Typical Photovoltaic Backsheet Failure Mode Analysis under Different Climates in China

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Backsheet Materials Are Critical to Solar Module Durability and Performance

**Backsheets protect PV modules from many hazards**

- **Ultra Violet (UV)**
  - Transmitted
  - Reflected

- **Temperature**
  - Peak
  - Cycling
  - Hot spots

- **Corrosive Environment**
  - Atmospheric chemicals
  - Ammonia
  - Marine/coastal environment

- **Electrical Damage**
  - Shock
  - Shorting

- **Moisture**
  - Humidity
  - Precipitation
  - Condensation

- **Physical Threats**
  - Abrasion (sand)
  - Impact (installation, debris)
Materials are Best Assessed by Looking at Outdoor PV Performance

- Photovoltaic modules are exposed to a wide range of stress conditions (UV, temperature, moisture, thermal cycling, and internal voltage) simultaneously or sequentially;

- Current IEC standards are very mild and mostly are single or double stress conditions’ tests at the same time due to equipment limitation;

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

DuPont Collaborated with Downstream Stakeholders to Assess PV Systems, Modules, and Materials in the Service Environment

- Inspected > 60 solar installations in NA, EU and AP by early 2015
- Age of 0-30yrs
- Including >200MW & 1.5 million solar panels

**Components visual defect ration**

- Cell, 24%
- Backsheet, 9%
- Encapsulate, 4%
- Mismatch, 1%
- Others, 1%

41% of inspected modules have visual defects

**Backsheets defect ration**

- PET, 30%
- FEVE, 11%
- PVDF, 58%
- Others, 1%
- Defects not detected, 59%

*IEEE PVSC (New Orleans, 2015, A. Bradley et al)*
Tedlar®-based Backsheets Have Widely Field Proven Under All Kinds of Climates in China

Arid Climate

24yrs, 93.0% power
17yrs, 86.7% power
20yrs, 92.3% power

Temperate

14yrs, 86.9% power

Tropical/subtropical

23yrs, 93.9%
23yrs, ~90% power
18yrs, 88.2% power
11yrs, 92.5%
Different Climates Present Different Environmental Stresses

<table>
<thead>
<tr>
<th>Climate</th>
<th>Weather station</th>
<th>Annual irradiation [MJ/m²]</th>
<th>25yrs UV on module rear side* [kWh/m²]</th>
<th>Annual average temperature [°C]</th>
<th>Annual average humidity [%]</th>
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</thead>
<tbody>
<tr>
<td>Arid</td>
<td>Dunhuang, Gansu</td>
<td>6560</td>
<td>273</td>
<td>10.8</td>
<td>41</td>
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<tr>
<td></td>
<td>Urumqi, Xinjiang</td>
<td>5519</td>
<td>230</td>
<td>4.5</td>
<td>54.8</td>
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<tr>
<td>Tropical and</td>
<td>Sanya, Hainan</td>
<td>5944</td>
<td>247</td>
<td>24.3</td>
<td>83</td>
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<tr>
<td>Subtropical</td>
<td>Guangzhou, Guangdong</td>
<td>4234</td>
<td>176</td>
<td>20.4</td>
<td>74.7</td>
</tr>
<tr>
<td>Temperate</td>
<td>Beijing</td>
<td>4912</td>
<td>204</td>
<td>11.9</td>
<td>57</td>
</tr>
<tr>
<td>Highland</td>
<td>Lasha, Tibet (subtropical)</td>
<td>7598</td>
<td>317</td>
<td>4.5</td>
<td>55</td>
</tr>
<tr>
<td>Seashore</td>
<td>Dongtai, Jiangsu (subtropical)</td>
<td>5019</td>
<td>209</td>
<td>15.1</td>
<td>76.5</td>
</tr>
</tbody>
</table>

Note*: 1) assume 5% UV ratio in solar irradiation and 12% albedo from ground surface; 2) 1 kWh/m² = 3.6 MJ/m²
Field Case: 20yrs Tedlar® TPT Backsheet Performs Good at Anti-fire Lookout Station of Yunnan (Subtropical)

- Good Tedlar® TPT backsheet appearance after 20yrs field exposure;
- Metal frame has serious corrosion.

36 cells monocrystalline-Si solar panels without apparent visual defect.

Junction-box was seriously yellowing and brittle; lid missed.
Field Case: 18yrs Tedlar® TPT Rooftop Solar Farm in Beijing Remains Good Appearance and Thickness Stability

Modules with Tedlar® TPT backsheets show 11.8% average power degradation in total after 18yrs field service, which is 0.65% in annual

No apparent Tedlar® thickness reduction in air side Tedlar® (nominal thickness is 38um) after 18yrs field exposure
18yrs Tedlar® TPT Backsheet Maintains Superior Chemical Stability and Mechanical Properties

Tedlar® film shows no apparently degradation after 18yrs field service

TPT backsheet sampled from the 18yrs fielded module remains 160.8% elongation and 92.1 Mpa tensile strength
Field Data of non-Tedlar® Backsheets:

Field Case: 4yrs PVDF Backsheet Shows High Percentage of Cracking and Delamination (Cold Arid Climate)

- 4yrs solar farm in north American with 200 modules and 200KW installation;
- PVDF Backsheet cracking & delamination ranged from 21% to 85% (avg 57%);
- No PVDF film remaining on some backsheets.
Field case: 5yrs PVDF Backsheet Show High Percentage Front Side Yellowing at Ningxia Province (Arid Climate)

- 5yrs solar farm in north China with 5.2MW installation;
- Around ~50% of PVDF Backsheet demonstrate front side yellowing. Similar results observed on 5 other countries on the world and all within 5yrs field service;
- Average power degradation of these modules is ~11% (industrial spec is 5% within 5yrs).
Yellowing is an indication of polymer degradation and can place modules at risk for failure and safety.

- Note significant loss of elongation when $db^* > 4$
- Field and UVA accelerated exposure data correlate % elongation loss with yellowing.

**Loss of Mechanical Properties vs Yellowness**

- UVA, 65W/sqm, 70°C BPT, 3000 hours = 195kWhr/sqm, 18 year desert equivalent
- Field exposures ranged from 4 to 14 years
Field case: 5yrs PVDF Backsheet Show Bubbling Issue at Seashore area of Jiangsu Province (Subtropical & Seashore)

- 5yrs solar farm in eastern China with 9.7MW installation;
- Around 6.3% of PVDF Backsheet shows apparent bubbling issue (no hot spot at bubbling areas); power degradation of the modules with bubbling PVDF backsheets is 11%~14.7%.
Field case: 4yrs PET Backsheet Shows Seriously Yellowing (Arid)

- 4yrs solar farm in Inner Mongolia, north China
- Yellowness value b* of backsheet is as high as 8-10

Bubble & yellowing

Yellowing and Hot spot
Field case: 9yrs PET Backsheet Peeled off and Yellowing (Highland)

9yrs field module in Tibet, seriously inner layer yellowing

Airside PET peeled off, especially at cell space areas

Cross-section with module label

21um thick airside white PET dismissed with 9yrs field exposure in Tibet (2.3um/yr)
PET Backsheet of Tibet Module Appears Highly Brittle and Apparently Mw Decrease

- **Molecular weight**
  
<table>
<thead>
<tr>
<th>Sample</th>
<th>Mw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core layer PET at cell shielding</td>
<td>19100</td>
</tr>
<tr>
<td>Core layer PET at cell space</td>
<td>12000</td>
</tr>
<tr>
<td>Outer layer PET at cell shielding</td>
<td>20400</td>
</tr>
</tbody>
</table>

- **Viscosity**

<table>
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<tr>
<th>Sample</th>
<th>IV , dL /g</th>
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</thead>
<tbody>
<tr>
<td>Core layer PET at cell shielding</td>
<td>0.929</td>
</tr>
<tr>
<td>Core layer PET at cell space</td>
<td>0.693</td>
</tr>
<tr>
<td>Outer layer PET at cell shielding</td>
<td>0.800</td>
</tr>
</tbody>
</table>

- **Mechanical property**
  
  - No appropriate size backsheet sample can be obtained for mechanical property test due to highly brittleness.
Field cases: Less Than 2yrs FEVE and PVDF Coating Backsheets Show Noticeable Thickness Reduction (Desert)

- 1.5yrs FEVE coating backsheet in Qinghai
- 16.5um outer coating layer left while nominal thickness is 20um.

- 1yr field PVDF coating backsheet in Xinjiang
- 15.5um outer coating layer left while nominal thickness is 20um and actual inner layer is 18.5um
Field case: 19yrs Glass/Glass Module (Operated 15yrs) in Hainan Totally Failed with Zero Power Output, Busbar wire corrosion and Encapsulant Yellowing & Delamination (Tropical)

All busbar wires corroded
Conclusions

• Long-term field proven records are important verifications for solar module materials and components. DuPont collaborated with downstream stakeholders to assess PV systems, modules, and materials in the service environment.

• Tedlar®-based backsheets demonstrate superior durability and have been widely proved in all kinds of climates up to 30+ years.

• PVDF-based backsheets have cracking, delamination, front side yellowing and bubbling issues at an early stage of field service.

• PET-based backsheets show cracking, yellowing and rapidly thickness reduction defects in field.

• Different climates present different environmental stresses for solar modules. Select widely long-term proven materials for your module and solar farm designs to protect various module applications under any climate conditions.
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