SAND2011-2206C

PV Performance and Reliability Validation Capabilities at Sandia National Laboratories and The National Renewable Energy Laboratory

PV MANUFACTURING WORKSHOP – MARCH 25, 2011

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Outline

- What does Product Validation encompass?
- Product Validation Expertise at the National Labs
- Generalized Validation Techniques for MW-scale production
- Validation Capabilities at Sandia
- Validation Capabilities at NREL
- Summary

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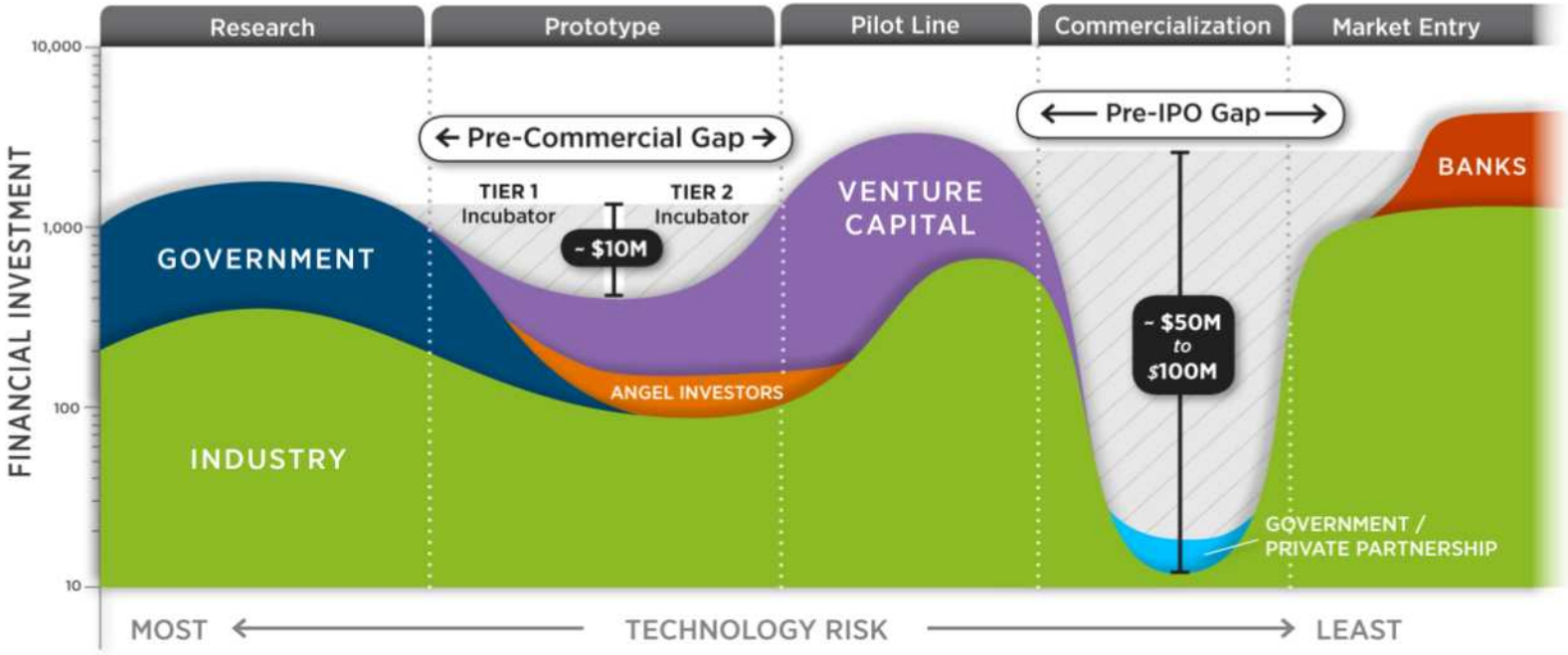
Valley of Death



In scaling up manufacturing and implementing large-scale systems in the field, **how can performance and reliability be validated?** What are the factors for bankability? What can be done to reduce risk?

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Product Validation

Product validation encompasses:

1. **Product performance (voltage, current, power) off the line**
2. **Expected product performance in the field, i.e., annual yield (kWhs)**
3. **Product performance over time: durability and reliability**

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Product Validation: STC Performance

1. Product performance (voltage, current, power) off the line

a) Manufacturing Quality Control/SPC (e.g. ISO 9001, Six Sigma)

b) Accurate in-line testing based on appropriate reference standards (e.g. ASTM 948, ASTM 1036)

c) 3rd party Materials/Cell/Module testing and calibration of appropriate reference devices (e.g. NREL, Sandia, NRTLs)

This primarily refers to validating repeatable STC performance

Product Validation: STC Performance

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Product Validation: Annual Yield

2. Expected product performance in the field, i.e., annual yield (kWhs)

A. Model expected performance based on test data

a) 3rd party module test to measure and calculate modeling coefficients needed to predict yield

b) Develop the model of expected performance (e.g. Sandia Array Performance Model, IEC 61853-1, Wisconsin 5 Parameter Model)

c) Small-systems (1-5 kW) testing for initial model validation

B. Prototype MW-scale system performing as expected upon installation

a) Initial field test of prototype installation for power at AC level

b) Sampling of DC IV curves at array, string, module level

c) Comparison of initial field test to model and small-systems results

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B. Prototype MW-scale system performing as expected upon installation

a) Initial field test of prototype installation for power at AC level – *provide guidance or perform as needed*

b) Sampling of DC IV curves at array, string, module level

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Product Validation: Reliability

3. Product performance over time: durability and reliability

A. Reproducible expected lifetime: Component scale

a) Product has gone through rigorous accelerated testing protocols and real-time degradation/failure testing
b) Product has passed standard and appropriate qualification tests (e.g. IEC 61215, UL standards)
c) Manufacturing Quality Control/SPC
d) 3rd party audits on-going (e.g. ISO, TUV, UL)

B. System performance and reliability over the actual lifetime: Based on prototype MW-scale installation

a) On-going system monitoring and analysis
b) Periodic sampling of DC IV curves at array, string, module level
c) Detailed collection of O&M data and analysis
d) Comparisons with “beta” test sites

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B. System performance and reliability over the actual lifetime: Based on prototype MW-scale installation

a) On-going system monitoring and analysis

b) Periodic sampling of DC IV curves at array, string, module level

c) Detailed collection of O&M data and analysis – *labs focus on O&M method and analysis*

d) Comparisons with "beta" test sites – *labs have available space for beta sites*

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Generalized Validation Approach:
Performance

Approaches to validate >multimegawatts worth of solar modules:

1. Component STC performance validation (modules or cells)
   - Manufacturer provides data on all modules
     - Spread sheet and graphical form histogram distribution of Pmax, Voc, Isc, etc.
   - Appropriate lab characterizes a statistical sample of modules/cells and compares with manufacturer's data on those same modules.
     - Modules/cells should be sampled over time to sample day to day and week to week variations
     - Newer technologies may require larger sampling
   - Outdoor characterization on a subset to validate modeling coefficients (modules)
2. Validation of performance once installed in a MW-scale system
   - Module-scale performance conditions tested at various reference points (IEC 61853)
   - Initial high-accuracy DC performance assessments
   - String-level monitoring (DC, AC) over time
   - Spot-check of module and string DC performance (IV-curves) annually
   - Compare output with performance models (DC and AC) at each stage
   - Compare MW field performance (measured and modeled) with beta test sites

Generalized Validation Approach:
Reliability

Step 0: Define the use conditions, including environmental conditions and system design

1. Module reliability validation
   - Apply a reliability-based test protocol on a sampling basis (similar to Performance validation sampling)
   - Small systems (~10 kW) testing to independently measure degradation rates and detect early failure modes
2. Reliability characterization in a MW-scale system
   - Develop an O&M strategy to capture more in-depth failure modes (beyond current O&M practices) – encourage implementation and data sharing for validation
   - Repeated DC performance checks over the lifetime to validate degradation rates and failure modes (combined with Performance)
   - Perform periodic field inspections to detect developing reliability issues (often due to materials and workmanship)
   - Comparison of MW field performance with beta test sites

Laboratory Transparency

Sandia and NREL, as part of the DOE team, can provide testing, analysis, characterization, and guidance as part of the validation process

The Labs:

- **Provide equal treatment to all partners with regard to data quality, reporting, etc.**
- **Maintain records and processes available for review**
  - NREL's Cell and Module Standards Lab has A2LA Accreditation and is ISO 17025 certified
  - Sandia' Module Lab is developing ISO 17025 processes
- **Protect proprietary information and intellectual property**

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Validation Techniques at Sandia

Performance

Continuous outdoor I-V curve and peak-power tracking measurements for flat-plate and CPV modules on 2-axis tracker

- Validate flash-test results and calculate modeling coefficients
- Includes thermal performance and off-angle characterization

Indoor module and cell characterization

- Dark IV, IR, UV (module)
- Light IV, dark IV, spectral response (cell)
- Soon to be added: module-scale simulator

Sensor calibration: (NIPs, PSPs, reference cells)

Small systems assessments on site (<10 kW)

- Validate string-level performance, develop energy yield and performance models, investigate possible interoperability issues

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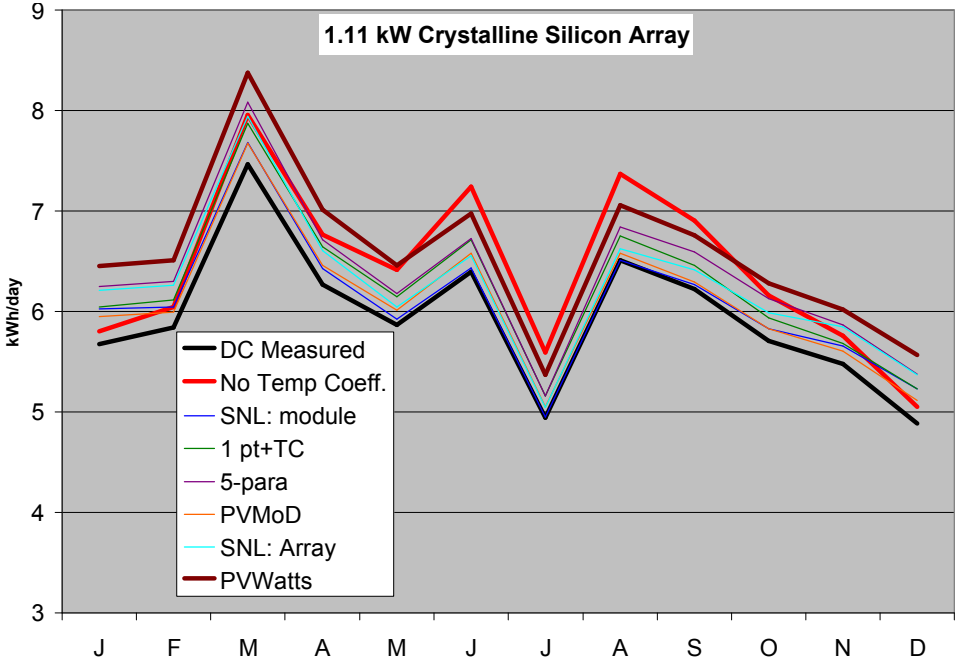
Validation Techniques at Sandia

Performance

- **Field testing: IV assessments, IR camera, AC analysis techniques, other diagnostics**
- **PV Demo Zone at Sandia to compare 50 kW – 250 kW scale systems (in-depth monitoring and analysis) with large field installations (beta test site)**
- **Systems modeling to compare expected with actual performance**



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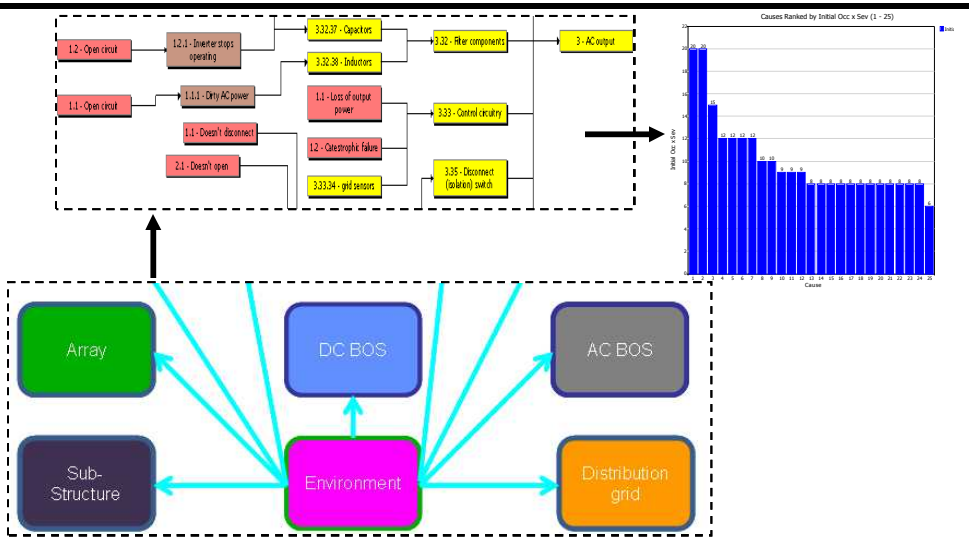
Validation Techniques at Sandia

Reliability

Facilitate Failure Modes and Effects Analyses for modules, components, and systems. Design changes can be caught and implemented prior to commercialization or based on issues found in the field.



Small Systems Testing: measure degradation rates, investigate early failures

- In coordination with Performance and Model validation
- Provide feedback to manufacturer for improvements
- Testing in multiple locations

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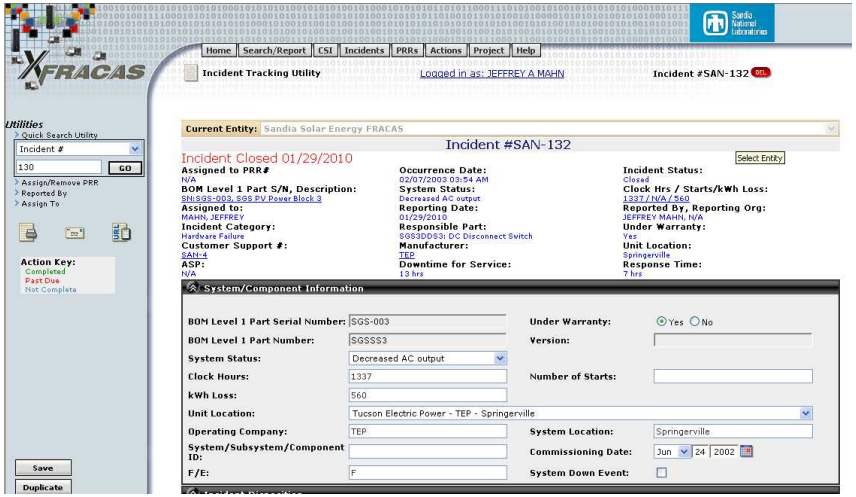
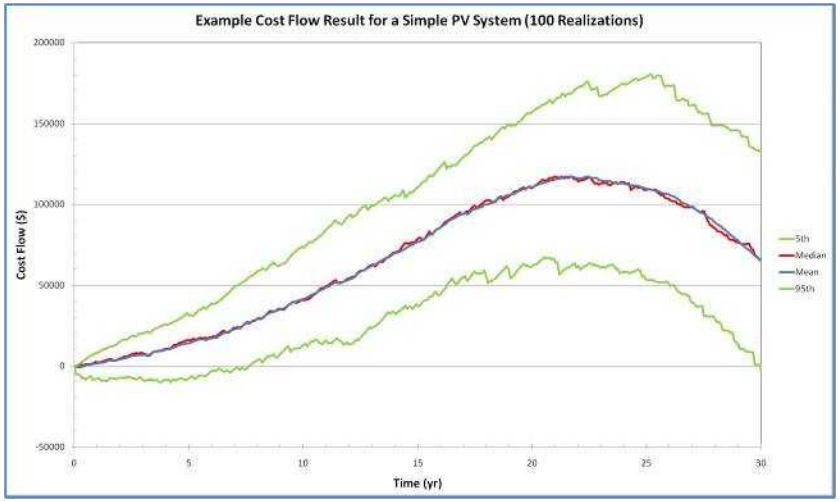
Validation Techniques at Sandia

Reliability

O&M Strategies and Data Analysis: Apply this standardized format for collecting PV systems field O&M data, optimized to allow direct data transfer from the database into analysis tools. O&M data can feed directly into predictive model.



Predictive Modeling: Sandia is developing an integrated performance, reliability, availability, weather and cash flow model. First of its kind model uses Monte Carlo processes and data distributions to model the range of expected energy outputs, reliability, availability, and cash flow.



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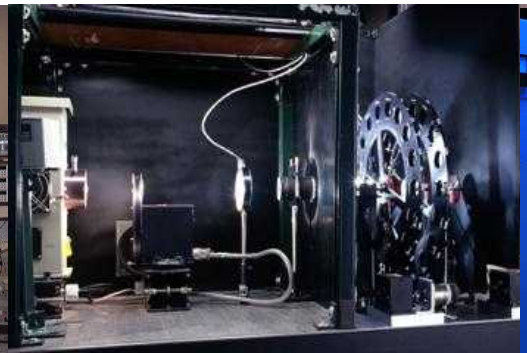
Validation Techniques at NREL

Performance

Performance-Based Capabilities and Techniques:

certificate number 2236.01
Accredited for photovoltaic secondary cell, secondary module, and primary reference cell calibration

- **Cell performance**
  - IV: One-Sun simulators for single-junction and multi-junction solar cells
  - Concentrator IV: Multi-sun up to 2000 suns, various cell sizes
  - The spectral mismatch factor is computed and applied to the reference cell calibration
  - QE: Cell level, 250–1350 nm Xe, and 400-3200 nm Tungsten
- **Indoor module characterization on module simulators**
  - Continuous Simulator - light, dark IV, full control of pre-measurement conditions and bias rate, poor spatial nonuniformity, good temperature control
  - Pulsed simulator - good spatial nonuniformity, marginal bias rate control, excellent temperature control


Validation Techniques at NREL

Performance

- **Continuous outdoor I-V curve and peak-power tracking measurements for flat-plate and CPV modules**
  - Duration of measurements from days to years
  - Provides data for efficiency, energy production, performance characterization, and degradation.
- **NREL Primary PV Calibration**
- **Test bed for determining the performance characteristics of BIPV systems**
- **Evaluation of the performance characteristics of micro-inverters and dc-to-dc converters**

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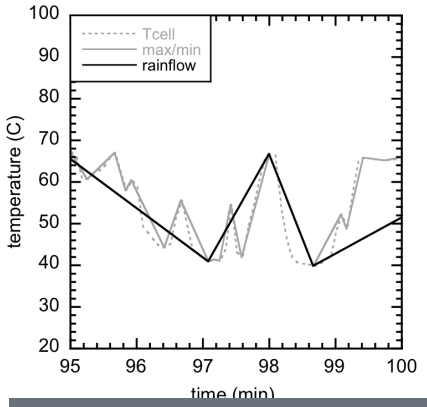
Validation Techniques at NREL

Reliability

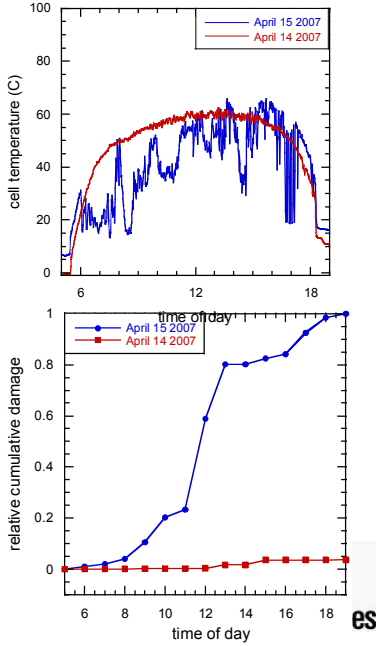
Long-term field monitoring
Why: Supports bankability
What: Any size: single modules, systems up to 1 MW

Modeling
Why: Predict field performance as function of weather
What: Identify ways to simplify weather data, then correlate to accelerated test data



Simplify temperature data

Partly cloudy day causes more damage than clear day



Validation Techniques at NREL

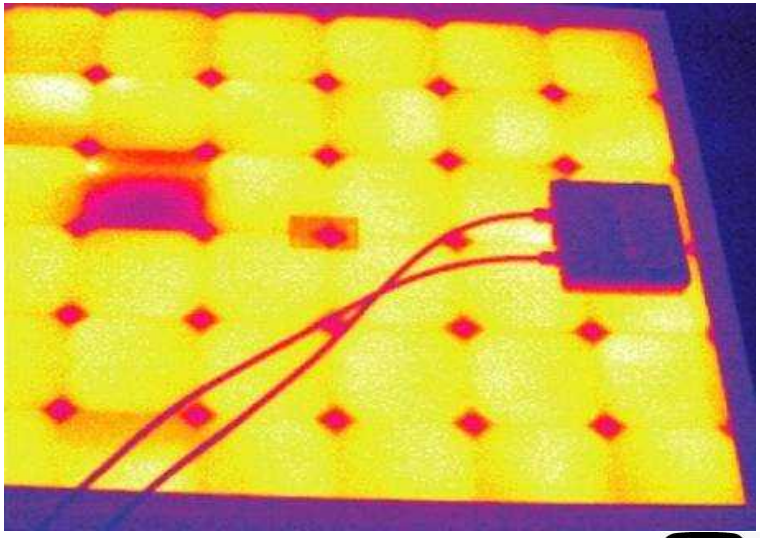
Reliability

Accelerated testing (both modules and components)
Why: Apply/develop tomorrow's standard test
What: Humidity, T, bias V, & light; permeation rates for H_2O & O_2

Module analysis

Why: Demonstrate quality of module before or after fielding

What: IR, EL imaging; Coring to measure adhesion strength



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Validation Techniques at NREL

Moving toward International QA Standards

The current state of the industry:

PV customers, investors and insurers are asking how to ensure quality

Many test labs have developed tests that "go beyond IEC 61215"

How to address this?

Define International Quality Assurance and Module Reliability standards Forum in May, 2011 to kick off effort

We anticipate new QA standards will be written in the next year – these new tests and protocols* will be piloted/tested at NREL and made available to DOE-funded projects

* Multilevel tests for assessing durability to thermal cycling, heat, humidity, voltage bias, light, etc.

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Summary

- The PV Manufacturing Initiative will require independent validation of performance and reliability
- NREL and Sandia, as part of DOE's team, have the capabilities to support the manufacturing initiative and provide validation from the cell level through MW-scale installations
- The labs provide transparent methods, apply them equally to all partners, and protect intellectual property
- More capabilities can be developed and capabilities can be altered for the specific product requirements
- We look forward to working with all awardees!

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