



Connecting the Dots

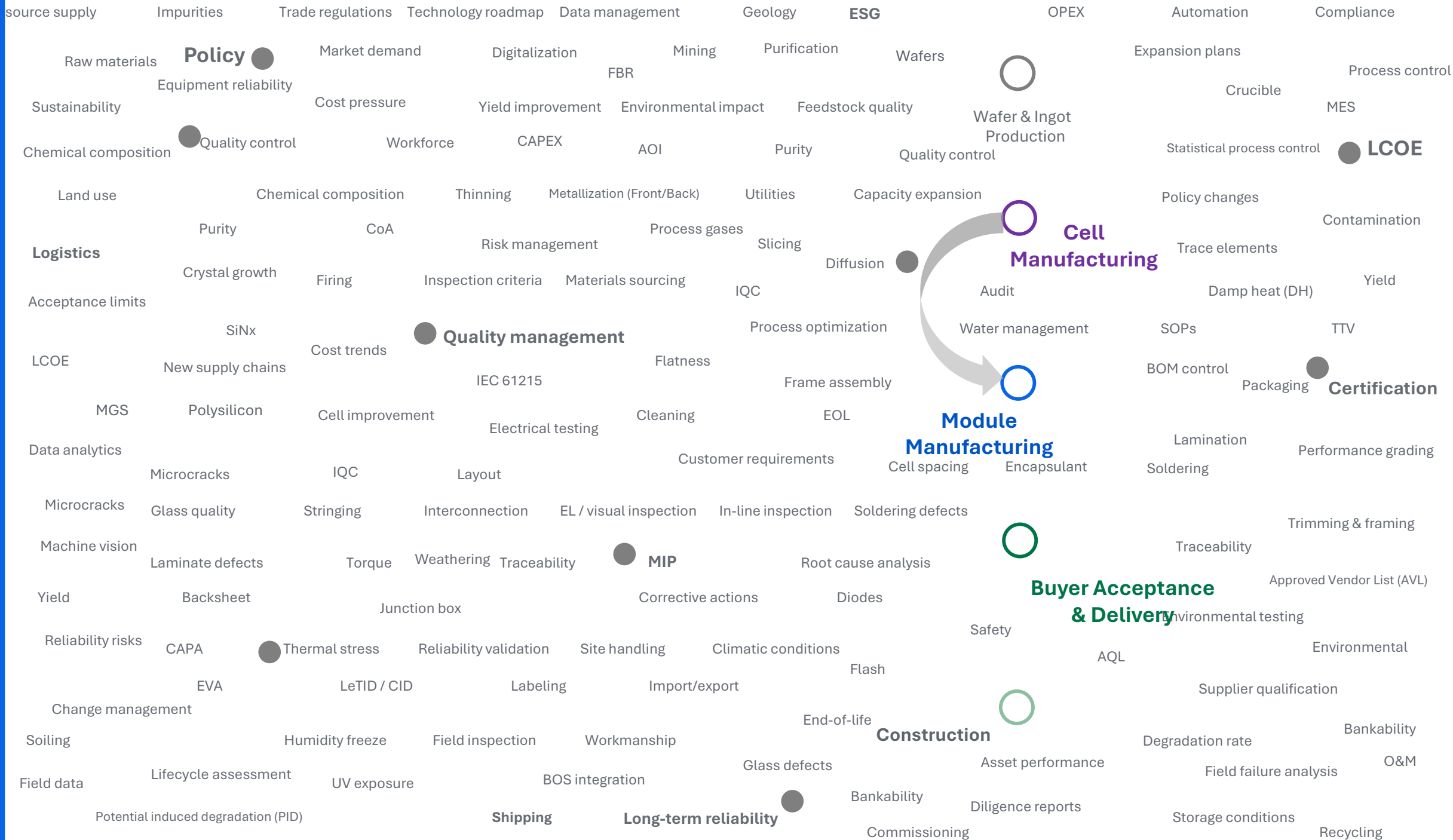
*Building confidence across the solar value chain between cell
suppliers, module manufacturers, and module buyers*

PV Cell Tech 2026 | San Francisco, California

Presenter: Don Cowan

MANAGING QUALITY	source supply	Impurities	Trade regulations	Technology roadmap	Data management	Geology	ESG	OPEX	Automation	Compliance
	Raw materials	Policy	Market demand	Digitalization	FBR	Mining	Purification	Wafers	Expansion plans	Process control
	Sustainability	Equipment reliability	Cost pressure	Yield improvement	Environmental impact	Feedstock quality	Wafer & Ingot Production	Crucible	MES	
	Chemical composition	Quality control	Workforce	CAPEX	AOI	Purity	Quality control	Statistical process control	LCOE	
	Land use	Chemical composition	Thinning	Metallization (Front/Back)	Utilities	Capacity expansion		Policy changes		
	Logistics	Purity	CoA	Risk management	Process gases	Slicing	Cell Manufacturing	Trace elements	Contamination	
	Acceptance limits	Crystal growth	Firing	Inspection criteria	Materials sourcing	IQC	Diffusion	Audit	Damp heat (DH)	Yield
	LCOE	SiNx	Cost trends	Quality management		Process optimization	Water management	SOPs	TTV	
		New supply chains		IEC 61215	Flatness	Frame assembly		BOM control	Packaging	Certification
	MGS	Polysilicon	Cell improvement	Electrical testing	Cleaning	EOL	Module Manufacturing			
	Data analytics							Lamination	Performance grading	
		Microcracks	QC	Layout		Customer requirements	Cell spacing	Encapsulant	Soldering	
	Microcracks	Glass quality	Stringing	Interconnection	EL / visual inspection	In-line inspection	Soldering defects			Trimming & framing
	Machine vision									
		Laminate defects	Torque	Weathering	Traceability	MIP	Root cause analysis		Traceability	
	Yield	Backsheet						Buyer- Acceptance & Delivery	Approved Vendor List (AVL)	
	Reliability risks		Junction box		Corrective actions	Diodes			Environmental testing	
		CAPA	Thermal stress	Reliability validation	Site handling	Climatic conditions		Safety		Environmental
		EVA	LeTID / CID	Labeling	Import/export	Flash		AQL		
	Change management								Supplier qualification	
	Soiling		Humidity freeze	Field inspection	Workmanship	End-of-life	Construction		Degradation rate	Bankability
	Field data	Lifecycle assessment	UV exposure		BOS integration	Glass defects	Asset performance		Field failure analysis	O&M
		Potential induced degradation (PID)		Shipping	Long-term reliability	Bankability	Diligence reports		Storage conditions	Recycling
						Commissioning				



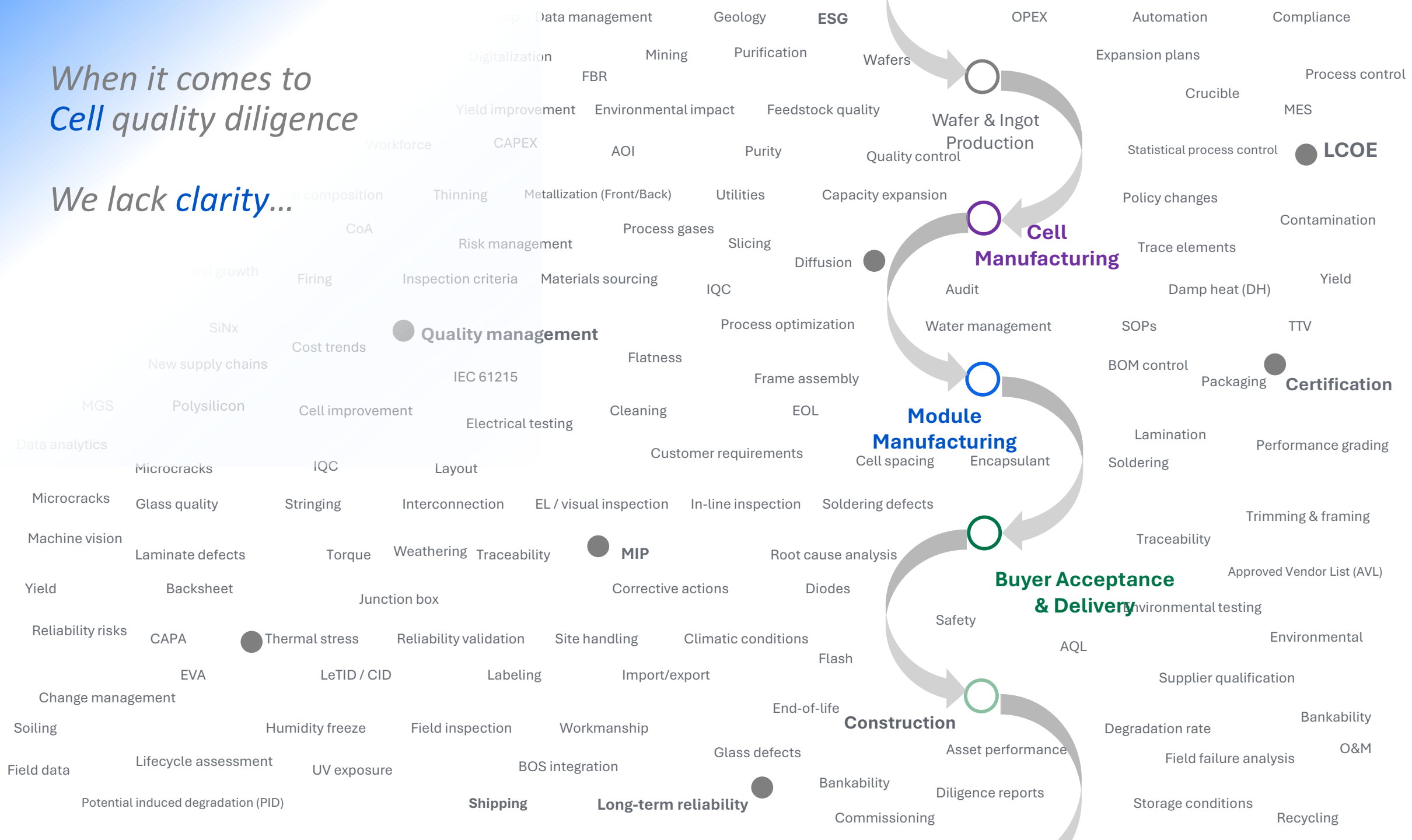


We don't lack content...



When it comes to
Cell quality diligence

We lack *clarity*...





Kiwa PI Berlin

1,000+

Factory Audits Conducted

230+ GW

PV Production Capacity
Evaluated

3 PV Labs in Key Markets

Berlin, Suzhou, California
(Kiwa PVEL)



Quartzite



MGS



Polysilicon
Production



Ingot & Wafer
Production



Cell
Manufacturing



Module
Manufacturing



Buyers &
Delivery
Acceptance



Construction



Asset
Operations



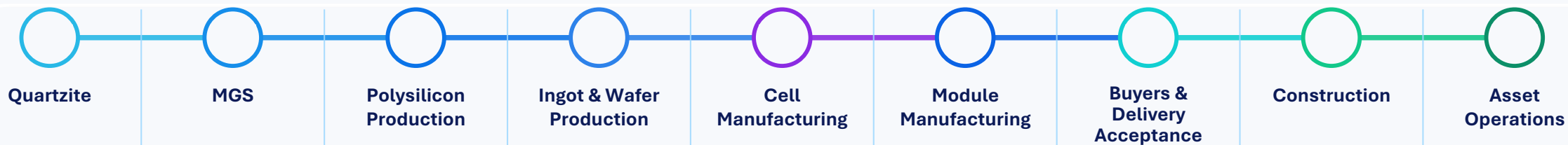
Kiwa PI Berlin

Trusted Technical Advisor:

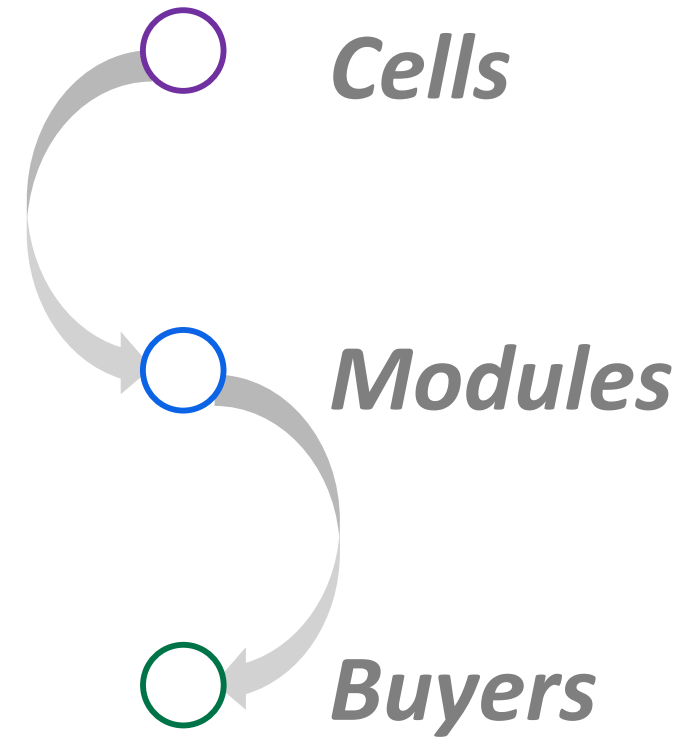
Global advisor and risk manager specializing in quality assessment for PV, storage, transformers, and inverters.

Industry Perspective:

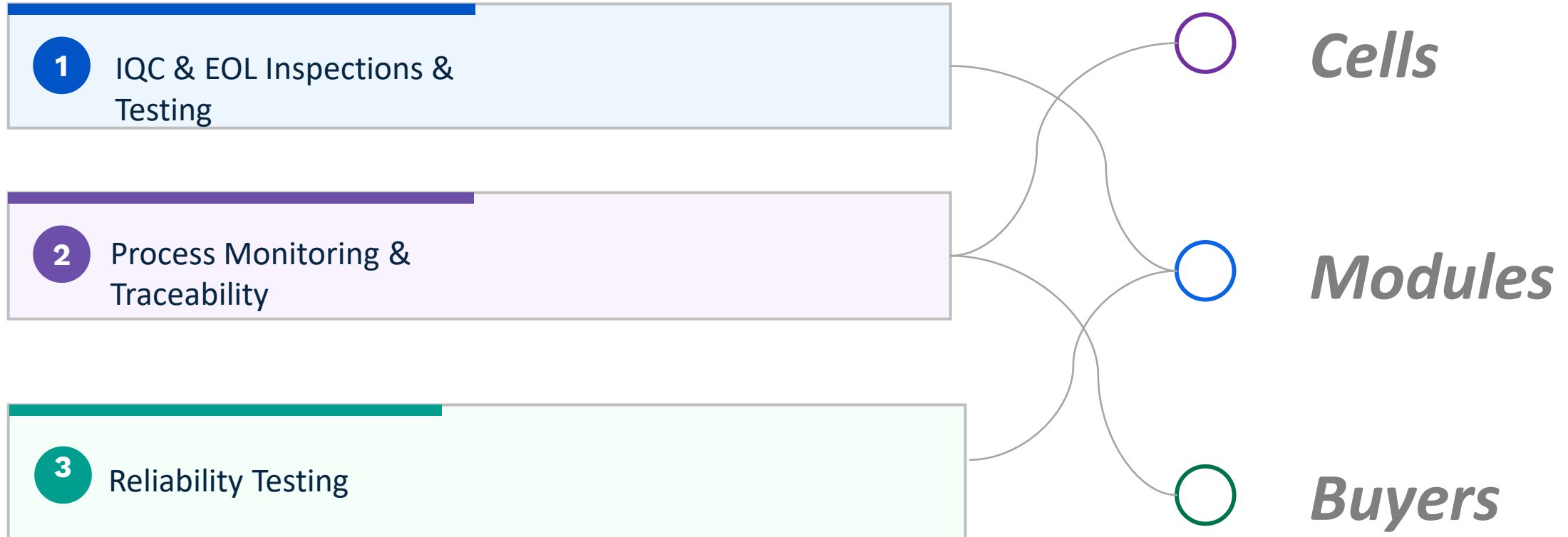
Working inside cell factories, module factories and buyers' projects, Kiwa PI Berlin sees where quality information breaks down across the supply chain and helps close those gaps to simplify PV deployment.



Alignment



Alignment - Quality Assurance Tools





Cells



Modules



Buyers

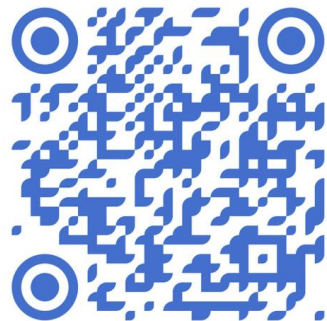
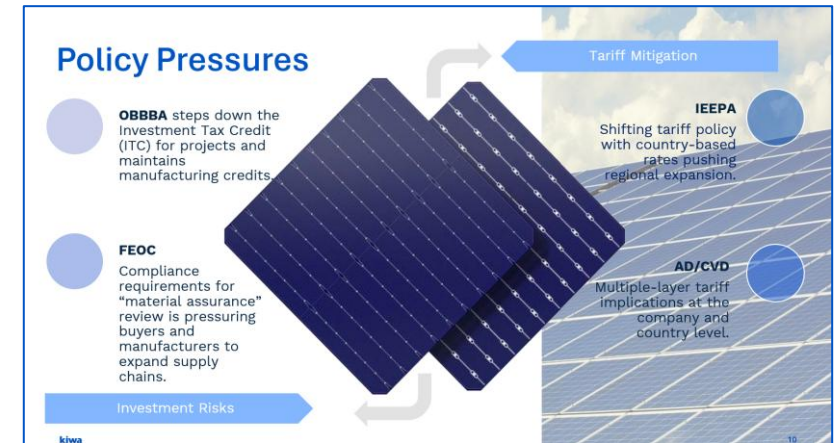


Cell Audit Analysis- Start With The Data

With PV module buyers asking more about what they need from managed cell quality and traceability, Kiwa published 2025 Q3 PV cell focused analysis whitepaper.



Process Step	PERC	TOPCon	HJT	Defects & Risks
Wafer Cleaning & Testing	✓ Wet or plasma etch	✓ Wet or plasma etch	✓ Wet or plasma etch	Incomplete cleaning → surface contamination, poor passivation, reduced efficiency
Emitter Formation	✓ Thermal diffusion	✓ Thermal diffusion	<i>X</i>	Non-uniform diffusion → cell mismatch, poor shunt resistance
Surface Passivation	✓ AlO _x /SiNx stack	✓ Tunnel oxide + Poly-Si	✓ a-Si layers	Defective passivation → high recombination, lower Voc and efficiency
Tunnel Oxide Deposition	<i>X</i>	✓ (thermal oxidation)	<i>X</i>	Thickness variation → tunneling failure, passivation loss
Poly-Silicon Deposition	<i>X</i>	LPCVD/PECVD	<i>X</i>	Poly grain boundary issues → higher recombination, instability
Intrinsic a-SiH Deposition	<i>X</i>	<i>X</i>	✓ (PECVD)	Thickness non-uniformity → passivation loss, optical absorption
Doped a-SiH Deposition	<i>X</i>	<i>X</i>	✓ p/n- a-SiH (PECVD)	Poor doping control → asymmetry in carrier collection, loss in fill factor
Transparent Conductive Oxide (TCO)	<i>X</i>	<i>X</i>	✓ (ITO/AZO sputtering)	TCO cracking or delamination → series resistance, adhesion failure
Metallization	✓ Screen printing + firing	✓ Screen printing + firing	✓ Low-temp curing or plating	Paste overflow, poor contact → shunting, cell-to-cell variation
Firing / Annealing	✓ High-temp (1-750-800°C)	✓ High-temp (1-750-800°C)	✓ Low-temp (>250°C)	Over-firing → metal spiking; under-firing → poor contact, increased resistance
Edge Isolation	✓ Laser/chemical etch	✓	✓	Incomplete isolation → edge shunting, leakage current
Final Cleaning & Inspection	✓	✓	✓	Missed defects → undetected microcracks, contamination, or warping



Testing Best Practices for Cell Quality

- In addition to PQP testing, Kiwa recommends performing:
 - **Batch Testing on random samples** for every 10 MW of modules produced
 - **Ongoing Reliability Monitoring on random samples** for every 50 MW of modules produced
- Key cell related tests are highlighted below:



Best Practice QA Recommendations for Cell Factory Management

- **On-site cell factory audits** assess quality risks which cannot be uncovered during module manufacturing.
- Identify **corrective actions** in advance of your production.
- Cell audits focus on **process control**, quality systems and execution.
- **Repeat audits** improve supplier qualification and quality over time.
- **BOM-level traceability** improves visibility into suppliers, material origins, and compliance for changing policy.

Toolbox- How We Align in Cell Quality Diligence

1 IQC & EOL Inspections

Incoming Quality Control:

Visual inspections, resistivity check, wafer type

End-of-line:

Flash test, EL test, Visual inspection (automated or manual) including dimensions and thickness, cell pull tests, cell four-point bending test, bifaciality

Out-of-box:

To verify EOL system is effective , Recheck offline flash, EL, visual and dimensions. Repeat pull, bending and bifaciality tests.

What matters:

Match reinspections to EOL results, correlate testers , lot-level IV distributions.

2 Process Monitoring & Traceability

Process monitoring:

Check diffusion resistance, texturing/ polishing reflectivity and weight loss, water-dripping, and refractive index.

Traceability:

Cell shipment records, sales orders, invoices, bills of lading, certificates of origin, customs documentation, warehouse inbound records, and cell production/MES records

What matters

Log measured values in MES, apply control plan limits, document processing metrics and link records to cell lots.

3 Reliability Testing

Testing:

Ongoing PID, LID, UVID and LeTID or CID.

What matters

Keep model and BOM results current.

Retest after process or BOM changes.

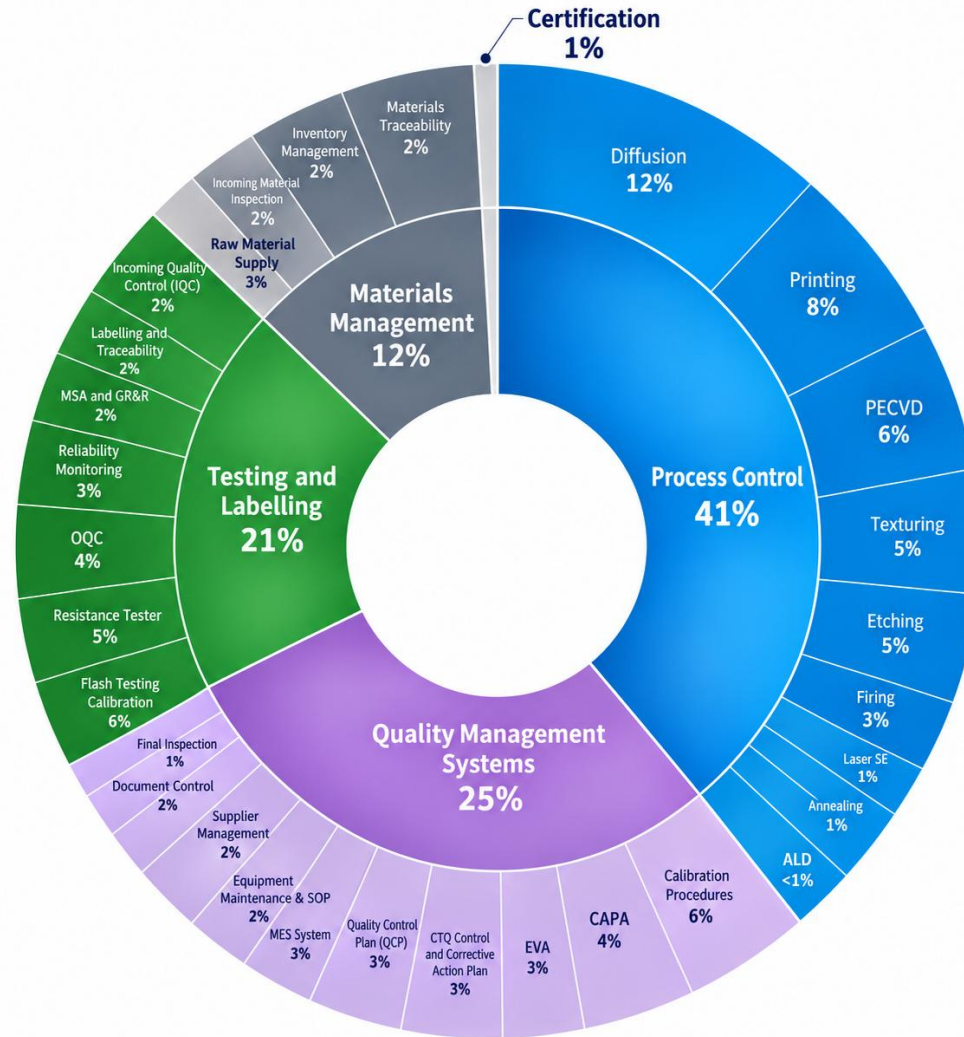
Cell Audit Findings

Process Control

- Minor parameter deviations can lead to latent field failures.

Quality Management System

- QMS gaps persist, particularly in emerging manufacturing regions.



Testing and labeling

- Calibration gaps and inconsistent metrology undermine reliability.

Materials Management

- Weak qualification and control introduce defects early in production.

Certification

- Missing certification prior to adoption

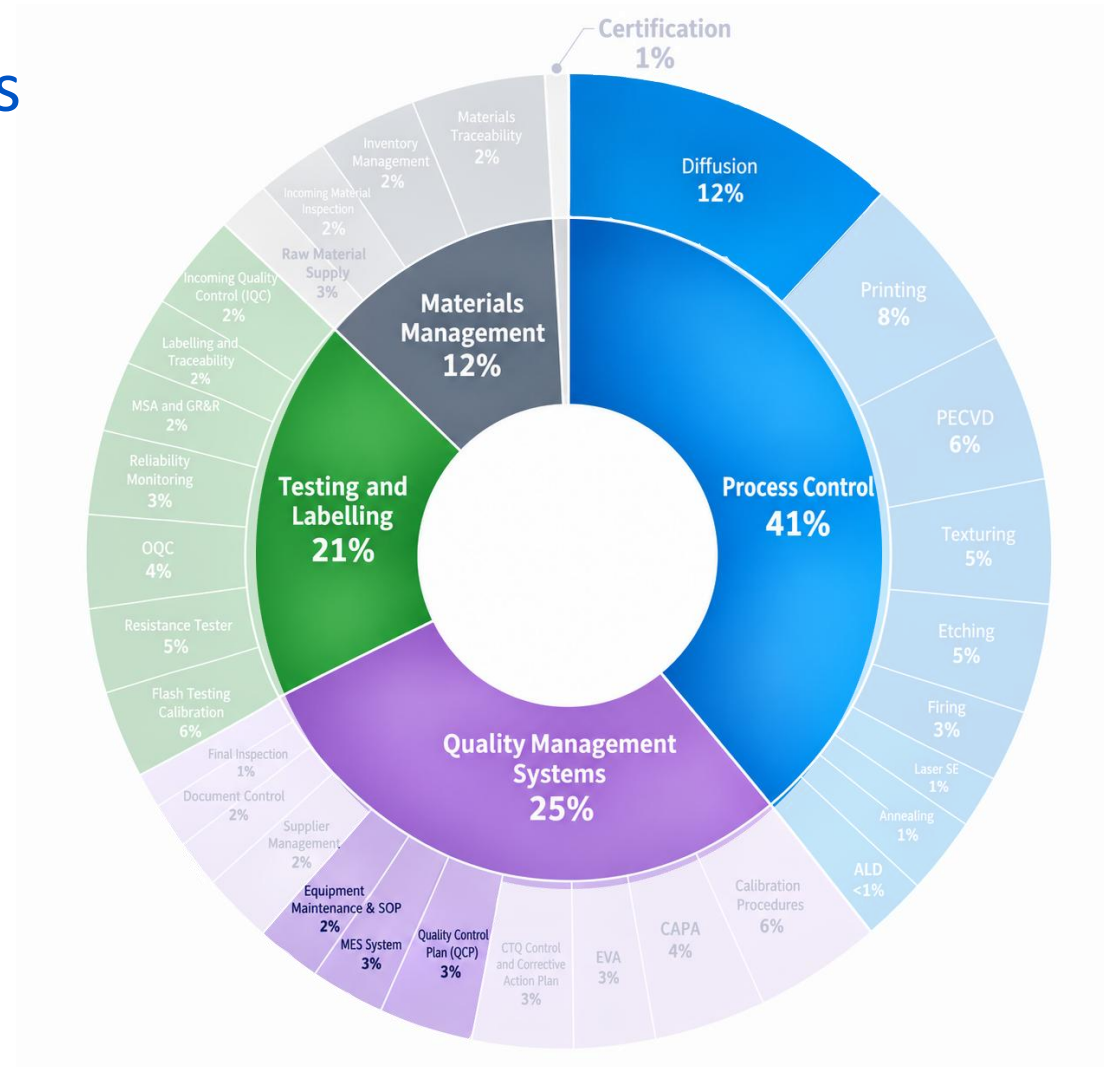
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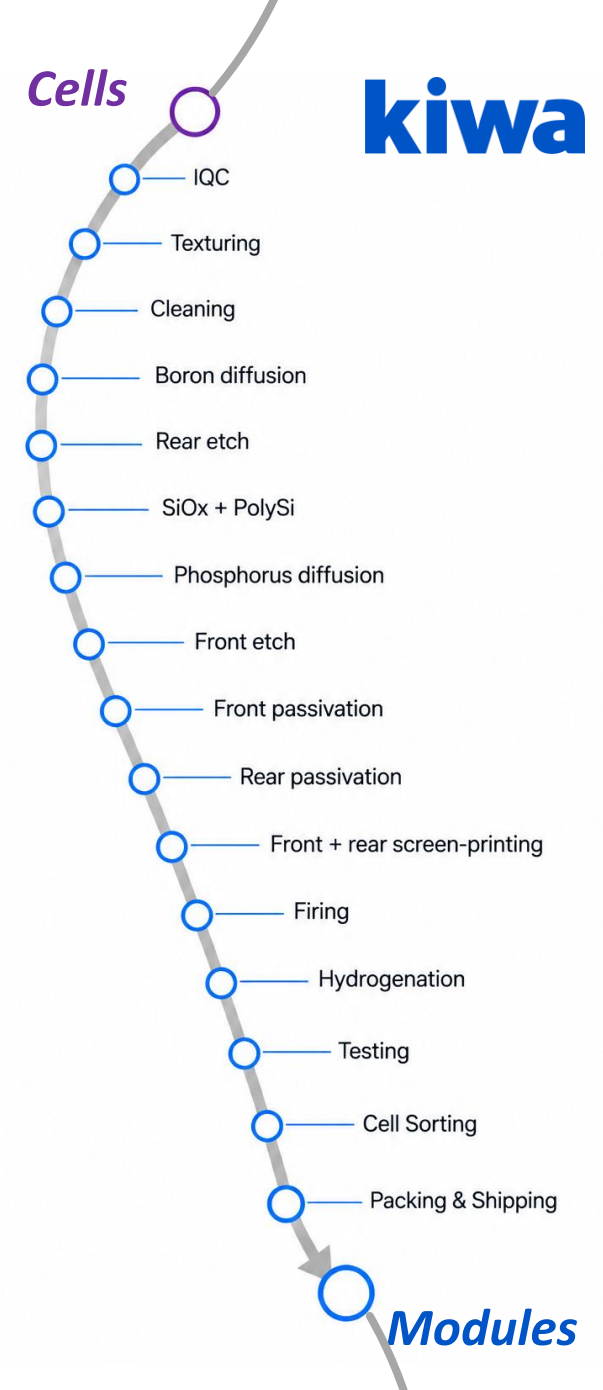
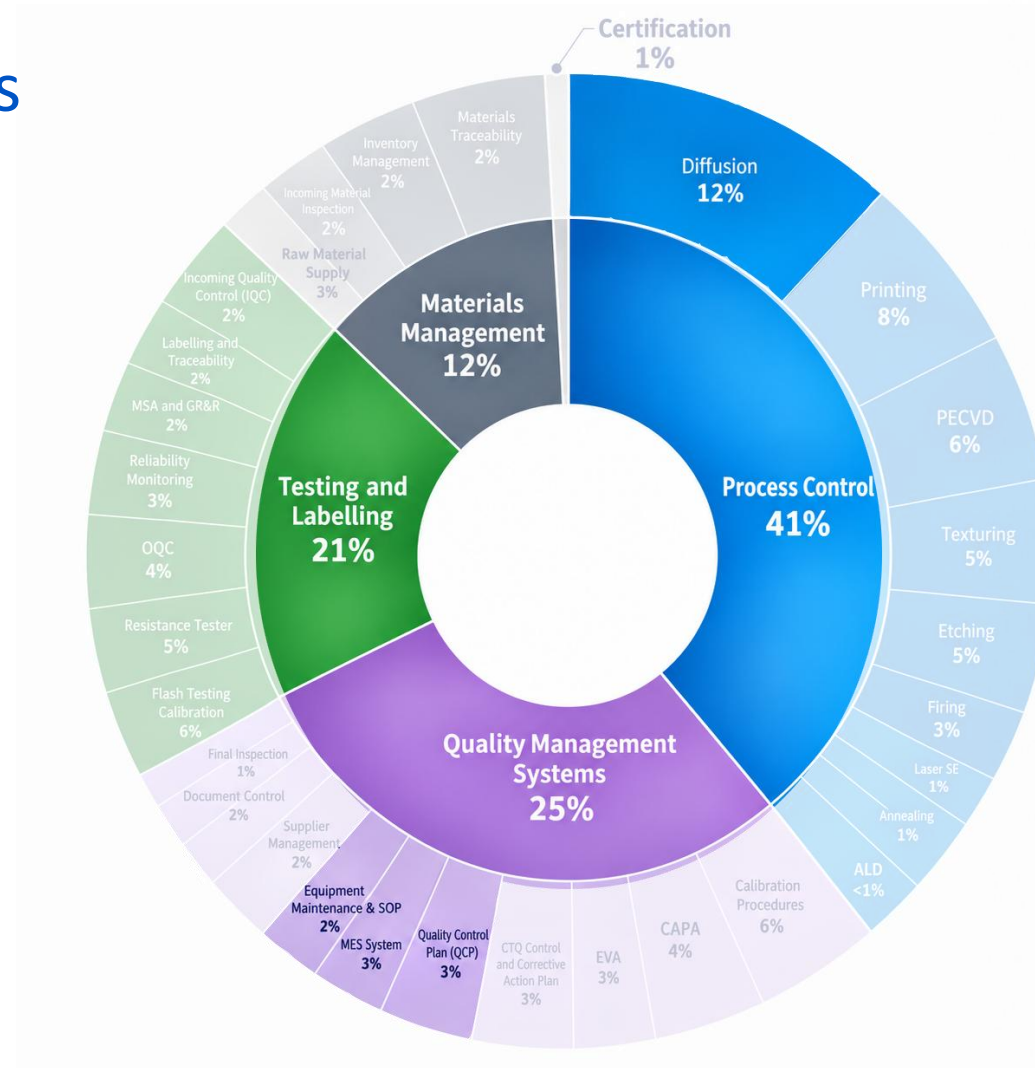
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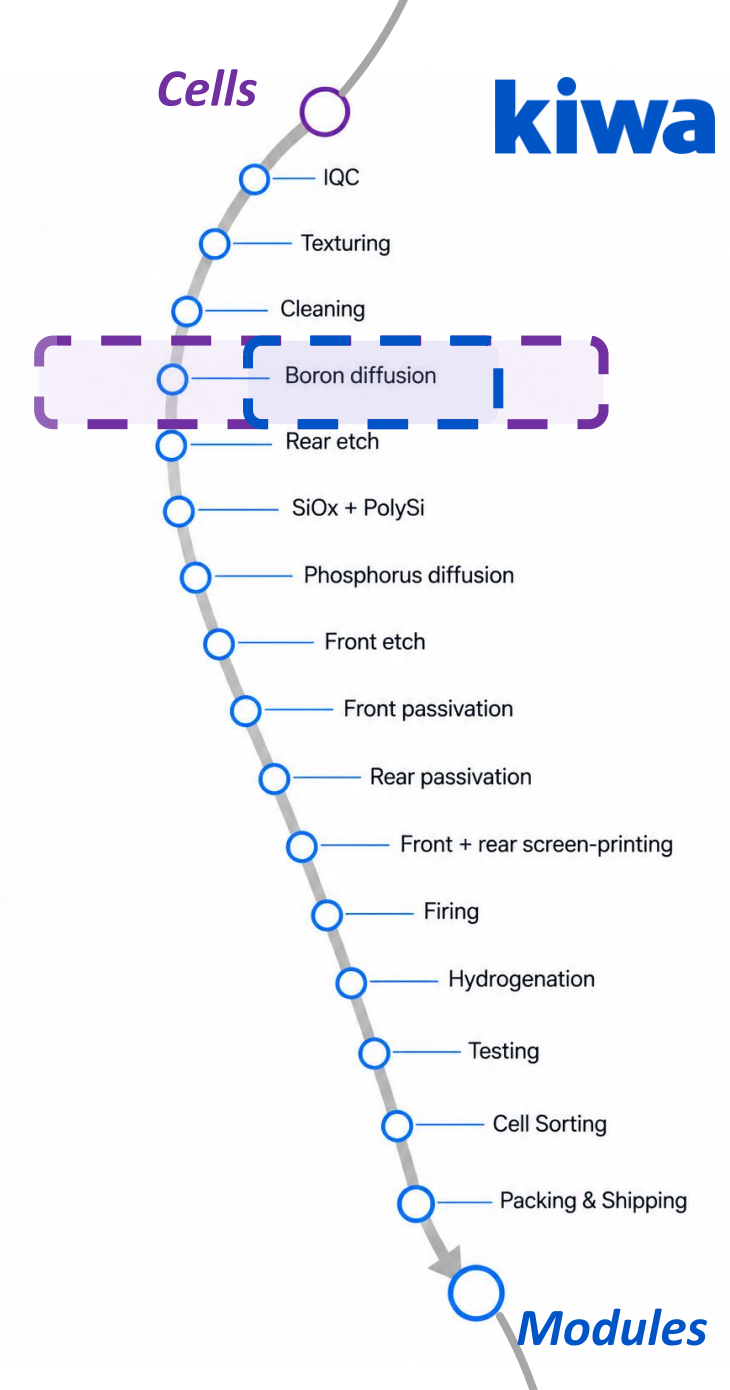
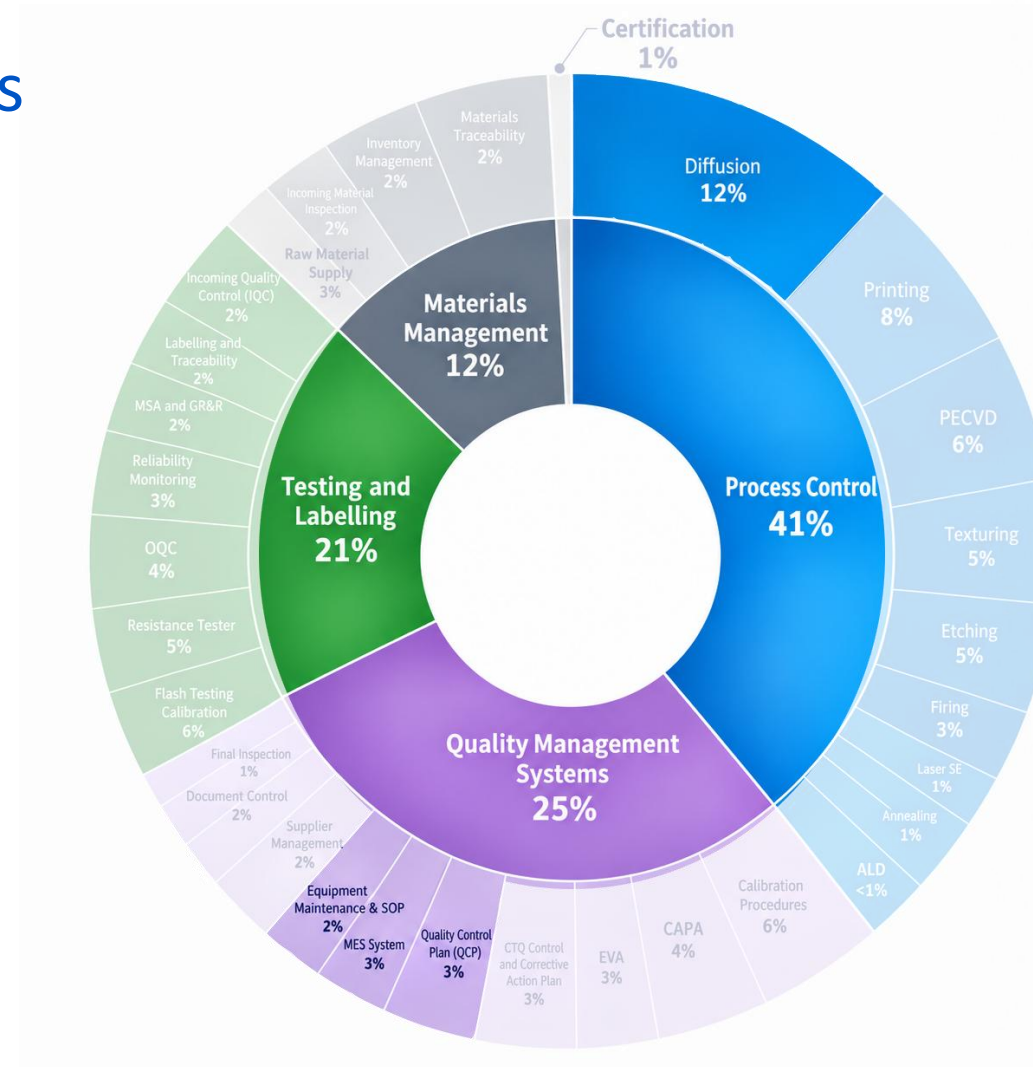
Cell Audit Findings

Process Control

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Quality Management System

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Diffusion

Processing Records & Traceability

Why it matters: The PV cell diffusion is a key process step; creates a doped semiconductor region that forms the p-n junction, allowing the cell to convert sunlight into electricity.

Important measurements for quality control:

- Sheet resistance mapping.
- Junction depth.
- IV, Efficiency, V_{oc} , & FF

What to verify: measured values, testing procedure, equipment calibration, Control Plan



Diffusion

Processing Records & Traceability

Defect detection

Diffusion defects can pass module assembly and routine inspection undetected

Potential field impacts

- Lower power output and energy yield
- Higher PID and UVID susceptibility from leakage paths and recombination
- Localized heating that degrades encapsulant and insulation

Key diffusion parameters and quality risks

Parameter	Importance	Potential issue if poorly controlled
Furnace temperature	Controls dopant diffusion and junction depth	Nonuniform emitter properties
Diffusion time	Affects dopant penetration	Excessive or insufficient junction depth
Furnace Pressure	Controls uniform dopant diffusion and junction depth	Inhomogeneous junction depth
Dopant gas flow	Controls dopant supply	Nonuniform sheet resistance
Wafer spacing and loading	Affects gas flow and thermal uniformity	Wafer-to-wafer variation
Edge isolation	Prevents electrical shunting around wafer edges	Low shunt resistance and reduced cell efficiency

Case Study: Boron Diffusion Control

Kiwa cell factory audit: major finding in diffusion and sheet-resistance control

Audit findings

Diffusion time: 700 s recorded vs. 900 s actual.

No boron gas-flow calibration interval.

Sheet-resistance readings were unstable.

Samples lacked furnace-zone mapping. The Control Plan lacked uniformity limits and acceptance criteria.

Edge defects remained unexplained, with insufficient data to link them to diffusion or furnace nonuniformity.

Potential module impacts

Power loss: nonuniform sheet resistance can increase cell mismatch and reduce module output.

Lower efficiency: an unsuitable emitter profile can increase recombination and affect Voc and fill factor.

Reliability concerns: defects may cause localized heating under mismatch or partial shading.

Corrective actions

Calibrate and verify gas-flow and sheet-resistance equipment.

Define sheet-resistance targets, uniformity limits and sampling requirements.

Map samples to furnace zones and correlate measurements with edge defects.

Align process records with actual settings and strengthen monitoring.

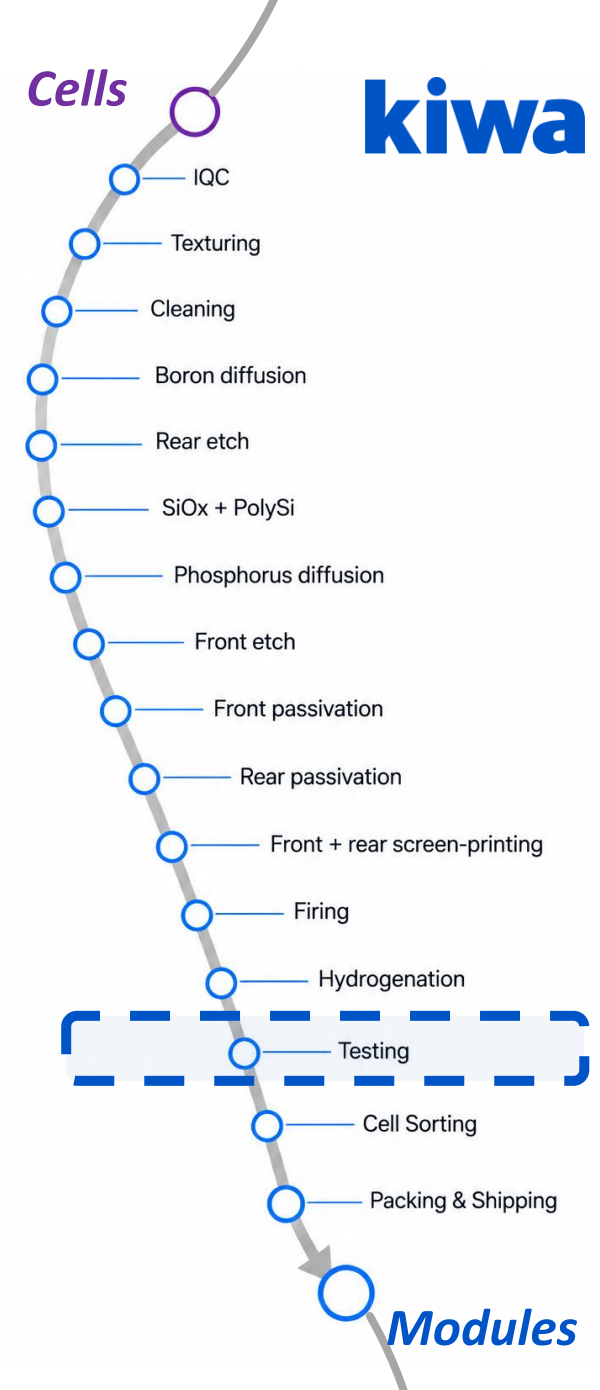
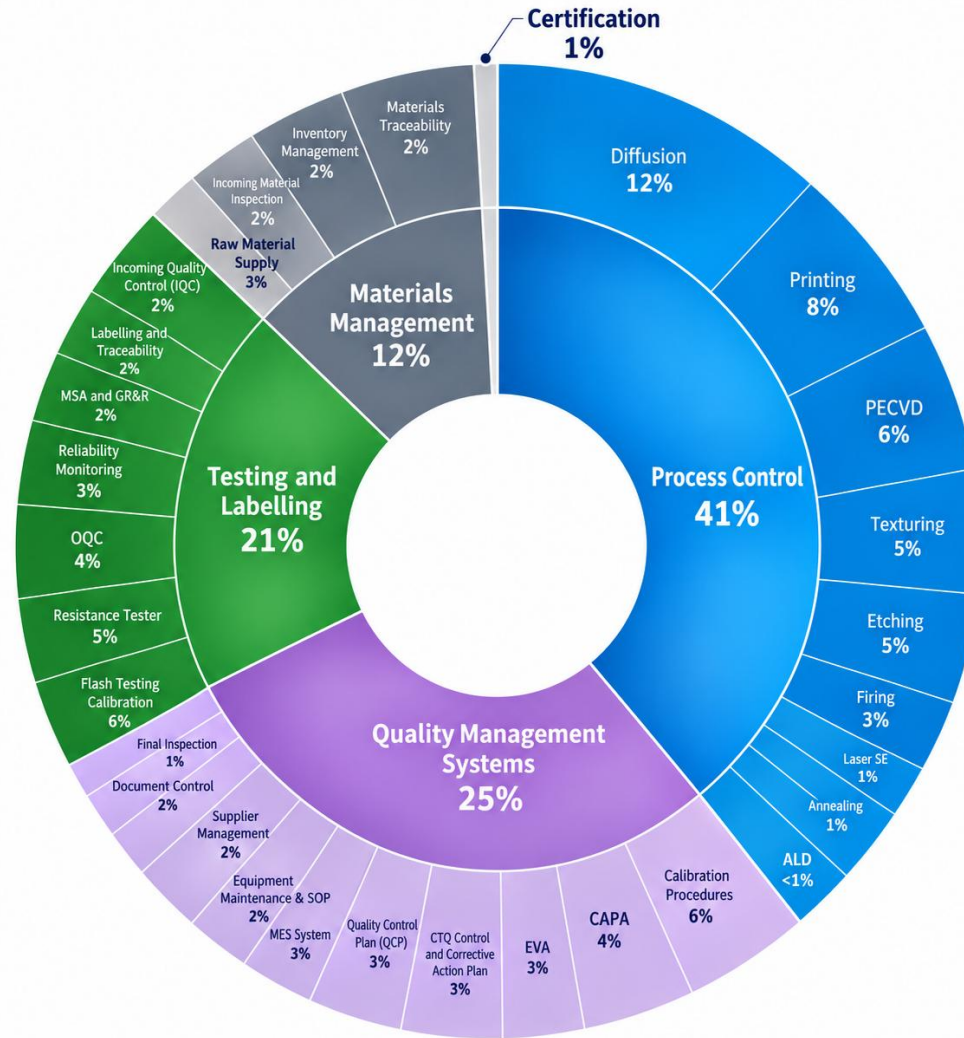
Cell Audit Findings

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Flash Testing

IQC and EOL Inspections/Testing

Flash Testing Determines Cell Performance, Quality, and Product Value

1. Verify Electrical Performance

Measures key parameters: I_{sc} , V_{oc} , I_{mp} , V_{mp} , power (P_{max}), and efficiency.

Confirms cells meet electrical specifications and performance targets.

2. Ensure Consistent Cell Sorting

Enables accurate power binning and matching of cells.

Reduces cell-to-cell mismatch and potential module power loss.



Flash Testing

● IQC and EOL Inspections/Testing

IV Tester Calibration & Measurement Accuracy Case Study

1. Key audit findings

No valid accredited calibration for reference cell or light sensors.

Incorrect temperature coefficients: Voc coefficient set to 1.87 %/°K versus 0.3 ± 0.03 %/°K; Isc coefficient set to 0.02 cm²/°K versus 0.6 ± 0.015 %/°K.

Xenon-lamp warning: 6M cycles vs 3M SOP limit.

2. Risk & impact

Inaccurate flash results and power ratings. Inconsistent binning and unreliable quality data.



Traceability

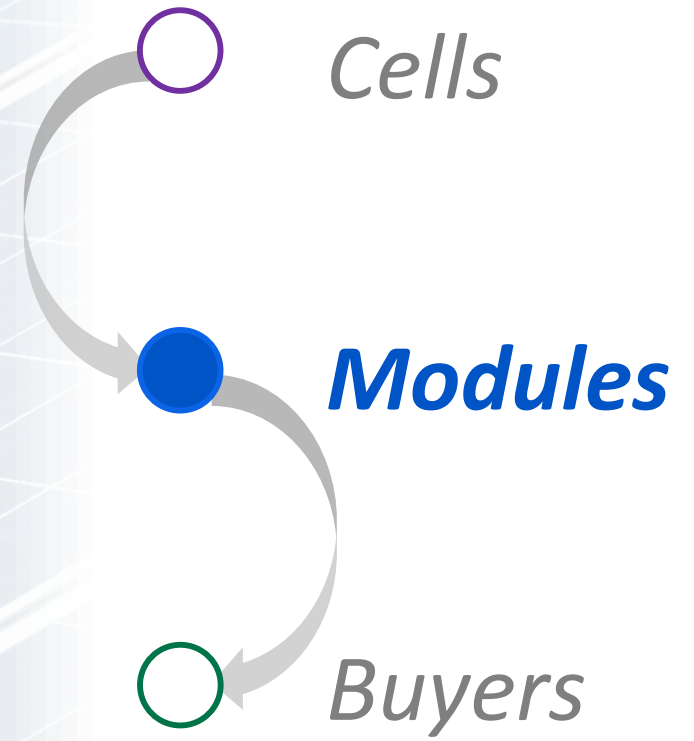
Increased traceability capabilities expanded in PV module suppliers with UFLPA, furthering with AD/CVD requirements

Wafer Traceability

- Wafer batch and material issue records
- Inbound records (delivery notes, IQC, CoA)
- Purchase orders, contracts, invoices, and payments
- BOLs, customs declarations, COO, and packing lists
- Production line delivery and consumption records

Cell Traceability

- Shipment records (packing lists, invoices, BOLs, COO, customs documents)
- Sales orders and payment records
- Warehouse inbound records
- Production and MES tracking records
- In-process inspection and sampling test records



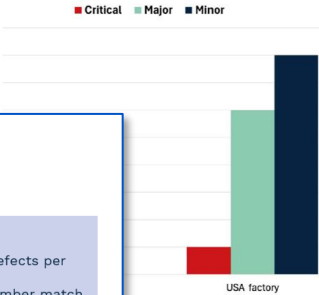
Module Quality Diligence

- Kiwa PI Berlin maintains a decade-long findings & defects database covering 125+ manufacturers, enabling industry-wide benchmarking of PV module manufacturing quality.
- Comprehensive factory data highlight emerging trends and recurring quality risks across global production lines.
- kiwa.com/2026pvmfrreport

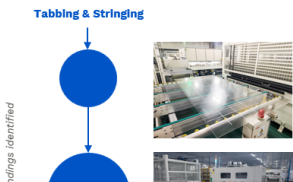


Quality Variability: Factories

- Comparing an established Asia factory with a new U.S. facility shows significant quality gaps despite the same OMS



Production Oversight



Factory Process

Front Glass Placement

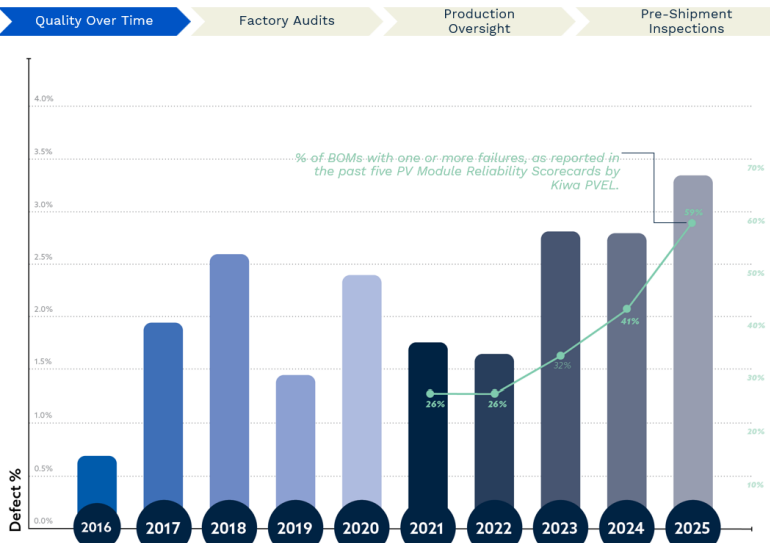
QA Checks

1. Verify correct glass orientation (front vs. rear).
2. Inspect the glass surface for scratches, stains, and other defects per SOP to prevent quality issues.
3. Confirm the glass manufacturer, dimensions, and model number match BOM and CDF specifications.

1. Verify the POE/EVA model and manufacturer match BOM and CDF

EOL Pre-Shipment Inspection Data

- Graph reflects consolidated PSI defect ratios across all inspected factories, providing a year-over-year view of manufacturing quality trends.
- Rising BOM-related quality issues are also evident in Kiwa's PQP/lab testing, where there is a clear uptick in BOM PQP failures alongside factory-level PSI defect increases.



kiwa 2026 PV Module Manufacturing Quality Report

Kiwa PI Berlin 12

routine audits
liability and safety

Kiwa PI Berlin 21

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Toolbox- Module Quality Assurance

1 IQC & Pre-Shipment Inspections

IQC and EOL Inspections

Verifies lot quality before modules are released for shipment.

Core checks

Visual inspection, EL imaging, flash-test facility measurements and dimensional checks.

Evidence

Lot findings, dispositions and release status.

2 Production Oversight

Control records

MES records and the approved Quality Control Plan.

Execution evidence

Recorded measurements during Production oversight activities provide proof and traceability documentation that the activities occurred.

Material control

BOM control, line-change approval and confirmation of materials used.

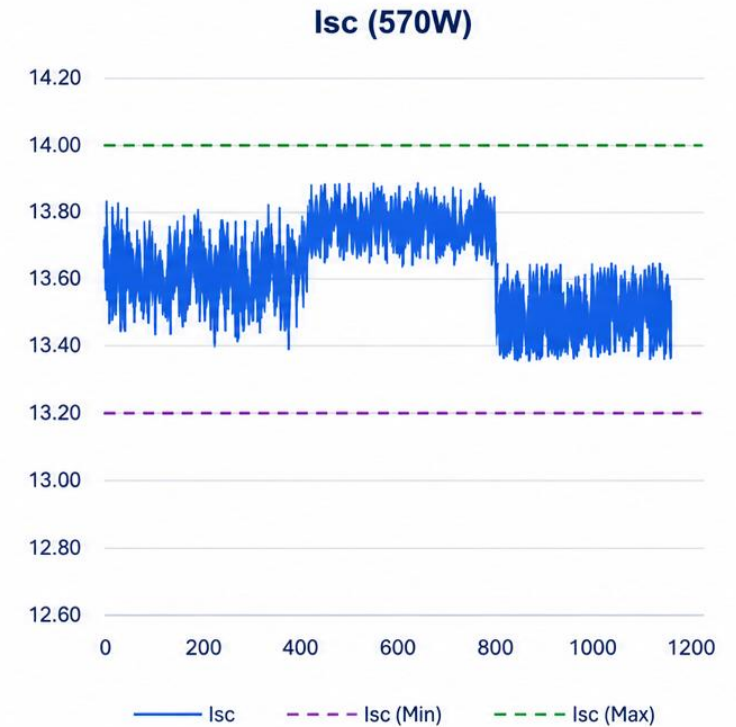
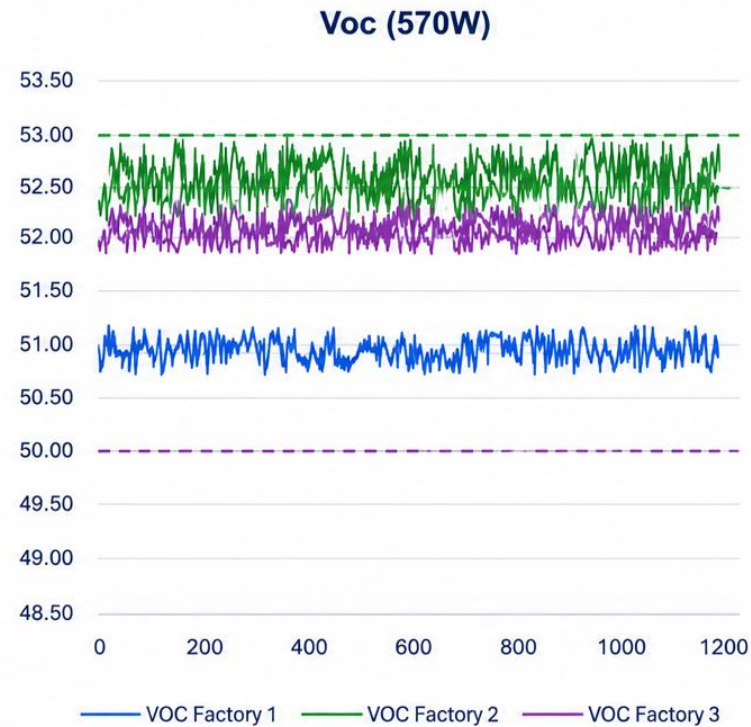
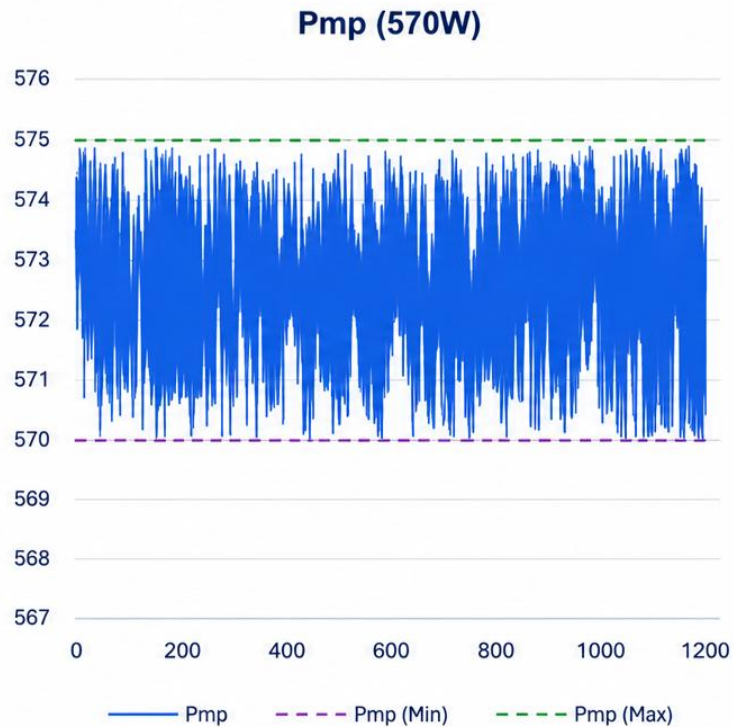
3 Batch & Extended Reliability Testing

Batch Testing

Short and mid duration testing on sampled modules from the production lot, track performance drift And continued material quality across production

Extended Reliability Testing

Longer-duration testing validates the current module design and BOM.



Case Study

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.

Modules – IQC & EOL

1 IQC & Pre-Shipment Inspections

EOL Inspections

Verifies lot quality before modules are released for shipment.

Core checks

Visual inspection, EL imaging, flash-test facility measurements and dimensional checks.

Evidence

Lot findings, dispositions and release status.

Incoming Quality Control

Incoming material checks to ensure BOM compliance and material quality

Cell Inspections

Visual inspections, sorting by efficiency, and electrical parameters to ensure proper performance in modules

Evidence

Verification IQC occurred at the module factory on a routine cadence. .

Modules

IQC

Glass Loading

Tabbing & Stringing

Layup

Pre-Lamination Inspection

Lamination

Trimming

Framing

Junction Box Installation

Final Inspection (EL / Visual)

Sorting & Bin Classing

Packaging & Shipping

Buyer- Delivery/Acceptance

IQC Workflow

1 IQC

Validate measurements

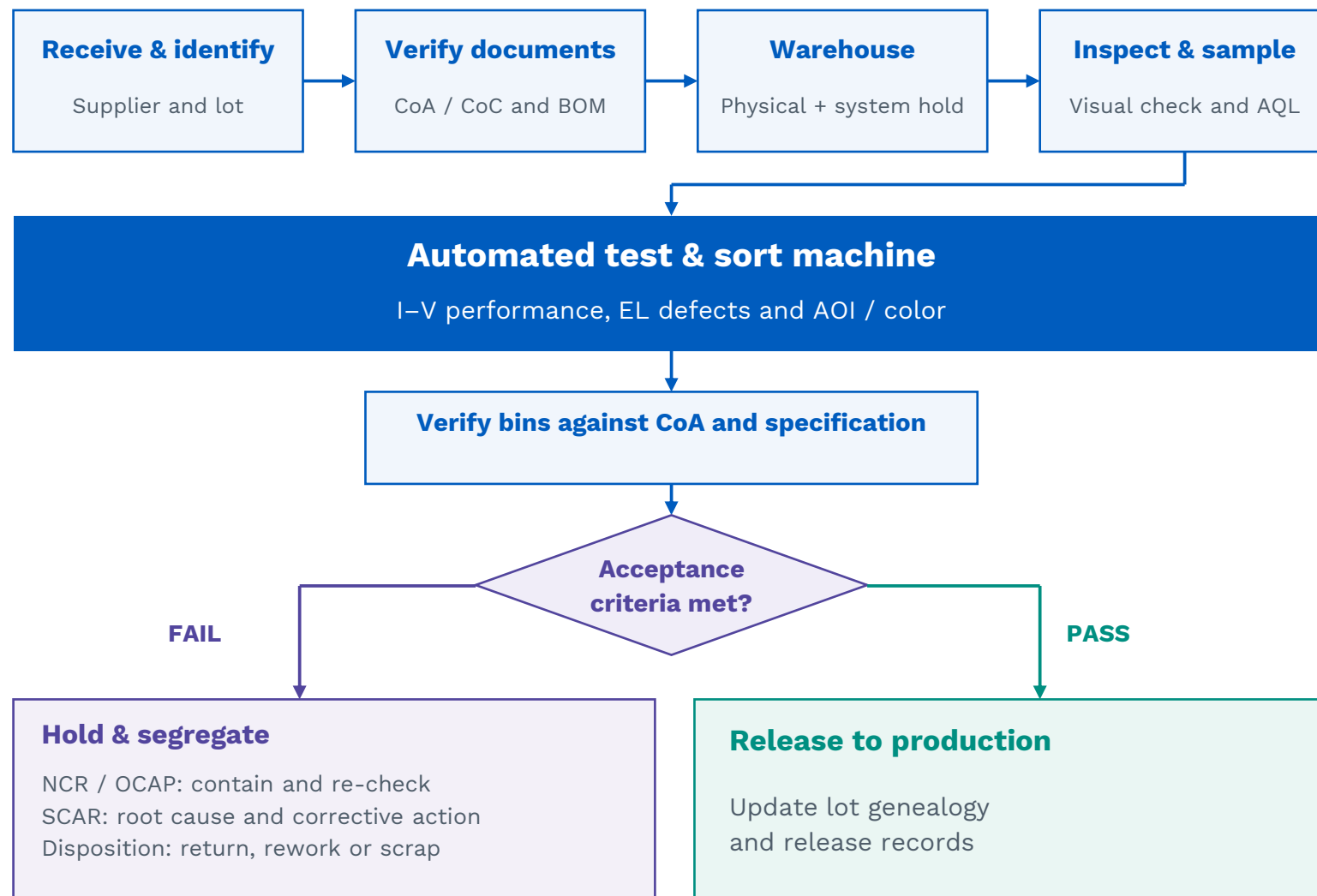
Use calibrated equipment, a reference cell and an approved test method.

Lot traceability

Link the supplier, lot and bin to the CoA / CoC and MES record.

Conformance evidence

Record electrical and defect results against the incoming specification and AQL plan.

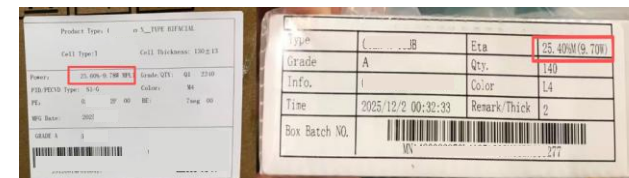


Case Study: IQC

1 Cause

Outer and rework labels showed 25.60% efficiency, but inner labels showed 25.40%.

Production released cells without reconciling labels, exposing gaps in identity checks, release verification and rework control.



2 Effect

Both efficiencies met customer requirements, but IQC, release and missed the mismatch.

Mixed cells increased resistance and reduced module power. EL brightness variation caused final rejection.

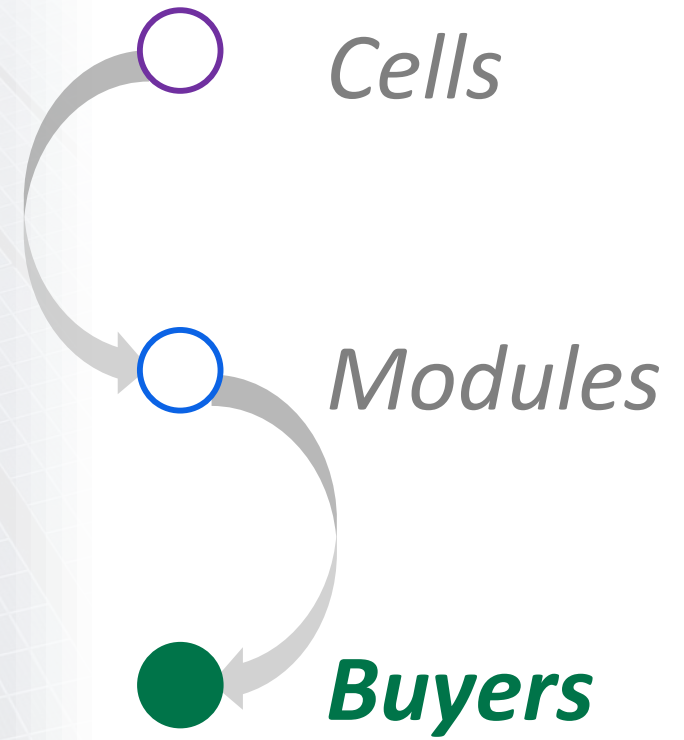


3 Closure

Hold and trace affected products.

Resolve labeling and release gaps through factory 8D and supplier SCAR.

Verify corrective actions before closure.



Buyers- Quality Diligence to Connect it all Together

1 IQC & Pre-Shipment Inspections

Why PSI matters

Verifies lot quality before modules are released for shipment.

Core checks

Visual inspection, EL imaging, flash-test facility measurements and dimensional checks.

Evidence

Lot findings, dispositions and release status.

2 Production Oversight Data

Control records

MES records and the approved Quality Control Plan.

Execution evidence

Recorded measurements and completed check sheets—not unchecked boxes.

Material control

BOM control, line-change approval and confirmation of materials used.

3 Testing Verification

Verify reliability testing reports

Check that reports confirm passing results for the supplied model and BOM.

Verify certification

Check that valid certification covers the supplied product and applicable standards.

Self-quality augmentation

Check that supplemental quality evidence addresses gaps in testing and certification.

Buyers- Quality Diligence to Connect it all Together

1 PSI Batch Reports



2 Production Oversight Summaries

kiwa

Section 2: Production Information

Table 2: Project-to-Date Production Totals

	Output Pieces	Output Power (MW)
Project-to-Date/Production Totals	312,492	105,030

Table 2-1a: Production Totals by Date Model 1:

Production Date	Output Pieces	Output Power (MW)
Total Production Prior to: 06/26/2025	174,756	100,470
06/26/2025	6,480	4,050
06/27/2025	6,334	3,960
06/28/2025	5,616	3,510
06/29/2025	5,666	3,640
07/01/2025	6,121	3,800
07/02/2025	5,904	3,660
07/03/2025	5,044	3,430
07/06/2025	5,472	3,390
07/07/2025	5,666	3,530
07/08/2025	5,666	3,640
07/09/2025	6,696	4,150
07/10/2025	6,408	3,970
07/11/2025	6,338	3,950
07/13/2025	5,366	3,530
07/14/2025	6,408	3,970
07/15/2025	6,088	3,770
07/16/2025	6,372	3,960
07/17/2025	6,460	4,130
07/18/2025	6,048	3,750
07/20/2025	5,292	3,290
07/21/2025	6,048	3,780
07/22/2025	5,760	3,580
07/23/2025	5,040	3,140
Total	137,736	85,560

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3 Testing Reports & Validation



Testing & BOM Validation

The issue

- Performance is BOM-specific, not just module-type-specific.
- Contracts should require like-module testing on the production BOM, a defined protocol with pass/fail criteria, and the required certifications.
- A certification covers only its listed components.

How to manage it

- Protocol: Tested protocol matches the contract.
- Results: Results meet contract pass/fail criteria.
- BOM: Tested, contracted and produced BOMs match.
- Certifications: Certificates and CDF/CDR cover the production BOM.
- Gaps: Flag testing, certification and traceability gaps, with risk recommendations.

3

Testing Reports & Validation



Key Takeaways

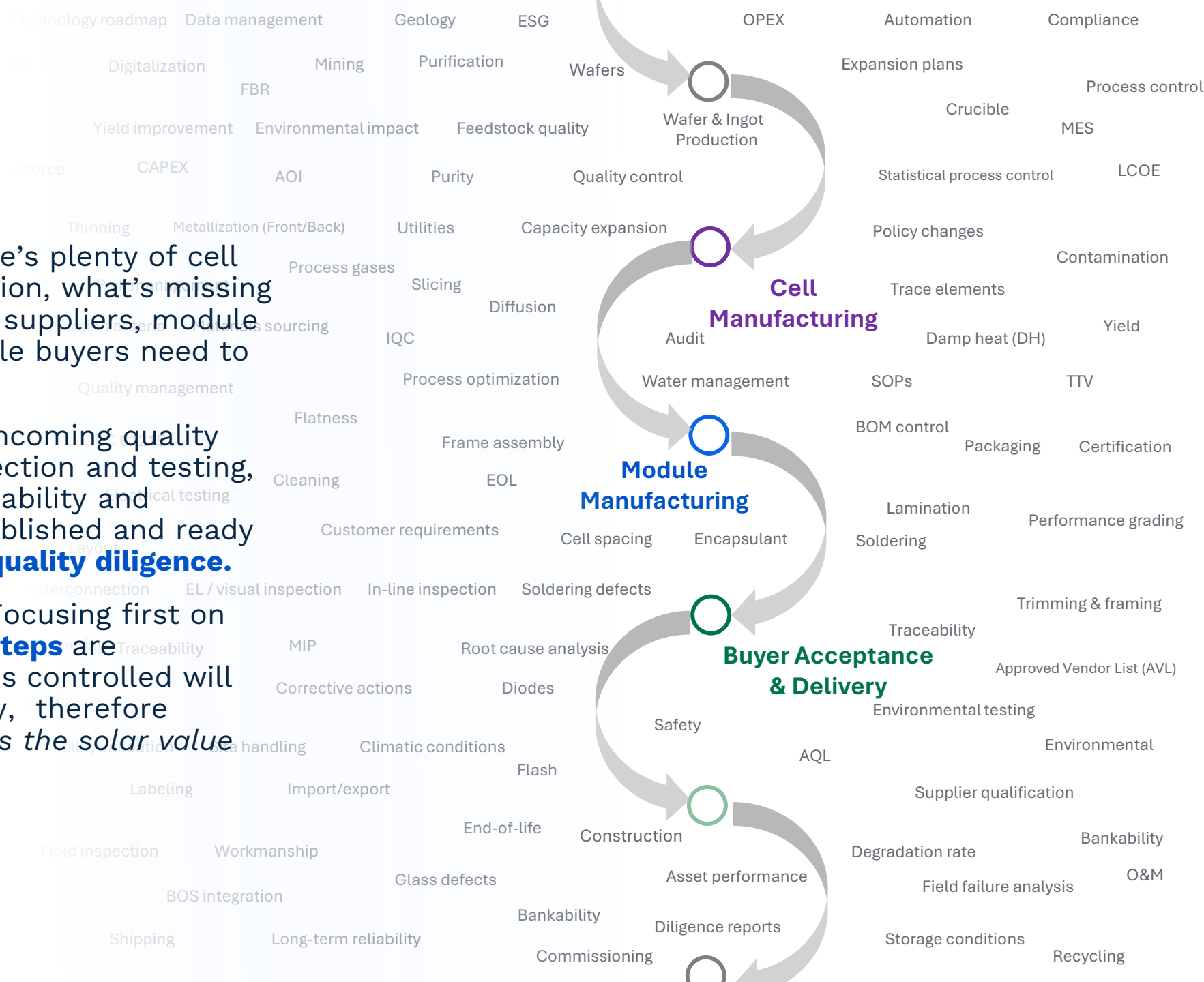


Key Takeaways



Key Takeaways

- 1. Clarity, not content.** There's plenty of cell quality diligence information, what's missing is **clarity** about what cell suppliers, module manufacturers and module buyers need to align on.
- 2. The tools already exist.** Incoming quality control, end-of-line inspection and testing, process monitoring, traceability and reliability testing are established and ready to use and **align for cell quality diligence.**
- 3. Focus on the key steps.** Focusing first on how **key manufacturing steps** are documented and quality is controlled will improve industry maturity, therefore *building confidence across the solar value chain.*



Thank you!

kiwa

