ANALYSIS OF PHOTOVOLTAIC INSTALLATIONS: A COMMERCIAL OWNER PERSPECTIVE ON PV PLANT OPERATION AND OPTIMIZATION

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DUPONT PHOTOVOLTAIC SOLUTIONS

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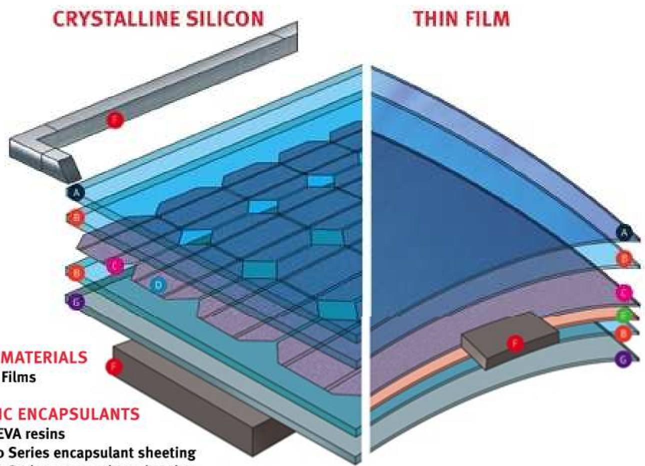
NREL Reliability Conference

Introduction

- Review and analysis of commercial installations provides insight and learning to help the industry's continued growth
- Address technical risk to commercial/industrial projects, from design through decommission
- Simple quality management actions/processes minimize safety and performance risks and improve financial returns
- Identify and share learnings and best practices regarding distributed generation projects
- Gather data to identify durability challenges and trends
- Observed degradation and failure modes associated with module/material design, manufacturing, installation, weather, and operation & maintenance (O&M).
  - The importance of module material design and manufacturing consistency is critical

DuPont Role in Photovoltaics

Broadest materials portfolio in the PV industry



System owner & PV electricity consumer

Shenzhen, China
Rooftop Thin Film

Taoyuan, Taiwan
Rooftop c-Si

Hyderabad, India
Rooftop Thin Film & c-Si

Waimea, HI
Ground Mount c-Si

Tlalnepantla, Mexico
Ground Mount TF

Parlin, NJ
Ground Mount c-Si

Wilmington, DE
Ground Mount c-Si

Wilmington, DE
Rooftop Thin Film

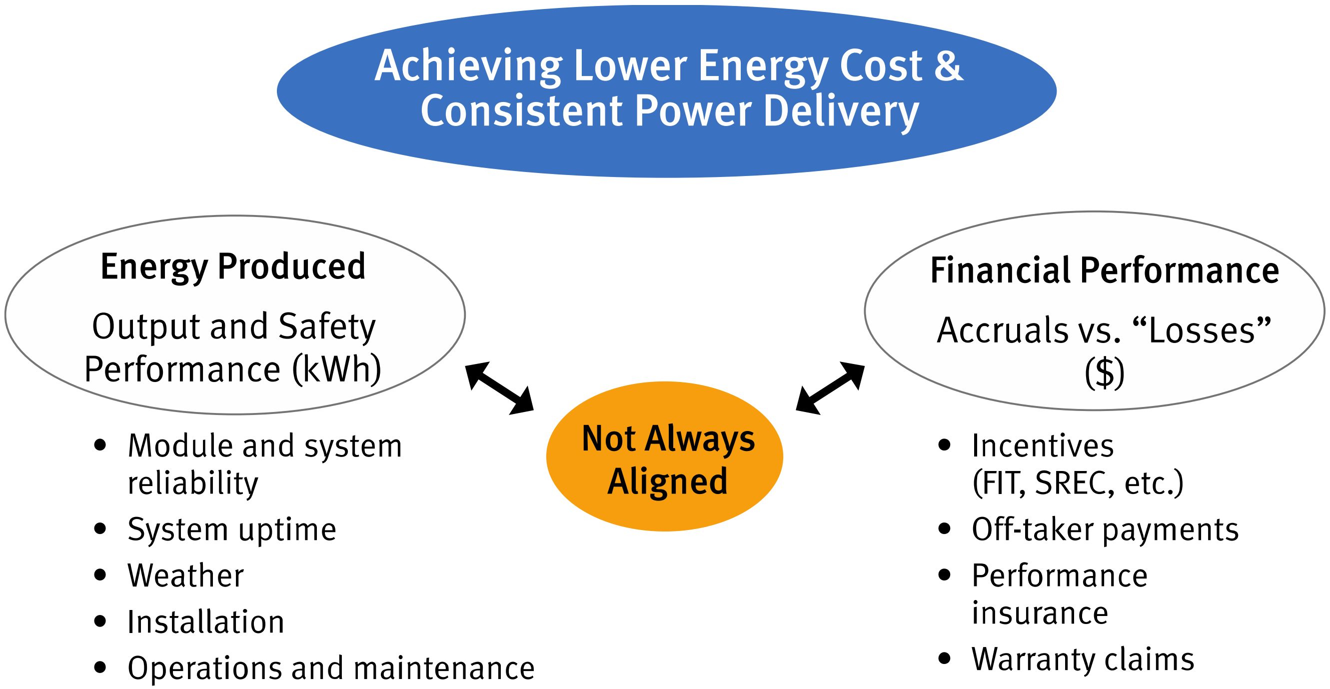
Wilmington, DE
Rooftop c-Si

3 Continents and 7 Countries
7 kW to 5 MW

Provide a unique industry perspective: largest material supplier and growing PV system owner

System Owners Recognize Lifetime is as Important as Cost and Incentives

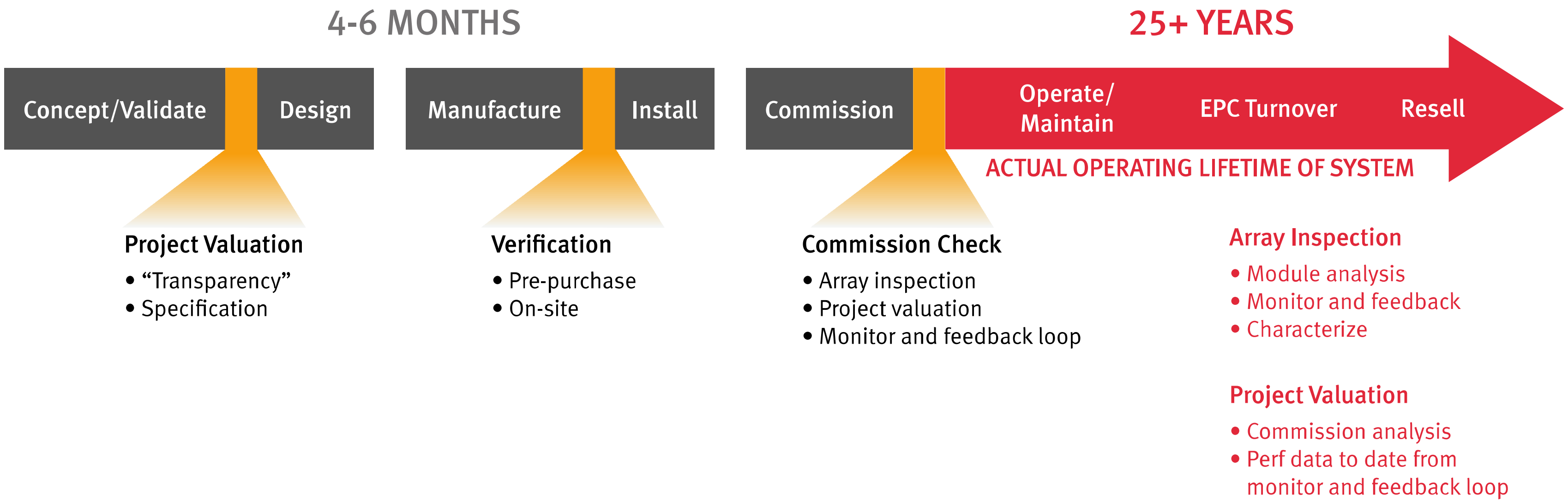
Achieving multiple objectives of economics, energy output and scale requires careful planning and execution



Risks are distributed among several stakeholders and vary depending on role in value chain.

Project Lifecycle: Risk Assessment and Valuation Over Time

- Performance and safety over 25 years needs appropriate upfront consideration
- Importance of PV system optimization increases as subsidies are reduced



Risks are distributed among several stakeholders and vary depending on role in value chain.

Overview

Background

- Inspected/Characterized >30 global installations (>100MW) in NA, EU, & AP ranging from newly commissioned to 30 years to gain technical learnings
- In last 36 months lab analyzed > 300 modules from service environment
- Observed and characterized over 30 different degradation modes
- Partnered with over 25 installers, developers, EPC, utilities, financial and academic institutions

Observations

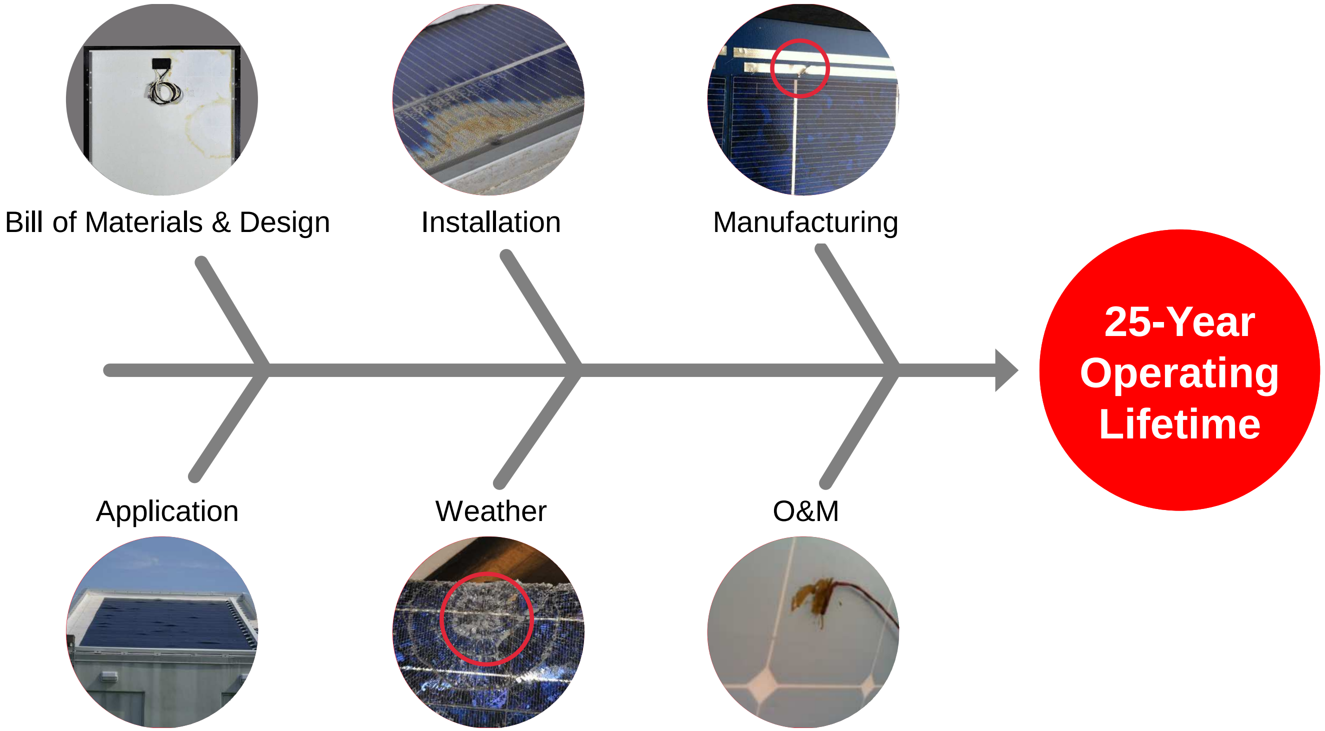
- Module overcapacity and race to grid parity is driving dramatic changes
- Safety and performance issues are typically underreported, but are arising and being identified through industry publications.
- A proliferation of new materials combined with multivariate stresses and concurrent phenomena requires careful analysis and assessment.
- Once commissioned options for mitigation are limited

Recommendations

- Better understanding of product quality and qualification is needed
- Development of enhanced durability test methodology is required
- Use best practices and processes to optimize in-field performance
- Adopt improved risk mitigation strategies and technical specifications

Quality Management Process: Storyboard the Performance Risk Issues

Identify and catalog degradation modes: mitigate risk with control plans



"Lifetime-prediction tests appropriate for full-sized modules would be possible only when a final module design is defined, all failure modes are identified for that module design, and acceleration parameters for each relevant environmental stress are known.

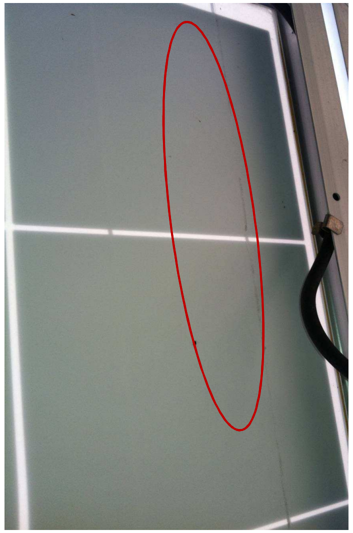
The development of a universal 30-year pass/fail certification for all PV module types cannot be expected."

Module 30 Year Life: What Does it Mean and Is it Predictable/Achievable?
T. J. McMahon, G. J. Jorgensen, R. L. Hulstrom, D. L. King and M. A. Quintana

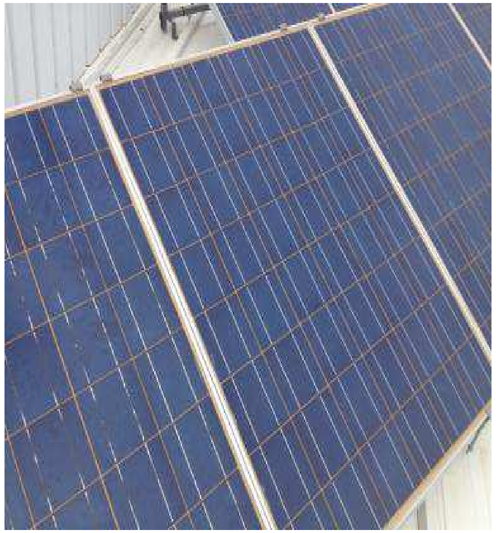
Identify and Catalog Degradation Modes:
Bill of Materials & Design

Material durability issues are widespread in modules less than 5 years in operation in the service environment

- Outer backsheet polyester cracked and delaminating
- 2.3 MW field estimated that ½ the field or approximately 5,000 modules in the park affected
- 2-year warranty on materials and workmanship elapsed, with no replacement of the panels



- Backsheet with embrittlement, cracking, and erosion of outer FEVE coated surface
- 1% of modules indicated early signs of degradation or gross damage after 3 years in service

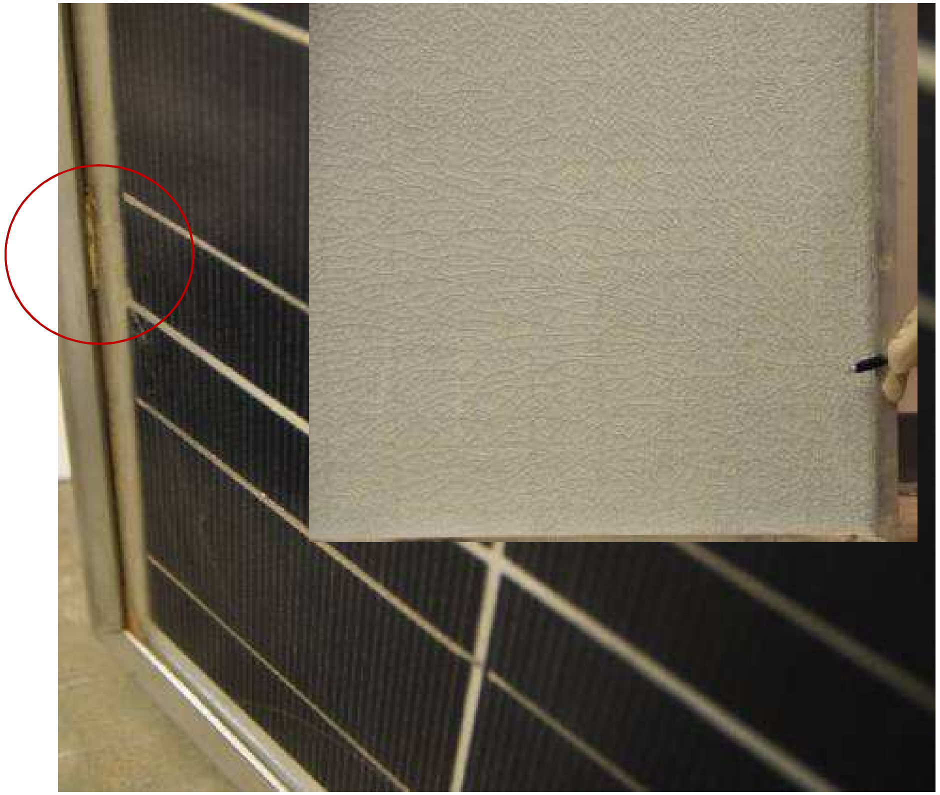


- Inner backsheet PE tie-layer discoloration (PVDF backsheet)
  - 5 different countries (>10MW)
  - 5 different manufacturers
  - Different certifying agencies

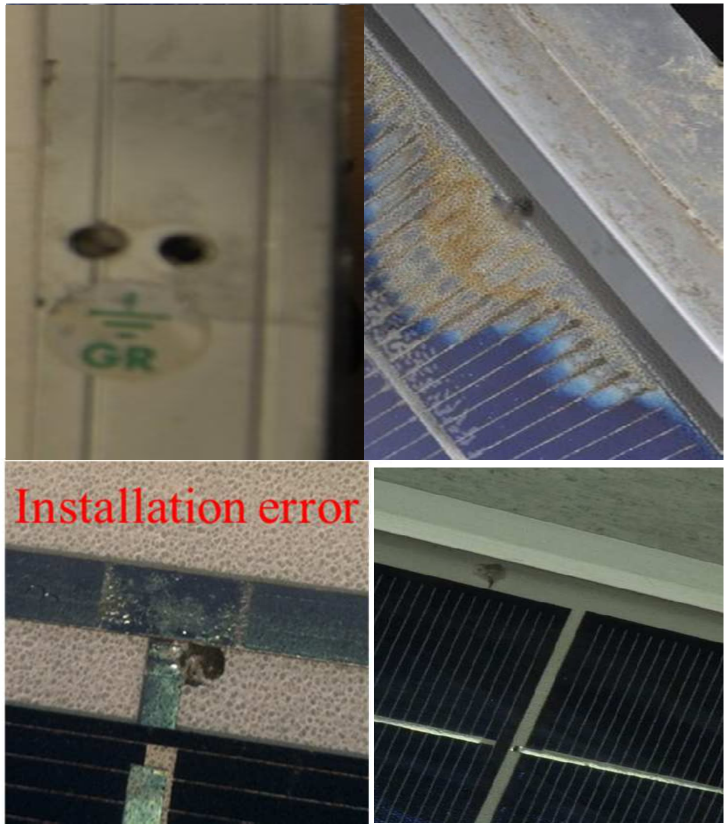
Backsheet and Module Durability and Performance and Comparison of Accelerated Testing to Long Term Fielded Modules.
Gambogie, W., et. al. EUPVSEC 2013.

Identify and Catalog Degradation Modes: *Installation*

Errors due to improper installation methods are typically localized



Shim between glass and frame

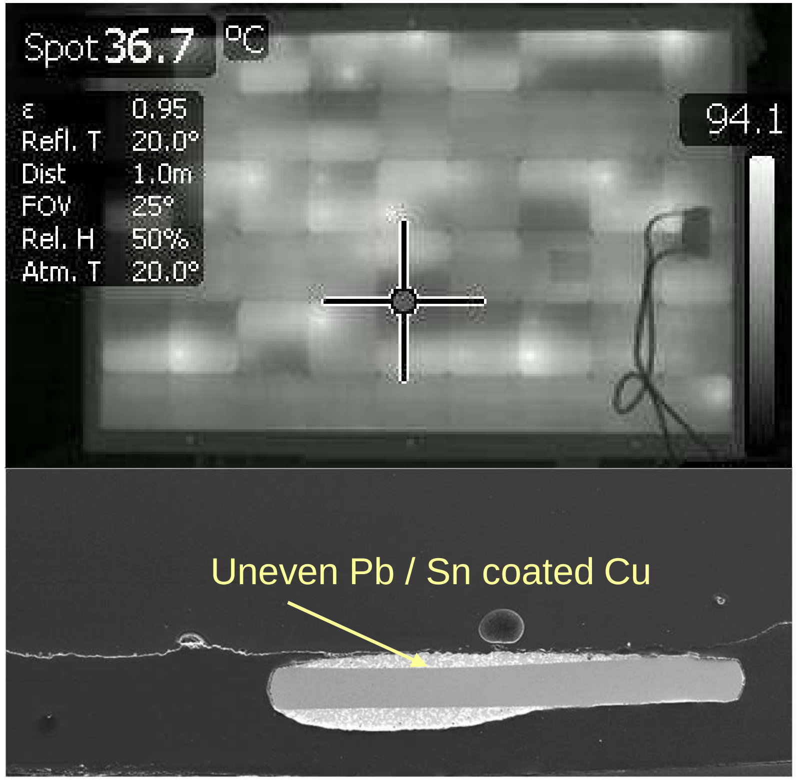


Extra drill hole at grounding bar

Identify and Catalog Degradation Modes: *Manufacturing*

Safety and performance issues due to inconsistent manufacturing

Bent bus bar and misaligned cells



Non-uniform solder

Identify and Catalog Degradation Modes: *Application Environment*

Varied site-specific requirements present different operating environments for distributed generation

BIPV/BAPV delamination

Ground mount, open vs. closed rack, operating temperature differences

Identify and Catalog Degradation Modes: *Weather*

Wide range of issues from instantaneous catastrophic failure to slow degradation

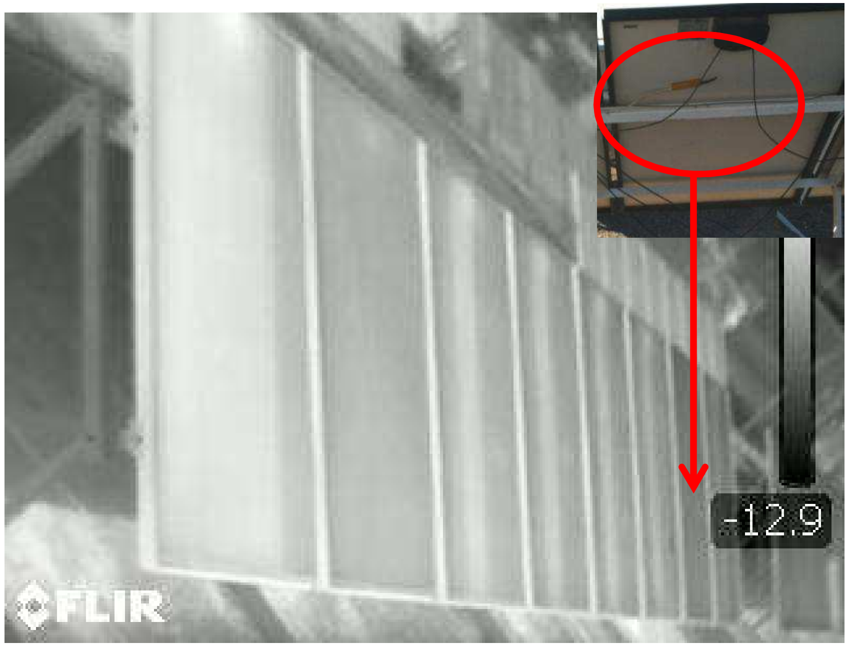
Hail damage

Soiling (temporary)

Glass Etching (permanent)

Identify and Catalog Degradation Modes:
Operation & Maintenance

Remote monitoring systems are needed in combination with thermal imaging and visual inspection



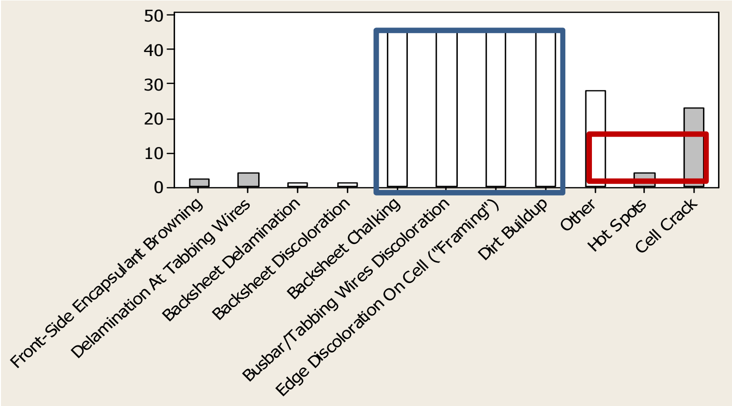
Thermal imaging used to identify underperforming modules: Average backside cell temperature is not always representative.

Visual inspection: Necessary, but not sufficient.

E. Kaplani, Detection of Degradation Effects in Field-Aged c-Si Solar Cells through IR Thermography and Digital, Image Processing.
International Journal of Photoenergy (2012).

Quantitative Assessment: DuPont PV Installation Case Study 1

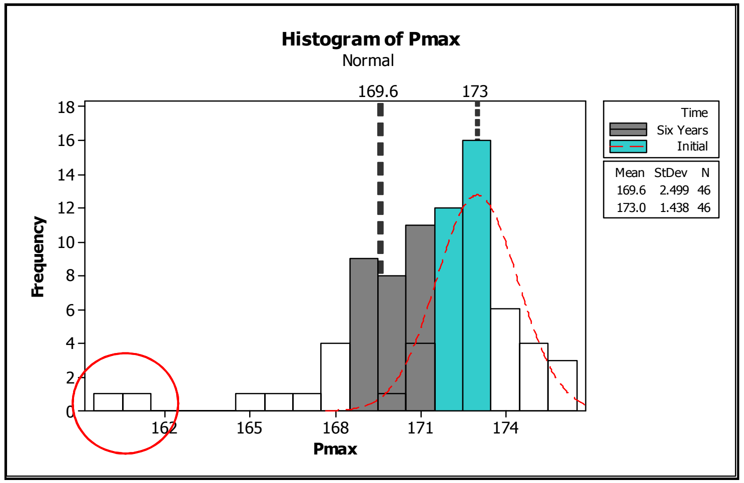
Project evaluation & documentation after six years



Pareto process & criticality analysis

- Degradation (Blue) modes with high frequency show a low degree of severity
- Degradations (Red) with low frequency have high degree of severity
- Ability to detect enhanced through thermal imaging

46.7 kW System



Performance: Pmax distribution

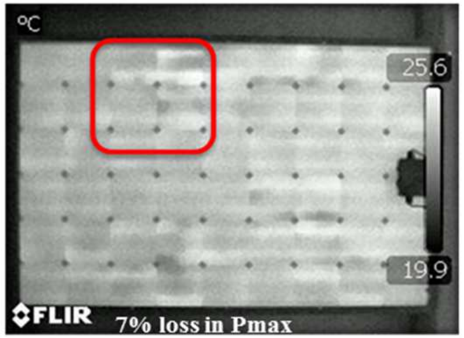
- Minimal power loss
- Mean change in power is -3.4 W (-2% drop); 95% confidence
- Degradation rate = 0.3% per year (assumed linear)

Safety: Electrical Insulation

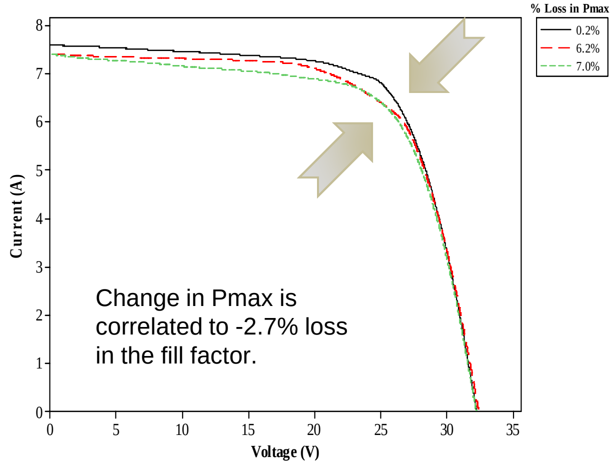
- EVA encapsulant and TPE backsheet maintained electrical insulation

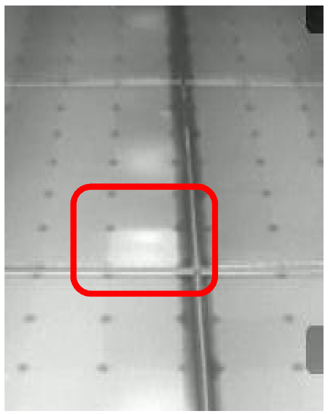
Safety and Performance Analysis of a Commercial Photovoltaic Installation. Bradley, A. Z., et. al. SPIE 2013.

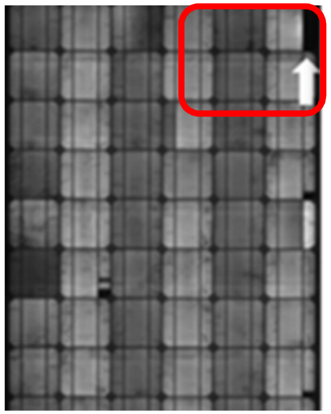
Electroluminescence and Thermal Imaging of Modules Indicated Different Degradation Modes Yield Similar Power Loss

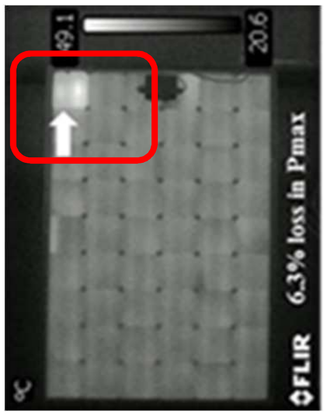


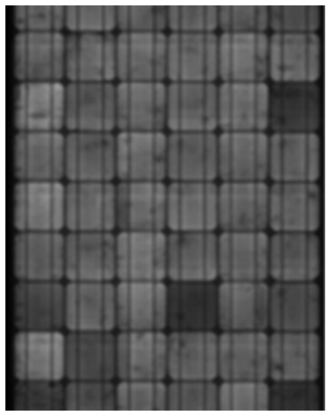
Some cracks are identifiable in the thermal image (damage location is at an elevated temperature)











Qualitative Assessment: DuPont PV Installation Case Study 2


- Reliability issue (37.8 kW system): Six 180W modules out of 210 have broken glass (2.8% broken) after 3 years
  - Mechanical/structural issues associated with installation
  - Broken interconnect on cells

- Current situation: Developer, module and inverter manufacturer are all out of business

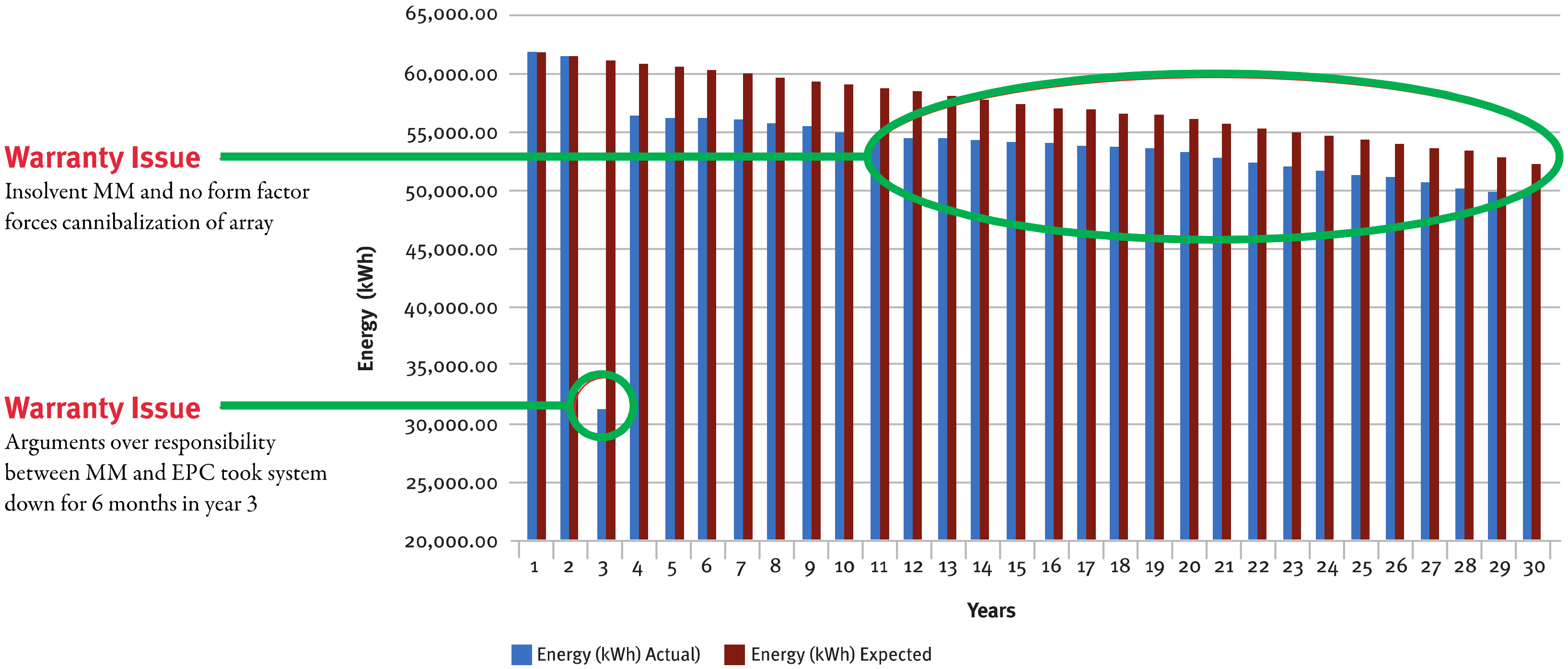
- Mitigation: Cannibalize a smaller string of the array (6.6% decommissioned)

- Control plan: Semiannual inspection and thermal imaging

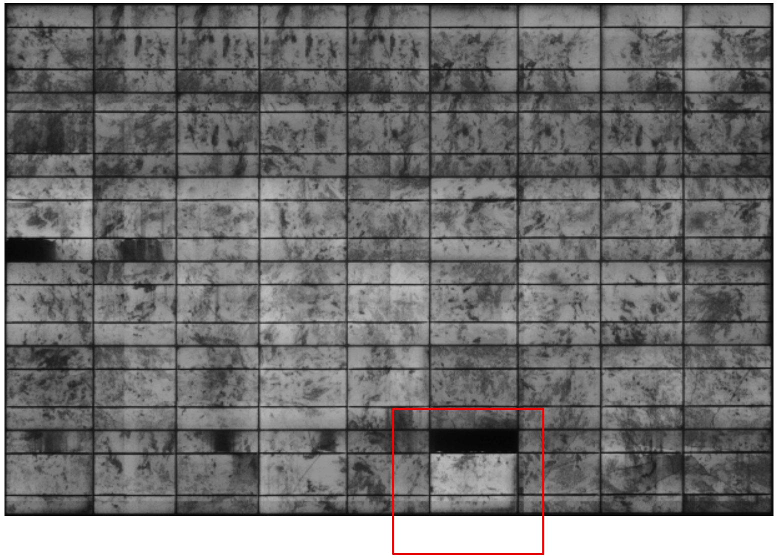
Analysis of Photovoltaic Installations:
A Commercial Owner Perspective on PV Plant Operation and Optimization; Bradley, A., et. al. EuPVSEC, 2013.

O&M is Not a Fixed Cost and Can Dramatically Increase Over the Lifetime of the System

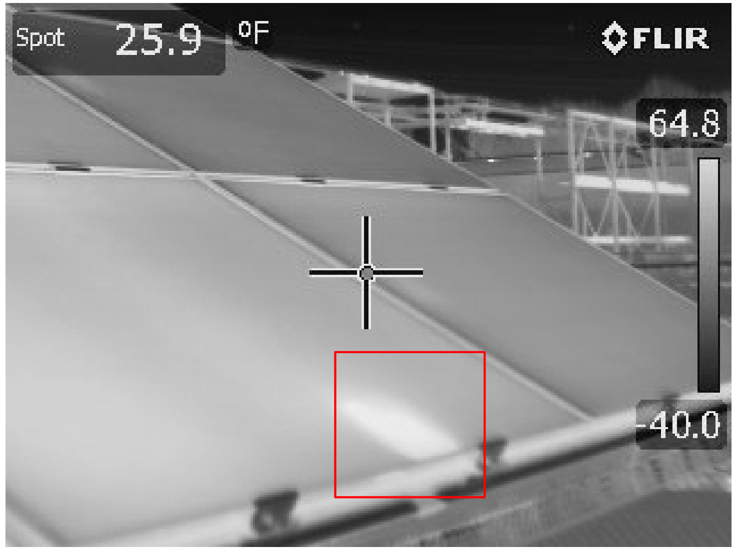
- O&M costs were up 235% in year 3 due to system issues
- Revenue loss due to system availability (short term) & kW size (long term)



Thermal Imaging Assessment: DuPont PV Installation Case 3



EL image of replacement module before installation



Hot spot identified immediately after installation

- Reliability issue (43 kW System): Seven 205W modules out of 210 have cell hot spots (3.3%)
  - Safety: Overheated cells accelerate degradation of encapsulant and backsheet materials
  - Performance: The use of thermal imaging is critical to the inspection process and has been instituted as a best practice to improve safety and performance

- Remote string level monitoring combined with thermal imaging identified underperforming modules
  - One percent of modules do not meet performance warranty after 3 years.

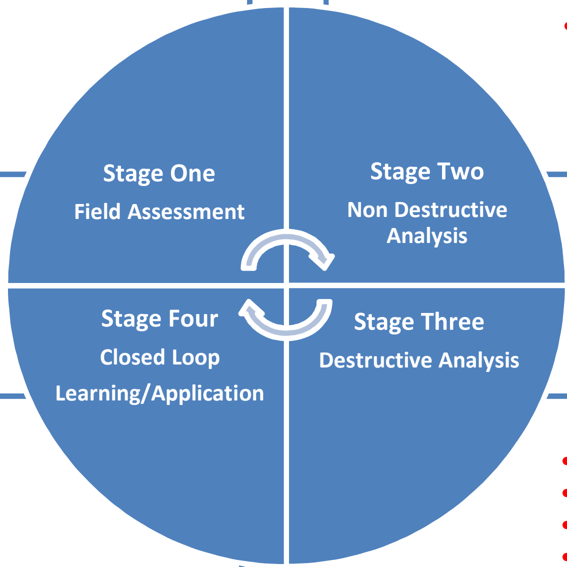
- Poor manufacturing initially characterized by EL imaging detected as a hot spot using thermal imaging

Bradley, A.Z. submitted SPIE 2014

Minimizing PV Performance Risk and Optimizing Energy Harvest

- Visual Inspection
- Thermal Imaging
- FTIR Analysis
- Criticality Matrix
- Pareto Chart

- Power Output Measurement (IV Curve)
- Electroluminescence (EL) Imaging
- Thermal Imaging Under Forward Bias
- Wet Leakage Current or Dry Insulation Test



Apply Lessons Learned to Future PV Installations

- Institute Best Practices
- Control Plans
- Technical Specification
- Continuous Improvement
- Energy Harvest
- System Optimization

- Sample Extraction Via Back Side Core
- Physical Layer Profile (SEM)
- Chemical Layer Profile (IR/SEM)
- Defect Pathways (X-Ray)
- Mechanical Properties

Failure Modes and Effects Analysis used to improve component and system design.

There are Straightforward Options to Mitigate Risk

	PV System Best Practices	Key Actions
Project Design	**Ensure Selection of Quality Modules**	Specify a **proven module BOM** that eliminates common module failure modes (e.g. electrical insulation materials)
		Require **transparency** of BOM to be provided in project solicitations
		Specify **Manufacturing Process Controls** that ensure design consistency, BOM & Process conditions
		Require **Letter of Conformance** & closed loop verification of modules vs. proposed/contracted
Contracting	**Assess Contractor Experience & Ensure Quality Asset Optimization Management**	Improve visibility of **contractor past performance** (beyond 5 years & problem resolution capabilities)
		Require/develop detailed plan for **long-term optimization & management** of the asset in project solicitations
Commissioning	**Enable Ongoing Safety & Performance Monitoring of the Asset**	Require **open access** to the facility, BOMs, plant designs and records
		Project Commissioning process to ensure conformance & establish baseline performance
		Ongoing data analysis of system (requirement of weather collection system to normalize data)

Summary

Documented material durability and module manufacturing issues in systems less than 5 years in operation in the service environment

O&M is not a fixed cost and can be significant

Difficult to standardize distributed generation systems – no one size fits all approach to global commercial/industrial installations

Simple best practices and quality management actions/processes minimize risk, optimize safety/performance, and improve financial returns

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