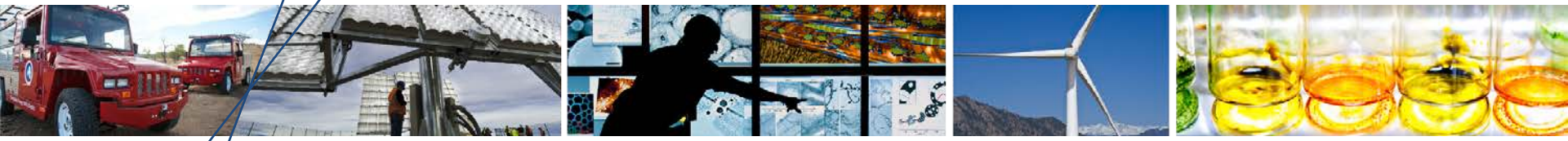
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Task Group 3:
Humidity, Temperature and Voltage



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NREL PV Module Reliability Workshop

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Introduction

- **Group 3 on Humidity, Temperature and Voltage is chartered to develop accelerated stress tests that can be used as comparative predictors of module lifetime versus stresses associated with humidity, temperature and voltage.**
- **The tools we have to utilize are:**
  - **Outdoor test results**
  - **Accelerated stress tests results**
  - **Modeling**

Where we stand today

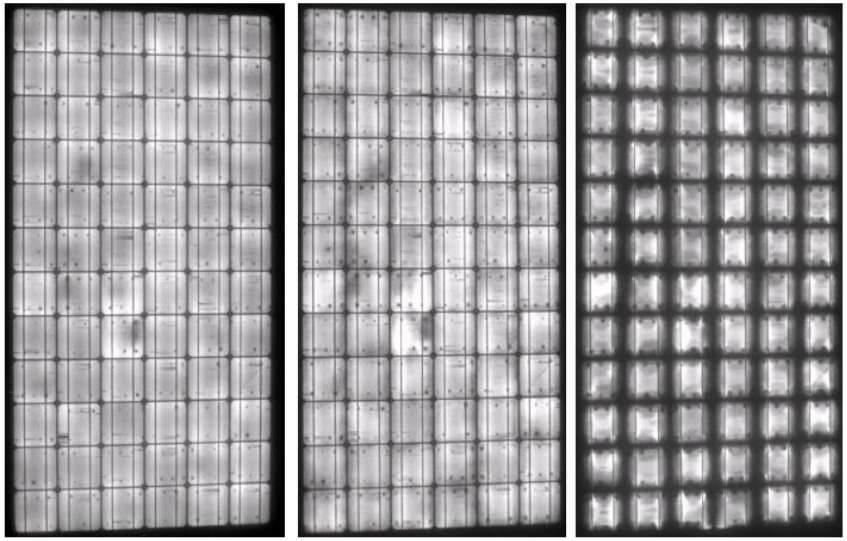
- **The module qualification test sequence IEC 61215 for cry-Si & IEC 61646 for Thin Films contain:**
  - **a 1000 damp heat test (85 °C at 85% RH) and**
  - **a humidity-freeze test (10 cycles from 85 °C at 85% RH to -40 °C) performed after a short UV exposure and 50 Thermal Cycles.**
- **These stress test appear to do an excellent job of screening out module designs and materials that would fail in the field in short time periods.**
- **So TG 3 is looking to find field failures that are not identified in the qualification test sequence, but are limiting the lifetime of PV modules.**
- **TG3 is also using modeling to better understand what the accelerated testing represents.**

Results from Long Term Field Exposure

- **Two failure modes identified**
  - **PID leading to significant power loss.**
    - **We had a whole session on this yesterday so I won't add anything except to remind you that IEC has a draft standard under development**
  - **Corrosion Associated with Delamination**
    - **Lets review what we see in the field and how we might duplicate it in the laboratory**

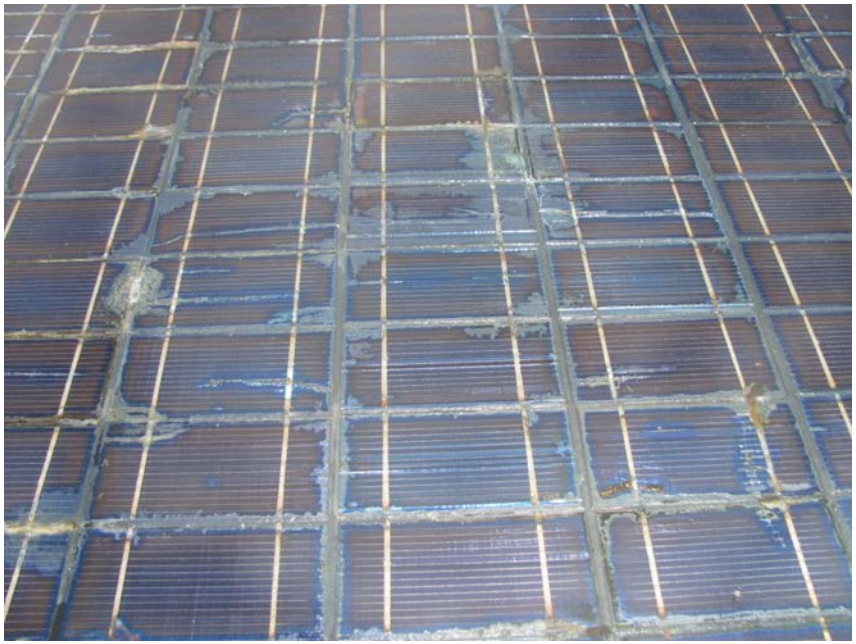
Approaches to Testing for Corrosion

Prolonged damp heat testing causes corrosion and power loss, but no visual evidence of metal corrosion. Not the same corrosion we see in the field



1000 hrs 2000 hrs 3000 hrs

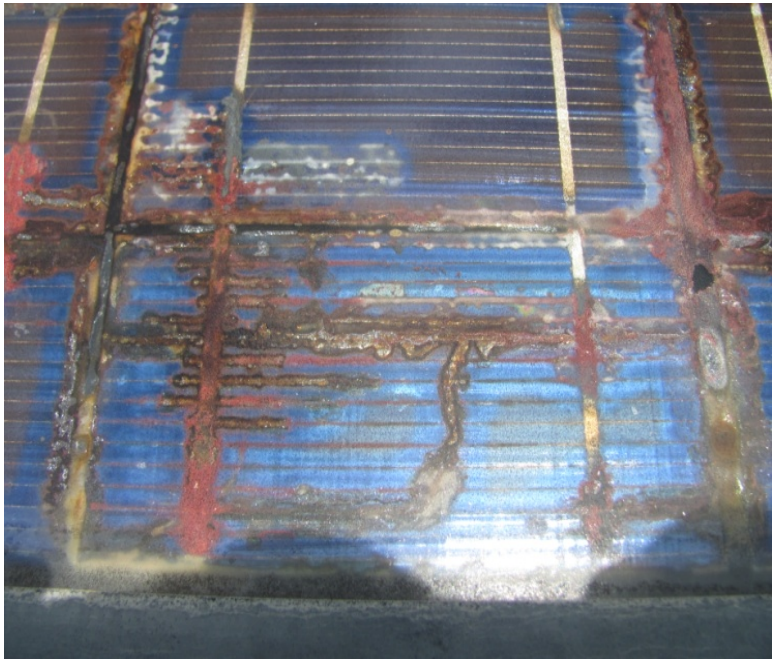
Corrosion seen in the field is associated with delamination.



Conclusion: We should move away from prolonged damp heat testing and move toward test sequences that cause delamination.

Delamination

- Delamination of encapsulant from glass or cells is a failure mode seen regularly in the field. See picture.
- Much of the evidence of corrosion comes in conjunction with delamination.
- Any of the metals (grid lines, interconnect ribbons, solder bonds) will likely corrode if exposed to liquid water.
- Delamination is not adequately evaluated in the present qualification test sequence nor is it caused by extending the time for the 85/85 test.



Corrosion of cell metallization occurring with delamination of the encapsulant. No adhesion promoter was used on the cell or in the encapsulant, but the glass was primed. This module was exposed in Florida for 23 years.

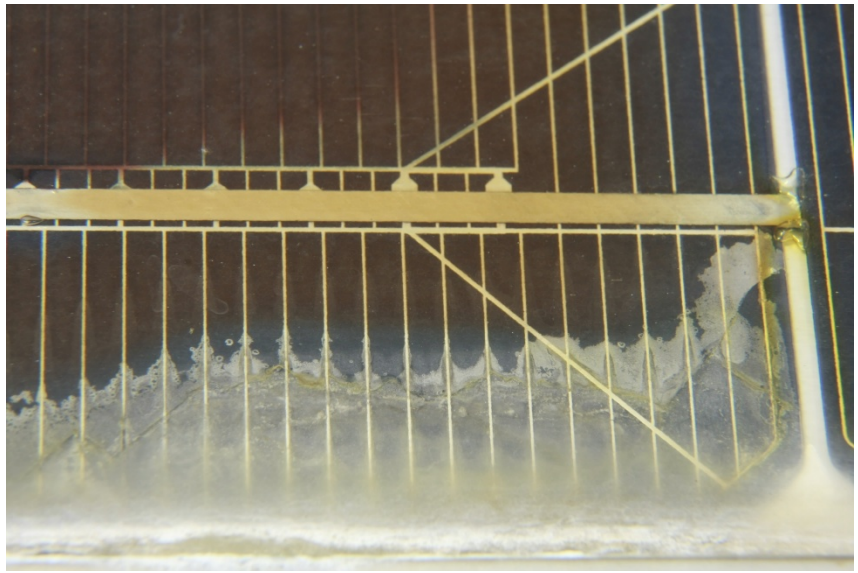
Why do Modules Suffer Delamination?

- **Manufacturing issues:**
  - **Inadequate priming**
  - **Inadequate or incorrect glass cleaning**
  - **Use of wrong glass; too much sodium**
  - **Selection of wrong encapsulation material**
  - **Inadequate processing; either lack of cross-linking or primer reaction**

Corrosion of cell metallization occurring with delamination of the encapsulant. Glass/glass module after 13 years in Tucson, AZ.

What Stresses Cause Delamination?

- UV Exposure Degrading the Adhesion
- Thermal Cycling
- Humidity Freeze
- Dynamic Mechanical Loading especially for glass/glass.
- Damp Heat especially after adhesive bonds are weakened.



Corrosion of cell metallization occurring with delamination of the encapsulant. Glass/polymer backsheet module after 27 years in California.

Status of Test Development

- **TG5 is running a large experiment to measure the change of adhesion between the encapsulant and the glass as a function of UV exposure, temperature and humidity.**
- **There is a materials task group that is looking at the best method for measuring adhesion.**
- **This may not be simple because of glass breakage. The adhesion value a glass/glass double cantilever beam wedge sample can measure is an order of magnitude less than the pristine adhesion value for EVA to glass.**

Status of Test Development (cont)

- **The qualification test already has a sequence of UV/TC/HF. (Probably why we don't see delamination occurring rapidly in qualified designs.)**
  - **UV irradiation can break the adhesive bonds formed between the encapsulant and glass or encapsulant and cells.**
  - **Thermal cycling puts mechanical stress on the interfaces because of different thermal expansion coefficients.**
  - **Humidity freeze pumps moisture into the package.**
  - **During the cold part of the cycle the moisture in any voids that have formed at the interface will condense as liquid water and then freeze.**
  - **This rips apart any weakened interfaces.**
- **WG2 has a draft standard for Dynamic Mechanical Loading (DML) with a plan to propose a UV/DML/TC/HF sequence. DML will add additional mechanical stress on the interfaces especially for glass/glass constructions.**
- **Hopefully the TG5 experiment will provide data on the appropriate UV exposure to improve the sequence for incorporation into the Comparative Testing Standard.**
- **Both NREL and JRC are planning experiments with sequential tests to validate their ability to duplicate the observed field failures.**

Conclusions

- **TG3 is looking for a combined set of accelerated stresses that can lead to delamination. Likely using the UV/DML/TC/HF sequence (with improved test levels especially for UV) followed by an appropriate damp heat exposure.**
- **TG3 is continuing to investigate field failures and is looking to:**
  - **Inspect older arrays (>10 years), especially those exposed in hot/humid environments.**
  - **Determine the correlation between visual corrosion (with or without delamination) and power loss due to lower fill factor.**
  - **Use failure analysis to identify failure mechanisms and then try to duplicate them using sequences of accelerated stress tests.**
- **The goal of this effort is to develop comparative tests for moisture driven failure modes in PV modules.**