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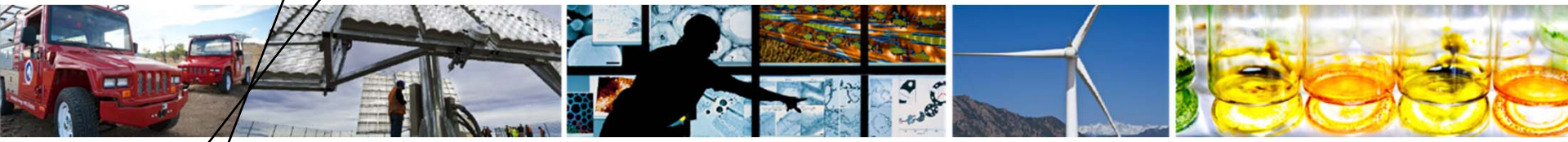
PV Reliability – Where We've Been and Where We're Going



Sarah Kurtz

Acknowledge:
Reliability group at NREL
International efforts of IEC and PVQAT

SNEC (2017) International Photovoltaic Power Generation & Exhibition

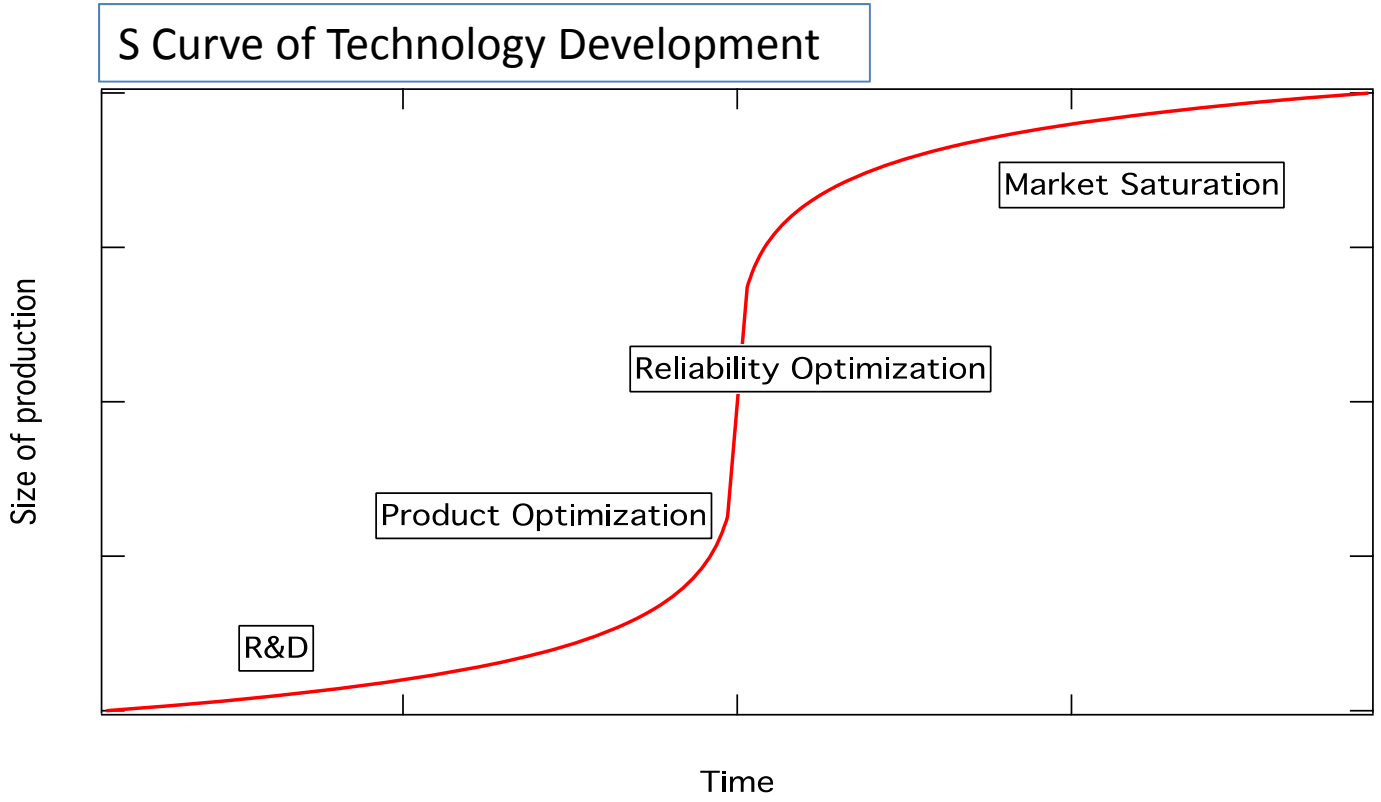
Shanghai, China

April 19, 2017

NREL/PR-5F00-68418

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.

Focus on reliability is natural step



As a technology develops, reliability optimization is a natural step
Can the cost be reduced without reducing reliability?

Outline

- **Evolution of reliability issues**
  - Discoloration and loss of photocurrent
  - Now, discoloration has decreased; failure mechanisms are shifting
- **Delamination: Recent progress toward understanding**
  - Gas formation
  - Quantifying adhesion
- **Strategies for developing confidence in predictions**
  - Using standards to leverage knowledge

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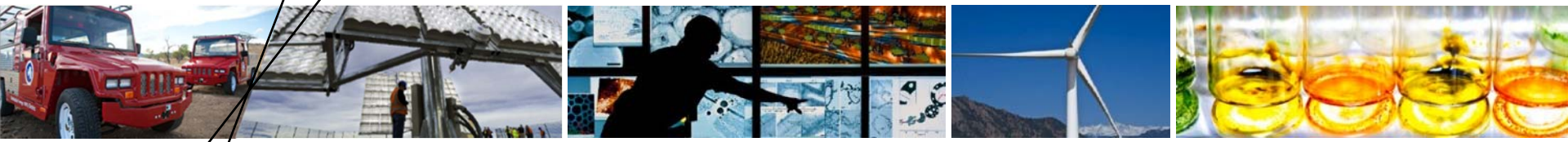
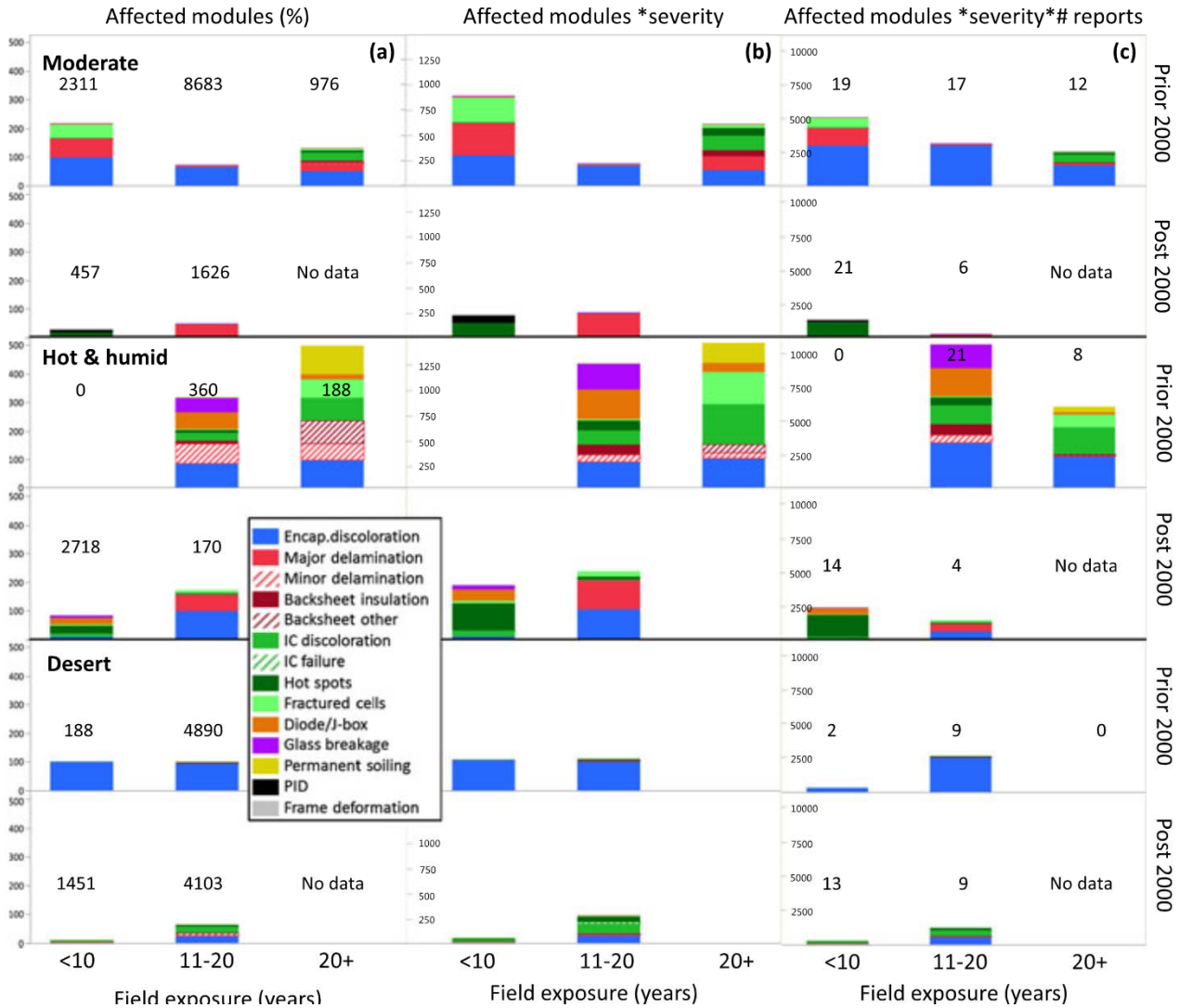


Evolution of reliability issues

Summary of degradation modes



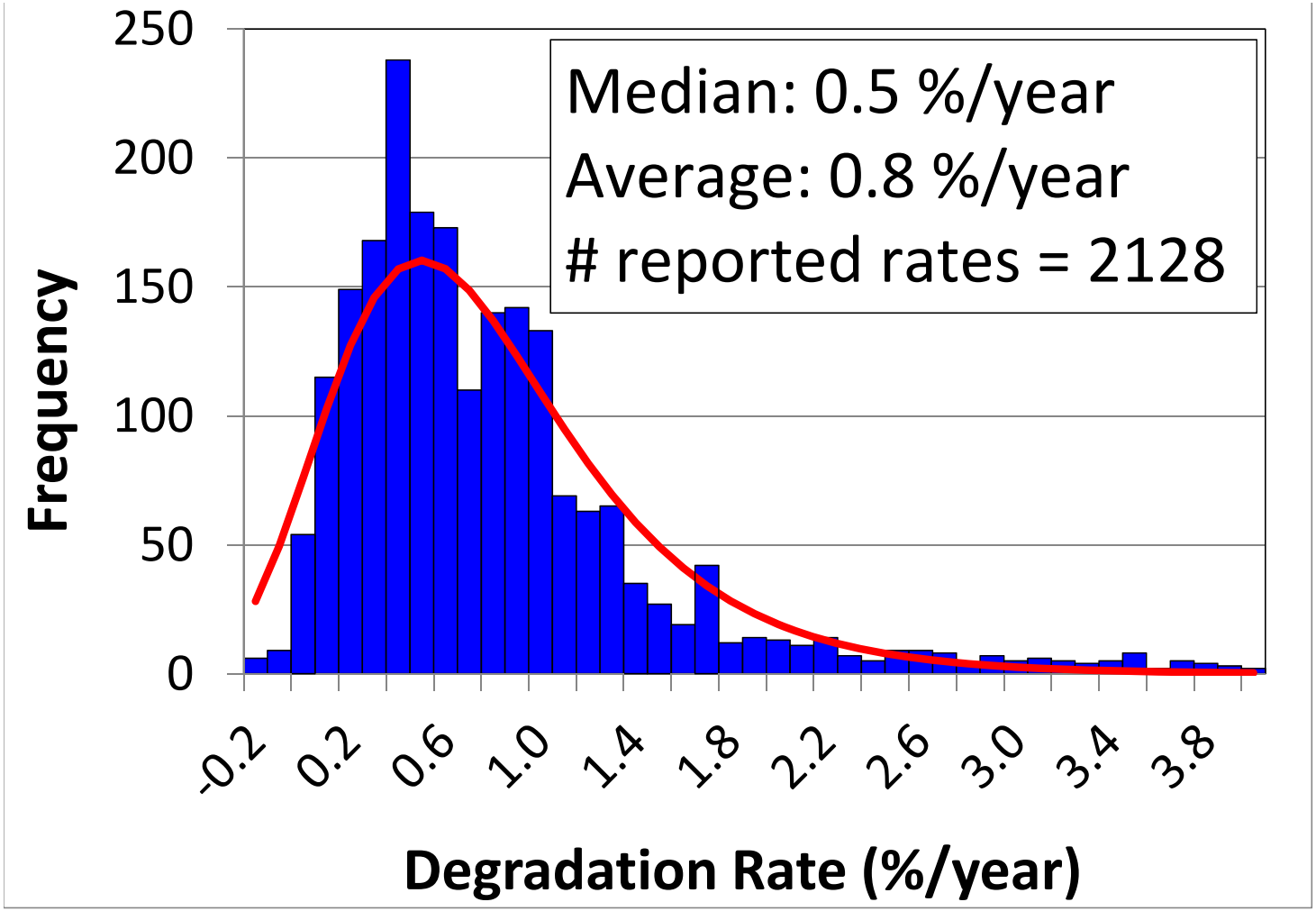
Recent summary of reports of types of failure modes for > 25,000 modules

First conclusion is that the # of problems is decreased

What are other key conclusions?

Published January 2017, Jordan, et al. Prog. In PV 2017; 25:318. DOI: 10:1002/pip.2866.

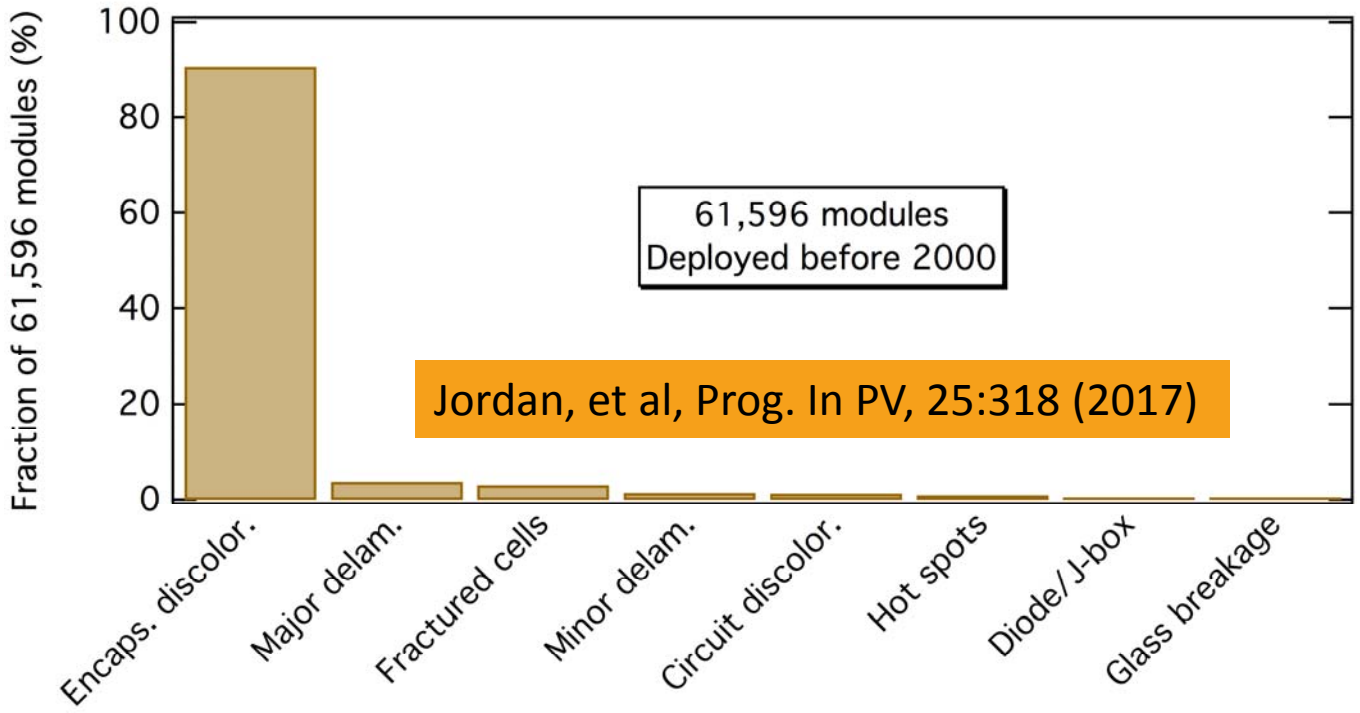
Degradation rates of ~0.5%/y - 0.8%/y

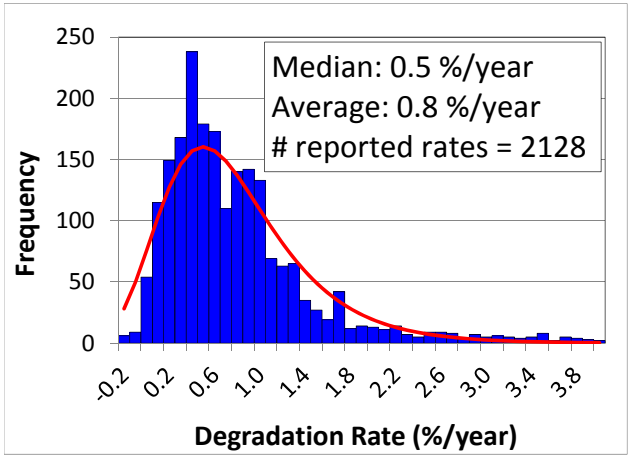


What causes this degradation? Not likely to be a single cause…

Progress in PV, Jordan, et al. 2013; 21:12. DOI: 10:1002/pip.1182.

Discoloration has been common



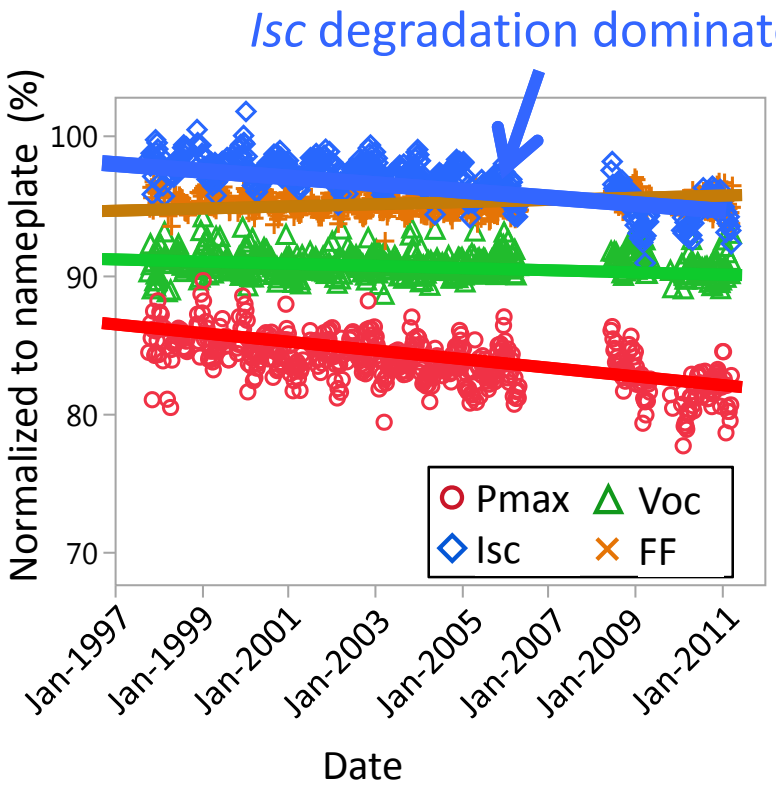


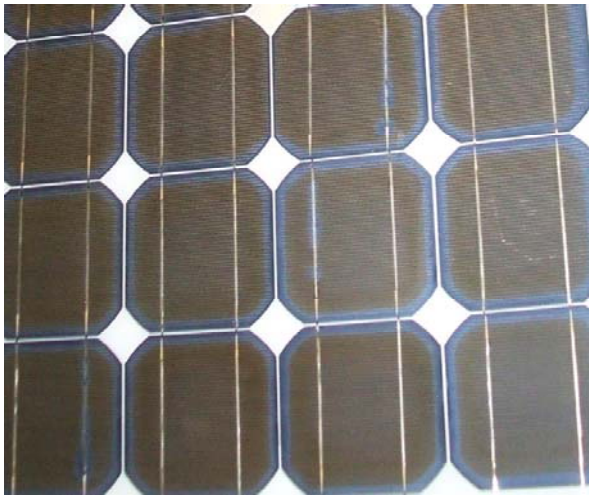
Literature survey shows primarily:

- Visual 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!

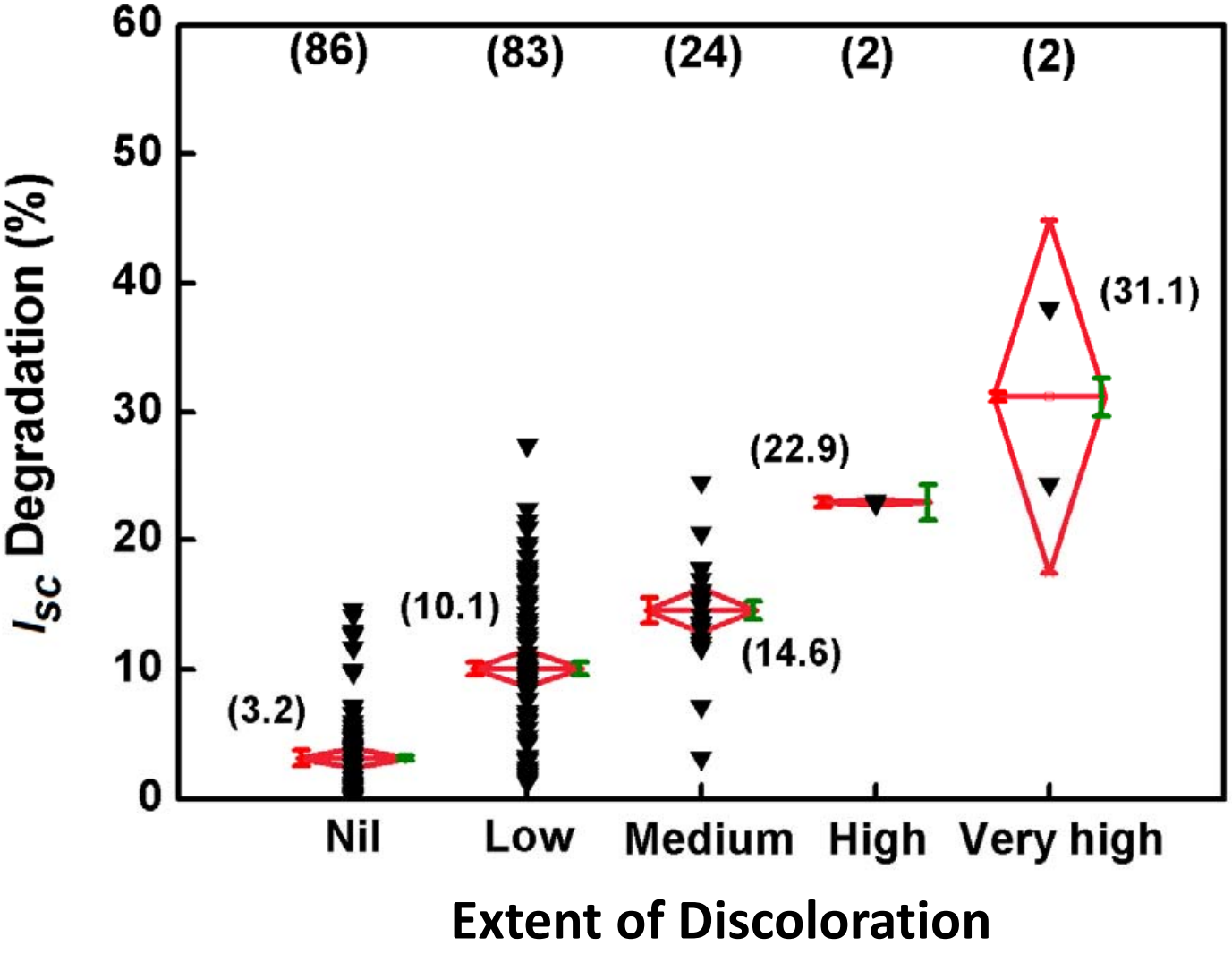
Encapsulation discoloration appears linear





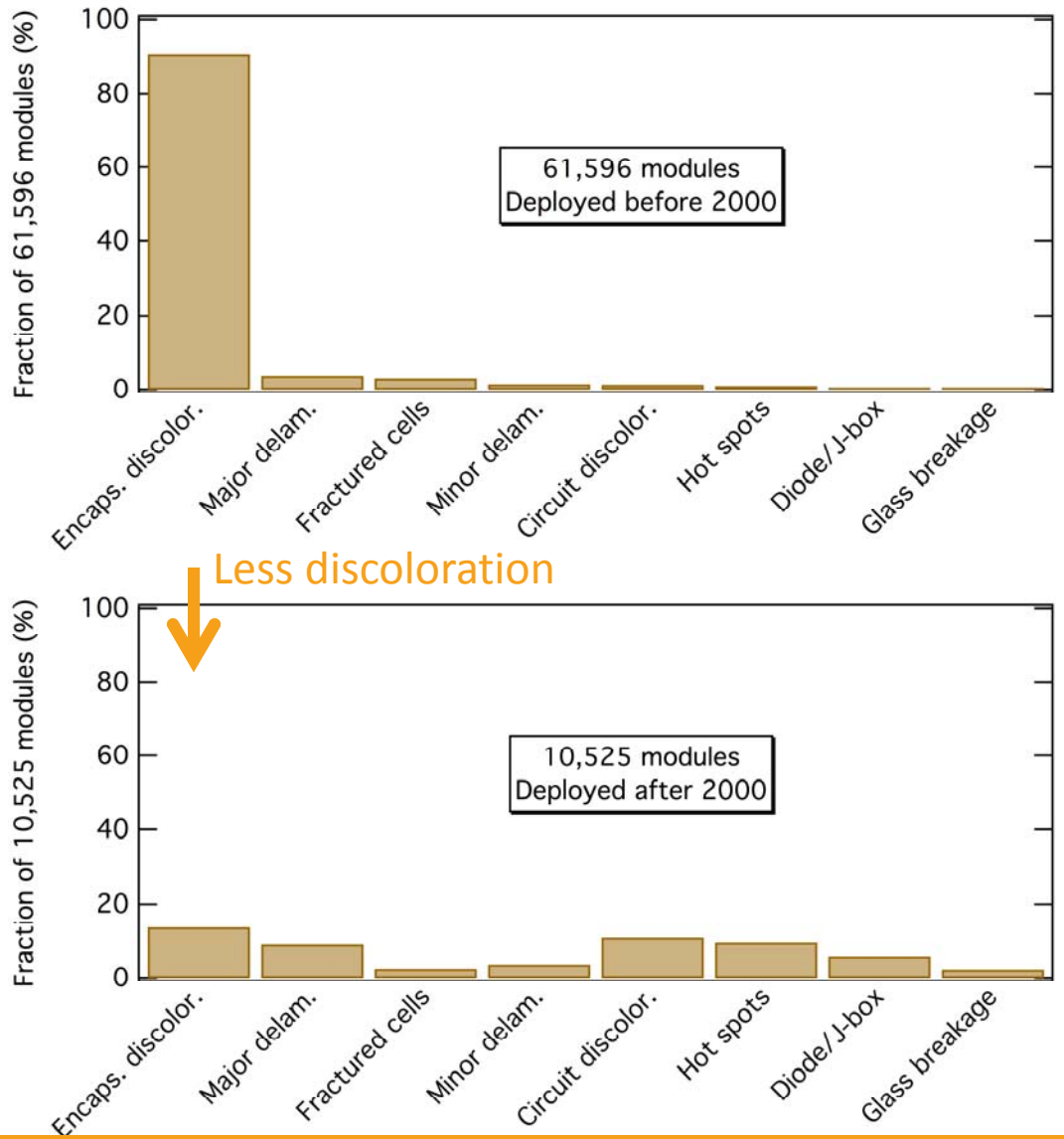
Encapsulant discoloration apparently causes linear decrease of Isc.
Note: defining "linear" vs "nonlinear" can be challenging

Discoloration correlates with Isc decrease



Dubey, et al. 2016; IEEE PVSC.

Discoloration has decreased

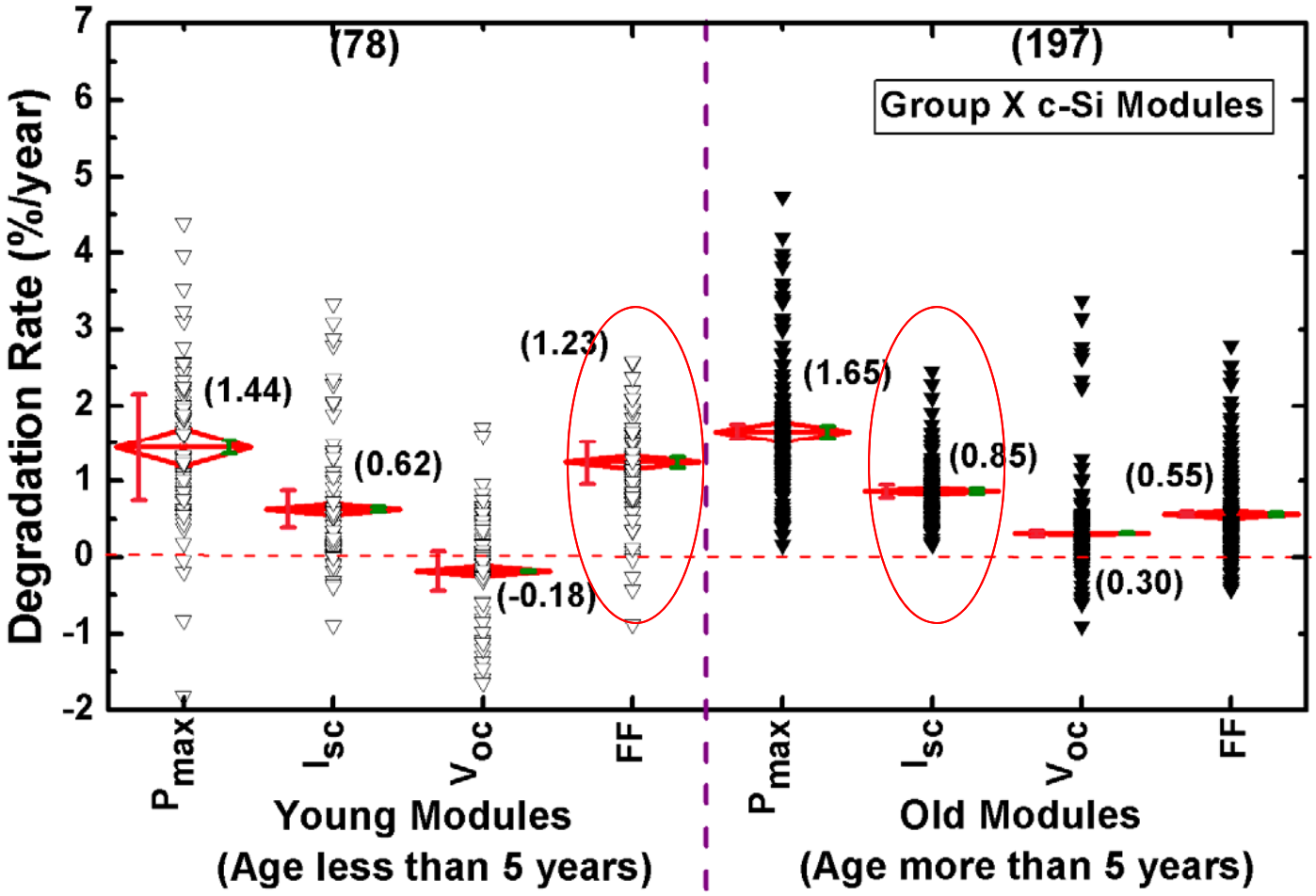


Modules deployed after 2000 report much less discoloration

Other problems have been reported more frequently

Published January 2017, Jordan, et al. Prog. In PV 2017; 25:318. DOI: 10:1002/pip.2866.

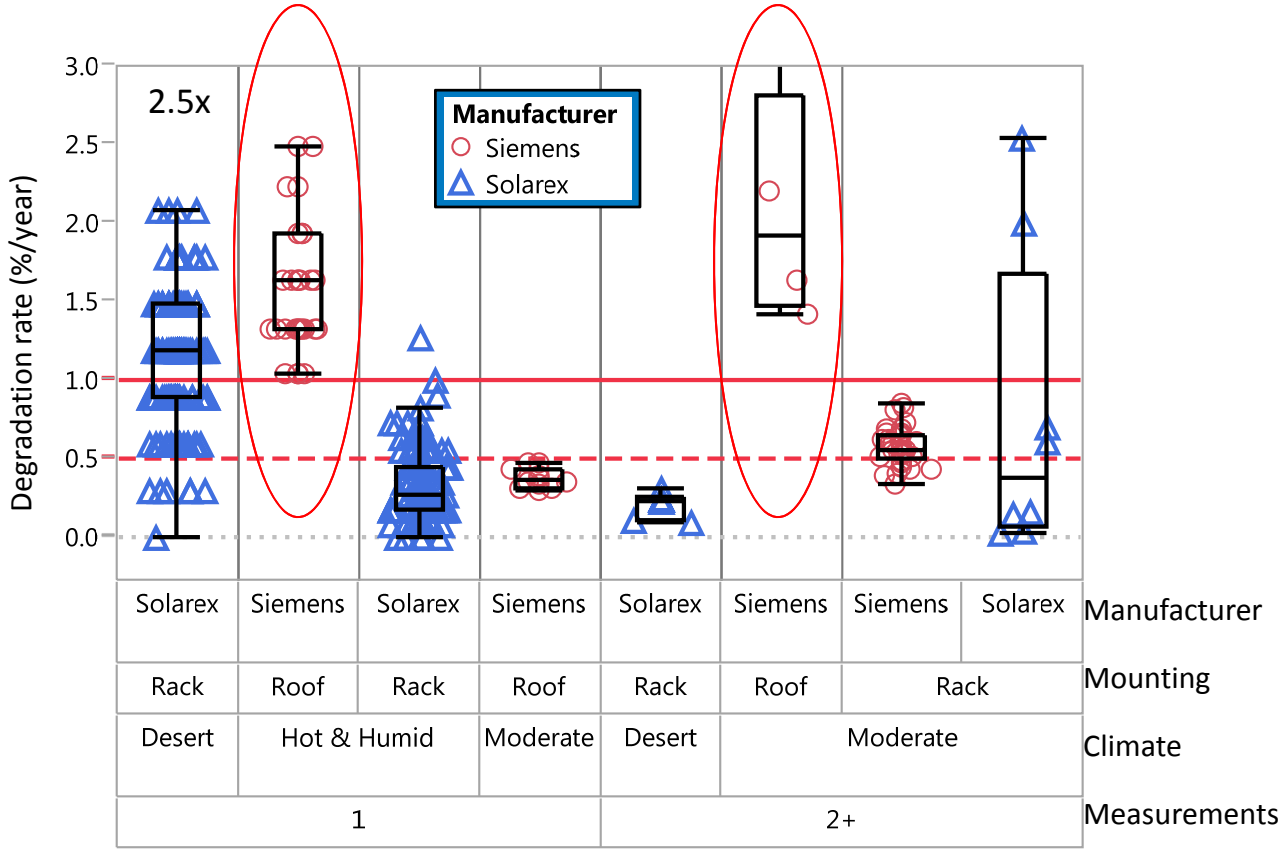
Newer modules show more FF than Isc change



Change from Isc to FF degradation is correlated with decrease in discoloration

Dubey, et al. 2016; IEEE PVSC.

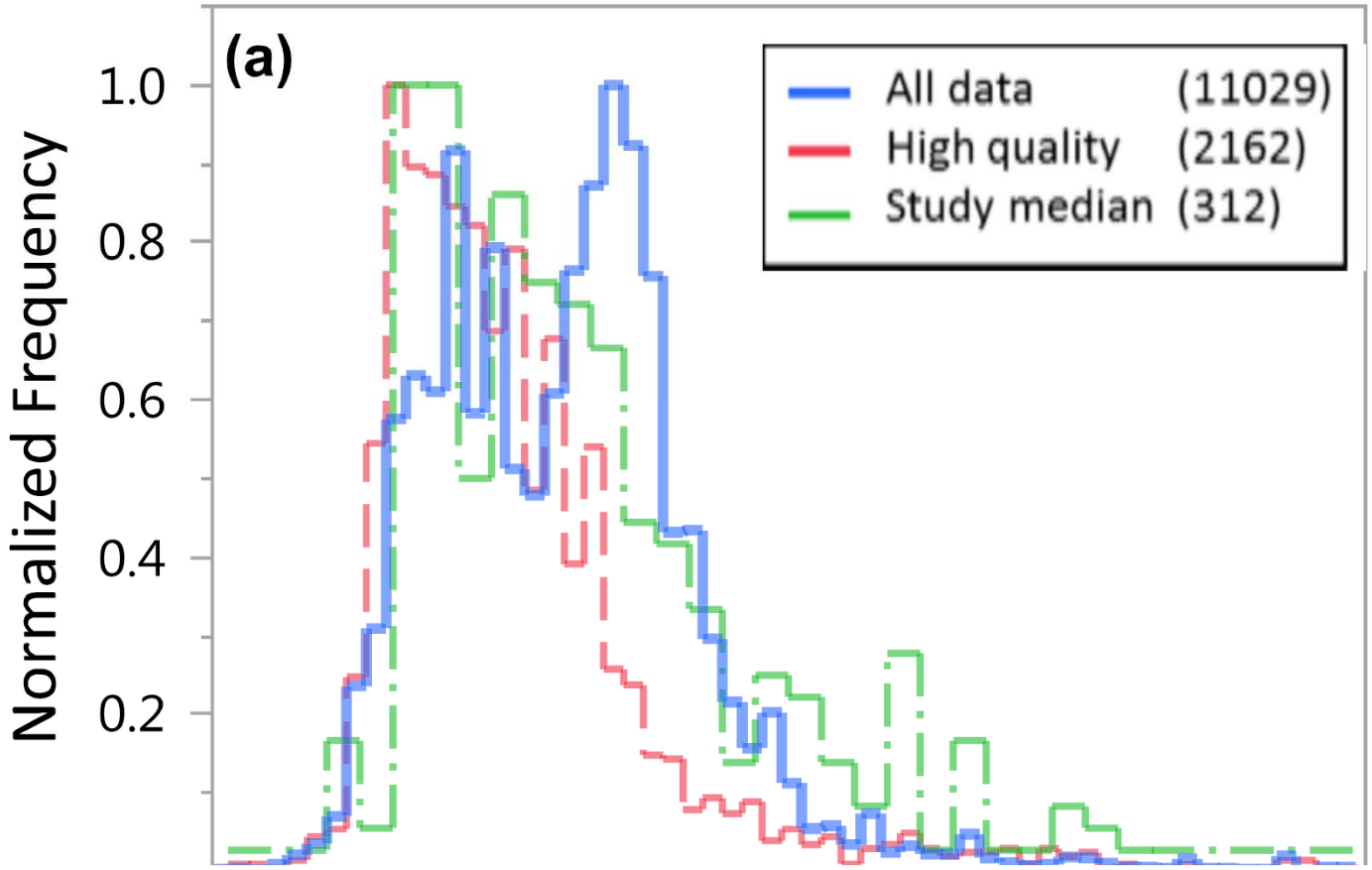
Hotter operation can show more degradation



Roof mounting sometimes shows higher degradation rates

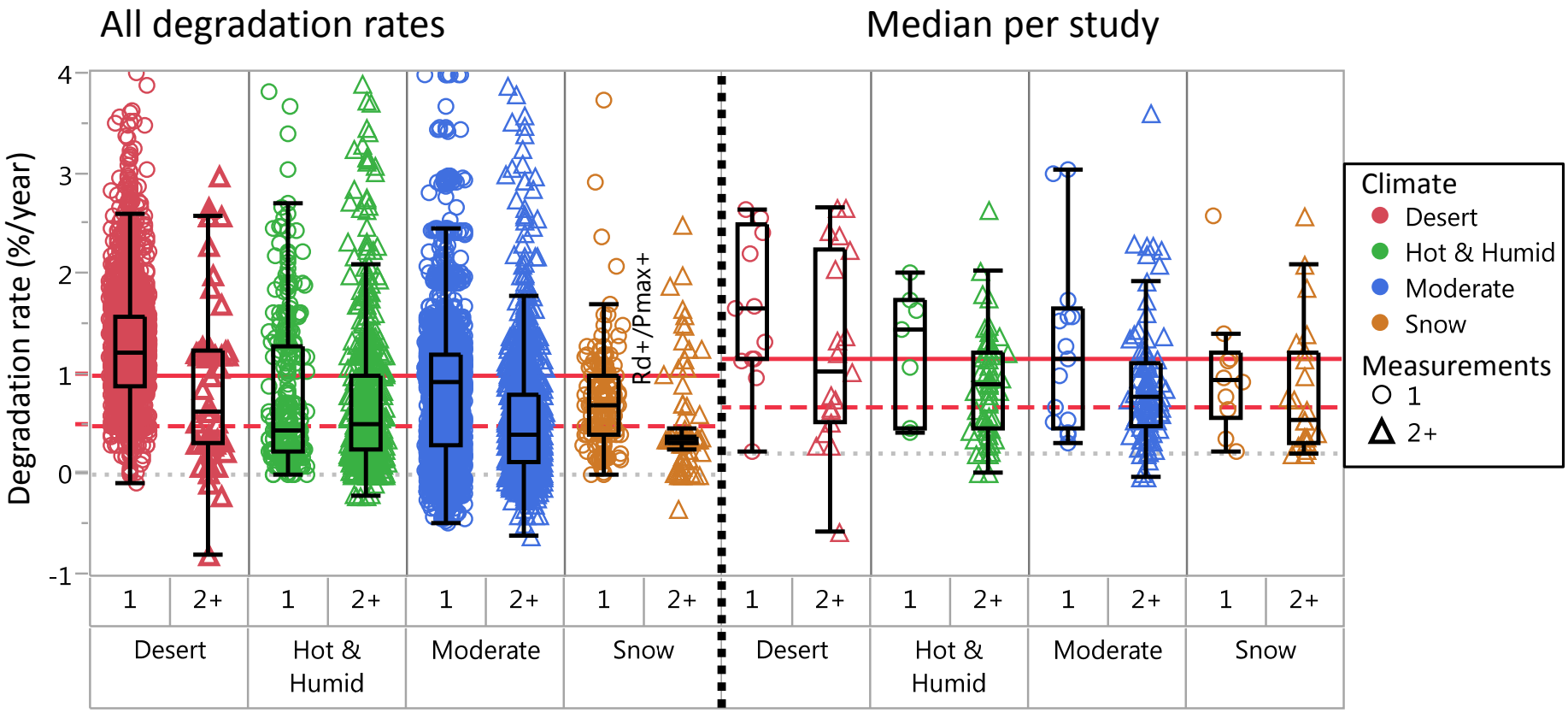
Updated degradation rates summary

Recent literature summary



Jordan, et al. Prog. In PV 2016; 24:978. DOI: 10:1002/pip.2744.

Does the climate matter?

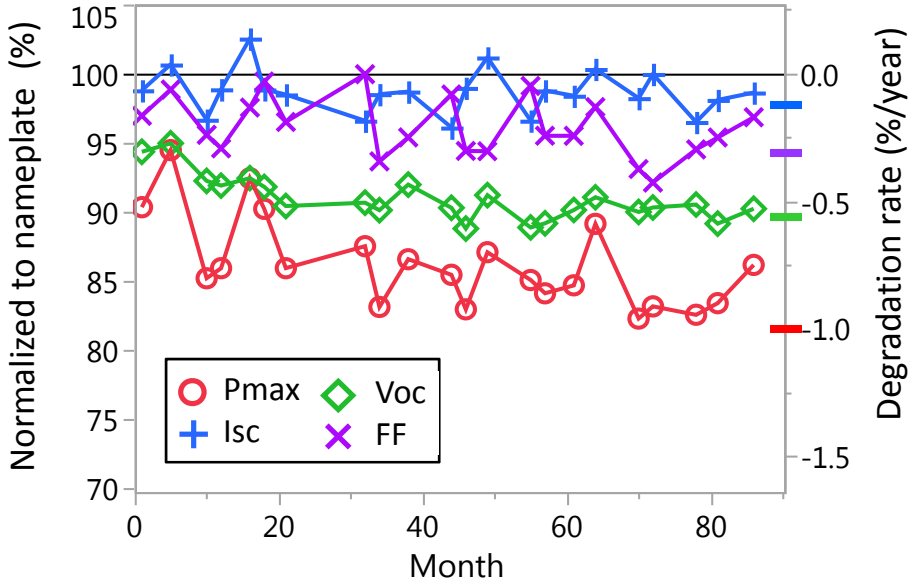


Number of measurements shows biggest correlation!
Multiple measurements removes initial uncertainty of nameplate rating
Conclusion about climate is less clear

Jordan, et al. Prog. In PV 2016; 24:978. DOI: 10:1002/pip.2744.

Observations depend on product

Sanyo HIT (heterojunction with intrinsic thin layer) shows photovoltage loss

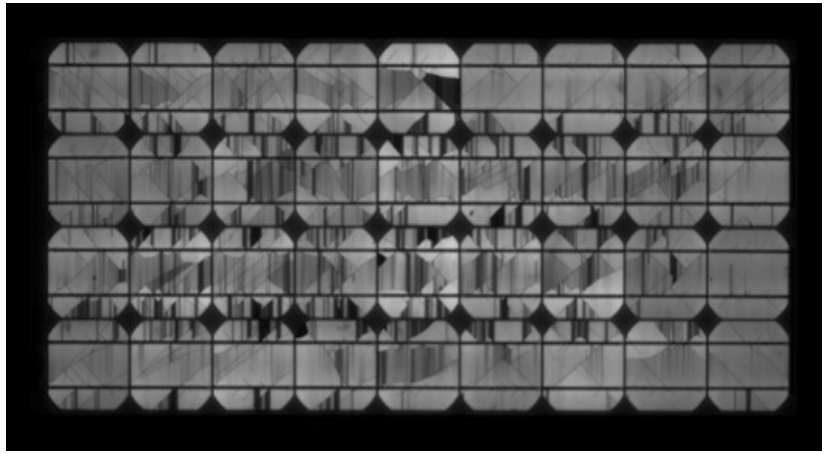


- 2007 system consists of 5 Sanyo HIP-200BA3 modules
- Photovoltage loss is unusual for silicon technology
- Is degradation linear?
- Degradation is within warranty

Jordan, et al, to be presented at PVSC 2017

What should we be looking for?

- **As cost is reduced, look for mechanical problems**
  - Bent frames
  - Broken cells
- **Mechanical problems can arise during:**
  - Transportation
  - Installation
  - Operation
- **New system designs**
  - Higher voltage
  - Mounting and grounding



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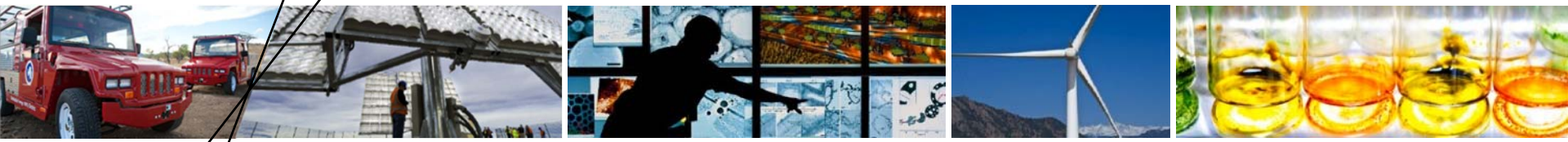
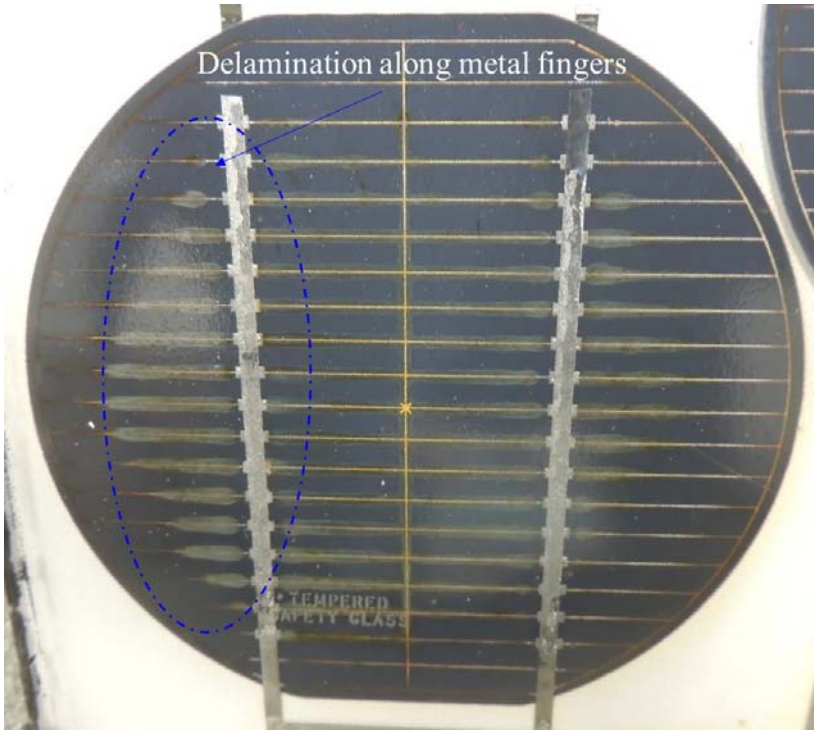


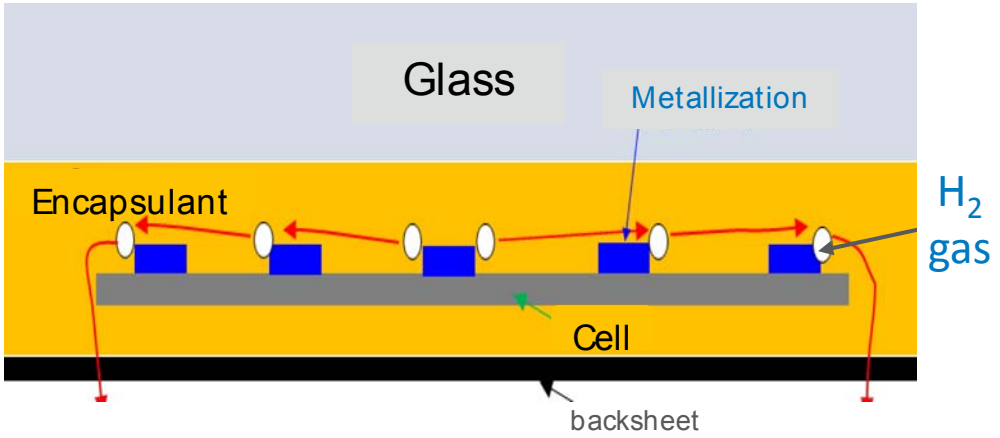
Delamination: Recent progress toward understanding

Leakage-current induced gas formation & delamination



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

Gas formation may cause delamination



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

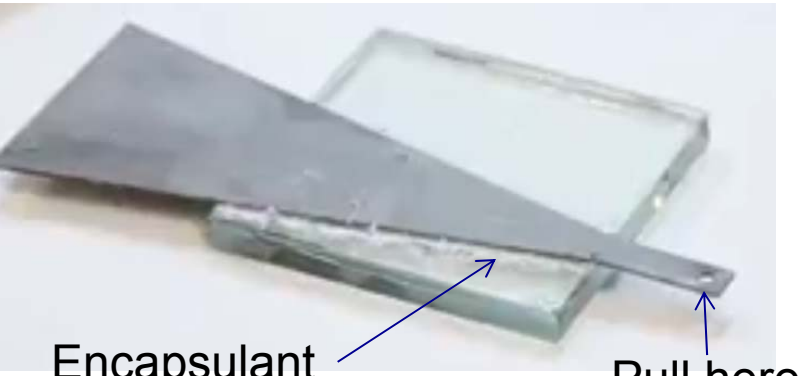
Water diffuses in, then is split into H_2 and OH^-
Hydrogen builds up and causes delamination

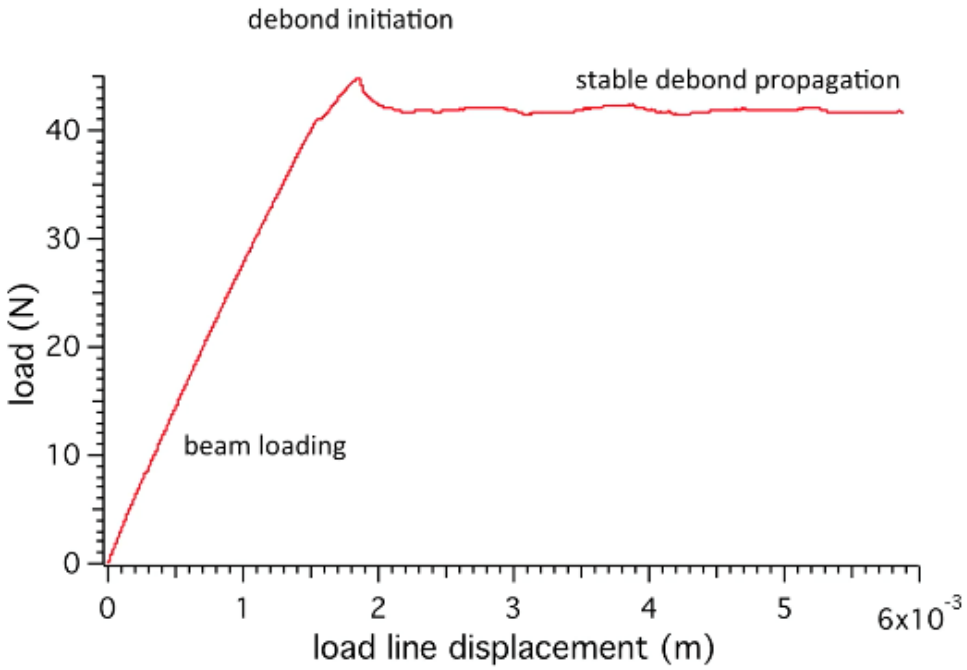
Once delamination occurs, corrosion is more likely

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

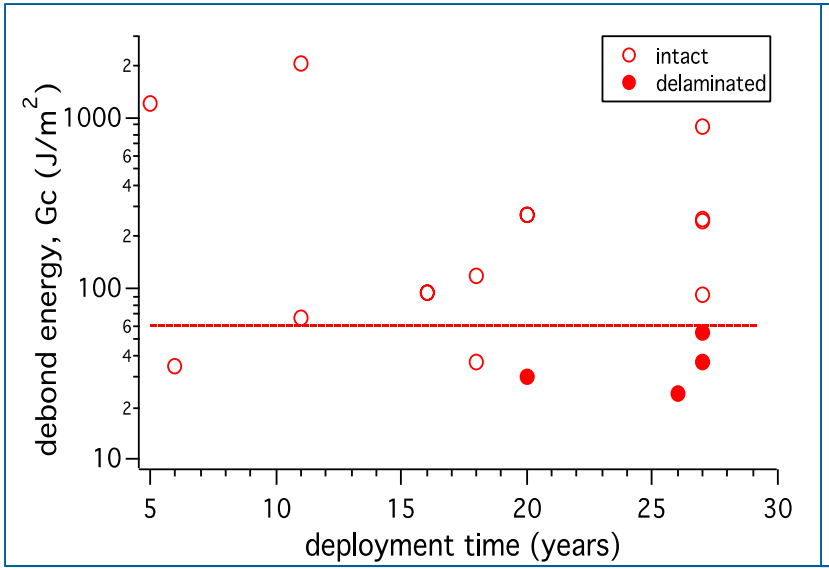
By attaching a beam with specific geometry and pulling in a controlled direction, then applying the calculation, more consistent measurement of the de-bond energy is obtained.

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

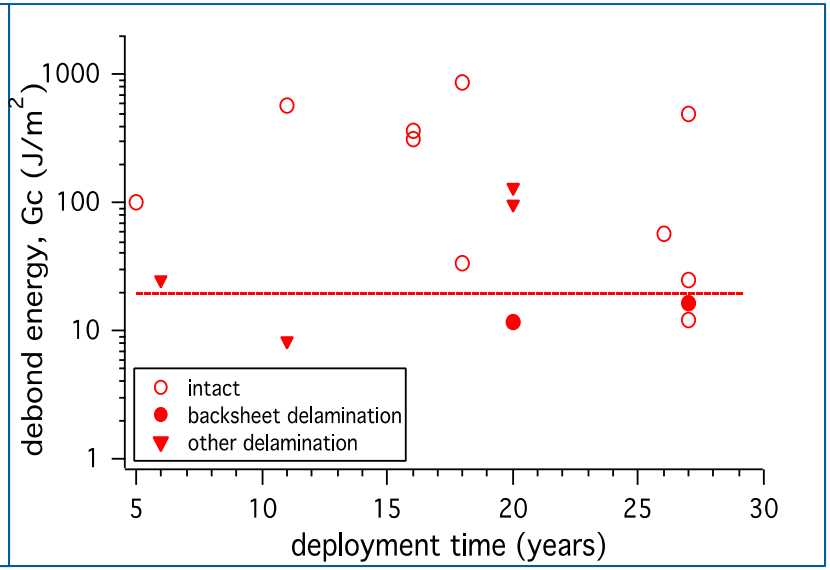
Cantilever beam measurement on *modules*

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

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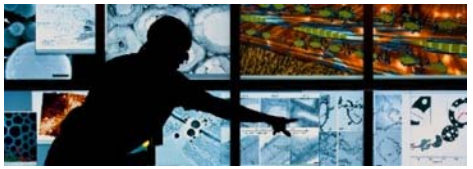
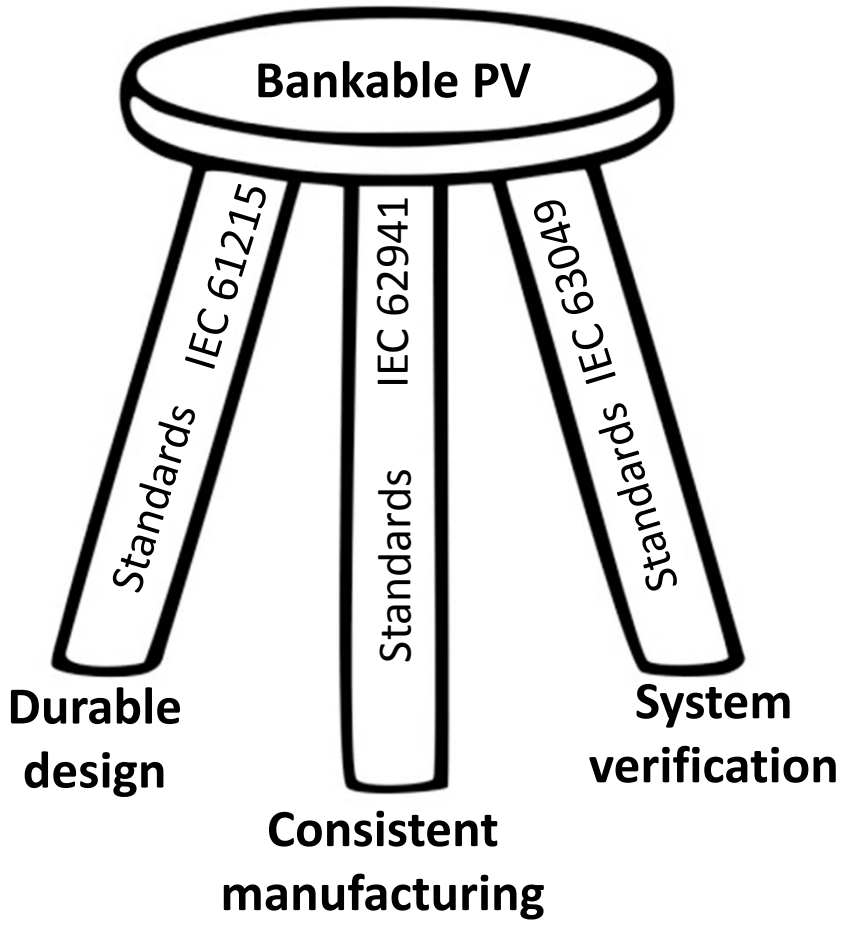


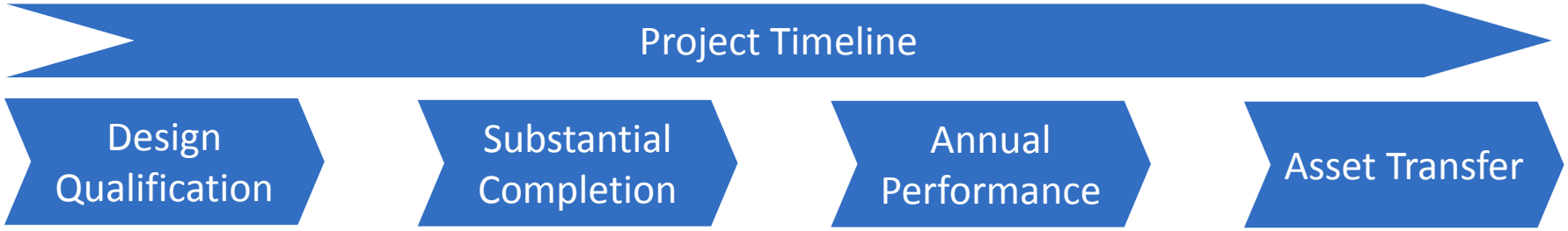
Strategies for developing confidence in predictions

Elements to achieve confidence

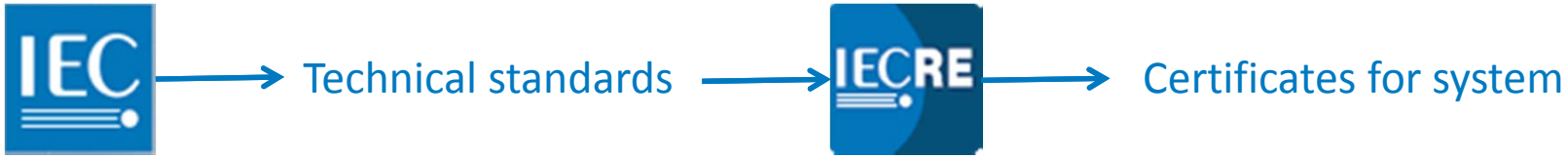
1. *Qualification of durability of design of products* for chosen climate and mounting
2. *Guide for audit of consistent manufacturing* of products built to that design
3. *Certification process for system verification* to ensure adequacy of design, installation, and operation



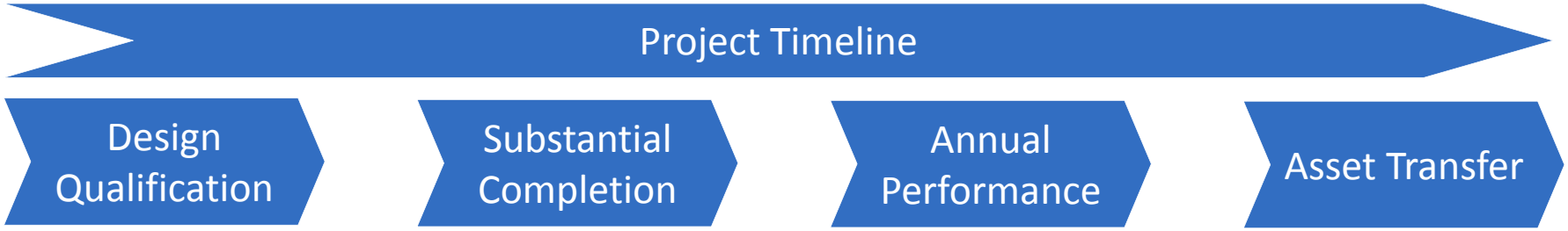
IECRE Certificates for each step in PV System Timeline



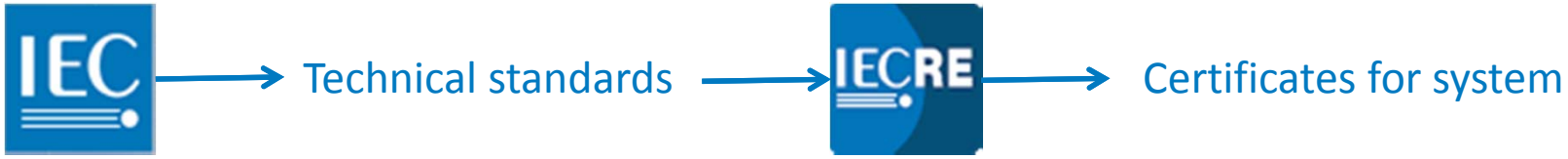
- Need confidence that *each step* during a project is completed correctly
- Example steps include:
  - Design qualification (ready to proceed with construction)
  - Substantial completion (ready to operate)
  - Annual performance (final completion, or annual check up)
  - Asset transfer (define health of plant before sale of plant)



Why IECRE?



- Standards represent collective knowledge
- Consistent practices reduce cost
- Single set of international standards make sense for international market
- IECRE certificates apply decades of work by IEC, Technical Committee 82



Recent progress in IEC standards

- **Edition 3 of IEC 61215: Qualification test**
- **Edition 2 of IEC 61730: Safety test**
- **IEC 62941: Quality assurance guideline for modules**
- **IEC 63049: Quality assurance for system**

- **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 failure modes are evolving**
  - ***Less discoloration may mean less Isc degradation***
  - ***Mechanical problems are becoming more common***
- **Understanding delamination may benefit from:**
  - ***Understanding gas formation, especially when voltage is applied***
  - ***Quantitative measurements show that modules may require an interface toughness of > 20-60 J/m²***
- **Approach for standards**
  - ***Many standards have been recently updated to reflect latest scientific understanding***
  - ***IECRE provides an international platform to establish confidence in PV systems***

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