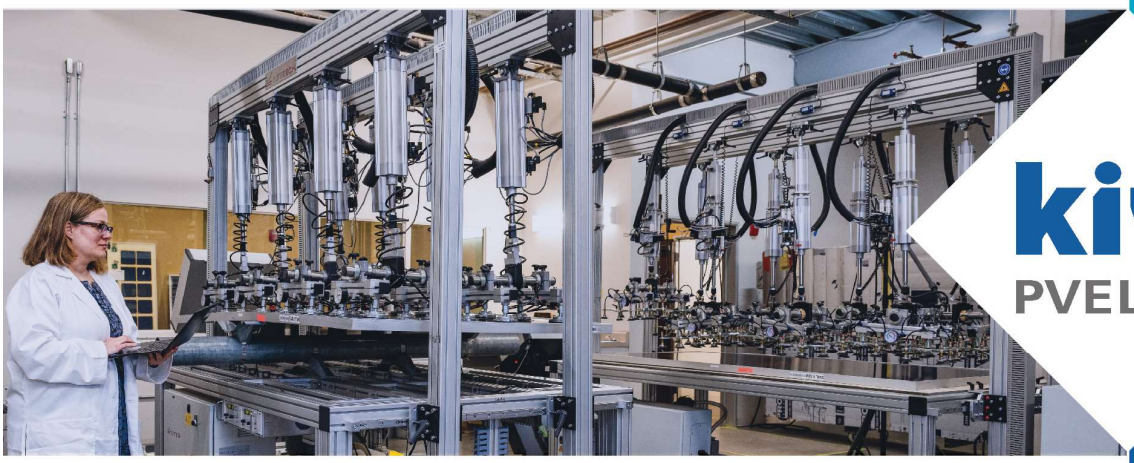
Product Qualification Program

Final Hail Stress Sequence Report 50 mm

Canadian Solar

CS6.1-54TM-450H
BOM 1



Report Number: R9661E-2

Date: 17 June 2024

Kiwa PVEL

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We Create Trust

Report details

Report no.	R9661E-2	Customer	Canadian Solar (USA) Inc.
Project no.	9661	Customer Contact	Philippe Gregoire
Date of issue	17 June 2024		

Approval

	Name	Title	Signature
Preparation	Charan Gurram	Report Writer	
Verification	Jeff Cleland	Project Manager	
Approval	Jean-Nicolas Jaubert	Director of Operations, China	

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Revision	Date	Reason for Issue	Preparation	Verification	Approval
1	5/17/2024	Initial Release	Sai Kiran Miriyala	Jeff Cleland	Jean-Nicolas Jaubert
2	6/17/2024	Retested with new modules.	Charan Gurram	Jeff Cleland	Jean-Nicolas Jaubert

The test results in this report relate just to the test objects.

Table of Contents

1. Summary

Canadian Solar (Canadian Solar (USA) Inc.) submitted CS6.1-54TM-450H photovoltaic (PV) modules for accelerated stress testing and characterization under PVEL LLC's (Kiwa PVEL) Product Qualification Program (PQP). All testing in this report was completed at Kiwa PVEL's lab in Jiangsu, China. Real-world failure mechanisms outlined in Appendix C are simulated in a controlled laboratory environment, and state-of-the-art module characterization techniques are utilized to measure the performance of the modules as they progress through the protocol. The results of the PQP testing are presented in this report.

This report is part of Kiwa PVEL's PQP project 9661. Please refer to Appendices A and B for more details. BOM information can be found in reports R9661A and R9661G.

1. 1. Manufacturer specifications

The module specifications were taken from the datasheet provided by the customer. The datasheet can be found in Appendix F.

CS6.1-54TM-450H Datasheet Specifications						
Model	**P_{MAX} [W]**	**V_{OC} [V]**	**V_{MP} [V]**	**I_{SC} [A]**	**I_{MP} [A]**	**FF [%]**
CS6.1-54TM-450H	450	38.90	33.00	14.55	13.66	79.64

1. 2. Test data summary

Average Post-stress Change in P_{MAX} Relative to Initial Measurement [%]	
Model	**HSS Post-Hail**
CS6.1-54TM-450H	-0.50
Visual Inspection Findings[1]	
CS6.1-54TM-450H	None
Wet Leakage Insulation Resistance Meets IEC 61215-1:2021 Requirements[2]	
CS6.1-54TM-450H	Yes
Electrical Circuitry[3]	
CS6.1-54TM-450H	Pass

Note: A retest of Hail modules was conducted. The results of the retest are included in this report.

[1] Major visual defects, if present, are defined as such by IEC 61215-1:2021.
[2] For reference, IEC 61215-2:2021 MQT 15 defines a passing insulation resistance for the type of module tested to be no less than 40 MΩ·m²
[3] Electrical circuitry failures encompass samples exhibiting an open-circuit during or post-test, as well as bypass diode failure (as recorded in the bypass diode functionality test after the thermal cycling and mechanical stress sequences or as detected in EL pictures after other test sequences).

2. Hail Stress Sequence

As the global climate changes and PV deployment increases to a variety of locations around the world, PV modules mounted in the field may be exposed to severe hail impacts beyond what is covered by the IEC 61215 baseline hail test. These hail impacts can result in broken glass and/or cracked cells, and those cracked cells can eventually lead to power loss for hail damaged modules. Kiwa PVEL's HSS test is focused on determining a module's susceptibility to these hail impact failure modes.

The test sequence starts when test samples are struck by a 50±2.5 mm / 60.2±3 g lab-manufactured ice ball at terminal velocity (32.4±1.6 m/s) in 11 different locations normal to the module as indicated by IEC 61215-2:2021 MQT 17. These hail strikes deliver a nominal impact energy of 31.5 joules.

Shot No.	Module Location
1	Any corner of the module window, not more than one radius of ice-ball from the module edge.
2	Any edge of the module, not more than one radius of ice-ball from the module edge.
3, 4	Over the circuit near interconnects (i.e., cell interconnects and bus ribbons).
5, 6	Over edges of the circuit (e.g., individual cells).
7, 8	On the module window, not more than half diameter of ice ball from one of the points at which the module is mounted to the supporting structure.
9, 10	On the module window, at points farthest from the points selected above.
11	Any points which may prove especially vulnerable to hail impact like over the junction box.

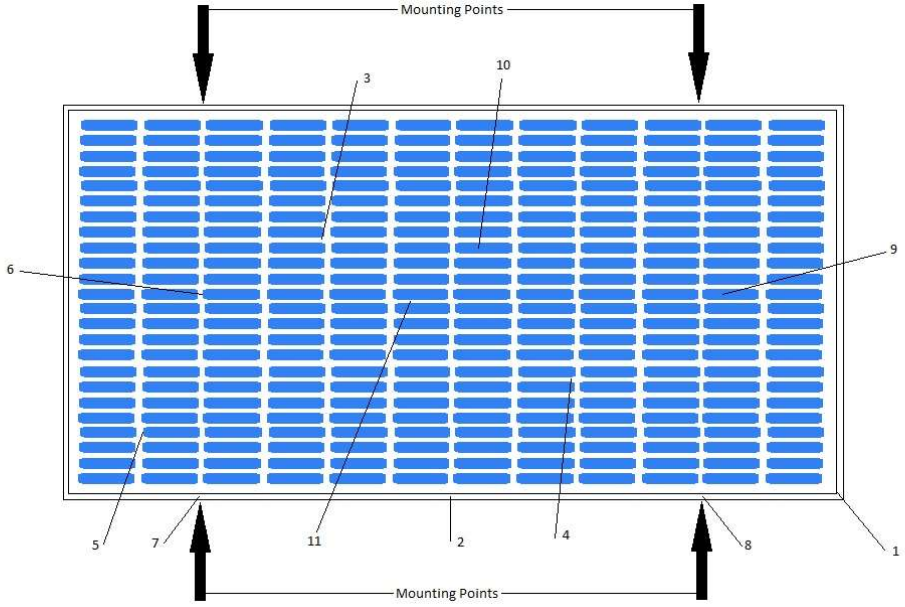


Figure 2-1: Location of 11 hail strikes.

The actual hail diameter, mass, velocity and impact locations achieved during testing were all within the allowable tolerances specified in IEC 61215-2:2021 MQT 17.

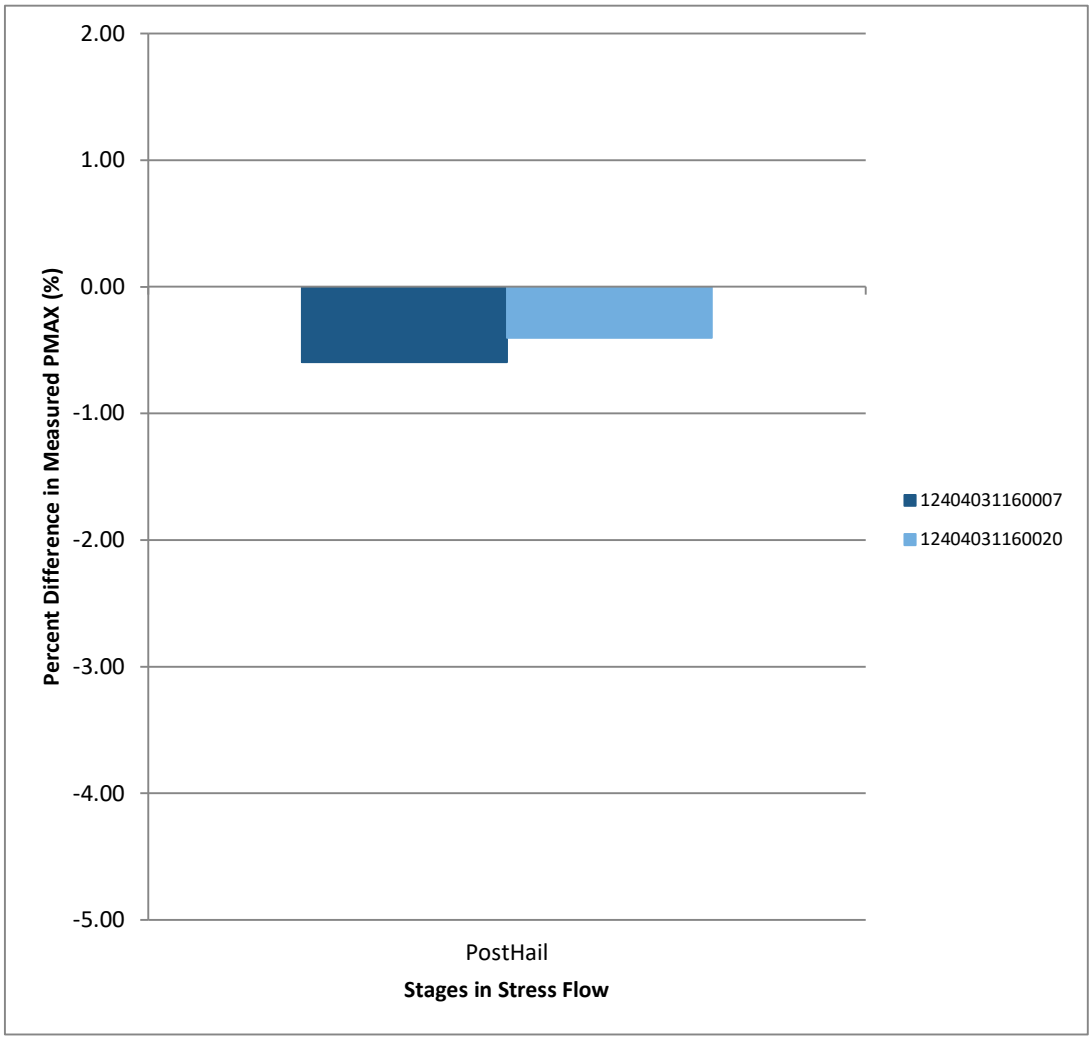


Figure 2-2 Percent deviation in measured P_{MAX} due to stress

2. 1. Front side STC performance test data - HSS

Pre-stress Test Data							
Model	Serial Number	P_{MAX} [W]	V_{OC} [V]	V_{MP} [V]	I_{SC} [A]	I_{MP} [A]	FF [%]
CS6.1-54TM-450H	12404031160007	454.4	39.74	33.67	14.20	13.50	80.55
CS6.1-54TM-450H	12404031160020	452.0	39.71	33.50	14.21	13.49	80.09

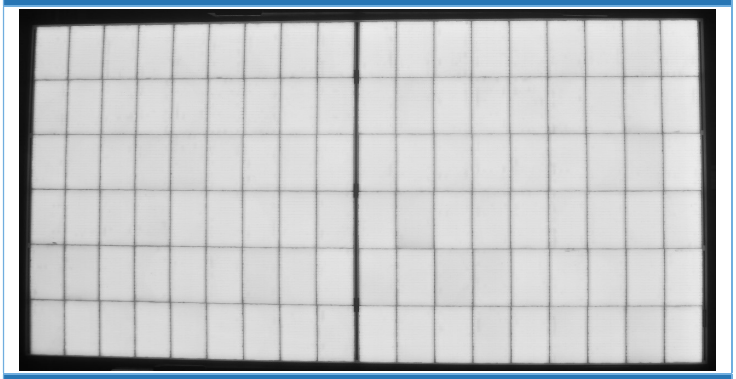
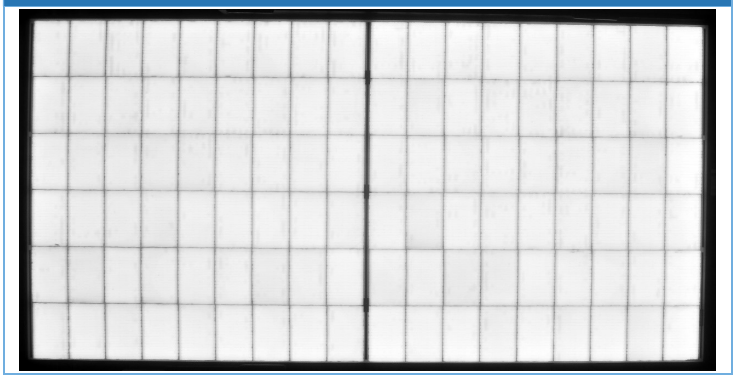
Post-Hail Test Data							
Model	Serial Number	P_{MAX} [W]	V_{OC} [V]	V_{MP} [V]	I_{SC} [A]	I_{MP} [A]	FF [%]
CS6.1-54TM-450H	12404031160007	451.7	39.80	33.63	14.10	13.43	80.48
CS6.1-54TM-450H	12404031160020	450.2	39.78	33.64	14.17	13.38	79.85
Percent Deviation from Pre-stress Test Data							
Model	Serial Number	P_{MAX} [%]	V_{OC} [%]	V_{MP} [%]	I_{SC} [%]	I_{MP} [%]	FF [%]
CS6.1-54TM-450H	12404031160007	-0.59	0.15	-0.12	-0.70	-0.52	-0.08
CS6.1-54TM-450H	12404031160020	-0.40	0.18	0.42	-0.28	-0.82	-0.30

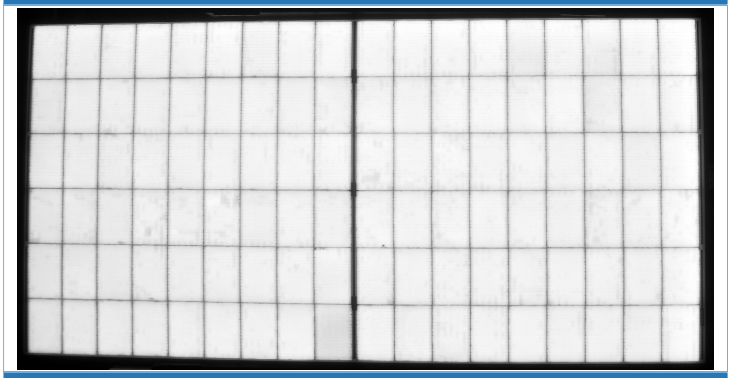
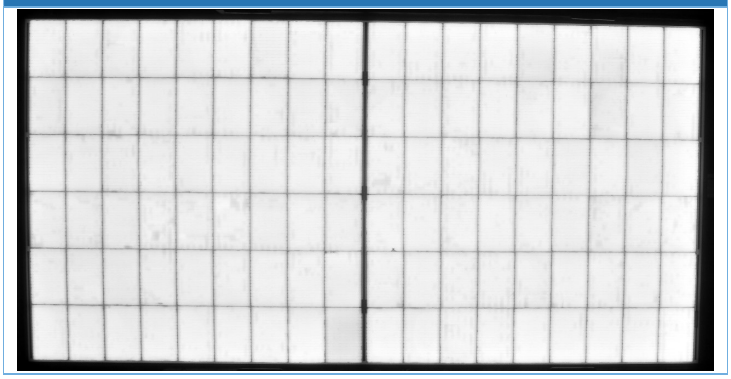
2. 2. Front side 200 W/m² performance test data - HSS

Pre-stress Test Data							
Model	Serial Number	P_{MAX} [W]	V_{OC} [V]	V_{MP} [V]	I_{SC} [A]	I_{MP} [A]	FF [%]
CS6.1-54TM-450H	12404031160007	87.2	37.71	32.63	2.84	2.67	81.35
CS6.1-54TM-450H	12404031160020	86.3	37.63	33.33	2.85	2.59	80.49

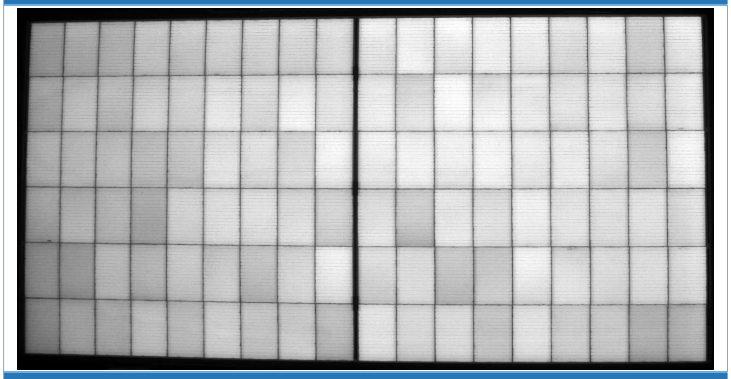
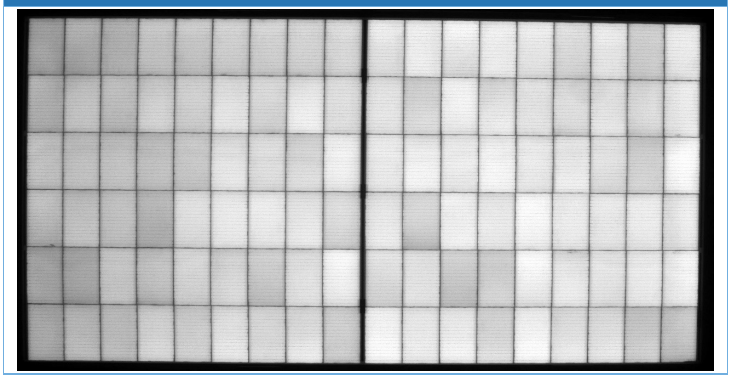
Post-Hail Test Data							
Model	Serial Number	P_{MAX} [W]	V_{OC} [V]	V_{MP} [V]	I_{SC} [A]	I_{MP} [A]	FF [%]
CS6.1-54TM-450H	12404031160007	87.0	37.80	32.65	2.83	2.66	81.19
CS6.1-54TM-450H	12404031160020	86.8	37.74	33.02	2.84	2.63	81.02
Percent Deviation from Pre-stress Test Data							
Model	Serial Number	P_{MAX} [%]	V_{OC} [%]	V_{MP} [%]	I_{SC} [%]	I_{MP} [%]	FF [%]
CS6.1-54TM-450H	12404031160007	-0.17	0.24	0.06	-0.35	-0.37	-0.20
CS6.1-54TM-450H	12404031160020	0.61	0.29	-0.93	-0.35	1.54	0.66

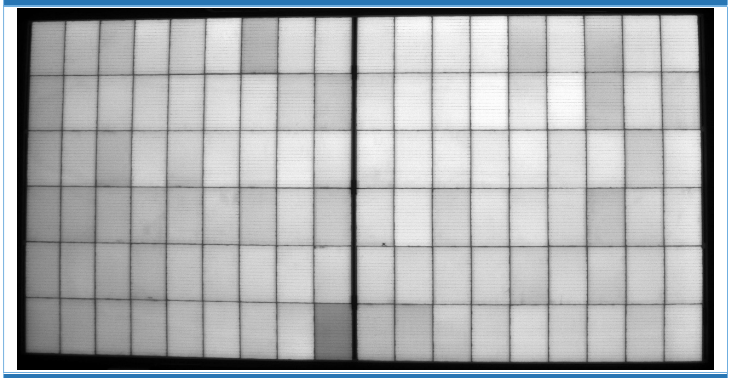
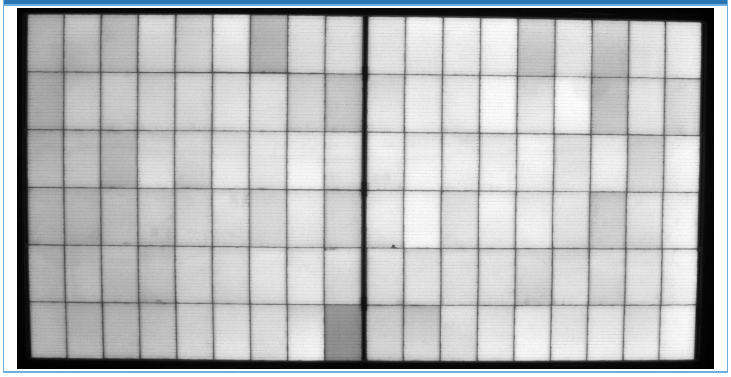
2. 3. 1.0 * I_{SC} Electroluminescence images – HSS

Model: CS6.1-54TM-450H Serial Number: 12404031160007
Pre-stress

Post-Hail Test


Model: CS6.1-54TM-450H Serial Number: 12404031160020
Pre-stress

Post-Hail Test


2. 4. 0.1 * I_{SC} Electroluminescence images - HSS

Model: CS6.1-54TM-450H Serial Number: 12404031160007
Pre-stress

Post-Hail Test


Model: CS6.1-54TM-450H Serial Number: 12404031160020
Pre-stress

Post-Hail Test


2. 5. Visual inspection notes – HSS

Pre-stress Inspection Notes				
Model	Serial Number	Notes	Defect Category	Photo
CS6.1-54TM-450H	12404031160007	Not Applicable	None	Not Applicable
CS6.1-54TM-450H	12404031160020	Not Applicable	None	Not Applicable

Post-Hail Test Inspection Notes				
Model	Serial Number	Notes	Defect Category	Photo
CS6.1-54TM-450H	12404031160007	Not Applicable	None	Not Applicable
CS6.1-54TM-450H	12404031160020	Not Applicable	None	Not Applicable

2. 6. Wet leakage current test data – HSS

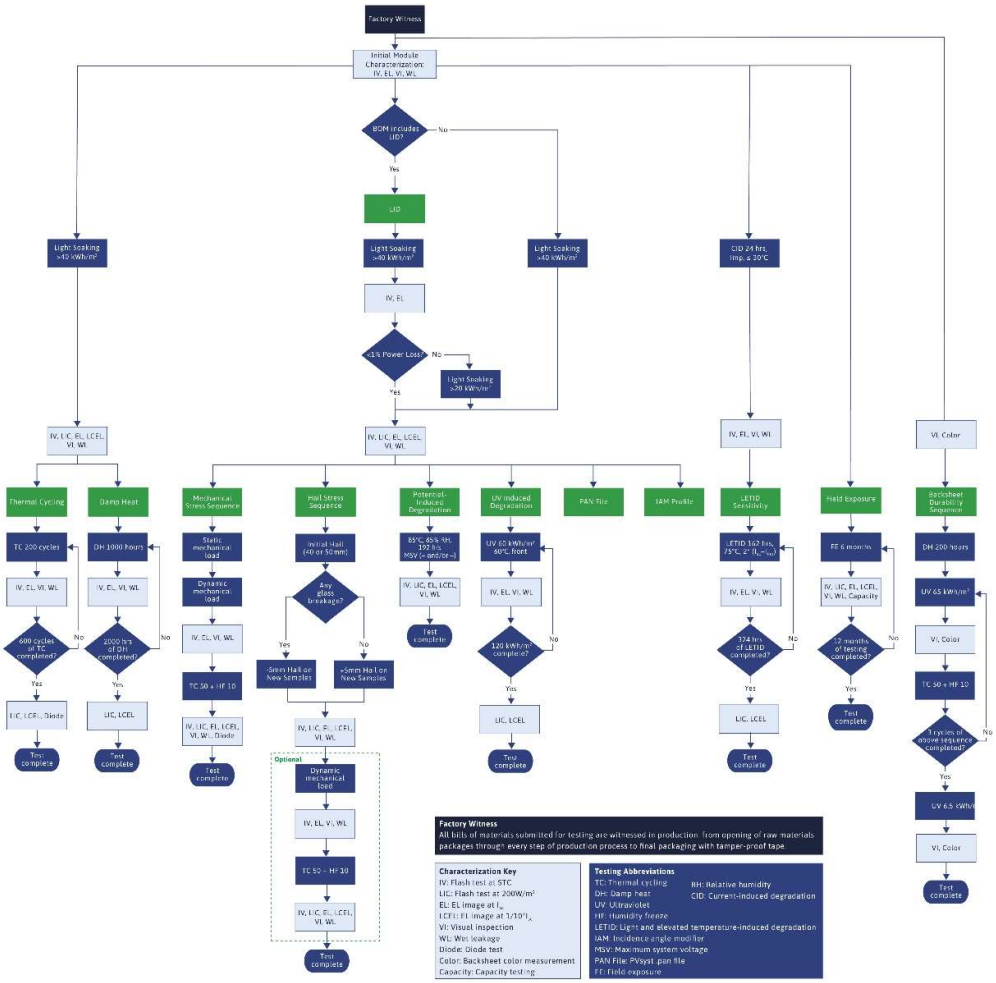
Pre-stress Test Data			
Model	**Serial Number**	**Insulation Resistance [MΩ·m²]**	**Within IEC 61215's Requirement**
CS6.1-54TM-450H	12404031160007	13648	Yes
CS6.1-54TM-450H	12404031160020	14423	Yes

Post-Hail Test Data			
Model	**Serial Number**	**Insulation Resistance [MΩ·m²]**	**Within IEC 61215's Requirement**
CS6.1-54TM-450H	12404031160007	8854	Yes
CS6.1-54TM-450H	12404031160020	8752	Yes

Exhibit A – BOM Details

PI Berlin witnessed the production of the modules tested in this report and verified the BOM components. BOM information can be found in Kiwa PVEL Reports R9661A and R9661G.

Appendix A – Product Qualification Program (PQP)



Appendix B – List of Reports

The following is a list of all reports issued over the duration of an entire module PQP.

- Witness Report
- Intake Report
- Light-induced Degradation Report
- Hail Stress Sequence Report
- Interim Reliability Report
- Final Reliability Report
- Interim Backsheet Durability Report (not required for glass//glass modules)
- Final Backsheet Durability Report (not required for glass//glass modules)
- Optional: PAN File Parameter Measurement Report
- Optional: Incidence Angle Modifier Report
- Optional: Interim Field Exposure Report
- Optional: Final Field Exposure Report

Appendix C – Typical PV Module Failure Mechanisms

	Light induced Degradation	Light and Elevated Temperature Induced Degradation	Thermal Cycling	Damp Heat	Backsheet Durability Sequence	Mechanical Stress Sequence	Hail Stress Sequence	Potential-Induced Degradation (PID)
Corrosion of cell metallization				✓		✓	✓	
Junction box failure (solder joints, arcing, etc.)			✓			✓	✓	
Glass fracture						✓	✓	
Bypass diode failure (short or open)			✓	✓		✓	✓	
Cracked cells			✓			✓	✓	
Solder joint degradation			✓			✓	✓	
Delamination				✓	✓			
Junction box detach				✓				
Connector embrittlement (moisture ingress)			✓	✓	✓			
Frame tape or frame adhesive failure						✓		
Frame fatigue						✓		
Optical degradation of encapsulant and backsheet					✓			
Light-Induced Degradation (LID)	✓							
Light and Elevated Temperature Induced Degradation (LETID)		✓						
Outgassing of in-laminate materials (Chemical incompatibilities)			✓	✓	✓	✓	✓	
Backsheet embrittlement leading to cracks			✓	✓		✓	✓	
Busbar sharp edges, solder peaks, cutting through backsheet			✓					
Electrochemical corrosion of busbars or cell metallization								✓
Ion migration / Polarization / Potential-Induced Degradation (PID)								✓
Discoloration of frame, junction box, or polymeric materials				✓	✓	✓	✓	
Backsheet stack layer delamination				✓		✓	✓	
Hail damage							✓	

Appendix D – Flash-Test Measurement Summary

HALM CetisPV-Moduletest3 pulsed solar simulator (flash-tester)

- Class A+A+A+
  - Non-uniformity of irradiance ≤ 1%
  - Long-term pulse instability ≤ 1%
  - Spectral irradiance distribution ≤ ± 12.5%
- All performance values are extracted from the measured I-V data
- Expanded (k = 2) uncertainty values at STC (assuming a spectral mismatch factor of 1 and not including module metastability behavior):
  - I_{SC}: ± 2.0%
  - V_{OC}: ± 0.8%
  - P_{MAX}: ± 2.1%
- Maximum deviation of achieved temperature/irradiance from target temperature/irradiance:
  - Temperature: ± 1°C
  - Irradiance: ± 0.5%

PI's HALM CetisPV-Moduletest3 pulsed solar simulator was calibrated using the reference module listed below.

Tested Device Technology	Reference Module Identifier	Reference Module Technology	Calibration Laboratory	Next Calibration Due Date
p-type crystalline-Si PERC	750007740237001726	p-type crystalline-Si PERC	NIM	May 8, 2025

After calibrating the flash-tester to the reference module, the modules were flash-tested following the guidance of IEC 60904-1:2020.

Appendix E – List of Abbreviations

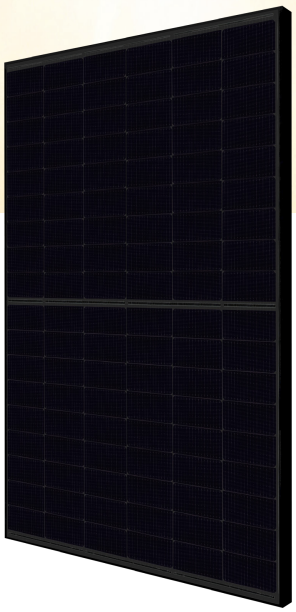
Abbreviation	Meaning
BOM	Bill of Material
BSF	Back Surface Field
CdTe	Cadmium Telluride
Kiwa PVEL	Kiwa PVEL LLC
EL	Electroluminescence
HJT	Heterojunction
IEC	International Electrotechnical Commission
IBC	Interdigitated Back Contact
I_{MP}	Current at maximum power
I_{SC}	Short-circuit current
PERC	Passivated Emitter and Rear Contact
P_{MAX}	Maximum power
PQP	Product Qualification Program
PV	Photovoltaic
STC	Standard test conditions
V_{MP}	Voltage at maximum power
V_{OC}	Open-circuit voltage

Appendix F – Manufacturer Datasheet

The manufacturer's datasheet(s) are included on the following pages.

NEW

CanadianSolar



TOPHiKu6 (All-Black)

N-type TOPCon Technology

445 W ~ 470 W

CS6.1-54TM-445|450|455|460|465|470H

MORE POWER

- Module power up to 470 W
  Module efficiency up to 23.0 %
- Excellent anti-LeTID & anti-PID performance.
  Low power degradation, high energy yield
- Lower temperature coefficient (Pmax): -0.29%/°C,
  increases energy yield in hot climate
- Lower LCOE & system cost

MORE RELIABLE

- Minimizes micro-crack impacts
- Heavy snow load up to 8100 Pa,
  wind load up to 5000 Pa*

25 Years **Industry Leading Product Warranty on Materials and Workmanship***

30 Years **Linear Power Performance Warranty***

1st year power degradation no more than 1%
Subsequent annual power degradation no more than 0.4%

*Subject to the terms and conditions contained in the applicable Canadian Solar Limited Warranty Statement. Also this 25-year limited product warranty is available only for products installed and operating on rooftops in certain regions.

MANAGEMENT SYSTEM CERTIFICATES*

ISO 9001:2015 / Quality management system
ISO 14001:2015 / Standards for environmental management system
ISO 45001: 2018 / International standards for occupational health & safety
IEC62941: 2019 / Photovoltaic module manufacturing quality system

PRODUCT CERTIFICATES*

IEC 61215 / IEC 61730
IEC 61701 / IEC 62716 / IEC 60068-2-68
Take-e-way

* The specific certificates applicable to different module types and markets will vary, and therefore not all of the certifications listed herein will simultaneously apply to the products you order or use. Please contact your local Canadian Solar sales representative to confirm the specific certificates available for your Product and applicable in the regions in which the products will be used.

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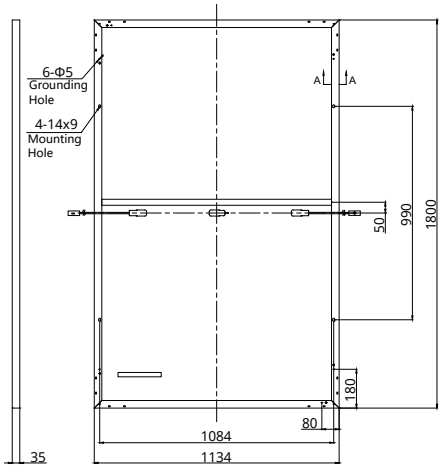
* For detailed information, please refer to the Installation Manual.

CSI Solar Co., Ltd.
199 Lushan Road, SND, Suzhou, Jiangsu, China, 215129, www.csisolar.com, support@csisolar.com

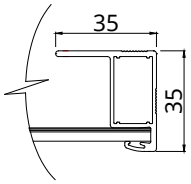
ENGINEERING DRAWING (mm)

Rear View

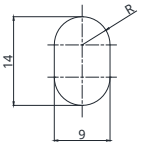


Frame Cross Section

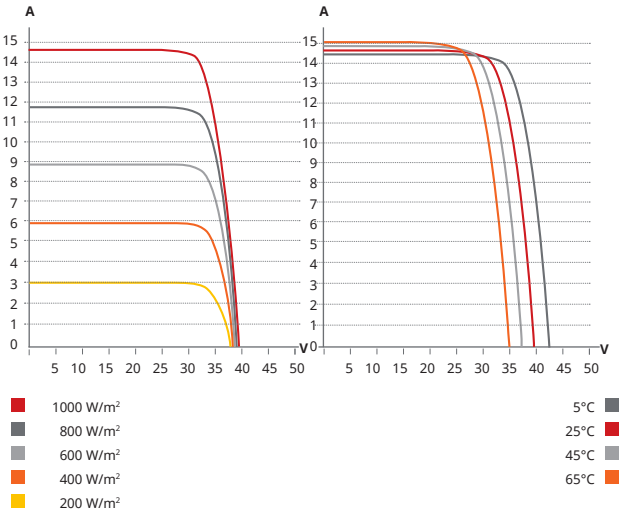
A - A



Mounting Hole



CS6.1-54TM-455H / I-V CURVES



ELECTRICAL DATA | STC*

CS6.1-54TM	445H	450H	455H	460H	465H	470H
Nominal Max. Power (Pmax)	445 W	450 W	455 W	460 W	465 W	470 W
Opt. Operating Voltage (Vmp)	32.8 V	33.0 V	33.2 V	33.4 V	33.6 V	33.8 V
Opt. Operating Current (Imp)	13.59 A	13.66 A	13.72 A	13.78 A	13.85 A	13.91 A
Open Circuit Voltage (Voc)	38.7 V	38.9 V	39.1 V	39.3 V	39.5 V	39.7 V
Short Circuit Current (Isc)	14.48 A	14.55 A	14.61 A	14.69 A	14.77 A	14.86 A
Module Efficiency	21.8%	22.0%	22.3%	22.5%	22.8%	23.0%
Operating Temperature	-40°C ~ +85°C					
Max. System Voltage	1500V (IEC/UL) or 1000V (IEC/UL)					
Module Fire Performance	TYPE 1 (UL 61730 1500V) or TYPE 2 (UL 61730 1000V) or CLASS C (IEC 61730)					
Max. Series Fuse Rating	25 A					
Application Classification	Class A					
Power Tolerance	0 ~ + 10 W					

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m2, spectrum AM 1.5 and cell temperature of 25°C.

MECHANICAL DATA

Specification	Data
Cell Type	TOPCon cells
Cell Arrangement	108 [2 X (9 X 6)]
Dimensions	1800 × 1134 × 35 mm (70.9 × 44.6 × 1.38 in)
Weight	23 kg (50.7 lbs)
Front Cover	3.2 mm tempered glass with anti-reflective coating
Frame	Anodized aluminium alloy
J-Box	IP68, 3 bypass diodes
Cable	4 mm² (IEC), 12 AWG (UL)
Connector	T6 or MC4 or MC4-EVO2 or MC4-EVO2A
Cable Length (Including Connector)	Portrait: 350 mm (13.8 in) (+) / 250 mm (9.8 in) (-); landscape: 1150 mm (45.3 in)*
Per Pallet	31 pieces
Per Container (40' HQ)	744 pieces

* For detailed information, please contact your local Canadian Solar sales and technical representatives.

ELECTRICAL DATA | NMOT*

CS6.1-54TM	445H	450H	455H	460H	465H	470H
Nominal Max. Power (Pmax)	335 W	339 W	343 W	347 W	351 W	354 W
Opt. Operating Voltage (Vmp)	30.9 V	31.1 V	31.3 V	31.5 V	31.7 V	31.9 V
Opt. Operating Current (Imp)	10.85 A	10.91 A	10.96 A	11.02 A	11.07 A	11.12 A
Open Circuit Voltage (Voc)	36.5 V	36.7 V	36.9 V	37.1 V	37.3 V	37.5 V
Short Circuit Current (Isc)	11.68 A	11.74 A	11.79 A	11.85 A	11.92 A	11.99 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.29 % / °C
Temperature Coefficient (Voc)	-0.25 % / °C
Temperature Coefficient (Isc)	0.05 % / °C
Nominal Module Operating Temperature	42 ± 3°C

PARTNER SECTION

* The specifications and key features contained in this datasheet may deviate slightly from our actual products due to the on-going innovation and product enhancement. CSI Solar Co., Ltd. reserves the right to make necessary adjustment to the information described herein at any time without further notice. Please be kindly advised that PV modules should be handled and installed by qualified people who have professional skills and please carefully read the safety and installation instructions before using our PV modules.

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