PV Solar Assets
Risk Mitigation
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DuPont Photovoltaic Materials Portfolio

Over 50% of panels installed in the field since 1975 contain DuPont materials

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DuPont Global Field Reliability Program

Run since 2011 to inspect, assess, gather data and understand the performance and material degradation of fielded PV modules of different ages, having a variety of Bill of Materials, and from different geographies and climates over North America, Europe, Asia Pacific and the Middle East

- One of the most comprehensive surveys of module and component degradation
- Multi-step inspection protocol
- Statistical analysis of data by climate, component, material, mounting, age
- Modules selected for extensive post-inspection analytical characterization
- Collaboration with field partners, customers, downstream developers
PV Panel Degradation in the Field

- Photovoltaic panels are exposed to a wide range of stress factors, for a very long period of time
- Stresses induce fatigue, leading to degradation of the panels

- Loss of electrical protection/safety issues
- Loss of conversion efficiency/power output degradation
Midlife Failure of PV Modules

Typical PV Module Degradations

Source: IEA, PVEL (DNV GL)
Global DuPont Field Surveys (2019)

- Nearly 2 GW of fields inspected
  - Total module defects observed: 34%
  - Total backsheet defects observed: 14%

Backsheet defects increased by 47% vs 2018

Cracking accounts for 66% of the backsheet defects

Average age < 4 years old
Case 1: Backsheet Degradation

- Initial year of operation: 2011
- Region: Arizona, USA
- Service Time: 7 years
- Plant size: 12 MW
- Number of modules: 43,000
- Mounting configuration: Single-axis tracking
- Manufacturer: Tier I module maker
- System voltage: 1000V
- Module type: 72 cells
- Technology: Poly
- Surface: Desert, rock
- Climate: Dry, hot and cold
- Backsheet: 4 Different types

Inspection Summary

<table>
<thead>
<tr>
<th>Materials</th>
<th>MW</th>
<th>Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>6</td>
<td>100% full cracks</td>
</tr>
<tr>
<td>PET</td>
<td>3</td>
<td>100% inner cracks</td>
</tr>
<tr>
<td>PVDF</td>
<td>1.5</td>
<td>100% outer cracks</td>
</tr>
<tr>
<td>PVF</td>
<td>1.5</td>
<td>No defect</td>
</tr>
</tbody>
</table>

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Case 1: Financial Impact

Arizona, USA, 7 years

Complete module replacement due to serious backsheet issues

Due to severe weather conditions, the replacement process took longer than expected, leading to higher labor cost and power generation loss

Modules waiting to be re-installed
Glass-Glass Panels in the Field

Risk factors: Extra mechanical load, Cracks, Na+ migration, Delamination, Soiling (front & back)
Risk Mitigation: Know and Specify the Right BoM

KNOW YOUR BoM: PVEL 2019 Reliability Scorecard

• Modules with same model number but with different BoMs performed significantly differently in PVEL test

• If the BoM is not specified, panel manufacturers can use any combination of materials that have been certified
  • Module buyers and asset owners may experience various performances from the reliability standpoint in the field
  • To confirm the type of BoM used, additional panel level testing is required on-site

Know and specify the BoM and ensure your module supplier uses it
O&M: Plant Bill of Health
O&M: What can go Wrong?

All components can affect the operational safety & performance of the PV system

**Mechanical**
- Mounting system design /or loss of integrity
- Tracking system defects

**Power Generation**
- Shading (design/vegetation)
- Soiling
  - Panel Ageing/Efficiency Loss/Safety

**Electrical Path**
- Cabling / Connector / Grounding
- Combiner Box
- Inverters (e.g. faults)
- AC/AC transformer
O&M: Panel Level Degradation

PV panels can degrade faster than expected, after only a few years of operation

Typical Issues
- Broken cells/glass
- Na+ migration/PID
- Water ingress
- Loss of dielectric protection / backsheet
- Defective diodes
- Increase of contact resistance / busbars
- EVA yellowing

Impact

**Power:** Hot spot, PID, gradual degradation

**Safety:** Current leakage, loss of electrical protection (backsheet, glass)

< 4 years old
Detecting Panel Degradation: a Multimodal Approach

Panels affected by thermal anomalies are a large contributor to power loss.

Visual inspection & lab analysis can determine and confirm the nature of degradations and safety risks.

Visual & Lab Analysis/Safety

Power & Safety Performance

Electrical IV: String/Panel Level

Gradual loss can be quantified by IV measurement, compared to nameplate power.

Power data analysis can shed light on quantitative historical losses and trends.

Historical/Trend Power Data

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Case 2: When Tracking goes Wrong

• Many trackers on failsafe position (horizontal)
• Others facing away from the sun (North orientation)

What can happen after resolving the tracking problem?

1. The power production may not entirely go back to normal power production
   • The panels stuck in horizontal position worsen the soiling accumulation => Higher risks of hot spots
   • Hot spots can accelerate material degradation (encapsulant, backsheet)

2. The electrical safety may be compromised
   • Compromised electrical insulation of the panel, e.g. cracking of the backsheet or delamination between layers
   • Decreased shunt resistance of the cells subjected to hot spots for long periods of time

Only a multimodal analysis (IR, IV, visual) can determine the extent of the degradation
Case 3: Panel Level Power Losses

Capacity: 11MW
Area: Mediterranean region
Commissioning date: 2011 (8 years)

Multimodal analysis enables power loss quantification

Heavy soiling in high traffic zone

IV measurements

2.4%
6.0%
8.7%
17.1%

Soiling
Aging

Visual survey
Case 4 – Panel Level Power Losses - Hot Spots

Capacity: 3MW
Area: Mediterranean region
Commissioning date: 2011 (8 years)

19.5% of panels with hot spots:
- 11% between 0 °C and 5 °C: moderate hot spots
- 44% between 5.1 °C and 15.0 °C: materials aging accelerated by 2x
- 40% between 15.1 °C and 30 °C: drastic materials aging, accelerated by 4x + risk of delamination + cell degradation
- 4% above 30 °C: delamination risk, cell degradation + risk of fire
LCOE Sensitivity

- Efficiency (18%)
- Power Output (1800kWh/kWp)
- Lifetime (25 years)

LCOE Variation

- 2.3 USD cents/kWh

- Efficiency: -20%
- Power Output: +2%
- Lifetime: +30 years

Factors:
- PERC
- n-type
- HJT
- Irradiation
- Bifacial
- Trackers
- Durability
- Efficiency loss/ageing
- Reliability
- System design
- BoS
- BoM/Panels

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Summary

- Think in terms of USD/kWh rather than USD/W$_p$ while developing your PV projects: reliability & durability are critical
- Specify the BoM at the panel level, to mitigate risks
- Carefully monitor your plant (power, scheduled maintenance) to detect any unexpected degradation
- Consider a plant level “Bill of Health” to refine the diagnosis
  - Recommendation: 2 years (post-infant failure); 5 years (materials ageing); 9 years (before end of workmanship warranty); buy/sell assets
- A multimodal analytical approach can be considered to quantify the loss vs expected, identify the type of degradation and determine what curative actions may be needed, including revamping options
- Future: big data analytics, remote diagnosis, predictive degradation modeling/AI, preventive maintenance schedule
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