PV Module Quality Assurance Toolbox

PV ModuleTech 2026

Napa, California

Agenda

- Quality Over Time
- Defect Distribution
- **QA Toolbox**
  1. The Good News
  2. Creepage Distance Defects: How are we doing?
  3. Managing BOM Variations
  4. Collaboration In Action
- Toolbox Takeaways

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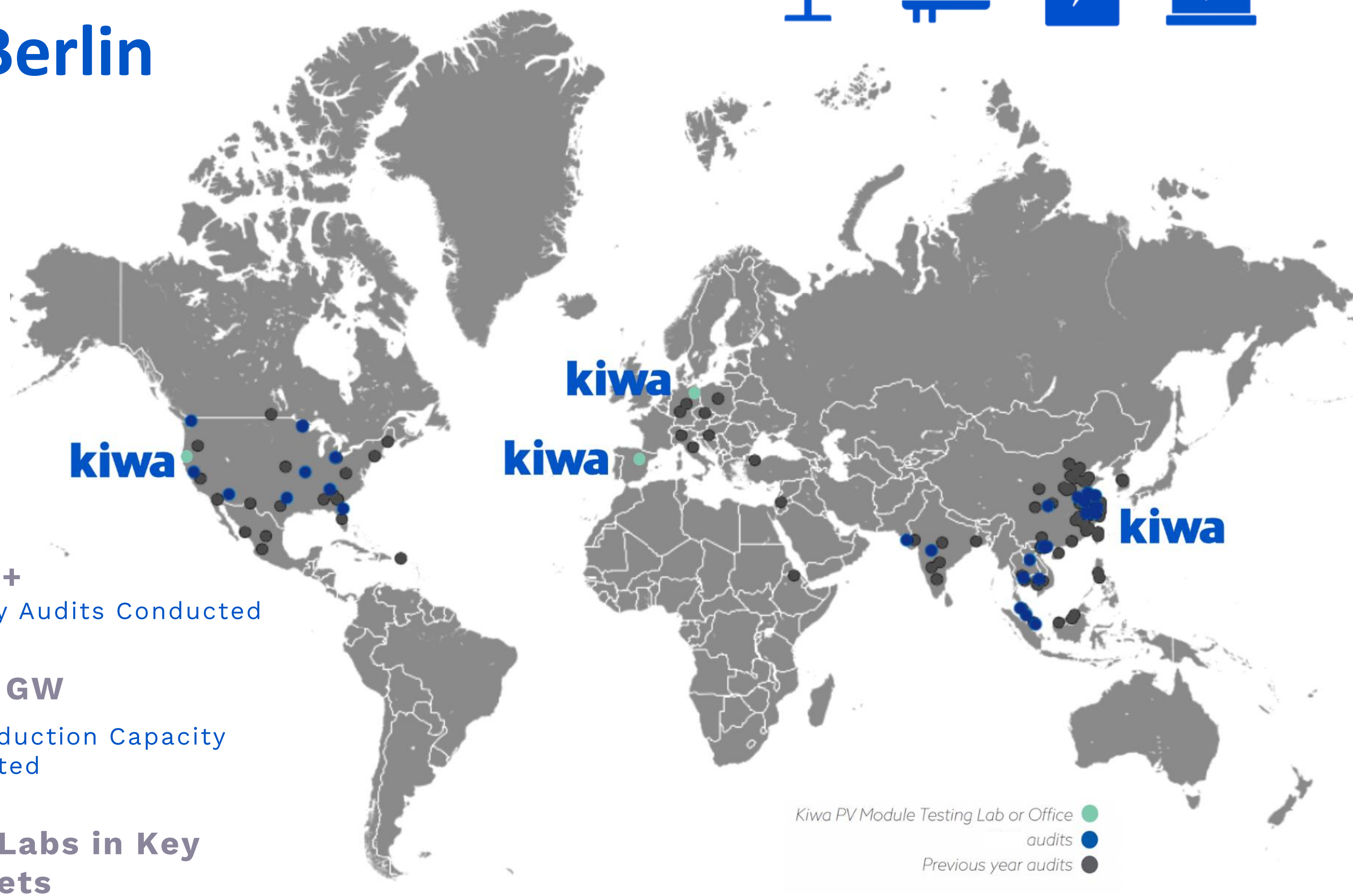
Kiwa PI Berlin



1,000+
Factory Audits Conducted

200+ GW

PV Production Capacity Evaluated

3 PV Labs in Key Markets

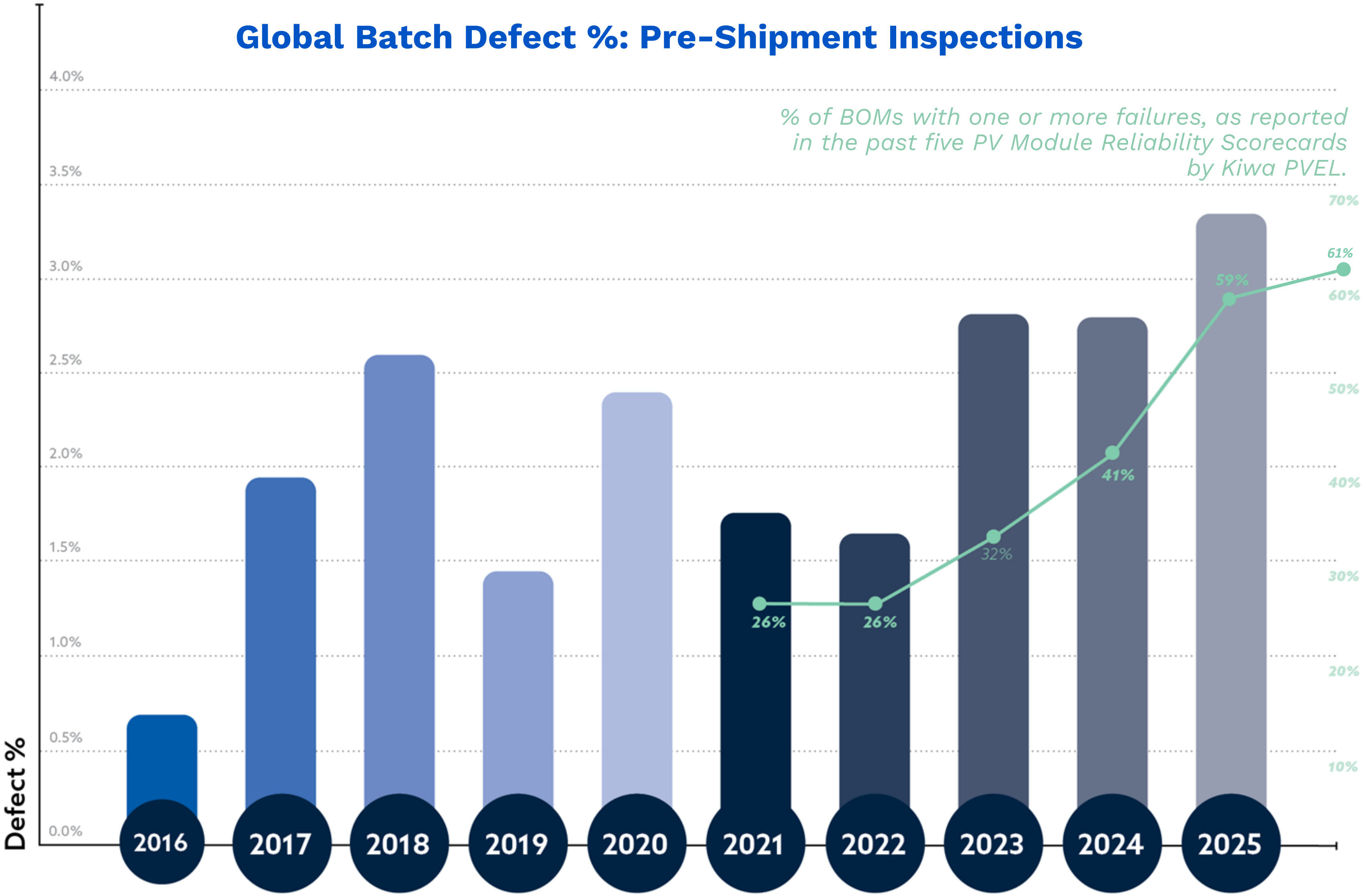
Berlin, Suzhou, California (Kiwa PVEL)

Quality Over Time

Kiwa PI Berlin's 10+ year database spans 125+ PV manufacturers, providing a benchmark for global module quality trends.

Key Point: Consolidated PSI data shows defect rates increasing across factories worldwide.

PQP testing reveals a parallel rise in BOM-related failures, reinforcing the upward defect trend observed in PSI inspections.



Defect Distribution

79.1%

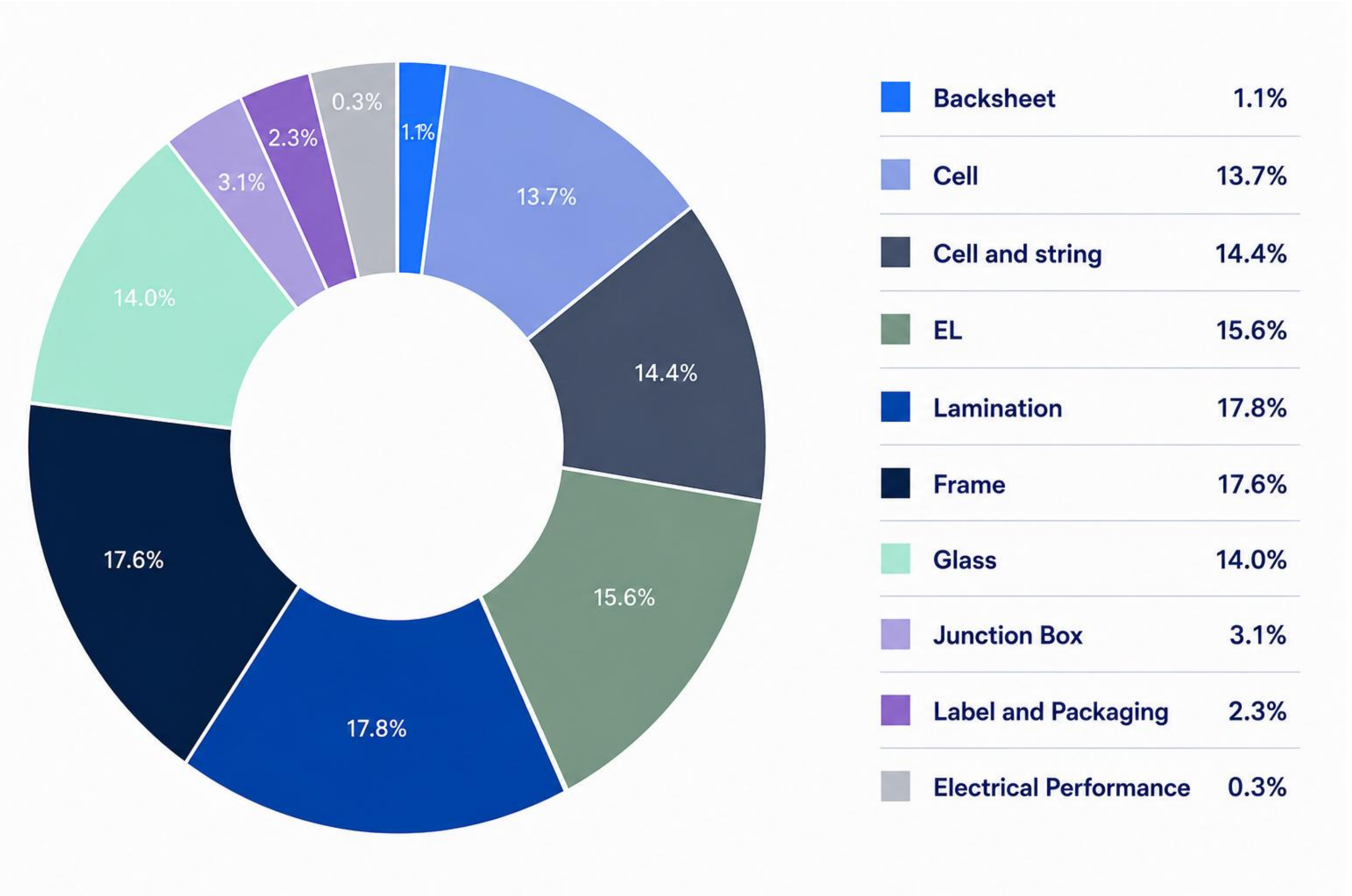
of all defects identified from five categories

TOP 5 CONTRIBUTORS		
1	Lamination	17.8%
2	Frame	17.6%
3	EL Findings	15.6%
4	Cell & String	14.4%
5	Cell Defects	13.7%

- Over the last year, **Kiwa PI Berlin performed PSI on nearly 160,000 PV modules** across 65 global manufacturing facilities.

- Inspections followed contractually agreed to criteria, with defects evaluated against AQL requirements.

- End-of-line data showed greatest defects came from lamination, cell/string interconnect, cells, frame, and glass-related issues.

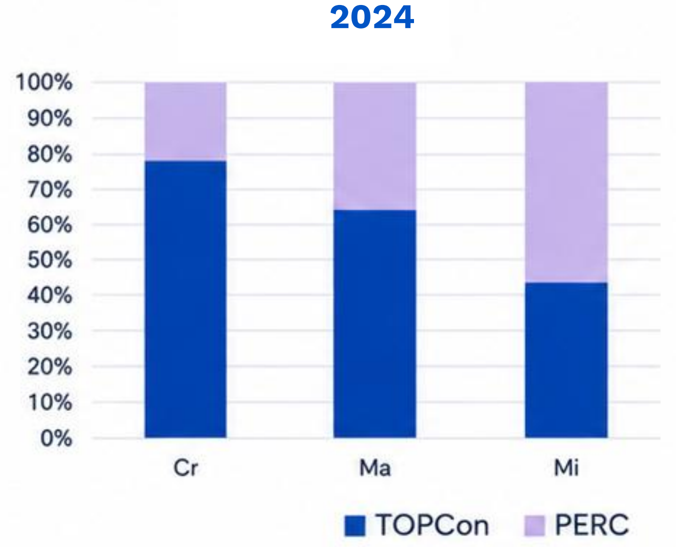


PSI Defect Distribution

Quality Assurance Toolbox

- The Good News
- Creepage Distance & Cell Spacing: How are we doing?
- Managing BOM Variations
- Collaboration In Action

The Good News: **Quality Improvements**

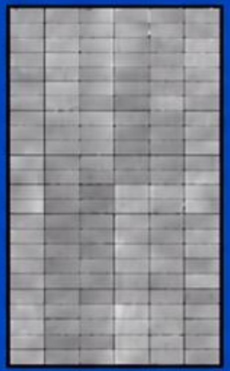


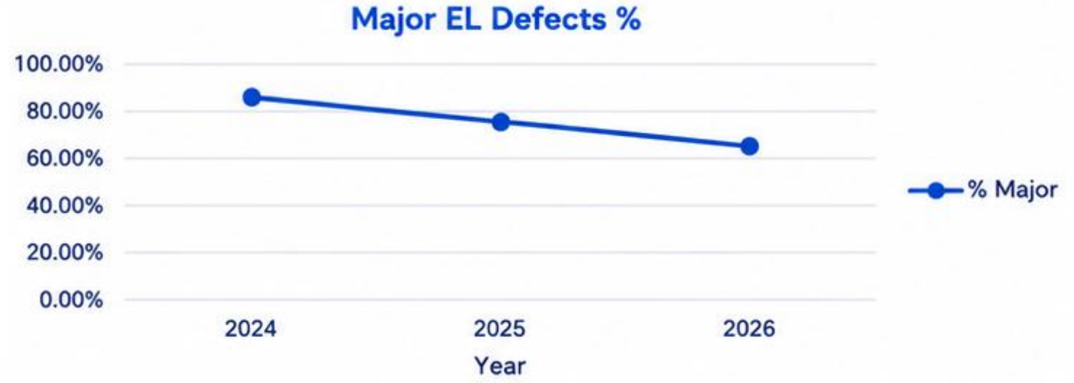
Another positive trend has been the reduction of **TOPCon-related findings** during production oversight compared with the prior year, when TOPCon showed higher **Major** and **Critical** defect rates versus **PERC**.

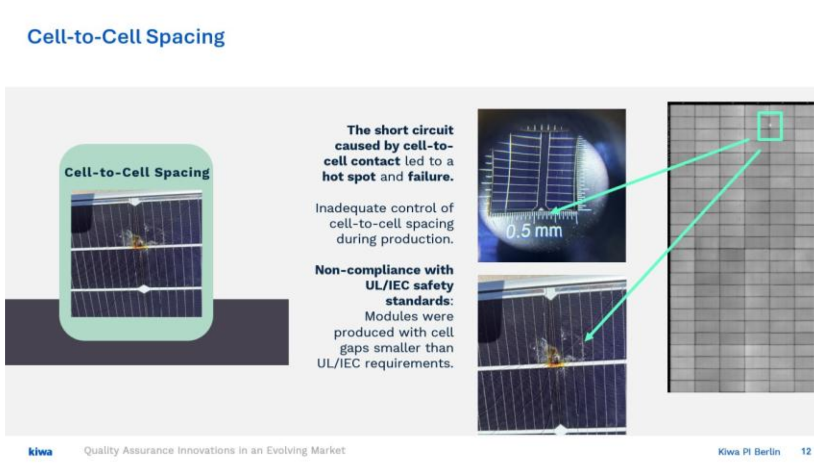
Findings have now leveled into a more balanced distribution between technologies, allowing buyers to apply similar QA coverage, quality requirements, and inspection plans without requiring heightened **TOPCon-specific** controls.

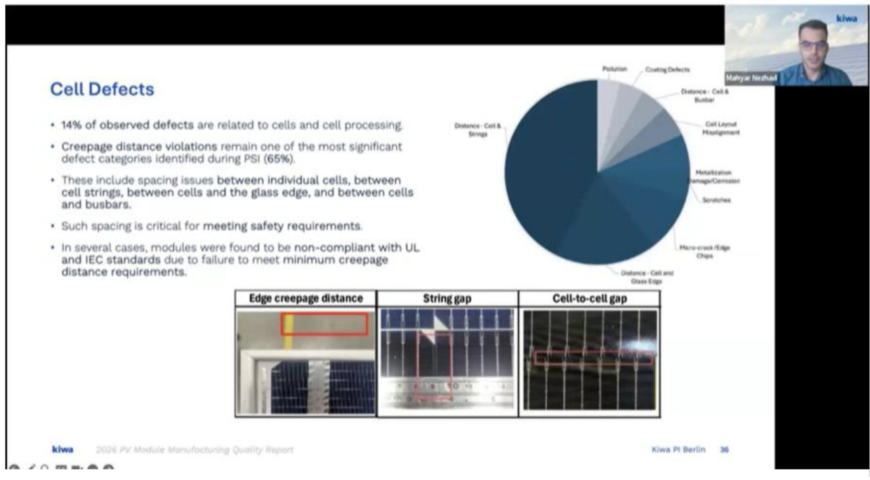
EL Defect Reductions Over Time

A positive trend in recent years has been the reduction of Major EL defects relative to total defects identified during global pre-shipment inspections.

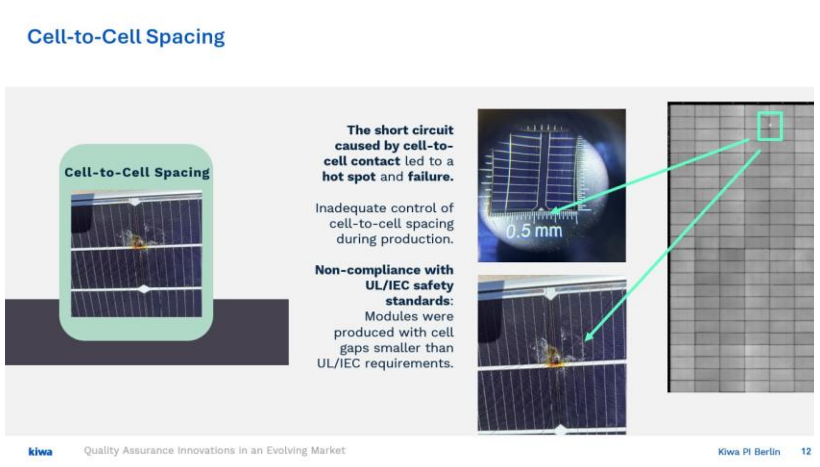


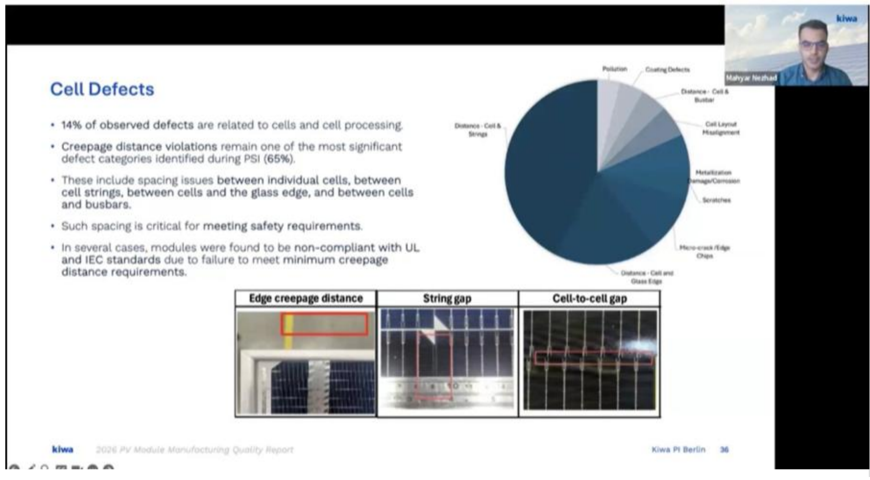






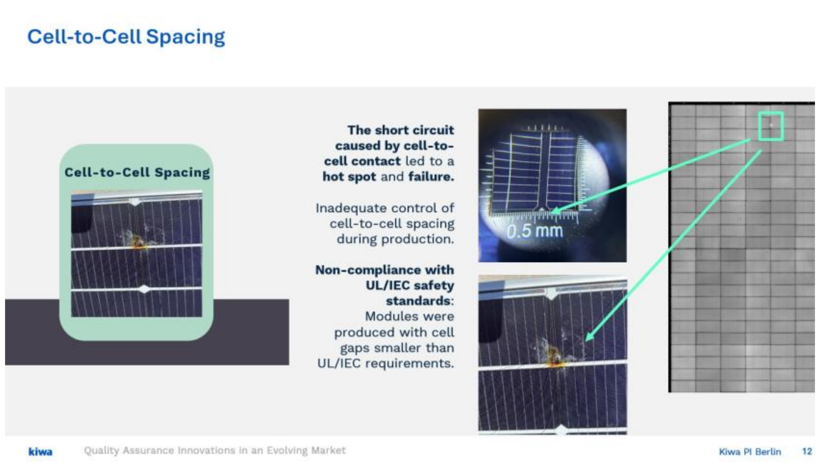
Creepage Distance Defects

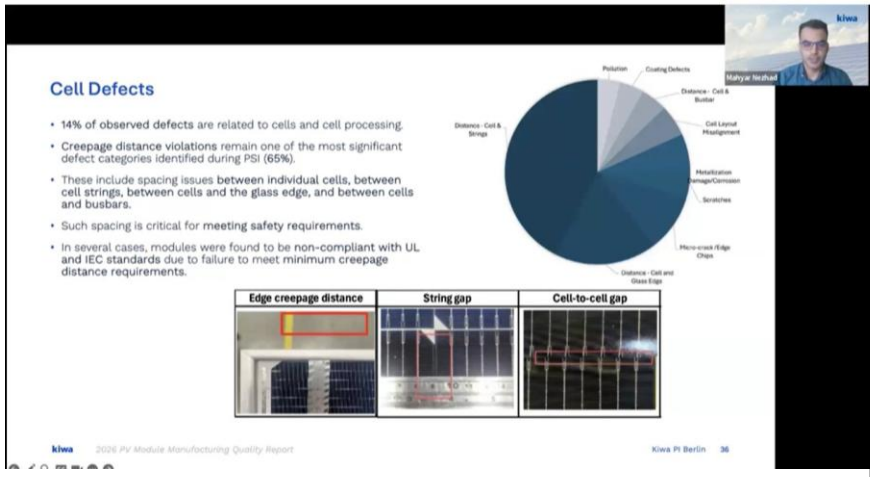




Creepage Distance Defects

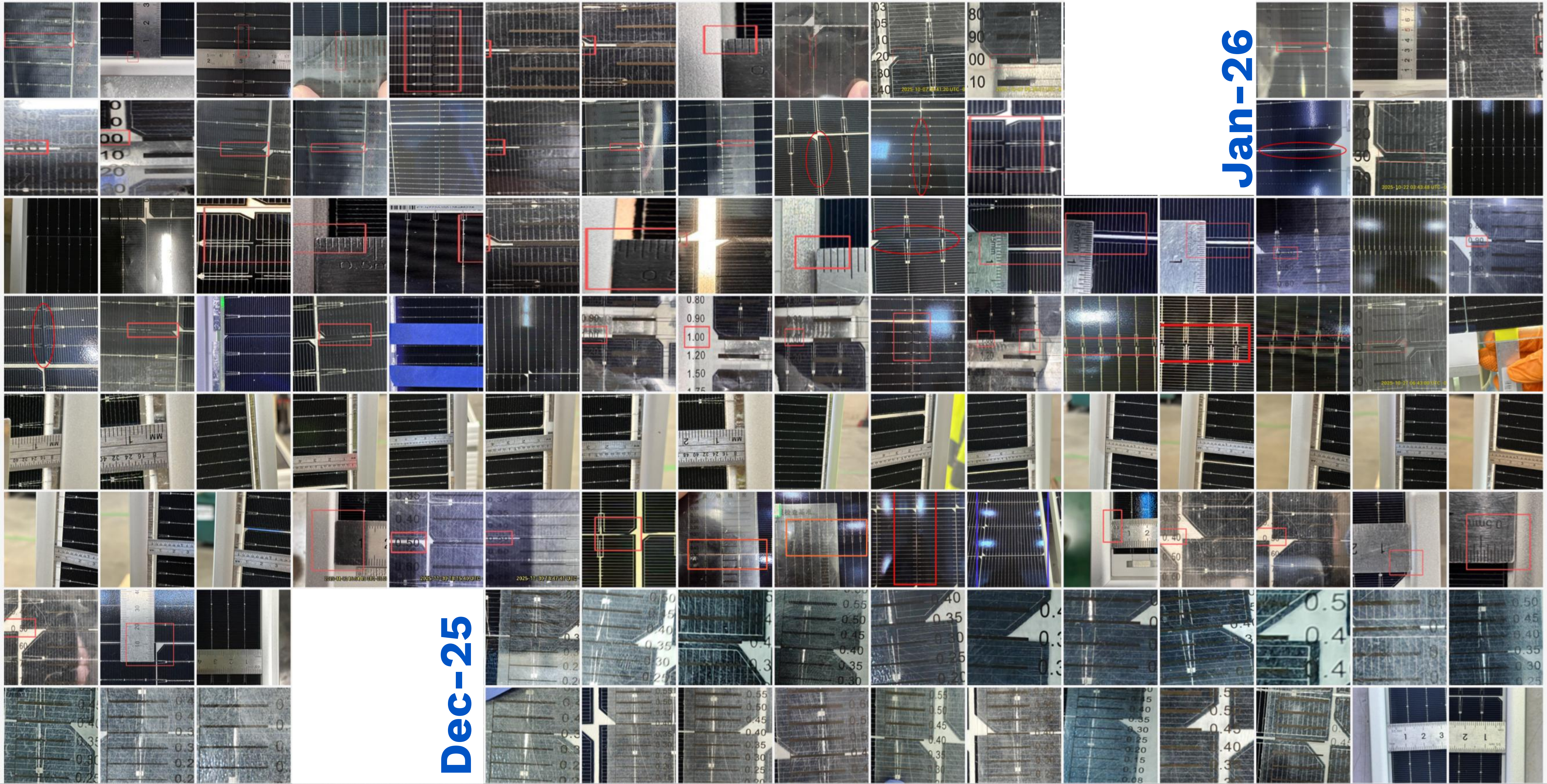
How are we doing?





Creepage Dist
Defects

Creepage **Distance** Defects



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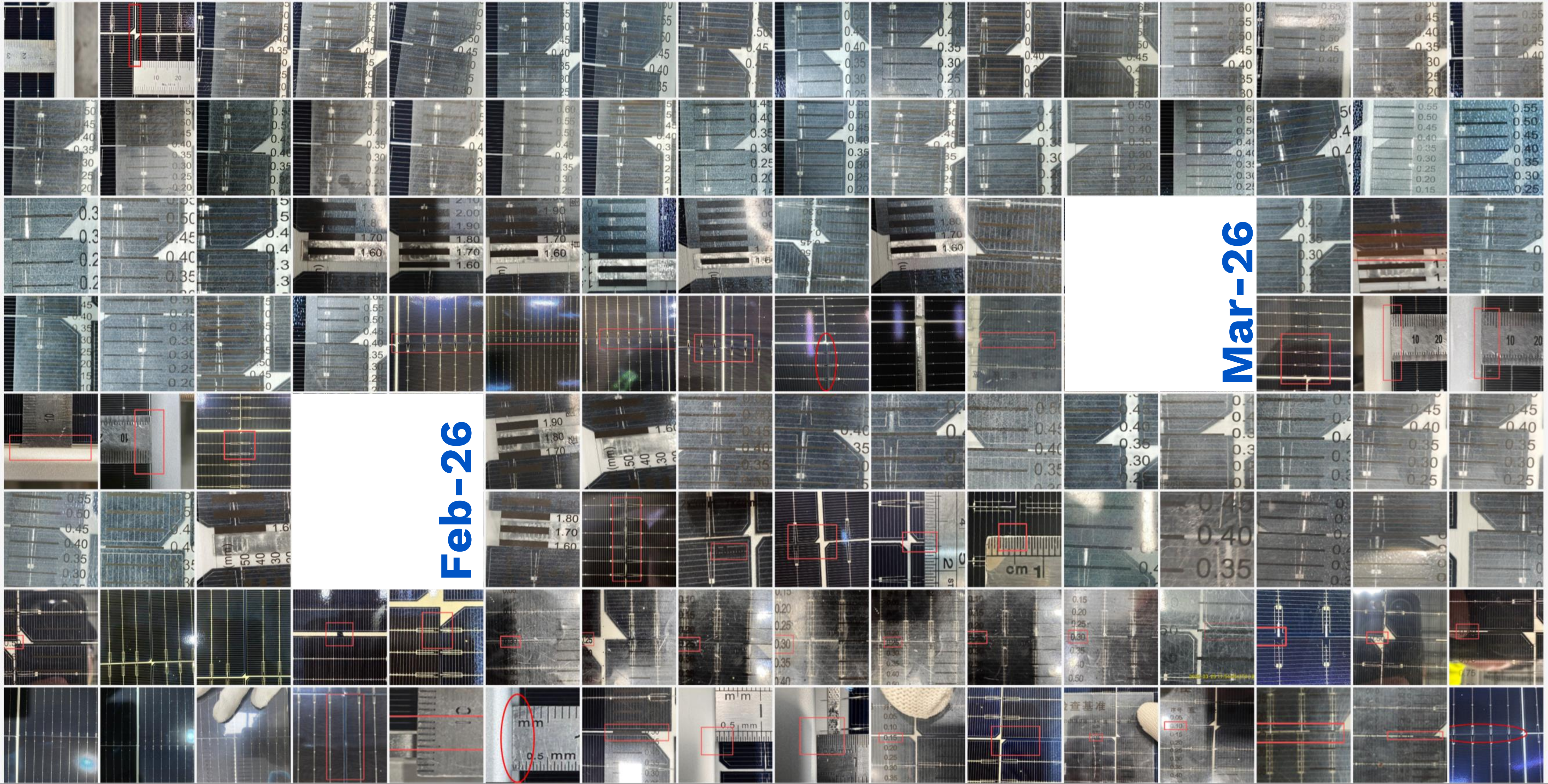
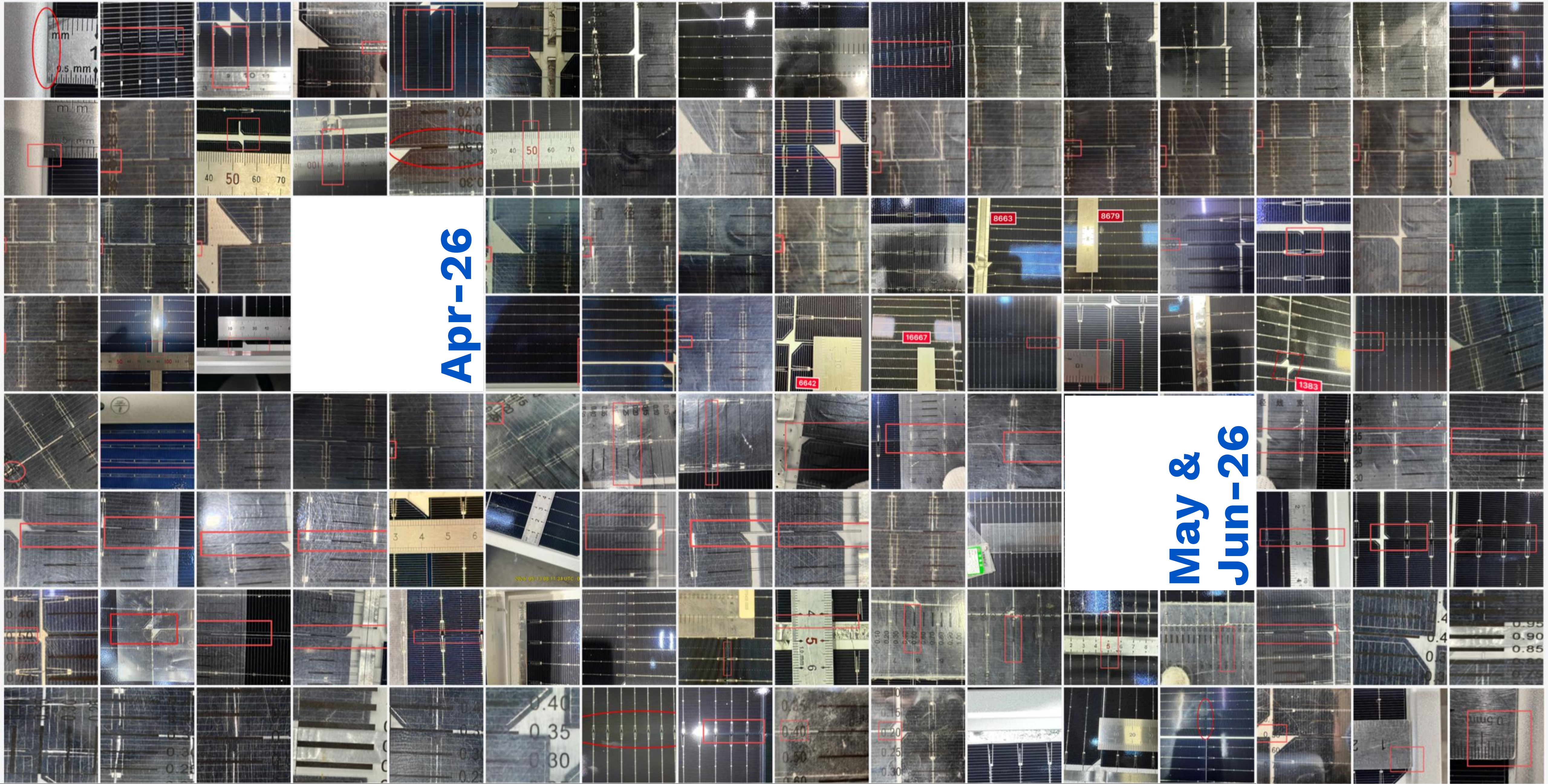
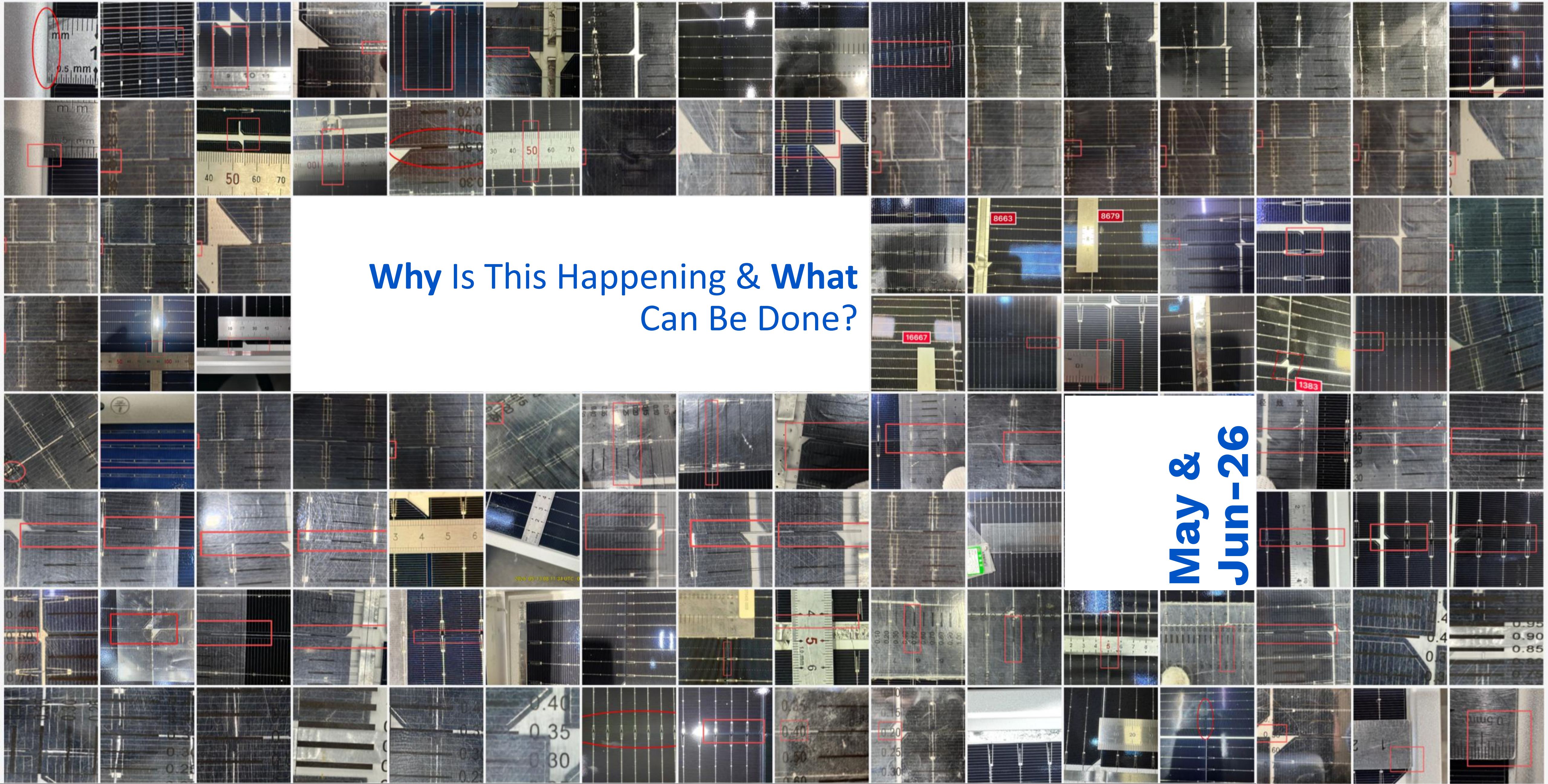


Creepage **Distance** Defects





Why Is This Happening & **What** Can Be Done?

May & Jun-26

Creepage Distance

Why is this Happening?

- With larger cells, manufacturers minimized inactive areas to maximize the efficiency.
- Tight spacing design without minimal tolerance allowances
- Equipment calibration often needs increased frequency
- Inadequate inspection criteria and screening- it ***can*** be identified in factory.
- *kiwa.com/2026pvmfrreport*

QA Toolbox Tools: **Inspection Criteria**

Managing Creepage Distance Risk Through Contractual & Inspection Controls

- Creepage distance findings are directly linked to **UL/IEC 61730 safety requirements**
- If classified as **Major** instead of **Critical**, limited occurrences may be allowable under PSI sampling criteria
- Inspection criteria and quality agreements should define these as non-conformances: including insufficient creepage distance and exposed conductive risk, as a **Critical defects** requiring escalation by the supplier, buyer, and quality assurance provider.

Distance between cell or any conductive material and glass edge*	**Non-conforming if:** • Distance (S) <8.4mm (1000V rated Module) • Distance (S) <10.4mm (1500V rated Module that is IEC or UL 61730 certified)	Critical

Generally, distance between cell or any conductive material and the glass edge is difficult to measure in a finished Module with an assembled frame.

When conducting inspection of the creepage distance in this case, the distance can be calculated based on the frame groove depth, frame wall thickness, sealant thickness, distance between frame inner side and conductive parts.

If there is any doubt or ambiguity, the frame can be removed to measure the actual creepage distance.

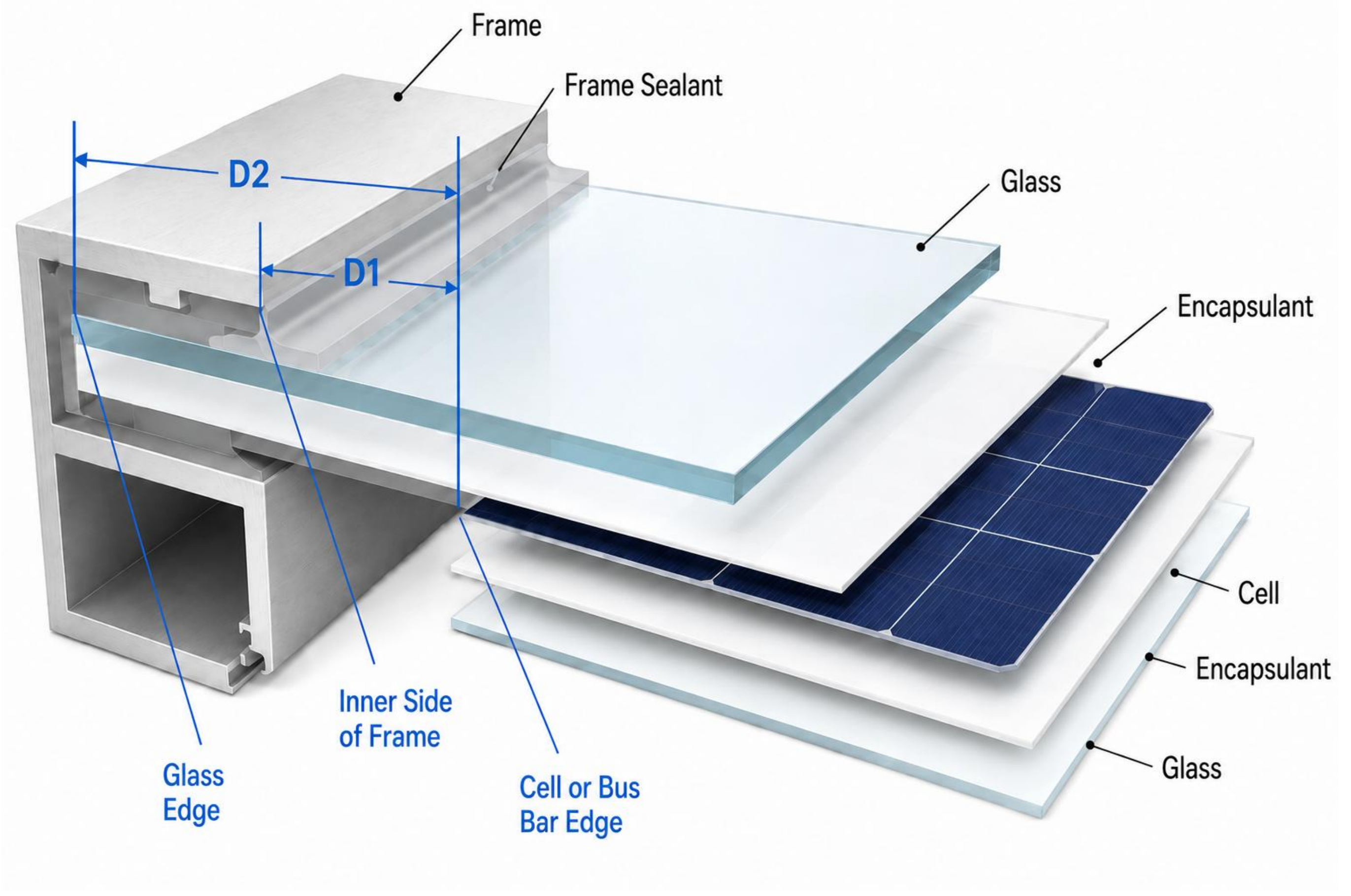
QA Toolbox Tools: **Pre-Production Factory Audits**

Identifying Higher Creepage Distance Risk Through Factory Audit Observations:

Case Study:

- During a pre-production audit, the auditor identified a potential safety risk related to tight spacing tolerances.
- The inspection standard requires **D1**, measured from the cell/busbar edge to the inner frame, to be **>1 mm**.
- With a measured frame groove depth of **9.4 mm**, any inconsistent glass alignment or sealant application could reduce the effective distance from internal live parts to the glass edge.
- As a result, the effective creepage distance may fall below the **10.4 mm minimum requirement under UL 61730**, creating a potential safety compliance risk.

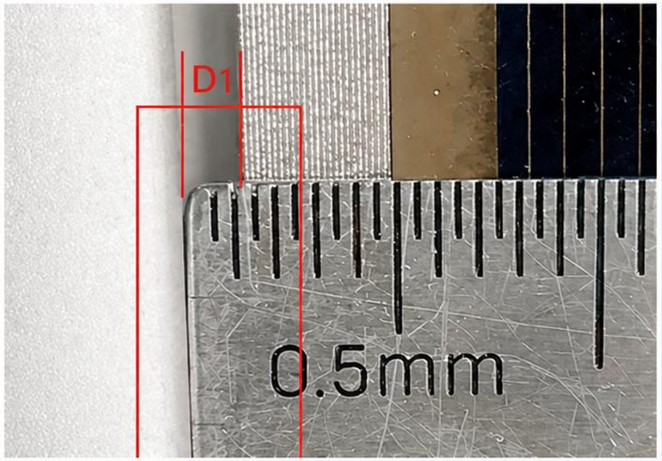
PV Module Cross Section and Key Creepage Distances



QA Toolbox Tools: **Active Production**

Mitigating Risk During Active Production via Pre-Shipment Inspections:

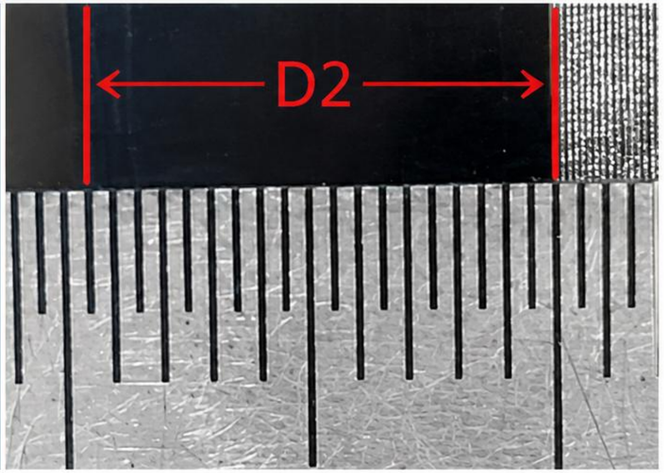
- During the first Pre-shipment Inspection batch #1: Two Major Defects were reported for: “Distance from the cell to the inner side of the frame ≤1 mm, not allowed.”
- Due to the Audit Finding, further investigated and removed the frame to directly measure the creepage distance
- Found to be nonconforming to the UL 61730 creepage requirement, measuring less than 10.4 mm.
- **This resulted in upgrading defect from Major to Critical, resulting in PSI Batch 1 failure.**



Major Defect –
Glass to Cell Edge ≤ 1mm

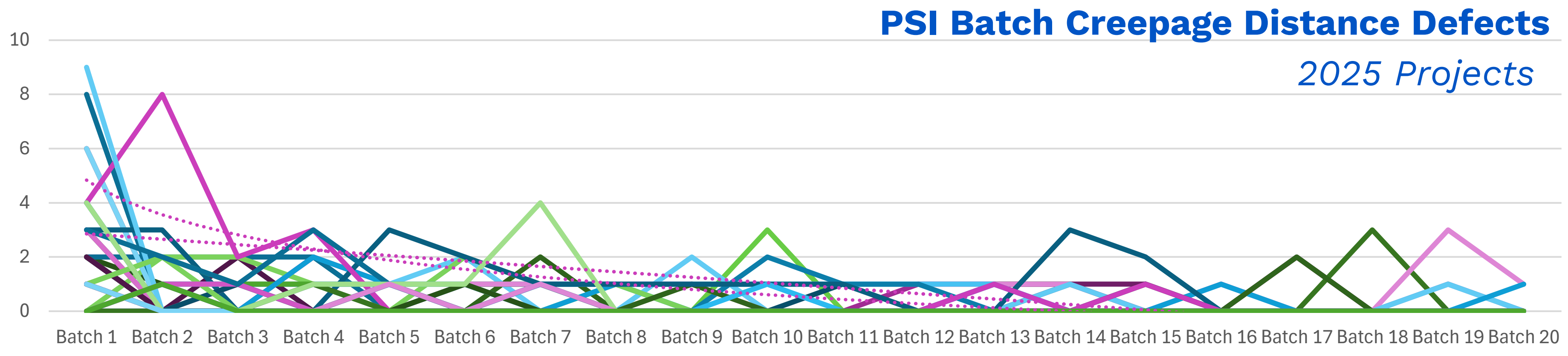
Follow Up Investigation
After Frame Removal:

Critical – Distance Glass Edge to Cell Edge < 10.4mm



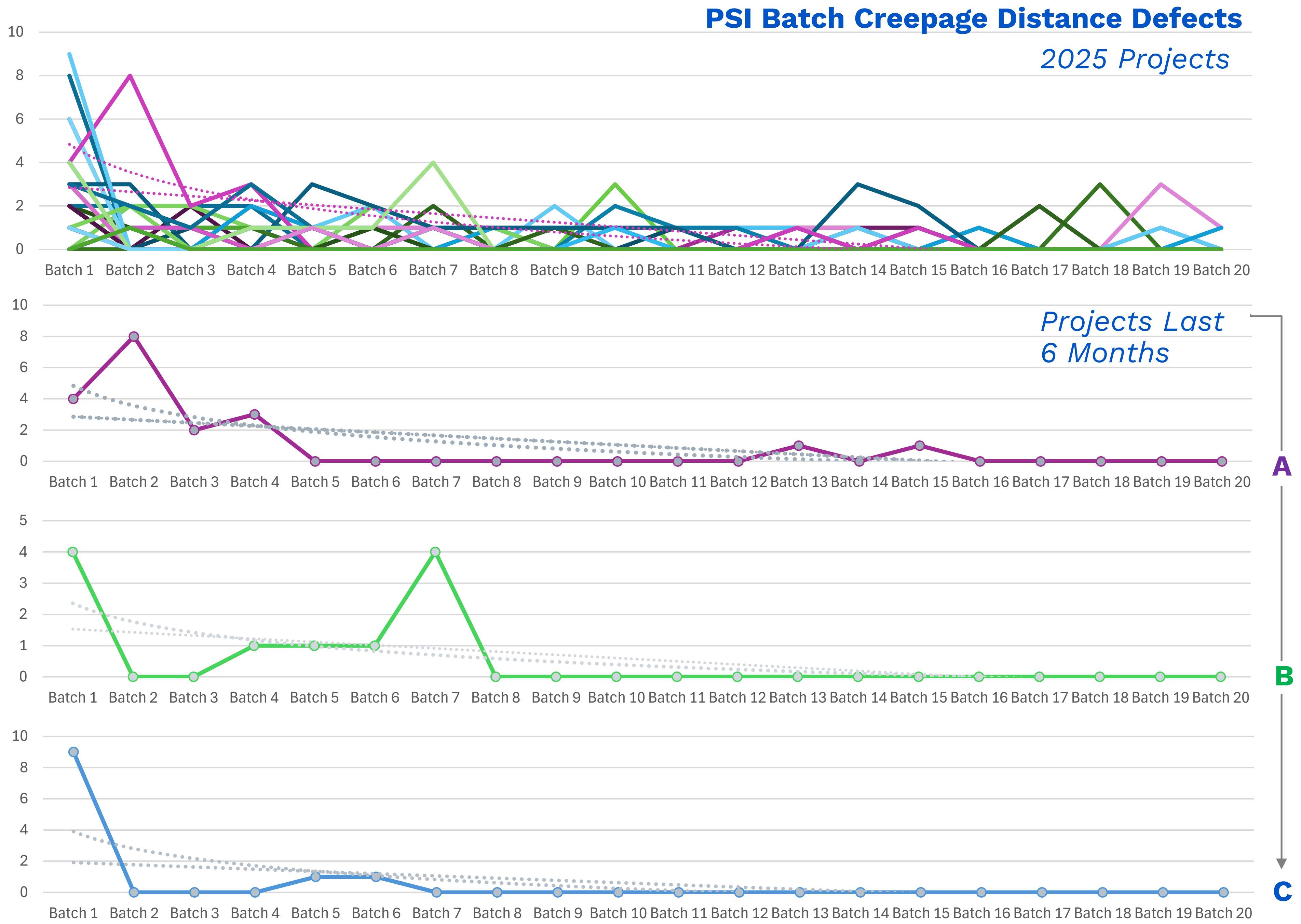
PSI Batch **Results**

- Mitigation effectiveness is tracked and evaluated across production batches
- Previous-year projects showed higher recurrence of creepage distance defects



Toolbox Takeaways

- Mitigation effectiveness is tracked and evaluated across production batches
- Previous-year projects showed higher recurrence of creepage distance defects
- Increased inspection focus and targeted controls have **helped identify defects earlier and reduce recurrence** in recent projects



Managing BOM Variations

Evolving supply chains, domestic content requirements, and mixed sourcing strategies are increasing variation in cell supply and key BOM materials.

As BOM materials change before or during production, electrical performance must be evaluated beyond **Pmax** alone, including parameters such as **Voc, Isc, Vmp, and Imp**.

Even when modules remain within specification, material variation can shift electrical parameters and create downstream challenges for project design, EPC installation, and field commissioning.

Component	
Key materials	**Additional materials**
Cells	Cell ribbons
Glass (superstrate)	Cell soldering flux
Encapsulant (front of cells)	String ribbons
Encapsulant (behind cells)	Frame
Glass (substrate)	Frame adhesive
Junction box	**Silicon materials**
Junction box pottant	Quartzite
Junction box adhesive	Metallurgical grade silicon (MGS)
Bypass diodes	Polysilicon
Cables	Silicon ingots
Connectors	Silicon wafers

BOM material sourcing strategies continue to evolve in response to customer requirements, buyer procurement priorities, and efforts to maximize financial incentives. This includes changes to both finished module components and upstream materials, such as polysilicon supply.

Managing BOM Variations
Electrical Properties

Key Properties & Moving Further than Pmax

Pmax has historically been the primary metric for performance tracking and quality control.

Modern projects require tighter tolerances for electrical parameters to ensure accurate system design, affecting string sizing and overall layout.

Electrical Properties

Testing Condition	Front Side	Front Side	Front Side	Front Side	Front Side
Peak Power (Pmax) (W)	370	375	380	385	390
MPP Voltage (Vmp) (V)	34.5	34.7	34.9	35.1	35.3
MPP Current (Imp) (A)	10.73	10.81	10.89	10.97	11.05
Open Circuit Voltage (Voc) (V)	41.4	41.6	41.8	42.0	42.2
Short Circuit Current (Isc) (A)	11.36	11.45	11.54	11.62	11.69
Module Efficiency (%)	19.95	20.22	20.49	20.76	21.03

*STC: Irradiance 1000 W/m², Cell Temperature 25°C, AM1.5
The data above is for reference only and the actual data is in accordance with the pratical testing
Power Measurement Tolerance ±3%

Pmax

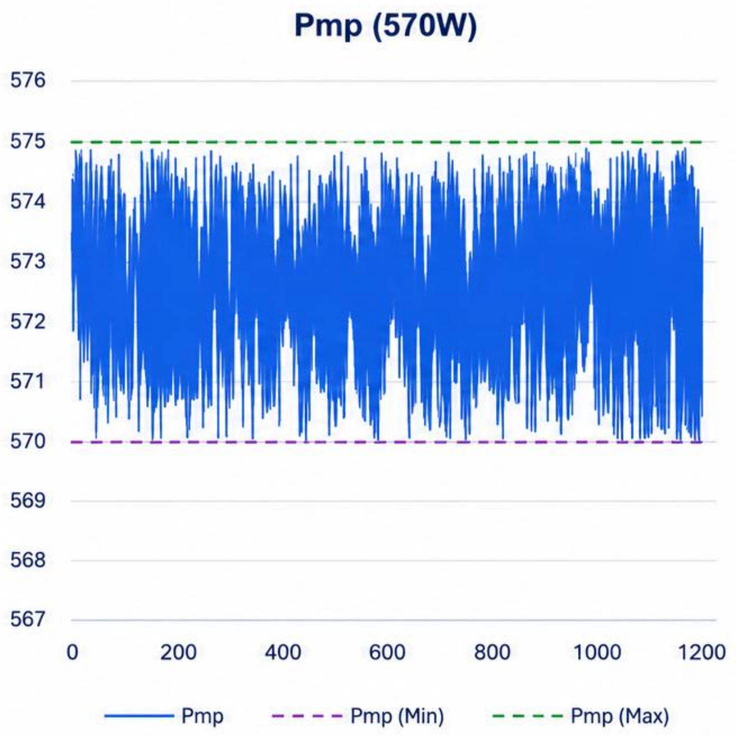
Maximum Power Represents the highest power output a PV module can deliver under standard test conditions (STC). Pmax = Vmp × Imp

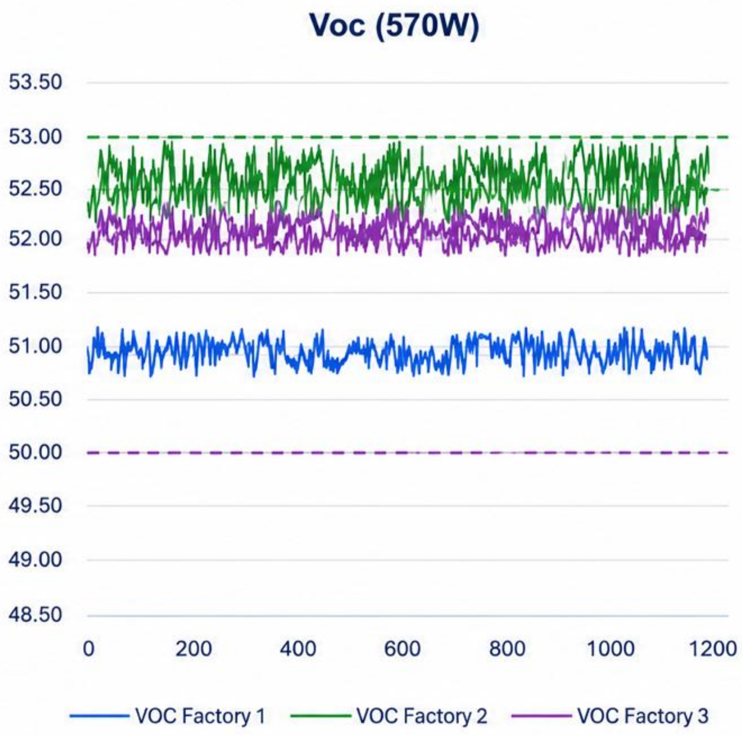
Isc

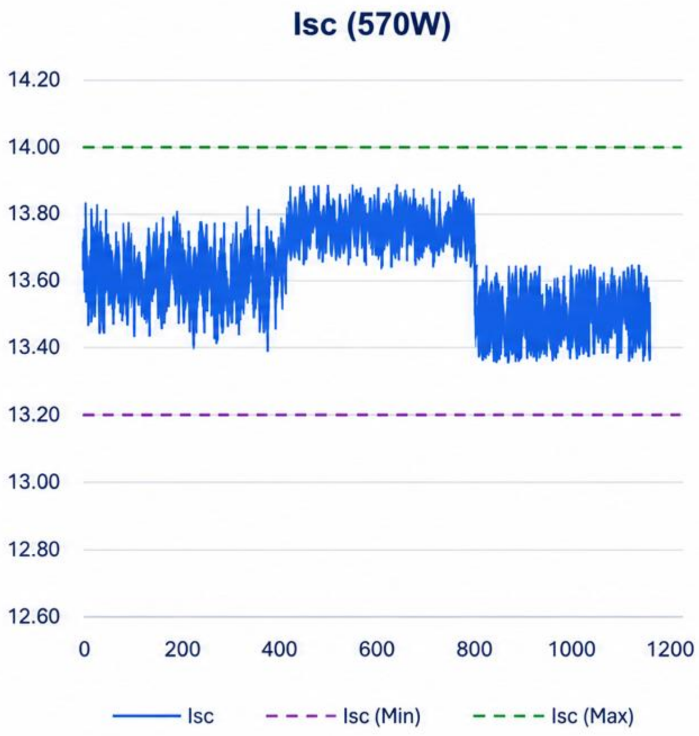
Maximum current under STC when module terminals are shorted (zero voltage). Indicator of Irradiance & Cell Health. Helps assess module performance and detect shading or cell degradation.

Voc

Open-Circuit Voltage: Maximum voltage under STC with no load connected. Critical for string sizing and inverter limits; exceeding ratings risks damage and safety non-compliance (UL 61730).



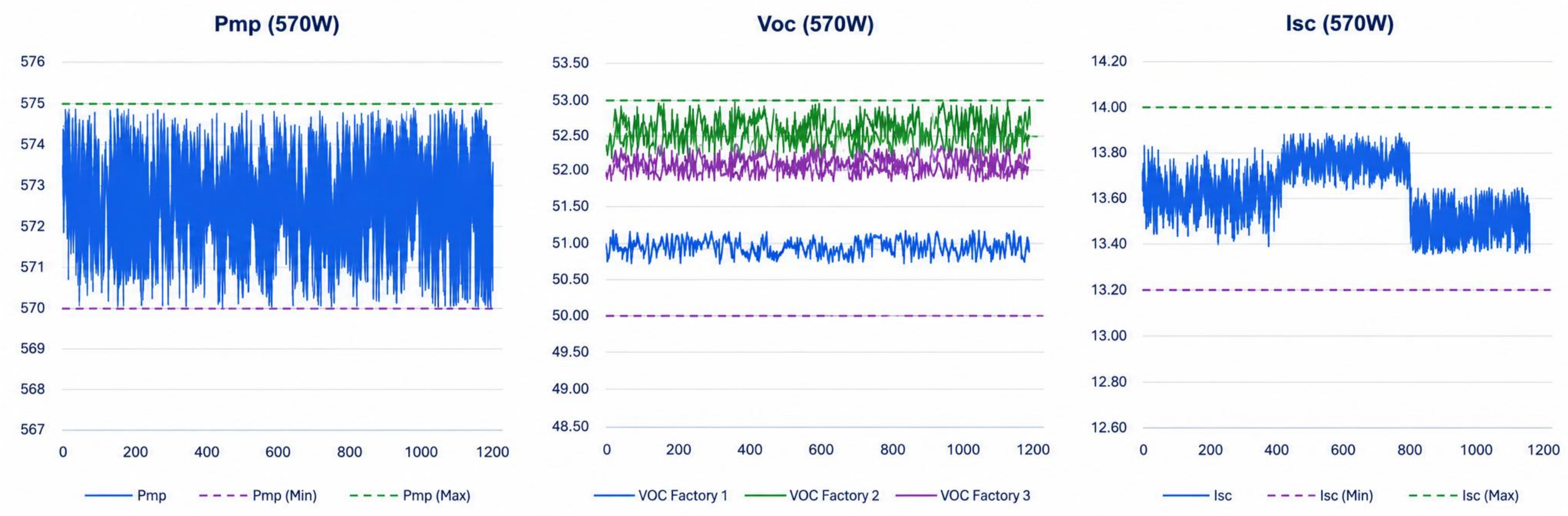




When BOM changes are managed only against **Pmax**, electrical parameters can shift and affect string sizing, inverter compatibility, and project performance.

Voc variation may reduce the allowable modules per string, for example when modules from different factories or BOM configurations are combined.

As module electrical properties are interconnected, all key parameters should be reviewed following BOM changes to confirm alignment with project design requirements.



Toolbox Takeaways

When BOM changes occur, electrical review should extend beyond maximum power. Confirming **key properties align with project design and string-sizing requirement**s helps avoid redesign costs.

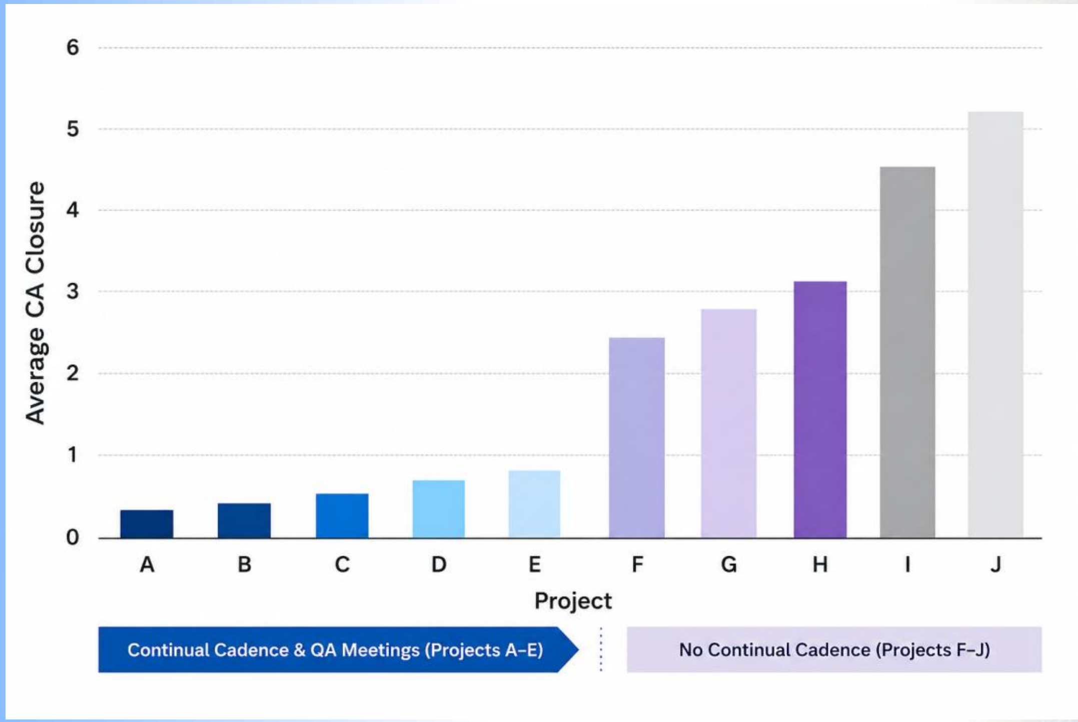
If variation is identified **during production**, buyers can work with suppliers to adjust before shipment.

Collaboration in Practice: Corrective Actions

- As domestic production and global supply complexity increase, **routine alignment between buyers, manufacturers, and QA providers** becomes critical.
- Structured quality reviews help **accelerate agreement and implementation of corrective actions** during active production.
- If findings remain open while production continues, defect exposure can expand across additional batches or projects.
- Timely issue closure reduces quality risk, protects project performance, and limits downstream cost impacts.

Collaboration in Practice: Corrective Actions

- When meeting regularly between buyers, manufacturers, and QA insurance providers, reduction in quality corrective action time results in projects



Toolbox
Takeaways

- **Quality Improvements:** TOPCon production and EL defect performance continue to improve.
- **Key Risk Areas:** Creepage distance and cell spacing remain critical but can be controlled through inspection criteria, factory audits, and in-factory QA.
- **BOM Variations:**
  Tracking **Voc** and other key electrical parameters helps prevent design impacts and costly redesigns.
- **Collaboration in Action:** Buyers, manufacturers, and QA providers are aligning faster on corrective actions and product quality improvements.

Thank You!