Creepage, Clearance, and Compliance
Quality Assurance Lessons from Domestic Manufacturing

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Agenda

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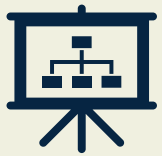
2. Quality Over Time
3. Creepage & Clearance
4. Root Causes
5. Case Studies
6. How We Can Reduce Defects
7. Conclusion

Services for the entire supply chain



Market Intelligence

Industry leading reports, from analysis of key solar and energy storage components pricing, technology trends, policy updates, as well as custom data and reporting.

Technical Advisory

We support investors, developers, EPC contractors, asset managers to procure high quality equipment, optimize system performance and conduct technical due diligence.

Engineering

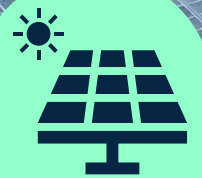
Owner's engineering services for PV and BESS plants in order to support investors in the development and construction of reliable assets.

Product Testing

Independent, industry-leading performance testing of PV modules, inverters, battery energy storage, and other key solar equipment.

Factory Inspection

Factory audits and inspections benchmarking manufacturing quality based on our expertise in processes, materials, and technologies to ensure the long-term performance, reliability, and safety of key equipment.



Field Services

Expert assessments of PV and BESS power plants during construction and operation to ensure high quality installations and long-term optimal performance.

Who is Kiwa PI Berlin

Trusted Technical Advisor:

Global advisor and risk manager specializing in quality assessment for PV, storage, transformers, and inverters.

Comprehensive Quality Management

Technical diligence, procurement support, and quality assurance: from factory to the field.

PI Berlin was founded in 2006 and joined Kiwa in 2022.

1,000+

Factory Audits Conducted

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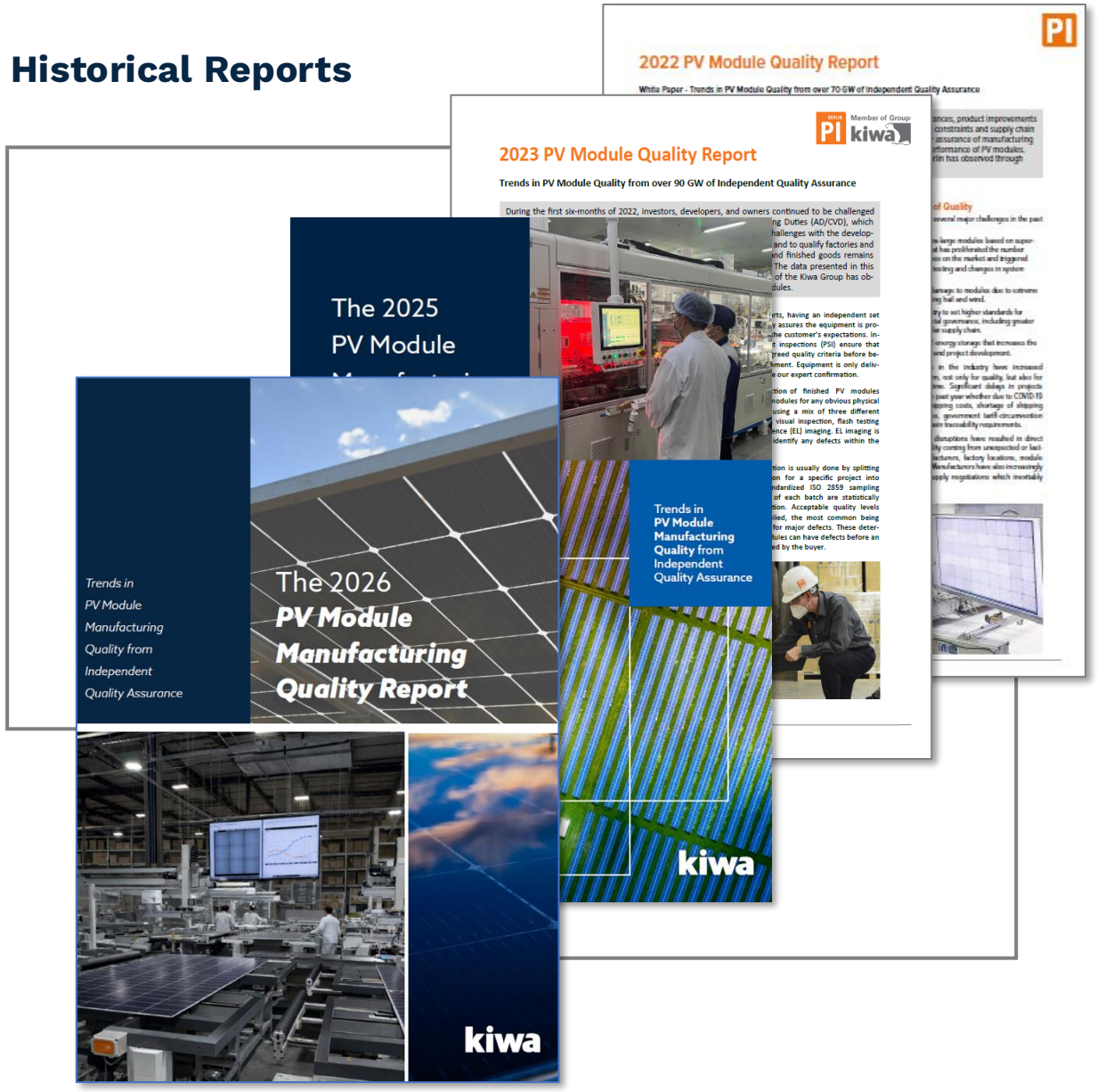
Introduction

- Over 10+ years of systematic QA documentation across global PV manufacturing
- Kiwa PI Berlin QA data shows increasing non-conformances across production lines
- The 2026 PV Module Manufacturing Quality Report highlights key high-defect areas.

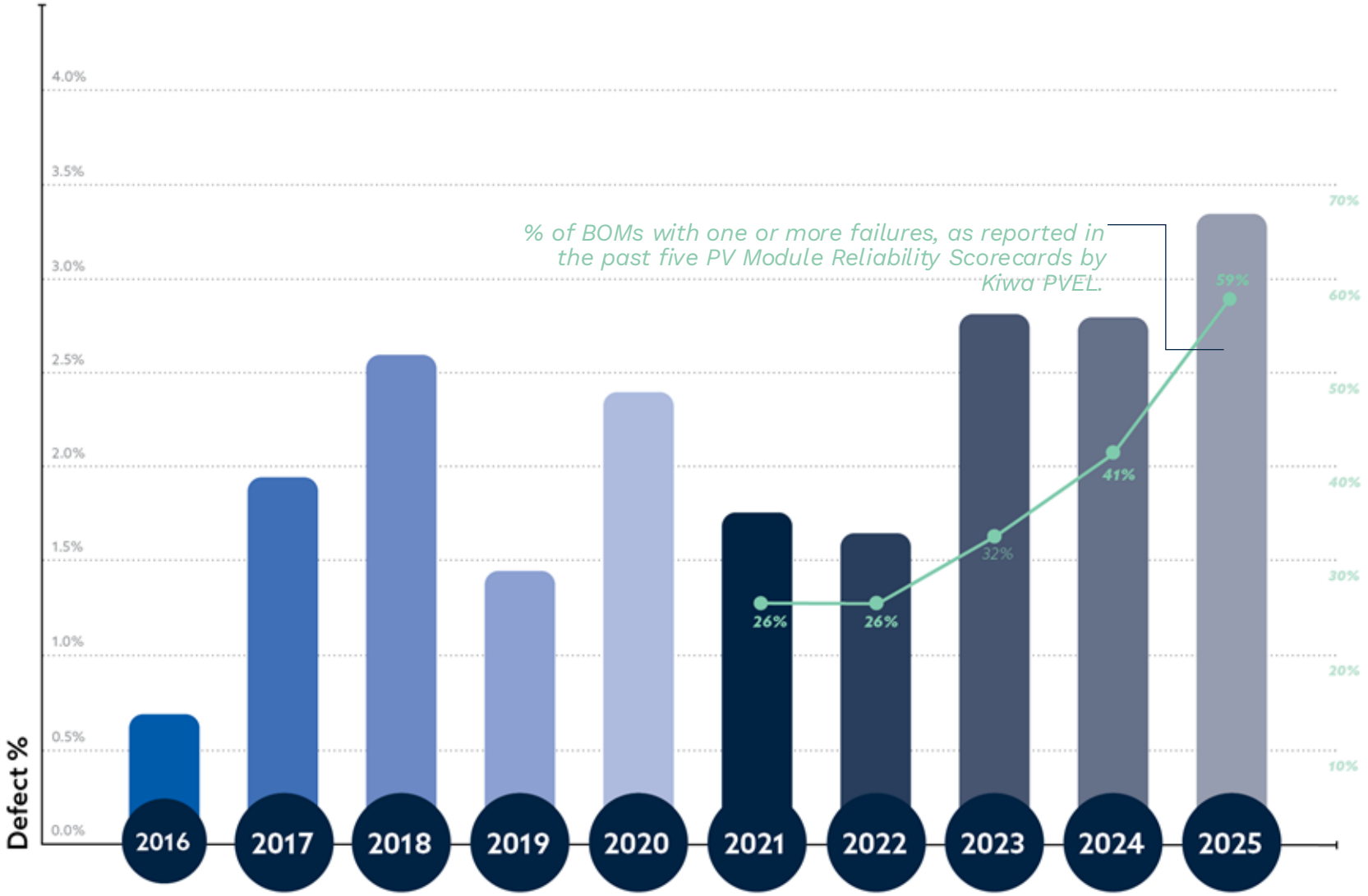
kiwa.com/2026pvmfrreport

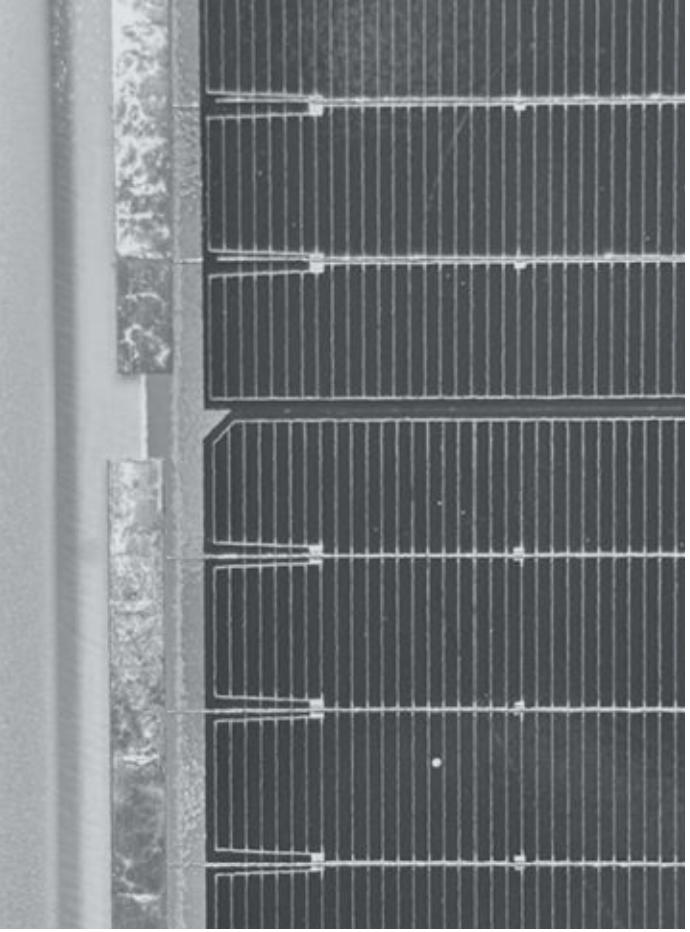
Historical Reports

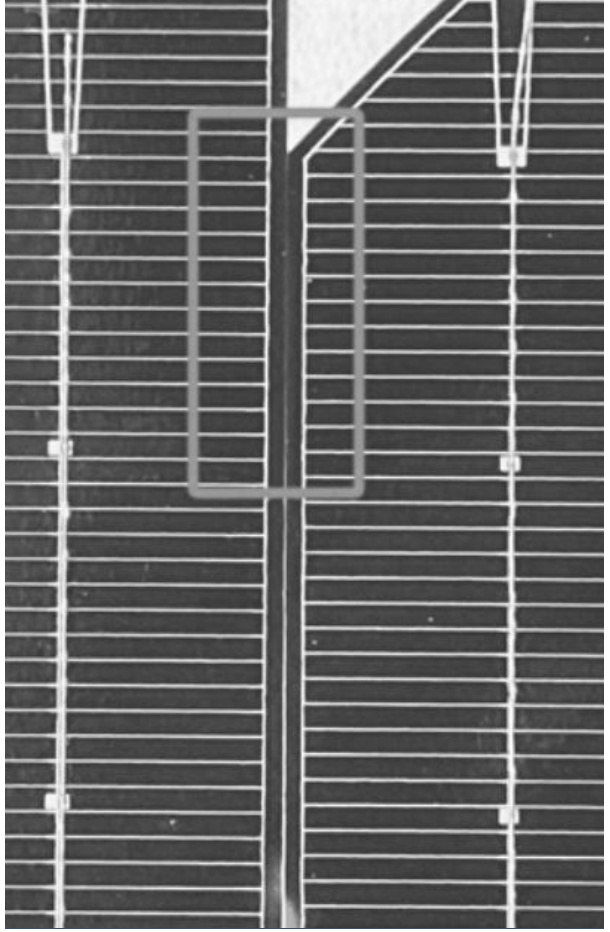


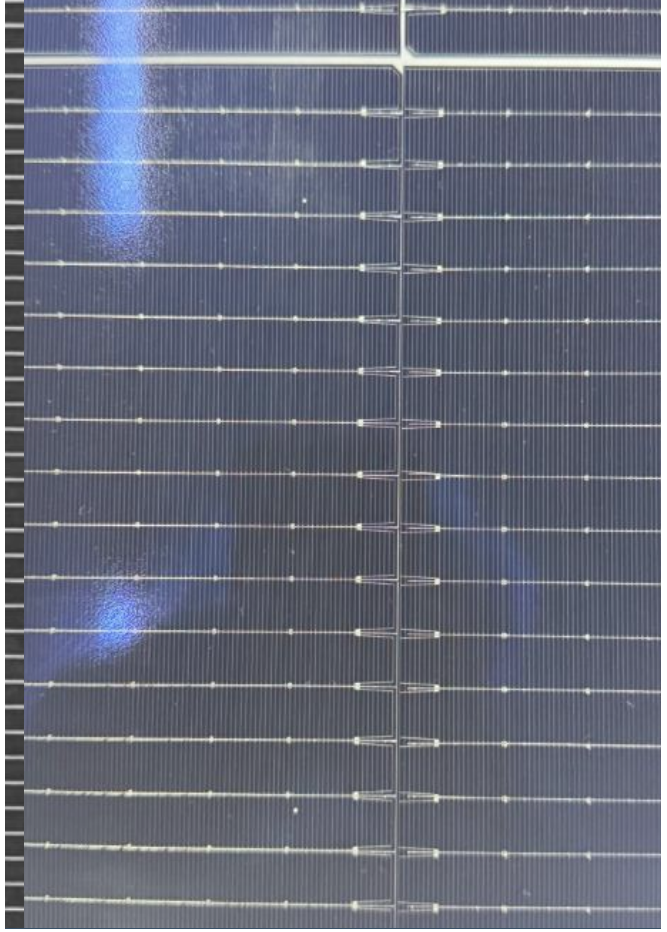
Managing Quality Over Time

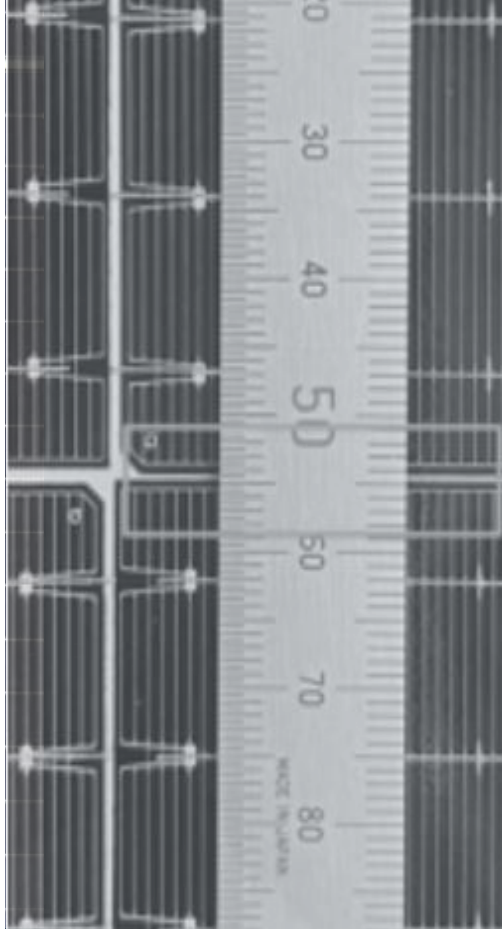
- Kiwa PI Berlin maintains a decade-long defects database spanning 125+ manufacturers, enabling industry-wide benchmarking of PV module quality.
- The graph shows consolidated PSI defect ratios across all inspected factories, illustrating year-over-year quality trends.
- Rising BOM-related issues also appear in Kiwa's PQP/lab testing, with a clear increase in BOM-linked PQP failures mirroring higher PSI defect rates.

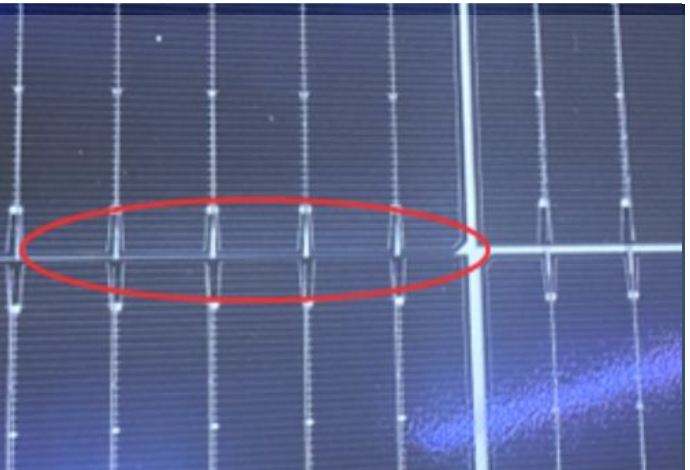




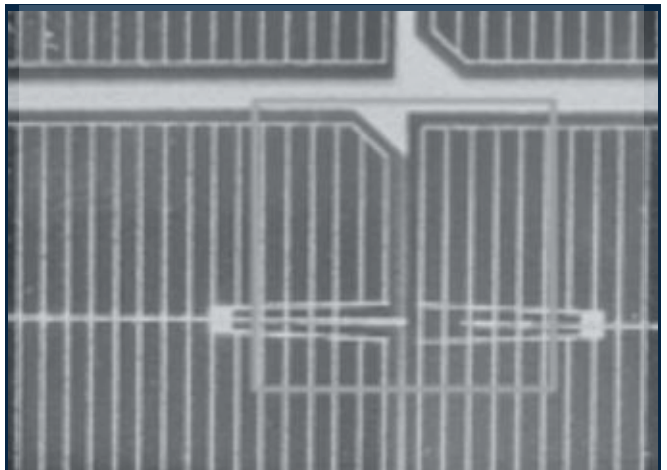








Creepage & Clearance



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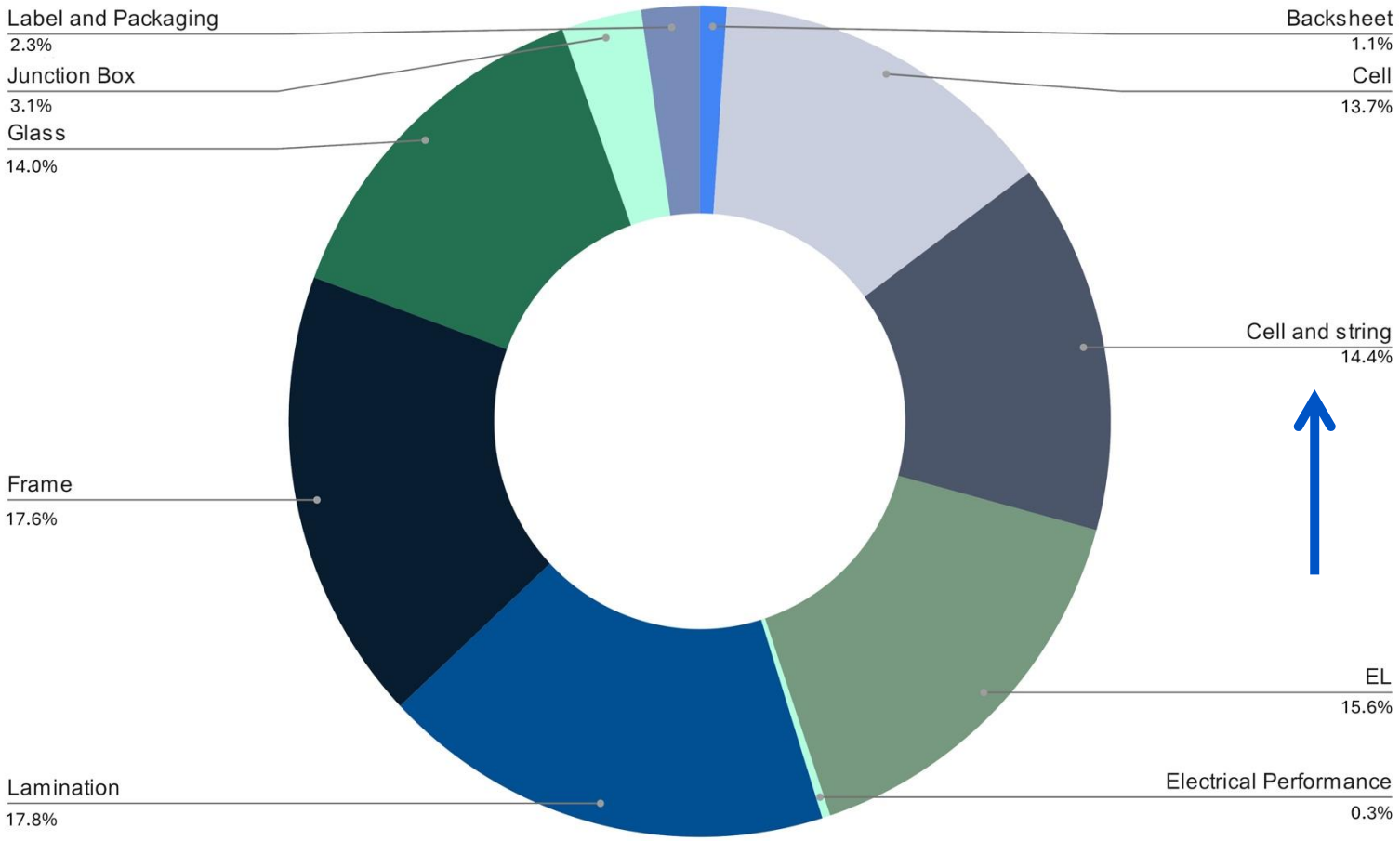
PV Module Defect Distributions

- The majority of defects originate from lamination, cell and string interconnects, cells, frame, and glass, accounting for over 75% of observed issues.
- The ratio of some high-risk defects has increased significantly in recent years due to new module designs and BOM changes.
- Overall defect trends highlight challenges in material selection, process control, and equipment calibration.
- Persistent gaps in inspection and monitoring allow high-risk modules to enter the field, despite the increasing number of reported failures, one focus for the industry continues to be in **cell spacing.**



Pre shipment Inspection Observed Defects 2025

Ul/IEC 61730: safety requirement for PV module creepage and clearance

Purpose:
The industry should enforce strict quality controls and risk-based inspection criteria to prevent safety-related PV module defects. Creepage distance and bubble defects must be treated as critical safety issues, with assessments based on size, location, and shape. QA teams should flag high-risk defects and advise buyers accordingly.

Minimum Required Spacing (safety critical):
- Cell-to-cell distance (within one string)
- String-to-string distance
- Ribbon-to-ribbon distance (Junction box)
- Ribbon-to-cell distance
- Distance from cells/ribbons to glass edge

Special Case – Bubbles
- Considered as conductive paths
- Must be included in creepage & clearance evaluation
- Can reduce effective insulation distance

Compliance Rule:
All measured distances must meet UL/IEC 61730 minimum values.
Modules not meeting these limits → **NON-COMPLIANT with safety standard**

Creepage Distance Defects Due to Cells Alignment:

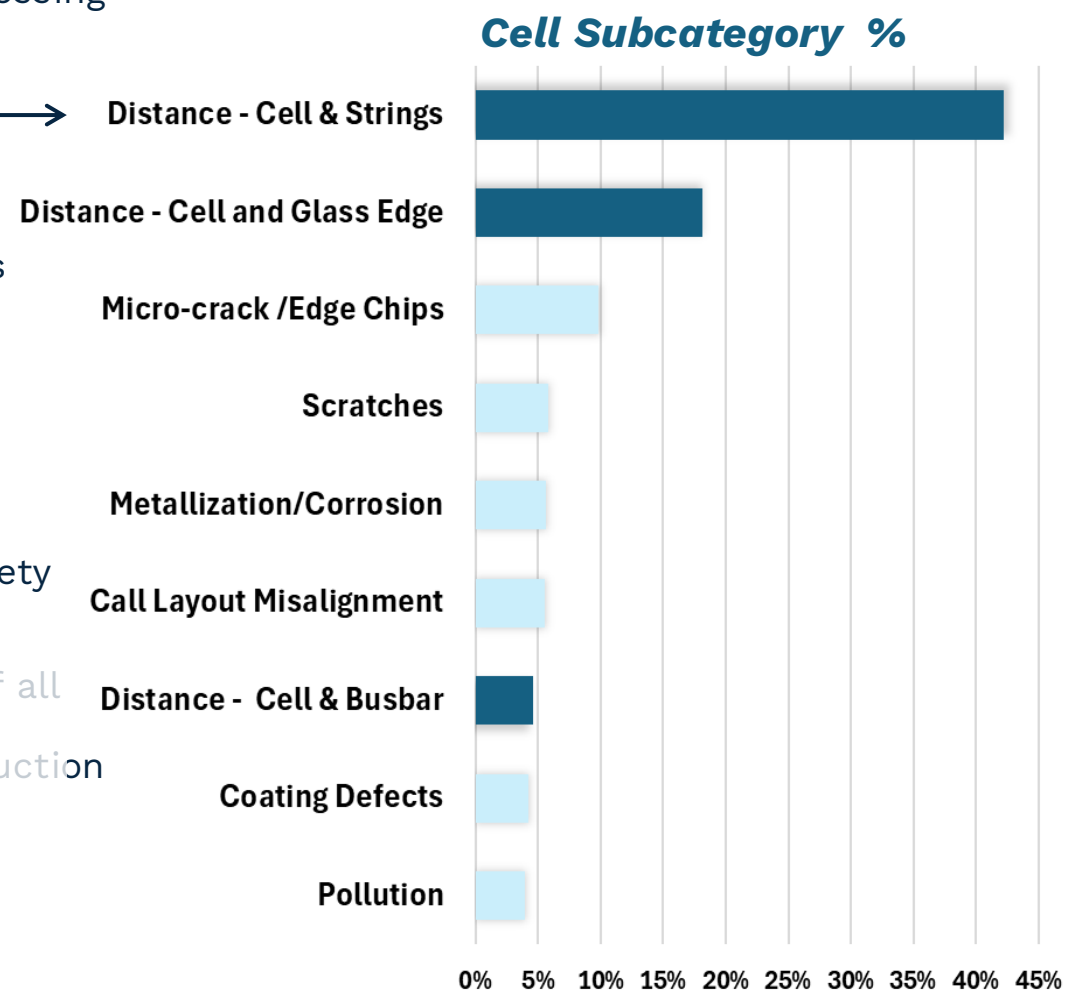
Most Significant Defect Category (65% of total findings of cell processing
- Cells ↔ adjacent cells / cell strings → 43%
- Cells ↔ glass edge → 18%
- Cells ↔ busbars → 5%

Why This Matters
- These spacings are safety-critical to maintain proper insulation.
- Multiple modules were non-compliant with UL & IEC requirements

Engineering & QA Impact
- Critical for design qualification & certification
- Must be tightly controlled during production and PSI inspections.
- Directly linked to field failures and fire incidents when violated.

Key Takeaway:
Creepage distance control is not a cosmetic issue — it is a core safety compliance requirement.

Domestic manufacturing-related defects represented over ~40% of all instances of this defect type in Kiwa PI Berlin's global 2025 dataset, highlights a significant quality-control gap within U.S. production lines relative to broader international manufacturing performance.



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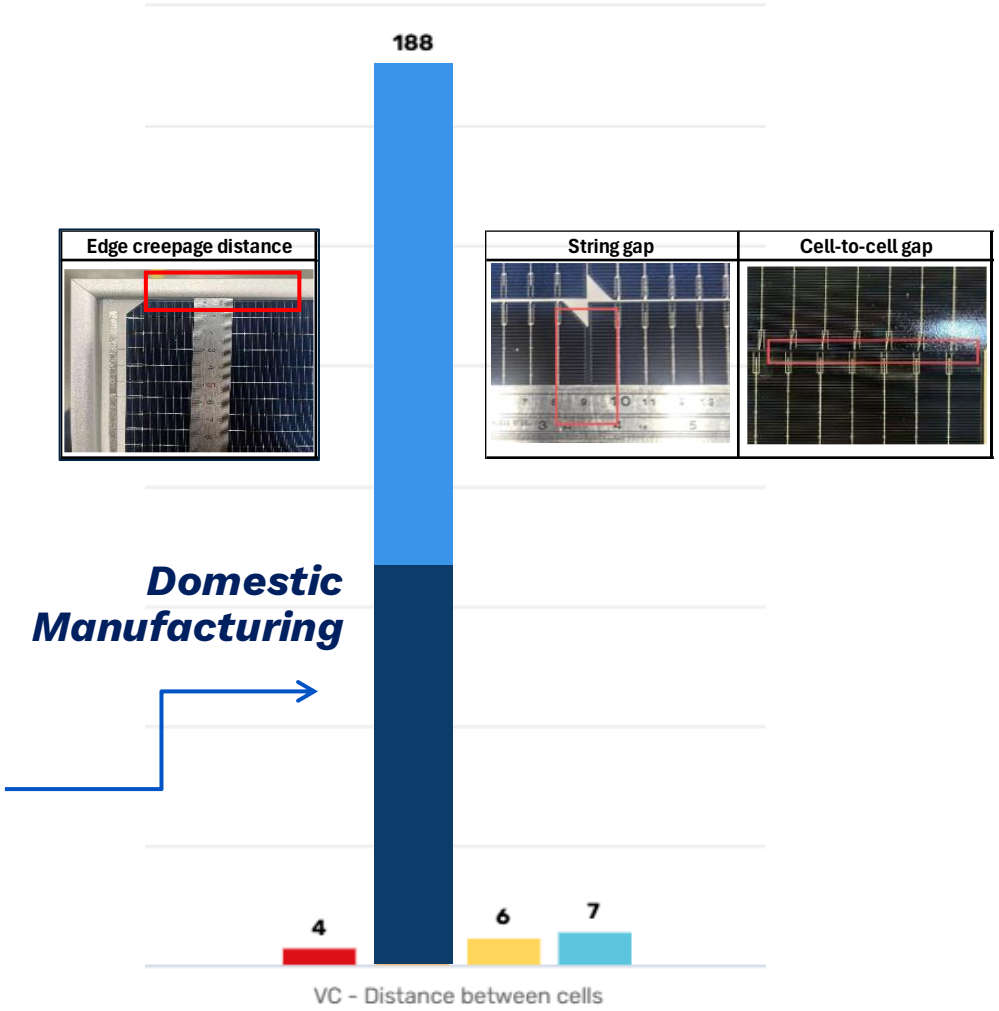
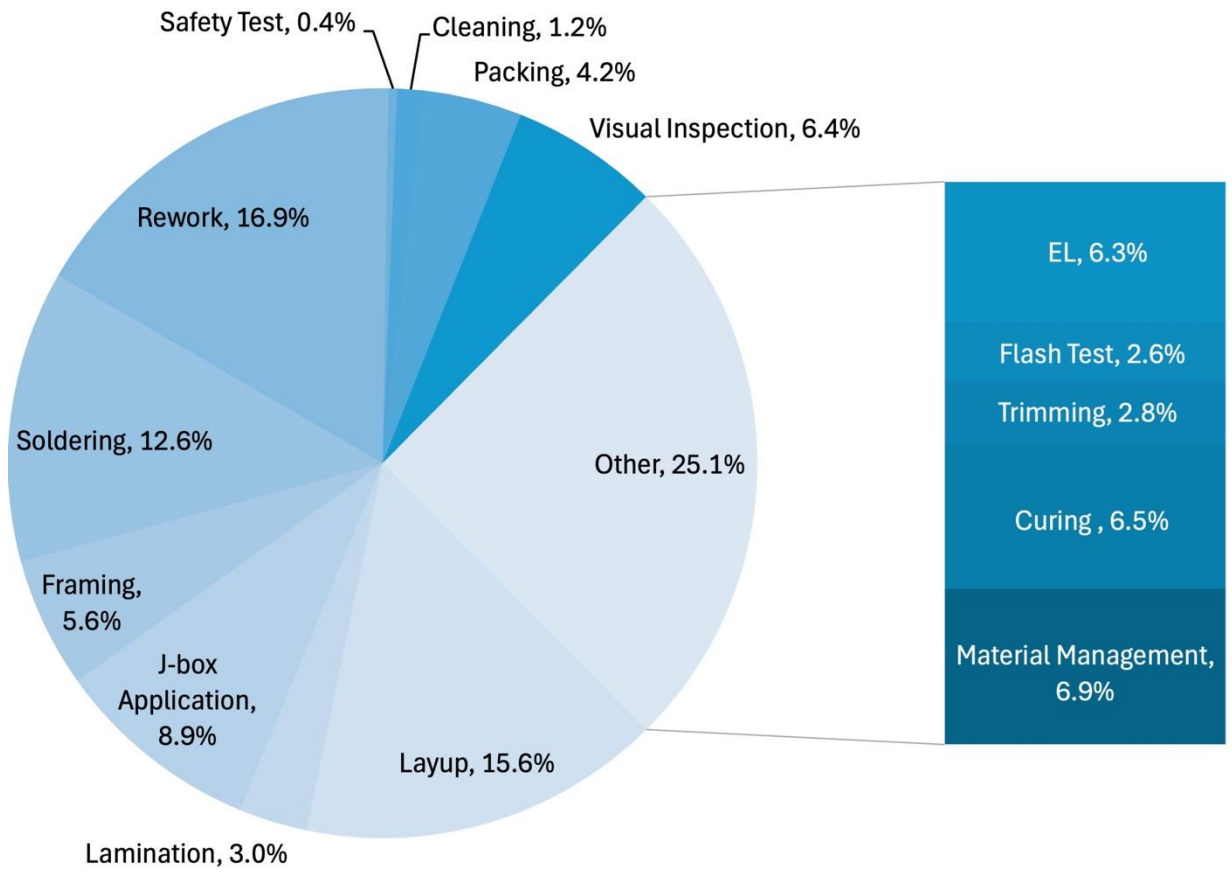


Root Causes, Cell Creepage – Oversight Findings

- Overly tight spacing design without allowance for equipment tolerances
- Equipment calibration/alignment not maintained to the required accuracy (Layup – 16%)
- Limited awareness of safety and field-failure risks (Rework – 17%)
- Inadequate engineering inspection criteria and screening in QA/PSI (Visual Inspection – 6%)



Production Oversight findings 2025

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Case Study – PV Module Field Failure Due to String to String Gap

Background
Kiwa PI Berlin's failure analysis team has investigated multiple field incidents over the past year where inadequate creepage distances were identified as a root cause.

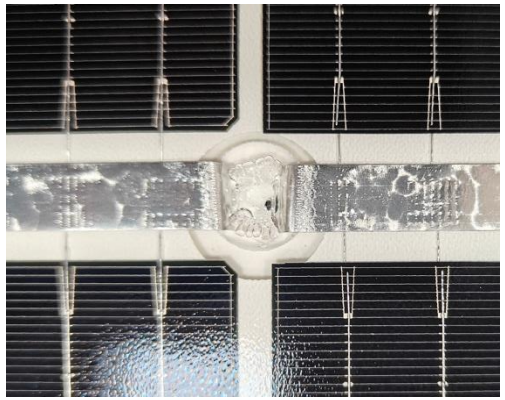
Failure Finding
- Fire due to short circuit formed by contact between two strings of opposite polarity.
- Visual inspection revealed many modules failed **IEC/UL 61730** requirements.
  - Required creepage distance: 0.3 mm
  - Measured creepage distance: 0–0.2 mm

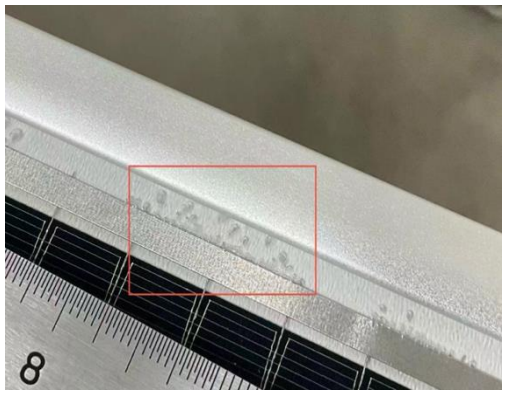
Risk Assessment
- Modules with non-compliant safety gaps present safety risks.

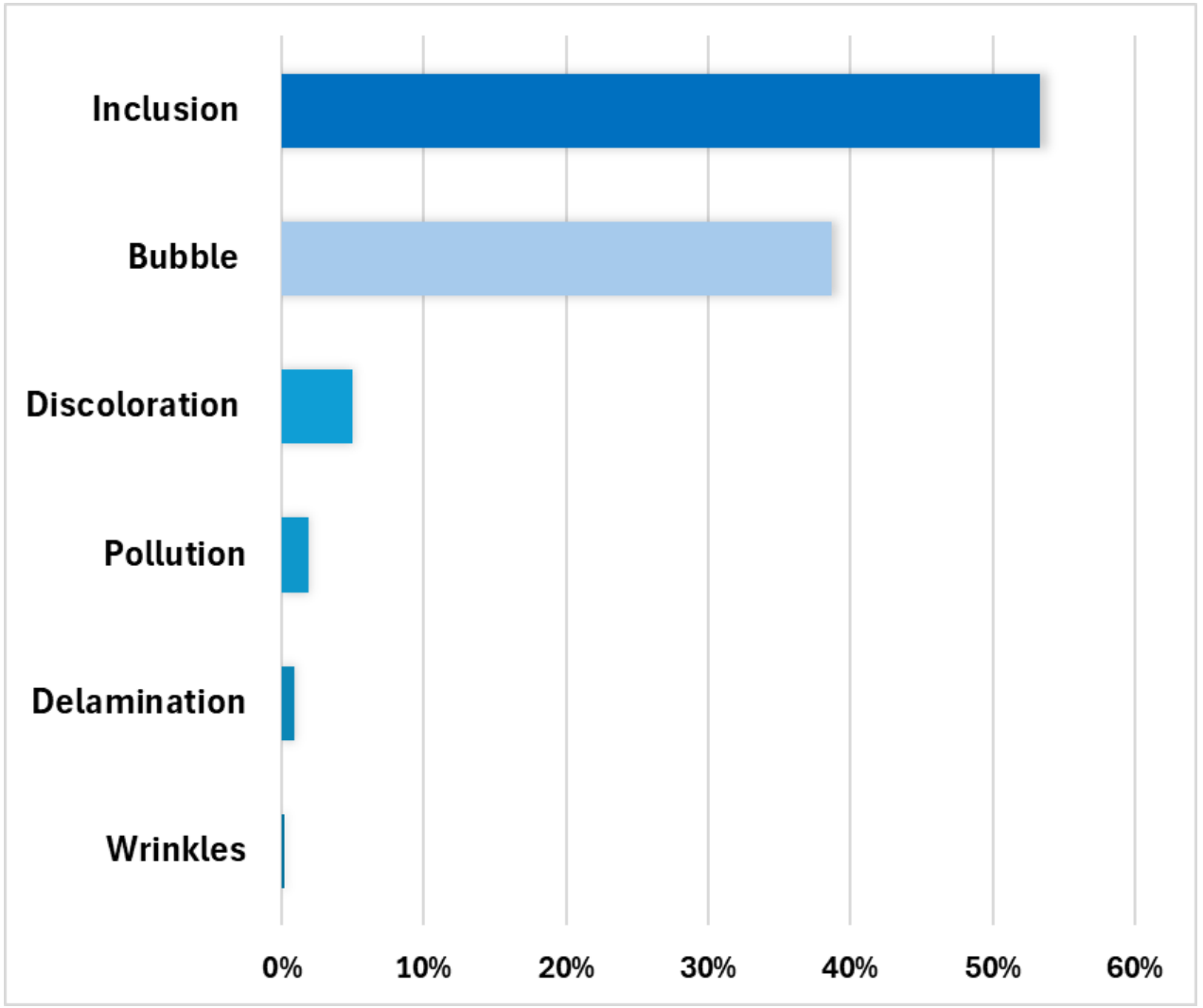
Creepage Distance Violations Caused by Bubbles:

Based on UL 61730, bubbles are assumed to be conductive. So, High-risk bubble locations are:

- Bubbles between two live parts
- Creepage areas (edges of the module)
- Bubbles are among the most prevalent lamination defects.
- Edge-located bubbles significantly increase the risk of delamination and compromise the UL/IEC safety requirements for creepage distance.

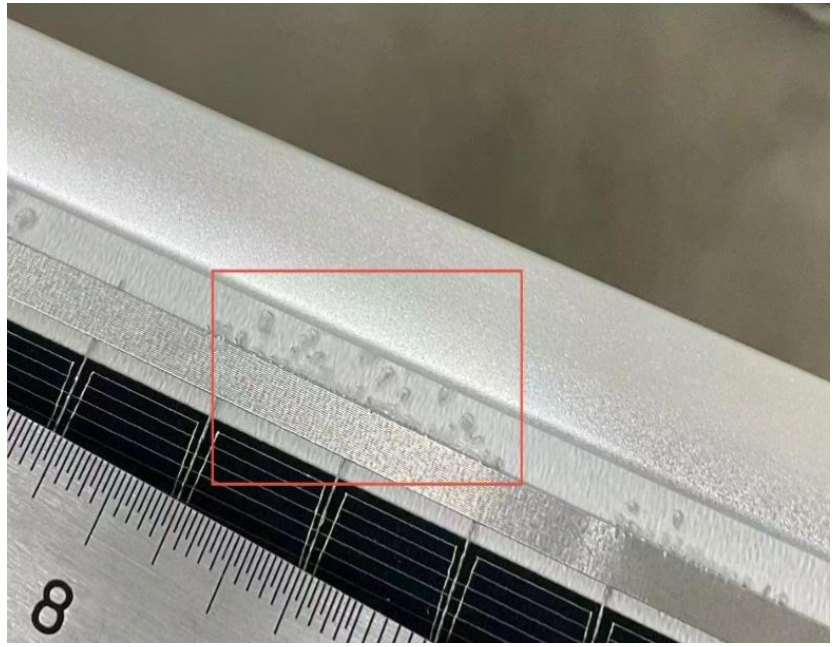


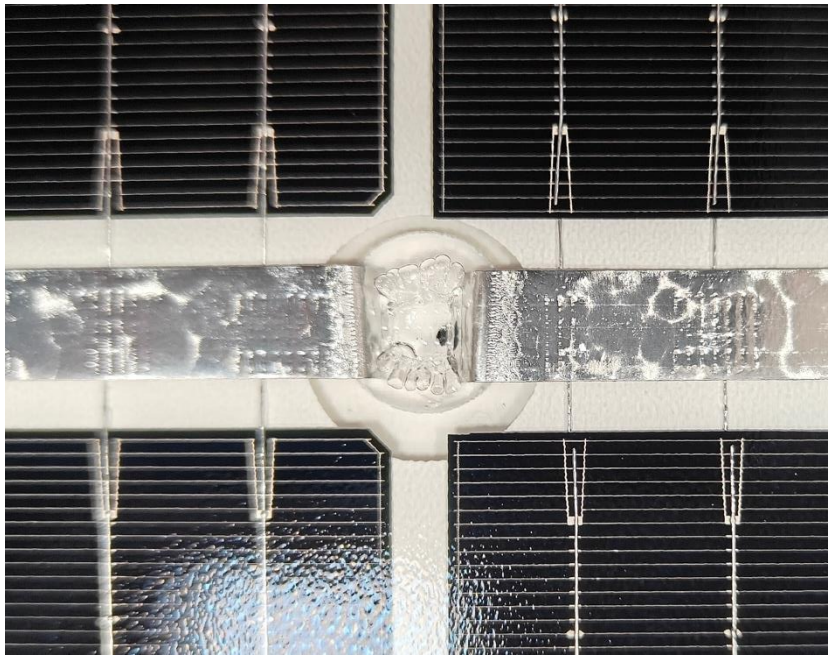




Root Causes for Lamination Defects

- Improper storage conditions for encapsulant materials.
- Failure to follow shelf-life and use of expired materials.
- Operation of the laminator outside standard process parameters (temperature, time and pressure).
- Poor equipment condition, inadequate maintenance, or lack of proper calibration.
- Edge pinching.
- Reduced encapsulant thickness and dimensions as a cost-saving measure.

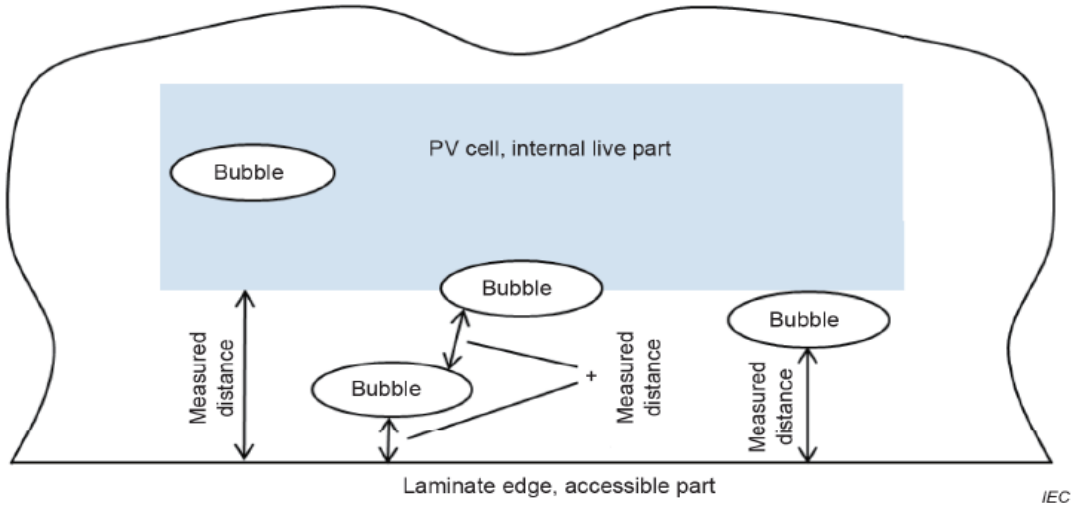




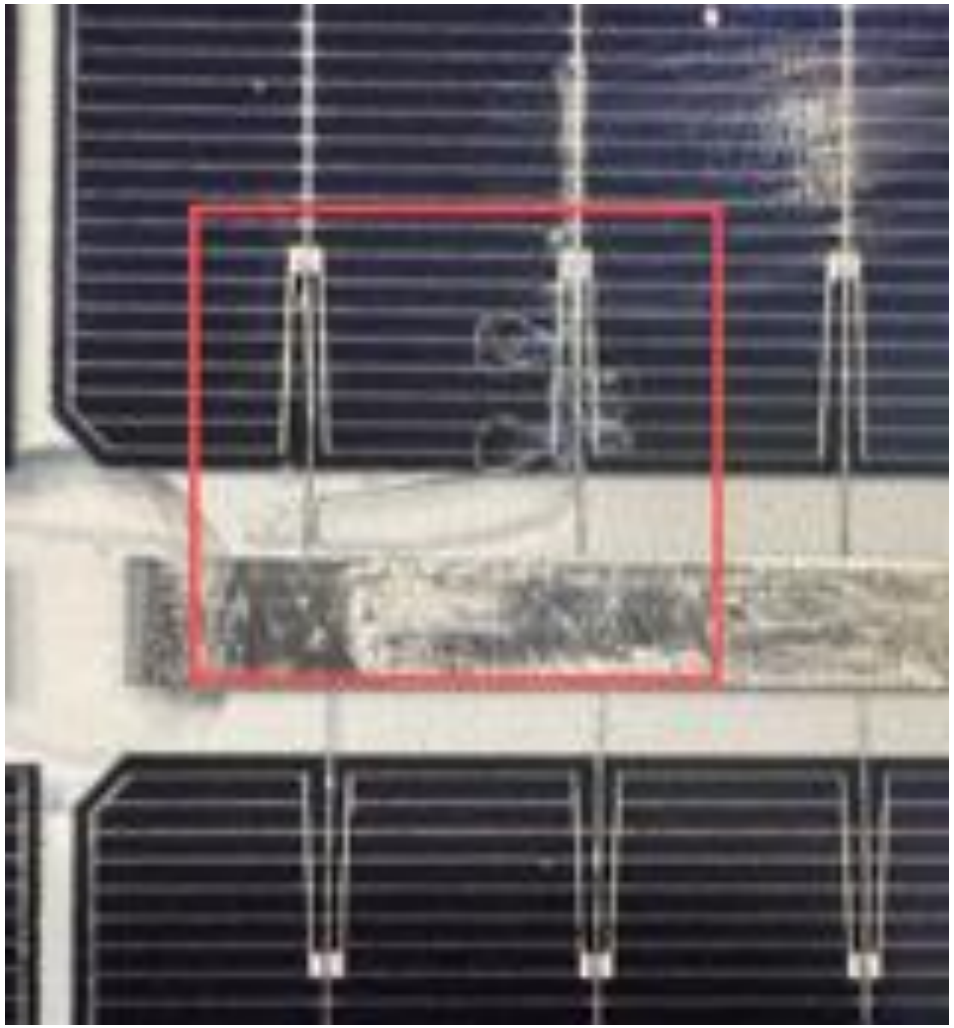
Creepage Distance Risk Associated with Bubbles – Safety, Compliance, and Industry Classification Gap

- Based on UL 61730, bubbles are assumed to be conductive.
- Bubbles can compromise the required creepage distance.
- This condition can lead to a short circuit and potential safety risk.

Gap: Many manufacturers currently classify bubbles as minor or major defects without evaluating their impact on creepage distance compliance.



a) Example for delamination assessment when measuring creepage distances and clearances, or distance through insulation



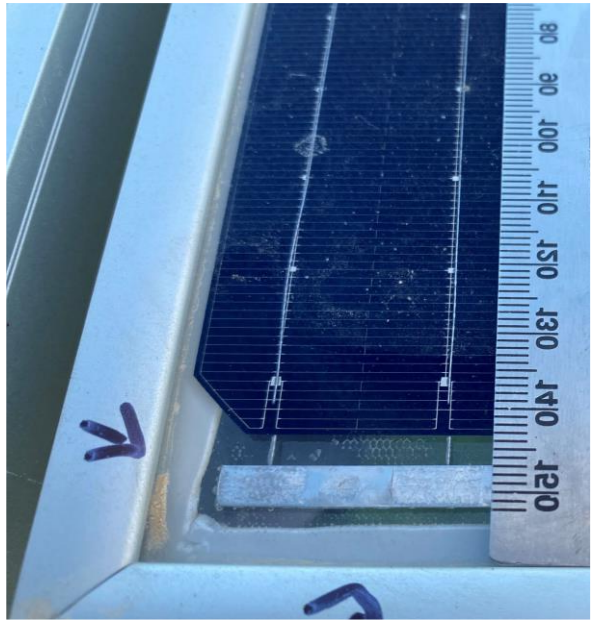
Case Study – PV Module Field Failure: Edge Bubble

Background

- Field fire reported; modules investigated by KPIB.

Failure Finding

- Bubbles at the glass edge compromised the required creepage safety distance (UL/IEC 61730-1: 10.4 mm for 1500 V modules).
- A continuous conductive path formed between the internal electrical circuit and the frame.
- Insufficient creepage distance resulted in electrical arcing and subsequent fire failure.



Images show field failure sequence illustrating this mechanism step by step.

Conclusion

The industry should press for strict quality controls and process compliance to prevent these known and observable creepage distance defects:

- **Update inspection criteria** to reflect the engineering risk associated with defects.
- QA inspection teams must **flag high-risk defects** and advise buyers accordingly, while recognizing that creepage distance is a **safety requirement**, not a cosmetic issue.
- Assess bubble defects based on **size, location, and shape**; classification must cover all angles of risk.
- Any defect compromising creepage and clearance per **UL/IEC 61730** must be classified as **Critical**.