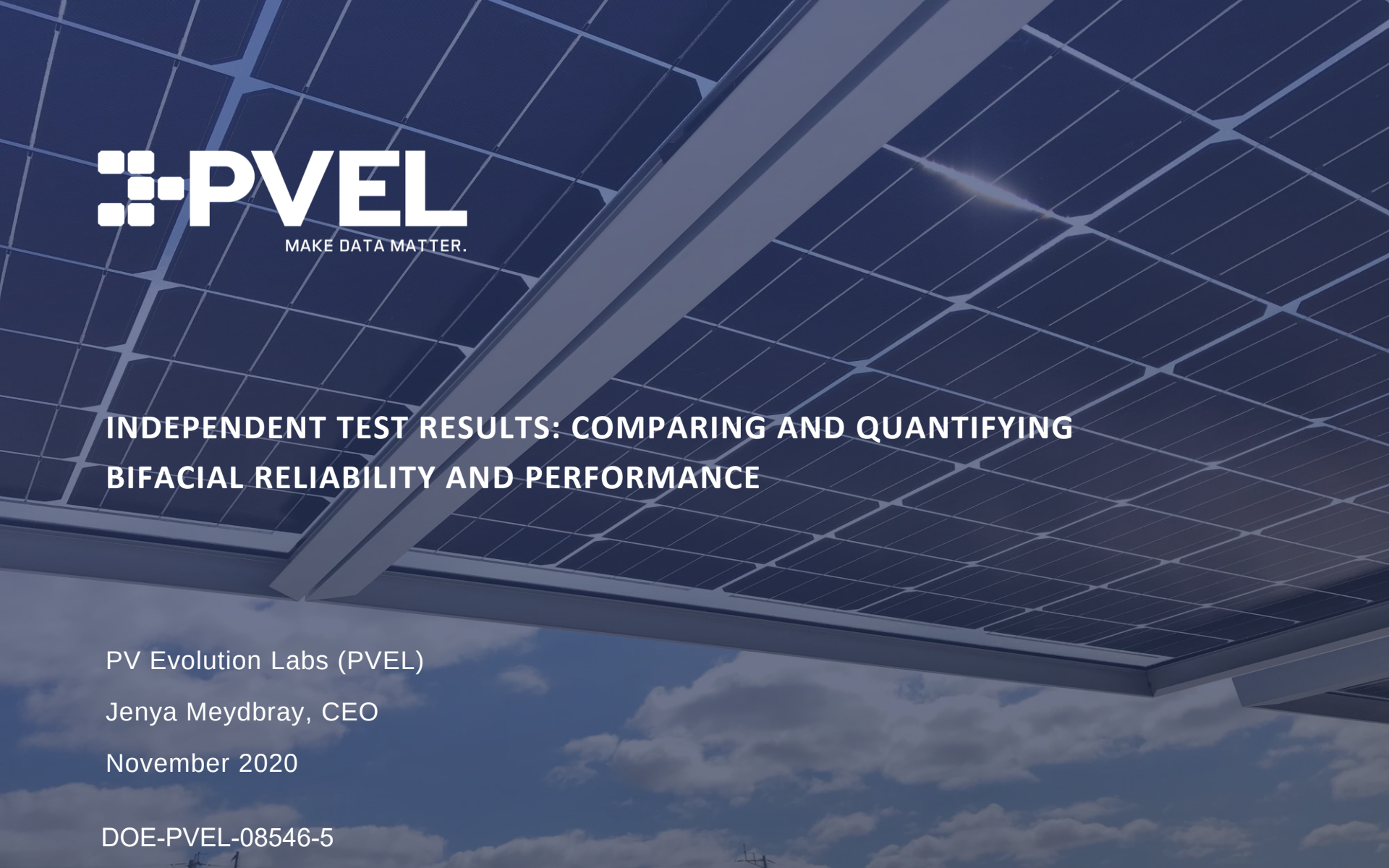

INDEPENDENT TEST RESULTS: COMPARING AND QUANTIFYING BIFACIAL RELIABILITY AND PERFORMANCE

PV Evolution Labs (PVEL)

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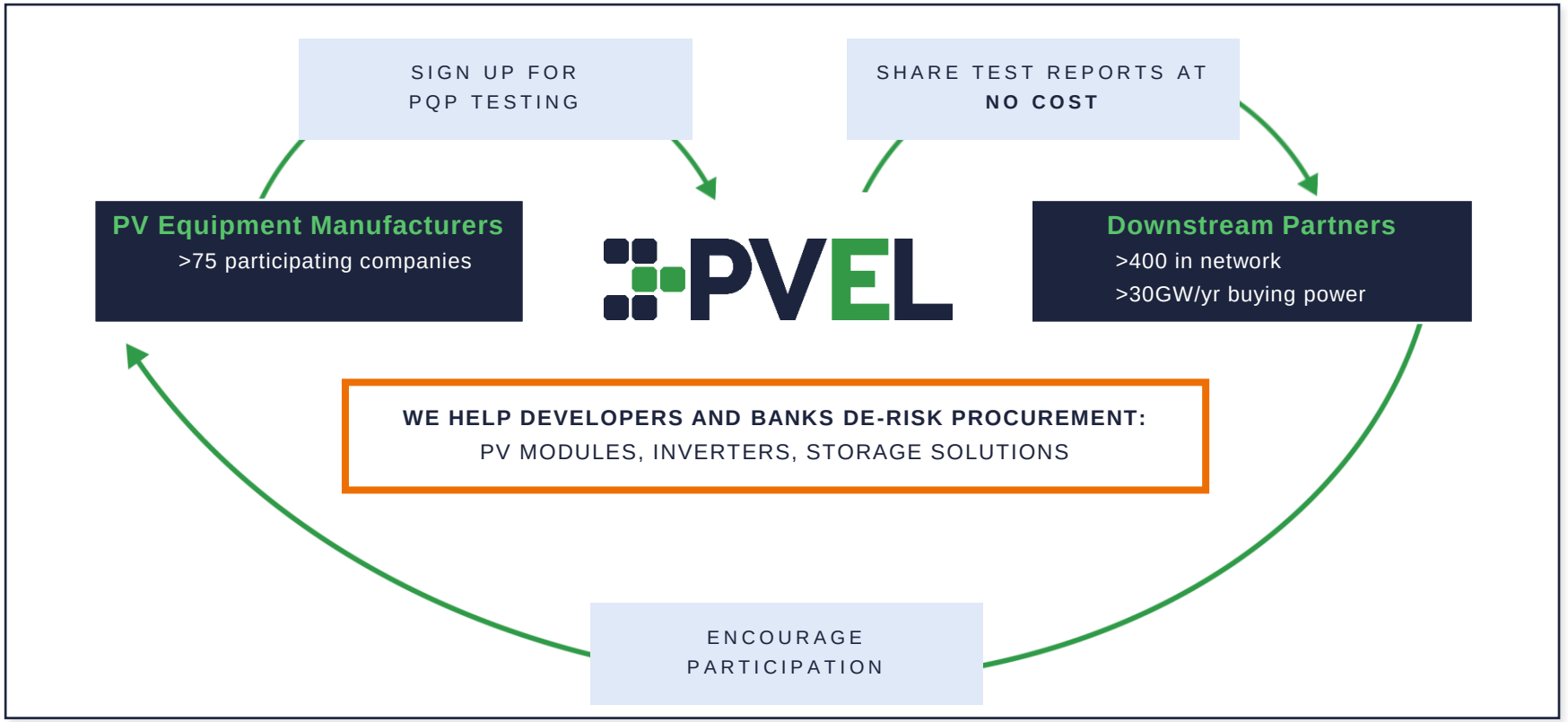
PVEL is the Independent Lab of the Downstream Solar Market

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

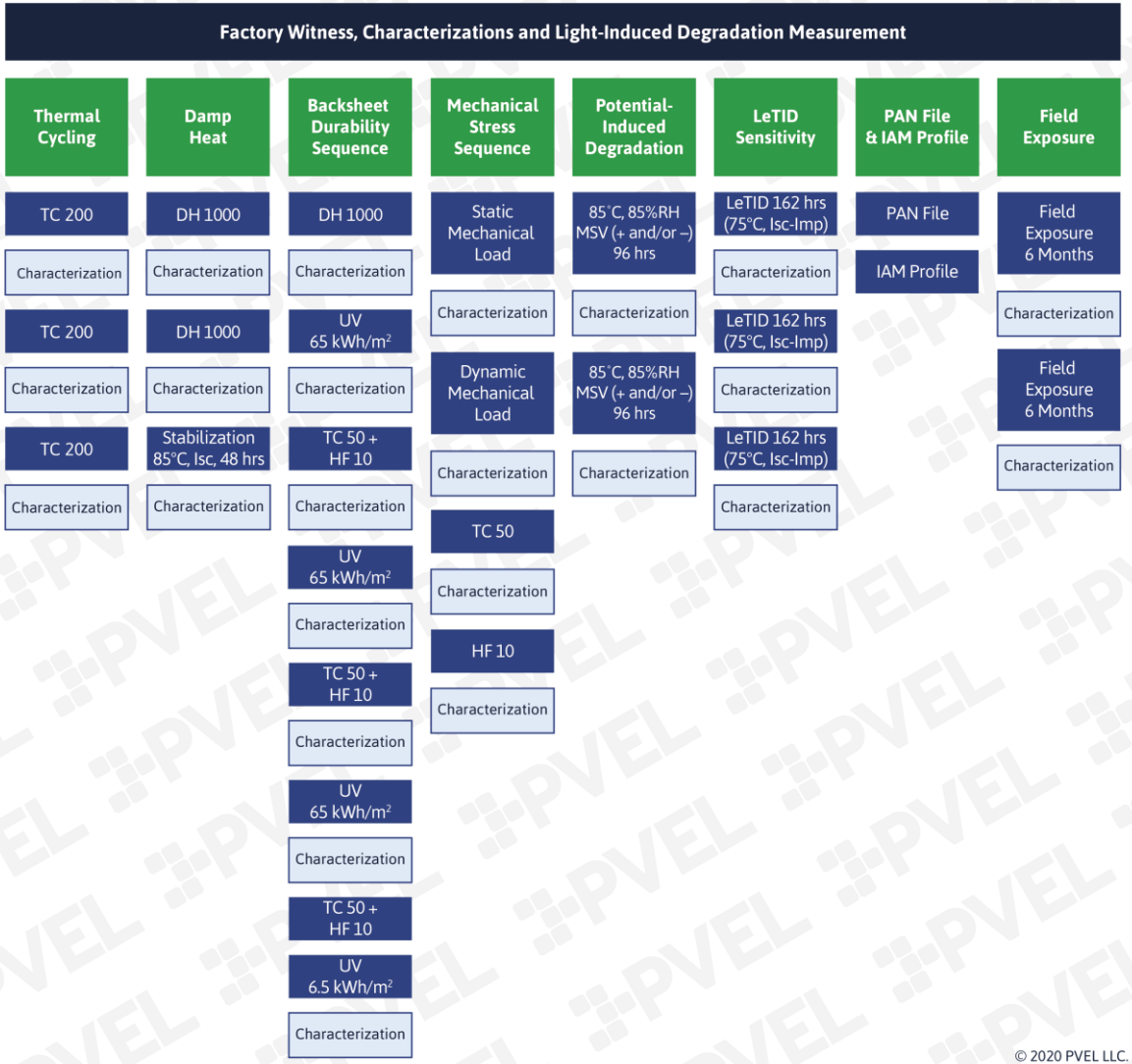
10	400+
Years of experience	Bills of materials tested

400+	30+GW
Global downstream partners	Annual project pipelines supported

How PVEL's PQPs Work



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)

Bifacial PQPs Currently Under Test at PVEL

PVEL leads the industry in bifacial extended reliability and performance data

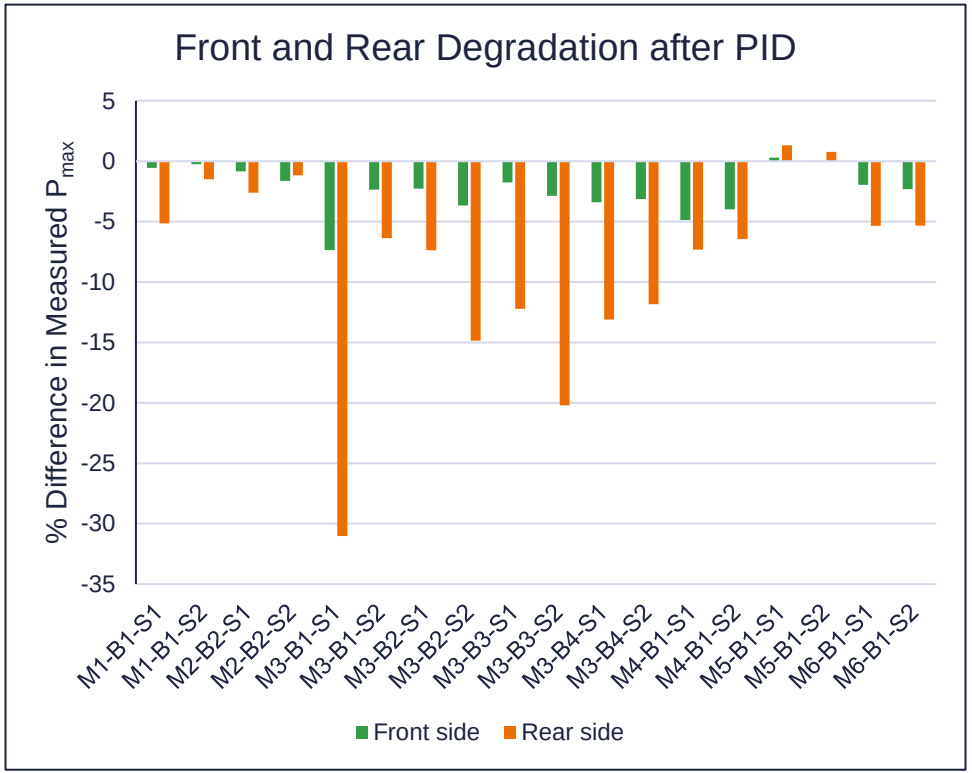
- Current PQP – 37 bifacial BOMs, from 14 manufacturers:
  - full cell, half-cut cells
  - 156.75, 158.75, 166mm cells
  - 5BB, 6BB, 9BB, interdigitated back contact (IBC)
  - p-type, n-type
  - glass//glass, glass//backsheet
- Last year's PQP – 13 bifacial BOMs, from 5 manufacturers:
  - full cell, half-cut cells
  - 156.75, 158.75, 166mm cells
  - 5BB, 6BB
  - p-type
  - glass//glass, glass//backsheet

Understanding bifacial performance: bifaciality factors vs. reality for p-type PERC modules

- **50% of manufacturers did not list bifaciality factors on datasheets**
- Datasheet values are often accurate
- PVEL-measured bifaciality factors ranged from 59.5% to 83.6%
  - Median of 69.6%
  - Average of 71.0%.
- Datasheet bifaciality factors ranged from 65.7% to 75.3%
- 20% of BOMs had a PVEL-measured bifaciality >5% lower stated
  - Worst performer is 15% lower

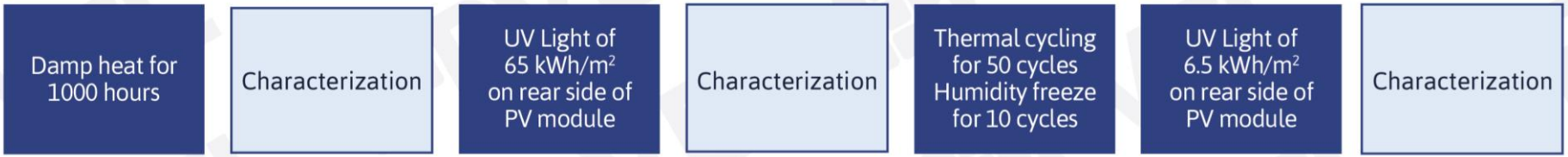
Bifacial reliability: varying front side and rear-side rates of potential-induced degradation (PID)

- Extended duration PID testing across 20 different p-type PERC bifacial modules
- Wide range of performance:
  - Front: 0% to over 7% degradation
  - Rear: Power gains to over 30% degradation
- Broad range of rear-side degradation observed for glass//glass and glass/backsheet BOMs
- Rear-side degradation may not be field representative

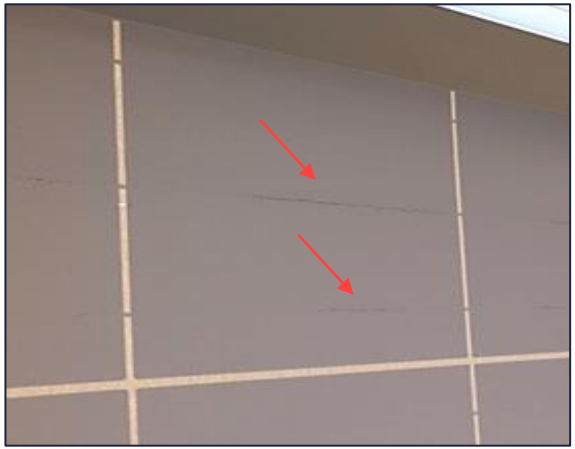


PVEL's backsheet durability sequence (BDS)

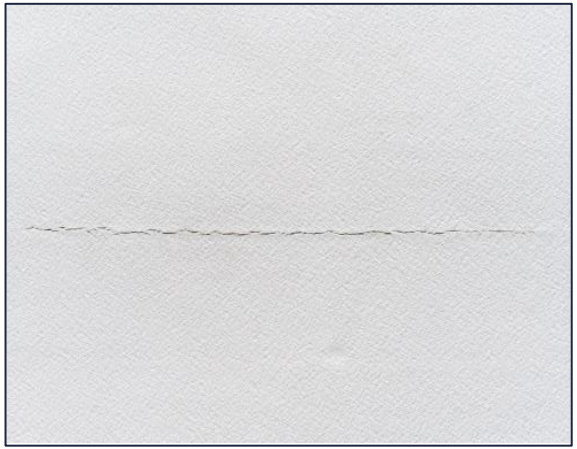
- PVEL' submits modules to various stresses including extended UV exposure and thermal cycling to provide field-relevant backsheet durability results



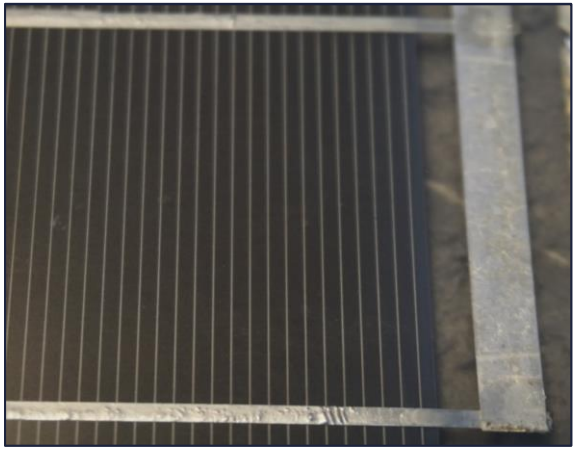
PVEL's Backsheet Test Results



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



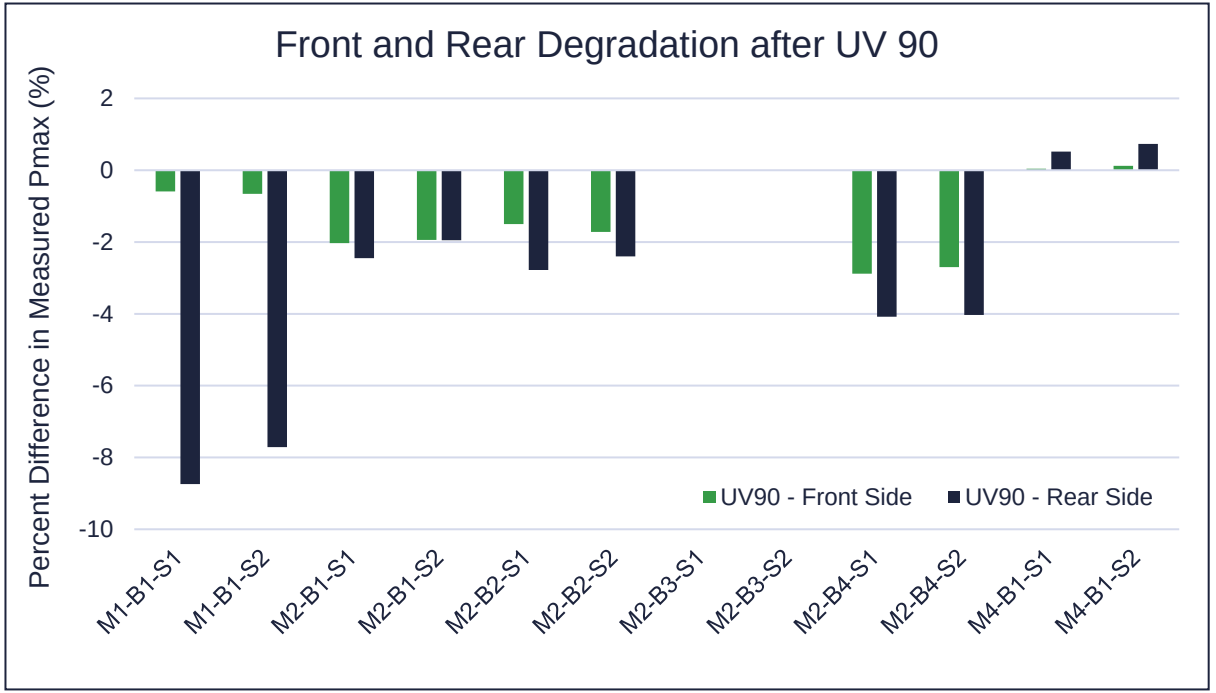
Accelerated Lab Failure of PVDF (polyvinylidene fluoride)
Source: PVEL



Clear Tedlar Shows No Cracking Following MAST
Source: PVEL

Initial Results: Front-Side UV

› UV aging appears to cause a range of impacts on rear side power degradation



Damp Heat Performance: Glass//glass vs. Backsheet

- Glass//glass modules performing comparably to glass//backsheet designs
- Manufacturers appear to have overcome early issues with glass//glass designs

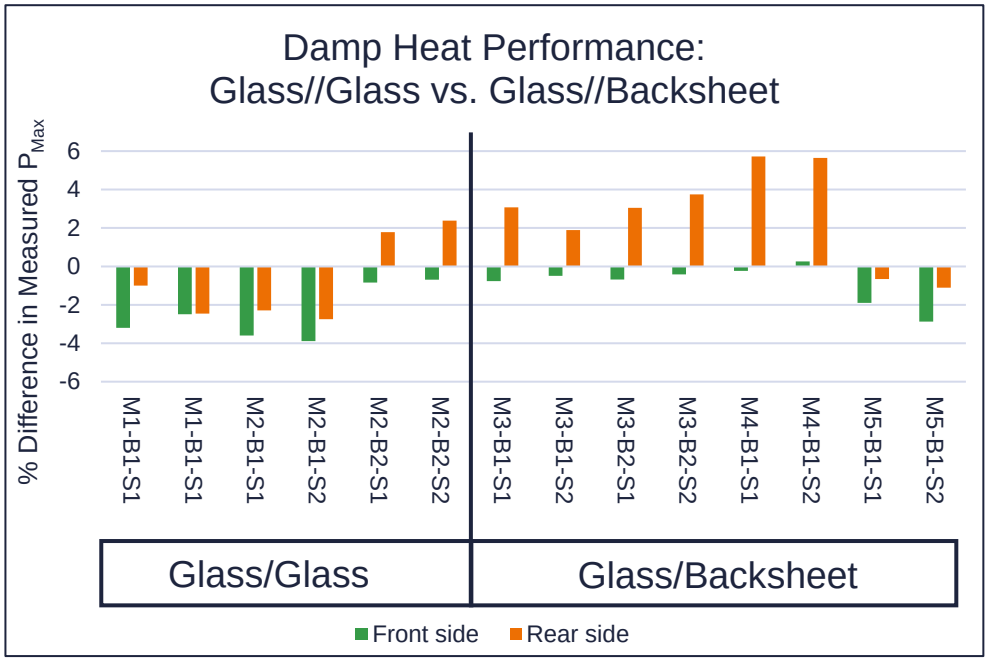


Image above: glass/glass PV module failure.
Source: PVPS, Report IEA-PVPS T13-09:2017

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: Summary

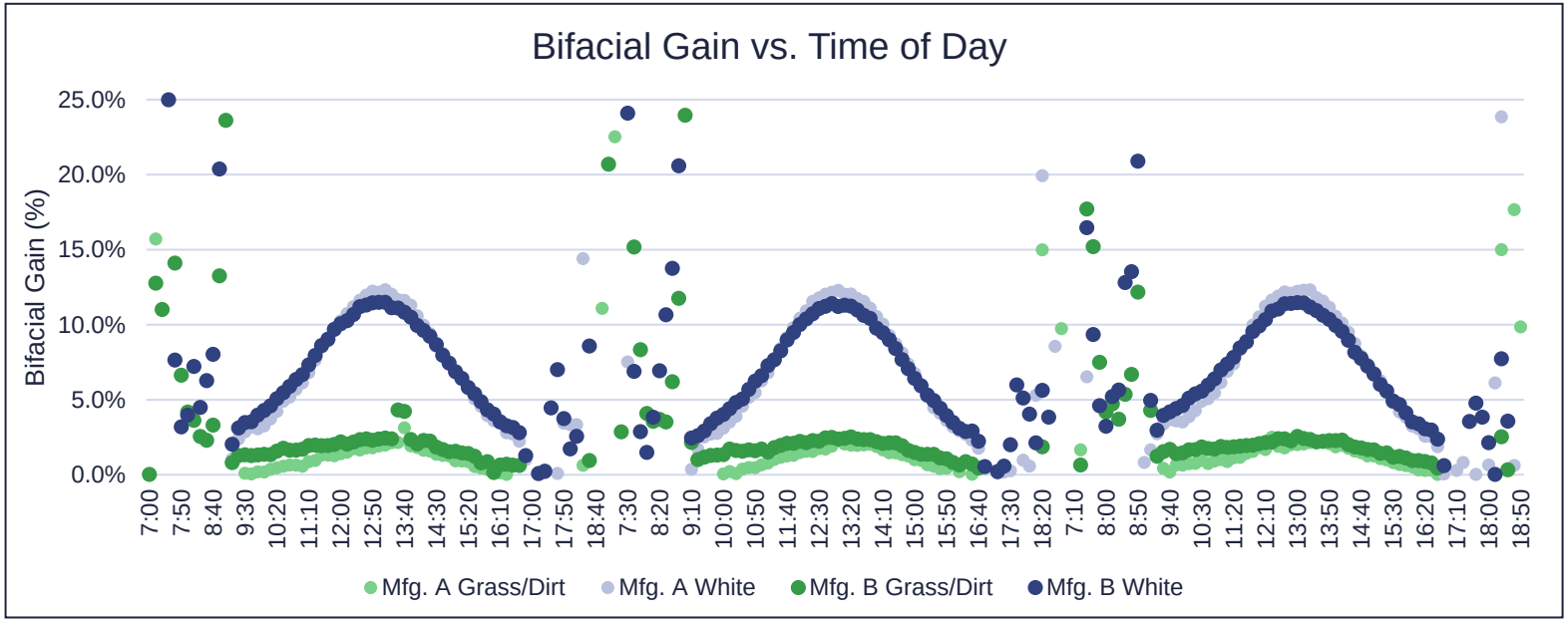
Total bifacial gains since inception, per manufacturer

	Bifacial Gain Grass	Bifacial Gain White
Mfr. A	5.57%	8.28%
Mfr. B	6.57%	8.78%
Mfr. C	7.46%	11.44%
Mfr. D	7.23%	10.73%

Data normalized to pre-light soak flash

Outdoor Performance Results: Bifacial Gains by Time of Day

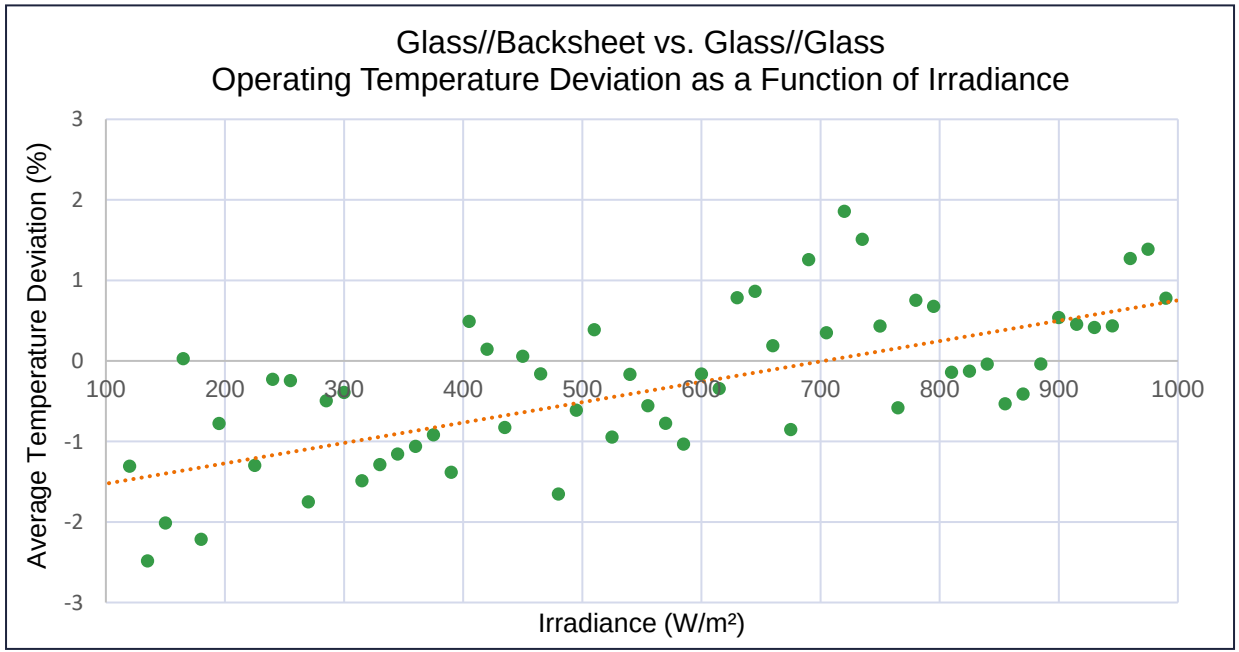
- Generally gains are highest mid-day, which could be lost to inverter clipping
- Lots of noise at start and end of day



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.


PVEL
MAKE DATA MATTER.
THANK YOU

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.