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Bifacial Modules with transparent backsheet – performance, reliability and insurance

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INSIGHTS FROM PVEL'S INDOOR AND OUTDOOR BIFACIAL TESTING

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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

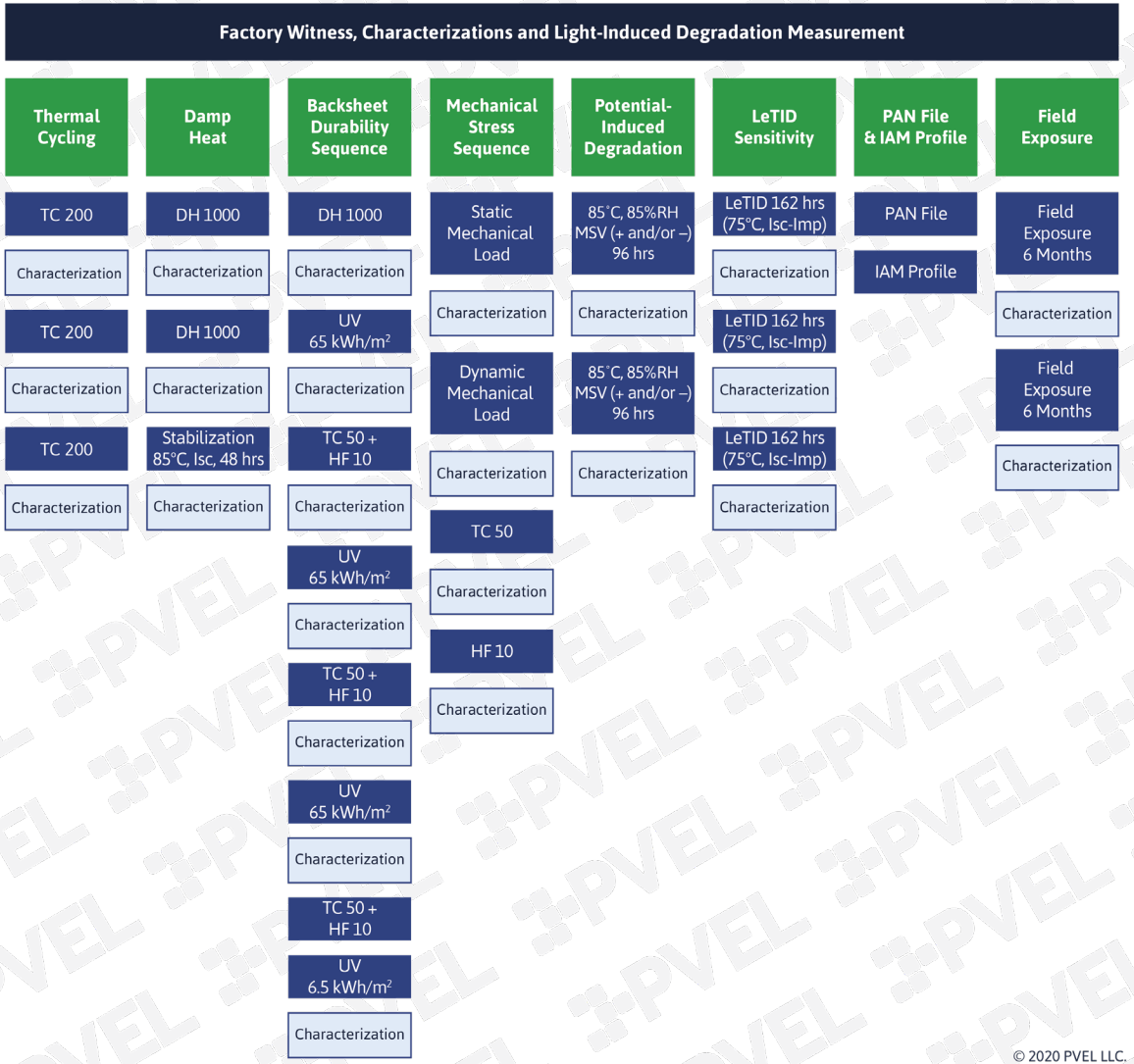
Experienced

Pioneered bankability testing for PV products nearly a decade ago

Market-driven

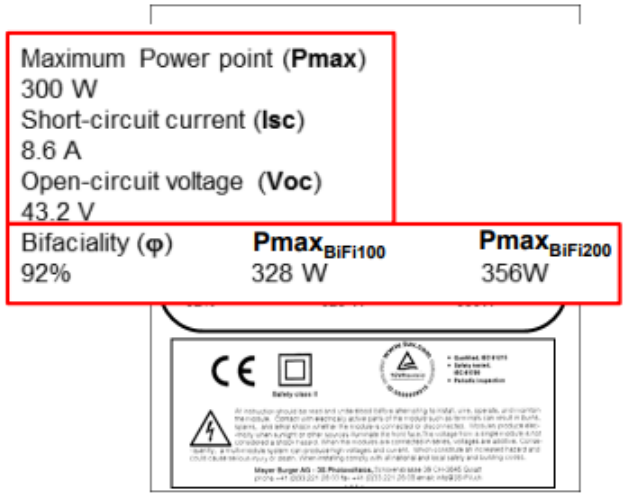
Continuously refining test programs to meet partner needs

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

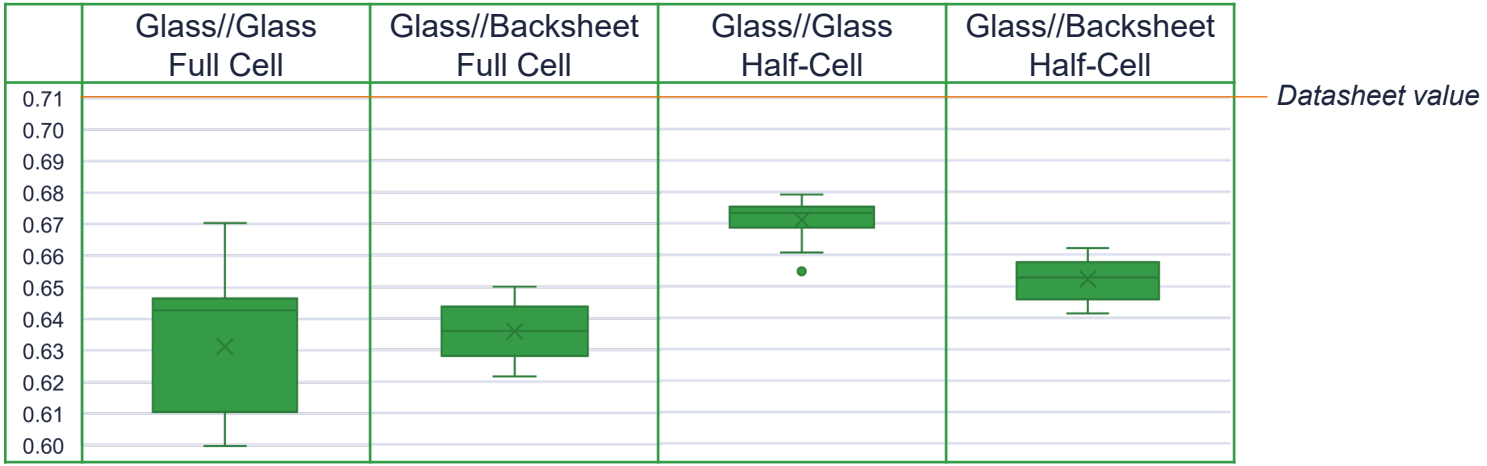
Bifacial PQPs Currently Under Test at PVEL

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

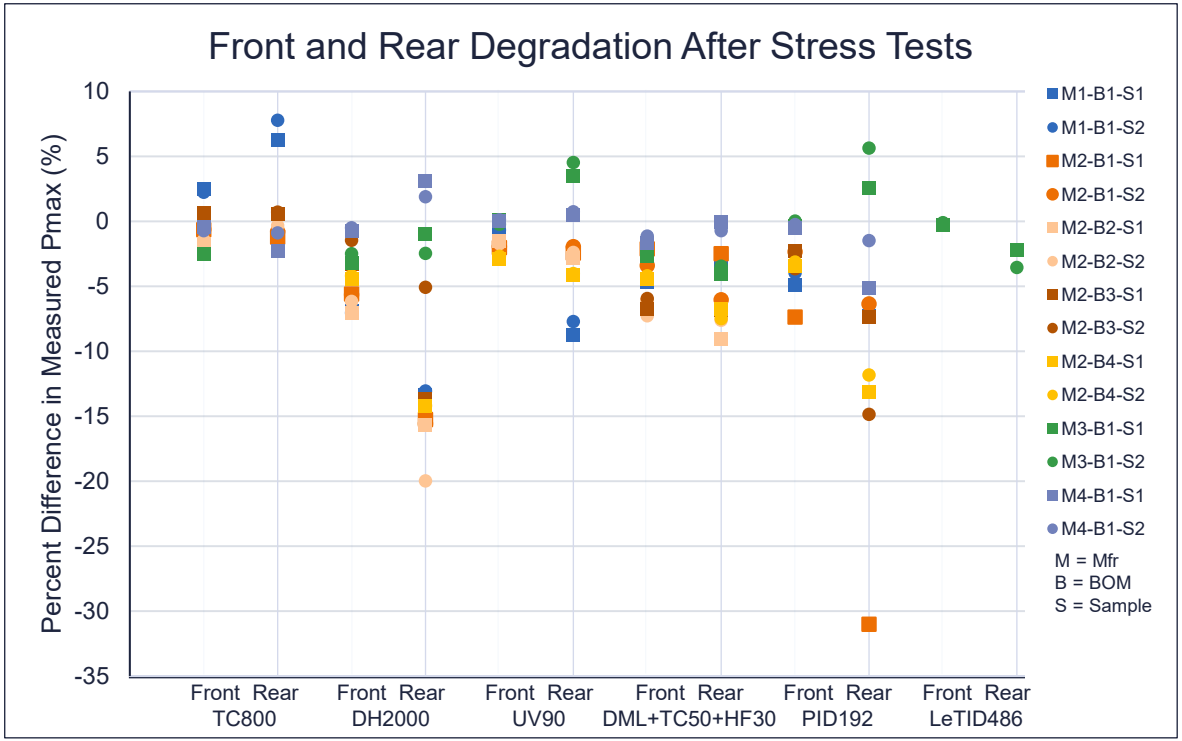
Initial Results: Bifaciality Ranges

- 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



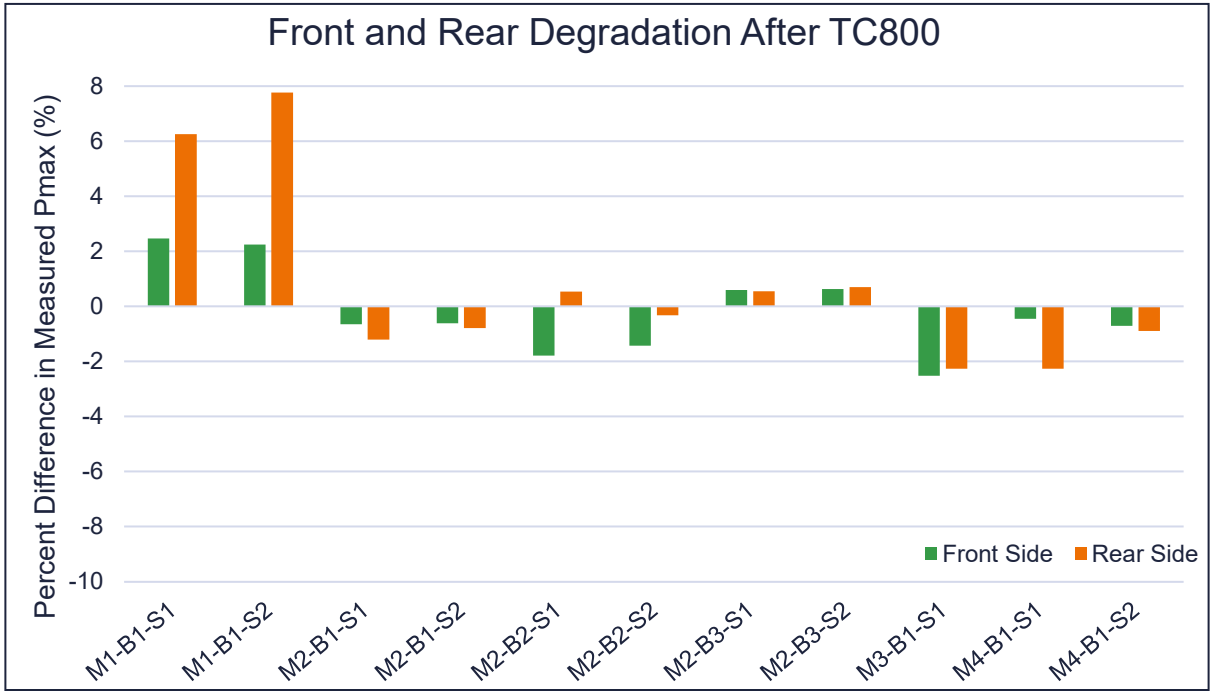
Initial Results: Reliability Testing at a Glance

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



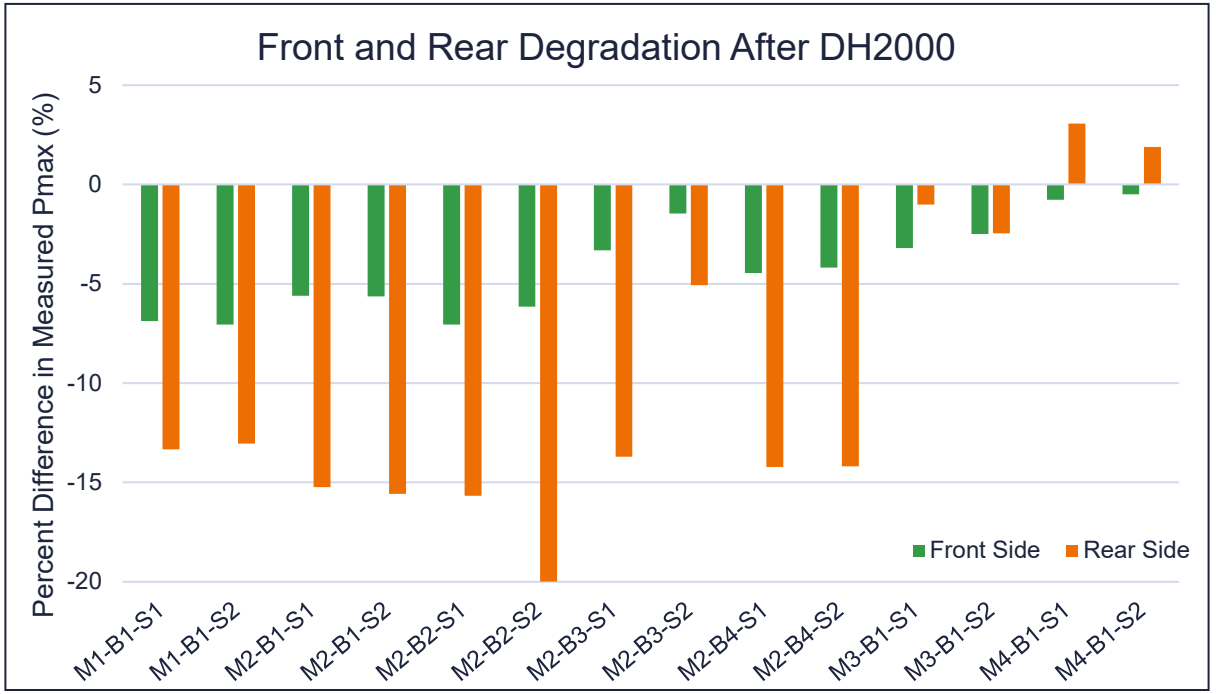
Initial Results: Thermal Cycling

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



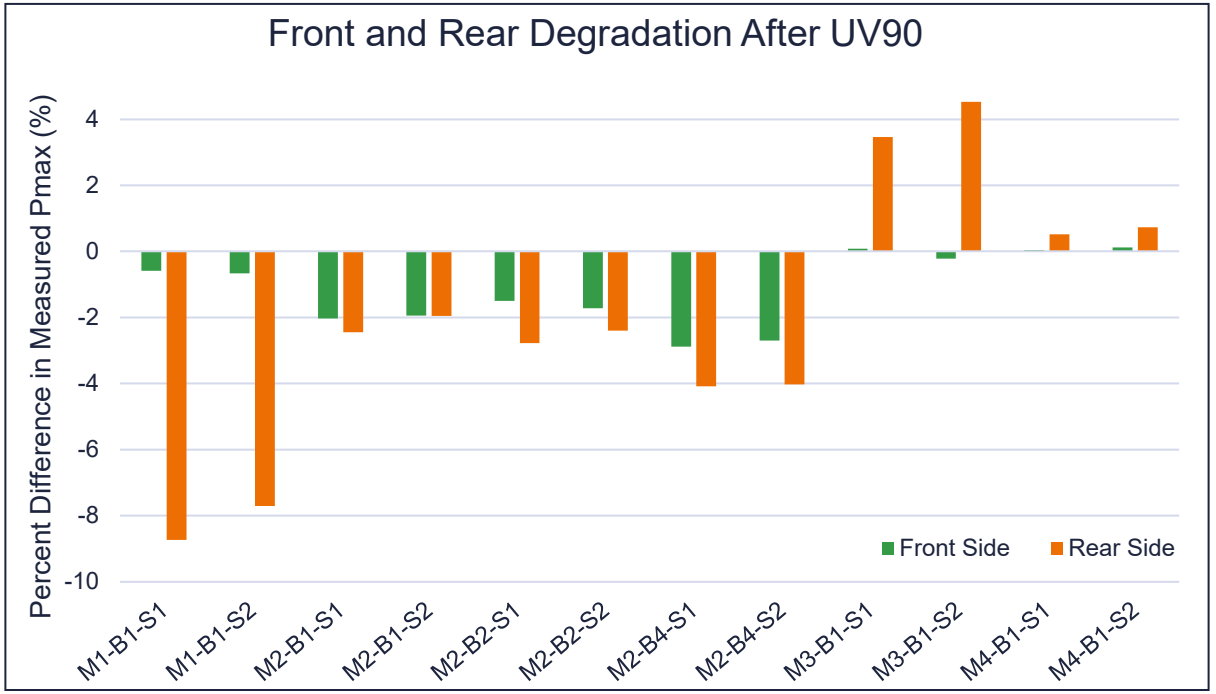
Initial Results: Damp Heat

- 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



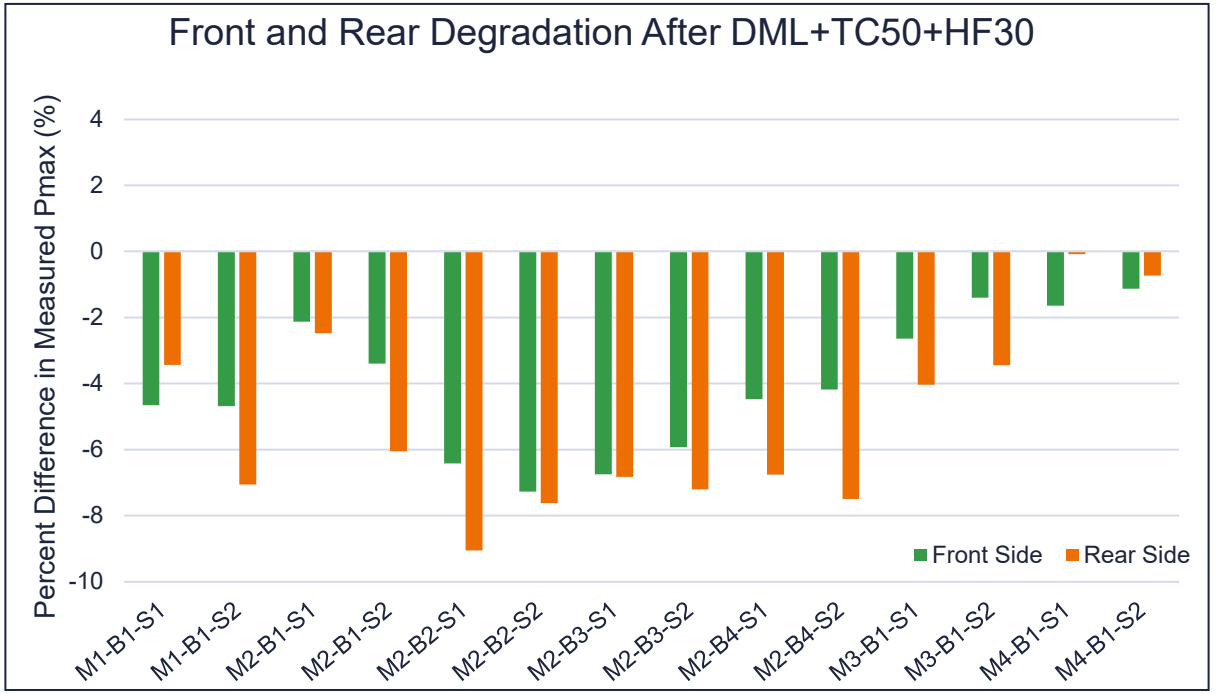
Initial Results: Front-Side UV

- 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



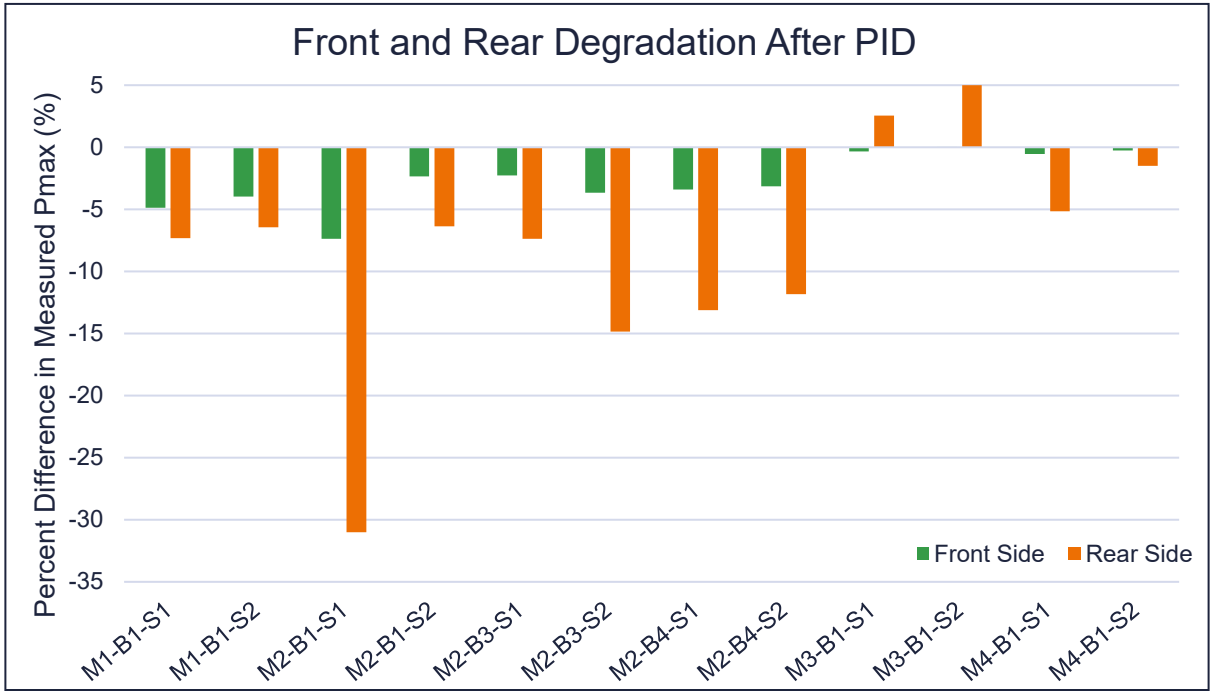
Initial Results: DML+TC50+HF30

- 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



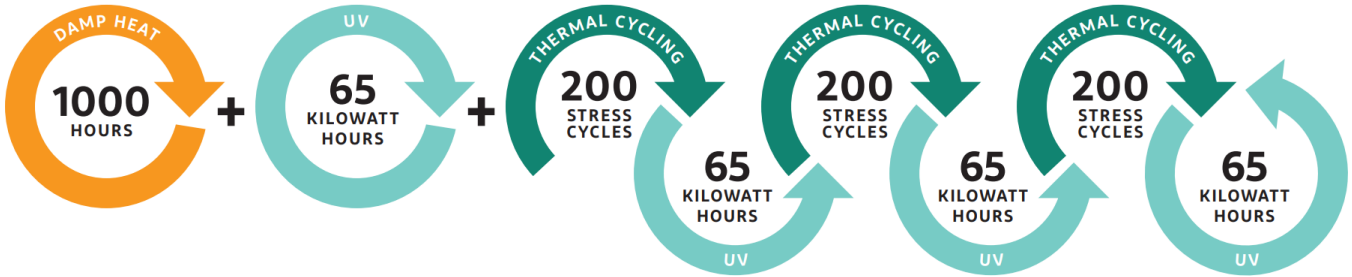
Initial Results: Potential-Induced Degradation

- 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**

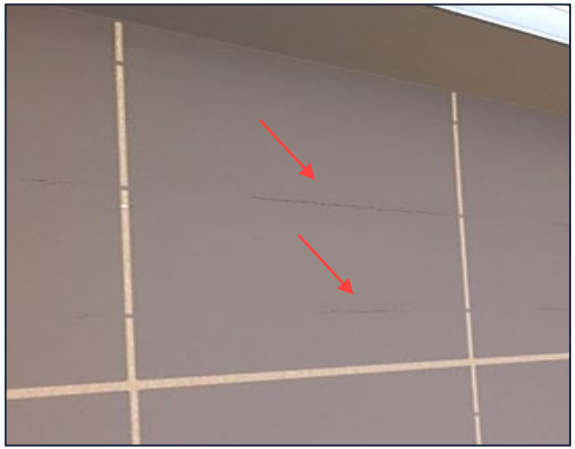


Backsheet Testing

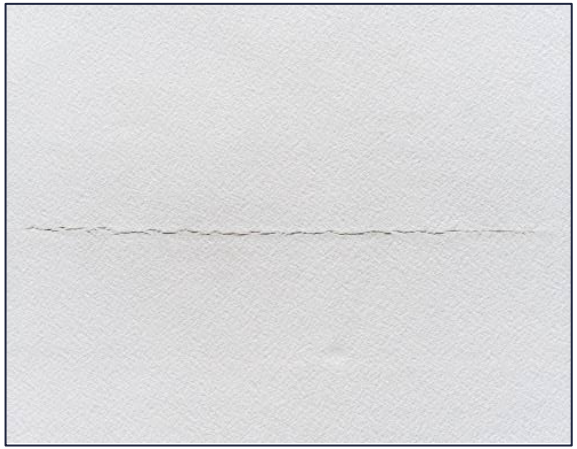
- PVEL has completed a variety of backsheet tests with DuPont using their MAST test protocol
- MAST submits modules to various stresses including extended UV exposure and thermal cycling to provide field-relevant backsheet durability results



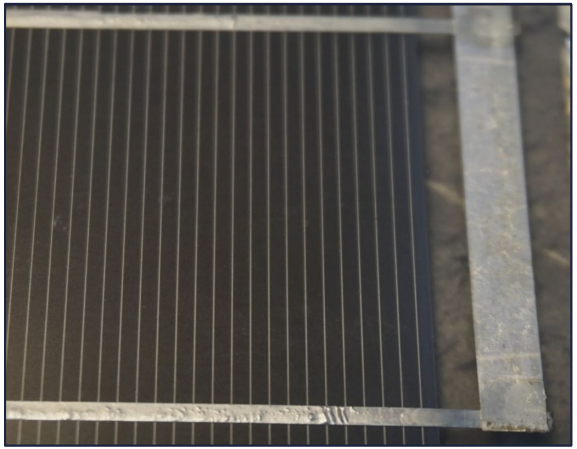
PVEL's Backsheet Test Results



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

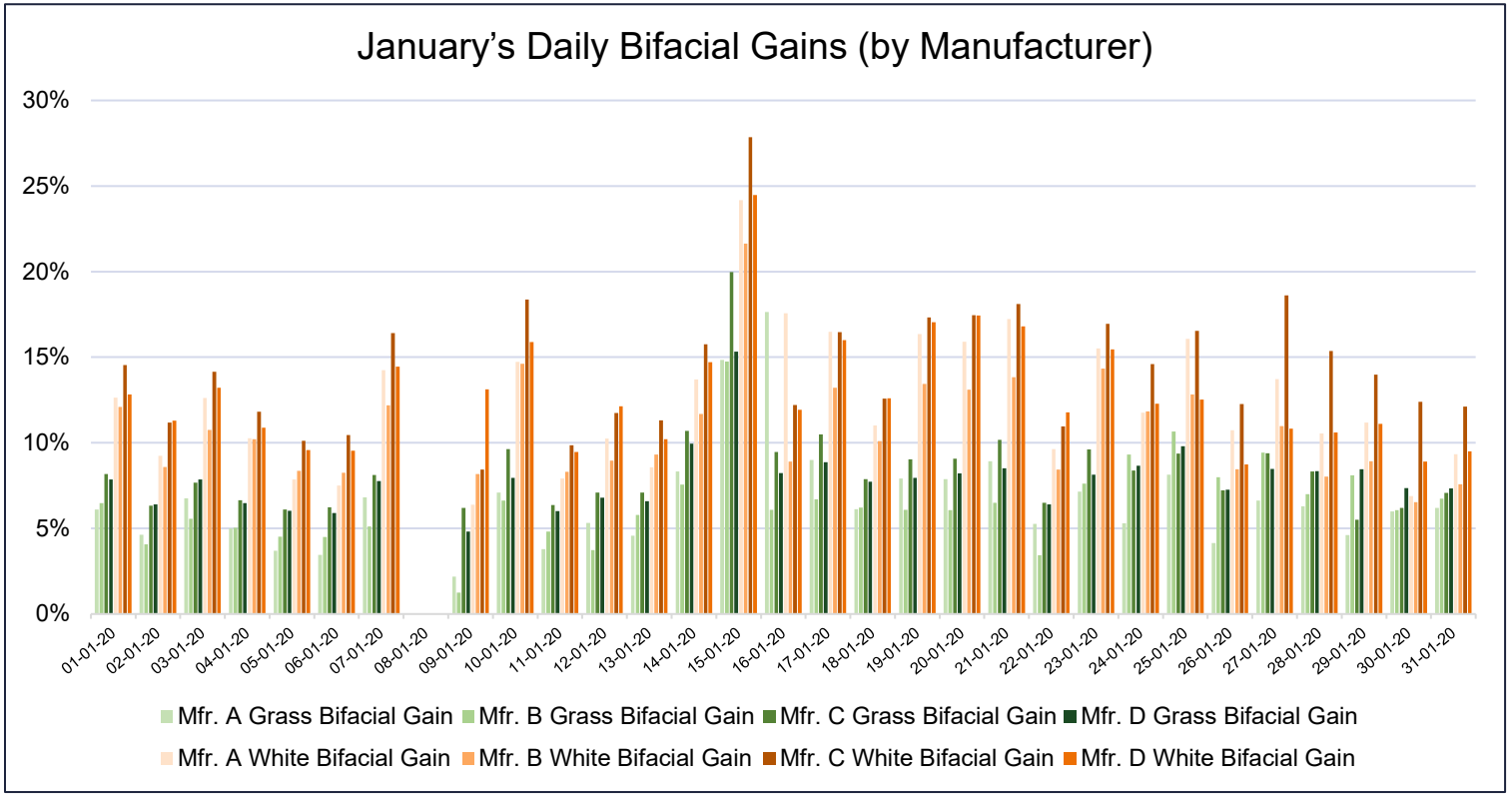
PVEL's 1500V Bifacial Testing in Davis, CA

- 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

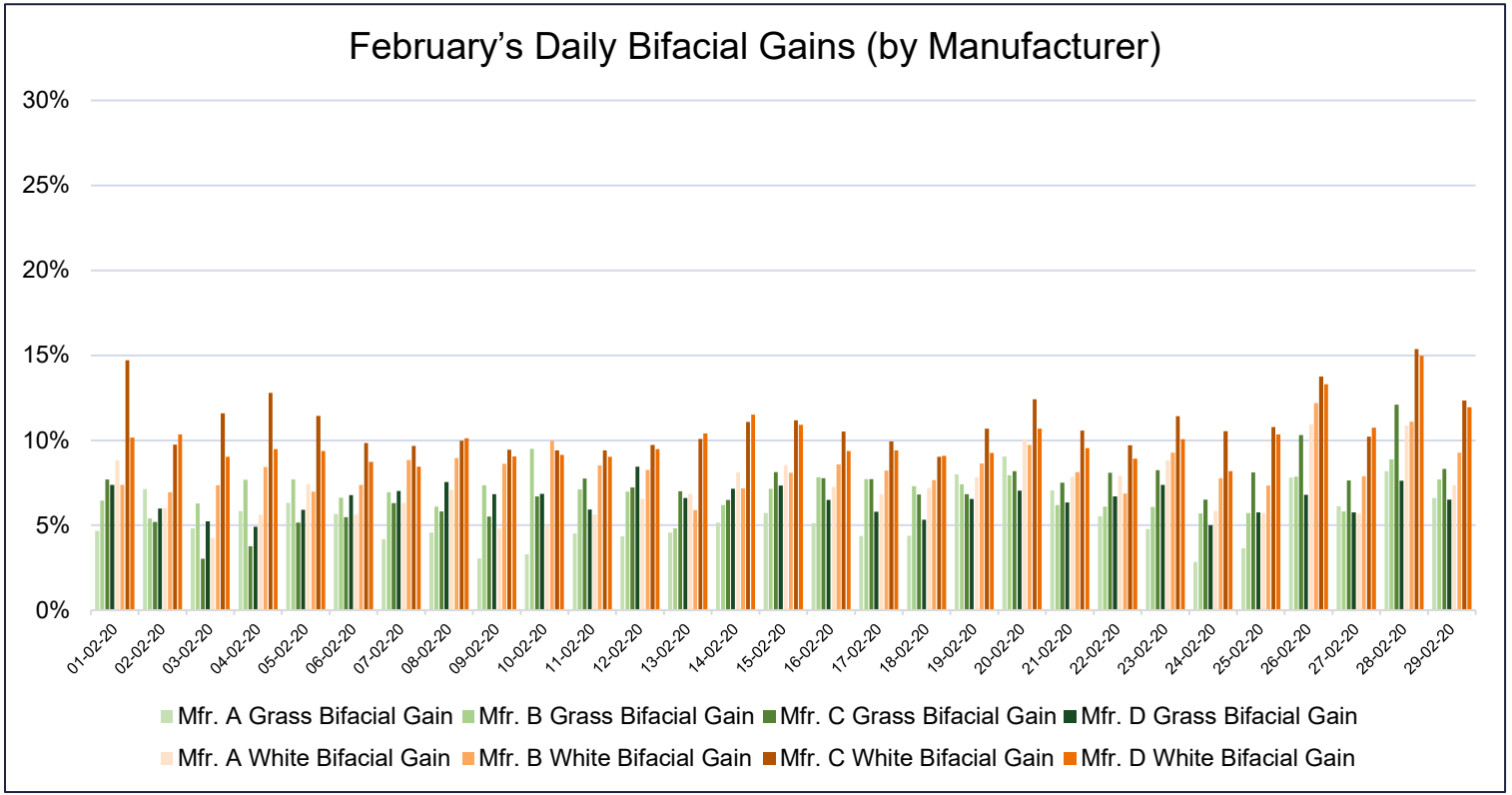
- Additional manufacturers are participating on the same trackers with smaller sample sets
- Study participants:
  - Astronergy (including 1500V strings)
  - ET Solar
  - First Solar
  - GCL
  - Jinko
  - LONGi (including 1500V strings)
  - Morgan Solar
  - Q CELLS (including 1500V strings)
  - Trina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

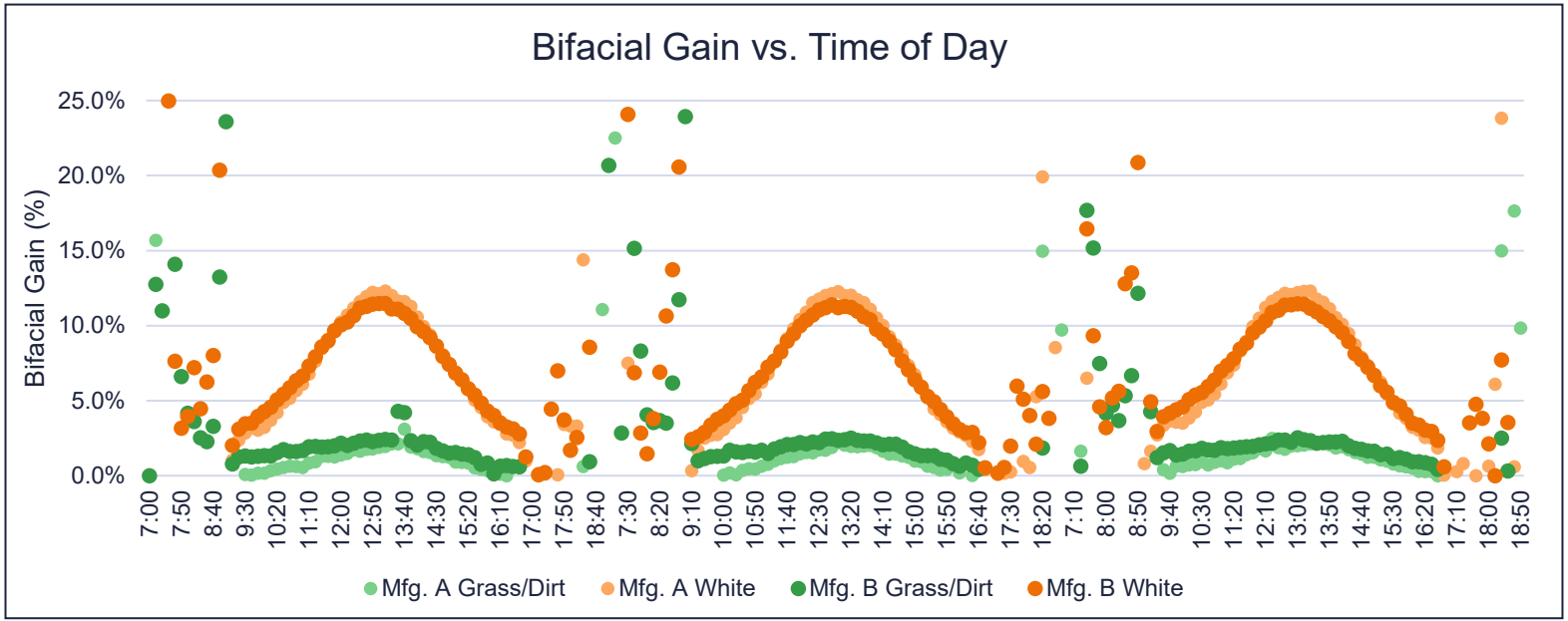
- Total bifacial gains for each month, per manufacturer:

	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

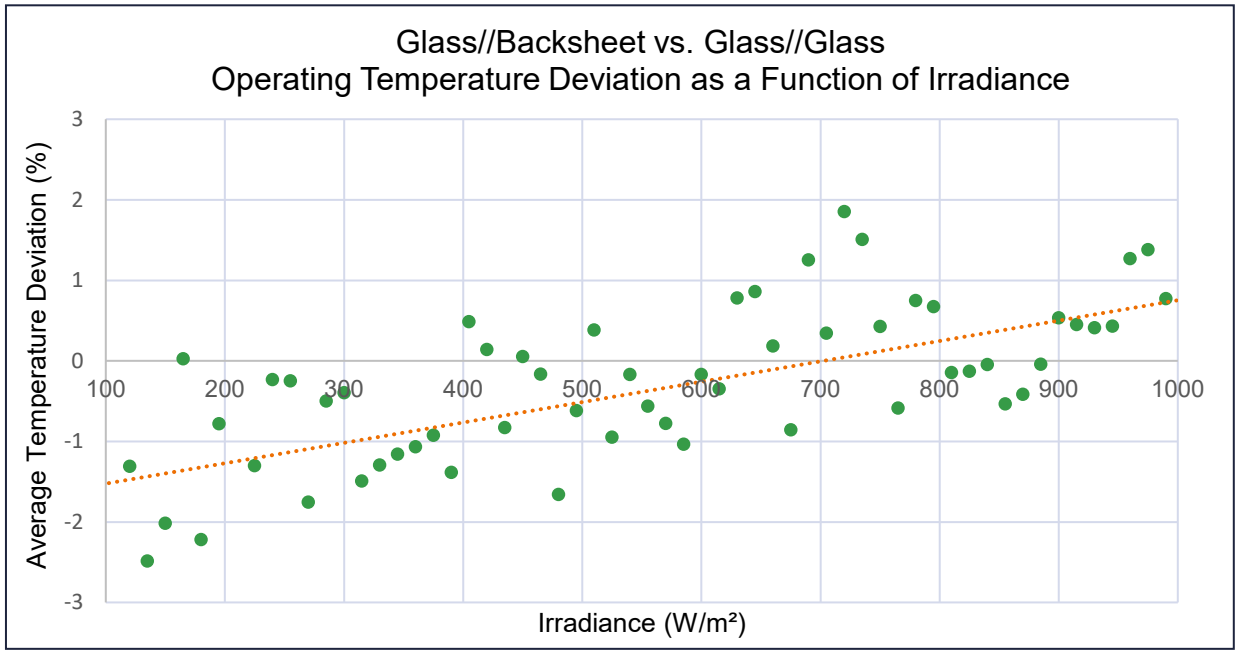
- Generally gains are highest mid-day, which could be lost to inverter clipping
- Lots of noise at start and end of day



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.

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