A Comparison of Key PV Backsheet and Module Properties from Fielded Module Exposures and Accelerated Test Conditions

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Positions on Durability Testing

Damp Heat Durability

Damp heat testing of backsheets beyond 1000h is not predictive of actual outdoor performance

Technical Basis

- Comparison of key properties (mechanicals, power loss, EL imaging, WVTR, electrical insulation) from fielded modules shows significantly less change than results from >1000h damp heat exposure
- Modeling (NREL) predicts that hydrolysis damage due to PET under typical weather conditions for several geographic locations over 25 year period outdoors is significantly less than 1000h damp heat

UV Durability

UV stability of backsheets should be assessed based on expected outdoor exposure using albedo and climate conditions

Technical Basis

- UV exposure in the field can be substantial over 25 year period and influenced by location, mounting method and reflected light from the ground (albedo)
- UV exposure requirements in qualification standard represents ~ 70 days UV exposure and backsheet side is untested
- Using published irradiance data for various locations and albedo data for various ground cover, appropriate exposure levels can be determined
- Dosage for UV testing should match 25 year outdoor exposure to insure durability. Testing at lower dosages introduces risk in the field. Testing at higher intensity can shorten exposure times.

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DuPont Testing Protocols

Test	Exposure Condition	Evaluation	Technical Reason
Damp Heat	85°C, 85%RH	1000h	adequate for PET hydrolysis damage
		2000h	assess materials stability
		>3000h	test-to-failure
UV	UVA, 70°C BPT, 1.2W/m²-nm at 340nm, 65 W/m² (250-400nm)	275 kWh/m² (4230 h)	desert condition (18x IEC*)
		235 kWh/m² (3630 h)	tropical condition (16x IEC*)
		171 kWh/m² (2630 h)	temperate condition (11x IEC*)
Thermal Cycling	-40°C, 85°C, 200cyc	1x, 2x, 3x	assess durability
Thermal Cycling Humidity Freeze	-40°C, 85°C (50cyc); -40°C, 85°C 85%RH (10cyc)	1x, 2x, 3x	assess durability

* IEC 61215 pre-conditioning, 15 kWh/m² (280-385nm), **front exposure only**

- Damp heat testing to 1000 hours is more than sufficient for PET hydrolysis over 25 years of outdoor exposure
- UV testing needs to be extended to adequately address backsheet performance in the outdoor environment
- Dosage for UV testing should match 25 year outdoor exposure to insure durability.

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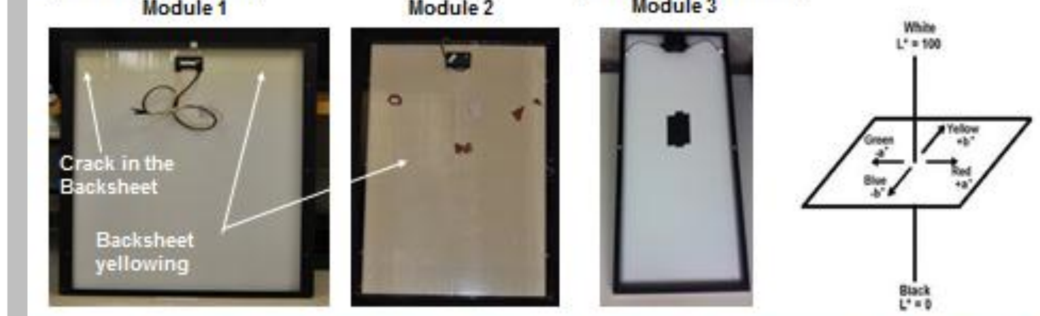
PET and Tedlar® Fielded Modules

PET Backsheets — Module 1, Module 2; Tedlar® Backsheet — Module 3



	Duration in Service	Nameplate Rating Cell Type	Backsheet	Wet Leakage	IV Measurement % Degradation % Degradation/Yr	b* Color Data
Module 1	10 Yrs	143 W mono-Si	Standard PET	Pass	77W 46% 4.6%	9.0
Module 2	12 Yrs	125 W poly-Si	Standard PET	Fail	105 W 16% 1.3%	14.2
Module 3	11 Yrs	100 W mono-Si	Tedlar®	Pass	91 W 9 % 0.8%	2.7

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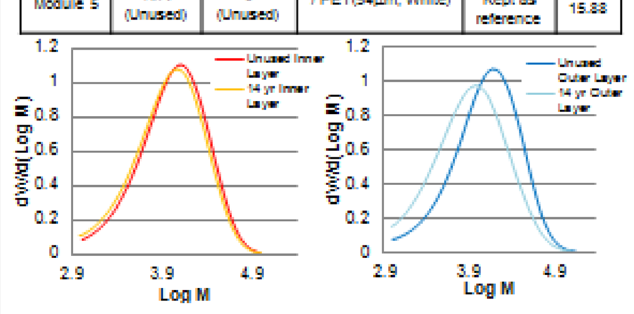
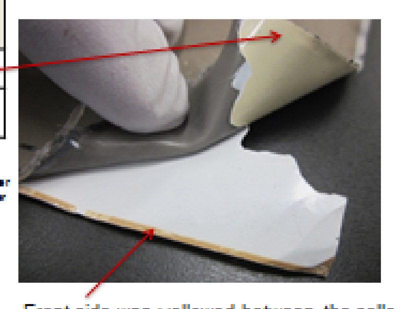
Additional Fielded PET Modules 4 & 5

	Field Location	Time in service	Backsheet Construction (thickness/µm color)	Mount Type	b*
Module 4	Ishikawa	14 yrs	PET(16µm, Clear) / PET(54µm, White)	Roof Top	27.35
Module 5	N/A (Unused)	0 (Unused)		Kept as reference	15.88





Front side was yellowed between the cells

AIST PET Samples	Time in Service (years)	Mn	Mw	Mw/Mn
Inner Layer	0	7,000	14,100	2.01
Outer Layer	0	8,200	17,700	2.16
Inner Layer	14	6,200	12,900	2.08
Outer Layer	14	5,500	12,600	2.29

Comparison of Unused to 14 Year Exposed Modules

- Molecular weight analysis shows a drop and broadening in PET Mw of outer layer. Little changes on inner layer.
- These changes are most likely due to stresses during service (UV, moisture, cycling, etc.)
- Yellowing of outer layer and in-between cells on inner layer
- PET backsheet became brittle
  - Film layers easily separated

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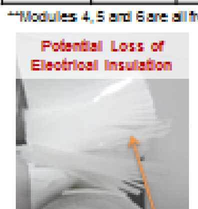
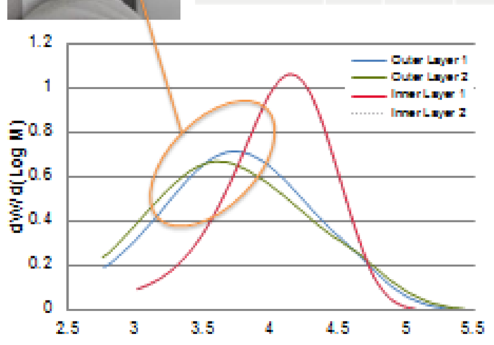
Additional Fielded PET Module 6

	Field Location	Time in service	Backsheet Construction (thickness/µm color)	Mount Type	b*
Module 6	Japan	9 yrs	PET(12µm, Clear?) / PET(50µm, White)	Open Rack	5.77

**Modules 4, 5 and 6 are all from the same manufacturer.



PET Layer Tested	Mn	Mw	Mw/Mn
Outer Layer 1	3,340	13,000	3.90
Outer Layer 2	3,000	13,700	4.56
Inner Layer 1	7,400	15,800	2.14
Inner Layer 2	7,300	15,600	2.15



Analyses of PET Layers

Molecular Weight Analysis

- Outer PET layer shows likely drop and broadening of Mw
- Inner PET layer no changes were observed
- These Changes are most likely due to stresses during service (UV, moisture, etc.)

Mechanical Properties

- Compared to a standard PET, the inner layer of PET dropped 60% in tensile (MD) and 40% in elongation properties
- Outer layer lost all mechanical properties

Outer PET degraded – Mw changes and loss of mechanical properties
Inner PET degraded – loss of mechanical properties with no Mw changes

	Inner PET Layer	Control PET	% Retention
Tensile (Mpa)	127.50	207.00	61.59
Elongation (%)	71.14	150.00	47.43

**Could not measure air side - no mechanical integrity

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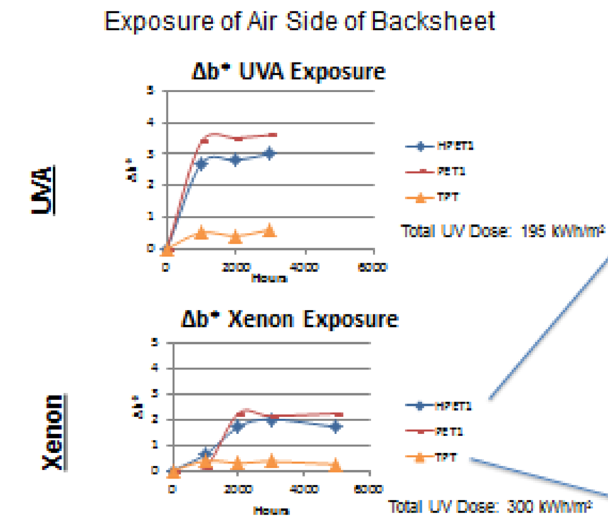
TPT vs PET : QUVA and Xenon Exposures of Backsheets

Exposure of Air Side of Backsheet



HPET1 inner tie layer cracking after 5000 hour air side xenon exposure

TPT- E side - no cracking after 5000 hour air side xenon exposure

Yellowing of PET backsheets using recommended UVA and UVX exposure and tie layer cracking with UVX

UVX: 65°C BPT, 60W/m² (300 - 400nm), 50%RH, no water
UVA: 70°C BPT, 65W/m² (250 - 400nm), ambient humidity, no water

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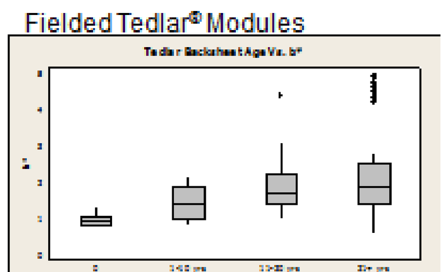
Comparison UV and Damp Heat to Fielded Performance

Fielded Tedlar® Modules



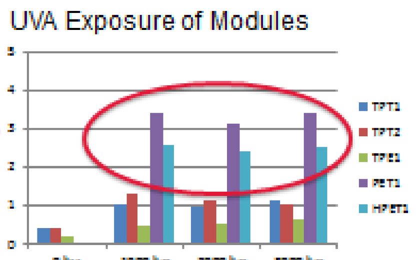
227 modules from various locations and manufacturers

- Small color change consistent with changes seen in damp heat and UVA exposure for Tedlar® backsheets
- Significantly larger changes in b* (9~27) for PET backsheets indicating polymer damage and degradation

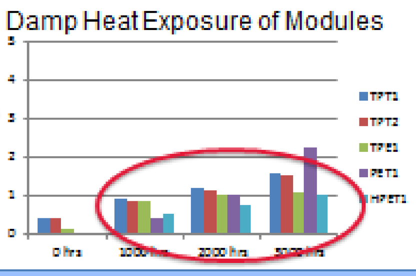
UV exposure of PET backsheets more damaging and likely responsible for much higher yellowing observed in the field

Damp Heat : 85°C, 85%RH
UVA: 70°C BPT, 65W/m² (250 - 400nm), no water

UVA Exposure of Modules



Damp Heat Exposure of Modules



- Level of yellowing in damp heat not changing appreciably from 1000 to 3000h.
- Level of yellowing for PET modules in damp heat not consistent with yellowing in the field

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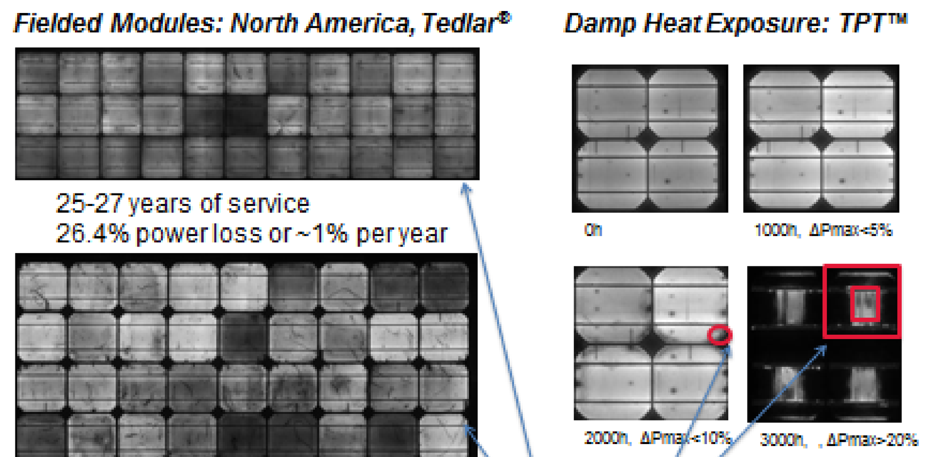
Comparison of EL Imaging From Damp Heat and Outdoor

Fielded Modules: North America, Tedlar® — *Damp Heat Exposure: TPT™*



25-27 years of service
26.4% power loss or ~1% per year

20 years of service
17.4% power loss or ~0.9% per year

Dark areas in EL image near edges at 2000h and extending over most of the cell at 3000h and associated power loss in damp heat are not observed in fielded modules

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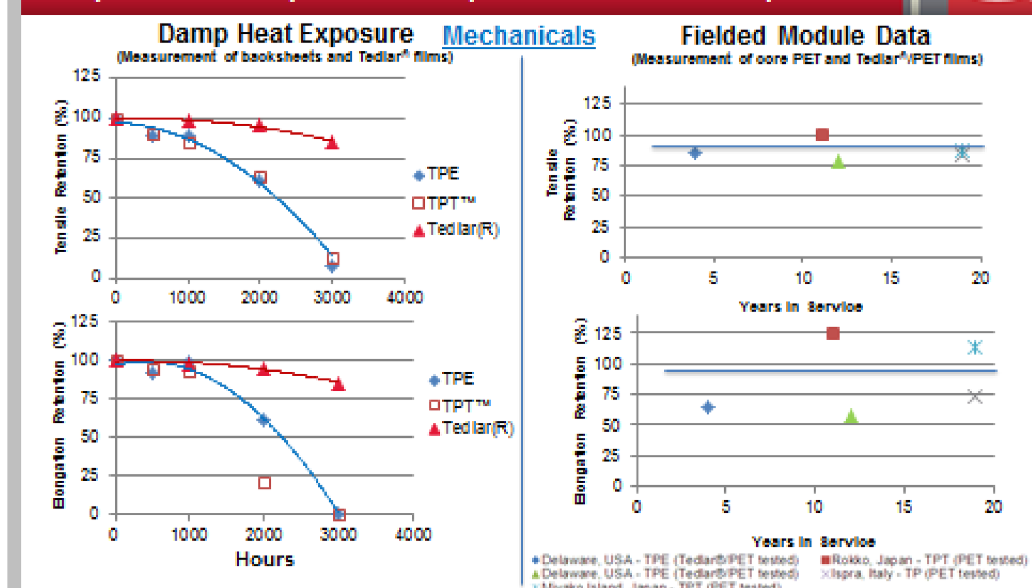
Comparison of Properties - Damp Heat and Fielded Exposure

Damp Heat Exposure (Measurement of backsheets and Tedlar® films) — **Mechanicals** — **Fielded Module Data** (Measurement of core PET and Tedlar®/PET films)



- Loss in mechanical properties in damp heat (>1000h) due to hydrolysis of PET core layers (not Tedlar®)
  - No loss in mechanical properties for humid environment – Miyako Island, Japan
- Mechanical loss at 2000h and 3000h much greater than observed in the field
- Fielded modules from different environments obtained from DuPont (USA), AIST (Japan) and JRC (Italy)

*A general purpose PET for PV use was chosen for mechanical property comparison with fielded modules

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Comparison of Properties - Damp Heat and Fielded Exposure

WVTR, Breakdown Voltage & Partial Discharge

Accelerated Testing

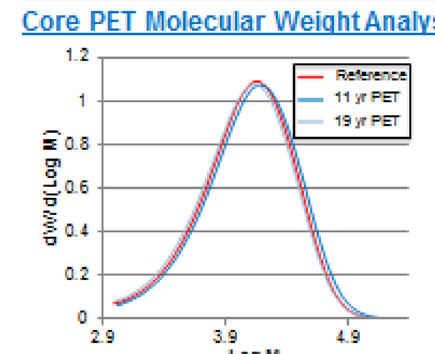
Samples	Thickness (µm)	WVTR (gm/m²-day) 0h	DH 1000h	DH 2000h	DH 3000h
TPT™	350	2.1	2.6	2.4	2.5
TPE	360	2.1	2.3	2.2	x

- WTVR stable in damp heat beyond 1000h
- No degradation seen in WVTR and electrical insulation in backsheets from fielded modules

Field Modules Testing (From AIST modules)

PVF/Adhesive/PET Samples (38 µm/5-10 µm/75 µm	Reference (118 µm)	11 yrs exposed (118-122 µm)	19 yrs exposed (118-122 µm)
Location in Japan	–	Rokko	Miyako Island
Break Down Voltage (KV)	13.5 ± 0.932	13.4 ± 0.737	13.8 ± 0.434
Partial Discharge (VDC)	762	755	740
WVTR (g/m2/day @ 40C/90%RH)	4.5	5.1	5.0

Core PET Molecular Weight Analysis From AIST Field Module with TPT™



Samples	Mn	Mw	Mw/Mn
Reference PET	7800	16200	2.08
11yrs core PET	8300	17800	2.14
19yrs core PET	7300	15600	2.14

No major changes over time observed in the PET core of TPT™ backsheets on 11 and 19 year old modules

- No evidence of PET hydrolysis damage
- No changes observed in mechanical, WVTR, breakdown voltage, and partial discharge testing
- Indicates the PET core was well protected by Tedlar®

*A general purpose PET for PV use was chosen for property comparisons with fielded modules

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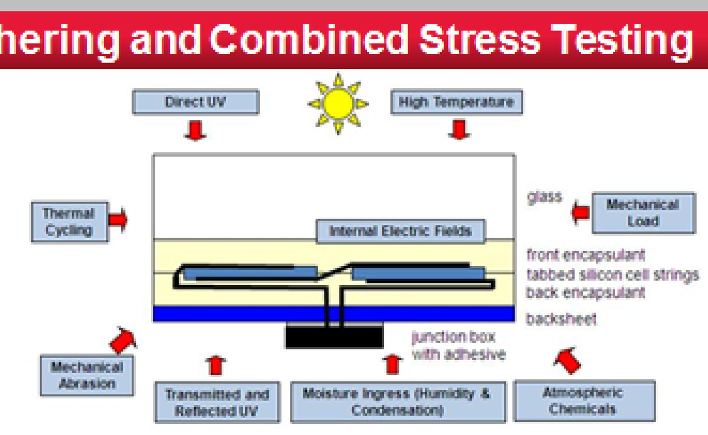
Weathering and Combined Stress Testing



Photovoltaic modules are exposed to a wide range of stress conditions including: UV, temperature, moisture (water, humidity, condensation), thermal cycling, and internal voltage

Stresses described above can operate on the module simultaneously or sequentially and synergistic effects are observed.

Accelerated test combinations under investigation:

- Weathering (UV, Temperature, Water) — First results
- Sequential (UV, DH, TC, HF) — First results
- Simultaneous (UV, DH, TC, HF) — In design
- Loaded (UV, Temperature, Resistive Load) — Underway

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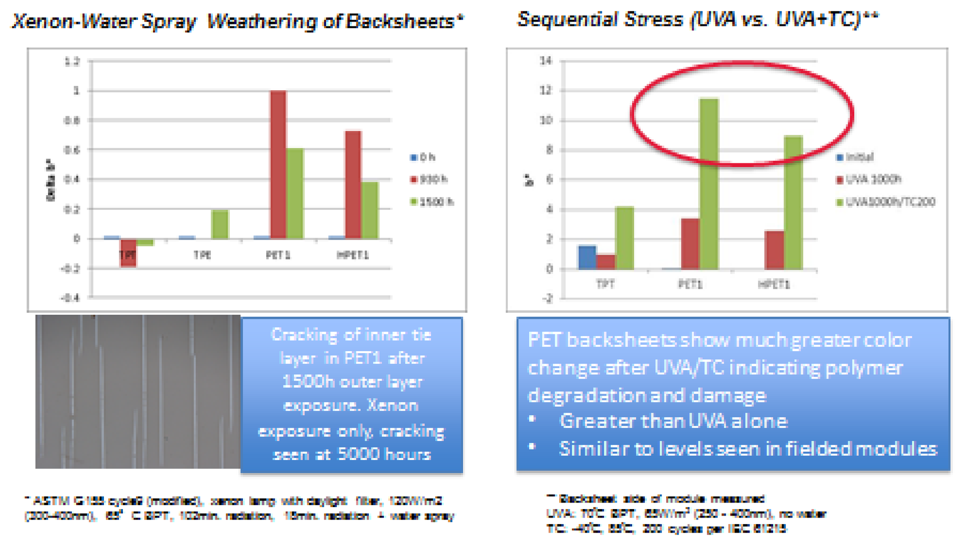
Weathering and Combined Stress Testing, Early Results

Combinations of UV/visible radiation, temperature, moisture (water spray, condensation and/or chamber relative humidity) and thermal cycling are more relevant to the outdoor environment

Xenon-Water Spray Weathering of Backsheets — *Sequential Stress (UVA vs. UVA+TC)*



Cracking of inner tie layer in PET1 after 1500h outer layer exposure. Xenon exposure only cracking seen at 5000 hours

PET backsheets show much greater color change after UVA/TC indicating polymer degradation and damage

- Greater than UVA alone
- Similar to levels seen in fielded modules

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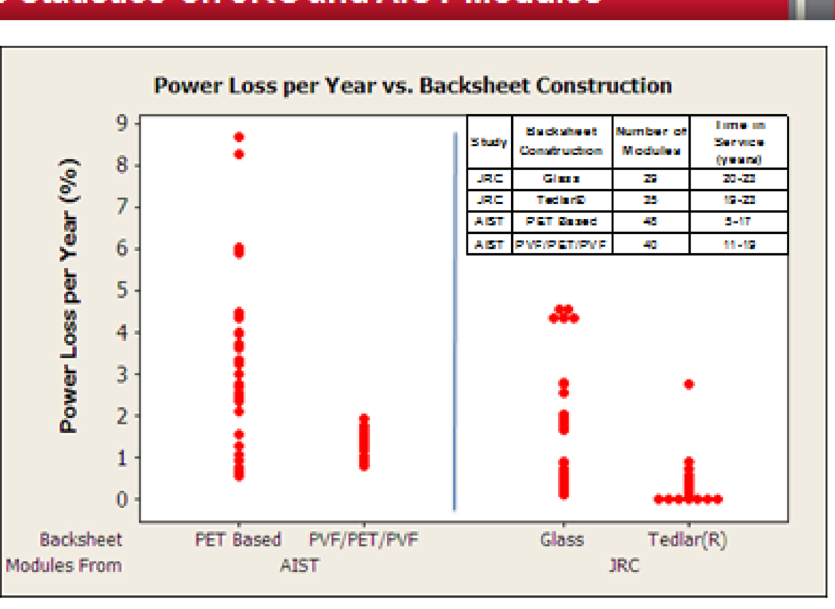
Basic Statistics on JRC and AIST Modules



In two separate studies, modules containing Tedlar® based backsheets showed lower power loss and less variability than modules using glass or PET based backsheets.

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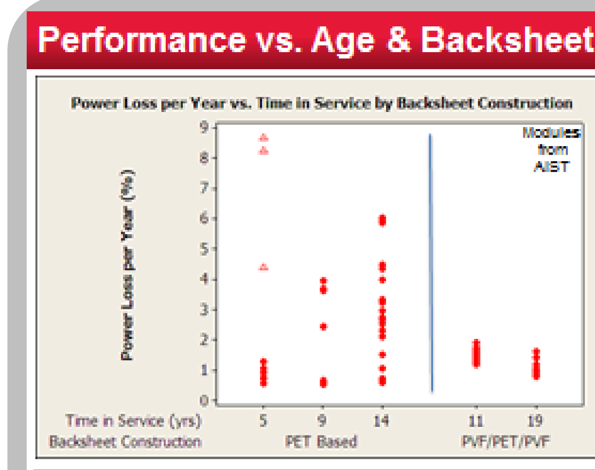
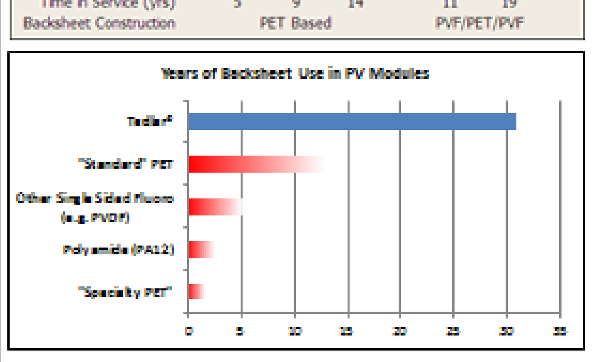
Performance vs. Age & Backsheet Construction



Further analysis of AIST modules:

- Each set of data shown at left is a different PV module model
- Two different PET module designs at 5 years show wide variation
- PET based modules demonstrated large power loss variation with age.
- TPT™ modules demonstrated very little power loss variation with age.



Competitive offerings have not been in the field long enough to judge their durability over the lifetime expectancy of solar modules

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Conclusions

DuPont accelerated test protocols have been designed to simulate the real environment

- UV dosages are based on 25 years exposure in different climates
- Damp heat exposure of <1000 hrs adequately addresses hydrolysis damage to PET based on analysis of fielded modules.

Fielded Modules Analysis and First Correlations to Accelerated Tests

- Yellowing of Tedlar® and PET backsheets in fielded modules correlate with accelerated UV and combined UV with other stresses.
- PET backsheets including HPET backsheets showed much higher yellowing than Tedlar®
- Most (60%) of yellowed PET modules also displayed brittleness and cracking in fielded modules
- Yellowing is a good visual indication of degradation and possibly more serious problems (cracking)
- Mechanical property changes observed in damp heat (>1000h) are not observed in fielded modules
- No loss of molecular weight or evidence of hydrolysis in PET core of TPT™ in fielded modules

Combined Stress and Weathering

- Current single stress testing does not adequately predict fielded module performance
- Weathering and multi-stress test protocols are producing effects more consistent with fielded performance
- UV with temperature cycling shows best correlation so far with fielded modules

Fielded Module Performance Studies

- Two fielded studies show low power loss and reduced variability for Tedlar® based backsheets compared to Glass and PET backed modules

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This poster contains no confidential information. *

Special thanks to JRC (European Commission Joint Research Centre) and AIST (The National Institute of Advanced Industrial Science and Technology) for use of their fielded modules.