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PV module quality control and testing: using data and analysis to enhance safety and performance

9 October 2024

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Welcome!

Do you have any questions? ❓ 🙋

Send them in via the Q&A tab. 👉 We aim to answer as many as we can today!

You can also let us know of any tech problems there.

We are recording this webinar today. 🎥

We'll let you know by email where to find it and the slide deck, so you can re-watch it at your convenience. 👀 💡

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INSIGHTS

Ensuring PV Manufacturing Quality

A guide to the most common quality issues in module manufacturing

October 2024

2023-2024 Data Reveals Concerning Quality Trends in PV Manufacturing

Nearly 60% of factories received a high-risk quality rating or worse

New production lines present significantly higher risks

The most critical problems are concentrated in the **early stages of production**

Over the Past 8 Years, CEA Has Conducted Over 70,000 Inspections in 300+ PV Module Factories

The following report summarizes our latest QA data and insights

CEA Collects Data From All Stages of Quality Assurance

1. Pre-production Factory Audit (findings)
2. Inline Production Monitoring (findings)
3. Pre-shipment Inspection (defects)
4. Container Loading Inspection (findings)
5. Batch Testing (test results)

Findings and defects are classified in three categories by severity:

Severity	Definition
Critical	Findings or defects that may result in severe safety risks and hazardous conditions. They are likely to cause damage to other products or property, trigger non-compliance regulatory issues, and generally constitute a breach of mandatory regulations.
Major	Findings or defects that may reduce the product's functionality or impact safety in the short or long term.
Minor	Findings or defects which do not pose a clear risk of product failure, but rather fall outside the quality requirements.

Pre-production Factory Audit

Before production begins, two auditors visit a supplier's factory to check how well the factory's quality and production processes are working. They examine both the written procedures and how things are actually done on the ground. The goal is to see if the factory can meet the quality standards set by the client and ensure they can consistently deliver products that meet these expectations.

Examples of inspection areas (1000+ items in CEA's checklists):

A. Change control management
B. Customer complaints management
C. Employee management
D. Material management
E. Production area environment
F. Production process management
G. Equipment management evaluation
H. Quality control
I. Finished product management
J. Loading and logistics management
K. Testing laboratory management

CEA assigns a severity to each finding depending on the risk level of the issue. Findings of each stage are then classified in three categories by severity:

- Minor
- Major
- Critical

The findings result in a numerical risk score with a corresponding grade. The grade ranges are decided based on the global distribution of factory scores:

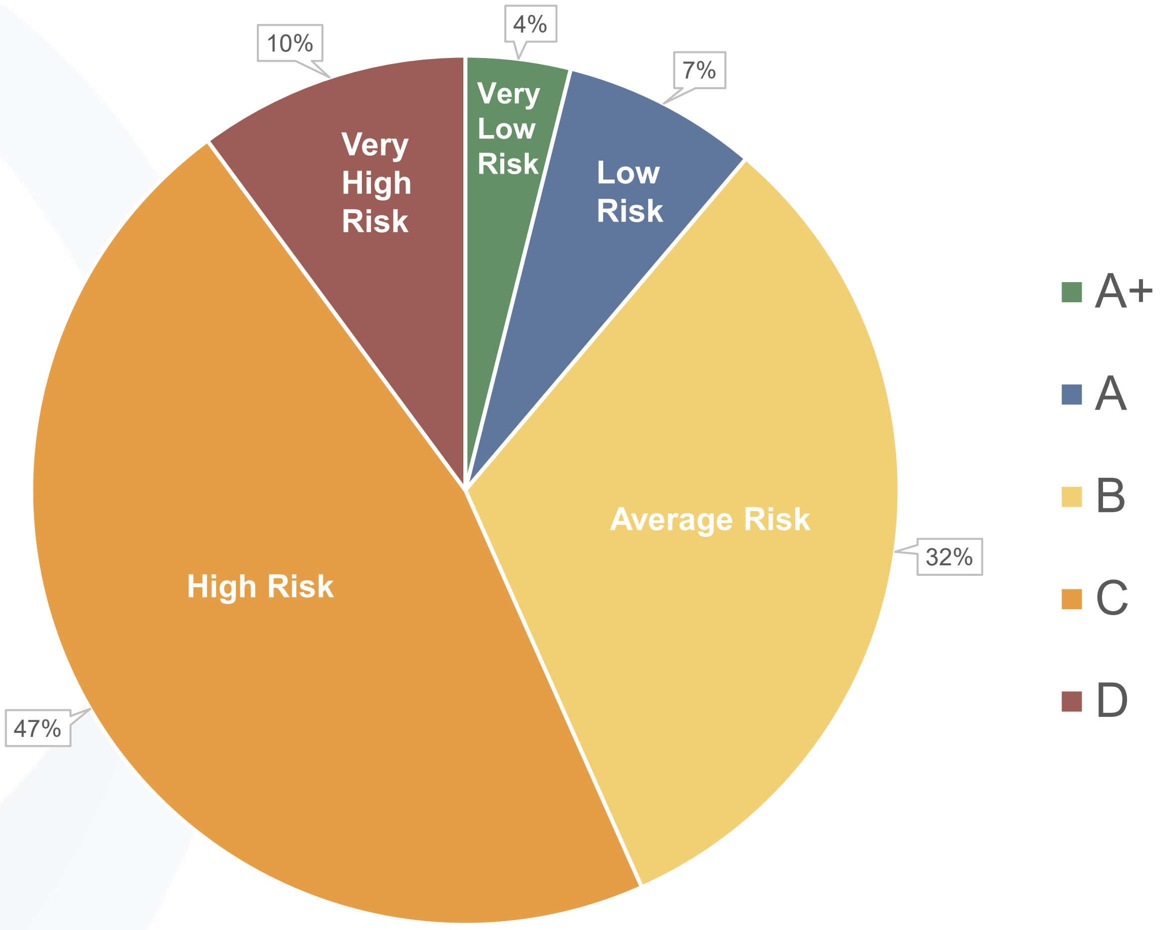
Grade	Description	Risk analysis
A+	Great location/supplier	Very low quality risk
A	Good location/supplier	Low quality risk
B	Average location/supplier	Average quality risk
C	Basic location/supplier	High quality risk
D	Risky location/supplier	Very high quality risk

Nearly 60% of Factories Received a High-Risk Quality Rating or Worse

*C or D rated factories typically have multiple **major** findings and possibly one or more **critical** findings*

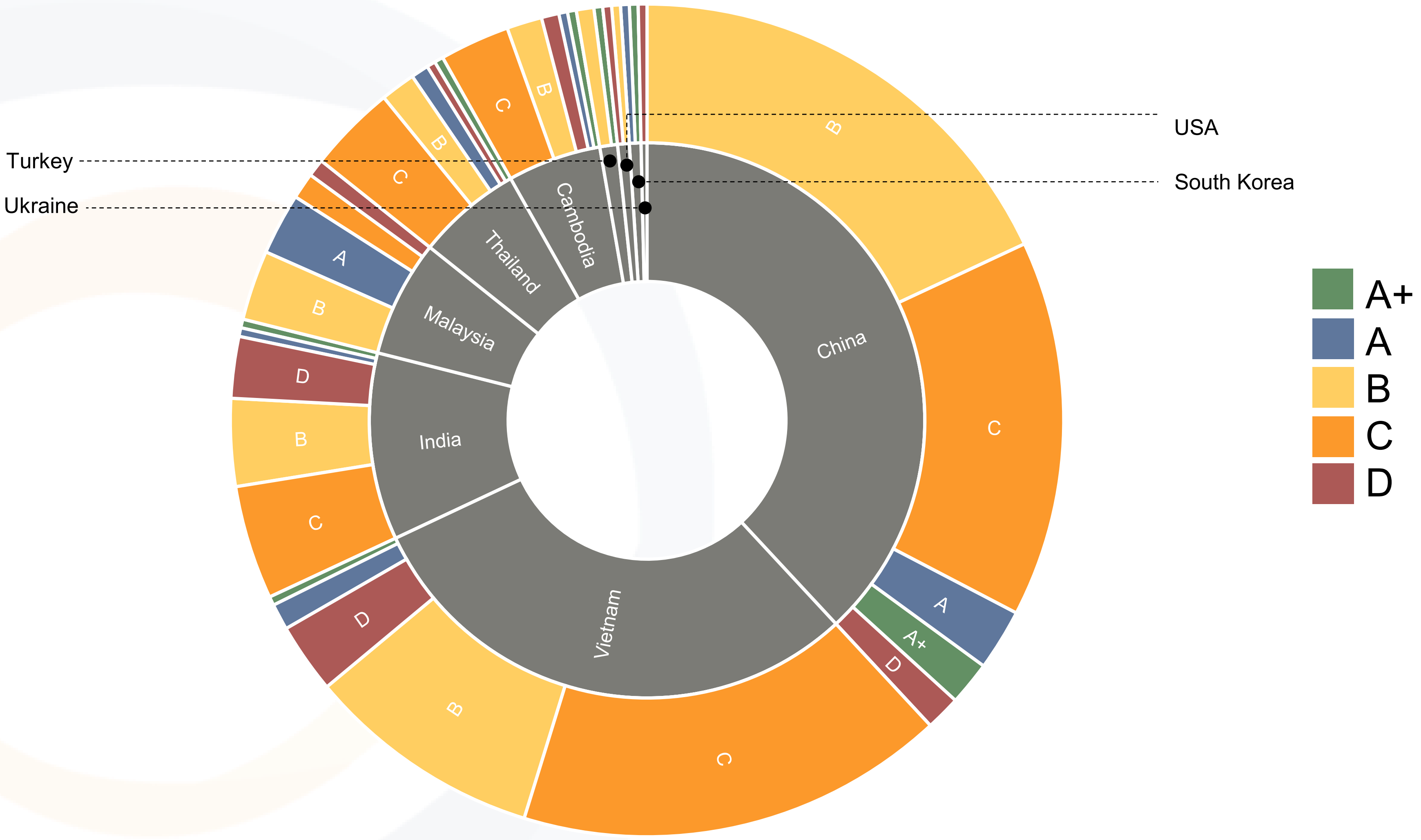
Major findings may reduce the product's functionality or impact safety in either short or long term.

Critical findings may result in severe safety risks and hazardous conditions and are likely to cause damage to other products or property, trigger non-compliance regulatory issues.



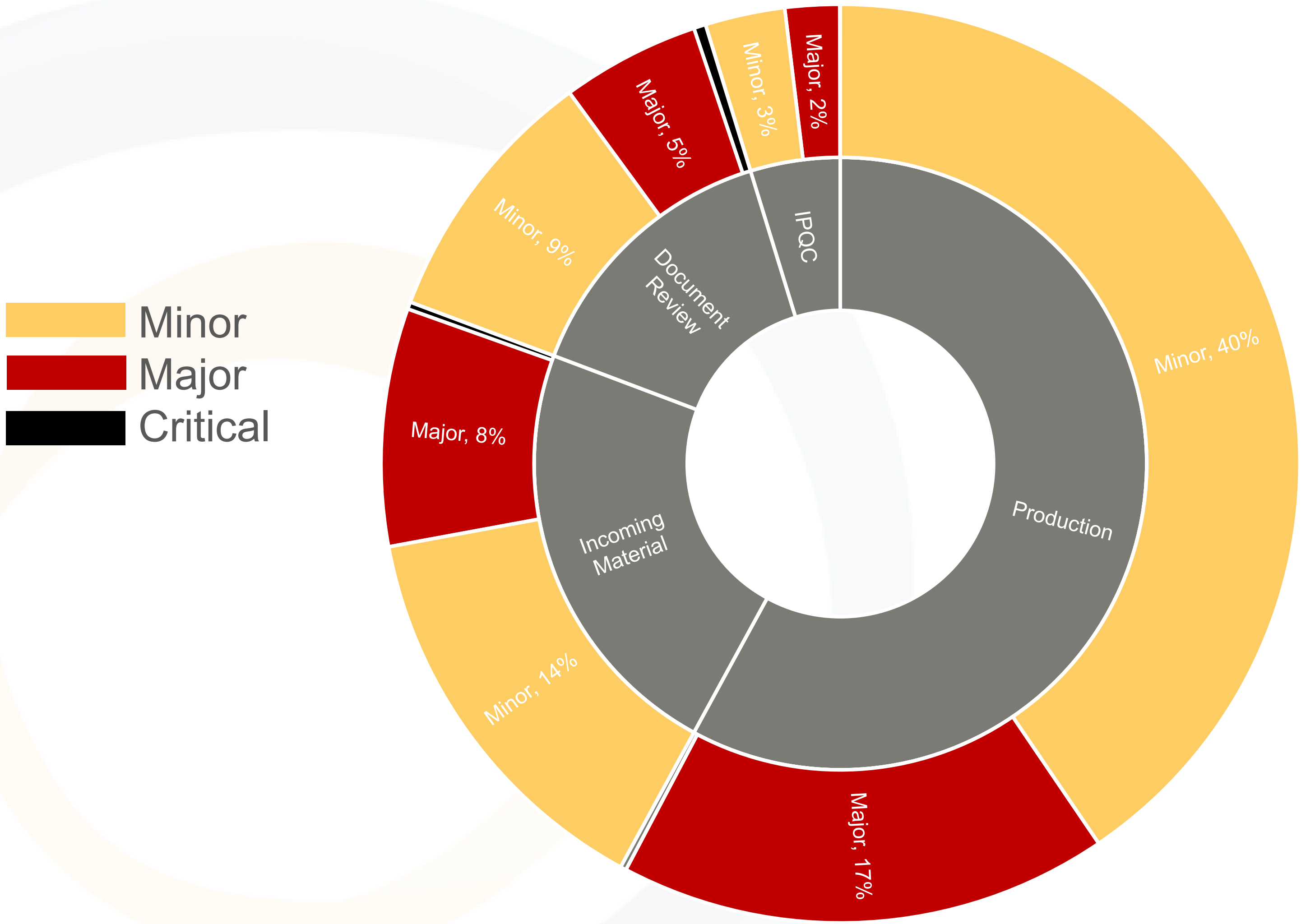
Share of factory average quarterly grade 2020-23

Significant Quality Problems Were Identified in Factories in Every Geography



FA factory quarterly average grade by country 2020-2023

Major Issues Occur at Every Stage of Factory Operations



Note: IPQC stands for In Process Quality Control

Factory Audit findings distribution by severity: 2020-23

Inline Production Monitoring

Ensuring Quality Throughout Production

Engineers supervise the production process according to requirements of the customer‘s contract:

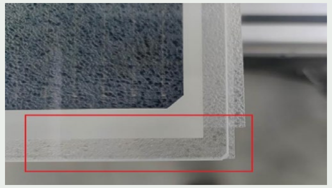
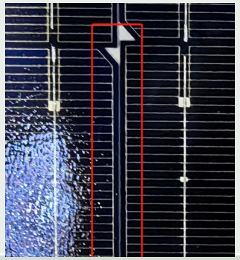
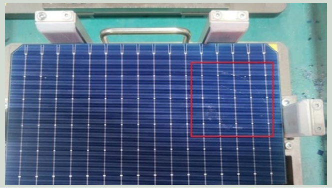
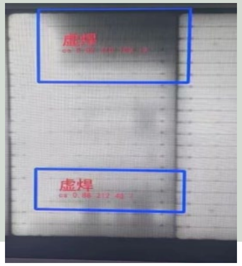
- The Quality Control Engineer (QCE) notes risks in manufacturing quality and monitors the adherence to the supplier's quality system in an objective and fair manner.
- Daily on-site inspections of the production process follow the supplier‘s quality control plan (QCP) and standard operating procedures (SOP) as well as industry best practices.

Examples of inspection areas (checklist of 280+ items):

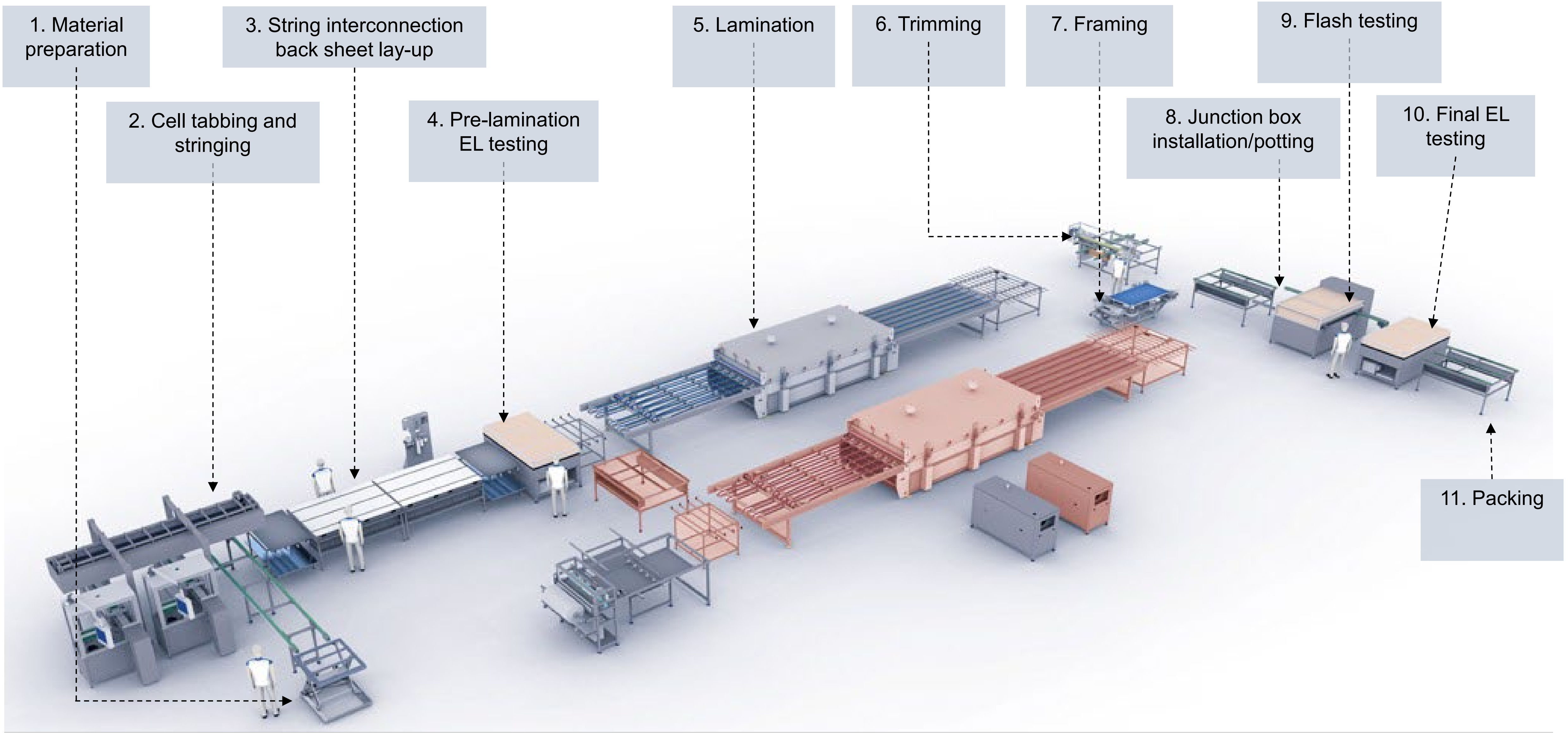
- Incoming materials quality control and inspection
- BOM conformity
- Instrument and production line calibration
- Inline QC monitoring
- Packaging and warehouse inspections

Major risks are escalated directly to the client, while CEA also actively provides recommendations for improvements to the manufacturer.

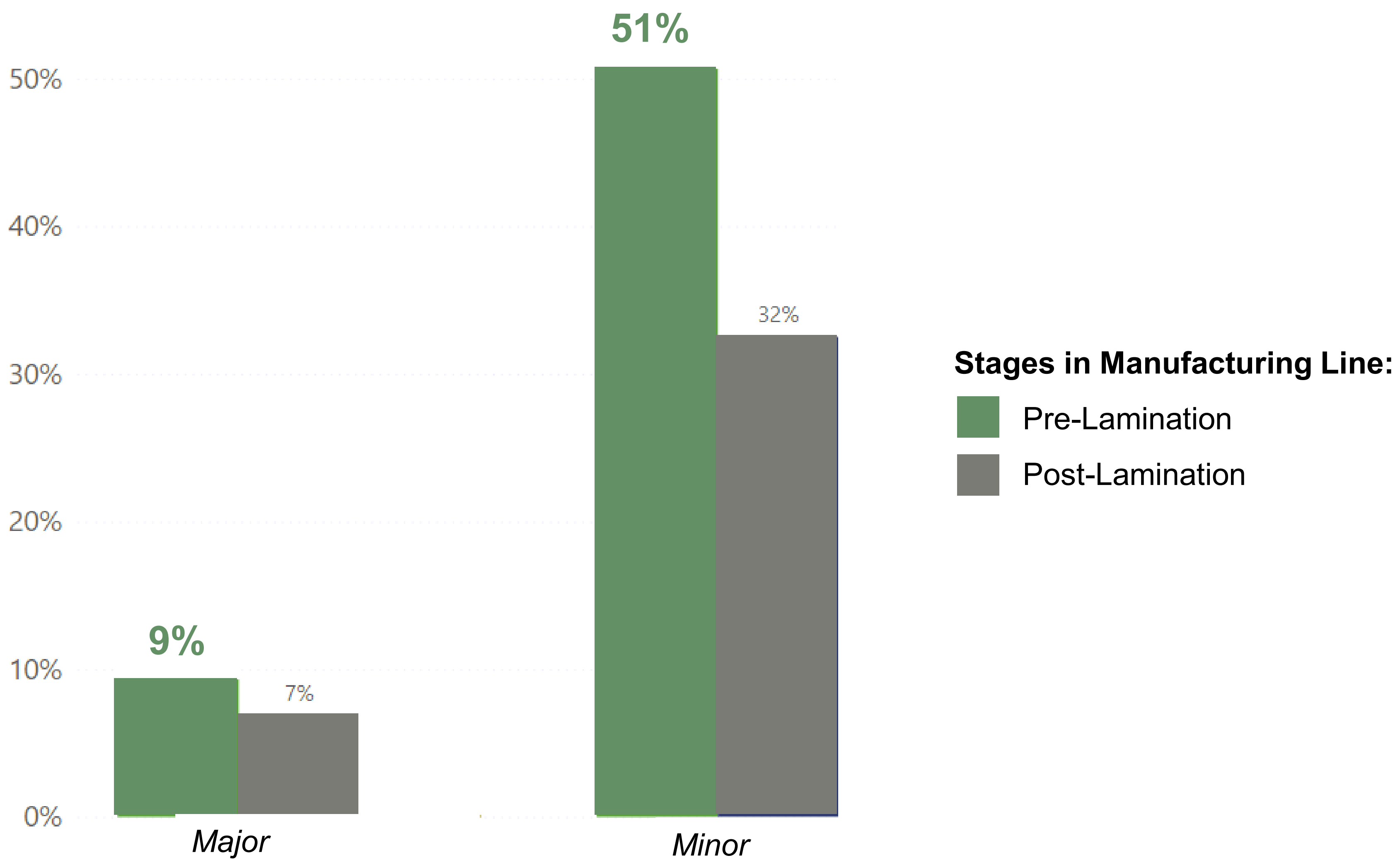
Common finding categories

Area	Description	Example
Re-work	1. Contaminations after manual re-work 2. Soldering temperature is lower than SOP	 
Lay-up	1. Misalignment of encapsulant 2. Distance between the cell strings	 
Tabbing & Stringing	1. Scratched cell used 2. Cold soldering	 

Understanding the Crystalline Silicon PV Module Production Line



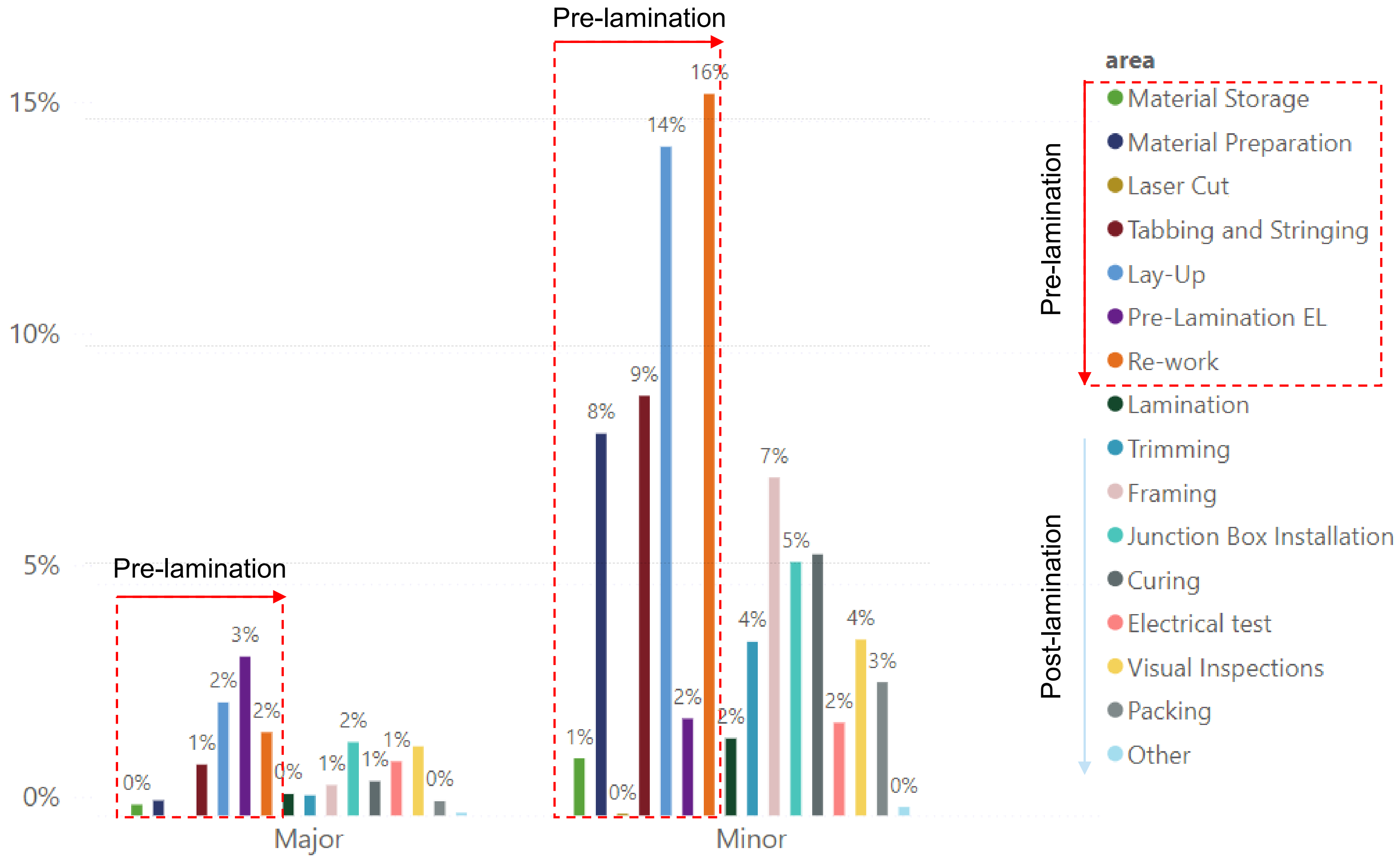
Most Findings Occur Before Module Lamination



IPM findings share in pre- and post- lamination stages

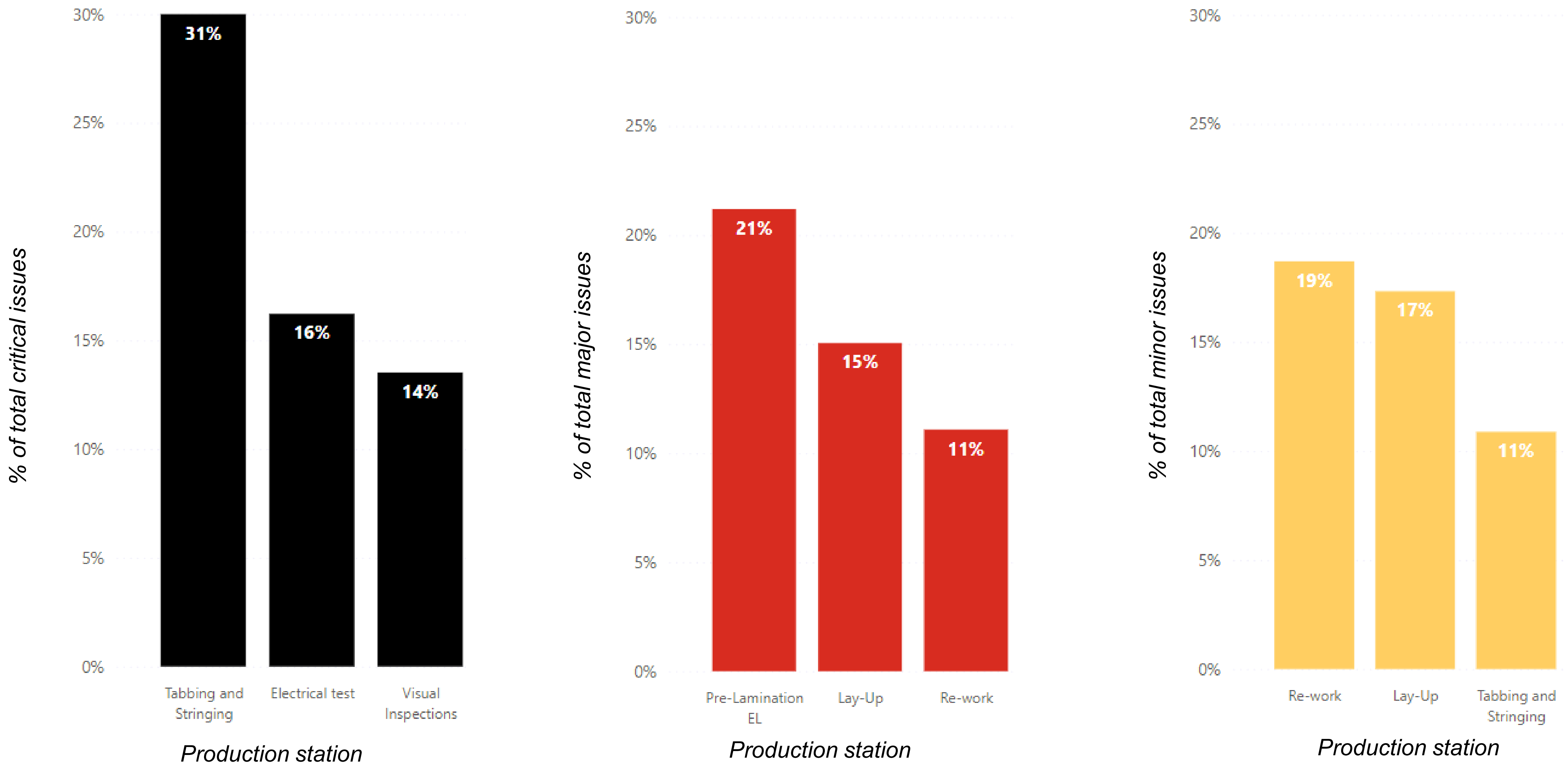
Distribution of IPM Findings

Timely detection avoids delays



IPM findings distribution by sequence: 2023-2024

Tabbing & Stringing Poses the Highest Risks With Most Critical Findings



Top 3 contribution by categories for each severity

Most Findings Occur During Re-Work, Lay-Up, and Tabbing & Stringing

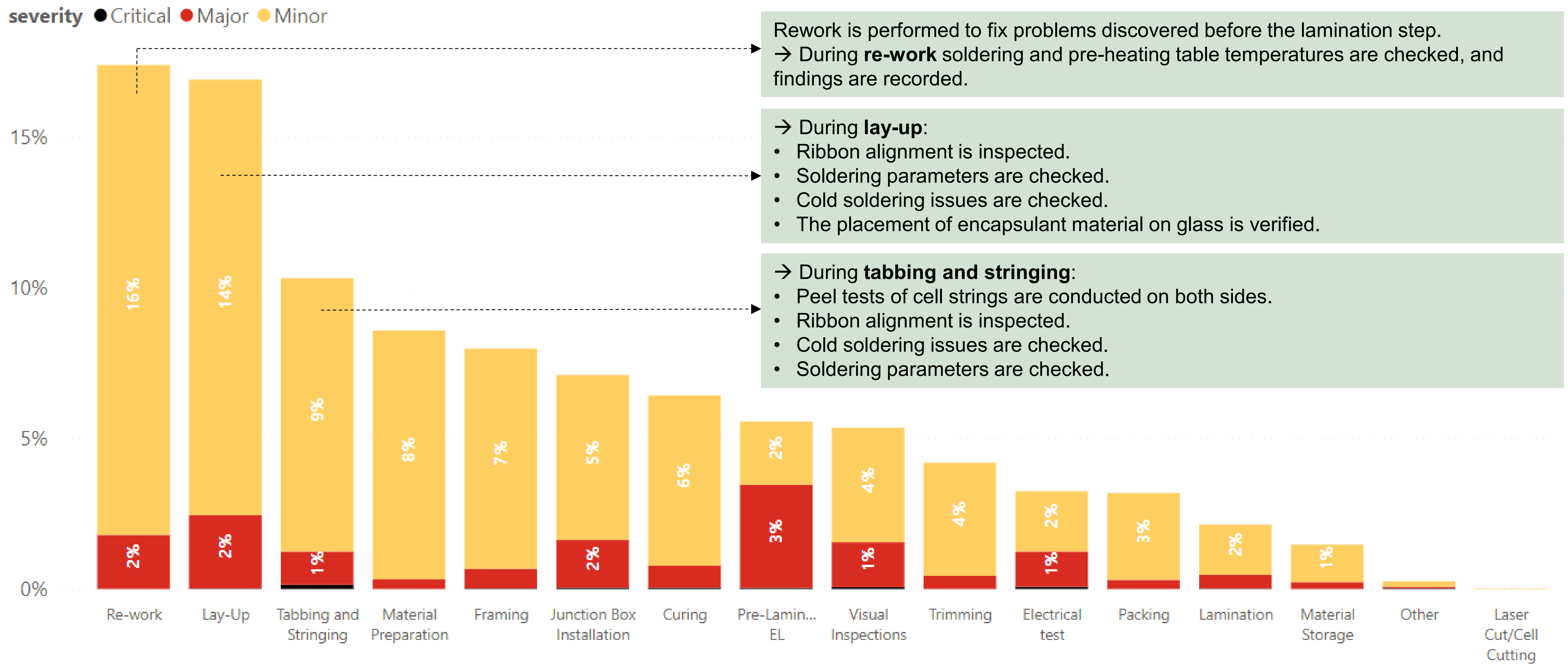
Rework is performed to fix problems discovered before the lamination step.
→ During **re-work** soldering and pre-heating table temperatures are checked, and findings are recorded.

→ During **lay-up**:

- Ribbon alignment is inspected.
- Soldering parameters are checked.
- Cold soldering issues are checked.
- The placement of encapsulant material on glass is verified.

→ During **tabbing and stringing**:

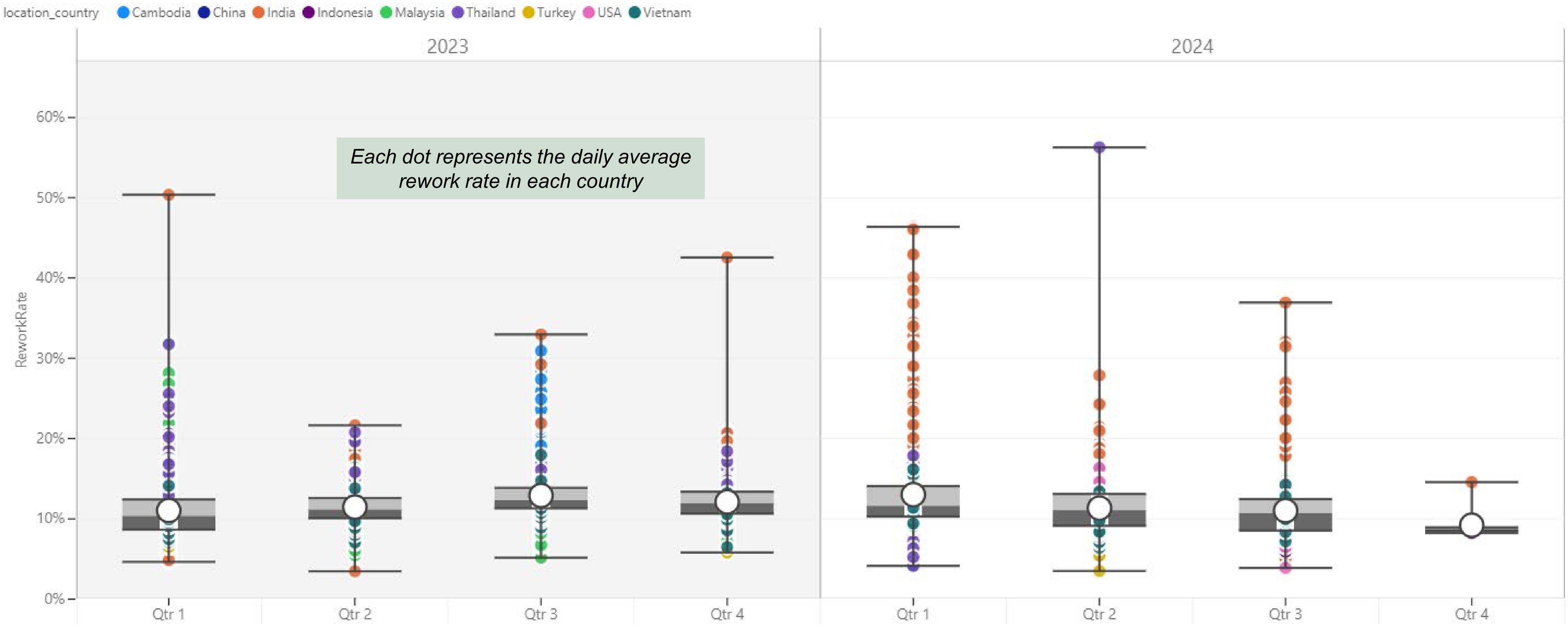
- Peel tests of cell strings are conducted on both sides.
- Ribbon alignment is inspected.
- Cold soldering issues are checked.
- Soldering parameters are checked.



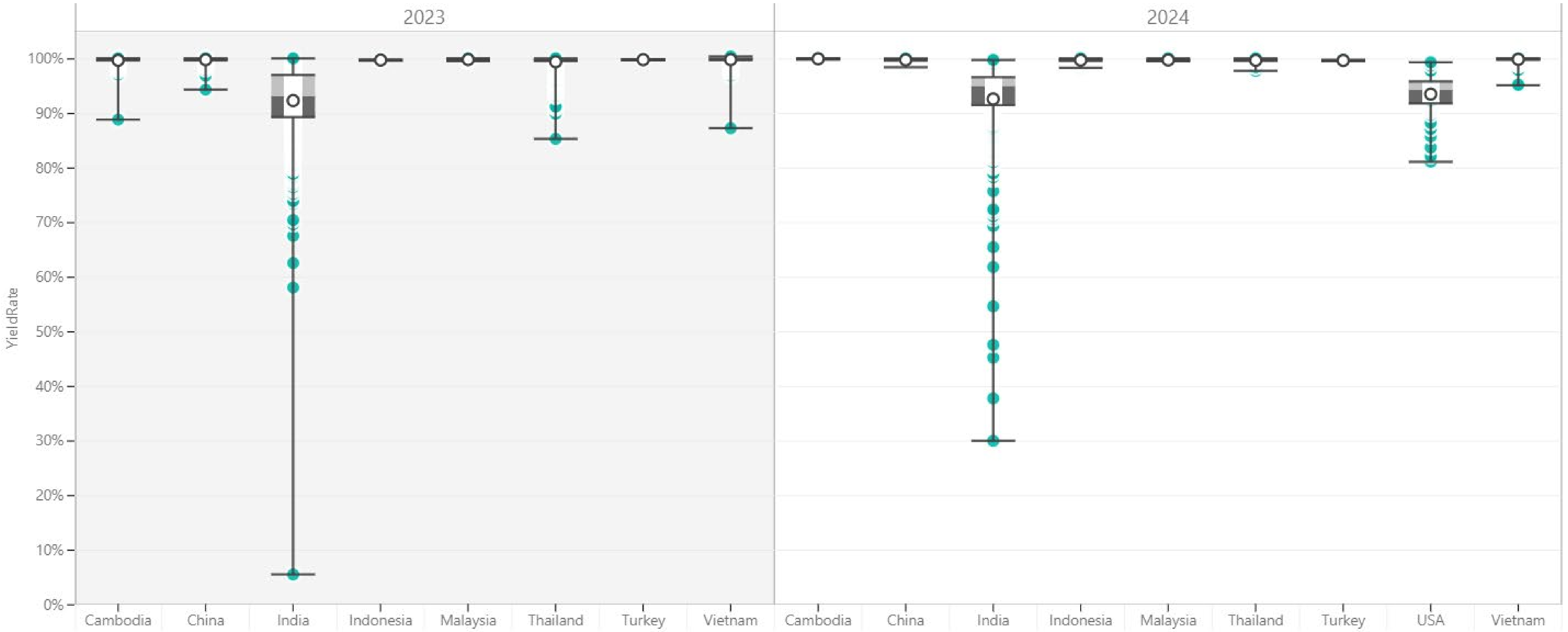
Overview of findings by stage of production line

Variation in Re-work Rate Indicates Production Instability

10%-15% re-work rate is typical but large deviations are common



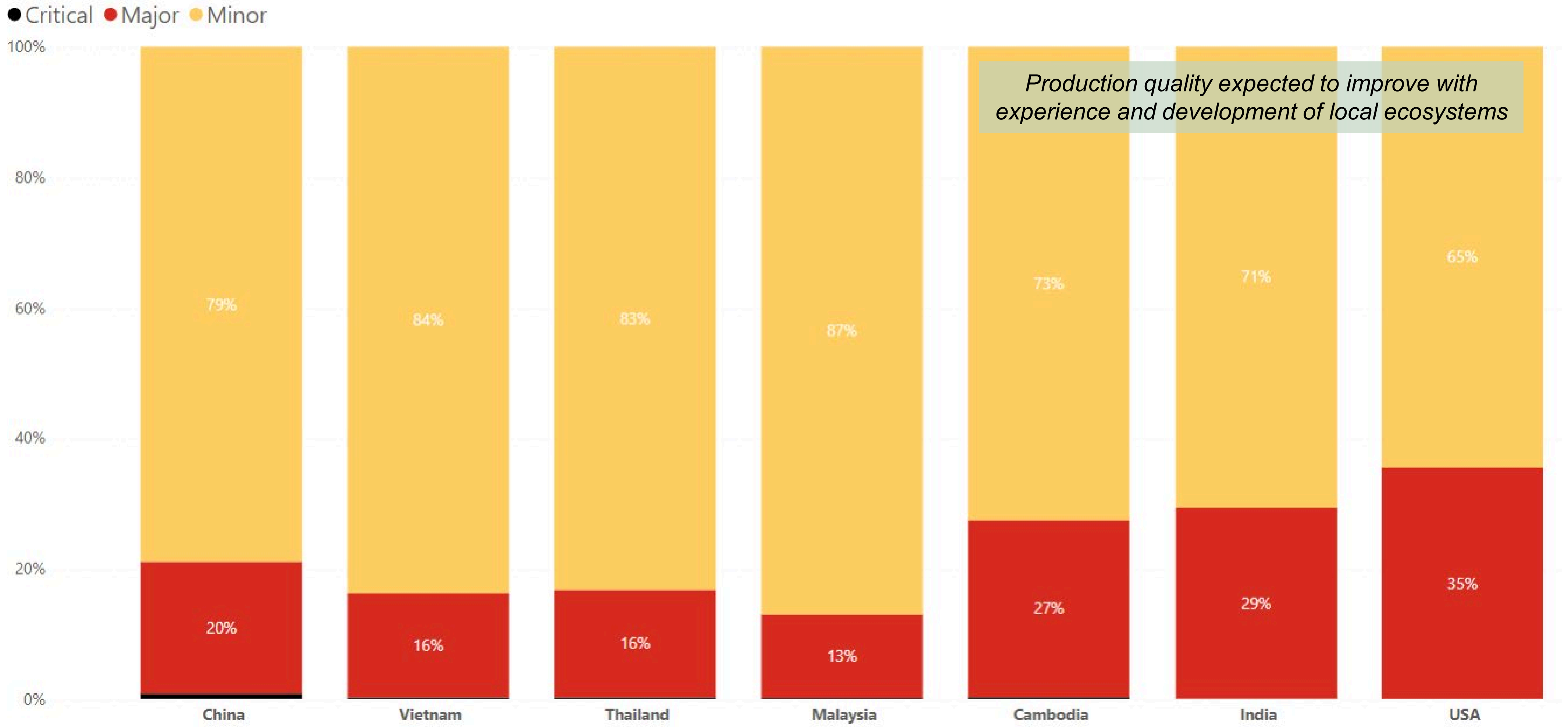
Many of the Low Yield Rates in the Last Two Years Come From Factories that Are Ramping Up Production



Daily average production yield rates of suppliers on country basis

Defect Distribution by Country

Higher major defect rates in countries that are ramping up new factories and don't have long track record of large-scale manufacturing



IPM defect distribution by country 2023-24

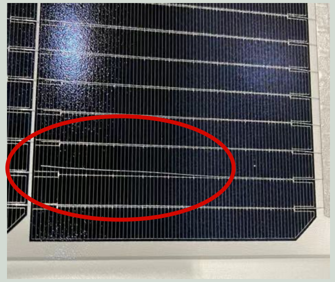
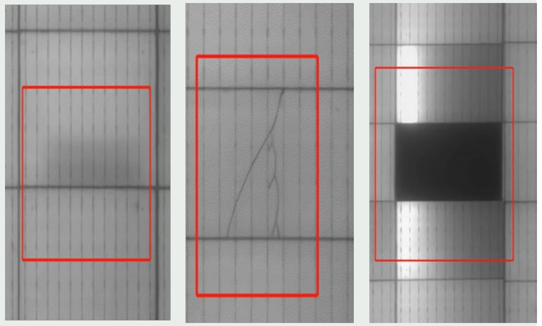
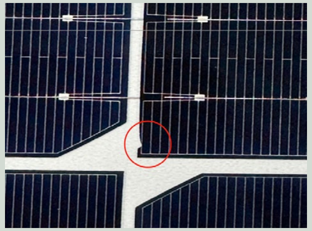
Pre-Shipment Inspection

A pre-shipment inspection involves selecting a statistically significant number of samples based on the Acceptable Quality Limit (AQL) method to check product quality at the manufacturing facility, following pre-defined criteria from the procurement contract, with potential shipment rejection or rework if standards are not met.

Main Inspection points:

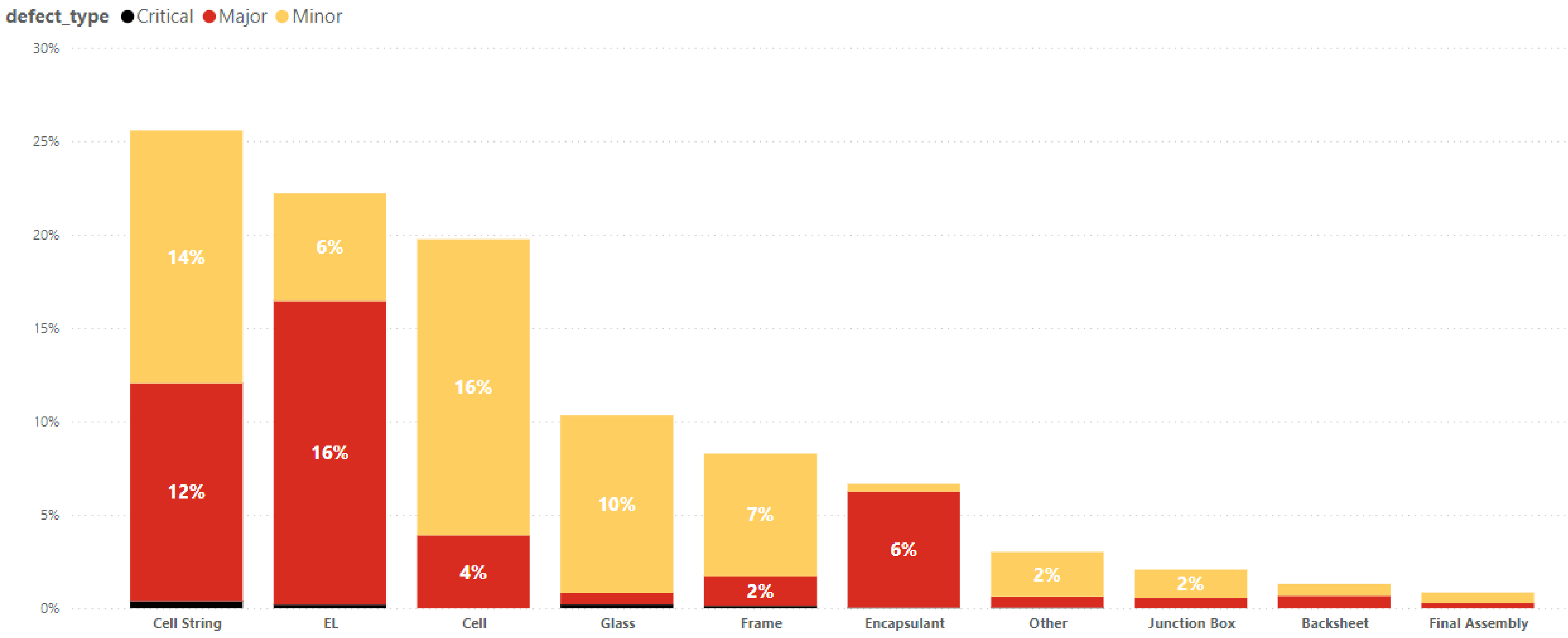
- Visual inspection
- Functional and performance testing (EL imaging and IV tracing)
- Safety testing (hi-pot test, ground test)
- Certification and nonconformance inspection
- Rejection protocols

Defect Categories

Category	Description	Example
Cell string	Misalignment of string is the most common defect in this category	
Electroluminescence (EL)	Defects identified under EL category are cold soldering, microcracks, and dark cell	
Cell	Cell cracking and cell chipping visible to naked eye come under this category	

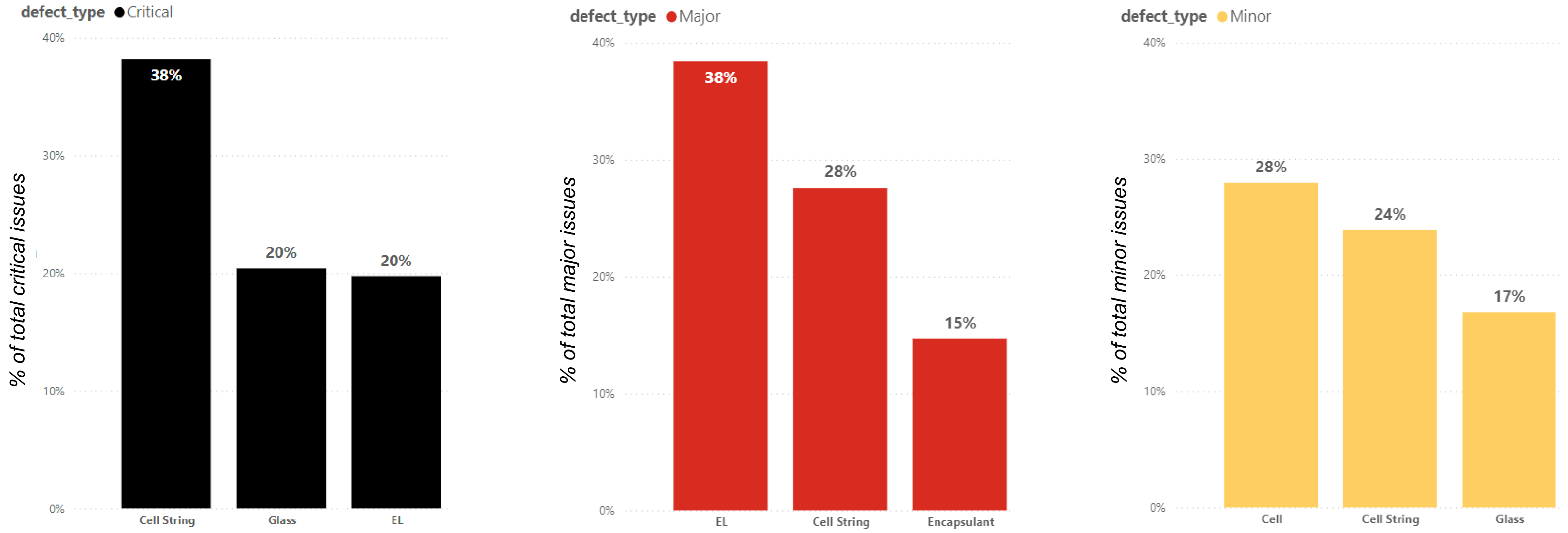
Most Defects Are Found at Cell String, EL, and Cell Categories

Mechanical stress on cell, string misalignment, and cold soldering are the major contributors to the defects.



Overview of pre-shipment inspection findings

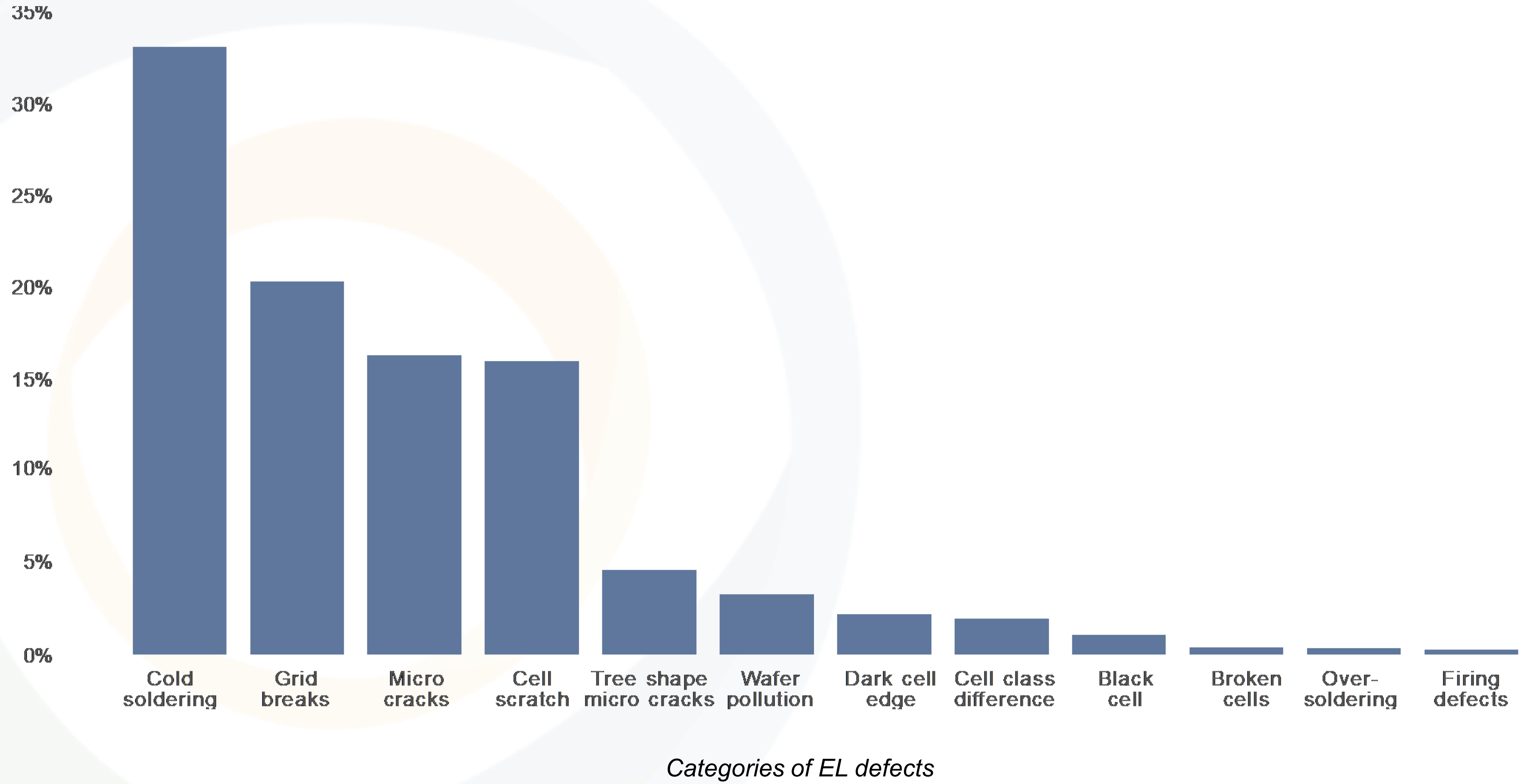
Cell String Carries the Highest Risks, with EL Testing Revealing Major Issues Missed by Visual Inspection



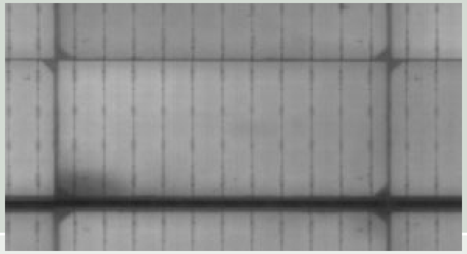
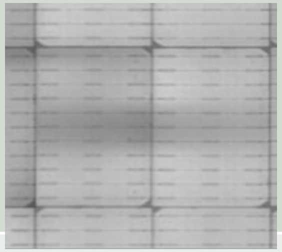
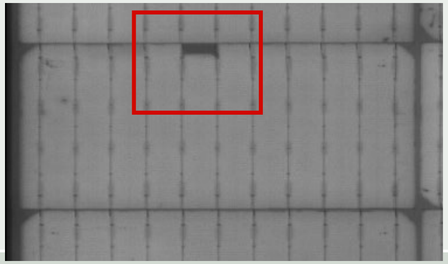
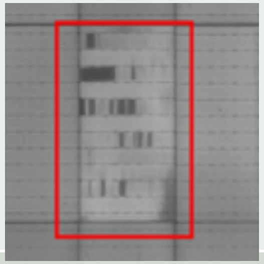
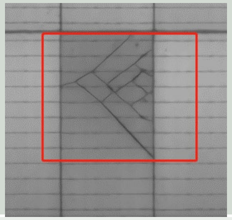
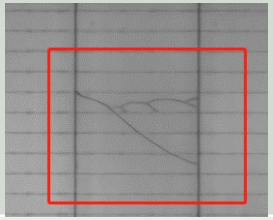
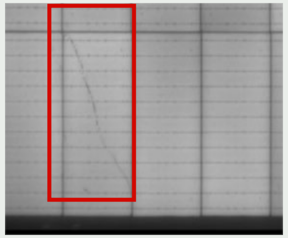
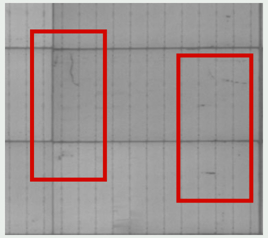
Top 3 contribution by categories for each severity

Cold Soldering, Grid Breaks, Microcracks, and Scratched Cells are Top EL Defects

Mechanical stress, soldering issues, and handling errors drive the most common EL defects



EL defects

Defect	Description	Example
Cold soldering	Occurs due to poor electrical contact between the cell and the ribbon during soldering. Higher resistivity leads to dark areas.	 
Grid breaks	Defective metallization during screen printing of cell fingers causes higher resistivity areas where the metallization is lacking. These areas appear darker.	 
Microcracks	Cracks in the cell cause electrical discontinuity and loss of active area leading to dark lines appearing. Stresses can cause the cracks to grow and branch.	 
Cell scratch	Scratched cell surface causes lower efficiency and leads to dark lines appearing.	 

Container Loading Monitoring (CLM)

Container Loading Monitoring (CLM) is executed at the supplier's warehouse. It is the final control point at the supplier site after IPM & PSI. Engineers verify the module data and monitor the whole process of module pallet loading into the containers.

CLM Checklist:

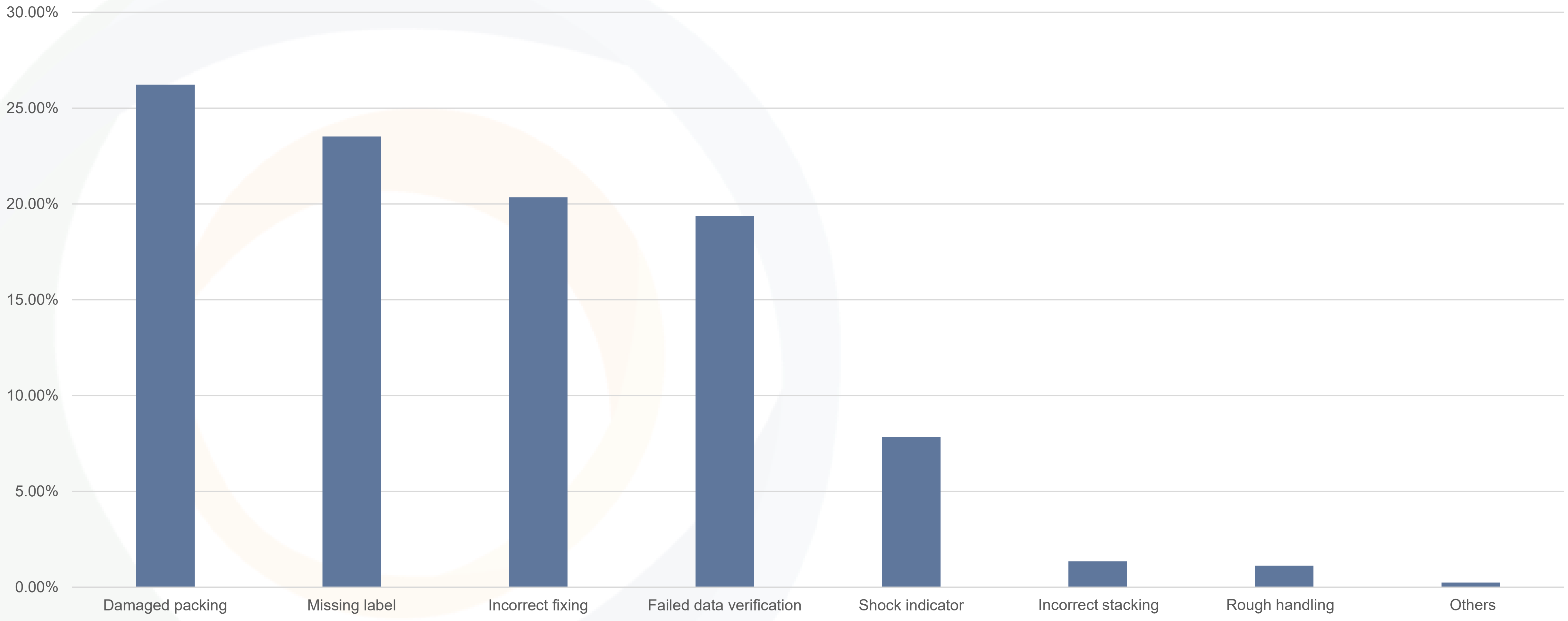
- Check consistency of shipped product against the purchase order in terms of product specification and quantity.
- Verify the shipped goods are the ones qualified during IPM & PSI and not mixed with unqualified products.
- Make sure the packing and stacking / loading method of pallets are consistent with the client's requirements.
- Monitor container loading process is compliant with supplier's SOP.
- Ensure packing material is complete and not damaged.
- Verify containers are in good condition.
- Record of the container number and seal for tracking.

Findings during CLM

Description	Example
Damaged packing	
Torn fixing tie	
Damaged outer wood shingling	

The Most Common CLM Finding Is Damaged Packing

Including Carton Box Damage, Pallet Damage, Torn Fixing Tie, etc.



Frequent defects during Container Loading Monitoring (CLM)

Batch Testing

PV manufacturers use multiple sources of raw materials that may have variations. Production processes may also suffer from instability. Batch testing is important for controlling any deviations in performance of a production batch before shipment, based on pre-agreed pass/fail criteria and representative sampling methods. Sample modules are selected from a production batch and tested in an internal or external lab, such as Intertek, to verify their performance and quality.

Tests that are typically conducted in a lab:

- Potential Induced Degradation (PID) Testing
- UV Induced Degradation (UVID) Testing
- Light and Elevated Temperature Degradation (LETID) Testing
- Light Induced Degradation (LID) Testing
- Hail Impact Testing
- Mechanical Stress Testing
- Special Tests Specific to Project

Some Important Module Degradation Modes

Potential-induced Degradation (PID)

PID is a type of module degradation caused by the high voltage between the PV cells and the glass surface, which is grounded via the substructure of the cell or the frame. PID affects the PV cells, causing a potentially irreversible efficiency loss.

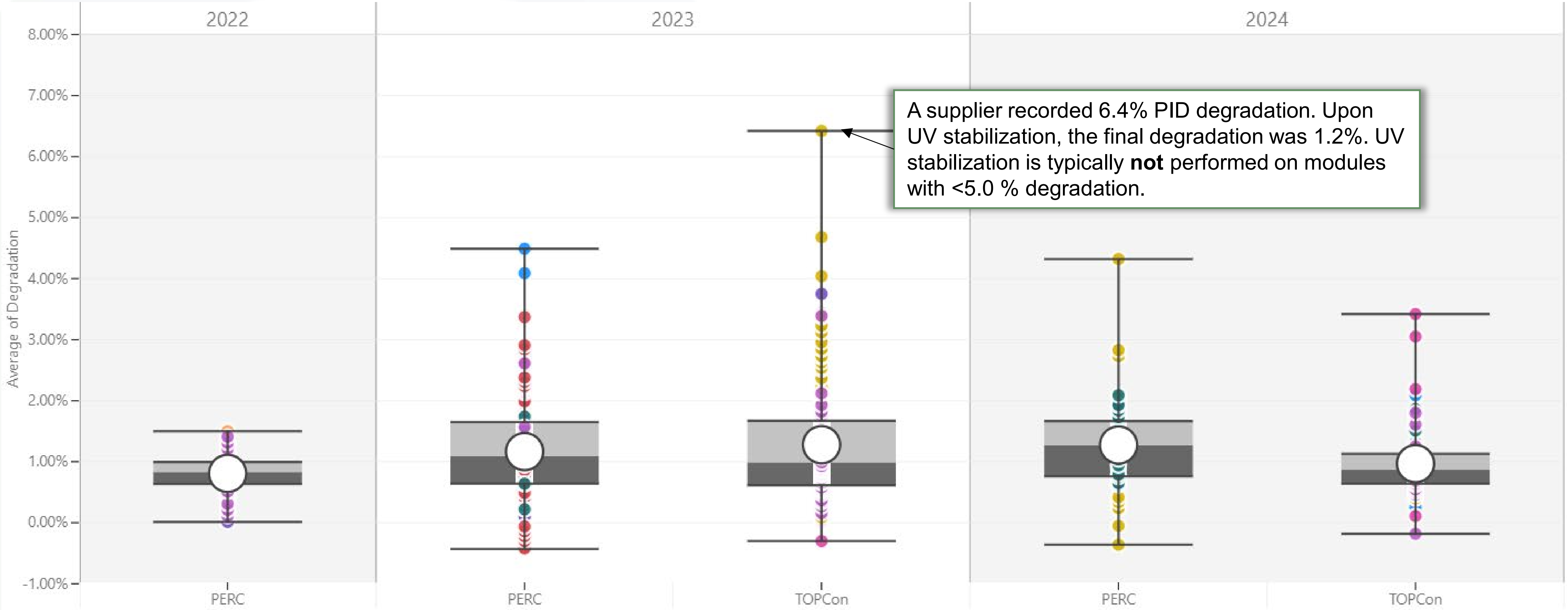
Light and Elevated Temperature Induced Degradation (LeTID)

LeTID is a form of solar cell degradation due to a combination of irradiance exposure at high temperatures. It typically takes 1-2 years to manifest. LETID may self-reverse, but at a very long, 10+ year timescale.

Light Induced Degradation (LID)

LID is a loss of efficiency of the PV cells which happens in the first hours of exposure to the sun. The cell efficiency loss is typically permanent.

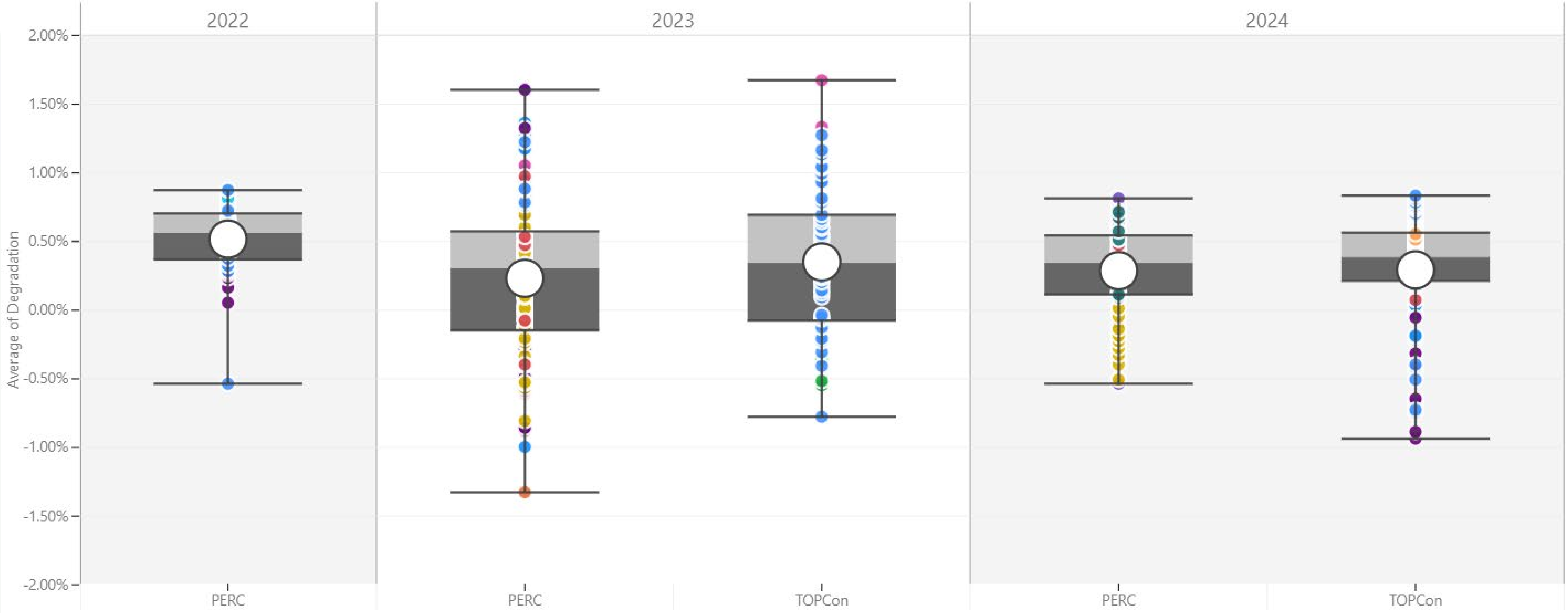
PID results: TOPCon showed high variability in 2023 but improved and showed better results than PERC in 2024



Notes | CEA batch testing data, multiple labs (PID at 85°C/85%, RH/96h). Different colors indicate different suppliers. Potential Induced Degradation (PID). PID testing is not always realistic with respect to actual field conditions as it is done in a dark chamber. UV stabilization is sometimes applied to mimic the effect of actual field conditions and the regenerative effect of light on PID.

LeTID results: Both TOPCon and PERC improved from 2023 to 2024, showing similar performance

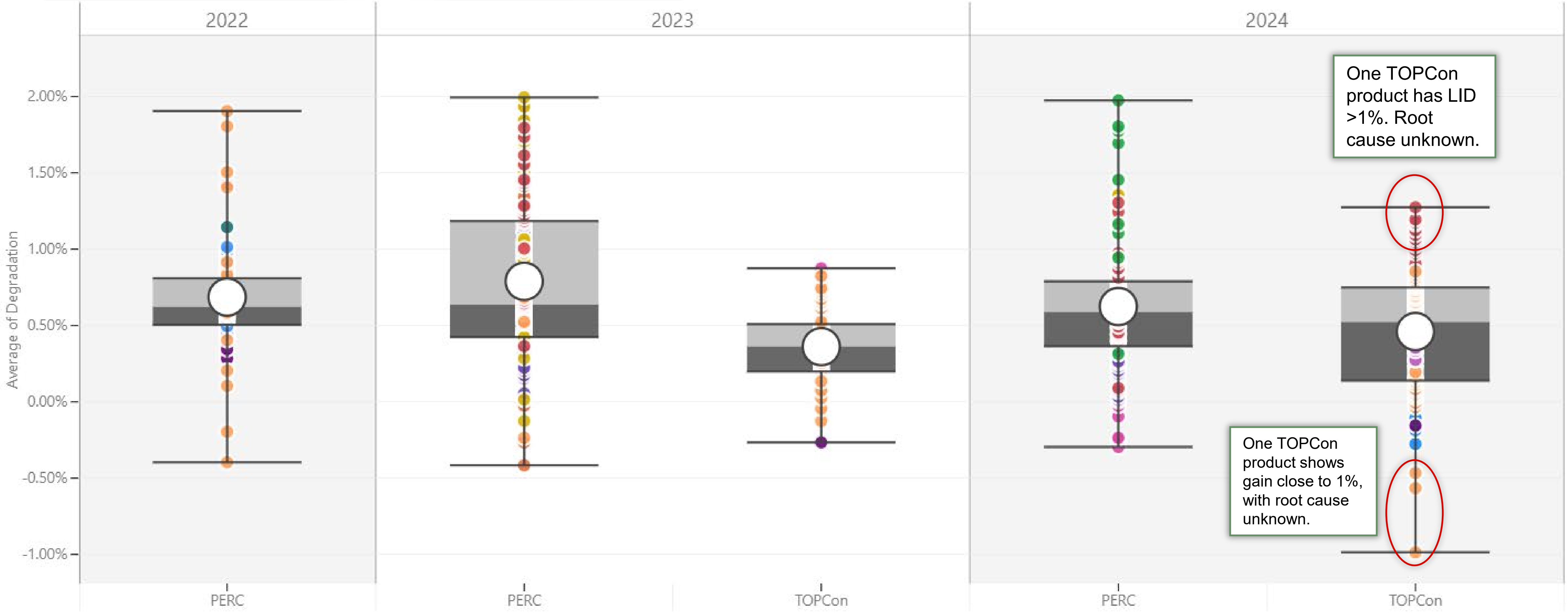
LeTID seems a minor concern now; more data will dictate if it is no longer an issue



Notes | CEA batch testing data, multiple labs (LETID 1x or 2x (Isc-Imp), 162/168 h, 324/336 h). TOPCon data from nine suppliers. Light and Elevated Temperature Induced Degradation (LETID).

LID results: TOPCon shows advantage over PERC, but a very small number of products show LID above the 1st year warranty limit of 1%

TOPCon products very rarely exhibit >1% LID



Notes | CEA batch testing data, multiple labs (LID at 20 – 80 kWh/m^2). Light-Induced Degradation (LID)

IPM Case Study—Junction box soldering quality

Finding

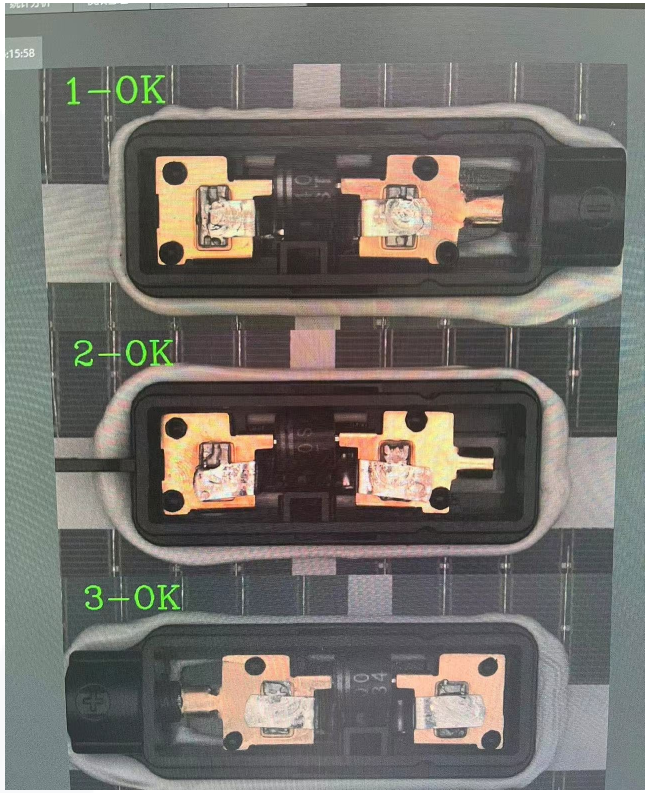
There has been an increase in thermal events (fires) in PV modules linked to poor junction box soldering quality. CEA found that the current soldering inspection methods at some factories were not effective in detecting these defects and required suppliers to strengthen controls by closely monitoring resin, flux, and solder ratios and implementing 100% physical inspections.

Why/How Did It Happen

As more PV factories adopt automated soldering and inspection for junction boxes, there has been a trend to reduce or eliminate physical inspections. This has led to inconsistent soldering quality because automated checks alone are not enough to catch all defects. Some manufacturers were found to be trying to bypass physical inspections on 100% of the junction boxes, which allowed these issues to go undetected.

Risk

Defective soldering in junction boxes can increase the risk of thermal events or fire, which can cause severe damage to the module, pose safety hazards, and lead to costly replacements.



AI supported visual auto-inspection of junction boxes

Unsoldered terminal

Burnt and damaged junction box

IPM Case Study—Low factory yield

Finding

The supplier initially overestimated their production output; a high number of production issues led to lower-than-expected finished product and shipments. With CEA's presence and continuous monitoring, the factory's output and quality gradually improved, and the daily IPM risk score decreased over time.

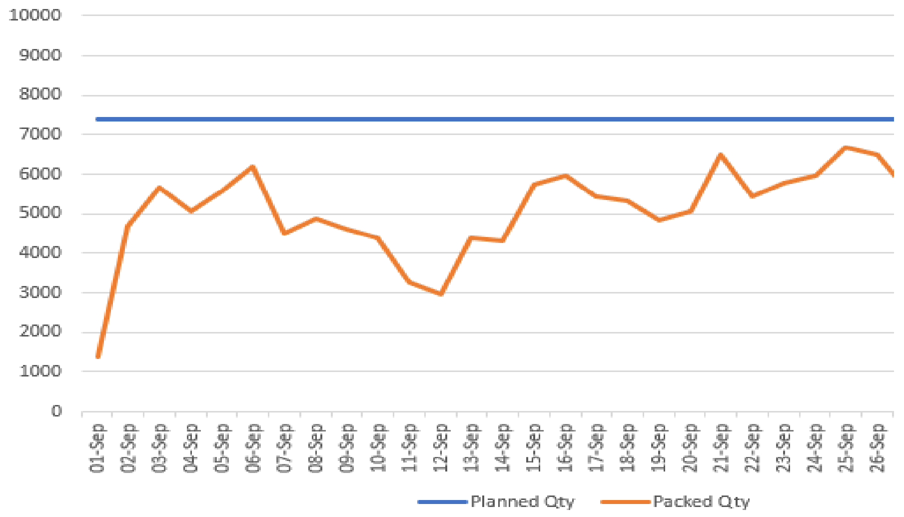
Why/How Did It Happen

The issue occurred because it was a new factory in the ramp-up phase, and the staff were inexperienced with international shipments and quality assurance (QA) requirements.

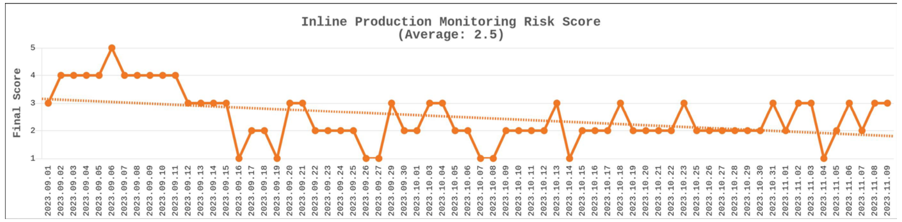
Risk

Low factory yield can lead to significant production delays, increased costs, and an inability to meet delivery commitments, which impacts project timelines.

Cumulative production trend vs. planned



Daily output



Inline production monitoring risk score

IPM Case Study—Module dimension out of specification

Finding

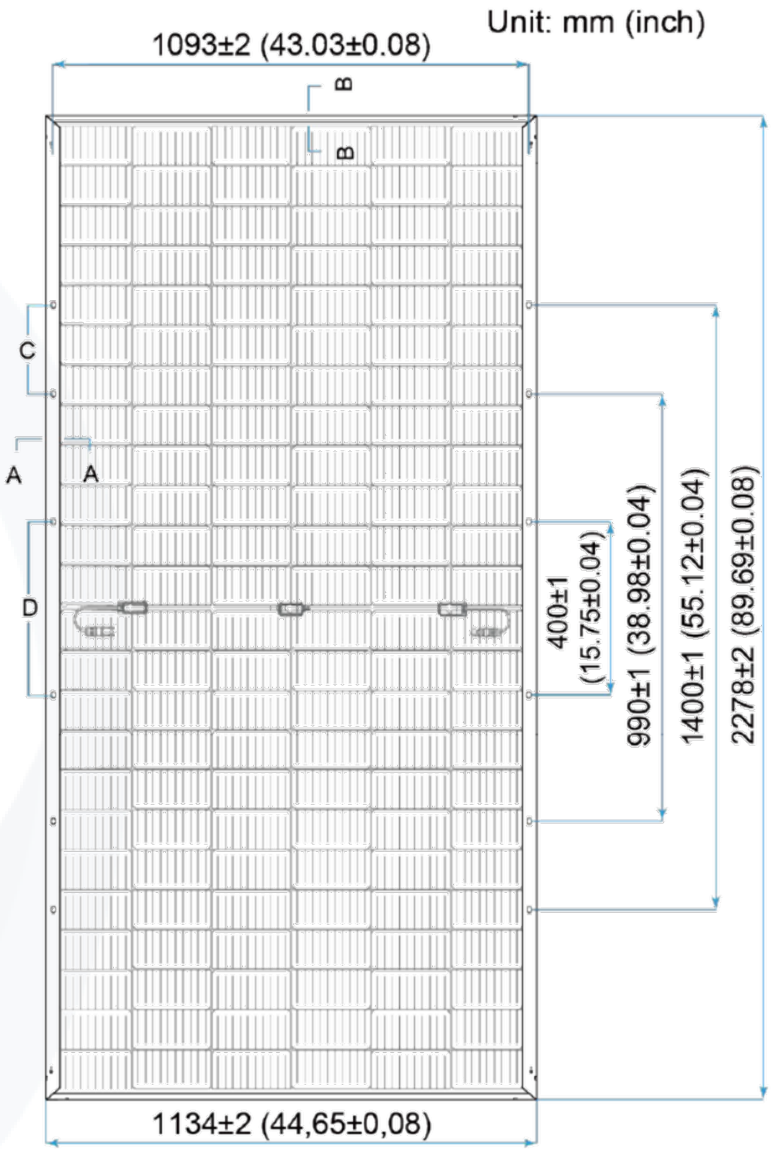
Auditors found that the module dimensions were out of specification when measured on the front side, while they appeared within specification when measured on the rear side. CEA identified 111 non-conforming products. Subsequently, we repeated the inspection on the whole batch to prevent unqualified modules from being shipped.

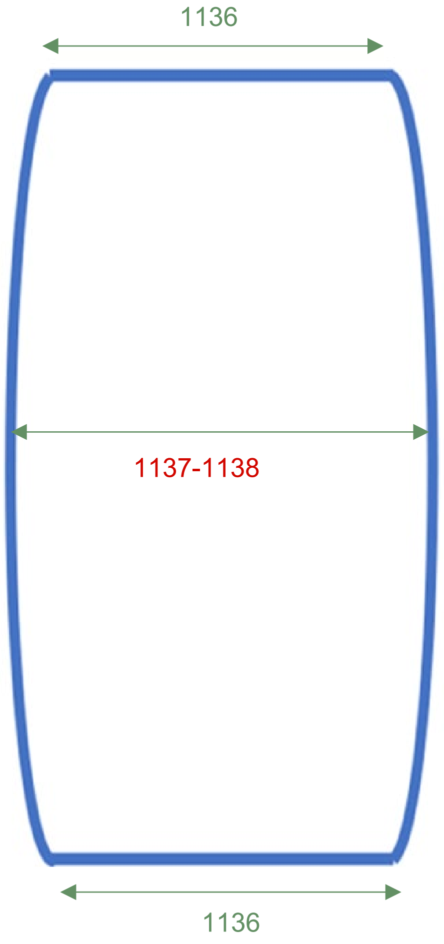
Why/How Did It Happen

When the production line changed to modules with a larger frame thickness, the framing machine parameters need to be adjusted to the new frame thickness. But based on the records checked by CEA, the supplier did not adjust the machine settings properly and no checks were done. Due to the wrong machine setting, the frames became warped, leading to variations in module dimensions.

Risk

The dimension discrepancy may lead to the rack row having insufficient spacing for thermal expansion or to fit all modules in a row.





Module with warped frame

PSI Case Study—Manipulated EL images

Finding

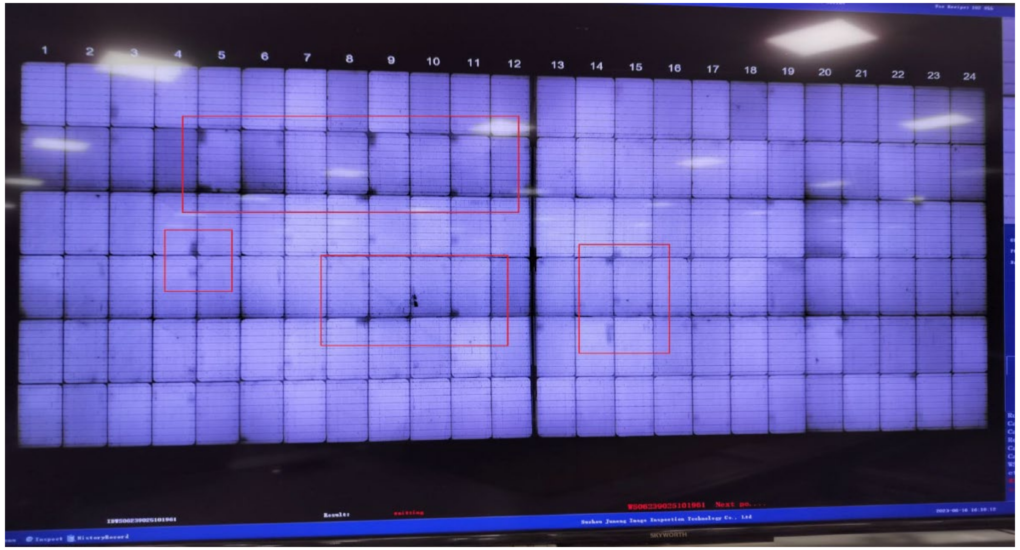
During IPM, an inspector found several defects at the electroluminescence (EL) imaging station and noted down the serial numbers of the affected modules. However, when checking these same modules during Pre-Shipment Inspection (PSI), the EL images provided by the supplier showed no defects. This raised concerns that the images might have been altered, indicating suspicious behavior during the factory inspections.

Why/How Did It Happen

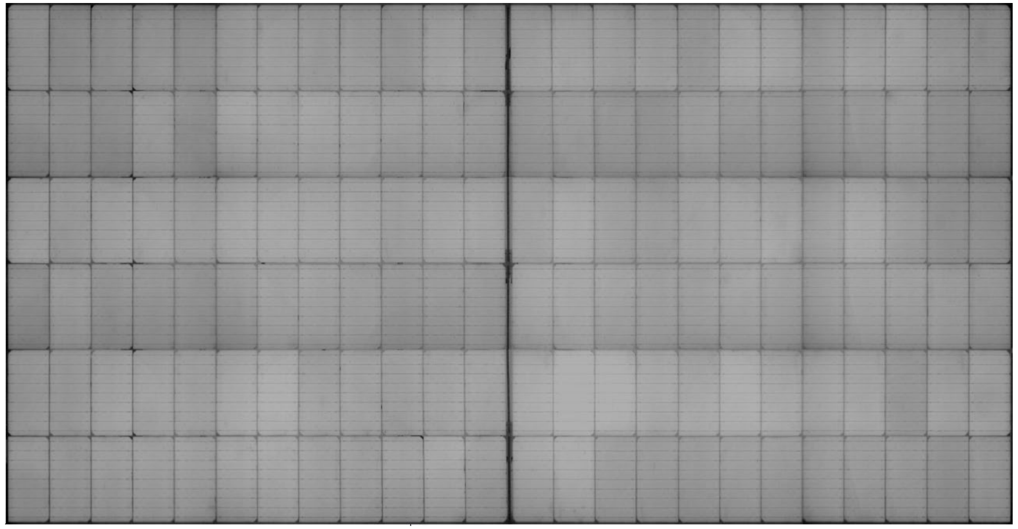
Most suppliers have good ethics, but in rare cases, CEA has observed misconduct. In this case, the supplier repeatedly delayed providing the EL images requested by CEA, providing various excuses. During PSI, it took 3 days for the inspector to start each inspection rather than the few hours typically needed. CEA detected that the EL data were tampered with to cover the fact that the supplier replaced defective samples to avoid lot rejection.

Risk

Defective modules with hidden issues could be shipped and installed, leading to reduced performance, higher failure rates, safety hazards, and costly replacements or warranty claims.



Shop floor EL with cold soldering



During PSI the same serial number module showed no cold soldering

IPM Case Study—Incorrect cable length

Finding

During an inspection at an Original Equipment Manufacturer (OEM), CEA found that the junction box cable length was incorrect. The inspector immediately asked the factory to stop production, isolate the affected modules, and track the work order to inspect the modules in the warehouse which were produced during the affected period.

Why/How Did It Happen

- After investigation, it was found that the OEM factory changed the cable length without approval from the module supplier; the quality was not properly controlled in the OEM factory.
- The communication and authorization process was not followed by the OEM factory.

Risk

Significant module installation issues on site.

Correct junction box cable length of 300/400mm

Incorrect junction box cable length of 200/400mm

IPM Case Study—Cold soldering defects

Finding

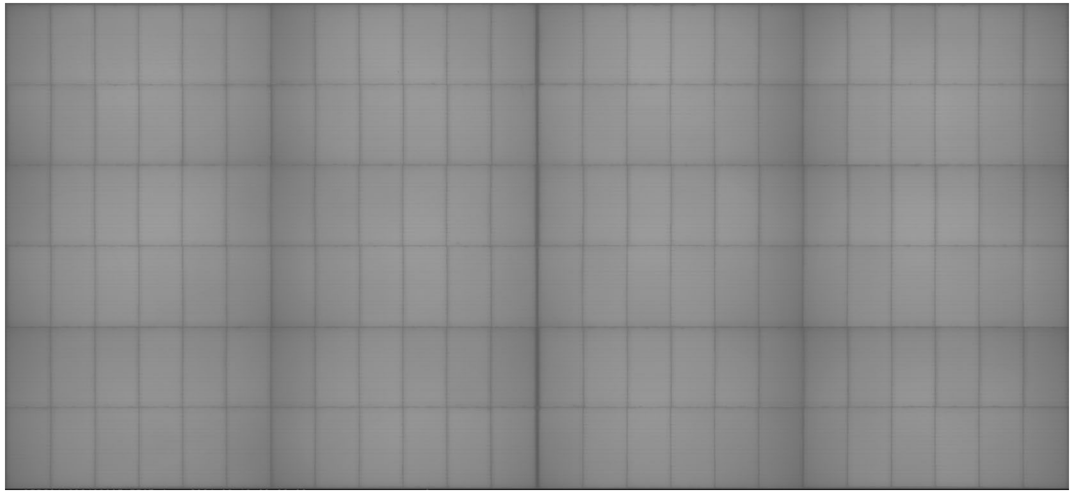
During the final electroluminescence (EL) inspection, the inspector found modules with cold soldering defects that the supplier had marked as ‘pass’. Upon re-inspection, CEA found more defective modules from the same shift.

Why/How Did It Happen

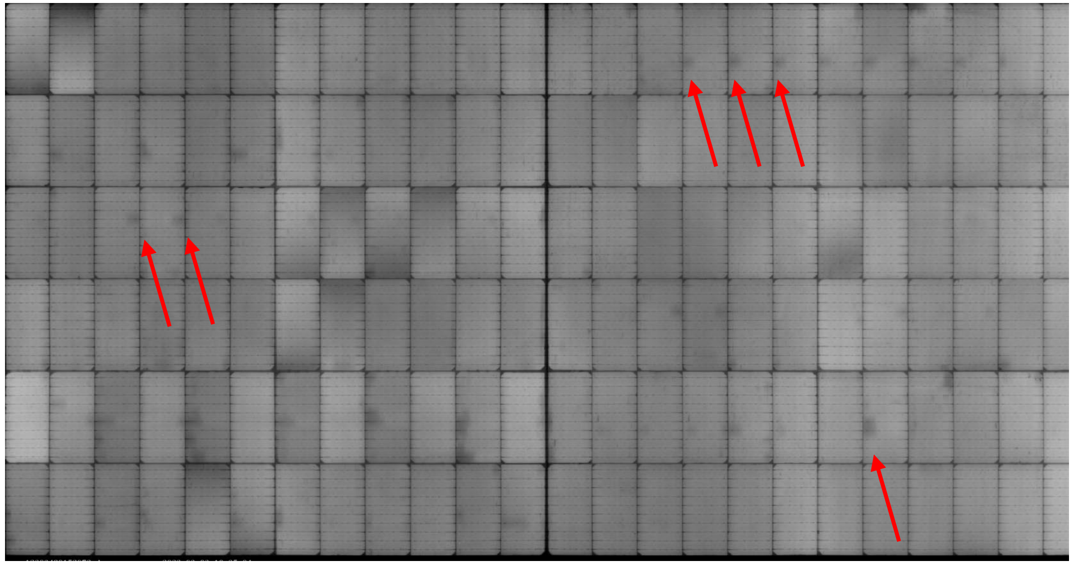
- The operator was temporarily assigned to this station without proper training and did not know the inspection standards.
- The root cause of the cold soldering was a dirty flux nozzle during the soldering process, which wasn’t cleaned properly.

Risk

Modules with cold soldering defects could be shipped, leading to poor electrical connections, reduced performance, and potential early failure.



EL image without cold soldering anomalies



EL image with cold soldering defect

IPM Case Study—Ribbon misalignment

Finding

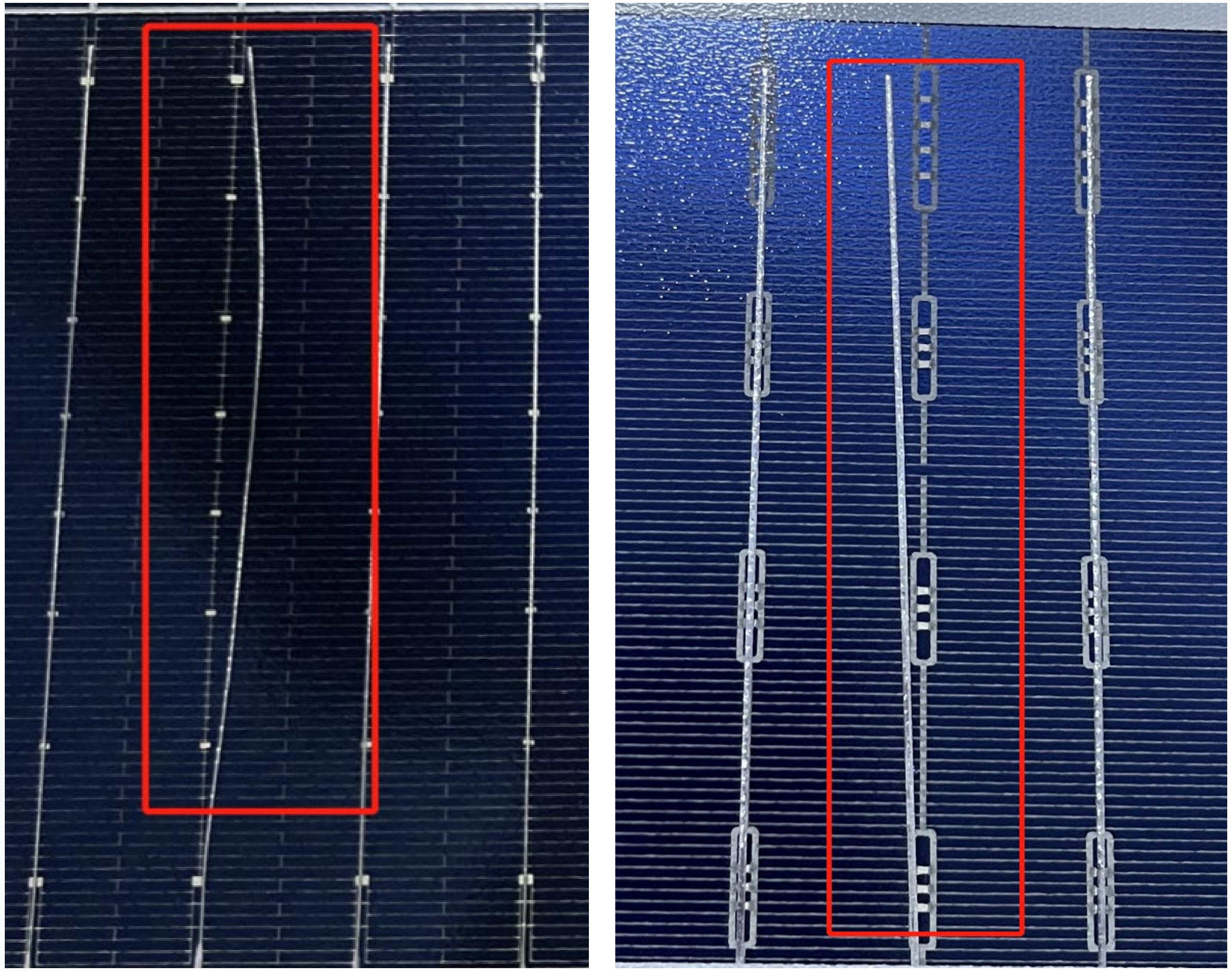
During the visual inspection, the inspector found that the cell interconnection ribbons were misaligned, but the supplier had marked these modules as 'pass' and sent them to the packing process. CEA isolated the affected modules to prevent unqualified products from being delivered to the client.

Why/How Did It Happen

The misalignment occurred because one of the tabbers in the stringer machine wasn't cleaned properly, causing flux residue to crystallize. This prevented the interconnection ribbon from being securely held, resulting in the ribbon twisting and being soldered in the wrong position.

Risk

Misaligned ribbons can lead to poor electrical connections, which increase resistance, reduce module efficiency, and cause hotspots that may result in module failure or even safety hazards over time.



Ribbon misalignment

CLM Case Study—Damaged packing

Finding

Inspector found that one pallet's packaging was damaged after loading. The inspector instructed the the supplier to halt loading and remove the damaged pallet. All module serial numbers were documented, and the modules underwent a re-inspection (visual, flash test, and EL inspection) to confirm no damage had occurred.

Why/How Did It Happen

The damage occurred when the fork of the forklift accidentally hit the bottom of the pallet while lifting it, tearing the wrapping film and denting the carton box. However, the forklift operator continued loading without stopping to check the damage visually, as required by the standard operating procedure (SOP).

Risk

The damaged packaging could indicate potential hidden damage to the modules, leading to performance issues or defects that might not be visible but could compromise the modules' integrity and reliability during transport or installation.

Damaged packing

What Can You Do To Ensure the Long-term Financial Health of Your PV Assets?

Golden Standard

Closing the Gaps: We review your procurement contract, project requirements, product specifications and quality assurance plans to ensure your PV modules perform well and safely, preventing any surprises.

Early Detection: We identify risks in the supplier's inspection criteria and product qualification tests early on, to save costs and extend your system's operational life.

Expert Check-Up: Our experts verify adherence to key safety and performance standards for reliable PV modules.

Negotiation Support: We support you in negotiating and adjusting the technical exhibit deviations.

Factory QA

Factory Audit (FA): Engineers check factories with a 1,000+ point checklist, assess risks, and recommend fixes.

Inline Production Monitoring (IPM): Engineers monitor production in real-time using a 280+ point checklist to ensure quality, spot issues, and suggest corrections.

Pre-Shipment Inspection (PSI): Engineers inspect and test a random sample of finished products, record findings, and advise on improvements.

Container Loading Monitoring (CLM): Engineers verify module data and oversee the entire process of loading the pallets into containers.

Batch Testing: Sample modules are selected from a production batch and tested in a lab to verify performance and quality

Contact us for a consultation!

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Q&A

9 October 2024

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11:00 am – 12:00 pm | EDT, New York City
5:00 pm – 6:00 pm | CEST, Berlin, Madrid

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Editor
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CEA

Cara Zhu
Associate Director of Modules
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Director, Engineering and Quality Assurance Services
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