PV System Performance and Reliability - Quo Vadis?

Mitigating risks of premature solar panel failure in the field

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DuPont: the Leading Material Supplier in PV

Solamet® Metallization Pastes
Driving higher energy conversion efficiency

Tedlar® PVF Films for Backsheet
Protecting PV modules

Elvax® and Ionomer Encapsulants
Delivering long term protection of cells

+110 Over the last 7 years, DuPont has introduced more than 110 new Solamet® pastes designed to boost solar panel power output.

+50% More than half of the world’s 700 million solar panels installed since 1979 have DuPont materials in them.

+30 YEARS Tedlar® film is the only backsheet material proven to protect solar panels for 30+ years in all weather conditions.

+11 TRILLION DuPont materials have been time-tested in 1+1 trillion panel-hours of solar installations across the globe since 1979.

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Industry Standards not Reflecting Long-term Performance

IEC testing protocols do not adequately simulate the performance in the environment

Qualification Tests
- 1 to 2 stresses in series
- 15 kWh per m² of UV radiation (front) – no irradiation on the back
- 200 thermal cycles
- No solar load (not in operation) in testing chambers

25 Years In-Field
- Multiple environmental and mechanical stresses
- 171 kWh per m² rear side of UV radiation (temperate) *
- 1000s of thermal cycles
- Higher operating temperature
- Stresses endured with solar load (in operation)

“Long-term outdoor exposure is the ultimate test for all module components, material quality and manufacturing quality.”*

* Artur Skoczek, Tony Sample, and Ewan D. Dunlop,
The Results of Performance Measurements of Field-aged Crystalline Silicon Photovoltaic Modules, Wiley InterScience, 2008
Independent Testing Validates Performance Advantage of Tedlar® PVF: Long Module Life, with Low & Tightly Distributed Power Loss

**PV Module Power Loss After Years of Outdoor Operation**

**Glass vs. Tedlar®**

- Power Loss per Year (%)
- Backsheet: Glass, Tedlar®-based
- Age of tested modules: 20-23, 19-23

**PET vs. Tedlar®**

- Power Loss per Year (%)
- PET-based, Tedlar® TPT-based
- Age of tested modules: 5-14, 11-19

**PVDF vs. Tedlar®**

- No PVDF data available
- Not used in PV 10+ years ago
- Variable PVDF film characteristics from 5+ film providers

**Tedlar® is the only backsheet material proven to deliver superior outdoor PV performance for decades**

Source: * Joint Research Centre (Italy)
** AIST (Japan)
DuPont™ Tedlar® PVF Film-Based Backsheet Demonstrates Outstanding Reliability

Visual Defects by Component:
- Cell 59%
- Encapsulant 10%
- Glass 5%
- Mismatch 2%
- Others 2%
- Backsheet 22%

PVF Film-Based Backsheet Demonstrates Outstanding Reliability

% of Backsheet with Visual Issues:
- Tedlar® (PVF) 1%
- FEVE 11%
- PET 30%
- PVDF 58%

Source: DuPont Field Module Program, which analyzed 60 global installations
Note: All percentage numbers are based on MW
* PVF (Polyvinyl Fluoride), PVDF (Polyvinylidene Fluoride)
PET (Polyethylene Terephthalate), FEVE (Fluorinated Ethylene Vinyl Ether)
### Fielded Module Program Summary

- **Surveyed:** >60 global solar installations in NA, EU & AP
- **45 module manufacturers,** > 150 MW, > 700,000 modules
- **Range of Exposure:** Newly commissioned modules to 30 years in the service environment

<table>
<thead>
<tr>
<th>Backsheet Based:</th>
<th>Tedlar®</th>
<th>PVDF</th>
<th>PET</th>
<th>FEVE</th>
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</thead>
<tbody>
<tr>
<td>Profile of Sample Size</td>
<td>30 Installations</td>
<td>24 Installations</td>
<td>15 Installations</td>
<td>4 Installations</td>
</tr>
<tr>
<td>20 MW</td>
<td>104 MW</td>
<td>23 MW</td>
<td>21 MW</td>
<td></td>
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<tr>
<td>122K Modules</td>
<td>403K Modules</td>
<td>112K Modules</td>
<td>102K Modules</td>
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</tbody>
</table>

| Avg System Age | 10.5 years | 3.2 years | 6.5 years | 3.75 years |
| Avg Range     | 2 - 27 years | 2 - 5 years | 2 - 15 years | 3 - 5 years |

| Fields with Identified Defects | 3/30 (10%) | 12/24 (50%) | 11/15 (73%) | 2/4 (50%) |

| Percentage Defects on MW Basis | 0.1% (15kW / 20MW) | 43% (44/104 MW) | 39% (9/23 MW) | 29% (6/21 MW) |

<table>
<thead>
<tr>
<th>Types of Defects Observed</th>
<th>Delamination</th>
<th>Frontside Yellowing</th>
<th>Frontside or Backside Yellowing</th>
<th>Backside Yellowing Delamination / Cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cracking*</td>
<td>Cracking</td>
<td>Delamination / Cracking</td>
<td></td>
</tr>
</tbody>
</table>

* Only in 4 mil single layer

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Two very different outcomes

6 Years Later:
“Faulty solar panels pulled from 24 schools”*

Stated Expectations (2006, 2007; PPA):
• “Wanted on-site generation at predictable rates but we didn’t want any upfront costs.”
• “Expected to provide the lion’s share of our peak power needs”

Results – after 6 years:
• Defect discovered that created potential safety hazard
• SDCS lost future savings from the PV (now purchasing power from the grid)

28 Years Later:
“SMUD forges a new path in Photovoltaics Generation”*

Stated Objectives
• “PV is an excellent match for our generating needs”
• “The Utility specified the type and level of quality assurance it would expect”
• “We laid down the basic criteria for the design and manufacture of the PV modules”

Results – 28 Years with Tedlar® PVF Backsheet
• First large scale (1 MW) utility PV generation facility in the world
• Expected power provided for 28 years

*Source: San Diego Union Tribune: Sept 13, 2012
*Source: Electric Light & Power, August 1984
Minimal Cost Difference Between Tedlar® PVF Film-Based Backsheet and “Non-Proven” Backsheets

Cost difference between Tedlar® PVF film-based backsheet and specialty PET-based backsheet

$0.003~0.015/W*

Days of operation needed to cover the cost difference

Only 5~25 days**
operation out of entire lifetime

* Difference derived from TPT (Tedlar®/Polyester/Tedlar® backsheet) and TPE
** DuPont calculation based on following assumptions
*** Financial calculation varies by location
Location: California, U.S.
Panel output: 270W
Efficiency rate: 18%
Performance ratio: 78%
Source of electricity price data: U.S. EIA

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