DuPont™ Tedlar® PVF Based Back-sheets – Performance comparison vis-a-vis PVDF and PET based backsheets
Backsheet Deemed Most Critical Material to Protect Solar Module

Most Critical Component

Crystalline Silicone PV Module Structure

PV Backsheet Structure

Backsheets protect modules from many hazards:

- **Ultra Violet (UV)**: Transmitted, Reflected
- **Moisture**: Humidity, Precipitation, Condensation
- **Corrosive Environment**: Atmospheric chemicals, Ammonia, Marine/coastal environment
- **Temperature**: Peak, Cycling, Hot spots
- **Physical Threats**: Abrasion (sand), Impact (installation, debris)
- **Electrical Damage**: Shock, Shorting

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Wrong selection of back-sheet can result in increased power loss and thus warranty claims.

### Failure modes of backsheets in field

- **Discoloration**: Yellowing and indelible stains on the surface of backsheet
- **Cracking**: Cracking of backsheet
- **Bubbling under hotspot**: Burn holes on backsheet surface
- **Separation of backsheet into layers**: Delamination
- **Bubble on the backsheet mainly found along the interconnector line**: Bubbling to cracking
- **Module with PVDF backsheet showing significant yellowing of layers behind the cells after <2 years in the field**: Yellowing
Typical PV Back-sheet Structures

Backsheet structure is critical for module’s long term performance in different climatic conditions

PVF: Poly Vinyl Fluoride Film
PVDF: Poly Vinylidene Fluoride Film
FEVE: Fluoroethylene-Alkyl Vinyl Ether Coating

HPET: Hydrolysis Resistance Polyester
PET (Polyester): Polyethylene Terephthalate
Tie-layer: EVA / Polyethylene / Polyolefin / Polyamide / Primer / Fluoro-coating, etc
DuPont Tedlar® PVF Based Backsheets
What is Tedlar®?

• Base molecule is called vinyl fluoride (VF).
• VF is polymerised to form polyvinyl fluoride (PVF).
• PVF is a member of fluoropolymer.
• Fluorine, being the most electronegative element, forms a very strong bond with carbon atoms in the polymer.
The Foundation of Backsheet Design and Module Qualification Tests – NASA PV Program

This program resulted in adoption of Glass/EVA/Tedlar® Backsheet as the safe and reliable PV Module Construction.
DuPont Tedlar® PVF based backsheets

- DuPont is the supplier Tedlar® Polyvinyl Flouride (PVF) film supplied from its Circleville, OHIO facility
- DuPont is the only manufacturer and supplier of Tedlar® Polyvinyl Film
- DuPont Tedlar® PVF films has been used in PV industry for over 4 decades

**Types of Tedlar® based backsheet construction**

**TEDLAR® TPT™ BACKSHEET**

| Tedlar® PVF film | PET | Tedlar® PVF film |

**TEDLAR® TPE BACKSHEET**

| Tedlar® PVF film | PET | Tie Layer |

**Tedlar® PVF Properties**

- ✔️ Weatherable
- ✔️ Moisture, heat, and UV resistant
- ✔️ Strong and durable adhesion
- ✔️ Mechanically tough film
- ✔️ Chemically resistant

**Tedlar® PVF films provide the benefits and proven performance to all Tedlar® based backsheets**

Circleville, Ohio, USA Plant
25 GW Capacity
Tedlar® Has a Distinguished PV Performance History of >30 years; Competitors Do Not

Very old modules with Tedlar® are still performing well...

...While unproven backsheets are failing early in the field

Why risk module protection by using unproven backsheets?
Tedlar® Based Backsheets Demonstrates Excellent Performance in Different Climates

11 – 27 years old installation in China
- <0.8% power annual power loss
- All modules have Tedlar® PVF film-based backsheets

Tedlar® PVF Film-Based Backsheets Demonstrate Excellent Field Performance
Module Field Data Demonstrate Issues in Non-Tedlar® Based Backsheets

Visual Defects by Component

% of Backsheet with Visual Issues

- Inspected >60 global installations (>200 MW & 1.5 million panels) in NA, EU, & AP ranging from 0-30 years installed
- 10 installations in India
- Data includes c-Si panels from > 45 panel manufacturers

Tedlar® PVF based backsheets demonstrate superior field performance

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)
Performance Comparison – Tedlar® PVF vs PVDF
Tedlar® PVF films outperform competitive PVDF films, offering consistent stability under various tests.

**Tedlar® PVF Film**
- Consistent, excellent performance from DuPont
- No plasticizer
- Tough film
- High surface tension
- Durable adhesion
- Good weatherability
- No reaction to any major solvent
- High Melting Temperature (~200°C)

**PVDF Films**
- Variable formulations and performance
- 30 to 50% acrylic, results in plasticizer migration
- Poor tear resistance
- Poor resistance to damp heat and UV
- Poor resistance to ammonia and strong solvents
- Low Melting Temperature (160-170°C)

Acrylic (PMMA) seriously decreases the weather resistance of PVDF film.
PVDF film suppliers have different constructions and additives

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Thickness</th>
<th>Additives</th>
</tr>
</thead>
</table>
| Supplier A | 30um     | • 5u PVDF  
• 20u PVDF+Acrylic +TiO2  
• 5u PVDF |
| Supplier A | 25um     | • PVDF    
• PVDF+Acrylic +TiO2  
• PVDF |
| Supplier B | 24um     | • PVDF+Acrylic +TiO2 |
| Supplier B | 18um     | • PVDF+Acrylic +TiO2 |
| Supplier C | 25um     | • PVDF+Acrylic +TiO2 |

Additives and different constructions result in inconsistent performance. The polymer in Tedlar® PVF film is 100% polyvinyl fluoride.
Accelerated Testing: PVDF Film loses Elongation Under Damp Heat Conditions

Complete loss of elongation in PVDF after 500 hrs
Test Condition: 85° C, 85%RH

Complete loss of elongation in PVDF after 25 hrs
Test Condition: 120° C, 100% RH

Third Party*
Complete loss of elongation in PVDF after 25 hrs
Test Condition: 120° C, 100% RH

Loss in elongation increase risks of PVDF Film Cracking

Accelerated Testing: PVDF Backsheet Cracks After Sequential Testing

**Backsheet Type**

**PVDF Based Backsheets**
- PCT / DH / UVA → Loss in Elongation of PVDF Film (Consistent with our findings for PVDF Film, Slide #5)
- TC 200 → Brittle PVDF Film cracked due to thermal expansion and contraction

**PVF Based Backsheets**

**PCT48 + TC200**
- 2-sided PVDF Backsheet

**DH1000 + TC200 + Dh1000 + TC200**
- 1-sided PVDF Backsheet

**DH1000 + UVA1000 + TC200**
- 1-sided PVDF Backsheet

No Cracking

Poor mechanical properties of PVDF Film increases risk of back-sheet cracking

PCT48: Pressure Cooker Test, 48 hrs @ 120° C 100% RH; TC200 → Thermal Cycling 200 cycles 85° C ↔ -40° C; UVA1000 → UV exposure 1000 hrs UVA 1.2 W/sqm @ 340nm, 65 W/sqm (300-400nm), 70C BPT, no condensation

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Field Data: PVDF-Based Backsheet Cracking and Delamination

- Cracking and backsheet delamination
- No PVDF film remaining on some backsheets
- Observed in 57% of the installed modules

Findings (Cracks) consistent with those observed in lab testing
### Field Data: PVDF Based Backsheet Melting and Yellowing

<table>
<thead>
<tr>
<th>Backsheet Type</th>
<th>Location</th>
<th>Age of Module</th>
<th>Backsheet Issue</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVDF Based</td>
<td>Arizona, USA</td>
<td>2 years</td>
<td>Bubbling and cracking of PVDF film due to hotspots</td>
<td>Low melting &amp; softening temp. of PVDF film</td>
</tr>
<tr>
<td>PVDF Based</td>
<td>Israel</td>
<td>2 years</td>
<td>Melting of PVDF film caused by hot spots</td>
<td>Poor UV stability of Inner layer</td>
</tr>
<tr>
<td>PVDF Based</td>
<td>5 different countries</td>
<td>&lt; 5 years</td>
<td>Front side yellowing due to UV exposure</td>
<td></td>
</tr>
</tbody>
</table>

**Backsheet delamination and cracking risk module performance and safety**
Performance Comparison – Tedlar® PVF vs PET
Poor UV resistance of PET based back-sheets leads to yellowing and cracking

<table>
<thead>
<tr>
<th>Backsheet Type</th>
<th>Location</th>
<th>Age of Module</th>
<th>Backsheet Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET Based</td>
<td>Spain</td>
<td>5 years</td>
<td>• Severe cracking of PET layer&lt;br&gt;• Approx. 5000 modules impacted&lt;br&gt;• 32% power loss over 5 yrs</td>
</tr>
<tr>
<td>PET Based</td>
<td>Spain</td>
<td>5 years</td>
<td>• Deep crack in the backsheet</td>
</tr>
<tr>
<td>PET Based</td>
<td>China</td>
<td>9 years</td>
<td>• Severe cracking, peeling and yellowing</td>
</tr>
<tr>
<td>PET Based</td>
<td>Arizona, USA</td>
<td>6 years</td>
<td>• Severe Yellowing &amp; Cracking of PET film&lt;br&gt;• 11-42% power loss*</td>
</tr>
</tbody>
</table>

* "I–V curves and visual inspection of 250 PV modules deployed over 2 years in Tucson" Kopp, E.S.; Lonij, V.P.; Brooks, A.E.; Hidalgo-Gonzalez, P.L.; Cronin, A.D. Photovoltaic Specialists Conference (PVSC), 2012 38th IEEE

Not a good choice for India owning to high UV radiation
Case Study: PET-Based back sheets showing yellowing and delamination

**Backsheet Type: PET Based**
- 4 years old plant in North China
- Significant yellowing of backsheet (b* = 8-10)
- Bubbling and Delamination

Yellowing is a Visible Sign of Material Degradation (Brittleness) and Can Lead to Cracking
Case Study: PET-Based back sheets showing yellowing and cracking and resulting in power loss

- 6 years old, 9 PET modules located in AZ, USA
- Severe yellowing and brittle to the touch
- FTIR scan shows evidence of polymer degradation to monomers
- Note: these fielded results are consistent with accelerated aging results
- 11-42% power loss!*

Yellowing is a sign of polymer degradation and can lead to cracking, module failure, and a safety hazard

* "I–V curves and visual inspection of 250 PV modules deployed over 2 years in Tucson" Kopp, E.S.; Lonij, V.P.; Brooks, A.E.; Hidalgo-Gonzalez, P.L.; Cronin, A.D. Photovoltaic Specialists Conference (PVSC), 2012 38th IEEE
Independent Studies Validates Performance Advantage of Tedlar®

**PV Module Power Loss After Year of Outdoor Exposure**

The Joint Research Centre (JRC) demonstrated that modules including Tedlar®-based backsheet showed superior power loss performance compared to modules with Glass-based backsheet.*

National Institute of Advanced Industrial Science and Technology (AIST) showed modules with Tedlar®-based backsheet to have superior power loss performance vs. modules with PET-based backsheet.

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

*2008: Joint Research Center (JRC), Italy
**2012: National Institute of Advanced Industrial Science and Technology (AIST)
Summary

• Backsheet is the most critical component in solar module from durability and safety standpoint, and thus should be selected prudently.

• Currently available backsheets typically have tri-layer construction. Common materials used as outer layer (exposed to climate) are – PVF Film, PVDF Film, FEVE coating, and PET/HPET film.

• DuPont Tedlar® PVF Film based backsheets are the only backsheets having >30 years of field proven experience. Most other backsheets are less than 7 years old and thus not field proven.

• PVDF based backsheet possess poor mechanical properties which increases risk of cracking in the field. Also, low melting point of PVDF film increases risk of its melting and cracking due to hot spots.

• PET material doesn’t possess good UV resistant properties. Many instances of PET based backsheet yellowing and cracking due to reflected UV radiation have been observed in the field.