Assessing the reliability of transparent polymeric backsheets for durable bifacial modules
DuPont’s Approach to Understanding Module Reliability

Begins in the Field….

Continues in the Labs @ Wilmington (US), Shanghai & Japan

Augmented by robust Accelerated Testing Protocols

Leveraging global network of Labs, People and Analytical Capabilities
# A History of Transparent Tedlar® Backsheets

Old Tedlar® Transparent Film was used in BPIV applications – a niche market

Shown here is our oldest known field case:

<table>
<thead>
<tr>
<th>Age at Inspection</th>
<th>18 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Amsterdam, Netherlands Overhang of a building</td>
</tr>
<tr>
<td>Number of Modules</td>
<td>51 full-size</td>
</tr>
<tr>
<td>System Size</td>
<td>6.228 kWp</td>
</tr>
<tr>
<td>Backsheet ID</td>
<td>Tedlar®-based</td>
</tr>
</tbody>
</table>
| Status            | • No backsheet yellowing  
                   | • No backsheet delamination  
                   | • Slight ARC delamination  
                   | • Slight EVA yellowing  
                   | • Slight yellowing of insert used on junction box connection |
Benefits of Transparent Tedlar®-based Backsheets

- Glass/backsheet module structure has demonstrated reliable performance over more than 35 years in all climates
- Glass/backsheet structure prevents localized mechanical stress and possible delamination and cracking
- Permeable backsheets prevent corrosive encapsulant byproducts from being trapped and causing higher degradation
- Lighter weight of glass/backsheet structure reduces the cost of transportation, mounting and installation
- Glass/backsheet module structure is compatible with established processing and equipment, lowering manufacturing costs

Nara, Japan, 1983
0.2% annual power loss

Mont Soleil, Switz., 1992
0.3% annual power loss

Beijing, China 1999
0.7% annual power loss
Benefits of Transparent Tedlar®-based Backsheets

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- **Permeable backsheets prevent corrosive encapsulant byproducts from being trapped and causing higher degradation**
- Lighter weight of glass/backsheet structure reduces the cost of transportation, mounting and installation
- Glass/backsheet module structure is compatible with established processing and equipment, lowering manufacturing costs

Severe delamination on glass/glass module 10 years, Arizona USA

G/G modules cracking at clamps due to local strain 1.5 years, NW China

Severe busbar corrosion on glass/glass module 15 years, Danzhou China
New Transparent Tedlar® PV3001

High transparency
Robust mechanical properties
Excellent UV protection for PET-core backsheet

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>25 µm</td>
<td>Micrometer</td>
</tr>
<tr>
<td>Optical Transmission</td>
<td>94 %</td>
<td>ASTM D1003</td>
</tr>
<tr>
<td>MD Elongation at Break</td>
<td>150 %</td>
<td>ASTM D882</td>
</tr>
<tr>
<td>TD Elongation at Break</td>
<td>140 %</td>
<td>ASTM D882</td>
</tr>
</tbody>
</table>

PV3001 Transmission Spectrum

Typical PET Optical Density
UV Durability of New Transparent Tedlar® PV3001 Film

Xenon Exposure: RightLight filter, 90°C BPT, 0.8 W/m²-nm @ 340 nm
Comparison of Old TUT and New Tedlar® PV3001 Film

- UV Absorbance (%)
- Yellowness Increase ($\Delta b^*$)
- Retained Elongation at Break (%)
- Optical Transmission (%)

Xenon Exposure: boro/boro filter, 70 °C BPT, 0.55 W/m²-nm @ 340 nm

1/8/2020
Elongation Retention of Tedlar® PV3001 Film Over a Wide Range of Temperatures

![Graph showing elongation retention of different films at various temperatures.]

- **Tedlar® PV 3001**
  - 23°C: High retention
  - 0°C: Moderate retention
  - -20°C: Low retention
  - -40°C: Moderate retention

- **Comp Clear film 1**
  - 23°C: Low retention
  - 0°C: Low retention
  - -20°C: Minimal retention
  - -40°C: Minimal retention

- **Comp Clear film 2**
  - 23°C: Low retention
  - 0°C: Low retention
  - -20°C: Minimal retention
  - -40°C: Minimal retention
UV Durability of Transparent Tedlar®-based Backsheets

Xenon Arc – RightLight filter
90 °C BPT, 0.8 W/m²-nm @ 340 nm

UVA-340 Fluorescence
70 °C BPT, 1.2 W/m²-nm @ 340 nm

Solar Transmission (%)

Elongation at Break (%)

Machine Direction
Transverse Direction

Sample 1 - Transmission
Sample 2 - Transmission
Sample 1 - Yellowness Increase
Sample 2 - Yellowness Increase

Sample 1 - Transmission
Sample 2 - Transmission
Sample 1 - Yellowness Increase
Sample 2 - Yellowness Increase

Sample 1 - Transmission
Sample 2 - Transmission
Sample 1 - Yellowness Increase
Sample 2 - Yellowness Increase

Sample 1 - Transmission
Sample 2 - Transmission
Sample 1 - Yellowness Increase
Sample 2 - Yellowness Increase

Sample 1 - Transmission
Sample 2 - Transmission
Sample 1 - Yellowness Increase
Sample 2 - Yellowness Increase

Sample 1 - Transmission
Sample 2 - Transmission
Sample 1 - Yellowness Increase
Sample 2 - Yellowness Increase

Sample 1 - Transmission
Sample 2 - Transmission
Sample 1 - Yellowness Increase
Sample 2 - Yellowness Increase
Elongation retention of Transparent Tedlar®-based Backsheets under Damp Heat

Test Condition: 85°C, 85% RH

We are not a fan but we do it anyway…
Durability of Transparent Tedlar®-based Backsheets
Outer Layer (Air Side)

Testing with a single stress (UV, accelerated with heat):
• Excellent stability of clear PVF backsheets
• Higher intensity MH exposures with appropriate filtering correlates to other UV sources
• UVA fluorescent, xenon and metal halide exposures identify yellowing issues with PET backsheets
• Drop in mechanical properties identified for PA backsheet as seen in field

<table>
<thead>
<tr>
<th>Color (b*)</th>
<th>MH1 b*</th>
<th>Xenon b*</th>
<th>UVA b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 hr</td>
<td>55 kWh/m2</td>
<td>110 kWh/m2</td>
<td>155 kWh/m2</td>
</tr>
<tr>
<td>1s-PVF1 clear</td>
<td>3 1.9 2.1 2.2 2.2 2.4</td>
<td>1.8 1.9 2.0</td>
<td>1.9 1.9</td>
</tr>
<tr>
<td>2s-PVF1 clear</td>
<td>3.2 1.9 2.1 2.0 2.0 2.1</td>
<td>1.8 1.9 1.9</td>
<td>1.9 2.0</td>
</tr>
<tr>
<td>2s-PVF1 white</td>
<td>0.7 1.5 1.8 1.3 1.2 1.5</td>
<td>1.4 1.2 1.4</td>
<td>1.8 1.7</td>
</tr>
<tr>
<td>1s-PVF1 white</td>
<td>0.9 1.1 1.0 1 0.8 1.1</td>
<td>1 0.9 1</td>
<td>1.2 1.4</td>
</tr>
<tr>
<td>1s-PET1 white</td>
<td>1.7 4 5.2 5.2 4.8 6.1</td>
<td>2.2 2.9 4.9</td>
<td>3.6 5.2</td>
</tr>
<tr>
<td>2s-PA white</td>
<td>1.8 1.8 1.9 1.7 1.4 2</td>
<td>1.4 1.4 1.6</td>
<td>1.7 2.1</td>
</tr>
<tr>
<td>1s-PET2 white</td>
<td>2.5 4 5.1 4.5 3.7 5.9</td>
<td>2.6</td>
<td>3.9 4.1</td>
</tr>
<tr>
<td>1s-PVDF white</td>
<td>1.7 1.4 1.4 1.4 1.3 1.4</td>
<td>1.3 1.3 1.4</td>
<td>1.4 1.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elongation Loss</th>
<th>MH direct JB side</th>
<th>Xenon direct JB side</th>
</tr>
</thead>
<tbody>
<tr>
<td>55 kWh/m2</td>
<td>110 kWh/m2</td>
<td>165 kWh/m2</td>
</tr>
<tr>
<td>1s-PVF1 clear</td>
<td>-27%</td>
<td>-21%</td>
</tr>
<tr>
<td>2s-PVF1 clear</td>
<td>-15%</td>
<td>-30%</td>
</tr>
<tr>
<td>2s-PVF1 white</td>
<td>-10%</td>
<td>1%</td>
</tr>
<tr>
<td>1s-PVF1 white</td>
<td>-24%</td>
<td>-28%</td>
</tr>
<tr>
<td>1s-PET1 white</td>
<td>5%</td>
<td>7%</td>
</tr>
<tr>
<td>2s-PA white</td>
<td>-56%</td>
<td>-95%</td>
</tr>
<tr>
<td>1s-PET2 white</td>
<td>-28%</td>
<td>-42%</td>
</tr>
<tr>
<td>1s-PVDF white</td>
<td>-13%</td>
<td>-19%</td>
</tr>
</tbody>
</table>
Durability of Transparent Tedlar®-based Backsheets

Inner Layer Verification

The most accurate way to simulate this exposure is using a glass and encapsulant laminate to filter the light coming between the cells from the front side.

The fastest way to test materials is using a direct inner layer exposure.
Durability of Transparent Tedlar®-based Backsheets
Inner Layer

- Commercial white and clear backsheets tested using filtered metal halide and xenon exposure
- White backsheets with inner layer cracking and yellowing in the field correlated

<table>
<thead>
<tr>
<th>Color (b*)</th>
<th>MH b*</th>
<th>Xenon b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure from source</td>
<td>Initial</td>
<td>241 kWh/m²</td>
</tr>
<tr>
<td>1s-PVF1 clear</td>
<td>1.5</td>
<td>2.1</td>
</tr>
<tr>
<td>2s-PVF1 clear</td>
<td>1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>2s-PVF1 white</td>
<td>0.7</td>
<td>1.8</td>
</tr>
<tr>
<td>1s-PVF1 white</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1s-PET1 white</td>
<td>2.0</td>
<td>6.1</td>
</tr>
<tr>
<td>2s-PA white</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>1s-PET2 white</td>
<td>1.4</td>
<td>5.3</td>
</tr>
<tr>
<td>1s-PVDF white</td>
<td>-0.3</td>
<td>0.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elongation Loss</th>
<th>MH1 filtered</th>
<th>Xenon filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure from source</td>
<td>241 kWh/m²</td>
<td>482 kWh/m²</td>
</tr>
<tr>
<td>1s-PVF1 clear</td>
<td>6%</td>
<td>1%</td>
</tr>
<tr>
<td>2s-PVF1 clear</td>
<td>18%</td>
<td>12%</td>
</tr>
<tr>
<td>2s-PVF1 white</td>
<td>-10%</td>
<td>-8%</td>
</tr>
<tr>
<td>1s-PVF1 white</td>
<td>11%</td>
<td>-5%</td>
</tr>
<tr>
<td>1s-PET1 white</td>
<td>-95%</td>
<td>-96%</td>
</tr>
<tr>
<td>2s-PA white</td>
<td>-93%</td>
<td>-88%</td>
</tr>
<tr>
<td>1s-PET2 white</td>
<td>1%</td>
<td>-46%</td>
</tr>
<tr>
<td>1s-PVDF white</td>
<td>-22%</td>
<td>-68%</td>
</tr>
</tbody>
</table>
Color Stability of Tedlar®-based Backsheets in UV exposure

Super UV Exposure:
- 1500 W/m² from 290-450 nm, 52°C Black Panel Temperature, 50% Relative Humidity, No water spray
Abrasion Resistance of Transparent Backsheets


Backsheet samples after 100 liters of sand and surface cleaning

GB/T 23988-2009, Determination for abrasion resistance of - Coatings by falling abrasive material
Amount of sand refers to the amount required to wear through this layer
The outer layer of PET back-sheet has 2um UV resistant coating
Bifacial Module Testing

– compared to GG design
**PID Performance of G/BS and G/G Modules**

- Full size Glass/Backsheet and Glass/Glass bifacial modules
- Same BOM (POE encapsulant and identical bifacial p-PERC cells)
- -1500V, 85°C, 85%RH. Module power measured at 96 hour intervals.

**Lower power loss in Glass/Backsheet structure** with appreciable difference on the back side of bifacial module
- Use of POE does not prevent PID
Performance in IEC Hot Spot Testing

<table>
<thead>
<tr>
<th>Structure</th>
<th>Max. Temperature (°C)</th>
<th>Hot Spot Temperature (°C)</th>
<th>Delta (°C)</th>
<th>Power Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GB1</td>
<td>53.3</td>
<td>67.3</td>
<td>14.0</td>
<td>-0.49%</td>
</tr>
<tr>
<td>GB2</td>
<td>54.8</td>
<td>61.6</td>
<td>6.8</td>
<td>-0.68%</td>
</tr>
<tr>
<td>GG1</td>
<td>54.5</td>
<td>65.9</td>
<td>11.4</td>
<td>-0.30%</td>
</tr>
<tr>
<td>GG2</td>
<td>55.2</td>
<td>72.9</td>
<td>17.6</td>
<td>-0.65%</td>
</tr>
</tbody>
</table>

No appreciable difference in hot spot performance in standard IEC hot spot test conducted by third party (RETC)
Durability in Module Accelerated Sequential Test (MAST)

No cracking, yellowing, or delamination observed in third party (UVA) and internal (UVX and UVMH) MAST testing

Transparent Tedlar® PVF-Based Backsheet

No cracking, yellowing, or delamination observed in third party (UVA) and internal (UVX and UVMH) MAST testing

Backsheet cracking in MAST testing of 60-cell commercial module by third party (PVEL)

Same backsheet cracking Large MD crack 4 years in field

1/8/2020
Summary

• DuPont commercialized Tedlar® PV3001, a durable transparent Tedlar® PVF film with high performance and reliability

• Transparent Tedlar® PVF film based backsheets have shown good performance in the field in the past; current generation undergoing multiple field testing

• Transparent backsheets offer a pathway to have bifacial modules with long term durability using established materials and processes

• Initial results indicate that transparent Tedlar® based backsheets offer some cost, performance and durability advantages over glass/glass module structures