Failures, fiascos and fires: How to avoid trouble from manufacturing, through design, to installation

Quality Roundtable – Solar Power International 2019

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Agenda

Part I

2:00	**Welcome and introductions**
2:05	**Opening presentation from Initiative Partner DuPont**
2:15	**Presentation of quality cases with moderated audience discussion**
2:45	**PANEL DISCUSSION: All about the BoM: The role of bill of materials in module quality and field performance**

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Agenda

Part II

3:25 **PRESENTATION of quality cases with moderated audience discussion**

3:40 **DISCUSSION Best practices to ensure maximum tracker uptime**

3:50 **PANEL DISCUSSION: Component selection and installation practices to avoid fires**

4:25 **Closing remarks**

Networking

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Opening presentation

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Kaushik Roy Choudhury

Senior Scientist and Project Leader

DUPONT

DuPont Photovoltaic Solutions

Sept 25, 2019

Materials choices to avoid field failures

Dr. Kaushik Roy Choudhury

Technical Manager, Global PV Reliability

DUPONT™

DuPont Photovoltaic Materials Portfolio

DuPont™ Solamet® METALLIZATION PASTES | 30+ YEARS
RELIABLE INNOVATION PARTNER

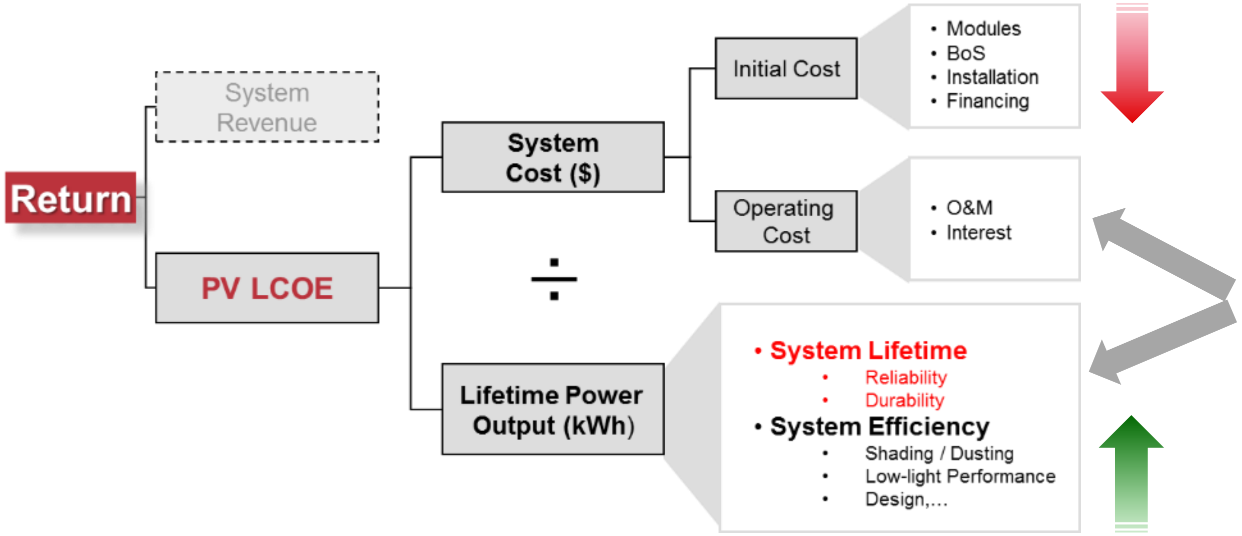
DuPont™ Tedlar® BASED BACKSHEETS | 30+ YEARS
FIELD-PROVEN PERFORMANCE

Dow Corning™ SILICON-BASED PV SOLUTIONS | 30+ YEARS
SERVING THE SOLAR INDUSTRY

Delivering Quality for 30+ Years
Proven Performance (efficient + reliable)
Driving Lower LCOE for Higher Return

Levelized Cost of Energy (LCOE)

A prime metric for any market with eyes on long-term return



Expectation All modules need to meet claims for degradation and performance over lifetime (~~25~~ 30+ years)

DuPont global field reliability program

- Quantitative analysis: components, materials, age, failure mode
- Post-inspection analytical characterization
- Collaborative: field partners, developers, government labs, universities

Improved accelerated tests and informed materials selection

6.5 M
modules

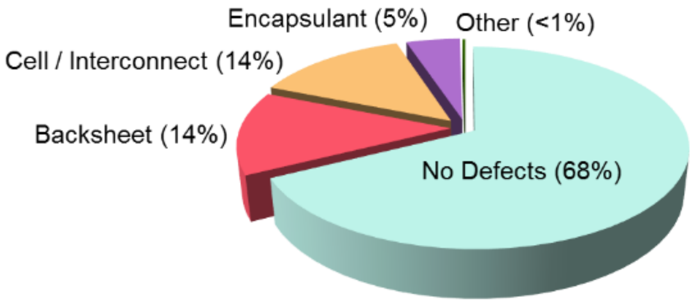
355
installations

1.8 GW
power

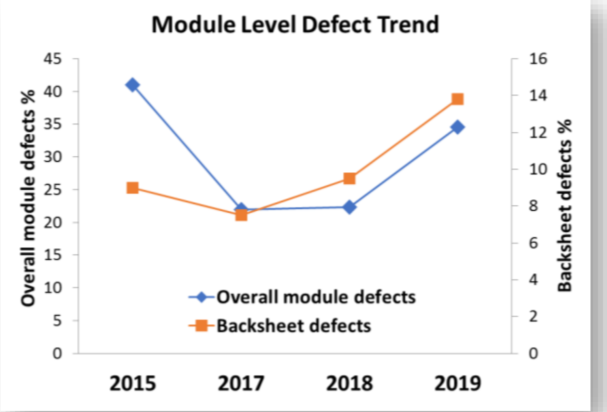
2019 Global field data analysis summary

- Nearly **2 GW** of fields inspected
  - Total module defects observed: 34%
  - Total backsheet defects observed: 14%
  - Backsheet defects increased by 47% from 2018 analysis
  - Cracking constitutes 66% of all backsheet defects

Module Defect Trends*



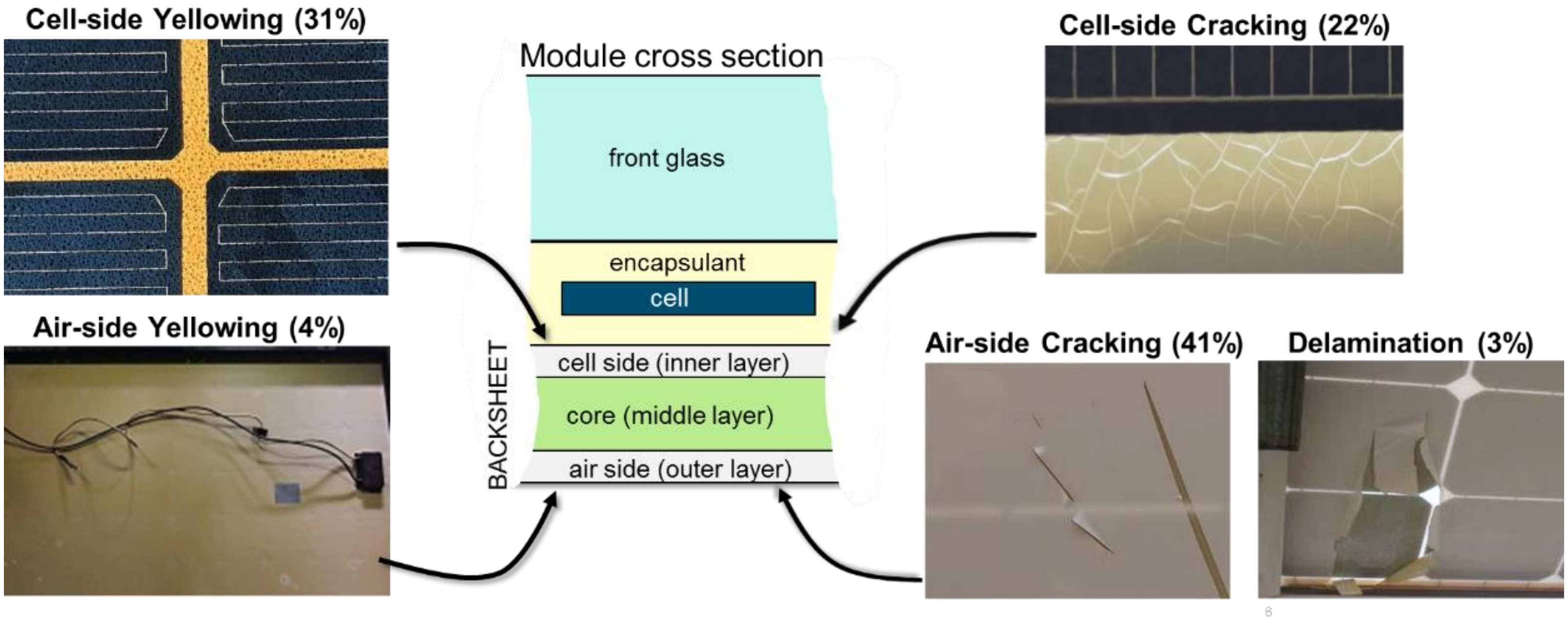
Cell / Interconnect: corrosion, hot spot, snail trails, broken interconnect, cracks, burn marks	
Backsheet: outer layer (air side) and inner layer (cell side) cracking, delamination, yellowing	
Encapsulant: discoloration, browning, delamination	
Other: glass defects, loss of AR coating, junction box	



Backsheet is one of the main component affected

* Actual module defects can be higher due to defects not picked up by initial inspection protocol (eg. cell cracking evidenced by subsequent EL or PID test)

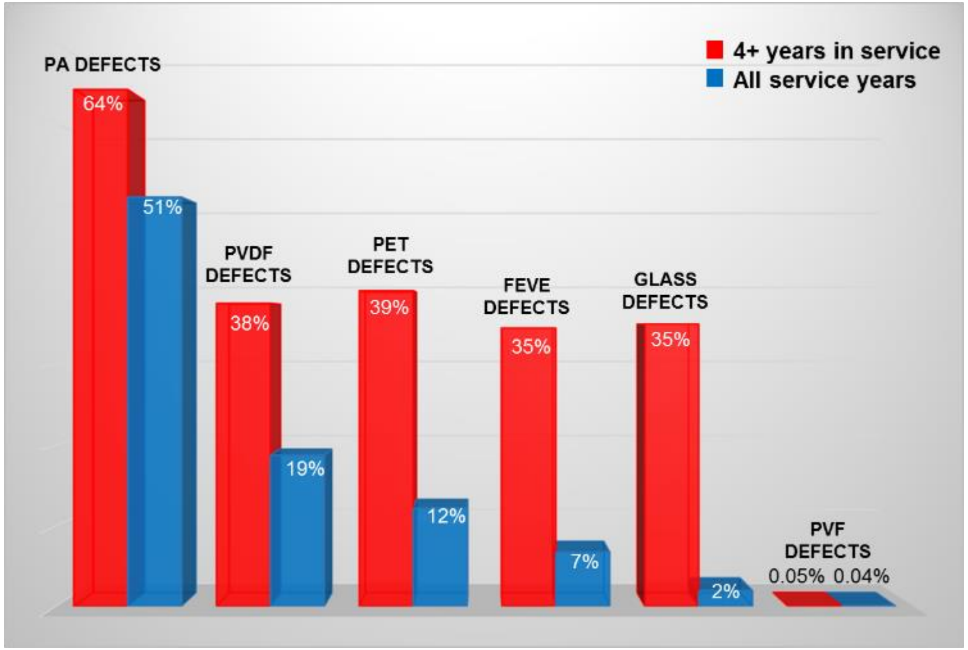
Backsheet defects by degradation mode



Cracking and delamination can compromise electrical insulation of the module

Yellowing can be a precursor to mechanical degradation and embrittlement of many backsheet polymers

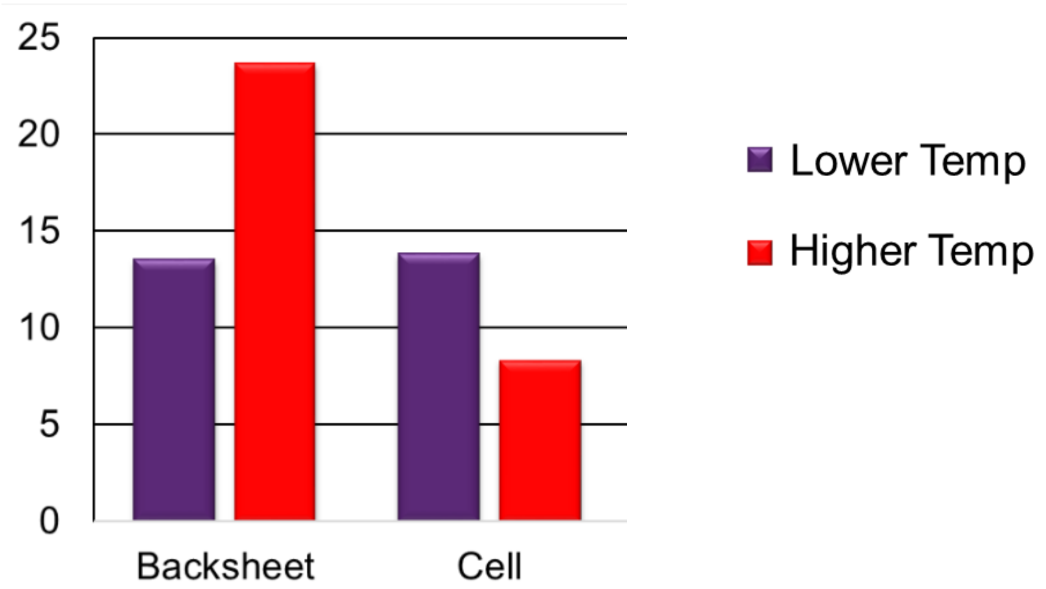
Sharp increase in backsheet defects after 4 years in the field



PA = Polyamide
PVDF = Polyvinylidene Difluoride
PET = Polyethylene Terephthalate
FEVE = Fluoroethylene Vinylether
PVF = Polyvinyl Fluoride; Tedlar®

Defects kick-in after a few years in the field
Not all materials are affected the same way

Higher temperatures and stronger UV accelerate defects



Higher backsheet defect rates in hot climates and in roof installations

Backsheet defects are 125% greater in hot climates

Backsheet defects are 75% greater for roof mounted systems

Learn from Mistakes

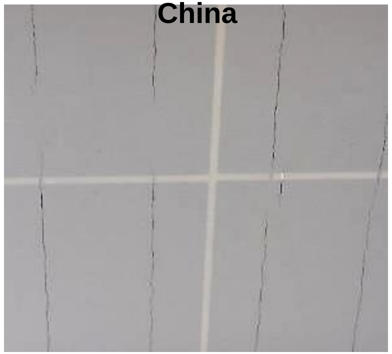
Global concern of Polyamide backsheet failure

Widespread backsheet through-cracks

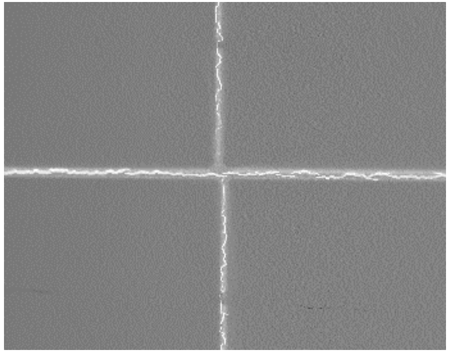
- Prevalent along busbar ribbons, but extends to cell gaps and other regions with continued weathering
- Arcing and shorts often lead to localized burn-through and sometimes full module fires
- Reported inverter tripping and ground faults

7 years, Sonoran Desert, USA

6 years, NW China



6 years, Sonoran Desert, USA



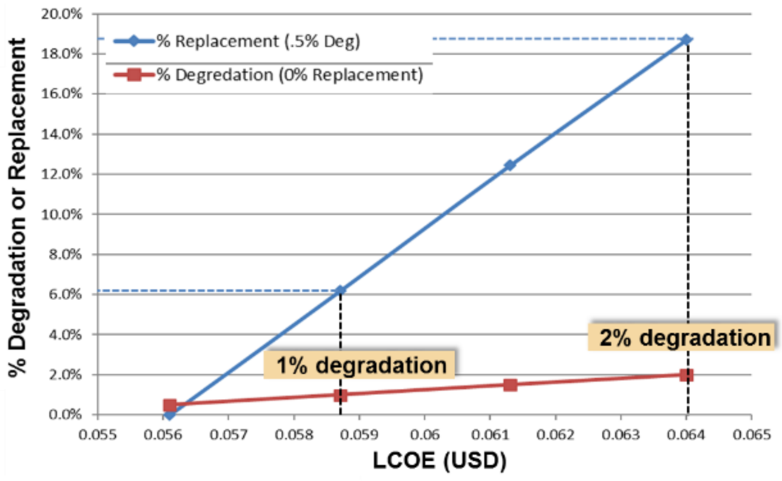
6 years, High Desert, Nevada, USA

* Backsheets were qualified by IEC testing

Impact of failures on You and Your System

Field failures after a few years threaten the long-term performance, durability and ROI

- Increase replacement costs and a system's LCOE
  - In an actual case study, replacing 6% of modules in a system is equal to an extra 0.5% annual degradation



Summary

- Field data from 1.8 GW of PV capacity across the globe demonstrates backsheet and cell defects are most prominent failure modes of PV modules
- Field failures after a few years can threaten long-term performance and ROI
- High temperature, strong UV irradiation and a fast growing market pose significant challenges to ensuring durable PV materials
- Attention to the quality of the Bill of Materials is critical
- Coupling field data with failure analysis should inform materials selection, and hopefully will help mitigate financial risks

2 Quality cases

Sept 25, 2019

Quality case from the field

Learning opportunities

Dr. Kaushik Roy Choudhury

Technical Manager, Global PV Reliability

Mysterious faults

North America

Service Time	7 years
Location	SW USA
System size	Utility scale, 12 MW
Mounting configuration	Ground mount
Tracking	Single-axis tracking
Technology	Mono-crystalline Si
Climatic conditions	High-desert

Indicators

- initial alarm raised with moisture ingress into modules leading to severe busbar and ribbon corrosion, ground faults, sometimes leading to module fires
- no issues with wiring, junction boxes, connectors
- further inspection by O&M revealed backsheet cracking in >75% of modules in field

Inspection results: the curious case of Mixed BOMs

Module backsheet and degradation identified on-site

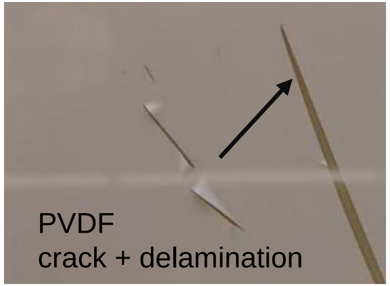
Illumination from rear to reveal cracks in the inner layer

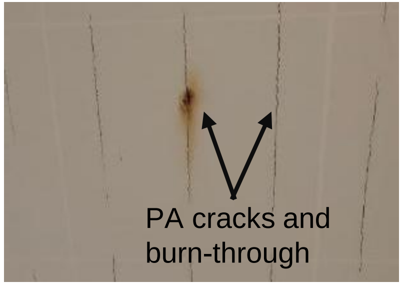
- *prominent near busbars*

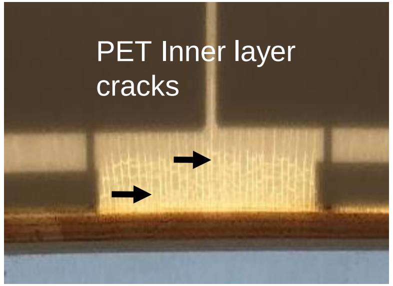
Multiple Bills Of Material (four types of backsheets revealed, possibly other components) in the same model number with mixed serial numbers from a single module maker (BS1: 50% of field, BS2, BS3, BS4: ~16% each)

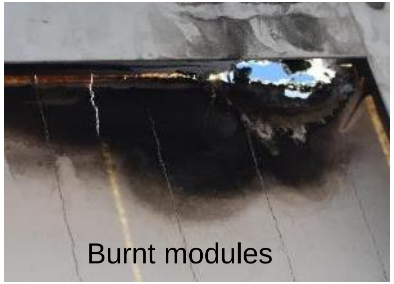
Different backsheets degrade differently though all are qualified by IEC certification

- **Three backsheets degrade significantly while one is completely defect free**









Inspection results: findings

All PVDF, PET, PA-based backsheets exhibited cracking

- 100% PA backsheets cracked along busbar ribbons, with several instances of burn-through
- 100% of PVDF backsheets have cracked outer layer leading to delamination
- 100% PET backsheets have cracked inner layer

No issues in Tedlar® backsheets

Cracking facilitates moisture ingress, often leading to busbar corrosion

Exposure of module interiors to moisture leads to shorting, inverter trips, power loss, and several instances of module fires

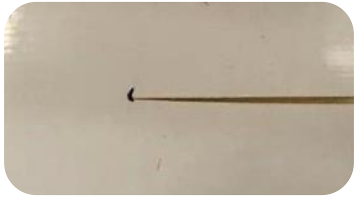
Inverter tripping most frequently observed after moist nights and rain

Failures cause serious safety and performance issues, ultimately resulting in significant economic losses

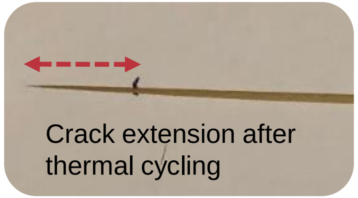
Field failures rising: know your BOM and do proper testing

Simple testing illustrates vulnerability of material

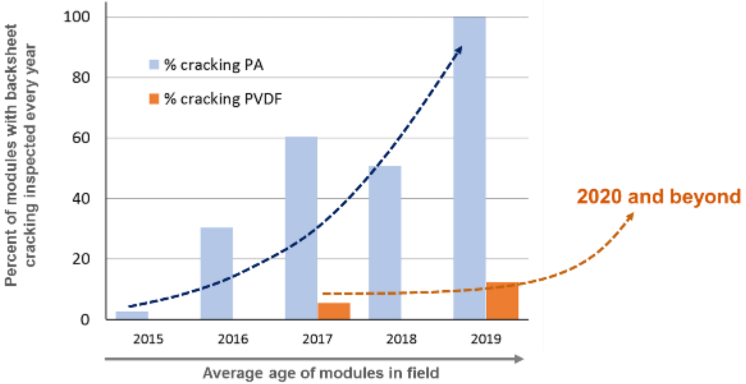
Cracked PVDF from the 12 MW field in NA



25 cycles 40 to 85° C



Similar trends of backsheets failing in the field: rapid rise of cracking after break-in period



Similar pattern observed in defective PA and PET based backsheets:

accelerated testing in lab forms cracks → cracked modules subsequently observed in the field → **rapid rise in rate of cracking defects observed in field**

12 MW field: All modules being replaced: do your math (replacement, recycling cost, lost revenue)

Know your BOM!

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Tristan Erion-Lorico

Head of PV Module Business

PVEL

PVEL

MAKE DATA MATTER.

MODULE UNDERPERFORMANCE CASE STUDY

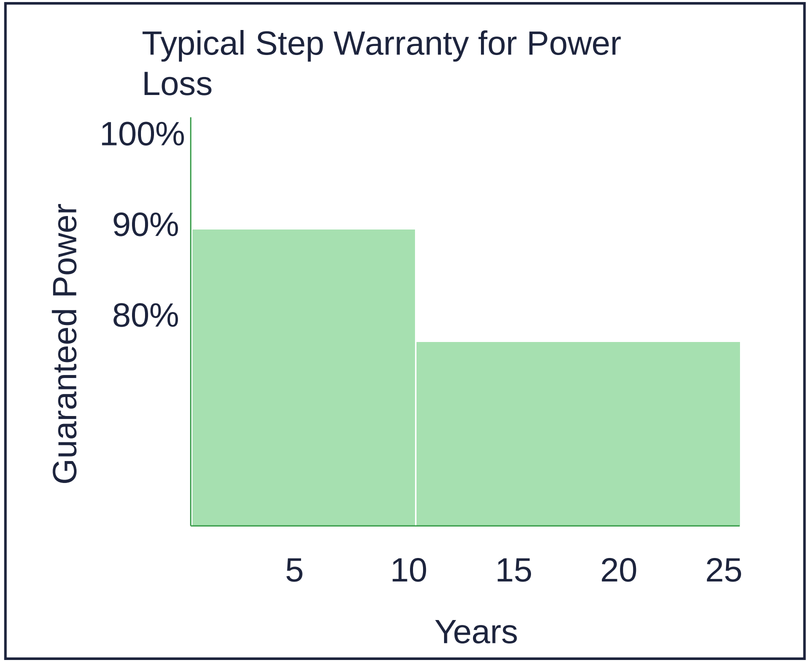
Tristan Erion-Lorico

Head of PV Module Business

PVEL

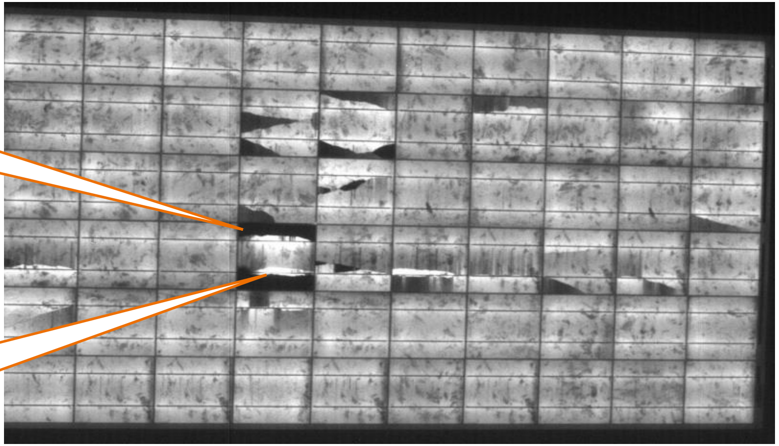
Building a 10 MW Project in California

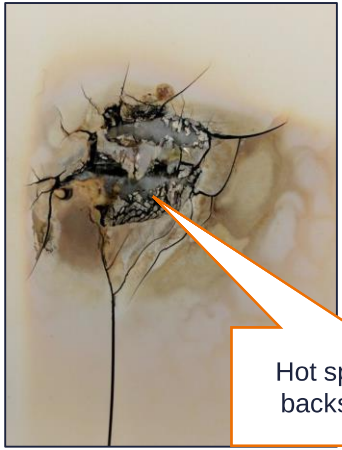
- Project constructed in 2011
- The modules used were:
  - Covered by 5-year product warranty for workmanship
  - Covered by step performance guarantee for power loss – not linear
  - Produced by a financially unstable manufacturer
- Operations began in late 2011



“Unforeseen” Issues Arise

- Original owner sold the project to a third party in 2016
- Microcracks soon began to cause hot spots and subsequent backsheet burns
- **This created a safety hazard that had to be immediately remedied**

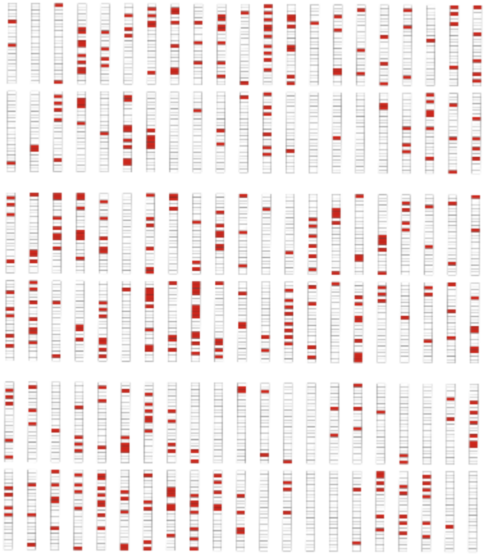




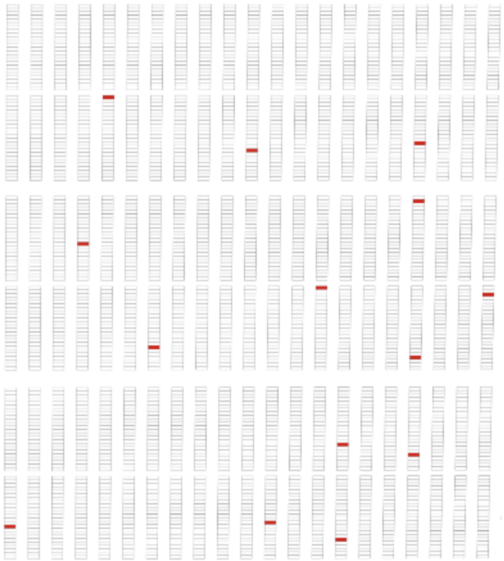
Issues observed after 5 years in field

Results of Heliolytics' Thermal Aerial Scan are Troubling

- Owner conducts aerial thermal scan to quantify module defects
- Half the site had excessive hot spots throughout; the other half had far fewer hot spots



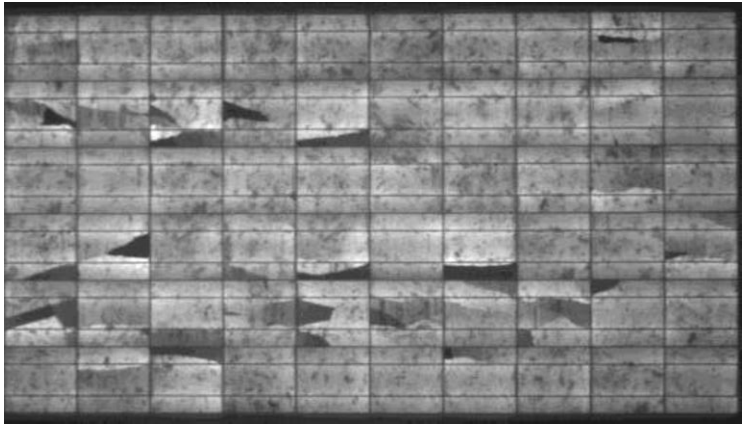
Module Batch #1
Source: Heliolytics



Module Batch #2
Source: Heliolytics

Quality Issues Were Identified During Module Production

- In 2011, PVEL completed serial defect testing for a batch of modules used in project
- EL images of most samples showed signs of excessive microcracks originating at the cell bus bars, pointing to a soldering-related root cause
- Thermal cycling caused the potential power loss to be realized
- **PVEL's results were not fully considered and the module installation proceeded**



Post Thermal Cycling 200
Source: PVEL

Module Replacement Woes

- Insolvent manufacturer with an uncooperative new owner
- Insufficient warranty protection
- 5-year workmanship warranty had just expired
- Frame size and power class no longer available on the market, so needed to re-engineer for replacements
- Replacing the worst cases of hot spot modules cost hundreds of thousands of dollars – adding up to more than two years of the entire **portfolio's** O&M budget

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MAKE DATA MATTER.

QUESTIONS AND OPEN DISCUSSION

Panel discussion

All about the BoM: The role of bill of materials in module quality and field performance

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4

Quality cases

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Proactive identification and risk management of systemic issues

Rob Andrews Heliolytics

Summary:

A systemic fault is defined in this case as an issue occurring in a PV array which can be tracked back to a distinct process, manufacturing issue, or other correlating dataset on a site. This allows for identification and classification of these issues using statistical means, and therefore it is possible to asses the full risk profile of these types of faults.

In this case, we will present an example of a systemic fault identified in a project, how it was detected, and discuss recommended next steps were for mitigating risk in the system.

Findings

A routine aerial inspection was performed on a utility scale PV project. Based on initial findings, it was seen that approximately 0.2% of the site exhibited sub-module faults. This level of faults places the project in the 20th percentile of projects, meaning that 80% of comparable projects would have a fault rate less than this amount, indicating a potential warrantable issues.

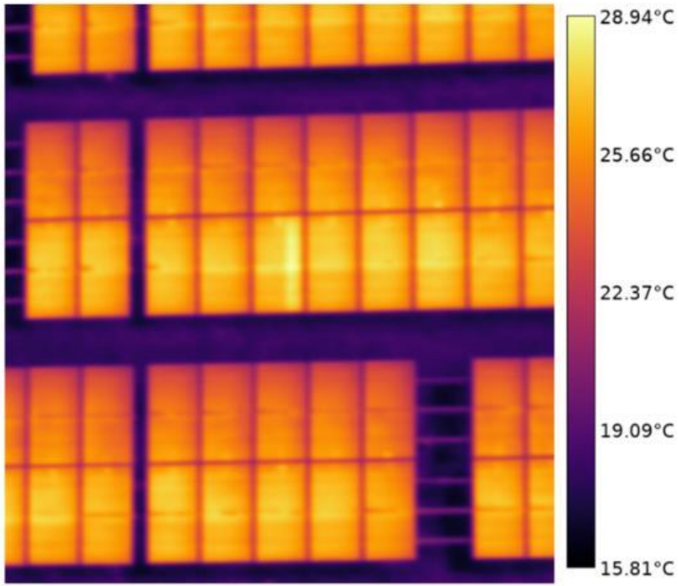

Figure 1: Example of a sub-module defect seen from aircraft IR caused by diode activation or solder bond failure

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Findings

Serial number data was also available for each module in this project, and was incorporated into the digital twin model for the array, and the results can be seen below, with the 'x' representing the location of the sub-module fault, and the shade of orange representing serial number bins.

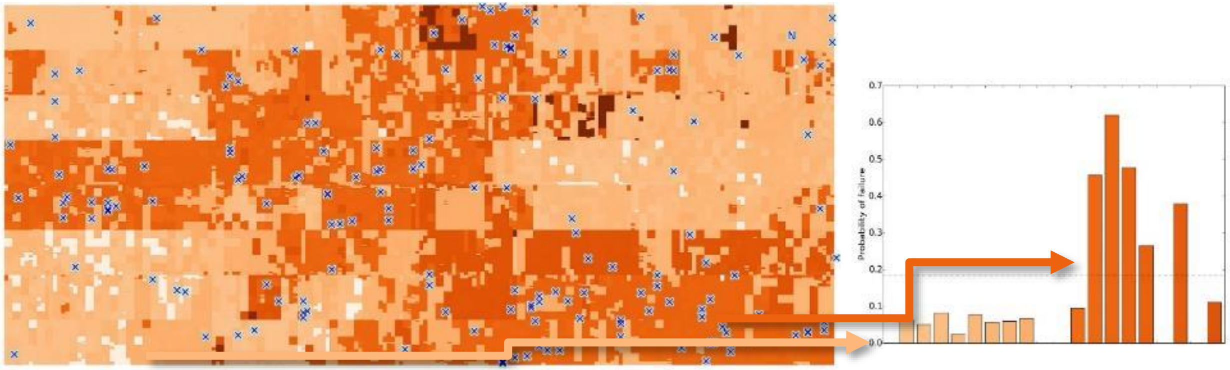

Figure 2: Serial number correlation analysis, showing a correlation between diode faults (x) and serial number batch (shade of orange). The bar graph shows the difference in probability of failure between the light orange and dark orange serial number bins.

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Findings

It can be seen that the location of sub-module faults correlated with a specific subset of serial numbers on site. Upon further investigation of the identified serial numbers, it was seen that all affected modules came from the same plant, production line and soldering machine. Upon further investigation with the manufacturer, it was identified that a soldering machine was out of calibration during manufacturing, affecting 1/5 of the modules on site.

Other common causes of systemic faults:

Some other common causes of systemic faults seen from aerial inspections along with the dataset used to correlate the failure are:

- Fuse failures caused by improper manufacturing techniques (Fuse Serial number)
- Connector failures caused by improper cross-mating (System as-builts/connector manifest)
- Connector failures caused by water and dirt ingress during installation (Date of installation)
- Module degradation due backsheet failure (Module Bill of Materials by serial number)
- Module degradation due to improper cell sorting (Date of manufacture)

Conclusions

It is common that failures in a PV system are not truly “stochastic” or random, but rather are being forced by a specific root cause. By utilizing advanced data and analysis tools, the random characteristics of a failure can be peeled away, and a more detailed root cause can be identified. This root cause can then be used to better identify recommended next steps and predict future performance of a component or a project.

In this specific case, this information allowed the customer to better identity underlying risks in the project, and to negotiate a more beneficial settlement to the warranty for these modules, which included a consideration for the potential of future module failures.

Questions

- What processes would have avoided this root cause during project development/construction/operations?
- What other sources of data can be useful in the identification of fault root causes?
- Do current warranty contracts include systemic failure clauses? If not, why not?

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Discussion

Best practices to ensure maximum tracker uptime

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Kent Whitfield

VP of Quality

NEXTracker A Flex Company

Christian Roselund

U.S. editor

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6 GW – How much is that?


Three Peaks, UT

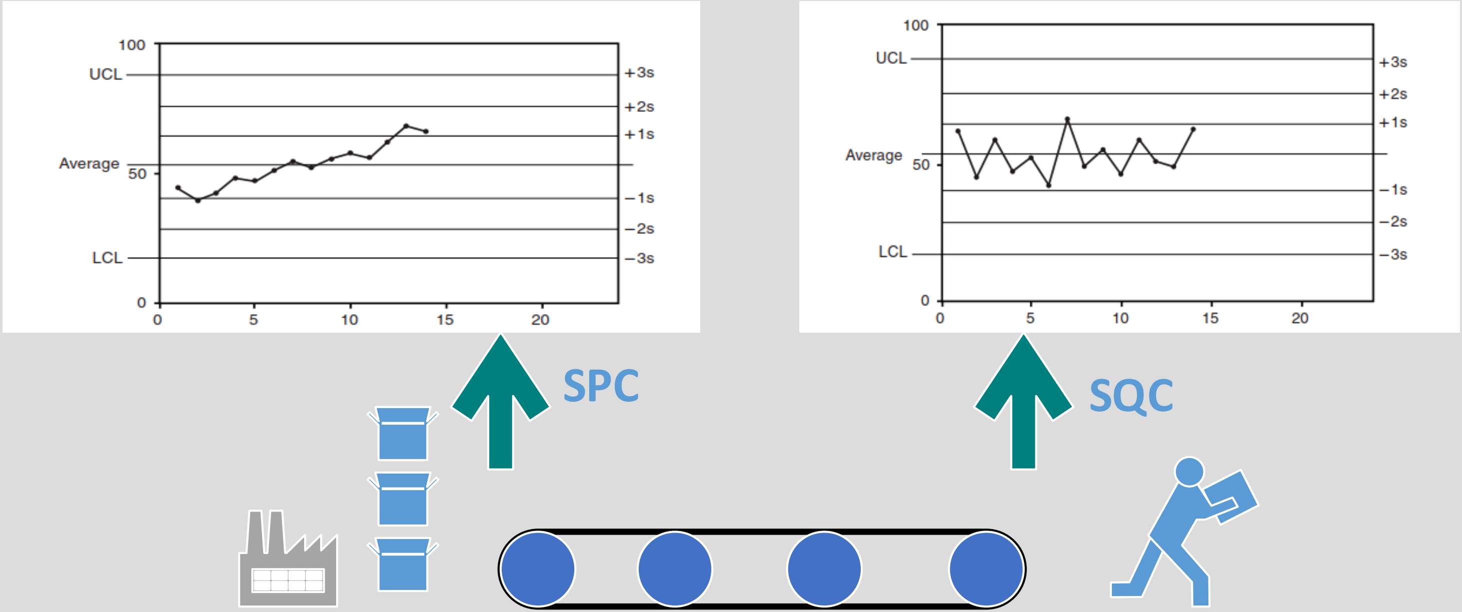
Process Capability, Cpk	Percentage of good parts
1.0	99.7%
1.2	99.97%
1.33	99.99%

- 115 MW/week
  - ~50,000 Piers, slews, torque tubes
  - ~370,000 modules, rails, fasteners

- Cumulative worldwide installed PV as of 2006
- 56 systems like this 107MW site in Utah
- *What level of quality control is good enough?*

Where do we need to go?

Process capability at the start of HVM → continuous capability and SQC → SPC



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Panel discussion

Component selection and installation practices to avoid fires

Dean Solon

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Head of Global Sales, Solar and Wind

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Brian Mills

Product Manager Photovoltaics

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Kim Primerano

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Longroad Energy

Networking session

Failures, fiascos and fires: How to avoid trouble from manufacturing, through design, to installation

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