The miracles of science™

MATERIALS MATTER™

Protect your modules and brand with DuPont™ Tedlar® PVF film-based backsheet–
the industry standard for reliability and field-proven performance for more than 30 years.

LONGER MODULE LIFETIME PROVIDES GREATER INVESTMENT RETURNS. DUPONT PV MATERIALS STAND THE TEST OF TIME.

For the past several years, there has been an important shift underway in the solar photovoltaic (PV) industry– solar efficiency has been improving and prices have been dropping.

Grid parity has already been achieved in some parts of the world and by 2015 we expect to reach grid parity in many parts of the world. To maintain this progress, solar installations must continue to deliver a reliable source of energy, as well as a reliable return on investment.

Long life systems are critical to achieving the required levelized cost of energy (LCOE), which is essential for reaching grid parity, creating a sustainable industry and ensuring global adoption of solar energy.

Three factors significantly impact system lifetime– the bill of materials, component design and manufacturing practices. Our portfolio of "best-in-class" PV materials enables you to offer modules that deliver the expected power output and lifetime requirements of your customers.

"The goal of our industry is not only to produce affordable components, but also to generate low-cost electricity. This can be achieved through an increase of performance and reliability. Quality is achieved by improved manufacturing processes (more automation, in-line controls), products (sustainability of materials, encapsulation...) and proved by testing in the field."

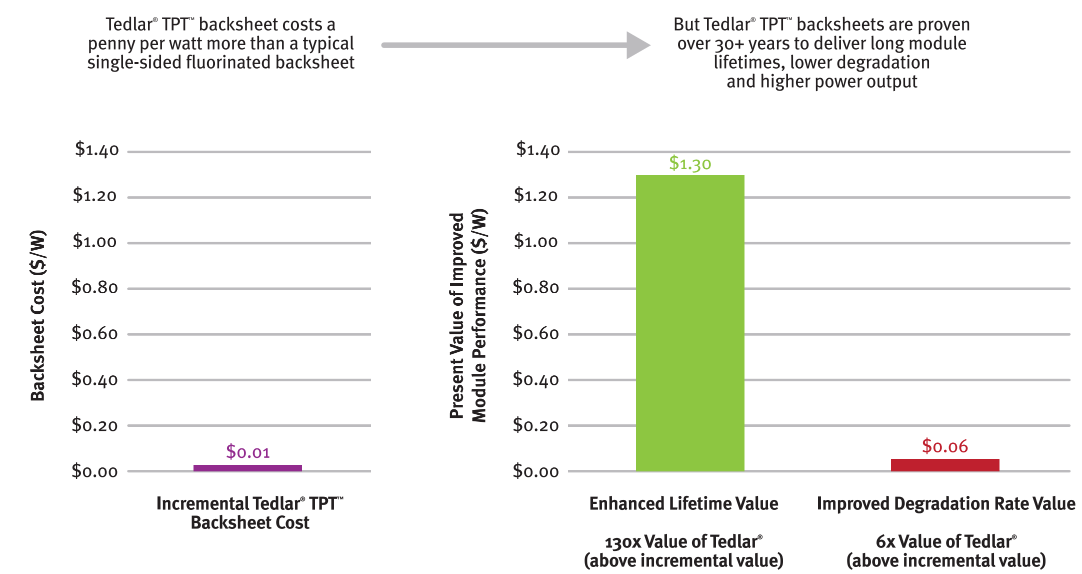
Reinhold Buttgereit,
Secretary General, EPIA

DUPONT™ TEDLAR® PVF FILM FOR MODULE BACKSHEETS HELPS ENSURE GREATER LIFETIME POWER OUTPUT AND INVESTMENT RETURNS

Using DuPont™ Tedlar® PVF film in your PV module's backsheet will help position your PV module brand as high quality and reliable, as well as help to reduce the risk of warranty issues and reputation damage from failures in the field.

The bottom line is that for approximately a penny a watt ($.013), you can help protect your company and your customers from expensive failures and safety issues. The lifetime gains and resulting financial benefits far outweigh the incremental investment in higher quality materials. In today's dynamic market environment, it makes good sense to offer PV modules that stand the test of time.

A small investment delivers tremendous value



Lifetime value and degradation value represent the present value of power output over the expected lifetime of the module.
Lifetime value: Compares 25 years of lifetime for Tedlar® TPT™ backsheet vs. 5 years of lifetime for competing backsheets that have early catastrophic failure.
Degradation rate value: Compares 0.5% annual degradation rate enabled by Tedlar® TPT™ backsheet to a module with 1.0% annual degradation.
Assumes: 8 cent/W electricity value in year 1, inflating at 3% per year over lifetime of module; 250 watt average per module. Central China installation, 9% discount rate.

WHY BACKSHEETS ARE IMPORTANT

Backsheets play a critical role in protecting PV modules and delivering needed module lifetime. They protect the modules from the environment while providing electrical insulation. Backsheet failures can lead to module failure modes such as catastrophic failure, unacceptable power degradation and safety failures. The impact can be very significant, ranging from brand and reputation damage to bodily harm.

Examples of some primary backsheet failure modes observed in the field are shown in the photos on page 4 and include discoloration, bubbles, cracking, delamination and yellowing.

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Failure modes of backsheets in field

Discoloration

Yellowing and indelible stains on the surface of backsheet


Delamination

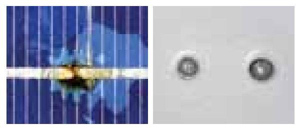
Separation of backsheet into layers


Cracking

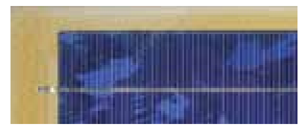
Cracking of backsheet


Bubbling to cracking

Bubble on the backsheet mainly found along the interconnector line


Bubbling under hotspot

Burn holes on backsheet surface


Yellowing

Module with PVDF backsheet showing significant yellowing of layers behind the cells after <2 years in the field

Decades ago, the U.S. Department of Energy contracted NASA's Jet Propulsion Laboratory (JPL) to develop a reliable, durable and safe 30-year PV module. Many different types of materials were tested throughout the nine-year, $150 million ($700 million in 2013 dollars) program, including hundreds of design iterations and the deployment of thousands of fielded modules. All of the recommended final designs contained Tedlar® PVF film-based backsheets.

LONG-TERM OUTDOOR EXPOSURE IS THE ULTIMATE TEST FOR SELECTING THE RIGHT BACKSHEET

Not all backsheets are created equal. In order to protect a module for 25 years, the backsheet must have three critical properties: weatherability, mechanical strength and adhesion; however, the most important thing is the optimal balance of these three properties.

In the absence of long-term, field-proven performance, many of today's newer backsheet materials rely on various lab tests to suggest performance in the field. However, well-established scientific bodies, such as NASA's JPL and other leading PV research labs, have made it clear that lab tests do not predict lifetime performance. As many scientists have pointed out, long-term outdoor exposure is the ultimate test for all the module components, material quality and manufacturing quality.

Specifically, IEC qualification tests were not designed to predict long-term performance and are not adequate for this purpose. Reliability tests should be used with caution because they have an unknown correlation with field performance; accelerated tests may produce failures not seen in the field; and modeling is both costly and complicated.

"Ideally, the lifetime of a module would be predicted by a relatively short set of accelerated stress tests. However, a technical basis for predicting lifetimes has not been established."

NREL, July 2011; Ensuring Quality of PV Modules; http://www.nrel.gov/docs/fy11osti/50651.pdf

ONLY TEDLAR® PVF FILM-BASED BACKSHEETS HAVE DEMONSTRATED LOW POWER LOSS IN LONG-TERM PV MODULE APPLICATIONS

A recent study conducted by the Joint Research Centre (JRC) confirms the JPL finding that modules containing EVA/Tedlar® demonstrate excellent performance for extended periods in the field. To date, Tedlar® PVF film-based backsheets are the only backsheets with more than 30 years of field-proven lifetime. Other backsheets being used in the field have as little as three to six years of operating history.

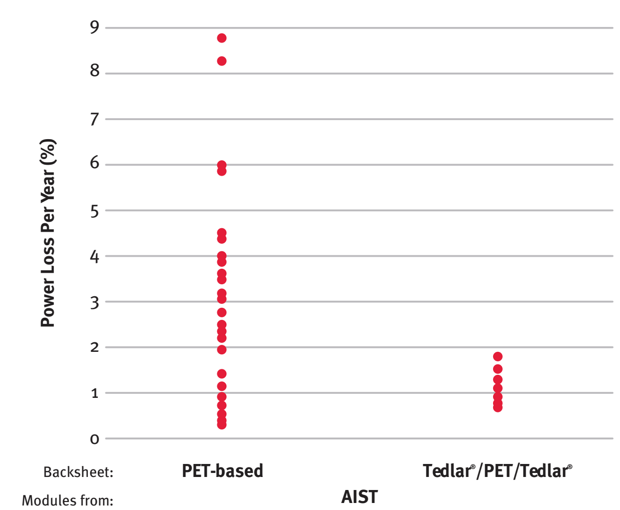
In addition to these studies, there are many other independent studies that show less than 1% per year power degradation from modules using Tedlar® PVF film-based backsheets. The issue is that there are very limited examples of the newer backsheet materials being used in the field that can be studied. Tedlar® PVF film-, PET- and glass-based backsheets have been in service for more than 15 years. Most other constructions have been in service for only about five years.

Although field testing is the best predictor of long-term performance, reliability tests can indicate differences between materials. Currently, DuPont and others are working on correlating reliability tests with field performance; however, this has not yet been achieved. Recent work in this area shows that damp heat is typically over-tested and UV is typically under-tested versus actual field exposure.

To select the right backsheet, the appropriate test methods and standards must be defined and the test results compared.

Results of the JRC study of modules containing EVA encapsulant and the AIST study

Demonstrated low power loss (0.3% per year) of modules with Tedlar® PVF film-based backsheets after 20+ years in field



Source: 2012 AIST Modules and Joint Research Centre 2008 Study.

"Long-term outdoor exposure is the ultimate test for all module components, material quality and manufacturing quality."

Artur Skoczek, Tony Sample, and Ewan D. Dunlop. *The Results of Performance Measurements of Field-aged Crystalline Silicon Photovoltaic Modules* Wiley InterScience, 2008.

DuPont recommended tests and criteria for evaluating PV backsheets

Condition	DurationP	roperty	Unit	Measurement Standard	Criteria		
					●	●	●
Outer Layer UVA	>3000h	Yellowing (Junction Box Side)	Δb*	ASTM E308	≥2	<2	<1
	>3000h	Elongation	% Loss	ASTM D882	≥80%	<80%	<50%
Outer Layer UV - Xenon	5000h	Inner Layer Stability	n/a	Visual	Cracked	Slightly Cracked	Good
Damp Heat	1000h	EVA Adhesion	% Loss	ASTM D903 (180 deg) ASTM D1876 (t-peel)	≥50% or Break	<50%	<20% or Glass Peel
	1000h	Elongation	% Loss	ASTM D882	≥80%	<80%	<50%
Thermal Exposure	Varies	Inner Layer Softening Temp.	°C	JIS K7196	n/a	<170	>170
Initial	0h	Coefficient of Thermal Expansion (MD, TD)	(μm/C*m)	Internal	≥100 (MD or TD)	<100 (MD or TD)	<50 (MD or TD)
Outdoor Performance	Varies	Years Used in PV Backsheet*	Years	n/a	<20	n/a	≥20

TEST/PROPERTY DETAIL

Damp Heat: 85°C, 85% RH.
UVA: 70°C, QUV 340 nm, 1.2 W/m²-nm at 340 nm, continuous.
Xenon: ASTM G155 cycle 7A (modified), Xenon .55 W/ m²-nm at 340 nm, daylight filter, 65 BPT, continuous, no water spray.
CTE: -40°C to 85°C.
*For non-TPT™ backsheets, numbers shown are based on commercial introduction from Photon 2011 Survey.

DEFINING TEST METHODS AND STANDARDS

Lab tests should be designed to enable the best prediction of performance in three areas: reliability (IEC61215), durability (25-year lifetime) and safety (UL1703 in the US and IEC61730 internationally).

Recent studies by industry leaders, including NREL, indicate that damp heat testing beyond 1,000 hours is not necessary or relevant and using expensive specialty PET materials in order to pass extended duration damp heat testing simply does not make sense. This is supported by successful field experience with DuPont™ Tedlar® TPT™ backsheet using standard PET core materials. While damp heat is typically over-tested, NREL and others recognize that UV is severely under-tested.

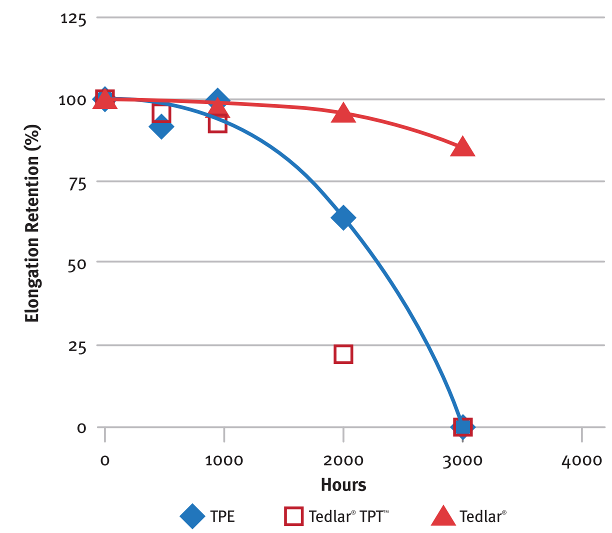
MORE THAN 1000 HOURS DAMP HEAT TESTING IS IRRELEVANT TO FIELD PERFORMANCE	• Hydrolysis damage is not a real-world failure mechanism • Tedlar® TPT™ backsheet has used standard PET cores for 27 years • NREL modeling shows ‹1000 hrs damp heat is sufficient • “Bake-offs (long times at 85/85) do not duplicate field failures and for PET Hydrolysis are massive overkill”*
UV EXPOSURE AND UV + WEATHERING MISSING FROM IEC TEST CONDITIONS	• IEC qualification UV level represents ‹70 days real exposure • There is no required exposure to the back of the module • Increased backside UV exposure and combined UV & weathering tests needed to better understand real-world performance • Real-world conditions suggest UV exposure levels of 2600 to 4200 hours to simulate 25 years

*Temperature, Humidity and Voltage, National Renewable Energy Laboratory (NREL), PV QA Task Force, Group 3, 2012.

A good example of how damp heat exposure testing does not correlate with field data is shown in the figure below where mechanical loss at 2,000 and 3,000 hours was much greater than observed in the field.

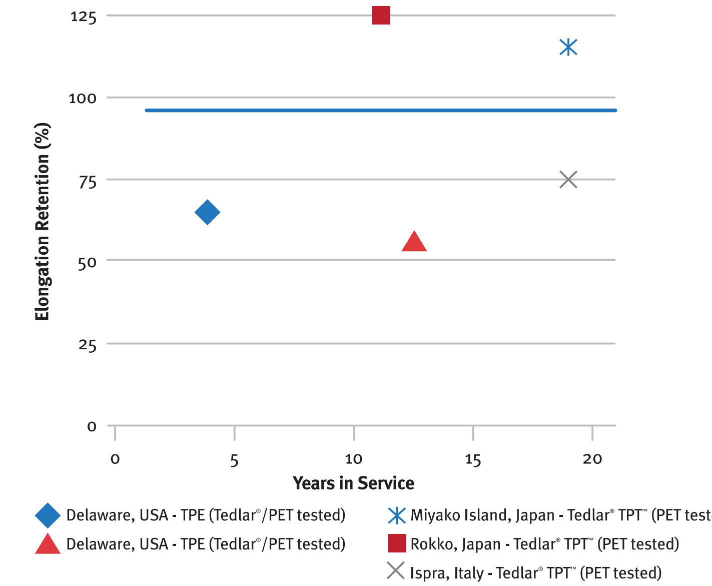
Damp heat exposure

Measurement of backsheets and Tedlar® PVF films



Fielded module data

Measurement of core PET and Tedlar®/PET films



Loss in mechanical properties in damp heat (›1000 hours) due to hydrolysis of PET core layers (not Tedlar®)

No loss in mechanical properties for humid environment– Miyako Island, Japan

Mechanical loss at 2000 and 3000 hours much greater than observed in the field

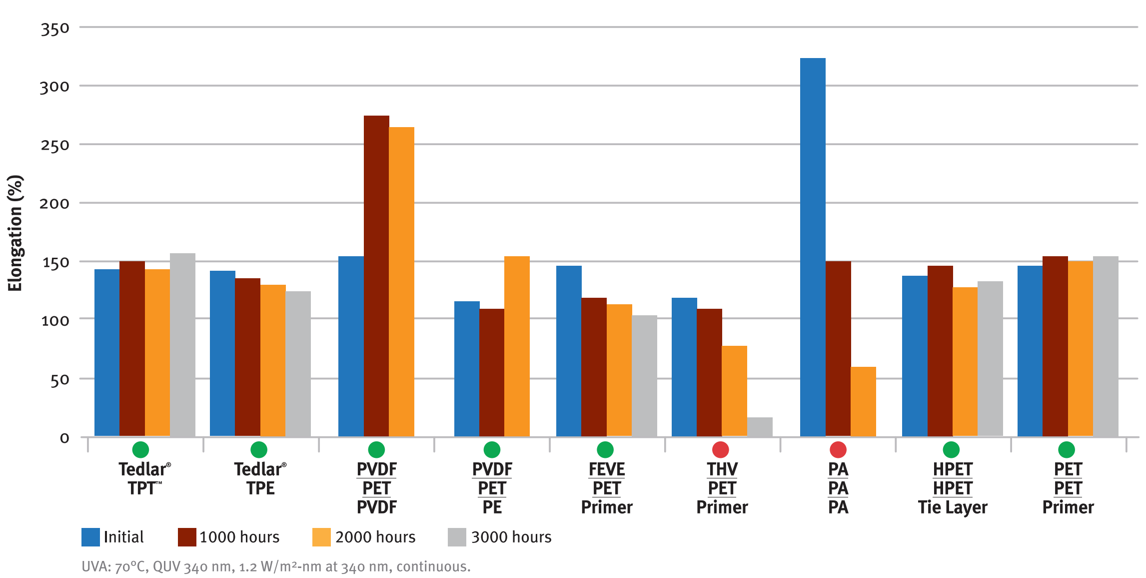
Fielded modules from different environments obtained from DuPont (USA), AIST (Japan) and JRC (Italy)

Recognizing that UV is typically under-tested, DuPont reviewed numerous industry expert studies to establish annual UV dosages in various regions. We used this information and the calculated reflection of light from the ground to the backsheet (albedo) to develop the recommended number of hours of exposure at test conditions to simulate 25 years of outdoor exposure in desert, tropic and temperate climates. It is important to note that these recommended exposures–4,230 hours for desert; 3,630 hours for tropic; and 2,630 hours for temperate climates–are two to 18 times higher than those used by most module makers in their current testing protocols.

To better simulate real outdoor conditions, we also recommend combined tests for both UV and damp heat.

In the comparison shown below of the UV stability of various backsheets, it is easy to see that Tedlar® TPT™ and Tedlar® TPE backsheets offer outstanding UV stability. Unlike THV- and PA-based backsheets that exhibit significant loss of elongation, which can lead to backsheet failure in the field, Tedlar® TPT™ and Tedlar® TPE are stable after UV exposure. And, while THV-, HPET- and PET-based backsheets exhibit yellowing after UV exposure that indicates polymer degradation, Tedlar® TPT™ and Tedlar® TPE backsheets show little color change.

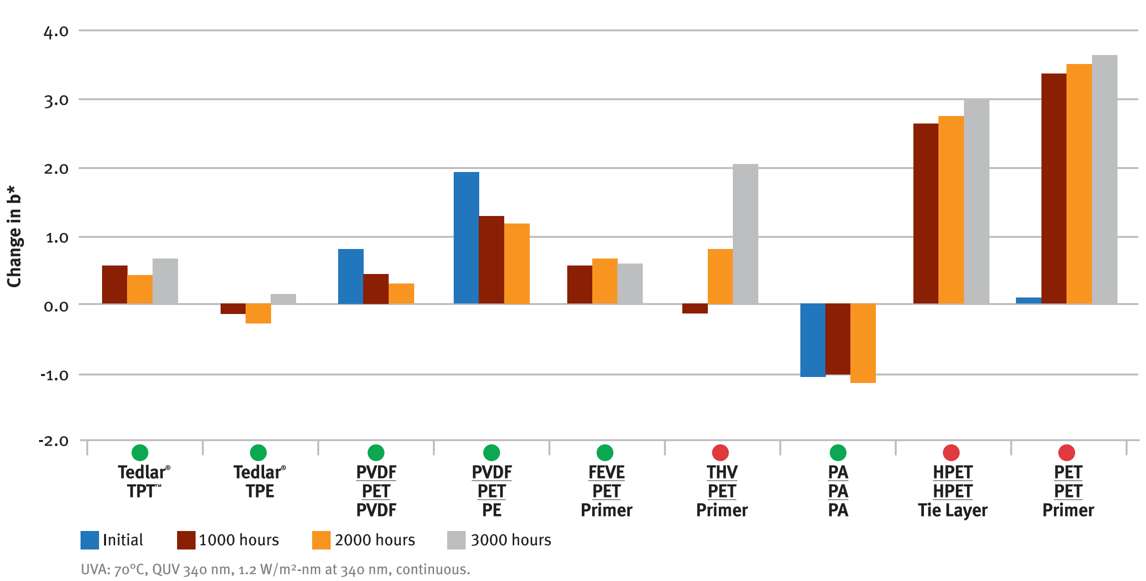
Tedlar® TPT™ backsheets offer outstanding UV stability



Tedlar® TPT™ and TPE backsheet mechanicals stable after UV exposure

THV- and PA-based backsheets losing significant elongation

Loss of elongation can lead to backsheet failure in the field



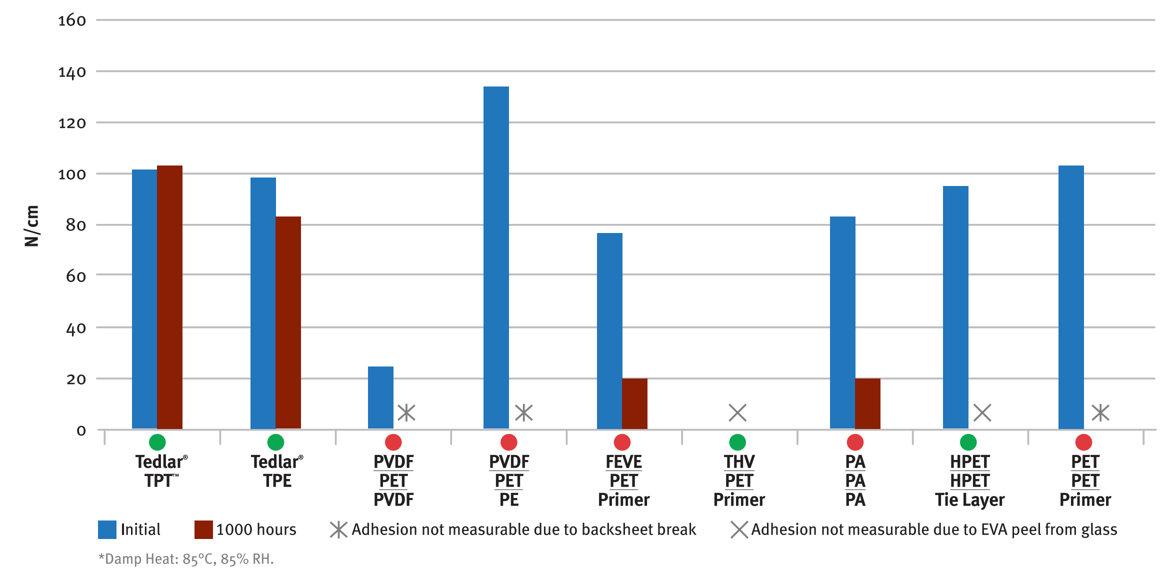
Tedlar® TPT™ and TPE backsheets showing little color change

THV-, HPET- and PET-based backsheets yellowing under UV exposure

Yellowing indicates polymer degradation

When the same group of backsheet materials was compared in damp heat testing, Tedlar®-based backsheets once again outperformed the others, offering outstanding stability after damp heat exposure. In contrast, as shown below, PVDF- and PET-based backsheets became embrittled and broke when tested for adhesion after damp heat exposure and FEVE- and PA-based backsheets lost more than 70% adhesion, which can lead to delamination. It is also important to note that single-sided PVDF- and PA-based backsheets lost a significant percentage of elongation after damp heat exposure, which can lead to backsheet failure in the field.

Tedlar® TPT™ backsheets offer outstanding damp heat stability

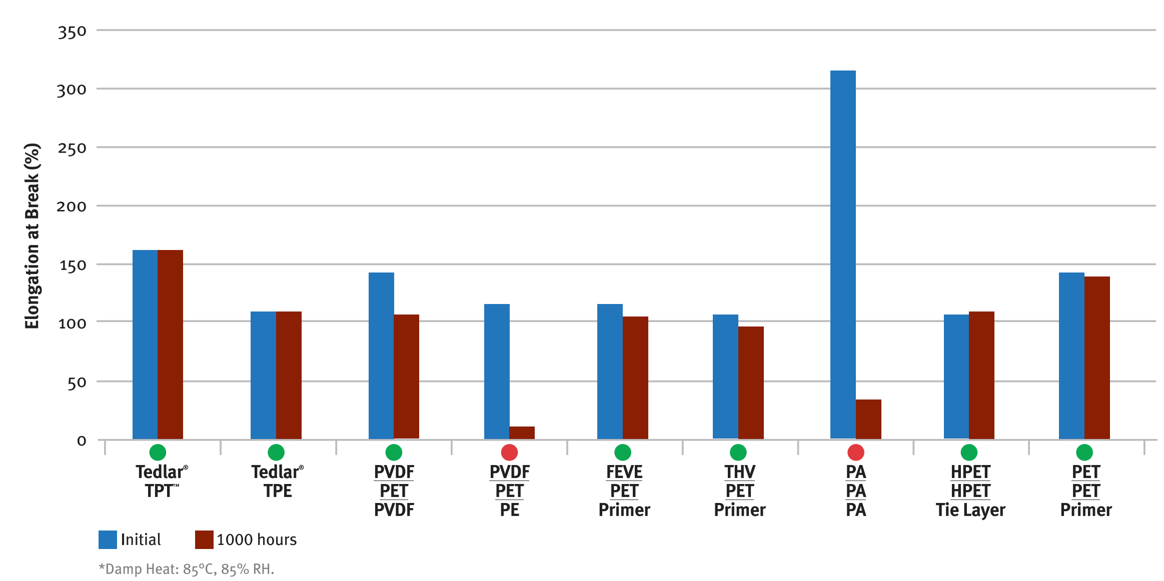


Tedlar® TPT™ and TPE backsheets adhesion stable after damp heat exposure

PVDF- and PET-based backsheets embrittled and broke when tested for adhesion

FEVE- and PA-based backsheets lost more than 70% adhesion

Loss of adhesion can lead to delamination



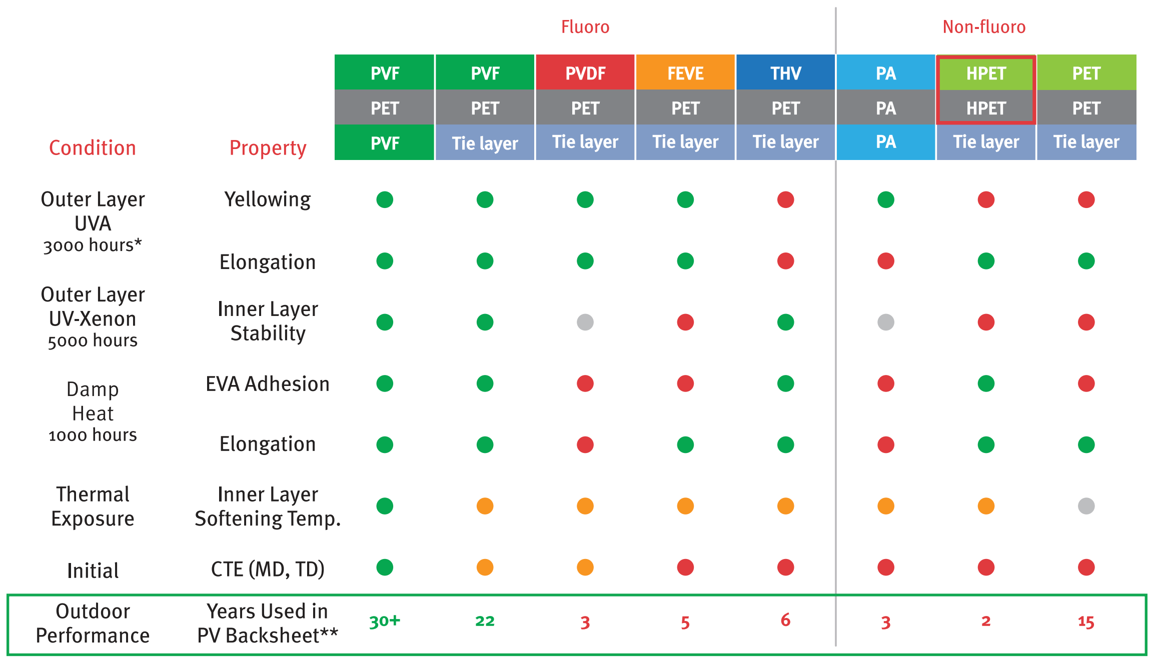
Tedlar® TPT™ and TPE backsheets stable after damp heat exposure

Single-sided PVDF- and PA-based backsheets losing significant elongation

Loss of elongation can lead to backsheet failure in the field

After defining the appropriate testing methods, the next step is to compare the test results to determine which backsheet offers the best balance of properties for long module lifetime. As shown here, Tedlar® PVF film-based backsheets demonstrate the optimal balance of properties for weatherability, adhesion and mechanical strength, properties that are required for long module lifetime.

Field performance is the best indicator of long-term performance, but reliability tests can also be used to determine the best balance of properties



*PVDF- and PA-based backsheets were tested to 2000 hours, while all others were tested to 3000 hours.
**For non-TPT® backsheets, numbers shown are based on commercial introduction from Photon 2011 Survey.

FIELDED MODULES DEMONSTRATE THAT "MATERIALS MATTER™"

In 2011, DuPont initiated an international study of PV modules obtained from all kinds of geographies and climates. The focus of the study was on reliability and other issues affecting the integrity of PV modules. There were many examples of modules produced with PET-based backsheets exhibiting issues such as cracking and yellowing, which leads to module failure. These issues were not observed in the modules made with Tedlar®-based backsheets.

PV modules display a wide range of safety and performance, as shown by these three modules from the study. Comparing these modules, which are each less than half the age of a typical 25-year industry warranty, demonstrates that durability issues may take a long time to manifest as specific degradation modes.

Yellowing (observed in modules 1 and 2) is a sign of degradation and an early indicator of a performance issue. Cracking is often associated with yellowing. It is important to note that poor performance can be magnified because cells and modules are linked in series.

Material choices drive real differences in lifetime power output and failure

MODULE	DURATION IN SERVICE	NAMEPLATE RATING CELL TYPE	BACKSHEET	WET LEAKAGE	IV MEASUREMENT % DEGRADATION % DEGRADATION/YR	b* YELLOWING OF BACKSHEET
1	10 years	143 W mono-Si	Standard PET	Pass	77 W 46% 4.6%	9.0
2	12 years	125 W poly-Si	Standard PET	Fail	105 W 16% 1.3%	14.2
3	11 years	100 W mono-Si	Tedlar®	Pass	91 W 9% 0.8%	2.7

In the comparison of these three modules, the financial impact of the degradation rate of module 1 will result in a greater than 60% reduction in Net Present Value (NPV) of an installation vs. plan. Module 2 failed the wet leakage test and is therefore unsafe to operate after only 12 years.

Module 3, produced with a Tedlar® PVF film-based backsheet, shows low power degradation, maintains electrical integrity and continues to perform as expected in most system owner's financial models.

"This (fielded module program) is a unique initiative, one that provides us and system owners with a significant amount of information... DuPont PV materials have been out in the service environment for well over 30 years. Since we haven't changed the recipes for some of our materials very much, we can learn a lot by understanding how these materials perform over an extended period of time and throughout the module lifetime."

INTERVIEW WITH DR. ALEX Z. BRADLEY, PRINCIPAL INVESTIGATOR, DUPONT PHOTOVOLTAIC SOLUTIONS, PUBLISHED IN *SOLARPRO* MAGAZINE, FEBRUARY/MARCH 2013.

TEDLAR® PVF FILM IS THE INDUSTRY STANDARD FOR BACKSHEETS

Tedlar® PVF film-based backsheet designs have now been in the field for more than 30 years in all kinds of climates (such as desert, tropical, seashore and mountain) and continue to provide critical, long-life protection to the module, safeguarding the system and enabling long-term PV system returns. Tedlar® PVF film offers the optimal balance of properties for weatherability, adhesion and mechanical strength—properties that are required for long module lifetime.

DuPont offers Tedlar® PVF film for two types of backsheet constructions. Both types of backsheet constructions are commercially available and are currently being used in solar PV modules throughout the world. Each type delivers the high performance properties and standards that Tedlar® is known for throughout the industry.

TEDLAR® TPT™ BACKSHEET

Tedlar® PVF film
PET
Tedlar® PVF film

Key features of Tedlar® TPT™

- In harsh climates, best protection from UV, thermal, moisture, mechanical and chemical stresses
- Inner Tedlar® PVF film more stable under heat and UV exposure than single-sided tie layers

TEDLAR® TPE BACKSHEET

Tedlar® PVF film
PET
Tie Layer

Key features of Tedlar® TPE

- Critical outer layer features Tedlar® PVF film that has protected PV modules for more than 30 years
- Offers the best balance of properties in single-sided backsheets for general-purpose applications

KEY PERFORMANCE ISSUES WITH BACKSHEETS

There are three basic categories of backsheets–double-sided fluoropolymers, single-sided fluoropolymers and non-fluoropolymers–and various constructions within each category. Numerous performance issues that can lead to backsheet failure in the field have been observed in non-Tedlar® PVF film-based backsheets.

PVDF-based backsheets lose mechanical properties and become embrittled after 1,000 hours of damp heat exposure. Embrittlement can lead to delamination, cracking and tearing. Yellowing indicates polymer degradation and can lead to other performance issues.

Single-sided THV-based backsheets begin yellowing after 2,000 hours of UV exposure and become embrittled after 1,000 hours of damp heat exposure. Yellowing indicates degradation of the polymers in the backsheet. Embrittlement can lead to delamination, cracking and tearing.

Single-sided FEVE-based backsheets lose adhesion after 1,000 hours of damp heat exposure. Embrittlement can lead to delamination, cracking and tearing. In addition to this problem of embrittlement, users have reported other issues, such as low abrasion resistance.

Polyamide-based backsheets show a significant loss of adhesion and mechanical properties, becoming embrittled after 1,000 hours of damp heat exposure. Loss of adhesion after damp heat exposure indicates a higher risk of delamination. Polyamide-based backsheets also exhibit a significant loss of elongation after 2,000 hours of UV exposure. Loss of elongation can lead to cracking and tearing in use.

PET-based backsheets exhibit significant yellowing and hazing in the outer layer after 1,000 hours of UV exposure. Yellowing and hazing indicate polymer degradation. Significant loss of adhesion after 1,000 hours of damp heat exposure is also observed, indicating a higher risk of delamination and failure in the field.

DUPONT IS YOUR PROVEN PARTNER AND CAN HELP YOU GROW YOUR BRAND AND BUSINESS

DuPont has the broadest materials portfolio in PV and offers six of the eight most critical materials for any given module. Our capabilities extend from materials to modules, which include fundamental PV materials science and cell and module processing, architecture and testing. DuPont is also a PV system owner and PV electricity user, with solar systems at DuPont facilities around the world.

DuPont is a market-driven science company. Our vision is to be the world's most dynamic science company, creating sustainable solutions essential to a better, safer, healthier life for people everywhere. We are applying our science to create sustainable solutions that make a difference in the world.

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+50%

More than half of the world's 400 million panels installed since 1975 have DuPont materials in them.

"Maintaining and improving PV module reliability is critical to investor and consumer trust and confidence. The use of field-proven, high quality materials and best practice manufacturing processes will pay off for owners and investors and enable greater adoption of solar in the U.S. and worldwide."

Rhone Resch, SEIA

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Materials Matter™ for long-life systems and higher returns.

For more information about how DuPont can help you grow your brand and your business, visit photovoltaics.dupont.com

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