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NATIONAL RENEWABLE ENERGY LABORATORY

Moving to a Higher Level for PV Reliability through Comprehensive Standards Based on Solid Science

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6th World Conference on Photovoltaic Energy Conversion

Kyoto, Japan

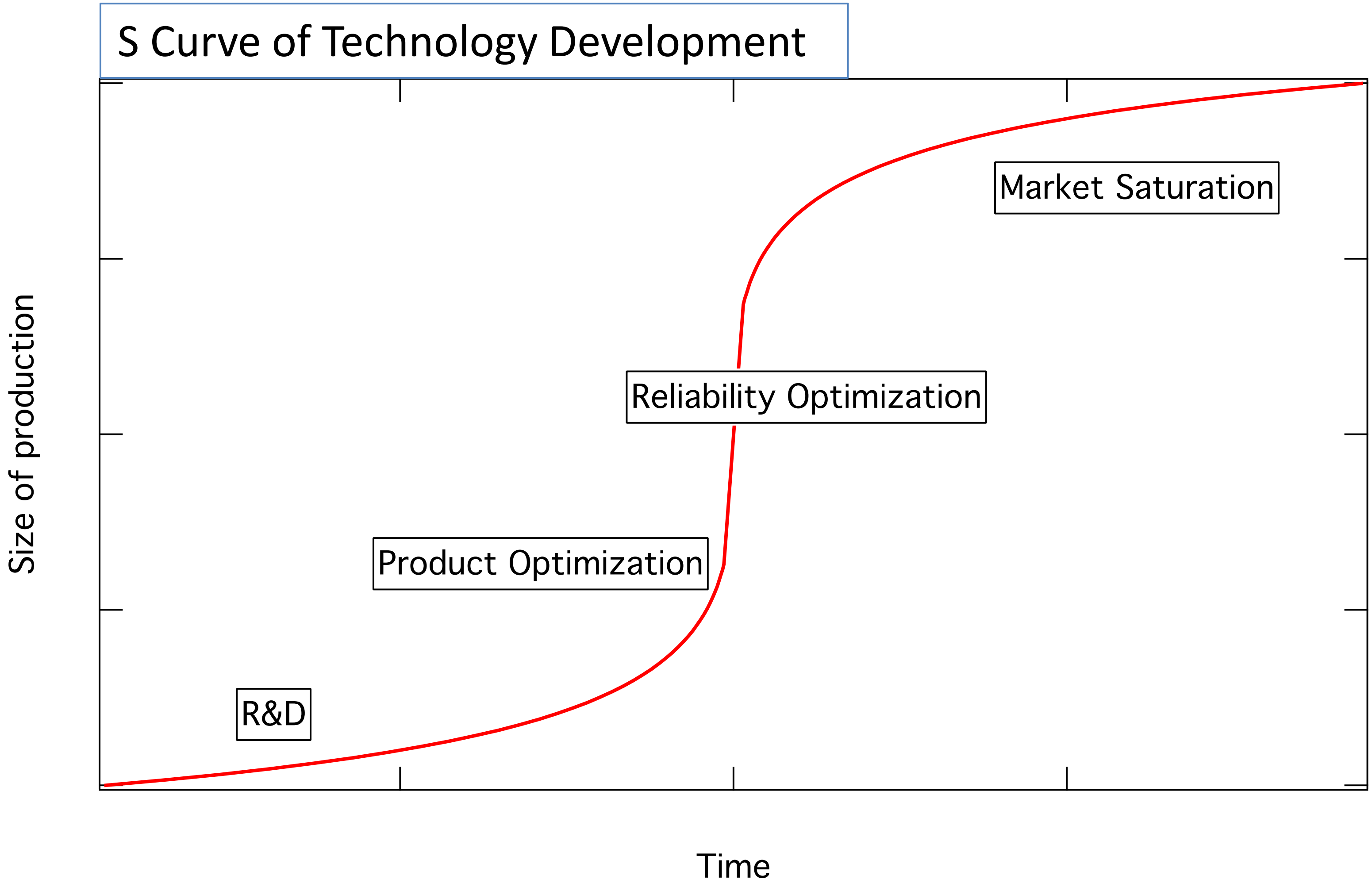
Nov. 27, 2014

NREL/PR-5J00-63303

Outline

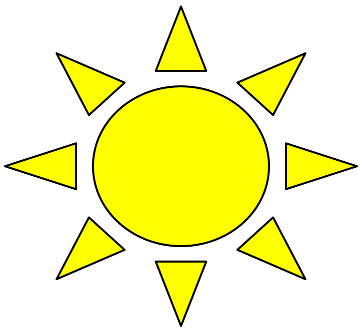
- **Motivation: PV Reliability as a foundation for continued industry growth**
- **Challenges: Is it possible to be practical and scientific at the same time?**
- **Examples: Things we know; things we need to learn!**
- **End goal: Comprehensive set of test standards that reflect a scientific understanding and are practical!**

Reliability Optimization is a Key Step Toward Technology Maturity

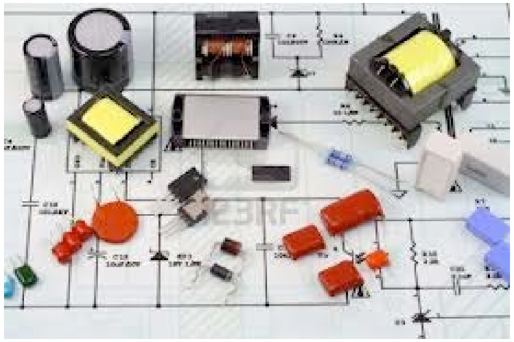


Reliability is key to continued growth and cost reduction

Reliability Challenge for PV – Combine all Stresses in variable ways



Weathering



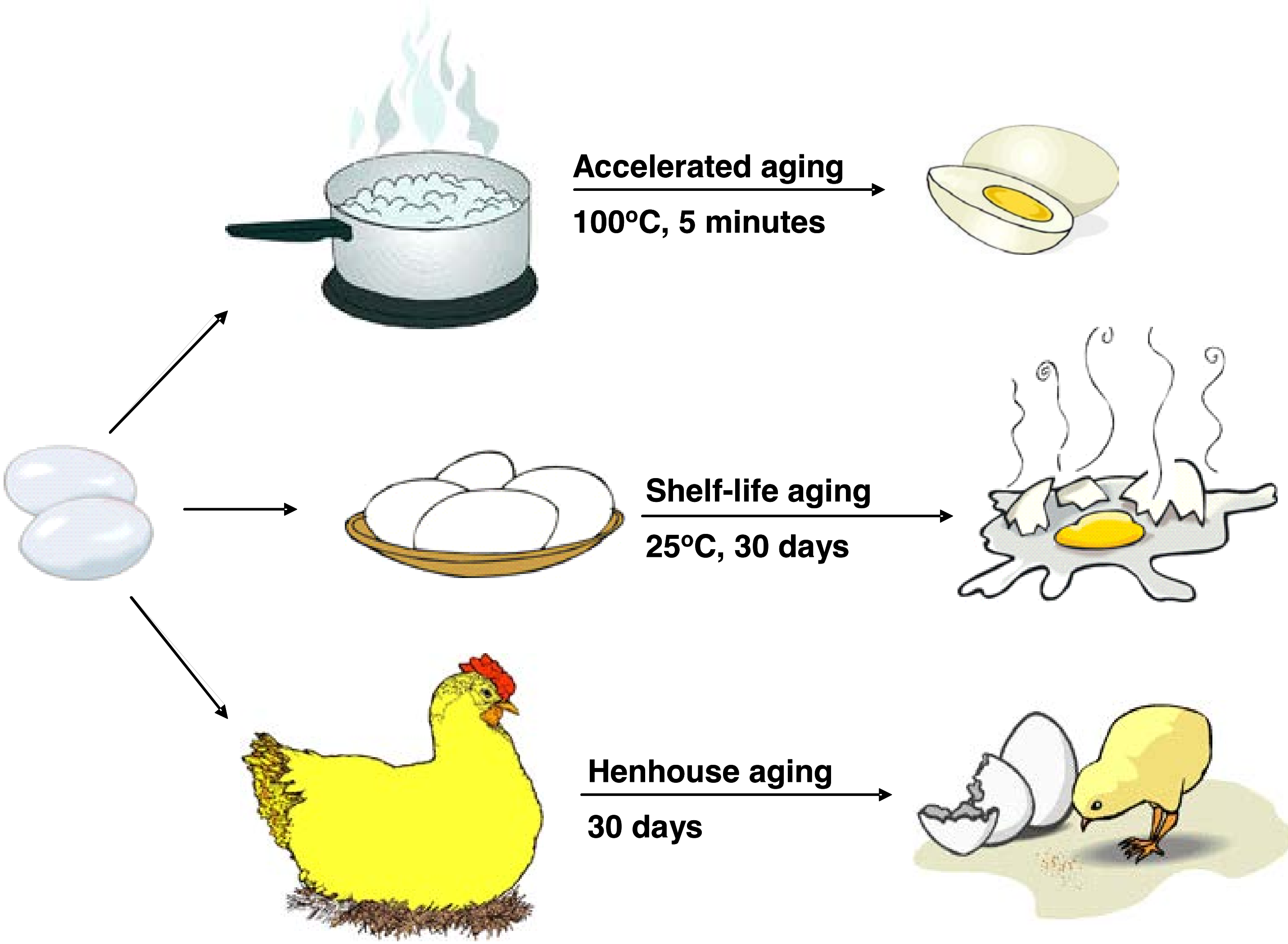
Electrical

Mechanical

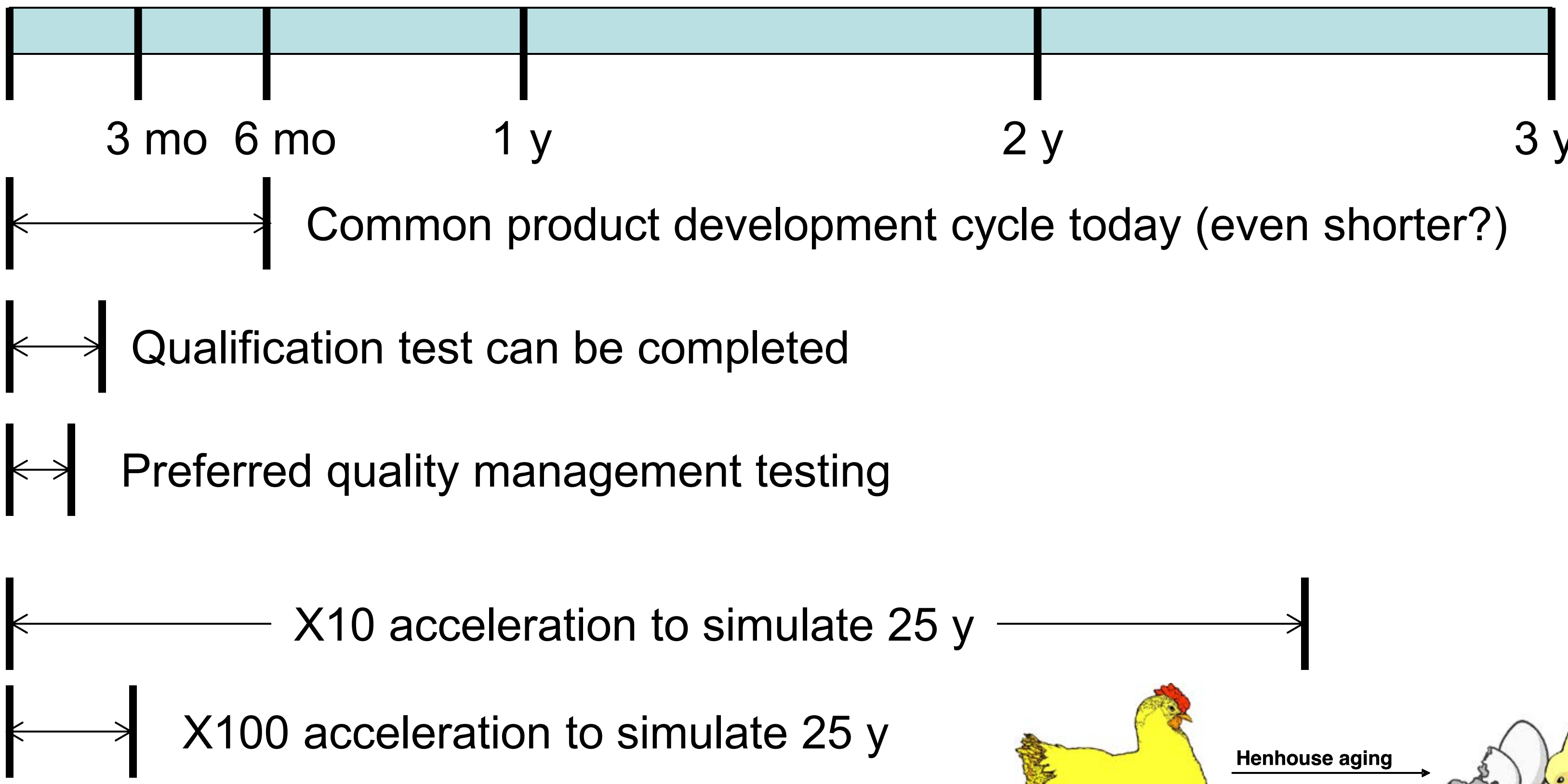
PV must consider many stresses; the order in which these are applied may determine the outcome

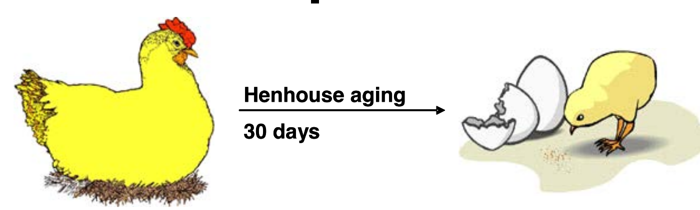
Accelerated > 20 years is hard!

We have our choice between: doing it “right” and doing it “in time”



Timeline Challenge





Too much acceleration may answer the wrong question!

We have our choice between being practical and being scientific!

Practical versus scientifically accurate

- **Time (length of test)**
  - A quick test risks getting an irrelevant result
  - A slow test misses the business opportunity
- **Use environment**
  - Use the same test for all use environments?
  - Or, adjust stress tests for intended use?
- **Accurate testing**
  - The community would like to compare products side by side using the same test
  - Acceleration factors vary by product: accurate results require measuring the kinetics for every product

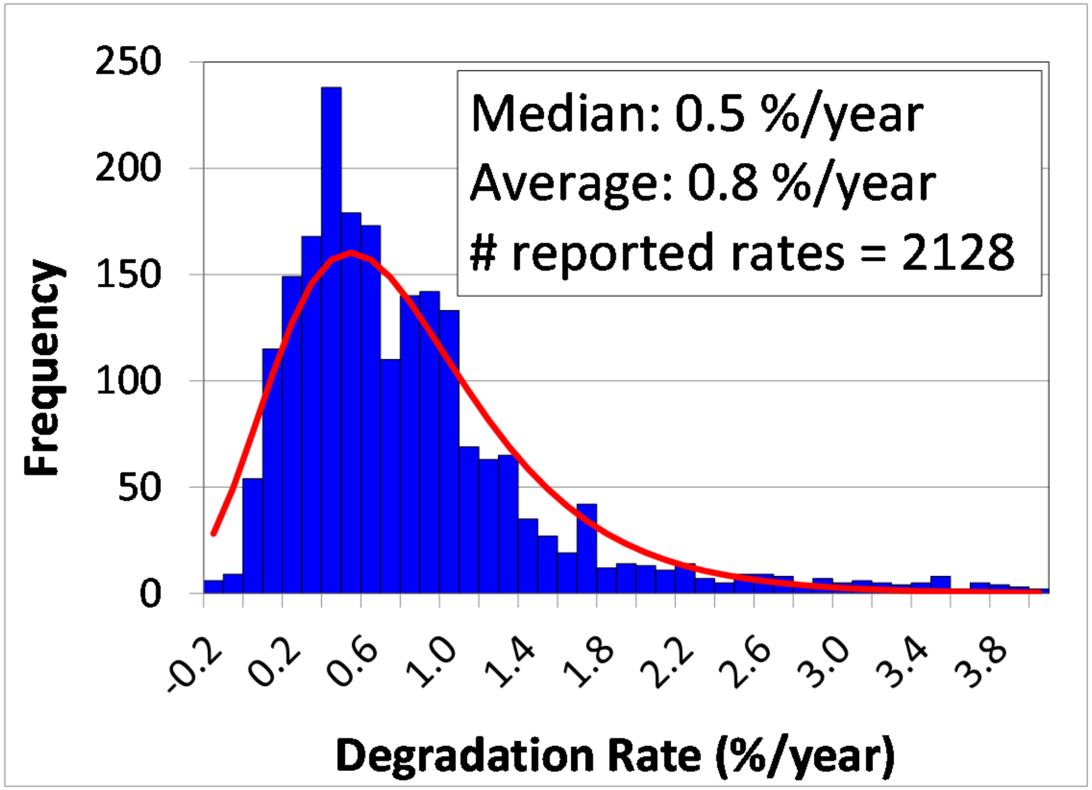
Many problems have been observed

- **Broken interconnects**
- **Broken cells**
- **Corrosion**
- **Delamination**
- **Encapsulant discoloration**
- **Solder bond failures**
- **Broken glass**
- **Hot Spots**
- **Ground faults**
- **Junction box and module connection failures**
- **Structural failures**

Strategy:

1. ***Quickly duplicate the field failure to screen for and eliminate most design flaws***
2. ***Quantify only those that can't be eliminated, using our knowledge!***

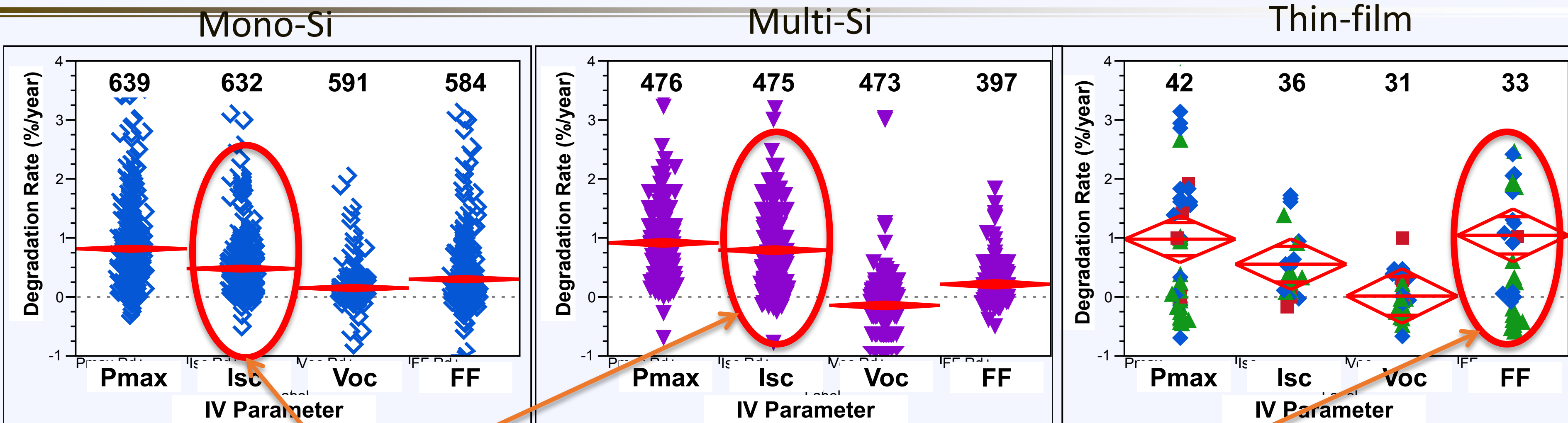
Statistical analysis of degradation rates

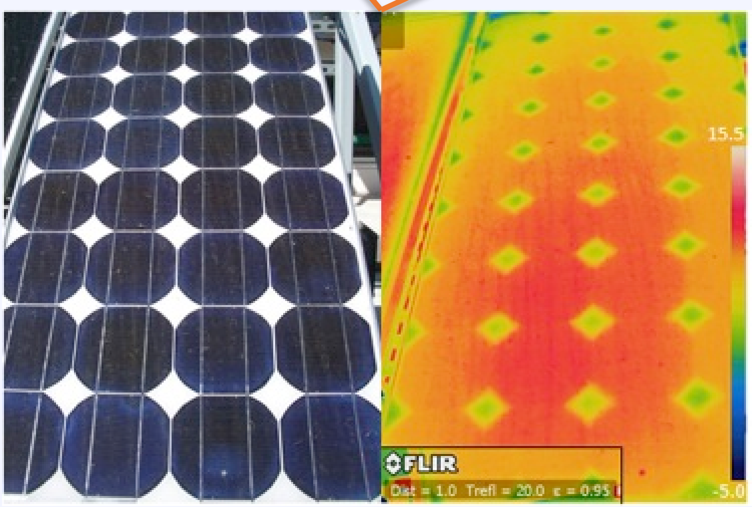


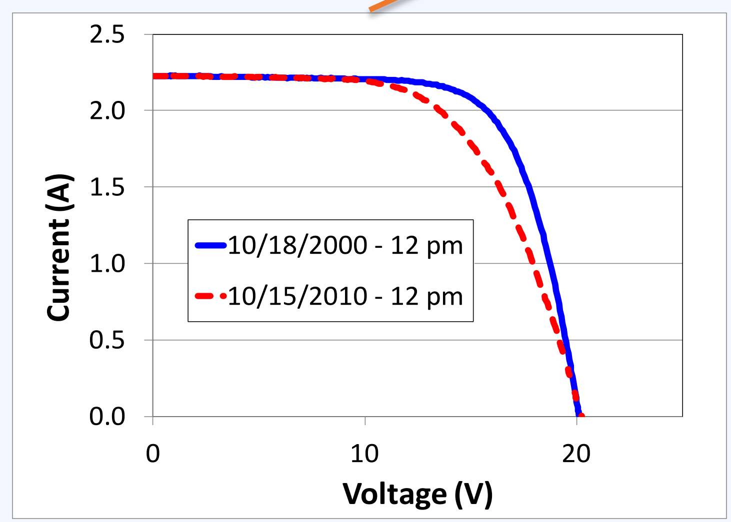
Literature data show statistical distribution of degradation rates: Majority meet performance warranty

Jordan, Prog. Photovolt: Res. Appl. 2013; 21:12–29. DOI: 10.1002/pip.1182

Degradation Differs for Si and Thin Film





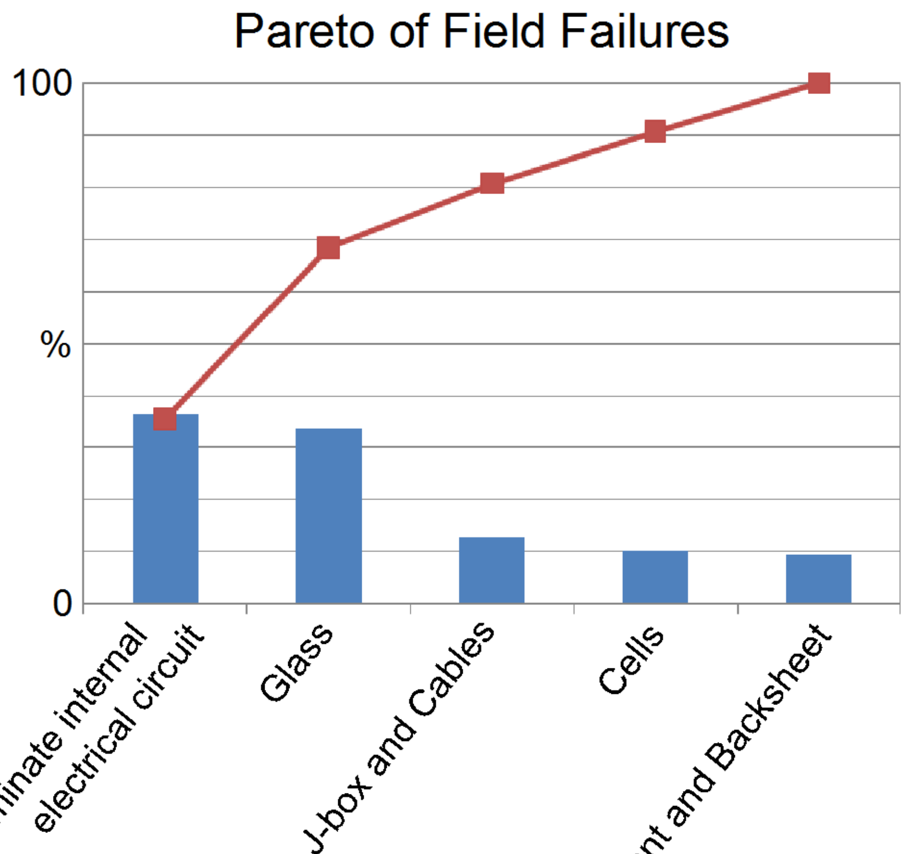


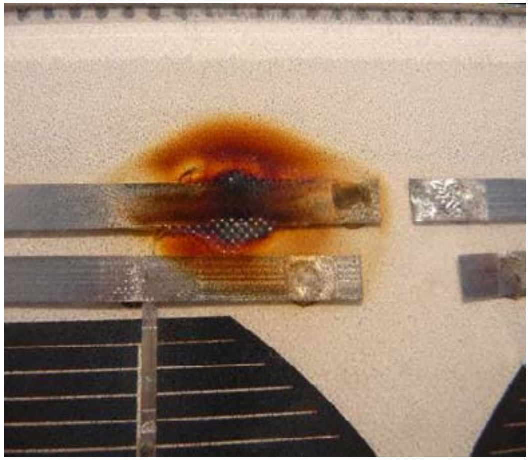
Pmax correlated to Isc loss for Si

Pmax correlated to FF loss for thin film

Internal Electrical Circuit Issues Often Dominate

David DeGraaff
http://www1.eere.energy.gov/solar/pdfs/pvmrw2011_01_plen_degraaff.pdf

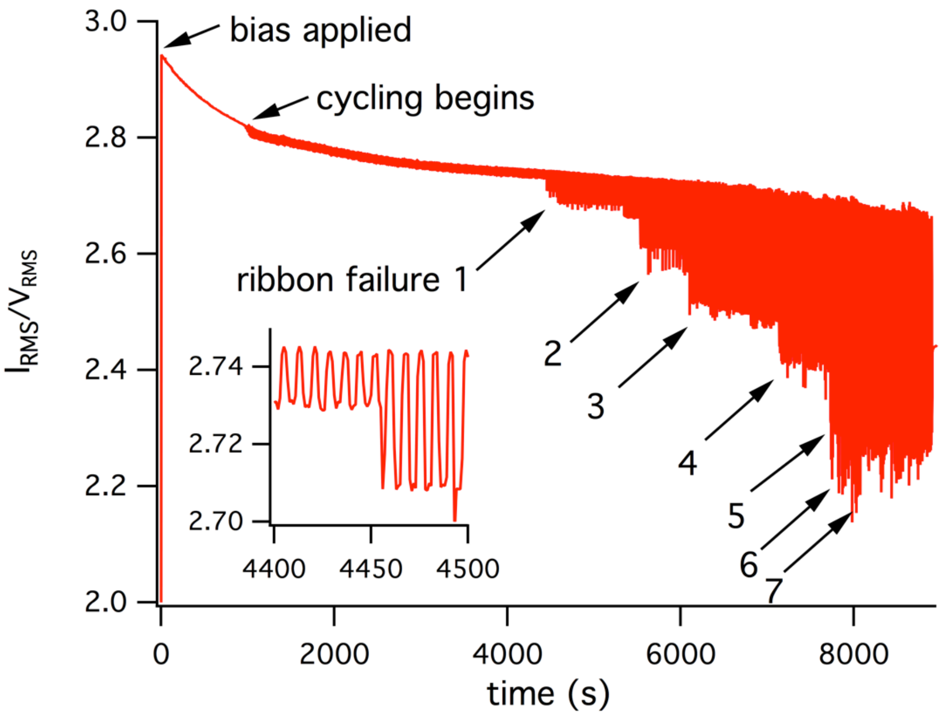




Mfg B: 1.5% failure rate

Mfg C: 2.9% failure rate

Cyclic Mechanical Loading Detects Ribbon Failure



Purpose: reduce time needed to apply a lifetime of stress:

- *use cyclic mechanical load instead of thermal cycling*

Results:

- *Ribbon testing can be completed in hours!*
- *Solder bonds are not stressed appropriately*

Still needed:

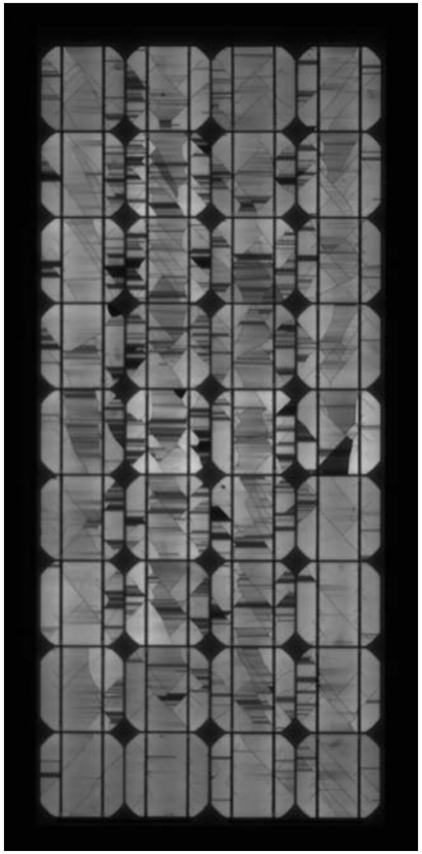
- *Faster way to test solder bonds*
- *Methods for quality control*

Work reported by Nick Bosco

Example of failure mechanism that is relatively well understood and can be highly accelerated without causing irrelevant failures

Three types of failures in the laminate

- **Broken ribbons**
  - Testing is much like testing a paper clip
  - Cyclic mechanical stress gives very high acceleration
- **Broken solder bonds**
  - Time-dependent response to stress increases time needed to induce damage
  - Acceleration factors are smaller and harder to quantify, but testing is effective; 200-2000 cycles?
- **Cracked cells**
  - Power loss occurs if cracked piece becomes disconnected
  - Problems are uncovered by mechanical load followed by thermal cycling

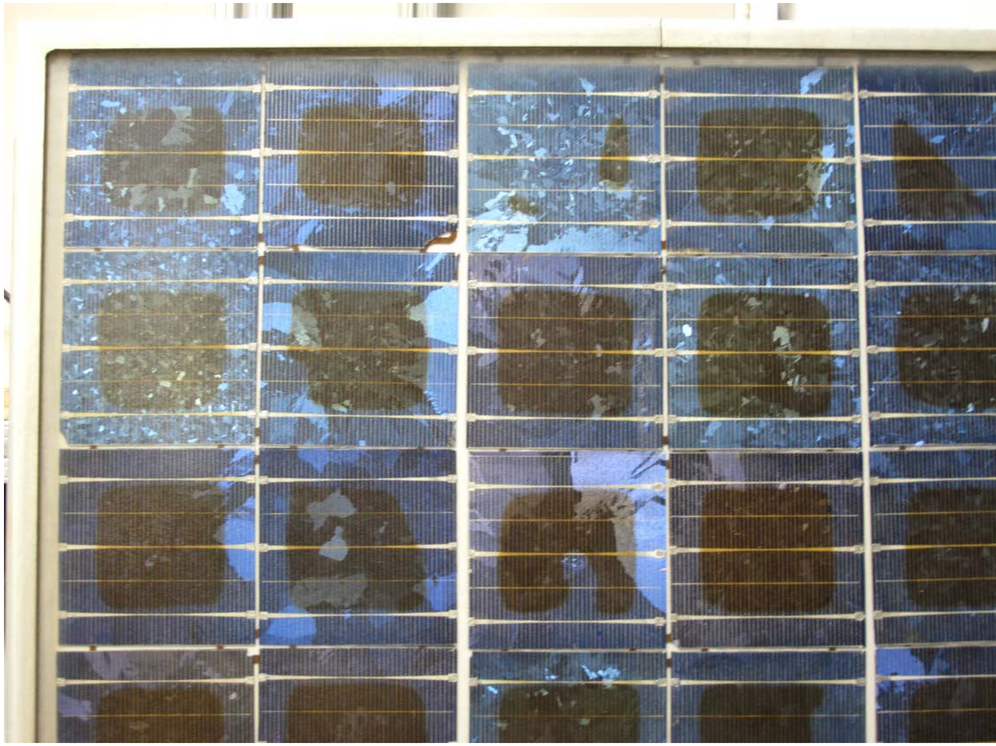


We know how to detect design flaws that cause these failures!

But, we'd like to detect the problems faster and nondestructively!

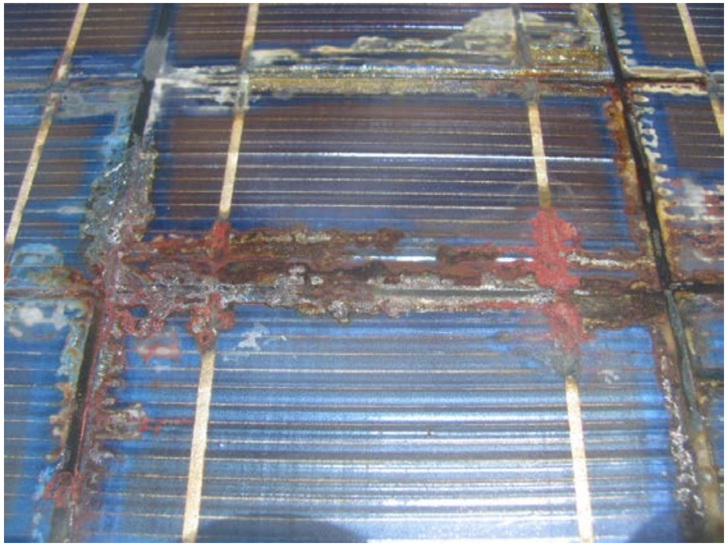
Encapsulant Discoloration

- Discoloration may be primary source of degradation (Isc loss)
- Competing reactions cause discoloration and bleaching
- What if bleaching is accelerated more than discoloration? *High acceleration factors may result in "wrong" answer*



Chemistry of polymers can be complex
What to do?
Be relevant by using high acceleration BUT, be scientific by defining degradation kinetics and doing parallel tests with low acceleration factors!

Corrosion – is damp heat the "right" test?



- Corrosion is associated with delamination
- In the lab, delamination can be induced by UV, then humidity freeze, then damp heat?

Is it paradoxical that to test for corrosion, we should define how to test for delamination?

What do we know or not know about delamination?

- Know:
  - UV can weaken adhesion
  - May weaken more at higher temperatures
  - Humidity freeze is useful for materials that absorb moisture
- Don’t know:
  - What adhesion is needed?
  - Does the needed adhesion depend on design?
  - Do fracture mechanics apply equally to viscoelastic materials?
- This is a research opportunity!

From Knowledge to Standards

- **International efforts are underway:**
  - Pool knowledge to improve test methods
  - Incorporate this knowledge into international standards
  - Use these standards as a foundation for a healthy PV industry!

A little history

International PV Module Quality Assurance Forum

San Francisco, July 2011

Goals:

1. Create a QA rating system to differentiate the relative durability of module designs

1) Compare module designs
2) Provide a basis for manufacturers' warranties
3) Provide investors with confidence in their investments
4) Provide data for setting insurance rates

2. Create a guideline for factory inspections of the QA system used during manufacturing.

Hosted by
NREL
AIST
PVTEC

Effort started in 2011 by AIST and NREL has now grown as "PVQAT"

Supported by
METI
US DOE
JRC, SEMI PV Group

Technical Challenges

1. **How can we determine that a module design is adequate for the warranty?**
   - Compressing 25 years of testing into 3 months is like trying to hatch a chick in 6 hours!
2. **How can we ensure that modules coming off the production line reflect the intended design?**
   - If something goes wrong and it takes us 3 months to discover it, we'll have a lot of out-of-spec modules!
3. **How can we ensure that the entire system is put together and functioning correctly?**
   - Even if all of the components are perfect, the system can fail in many ways

1. Durable Design – Climate-specific testing

Technical work led by PVQAT

- **Baseline test designed for temperate climate using open-rack mount**

- **Additional tests according to use environment:**
  - **Desert climates**
  - **Tropical climates**
  - **Roof mount**
  - **High snow or wind load**
  - **Salt or marine environment**
  - **Sand (abrasion)**
  - **Low temperatures**

2. Consistent Manufacturing – PV QMS

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Proposal for a Guide for Quality Management Systems for PV Manufacturing: Supplemental Requirements to ISO 9001-2008

Paul Norum
Amonix

Ivan Sinicco
Tokyo Electron

Yoshihito Eguchi
Japan Electrical Safety and Environment Technology Laboratories (JET)

Sumanth Lokanath
First Solar

Wei Zhou
Trina Solar

Gunnar Brueggemann
Tokyo Electron

Alex Mikonowicz
Powermark

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National Institute of Advanced Industrial Science and Technology (AIST)

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Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

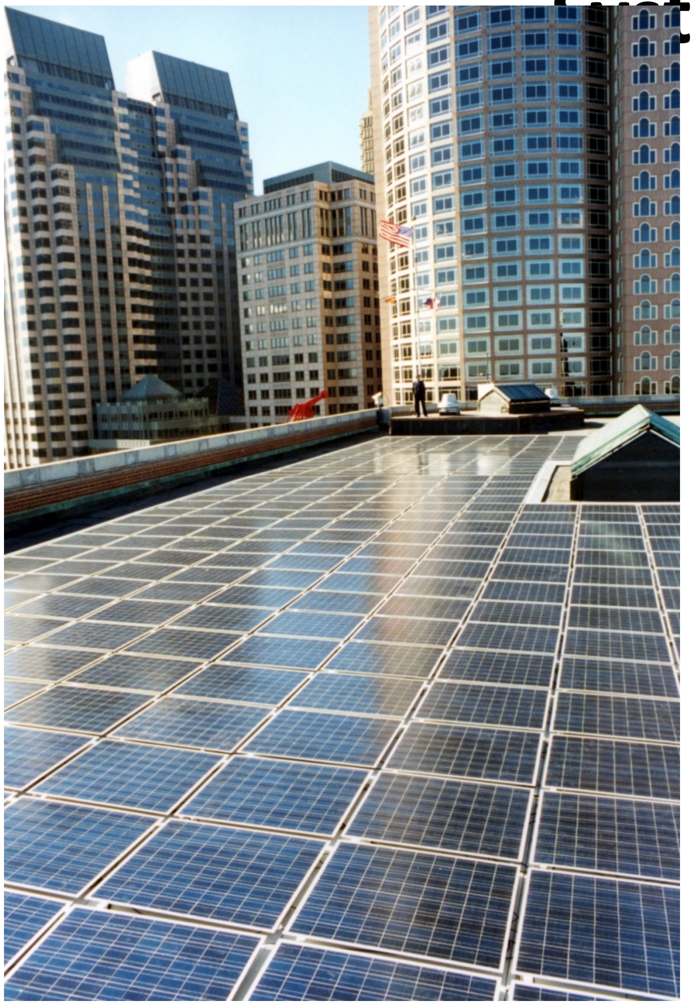
Technical Report
NREL/TP-5200-58940
May 2013

- Plan to complete a PV-specific version of ISO 9001 in 2015
- Guide for PV Quality Management System http://www.nrel.gov/docs/fy13osti/58940.pdf
- Builds on Japanese standard*
- What will it take to be "trusted" by others?

*JIS Q8901-2012 Terrestrial photovoltaic (PV) modules-Requirement for reliability assurance system (design, production, and product warranty)

3. System Verification – IECRE

IEC has formed IECRE for Renewable Energy System verification

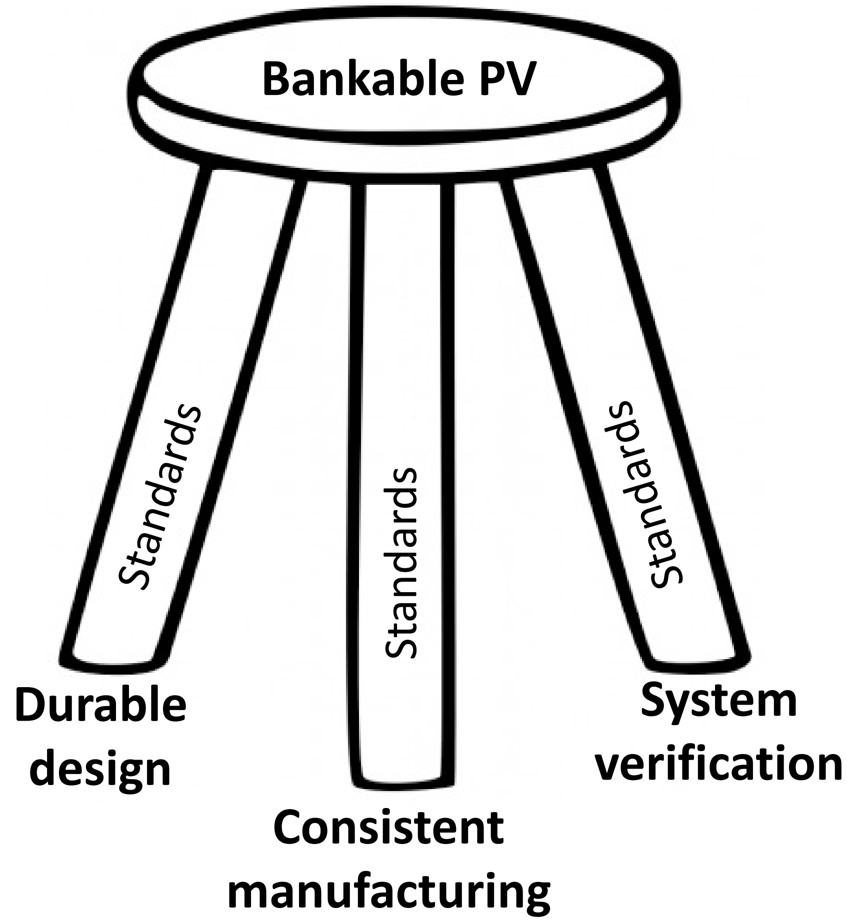


PV Standards for testing all aspects of PV Systems:

- Component quality
- System
  - Design
  - Installation
  - Operation
- Training of personnel

Three-prong effort addresses three questions

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**



PVQAT welcomes volunteers!

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International PV Quality Assurance Task Force

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he International PV Quality Assurance Task Force (PVQAT, "PV cat") leads global fforts to craft quality and reliability standards including:

MODULE DURABILITY

A rating system to ensure durable design of PV nodules for the climate and application of interest

MANUFACTURING CONSISTENCY

A guideline for factory inspections and quality assurance (QA) during module manufacturing

SYSTEM VERIFICATION

A comprehensive system for certification of PV systems, verifying appropriate design, installation, and operation

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PVQAT Timeline

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www.pvqat.org 12 task groups; ~ 500 volunteers

Service Life Prediction

1. Identify failure/degradation mechanisms that determine end of life
2. Quantify kinetics
3. For given use environment, apply kinetics within model to estimate expected lifetime
4. Verify model by comparing with field data

This step-by-step procedure is clear, but the actual tests are not

This procedure is similar to quality management

Creating a standard for service life prediction

- **Product development cycle needs to slow enough to allow time for longer tests**

- **Start today:**
  - Screen for and eliminate design flaws
  - In parallel, begin to quantify failure/degradation rates for stubborn problems for this specific product
  - Implement standard for service life prediction through the quality management system (a quality system should strive to deliver a product that meets the warranty!)

Conclusions

- **Industry has matured: it's natural to focus more on reliability now!**
- **PV reliability is just starting to mature (we have a great track record, but have a long way to go)**
- **Can be practical and scientific by:**
  - Understand mechanisms so as to detect during quality control or as small change early in process
  - Use short tests for screening, but longer, scientifically accurate tests in parallel
  - Differentiate use environments
  - When possible, track evidence of degradation before full test
  - Recognize that not all products will show same kinetics: implement service life prediction in the quality management system!
- **Join PVQAT & share scientific understanding!**

Be practical, but work toward being true to the science

Thank you!

- **John Wohlgemuth and others at NREL**
- **Michio Kondo, Masaaki Yamamichi, Tony Sample, George Kelly, Jim Sites and hundreds of others who are joining together to apply their scientific knowledge to practical, healthy industry growth!**
- **Department of Energy for funding!**
- ***To all of you for your attention!***
- ***sarah.kurtz@nrel.gov***