Raising the Bar

Understanding acceptable levels of quality for PV modules

Kiwa PVEL | Kiwa PI Berlin

We Create Trust

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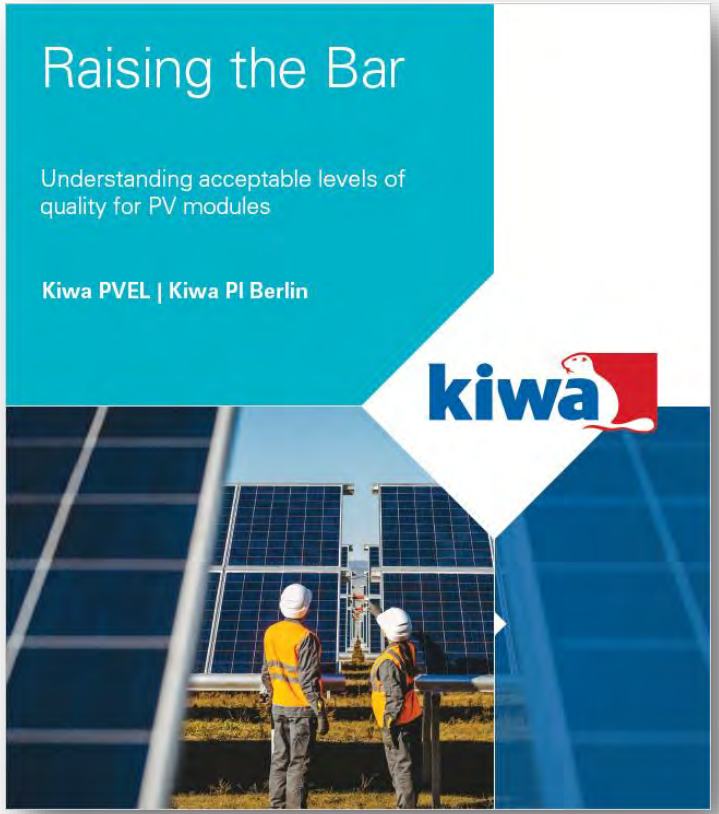


Today's Speakers

Presenters

Tristan Erion-Lorico
VP of Sales and Marketing
Kiwa PVEL

Don Cowan
Director of Sales & Marketing
Kiwa PI Berlin

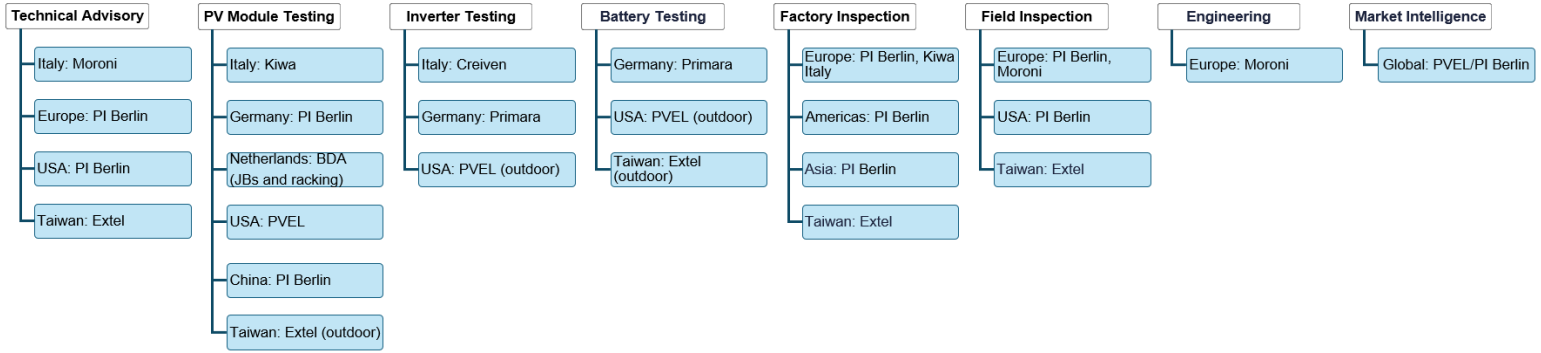
Mahyar Nezhad
Principal PV Module Consultant
Kiwa PI Berlin

Moderator

Max Macpherson
Senior Program Manager
Kiwa PVEL

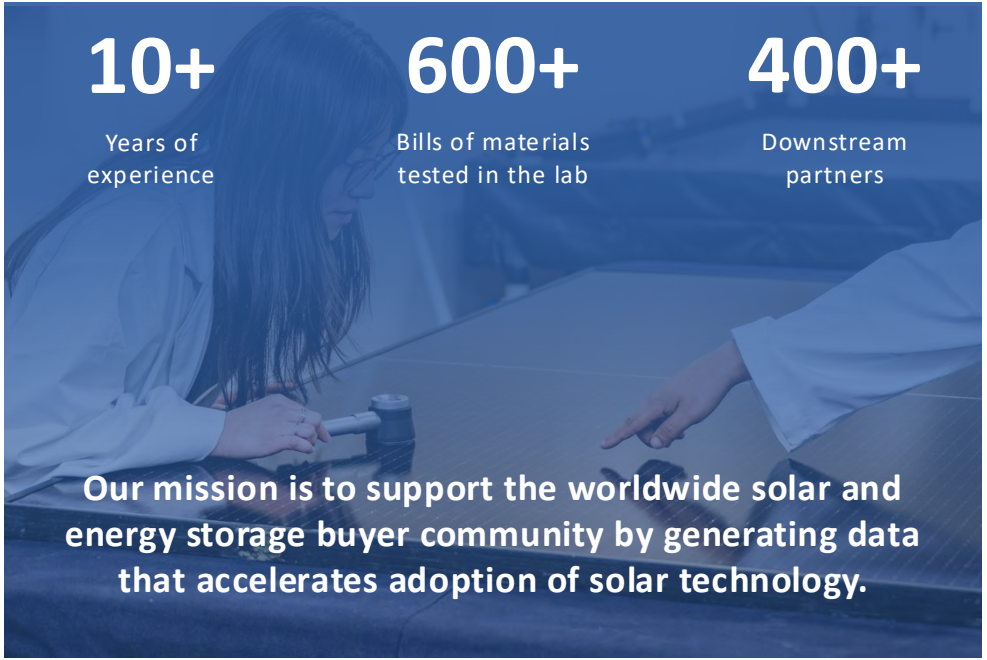
Kiwa Overview

- Kiwa is a global testing, inspection and certification (TIC) company, founded in 1948.
- Headquartered in Rijswijk, the Netherlands with more than 10,000 employees, working in over 37 countries. Kiwa is primarily active in renewable energy, construction, manufacturing, fire safety, medical devices, food & water.
- Kiwa's solar businesses at a glance:



- Kiwa's mission is to create trust by contributing to the transparency of the quality, safety and sustainability of products, services and organizations as well as of personal and environmental performance.

Kiwa PVEL is the Independent Lab of the Downstream Solar Market



Services at a glance

- Extended reliability and performance testing for PV modules
- Batch testing of PV modules
- Outdoor testing at PVUSA, an iconic grid-connected research site
- Data services for PV buyers and investors

See more details at kiwa.com/pvel

Kiwa PI Berlin: Trusted Solar and Storage Advisors

1,000+

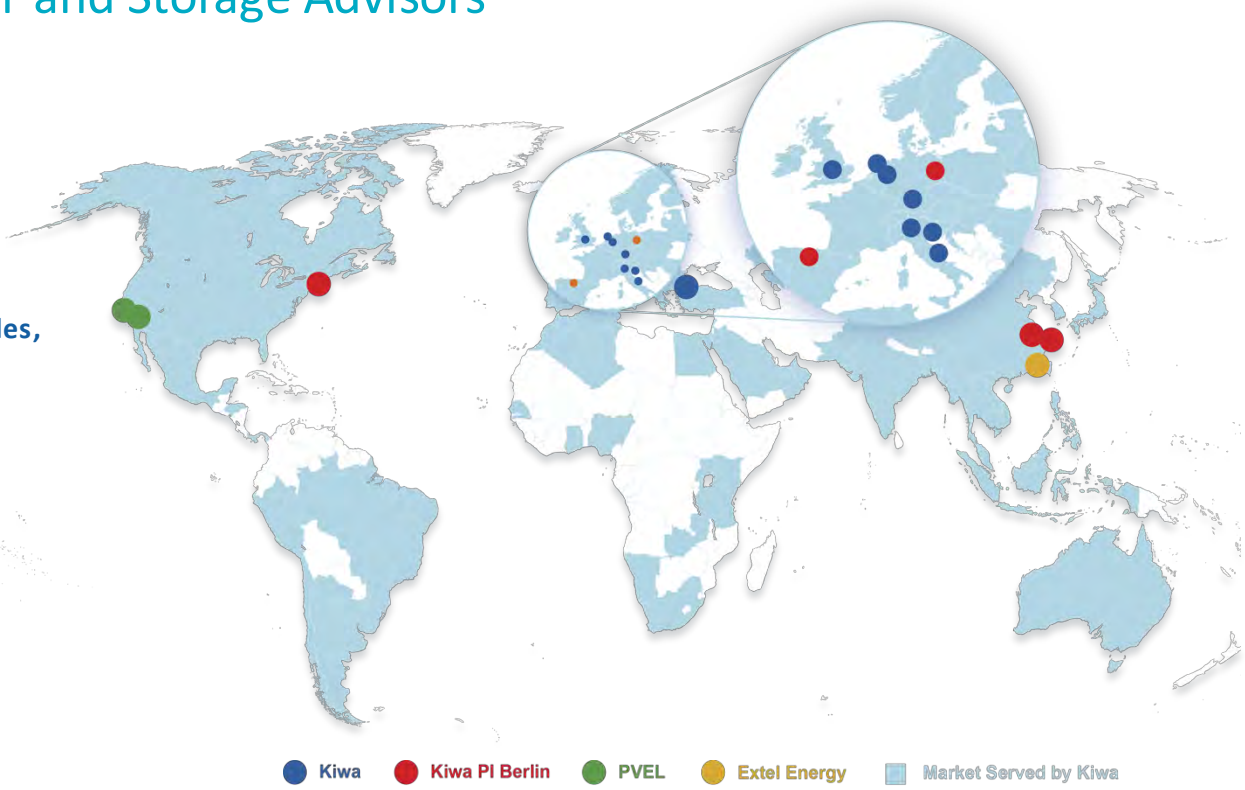
Factory Audits Conducted across PV Modules, Inverters, BESS and Transformers

175+ GW

PV Production Supervised

3 PV Labs in Key Markets

Berlin, Suzhou, California (PVEL)



Managing Quality From Qualification to Production

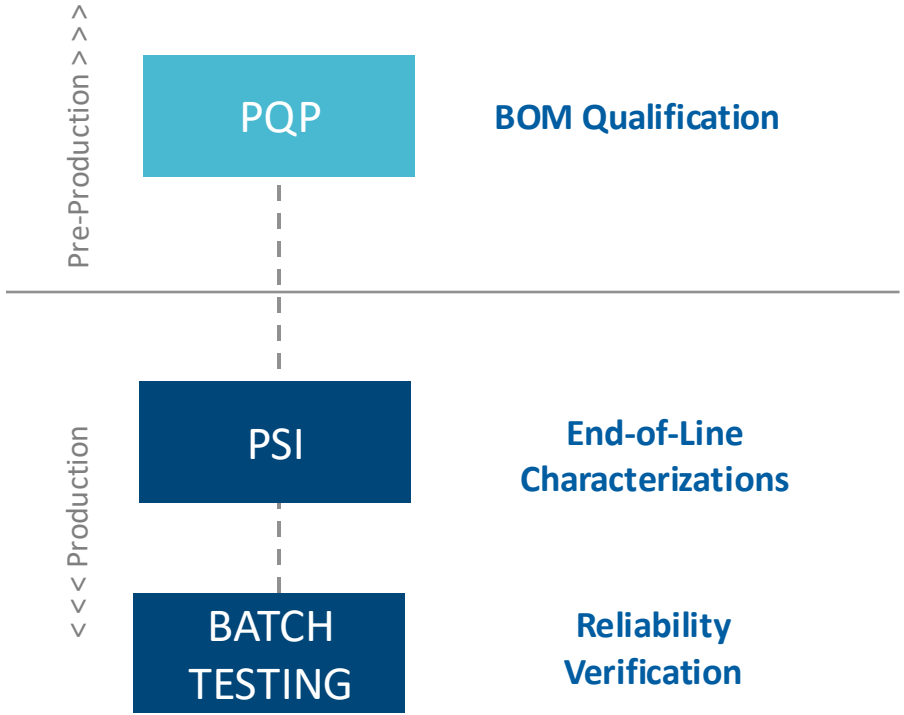
The presented quality assurance tools are key elements of Kiwa's PV Module Procurement Best Practices: kiwa.com/modulebestpractices

Pre-production:

- Qualify the product
  - Includes Product Qualification Program (PQP) testing
- Set contractual requirements
- Audit the factory

Production:

- Verify production quality
  - Includes Pre-Shipment Inspection (PSI), Batch Testing and Ongoing Reliability Monitoring (ORM)
- Validate quality onsite



Product Qualification Program Guidance

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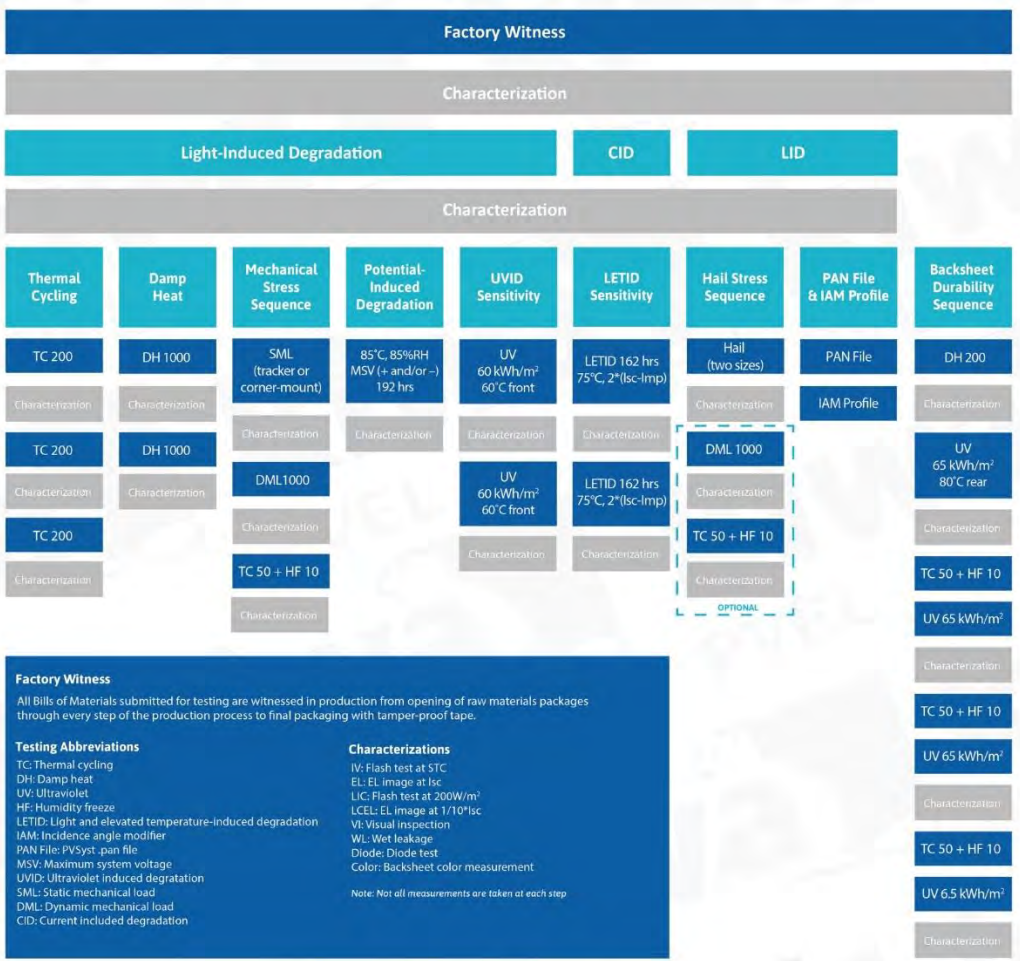
PQP Test Sequence

The PQP evolves every two years based on feedback from Kiwa PVEL's downstream partners, module manufacturers, and the industry's collective understanding of module failure modes and test mechanisms.

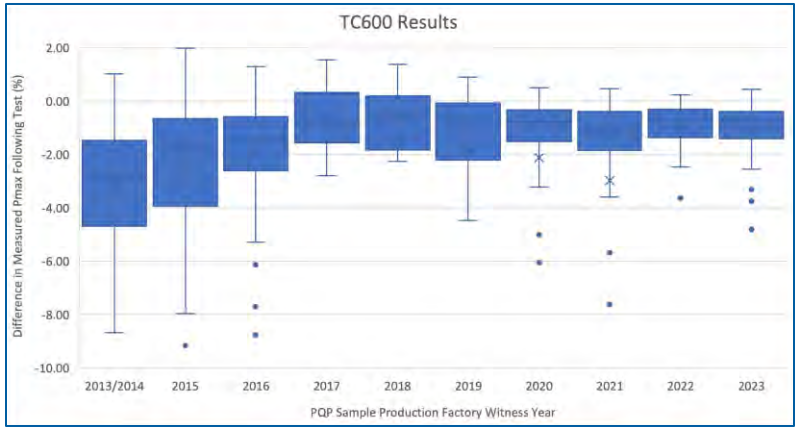
The most recent update introduced the new UVID test and streamlined many of the tests leading to faster execution of PQP projects.

Learn more about the current version of the PQP test plan at kiwa.com/pvel/pqp.



PQP Result Trends

- Results have improved over time. For example:



see more trends at scorecard.pvel.com.

- PQP results by test for the past two years:

TEST	<3%	3-5%	≥5%	OTHER FAILURES*
TC	95%	4%	1%	7%
DH	92%	6%	2%	8%
MSS	99%	1%	0%	6%
PID	83%	11%	6%	2%
UVID	25%	35%	22%	17%
TEST	**<1%**	**1-2%**	**≥2%**	**OTHER FAILURES****
LID+LETID	84%	15%	1%	13%

PQP Acceptance Guidance

TEST	ACCEPTANCE LEVEL	POWER DEGRADATION	OTHER CHARACTERISTICS
TC, DH, MSS, PID	Clear Pass:	<3%	No visual inspection majors, wet leakage failures or diode failures (for TC and MSS).
	Conditional Pass:	3-5%	Visual inspection majors, wet leakage failures and/or diode failures (for TC and MSS) with positive RCCA (e.g. no design/process flaws).
	Clear Fail:	≥5%	Visual inspection majors, wet leakage failures and/or diode failures (for TC and MSS) with no or negative RCCA.
LID plus LETID	Clear Pass:	<1%	No visual inspection majors or wet leakage failures.
	Conditional Pass:	1-2%	Visual inspection majors and/or wet leakage failures with positive RCCA (e.g. no design proces flaws).
	Clear Fail:	≥2%	Visual inspection majors and/or wet leakage failures with no or negative RCCA.

TEST	ACCEPTANCE LEVEL	POWER DEGRADATION	OTHER CHARACTERISTICS
HSS (hail size determined by project site's susceptibility to hail impacts)	Clear Pass:	Less applicable	No glass breakage, no other visual inspection majors or wet leakage failures.
	Conditional Pass:		Visual inspection majors (other than glass breakage) and/or wet leakage failures.
	Clear Fail:		Glass breakage
BDS	Clear Pass:	Not applicable	No visual inspection majors, delta b* ≤5
	Conditional Pass:		Visual inspection majors (other than backsheet cracking) and/or delta b* >5
	Clear Fail:		Backsheet cracks

A conditional pass is based on the module manufacturer completing a detailed root cause corrective action (RCCA) analysis to the module buyer's satisfaction.

Pre-Shipment Inspection Guidance

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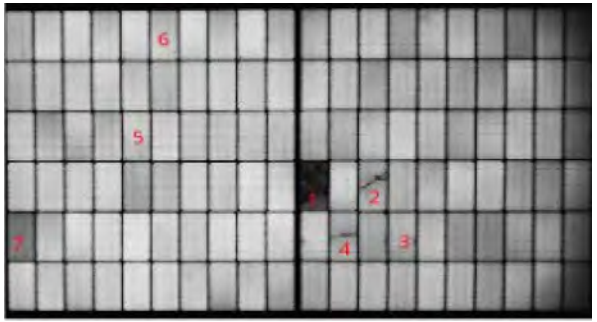
Pre-Shipment Inspections

What are Pre-Shipment Inspections (PSI)?

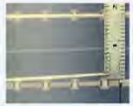
- End of production line inspections and characterizations.
- Typically are “re-inspections” to verify the factory is meeting agreed-to inspection criteria.
- Rapid inspections on each batch prior to the modules leaving the factory.

Key Aspects of PSI:

- Visual Inspections
- Flash Testing
- Bifaciality Measurements
- Dimensional Verification
- Electroluminescence (EL) Imaging

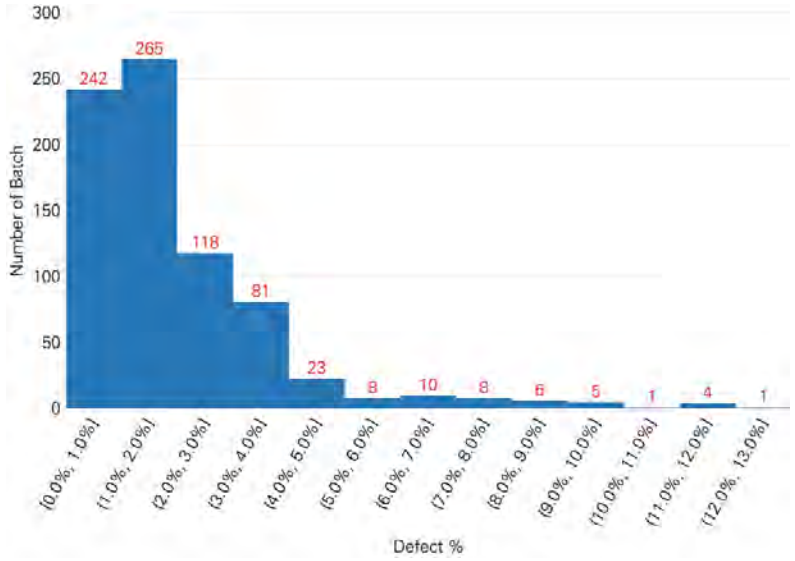


Electroluminescence (EL) Example

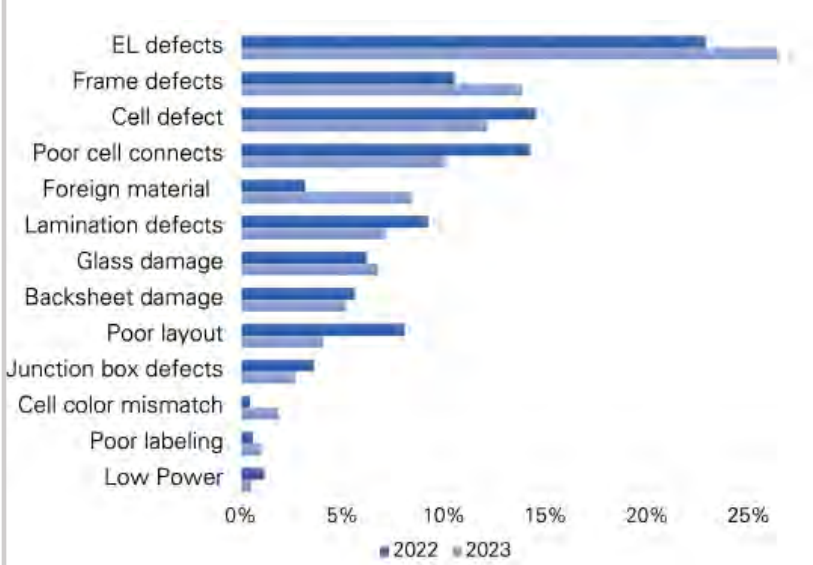
Component	Description	Defect class	Image
Cable	Cable insulation damaged resulting in exposed wires	Critical	
Cell	Misaligned wire	Major	
Frame adhesive	Silicone residue	Minor	

Visual Inspection Examples

Pre-Shipment Inspections- What is Being Found?

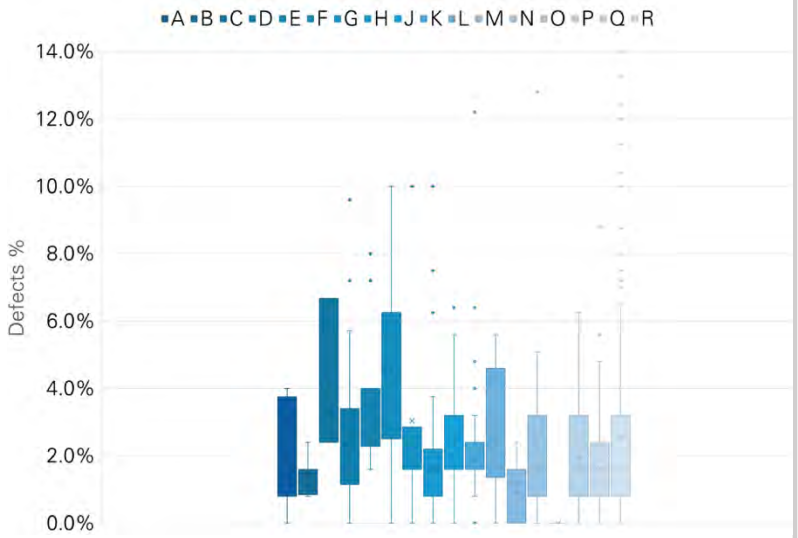


Kiwa PI Berlin conducted an analysis of PSI on 774 batches of PV modules, the figure above shows % defect ranges for each batch.

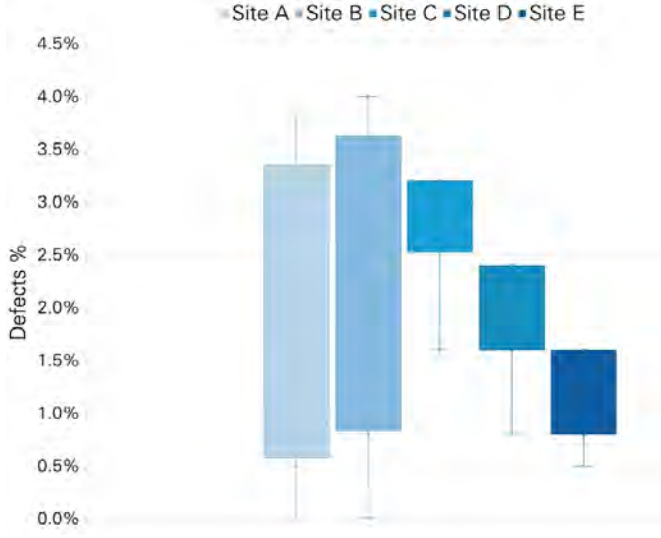


% of defect categories identified

Pre-Shipment Inspections - Manufacturer Comparison



Defect rates across different manufacturers.

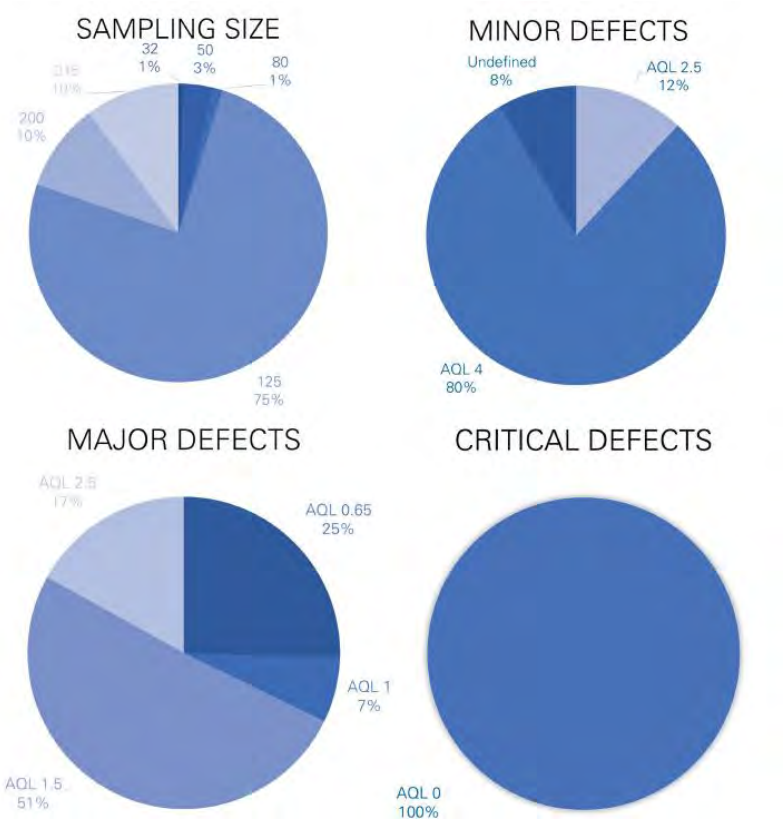


Defect rates across one manufacturer's factory locations.

Acceptable Quality Limits

AQL Analysis

- Manufacturers commonly use ISO-2859-1 sampling standard, Acceptable Quality Limits (AQL).
- Kiwa PI Berlin performed an analysis comparing AQL values across 59 recent utility-scale projects involving 25 manufacturers.
- An AQL of 0 was applied for critical defects in 100% of the projects. Over 80% of the projects used an AQL of 0.65–1.5 for major defects and 2.5–4.0 for minor defects



Pre-Shipment Inspection - Guidelines

Sampling Size Guidelines

- Batch based on ISO 2859-1: GI Level II
- Recommend batch size of 10 MW or one week of production, whichever is less.

AQL Guidelines

- 0 for critical defects
- 1.5 for major defects
- 4.0 for minor defects.

TEST	MINUMUM SAMPLE SIZE	DEFECT CATEGORY	MAXIMUM AQL
Visual Inspection, Flash Testing, Bifaciality, Dimensional Verification, EL Imaging	ISO 2859.1 General Inspection Level II	Critical	0
		Major	1.5
		Minor	4

Production Module Testing Guidance

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Potential Risks of BOM and Process Variations Beyond PQP Testing

Is PQP data alone enough to guarantee the BOM and process variations for a large project like a 200MW installation?

Project size (MW)	Module Power (W)	Number of modules
200	570	**350877**

PQP testing offers comprehensive data for module design/BOM qualification and benchmarking purposes. However, several factors can impact performance and reliability during mass production, including:

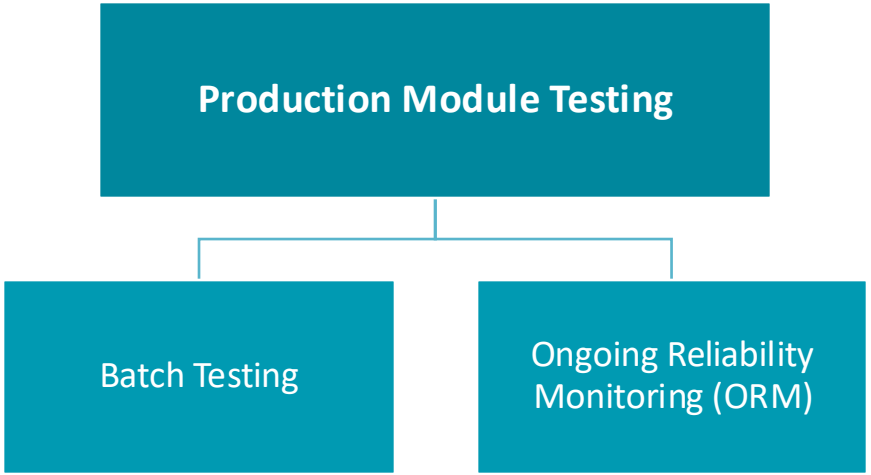
- Minor changes in lamination temperature
- Soldering time variations for the stringer
- Humidity variations in the curing room
- Small bubbles in the glass
- Inconsistencies in Cell batch quality
- Electrical Connection Variations

To continuously monitor the process and materials during production and minimize risks, a comprehensive testing and monitoring program has been developed to evaluate PV modules at different stages of production and across various batch sizes.

Production Module Testing

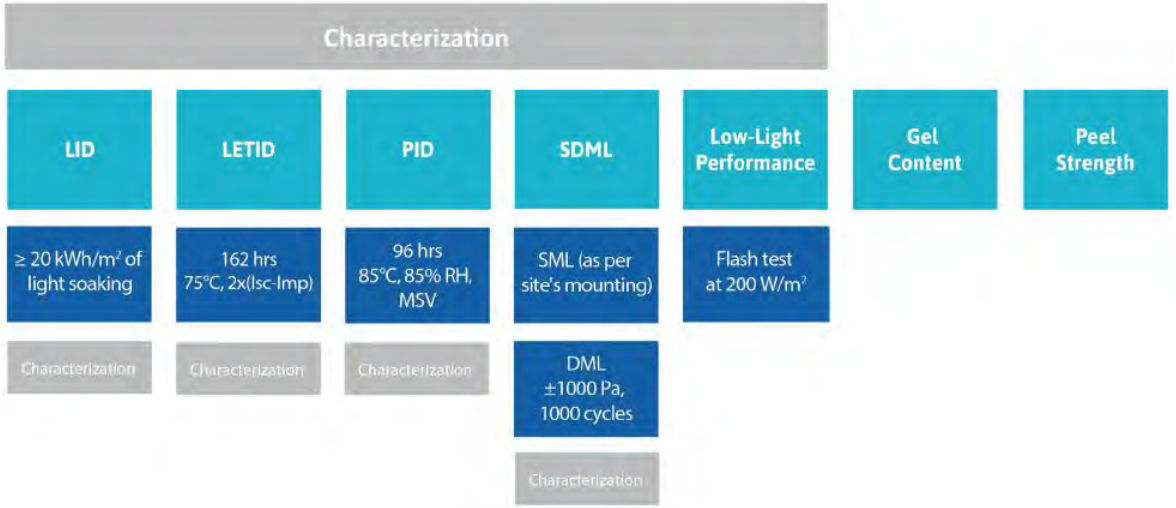
What is Batch Testing and Ongoing Reliability Monitoring (ORM)?

- Evaluates PV modules at different stages of production.
- Stress tests for verifying material and process stability.
- Short and mid duration testing at various internals allows unseen issues affecting consistent quality and reliability.
- Validates buyer's produced supply matches performance contractual expectations.



Batch Testing Protocol

- Batch Testing validates short-duration testing results.
- Performed at a third-party lab, or onsite lab.
- Includes LID, LETID, PID, and low-light performance tests to identify potential issues that are not detectable via production oversight/PSI.
- Mechanical load testing is included to minimize risks of onsite module breakage.
- Gel content and peel strength testing is performed on coupons.

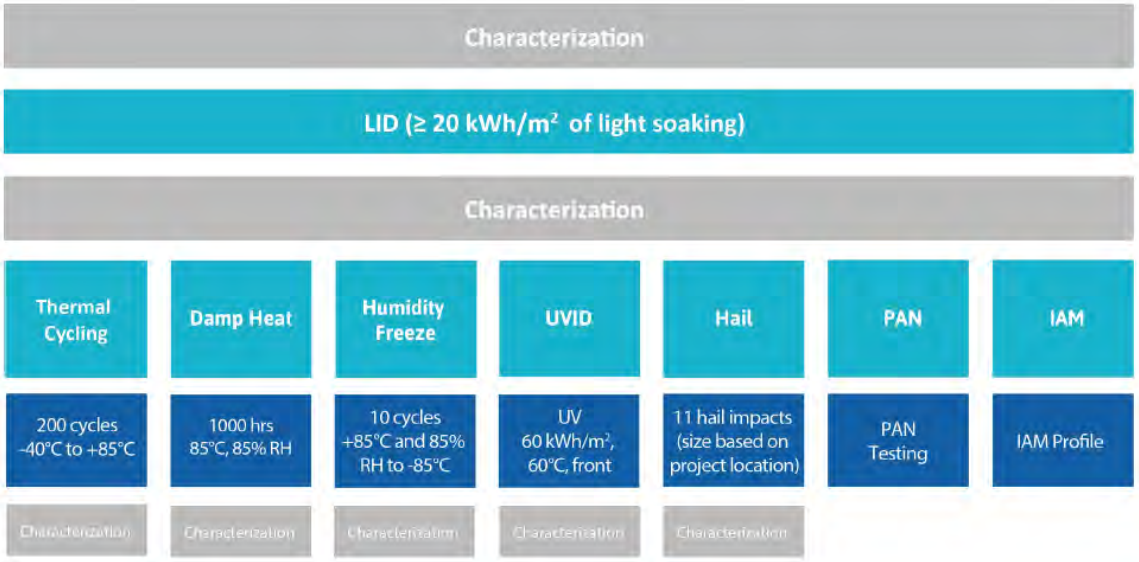


Batch Testing Criteria

- Batch Testing Criteria compliance is measured by power degradation variances, VI, or WL failures.
- Testing conformance is recommended for batch release.
- In case of any failures, Kiwa supports customers in analyzing the RCCA.

TEST	POWER DEGRADATION	OTHER CHARACTERIZATIONS
Flash testing	≥minimum power specified on datasheet and power label	N/A
Bifaciality	≥minimum bifaciality factor specified on datasheet and power label	N/A
LID, LETID	Power degradation ≤ 1%	No major visual defects or wet leakage failures.
PID, SDML	Power degradation ≤ 3%	No major visual defects or wet leakage failures.
Low light performance	Module performance ≥ the initial PAN file	N/A
Peel strength	> 60 N/cm at both interfaces	N/A
Gel content	Gel content > 75% for each measured point	N/A

Ongoing Reliability Monitoring Protocol



Testing Abbreviations
LID: Light induced degradation
UVID: Ultraviolet induced degradation

Characterizations
IV: Flash test at STC (front and rear if bifacial)
EL: EL image at ISC
VI: Visual inspection
WL: Wet leakage

- ORM is designed for the long-term evaluation of consistent performance and reliability of the modules.
- Testing mainly based on the IEC/UL 61215 standard.
- The ORM program includes a variety of tests tailored to the latest cell technologies and module designs including hail test and UVID.

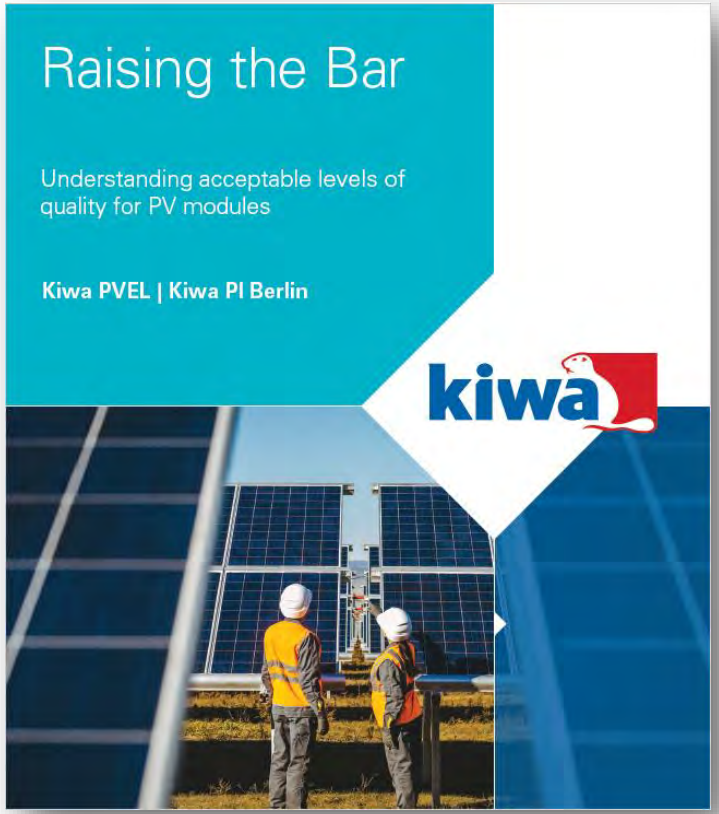
Ongoing Reliability Monitoring Criteria

TEST	POWER DEGRADATION	OTHER CHARACTERIZATIONS
TC200, DH1000, HF10, UVID60	Power degradation ≤ 3%	No major visual defects or wet leakage failures.
Hail test (hail size determined by project site's susceptibility to hail impacts)	Power degradation ≤ 3%	No glass breakage, no other major visual defects or wet leakage failures.
PAN/IAM	Module performance ≥ the initial PAN file	No major visual defects.

- Kiwa recommends performing ORM for every 50 MW or one month of production, whichever is less.
- Criteria compliance is measured by power degradation variances, glass breakage (hail), and WL failures.
- Similar to batch testing, in case of any failures, Kiwa supports customers in analyzing the RCCA.

Conclusion

- These guidelines are a part of Kiwa's holistic PV module procurement best practices.
- Product Qualification Program, Pre-Shipment Inspection, Batch Testing and Ongoing Reliability Monitoring provide a comprehensive testing framework for ensuring that PV modules meet the highest standards of quality and reliability.
- PV module quality should be evaluated from qualification to production.
- This set of testing and inspection guidance is intended to help *raise the bar* on module quality, resulting in higher performing PV projects across the industry.



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Q+A

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using the module on your screen.

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