Understanding Solar Module Test Failures:
Key Takeaways from Kiwa PVEL's PV Module Reliability Scorecard

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Kiwa PVEL

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kiwa

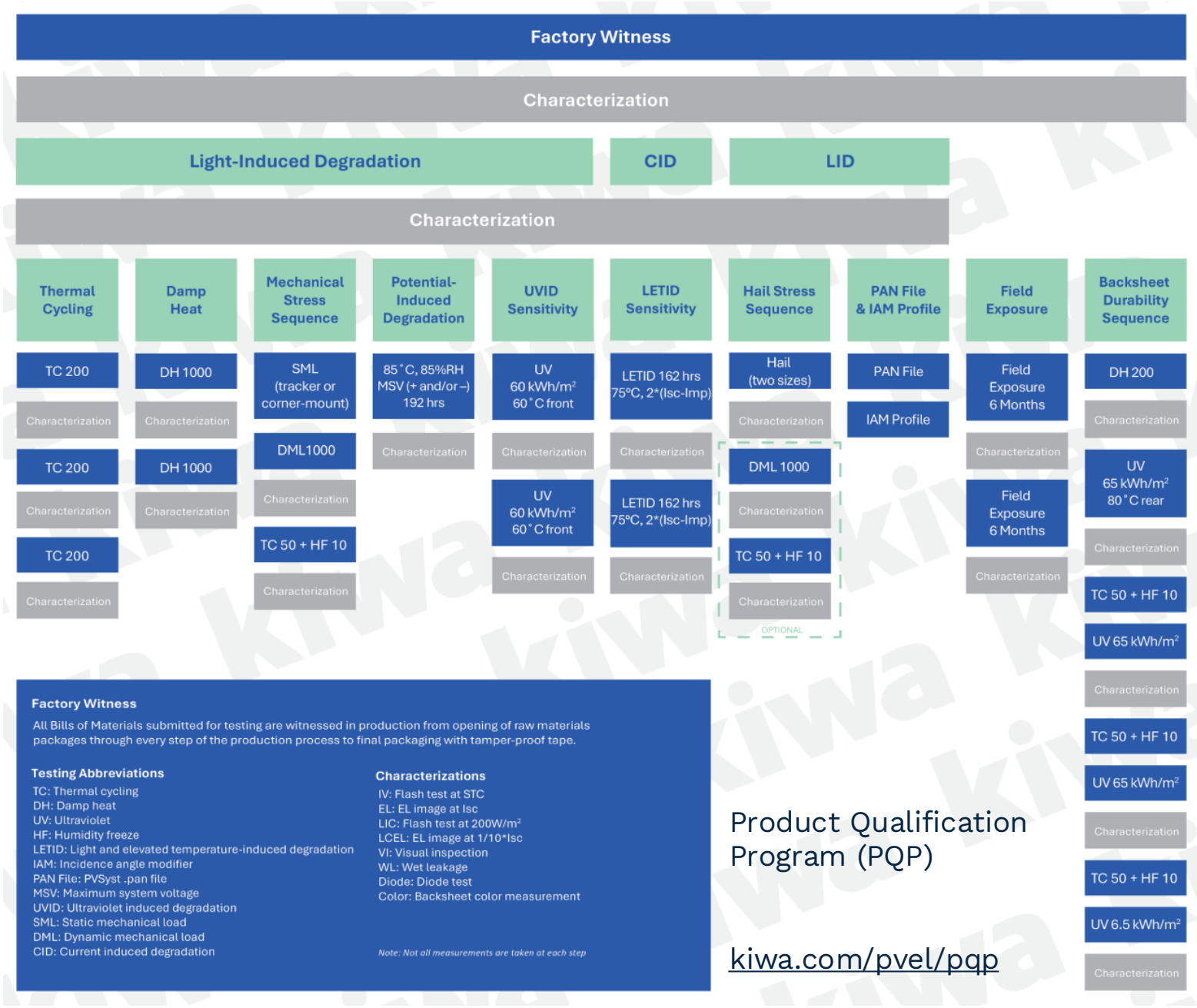
*creating trust, **driving progress***

Kiwa PVEL' PQP

- Independent lab for PV Module **Performance and Reliability Testing.**

- PQP evolves every two years based on feedback from downstream partners, module manufacturers, and the industry's collective understanding of module failure modes and test mechanisms.

- Test stress levels defined in PQP are beyond IEC.



Product Qualification Program (PQP)

kiwa.com/pvel/pqp

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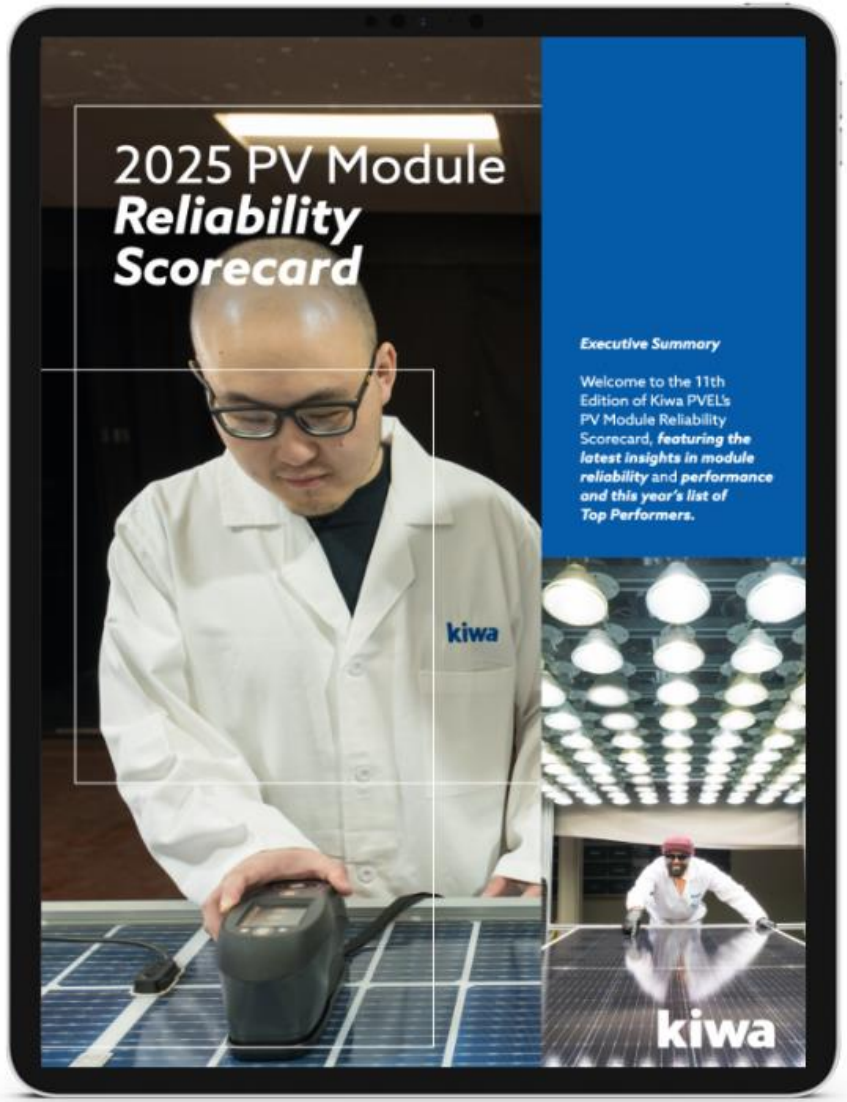
PV Module Reliability Scorecard

- Releases every year.
  - 11th edition released on June 4, 2025.

- Showcased a broad range of **Top Performer** manufacturers and module model types for their superior test results.

TOP PERFORMER 2025 kiwa PV MODULE RELIABILITY SCORECARD

Visit at *www.scorecard.pvel.com*



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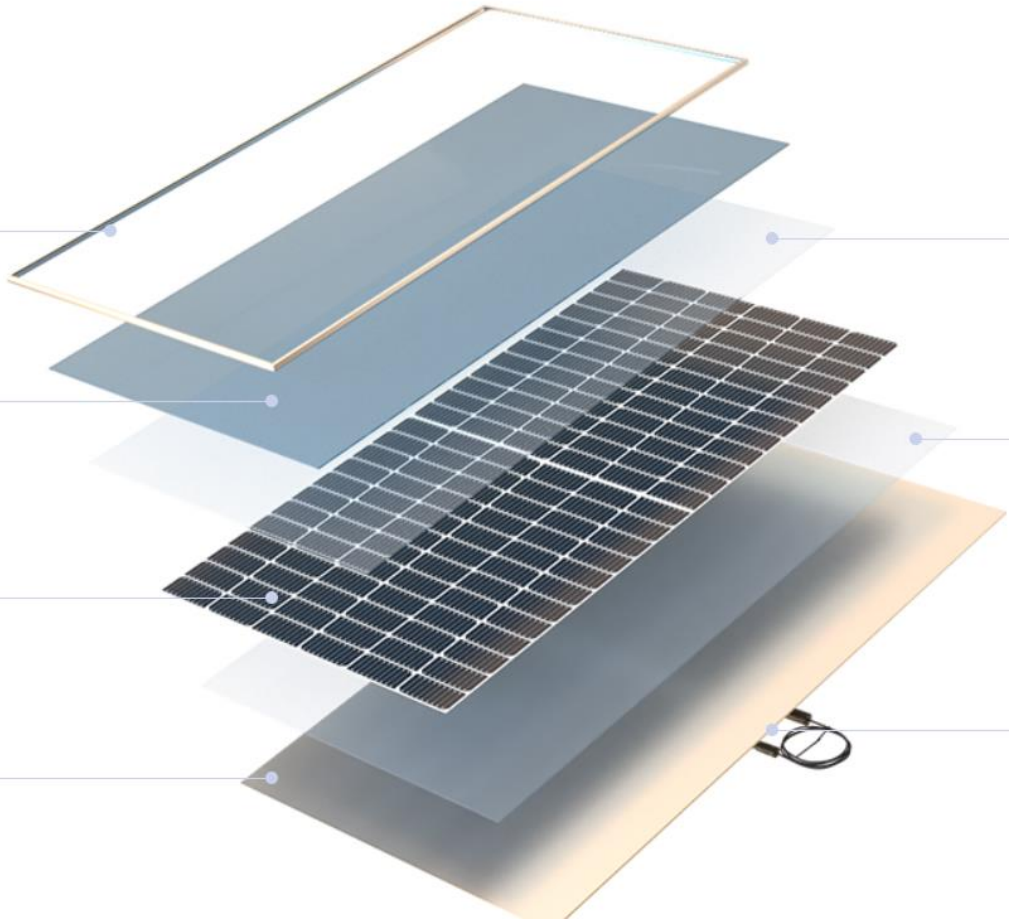
Bill of Materials (BOM)

Frame & Adhesives
***62 (frame)**, 25 (adhesives)*

Glass & Glass Coating
***19 (glass)**, 41 (glass coating)*

Solar Cell Layer
***52 (cell)**, 16 (interconnects), 33 (flux)*

Backsheet or Rear Glass
16 (backsheet)



Front Encapsulant
35 (encapsulant)

Rear Encapsulant
43 (encapsulant)

Junction Box & Adhesives
69 (JB), 20 (pottant), 46 (bypass diode), 21 (JB adhesive), 44 (connector)

***Manufacturers,** Model types

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‘Top Performer’ Status Criteria

- Top Performers are listed for **seven PQP test** categories.
- Modules must **NOT** have experienced
  - a wet leakage failure
  - a ‘major’ defect during visual inspection
  - a diode failure during that particular test

- TC, DH, MSS and PID must have **< 2% power degradation**.
- HSS must not have experienced glass breakage during hail testing using **40 mm hail or larger**.
- LID + LETID must have **< 1% power degradation** when combining the LID and LETID test results.
- PAN performance must place in the **top quartile** for energy yield in Kiwa PVEL’s PVsyst simulations.

- To be eligible for the 2025 Scorecard, manufacturers must have
  - Completed the PQP sample production **factory witness after Oct 1, 2023**.
  - Submitted at least two factory-witnessed PV module samples to all PQP reliability tests.

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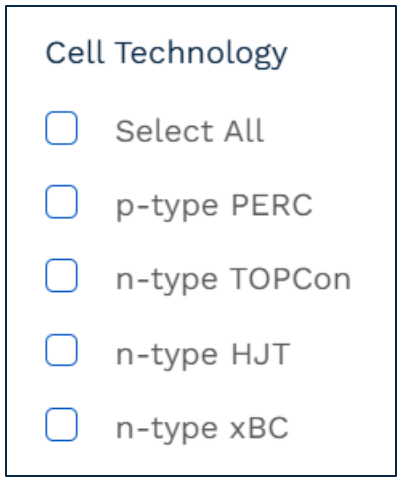
Top Performer Search Tool SnapShot



	MANUFACTURER	MODEL TYPE								MODULE DESIGN	CELL
Manufacturer Name +	JinKO Solar	JKMxxxN-66HL4M-BDV	✓	✓	1	40	✓	✓		bifacial - 2.0 glass//2.0 glass	n-typ
PQP Test +	JinKO Solar	JKMxxxN-72HL4-BDX	✓	✓	1	55	✓	✓		bifacial - 2.5 glass//2.5 glass	n-typ
Module Design +	ZNSHINESOLAR	ZXM7-UHLDD120-xxx/N	✓	✓	4	40	✓	✓		bifacial - 2.0 glass//2.0 glass	n-typ
Cell Technology +	ZNSHINESOLAR	ZXM7-UHLDD132-xxx/N	✓	✓	4	40	✓	✓		bifacial - 2.0 glass//2.0 glass	n-typ
Power Class Range +	ZNSHINESOLAR	ZXM7-UHLDD144-xxx/N	✓	✓	4	40	✓	✓	✓	bifacial - 2.0 glass//2.0 glass	n-typ
Wafer Size (mm) +	ZNSHINESOLAR	ZXM7-UHLDD144-xxx/N	✓	✓	4	40	✓	✓	✓	bifacial - 2.0 glass//2.0 glass	n-typ
Factory Location +	SERAPHIM 赛拉弗能源	SRP-xxx-BTC-BG	✓	✓	1	40	✓	✓		bifacial - 2.0 glass//2.0 glass	n-typ

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Key Takeaways

50 manufacturers included in the 2025 Scorecard as Top Performers. Nine of them have at least one model type listed as a Top Performer in each of the seven tests.

Only 21 module models achieved Top Performer status in all reliability tests (TC, DH, MSS, HSS, PID and LID+LETID). Of those, only three were Top Performers in those tests plus PAN performance.

PID and PAN results improved and MSS, HSS and LID+LETID power loss continues to be minimal. But TC and DH have worsened, and the module breakage rate for MSS and HSS has increased. UVID remains a source of concern for some BOMs, but has improved for others.

83% of module manufacturers and 59% of BOMs had at least one test failure, up from the 66% and 41% reported in the 2024 Scorecard, respectively.

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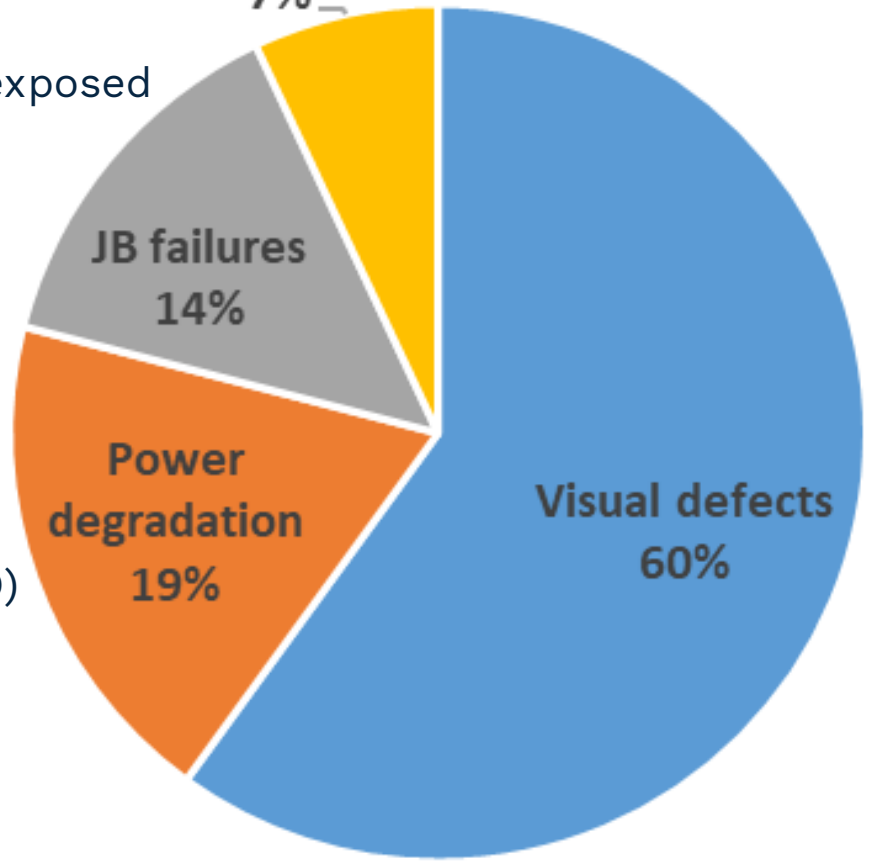
PQP Failures Statistics

Wet leakage electrical insulation (or safety) failure

JB covers falling off, loose cables/exposed wires, bypass diode failures, and melted/damaged connectors



UV-induced degradation (UVID), Potential induced degradation (PID)

Module breakage during mechanical stress and hail stress testing

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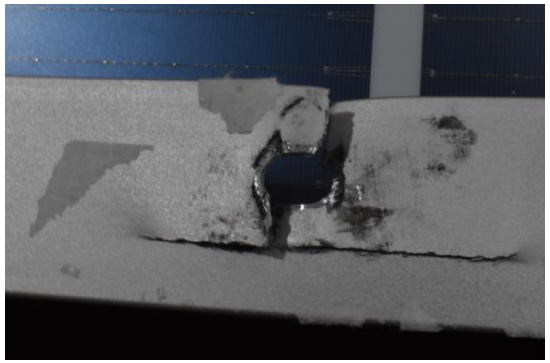
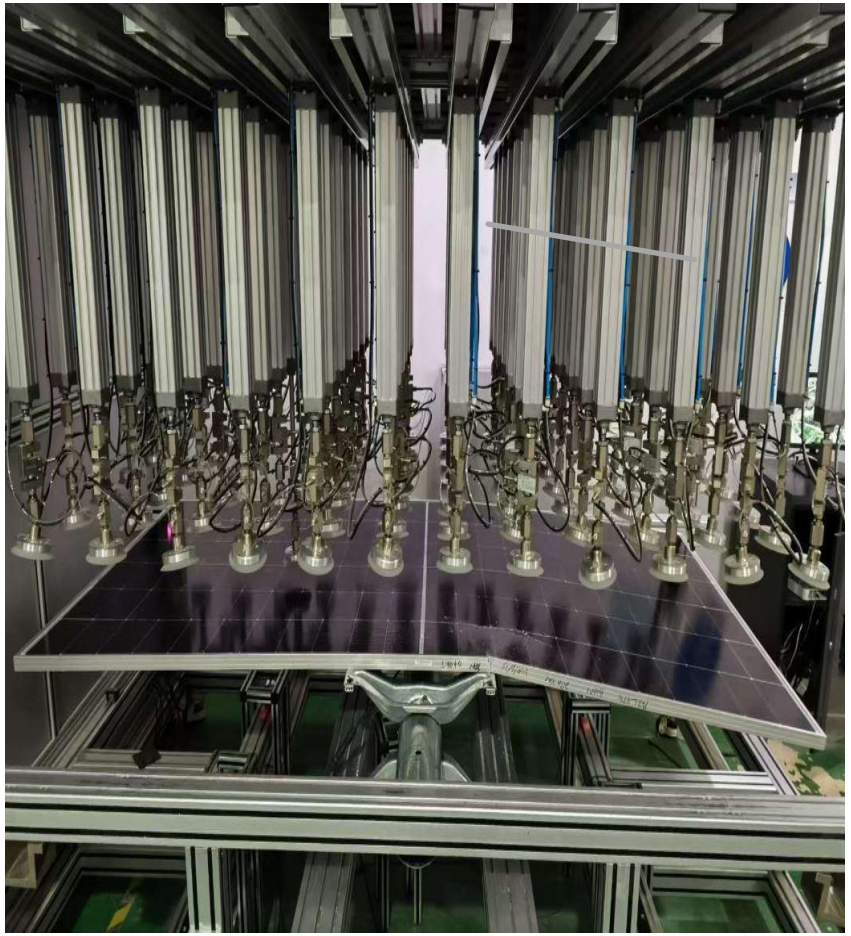
Failure Spotlights: Major Visual Defects

- Visual inspections identify issues that cause premature field failure.
- Major defects (delamination, corrosion, broken or cracked surfaces, etc.) as per IEC 61215 and IEC 61730 criteria.
- 20% of BOMs experienced one or more failures in MSS, increased from just 7% in the 2023 and 2024 Scorecards. **Most of these failures were due to glass breakage and/or frame damage,**



Frame deformation



Module frame and glass broke during DML testing, after being weakened during SML.

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Failure Spotlights: Major Visual Defects

- Visual inspections identify issues that cause premature field failure.
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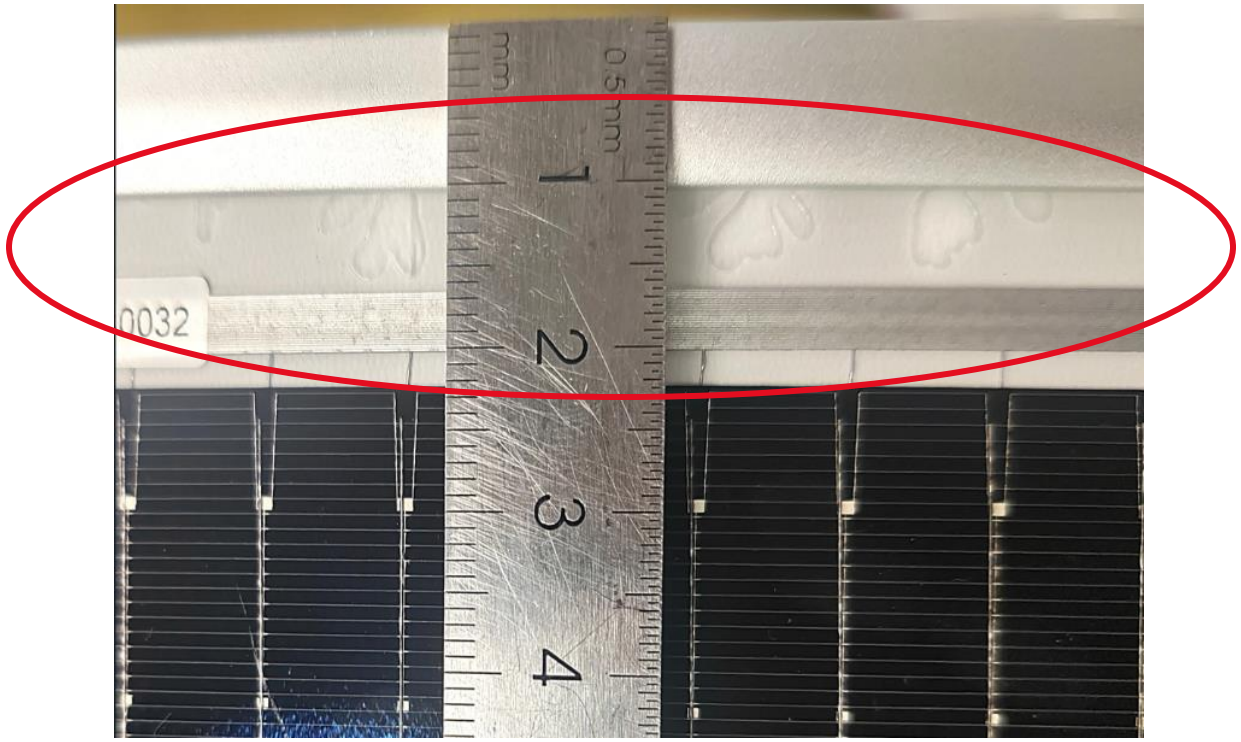
- 20% of BOMs experienced one or more failures in MSS, increased from just 7% in the 2023 and 2024 Scorecards. **Most of these failures were due to glass breakage and/or frame damage,**
- Bubbles formation causing delamination following TC and/or DH testing. They create a safety risk by forming a potential **electrical path from the module's current-carrying parts to the grounded frame**.



Bubbles can be seen between the frame and the ribbon (major defect)

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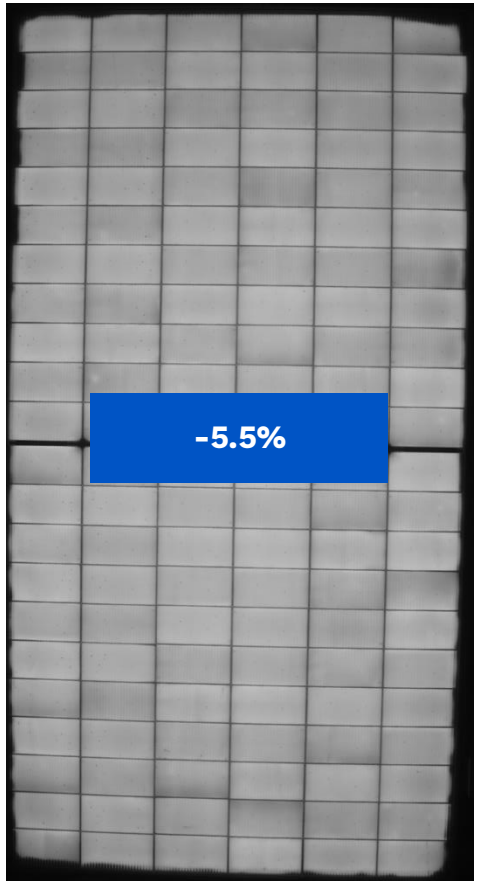
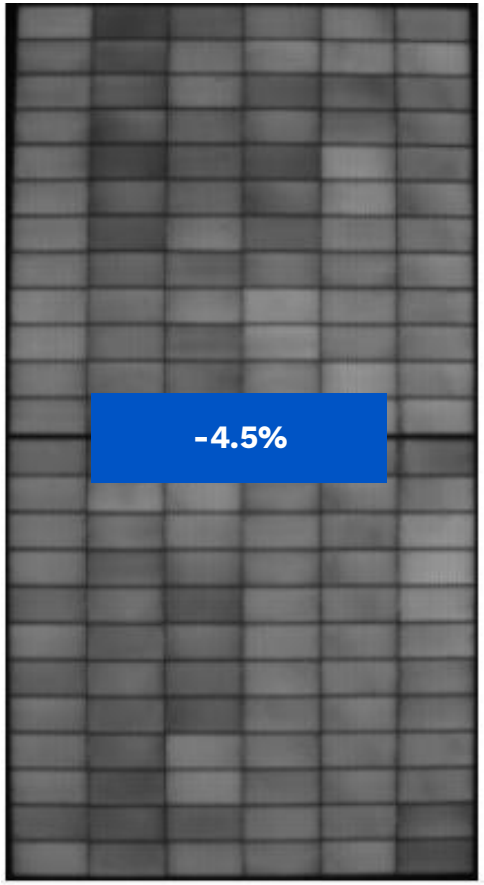
Failure Spotlights: Power Degradation

- Modules with power degradation failures may underperform in the field.
- PQP does not assign specific pass/fail thresholds for degradation, manufacturers may initiate a retest if power loss exceeds their or their customers' expectations.
  - Accounted BOMs that undergo a **retest due to power loss**.
- HJT module degraded 5.5% in DH2000 testing, triggering a retest request by the manufacturer. Linked to **potential corrosion** due to moisture entering G/G laminate along the perimeter and through JB holes.
- TOPCon module degraded to 4.5% following 120 kWh/m^2 of UV exposure (UVID testing). Likely attributed to **cell passivation loss**.



DH2000



UVID120

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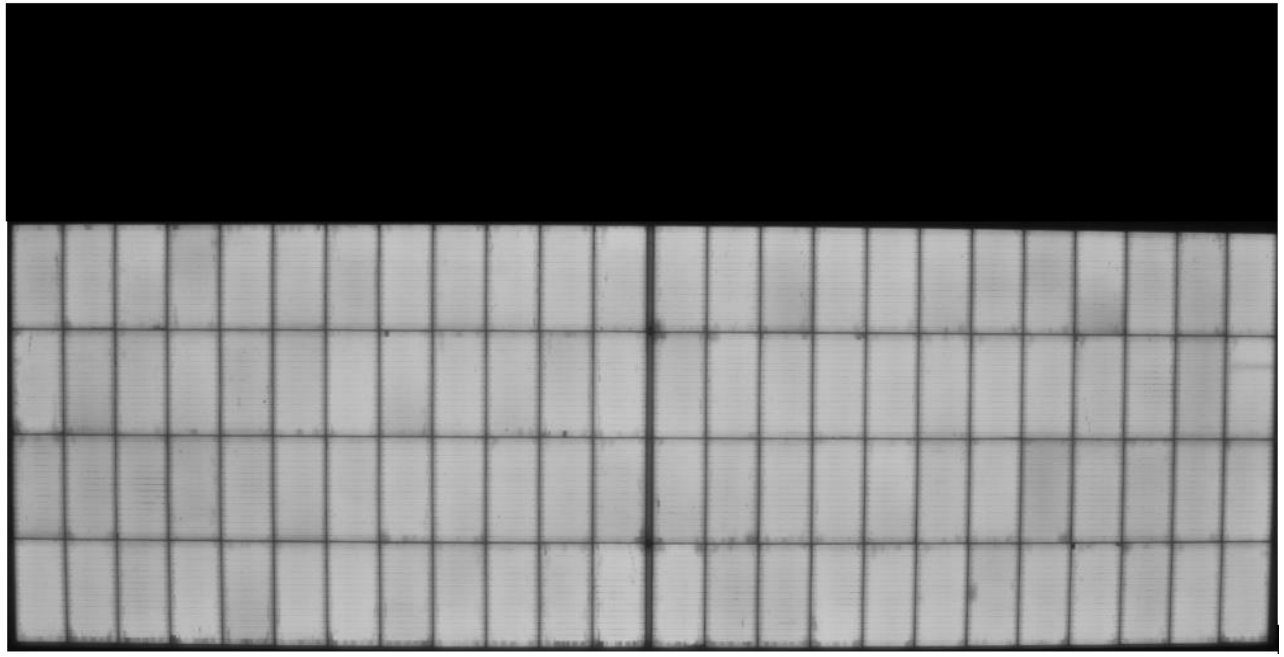
Failure Spotlights: Junction Box Failure

- Functionality of the module's bypass diodes evaluated after TC and MSS testing.
  - Accounted BOMs with non-functioning diodes in reverse and/or forward bias.
- Following TC600, this module had a **short-circuited bypass diode**, resulting in **33% power loss**.
  - This BOM passed the IEC duration TC200, but experienced catastrophic power loss following TC600.
- Two manufacturers had failing bypass diode.



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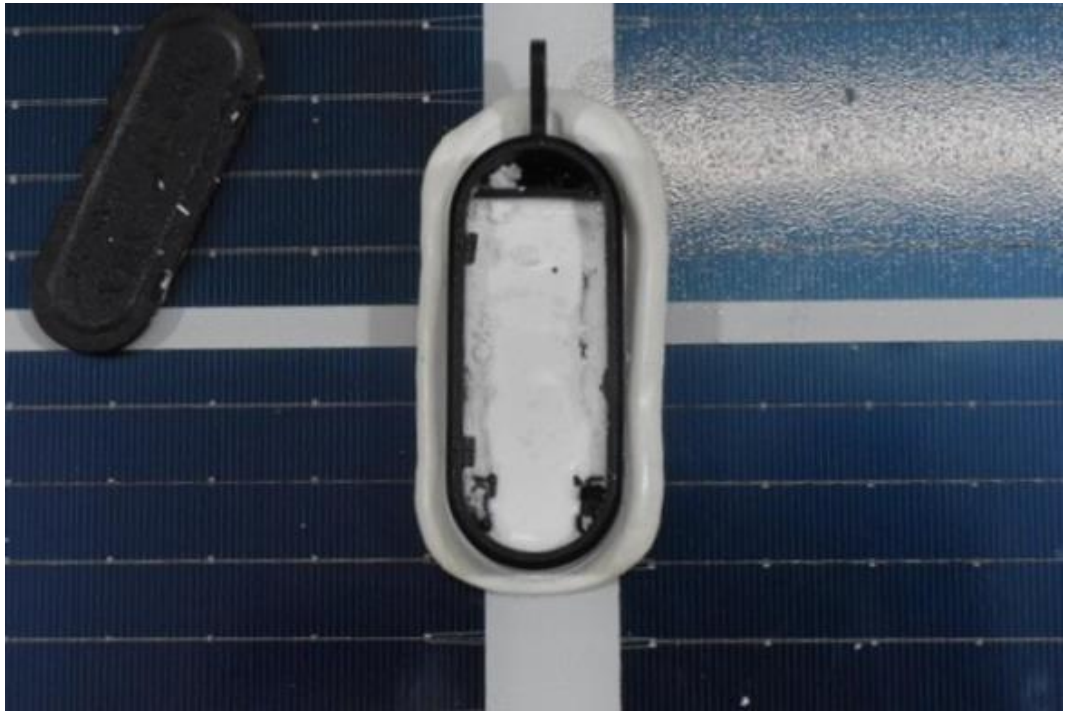
Failure Spotlights: Safety Failures

- Modules with safety failures may be hazardous to operate in the field.
- Module safe operation is determined via **wet leakage testing** using the IEC 61215 standard.
- This module failed wet leakage testing following TC200, meaning that it failed an IEC 61215 certification test.
  - **Improper curing of the pottant** inside the junction box, leading to exposed electrical circuitry.
- Detected at least seven BOMs from different manufacturers.



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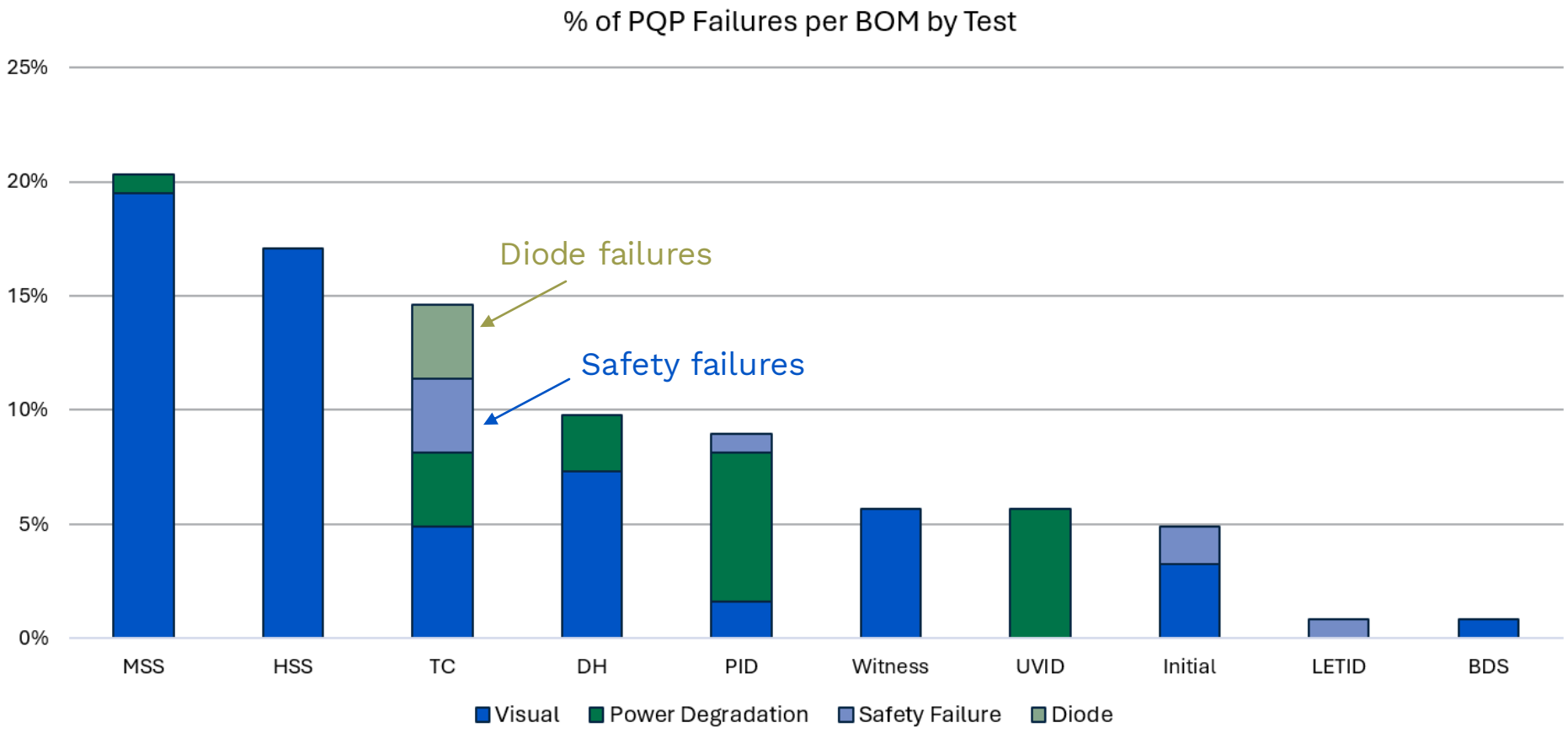
PQP Failure Statistics



Initial failures detected during characterizations prior to stress-testing.

Witness failures occurred when the manufacturer decided not to ship the modules following the PQP sample production factory witness due to a quality issue.

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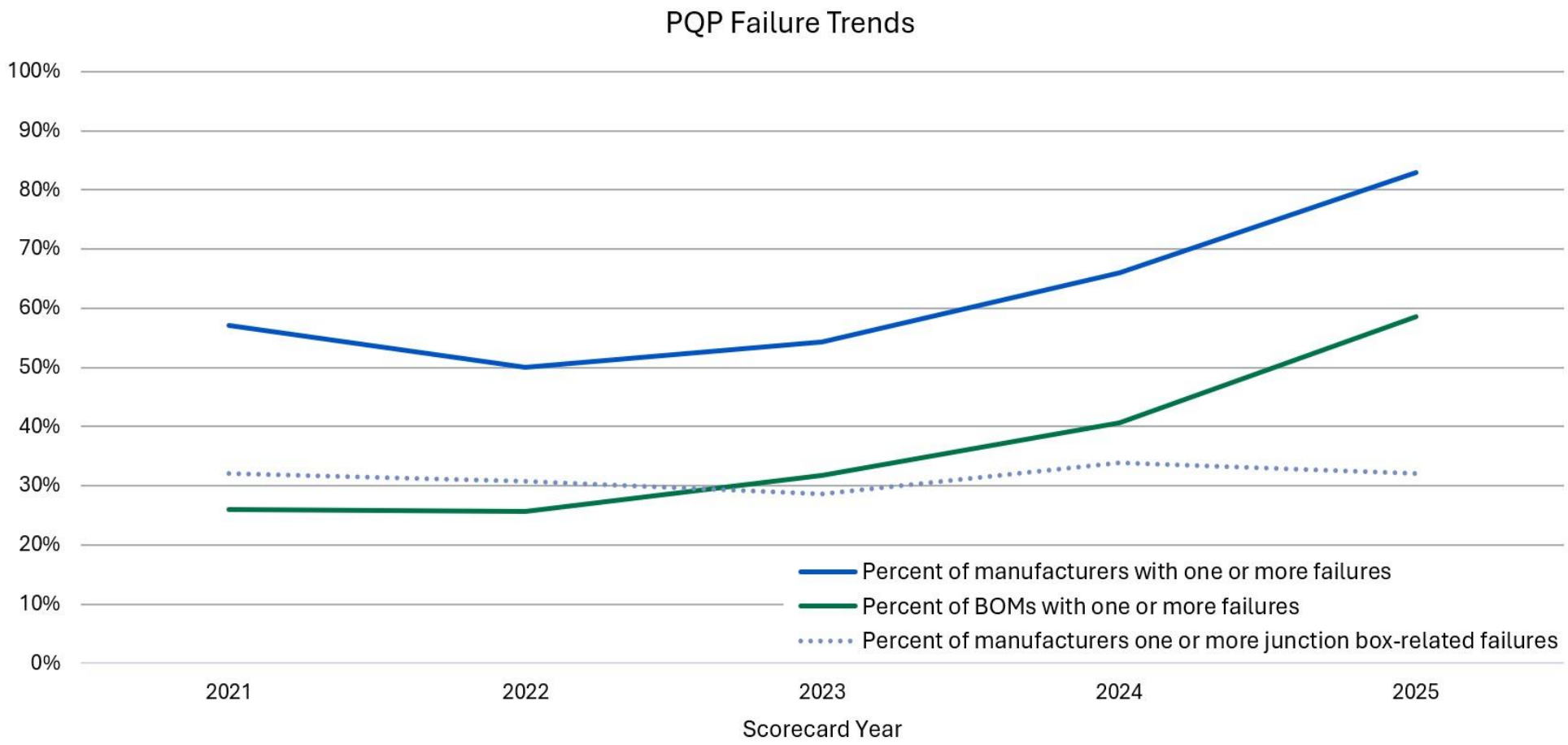
PQP Failure Statistics



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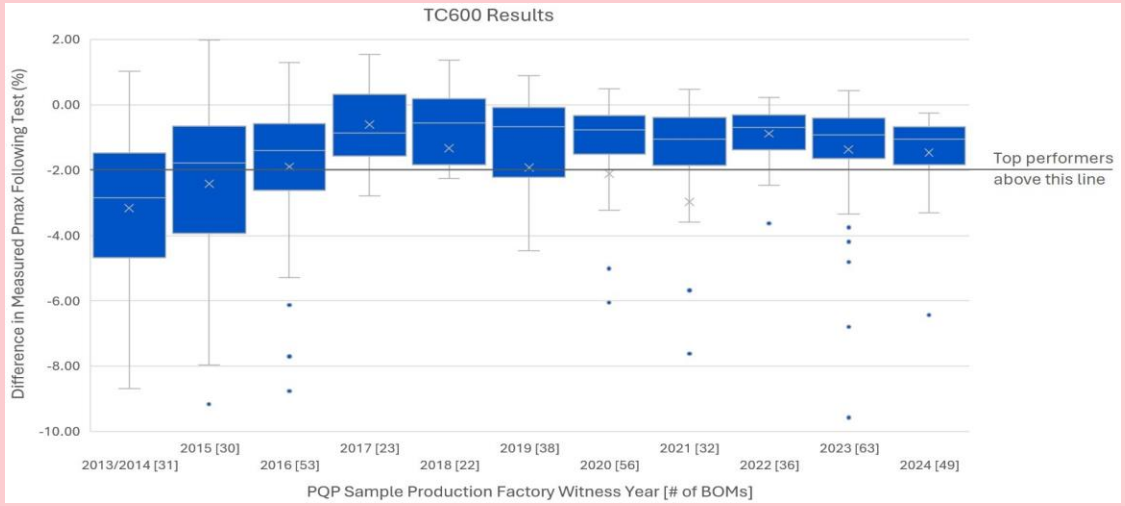
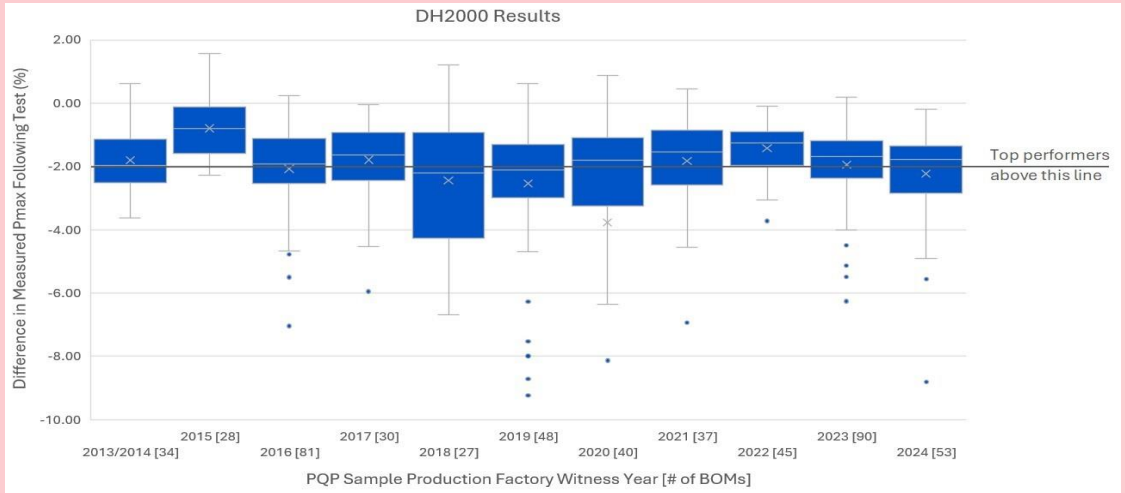
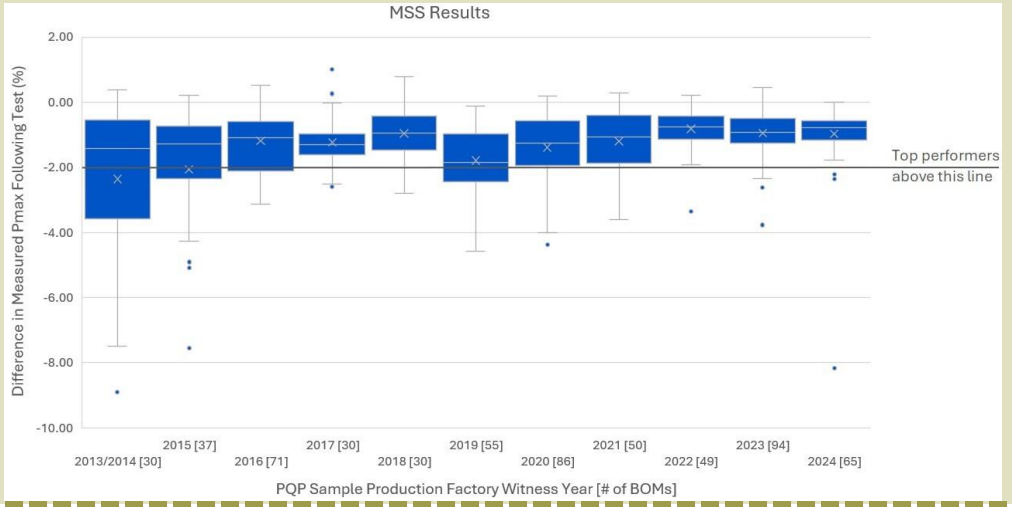
Performance Summary

Lower - TC, DH

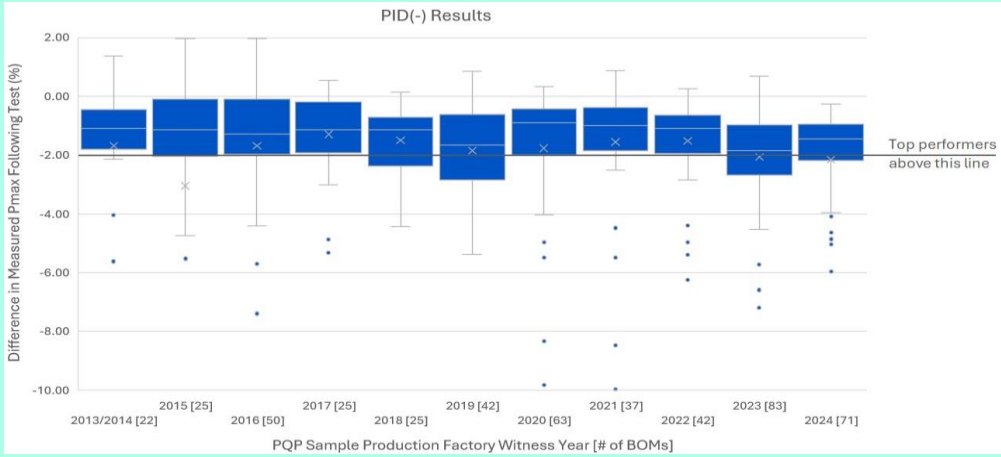




Minimal - MSS, HSS, LID+LETID



Improved - PID, PAN



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See more of the 2025 Scorecard including all Top Performers at www.scorecard.pvel.com

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