Durability of Photovoltaic Modules to UV and Weathering in Accelerated and Outdoor Exposure

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DuPont has developed New Test Protocols to better match real world observations

- Fielded module program used to understand backsheet failure mechanisms and to guide and validate accelerated test program
- Examples include:
  - Yellowing and cracking on the junction box side
  - Yellowing of the front side on the encapsulant side
- Redesigned UV test protocols and introduced sequential test protocols to better predict field performance
- Seeing same failures as the field
  - Yellowing/Cracking of the inner layer in junction box side UV testing
  - Yellowing, cracking observed in encapsulant side UV testing
  - Cracking observed in sequential testing

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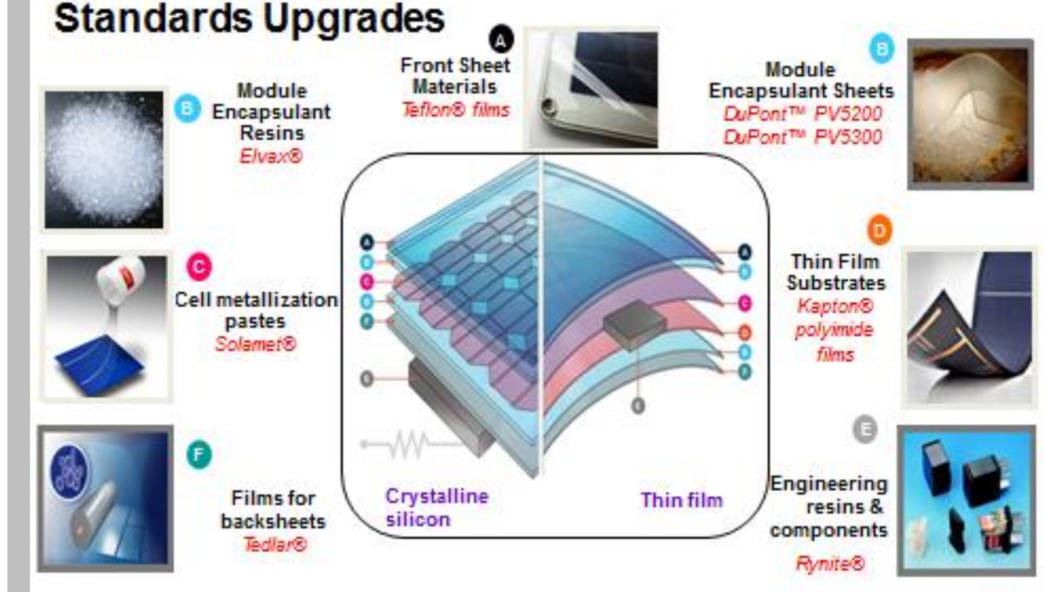
DuPont is Uniquely Positioned to Understand Standards Upgrades



Unique Breadth and Depth of Offerings, Business and Understanding of PV.

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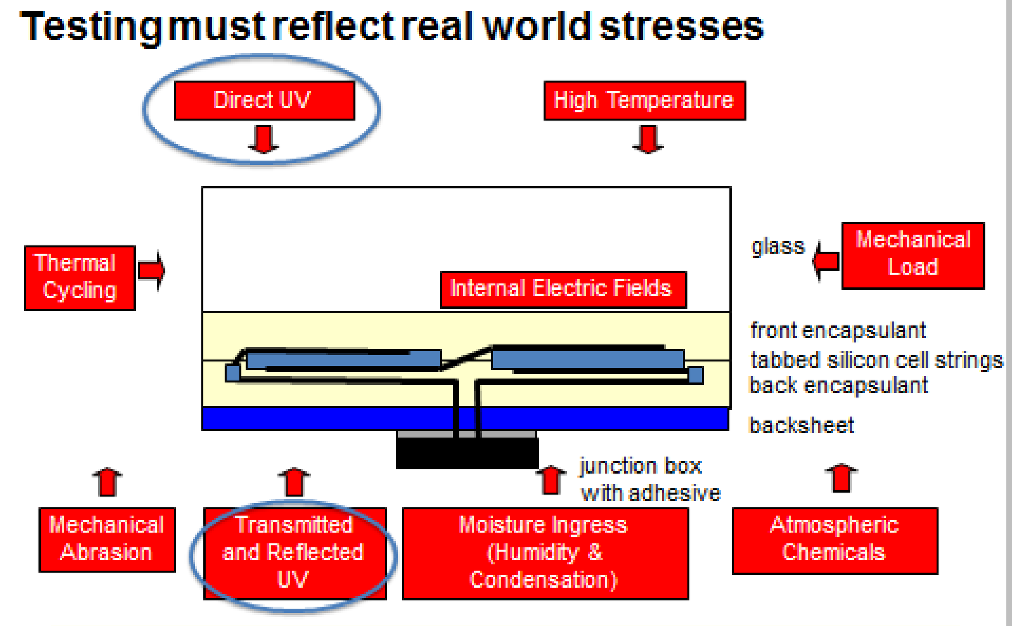
Testing must reflect real world stresses



UV exposure is a significant and undertested stress!

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DuPont has developed an extensive fielded module database

- Inspected/Characterized >30 global installations
  - Includes >100 MW / >150,000 modules) in Europe, Israel, China, Japan, India, Canada, and United States
  - Time in the field ranging from newly commissioned to 30 years to gain technical learnings
- Modules are measured and characterized in the service environment
- Additional testing of modules conducted in laboratory using PV and analytical test methods to understand failure mechanisms

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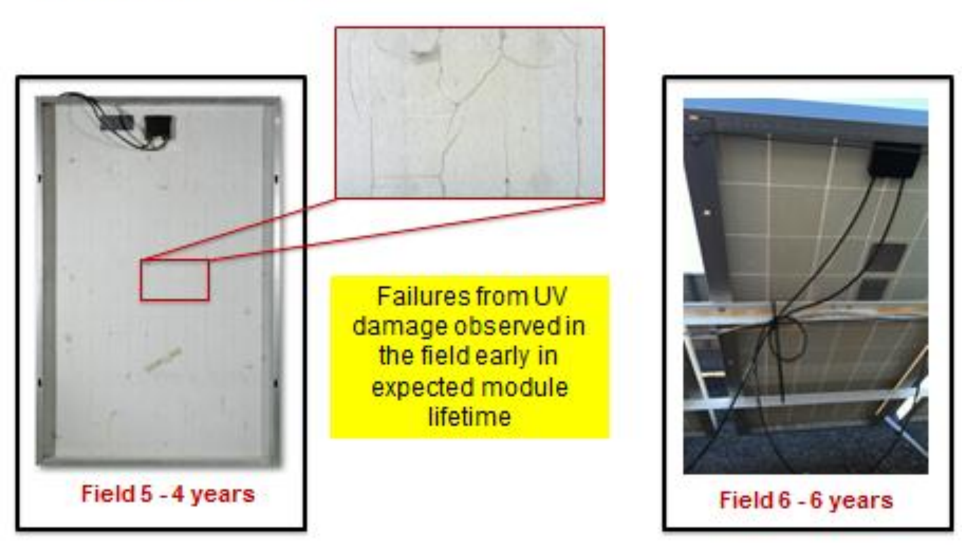
Backsheet cracking is a safety risk and may lead to module failure



Failures from UV damage observed in the field early in expected module lifetime

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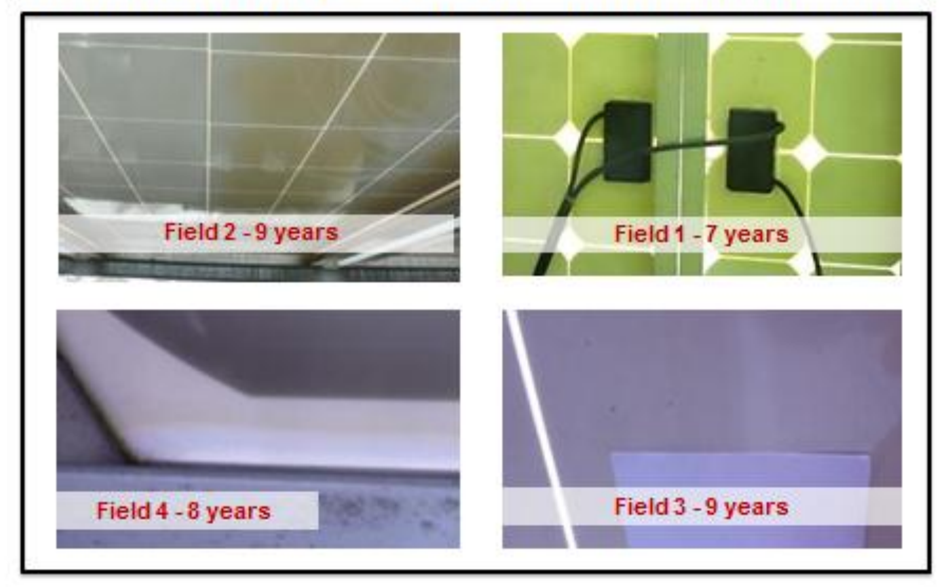
Backsheet yellowing is an indication of polymer breakdown and puts the module at risk of failure



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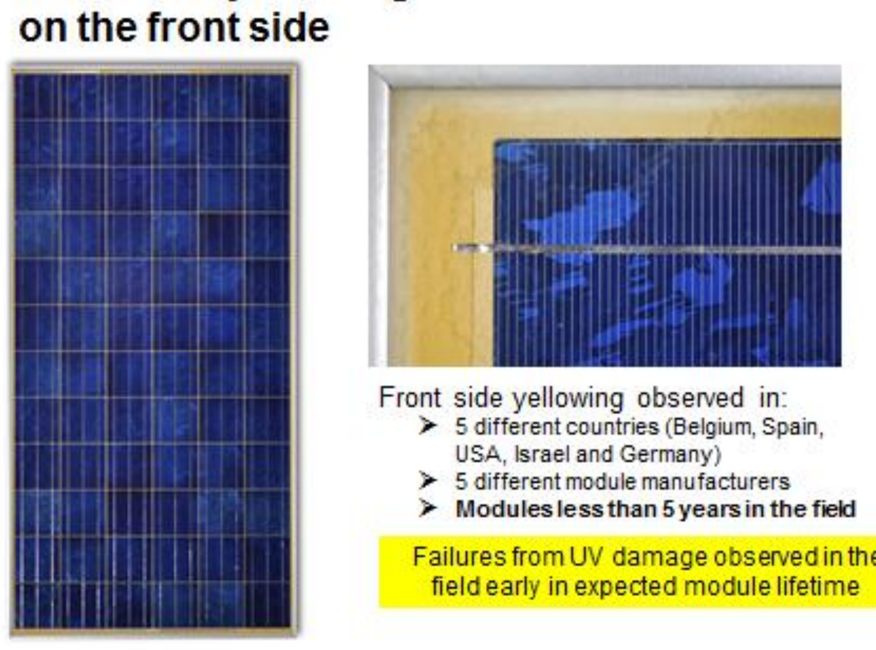
Backsheet yellowing has also been observed on the front side



Front side yellowing observed in:
- 5 different countries (Belgium, Spain, USA, Israel and Germany)
- 5 different module manufacturers
- **Modules less than 5 years in the field**

Failures from UV damage observed in the field early in expected module lifetime

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Backsheet durability issues are real and existing standards insufficient

- Durability issues related to the backsheet are real and documented in fielded modules (cracking, yellowing, delamination)
- We propose to add backsheet UV exposure to current industry standard (currently little or no UV exposure in qualification standards) consistent with the service environment
- Polymeric component testing of UV stability established in ASTM standards and used in other industries

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DuPont recommends increasing UV testing to better match real world observations

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 (Junction Box Side)	UV, 70°C BPT, 1.1W/m²-nm at 340nm, 120 W/m² (250-400nm)	275 kWh/m² (4230 h)	desert climate (25 year equivalent)
		235 kWh/m² (3630 h)	tropical climate (25 year equivalent)
		171 kWh/m² (2630 h)	temperate climate (25 year equivalent)
UV (Encapsulant side)	UV, 70°C BPT, 0.55W/m²-nm at 340nm, 65 W/m² (250-400nm), glass/EVA/EVA filter, std. EVA and UV transmissive EVA	550kWh/m² (4600 h)	desert condition (6 - 16 year equivalent)
		550 kWh/m² (4600 h)	tropical condition (7 - 19 year equivalent)
		550 kWh/m² (4600 h)	temperate condition (10 - 26 year equivalent)
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 UV pre-conditioning, 15 kWh/m² (280-385nm), front exposure only, ~70 days outdoors

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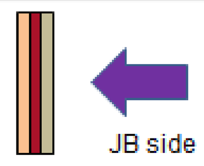
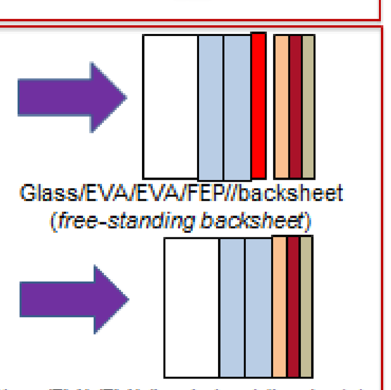
DuPont has developed testing protocols for both junction box and encapsulant side exposure

UV Test Method 1 (junction box side exposure)
Xenon (daylight) or UVA fluorescent exposure, 70C BPT, 275 kWh/m2 TUV, ~25y desert exposure**)



UV Test Method 2 (encapsulant side exposure)
Xenon (daylight) exposure, 70C BPT, 550 kWh/m2 TUV, ~6y desert exposure)

1. Test laminate and free-standing backsheet
2. UV exposure of backsheet through glass/2EVA/FEP filter
3. Test using standard and UV transmissive EVA



** Assumes 12% albedo

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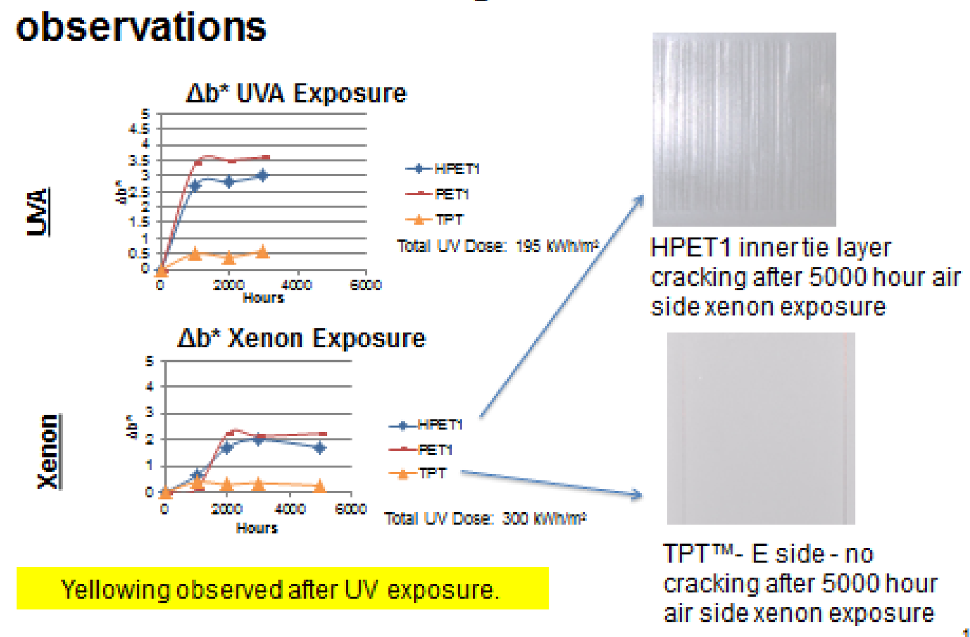
Junction box side testing reflects real world observations



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 observed after UV exposure.

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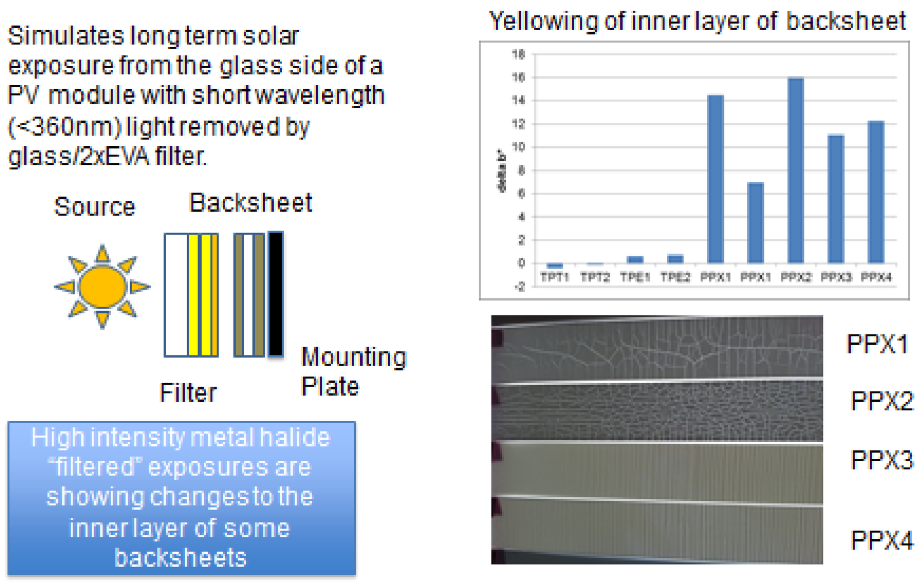
Encapsulant side testing reflects real world observations

Simulates long term solar exposure from the glass side of a PV module with short wavelength (<360nm) light removed by glass/2xEVA filter.



High intensity metal halide "filtered" exposures are showing changes to the inner layer of some backsheets

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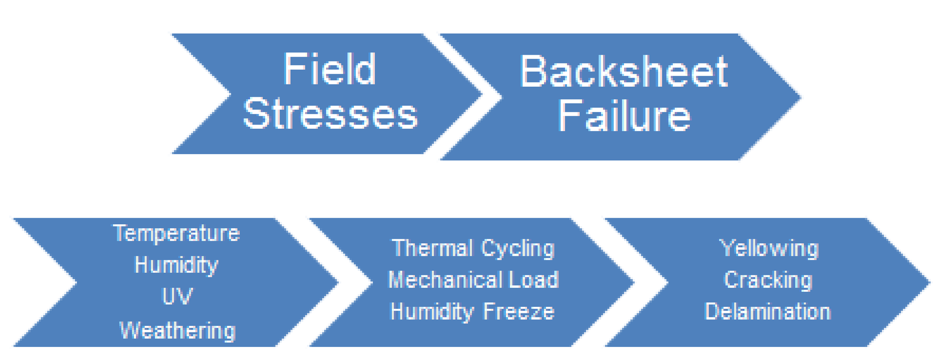
Sequential testing better reflects real world environment



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Sequential testing reflects real world observations

Cracking of a single-sided PVDF backsheet after sequential exposure to damp heat, UV and thermal cycling (contrast altered to highlight cracking)

Cracking of a single-sided PVDF backsheet after sequential exposure to damp heat and thermal cycling

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Inclusion of UV testing is critical to assuring module reliability and durability

- Backsheet degradation and failures from UV damage observed in the service environment.
- Redesigned UV and combined tests to better predict real world performance.
- Backsheet degradation (yellowing and cracking) in UV and combined tests similar to failures seen in the field.
- Inclusion of UV testing is critical to assuring module reliability and durability for long PV module life.

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