Reliability Demonstration Test

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Overview

For companies developing PV products and projects, PVEL is the premier solar panel performance and reliability testing lab.

We provide secure, expert testing and validation services so you can be confident that you're making intelligent decisions based on the most reliable data.

Capabilities

- We specialize in 3rd party performance and reliability reports for Bankability, R&D, and manufacturing.
- State-of-the-Art indoor lab facilities in Berkeley
- Outdoor Research Center in Davis called PV-USA

Why do we need testing?

Technical

- Solar panels deployed today will be under warranty in 2035
  - Your unborn children will be graduated from college

What	Range	Target
Initial Light Soak	+5% to -5% max power	+5% to -1%
Annual Degradation	0 to over -5% max power	0 to -0.5%
Catastrophic Failures (recalls/fires)	0 to 100%	minimal

Why do we need testing?

Commercial

- Project finance and insurance providers are risk averse
  - > 600 active PV module manufacturers (many more launching soon)
  - Module quality control in project dev is not widely adopted yet
  - Panel degradation and system downtime significantly impact LCOE

$$\text{LCOE} = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}}$$

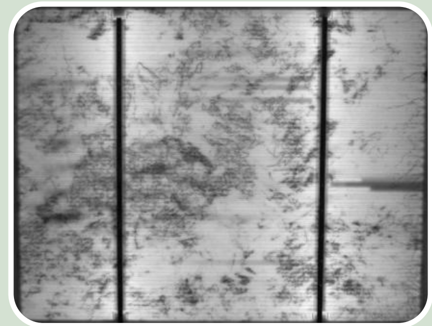
The above LCOE equation can be disaggregated for solar generation as follows:

$$= \frac{\text{Initial Investment} - \sum_{n=1}^{N} \frac{\text{Depreciation}^{n}}{(1+\text{Discount Rate})^{n}} \times (\text{Tax Rate}) + \sum_{n=1}^{N} \frac{\text{Annual Costs}^{n}}{(1+\text{Discount Rate})^{n}} \times (1-\text{Tax Rate}) - \frac{\text{Residual Value}}{(1+\text{Discount Rate})^{n}}}{\sum_{n=1}^{N} \frac{\text{Initial kWh/kWp} \times (1 - \text{System Degradation Rate})^{n}}{(1 + \text{Discount Rate})^{n}}}$$

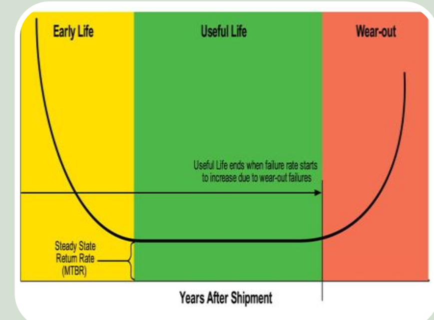
RDT Development Strategy

Compile List of Failure Modes Seen in the Field

Identify Stress Tests that stimulate failures



Identify Techniques to Characterize Failures



Draft Test Plan Based on Extensive Team Experience

Reliability Demonstration Test Development Team

Who	Organization	Experience
David King	PV Evolution Labs	35 years of working in PV reliability and testing
Jenya Meydbray	PV Evolution Labs	PVEL CEO, developed and developed and executed SunPower's solar panel supply quality strategy
Jennifer Granata	Sandia Nat'l Labs	Head of Sandia PV Test, Evaluation, and Characterization Technologies
Michael Quintana	Sandia Nat'l Labs	Head of Sandia PV Systems Reliability, manufacturing, and Diagnostics
John Wohlgemuth	NREL	Over 35 years in PV reliability and testing, chair of TC82 WG2
Joseph Del Cueto	NREL	Over 25 years in PV technology development, NREL senior scientist
Ralph Romero	Black & Veatch	Over 20 years in the industry, Leads of B&V bankability team
Derek Djeu	Black & Veatch	Lead IE engagements for lenders and project finance of utility-scale solar PV

Common PV Module Failure Modes

(no particular order)

Quick connector reliability (embrittlement, moisture ingress)	Cell/busbar arc to frame
Junction box failure (poor solder joints, arcing, etc.)	Light-induced cell degradation (LID)
Glass fracture	Outgassing of in-laminate materials (Chemical incompatibilities)
Bypass diode failure	Backsheet embrittlement leading to exposed conductor
Cracked cells (soldering processes, strain, etc.)	Busbar sharp edges, solder peaks, cutting through backsheet leading to exposed conductor
Solder joint degradation	Electrochemical corrosion of busbars or cell metallization
Reduced adhesion leading delamination	Polarization (charge build-up at interfaces)
Optical degradation of encapsulant	Ion migration from glass to cell surface creating leakage paths, ground faults

Correlation of Failures To Stress & Characterization (partial list)

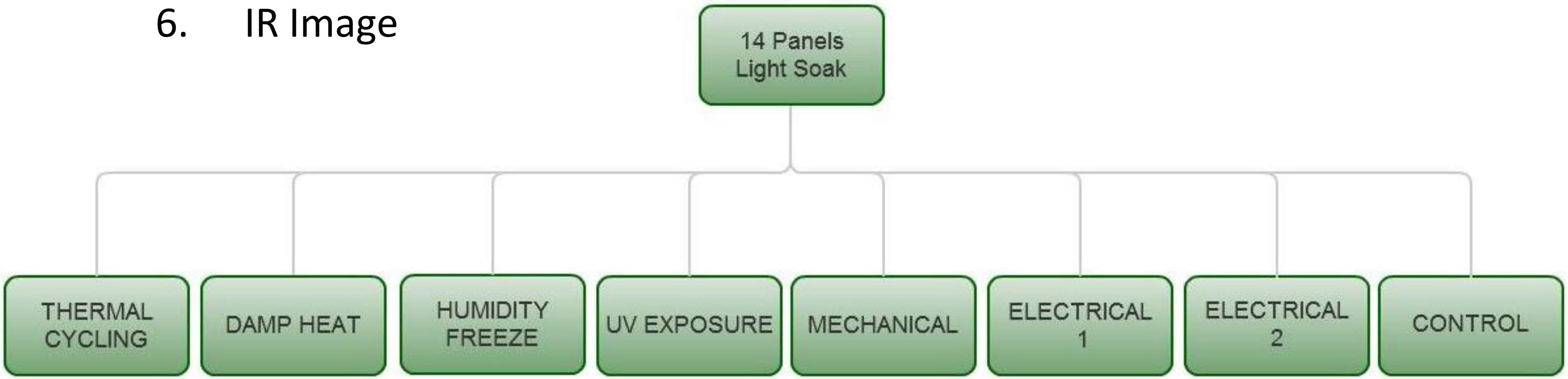
FAILURE MECHANISM	STRESS	CHARACTERIZATION
Cracked cells	TC, Load	EL, LIV
Reduced adhesion leading to corrosion and/ or delamination	DH, HF, UV	Visual, wet hipot, LIV
Light-induced cell degradation	Sun Soak	LIV
Delamination / Outgassing of in-laminate materials (Chemical incompatibilities)	DH, HF	Wet Hipot, Visual, UV-Vis
Polarization (charge build-up at interfaces)	LT V Bias	EL, LIV

"…it would be counterproductive to require a test that doesn't correlate with field experience", Sarah Kurtz, NREL

Test Plan

- Objective: Comprehensive assessment of all failure modes
- Test Duration: 5 Months

- <u>Module Characterization</u>
  1. Visual Inspection
  2. Light IV
  3. Dark IV
  4. Wet Hipot at 1kV
  5. EL Image
  6. IR Image



Test Plan – Continued

Thermal Cycling (600 Cycles)	
1	LIV + Visual Inspection
2	Outdoor exposure for 5kWh
3	Module Characterization
4	TC 200 cycles W/current injection
5	Module Characterization
6	TC 200 cycles W/current injection
7	Module Characterization
8	TC 200 cycles W/current injection
9	Module Characterization
10	Diode Test - for each cell string

Damp Heat (2,000 hrs)	
1	LIV + Visual Inspection
2	Outdoor exposure for 5kWh
3	Module Characterization
4	DH 1000 hrs
5	Module Characterization
6	DH 500 hrs
7	Module Characterization
8	DH 500 hrs
9	Module Characterization
10	Diode Test - for each cell string

Test Plan – Continued

Humidity Freeze (30 cycles)	
1	LIV + Visual Inspection
2	Outdoor exposure for 5kWh
3	Module Characterization
4	HF 10 cycles
5	Module Characterization
6	HF 10 cycles
7	Module Characterization
8	HF 10 cycles
9	Module Characterization
10	Diode Test
11	Static Mechanical Load

UV (125 kWh at 90C)	
1	LIV + Visual Inspection
2	Outdoor exposure for 5kWh
3	LIV + Visual Inspection
4	UV 125 kWh with Imp injected
5	Module Characterization
6	Diode Test

Test Plan – Continued

Mechanical	
1	LIV + Visual Inspection
2	Outdoor exposure for 5kWh
3	Module Characterization
4	1,000 mechanical load cycles
5	Module Characterization
6	TC 50 cycles
7	Module Characterization
8	HF 10 cycles
9	Module Characterization
10	Diode Test

Electrical - 1	
1	LIV + Visual Inspection
2	Outdoor exposure for 5kWh
3	Hot Spot Test
4	LIV + Visual Inspection
5	EL Image
6	IR Image
7	+ 1kV bias 1000 hrs (40C, < 50% RH)
8	LIV + Visual Inspection
9	EL Image
10	IR Image
11	Hot Spot Test
12	Bypass Diode Thermal Test
13	Diode Test

Test Plan – Continued

Electrical - 2	
1	LIV + Visual Inspection
2	Outdoor exposure for 5kWh
3	Hot Spot Test
4	LIV + Visual Inspection
5	EL Image
6	IR Image
7	- 1kV bias 1000 hrs (40C, < 50% RH)
8	LIV + Visual Inspection
9	EL Image
10	IR Image
11	Hot Spot Test
12	Bypass Diode Thermal Test
13	Diode Test

Control	
1	Outdoor exposure for 5kWh
LIV when testing modules under stress test	
Store in dark with leads shorted when between tests	
Following tests to be performed at the end	
2	LIV + Visual Inspection
3	EL Image
4	Wet Hipot at 1kV
5	IR Image

Things To Be Careful Of

What	PVEL Capabilities
Spectral Mismatch	Tester 2 times better than Class A spectrum (recently certified Class A+A+A+)
Light Uniformity	Better than 0.3% across panel (10 times better than Class A)
Current Injection for EL, IR, TC	Computer controlled custom system
Sample temperature Uniformity	Unique laminar air flow chambers (top to bottom air flow)
UV spectrum and intensity	Spectroradiometer characterization
Point loading in Mechanical Testing	Patented bladder based dynamic load tester

Thank You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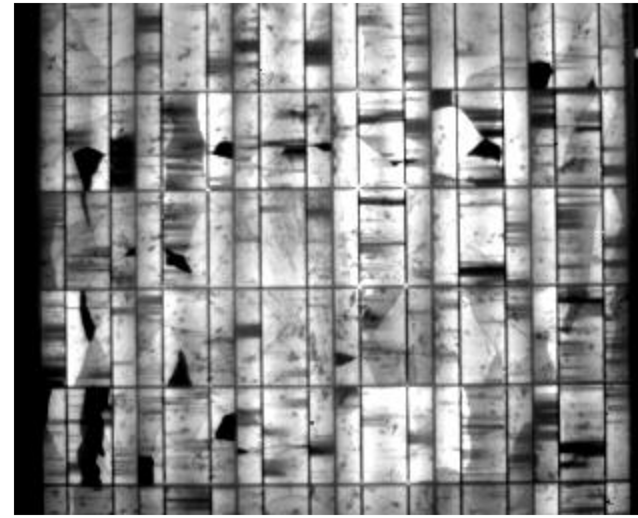

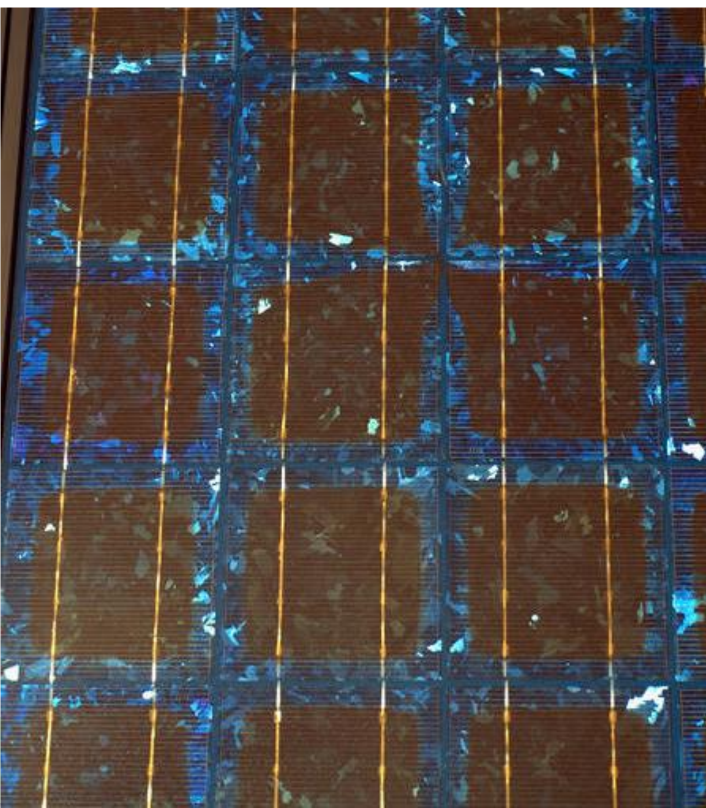

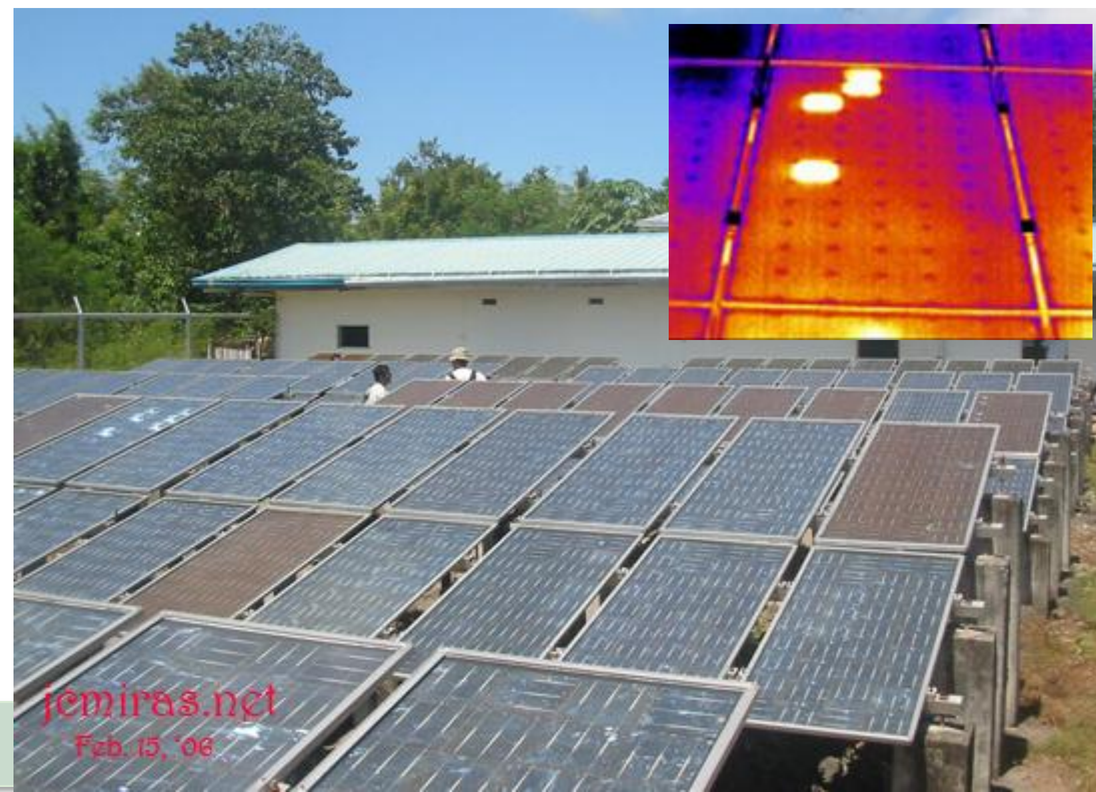
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