

Look While You Load: Electroluminescence and IV Testing of Solar Panels Under Mechanical Load

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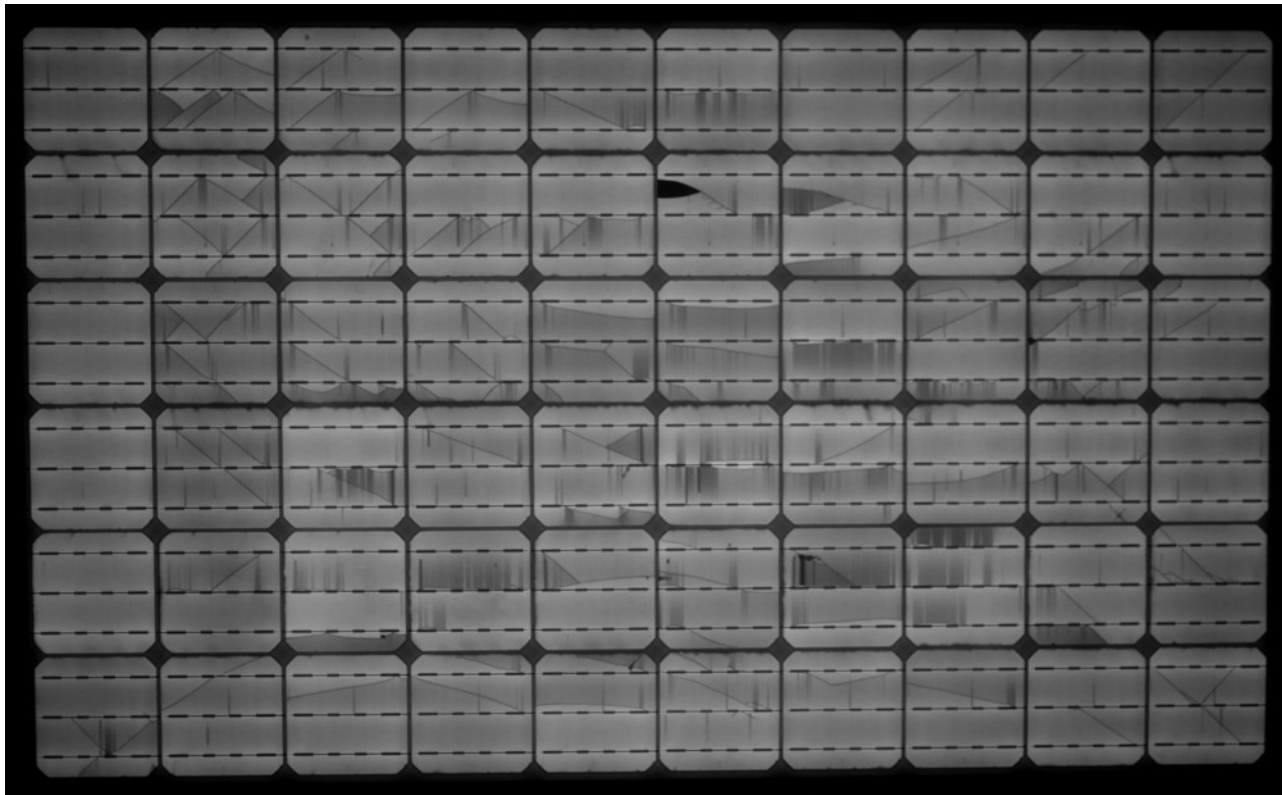
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Problem

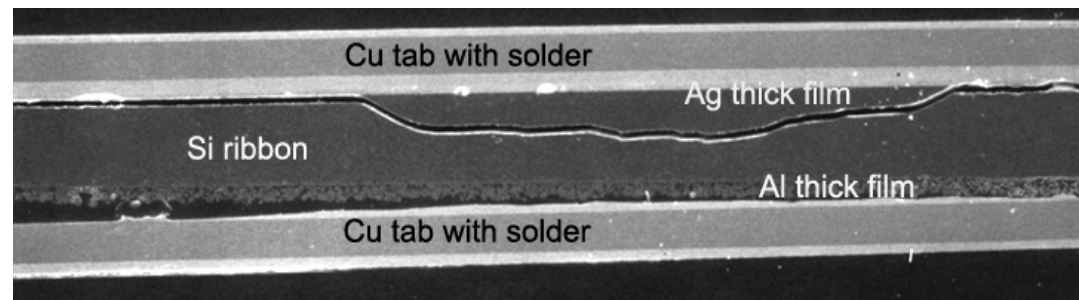
- Most panels (glass frontsheet, polymer backsheet) will develop cracks with front side loading



[BrightSpot EL Camera image]

Step 1

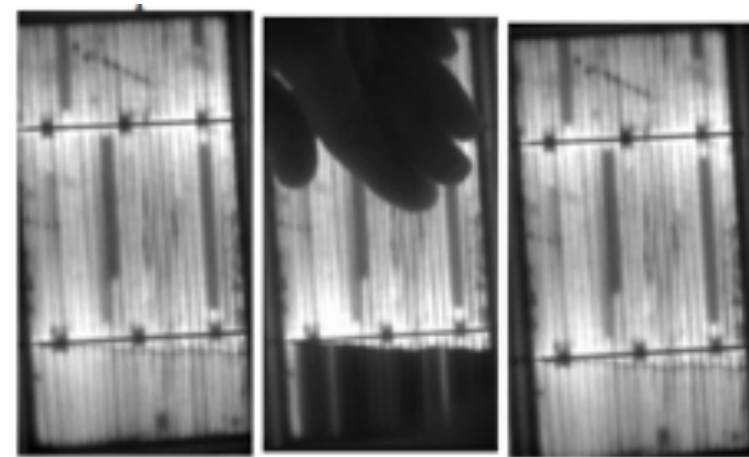
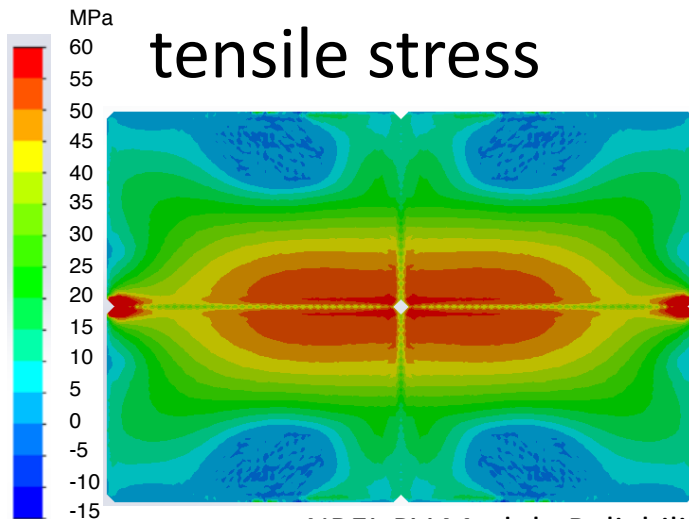
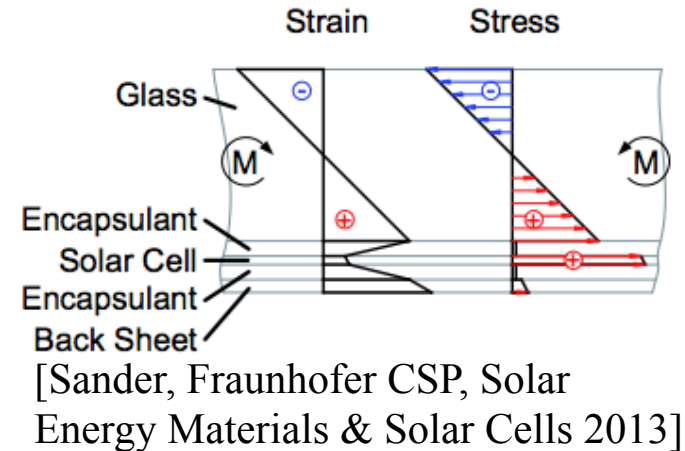
- Microcracks in Si under busbars from soldering
 - Differential contraction: Cu vs Si
- Other sources of damage



[Gabor, Evergreen Solar, PVSEC 2006]

Step 2

- Pressing on front side cause microcracks to propagate into full cracks (usually closed)
 - Asymmetric construction - cells not in neutral axis
 - Frontside loads puts cells into tensile stress



[Gabor, Evergreen Solar, PVSEC 2006]

[Gabor, BrightSpot, PVSC 2016]

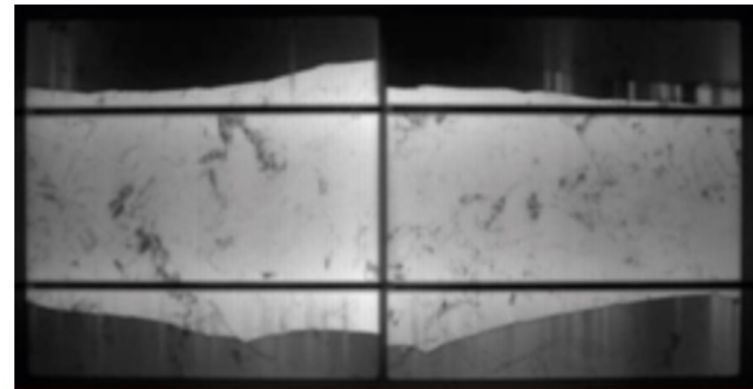
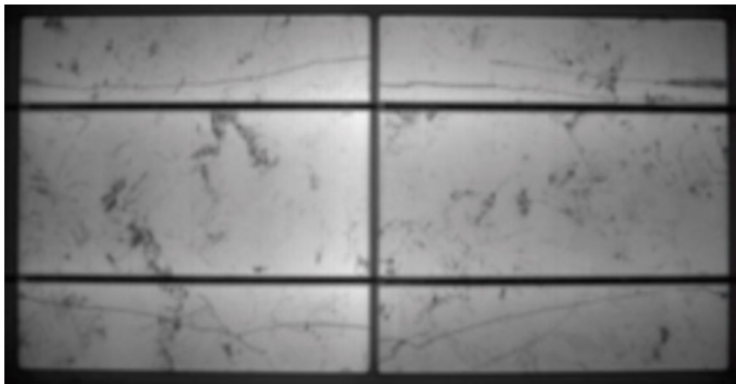
Step 3

- Subsequent loading/vibration and climate exposure can cause some closed cracks to “open up”
 - Power loss in module
 - Mismatch loss in system
 - Higher temp operation → further degradation
 - Higher sensitivity to shading

Source: MBJ-solutions.com

Solar cells before thermal cycling:
PMP [Wp] = 7.9

Solar cells after thermal cycling:
PMP [Wp] = 6.3



Scary anecdotes

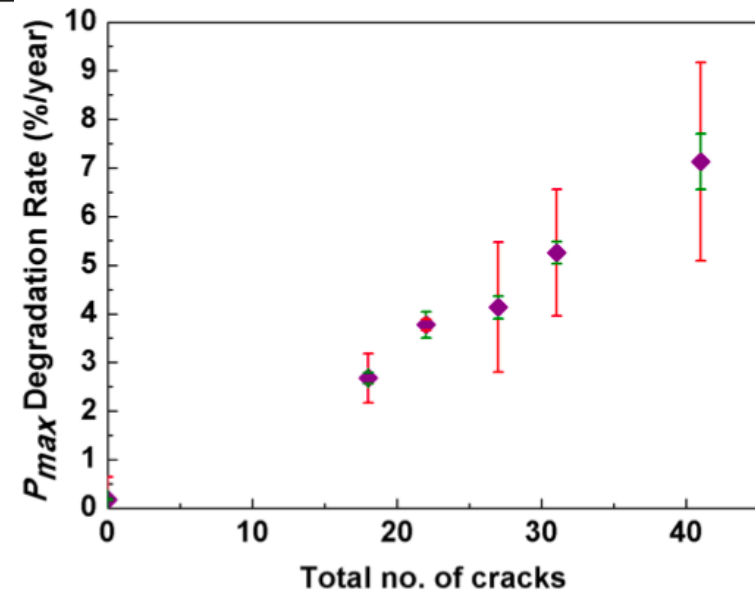
pv magazine group



Snail Trails: c-Si

Climatic Zone	Age Groups				Total
	0-5 Years	5-10 Years	10-20 Years	20-30 Years	
Hot & Dry	35% (74)	NA	0% (29)	0% (39)	18% (142)
Warm & Humid	17% (93)	0% (58)	0% (119)	0% (2)	6% (272)
Composite	0% (125)	0% (7)	6% (124)	NA	3% (256)
Moderate	56% (123)	NA	8% (12)	NA	52% (135)
Cold & Sunny	50% (34)	NA	0% (22)	NA	30% (56)
Cold & Cloudy	44% (112)	NA	NA	NA	44% (112)

[Kottantharayil, IIT,
*Lessons Learned from
the All India Survey of
Photovoltaic Modules*,
NREL PVMRW 2016]



Substandard module processing

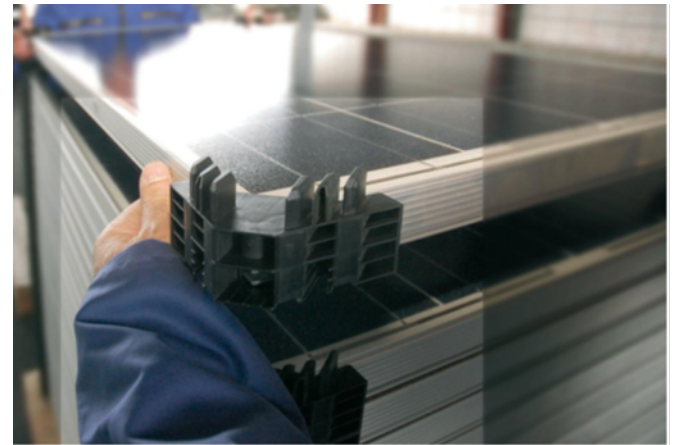
- Soldering
- Wire
- Handling



[Tier1 manufacturer, ~2012]

Substandard shipping and handling

- Pack on edge vs
- Sunnyside up vs
- Sunnyside down



[Enlog]

Substandard installation

- Rough handling
 - Hard to control
- Bad mounting



Loads in the field

- Wind
- Snow
- Snow + wind
- Improper O&M



Very hard to control



3 Options

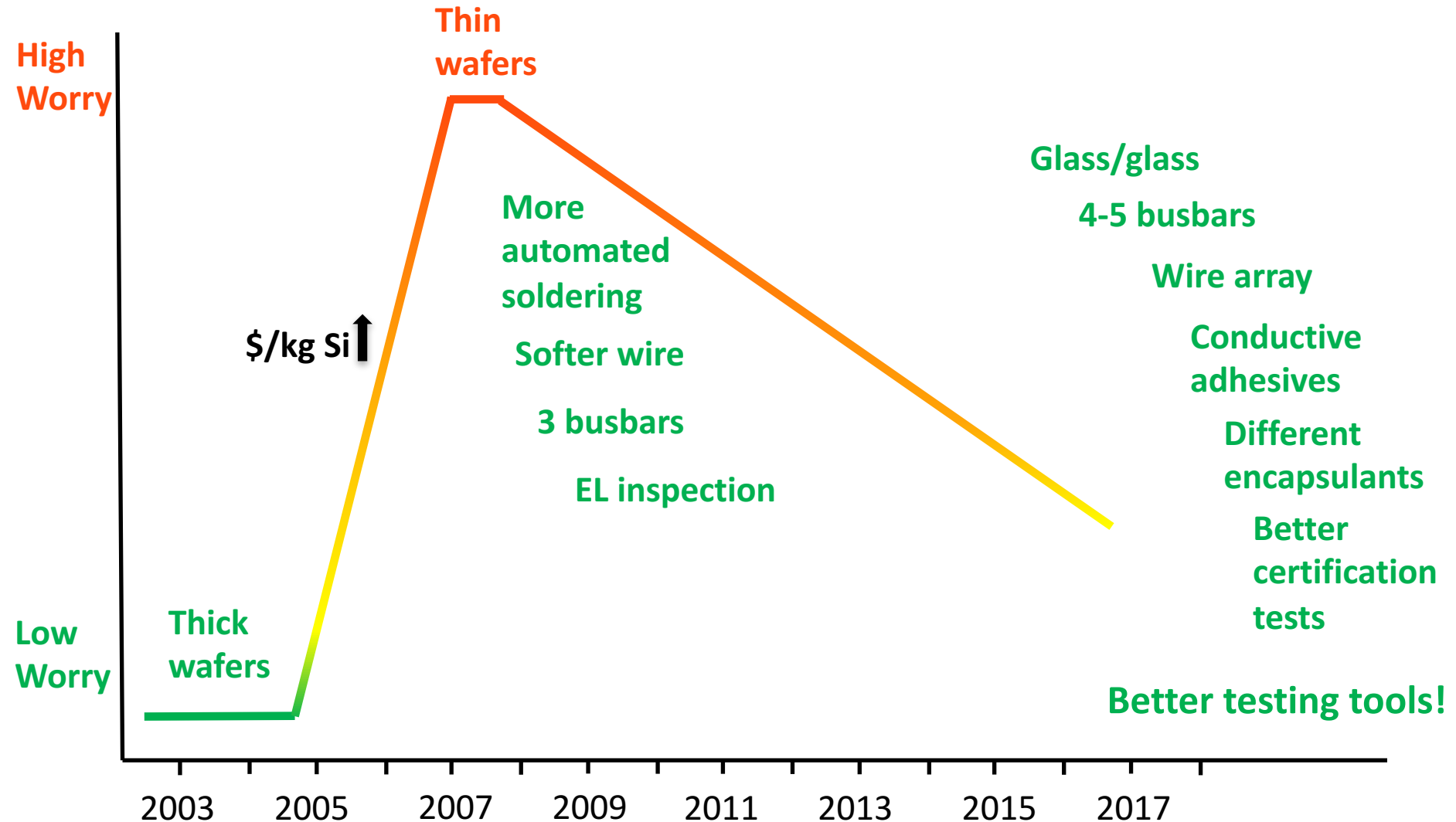
- Control everything so modules don't see crack producing conditions
- **Make modules that are less prone to cracking**
- **Make modules that are less prone to degradation from cracks if they do occur**

Cell Cracking Solutions

Method	Cure/ Bandaïd	Desirability
Optimize soldering and QC	Cure	High
Improved metallization	Cure	High
Racking to reduce bending	Cure	High
Glass/glass construction	Cure	High
Stiffer modules	Cure	High
Compressive stress from backsheets	Cure	High
Conductive adhesives	Cure	High
More wires	Bandaïd	High
Wires closer to edges	Bandaïd	High
Low reverse breakdown	Bandaïd	High
Strings wired in parallel	Bandaïd	Med
Cells wired in parallel	Bandaïd	Med
Rectangular cells + thin wires	Cure	Med
Module level electronics	Bandaïd	Med
Increased bypass diodes	Bandaïd	Med
Thicker wafers	Cure	Low

[Gabor, BrightSpot Automation, NREL PVMRW, 2015]

Crack Worry Trendline



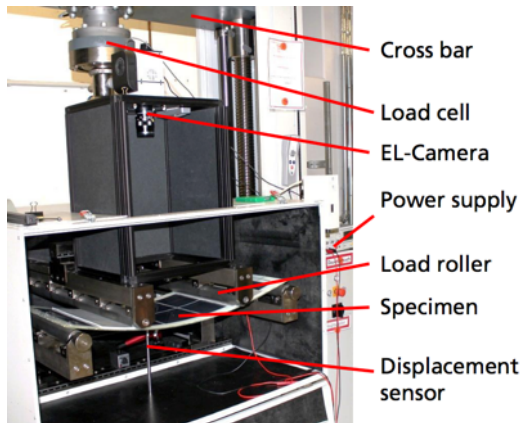
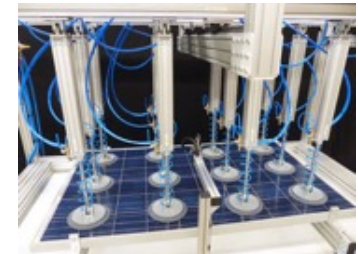
What tools would help?

- BrightSpot's conclusion
 - See when cracks form as load levels are increased
 - Higher resolution EL to better see tightly closed cracks (24 Megapixels vs <1.5 Megapixels)
 - Low-cost so everyone can afford



Existing Load Methods

- Most block front side
 - Prevent EL imaging
 - Uniformity?
- 4 bar bending of laminates
 - Allows EL!
 - But forces are different than in the field



Cross bar

Load cell

EL-Camera

Power supply

Load roller

Specimen

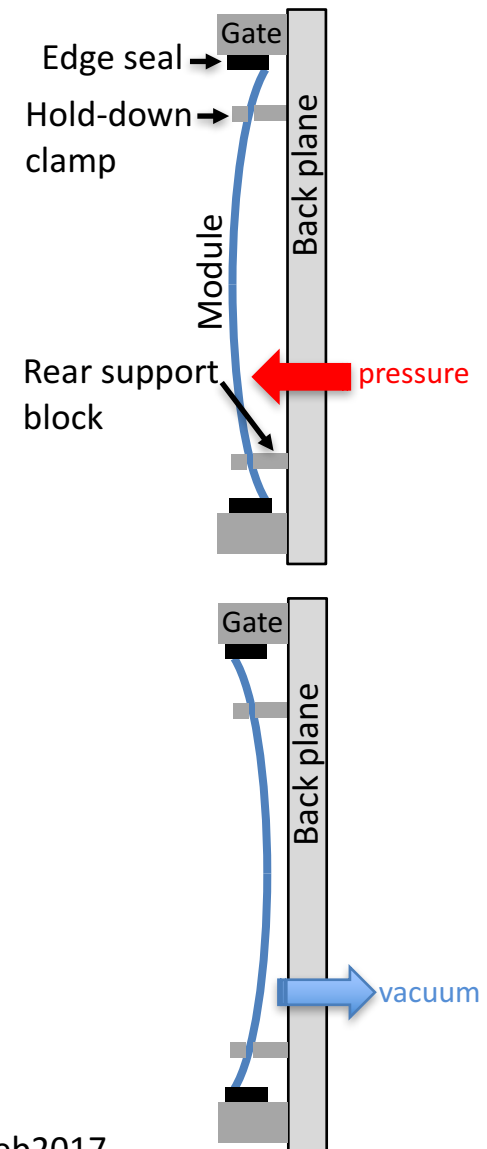
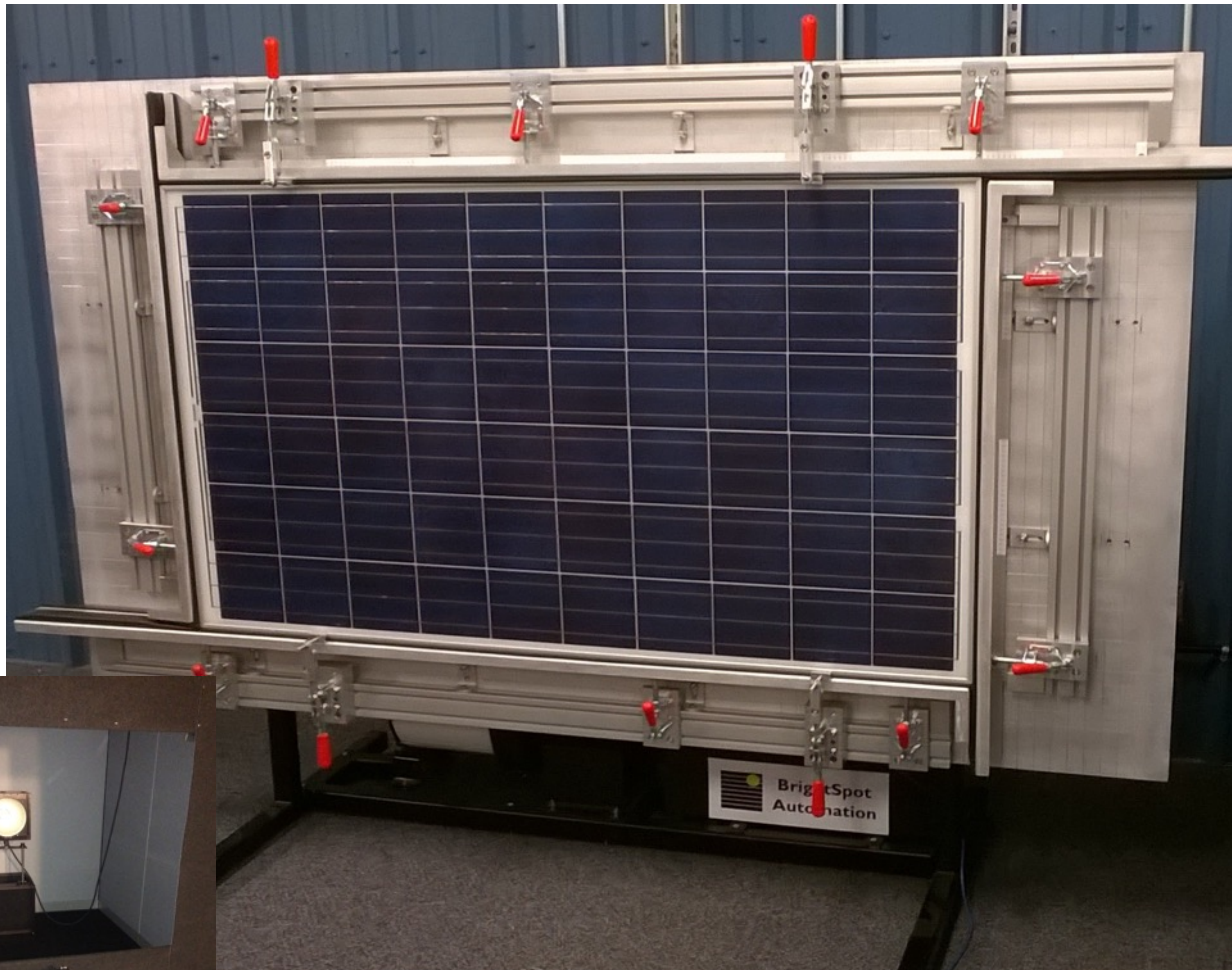
Displacement sensor

[Dietrich,
Fraunhofer
CSP 2015]

[Gade,
Jabil,
NREL
PVMRW,
2015]



The *LoadSpot* solution

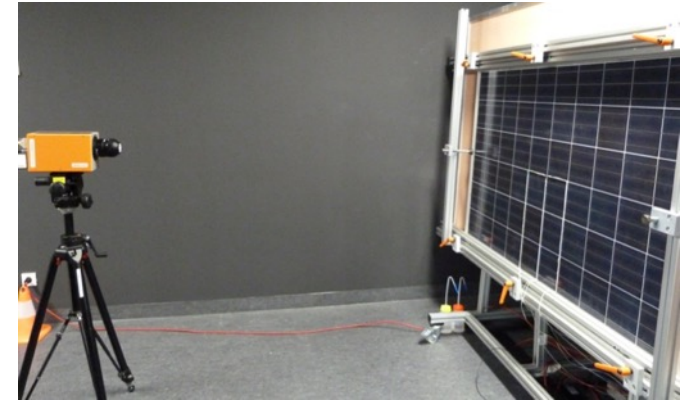


- Support at 4 mounting points
- Uniform loading

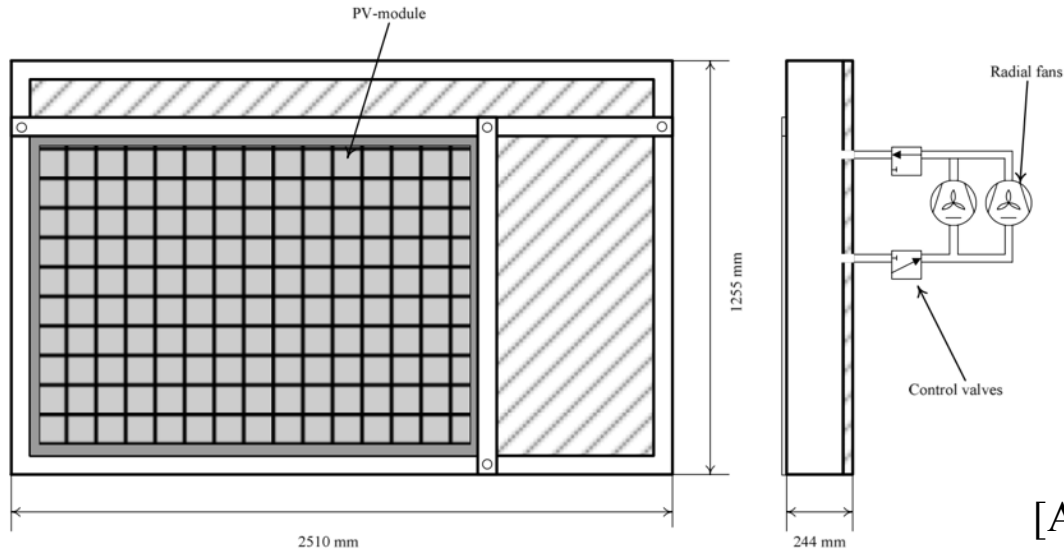
NREL PV Module Reliability Workshop - Lakewood CO, USA - 28Feb2017

Other backside vacuum solutions

- Full perimeter support

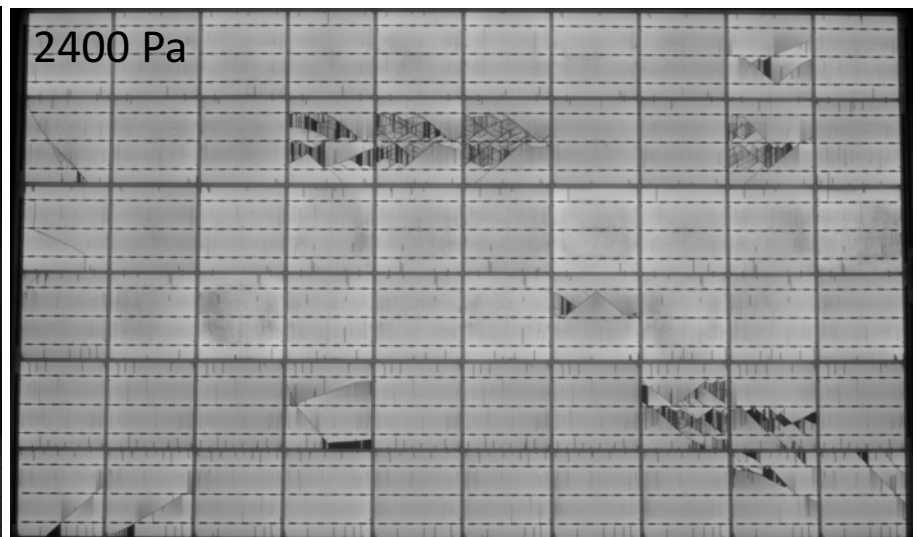
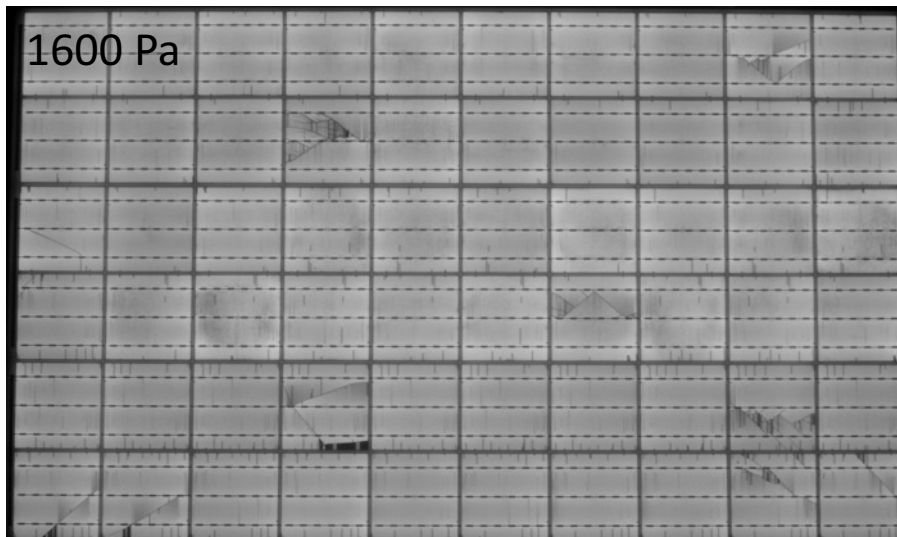
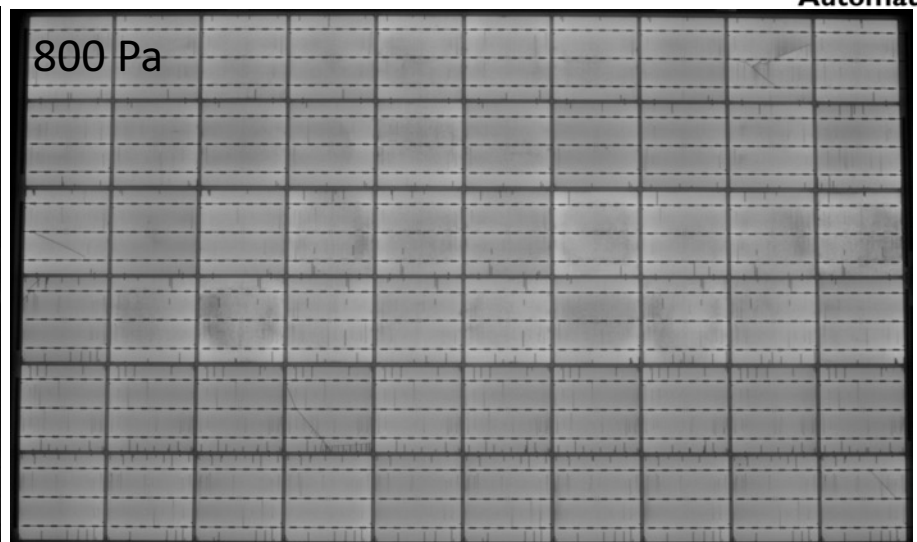
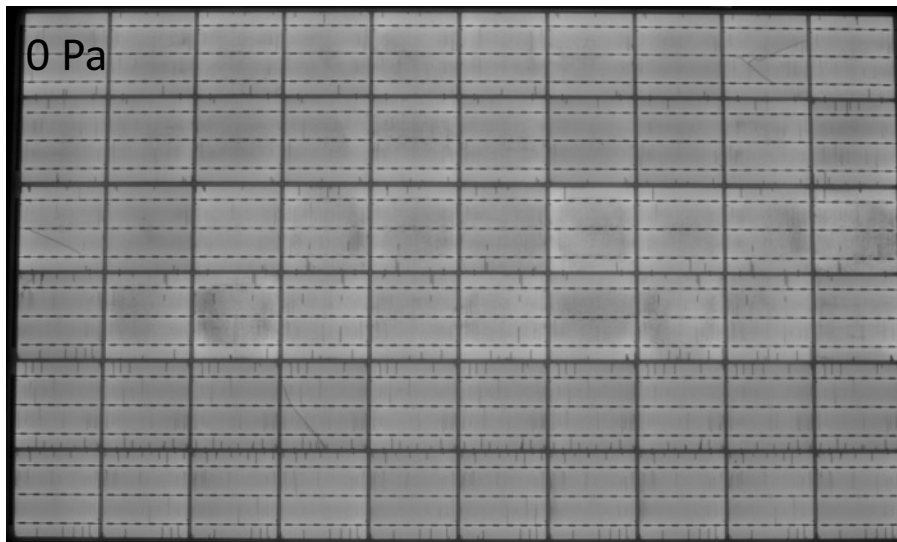


[ZAE Bayern, 2017]

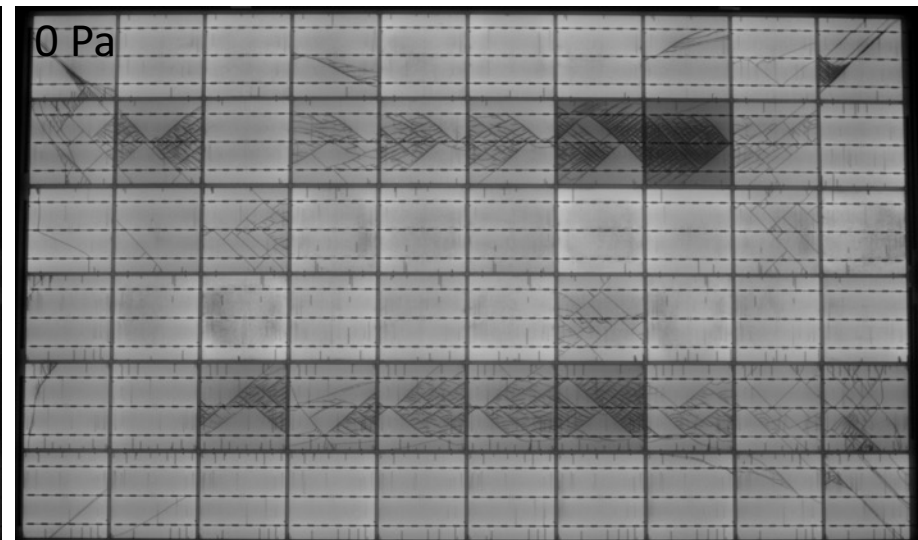
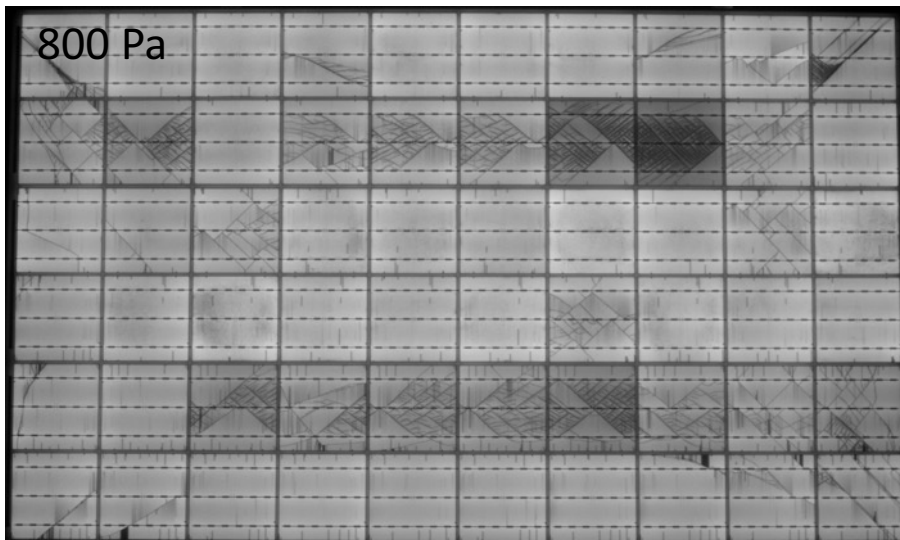
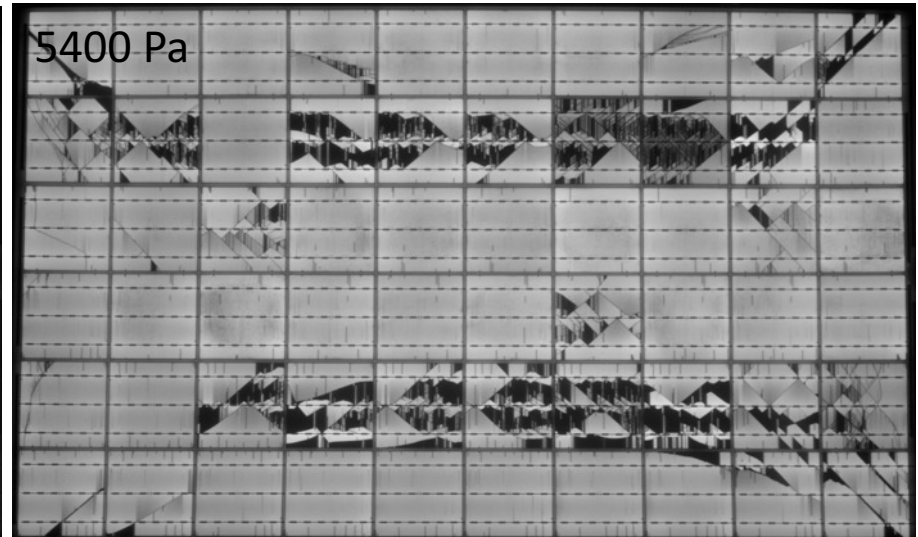
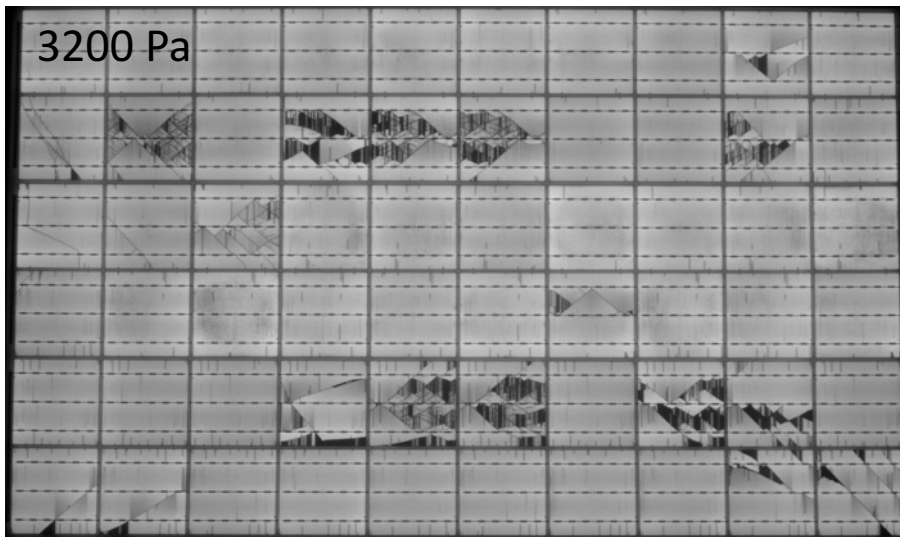


[Assmus, ISE, 2009]

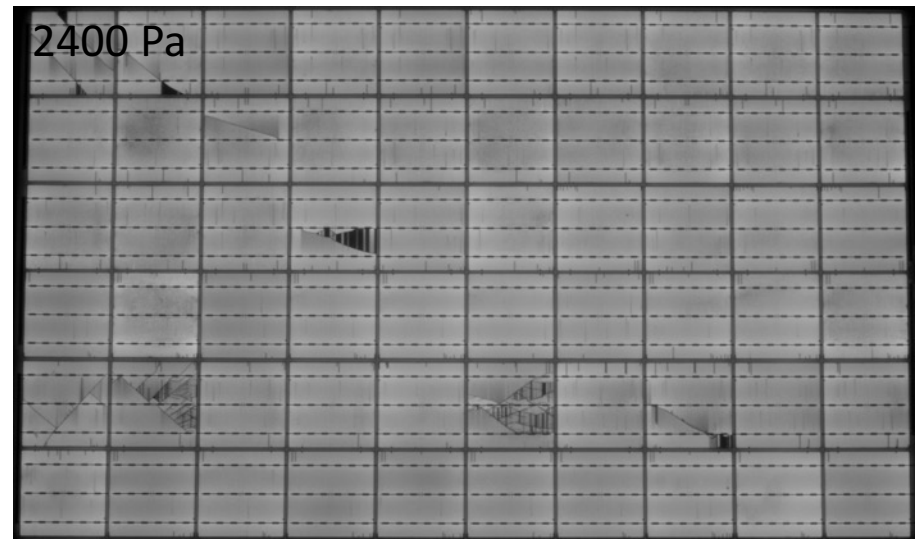
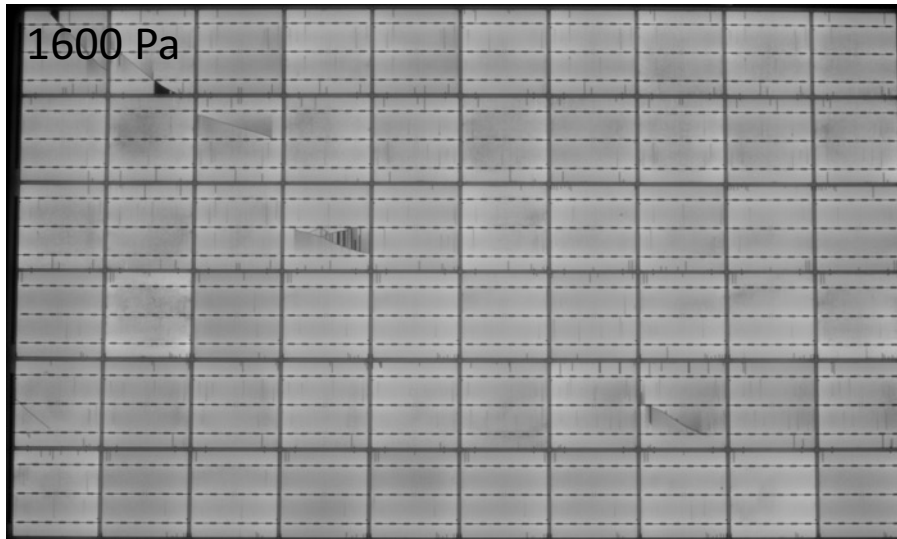
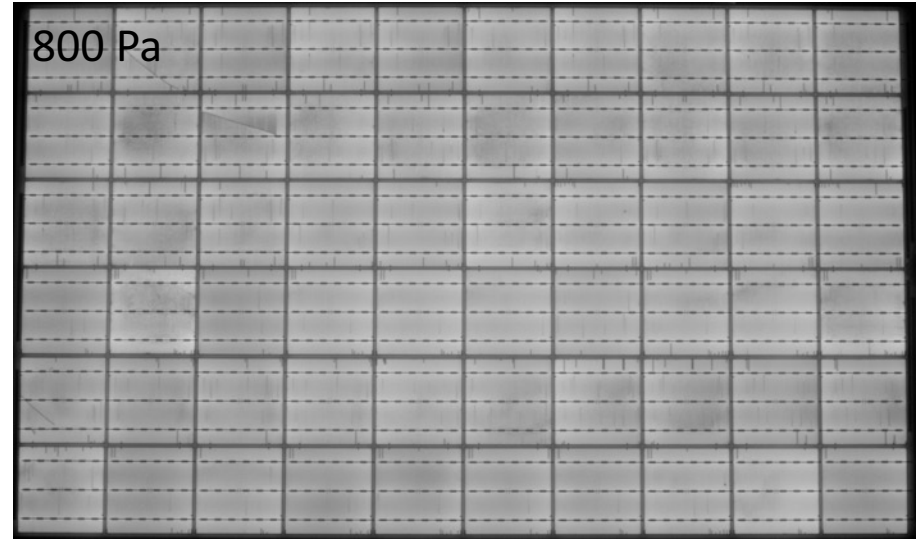
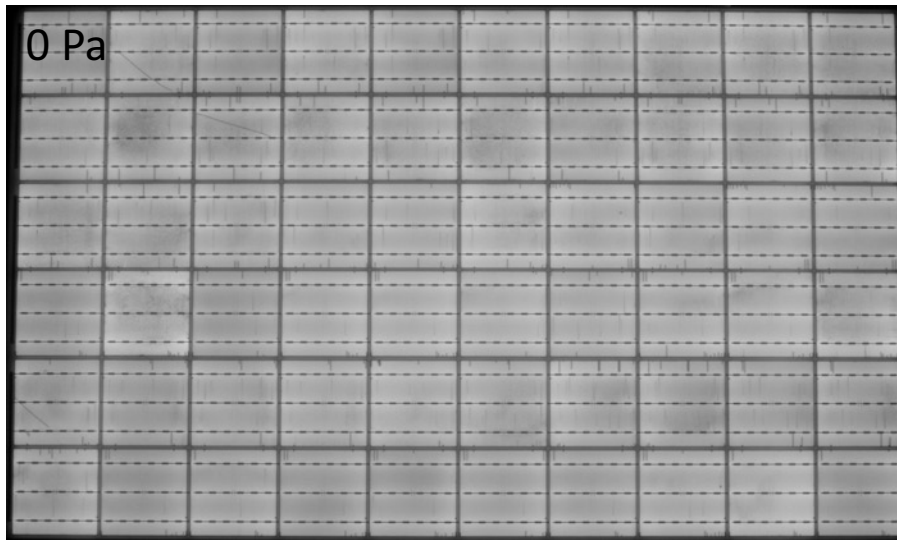
Crack evolution vs load – Panel1



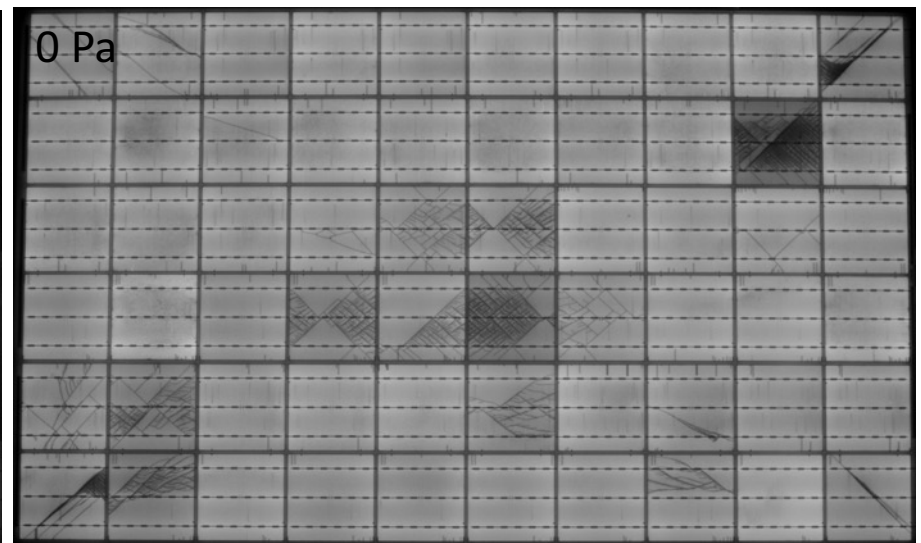
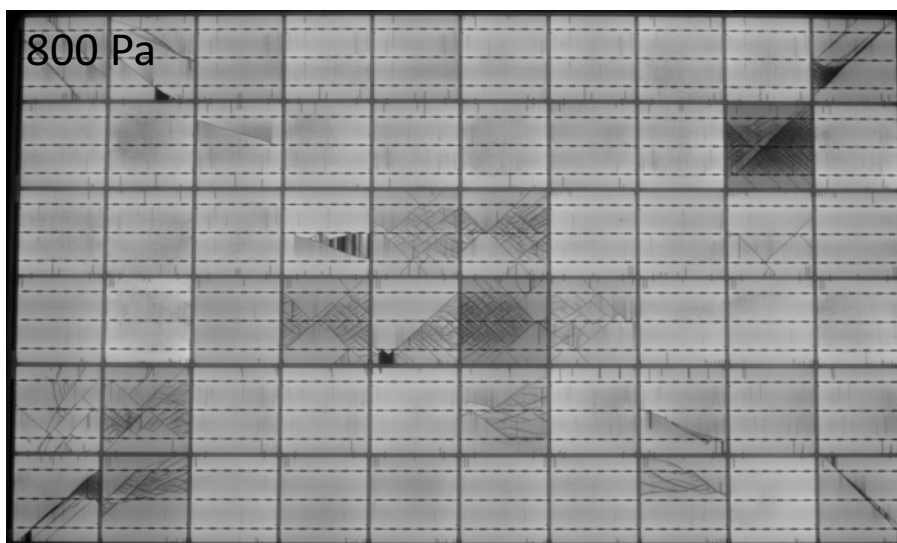
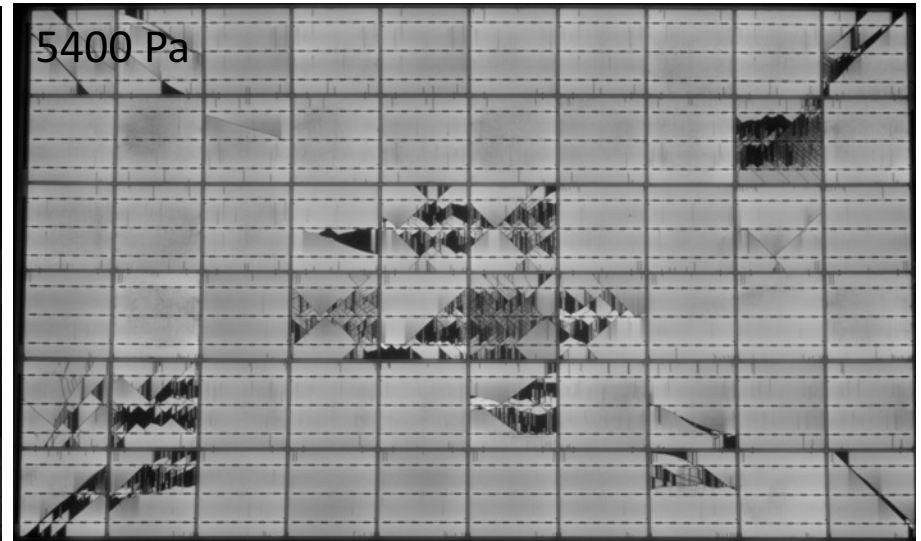
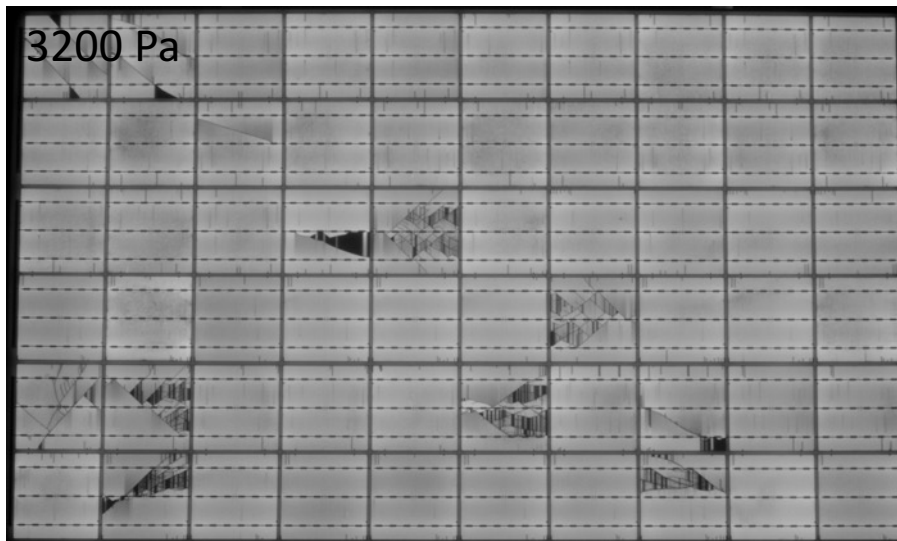
Crack evolution vs load – Panel1



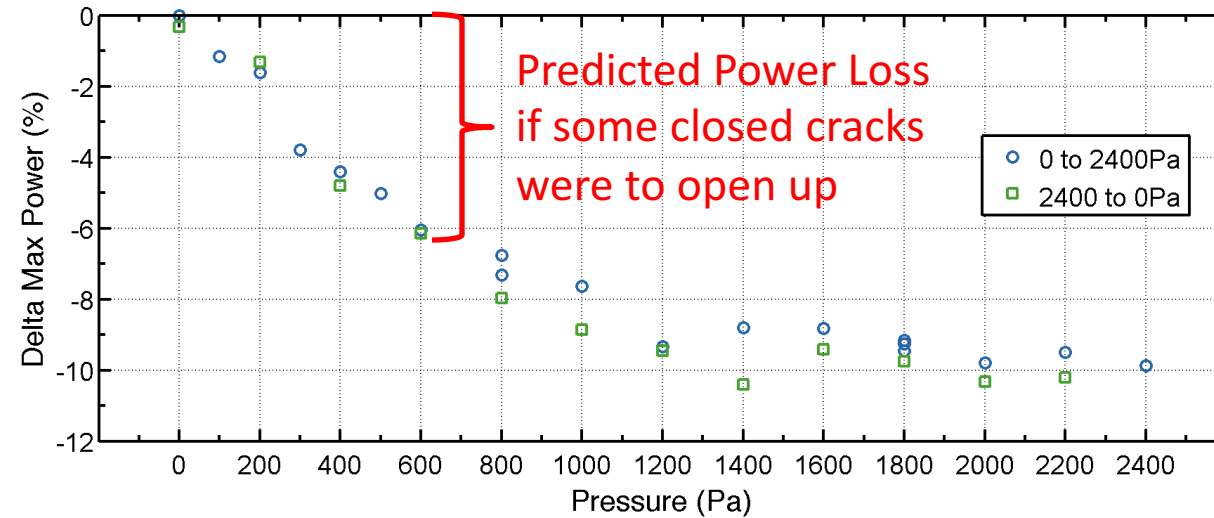
Crack evolution vs load – Panel2



Crack evolution vs load – Panel2

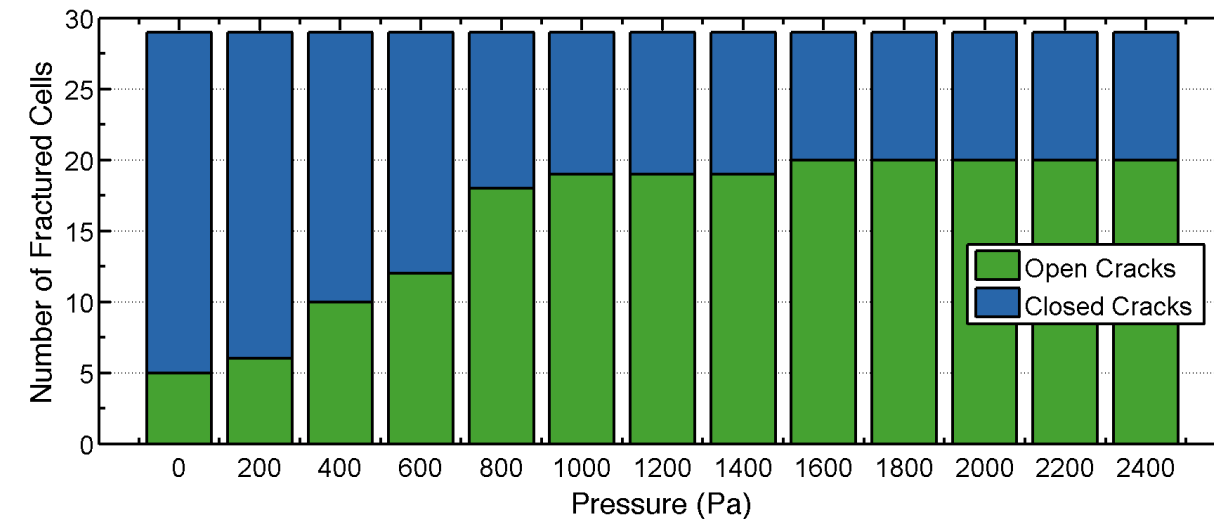
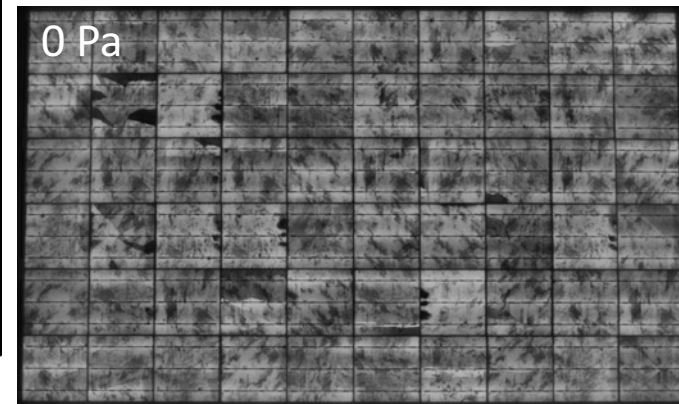
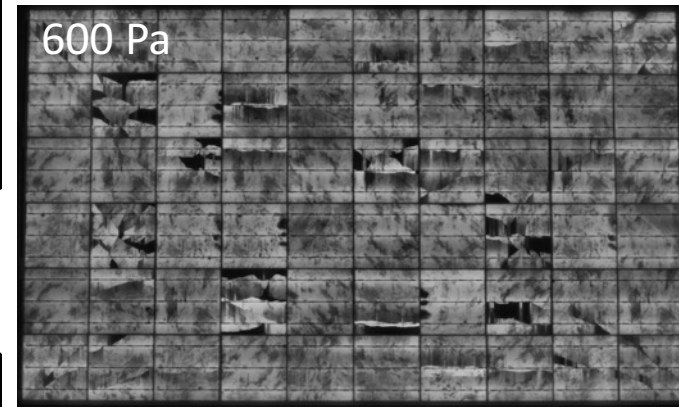


Predictive Crack Opening - PCO Test



Full perimeter frame support

- More uniform stress
- Easier to implement



Do module buyers care?

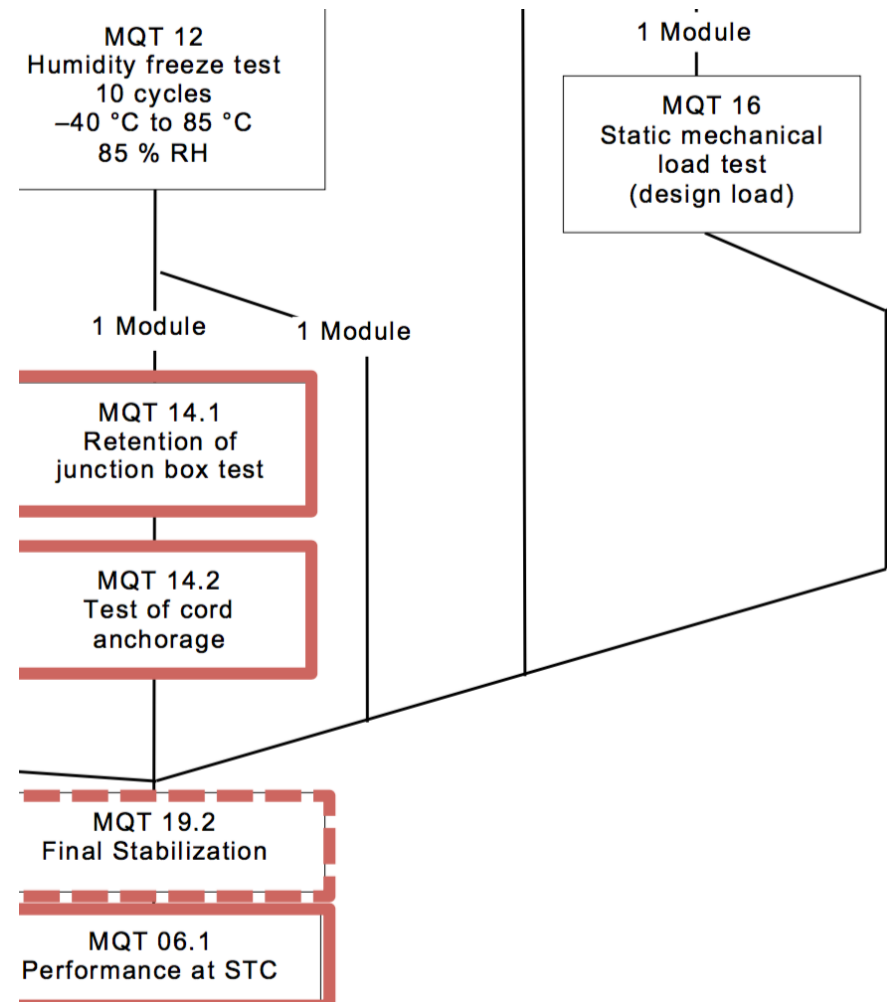
- What if you knew that modules from Vendor-A had fewer cracks at a given load than Vendor-B?
 - For similar price
 - For slightly higher price?
 - For similar weight
 - For similar warranty
 - For similar backsheet

What are the right tests?

- How best assess module durability regarding cracked cells?

Static load portion of IEC61215?

- 2400 Pa is higher than most installations will see from snow and wind
- Does backside load do anything?
- Is one hour any better than 1 second?
- Is 3 times front then back better than 1 time?
- Is it worthwhile doing this test if don't follow with "crack opening" sequence?
 - Too severe?
 - Are we afraid to do this?
- Is this test more about other failure modes?



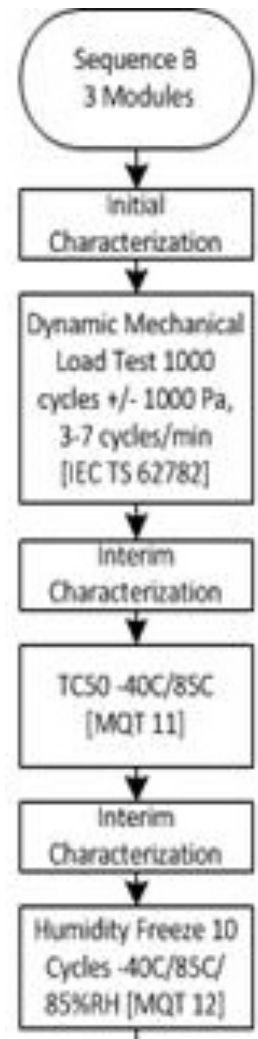
[Beck, Siva, NREL PVMRW 2016]

Cyclic Load Test IEC-TS-62782?

- Is +1000 Pa the right level for crack formation?
 - Initially mostly “closed” cracks
- Are +/-1000 Pa the right levels for crack opening?
 - Every cycle is a chance to allow the crack to become propped open (ISFH – Koentges)

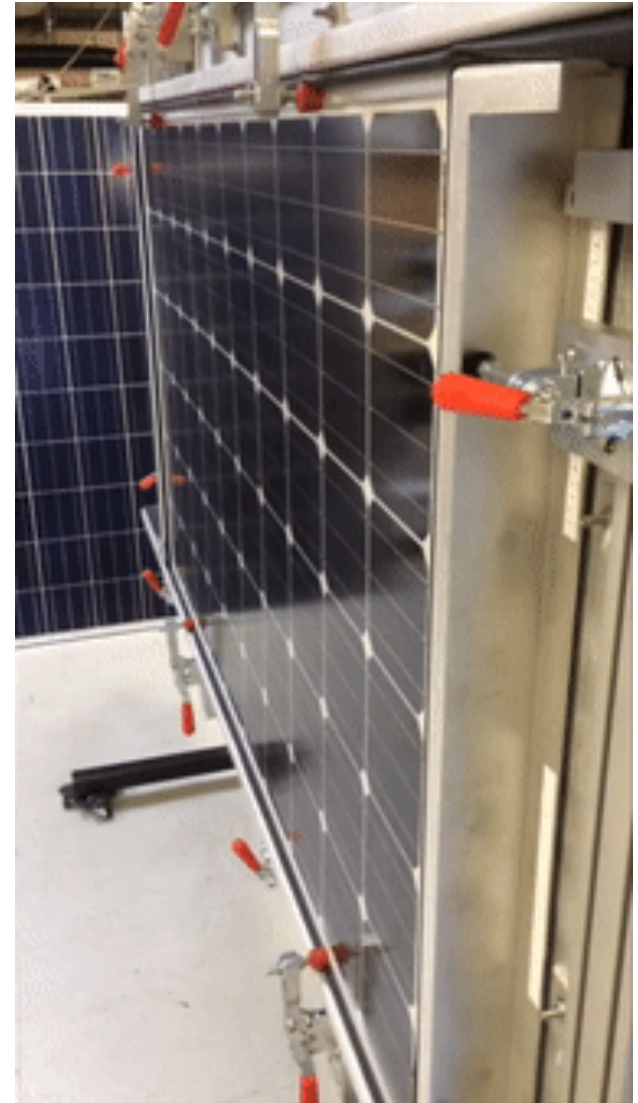
CSA Group: Exp450 Sequence B?

- Sequence (based on PVQAT)
 - 1000 cycles at +/-1000 Pa
 - 50 Thermal cycles
 - 10 Humidity-Freeze cycles
- Data?
- Mechanisms?
- > 20 days!



How use the *LoadSpot*?

- Crack formation vs load as a function of:
 - Module vendor
 - Mounting hardware
 - Mounting locations
 - Prior module history
- Predictive Crack Opening test
 - Correlate to environmental chamber degradation
- Fast cyclic loading
 - EL/IV progression



Other *LoadSpot* test ideas

- Loading at high and low temperature
- Interactions between shading and loading
- Different mounting hardware
- Different clamp positions
- Cyclic/static combinations
- **Your ideas!**



Who should use the *LoadSpot*?

- Product development and R&D groups
 - Modules
 - Efficiency/cost gains
 - Mounting hardware
- Quality control groups
- Testing and certification labs
 - Does the standard IEC static and cyclic tests
- Module buyers/investers

Test your modules at FSEC!

- Eric Schneller eschneller@fsec.ucf.edu See poster #86
- Joe Walters jwalters@fsec.ucf.edu
- Me gabor@brightspotautomation.com

