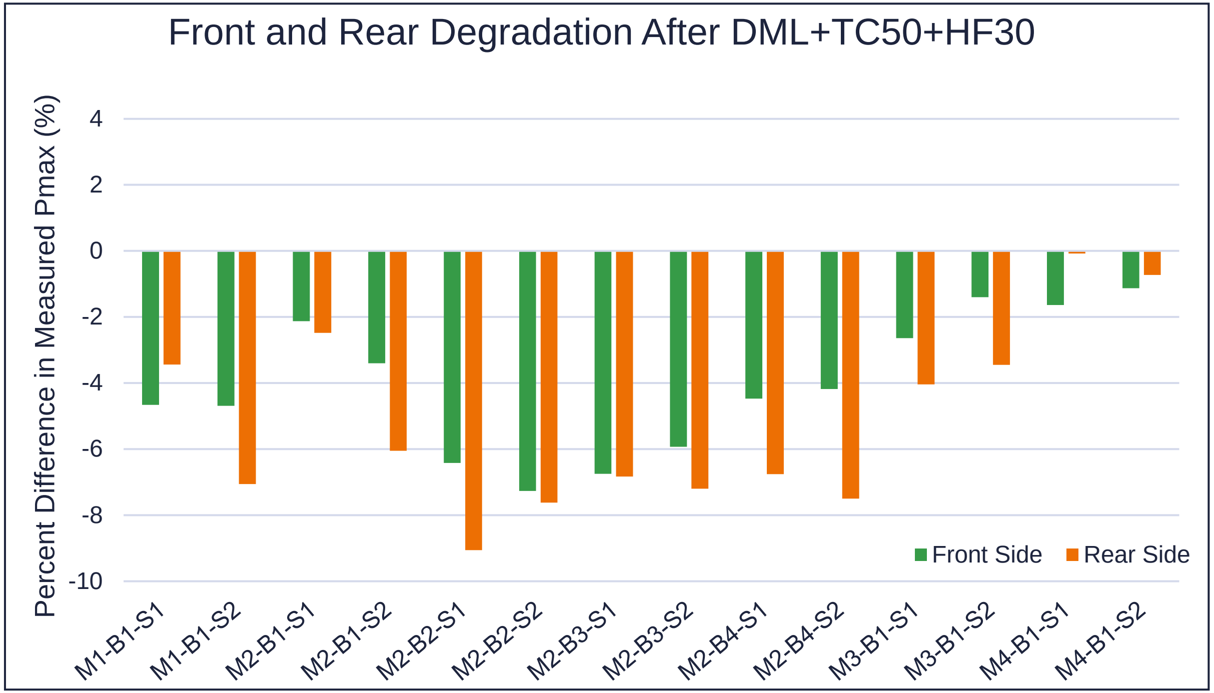
Initial Results: Front-Side UV

- 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



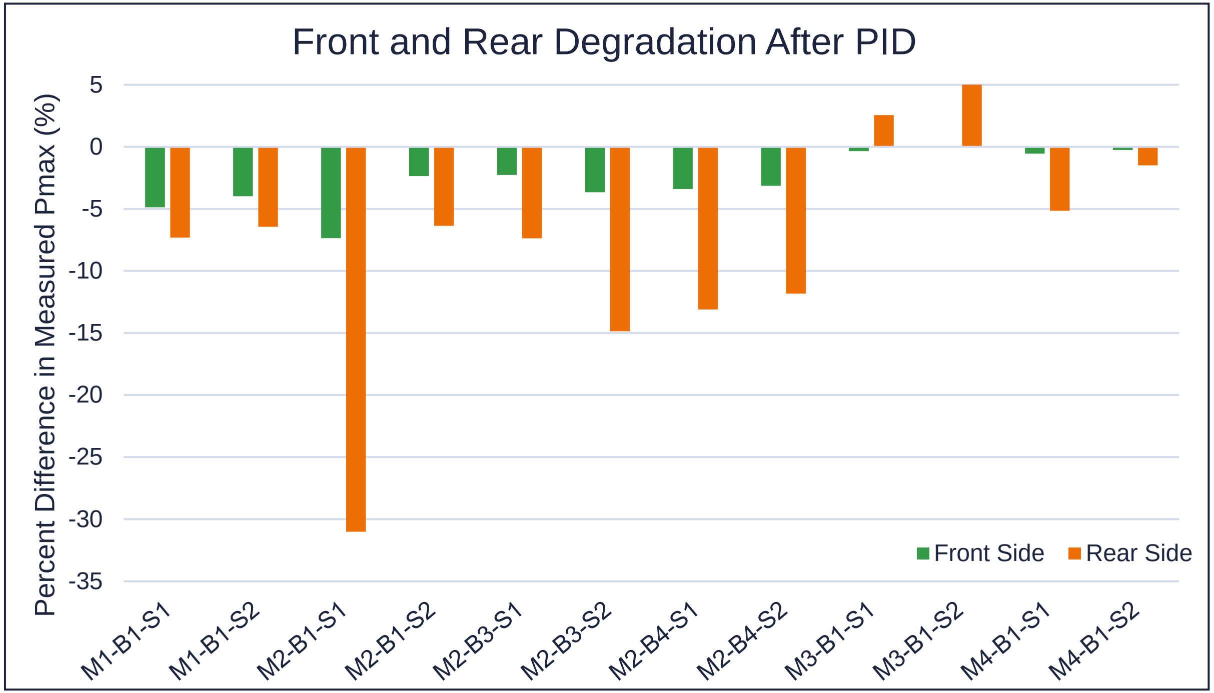
Initial Results: DML+TC50+HF30

- 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



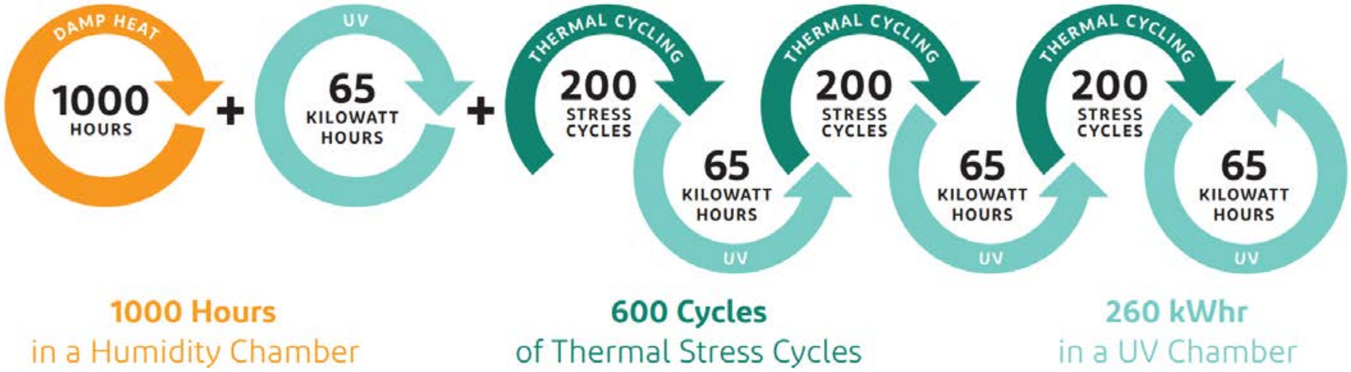
Initial Results: Potential-Induced Degradation

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

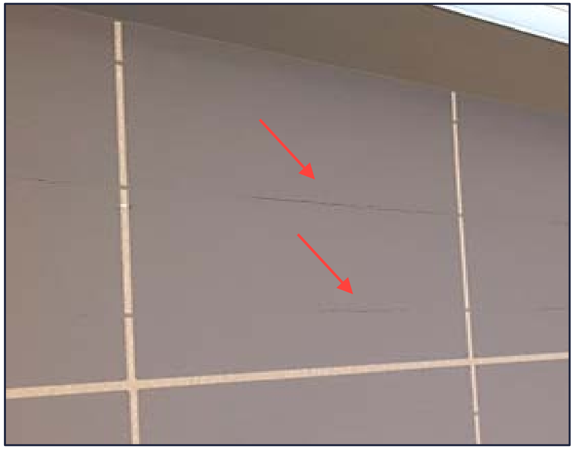


Backsheet Testing

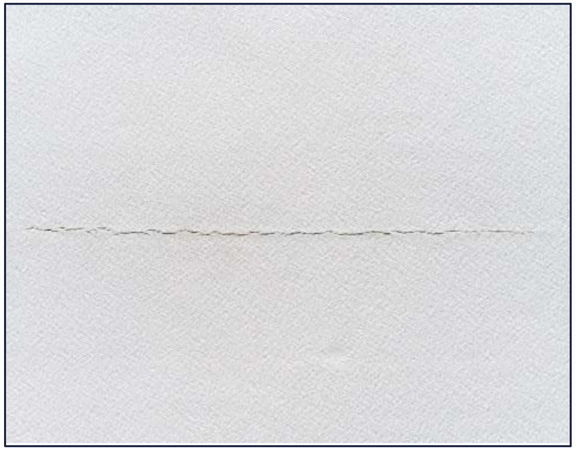
- PVEL has completed a variety of backsheet tests with DuPont using their MAST test protocol
- MAST submits modules to various stresses including extended UV exposure and thermal cycling to provide field-relevant backsheet durability results



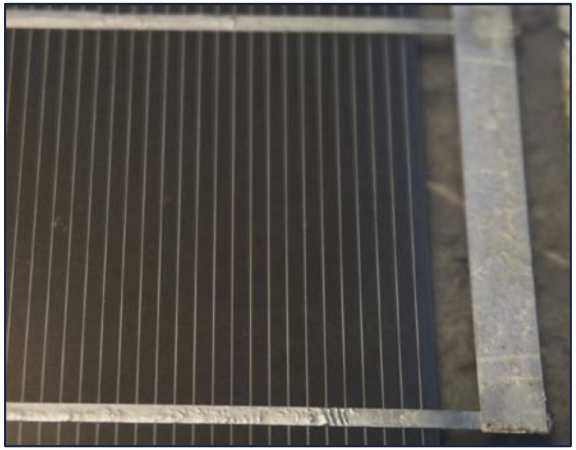
PVEL's Backsheet Test Results



Isovoltaic '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

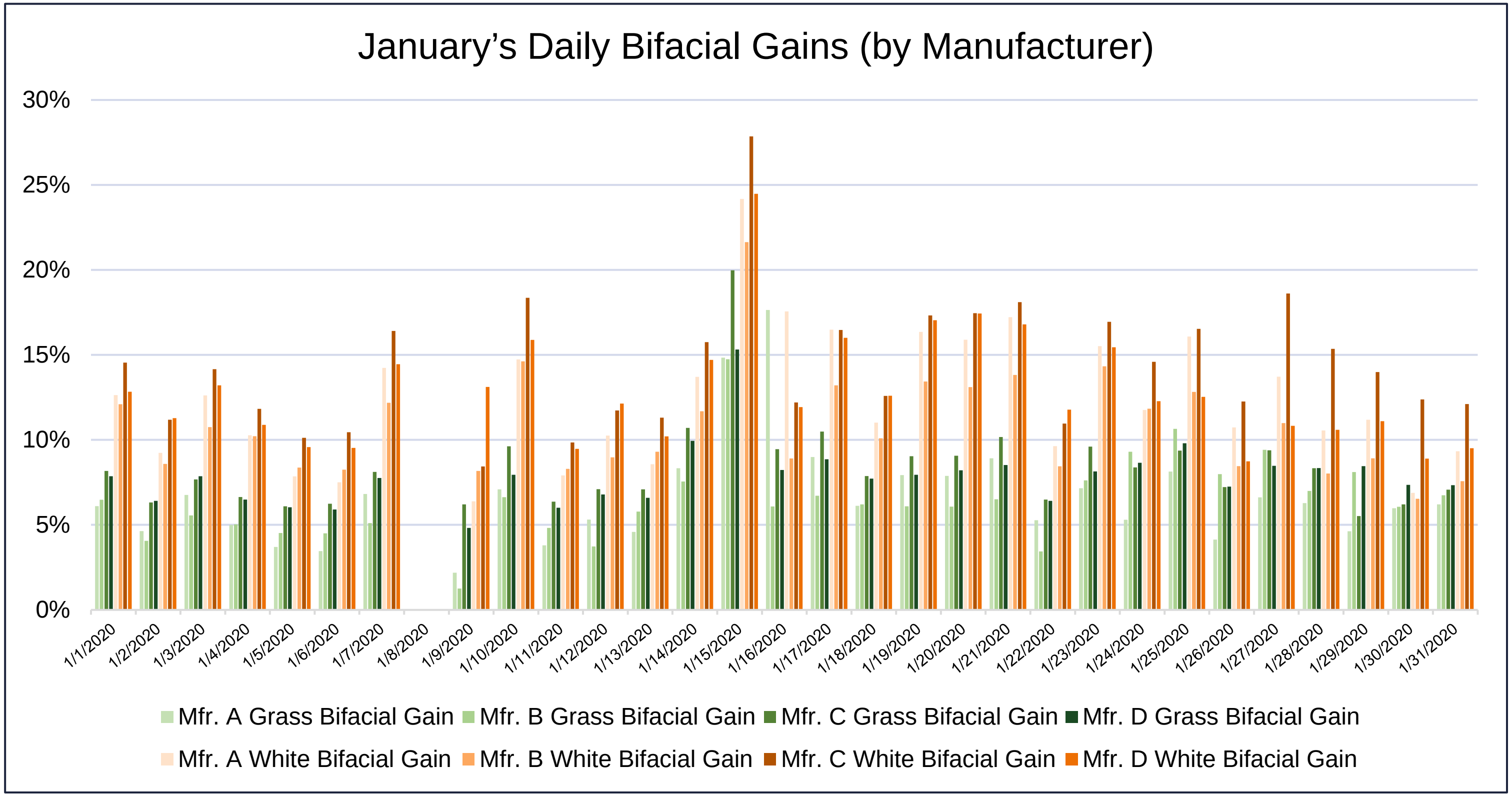
PVEL’s 1500V Bifacial Testing in Davis, CA

- 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

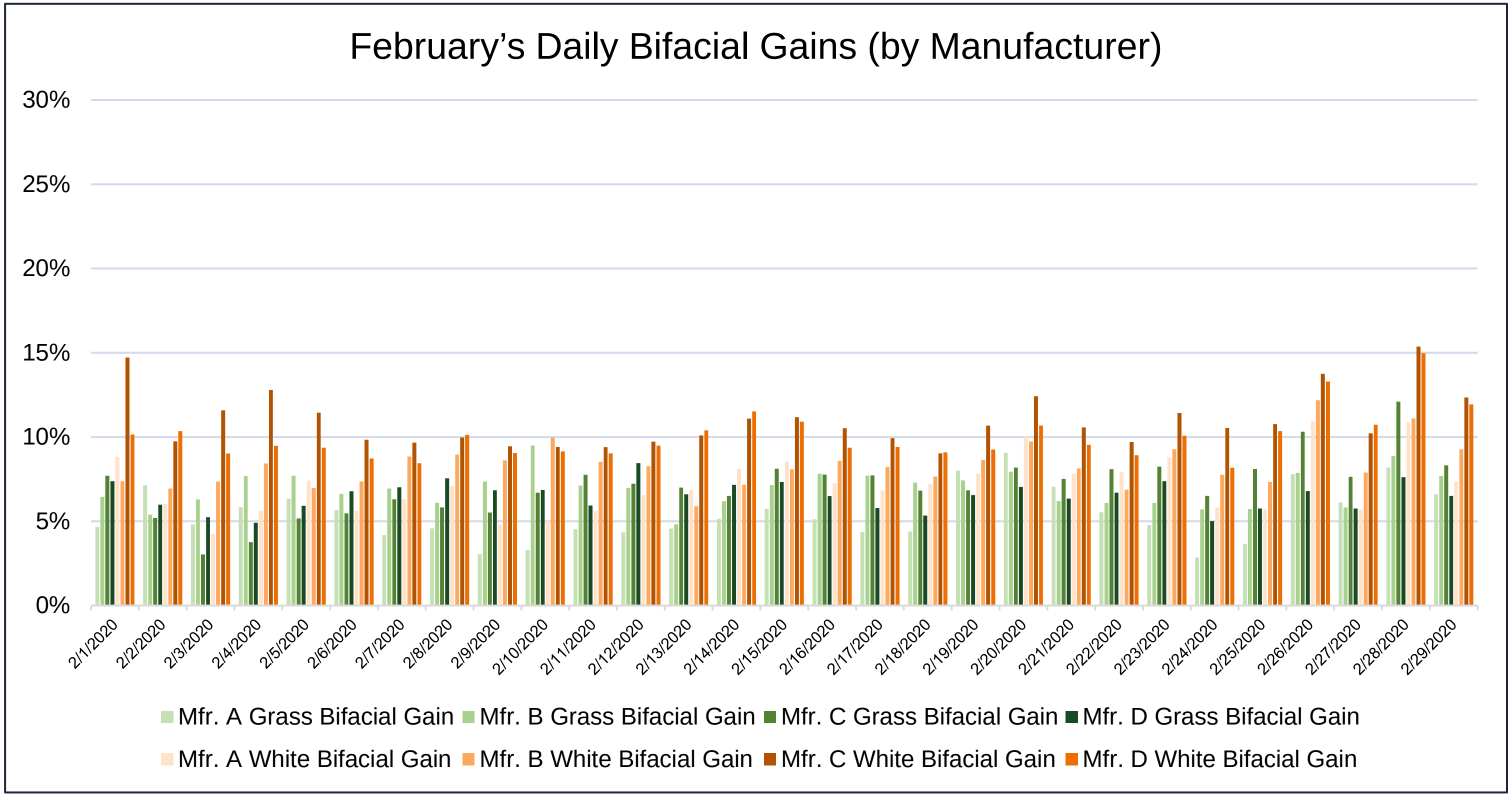
- Additional manufacturers are participating on the same trackers with smaller sample sets
- Study participants:
  - Astronergy (including 1500V strings)
  - ET Solar
  - First Solar
  - GCL
  - Jinko
  - LONGi (including 1500V strings)
  - Morgan Solar
  - Q CELLS (including 1500V strings)
  - Trina (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^2)	Albedo GHI (kWh/m^2)	GHI Albedo Ratio (%)	POA (kWh/m^2)	Albedo POA (kWh/m^2)	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%

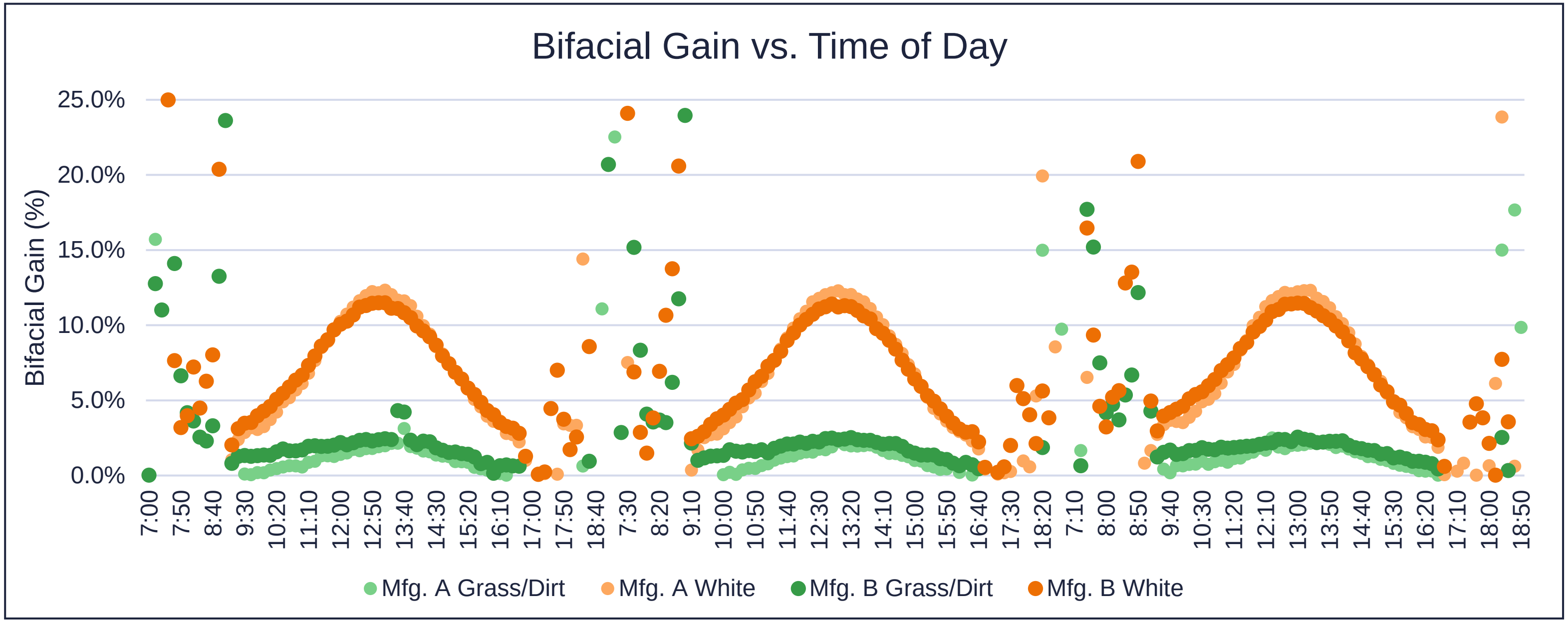
- Total bifacial gains for each month, per manufacturer:

	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

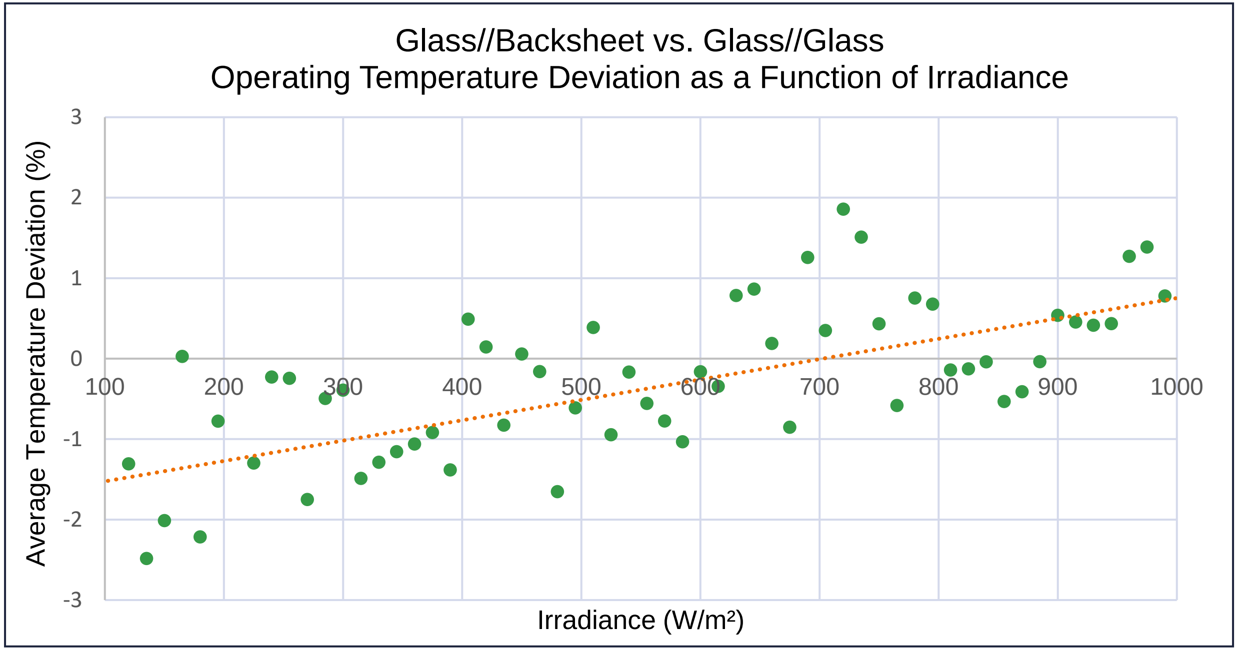
- Generally gains are highest mid-day, which could be lost to inverter clipping
- Lots of noise at start and end of day



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



Temperature and irradiance data taken in 5-minute intervals over 3 weeks.

THANK YOU!

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THIS MATERIAL IS BASED UPON WORK SUPPORTED BY THE U.S. DEPARTMENT OF ENERGY'S OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY (EERE) UNDER THE SOLAR ENERGY TECHNOLOGIES OFFICE (SETO), AWARD NUMBER DE-EE0008546.