Transparent Tedlar® PVF Backsheets for Durable Bifacial PV Modules

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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

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Benefits of Transparent Tedlar®-based Backsheets

Advantages Over Glass/Glass Structure

- **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 1999

0.7% annual power loss

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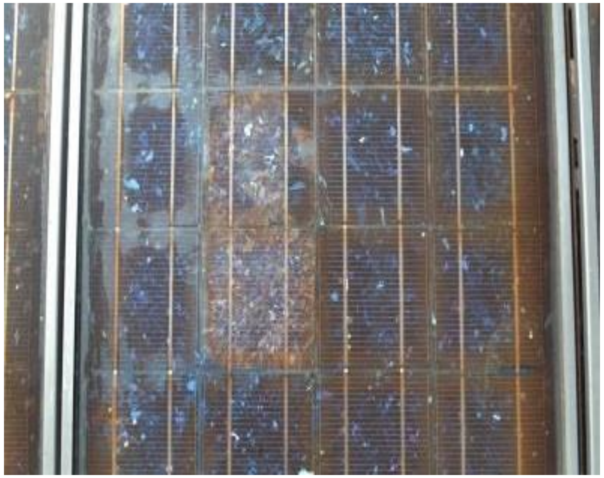
Severe delamination on glass/glass module
10 years, Arizona USA



Severe busbar corrosion on glass/glass module
15 years, Danzhou China

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Glass/backsheet bifacial module with transparent Tedlar®

Glass/glass structures are:

- × 30 % heavier
- × More expensive mounting hardware
- × Brittle, susceptible to chipping
- × Less able to withstand strains (inflexible)
- × Lower throughput manufacturing
- × Lower yield

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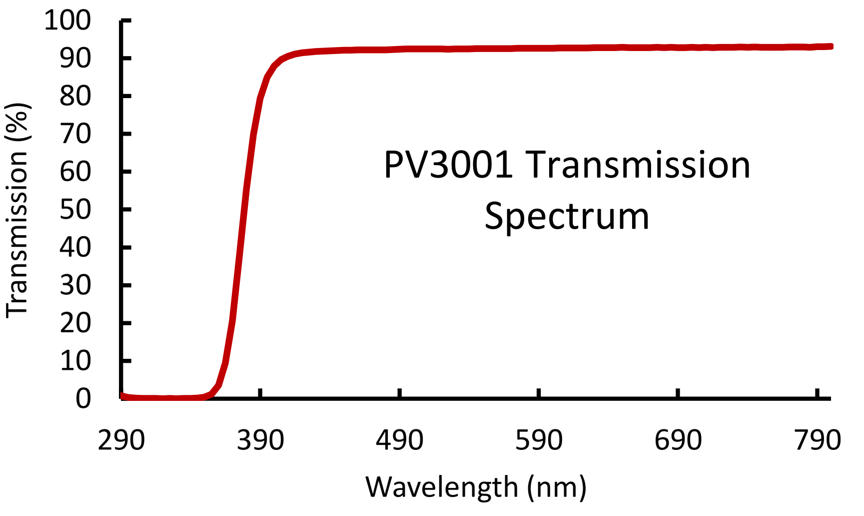
New Transparent Tedlar® PV3001

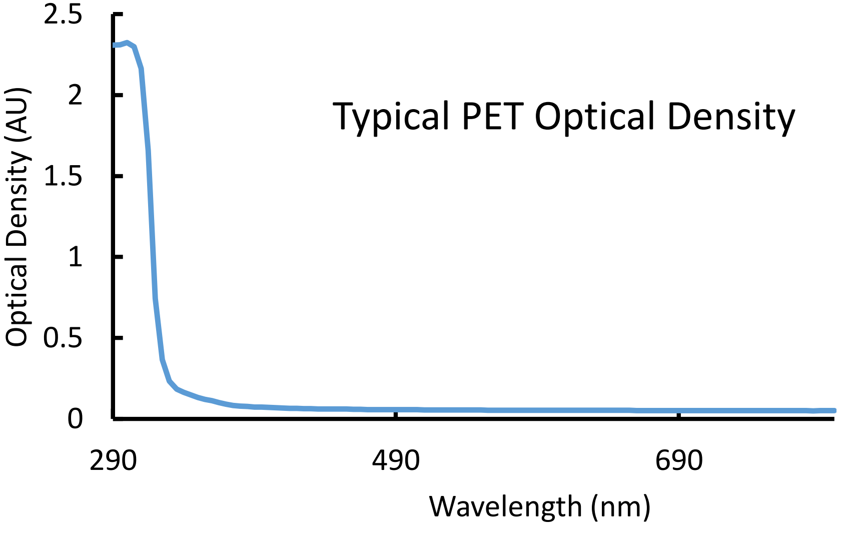
High transparency.

Robust mechanical properties.

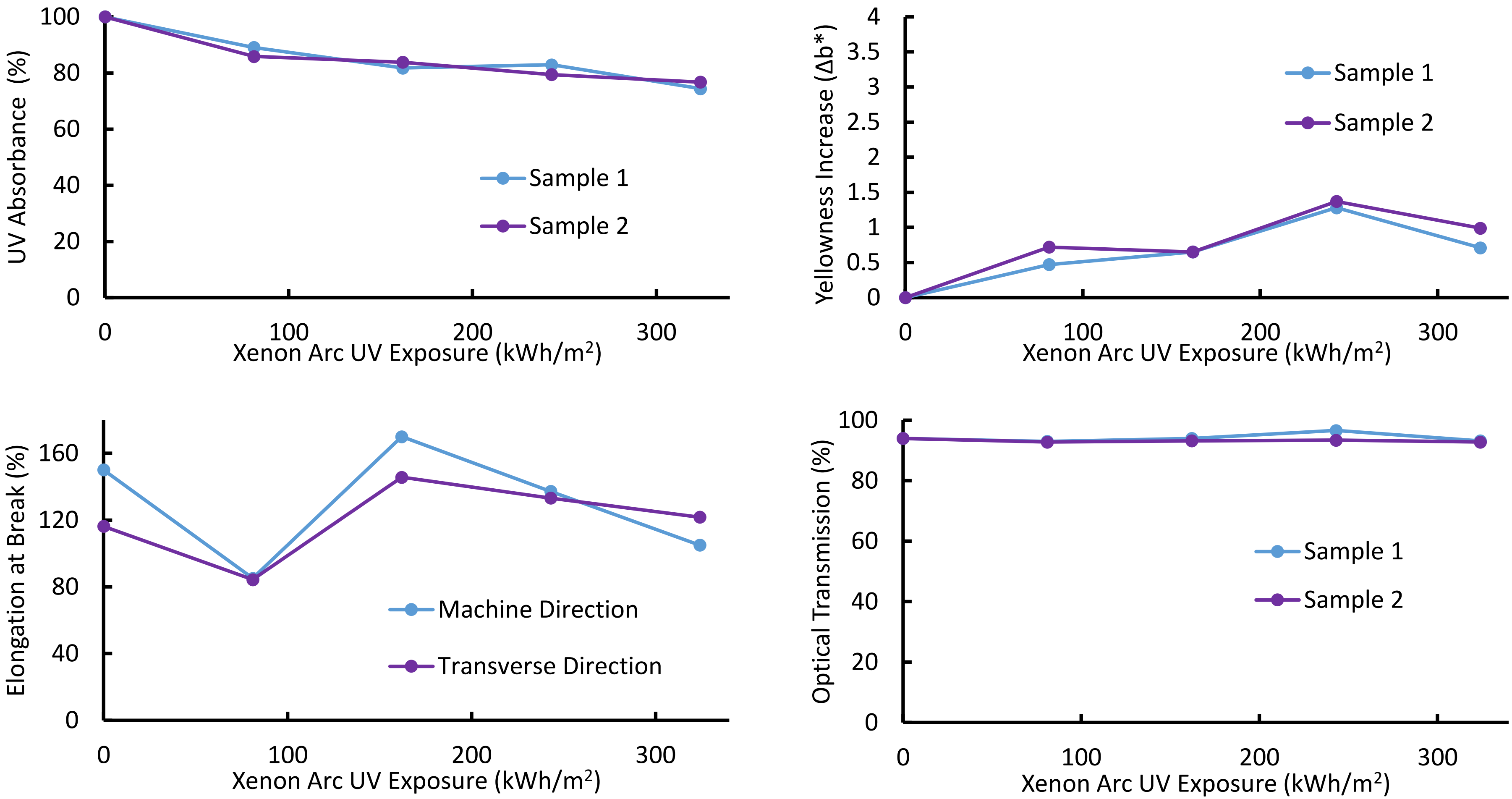
Excellent UV protection for PET-based backsheet.

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





Durability of Transparent New Tedlar® PV3001 Film



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

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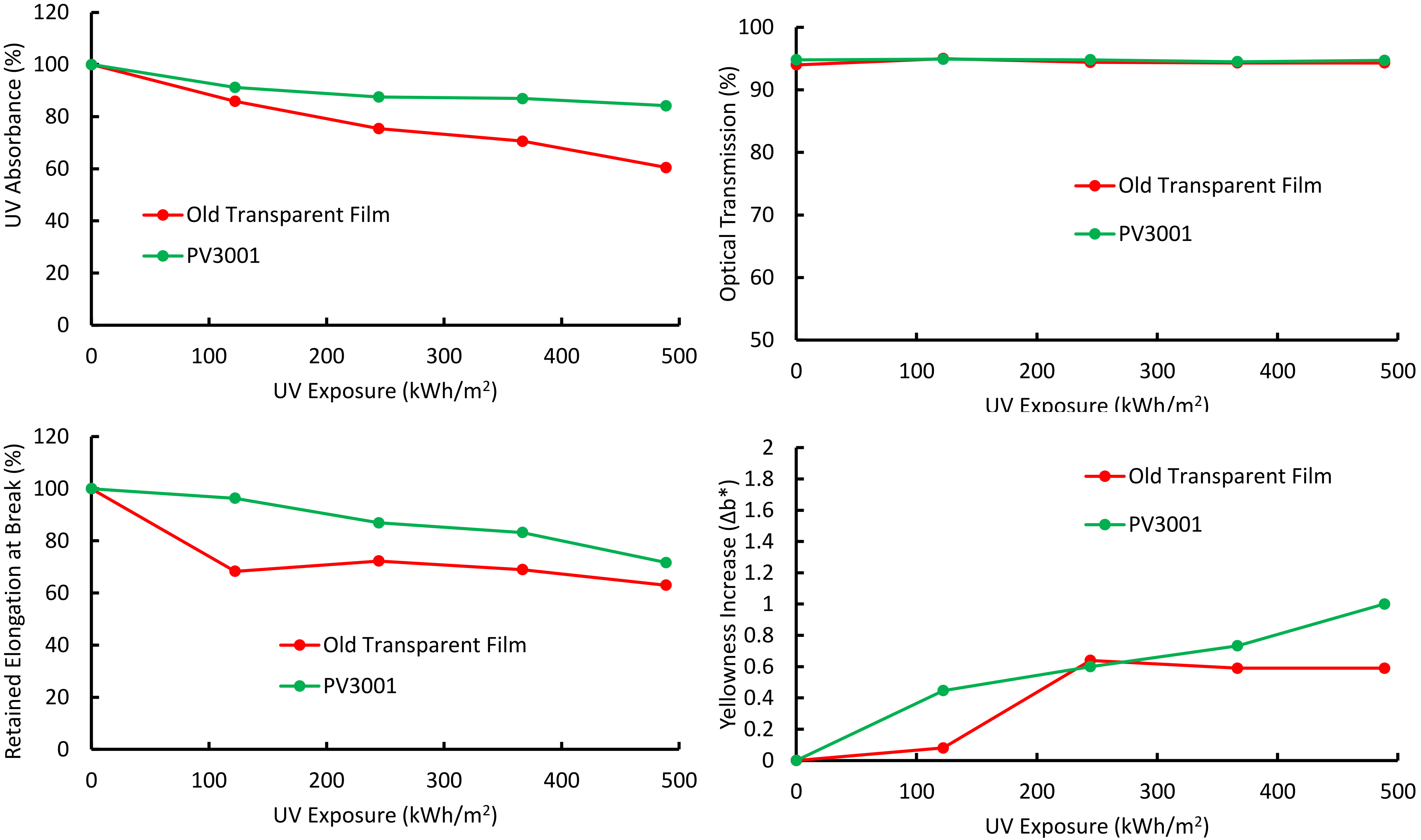
Comparison of Old TUT and New Tedlar® PV3001 Film

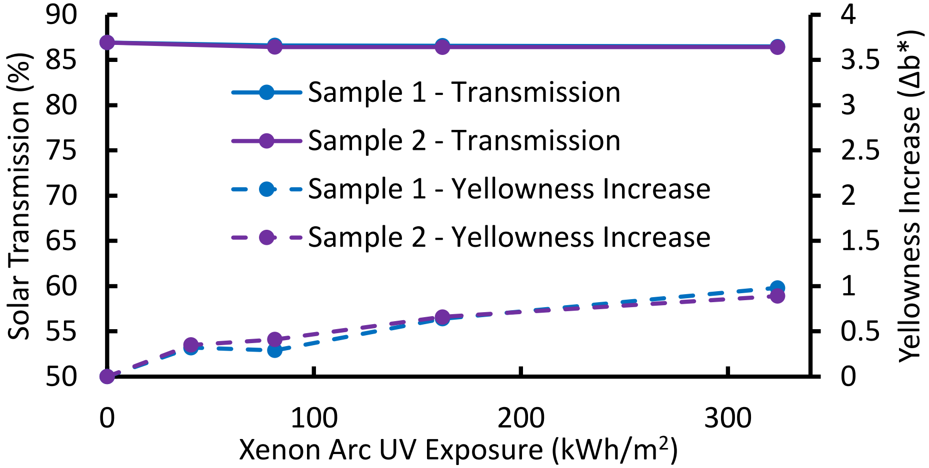


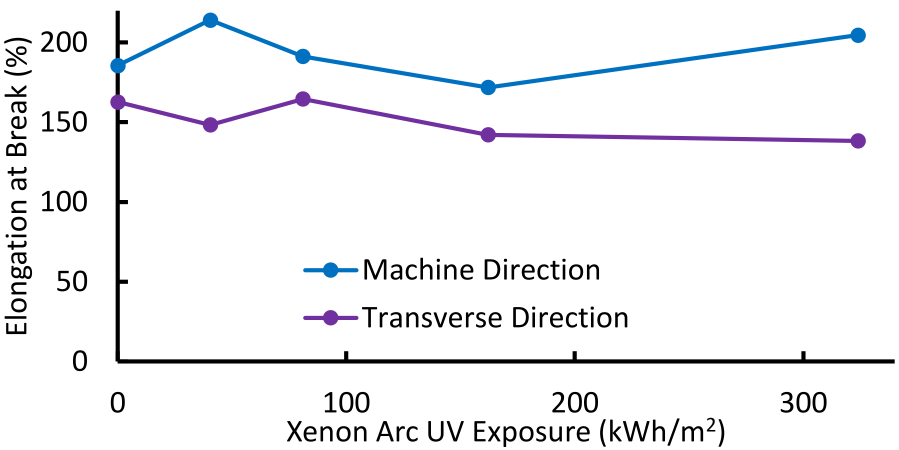
Xenon Exposure: boro/boro filter, 70 °C BPT, 0.55 W/m2-nm @ 340 nm

Durability of Transparent Tedlar®-based Backsheets

Xenon Arc – RightLight filter

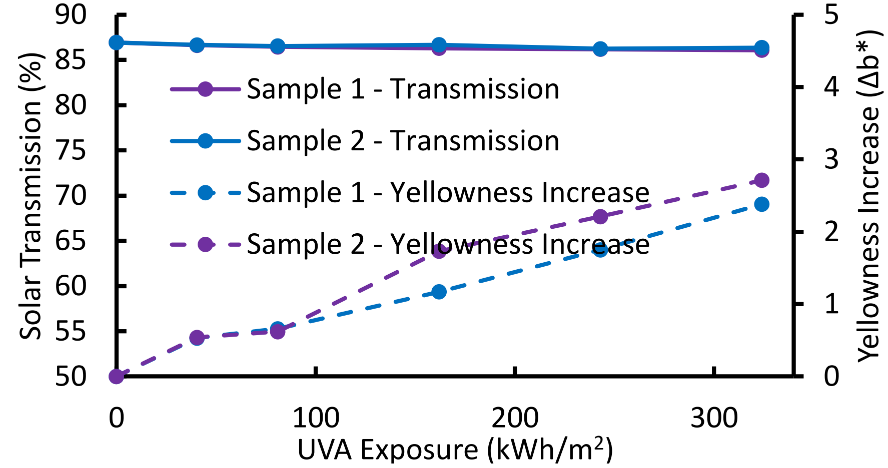
90 °C BPT, 0.8 W/m²-nm @ 340 nm

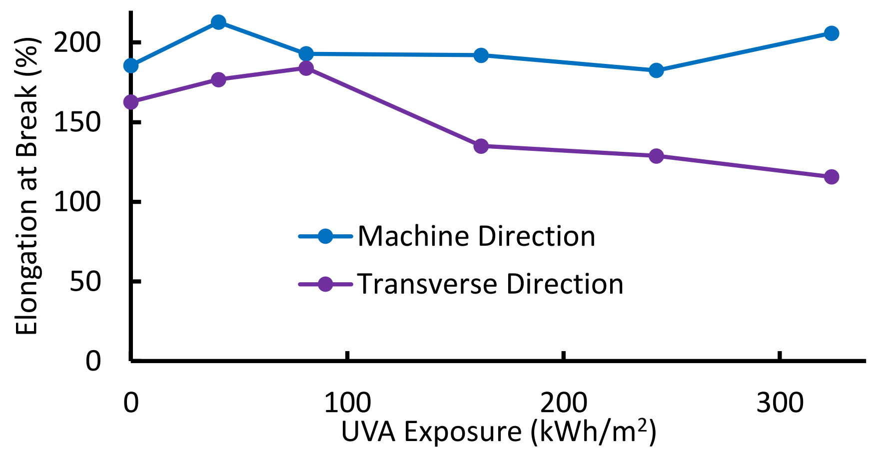




UVA-340 Fluorescence

70 °C BPT, 1.2 W/m²-nm @ 340 nm





Durability of Transparent Tedlar®-based Backsheets Outer Layer (JB/Air Side)

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

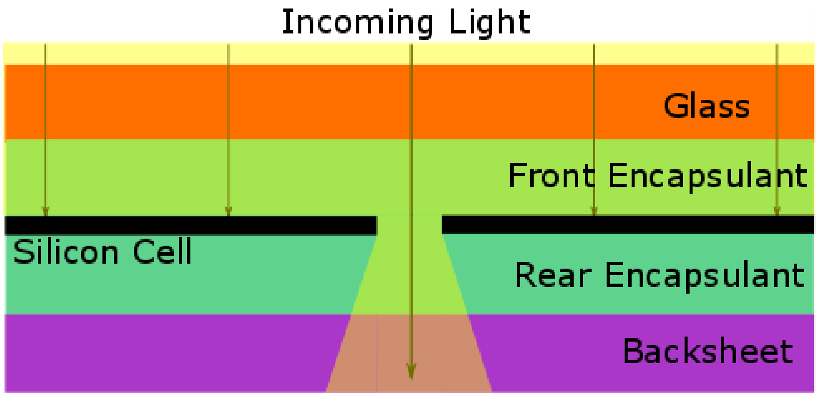
- Excellent stability of clear PVF backsheets
- Higher intensity MH exposures *with appropriate filtering* correlates to other UV sources
- UVA fluorescent, xenon and metal halide exposures identify yellowing issues with PET backsheets
- Drop in mechanical properties identified for PA backsheet as seen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

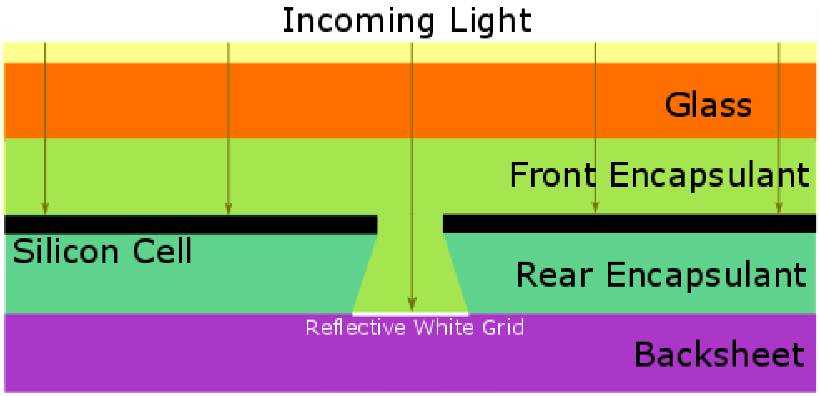
		MH1 b*					Xenon b*			UVA b*		
Color (b*)	**0 hr**	**55 kWh/m2**	**110 kWh/m2**	**155 kWh/m2**	**220 kWh/m2**	**275 kWh/m2**	**55 kWh/m2**	**110 kWh/m2**	**155 kWh/m2**	**55 kWh/m2**	**110 kWh/m2**	
1s-PVF1 clear	3	1.9	2.1	2.2	2.2	2.4	1.8	1.9	2.0	1.9	1.9	✓
2s-PVF1 clear	3.2	1.9	2.1	2.0	2.0	2.1	1.8	1.9	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			
Elongation Loss	**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%	✓

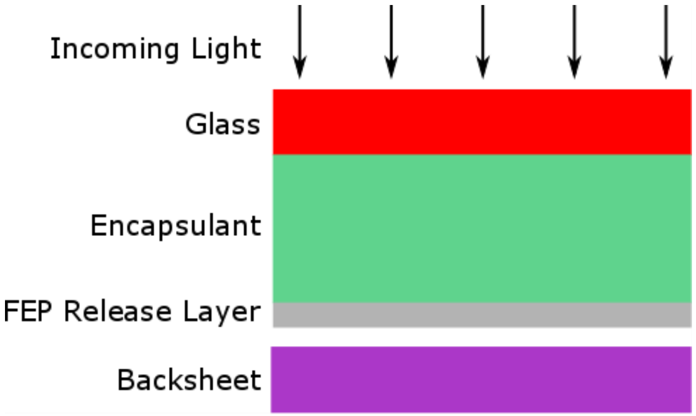
Durability of Transparent Tedlar®-based Backsheets Inner Layer Verification

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

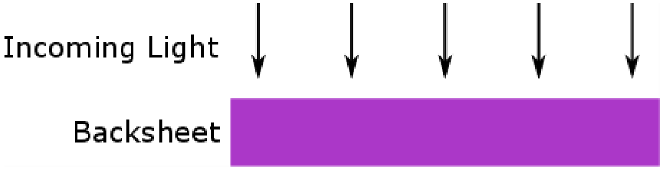




The most accurate way to simulate this exposure is using a glass and encapsulant laminate to filter the light.



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



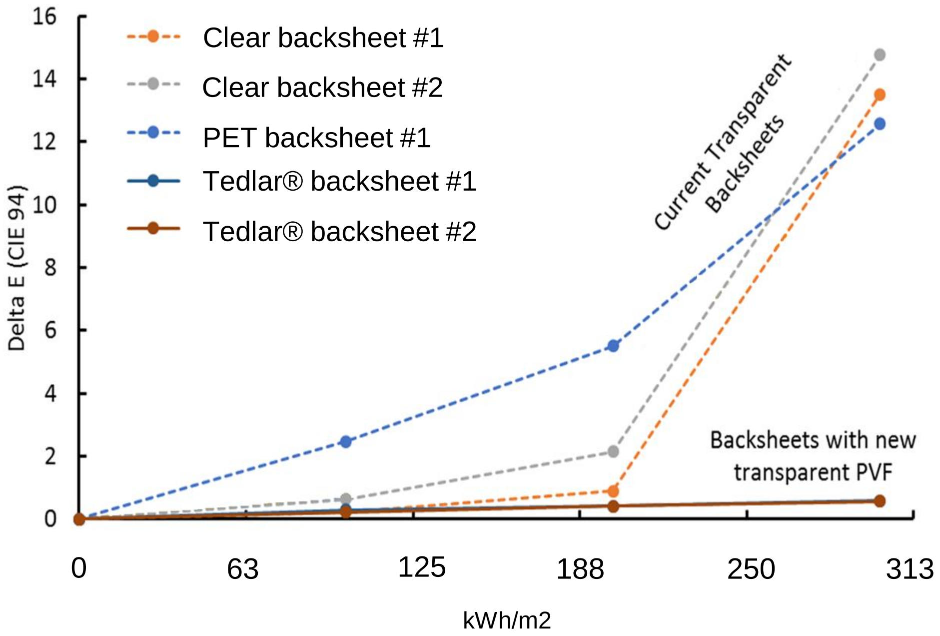
Durability of Transparent Tedlar®-based Backsheets Inner Layer

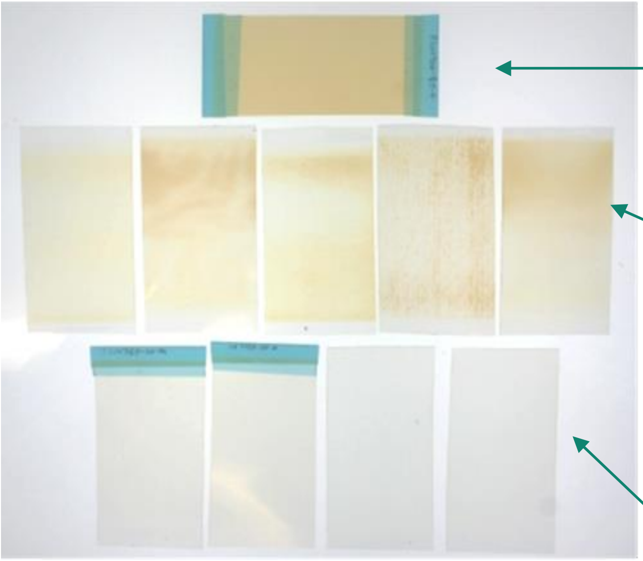
- Commercial white and clear backsheets tested using filtered metal halide and xenon exposure
- White backsheets with inner layer cracking and yellowing in the field correlated

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%	✗

Clear Tedlar® PVF film-based backsheets show superior color stability after UV exposure



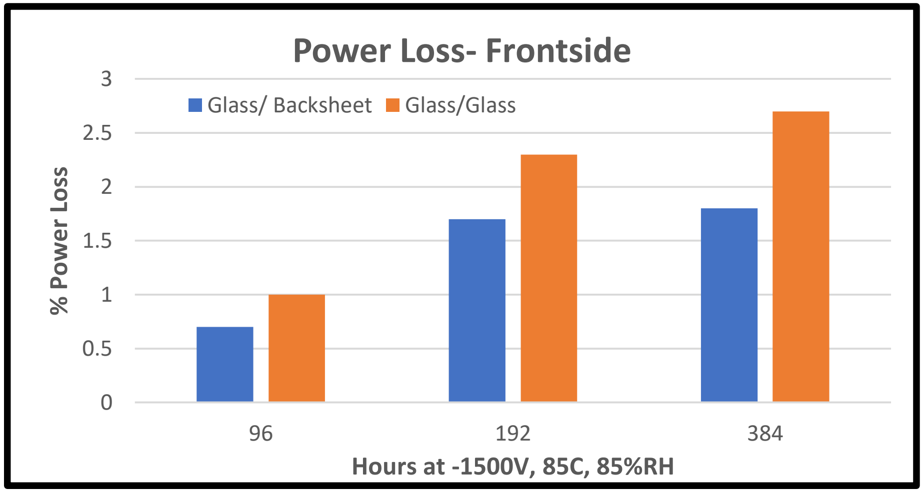


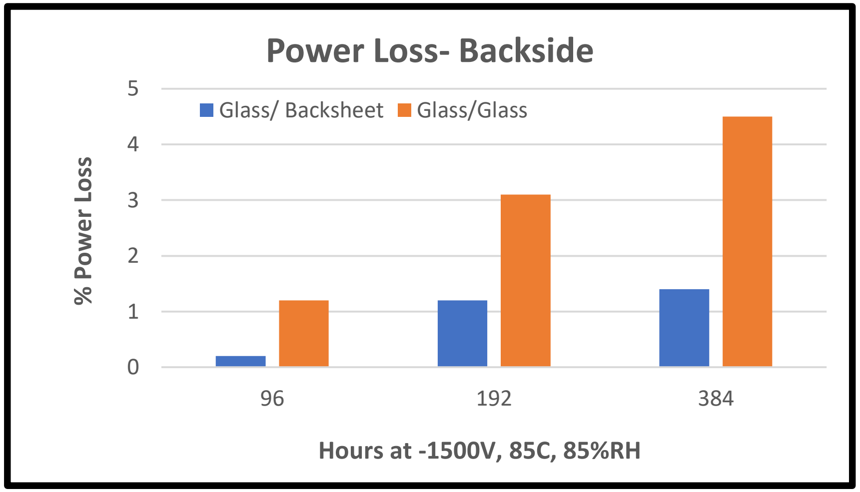
Super UV Exposure:

- 1500 W/m^2 from 290-450 nm, 52 ° C Black Panel Temperature, 50 % Relative Humidity, No water spray

G/B Module has better PID Performance than G/G Module

- 60-cell 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 back side of bifacial module**
- **Use of POE does not prevent PID in glass/Glass modules**

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Equivalent Performance in 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)

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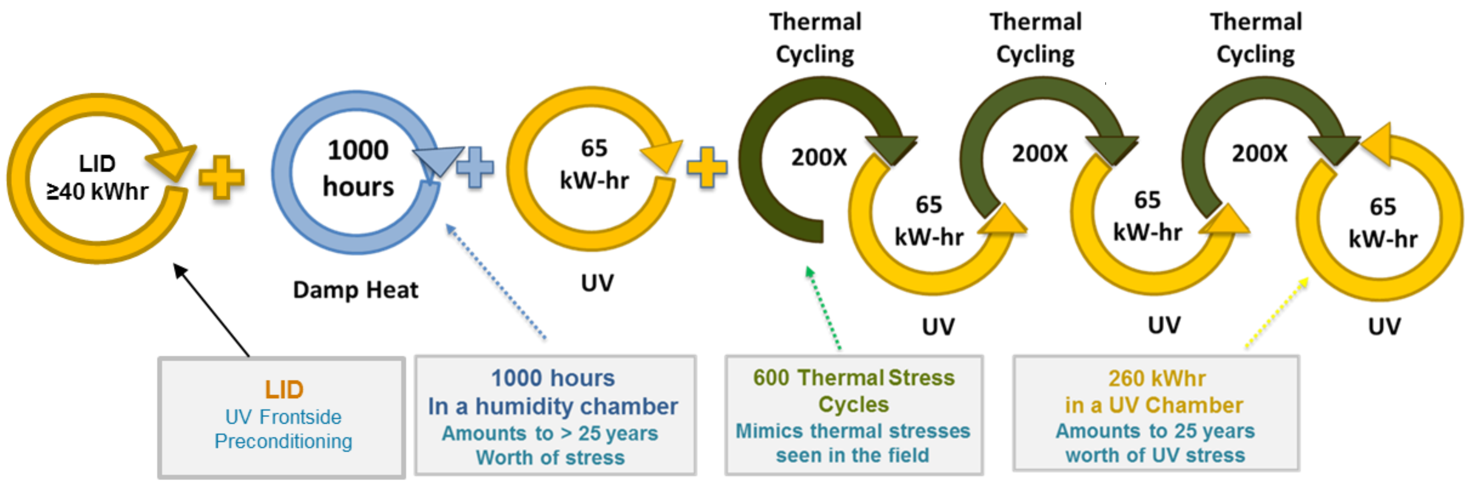
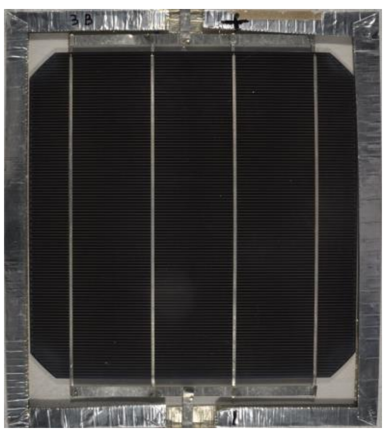
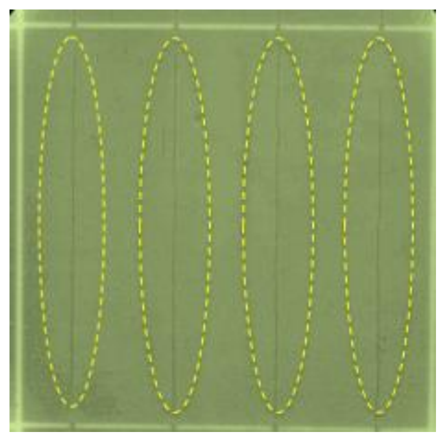
Durability of Transparent Tedlar®-based Backsheets Module Accelerated Sequential Test (MAST)



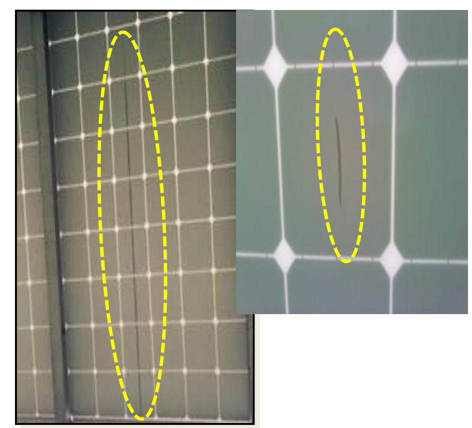
Transparent Tedlar® PVF-Based Backsheet



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



PVDF cracking in MAST testing of 60-cell commercial module by third party (DNV-GL)



PVDF cracking
Large MD crack 4 years in field

Conclusions

- DuPont has commercialized Tedlar® PV3001, a highly durable transparent Tedlar ® PVF film with superior performance and reliability
- Transparent Tedlar ® PV film based backsheets have shown good performance in the field
- Transparent backsheets allow bifacial modules with long term durability and using established materials and processes
- Transparent Tedlar ® PVF based backsheets provide performance and durability advantages over glass/glass module structures

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