NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Experience with CPV Module Failures at NREL



2012 Reliability Workshop, Golden CO

Matthew Muller

3/1/2012

NREL/PR-5200-54838

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Outline

- NREL CPV testbed and its purpose
- Definitions for failure and performance related issues
- Hail storm failures
- Cell failures
- Seal and Adhesion failures
- Condensation and dirt performance issues
- Lens temperature performance issues

NREL CPV Testbed & Its Purpose

- Modules are monitored on a 2-axis tracker for various reasons
  - Modeling/Performance analysis
  - Aid in design improvement
  - Standards work
  - Reliability
- Modules from at least 15 manufacturers have been tested
- Wide range of module types
  - Concentration LowX to 1000X
  - Silicon and III-V cells
  - Silicone-on-glass, Fresnel, wave guide, and reflective optics
- Modules on-sun from a few weeks up to three years
- While this presentation shows failures that have occurred over 3 years, NOTE:
  - Modules often prototypes
  - Sometime pre qualification testing
  - Sometimes handmade/not production modules

Definition of “Failure” and “Performance Issue”

As represented hereafter:

“Failure” ----- *the termination of the ability of any component of the CPV module to perform its original designed function*.

For example if one cell has degraded to the point that its bypass diode has been activated this would be considered a failure.

“Performance Issue”-----*defined by a 5% or more decrease in module power that can’t be explained by irradiance variation, spectral variation, cell temperature variation, tracker alignment, module alignment, or external soiling.*

For example condensation inside the module.
Module power often drops more than 5% but after it evaporates performance returns to baseline conditions.

Hail Storm, NREL June 11, 2010 ~14:00MST

- Short hail storm hit lasting 5-15 minutes
  - Most hail stones < 2.5 cm
  - Small quantities of hail stones > 2.5 cm found on NREL's site
  - No statistical analysis in regards to hail stone size
  - Winds from the W to NW, peaked at 10 m/s
  - No damage to hundreds of flat plate modules (S facing/latitude tilt)
  - Silicone-on-glass and polymer CPV lenses failed.
  - Cracked shields on Kipp and Zonen CM11's
  - NOTE: CPV tracker facing oncoming hail due to the time of day. Hail stones likely to have 90 degree angle of incidence with CPV lenses.

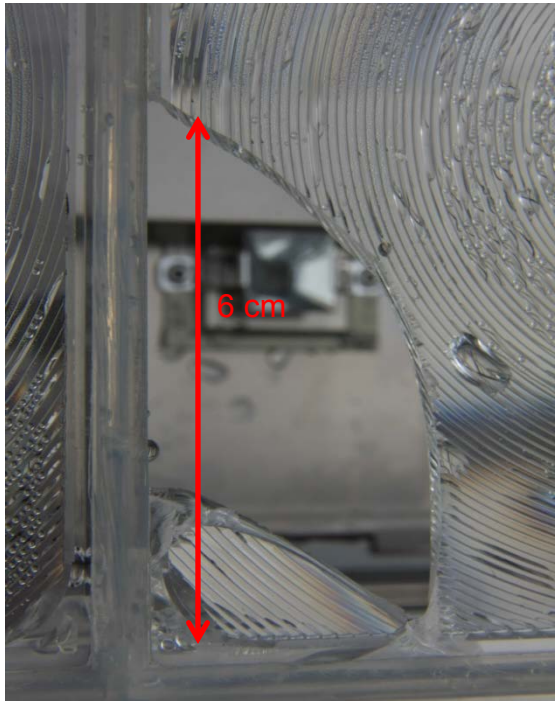


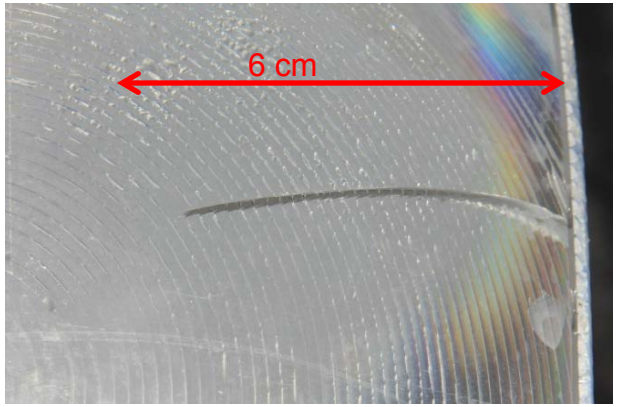


Irregular Shape

Hail Damage



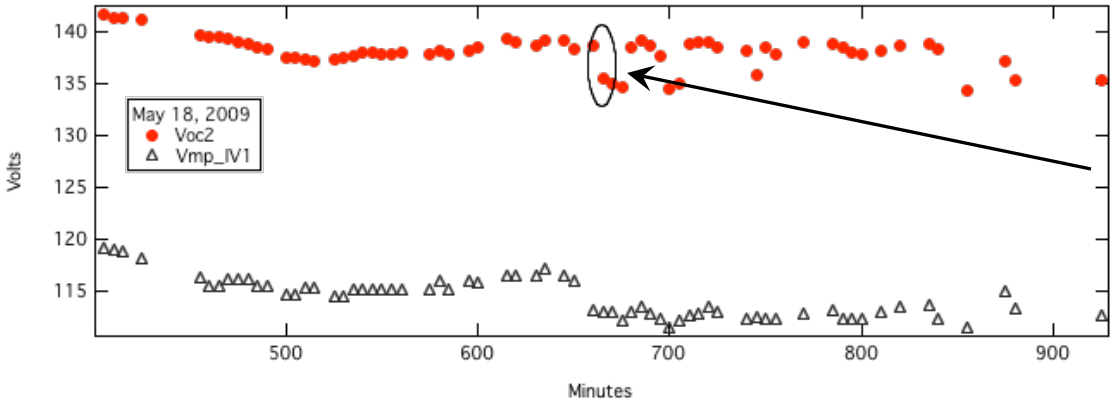




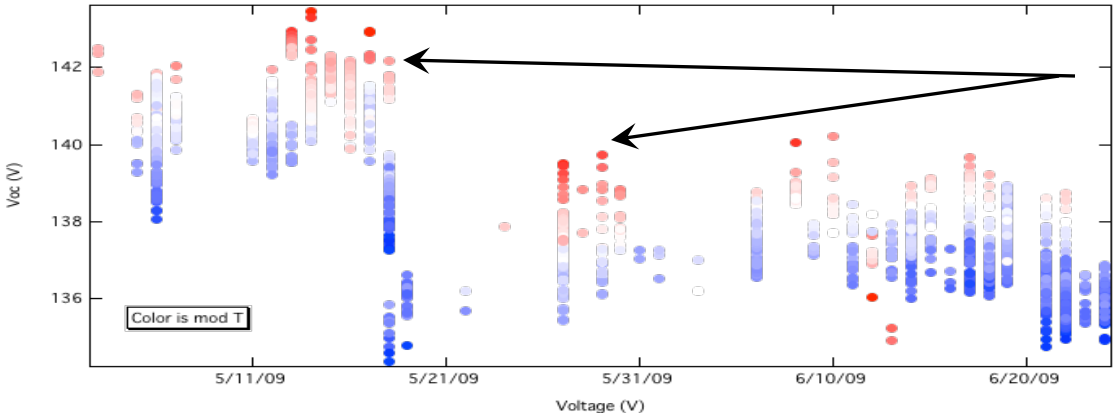


Cell Failures

- Five modules have had failures of the cell/cell package
  - In most cases, thermal runaway is the likely root cause
  - In one case the cell has appeared to tear (silicon not III-V)
  - In another case a ground fault was found associated with a solder connection



Pinpointing time of failure which appears intermittent on the first day

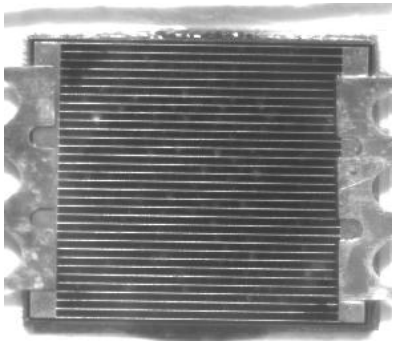


System stabilizes after May 18th

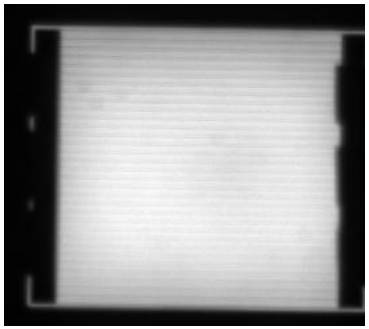
Cell Failures, Diagnostic images

Healthy Cell

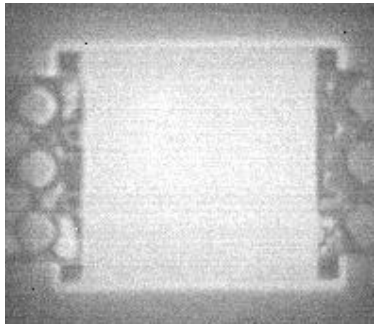
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EL

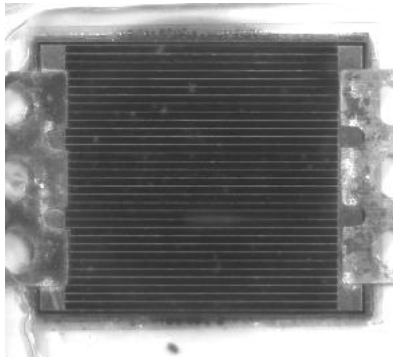


IR

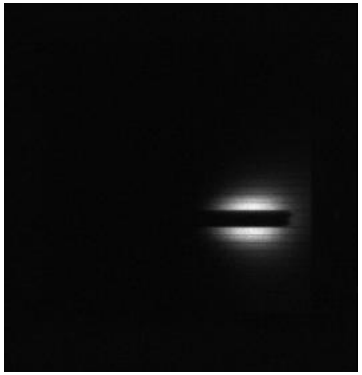


Damaged Cell, Shunted, possible grid finger failure (3 months on-sun)

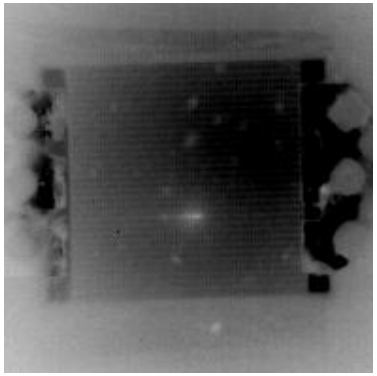
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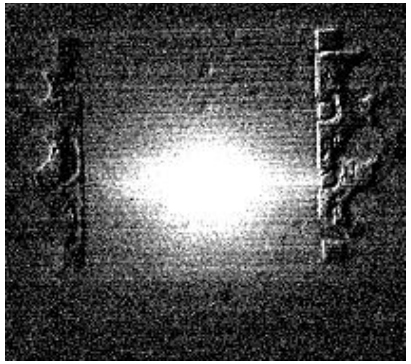
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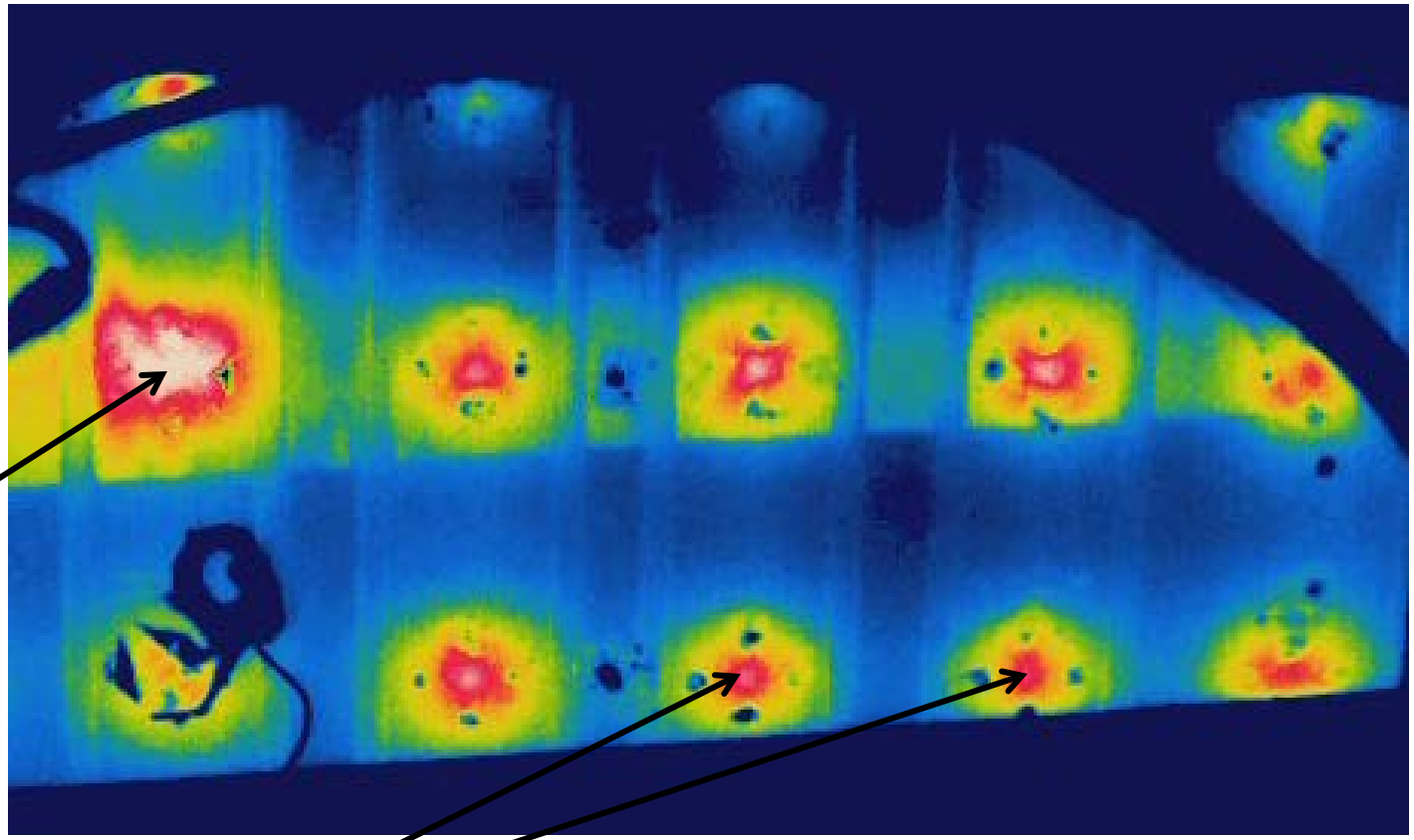


IR contrast (hot–cold)

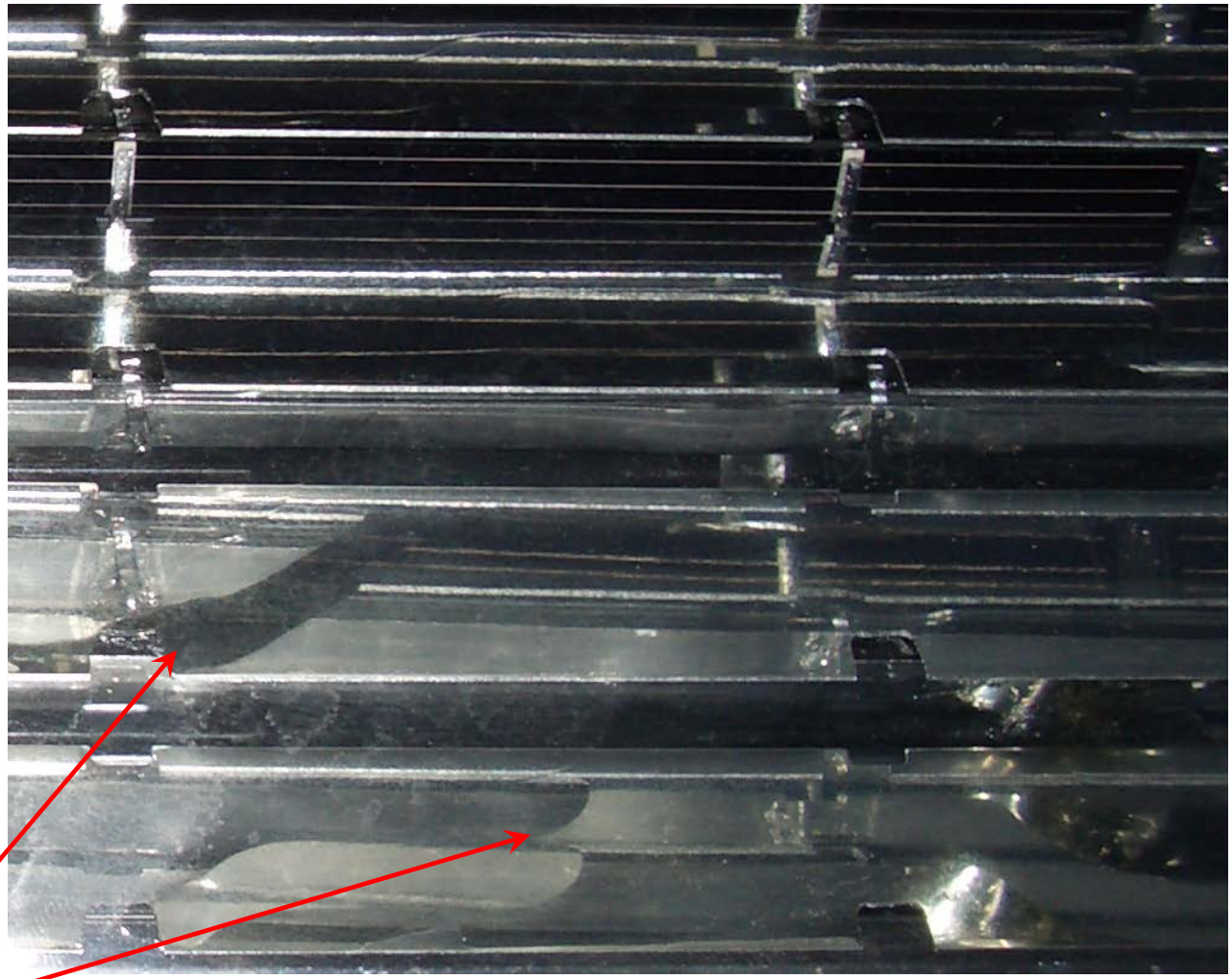


Images by Nick Bosco

Thermal Image of Cell Failure, Active Module

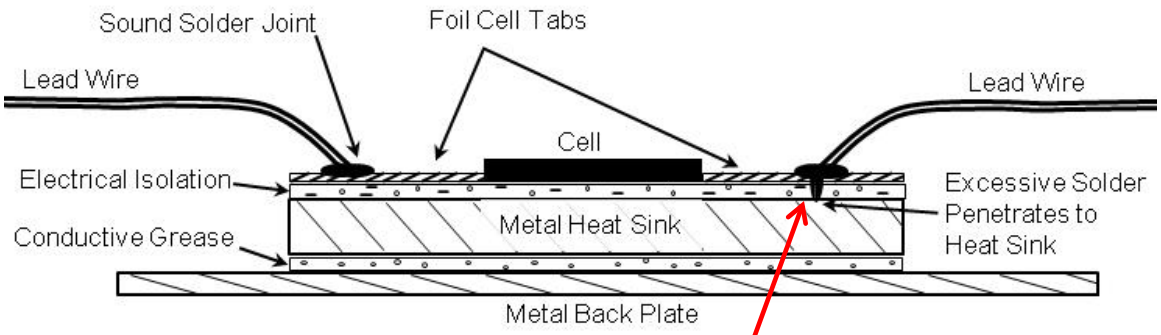


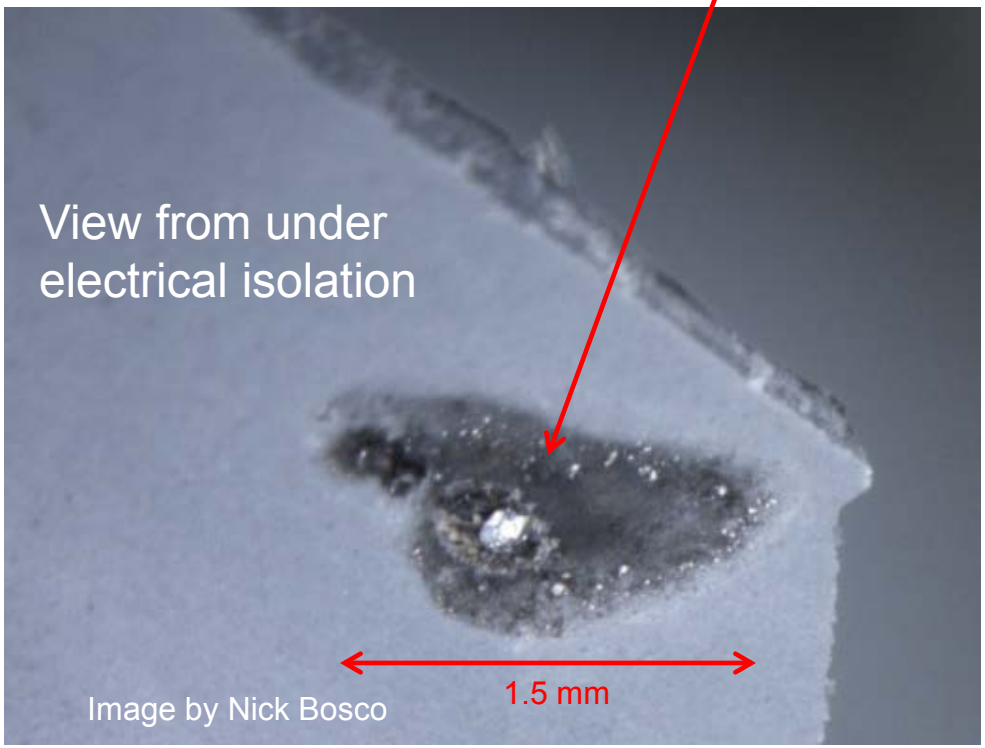
LowX Silicon Cell/Package Failure

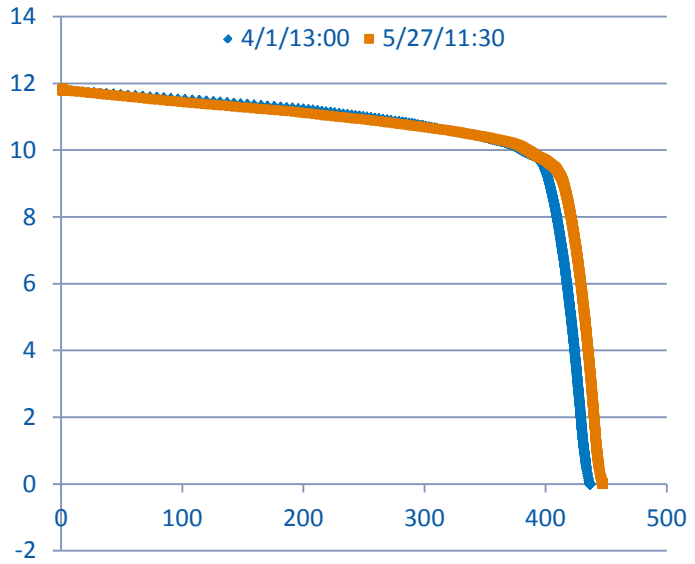


Reflector has lost adhesion to substrate, difficult to confirm but reflector and cell appear to have torn, (possibly a thermal mismatch issue)

Cell Interconnection Ground Fault



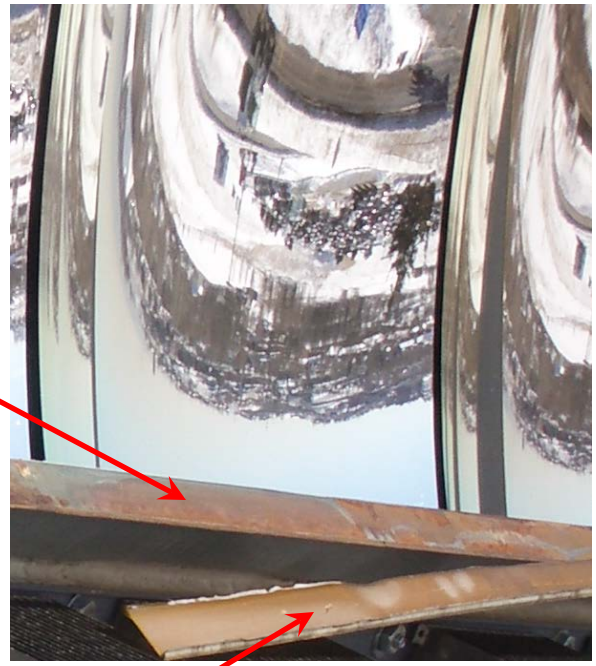




- CPV string trips inverter ground fault fuse.
- Difficult to see problem on IV curves
- Magnification shows solder has protruded through electrically insulating layers and created a grounding contact with the back metal heat sink plate.

Seal/Module Package Failures

- On a cold December day the glass cover fell off this module





Frame corrosion

Seal shows UV degradation

Glass on ground

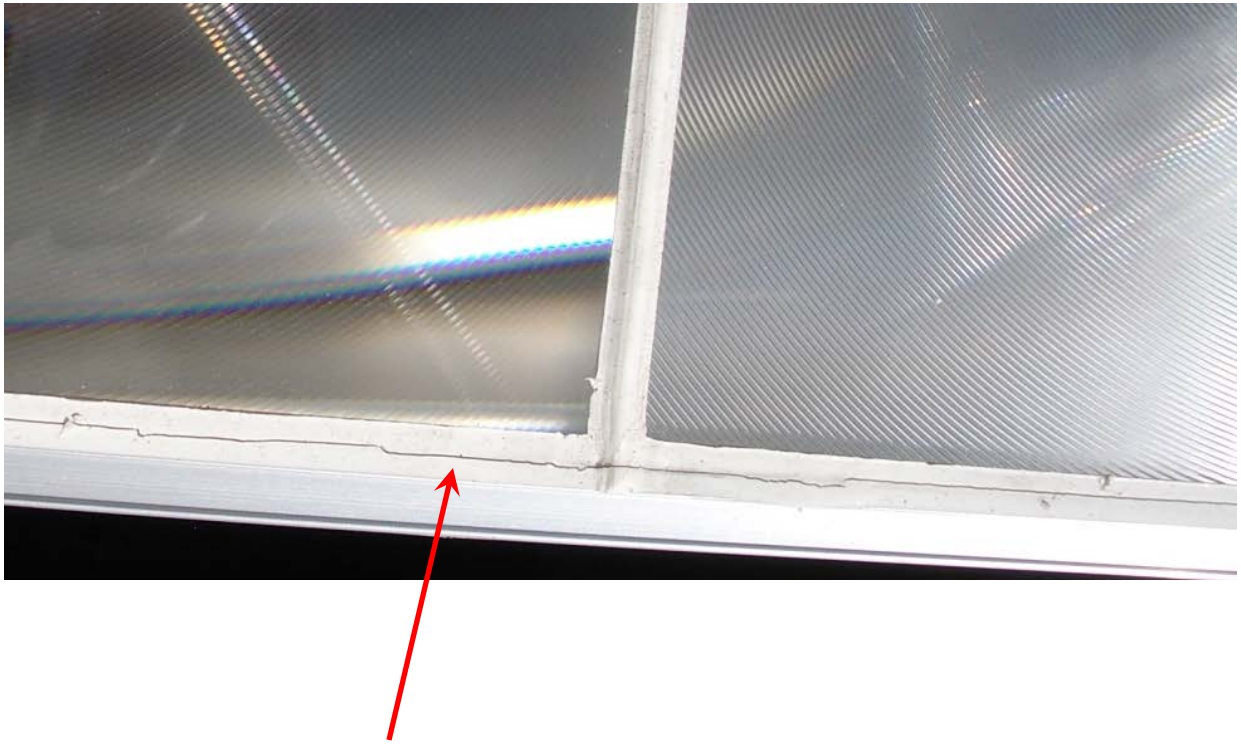
Piece of seal

Seal/Module Package Failures



Over multiple months on-sun this silicone seal lost adhesion between each lens parquet
(in the photo the silicone is being held up for clarity)

Seal/Module Package Failures



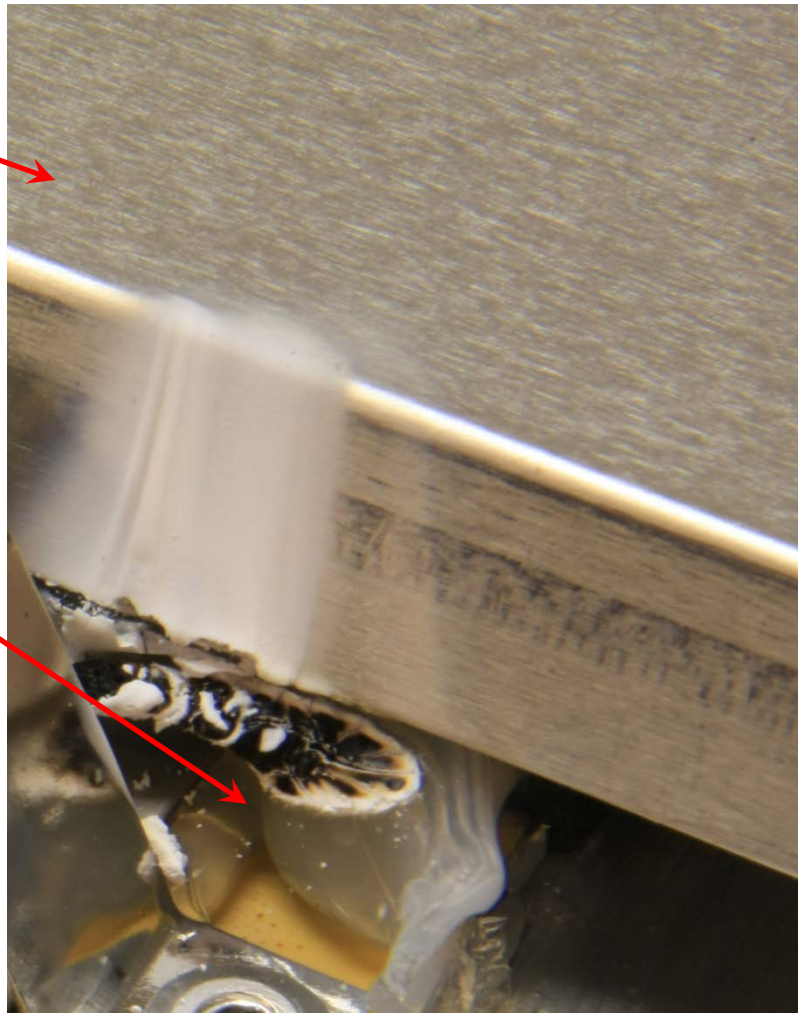
Seal has cracked between lenses and frame as a result of a mechanical impact (NREL was at fault in this case but event was similar to what might happen in transport)

Packaging Issues

Shield to protect wiring and area around cell assembly from concentrated light

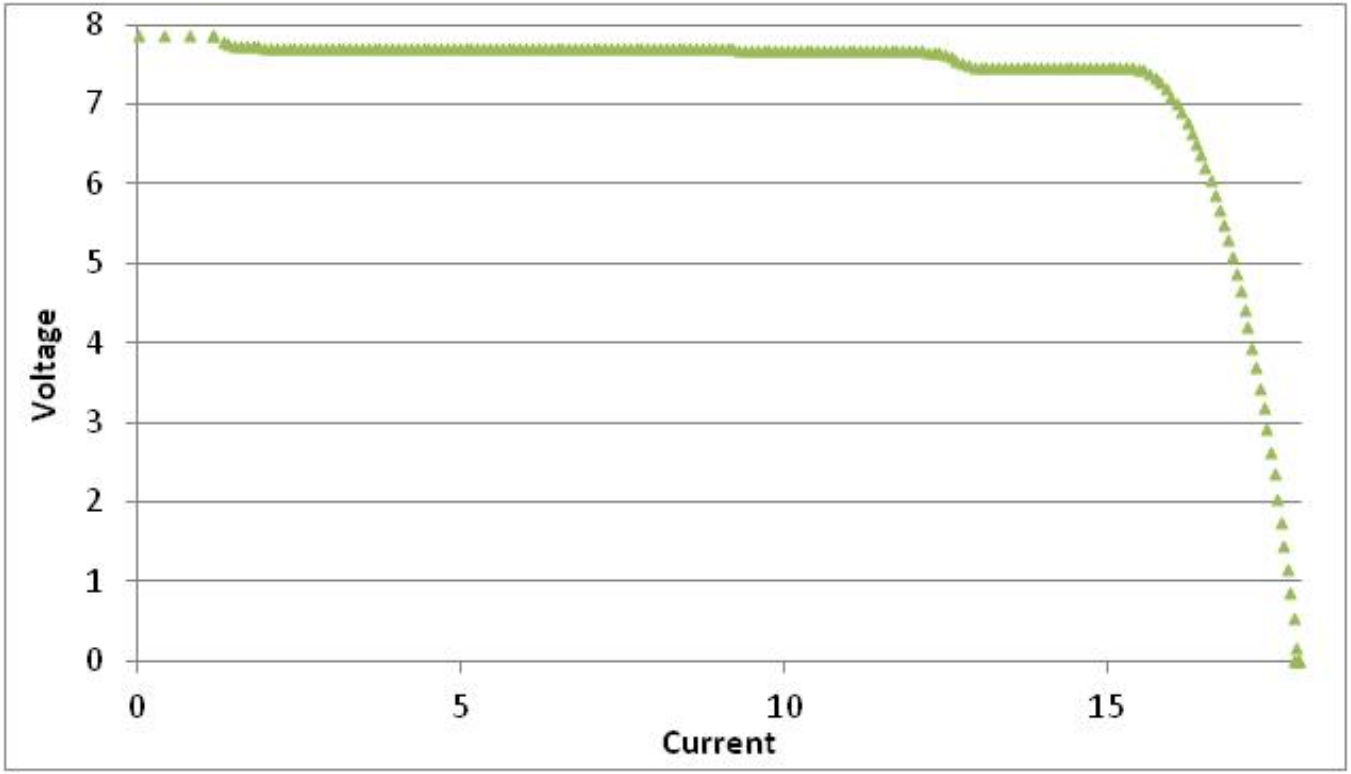
Shield not close enough to secondary optics as silicone was burned

Burn marks suggest ~ 500 °C

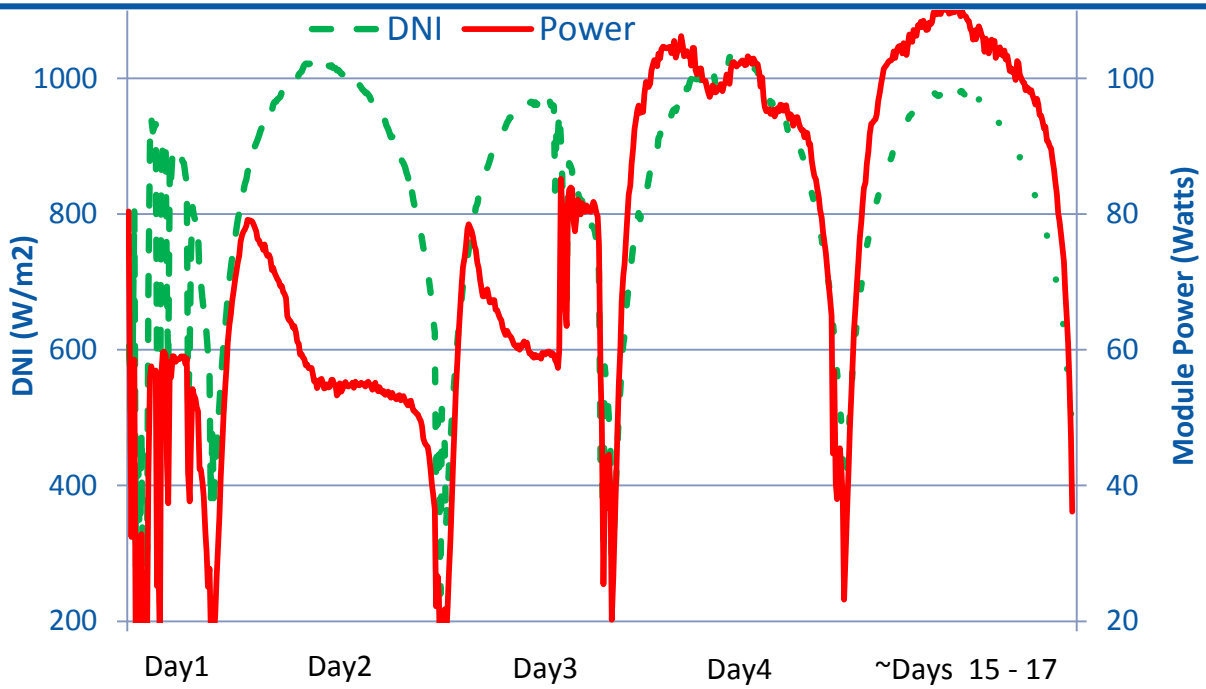


Manufacturing Issue

The steps in this IV curve are assumed to be the result of misaligned optics as the individual cells were closely matched for this module



Condensation Performance Issues



- For the 3 days before Day1 it was rainy

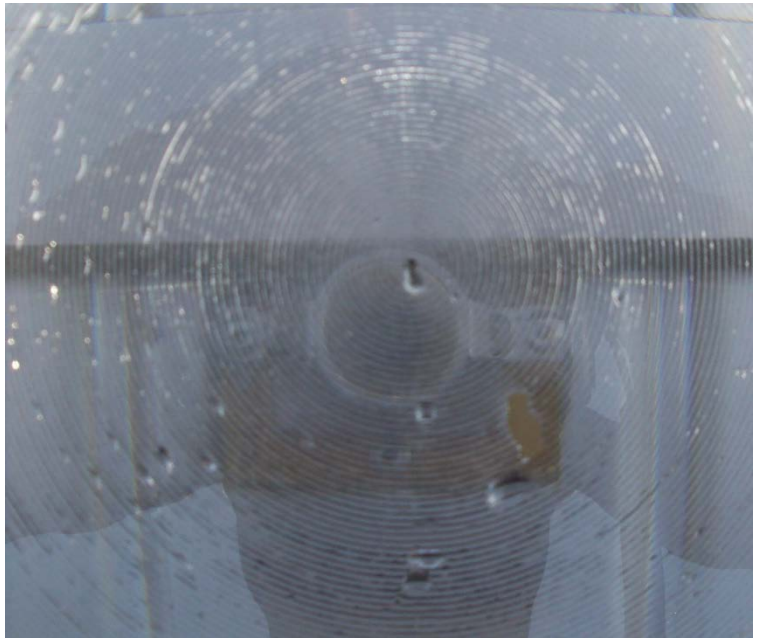
- Day1 the sun was out off and on with no rain
- Day2 it was clear skies, module power does not follow DNI
- Day3, mostly clear skies, module power does not follow DNI
- Day4, clear skies, module power mostly follows DNI
- Days 15-17 represent normal relationship between power and DNI

Condensation Performance Issues

- Many of the modules at NREL allow condensation to enter
- This is intentional in some cases and due to seal failures in other cases
- Some modules use moisture management systems
    - Dry is air is pumped through module
    - If the management system is not smart it can make the situation worse

- Modules with failed seals have allowed moisture in but then trap it inside
- Time for moisture to escape depends on system design an weather
- If a module is going to allow moisture in, difficult to model reduced performance

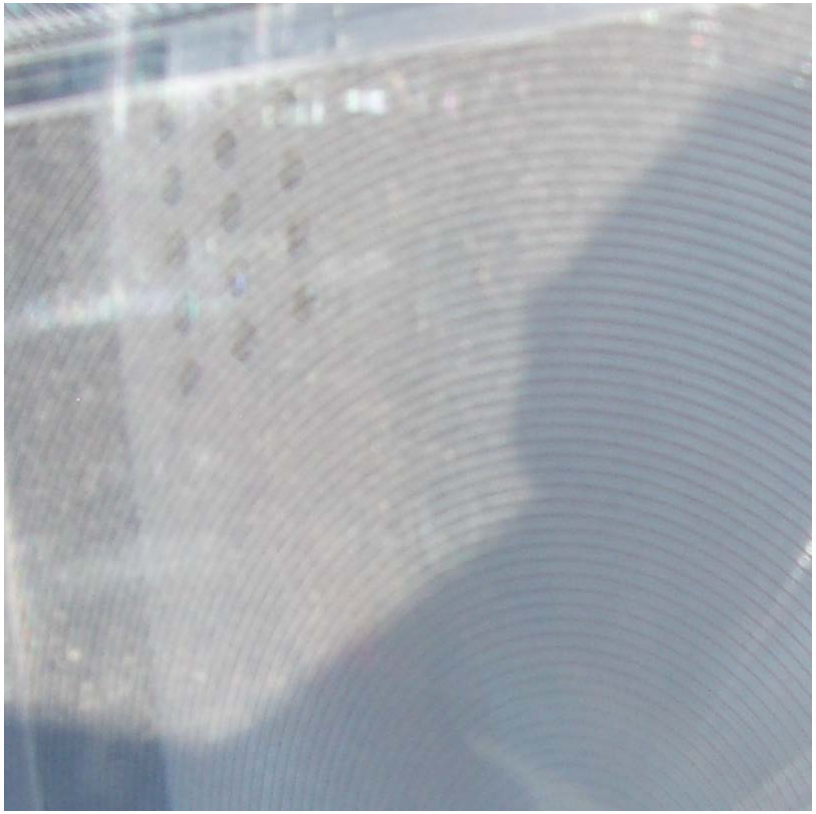




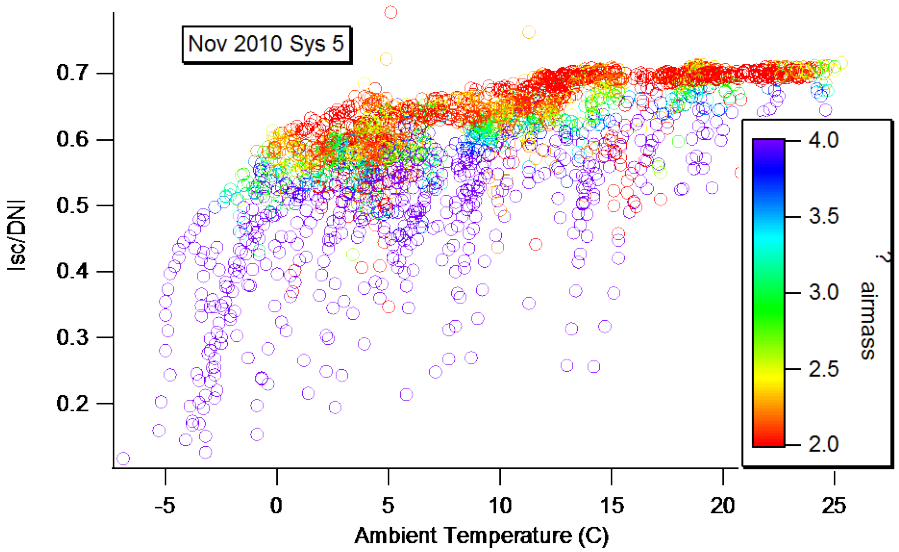
Condensation Soiling

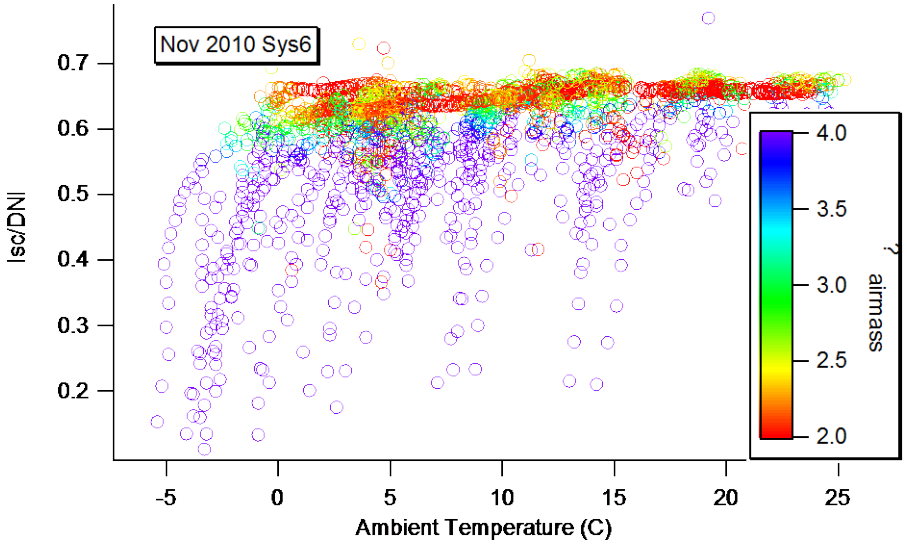
- Internal condensation has resulted in dirt build up on the back side of the lenses.
- This could be considered a failure or a degradation.
- Qualification test won't catch this problem
- CPV qualification test built from flat plate testing/no issues like this

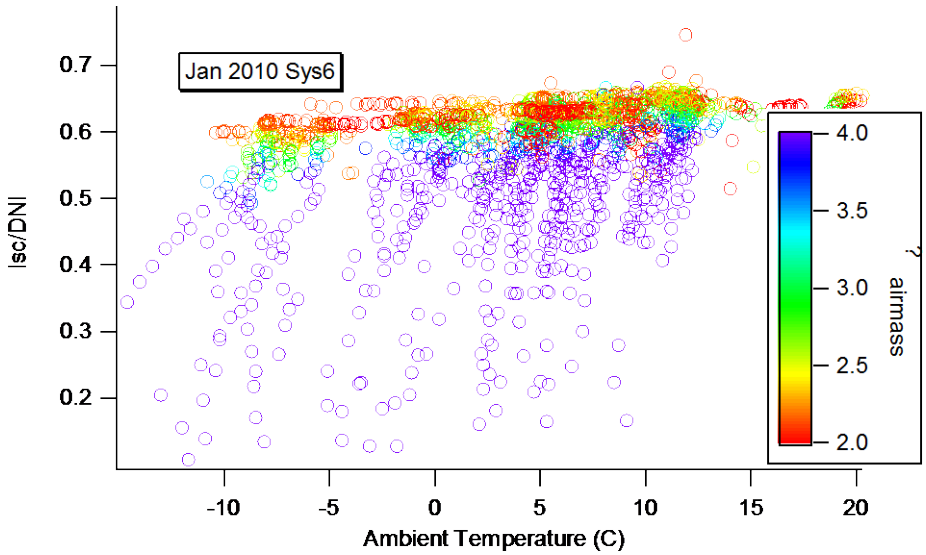




Lens Temperature Performance Issues







Summary

- A wide array of CPV module failures and performance issues have been experienced at NREL
- Many of the modules are prototypes and have not been through qualification testing
- It is assumed that the qualification test would have captured many of the problems
- Internal lens soiling due to condensation is not currently captured by the qualification test
- Lens temperature dependence can be built into modeling if CPV is to operate in cold locations

Thanks!

Questions???