Defining a Technical Basis for Confidence in PV Investments – A Pathway to Service Life Prediction

Sarah Kurtz, John Wohlgemuth, Mike Kempe, Nick Bosco, Peter Hacke, Dirk Jordan, David Miller, and others from the community

IEEE Reliability Symposium

Phoenix, Arizona

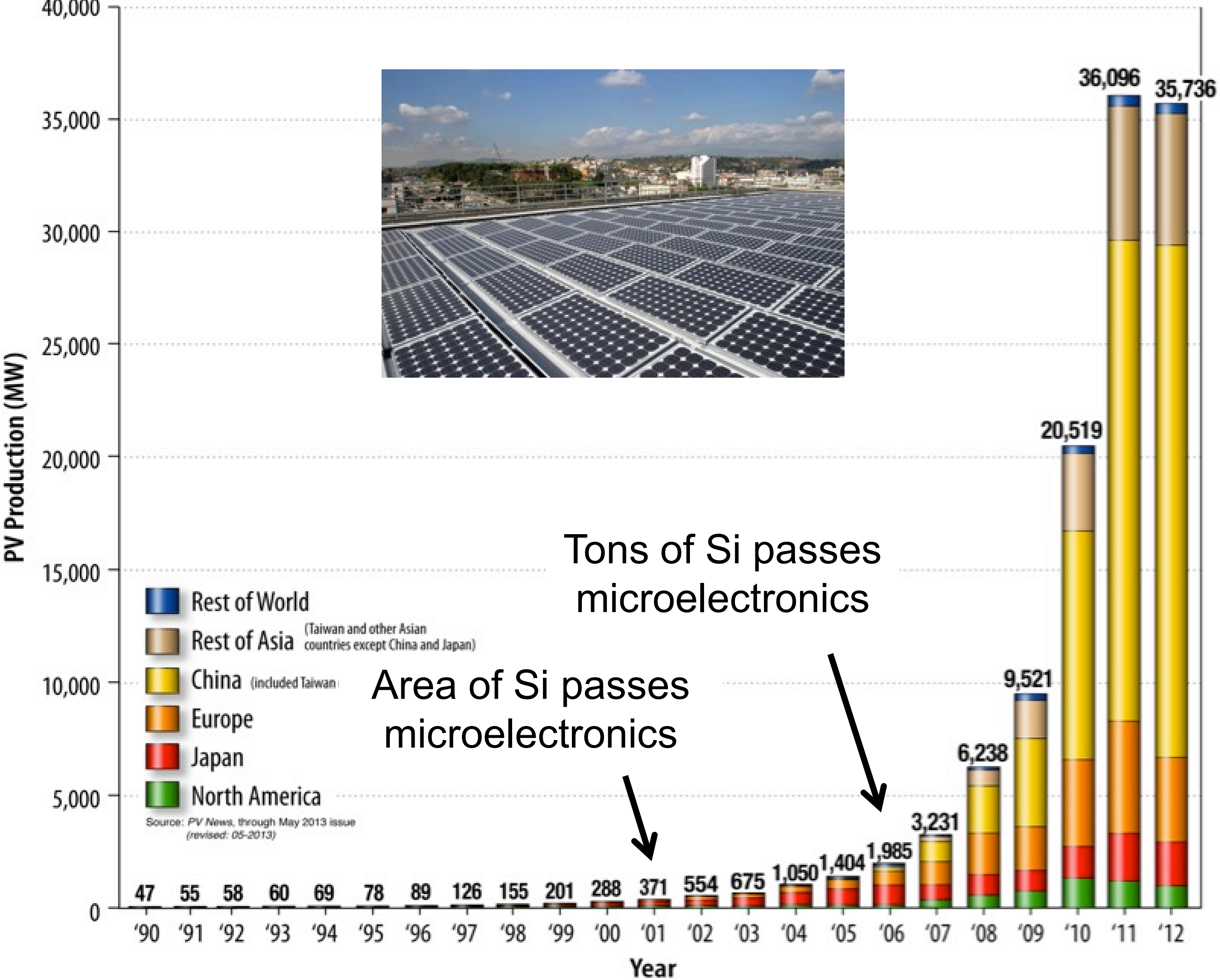
September 17, 2013

NREL/PR-5200-60554

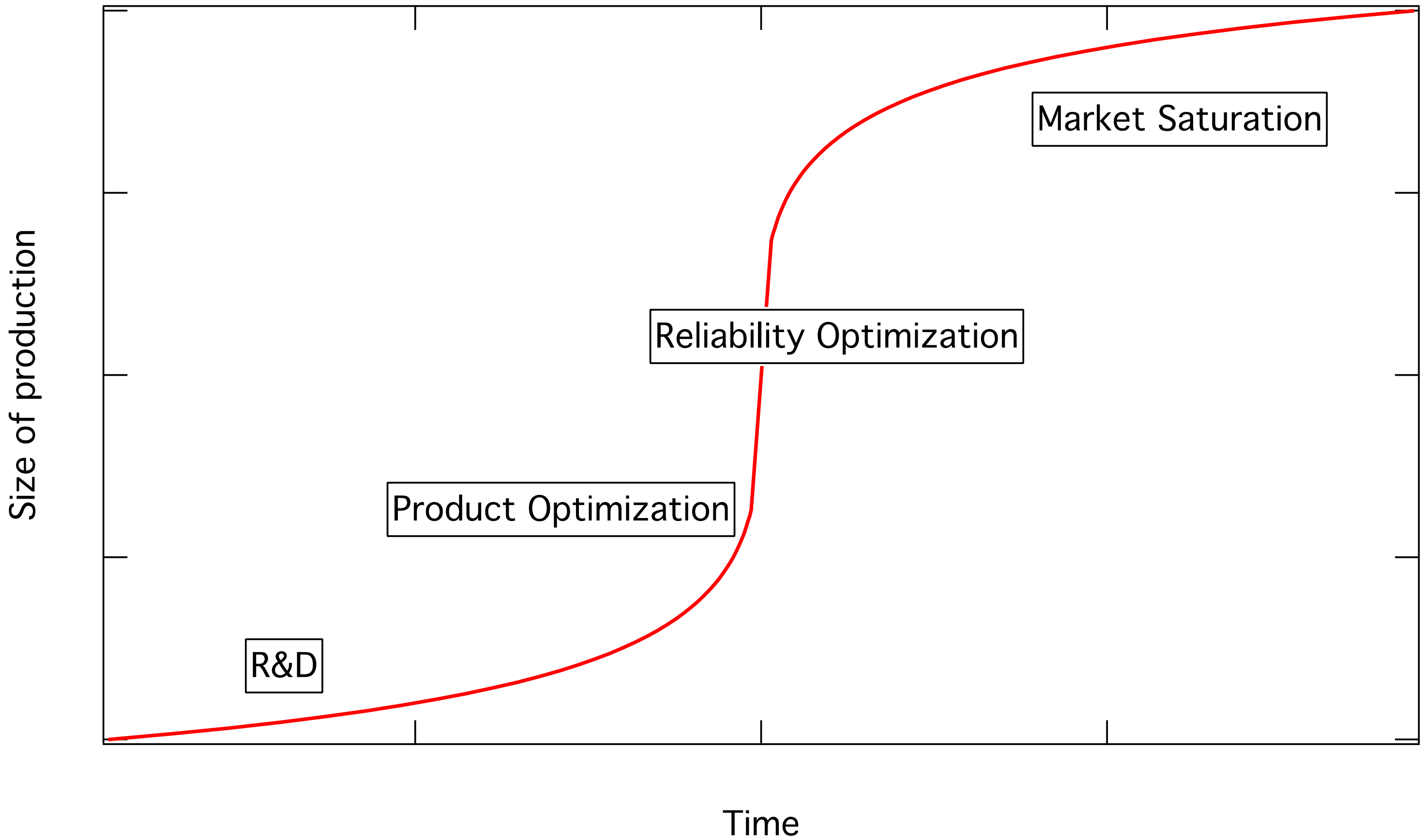
Outline

- Motivation: Importance of Reliability to PV Today
- Challenge: Squeezing 25 years into 3 months!!!
  - Qualification vs Qualification "plus" vs Comparative vs Quantitative
- What can we learn from history?
  - What's been demonstrated
  - Room for improvement
- Proposal for Qualification "plus" testing:
  - Additional tests
  - More thorough testing
  - Required quality program
- Comparative Testing (Climate/Application Specific)
- Quantitative Service Life Predictions

PV Industry has Grown to be Huge!



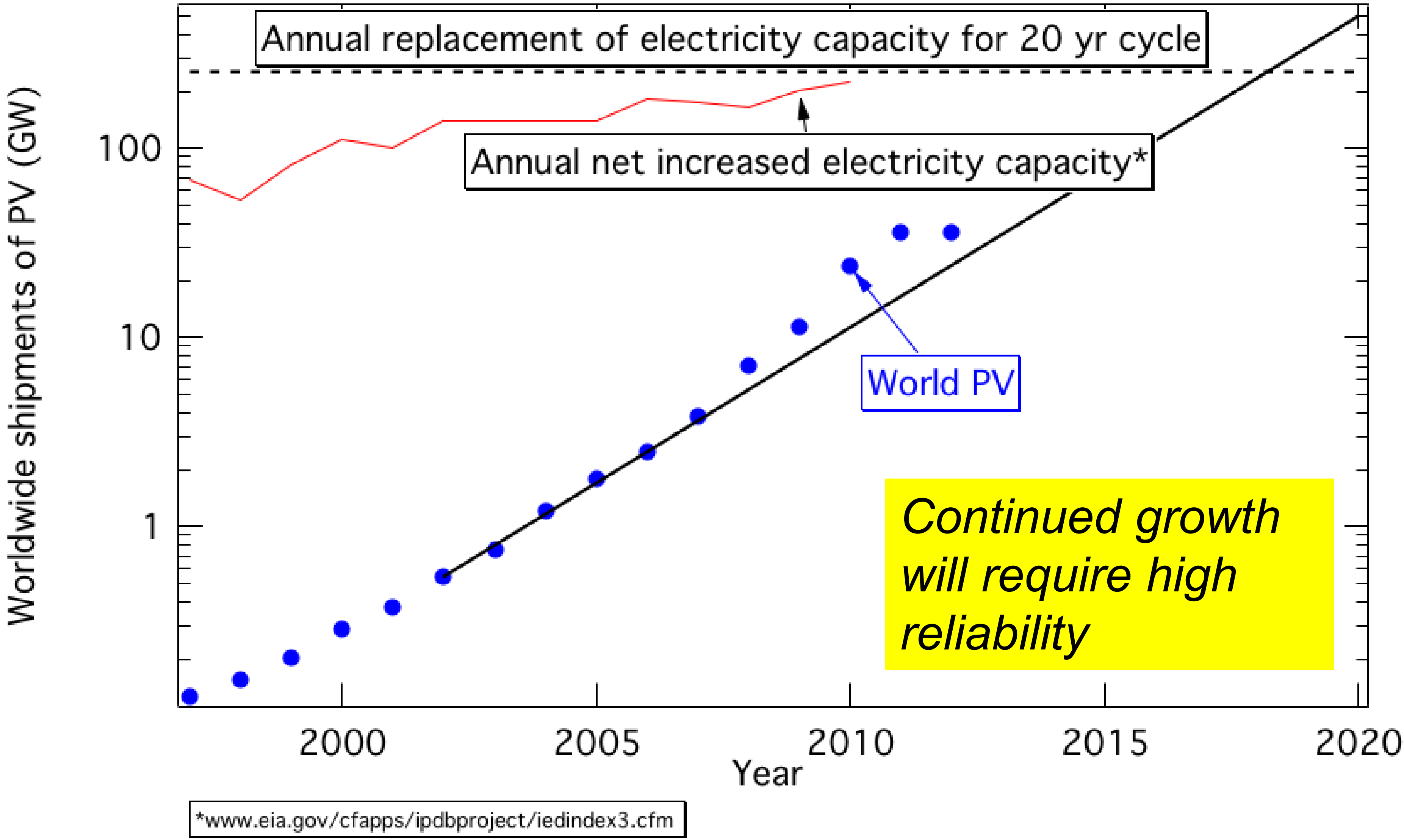
Reliability Optimization is an Important Element of Growth



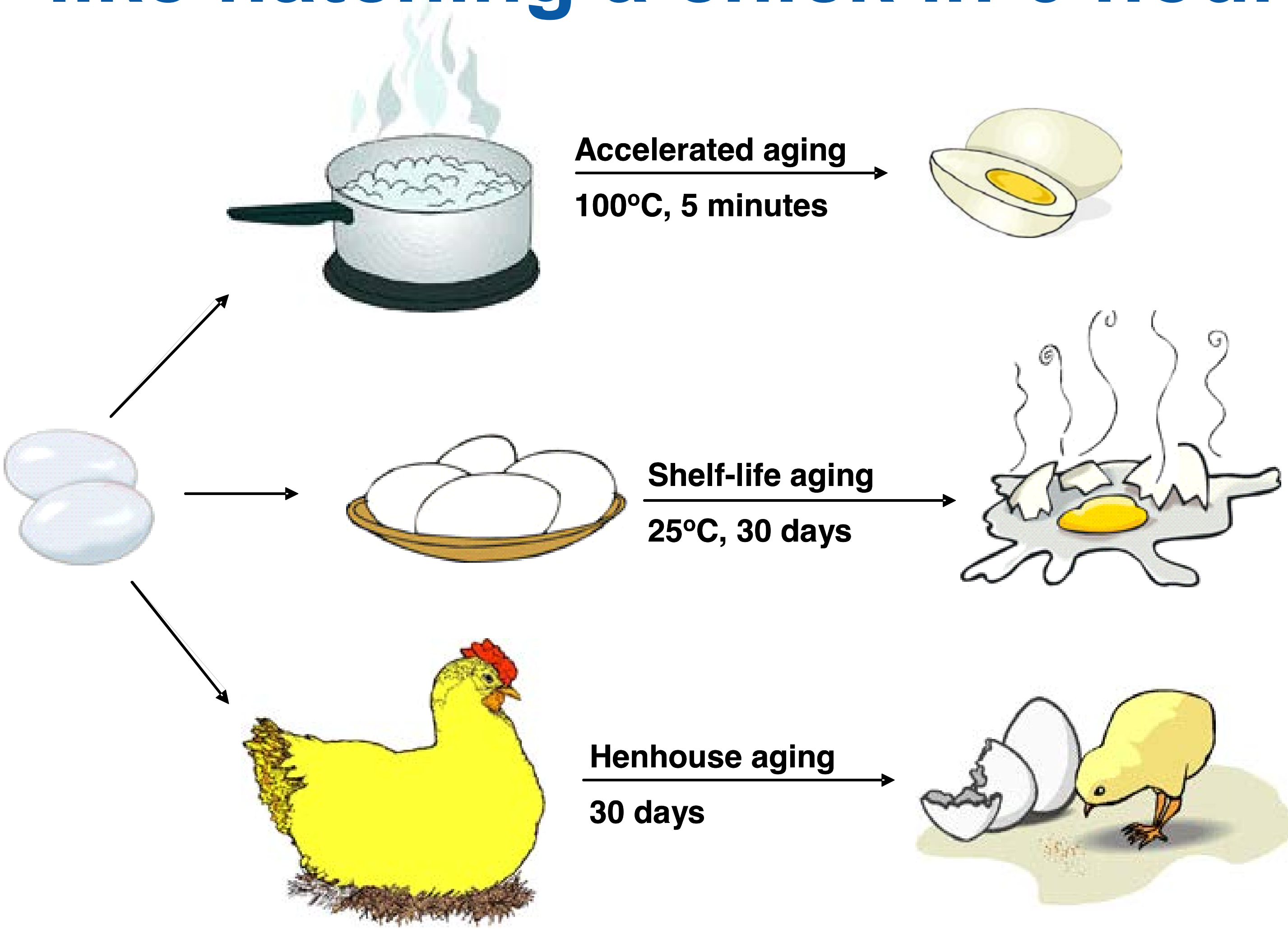
PV is now approaching ~$100 Billion/y

Reliability is key to continued natural growth

Growth of PV Industry Requires Reliability

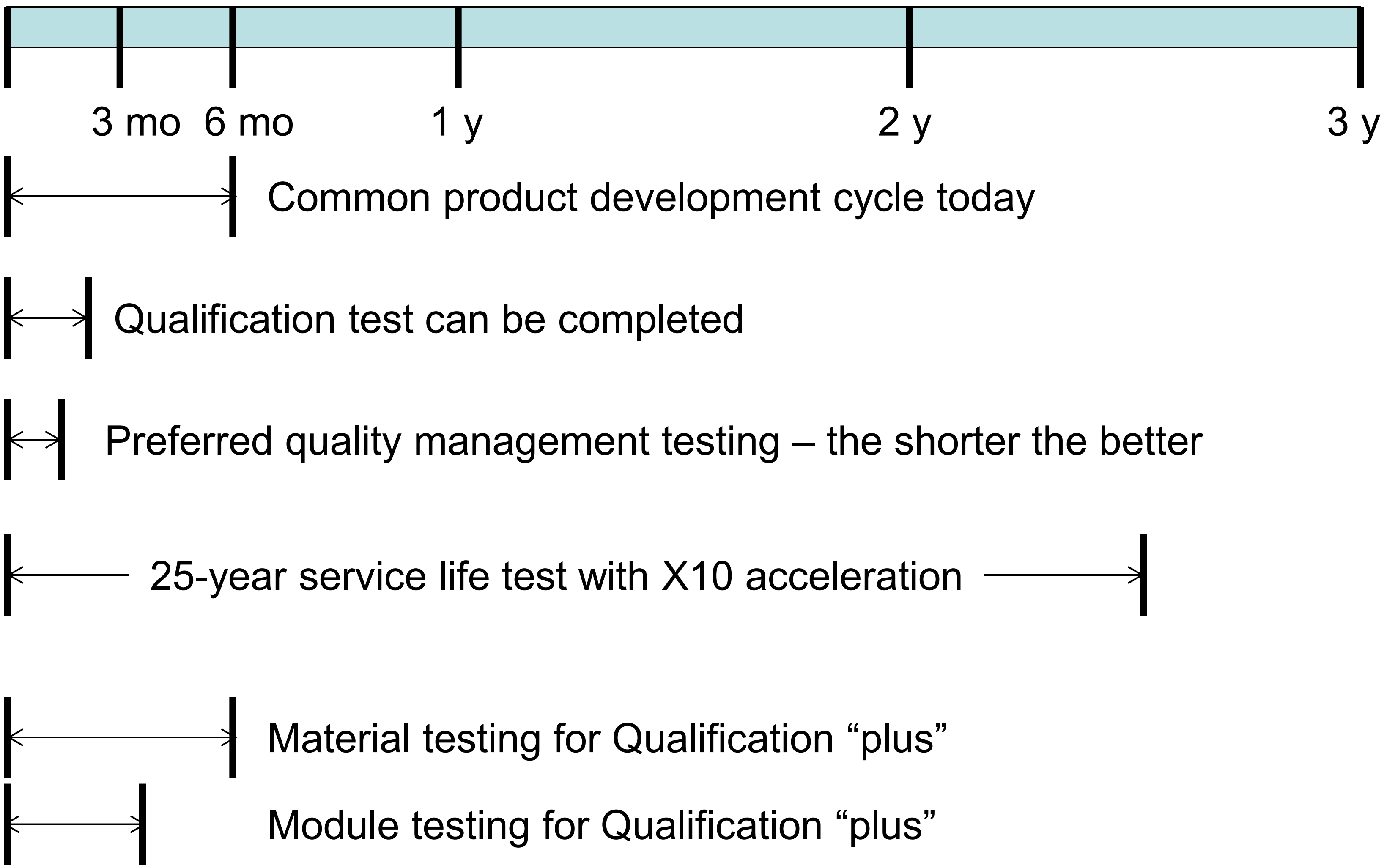


Accelerating 25 y into 3 months is like hatching a chick in 6 hours!

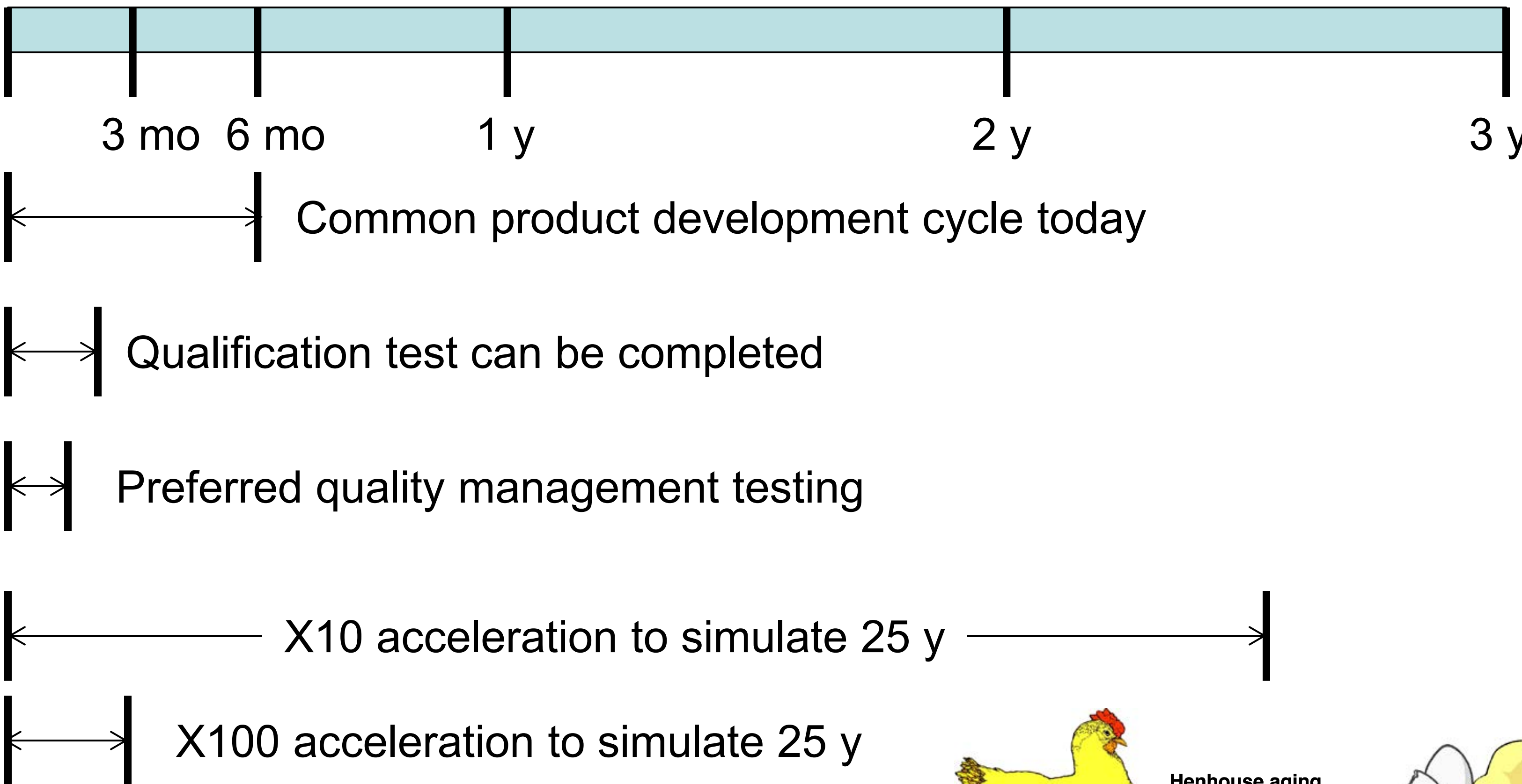


Some processes cannot be accelerated quantitatively > 10X

Timeline Challenge



Timeline Challenge



Some processes can be accelerated;
For others, too much acceleration answers the wrong question!

Some Levels of Accelerated Testing

	Qualification	Qualification "Plus"	Comparative	Service Life
Purpose	Minimum design qualification	Enhanced design qualification	Comparison of products	Substantiation of warranty
Quantification	Pass/fail	Pass/fail	Relative	Absolute
Climate or application (mounting)	Not differentiated	Not differentiated	Differentiated	Differentiated
Specificity	Silicon, thin-film, CPV	For today, discuss Si only	Package specific?	Product specific
Chamber test times	Modules: ~ 6 weeks	Modules: ~ 3 months Materials: ~ 6 months	TBD	3 years ?

Standard tests for qualifying modules – a starting point!

- Qualification tests were initially developed in 1970s-1980s
- Today we have:
  - IEC 61215 (silicon) or
  - IEC 61646 (thin film) or
  - IEC 62108 (CPV).
- When carefully implemented, these have had great success for avoiding infant mortality in most PV systems!

Why we need to test "beyond" the standard

- Despite PV's excellent success, some failures are seen in the field.
- New system designs cause new failures.
- Market is expanding into broader applications (climates)
- Low prices motivate manufacturers to cut corners – might the corner be cut too short?

Look first at what we're seeing in the field:

A data set summarizing > 1 GW

We correlate field experience and results from accelerated testing to choose new tests

Validation of the PVLife Model Using 3 Million Module-Years of Live Site Data

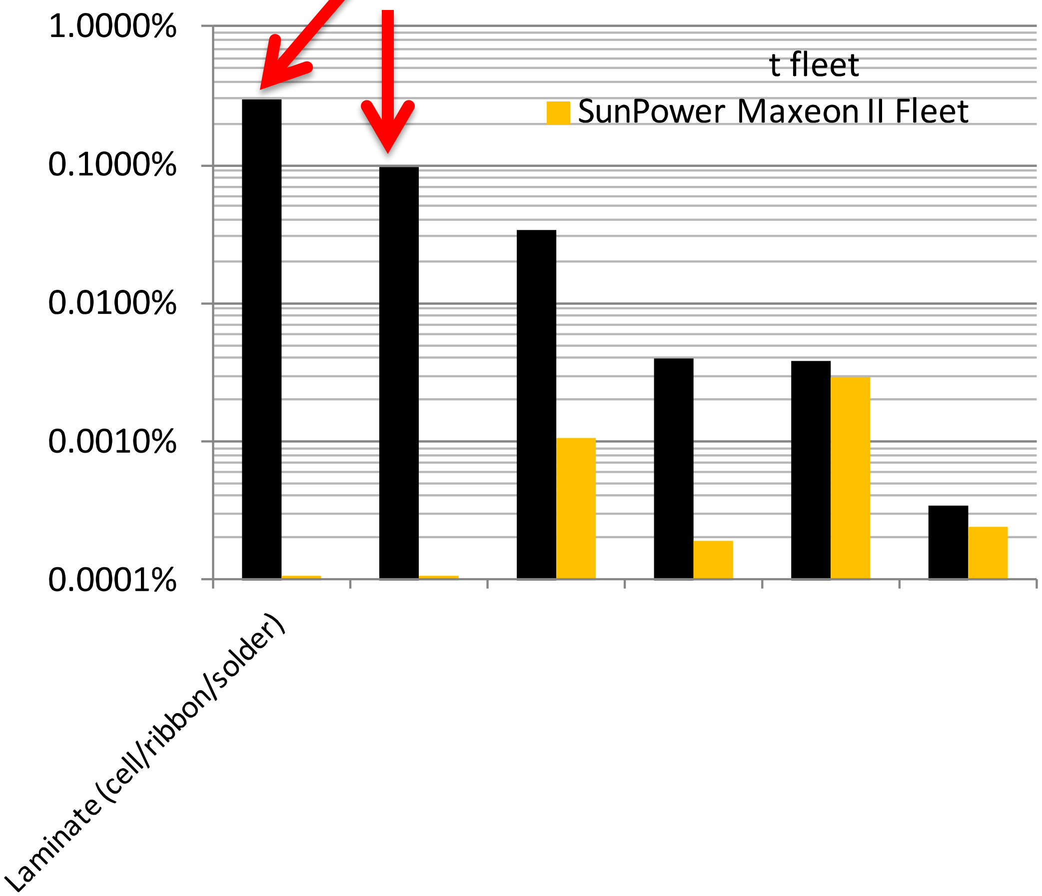
Presented at 39th PVSC

Represents data for > 1 GW fleet

Ernest Hasselbrink, Mike Anderson, Zoe Defreitas, Mark Mikofski, Yu-Chen Shen, Sander Caldwell, Akira Terao, David Kavulak, Zach Campeau, David DeGraaff

SunPower Corporation, 51 Rio Robles, San Jose, CA 95134 USA

Most common failures – be sure to address these



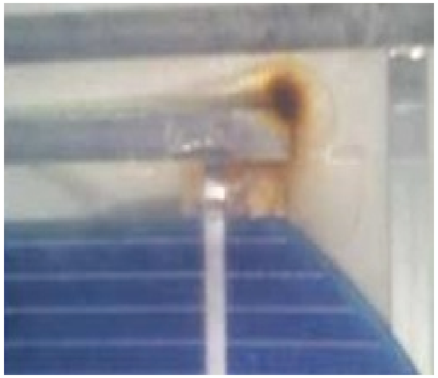
Return rates:

- 0.44% (for 3,400,000 front-contact silicon modules with average age of 4.9 y)
- 0.005% (for > 8,000,000 back-contact silicon modules with average age of 2.1 years)

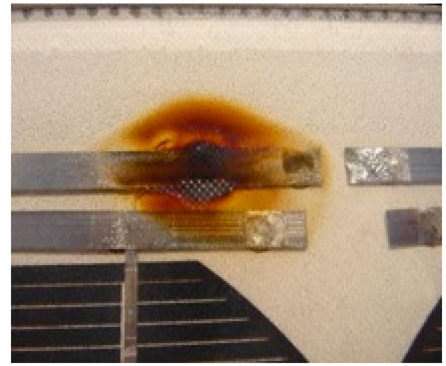
Failures of internal electrical circuit

Degraaff
NREL Reliability
Workshop, 2011

Mfg A:
0.3%
failure rate



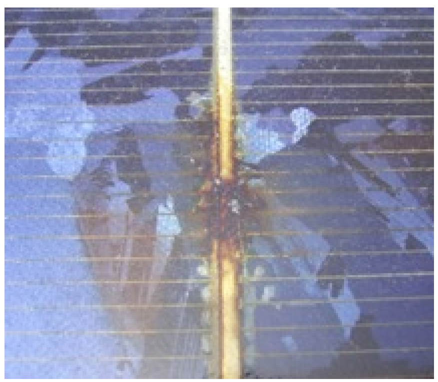
Mfg B:
1.5%
failure
rate



Note:

- Manufacturers differ by > 10X
- Current IEC tests not designed to identify 1% failure rates

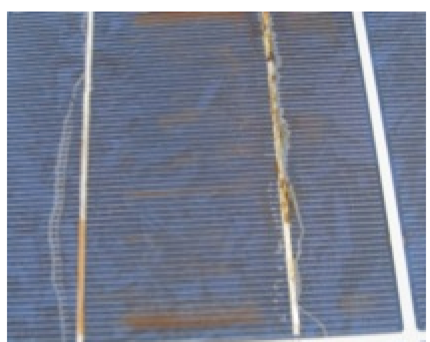
Mfg C:
2.9%
failure
rate



← Front

Back →

Mfg E:
0.1%
failure
rate



← Front

Back →

Summary of Selected Field Studies

Kurtz, et al. 39th PVSC 2013

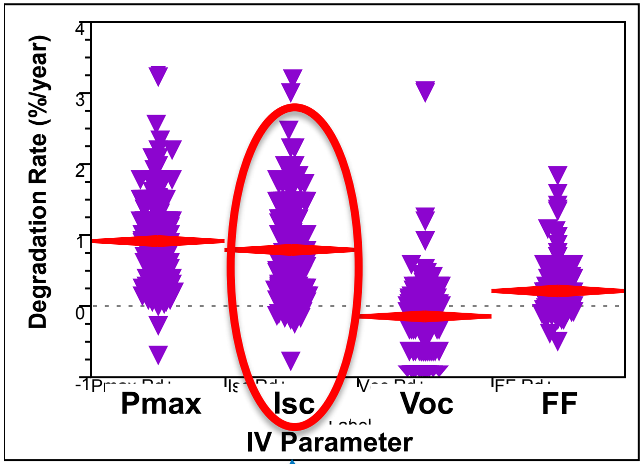
Observation	Sample Size	Reference
Laminate internal electrical circuit 36% of failures (~2% of modules failed after 8 years); glass 33%; j-box and cables 12%; cells 10%; encapsulant and backsheet 8%	21 manufacturers; ~60% of fleet of > 1.5 GW	DeGraaff
16% of systems required replacement of some or all modules because of a variety of failures, with many showing breaks in the electrical circuitry	483 systems	Kato
3% developed hot spot after < 7 years; 47% had non-working diodes	1232-module system	Kato
Encapsulant discoloration 66%; delamination 60%; corrosion 26%; glass breakage 23%; j-box 20%; broken cells 15%*	~2000 reports	Jordan

- Field failures differ, but some themes include:
  - Thermal-fatigue-induced broken ribbons and solder bonds
  - Encapsulant discoloration and delamination
  - Diode or junction box issues

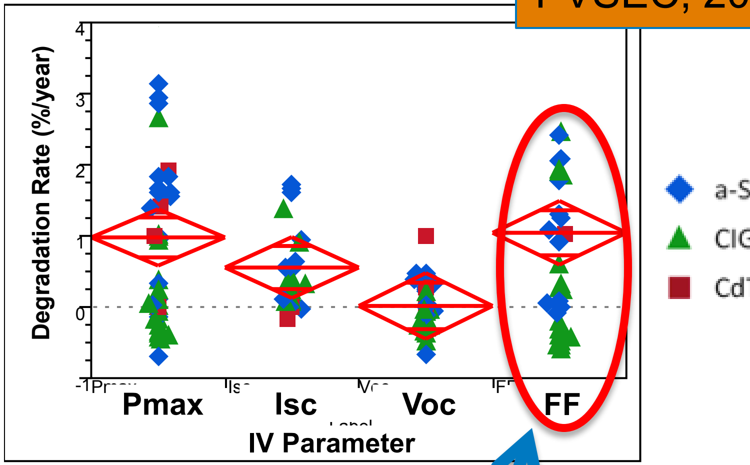
Wear-out mechanisms vary

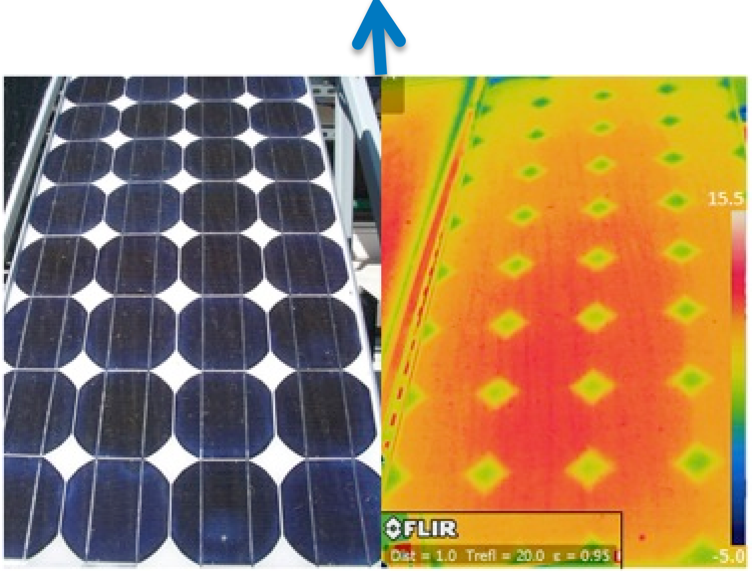
Jordan, 27th Eu. PVSEC, 2012

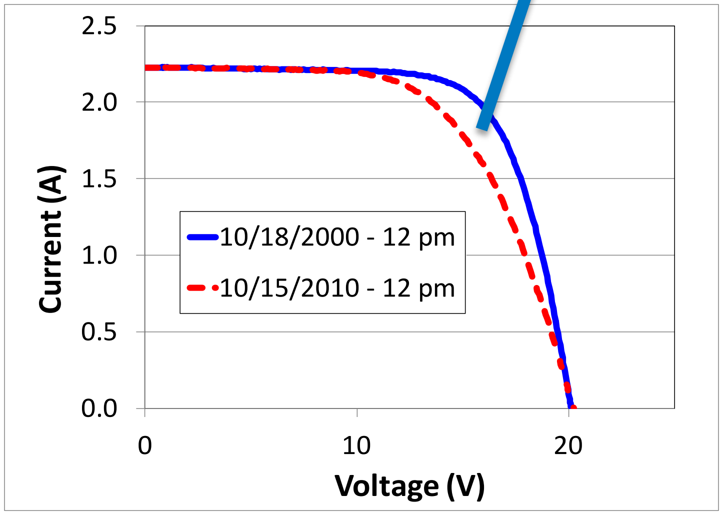
Multi-Si



Thin-film







Pmax correlated to ***Isc*** loss for Si

Pmax correlated to ***FF*** loss for thin film

Some Levels of Accelerated Testing

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Testing beyond current IEC tests

- Ed. 3 of IEC 61215 will have multiple revisions/additions
  - These will become available to the public over the next ~2 years
  - Can we adopt improvements sooner?

- The California Energy Commission (CEC) has given us the opportunity to define an optional “plus” version of their Eligibility Requirements
- Next slides describe the “plus” requirements

Proposal to test "beyond" the standard

- Despite PV's excellent success, some failures are seen in the field.
  - Propose 7 new tests
- Low prices motivate manufacturers to cut corners – might the corner be cut too short?
  - Propose more frequent/extensive testing
  - Propose oversight of quality management system
- Tests will continue to evolve

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#1 Proposed testing “beyond” IEC 61215

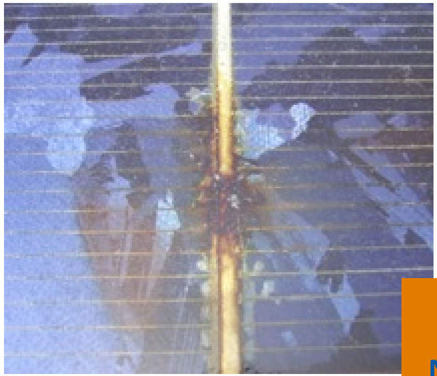
Failure type: Failure of connections within electrical circuit

Proposed change: Increase thermal cycling from 200 cycles (~ 6 weeks) to 500 cycles (~ 15 weeks).

Benefit: This type of failure can lead to fires and/or catastrophic module failure.

Comment: There is evidence that 200 cycles gives confidence for ~ 10 y in the field; 500 cycles may give confidence closer to 25 y.

Wohlgemuth, 23rd EU PVSEC, p. 2663, 2008



Degraaff
NREL Reliability Workshop, 2011

Wear-out mechanism

#2 Proposed testing "beyond" IEC 61215

Failure type: Cracked cells, etc. leading to disconnections

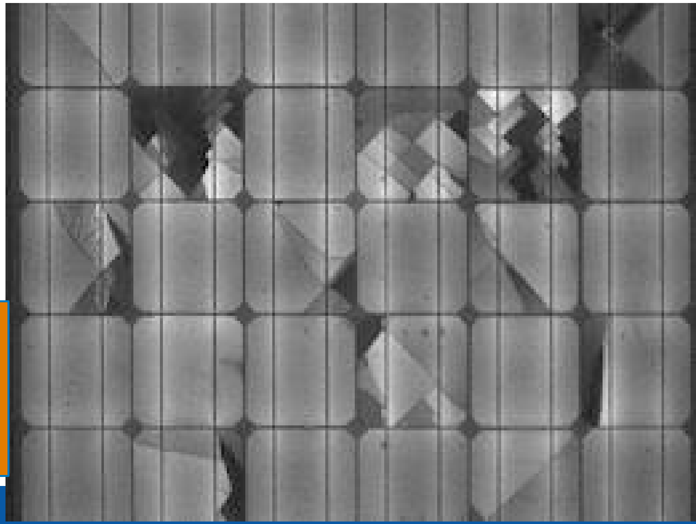
Proposed change: Apply Dynamic Mechanical Load before 50 thermal cycles and 10 humidity freeze cycles

Benefit: This type of failure can lead to fires and/or catastrophic module failure.

Comment: Today's thinner cells sometimes crack during shipping or snow/wind loading. At first, there may be no power loss, but after further stress, the metal interconnects may begin to break.

Note: this may be a faster way to achieve the stress of 500 thermal cycles – uncovers many types of failures

Wohlgemuth, 32nd PVSC, paper 420, 2008
Pingel, 24th European PVSEC, p. 3459, 2009
Koch, 25th European PVSEC, p. 3998, 2010



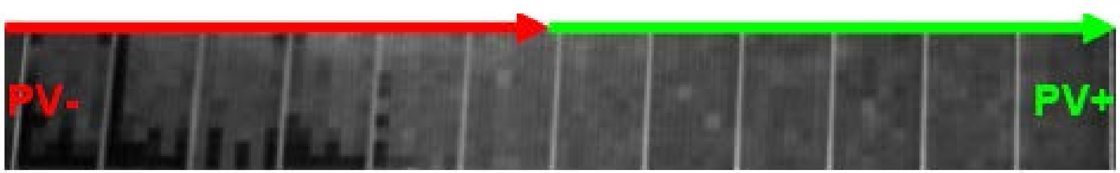
#3 Proposed testing “beyond” IEC 61215

Failure type: System-voltage (potential-induced) degradation (module failure is caused by system)

Proposed change: Apply system voltage during damp heat or similar condition.

Benefit: For systems that float (active circuit ungrounded), the degradation can be dramatic (tens of % in first year). New inverter designs have enabled this style of system design.

Comment: Test has been proposed to IEC.



Modules at negative end of string show degradation (indicated by black)

http://www.nrel.gov/docs/fy12osti/54581.pdf

#4 Proposed testing "beyond" IEC 61215

Failure type: Degradation of encapsulant (yellowing, delamination)

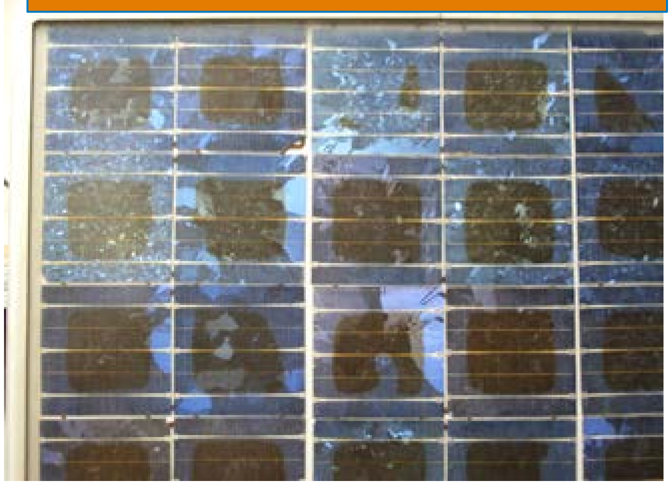
Proposed change: Expose materials in "module-like" configuration to UV and heat for ~ 6 months (use test that was defined by STR ~ 15 y ago)

Benefit: Avoids degradation. Yellowing causes slow power decrease.

Comment: May be done by encapsulant manufacturer.

Note: Historically, encapsulant manufacturers used this sort of test, so field failures were small. Now, newer manufacturers may or may not use adequate testing; it's not required in IEC 61215.

Wohlgemuth, 39th PVSC, 2013
Reid, SPIE, vol. 8825, 2013



Wear-out mechanism

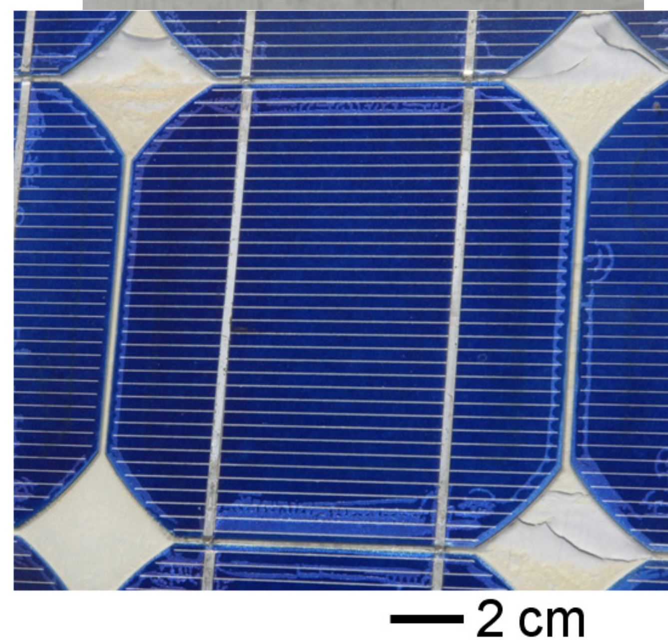
#5 Proposed testing “beyond” IEC 61215

Failure type: Degradation of backsheet (cracking, delamination) leading to losses in safety or performance

Proposed change: Expose inner and outer layers of backsheet to UV consistent with outdoor exposure

Benefit: Avoids safety and performance issues (e.g. if backsheet no longer provides adequate protection of the electrical circuit leading to shock hazard and/or to corrosion).

Comment: May be completed by backsheet manufacturer.



Wear-out mechanism

Gambogi, et al, EUPVSEC 2012,
Gambogi, et al, NREL PVMRW 2013,
Gambogi, et al, 39th PVSC 2013

#6 Proposed testing “beyond” IEC 61215

Failure type: Hot-spots from local reverse bias during partial shading

Proposed change: Use Edition 3 revised hot-spot test and retest random sample each month

Benefit: This type of failure can cause fires.

Comment: Is planned for adoption into IEC 61215.

ASTM E2481-06
TamizhMani & Sharma, SPIE 7048 (2008)

#7 Proposed testing "beyond" IEC 61215

Failure type: Bypass diode

Proposed change: Increase bypass diode thermal test from 1 h to 96 h.

Benefit: Some manufacturers used cheaper diodes that passed the 1-h test, but failed in the field.

Comment: Other bypass diode tests are in development. Failure of bypass diodes can lead to fires

Testing for Electrostatic Discharge (ESD) should be done in the factory

Zhang, et al, PVMRW 2013

Proposal to test "beyond" the standard

- **Despite PV's excellent success, some failures are seen in the field.**
  - **Propose 7 new tests**
- **Low prices motivate manufacturers to cut corners – might the corner be cut too short?**
  - **Propose more frequent/extensive testing**
  - **Propose oversight of quality management system**

Test (sampling) methods changes

1. Choose all test samples randomly from production (no engineering samples and no cherry picking)
2. Increase number of test samples per leg from 2 to 5
3. Randomly select samples (at least 2 per leg) from production for retest at least once per 3 months (small-volume manufacturers may have reduced requirement); address any failures.

Why we need to test "beyond" the standard

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  - Propose 7 new tests
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Quality Management: PV-specific ISO-9001

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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

Paul Norum
Amonix

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

Wei Zhou
Trina Solar

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Powermark

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

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Technical Report
NREL/TP-5200-58940
May 2013

Organization controls the PV module's design to align the expected lifetime with the warranty

- Builds on Japanese standard*
- Report at http://www.nrel.gov/docs/fy13osti/58940.pdf

***Before launching their recent incentive program, Japan created**: "JIS Q8901-2012 Terrestrial photovoltaic (PV) modules-Requirement for reliability assurance system (design, production, and product warranty)"

Levels of Accelerated Testing

	Qualification	Qualification Plus	Comparative	Service Life
Purpose	Minimum design qualification	Enhanced design qualification	Comparison of products	Substantiation of warranty
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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.

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NREL
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PVTEC

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METI
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US DOE
SEMI PV Group

A little history

The PV QA Task Force was formed at the conclusion of the Forum and consisted of five Task Groups:

Task Group 1: PV QA Guideline for Manufacturing Consistency (leaders Ivan Sinicco, Alex Mikonowicz, Yoshihito Eguchi, Wei Zhou, G. Breggemann)

Task Group 2: PV QA Testing for Thermal and mechanical fatigue including vibration (leader Chris Flueckiger, Tadanori Tanahashi)

Task Group 3: PV QA Testing for Humidity, temperature, and voltage (leaders John Wohlgemuth, Neelkanth Dhere, Takuya Doi)

Task Group 4: PV QA Testing for Diodes, shading and reverse bias (leaders Vivek Gade, Paul Robusto, Yasunori Uchida)

Task Group 5: PV QA Testing for UV, temperature and humidity (leader Michael Köhl, Kusato Hirota, Jasbir Bath)

These groups began meeting by teleconference in summer of 2011.
Since then, five other task groups have been added.

Additional Task Groups:

Task Group 6: Communication of PV QA Ratings to the Community
(leaders David Williams, Sarah Kurtz)

Task Group 7: PV QA Testing for Wind and Snow Loads
(currently inactive)

Task Group 8: Thin Film Testing
(leaders: Neelkanth Dhere, Veronica Bermudez, Tobias Roschek, Shuuji Tokuda)

Task Group 9: CPV Testing
(leaders: Itai Suez, Nick Bosco)

Task Group 10: Connectors
(leader: Juris Kalejs)

Proposed comparative rating system

Qualification	Qualification "plus"	Comparative		Service Life
IEC 61215	"Plus" list as optional version of CEC Eligible Hardware list	**IEC 60721-2-1 Climate Designation**	**New Tests Require Additional Stress**	Talk about next
		Moderate	Thermal cycling, UV, diodes	
		Warm Damp, Equable (Tropical)	Tests for delamination & moisture ingress in humid climates	
		Extremely Warm Dry (Desert)	Tests for higher temperatures	

Classes	
Rack mount	Close-roof mount

Mounting can be as important as climate!

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Service Life Prediction Standard?

- How would you write a standard for making a Service Life Prediction?

- The failure mechanisms that limit the life of a product vary

Steps to Service Life Prediction

1. Identify failure/degradation mechanisms that determine end of life
2. Quantify rates (model)
3. For given use environment, apply 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; Actual tests will build on comparative tests

This *procedure* is similar to quality management

Propose: Implement Service Life Prediction within Quality Management System

NATIONAL RENEWABLE ENERGY LABORATORY

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Technical Report
NREL/TP-5200-58940
May 2013

- The best quality management systems will include an assessment of whether the product can meet the warranty – this is the best place to quantify Service Life
- A complete Service Life Prediction takes years to create and verify – most aspects of the product design must be “frozen” first
- Propose to differentiate with ratings:
    - Platinum
    - Gold
    - Silver

Summary

- The PV Industry has grown
    - Current IEC standards have provided excellent reliability
    - There's opportunity to take these to the next level
- Qualification "plus" tests will provide incremental improvement as optional requirement for CEC list
    - Seven tests that go "beyond" standard tests (**new**)
    - Random product sampling and more frequent testing (**new**)
    - Robust quality management system (PV-specific version of ISO 9001) (**new**)
- International PV Module QA Task Force is developing comparative climate-specific tests
- Quality Management System is the pathway to defining a standard method for ascribing Service Life

Proposed approaches to PV Reliability

Qualification	Qualification "plus"	Comparative		Service Life
IEC 61215 ***What we have today***	"Plus" list as optional version of CEC Eligible Hardware list ***What we'll have next year***	**IEC 60721-2-1 Climate Designation (for rack and close-roof mounting)**	**New Tests Require Additional Stress**	**Implement through Quality Management System:** • **Platinum** • **Gold** • **Silver**
		Moderate	Thermal cycling, UV, diodes	
		Warm Damp, Equable (Tropical)	Tests for delamination & moisture ingress in humid climates	
		Extremely Warm Dry (Desert)	Tests for higher temperatures	

In development, using community's collective wisdom