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UV-resilient i-TOPCon cell design

3 September 2024

10:00 am – 11:00 am | EDT, New York City
4:00 pm – 5:00 pm | CEST, Berlin, Paris
7:30 pm – 8:30 pm | IST, Delhi

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Welcome!

pv magazine webinars

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. 👀 💡

part of the VDE GROUP

Reliability analysis of Trina Solar's UVID-resilient i-TOPCon cell design

Cherif Kedir | September 3, 2024

RETC

part of the VDE GROUP

Since 2009, downstream manufacturers, developers, independent engineers, and financiers have trusted RETC to test and vet their modules, inverters, energy storage systems, racking and tracking products.

- Complete design review & support
- Certification testing
- Pre-certification support
- Best-in-class turnaround time
- World-renown bankability testing data
- Global partnerships
- Close relationships with developers & banks

A2LA ISO / IEC 17025 Accreditation
Certificate Number: 3038.01

IEC CBTL
(Certifying Body Test Laboratory)

VDE Qualified Test Laboratory

Photovoltaics

Certification

- ✓ UL61730
- ✓ IEC61215 / IEC61730
- ✓ UL2703, UL3703
- ✓ CEC/FSEC Listing
- ✓ JET Listing
- ✓ Australia CEC Listing
- ✓ UL Fire Type / Class
- ✓ Factory Audits

Bankability

- ✓ Thresher Test
  - ❖ Annual PVMI
- ✓ PVSyst PAN File
- ✓ AOI/IAM
- ✓ 3rd Party Sampling
- ✓ Hail Durability Test
- ✓ Tracker Compatibility
- ✓ Salt Spray Test

PV MODULE INDEX REPORT
HIGHEST ACHIEVER
RETC

Engineering

- ✓ Production Level Testing (PLT)
- ✓ Inverter Characterization
- ✓ On-site Field Forensics
- ✓ Failure Analysis
- ✓ Super UV
- ✓ Long Term Outdoor Energy Yield Study
- ✓ Soiling

Power Electronics

Certification

- ✓ UL 1741
- ✓ IEC 62109
- ✓ Sunspec Compliance
- ✓ CEC Efficiency
- ✓ Factory Audits

Bankability

- ✓ PE Thresher Test
  - ❖ Inverter Performance & Durability
  - ❖ ESS Performance Validation
  - ❖ True Back-up power validation
- ✓ PVSyst OND File
- ✓ 3rd Party Inverter and ESS Sampling
- ✓ Extreme Weather Durability Test

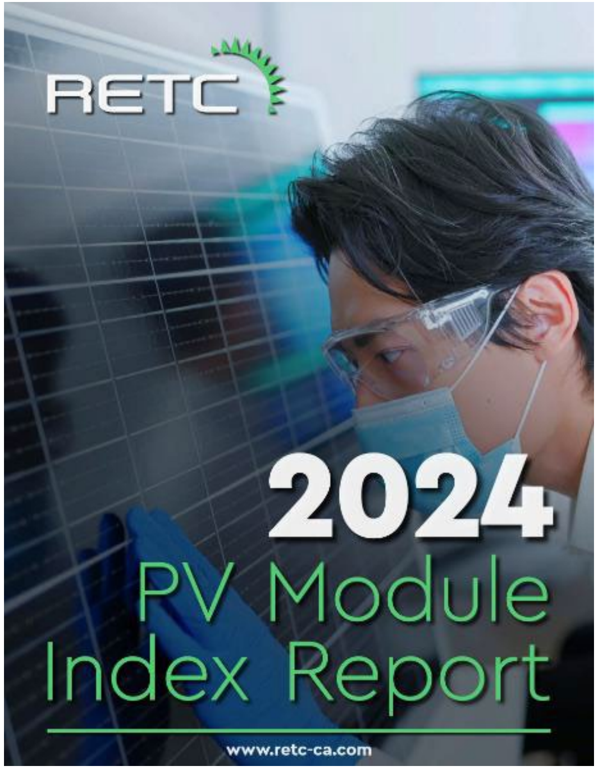
Engineering

- ✓ Production Level Testing (PLT)
- ✓ Inverter Characterization
- ✓ ESS Characterization
- ✓ Battery Cycling
- ✓ On-site Field Forensics
- ✓ Failure Analysis
- ✓ Long Term Outdoor Energy Yield Study

PV MODULE INDEX
OVERVIEW & RESULTS

About the PV Module Index (PVMI) Report

- **Annual solar module technology report** that compiles **beyond-certification test results**
  - Data aggregated between **Q2 2023** and **Q1 2024**
  - Sources of data include RETC's **Thresher Test product qualification** sequences and **California Energy Commission (CEC)** testing
- **Comparative test data** informs science- and engineering-based approaches to **technical risk mitigation**
  - The goal of a data-driven approach to project development is not to eliminate every risk at any cost but rather to allow stakeholders to balance risk mitigation based on a holistic cost-benefit analysis

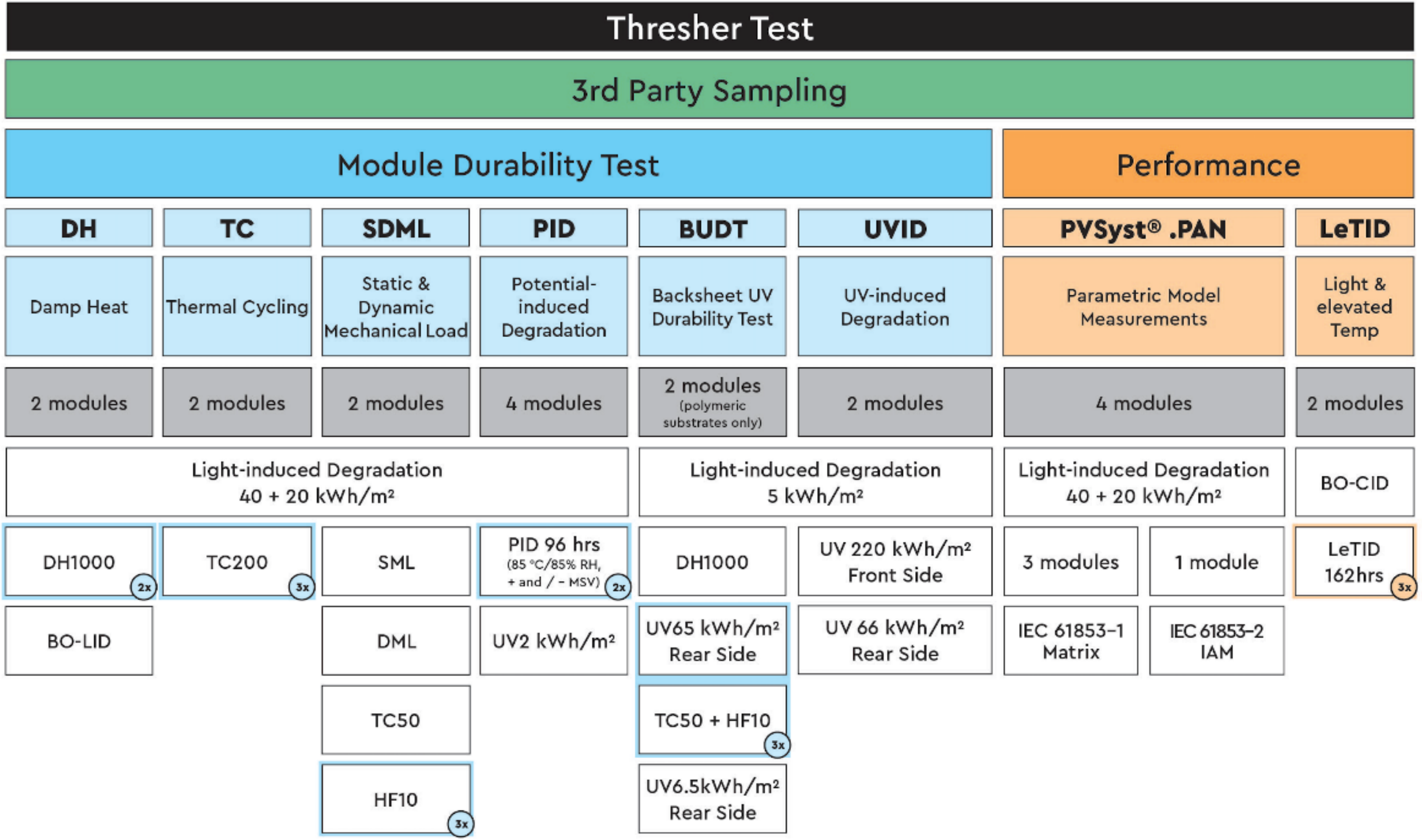


Categories for high achievement

Interrelated disciplines

- Module **Reliability**
  - Seven test sequences
- Module **Performance**
  - Seven test sequences
- Module **Quality**
  - Three evaluation criteria

Thresher Test product qualification overview



Categories for recognition

- Complete RETC's full Thresher Test program
- Meet model-level high achievement requirements in both the reliability and performance disciplines
- Meet criteria for recognition in the quality discipline (p. 32)

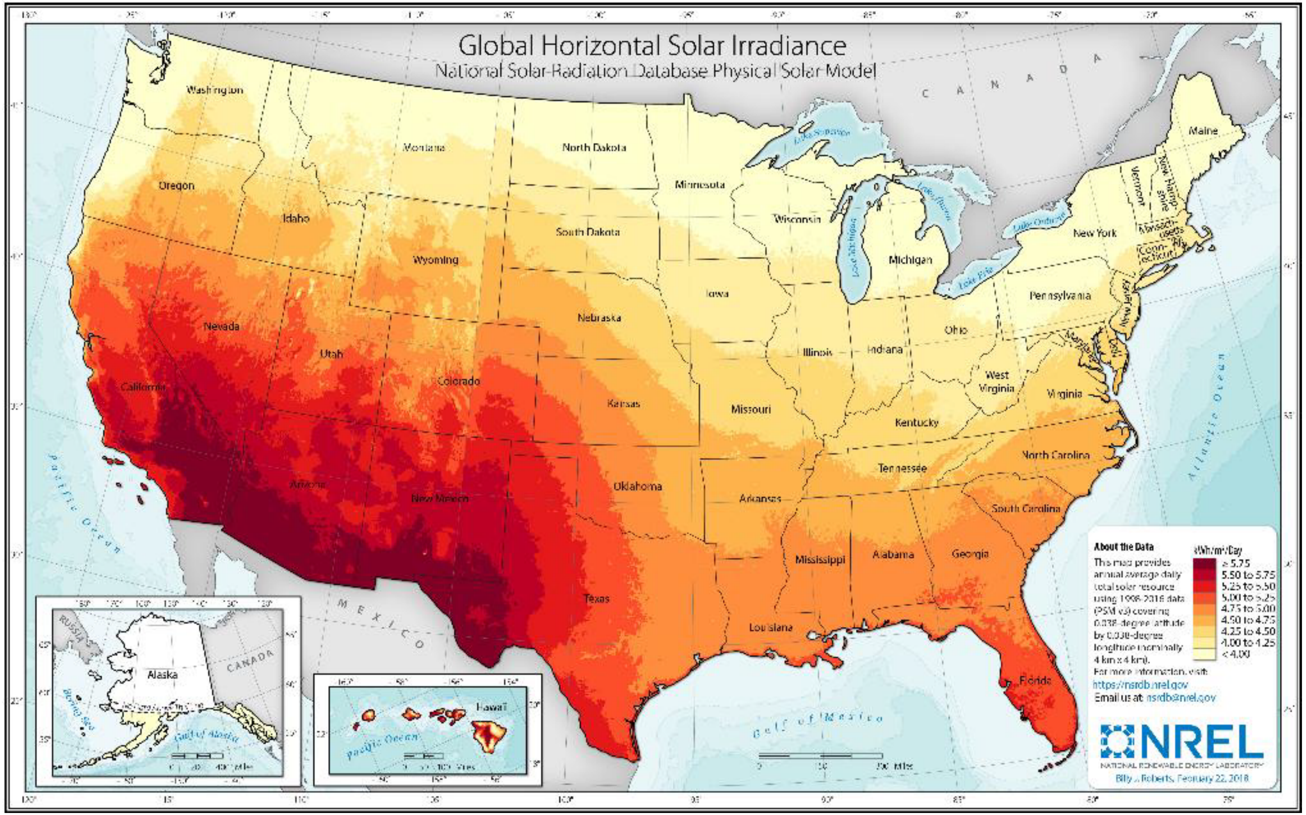
- Meet model-level high achiever requirements for at least three of the seven tests sequences within the performance discipline only

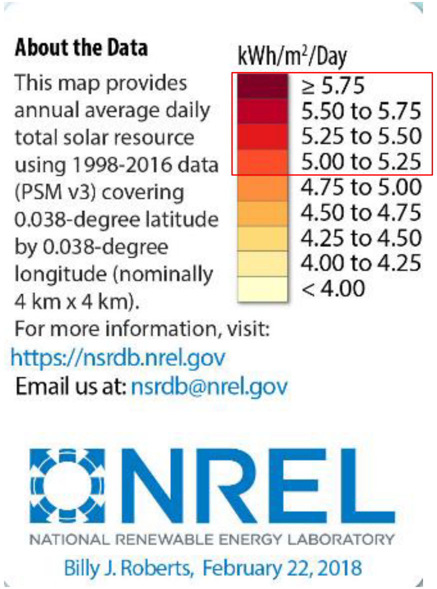
- Meet model-level high achiever requirements for at least three of the seven test sequences within the reliability discipline only*

- Meet model-level high achiever requirements for one or more individual test sequences only

KEY TAKEAWAYS
UVID RISK ON THE RISE

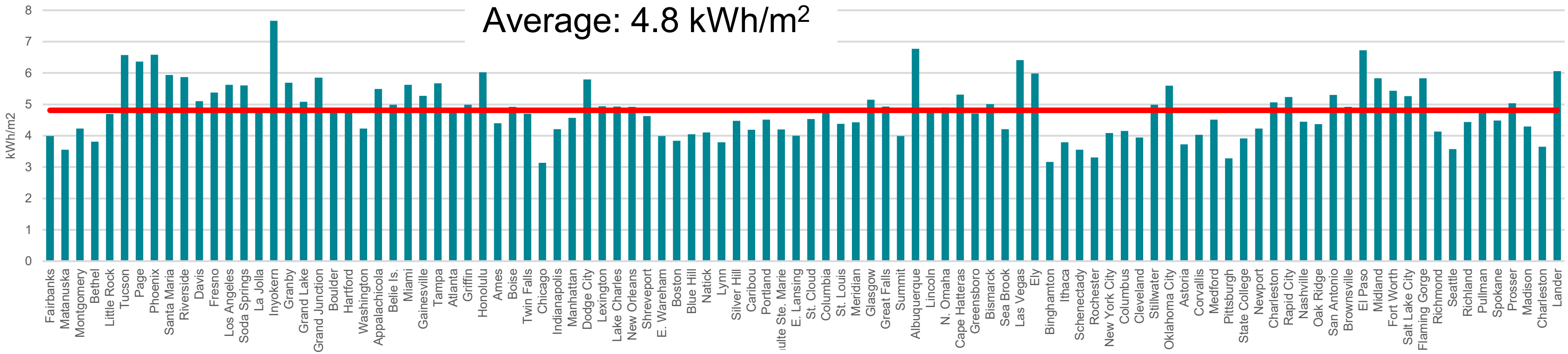
Determining UVID Exposure from National Irradiance



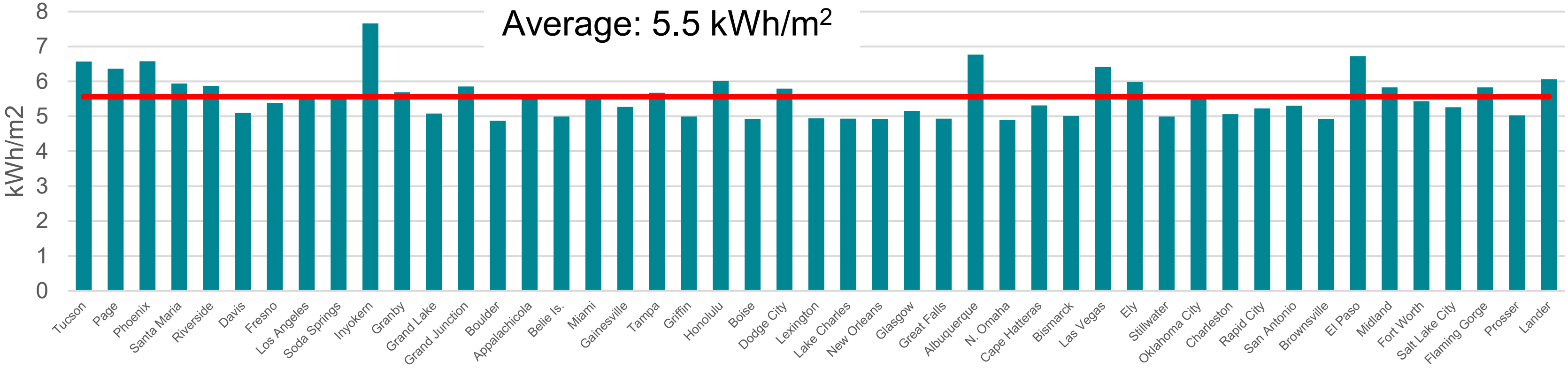


Determining UVID Exposure from National Irradiance

National Insolation Average



National Insolation Average >4.8kW/m^2



Determining UVID Exposure from National Irradiance

Reference Average Solar Radiation for Midland Texas for Fixed Tilt installations.

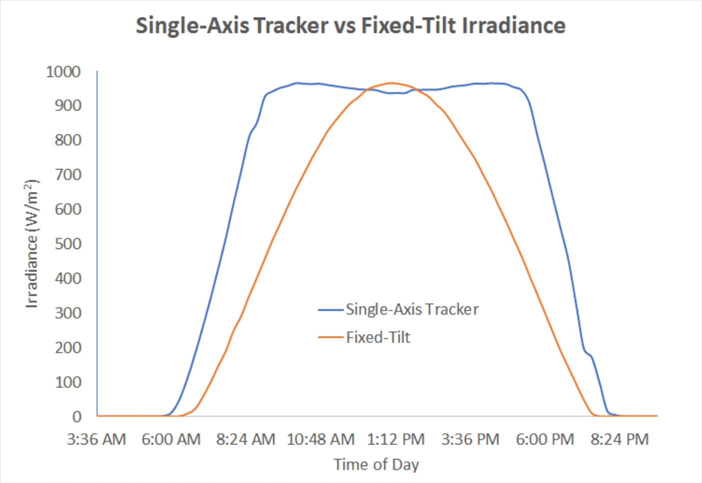
Source: NREL Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors William Marion and Stephen Wilcox

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	3.3	4.2	5.5	6.5	7.0	7.3	7.0	6.5	5.4	4.6	3.6	3.0	5.3
	Min/Max	2.8/3.8	3.6/4.8	4.8/6.1	5.7/7.3	6.4/7.4	6.7/8.2	5.9/8.0	5.7/7.1	4.4/6.1	3.9/5.2	2.7/4.1	2.6/3.6	5.2/5.5
Latitude -15	Average	4.3	5.1	6.2	6.8	7.0	7.1	6.9	6.6	5.9	5.5	4.6	4.1	5.8
	Min/Max	3.6/5.2	4.3/6.0	5.2/7.0	5.9/7.7	6.4/7.4	6.5/7.9	5.8/7.8	5.8/7.3	4.8/6.7	4.5/6.3	3.4/5.4	3.3/5.0	5.7/6.1
Latitude	Average	5.0	5.7	6.5	6.7	6.5	6.5	6.4	6.4	6.0	6.0	5.3	4.8	6.0
	Min/Max	4.0/6.1	4.7/6.7	5.4/7.4	5.8/7.6	6.0/7.0	6.0/7.2	5.4/7.2	5.6/7.0	4.8/6.8	4.8/6.9	3.8/6.3	3.8/6.0	5.8/6.2
Latitude +15	Average	5.4	5.9	6.4	6.2	5.8	5.6	5.5	5.8	5.8	6.1	5.6	5.2	5.8
	Min/Max	4.3/6.7	4.8/7.1	5.2/7.3	5.4/7.1	5.3/6.2	5.2/6.2	4.7/6.2	5.1/6.3	4.6/6.6	4.9/7.1	4.0/6.8	4.0/6.6	5.6/6.1
90	Average	4.7	4.7	4.2	3.2	2.4	2.0	2.2	2.7	3.5	4.5	4.8	4.7	3.6
	Min/Max	3.7/6.0	3.8/5.7	3.5/4.9	2.9/3.6	2.3/2.5	2.0/2.1	2.0/2.2	2.6/2.9	2.8/4.0	3.6/5.3	3.3/5.8	3.5/6.1	3.4/3.9

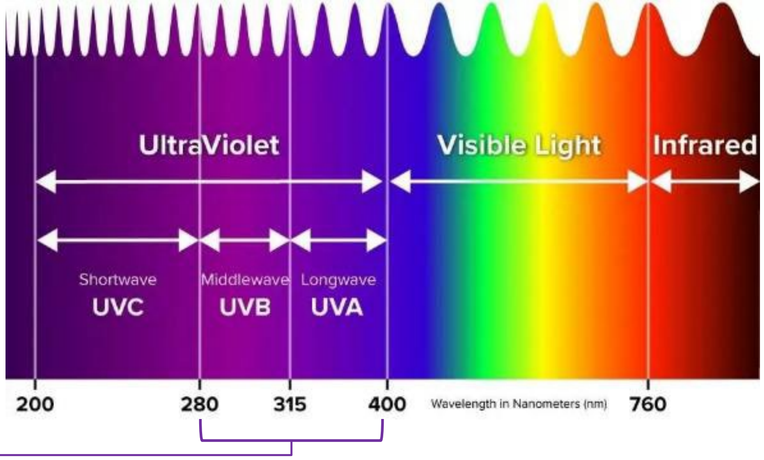
National GHI Average >4.8kW/m^2 is 5.5kWh/m2. Equivalent average insolation at Latitude Tilt (Fixed installations) is 6.23 kWh/m2

- Energy harvested on SAT is 15-30 percent compared to a fixed-tilt system.
- Assumed value increase in irradiance is 20%



Annual UV Dosage

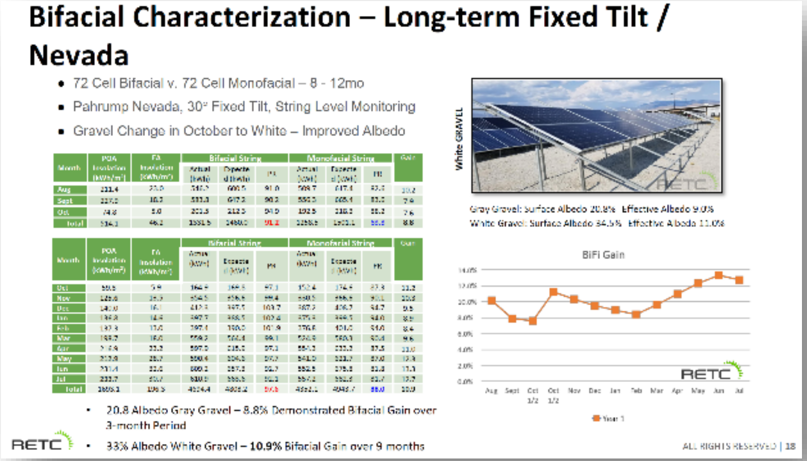
- Average Insolation for locations likely to have PV: 6.3 kWh/m^2
- Additional 20% harvest from SAT:
- $6.23 \times 1.2 = 7.5$ kWh/m^2
- UV Component (5%): $7.5 \times 0.05 = 373.8$ W/m^2
- Annual expected UV Dosage on SAT: 136.4 kWh/m^2
- Assuming a national average insolation of 5kWh/m^2, Annual UV dosage would be 110kWh/m^2

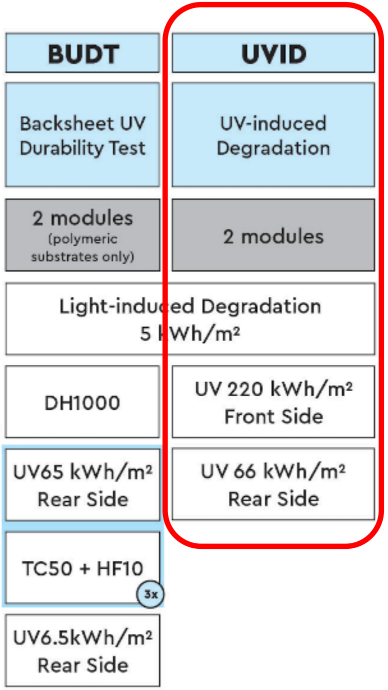


1 year in the field ~ 110kWh/m^2

RETC UVID Protocol

- Front Side: 220 kWh/m2
  - Equivalent to 2 years in the field on a SAT
- Backside: 66kWh/m2
  - Assumption: 30% Albedo [best albedo from RETC BiFi Assessments]





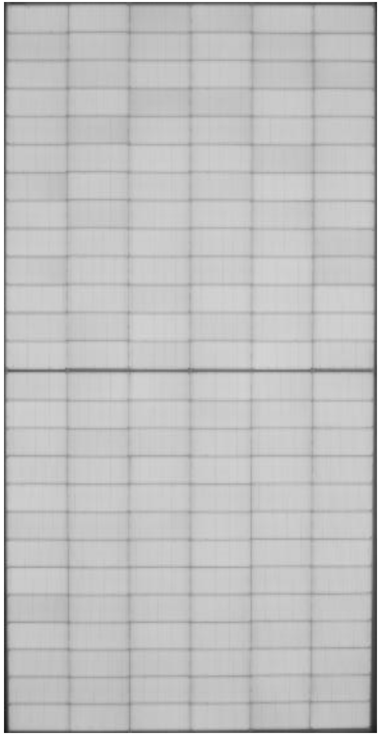
SUMMARY DATA & RED FLAGS BY MODEL

PV Module Index Report Test Category	High Achievement		Red Flag	
	Threshold	Percentage	Threshold	Percentage
Backsheet Ultraviolet Durability	No cracking	100%	Backsheet cracking	0%
Potential-Induced Degradation	<2% degradation	83%	≥5% power degradation	6%
Light- and Elevated Temperature–Induced Degradation	<0.5% degradation	82%	≥2.5% power degradation	0%
Static and Dynamic Mechanical Load	<2.5% degradation	68%	≥5% power degradation	7%
Thermal Cycling	<2% degradation	67%	≥5% power degradation	9%
PAN File Characterization	>85% PR	65%	—	—
Light-Induced Degradation	≤0.5% degradation	57%	≥5% power degradation	3%
Module Efficiency	>21%	56%	—	—
PTC-to-STC Ratio	≥94%	50%	—	—
Ultraviolet-Induced Degradation	<2% degradation	40%	≥5% power degradation	40%
Temperature Coefficient of Power	<0.3%/°C (abs)	27%	—	—
Incidence Angle Modifier	>88% at 70° AOI	27%	—	—
Damp Heat	<2% degradation	26%	≥5% power degradation	18%
Hail Durability Test	>20-joule impact	17%	—	—
OVERALL	**See p. 17**	**8%**	**—**	**14%**

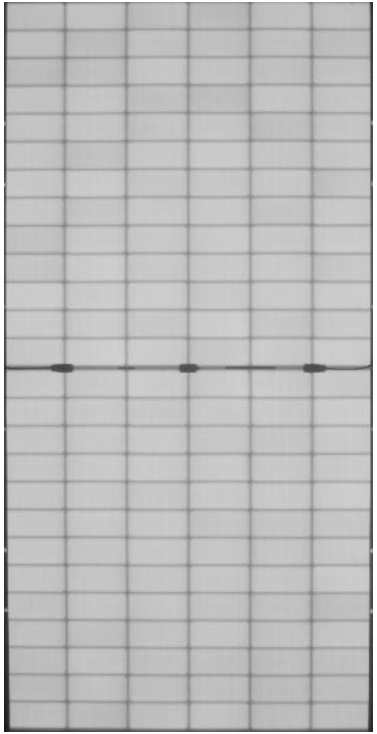
Ultraviolet-induced degradation (UVID)

- UVID testing in the 2024 PVMI
  - 220 kWh/m^2 of UV exposure (UV220)
  - Certification testing = 15 kWh/m^2 of UV exposure (UV15)
- **40% of models** tested returned a **red flag** result
  - **≥5% maximum power degradation** (red flag threshold)
  - **12-15% degradation noted** in some products
- UVID risk appears high in new cell technologies, namely TOPCon
  - Possible causes:
    - Silicon Nitride degradation
    - Bulk defects

Front-side UV - (ANON)



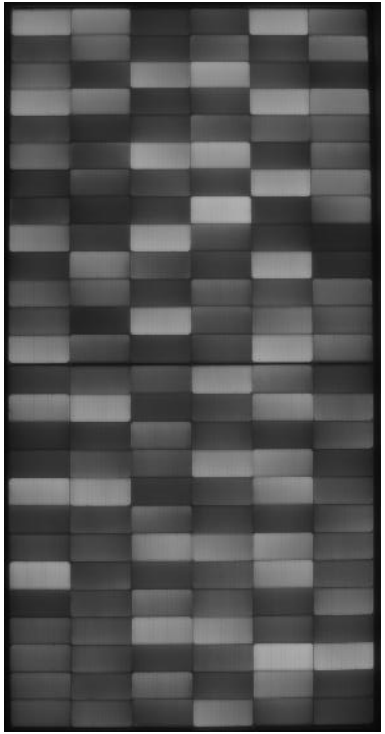
Front EL



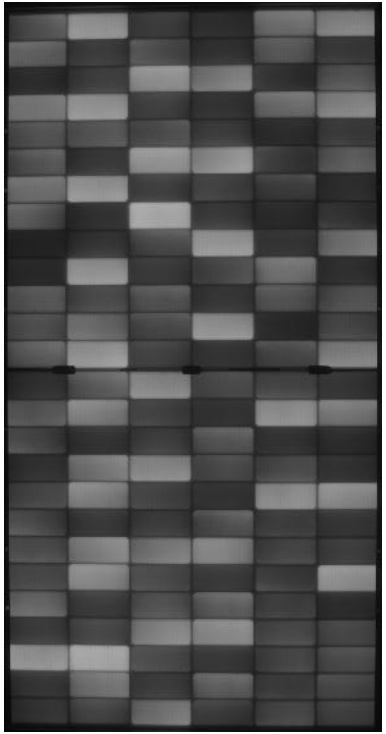
Rear EL

-12.5%

Power Drop

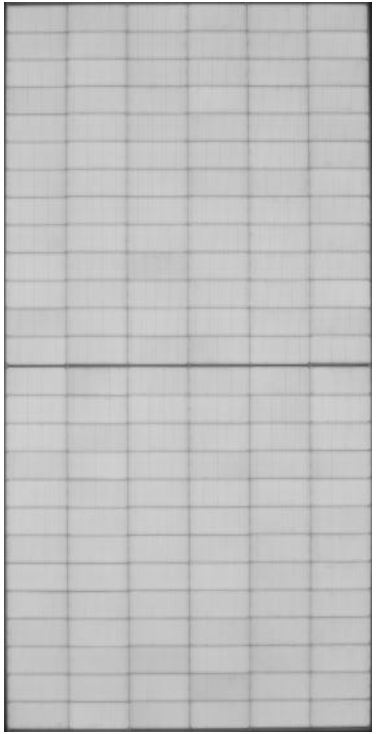


Front EL

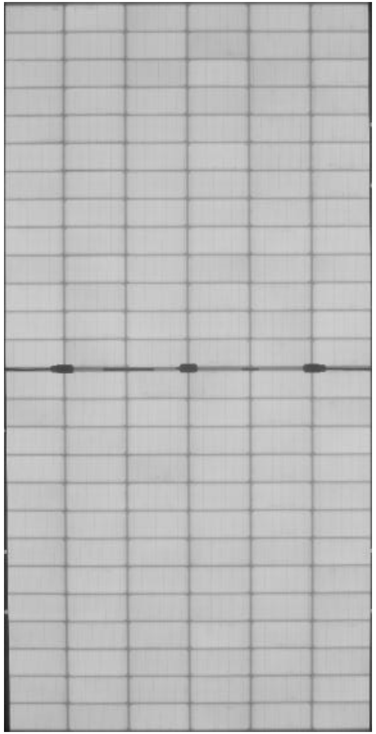


Rear EL

Rear-side UV - (ANON)



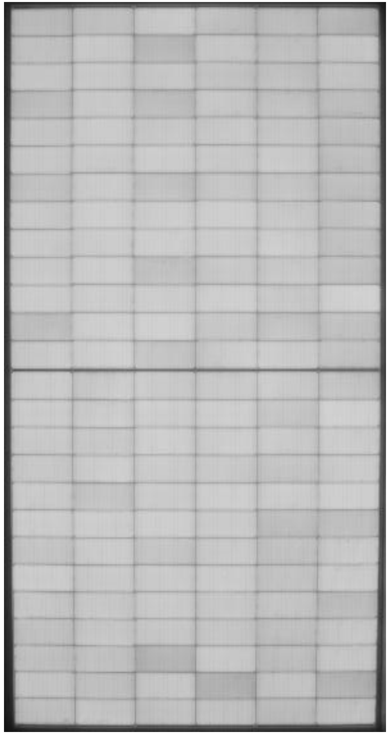
Front EL



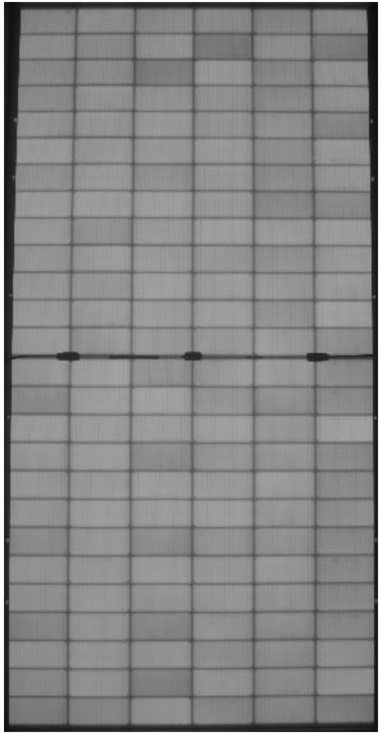
Rear EL

-4.8%

Power Drop

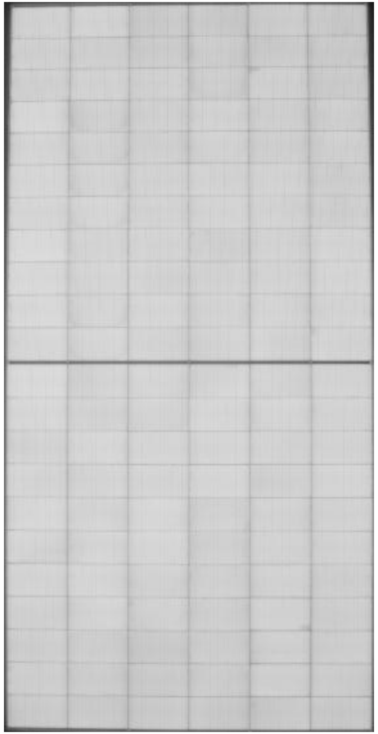


Front EL

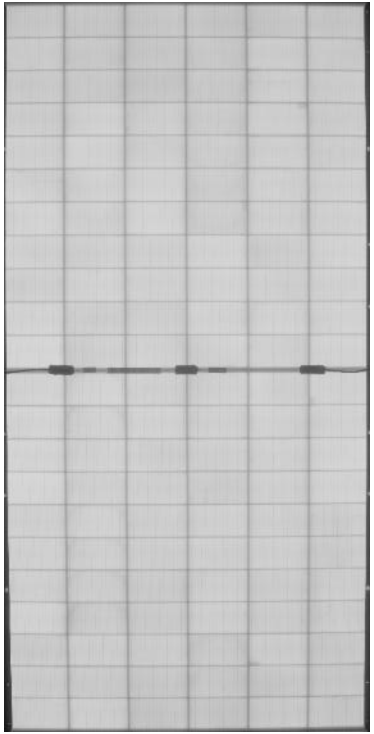


Rear EL

Front-side UV - (Trina)



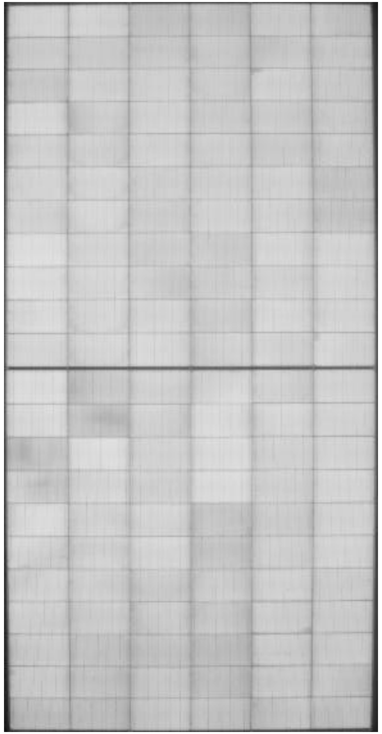
Front EL



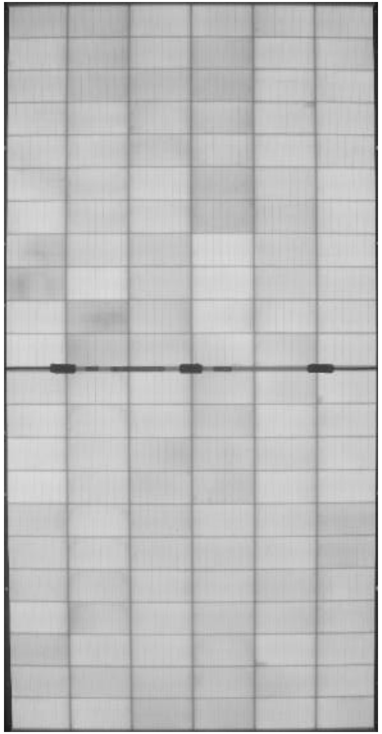
Rear EL

-1.44%

Power Drop

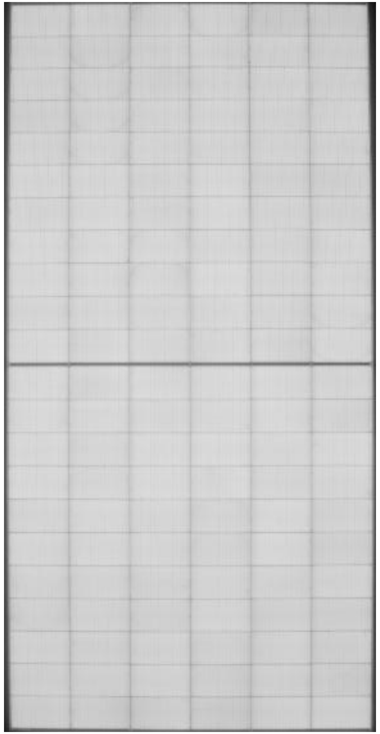


Front EL

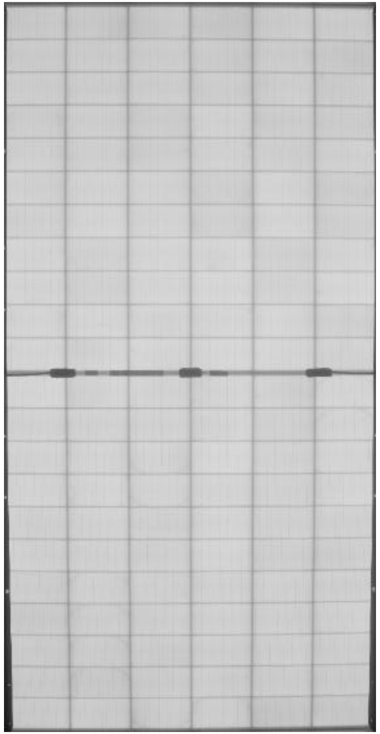


Rear EL

Rear-side UV - (Trina)



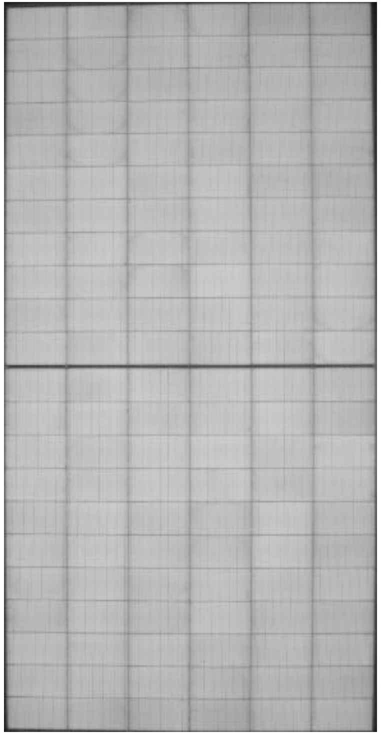
Front EL



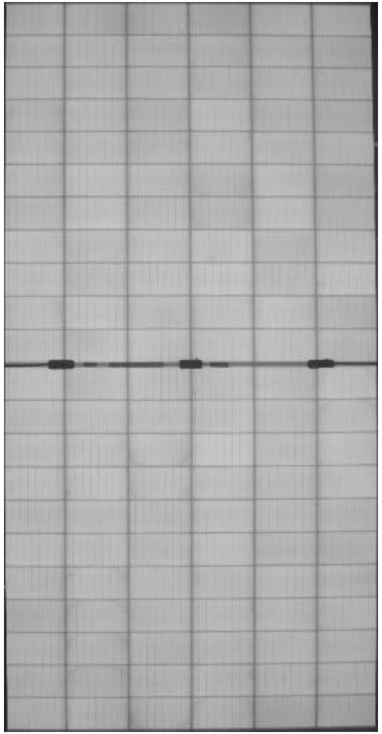
Rear EL

-1.06%

Power Drop



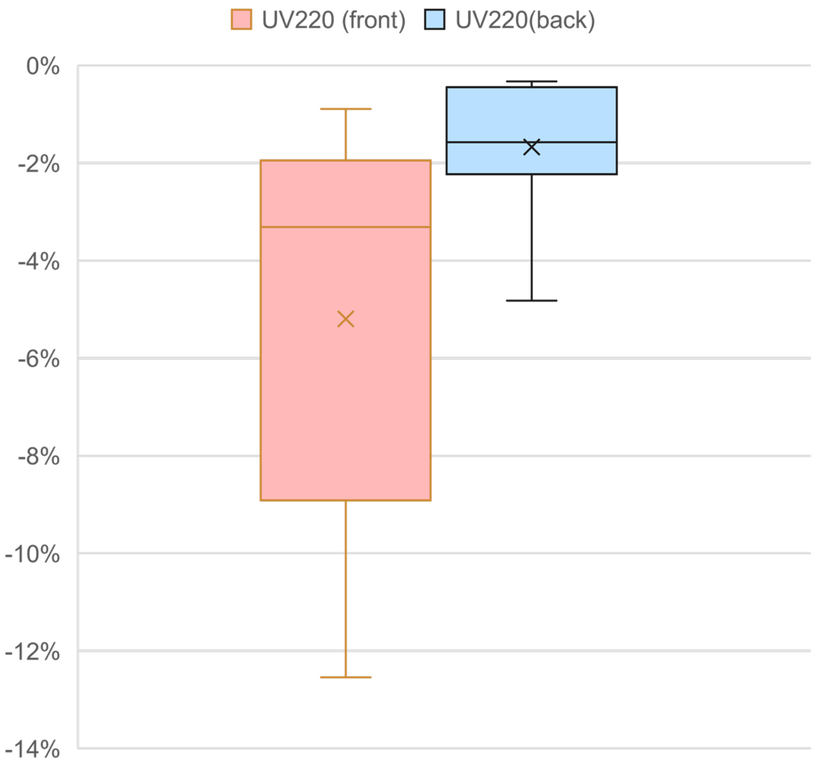
Front EL

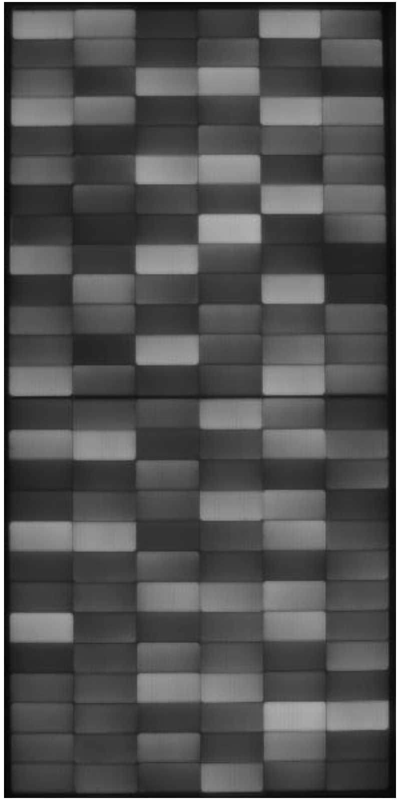


Rear EL

UVID Summary

- UVID on Front side
  - UV 220kWh/m2
  - Degradation observed up to -15%
- UVID on Rear side
  - UV 220kWh/m2
  - Generally lower degradation
- Degradation Theories
  - Silicon nitride passivation damage
  - Bulk Recombination





TRINA SOLAR IN THE PVMI REPORT

Module reliability evaluation criteria

RELIABILITY DISCIPLINE CRITERIA		
Category	**Evaluation Method**	**High Achiever**
Backsheet Ultraviolet Durability	DH1000 + [3 x (UV65 + TC50 + HF10)] + UV6.5	No backsheet cracking
Damp Heat	DH2000 + B-O LID	<2% degradation ★
Hail Durabilty Test	HDT + TC50 + Hot Spot	>20-joule impact
Potential-Induced Degradation	PID192 + UV2	<2% degradation ★
Static and Dynamic Mechanical Load	SML + DML + TC50 + HF30	<2.5% degradation ★
Thermal Cycling	TC600	<2% degradation ★
Ultraviolet-Induced Degradation	UV220	<2% degradation ★

★ Blue star indicates that Trina Solar met test category high achiever criteria

Module performance evaluation criteria

PERFORMANCE DISCIPLINE CRITERIA		
Category	**Evaluation Method**	**High Achiever**
Module Efficiency	CEC testing	>21%
Incidence Angle Modifier	CEC or Thresher Testing	>88% at 70° AOI
Light- and Elevated Temperature-Induced Degradation	B-O CID + LETID486	<0.5% degradation ★
Light-Induced Degradation	Outdoor light soaking per IEC 61215-2	≤0.5% degradation ★
PAN File Characterization	IEC 61853-1 and Performance Ratio (PR)	>85% PR ★
PTC-to-STC Ratio	CEC testing	≥94% ★
Temperature Coefficient of Power	CEC or Thresher Testing	<0.3%/°C (abs)

★ Blue star indicates that Trina Solar met test category high achiever criteria

Module quality evaluation criteria

QUALITY DISCIPLINE CRITERIA		
Category	**Evaluation Method**	
Bill of Materials	Third-party factory bill of materials verification	★
High Achievement in Reliability	Product recognized as high achiever in three or more reliability categories*	★
High Achievement in Performance	Product recognized as high achiever in three or more performance categories	★

*Glass-on-backsheet products must meet high achiever requirements for BUDT plus at least three additional reliability test sequences.

★ Blue star indicates that Trina Solar met test category high achiever criteria

Overall highest achiever in 2024 PVMI

FOR MORE INFO

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2024

i-TOPCon Cell Technology with High UV Resistance

2024/09

天赋能源合而为一
Power Beyond Solar

Catalog

1. Vertex N Leading UV Performance
2. Trina internal test results
3. Advantages of Vertex N UV Resistance
4. Trina i-TOPCon Technology Roadmap
5. Trina Vertex N Product Family Introduction

Outstanding UVID Test Data by 3rd Parties -- RETC

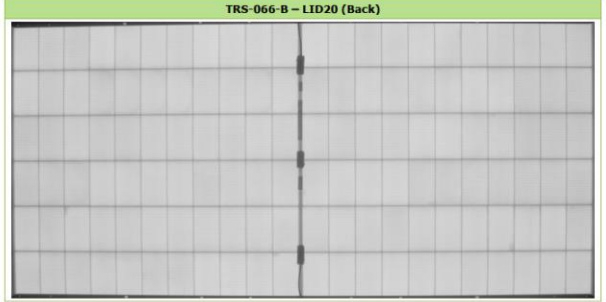
Performance Summary

RETC ID #	Sequence (Post)	Pmax	% Deg	Visual
TRS-066-B	Initial	595.15	-	No visual defects observed.
	LID40	594.28	-0.15%	n/a
	LID20	594.56	-0.10%	n/a
	UV Soak 220kWh/m2 (Frontside)	585.65	-1.44%	No visual defects observed.
TRS-066-C	Initial	597.25	-	No visual defects observed.
	LID40	596.26	-0.17%	n/a
	LID20	595.91	-0.22%	n/a
	UV Soak 220kWh/m2 (Backside)	589.18	-1.06%	No visual defects observed.

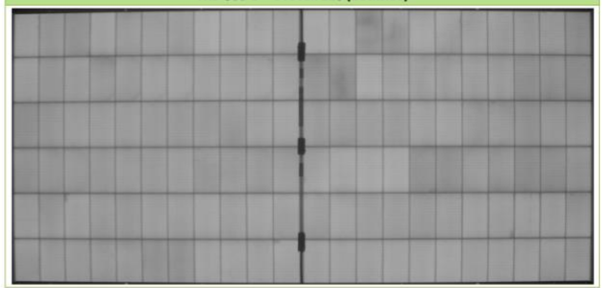
TRS-066-B – LID20 (Front)

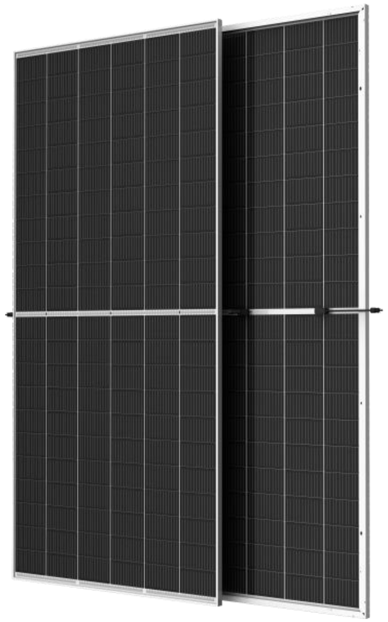
TRS-066-B – UVSoak 220 (Frontside)

TRS-066-B – LID20 (Back)



TRS-066-B – UVSoak 220 (Backside)





UVID 220

DH2000

PID

TC

SMDL*

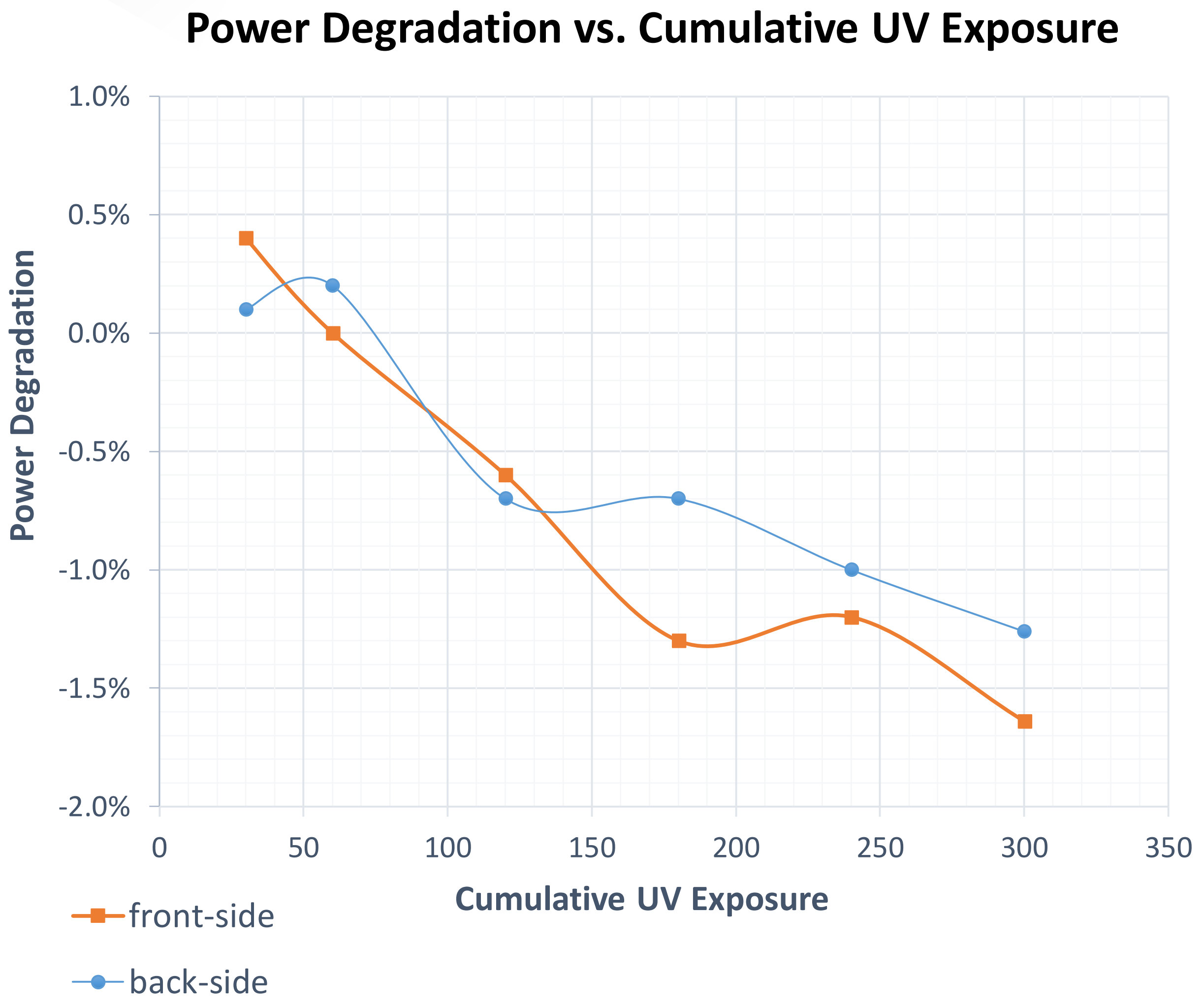
*SML+DML+ TC 50+ HF 30

210-Vertex awarded "Highest Achiever"

Product: NEG19RC.20 (Vertex N series 630W)

Result: The power degradation is kept **within 1.5% after UVID 220** compare to industry level.

Outstanding UVID Test Data by 3rd Parties- CGC (China General Certification Center)



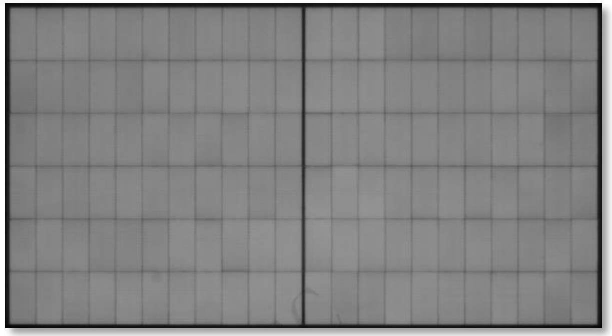
Product: NEG21C.20 (Vertex N series 720W)

Result:

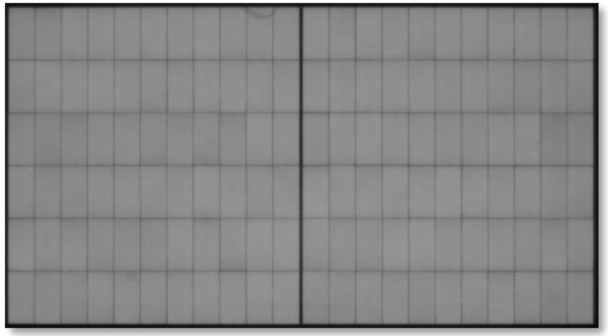
- After 300 kWh/m² of frontal ultraviolet irradiation (UV300), the power degradation is **1.64% on the front side and 1.26% on the back side**.
- Passed the insulation test and the wet leakage current test after each UV test cycle.

Note: The accumulative irradiance level for UV300 are **20 times of the IEC basic UV test (UV15)** and have been estimated by authorities to be equivalent to about **4 years of field UV exposure conditions**.

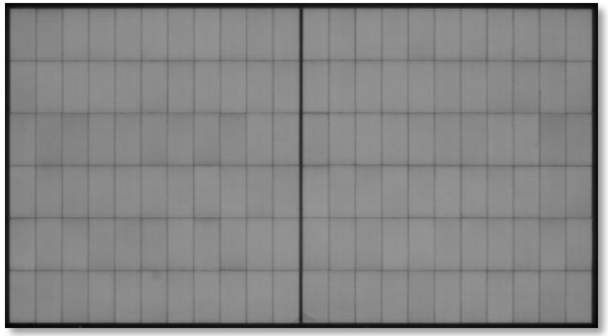
Outstanding UVID Test Data by 3rd Parties -- CGC



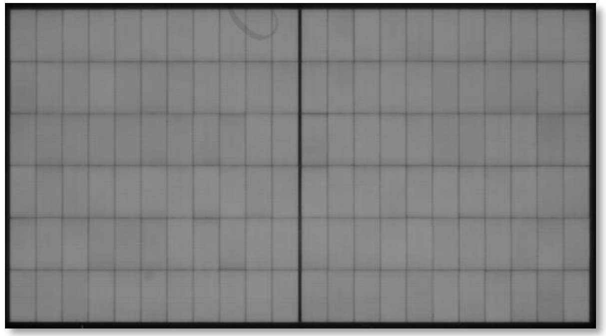
Initial-Before UV Exposure



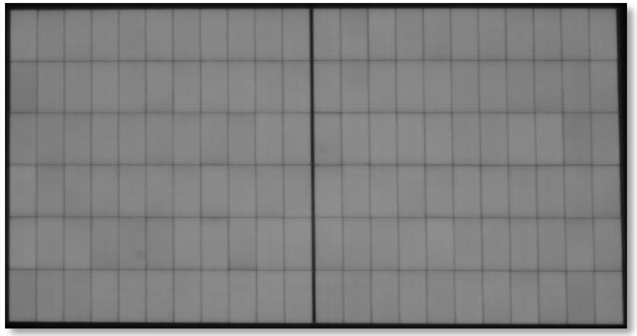
After UV30



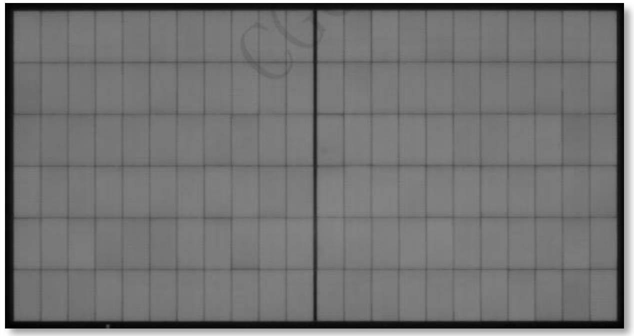
After UV60



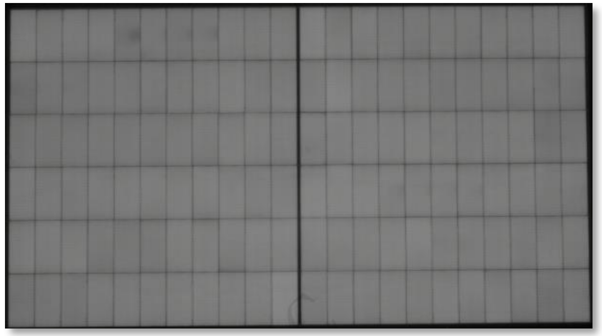
After UV120



After UV180



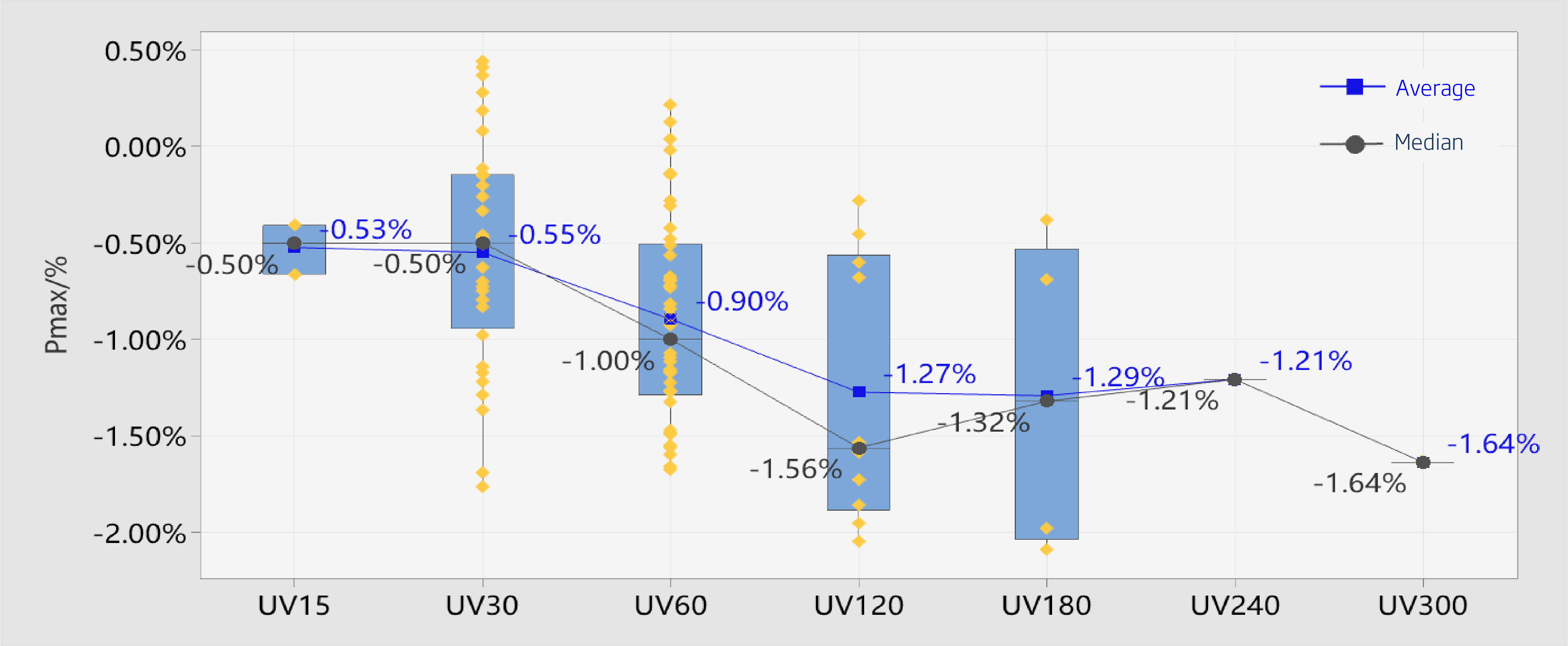
After UV240



After UV300

- The EL images before and after the test also show that the cells have no visible defects even after UV300.
- The performance of each cell on the module is very consistent.

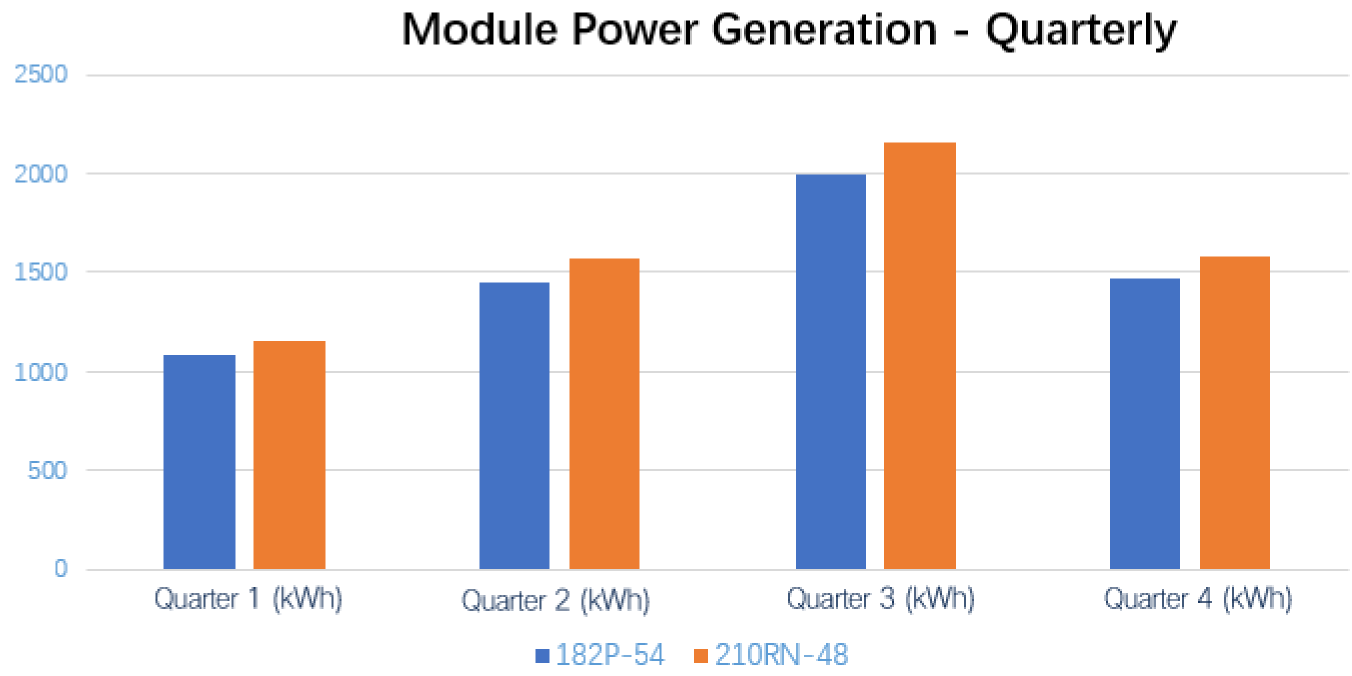
Outstanding UVID Test Data by 3rd Parties -- CGC



Hundreds of i-TOPCon modules (with different product types/production lines/production dates) were tested by CGC, with consistent test results.

Vertex N modules' Low Field Degradation – certified by CGC

- Location: Haikou, Hainan Province, China
- Climate: High Temperature & High Humidity
- Mounting Structure: Small Inclination Angle (9°) above the roof
- Ground Condition: Concrete
- Test Period: 2022.10.29-2023.10.29
- Test Module: 210RN-48 (NEG9R.28)
- Reference Module: 182P-54



According to the module power measurement results at the lab, Trina's Vertex N mono-facial modules' annual power degradation is as low as 0.81%.

Catalog

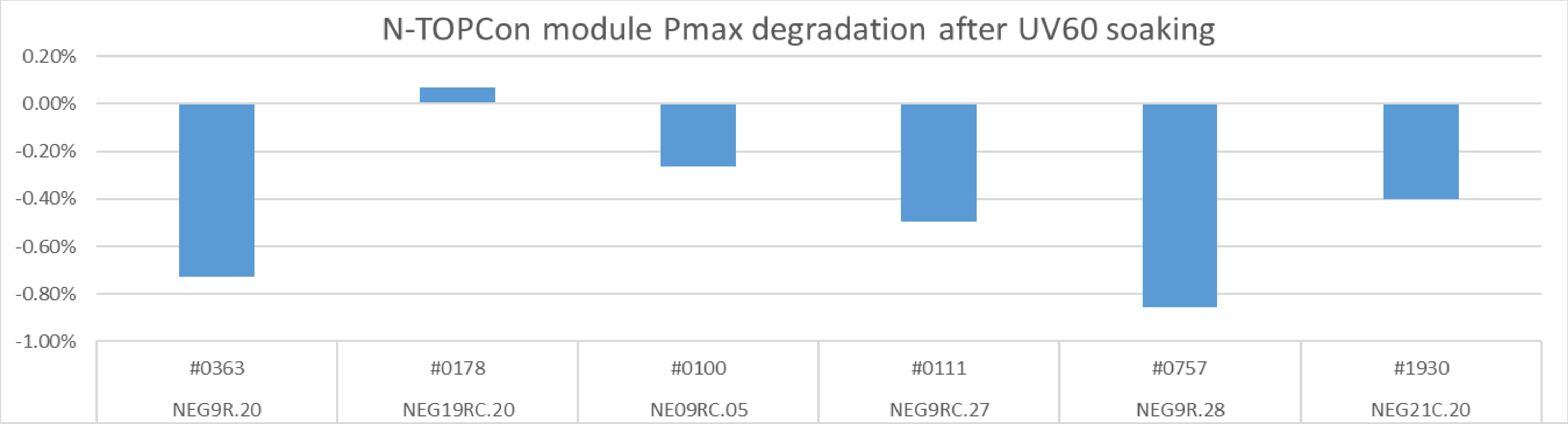
1. Vertex N Leading UV Performance
2. Trina Internal Test Results
3. Advantages of Vertex N UV Resistance
4. Trina i-TOPCon Technology Roadmap
5. Trina Vertex N Product Family Introduction

Trina Internal Test Results

Comparison of data with other mainstream manufacturers

UV60	Trina	A	B	C	D
Front-side Degradation	**-1.5% ~ -0.2%**	-4% ~ -1%	-2.8% ~ -1.5%	-3% ~ -1%	-5% ~ -4%
Back-side Degradation	-1.2% ~ -0.2%	/	/	-3%	-5%

Comparison of data for different module sizes in Trina



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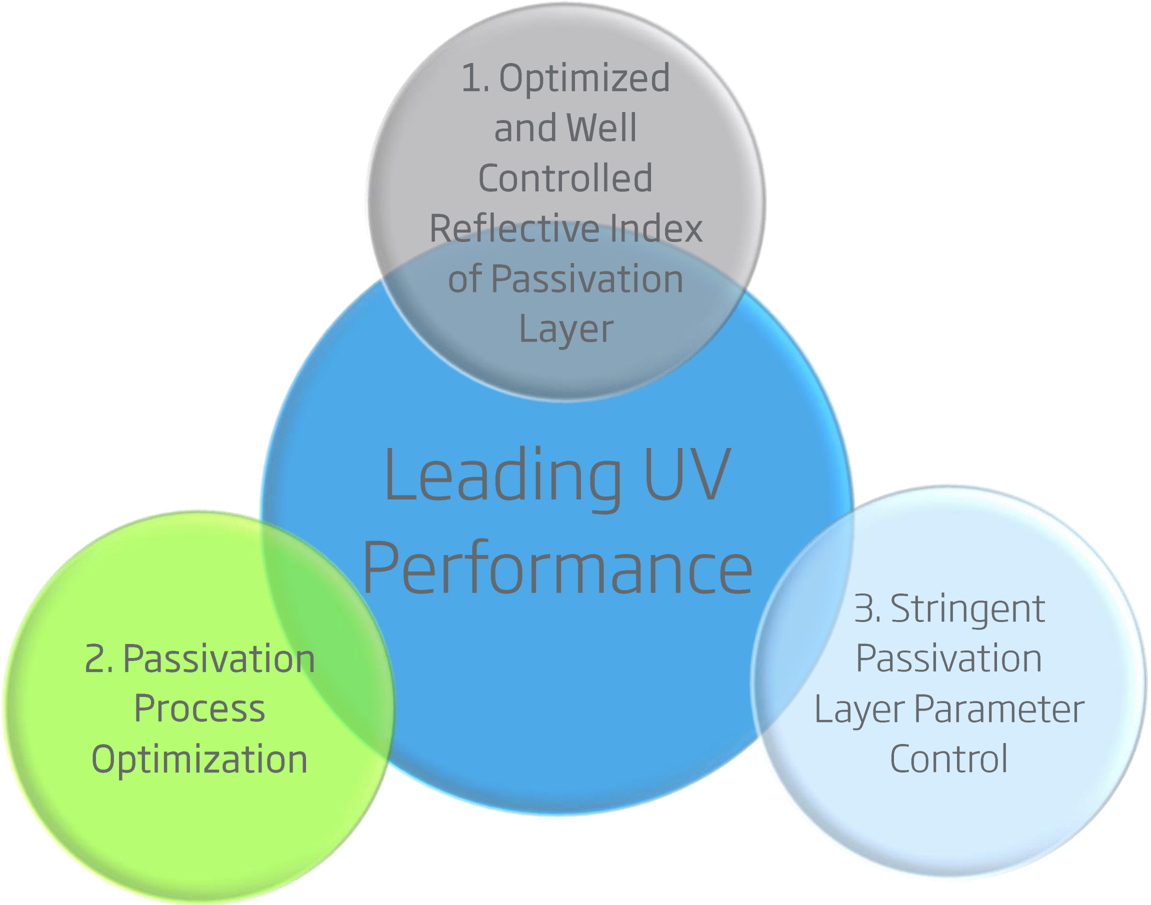
Advantages of Vertex N UV Resistance

UVID is the key element new PV cell technologies and irreversible under normal field conditions. Ultraviolet light exposure can cause efficiency changes of PV modules.

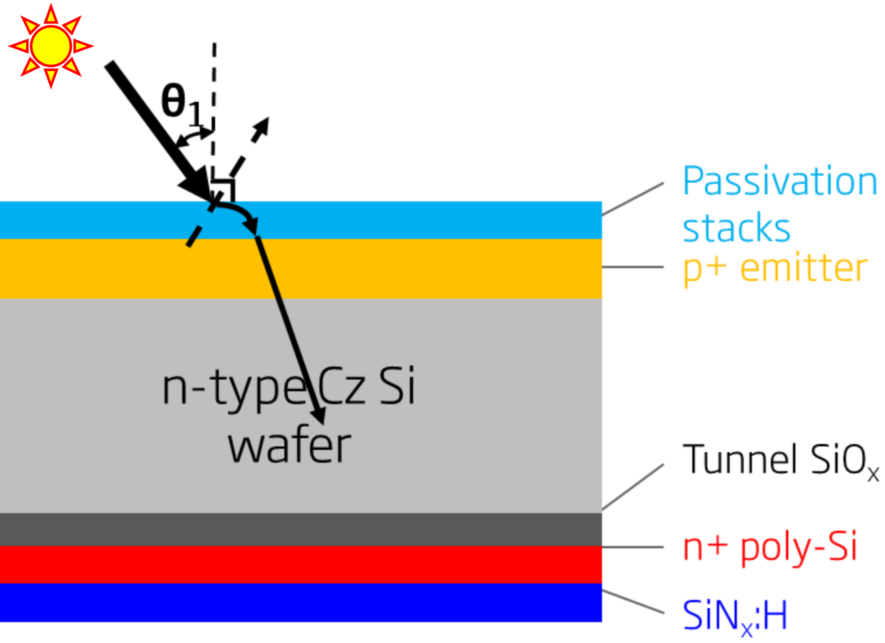
To solve this problem, Trina Solar focused on UVID resistance during the TOPCon cell design stage in various perspectives:



Advantages of Vertex N UV Resistance– Cell design

The unique anti-UV design of the cell reduces the degradation rate.

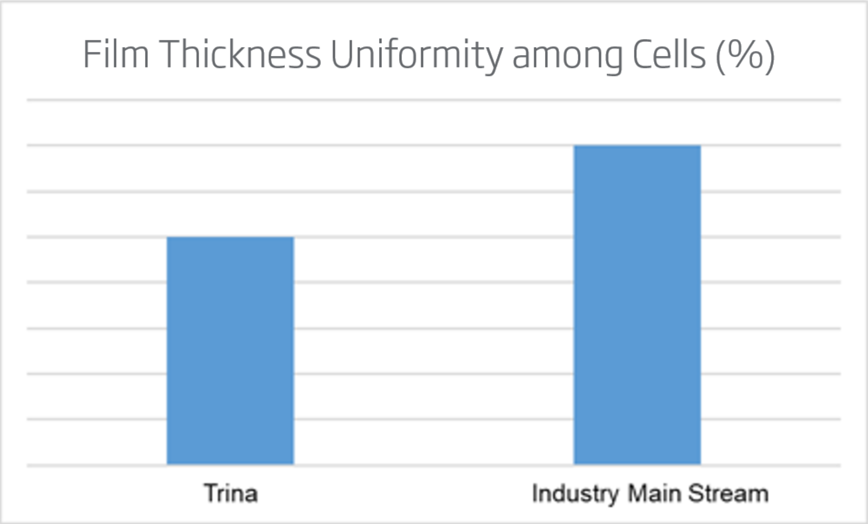
- Design: The Positive film passivation structure integrated low light self-absorption, low reflection, strong protection blocking ability during design and development, to achieve high cell efficiency with excellent UV resistance.

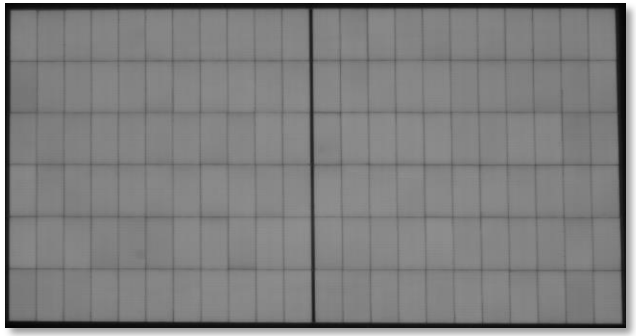


- The unique process of the passivation layer are with a good balance between chemical passivation and field-effect passivation. With the passivation process combining stronger passivation capability and higher stability, the resultant passivation layer has achieved optimal efficiency and enhanced UV resistance.

Advantages of Vertex N UV Resistance– Strict Control

- A more strict control standard leads to a better film uniformity and more consistent passivation capability among cells. When the consistency of cell passivation capability is ensured, UV resistance is also improved.
- Follow more rigorous monitoring methods and standards of passivation film thickness could achieve more accurate and better inter-sheet uniformity.
- To calculate the uniformity, other manufacturers use the average film thickness of each cell while Trina uses the average film thickness of several selected points on each cell.





Excellent Cell Uniformity Verified by EL

Strict Process Quality Control

Key Characteristics Recognition & Standardization
Process control of coating

Process control
IPD (Integrated Product development)
ECCB (Engineering Change Control Board)

ORT Monitoring
Regularly check
ORT: ongoing reliability monitoring

Process Monitoring
Intelligent information management of cell

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Trina i-TOPCon Technology Roadmap

2015-2019 — i-TOPCon

- In 2015, Base on Trina Solar's State Key Laboratory of Photovoltaic Science and Technology(PVST) ,i-TOPCon Lab was established.

- Innovative hydrogen passivation
- Wafer size 158.75mm×158.75 mm
- Cell efficiency 23.07% (JET certificate) 24.58% (ISFH certificate) mass production efficiency 23.2%
- 500 MW mass production line

2019.12 250MW
Tongchuan 'Top Runner' technical leader project

2019.6.30 250MW
Changzhi 'Top Runner' technical leader project

- The first TOPCon Cell World Record in China, 23.5% (2019)

2020-2022 — i-TOPCon Plus

- Wafer size: 210mm×210mm+ 18BB
- 500 MW TOPCon pilot line
- Average production cell efficiency 24.5%
- Cell efficiency 25.15% (ISFH certificate)

Vertex S in Europe

2020.9.30 137MW
Yellow River hydropower in Qinghai

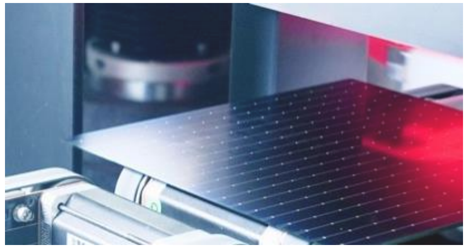
Cell efficiency record
- 25.25% (2022/2, ISFH certificate)
- 25.42%(2022/3, ISFH certificate)
- 25.5%(2022/3, China National Metrology Institute certificate)

2023-2024 — i-TOPCon Advanced

- Selective emitter, Rear planar reflector, Highly low rear TOPCon structure, Laser induced Firing，Edge Recovery Technology
- Large wafer：210,210R
- Lab efficiency reach 26% (German third-party certificates)
- Comprehensive product portfolio

2025+ — i-TOPCon Ultra & Tandem

- i-TOPCon cell efficiency can be improved by more than 1%, and module power can be improved by more than 30W
- i-TOPCon + Perovskite Tandem Cell: Efficiency ＞30%



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Trina Vertex N Product Family Introduction

- Small format module: 2m² extreme design， leading power and efficiency.
- Medium format module: excellent installation and electrical compatibility, best partner for tracker.
- Large format module: ultra high power, "designed for optimal LCOE".

Vertex N

210+N

VERTEX DNA

210
Innovative Technology Platform

210/210R
advanced wafer products in mass production

Half-cut technology
High shadow tolerance and reduced risk of hot spots

Non-destructive cutting
Lower risk of hidden cracks, higher product reliability

MBB (multi-busbar)
Perfect balance of efficiency and reliability

High density packaging
Reduced risk of hidden cracks, higher reliability

N
Trinasolar i-TOPCon

i-TOPCon Advanced technology upgrade drives continuous efficiency improvement.
Laser induced Firing , Rear planar reflector, Highly low rear TOPCon structure, Edge Recovery Technology

TOPCon core patent group, globally Risk-free
Stand at the forefront of the industry with over a hundred patents in the TOPCon field.


Trinasolar
Leading the way in Smart PV and
Energy Storage Solutions

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UV-resilient i-TOPCon cell design

Q&A

3 September 2024

10:00 am – 11:00 am | EDT, New York City
4:00 pm – 5:00 pm | CEST, Berlin, Paris
7:30 pm – 8:30 pm | IST, Delhi

Mark Hutchins
Magazine Director
pv magazine

Blathnaid O'Dea
Editor
pv magazine

Ling Zhuang
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Wednesday, 4 September 2024
10:00 am – 11:00 am EDT, New York City
4:00 pm – 5:00 pm CEST, Berlin, Madrid, Paris

Monday, 23 September 2024
1:00 pm – 2:00 pm BST, London
2:00 pm – 3:00 pm CEST, Berlin, Madrid, Paris

Many more to come!

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