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PV Module Bankability Testing Program

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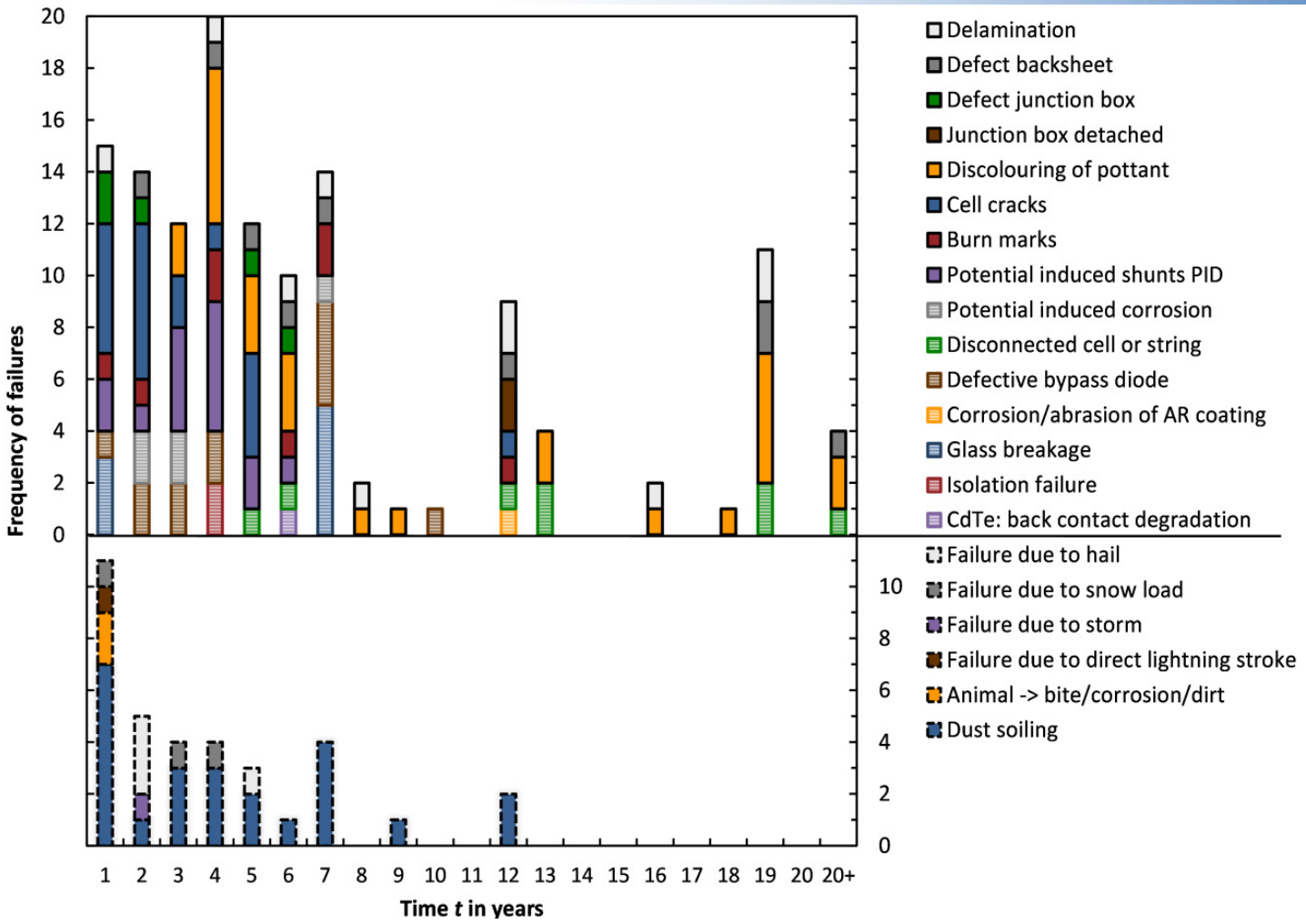
Why use the CFV Labs Bankability program?

PV modules are produced and sold with an expected service life of > 25-years, but is certification a reliable indicator of module lifetime?

- Issues with fielded modules, such as backsheet failure, delamination, corrosion, moisture ingress and power loss, to name a few, are commonly seen within < 10 years.
- Banks and developers are requiring extended reliability testing prior to project and supply contract approval.
- CFV Labs offers rigorous standard-based bankability testing with faster time-to-market.



International Energy Agency, *Assessment of photovoltaic module failures in the field*. 2017.

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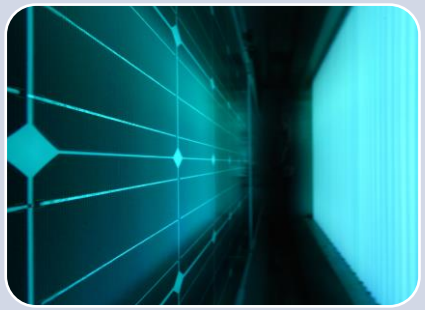
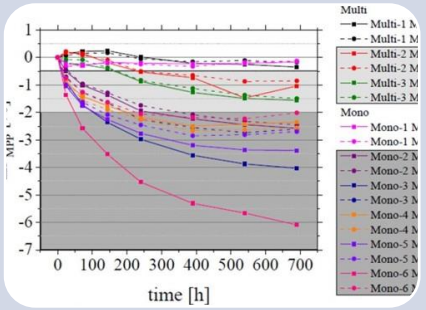
CFV Labs PV Module Bankability Testing Program

CFV's state-of-the-art bankability testing program combines the IEC TS 63209 draft protocol with a suite of customizable add-ons to provide comprehensive and industry accepted bankability analysis.

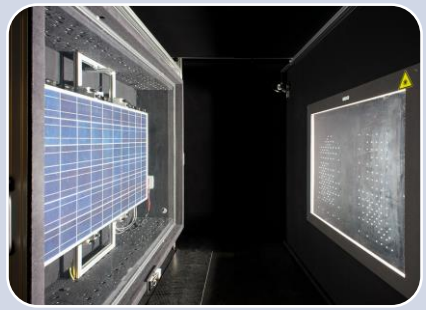


Material Durability Testing

Mechanical Durability Testing



Cell Degradation Testing



Performance Testing

Outdoor Testing

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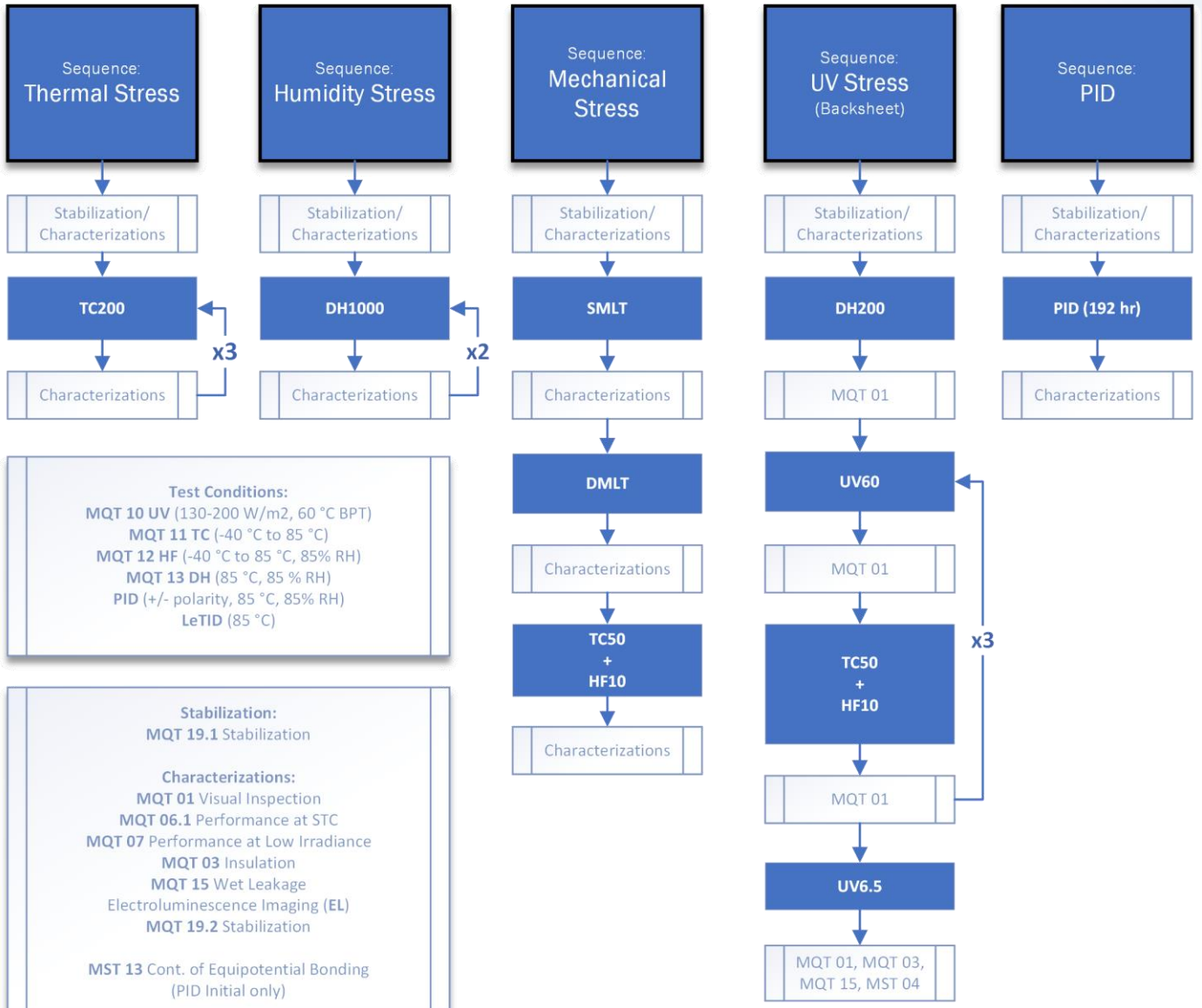
CFV's Bankability Program Base IEC TS 63209 Test Flow



- Based on the IEC TS 63209:
  - Solid foundation based on expert industry stakeholder consensus.
  - Very similar to legacy industry test protocols like PVEL PQP and Thresher Test.
- Common testing add-ons include:
  - LeTID evaluation
  - PAN Files
  - Outdoor Exposure
- Flexibility to add technology or package specific testing options as required
  - Bifacial Testing
  - Custom MLT

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Third Party BOM Verification and Report Sharing

CFV uses globally recognized QA firms to provide third party BOM verification for product sampling assurance.

The BOM verification program assures sample validity by using:

- On-site verification of raw materials listed in BOM(s), along with their certification status.
- Factory EL images, flash data and IV curves, safety test data, and construction process data.
- Factory witness of module construction, randomized test module selection, and module packing/shipping.
- CFV requires a sample set 30 % above those required for testing. This gives CFV the ability to select high quality samples, free of shipping defects.

Reporting:

- Due to CFV's transparent data reporting, standards-based protocols and top-tier reputation, reports are accepted by lenders, IE's, developers and the industry at large.
- CFV facilitates report sharing by granting access on a case-by-case basis to its ShareFile portal. This allows for rapid and traceable report distribution.

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BOM Variants and Retest Guidelines

To ensure timely project completion and the minimum testing possible, CFV utilizes a BOM variant testing matrix. Test legs are repeated whose results may strongly depend on a particular BOM change.

Interim reports are issued periodically, and test results and protocol are discussed with client to determine go-forward feasibility of continuing with individual test legs.

CFV BOM Variant Test Guidelines

Modification	Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5
Front Sheet		X	X		X
Encapsulation			X	X	X
Cell Technology	X	X			X
Cell and String Interconnect	X			X	
Backsheet			X	X	
J-box / Electrical Termination, J-Box Attach	X	X		X	
J-box Pottant	X				
Bypass Diode	X				
Electrical Circuitry	X				
Edge Sealing			X	X	
Frame and/or Mounting Structure		X			
Framed → Frameless		X		X	
Increase in Module Size	X	X		X	
New Factory	X	X		X	

Note: These are CFV Labs guidelines based on previous experience and an evaluation of IEC TS 62915. Retests may sometimes be avoided by proof of similarity of components in their application.

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Large Format Module Testing – Up to 2.5m x 1.4m at CFV Labs

- New module designs for 2021 and beyond will be much larger than current 72 cell 2m x 1m designs.
- 500w/600w and higher power modules have been announced with dimensions up to 2.5m x 1.4m.
- These new module designs and dimensions require test equipment that can accommodate them.
- CFV Labs has anticipated this market shift and is ready to test these new larger designs.
- Our environmental chambers, damp heat chambers, UV chambers, mechanical load stand and flasher are all able to test modules up to 2.5m for bankability testing.

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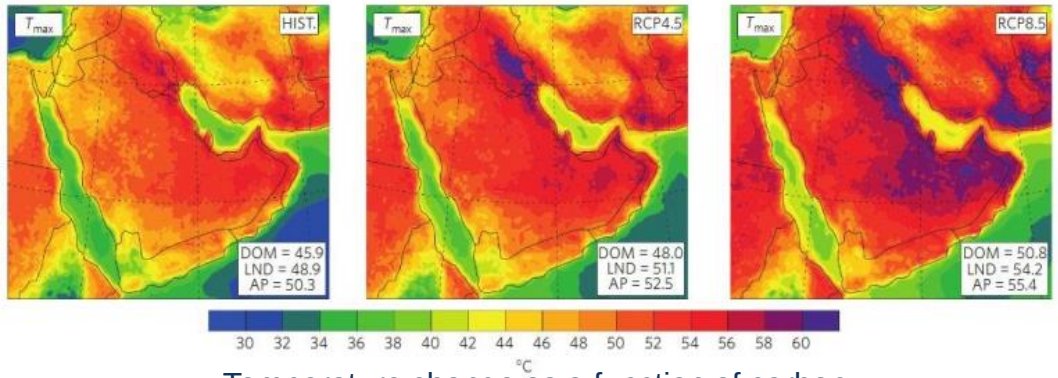
Testing for an Expansive New Generation

Competition to develop new module designs and technologies is only intensifying, and with it, the risk that unproven or under-tested materials and designs present unexpected issues. Further, the design cycle has accelerated to 6-12 months.

- The last several years have seen the rise of an abundance of different technologies and designs.
  - 10 different cell sizes: 156mm, 156.75mm, 157.25mm, 158.75mm, 161.7mm, 162mm, 166mm, 182mm, 210mm
  - 8 different cell technologies: p-type mono Al-BSF, p-type multi and mono PERC, n-type mono PERT, HJT n-type mono, p-type bifacial mono PERC, n-type bifacial mono PERT, CdTe
  - Cells with different numbers of busbars (3, 5, 6, 9, 12)
  - Monofacial and bifacial modules with glass-glass or glass-backsheet designs
  - 4 different cell interconnection types: Standard ribbons, ECA (shingled), interdigitated back-contact, metal wrap-through
  - Half- cut and shingled cells, novel cell-to-cell interconnect methods.
  - Thinner frames and glass, light-reflecting ribbon, novel encapsulants and backsheets.
  - Large format modules up to 2.4m long and 1.4m wide

PV deployments are expanding on rooftops and other high-stress environments.

- In the expanding rooftop PV market, modules routinely operate above 55 °C.
- Further, Solar continues to expand in extreme environments like 50 °C temperatures in Saudi Arabia and ~100 % humidity floating PV in China.
- With modules expected to last > 25 years, climate change could further stress existing systems.



Temperature change as a function of carbon emissions in Saudi Arabia[1]

[1] *Nature Climate Change*/Jeremy S. Pal & Elfatih A. B. Eltahir

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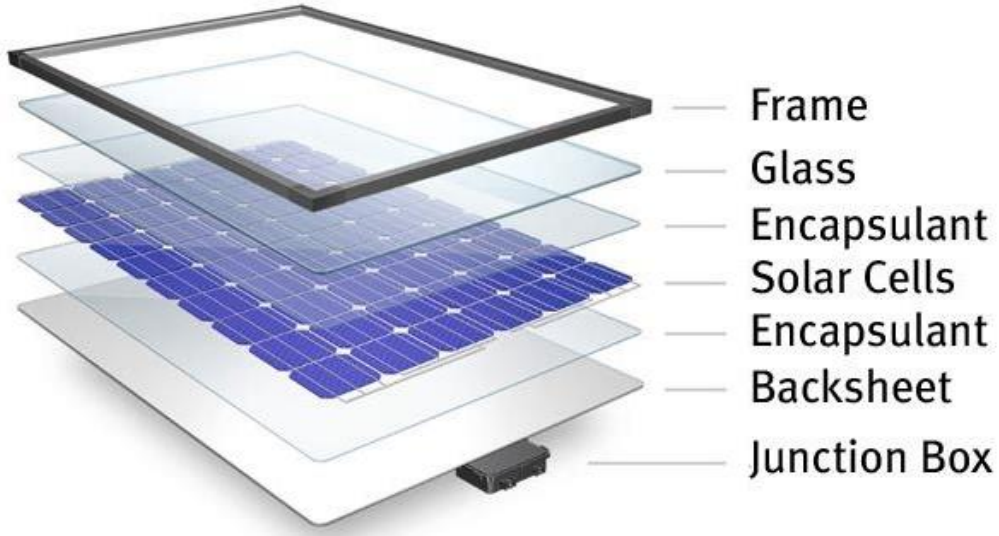
Material Durability – Temperature and Humidity

PV modules are constructed as a sandwich of different materials with different chemical and thermal properties.

- CFV's material durability sequences probe how the materials within a finished module react to temperature and humidity as part of a complete package

Module construction diagram



https://area-info.net/solar-panel-materials-market/

Test Flow

Damp Heat Sequence
@Initial Characterizations
MQT 19 Stabilization
Initial Characterizations
@DH1000 #1
MQT 13 Damp Heat (1000 hrs. @85C/85% RH)
Interim Characterizations
@DH1000 #2
MQT 13 Damp Heat (1000 hrs. @85C/85% RH)
@Final Characterizations
MQT 19 Stabilization
Final Characterizations

Thermal Cycling Sequence
@Initial Characterizations
MQT 19 Stabilization
Initial Characterizations
@TC200 #1
MQT 11 Thermal Cycling (200 cycles @ -40C/+85C)
Interim Characterizations
@TC200 #2
MQT 11 Thermal Cycling (200 cycles @ -40C/+85C)
Interim Characterizations
@TC200 #3
MQT 11 Thermal Cycling (200 cycles @ -40C/+85C)
@Final Characterizations
MQT 19 Stabilization
Final Characterizations

- Thermal and chemical mismatch between different materials can lead to unforeseen chemical and mechanical degradation modes that aren't predicted when materials are tested independently
- Recently, DH has been shown to degenerate the stabilization of the Boron-Oxygen complex in mono-PERC technology. As a result, CFV offers the option of an additional regeneration step using dark heat with current injection following the damp head sequence.

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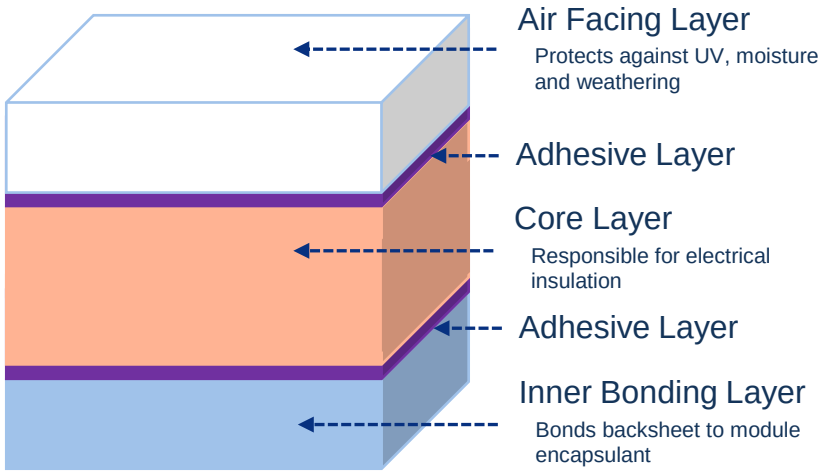
Material Durability – Backsheet

CFV's internal research efforts, in conjunction with those from other members of the IEC 63209 committee, have produced a state-of-the-art backsheet durability test sequence

- Backsheets are one of the module's first lines of defense against the elements, shielding the module against moisture ingress and loss of electrical insulation.
- While backsheets with the correct additives and polymer processing have a proven 25+ year lifetime, poor manufacturing processes and low-cost additives can produce a backsheet with substandard performance leading to cracking, loss of electrical insulation, and ultimately power loss and fire danger.



Backsheet Construction Diagram

Polyamide backsheet - Nine years in hot/dry climate

Two rounds of backsheet test

Test Flow

- UV / Backsheet Sequence
- @Initial Characterizations
- MQT 19 Stabilization
- Initial Characterizations
- @DH200
- MQT 13 Damp Heat (200 hrs. @85C/85% RH)
- @UV60/TC50/HF10 #1-#3
- MST 54 UV (60 kwh/m2 @ 60 C)
- MQT 11 Thermal Cycling (50 cycles @ -40C/+85C)
- MQT 12 Humidity Freeze (10 cycles @ -40C / +85C/85% RH)
- Interim Characterizations
- @UV6.0
- MST 54 UV (6.0 kwh/m2 @ 60 C)
- @Final Characterizations
- MQT 19 Stabilization
- Final Characterizations

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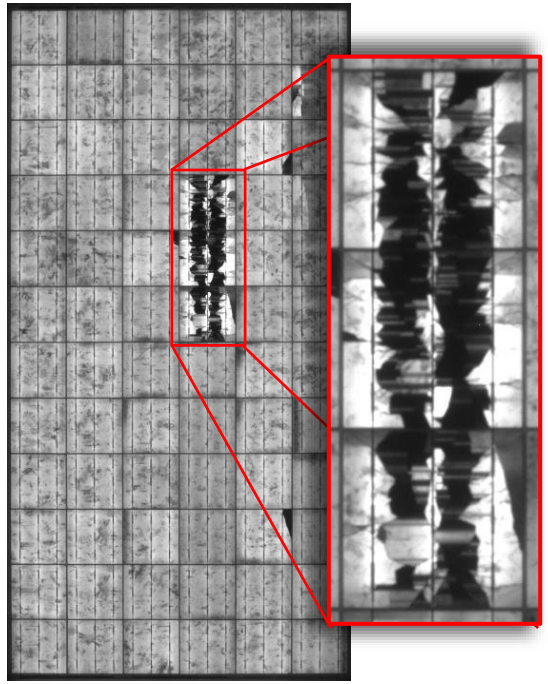
Mechanical Durability

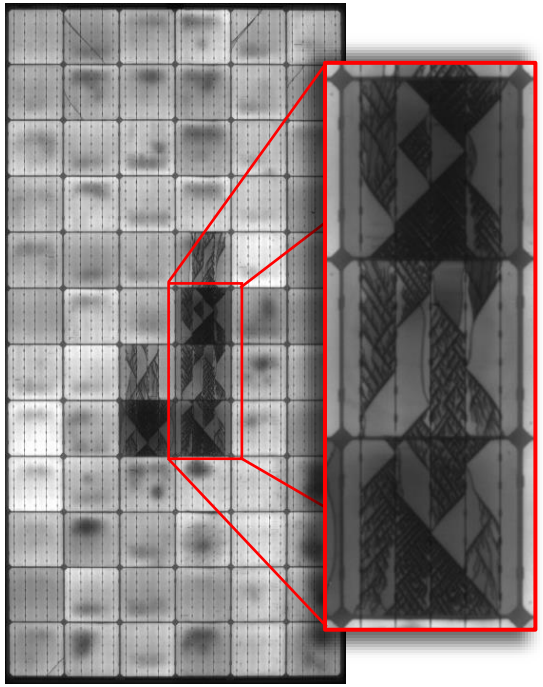
In 2019 CFV Labs pioneered its novel mechanical durability sequence*

- While previous testing utilized dynamic mechanical load testing (DMLT) only, CFV noted that DMLT alone was not producing results congruent with observations from the field
- Static mechanical load testing (SMLT) was added prior to DMLT as a crack initiator for susceptible modules
- DMLT then opens the cracks, which isolates cell regions and leads to a better estimation of real-world power change
- TC50 and HF10 follow to stress the cracks, interconnections, and other materials after the mechanical load

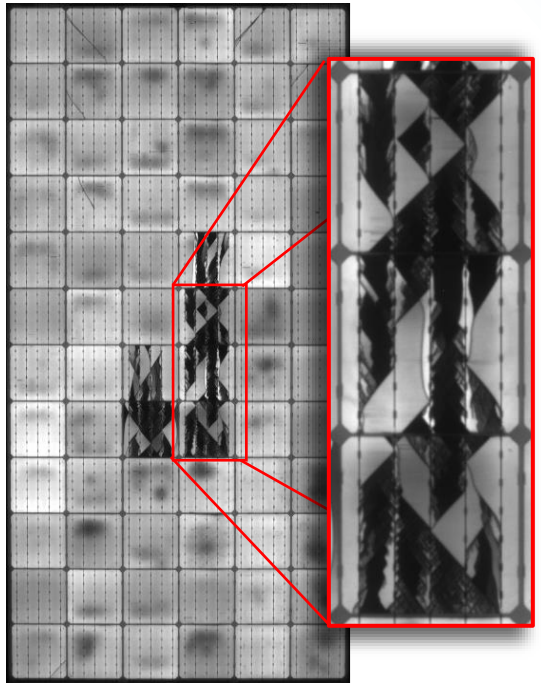
Fielded Module



SMLT



SMLT + DMLT



Test Flow

Mechanical Load Sequence
@Initial Characterizations
MQT 19 Stabilization
Initial Characterizations
@Static MLT
MQT 16 Static Mechanical Load (3 cycles, +- 2400 Pa)
Interim Characterizations
@Dynamic MLT
Cyclic Mechanical Loading (IEC TS 62782 , 1000 Cycles / +- 1000 Pa)
Interim Characterizations
@TC50
MQT 11 Thermal Cycling (50 cycles @ -40C/+85C)
Interim Characterizations
@HF10
MQT 12 Humidity Freeze (10 cycles @ -40C / +85C/85% RH)
@Final Characterizations
MQT 19 Stabilization
Final Characterizations

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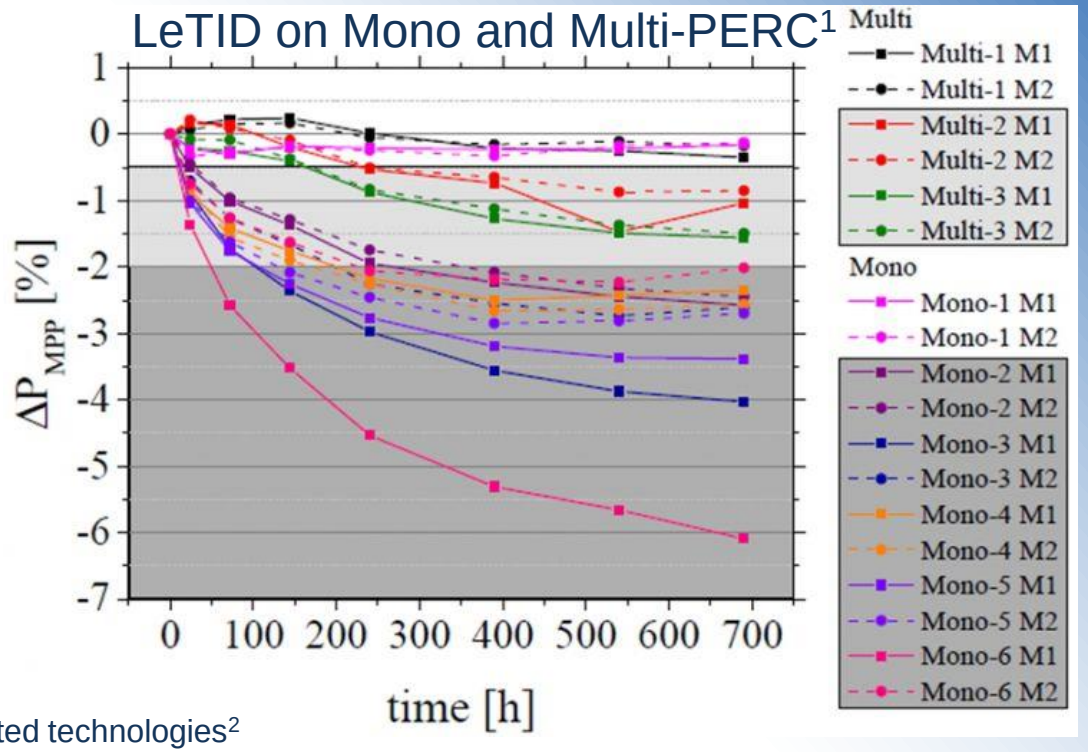
*https://b5bbce09-3b11-4fc9-ba15-19574889e9ae.filesusr.com/ugd/ad8416_309f49dbcc7646ccb8f3a69ff8723d05.pdf

Cell Degradation Testing

The PV cell is the active energy generation component of the PV module, but it is susceptible to power loss via stresses such as high voltage and/or high temperature operation that are common in deployments.

- Common degradation processes include potential induced degradation (PID), light induced degradation (LID), and light and elevated temperature induced degradation (LeTID).
- While modern manufacturing processes are designed to minimize or alleviate these degradation pathways, incomplete or inadequate stabilization can produce substandard cells.

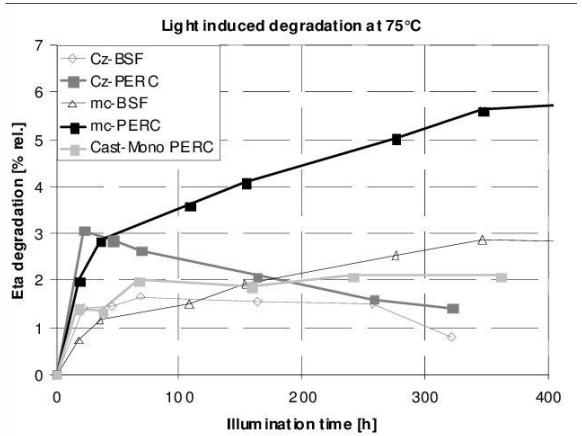
LeTID on Mono and Multi-PERC[1]



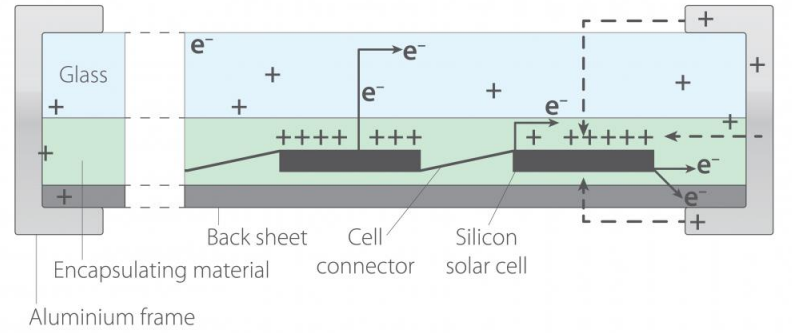
CFV's bankability program includes:

- Baseline testing:
  - Stabilization for LID
  - Potential induced degradation (PID) testing
- Additional testing options include:
  - Light and temperature induced degradation (LeTID) testing

LID and LeTID on assorted technologies[2]



PID Diagram[3]



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[1] R. G. M. Pander, M. Turek, J. Bauer, T. Luka, C. Hagendorf, M. Ebert, "Benchmarking Light and Elevated Temperature Induced Degradation (LeTID)," *Eur. Photovolt. Sol. Energy Conf.*, no. December, pp. 1265–1268, 2018.
[2] Ramspeck and A. S. , Sebastian Zimmermann1, Henning Nagel1, Axel Metz1, Yvonne Gassenbauer1, Bernhard Birkmann2, "LIGHT INDUCED DEGRADATION OF REAR PASSIVATED MC-SI SOLAR CELLS Klaus," *27th Eur. Photovolt. Sol. Energy Conf. Exhib. Light*, vol. 8, no. 9, pp. 1–58, 2017.
[3] https://www.gses.com.au/potential-induced-degradation-pid/

Performance Testing

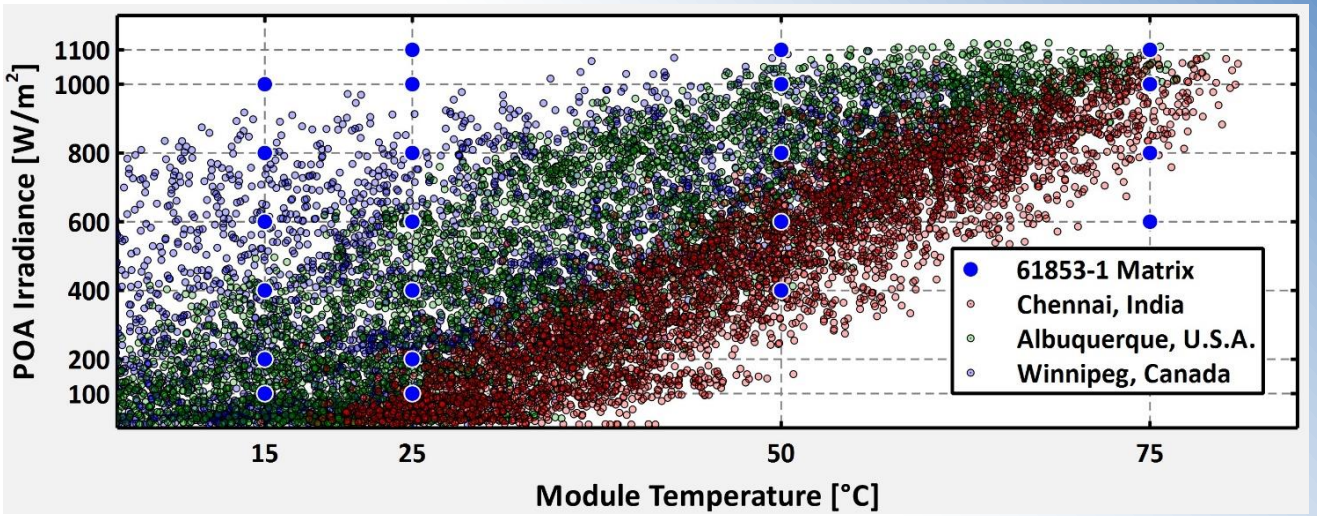
CFV Labs' world class flasher program is $A^+A^+A^+$ with Pmp uncertainty of 1.9 % on c-Si

- Module performance is the benchmark of any testing program.
- CFV Labs consistently performs among the top performing commercial labs in round robins with SNL, NREL, Fraunhofer ISE, and SERIS.

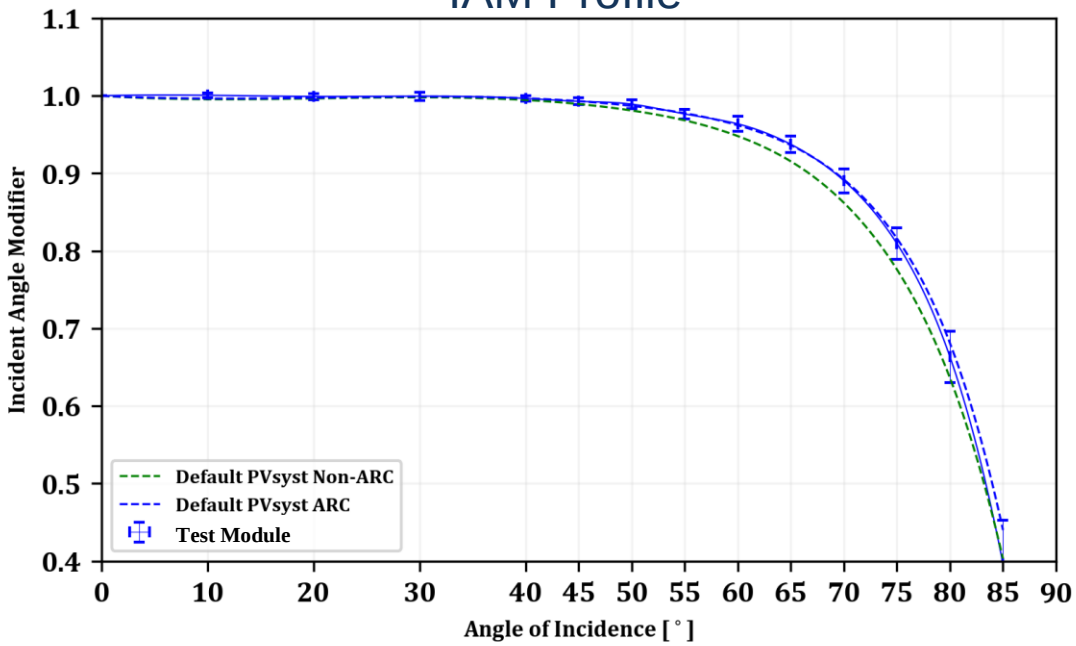
Additional testing options include:

- PAN files with PANOpt®, CFV's proprietary parameter optimization software
- Angle of incidence modifier (AOI)
- External quantum efficiency (EQE) measurements sub-contracted through NREL or Fraunhofer ISE
- Calibration modules

Performance Matrix Vs POA Irradiance



IAM Profile



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Outdoor Testing

CFV Labs' outdoor test yard is complete with 2-axis and 1-axis tracking, ample fixed rack space, and a realistic bifacial test yard.

- CFV's Bankability program offers an optional six months of outdoor performance monitoring

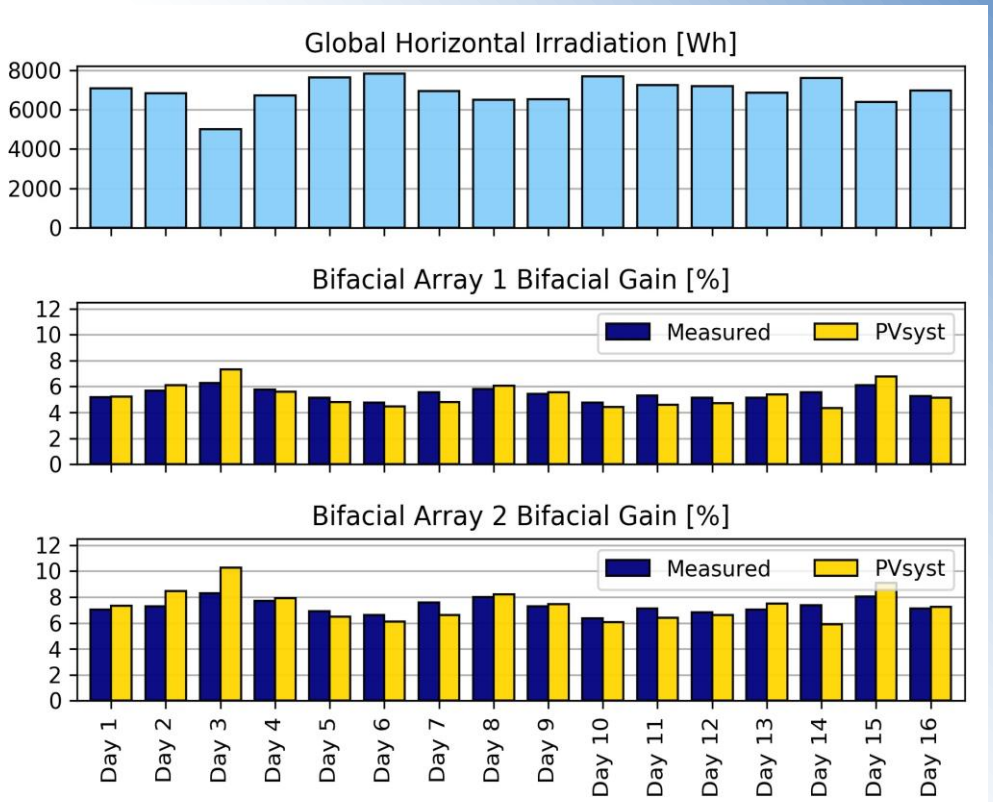

Chart and Analysis courtesy of Array Technologies, Inc.

Other testing options include:

- Bifacial performance in real-world conditions on our 5 row by 30 module array with a realistic GCR of 0.37, an albedo of 0.30, and monofacial reference strings.
- Custom string-level and module-level monitoring
- With ~310 sunny days/year, CFV can complete outdoor testing quickly
- Spectrally and thermally corrected data

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MAY 14, 2021

Thank you.

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