Progress and Strategies for Testing of Materials for Solar Panels

Sarah Kurtz (NREL)

Photovoltaic Polymer International Conference

Shanghai, China

April 16, 2017

NREL/PR-5F00-68417

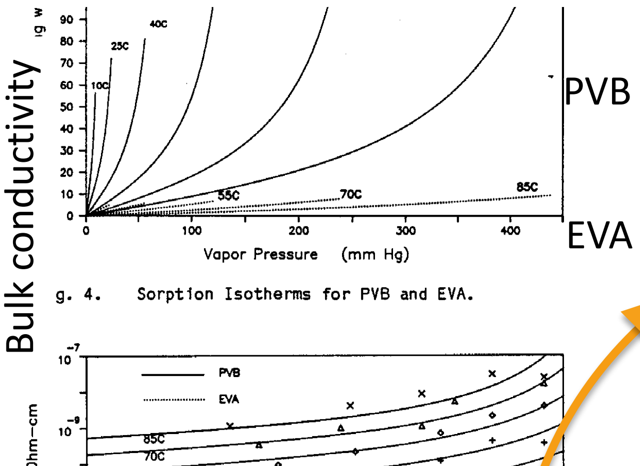
Outline

- **Historical studies related to PV materials**
- **Primary challenge – test times motivate high acceleration factors that give incorrect result**
- **Where do we stand? Some recent results:**
  - Discoloration of encapsulant materials
  - Delamination
- **Strategies for addressing primary challenge**

Historical studies related to PV materials

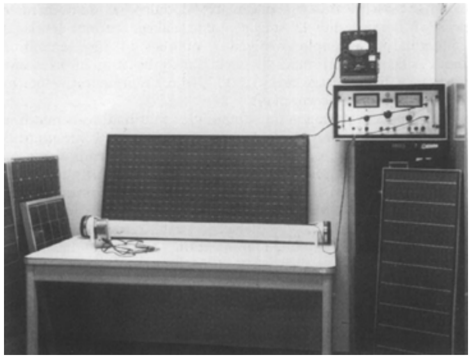
JPL development of module tests

Jet Propulsion Laboratory executed a series of "block buys"



PVB Modules corroded

19th EEIC 1989 p. 324



Solar Cells, 28 (1990) p. 103

Define tests

Design modules to pass tests

Deploy modules

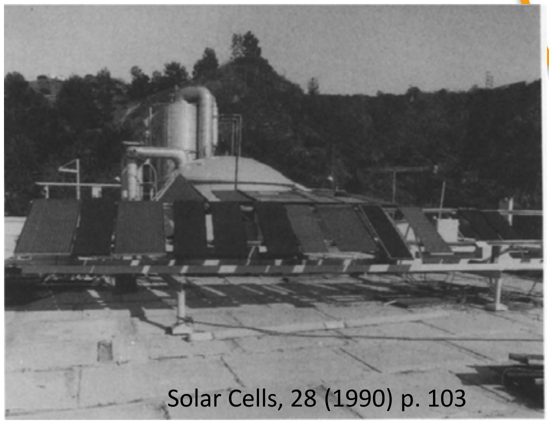
Identify failures

:rings ..e the rule, both for array reliability
nd, in ..ost cases, to avoid string lengths that
:cessi..ate bypass diodes at substring intervals
› pre..nt back-bias caused hot-spot failures.

..he data in Table 3, Module Electrical Perfor-
an.., was measured on a single sample of each
..le. Power values are high, ranging from 71 to
.. watts. Current values range up to 23.8 A,
esulting from the large number of parallel cells.
ne efficiencies are almost uniformly good, the
ibbon module being lowest. The efficiency values
or the Solarex modules and cells are particularly
oteworthy because they represent an increase in
ncapsulated cell efficiency and module cell
fficiency at 25°C from about 8% and 10%,
espectively, 2 1/2 years ago, to approximately
)% and 12% today (In clarification of the module

JPL Document No.	Application	Date Issued
5-342	Block I	June 1975
5-342-1, Rev. B	Block II	December 1976
5-342-1, Rev. C	Block III	May 1977
5101-16, Rev. A	Block IV Intermed. Load	November 1978

18th PVSC 1985 p.1150



Solar Cells, 28 (1990) p. 103

JPL Block Buys led to dramatic improvement

One study claimed (Whipple, 1993):

Pre-Block V:	→	Block V:
45% module failure rate	→	**<0.1%** module failure rate

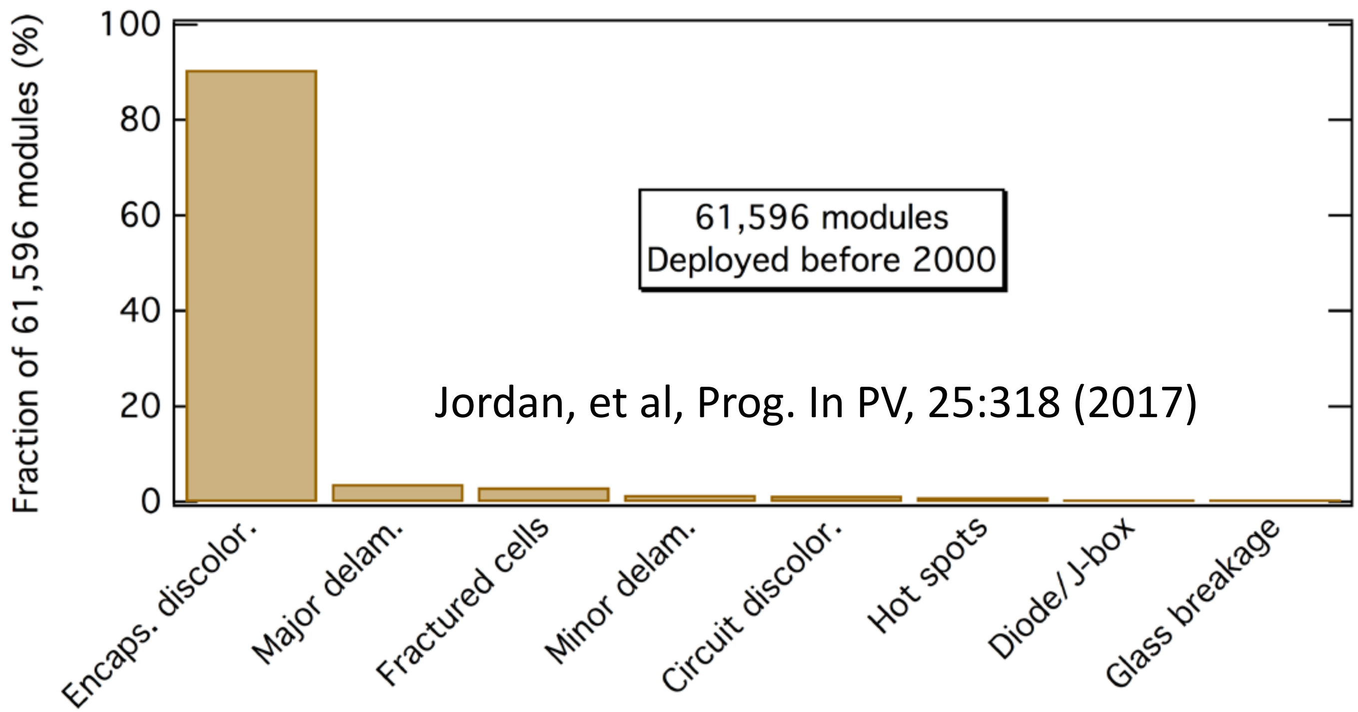
What was added in Block V?

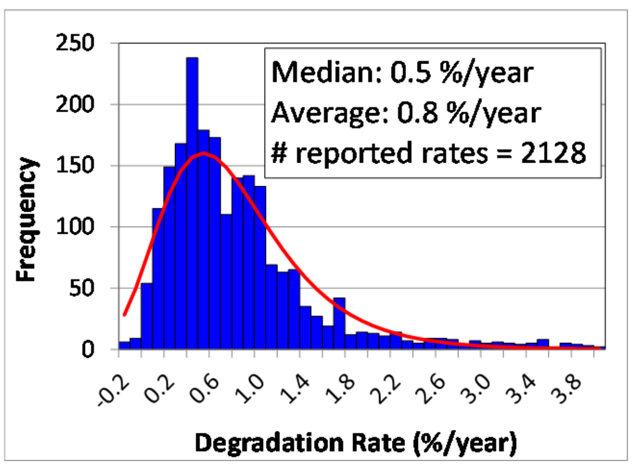
What were the tests that fixed the problems?

There were 3 primary changes for Block V that motivated module redesigns

Test	Block I	Block II	Block III	Block IV	Block V
Thermal Cycles	100 -40 to +90C	50 -40 to +90C	50 -40 to +90C	50 -40 to +90C	200 -40 to + 90C
Humidity (humidity/freeze)	70C,90% 68 hrs	5 cycles 40 C, 90%RH to -23 C	5 cycles 40 C, 90%RH to -23 C	5 cycles 54C, 90%RH to -23 C	10 cycles 85C, 85%RH to -40C
Hot Spot (intrusive)					3 cells 100 hrs
Mechanical Load		100 cycles ± 2400 Pa	100 cycles ± 2400 Pa	10000 ± 2400 Pa	10000 ± 2400 Pa
Hail				9 impacts ¾" –45 mph	10 impacts 1" – 52 mph
High Pot		<15 μA 1500 V	< 50 μA 1500 V	< 50 μA 1500 V	< 50 μA 2*Vs+1000

Discoloration has been common



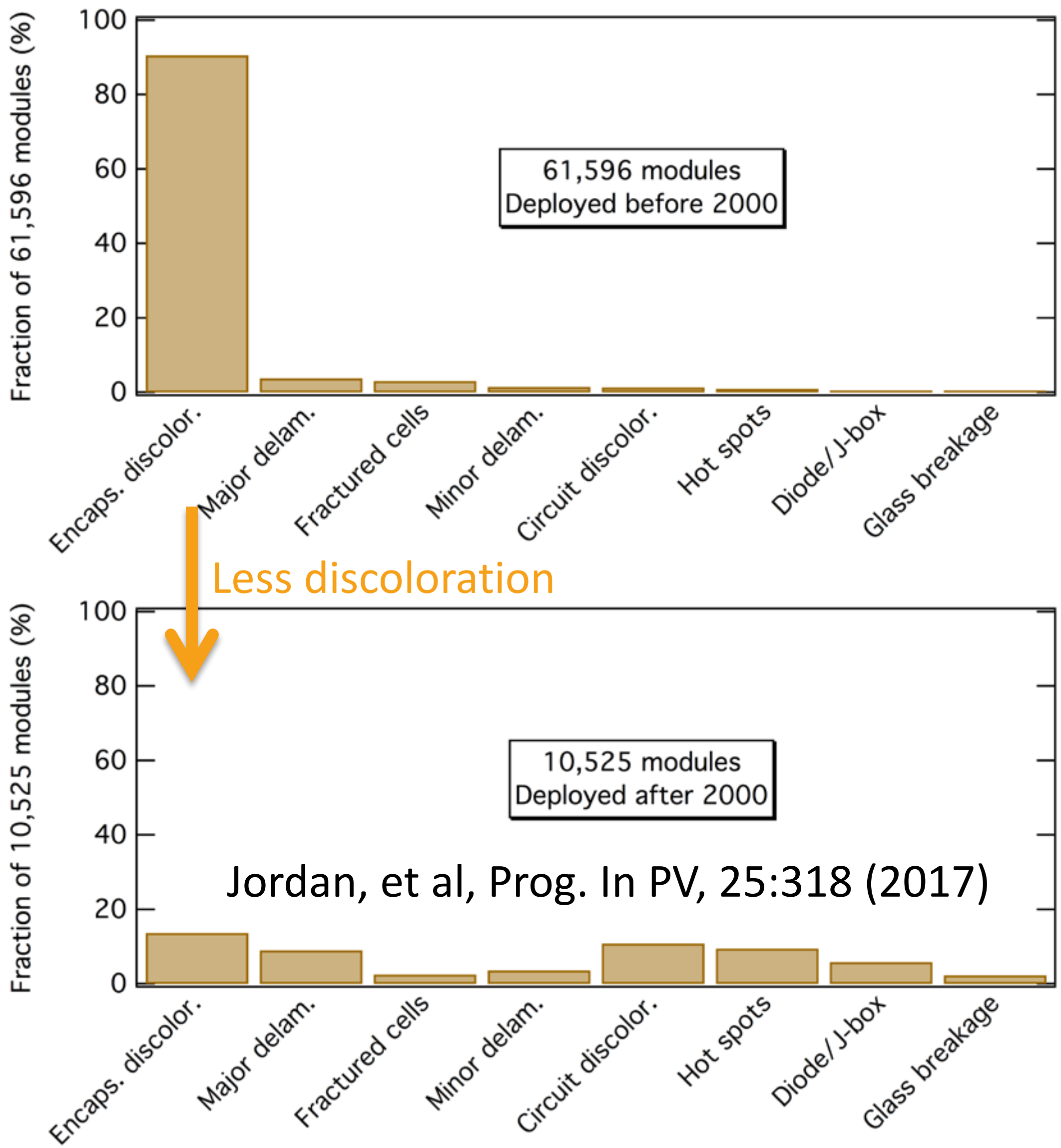


Literature survey shows primarily

- Observation: Discoloration
- Performance: Decrease in Isc (more than FF or Voc)

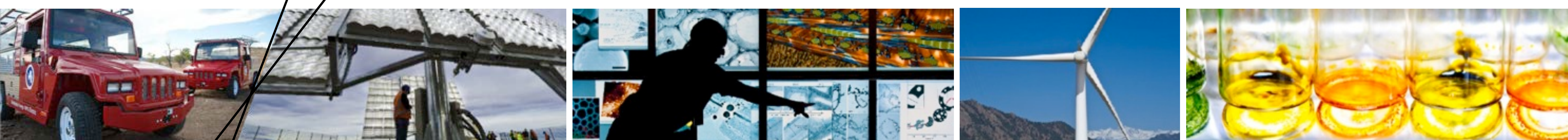
Discoloration apparently caused decrease in Isc and in many cases is the primary cause of degradation!

Discoloration has decreased



Modules deployed after 2000 show much less discoloration

Other problems have been reported more frequently

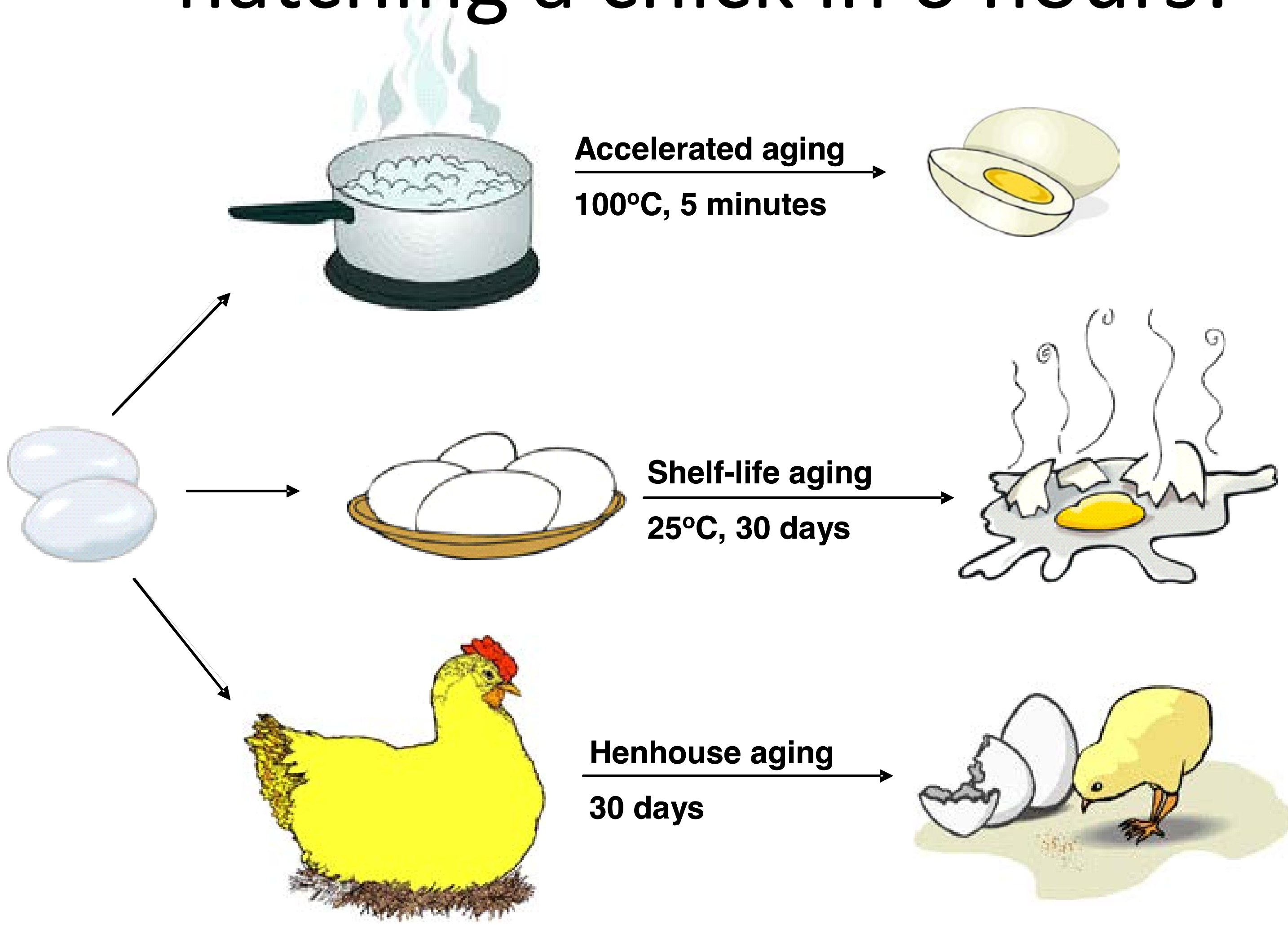


Primary Challenge – Long test times motivate high stress and the “wrong” result

Some failure mechanisms are easy to test

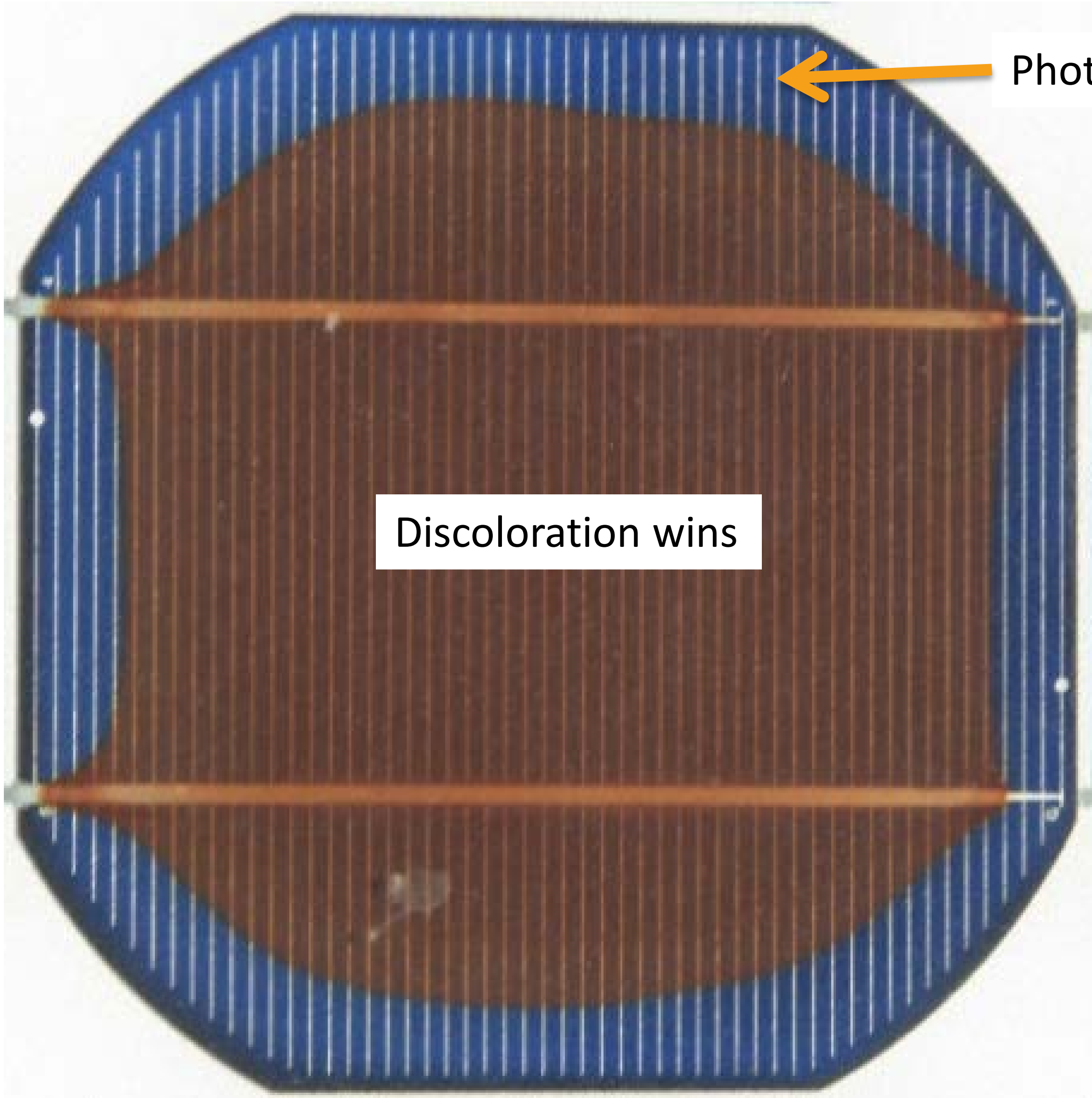
Ford Transit Custom Cargo Van sliding door slam test can test a lifetime of slams in ~ a day

Accelerating 25 y into 3 months is like hatching a chick in 6 hours!



Some processes cannot be accelerated quantitatively > 10X

Competing processes are hard to test



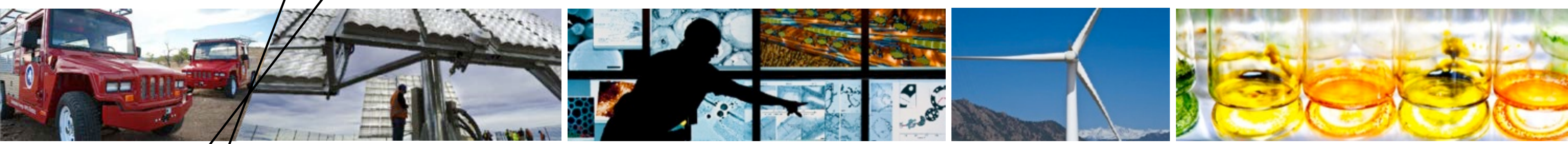
Competing reactions:

Discoloration vs Photobleaching

Kinetics include *diffusion* of reactants & reaction products as well as *chromophore formation* and *photobleaching*

Acceleration factors may vary for these. Will the accelerated test results reflect the result in the center, the result around the edge, or both?

Harshest operating conditions have best chance of being "right"



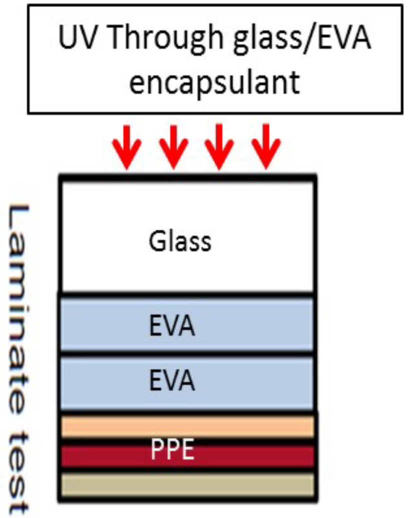
Recent advances;

Where do we stand?

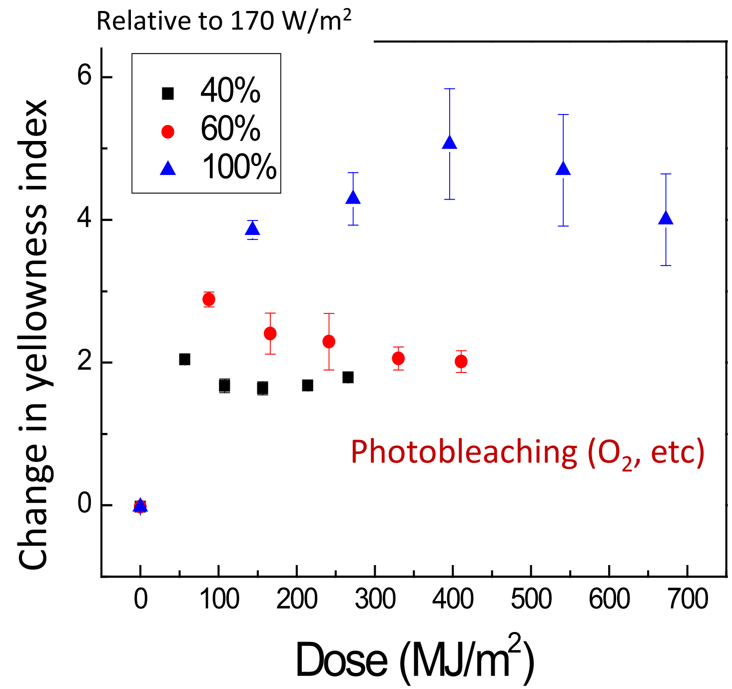
- Discoloration
- Delamination

Which result is "right"?

Glass/EVA/PPE system
UV/85°C/dry
NIST SPHERE



- Yellowness index increase depends on the conditions. These are reaching different final states: the hard-boiled egg *vs* the chick.

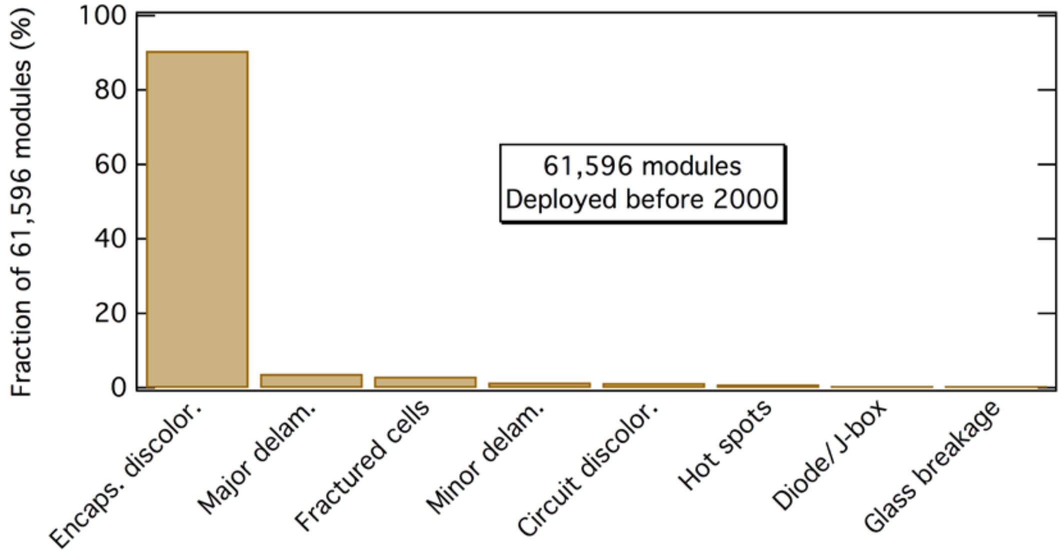


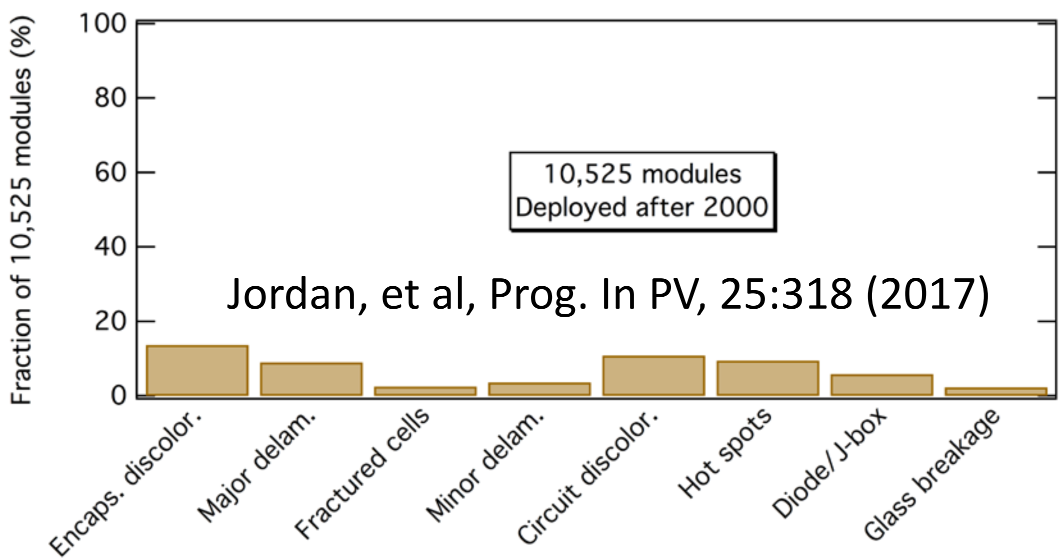
- **Varying light intensity with 40, 60, 80, and 100 % of ND filters (300-400 nm)** → 68, 102, 136, 170 W/m^2, specifically through filters on specimens

The results of application of UV, heat, and moisture can vary, *which is the "right" answer?*
Highly accelerated tests are best for screening.

Xiahong Gu, One of several datasets presented at PV Reliability Workshop 2017.
International PV Quality Assurance Task Force (PVQAT) is studying hundreds of samples
www.pvqat.org

Discoloration has decreased

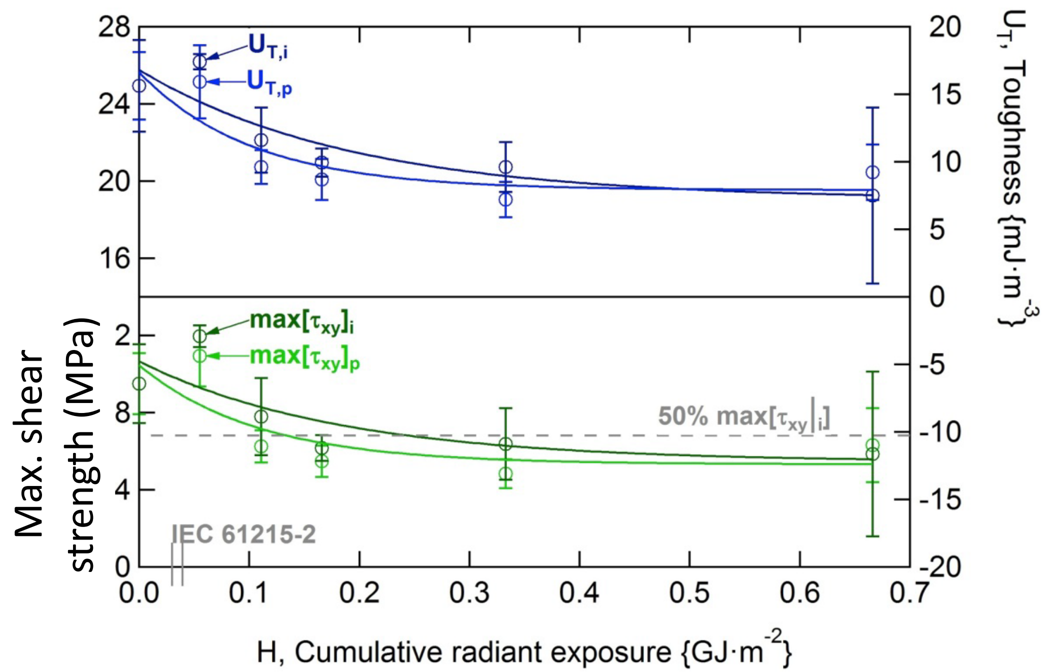


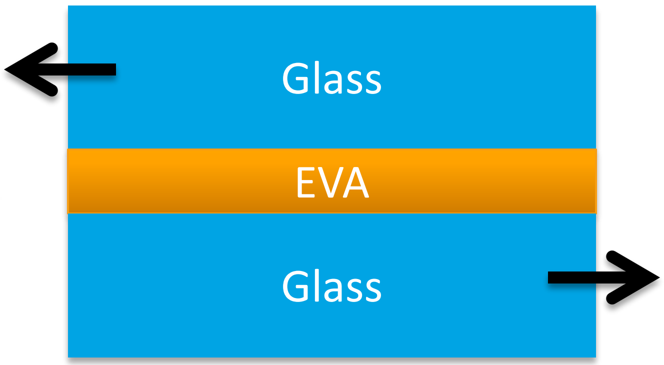


Modules deployed after 2000 show much less discoloration

But long-term testing is ***still*** *required for every new formulation or problems could recur!*

UV-exposure reduces shear strength



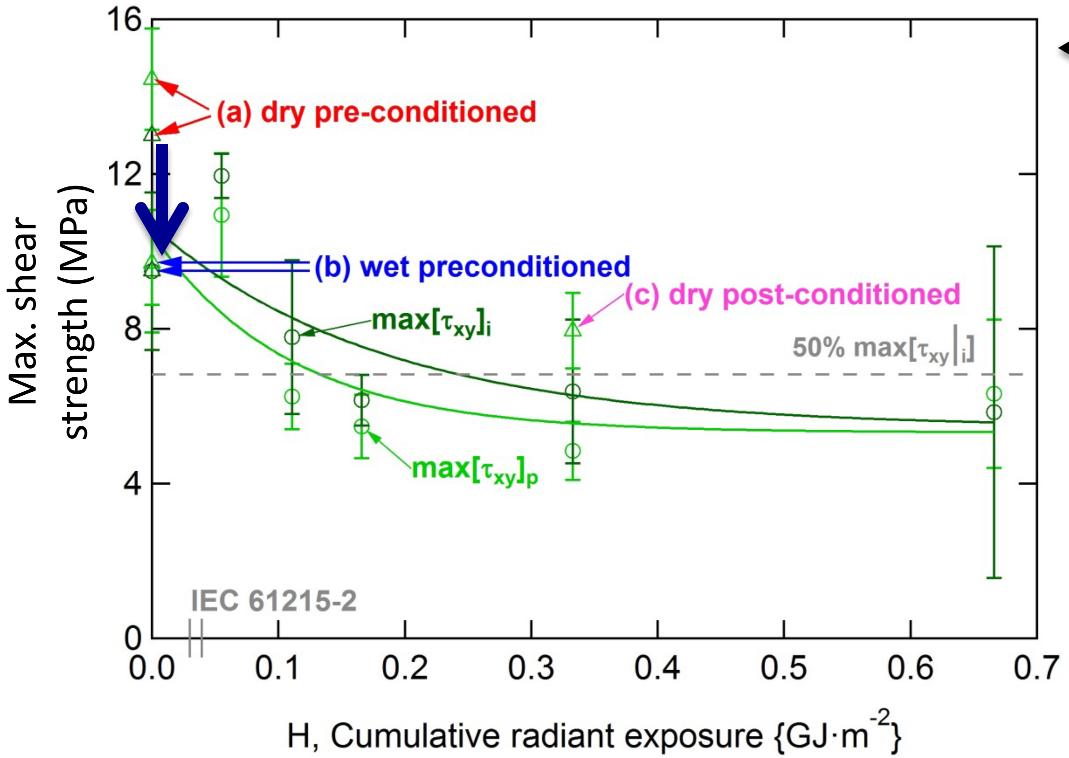


Study of encapsulant attachment as a function of weathering shows asymptotic behavior

Perhaps this is good news

Miller, et al, PVSC 2016

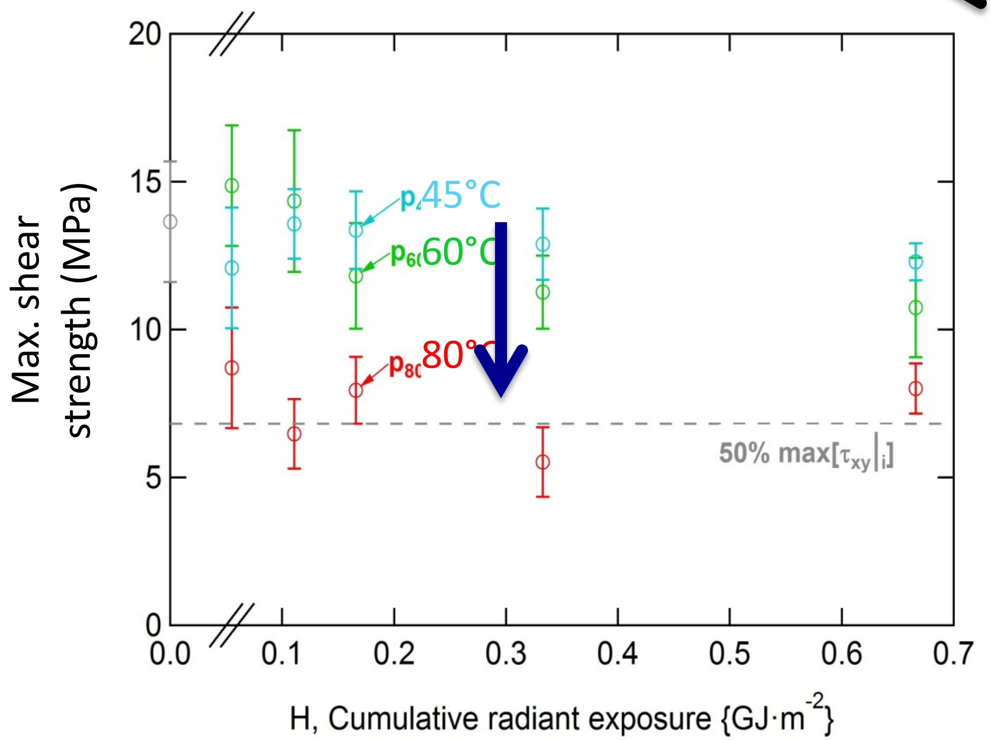
Moisture decreases shear strength

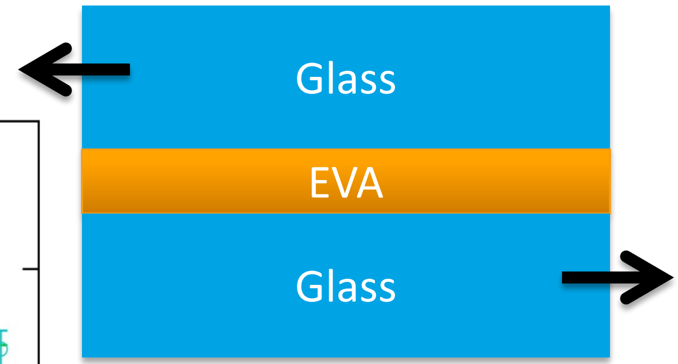


Wet preconditioning reduces shear strength

Miller, et al, PVSC 2016

Higher temperature reduces shear strength



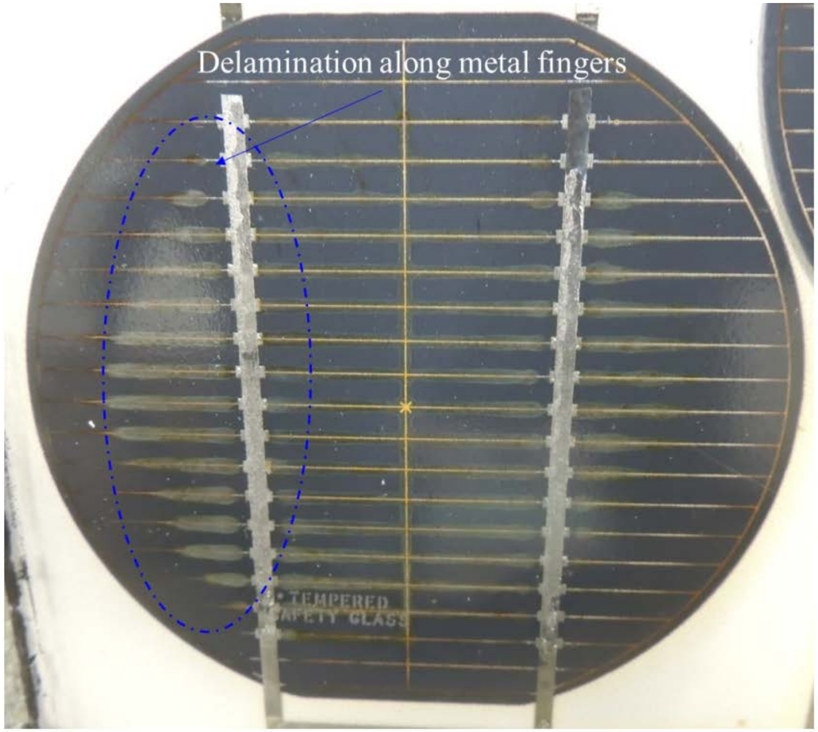


Higher temperature reduces shear strength

Conclusion: *UV exposure*, coupled with *higher humidity and temperature,* decreases strength of encapsulant bonding. However, the cohesive failure is not always seen.

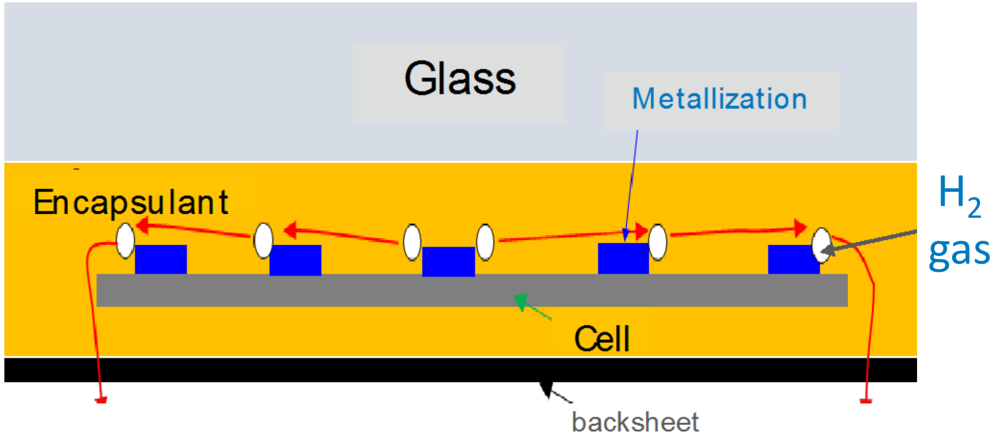
Delamination may occur at encapsulant-cell or encapsulant-glass interface!

Leakage-current-induces delamination and corrosion



PVB-based encapsulant Arco Solar (16-2300) built and deployed around early 80s, from NREL warehouse.

Delamination may occur at cell interface!



Delamination along grid lines may be induced by damp heat with voltage bias

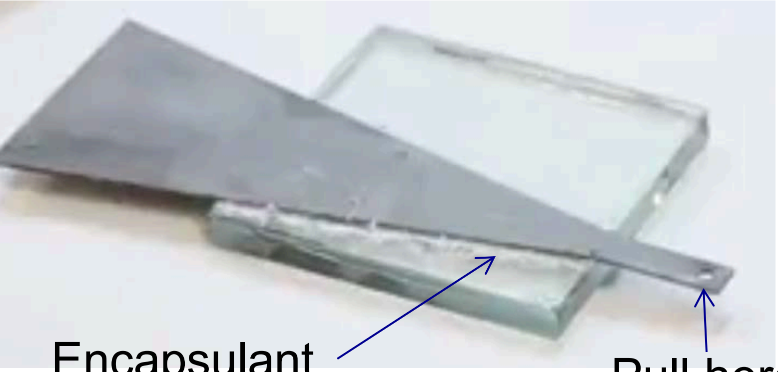
Water diffuses in, then is split into H_2 and OH^-
Hydrogen builds up and causes delamination
(note: this also causes basic environment)

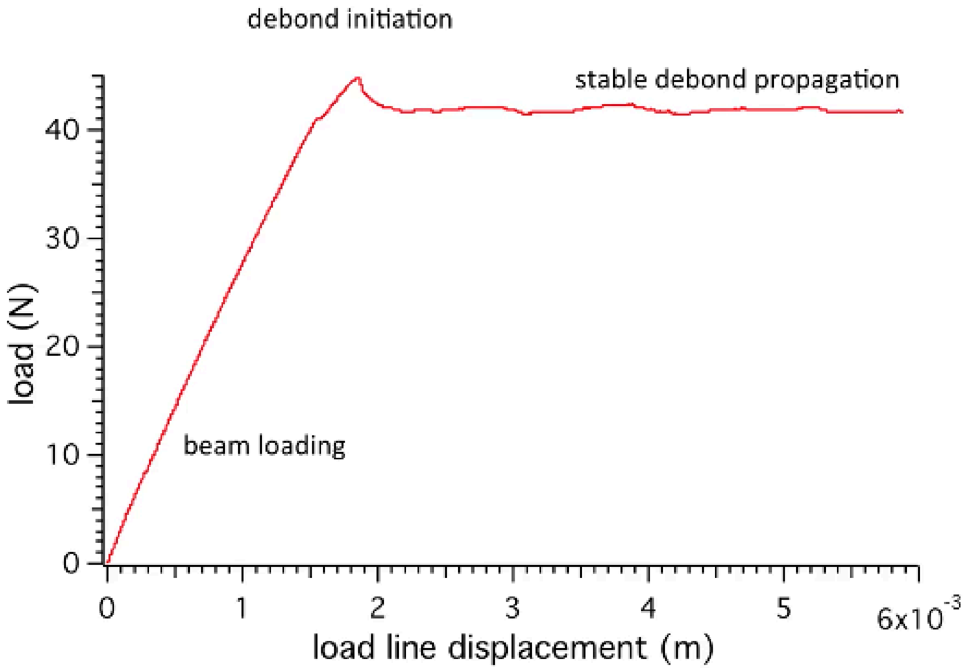
Once delamination occurs, corrosion is more likely

Shen, et al., PV Reliability Workshop 2017

Cantilever beam measurement of adhesion

Provides more quantitative measurement of de-bond energy





$$G_c = \frac{load}{2\tan(\theta/2)}\left(\frac{\Delta_f}{a_f^2}\right)$$

Δ_f : final load-line displacement

θ : width-tapered beam included angle

a_f : final debond length

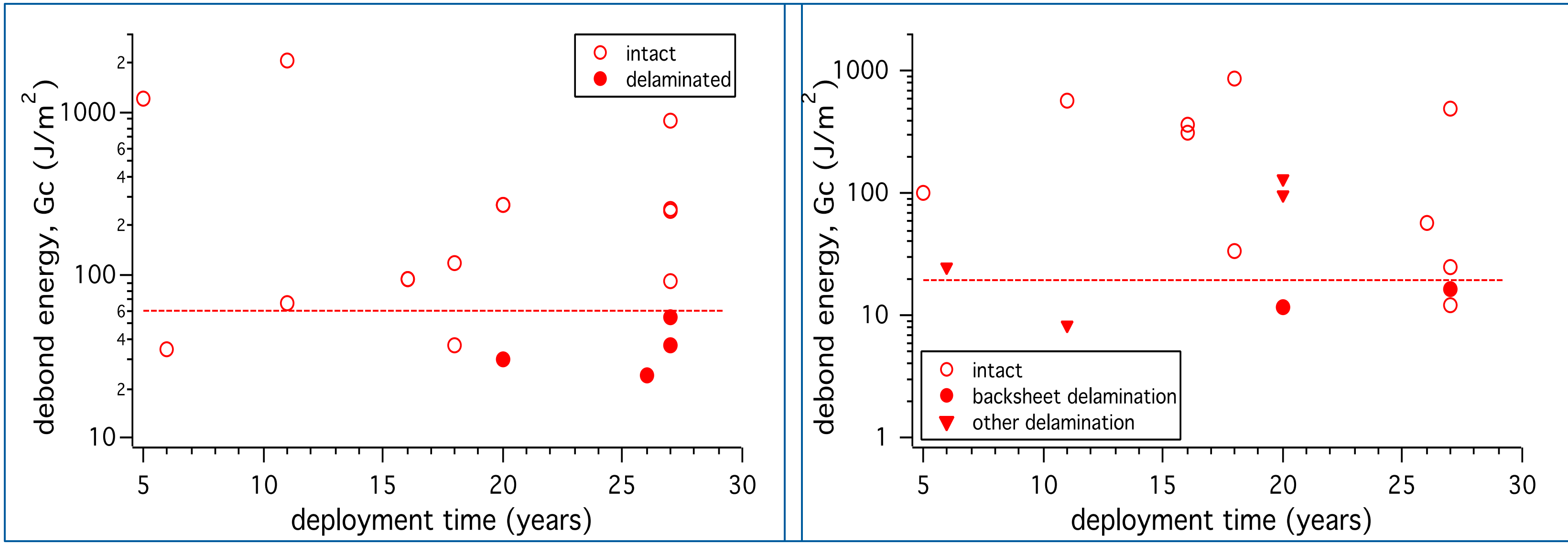
By attaching a beam with specific geometry and pulling in a controlled direction, then applying the calculation, more consistent measurement of the de-bond energy is obtained.

https://www.youtube.com/watch?v=qgeZb4YLg3M

Cantilever beam measurement on *modules*

Technique can be applied to modules from the field

Encapsulant　　　　Back sheet



Measurements for modules deployed in the field suggest that prevention of delamination requires adhesion:

- For encapsulants: > 60 J/m^2
- For backsheets: > 20 J/m^2

These quantitative measurements provide a reference to compare with accelerated test results

Nick Bosco will present this work at PVSC, June 2017

Strategies for addressing primary challenge: a module-level test is necessary, but takes too long

Dilemma

- **Using low acceleration factor that gives confidence takes a long time if the full exposure is desired**
- **High acceleration factor may not give correct result (though it may be useful for a screening test)**
- **What to do?**

Suggestion

- ***Modules*: Standard pass/fail module tests (IEC 61215 and IEC 61730)**
  - Short UV exposure to weaken bonds (may be adequate)
  - Humidity freeze to cause delamination
  - Add voltage bias to damp heat to cause bubble formation
- ***Materials*: Standardize weathering tests**
  - Use conditions similar to *harshest conditions seen in field* and apply for extended time to see discoloration
  - No pass-fail; record material property changes

Progress in standards

- **Edition 3 of IEC 61215: Qualification test**
- **Edition 2 of IEC 61730: Safety test**
- **IEC 62941: Quality assurance guideline**

- **IECRE: Gives ability to review all aspects of a PV system (look for OD-4XX documents at http://iecre.org/documents/refdocs/)**

Conclusions

- **Historical experience shows decreased discoloration**
  - ***May be best to use harshest use conditions to correctly balance discoloration and photobleaching***
- **Understanding delamination may benefit from:**
  - ***Temperature and water content can have large effects on bond strength***
  - ***Prolonged UV exposure may not be necessary for some degradation mechanisms***
  - ***Chemical reactions that generate gas can cause bubbles and delamination***
  - ***Quantitative method for measuring interface toughness***
    https://www.youtube.com/watch?v=qgeZb4YLg3M
- **Approach for standards**
  - ***Limit pass-fail module testing to shorter exposures that don't challenge business models***
  - ***Standardize data for long-term materials testing and encourage scientific analysis of the results rather than defining pass-fail criteria***

Thank you for your attention! Sarah.Kurtz@nrel.gov