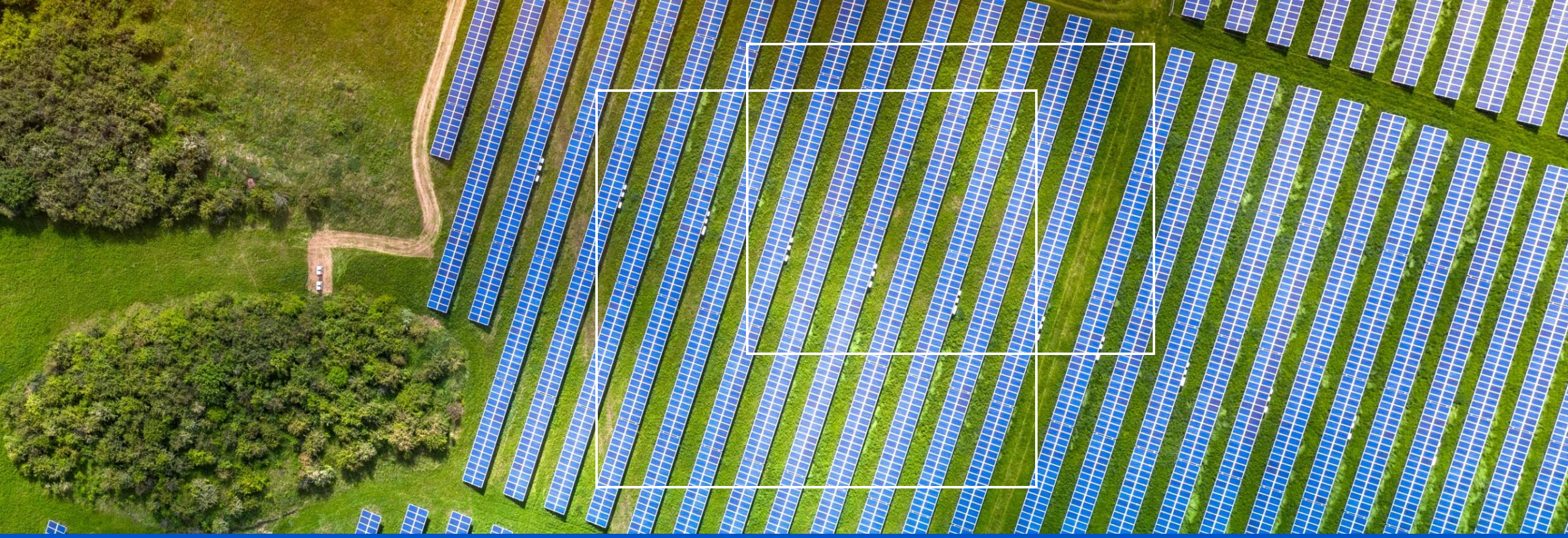

The 2025 PV Module Manufacturing Quality Report

Kiwa PI Berlin Feb 19th, 2025

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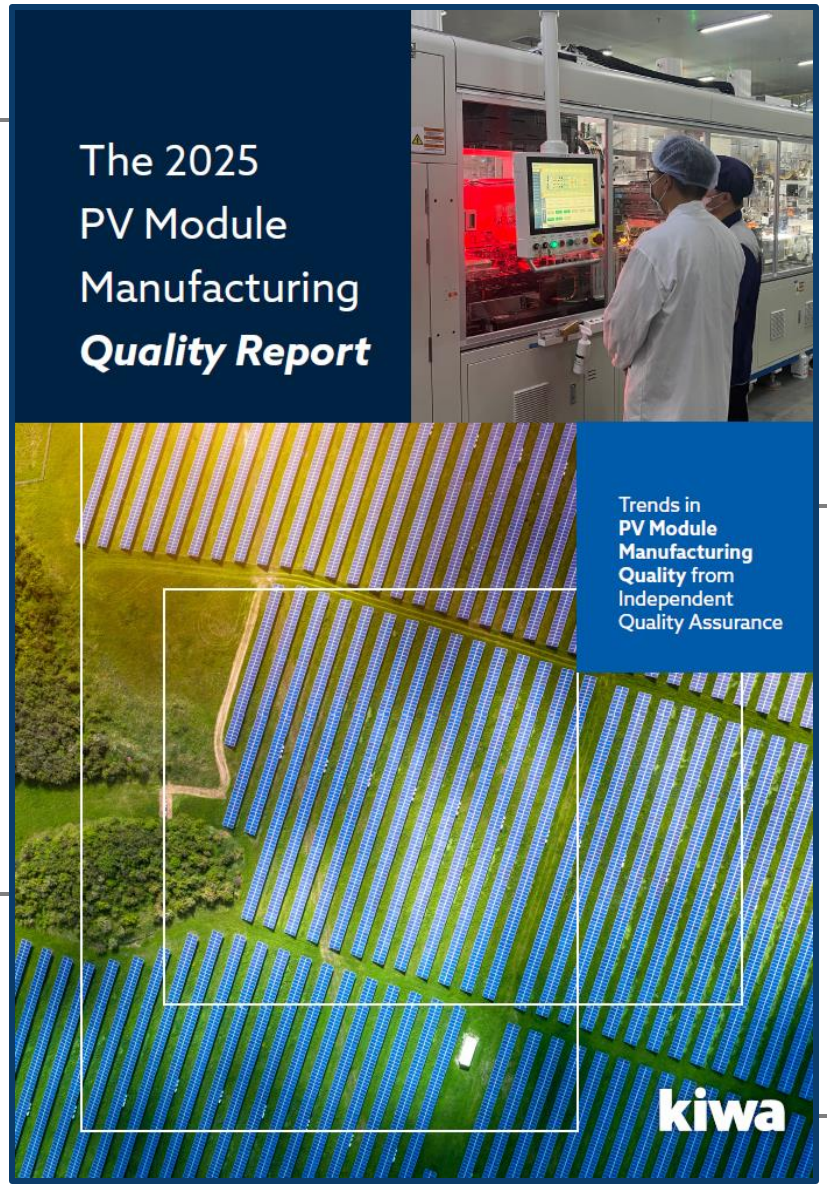
Agenda

1. Introduction
2. Today’s Speakers
3. Quality Over Time
4. Factory Audits
5. Production Oversight
6. PSI
7. Q&A

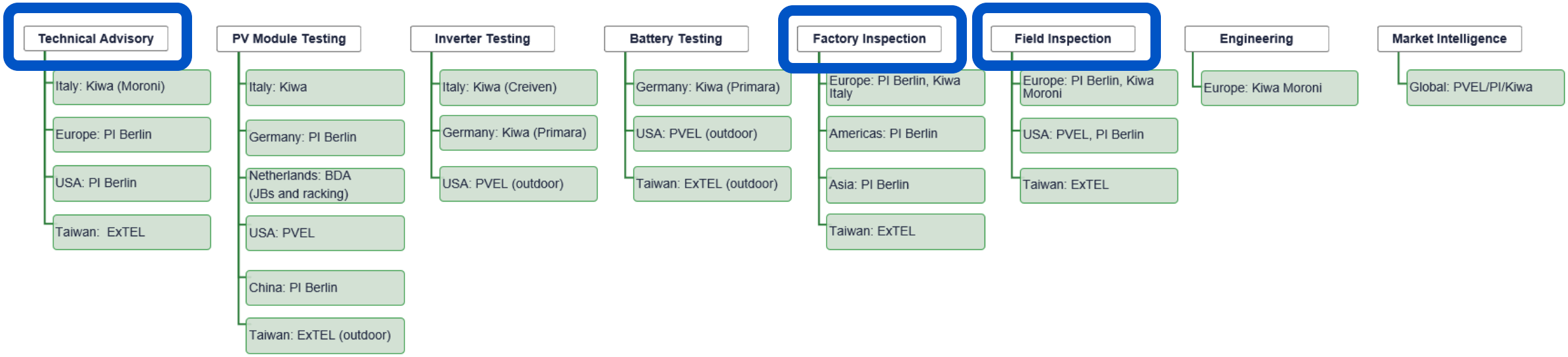
Annual Report Available Now

- Kiwa PI Berlin provides an annual report to help buyers better understand PV module manufacturing risks.
- Report now available:

kiwa.com/pvqualityreport



The Kiwa's Solar Businesses at a Glance:



Kiwa PI Berlin
Trusted Solar and Storage Advisors

A part of the Kiwa testing, certification, & inspection family of companies

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Kiwa PI Berlin

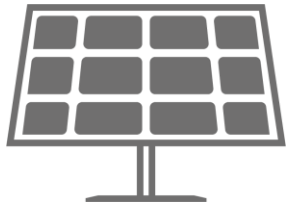
Trusted Solar and Storage Advisors

1,000+
Factory Audits Conducted

175+ GW
PV Module Production Overseen

3 PV Labs in Key Markets
Berlin, Suzhou, California (PVEL)

PV MODULES



c-Si, CdTe,
TOPCon, HJT

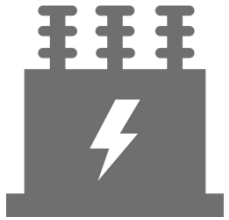
BATTERIES

LFP (Li-Ion),
NMC/NCA, Redox
Flow, NIB

INVERTERS

Central, String,
DC-DC Converters

TRANSFORMERS



Medium voltage, high
voltage GSU transformers
(substation components)

Today's Speakers

Don Cowan
Director of Sales and Marketing

Mahyar Nezhad
Principal Consultant

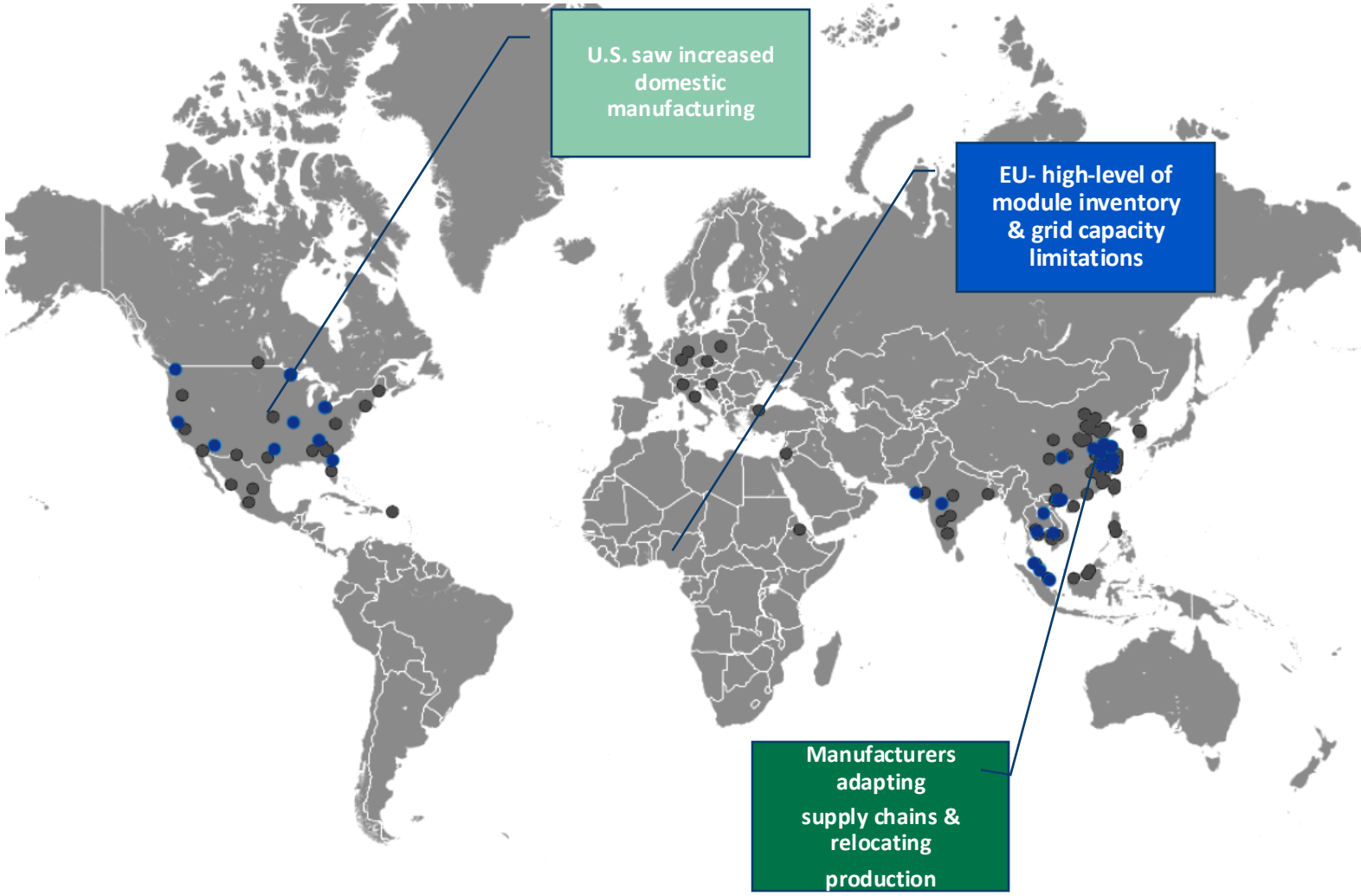
Matthew Lu
VP Global Factory Service

Moderator

Ashley Fallon
Head of Marketing

2024- A Constantly Evolving PV Module Market

- Regulatory policies, new online production capacity, and evolving BOM supply chains result in **constant change** globally for PV module manufacturing.
- **Active quality management** includes a dynamic blend of production-focused quality assurance actions.
- **Buyers Trust Kiwa PI Berlin-** with over a decade of quality assurance experience.

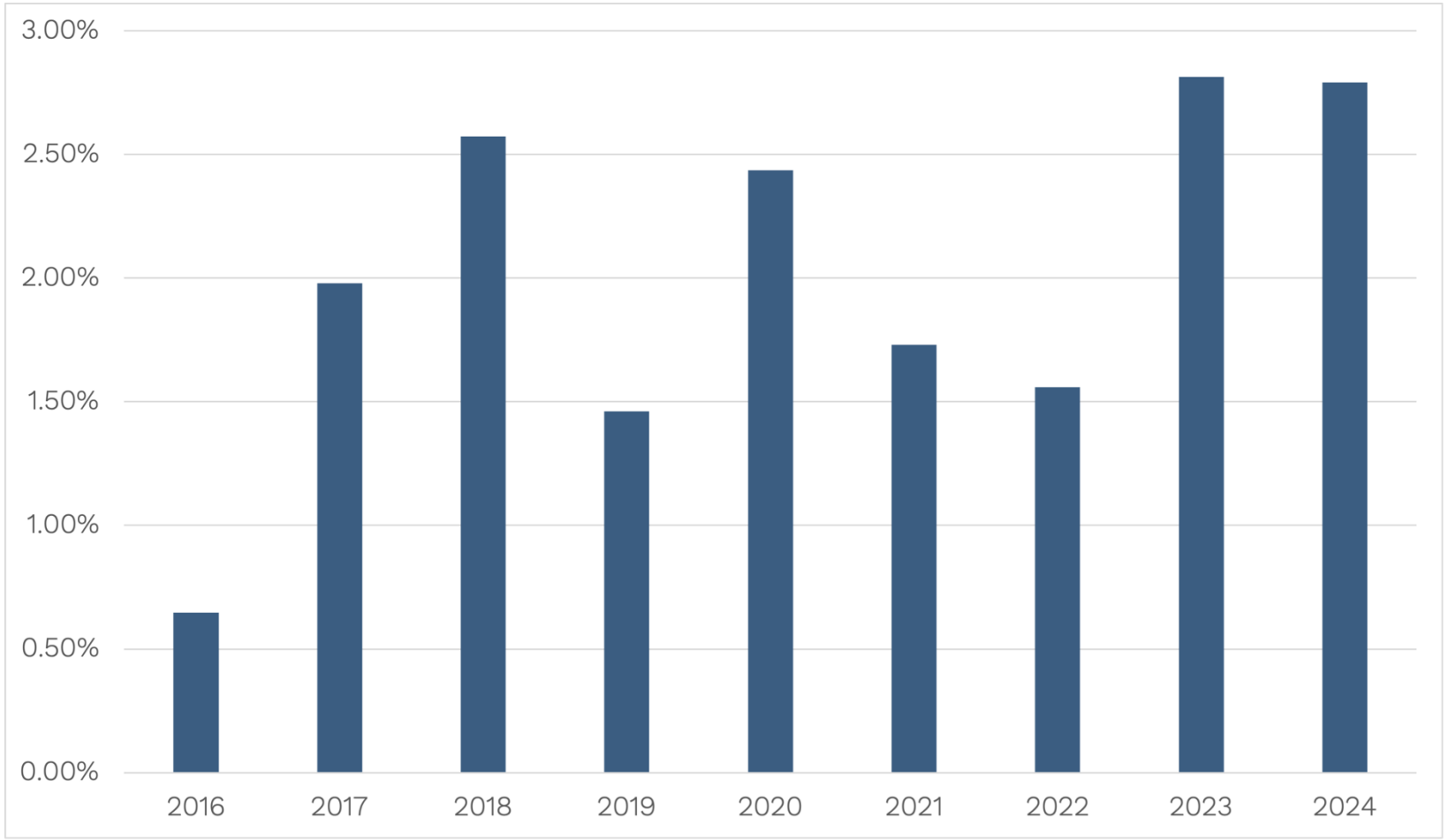


Managing Quality Over Time

Global Database

- Kiwa PI Berlin has developed a findings & defects database for benchmarking manufacturing quality across 125+ manufacturers over a decade. .

- Key Takeaway: Industry evolution, technological advancements, and policy shifts impact defect rates, underscoring the need for strong quality control measures.



Managing Quality Over Time

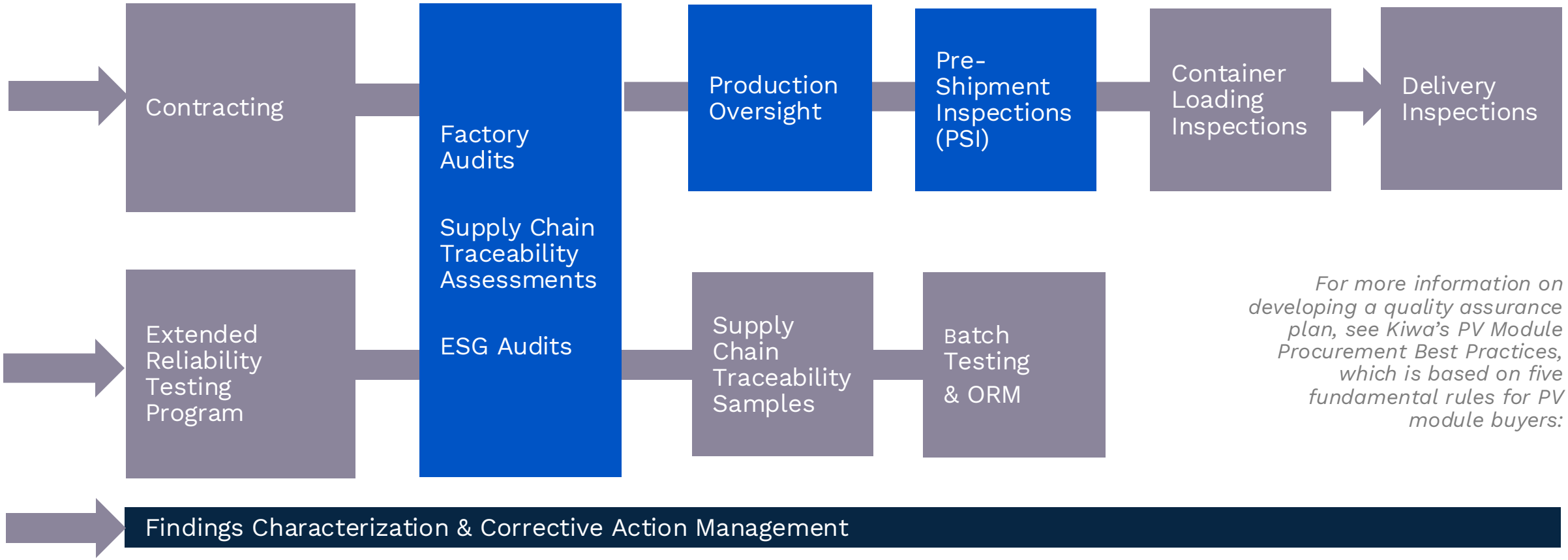
How do buyers use quality assurance data?

- Use quality assurance data to better understand higher manufacturing risks.
- Deploy the right level of quality assurance activities for each case.
- Provide insights for procurement decisions for developing projects and pipelines.

- Overall goal of performing quality insurance is to reduce manufacturing risk to buyers, and help manufacturers improve on the product quality.

Managing Quality Over Time

Common Quality Assurance Program



For more information on developing a quality assurance plan, see Kiwa's PV Module Procurement Best Practices, which is based on five fundamental rules for PV module buyers:

Factory
Audits

Assessment & Quality Assurance

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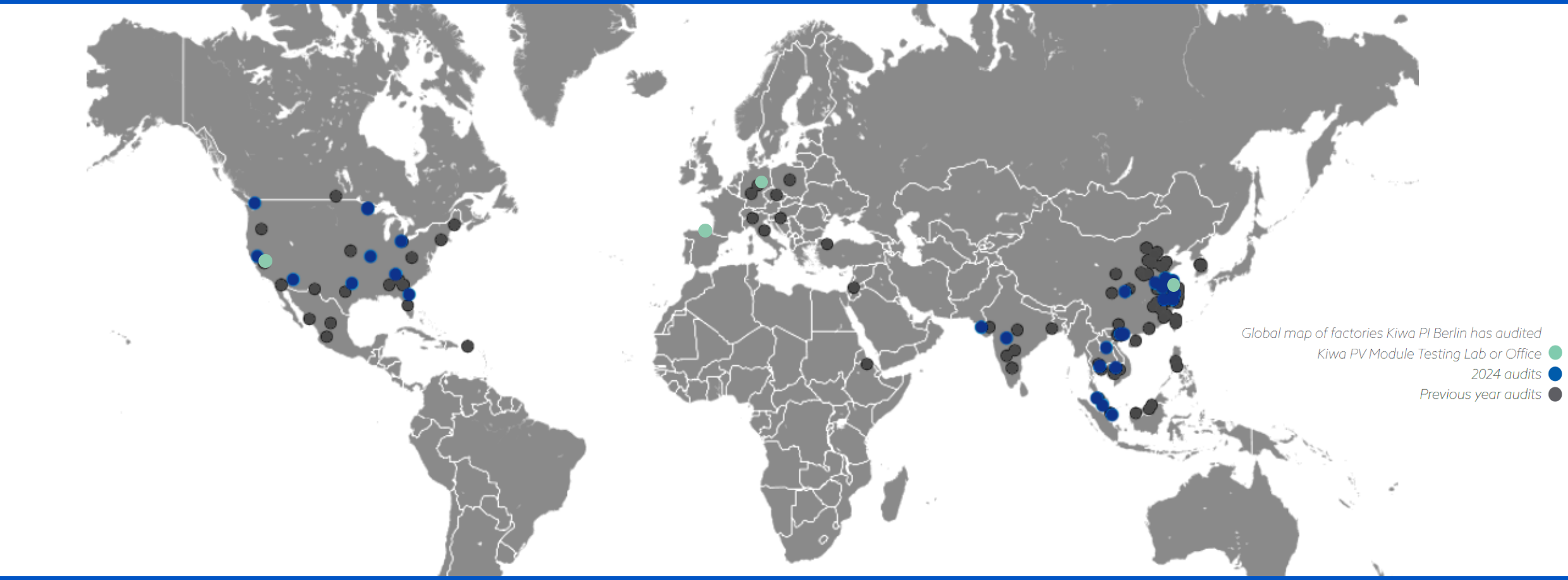

Factory audits are **pre-production quality assessments**

Focused on **safety, reliability, and performance**- ensuring manufacturers meet industry and buyer standards

Kiwa PI Berlin conducted **~100 factory audits in 2024**, covering various manufacturers and regions.

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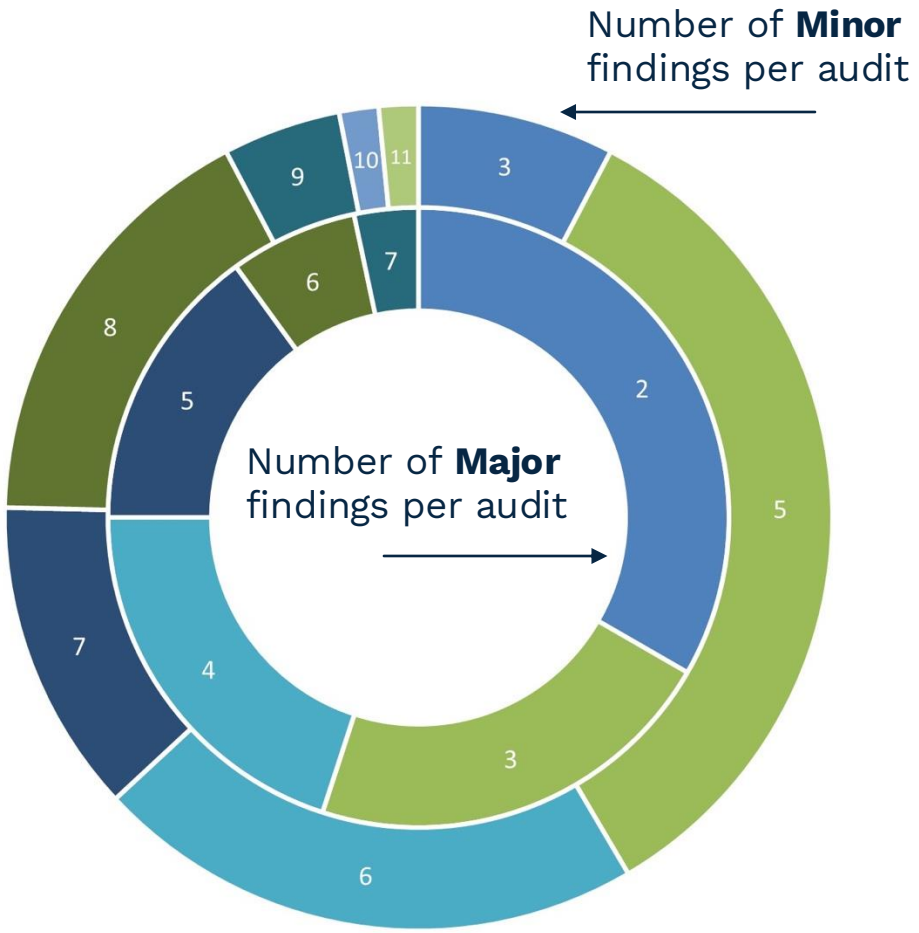
Factory Audits

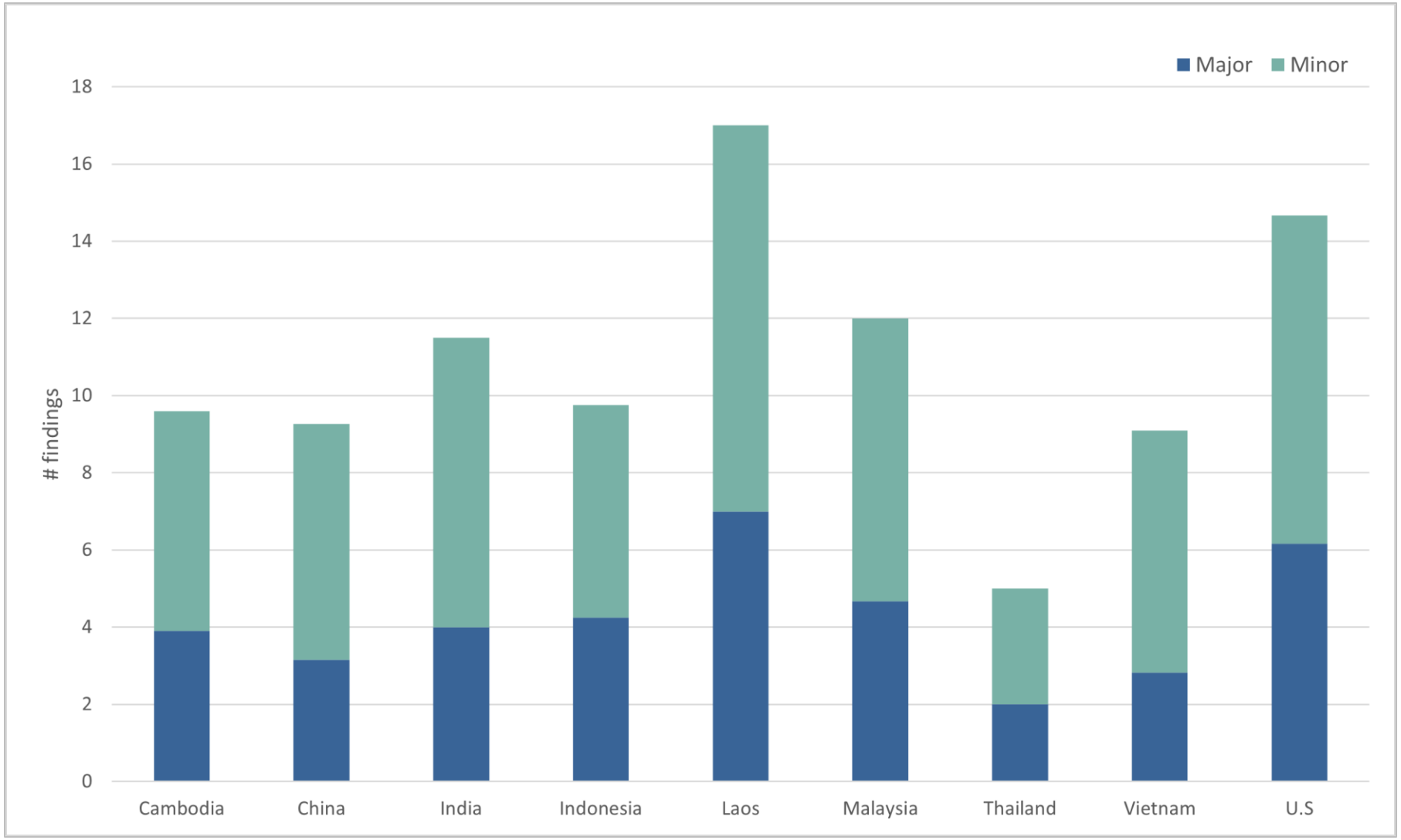
Audit Finding Analysis

- Factory audits assess overall manufacturing quality and performance and identify potential risks.
- Analysis reveals that over 70% of factories audited reported three or more Major findings,
- Audits provide characterized findings, and manufacturers will provide corrective plans which can be verified by production start.
- Quantity and severity of findings are a key input to developing coverage plans and if increased coverage is recommended.



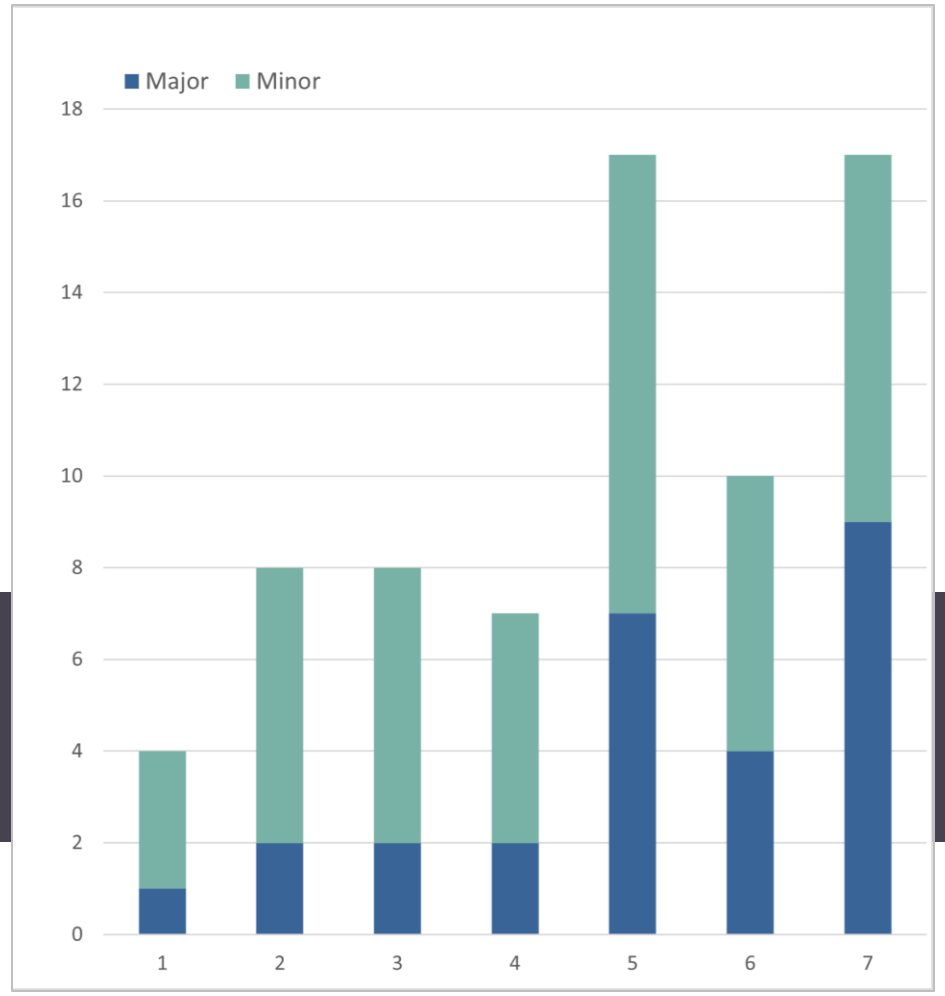
Quality Variability: Regional

- Higher number of findings in factories located in recently developed PV manufacturing hubs, such as the U.S, Laos, and India.
- Common quality findings identified in these factories include insufficient training for the equipment operators, poor equipment conditions, material mishandling.



- Bullet
- Bullet with two lines

Quality Variability: Factories

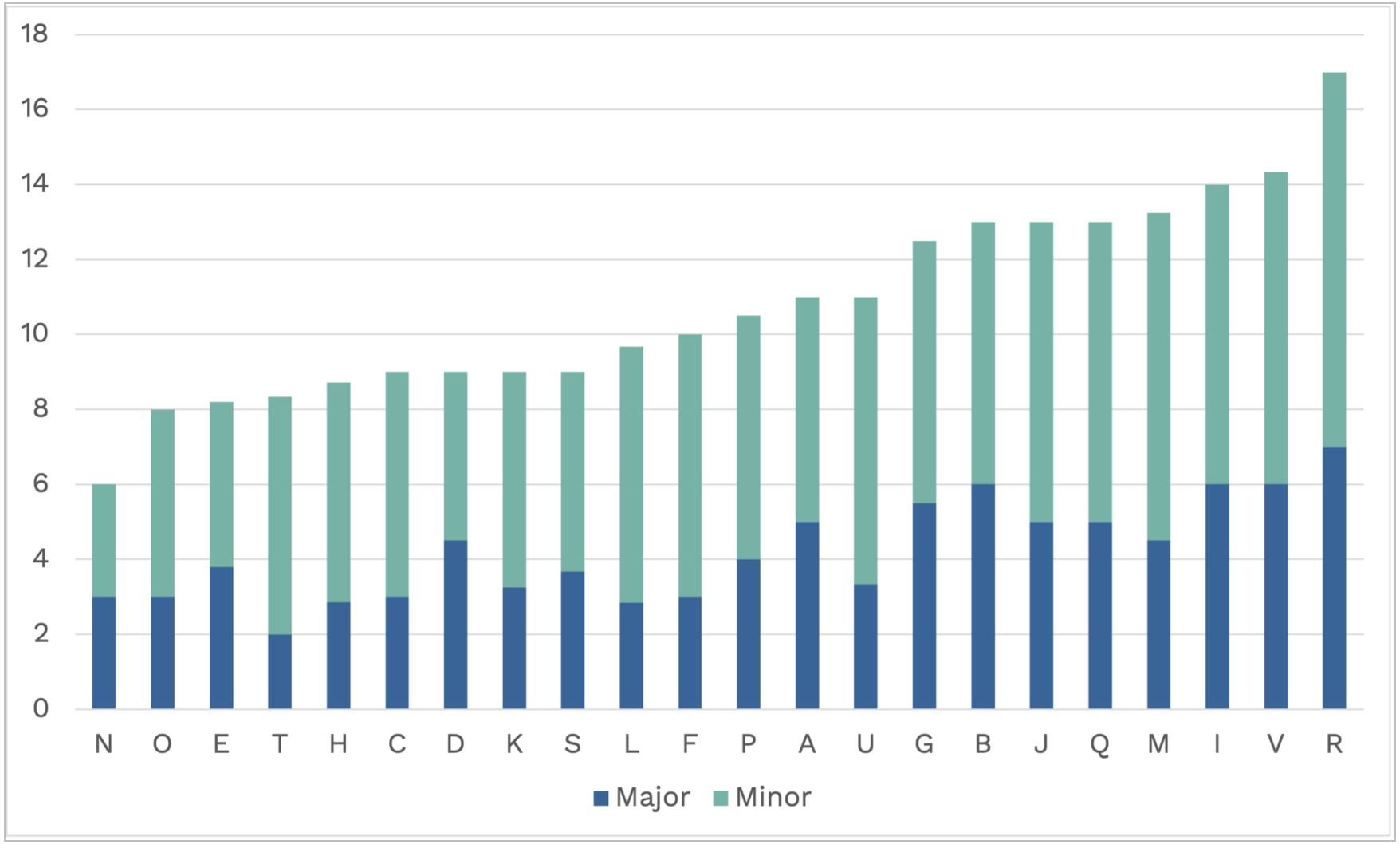


- Figure represents a case study of a single manufacturer's different factory locations.
- Significant variation among different factory locations
- While overarching QMS framework is consistent, the implementation of quality control me4asures can vary significantly.
- This variation underscores the importance of assessing each facility.

- Same "brand name" does not guarantee same level of each quality across factories or production lines.

Quality Variability: Manufacturers

- Similar variation occurs when comparing manufactures factory audit findings over 2024.
- This data also provides insight on the appropriate level of active production assurance activities to deploy for their produced batches.



Quality Variability: Manufacturers

Key Takeaways

- High level of quality issues (findings) are identified in new factories & regions.
- The same brand name does not mean the same level of quality
- End objectives include
- Corrective action plans and verification
- And Active and dynamic quality assurance plans and efficient scaling of activities.

Production
Oversight

Active Production Management

& Finding Characterizations

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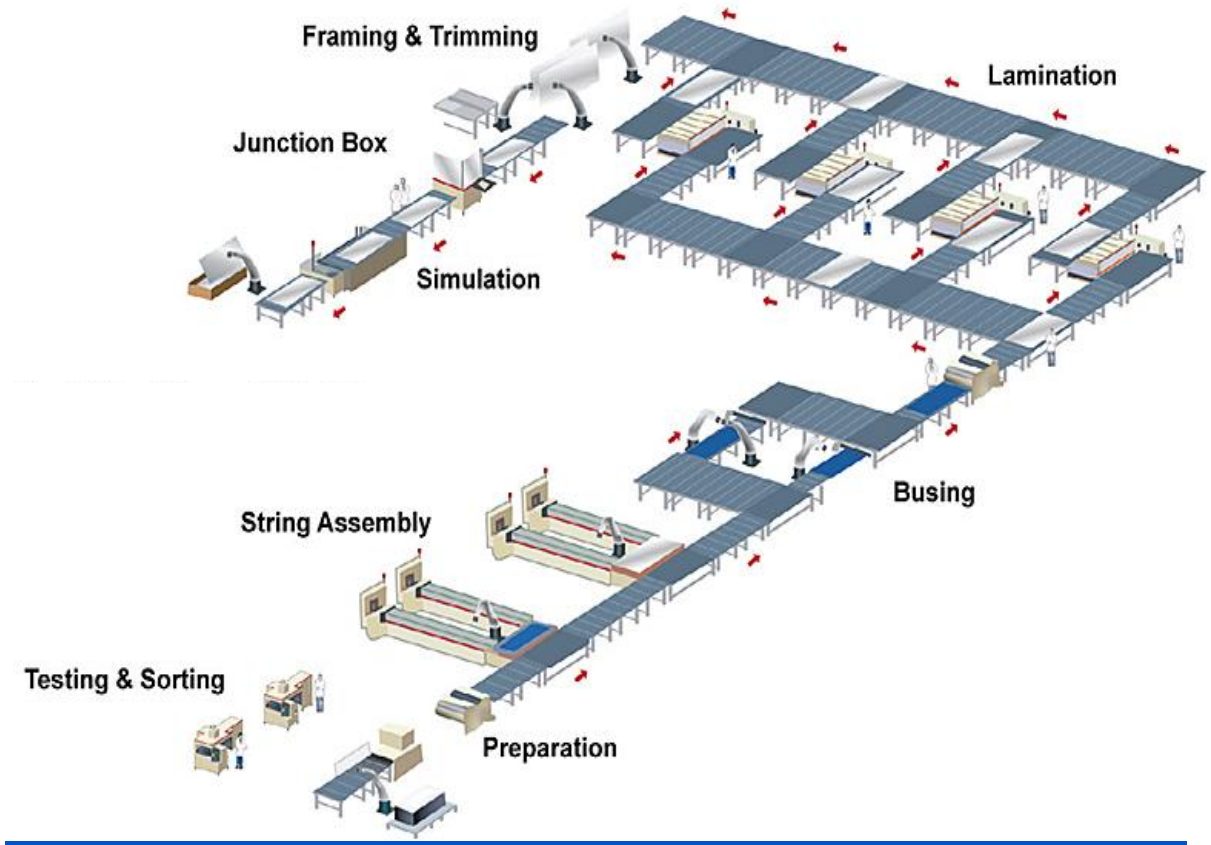
Production Oversight

At Kiwa PI Berlin, we provide *continuous in-factory monitoring* of PV module production to ensure the highest quality standards.

To mitigate these risks, our **production oversight** includes:

- In-factory monitoring of PV module production
- Quality assurance engineers deployed for oversight
- Ensuring correct application of materials, processes, and controls
- Conformance criteria applied at every production stage

Rapid Changes in the PV Industry and the Need for Continuous Monitoring



PV module manufacturing is a multi-stage process, where deviations and issues at any stage can lead to defects, posing risks to reliability and performance.

		2022	2024	2025 (Proj.)
Technology	TOPCon	18%	31%	55%
	PERC	82%	62%	35%
	HJT	1%	7%	10%
Busbars	MBB <10BB	64%	54%	35%
	SMBB >11BB	36%	46%	65%
Wafer size	M6	16%	8%	3%
	M10/M10R	69%	91%	96%
	M12	15%	1%	1%
Backsheet vs. glass:glass	Glass:Glass	63%	99%	99%
	Glass:BS	37%	1%	1%

Market *Trends*

- TOPCon and MBB continue to dominate year over year.
- The share of HJT and TOPCon modules has increased.
- Projection for 2025: TOPCon expected to exceed 55% market share.
- Industry has shifted to SMBB design.
- Wafer size has increased from M6 to M10.
- Nearly 100% of products are now glass-glass modules.

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Production Oversight

Factory, Product and BOM Certification Compliance

Bill of Materials (BOM):
- Incoming Quality Control
- Material Storage
- Materials Preparation
- WS and SOP

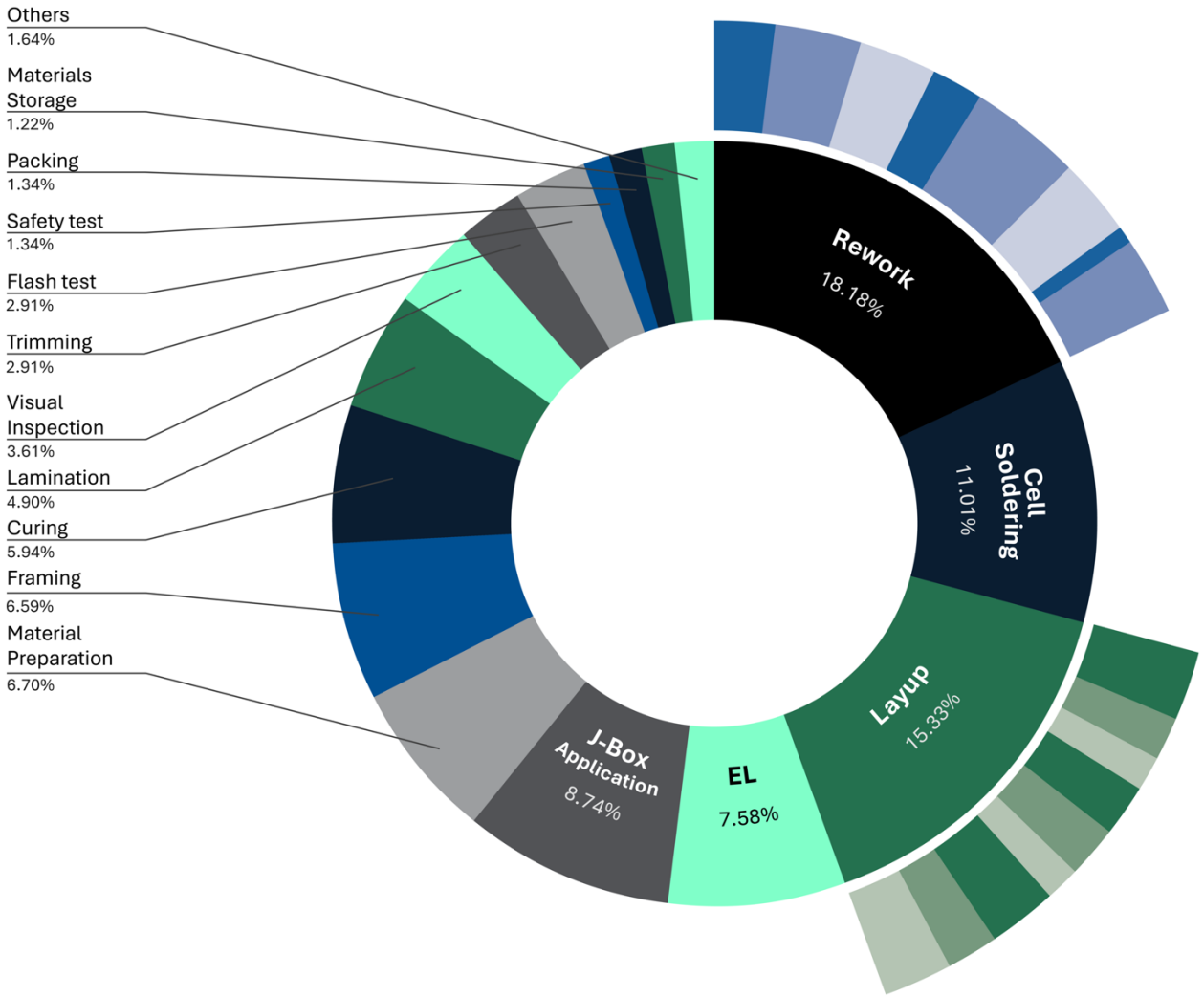
Equipment Control:
- Calibration
- Maintenance
- Management
- Commissioning
- WS and SOP

Production Process:
- Cell cutting
- Soldering
- Layup & Bussing
- Lamination
- Framing
- J- box installation
- WS and SOP

Testing & Inspection:
- Safety Tests
- Power Testing
- EL Inspection
- Visual Inspection
- Binning
- WS and SOP

Logistics:
- Packaging
- Storage
- Shipping
- WS and SOP

Findings Risk Assessment & Corrective Action Management



Oversight ***Observations***

- Every step of the production line and material flow is covered.
- Nearly 40% of defects are related to cell processing and soldering.
- The ratio of these findings has **increased** due to the introduction of **new cell and module technologies.**
- **Benchmarking manufacturers** using oversight metrics helps buyers assess **quality consistency**

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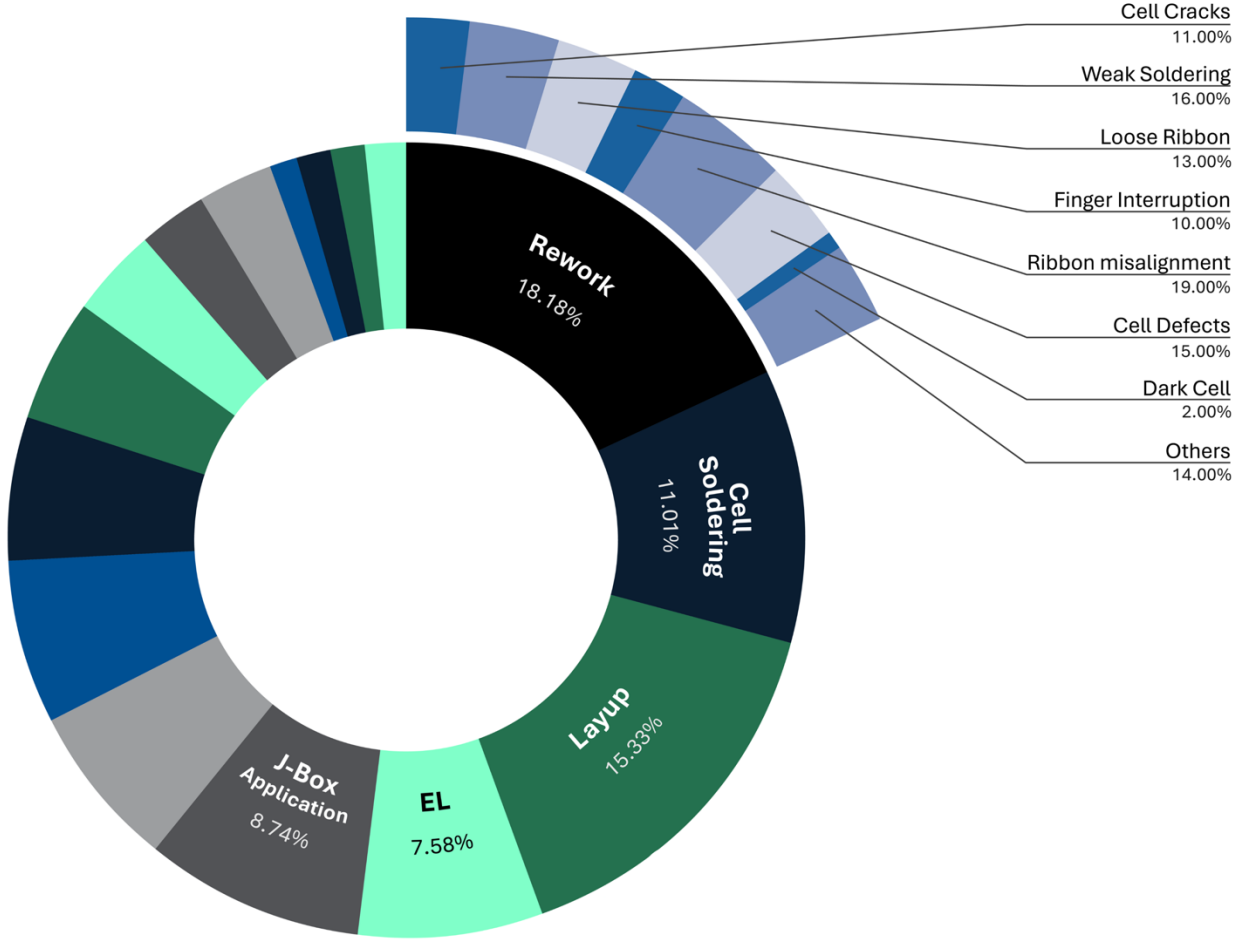

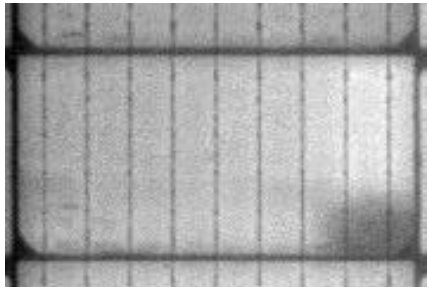

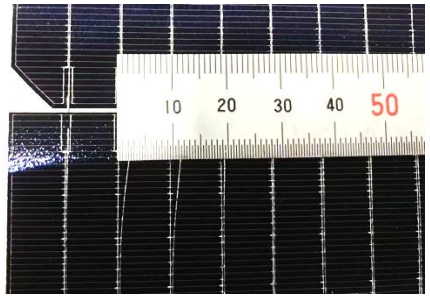

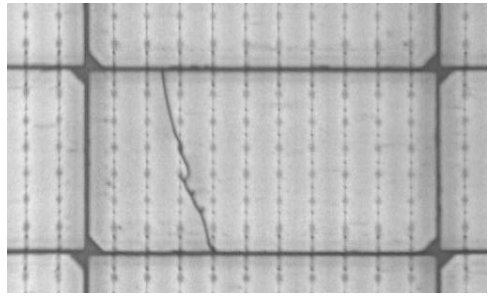

Cell Soldering & Rework

- New cell technologies are more sensitive to soldering & machine parameters
- Smaller process window for soldering in advanced cell designs
- New module designs contributing to higher rework rates

Challenges

- Manual soldering in rework poses high risks to module reliability & performance.

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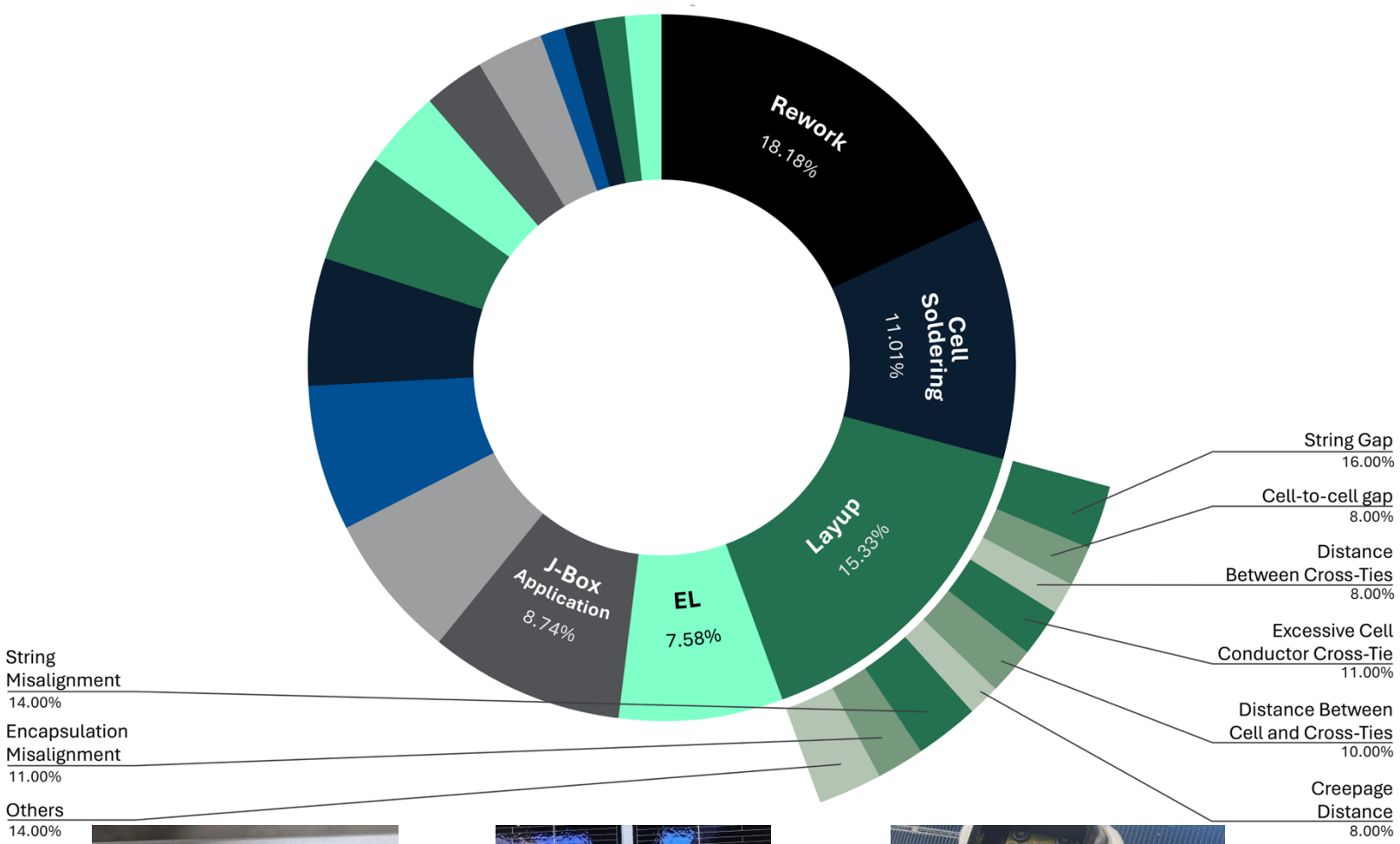

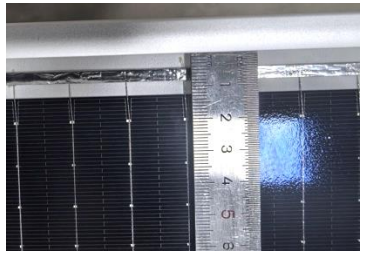

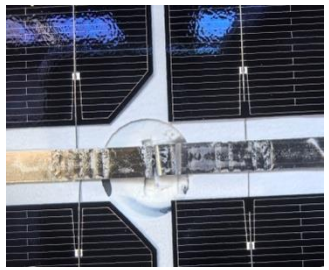

Layup

- Most layup findings have impact on **module safety**

Challenges:

POE encapsulant (low friction) increases misalignment risk

Larger PV cells reduce inter-cell gaps, making alignment critical

Junction Boxes

- **Main issues:** Improper installation, poor sealing and soldering defects

Risks:

Moisture ingress, electrical arcing, fire hazards

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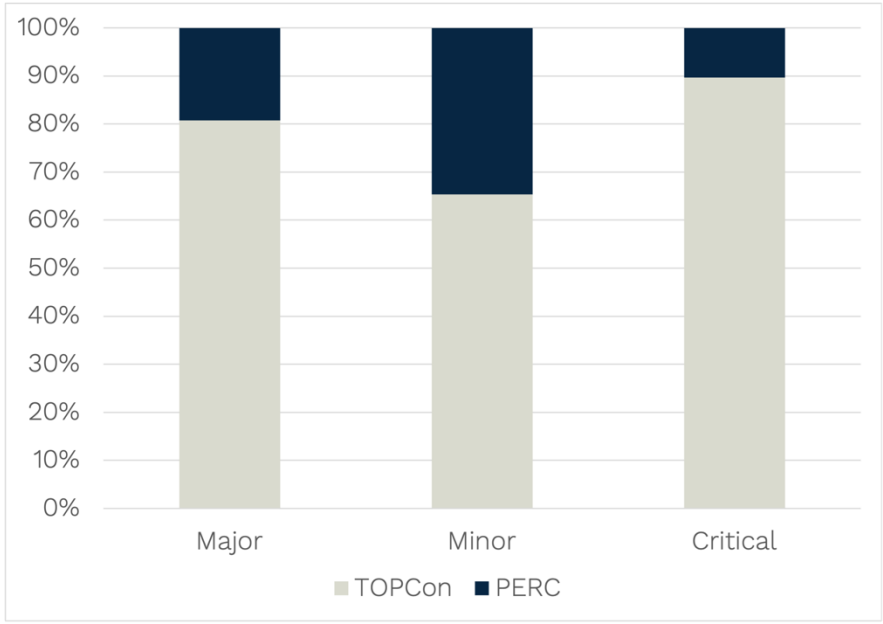
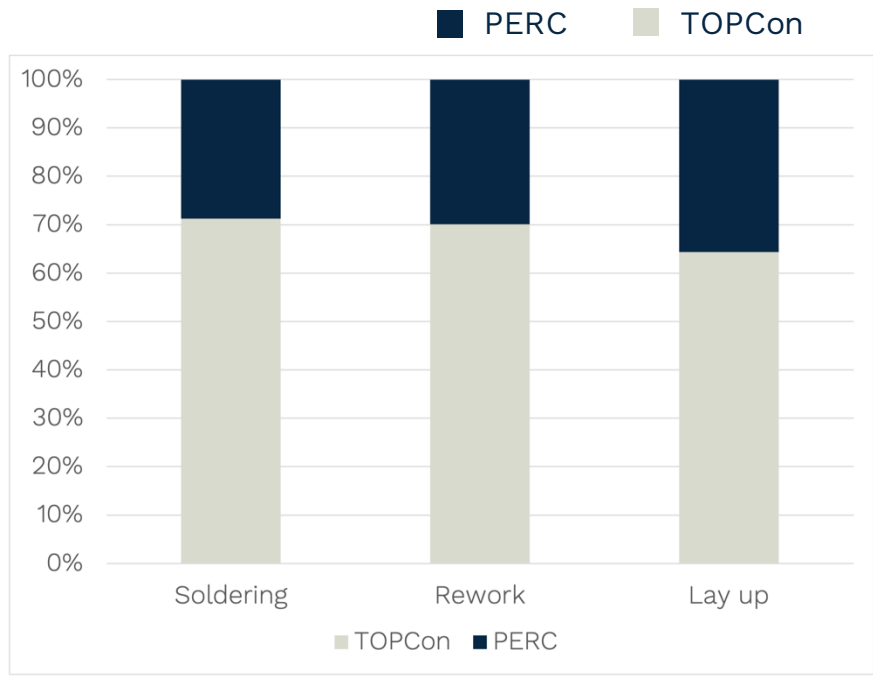
PV Cell Technology Variations

Defect Ratios by Cell Type

- TOPCon modules show significantly higher defect rates than PERC
- Key defect areas: Soldering, rework, layup misalignment
- Challenges with Emerging Technologies
- Sensitivity to soldering recipes & machine conditions
- Need for stricter process monitoring, calibration & staff training

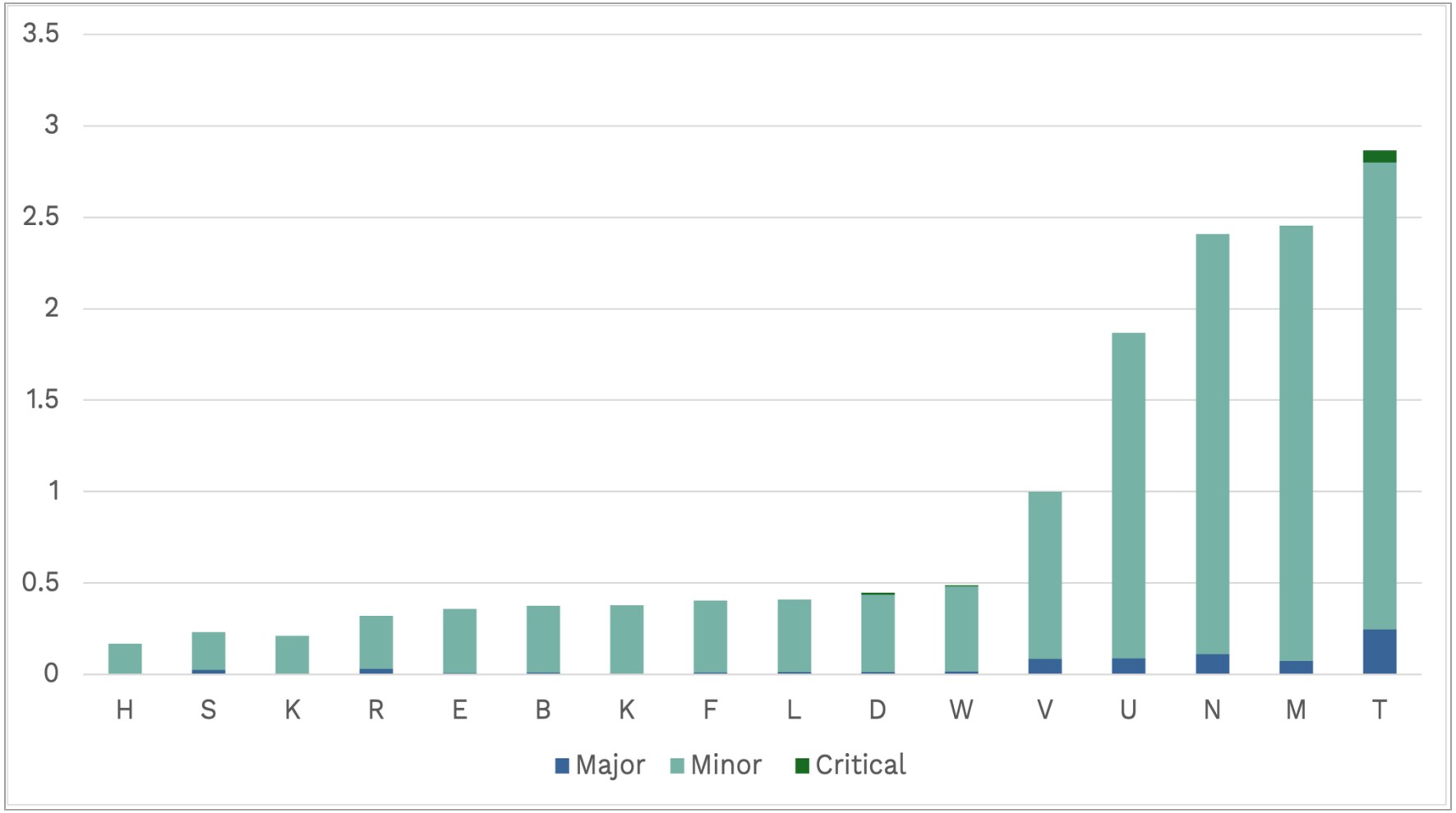




Industry Takeaway:
Stronger quality controls are essential for newer PV cell technologies

Quality Variations & Manufacturer Benchmarking

- Significant variation in findings across manufacturers.
- The top five manufacturers consistently demonstrate higher quality, while the bottom three exhibit notable gaps.
- This disparity highlights the need for continuous quality monitoring and detailed oversight.
- Maintaining consistency, reliability, and performance requires rigorous benchmarking.



Pre-Shipment
Inspections

Active AQL Management

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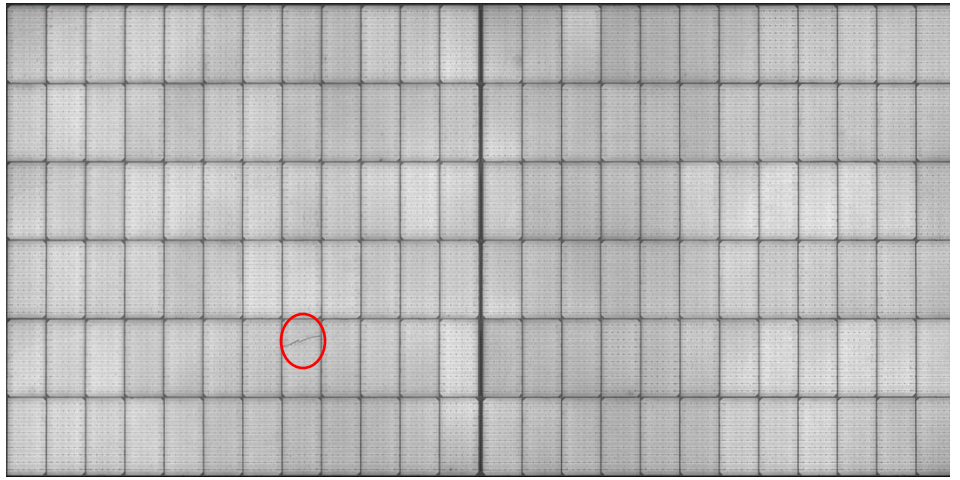
Overview

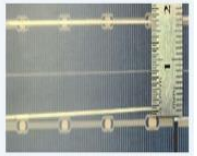
What are Pre-Shipment Inspections (PSI)?

- End of production line inspections and characterizations.
- Typically are “re-inspections” to verify the factory is meeting agreed-to inspection criteria.
- Rapid inspections on each batch prior to the modules leaving the factory.

Essentials

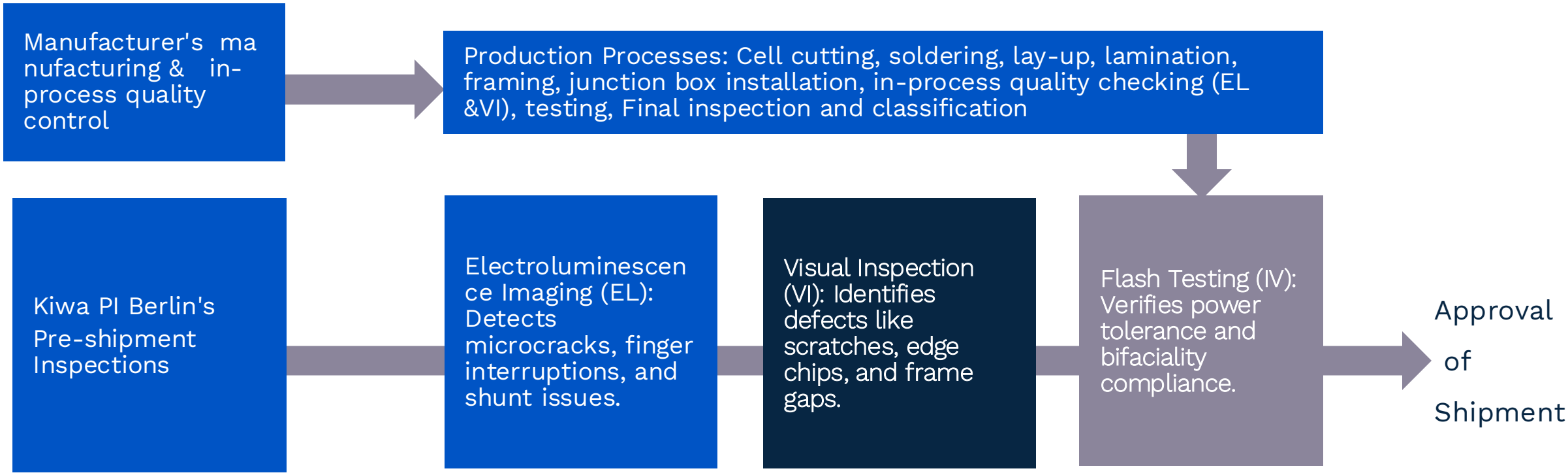
- **Definition**: End-of-line quality checks on finished goods before shipment.
- **Purpose**: Validate manufacturer quality control using ISO 2859-1:1999 & AQL standards.
- **Scope**: Conducted on a sample basis; defects documented for evaluation.
- **Impact**: Ensures quality compliance before shipment to buyers.



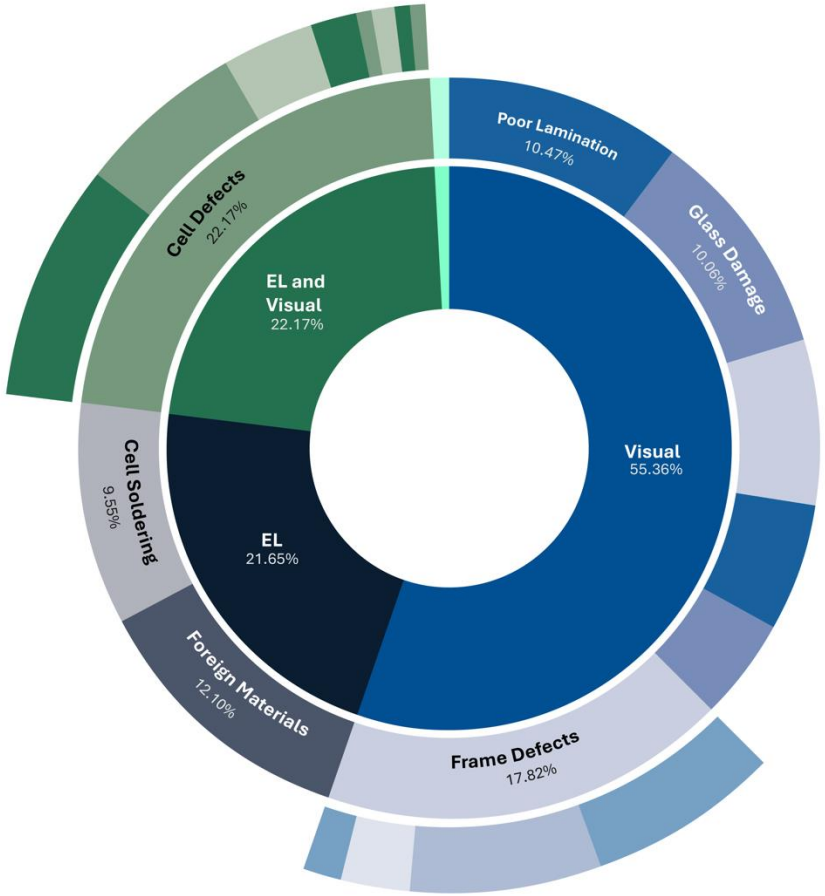
Component	Description	Defect class	Image
Cable	Cable insulation damaged resulting in exposed wires	Critical	
Cell	Misaligned wire	Major	
Frame adhesive	Silicone residue	Minor	

Overview

Key aspects of PSI



Common ***Defects***



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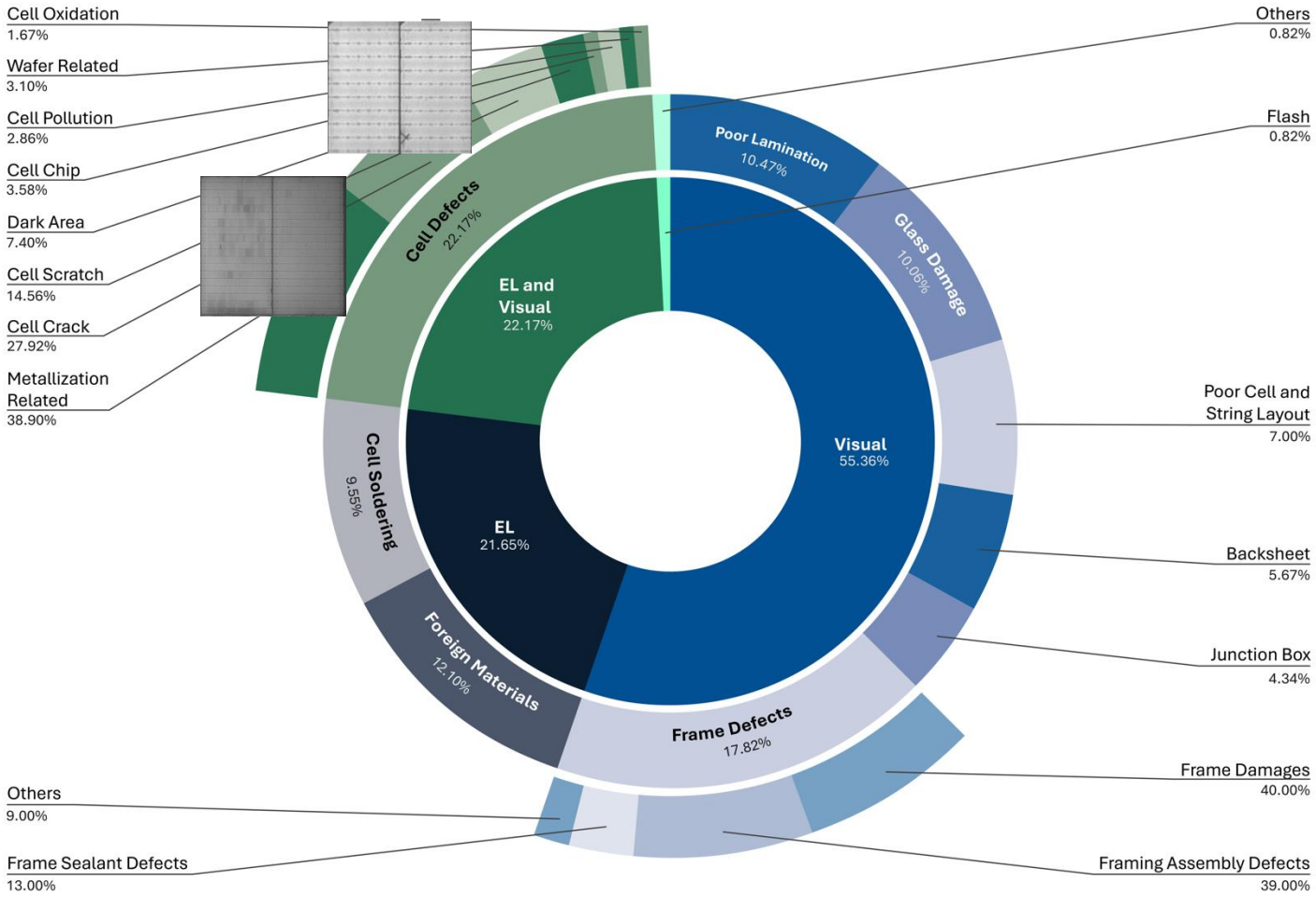

Common *Defects*

Trends

Cell defects are the most common issue, consistently accounting for more than one-fifth of all problems

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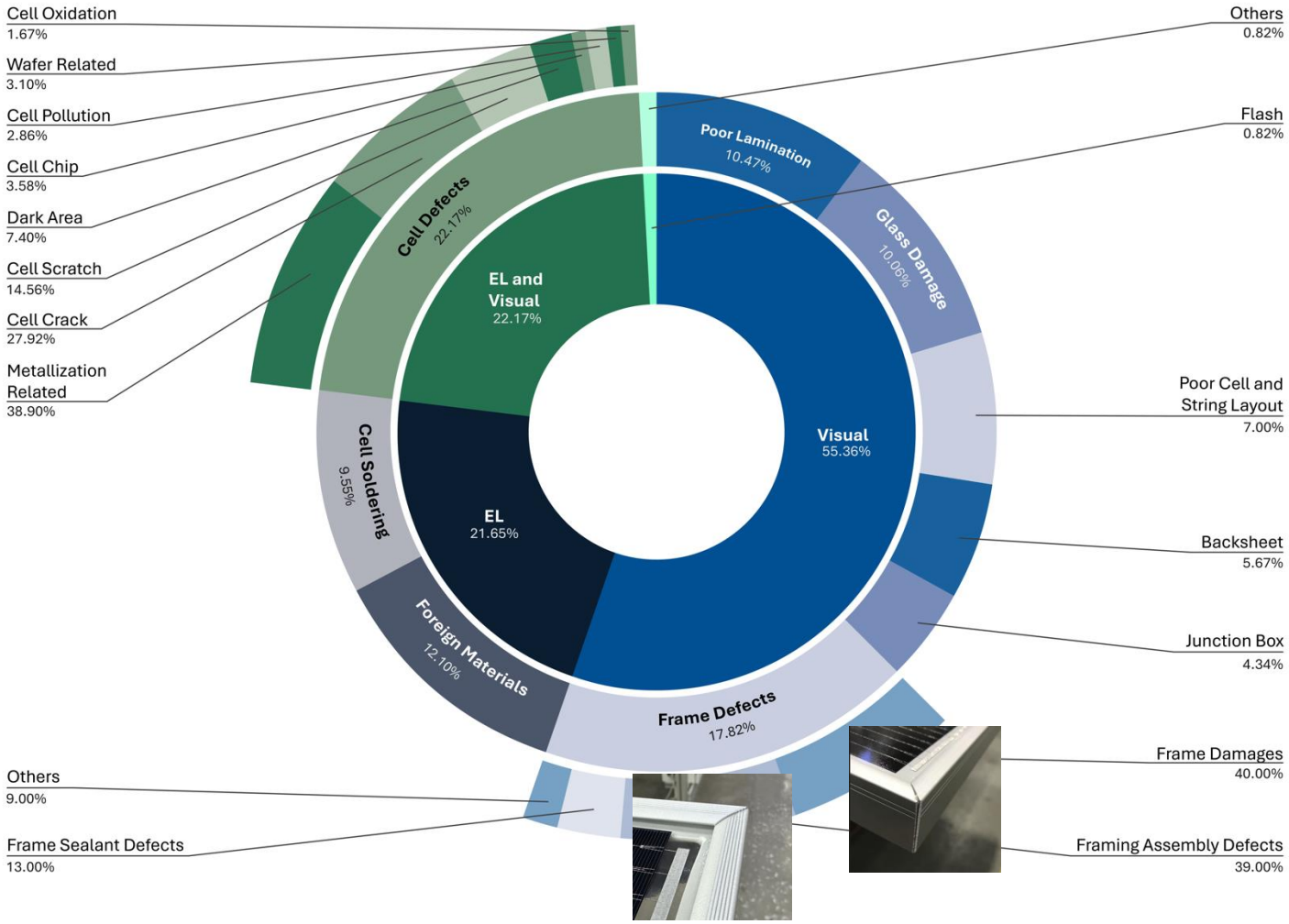

Common ***Defects***

Trends

Cell defects are the most common issue, consistently accounting for more than one-fifth of all problems

Frame damage unexpectedly ranks as the second-largest defect category (17.82%), with recent high module breakage rate in the field possibly linked to this issue

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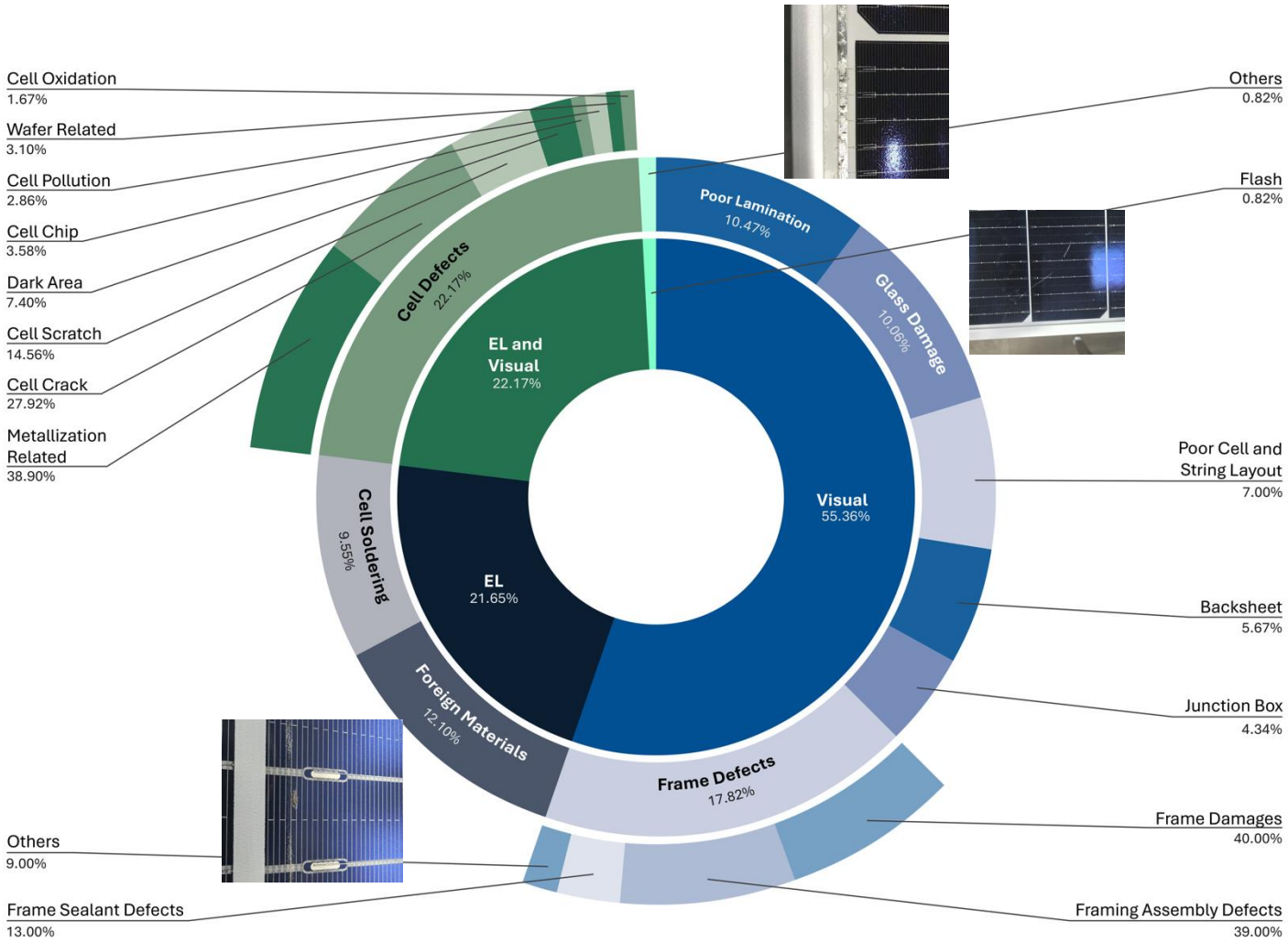

Common ***Defects***

Trends

Other Defects Impacting PV Module Reliability

Foreign Materials (12.1%) – Contamination can lead to mechanical &electrical degradation.

Poor Lamination (10.47%) – Increases risk of delamination & structural instability.

Glass Damage (10.06%) – Scratches weaken mechanical strength & durability caused high breakage rate in the field

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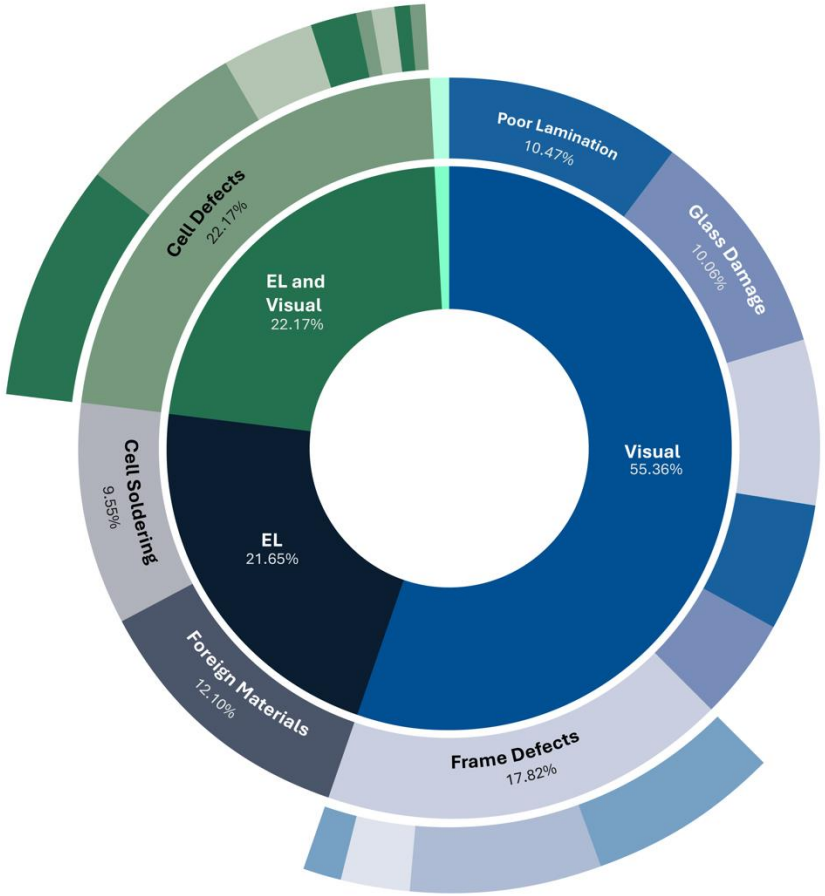

Common ***Defects***

Cell Defects

Cell Defects (22% of total defects)Industry shift from PERC to TOPCon increasing defect rates.

Metallization defects (39%) are the most prevalent, affecting module performance.

Cell cracks significantly impact structural integrity and reliability.

Solution: Enhanced quality control and audits of cell production facilities.

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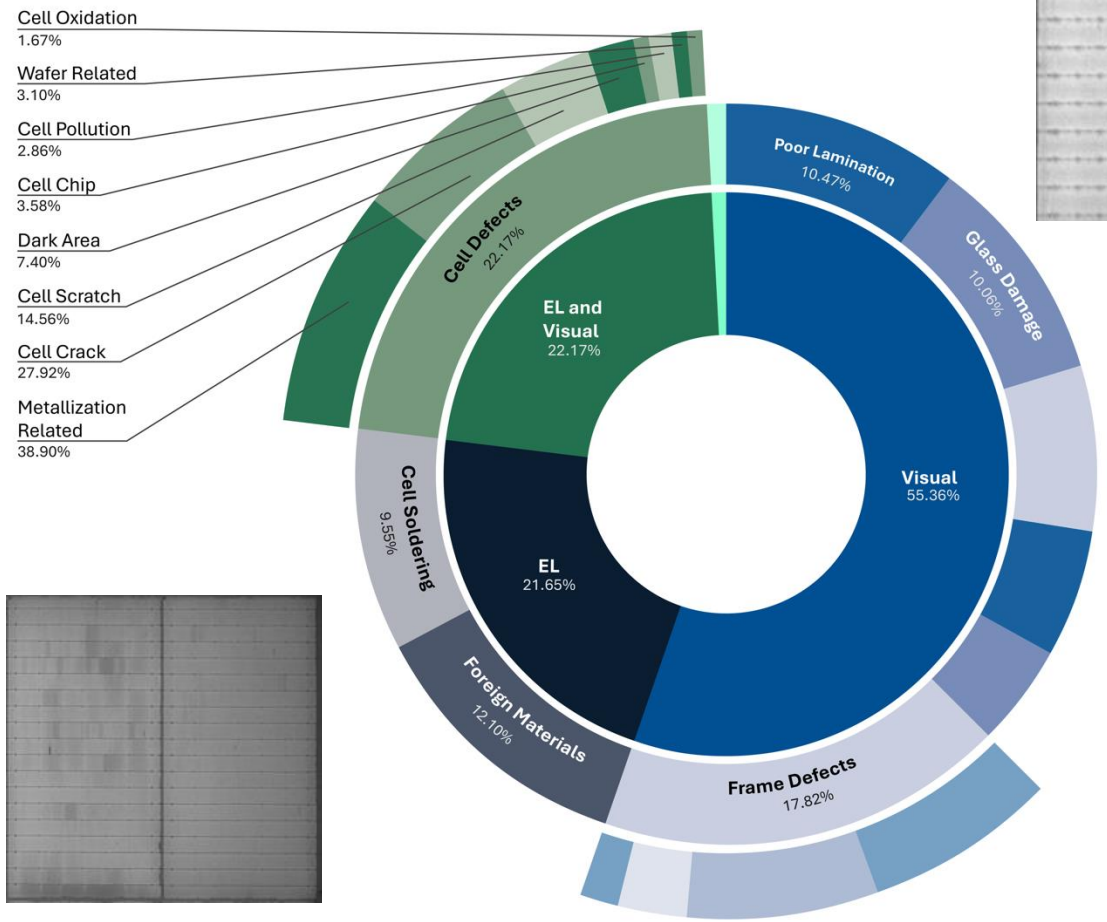

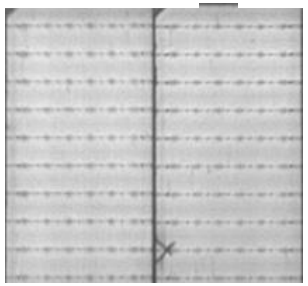

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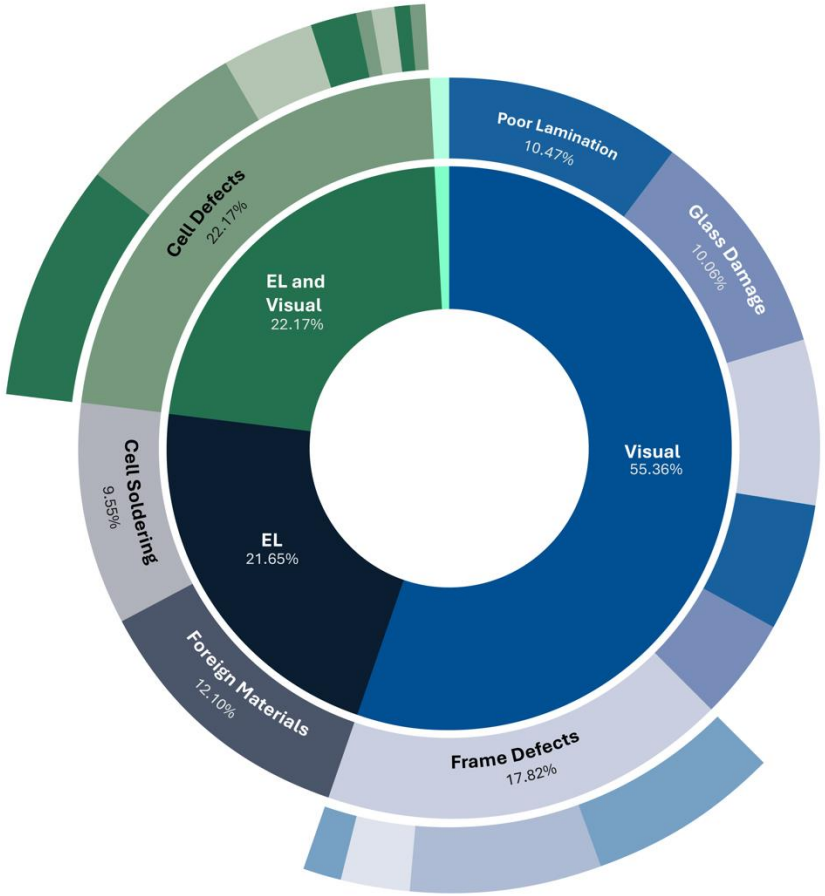


Common ***Defects***

Frame Defects

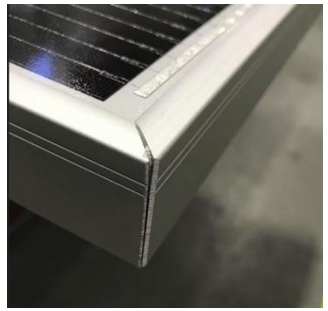
Frame damage (40%): Mostly superficial but requires monitoring.

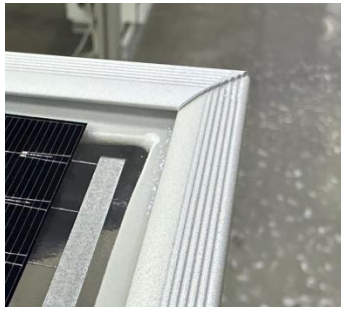
Framing & assembly defects (39%): Improper alignment, frame gaps, sharp corners.

Weak framing linked to module breakage during mechanical stress testing.

Example: Inadequate sealant application led to glass breakage and frame detachment.

Solution: Strict process controls, operator training, and quality audits.





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Common ***Defects***

Frame Defects

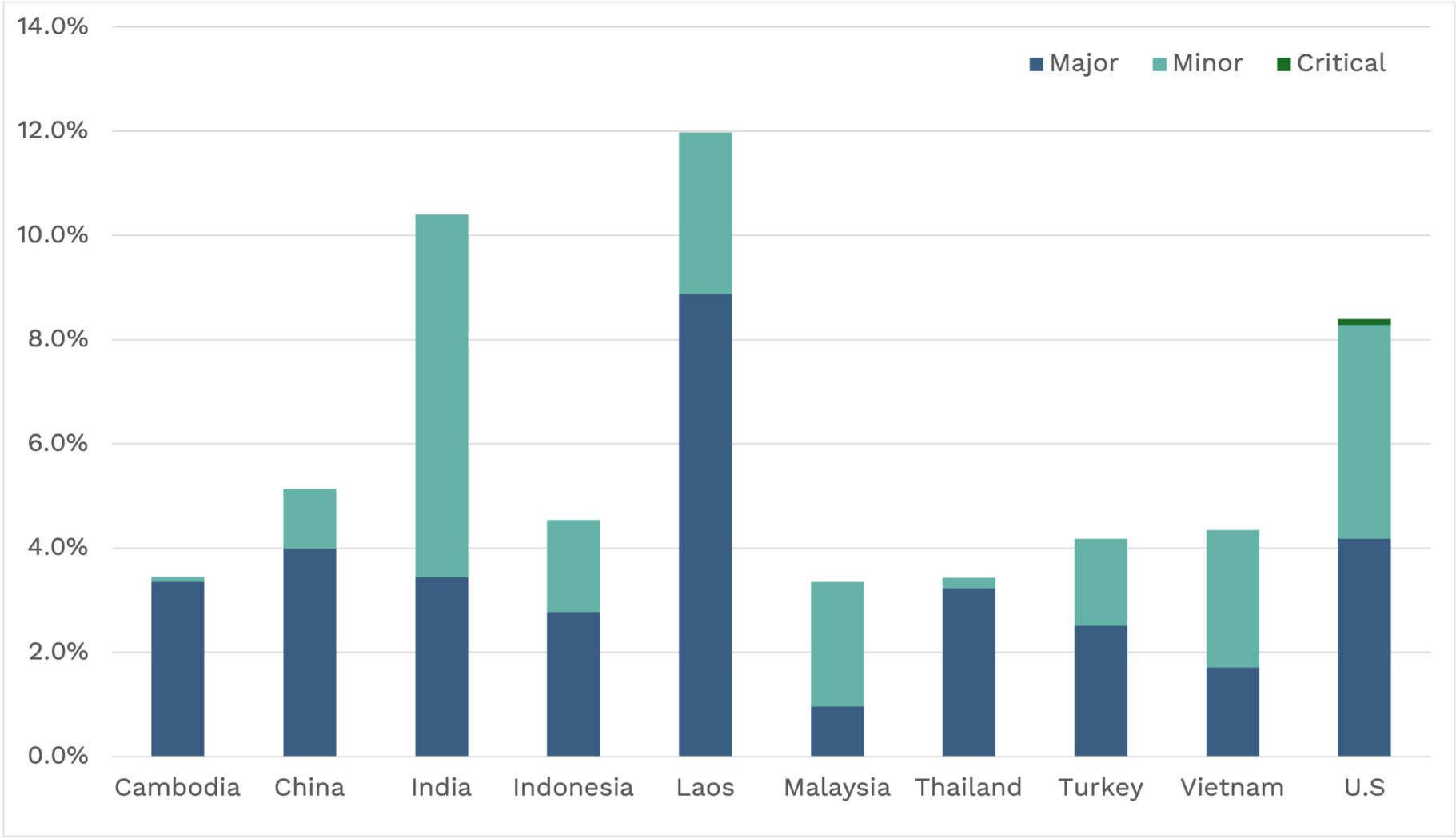
Sealant Defects (13%)Result from inconsistent application during manufacturing.

Can cause moisture ingress, compromising frame integrity. Missing sealant weaken mechanical strength to cause module breakage in the field.

Solution: Stringent quality control and more defection in sealant application.

Regional Variability

- High Defect Rates Linked to rapid expansion, workforce training challenges, and quality control gaps.
- Moderate Defect Rates - Large-scale production leads to variation in quality.
- New production but benefiting from prior experience.
- Low Defect Rates- Mature manufacturing systems, strong quality control, & efficient supply chains., material mishandling

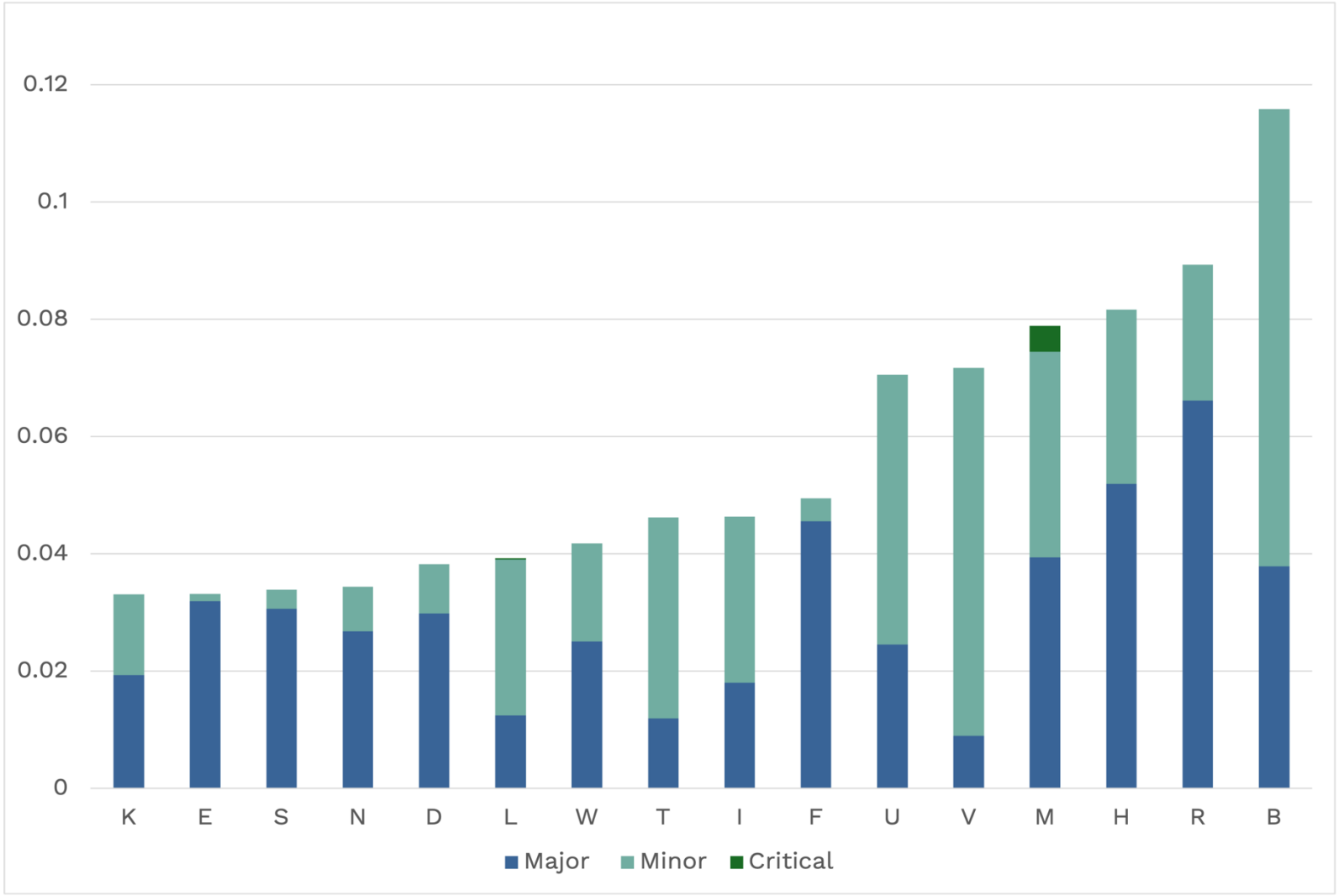


PSI Benchmarking

- Differences in Quality Management Systems (QMS), workforce training, and SOP adherence
- Training & Experience
- Standard Work Procedures: Clear guidelines ensure uniformity and reduce deviations.

Benchmarking Benefits

- PSI data allows buyers to compare manufacturers and improve quality control.
- Helps identify best-performing suppliers and drive industry-wide improvements.



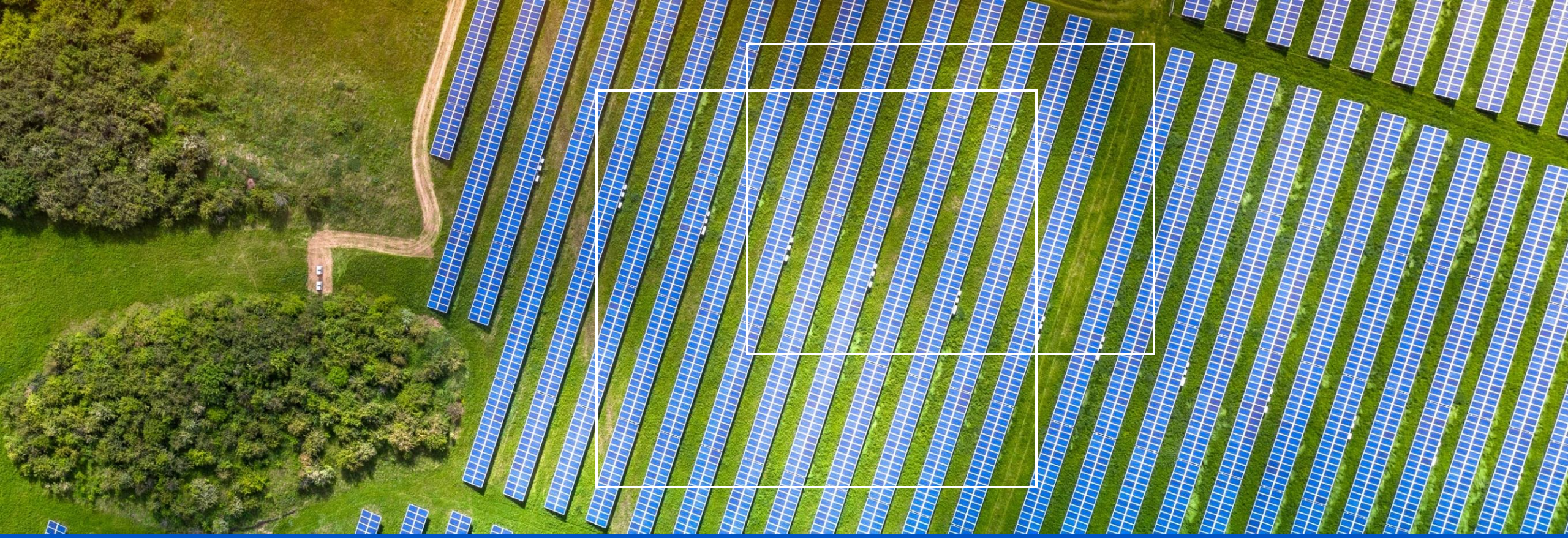
Overview

Key Takeaways

- 2024 Defects: Leading issues include PV cell metallization, cracking, and frame defects.
- Stricter AQL Needed: Buyers should negotiate tighter criteria to improve standards.
- Manufacturing Trends: Higher defect rates at newer hubs highlight the need for oversight.
- Benchmarking Value: Levelized PSI results allow buyers to compare supplier quality.

Conclusion

- Active Quality Management is Critical
  - 2024 highlighted the importance of buyers & investors managing PV module quality.
  - Tools like factory audits, supply chain assessments, and PSI help improve module reliability.
- Key Industry Insights
  - Regular factory-based QA trips reveal manufacturing trends & risks.
  - Third-party QA services protect solar investments and ensure long-term performance.
- Kiwa PI Berlin’s Expertise
  - Over a decade of global experience in PV quality assurance.
  - Trusted by utilities, investors, developers, and EPCs worldwide.
  - Expert teams in Asia, Europe, and the Americas, reducing risk in PV and storage assets.
- Key Takeaway: Independent QA oversight is essential to safeguard investments and drive quality improvements in the solar industry



Thank You!

Kiwa PI Berlin

Q&A

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