Power Your Business

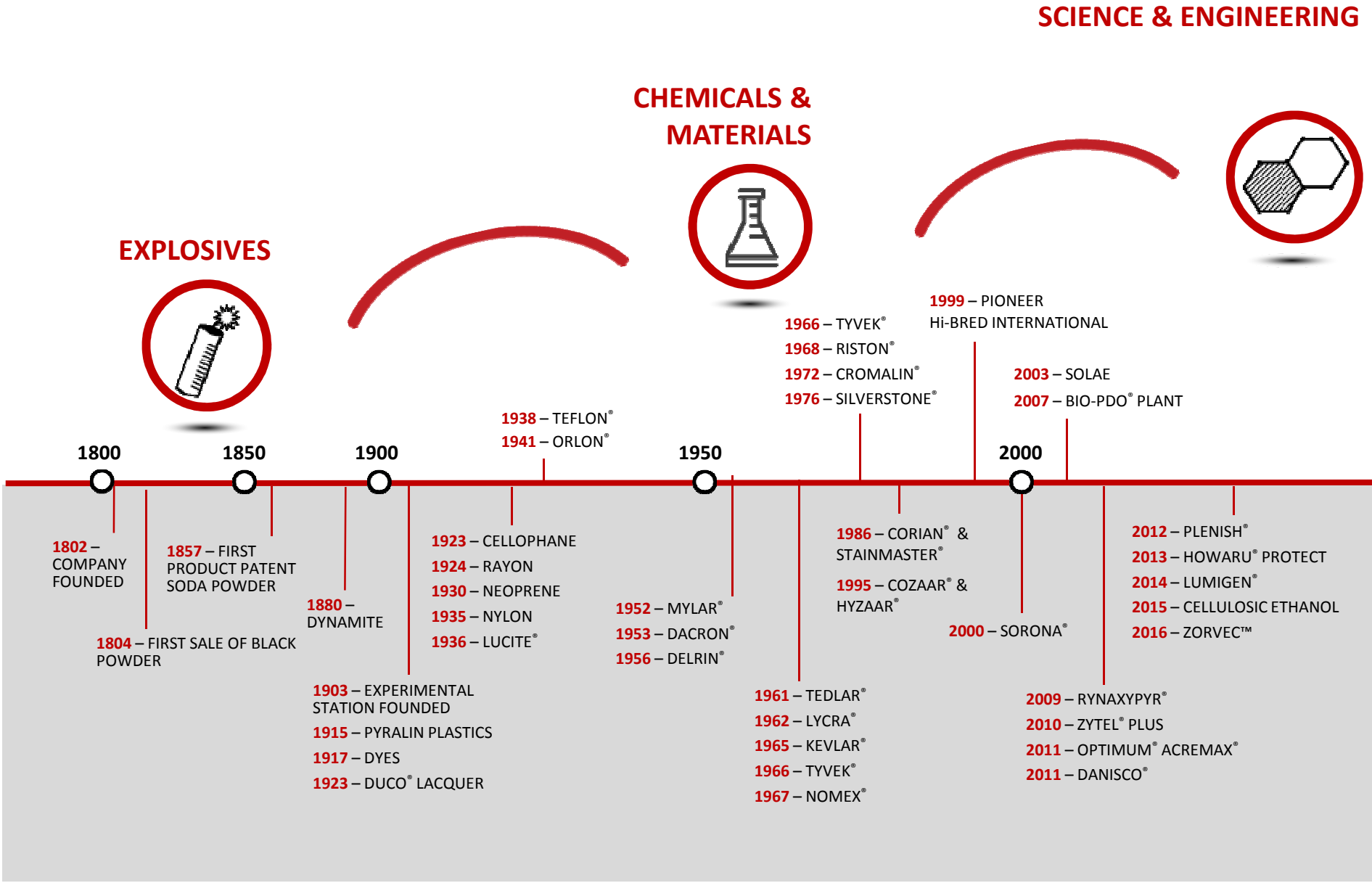
DuPont™ Tedlar® Backsheet Introduction

July 2017

For over 40 years

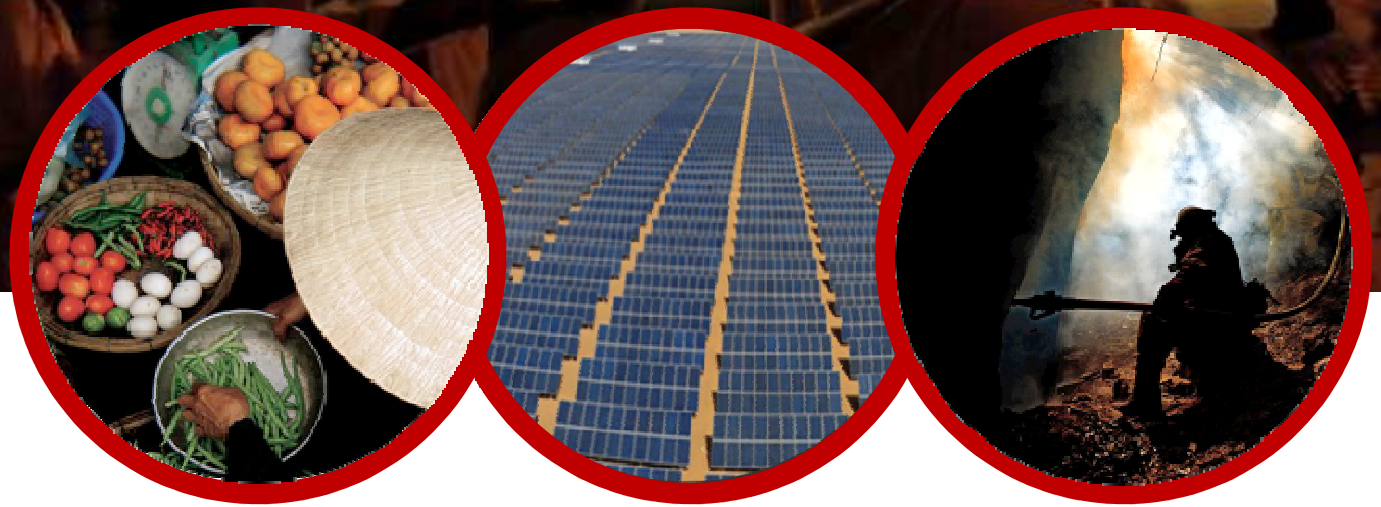
our material innovations have led the photovoltaics industry forward, and helped our clients transform the power of the Sun into power for us all. Today we offer a portfolio of solutions that deliver proven power and lasting value over the long term. Whatever your material needs, you can count on quality DuPont Photovoltaic Solutions to deliver the performance, efficiency and value you require, day after day after day…

Our Evolution Over Two Centuries



Our Areas of Focus

•As the global population climbs up to 9 billion people in 2050, DuPont uses its science-powered innovation to help solve the challenges facing the world, with a focus on:



FOOD **ENERGY** **PROTECTION**

THE DUPONT PORTFOLIO OF INNOVATIVE MATERIALS FOR SOLAR MODULES

CRYSTALLINE SILICON MODULE

A PHOTOVOLTAIC ENCAPSULANTS
DuPont™ PV5400 Series encapsulant sheeting
DuPont™ PV8600 Series encapsulant sheeting

B PHOTOVOLTAIC METALLIZATIONS
DuPont™ Solamet® photovoltaic metallizations

C SILICON DOPING TECHNOLOGIES
DuPont™ Innovalight™ silicon inks

D ELECTRICAL AND STRUCTURAL COMPONENT MATERIALS
DuPont™ Rynite® PET thermoplastic polyester resins
DuPont™ Crastin® PBT polybutylene terephthalate resins

E BACKSHEET MATERIALS
DuPont™ Tedlar® PVF films

DuPont Photovoltaic Materials Portfolio

DuPont™ Solamet®
Metallization Pastes

Driving higher energy conversion efficiency

DuPont™ Tedlar®
PVF Films for Backsheet

Protecting PV modules

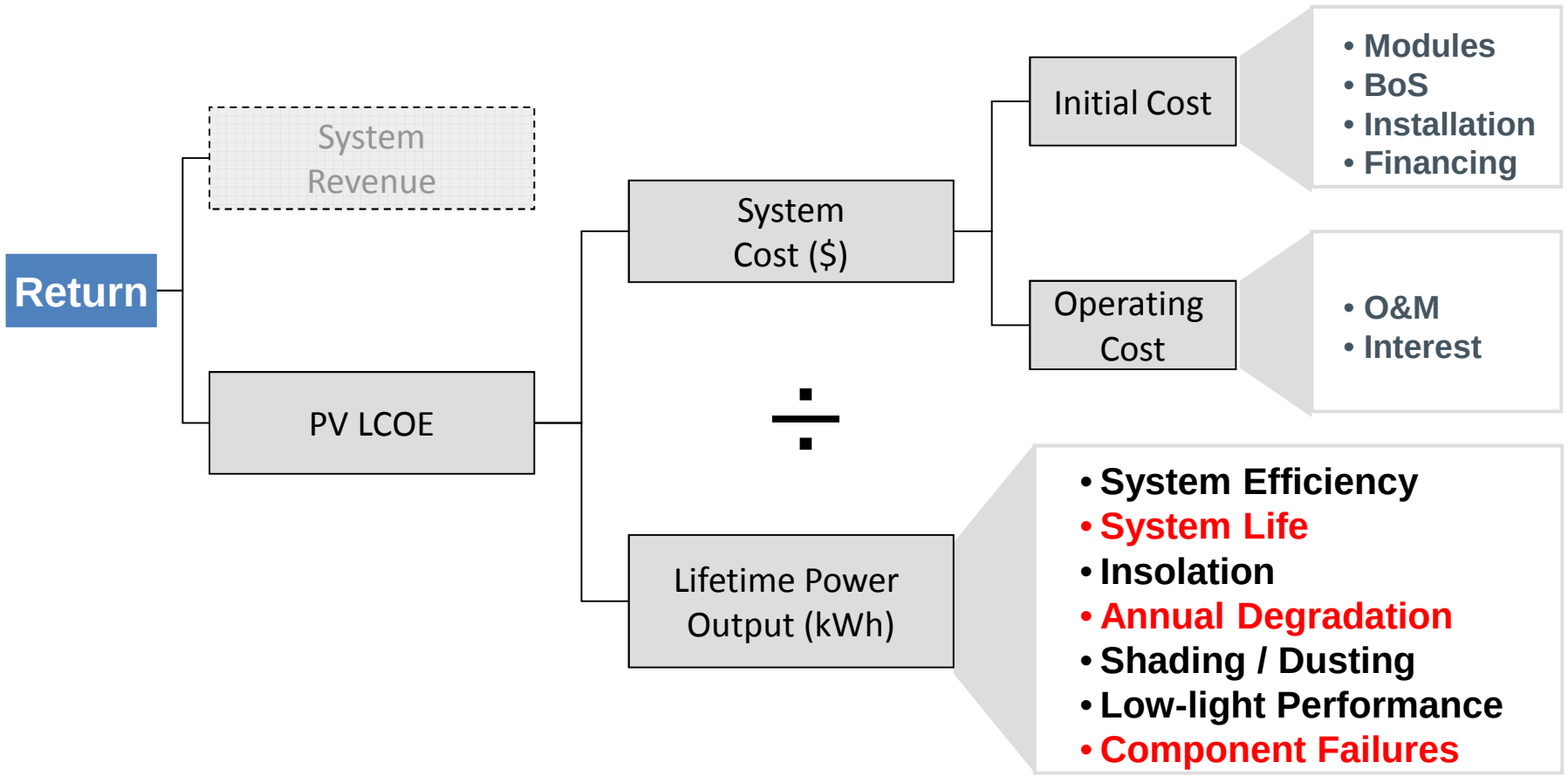
+130
Over the last 9 years, DuPont has introduced more than 130 new Solamet® pastes designed to boost solar panel power output.

+30 YEARS
Tedlar® film is the only backsheet material proven to protect solar panels for 30+ years in all weather conditions.

+50%
More than half of the world's 900 million solar panels installed since 1975 have DuPont materials in them.

+5 TRILLION
DuPont materials have been time-tested in >5 trillion panel-hours of solar installations across the globe since 1975.

Our Goal is to Lowre Levelized Cost of Energy (LCOE)

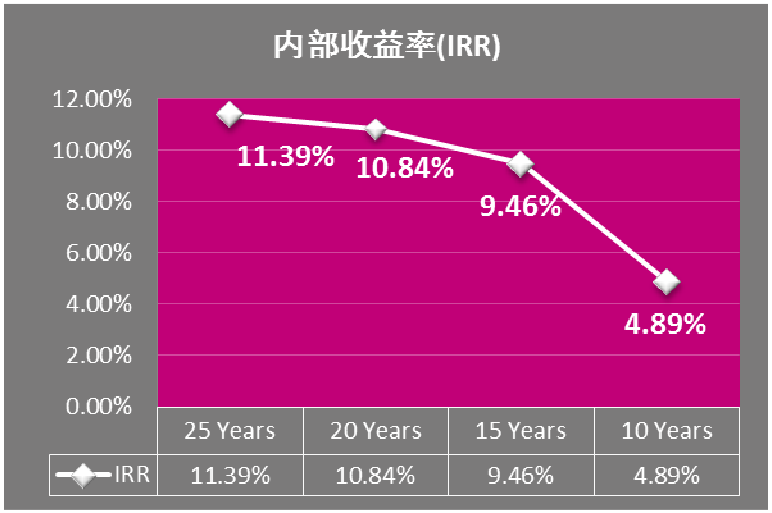


Reducing system lifetime by 5 years can increase the LCOE by ~30%
This is equivalent to an increase in system costs of ~ 35%

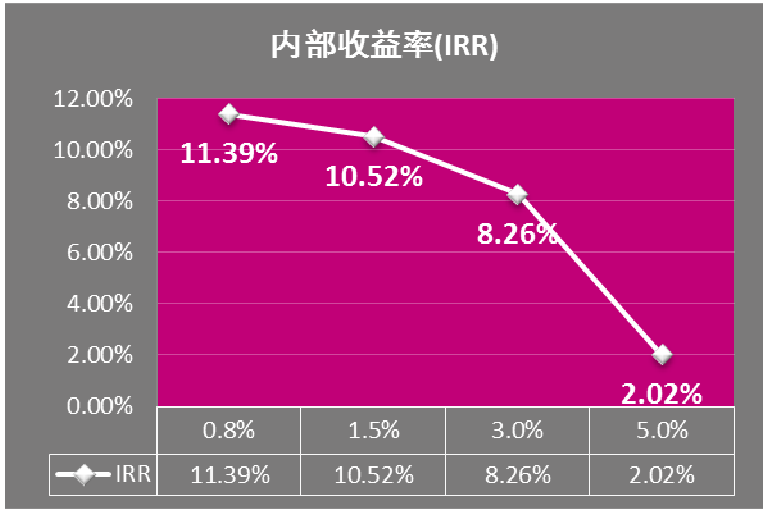
Module Quality is Critical to Financial Return of PV System

- Lifetime and power degradation have significant impact to financial return
- Module quality will impact both lifetime and power degradation

IRR vs Lifetime



IRR vs Annual Power Degradation



Annual Power Degradation = 0.8% **Lifetime = 25 years**

20MW Solar Farm in West China

- Annual Full Utilization Time: 1650 hours
- FIT：0.90 RMB/kWh（Class 1 Region）
- System Cost：9 RMB/kWh

- Loan Ratio：70%
- Interest Rate：7%
- Discount Rate：8%

Is Module a Module?

How to choose PV module?

- **Efficieny**
- **Price**
- **Brand**
- **What else?**

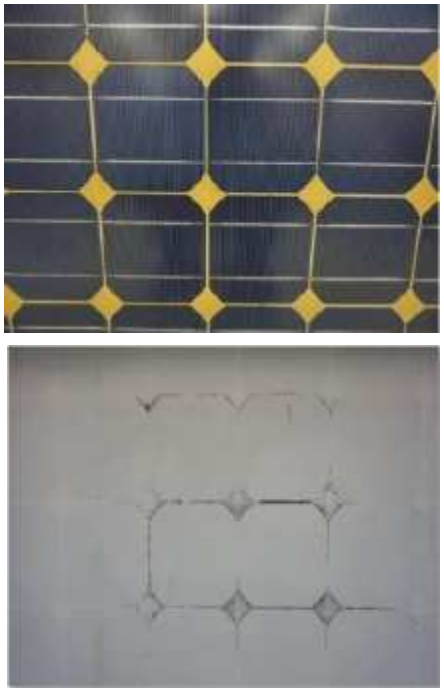
Is Module still Module after 10 Years?

Backsheet Type: PET

- 5 years old installation in Spain
- Yellowing and Cracking
- 32% power loss over 5 years (6.4%/year)
- Some modules failed wet leakage test – Safety Risks

Backsheet Type: PVDF

- 4 years old installation in North America
- Severe cracking and delamination of PVDF film
- 57% of the installed modules impacted



Backsheet Type: PET

- 9 years old installation in West China
- Severe cracking, chalking, peeling and yellowing

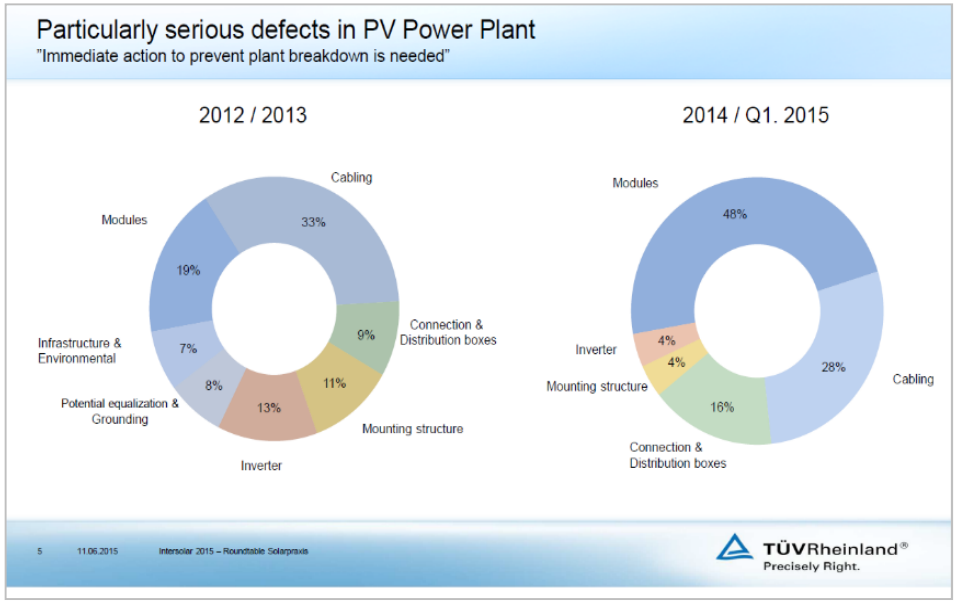
Backsheet Type: Polyamide (PA)

- 5 years old installation in Italy
- Severe cracking and delamination of PA film
- Inverter tripped due to current leakage

More Field Failures in Recent Years

TUV Rheinland 2015 Data

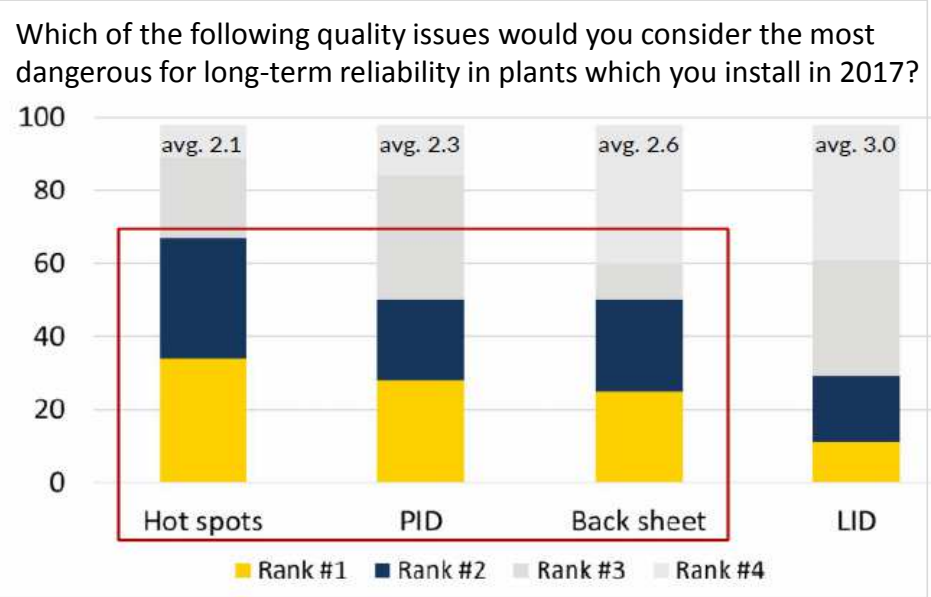
PV module defects increased from **19%** in 2013 to **48%**



[1] TUV Rheinland Intersolar 2015, Roundtable Solarpraxis

PV Magazine 2017 Quality Survey

Backsheet is among top 3 quality issues



[1] PV Magazine Intersolar 2017, Quality Forum

GW Level Field Module Failure due to Backsheet Cracking

Europe

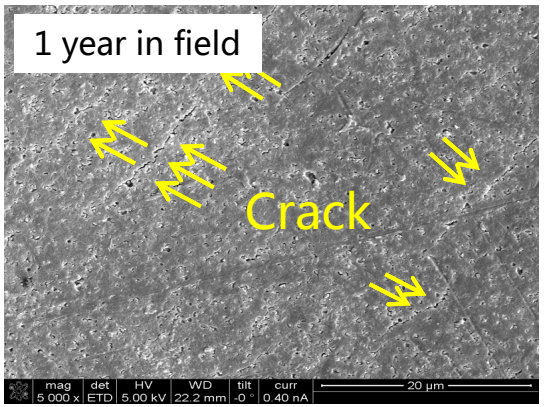
- Installed in 2012, inspected in 2015
- Backsheet cracking and delamination and corrosion as water ingression

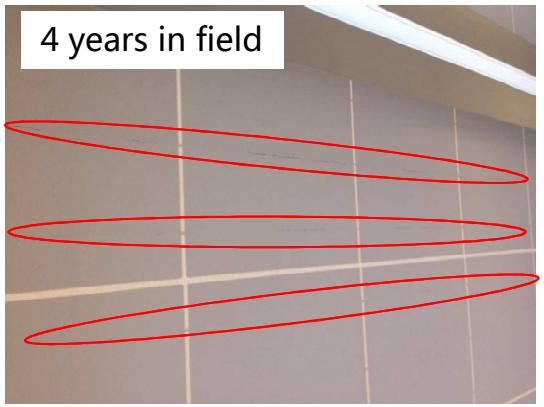
West China

- Solar farm installed in 2012
- Micro-cracks on backsheet found in 2013
- Cracks of backsheet found in 2016

East China

- 100MW fishpond application, installed in 2013
- Around 10% less power generation than expected in 2nd year in field
- 49.4% power degradation of sample module as PID
- Backsheet cracking





The quality issue were not discovered by IEC qualification tests and extended IEC tests

4 Years in North America
PVDF Backsheet
Severe Cracking and Delamination (57%)

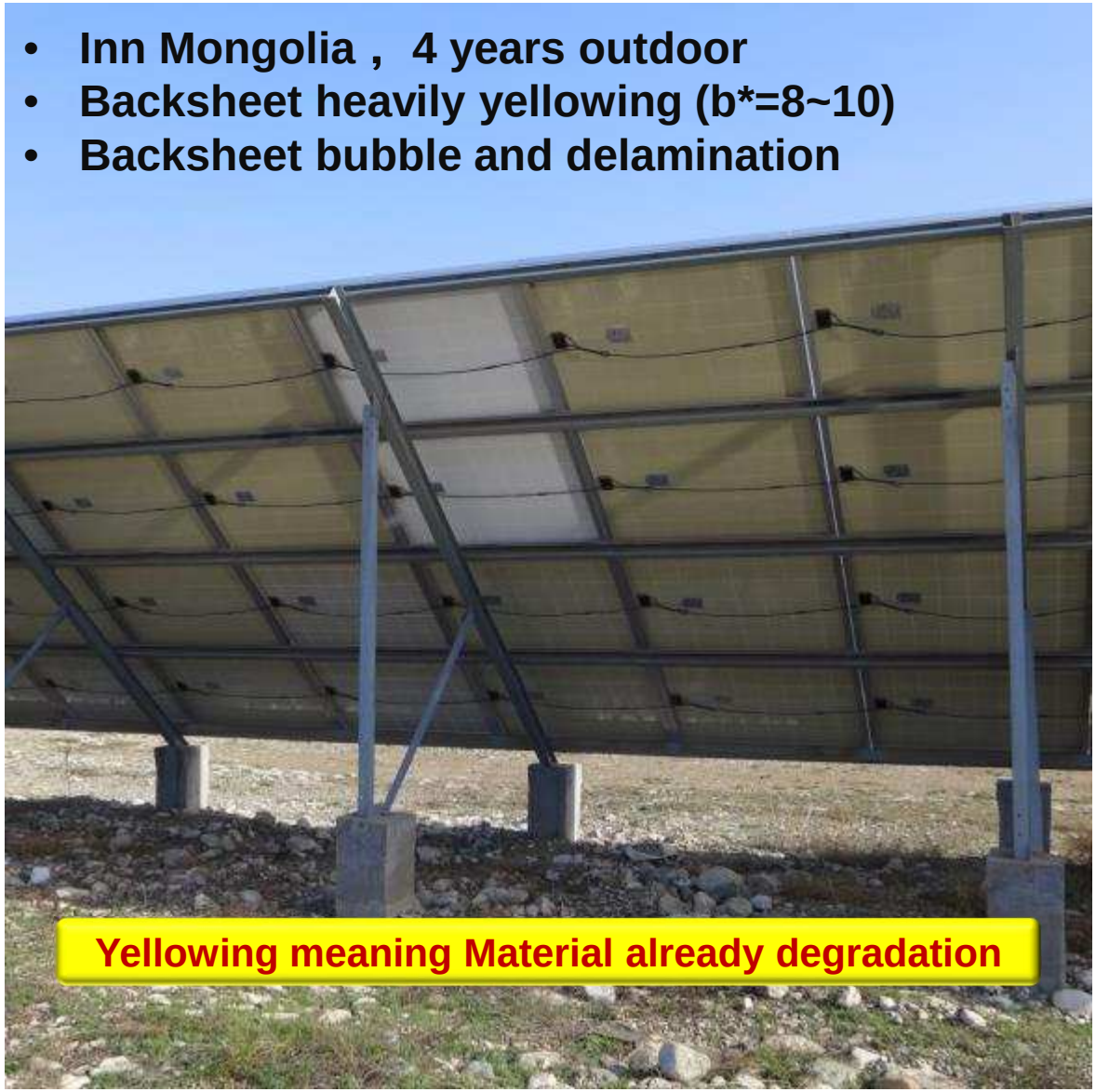
Spain 2.3MW Polyester-Based Backsheets-Severe Cracking After 4 Years

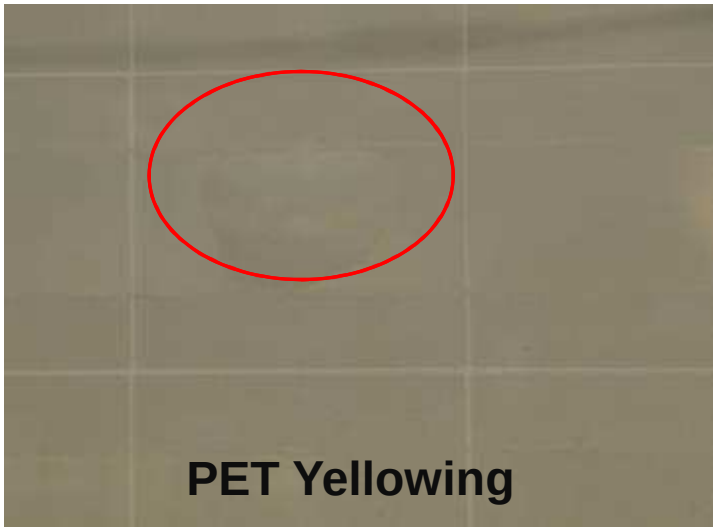
- 4 years old, 2.3 MW field located in Spain with two module types
- Based on sample observation, all polyester-based backsheets in this field showed cracking along the busbar ribbons
- Some modules failed wet leakage testing
- Owner could not obtain replacement panels

Cracking can lead to module failure and a safety hazard

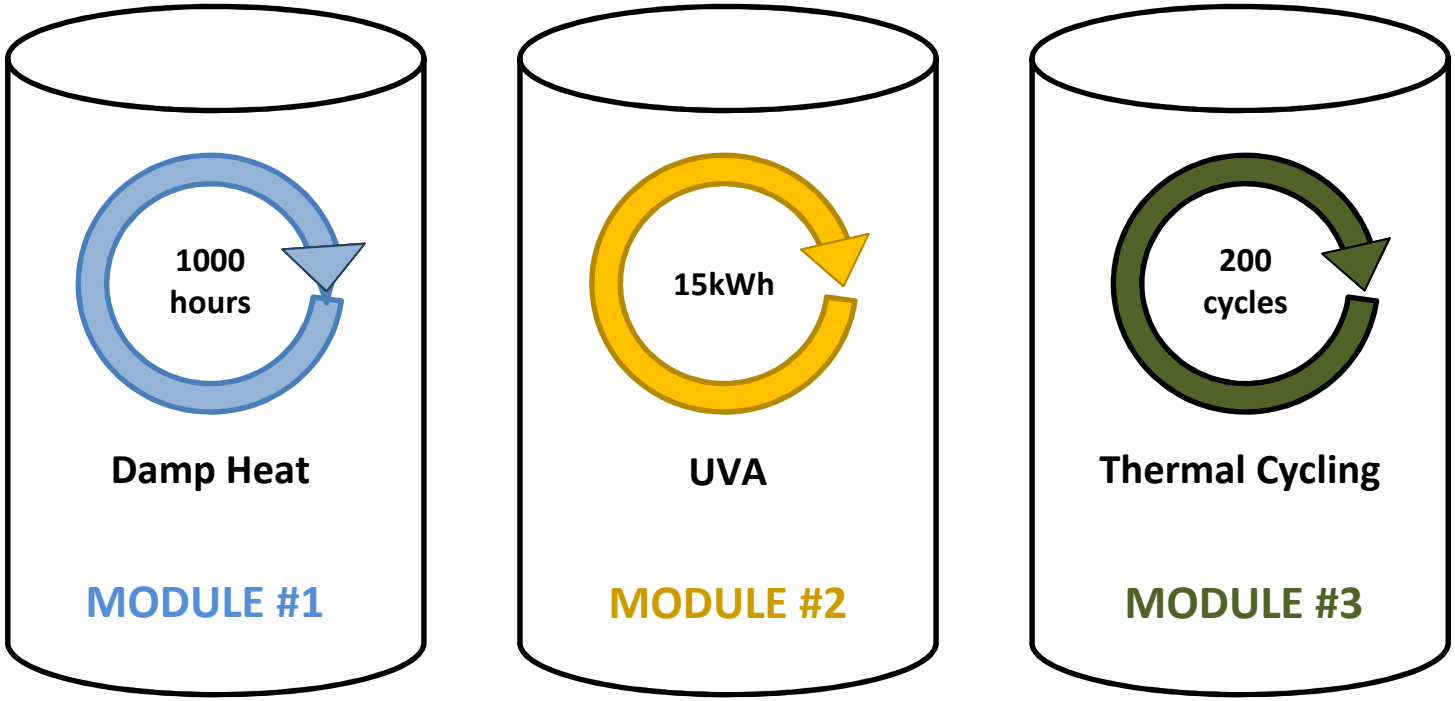
Field Failure Case Study: PET Heavily Yellowing and Delamination

- Inn Mongolia ， 4 years outdoor
- Backsheet heavily yellowing (b*=8~10)
- Backsheet bubble and delamination



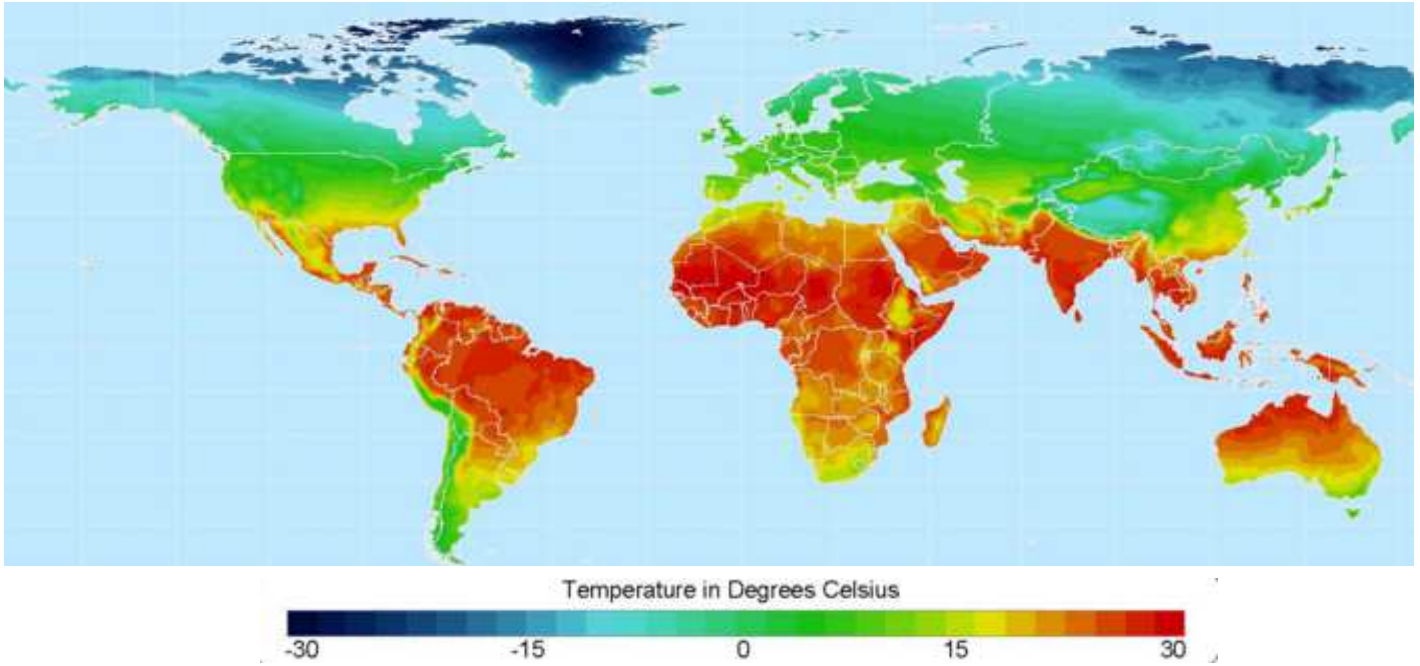


Root Cause 1: Current IEC Testing Method- Single Aging Stress Tests



Current lab testing standards are <u>not</u> rigorous enough to predict the durability of protective materials.

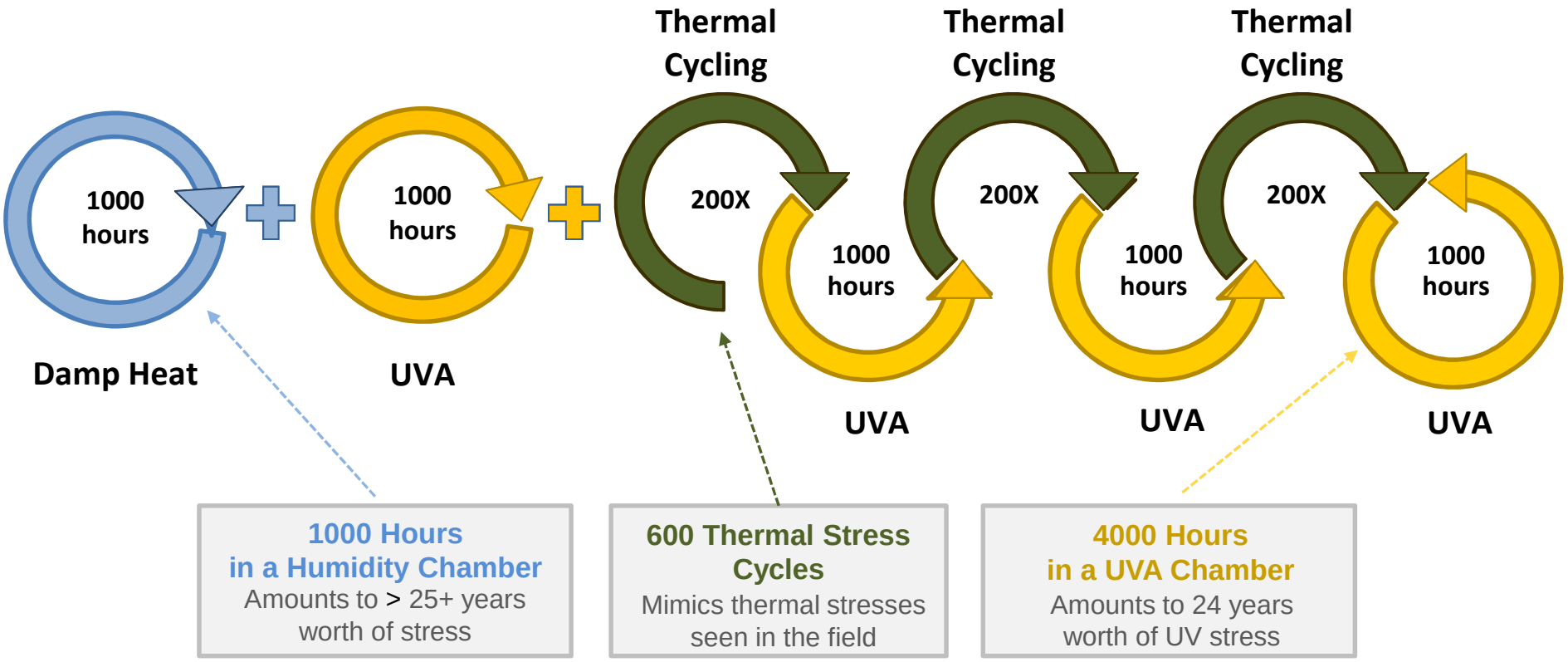
Root Cause 2: Insufficient UV doses and Thermal Cycles



	DESERT	TROPICAL	TEMPERATE
Annual UV (kWh/m2) **(source: Atlas)**	**92**	**79**	**57**
25 Year UV Exposure to Back of Module @12% albedo (kWh/m^2)	**275**	**235**	**171**
IEC	**15kWh/m2 pre-conditioning, can lead to no exposure on backsheet**		
UVA Exposure Level to Simulate 25 Years (hrs)	**4230**	**3630**	**2630**

Source: Wisconsin University

The Solution: Module Accelerated Sequential Testing (MAST)



Repeated sequential stress mimics field degradation not detected by single tests and current industry standards

Typical backsheets types and materials

Tedlar® backsheet	PVDF (“K”) backsheet	Fluoro coating backsheet	Polyester backsheet
TPT Backsheet	**KPK / 2-sided PVDF Backsheet**	**2-sided Coating Backsheet**	**PET Backsheet**
Tedlar® PVF film	PVDF film	FEVE Coating	HPET
PET	PET	PET	HPET
Tedlar® PVF film	PVDF film	FEVE Coating	Tie layer
TPX Backsheet	**KPX / 1-sided PVDF Backsheet**	**1-sided Coating Backsheet**	**PET Backsheet**
Tedlar® PVF film	PVDF film	FEVE Coating	HPET
PET	PET	PET	Tie layer
Tie Layer	Tie layer	Tie layer	

DuPont Fluoropolymers Development History

Perfluorinated 全氟化塑料

Partially Fluorinated 部分氟化塑料

Teflon® PTFE 聚四氟乙烯 (1938)

PVDF 聚偏氟乙烯 (1948)

Tedlar® PVF 聚氟乙烯 (1949)

Teflon® FEP 聚全氟乙丙烯 (1960)

Nafion® (1962)

ECTFE 乙烯和三氟氯乙烯共聚物 (1970)

Teflon® PFA (1973)

Tefzel® ETFE 乙烯和四氟乙烯共聚物 (1972)

Teflon® AF (1989)

Process G (1999)

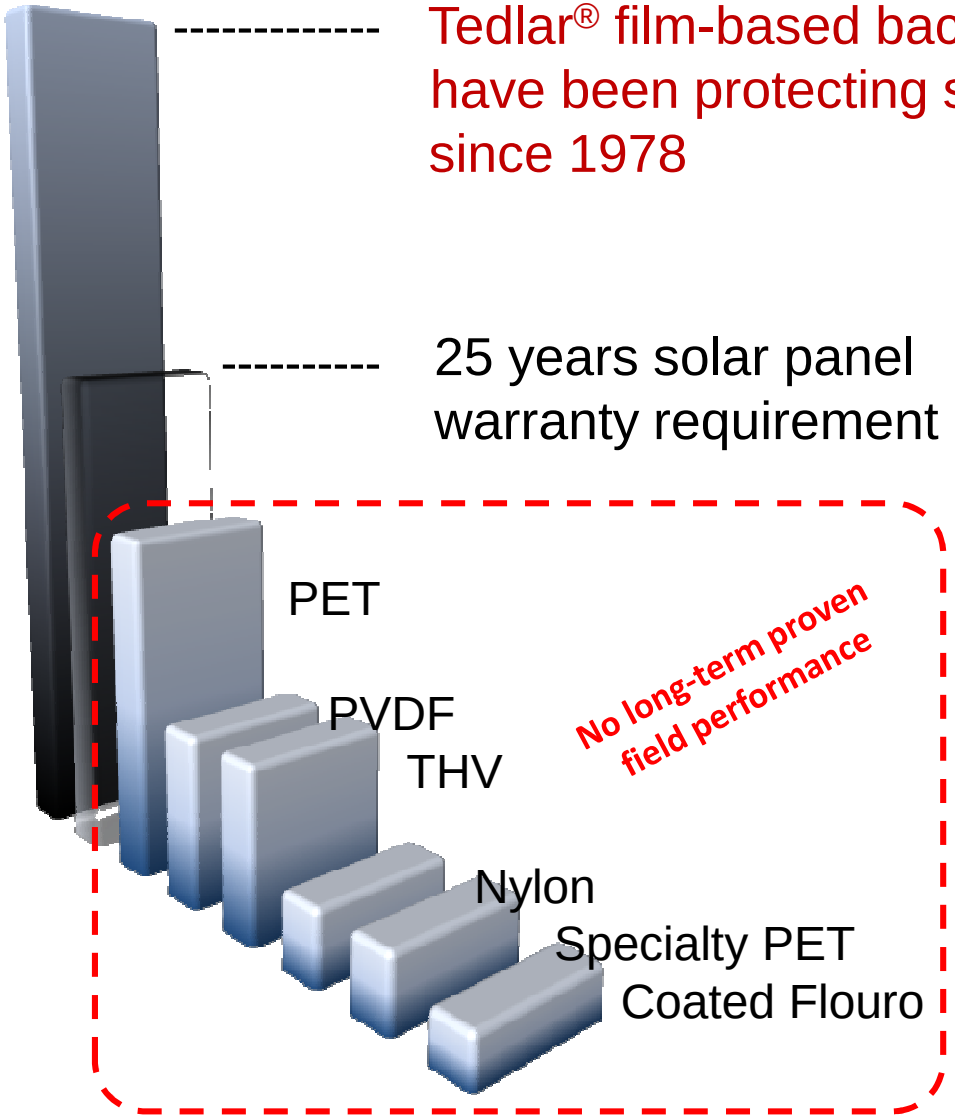
Teflon® PFA HP Plus(2000)

Teflon® PFA Low Permeation HP Plus(2003)

DUPONT 200 YEARS

DuPont Pioneered Fluoropolymer Technology

DuPont™ Tedlar® PVF Film Has 30+ Years of Proven Field Performance



Source: DuPont, various

Powering Reliably Since 1982

Summary of Tedlar® vs. PVDF-Based Backsheets

Tedlar® PVF Film

- Consistent, excellent performance from DuPont
- No plasticizer
- Tough film
- High surface tension
- Durable adhesion
- Good weatherability
- No reaction to any major solvent

PVDF Films

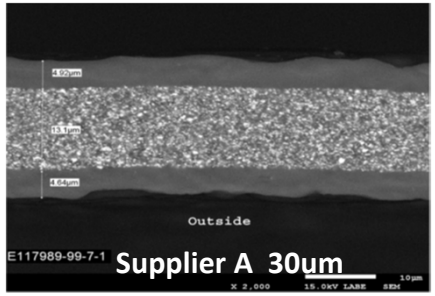
- Variable formulations and performance
- 30% to 50% acrylic, results in plasticizer migration
- Film degradation due to acrylic aging
- Poor tear resistance
- Low and variable surface tension
- Poor resistance to damp heat
- Poor resistance to ammonia and strong solvents

Tedlar® PVF films outperform PVDF films, offering consistent stability under various tests

PVDF film suppliers have different constructions and additives

Supplier A
30um

- 5u PVDF
- 20u PVDF+Acrylic +TiO2
- 5u PVDF

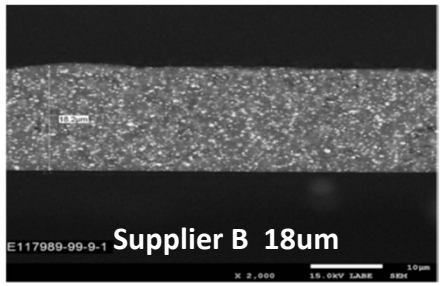


Supplier A
25um

- PVDF
- PVDF+Acrylic +TiO2
- PVDF

Supplier B
24um

- PVDF+Acrylic +TiO2

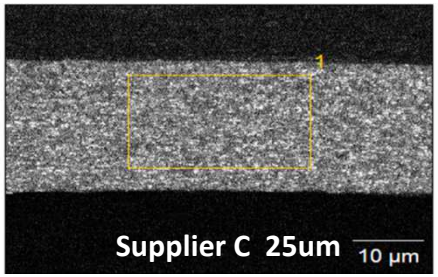


Supplier B
18um

- PVDF+Acrylic +TiO2

Supplier C
25um

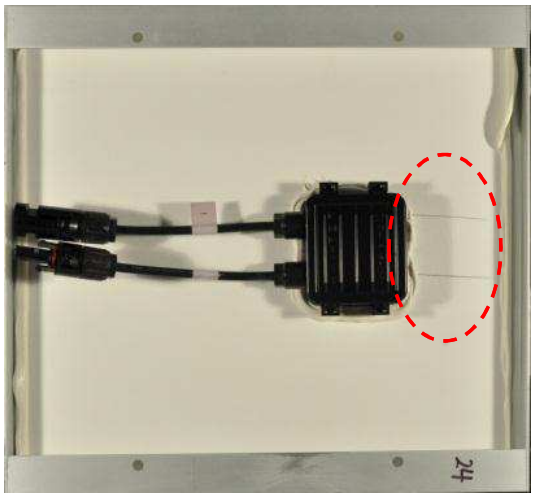
- PVDF+Acrylic +TiO2



Additives and different constructions result in inconsistent performance. The polymer in Tedlar® PVF film is not blended with any other polymer.

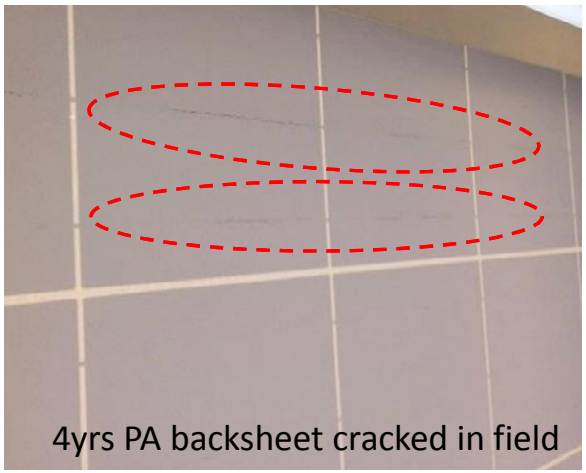
Sequential Aging Test Shows Consistent Results with Field Failures

1x Damp Heat 1000 hours 3X(Thermal cycling, 200X)

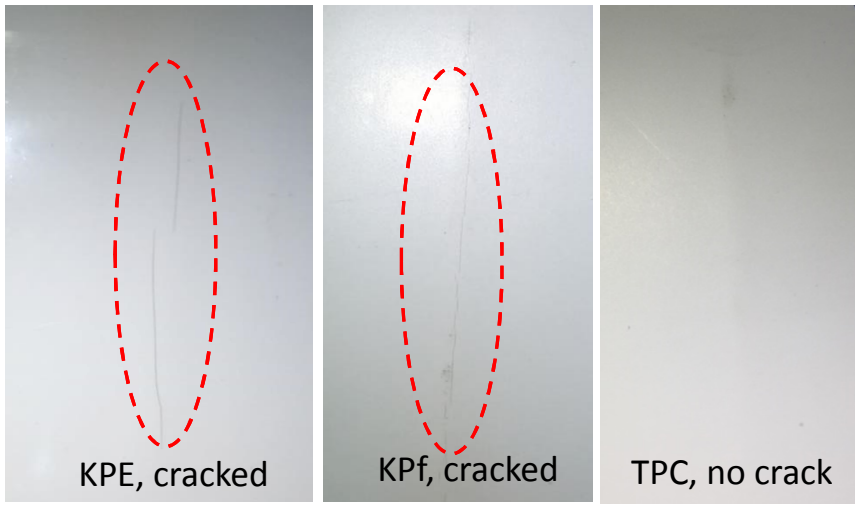


PA backsheet shows cracks after DH1000 +TC200 test similar to cracks in field

Cracks in 1s PVDF backsheet (KPf) after DH1000+TC400 similar to cracks observed in the field



4yrs PA backsheet cracked in field



KPE, cracked | KPf, cracked | TPC, no crack

Cracks in KPE and KPf along ribbon wires after TC600 similar to cracks observed in the field

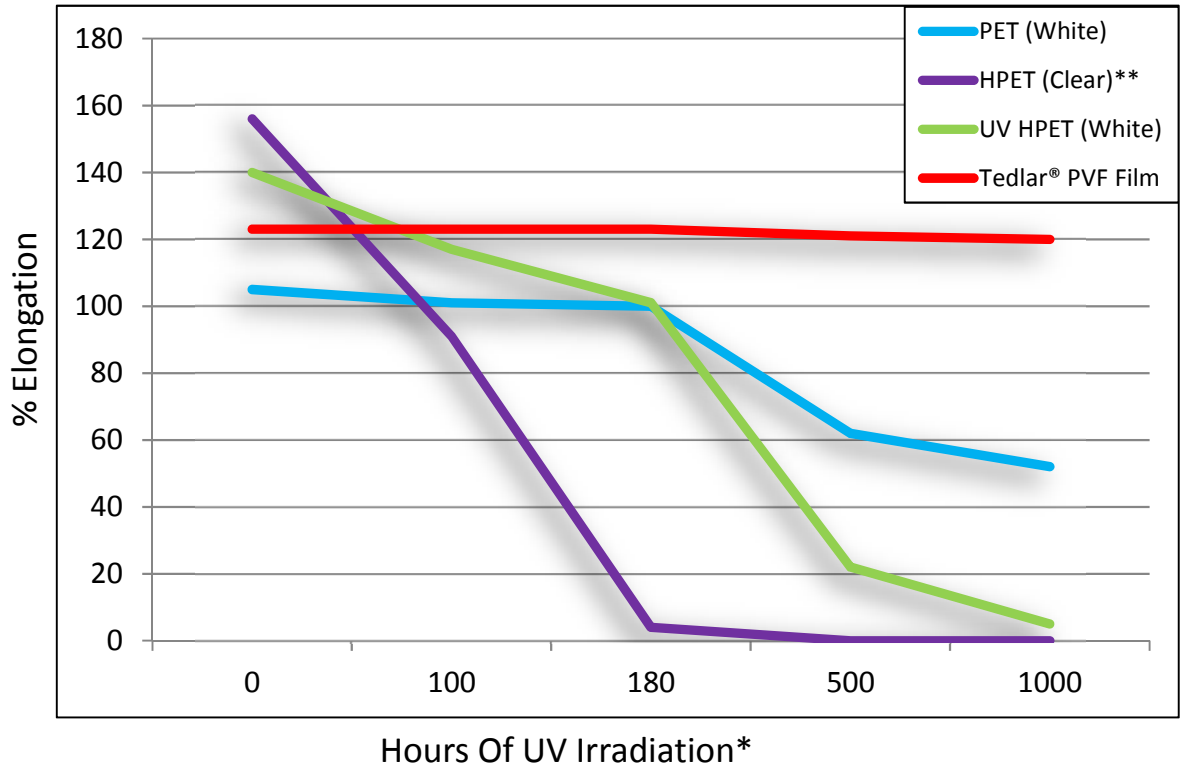
Summary of Tedlar® vs. PET-Based Backsheets

- PET film is inherently unstable to outdoor environmental factors vs. Tedlar®. That is why Tedlar® has been protecting the PET core in backsheets of solar modules for over 30 years.

- Accelerated aging tests that more accurately represent real world conditions, show PET-based backsheets are at increased risk for yellowing, cracking, delamination and module failure vs. Tedlar® based backsheets

- Analysis of actual fielded modules, many less than 10 years old, confirm PET-based backsheets yellowing, cracking and risk power loss and module failure.

Tedlar® Film Provides Superior Protection From The Sun's Radiation Effect On Mechanical Properties vs. PET Film



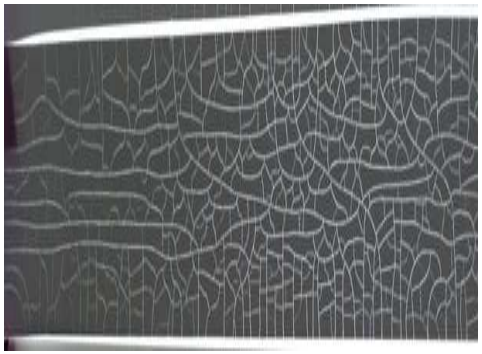
PET films are inherently not a good choice for backsheet protection; they will loose their mechanical properties and degrade quickly.

*Irradiation: 120 W/m^2, 300-400nm, 103°C BPT, 50%RH

** HPET=Hydrolysis resistant PET

Inner Layer of Hydrolysis-resistant PET-Based Backsheet Cracks After 9.5 Year Equivalent UV Exposure From Glass Side

HPET-based backsheet 1



HPET -based Backsheet 2

Tedlar® PVF-TPE backsheet

Frontside UV reaches the inner layer of the backsheet and weakens the primer layer of these PET backsheets, creating a delamination risk. This risk increases with new UV-transmissive EVA encapsulants, which transmit greater UV doses to the backsheet inner layer

*UV expose backsheet inner layer through Glass/2EVA/FEP filter/Backsheet
UV dosage is equivalent of 9.5 years temperate climate front side exposure. 1.5kW/m^2 metal halide exposure, 360 hours, 540 kWhr/m^2

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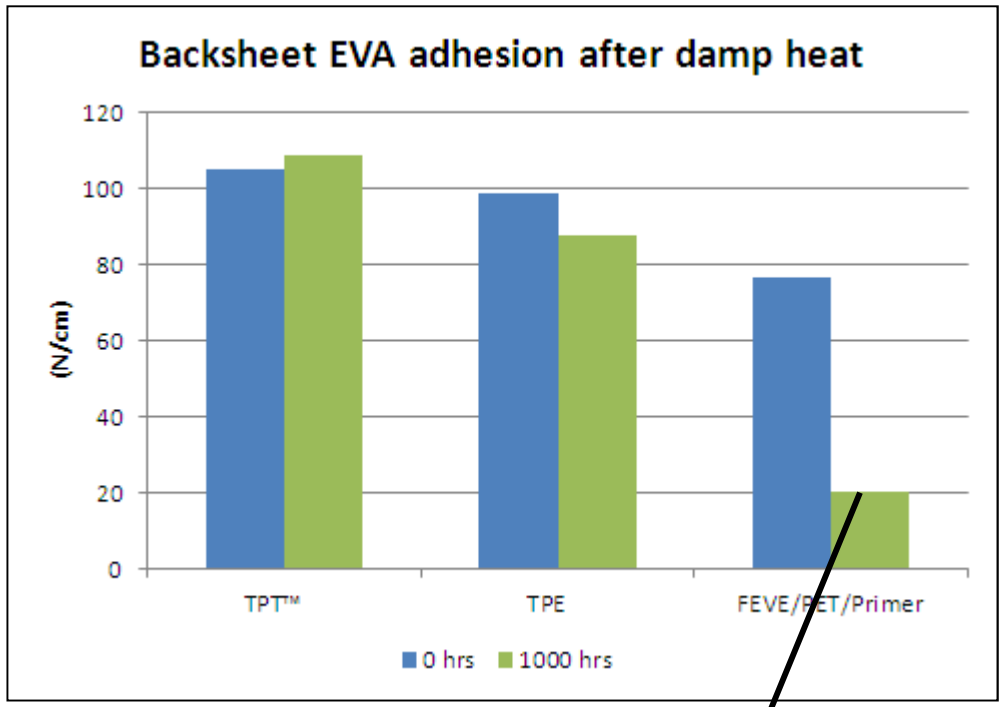
Summary of Tedlar® vs. FEVE-Based Backsheets

- Accelerated test results show Tedlar® PVF film-based backsheets demonstrated more reliable performance than FEVE-based backsheets

Tests	Observations
Damp heat aging test	FEVE-based backsheets showed greater loss of adhesion and yellowing than Tedlar®-based backsheets.
Accelerated UV aging test	FEVE-based backsheets showed cracking while no cracking was observed in Tedlar®-based backsheets.
Falling sand test	FEVE protective coating was removed with less sand volume than Tedlar®-based backsheets.
Coefficient of thermal expansion (CTE)	FEVE-based backsheets have higher CTE and greater risk of cracking than Tedlar®-based backsheets.

- Analysis of fielded modules less than 5 years old confirmed FEVE-based backsheets crack and delaminate, consistent with accelerated test results.

FEVE-Based Backsheets Losing Adhesion After 1000h Damp Heat, Many User Reports of Issues



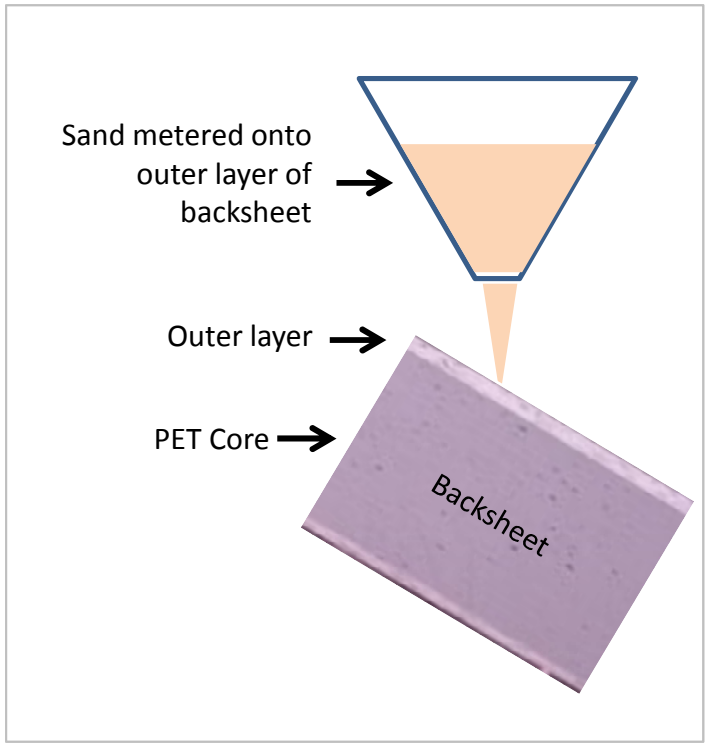
Other Issues

- Embrittlement, cracking & flaking observed in fielded module backsheets
- E-Layer cracking after airside Xenon exposure
- Multiple users report that FEVE coatings are easily scratched and have low abrasion resistance
- Multiple user reports of low adhesion to the j-box
- Users report poor EVA adhesion and delamination issues in the field

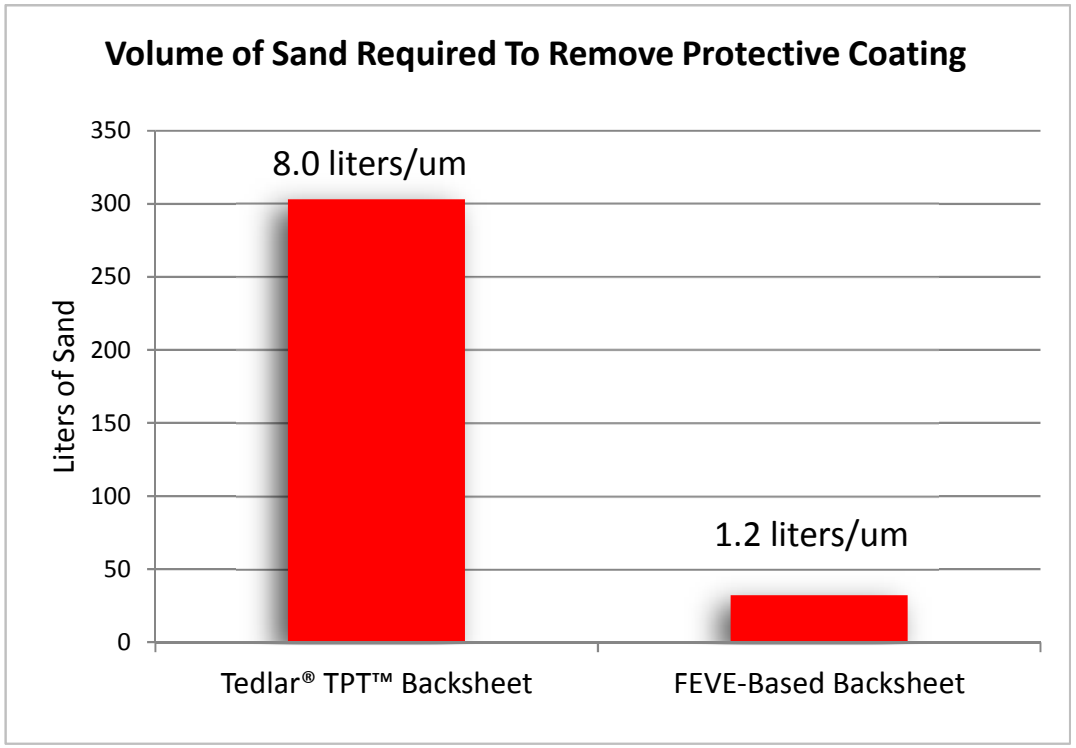
- FEVE-based backsheet lost over 70% of adhesion after damp heat exposure
- Loss of adhesion indicates a higher risk of delamination
- Cracked tie layers can lead to tearing, cracking and delamination in the field

FEVE-Based backsheets Underperform Tedlar®-Based Backsheets in Sand Abrasion Test

TEST METHOD[1]



RESULTS



Severe abrasion or deep scratching can compromise the backsheet, risking safety and module failure

[1]Modified ASTM D968 test method used to remove outer coating exposing PET Core layer.

DuPont Field Study Survey (2016 Summary)

- **Surveyed: >190 global solar installations in NA, EU & AP**
- **45 module manufacturers, 450 MW, 1,900,000 modules**
- **Range of Exposure: Newly commissioned modules to 30 years in the service environment**

Backsheet Based:	Tedlar®	PVDF	PET	FEVE
Profile of Sample Size	76 Installations 77.7 MW 368K Modules	35 Installations 166 MW 660K Modules	34 Installations 86.3 MW 375K Modules	10 Installations 44 MW 194K Modules
Age Range	2 - 27 years	1 - 5 years	2 - 15 years	3 - 5 years
Percentage BS Defects on MW Basis	**0.06%** (45kW/78MW)	**7%** (12MW/166MW)	**8.6%** (8MW/86MW)	**4.5%** (2MW/44MW)
Types of Defects Observed	Delamination Cracking*	Frontside Yellowing Cracking	Frontside or Backside Yellowing Delamination / Cracking	Backside Yellowing Delamination / Cracking

* Only in 4 mil single layer

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