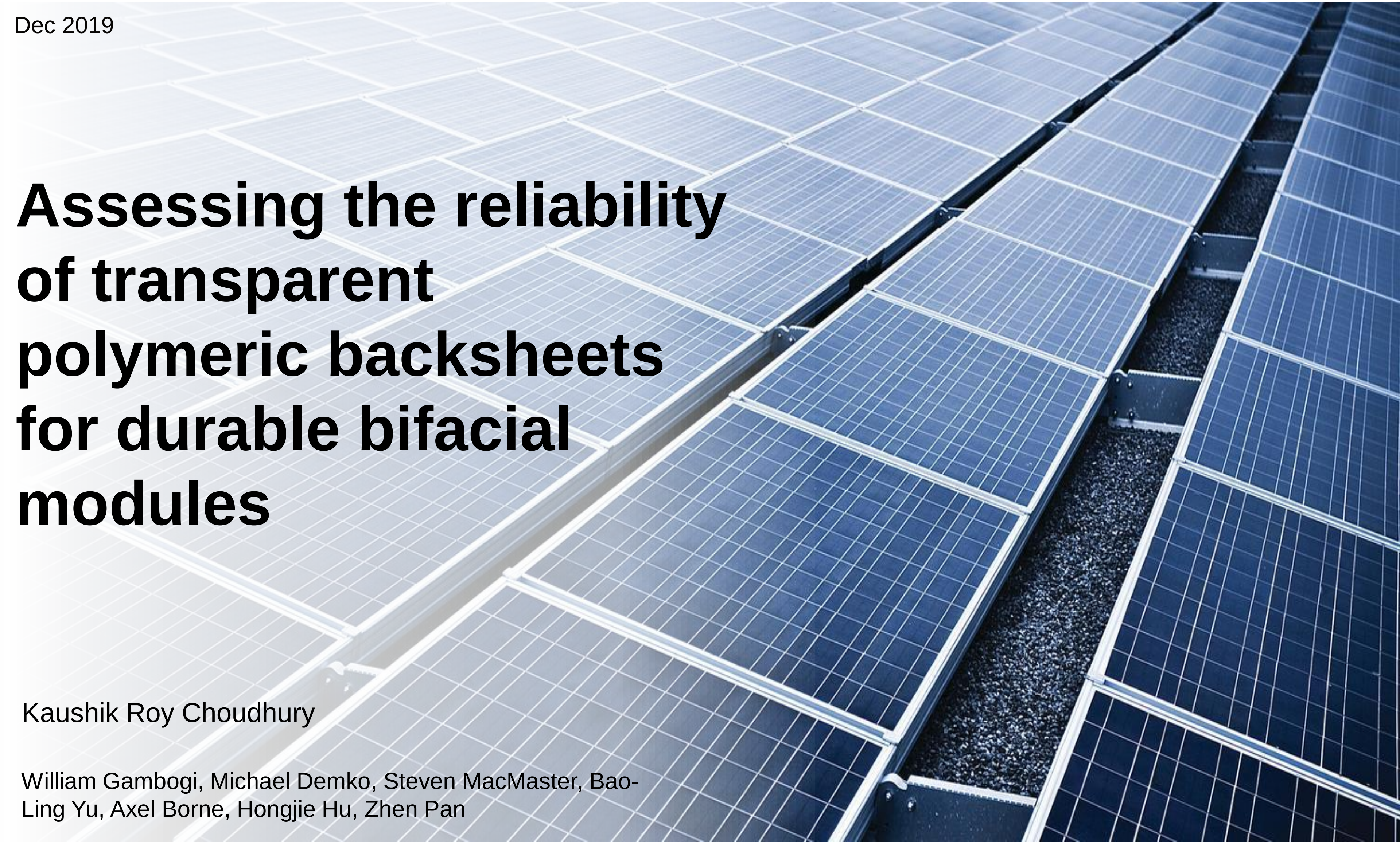
DuPont Photovoltaic Solutions

Dec 2019



Assessing the reliability of transparent polymeric backsheets for durable bifacial modules

Kaushik Roy Choudhury

William Gambogi, Michael Demko, Steven MacMaster, Bao-Ling Yu, Axel Borne, Hongjie Hu, Zhen Pan

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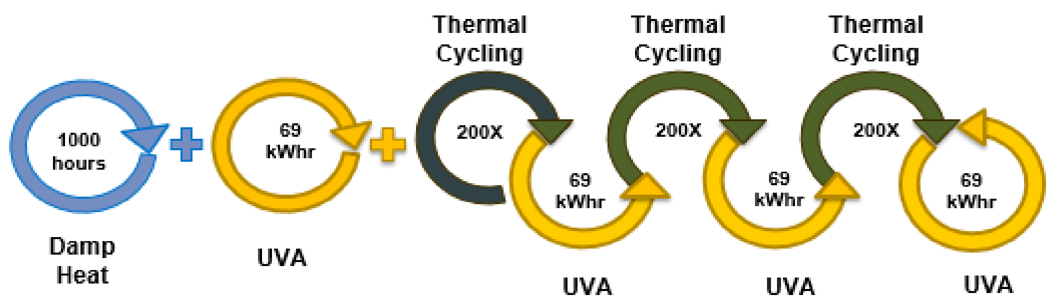
DuPont’s Approach to Understanding Module Reliability

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:

Age at Inspection	18 years
Location	Amsterdam, Netherlands Overhang of a building
Number of Modules	51 full-size
System Size	6.228 kWp
Backsheet ID	Tedlar®-based
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

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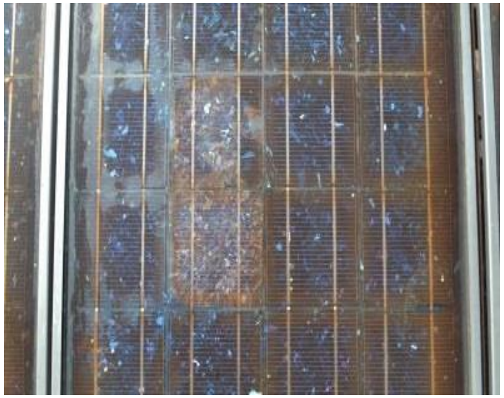
Severe delamination on glass/glass module
10 years, Arizona USA

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

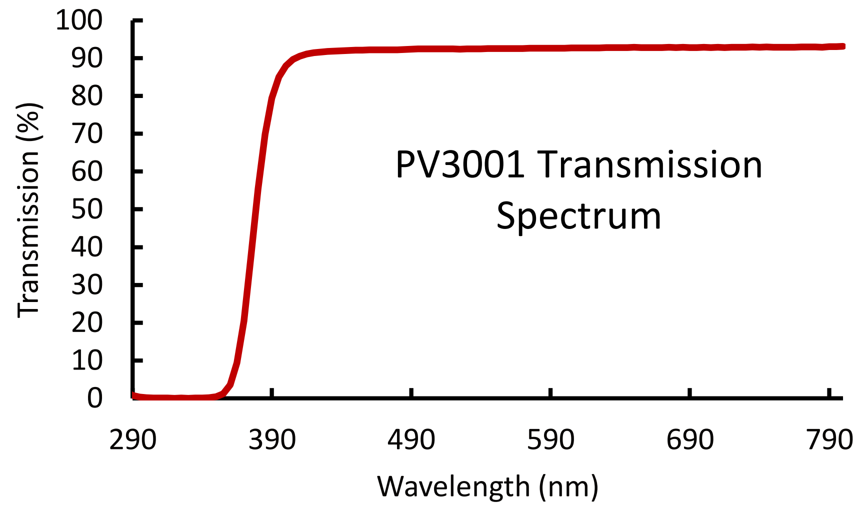
New Transparent Tedlar® PV3001

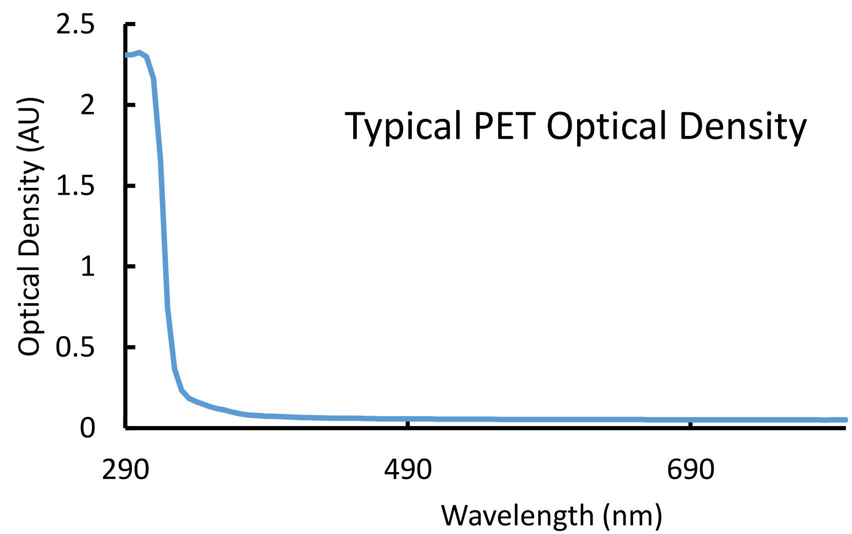
High transparency

Robust mechanical properties

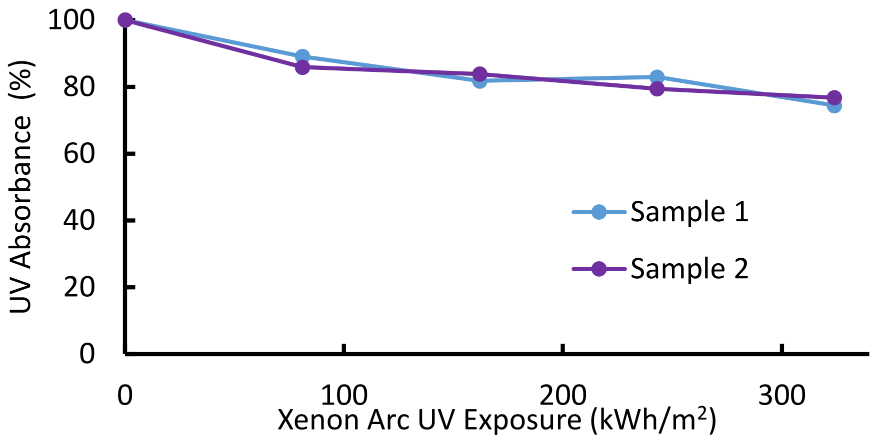
Excellent UV protection for PET-core backsheet

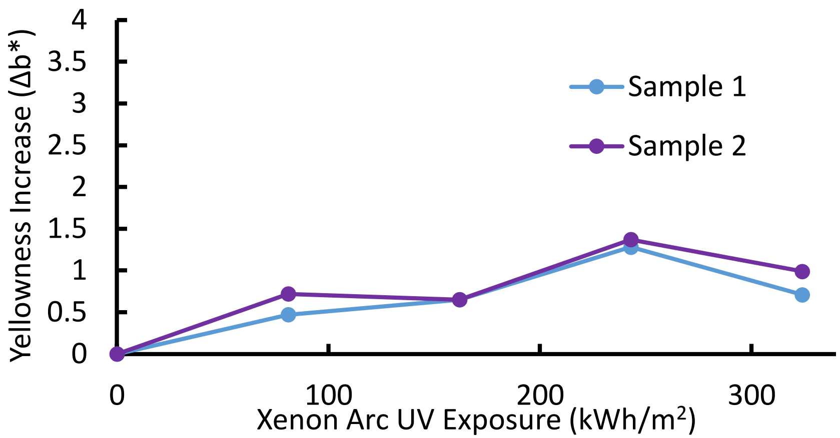
Property	Value	Method
Thickness	25 µm	Micrometer
Optical Transmission	94 %	ASTM D1003
MD Elongation at Break	150 %	ASTM D882
TD Elongation at Break	140 %	ASTM D882

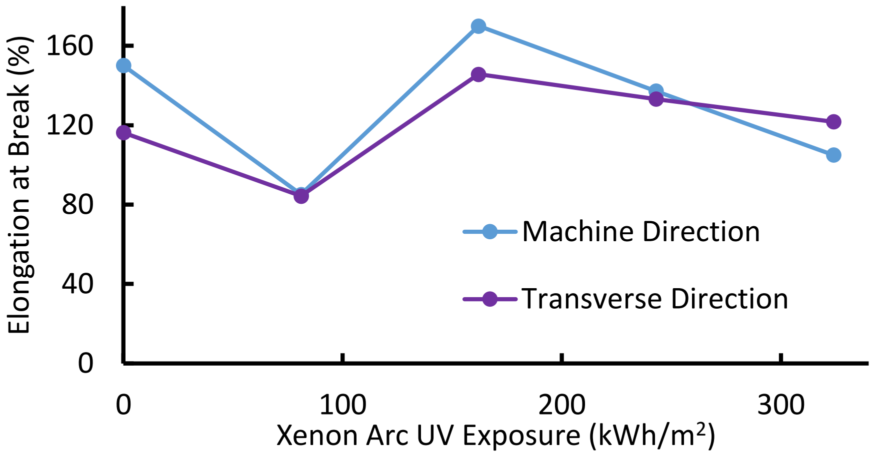


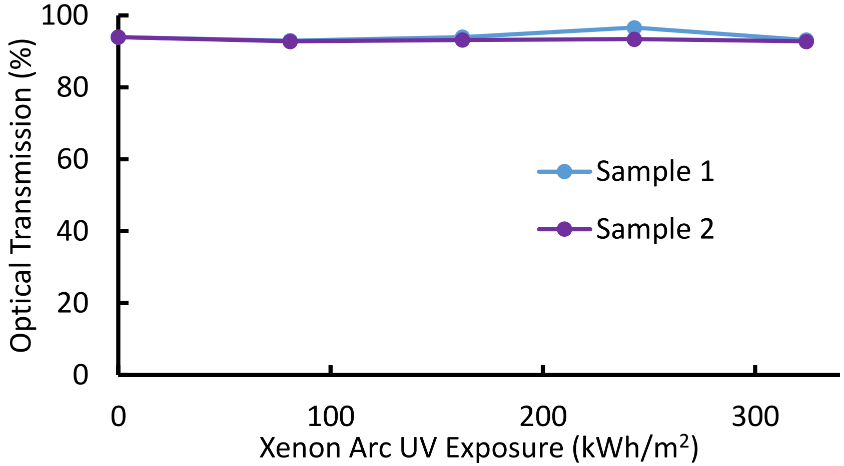


UV Durability of *New* Transparent Tedlar® PV3001 Film



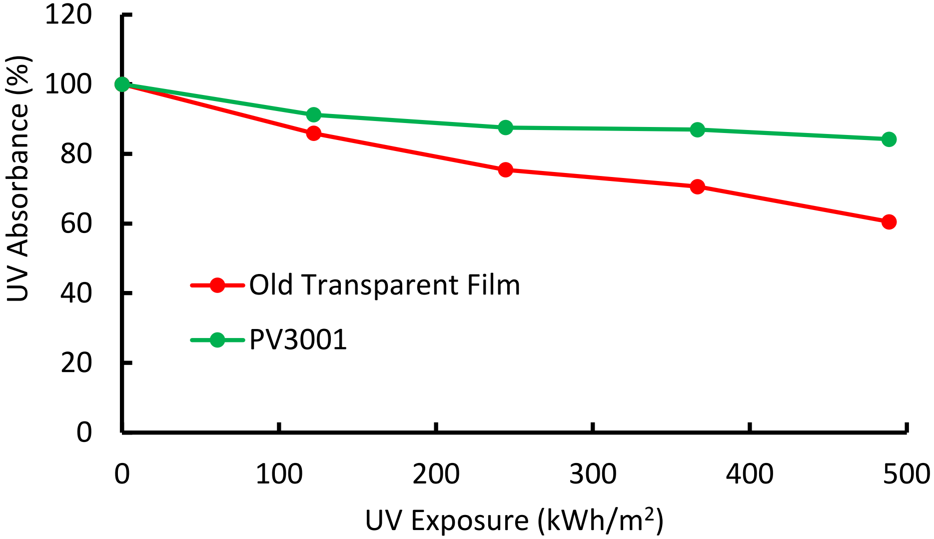


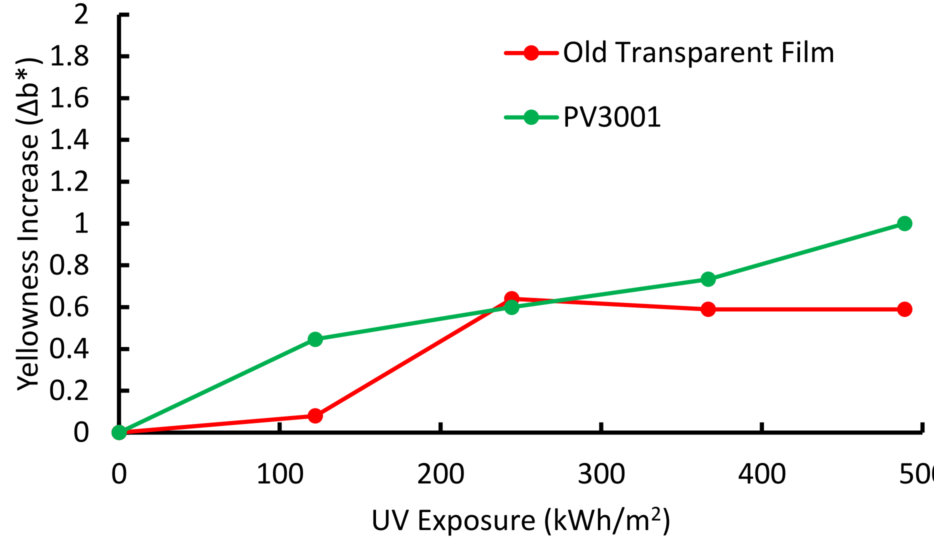


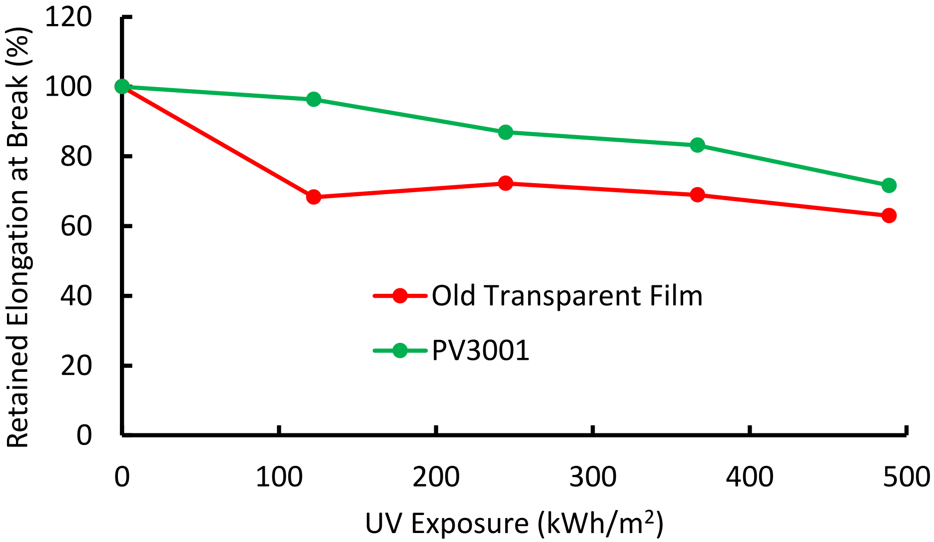


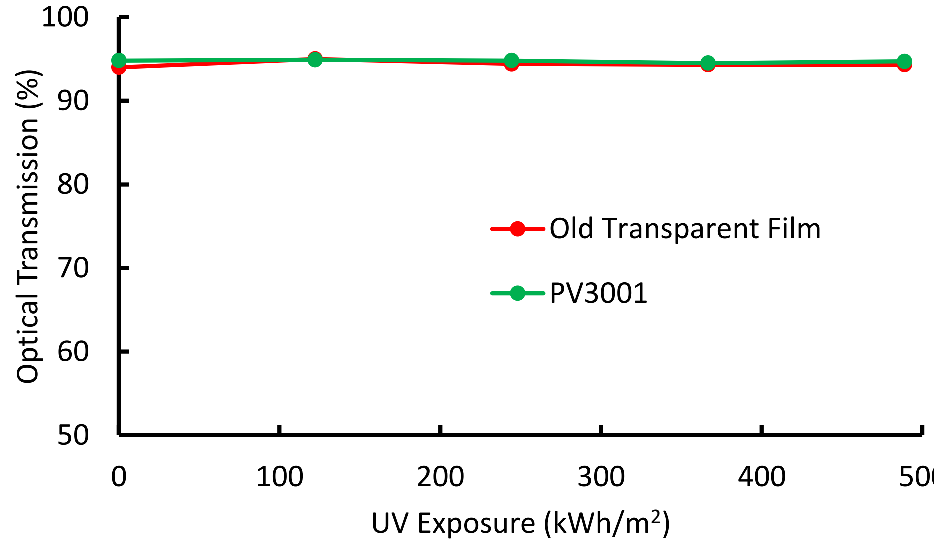
Xenon Exposure: RightLight filter, 90°C BPT, 0.8 W/m^2-nm @ 340 nm

Comparison of Old TUT and *New* Tedlar® PV3001 Film









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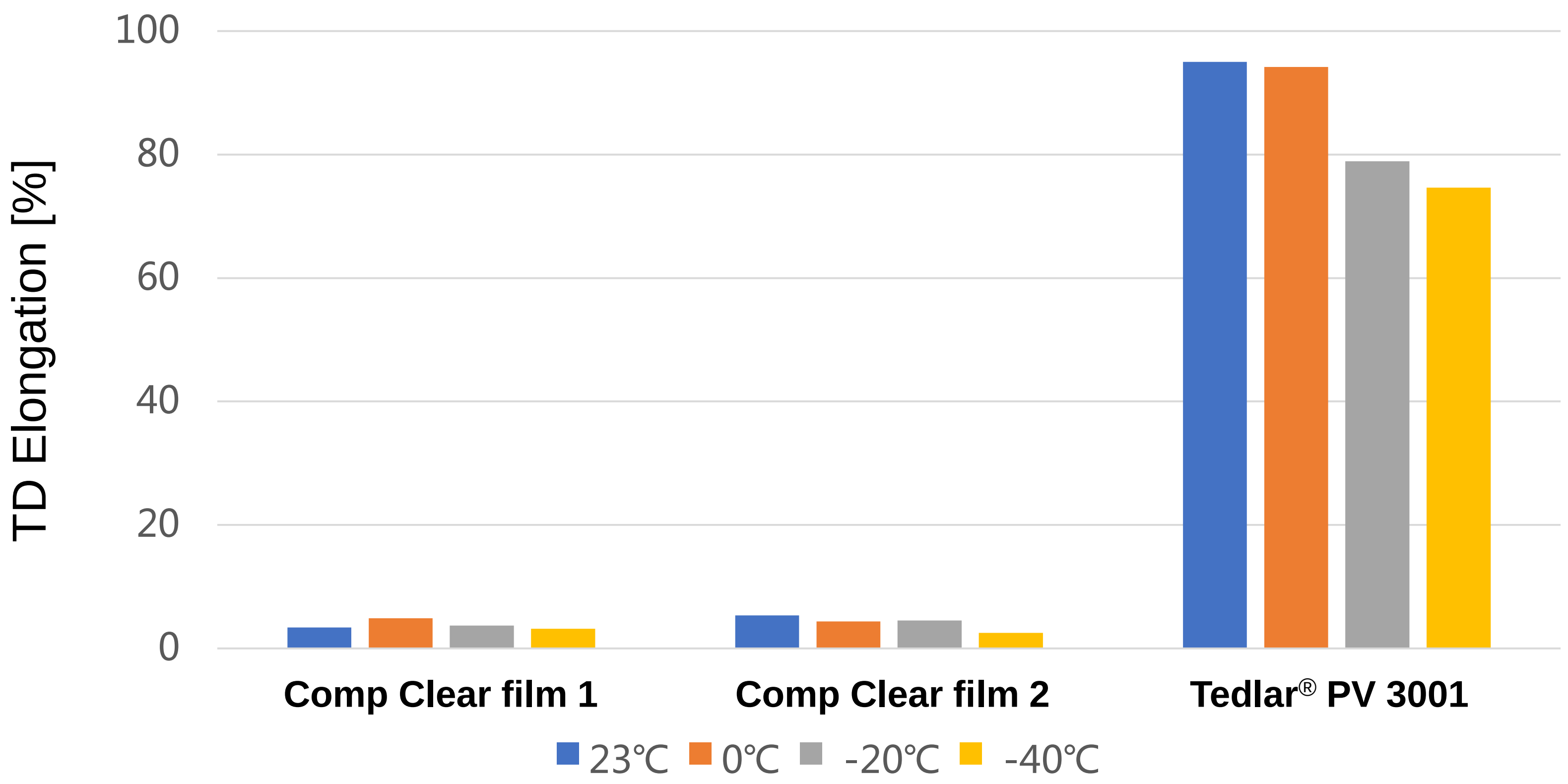
Xenon Exposure: boro/boro filter, 70 °C BPT, 0.55 W/m2-nm @ 340 nm

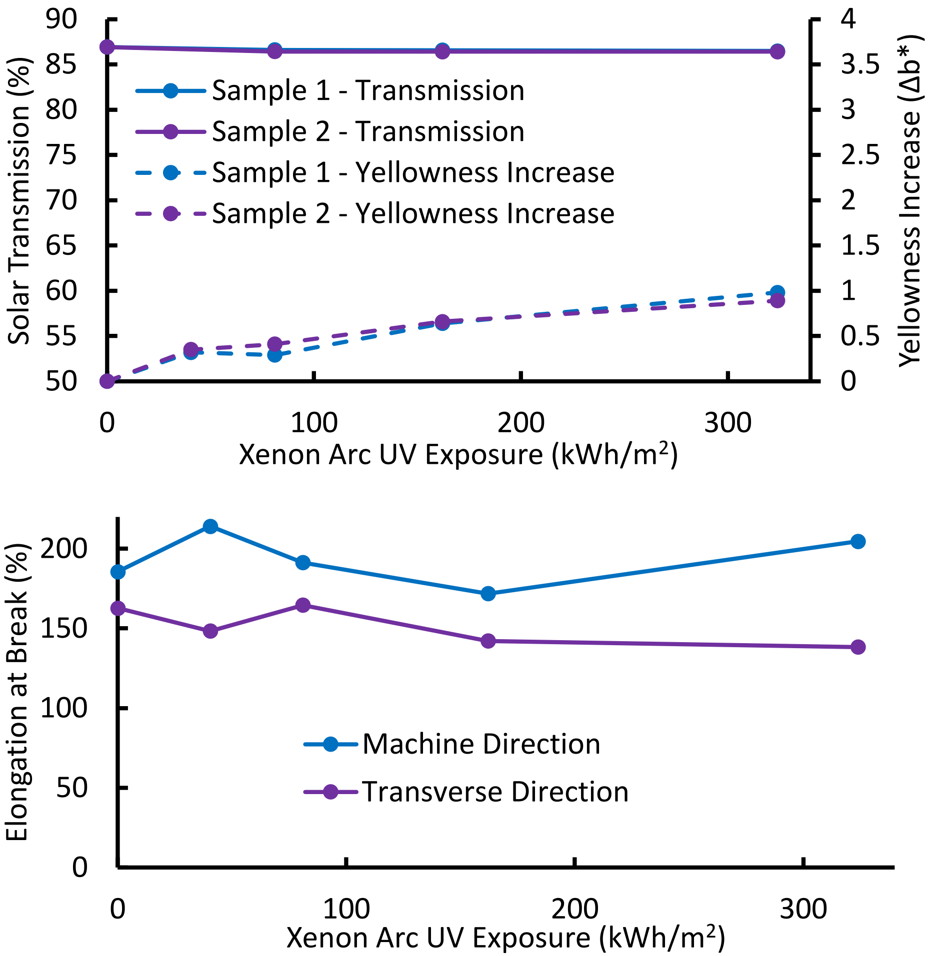
Elongation Retention of Tedlar® PV3001 Film Over a Wide Range of Temperatures



UV Durability of Transparent Tedlar®-based Backsheets

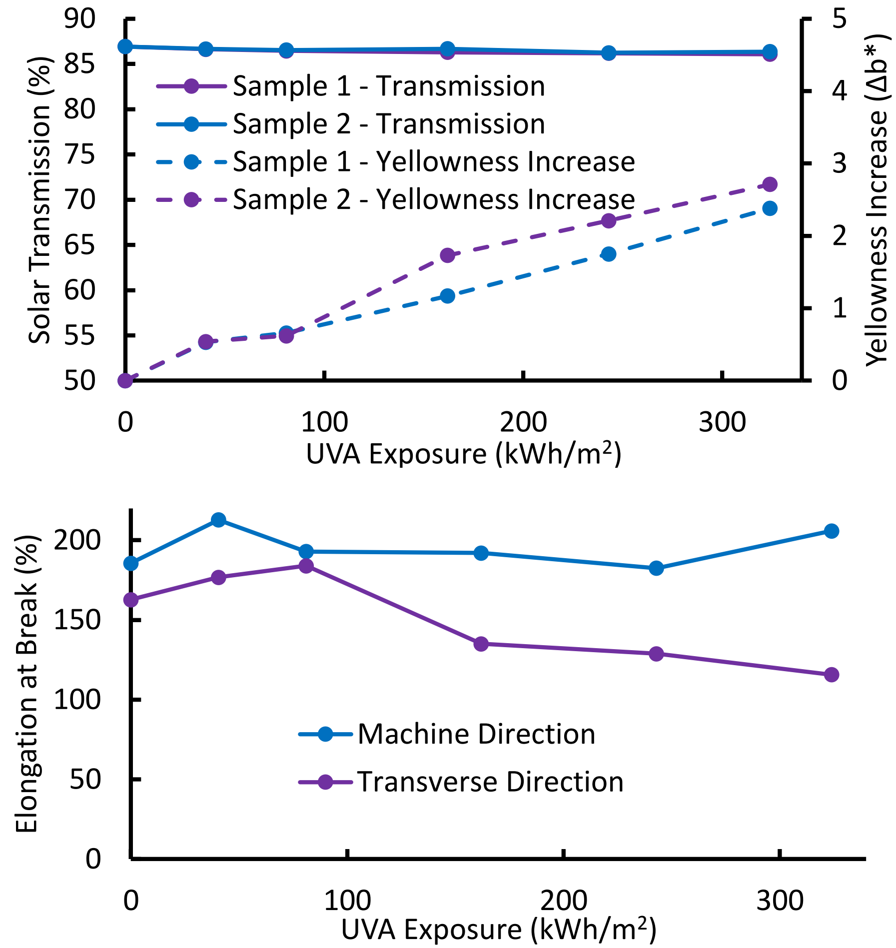
Xenon Arc – RightLight filter

90 °C BPT, 0.8 W/m²-nm @ 340 nm

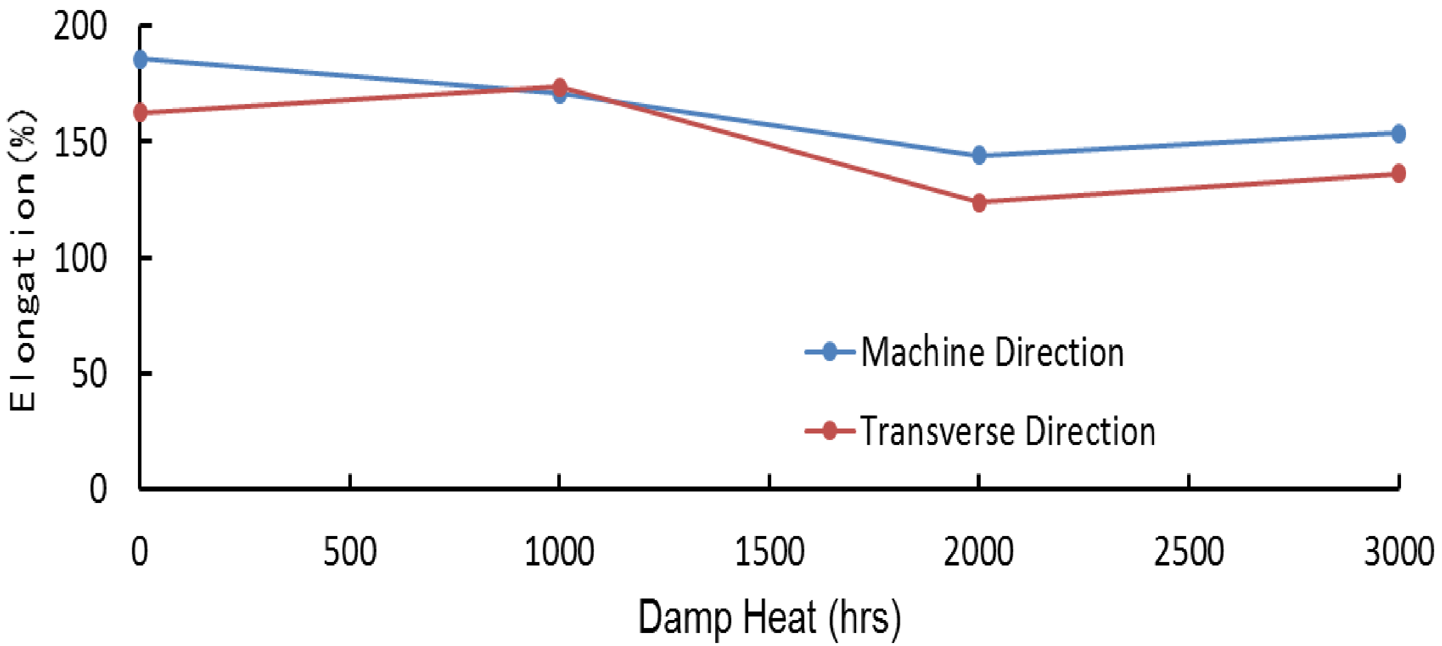


UVA-340 Fluorescence

70 °C BPT, 1.2 W/m²-nm @ 340 nm



Elongation retention of Transparent Tedlar®-based <u>Backsheets</u> under Damp Heat



Test Condition: 85°C, 85% RH

We are not a fan but we do it anyway…

Durability of Transparent Tedlar®-based <u>Backsheets</u> Outer Layer (Air Side)

Testing with a single stress (UV, accelerated with heat):

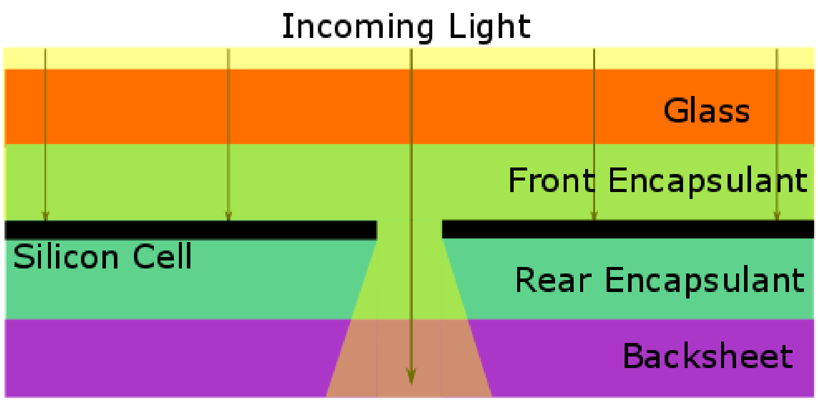
- Excellent stability of clear PVF backsheets
- Higher intensity MH exposures *with appropriate filtering* correlates to other UV sources
- UVA fluorescent, xenon and metal halide exposures identify yellowing issues with PET backsheets
- Drop in mechanical properties identified for PA backsheet as seen in field

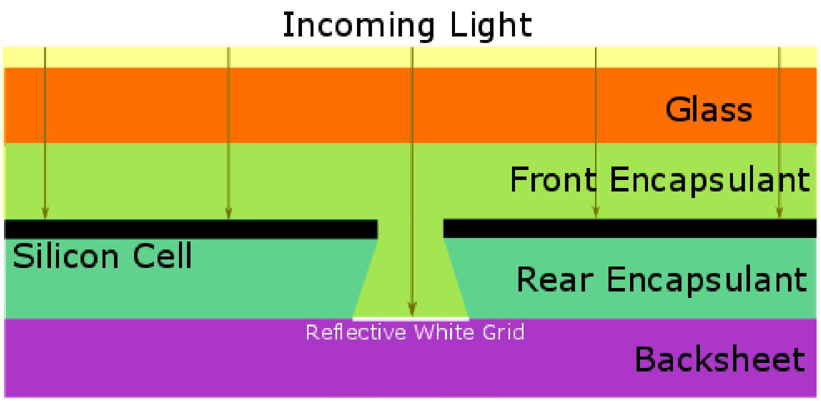
		MH1 b*					Xenon b*			UVA b*		
Color (b*)	**0 hr**	**55 kWh/m2**	**110 kWh/m2**	**155 kWh/m2**	**220 kWh/m2**	**275 kWh/m2**	**55 kWh/m2**	**110 kWh/m2**	**155 kWh/m2**	**55 kWh/m2**	**110 kWh/m2**	
1s-PVF1 clear	3	1.9	2.1	2.2	2.2	2.4	1.8	1.9	2.0	1.9	1.9	✓
2s-PVF1 clear	3.2	1.9	2.1	2.0	2.0	2.1	1.8	1.9	1.9	1.9	2.0	✓
2s-PVF1 white	0.7	1.5	1.8	1.3	1.2	1.5	1.4	1.2	1.4	1.8	1.7	✓
1s-PVF1 white	0.9	1.1	1.0	1	0.8	1.1	1	0.9	1	1.2	1.4	✓
1s-PET1 white	1.7	4	5.2	5.2	4.8	6.1	2.2	2.9	4.9	3.6	5.2	✗
2s-PA white	1.8	1.8	1.9	1.7	1.4	2	1.4	1.4	1.6	1.7	2.1	✓
1s-PET2 white	2.5	4	5.1	4.5	3.7	5.9	2.6			3.9	4.1	✗
1s-PVDF white	1.7	1.4	1.4	1.4	1.3	1.4	1.3	1.3	1.4	1.4	1.4	✓

	MH direct JB side			Xenon direct JB side			
<u>Elongation Loss</u>	**55 kWh/m2**	**110 kWh/m2**	**165 kWh/m2**	**27.5 kWh/m2**	**55 kWh/m2**	**110 kWh/m2**	
1s-PVF1 clear	-27%	-21%	-21%	-47%	-12%	-23%	✓
2s-PVF1 clear	-15%	-30%	-7%	-36%	1%	-17%	✓
2s-PVF1 white	-10%	1%	9%	6%	7%	1%	✓
1s-PVF1 white	-24%	-28%	-13%	-30%	-20%	-26%	✓
1s-PET1 white	5%	7%	8%	-6%	10%	-4%	✓
2s-PA white	-56%	-95%	-96%	-9%	-56%	-97%	✗
1s-PET2 white	-28%	-42%	-21%	-29%			
1s-PVDF white	-13%	-19%	-28%	-29%	-13%	-23%	✓

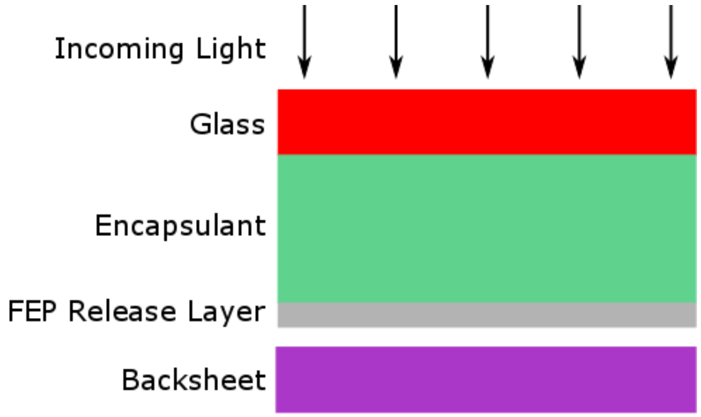
Durability of Transparent Tedlar®-based Backsheets Inner Layer Verification

Inner layers are exposed in the field to light coming between the cells from the front side

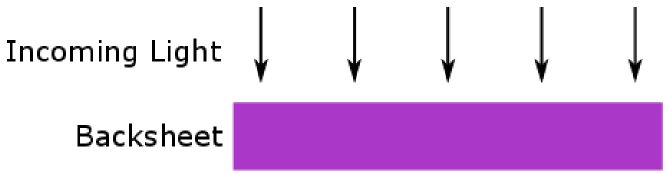




The most accurate way to simulate this exposure is using a glass and encapsulant laminate to filter the light



The fastest way to test materials is using a direct inner layer exposure.



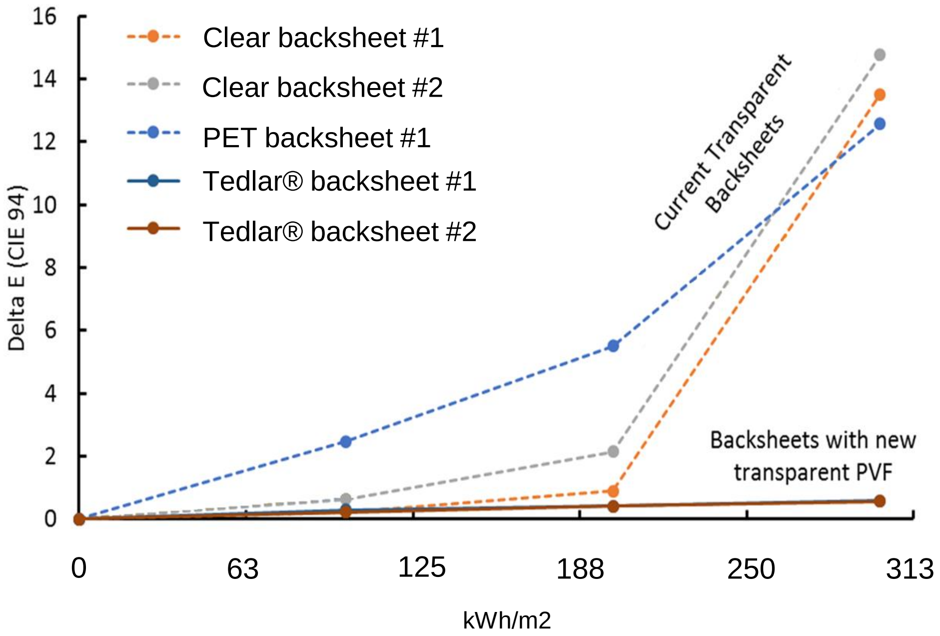
Durability of Transparent Tedlar®-based Backsheets Inner Layer

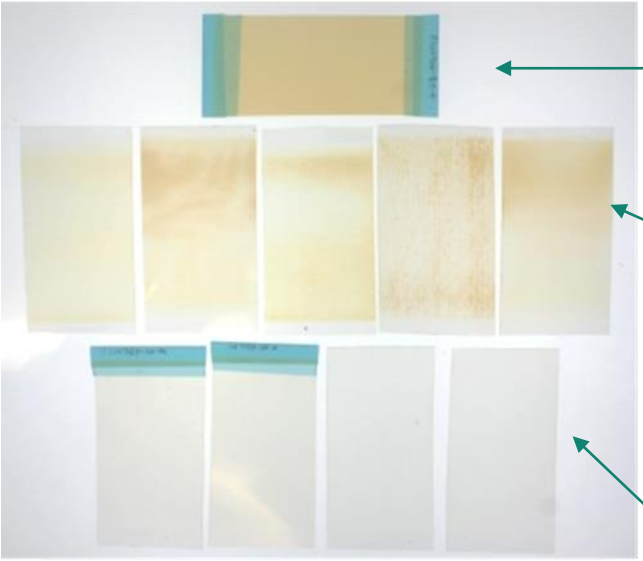
- Commercial white and clear backsheets tested using filtered metal halide and xenon exposure
- White backsheets with inner layer cracking and yellowing in the field correlated

Color (b*)		MH b*			Xenon b*		
Exposure from source	Initial	241 kWh/m2	482 kWh/m2	941 kWh/m2	241 kWh/m2	482 kWh/m2	
1s-PVF1 clear	1.5	2.1	2.5	3.5	2.2	2.5	✓
2s-PVF1 clear	1.6	1.8	2.4	3.4	2.0	2.4	✓
2s-PVF1 white	0.7	1.8	1.8	1.3	1.6	1.8	✓
1s-PVF1 white	0.5	0.5	0.4	0.9	0.7	0.8	✓
1s-PET1 white	2.0	6.1	5.9	29.5	5.3	7.4	✗
2s-PA white	1.9	2.0	1.6	2.9	2.2	3.5	✓
1s-PET2 white	1.4	5.3	6.1	9.7		6.3	✗
1s-PVDF white	-0.3	0.7	1.2	4.4	2.1	4.5	✗

Elongation Loss	MH1 filtered			Xenon filter		
Exposure from source	241 kWh/m2	482 kWh/m2	941 kWh/m2	241 kWh/m2	482 kWh/m2	
1s-PVF1 clear	6%	1%	-40%	-35%		✓
2s-PVF1 clear	18%	12%	-20%	-60%		✓
2s-PVF1 white	-10%	-8%	7%	-1%	-13%	✓
1s-PVF1 white	11%	-5%	-15%	22%	-17%	✓
1s-PET1 white	-95%	-96%	-98%	-96%	-97%	✗
2s-PA white	-93%	-88%	-98%	-96%	-98%	✗
1s-PET2 white	1%	-46%	-97%	-49%	-98%	✗
1s-PVDF white	**-22%**	-68%	-99%	-94%	-99%	✗

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

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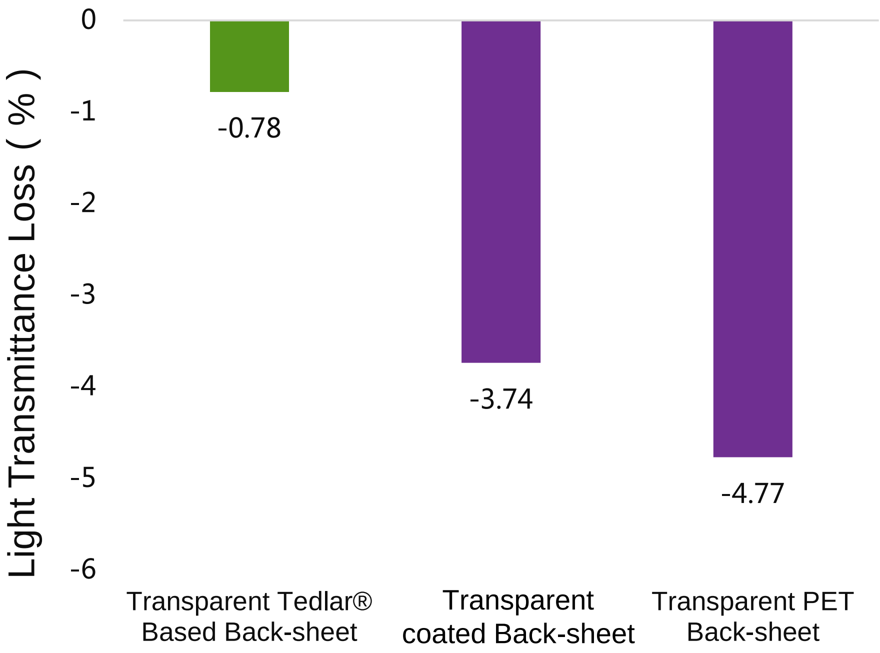
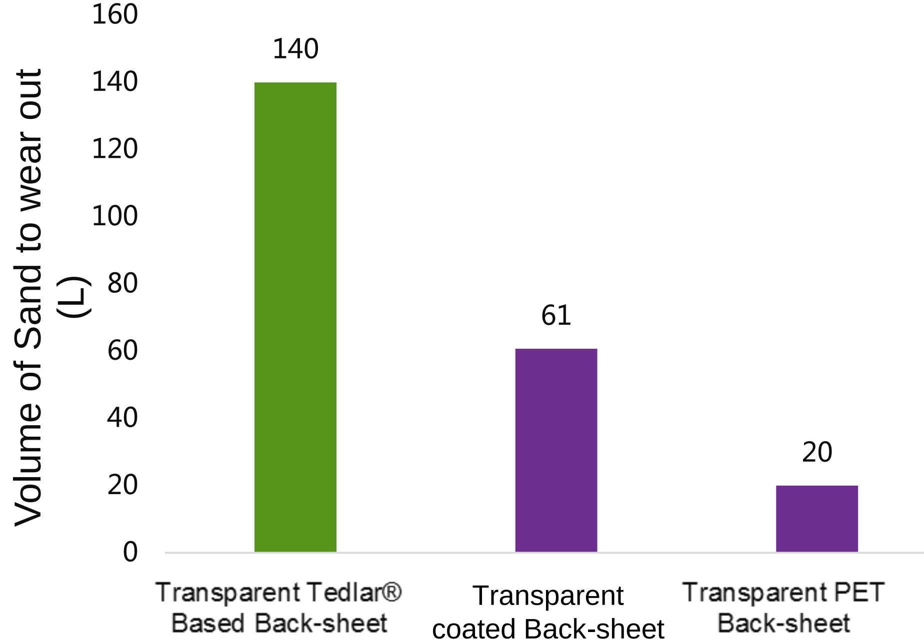
Abrasion Resistance of Transparent Backsheets





ASTM E424, Standard Test Methods for Solar Energy Transmittance and Reflectance (Terrestrial) of Sheet Materials
Wavelength: 400nm~760nm.
Backsheet samples after 100 liters of sand and surface cleaning

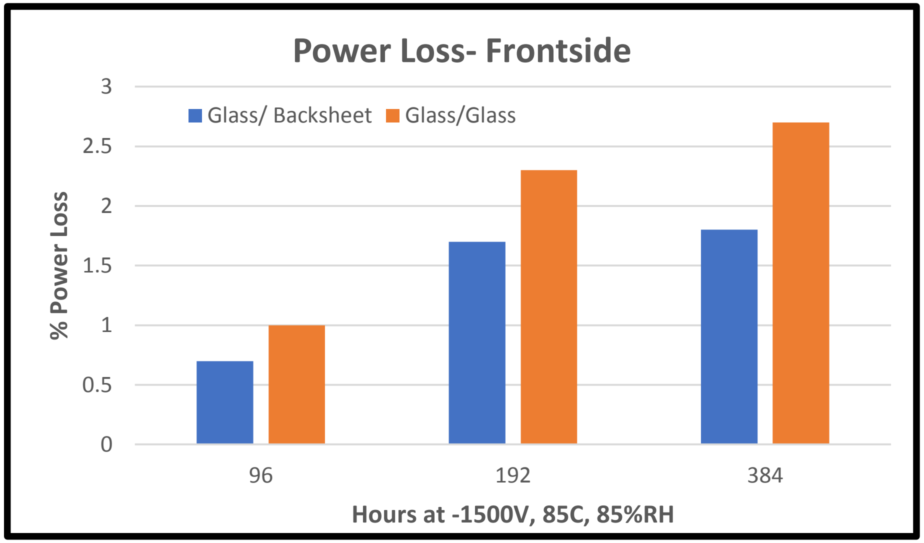
GB/T 23988-2009, Determination for abrasion resistance of - Coatings by falling abrasive material
Amount of sand refers to the amount required to wear through this layer
The outer layer of PET back-sheet has 2um UV resistant coating

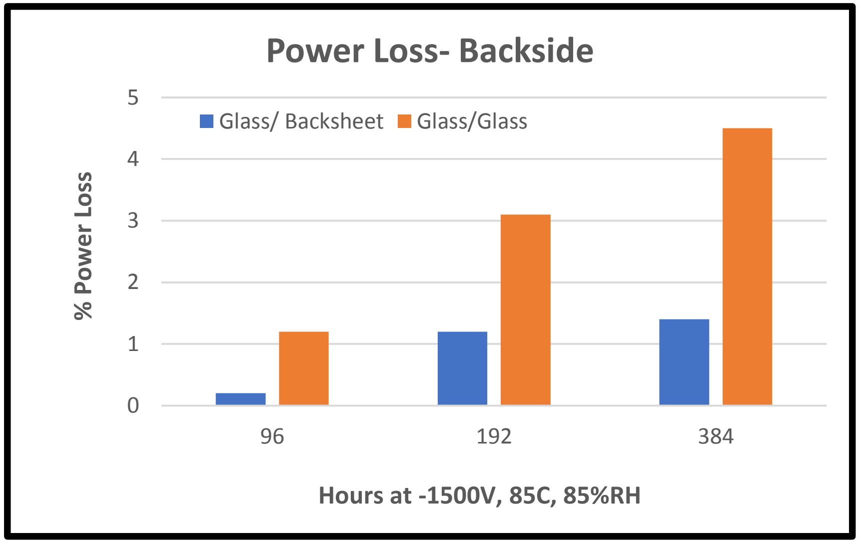
Bifacial Module Testing

– 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, 85ºC, 85%RH. Module power measured at 96 hour intervals.





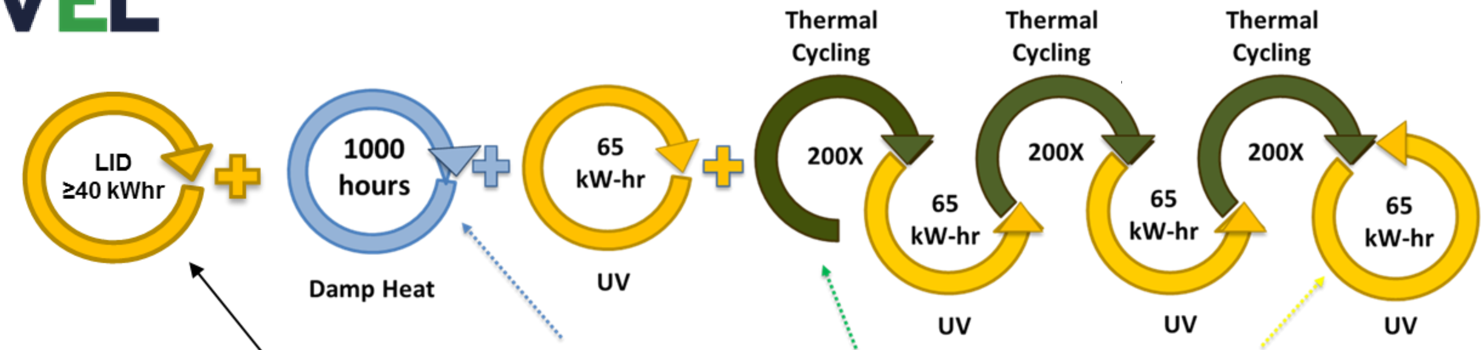
- **<u>Lower power loss in Glass/Backsheet structure</u> with appreciable difference on the back side of bifacial module**
- **Use of POE does not prevent PID**

Performance in IEC Hot Spot Testing

Structure	Max. Temperature (°C)	Hot Spot Temperature (°C)	Delta (°C)	Power Loss (%)
GB1	53.3	67.3	14.0	-0.49%
GB2	54.8	61.6	6.8	-0.68%
GG1	54.5	65.9	11.4	-0.30%
GG2	55.2	72.9	17.6	-0.65%

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)



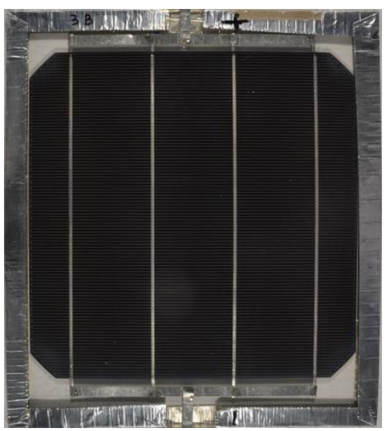
LID
UV Frontside Preconditioning

1000 hours
In a humidity chamber
Amounts to > 25 years Worth of stress

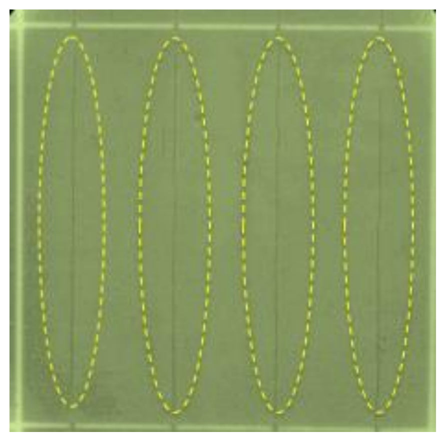
600 Thermal Stress Cycles
Mimics thermal stresses seen in the field

260 kWhr
in a UV Chamber
Amounts to 25 years worth of UV stress

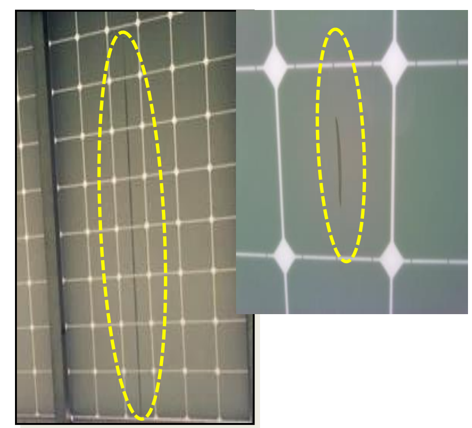
Transparent Tedlar® PVF-Based Backsheet



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

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

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