Photovoltaic & Advanced Materials

Sept 20 2018

# Field Evaluation of Backsheet Quality

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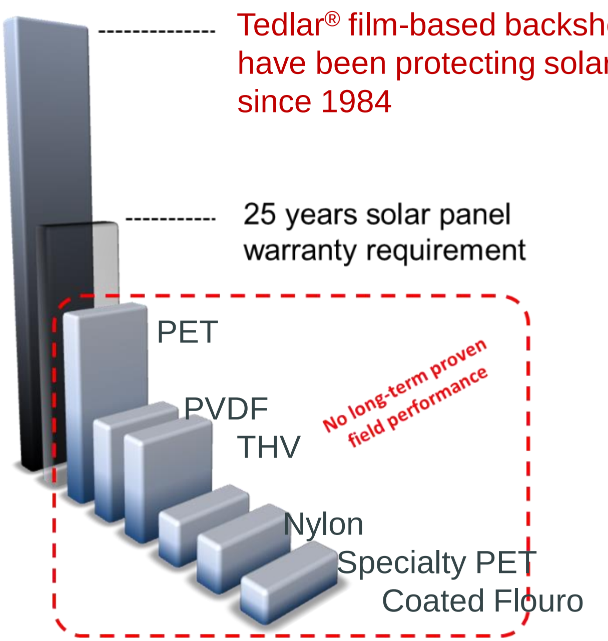
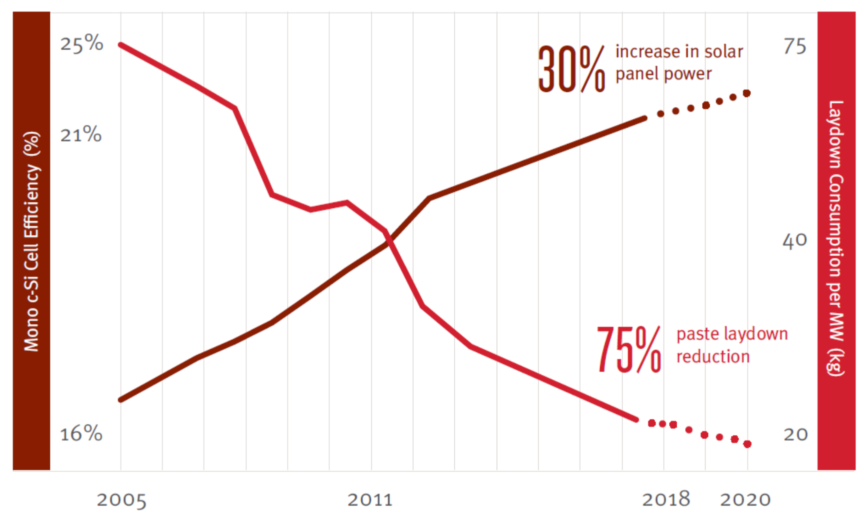
DuPont Photovoltaic Solutions

# DuPont Photovoltaic Solutions Has More Over 40 Years Experience in PV - From Materials to Power Generation

**DuPont Tedlar® PVF film is the ONLY backsheet material with 30+ Years field proven record**

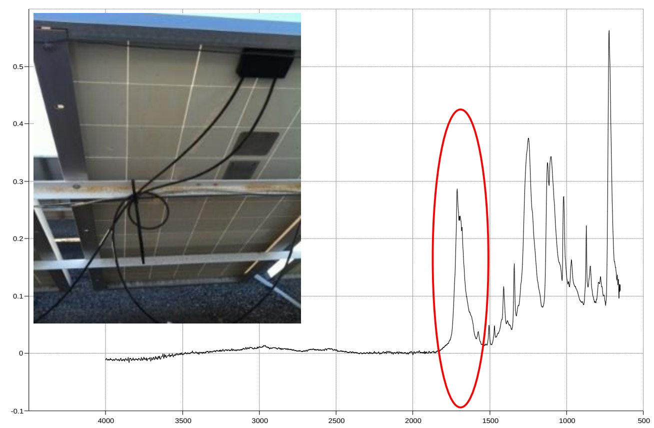



**DuPont Solamet® Metallization Pastes driving higher energy conversion efficiency**



# DuPont Collaborates with Downstream Stakeholders to Assess PV Systems, Modules, and Materials in the Service Environment

- Inspected ~400 solar installations in NA, EU and AP by 2018
- Including > 1GW & 4.2 million solar panels
- Age of 0-30+yrs

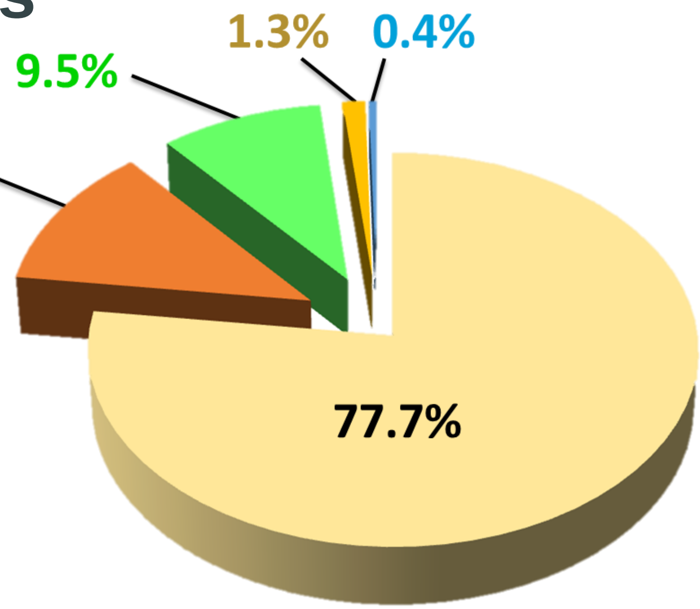



- Multi-step Inspection Protocol
  - ◆ Documentation of location, age, climate, module, energy production, visual imaging, thermal imaging, IR spectroscopy,
  - ◆ Defect categorization
- Defect Analysis (FMEA) and Statistics

# DuPont 2018 Field Analysis and Database - Overview

## 2018 Analysis

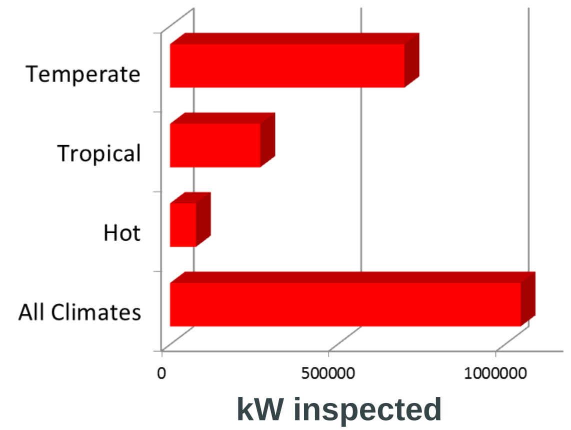
**1+ GW inspected**




cell
backsheet
encapsulant
others

| | 2018 |
|---|---|
| Installations | 275 |
| Number of panels | 4,234,324 |
| Average age (years) | 3.3 |
| GW | **1.047** |

Climate sample sizes 2018

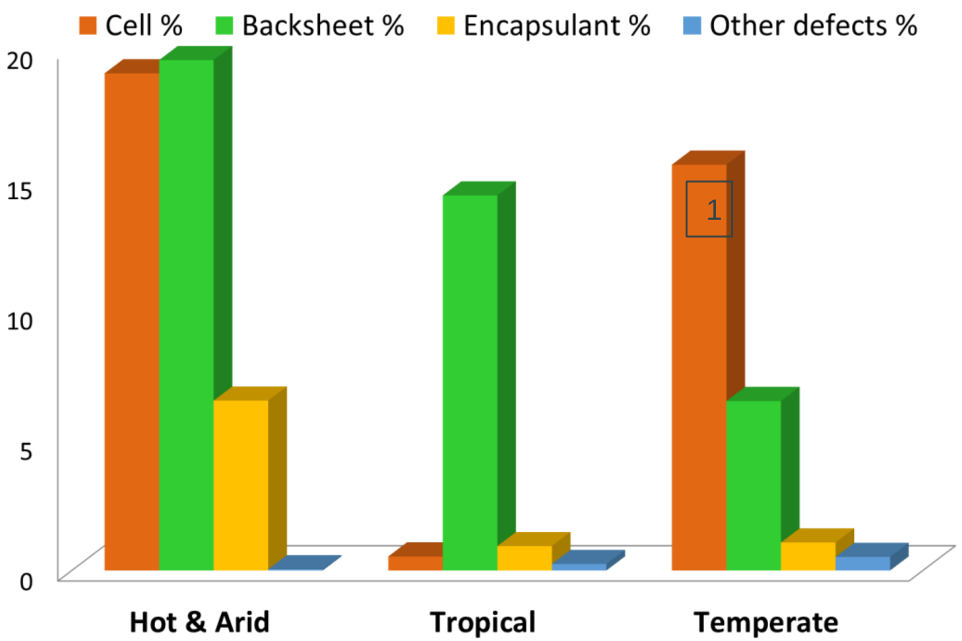


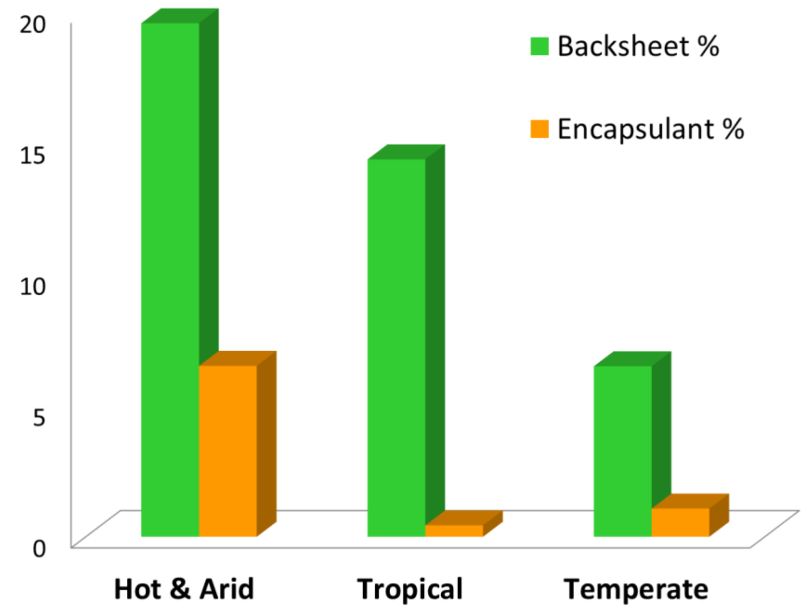

Statistical Analysis and Case Studies

Data size more than doubled from 2016 to 1+ GW

- All defects 22.3%
- Cell related defects 12%
- Backsheet defects 9.5%

# Analysis of Climate on Defects Rates



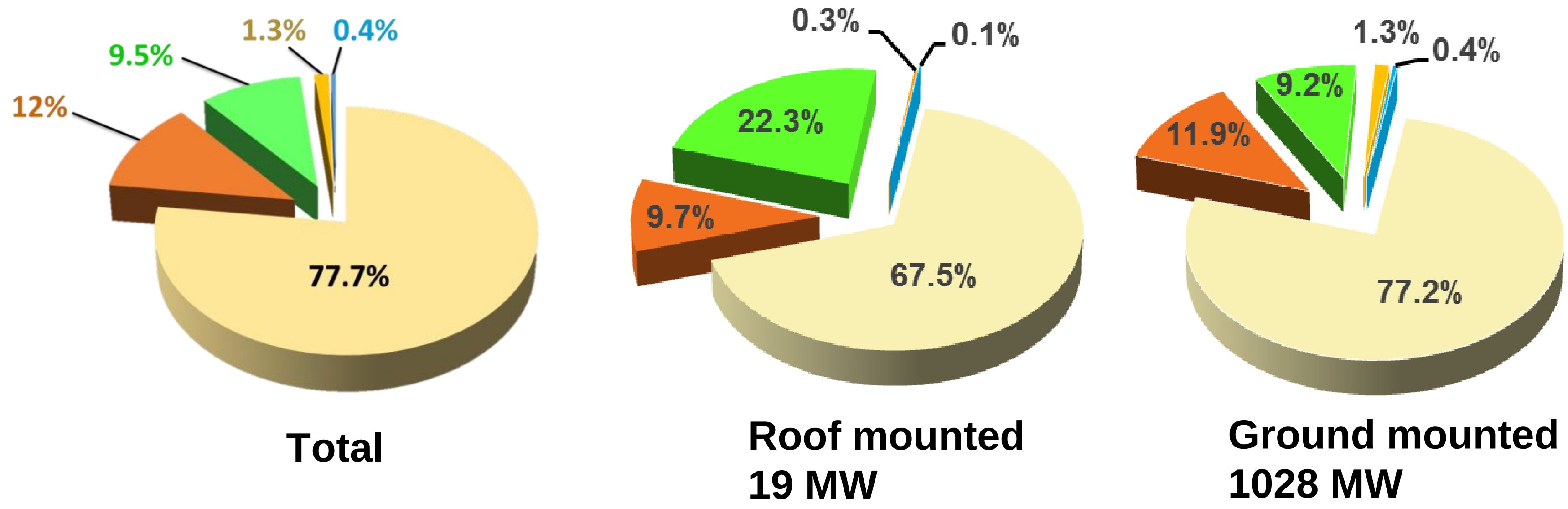

**Cell and Metalization show less or small effect with Climate**

**Polymer Components (Backsheet and EVA) show stronger trend**

- Hot arid > Tropical > Temperate
- Use Defect Rates to determine "harshness" of Climates?
- Dominant factors are likely Temperature and UV

[1] Temperate cell defects are dominated by Snail Trails, likely due to sampling

# Defect Rates for Roof vs. Ground Mounted Systems




**Overall Higher defect rates for roof vs ground installations**

- Backsheet defects are > 2.5X higher on roof systems
- Cell defects are similar for Roof and Ground

**Differences are likely due to higher temperatures for roof systems**

- Roof Systems are typically 15 °C higher than Ground Mounted[1]
- This trend with temperature is similar to the effect seen in climates

1 Creep in Photovoltaic Modules: Examining the Stability of Polymeric Materials and Components (2010) 35th IEEE Photovoltaic Specialists Conference (PVSC '10) Honolulu, David C. Miller, Michael Kempe

# Analysis of Defect Rate vs. Backsheet Materials


**Backsheet defects increased by 27% vs 2016 Analysis**

- **Polyamide increased by 18%**
- **PVDF increased by 51%**
- **Glass / Glass starting to show up**
- **Tedlar rate unchanged**

# Tedlar® PVF-based backsheets in the field: Low power loss and no degradation

SUPSI Switzerland 1982

0.4% annual power loss


Nara, Japan, 1983

0.2% annual power loss

SMUD USA 1984

0.9% annual power loss

SYSU China 1985

0.4% annual power loss

Mont Soleil, Switz. 1992

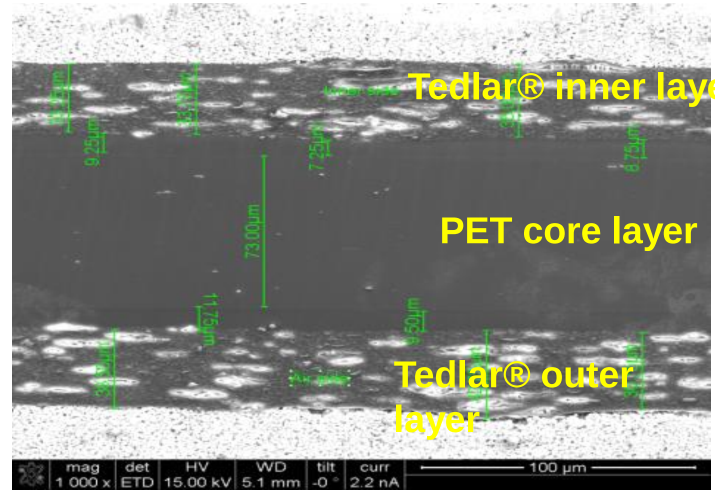
0.3% annual power loss

Beijing 1999

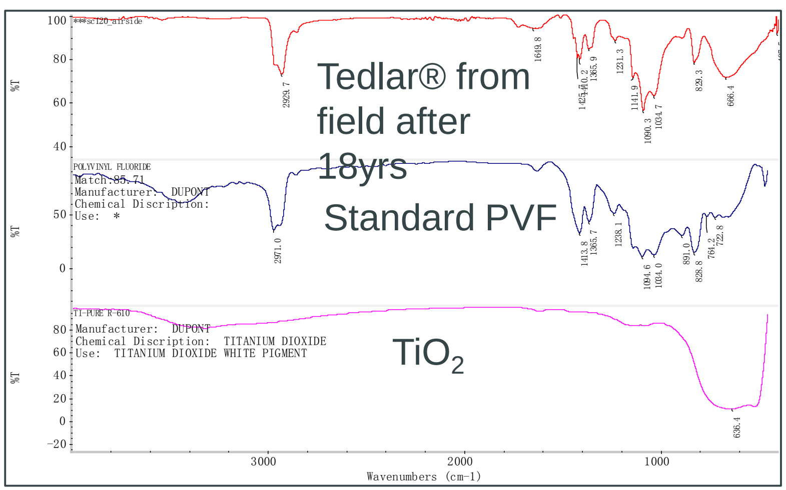
0.7% annual power loss

# <u>Tedlar® Field Case:</u> 18yrs Tedlar® TPT Rooftop Solar Farm in Beijing Maintains Good Appearance and Thickness Stability

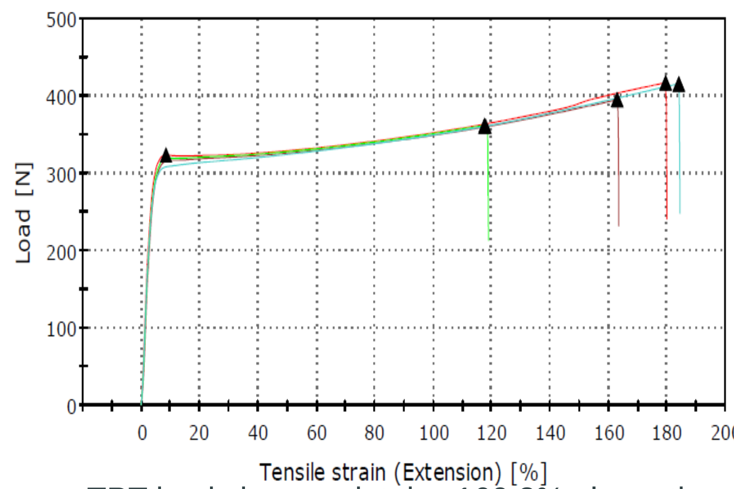
18yrs field module with TPT backsheet shows low power loss rate (0.7%/yr)




Low Tedlar® thickness reduction in both air side and inner side Tedlar® film (0.22um/year)




Tedlar® film shows no degradation after 18yrs field service

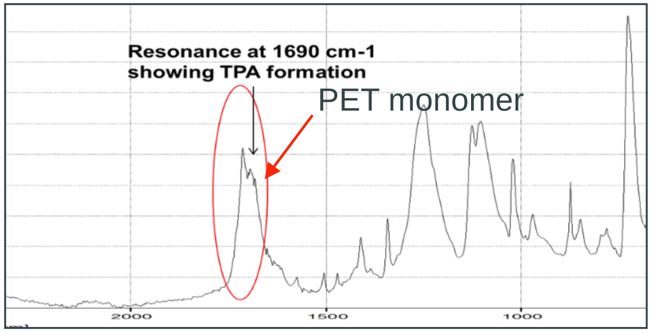


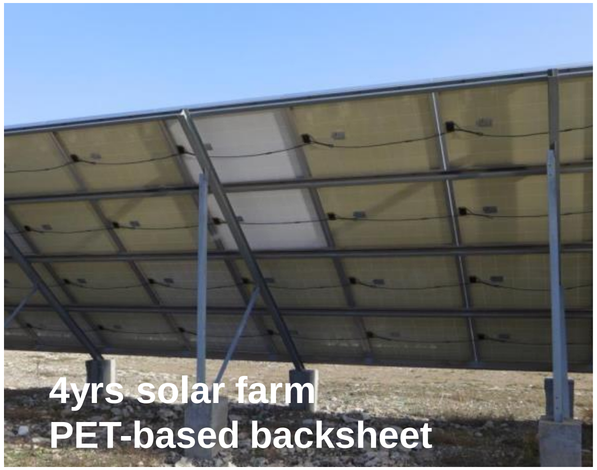

TPT backsheet maintains 160.8% elongation and 92.1 Mpa tensile strength

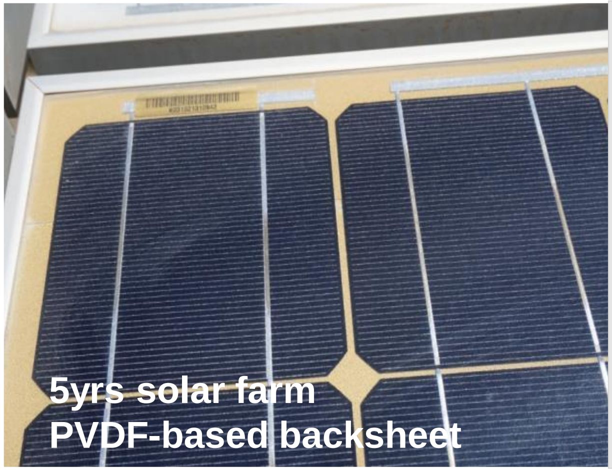
# <u>Yellowing:</u> Indicates Polymer Degradation and correlates with loss of Mechanical Properties

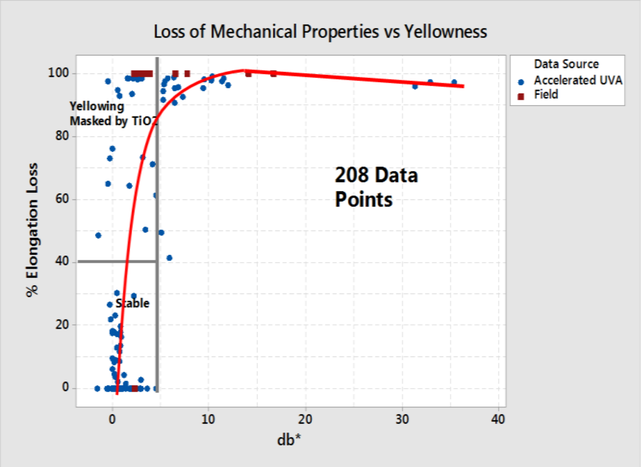
- Yellowing witnessed in many different fields, in > 6 different countries with less than 5 years in the field
  - China, USA, Germany, Belgium, Spain, Israel

FTIR of yellowed PET backsheet



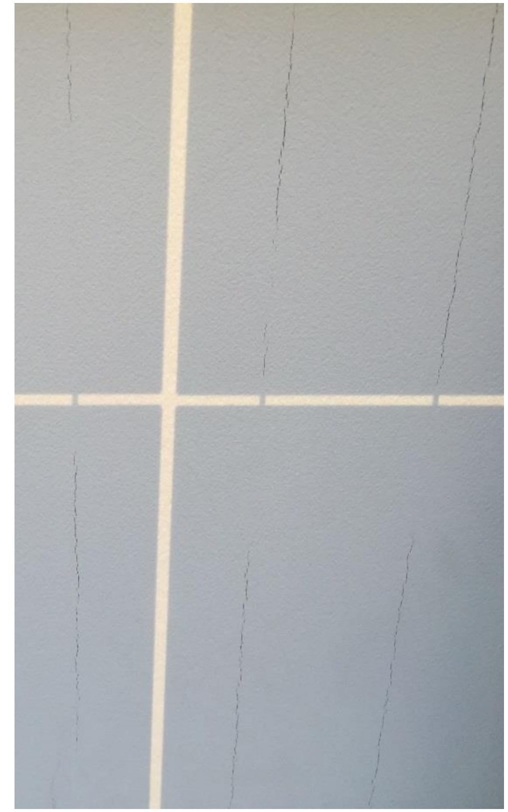




**Yellowing is an indication of polymer degradation and can place modules at risk for failure and safety.**

# <u>Cracking:</u> Backsheet Loses Insulation and Places Modules at High Risk for Failure and Safety

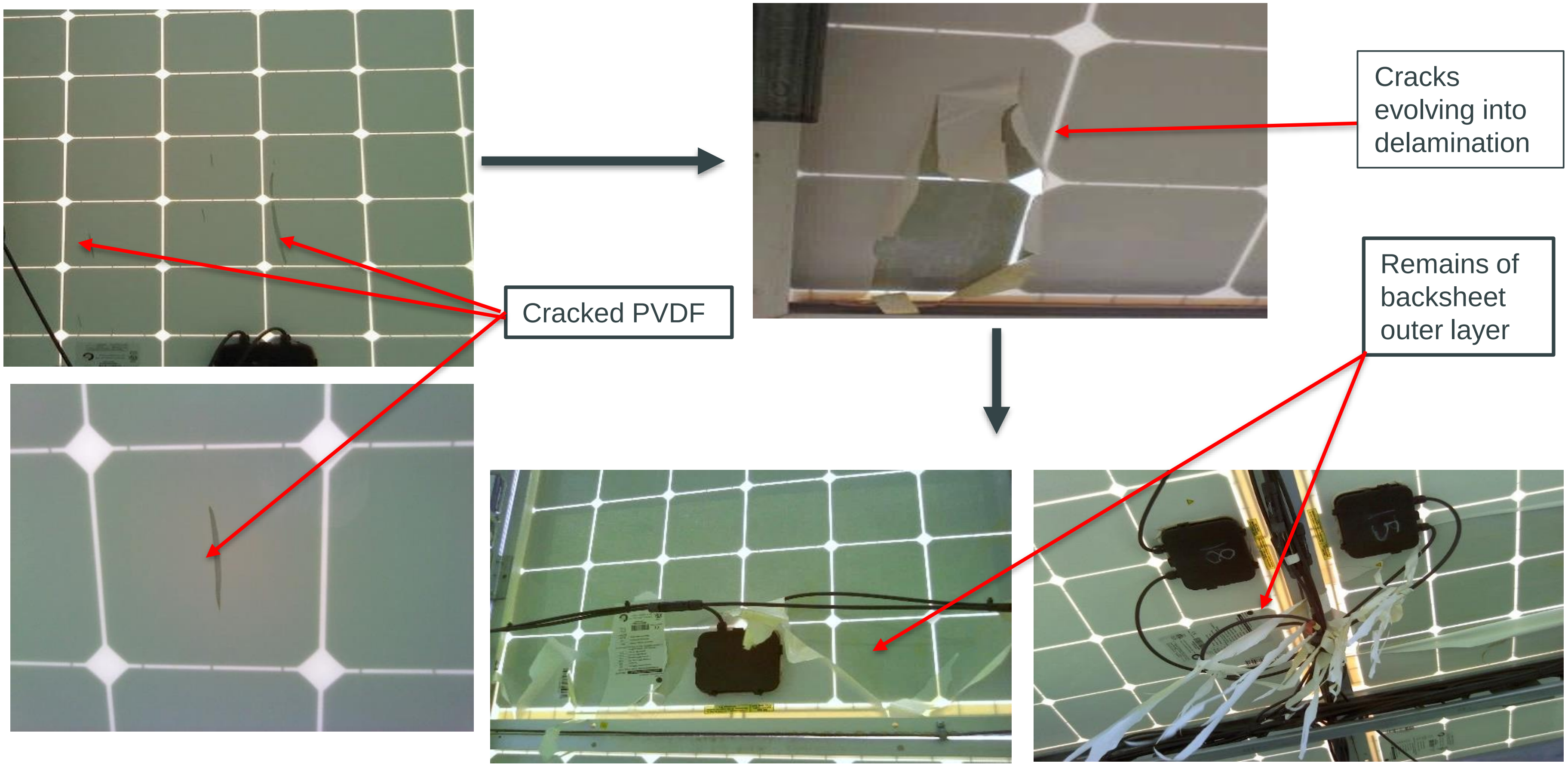
- 4yrs solar farm in Spain, 2.3MW;
- Polyester-based Backsheet cracking with ~50% of modules cracked. Some cannot pass wet leakage test.

- 4yrs solar farm in north American, 40kW;
- PVDF-based Backsheet cracking & delamination 57% of modules cracked



- 4yrs solar farm in west China, 20MW;
- PA-based Backsheet large amount of cracking with ~40% of modules cracked.

# Cracking and Delamination: PVDF-Based Backsheet Cracks Always Along with Mechanical Direction (MD)

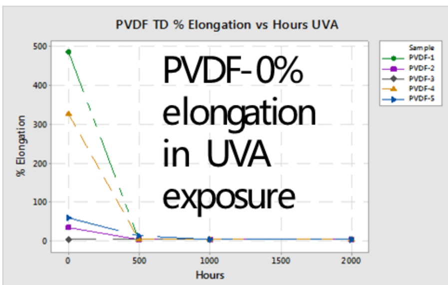



Significant level of PVDF degradation
- Starts with cracking
- Evolves into delamination and large area peel-off

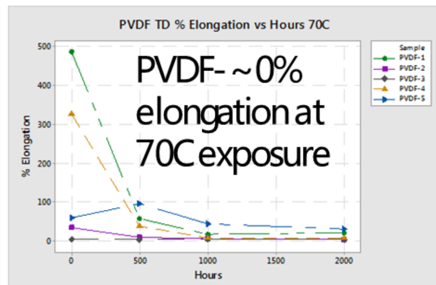
# PVDF Film Has Inherent Defect: Brittle in Transverse Direction (TD) which Results in High Cracking Risks Along with MD in Field

UVA | 70C | Damp Heat | PCT

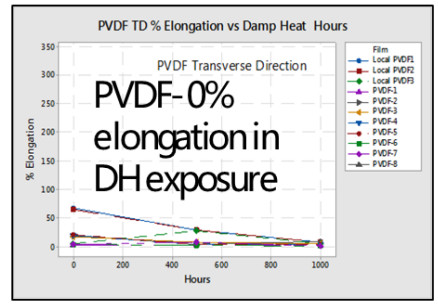
**PVDF**



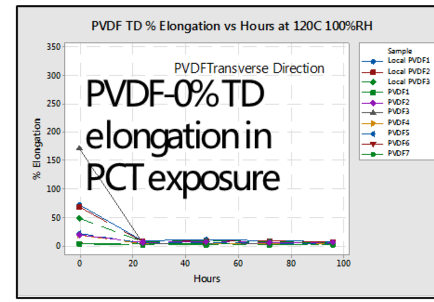

UVA 1.2W/sqm@340nm, 65W/sqm (300-400nm) 70°C BPT




70C dry ambient exposure

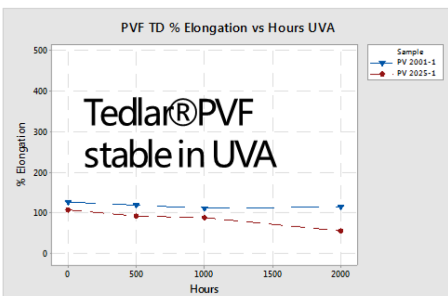



Damp Heat test: 85°C, 85%RH

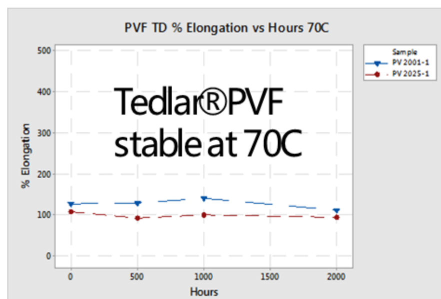



PCT Test 120C, 100% RH

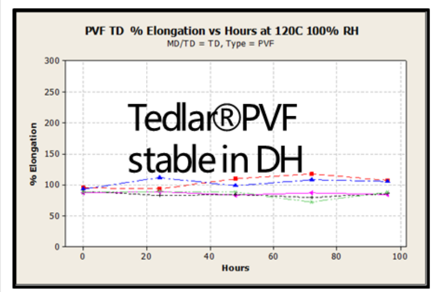
**PVF**

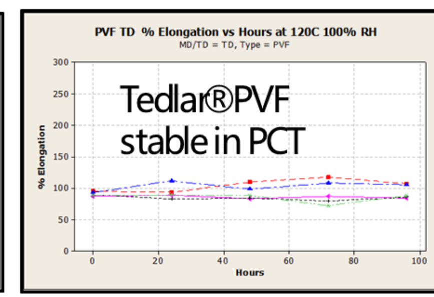



UVA 1.2W/sqm@340nm, 65W/sqm (300-400nm) 70°C BPT



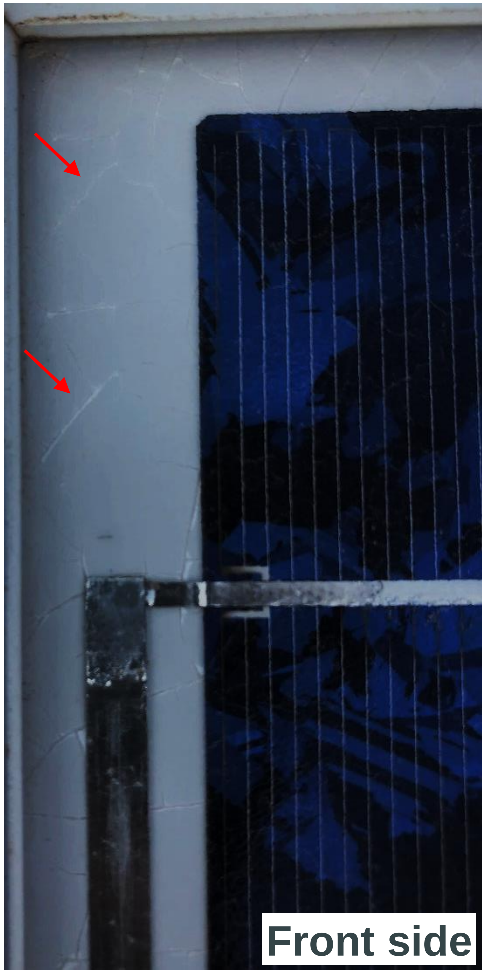

70C dry ambient exposure

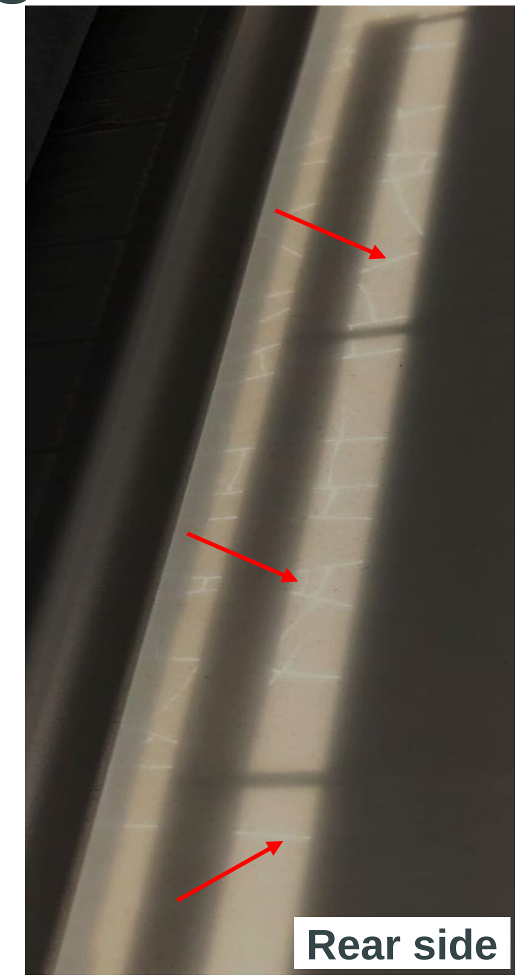



PVDF films loss elongation significantly in TD after UV, temperature, damp heat or pressure cooker test. PVF films are very stable and durable under the same test conditions.

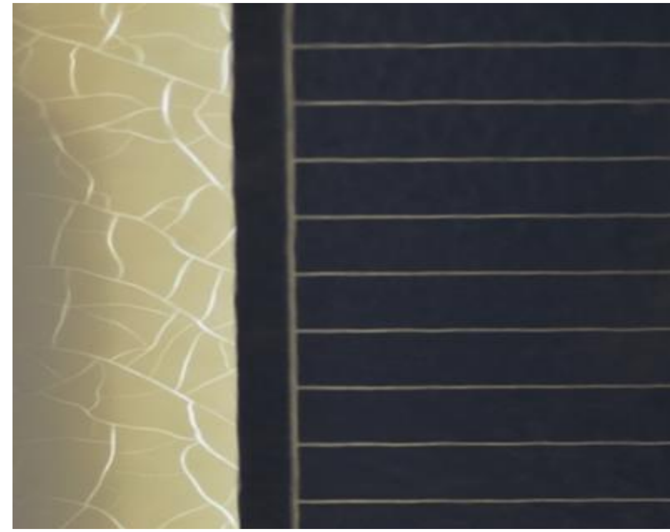
# Inner Layer Cracking: Electrical Insulation Failure and Power Loss




Fielded module with 5 years service in India, FEVE-coated backsheet

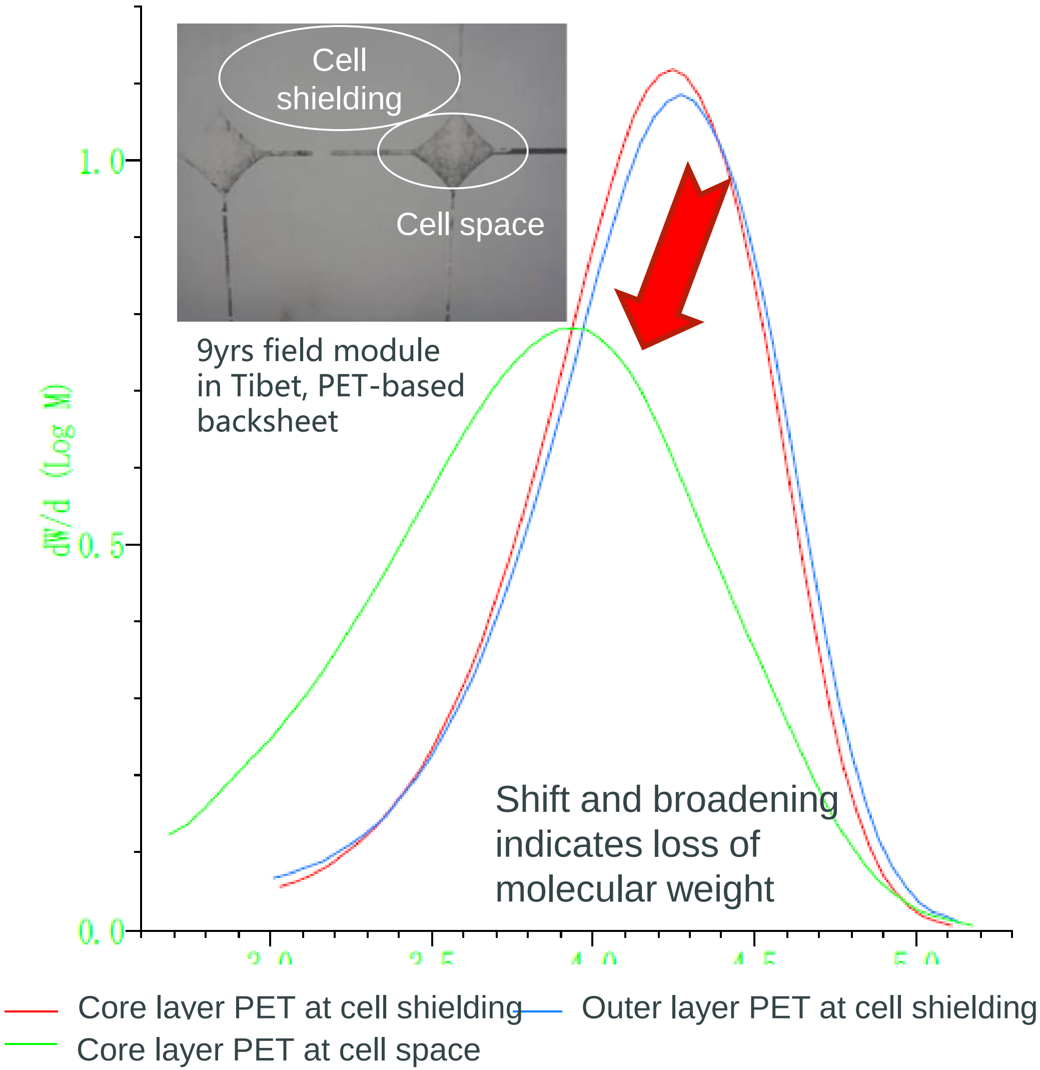
- ~70% of the inspected modules with FEVE backsheet show inner layer and backsheet outer layer cracking
- Ground faults and inverter tripping occurred during winter mornings and rains



Fielded module with 6 years service in NA, PET backsheet, 30MW

- 30% Power Loss in 5 years of service
- 6% linearized power loss per year

# PET Core Polymer Degradation: Correlates with Mechanical Property Loss




- **Molecular weight**

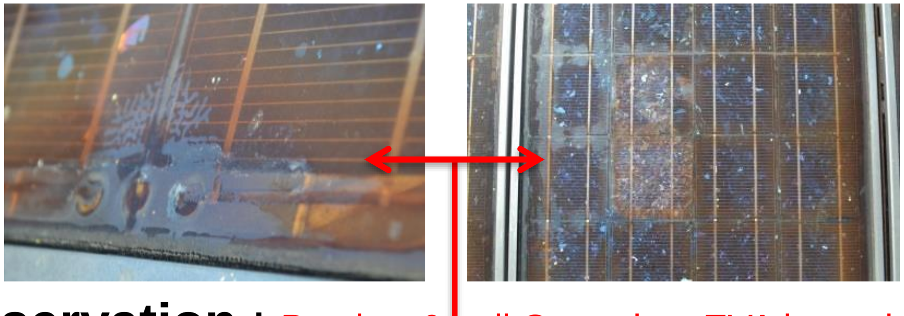
| Sample | Mw |
|---|---|
| Core layer PET at cell shielding | 19100 |
| Core layer PET at cell space | 12000 |
| Outer layer PET at cell shielding | 20400 |

- **Viscosity**

| Sample | IV , dL /g |
|---|---|
| Core layer PET at cell shielding | 0.929 |
| Core layer PET at cell space | 0.693 |
| Outer layer PET at cell shielding | 0.800 |

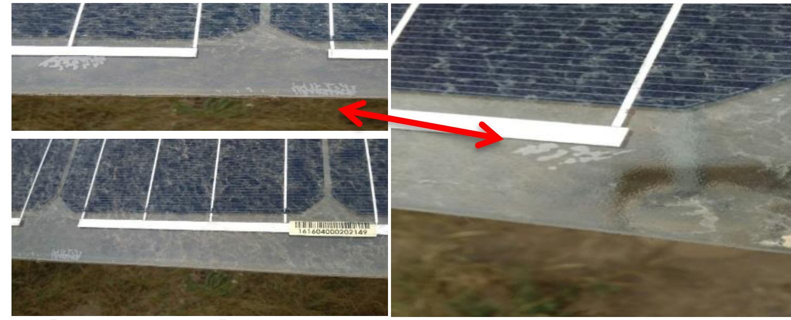
- **Loss of PET Mol wt and viscosity at cell spacing indicate polymer degradation from frontside UV light**
- **Backsheet was highly degraded. Backsheet could not be removed from module due to high brittleness**

# Breakage, Bending & Corrosion: Glass-Glass Field Failures Observed



**Observation** : Bus bar & cell Corrosion, EVA browning

Location: Hainan (China), Time: 15 years

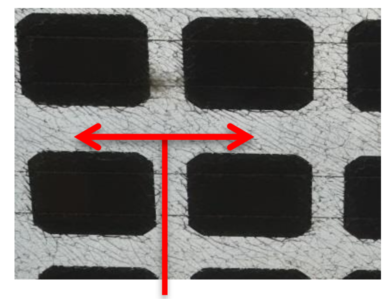


**Observation**: **Bus Bar Corrosion/delamination**

Location: Shanxi (China), Time:1 year

**Observation** : Bending & Breakage

Location: Guangdong & Qinghai (China), Time: 1yr



**Observation** : Extensive breakage

Location: Yunnan (China), Time:10 years

- **Multiple failures: Power Loss & Breakage across regions, and Applications (roof + ground)**
- **Higher corrosion rates are likely due to trapping of acetic acid by the glass backpanel**

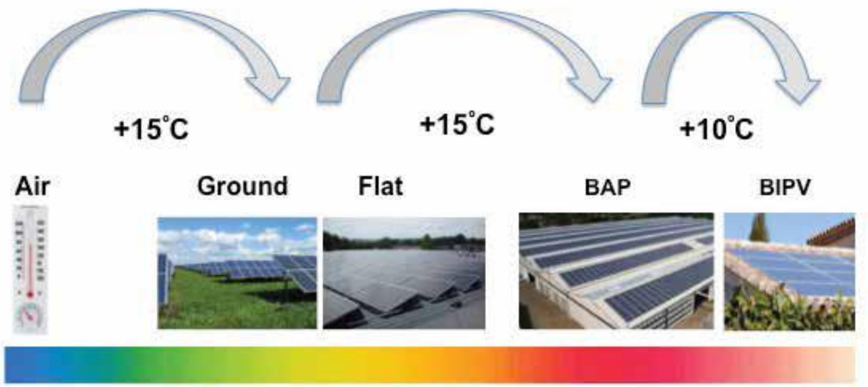
# Module and backsheet requirements for Rooftop PV

| Application requirements | Impact to module | Requirement for Backsheet |
|---|---|---|
| **Fire safety** | Fire resistance | • Fire resistance applications (Tedlar® as decoration of plane; building membrane structure…)<br>• Flame spread index (FSI), (Tedlar® class A; AAA class B) |
| **Durability** | Ensure 25yrs' lifetime and performance | • Long term field proven record<br>• Superior durability after various aging tests |
| **High Temp.** | High Temp. stability | • Melting point<br>• Thermal resistance (RTI; TI) |
| **Greater Temp. Range** | High TC resistance | • Strong mechanical properties in MD and TD directions<br>• Better co-efficient of thermal expansion (CTE) |
| **High Efficiency** | High Efficiency | • High reliability to ensure high efficiency output |
| **Aesthetics** | Color stability; Different colors; New structure designs | • Color stability<br>• Different colors |
| **High UV Albedo for open rack installation** | High Backsheet UV resistance | • High UV resistance |
| **Light Weight & Easy Installation** | Glass/backsheet structure; flexibility module; new designs | • Avoid to use glass backsheet except BIPV |

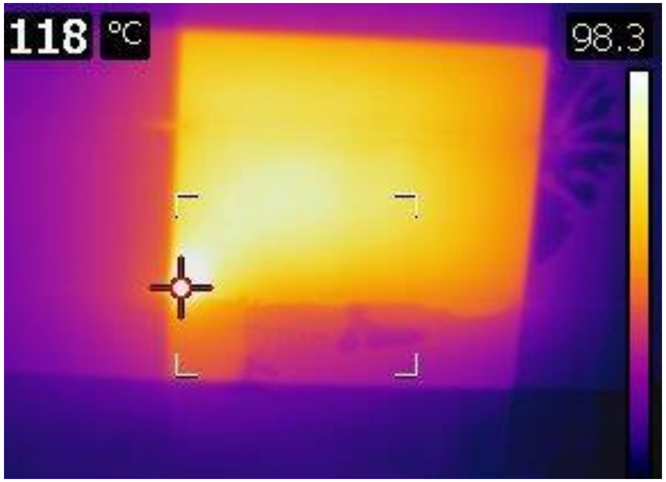
# Tedlar® Has Exceptional Smoke/Fire Performance and Has Been Used in Aircraft and High-speed Trains which Represent the Highest Safety Requirements

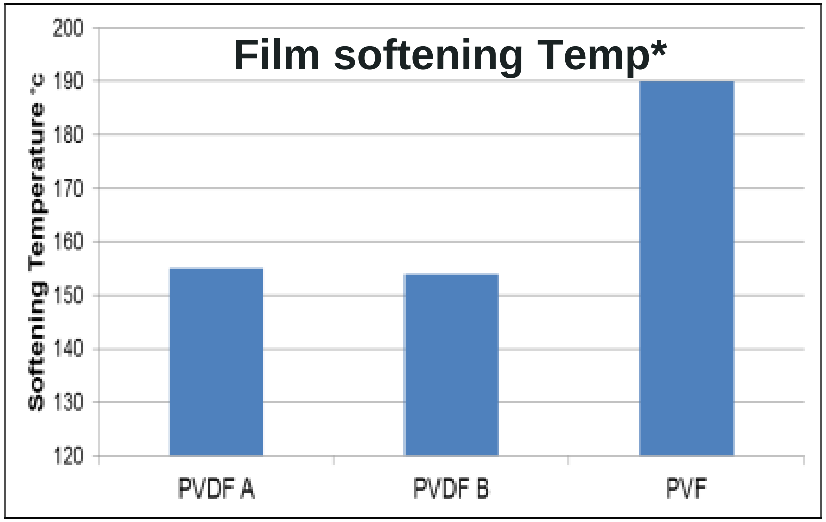
Tedlar® has US FAA and EU EASA Certifications and has been used in aircraft which have the highest fire-resistance requirements

# Rooftop PV Has the Highest Operating Temp which May Results in Bubble/Crack/Burn Through in Field

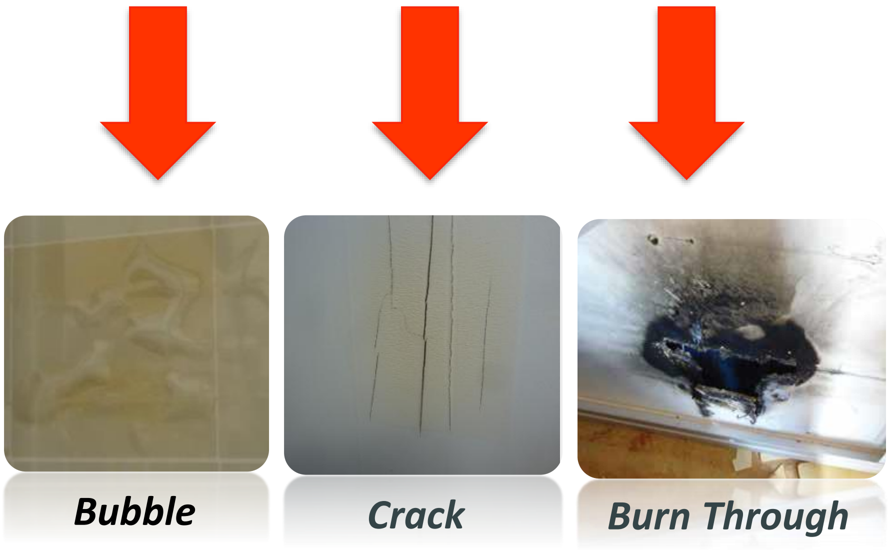



Between ground mounted and roof integrated installations, you should expect a 25°C operating temperature increase.




PVF Film Has 30~40ºC Higher Softening Temperature Than PVDF and Thus Better Hot Spot Resistance




*JIS K7196 Heat Deformation Test- weighted stylus impinges on sample being heated, thermal transitions noted

# Long-Term Durability of Rooftop PV Installation Requires a Reliable Rooftop!

- Industrial plants and public buildings, mainly use metal-color steel tile. This steel is easily **corroded**.
- Once the rooftop is corroded/damaged, there is a huge O&M cost to repair the rooftop or change the solar panels. The cost will **strongly impact the lifetime and LCOE of the solar farm**.

- Tedlar® film covered steel tile wall in Japan (installed in 1984)


- DuPont plant rooftop (installed in 1983)

# Environment Stresses and Chemicals of Over Water PV Application

- Environmental stresses
  - High humidity
  - Dynamic mechanical stresses by wind and floating
  - UV irradiation
  - Thermal Cycling
  - ……


Source: PV MODULE CORROSION FROM AMMONIA AND SALT MIST - EXPERIMENTAL STUDY WITH FULLSIZE MODULES. G. Mathiak, J. Althaus; S. Menzler, L. Lichtschläger, W. Herrmann. 27th European Photovoltaic Solar Energy Conference and Exhibition

- Chemicals
  - Water and water vapor $H_2O$
  - chloride $CL^-$
  - sulfate radical $SO_4^-$
  - hydroxy radical $OH^-$
  - ammonia $NH_3$
  - Metal ions $^+$
  - ……

| | 1-Year Immersion at Room Temperature | 2-Hour Immersion at Boil | 31-Day Immersion at 75°C (167°F) |
|---|---|---|---|
| **Acids** | | | |
| Acetic Acid (glacial) | × | | × |
| Hydrochloric Acid (10% & 30%) | | | × |
| Hydrochloric Acid (10%) | × | × | |
| Nitric Acid (20%) | × | | |
| Nitric Acid (10% & 40%) | | | × |
| Phosphoric Acid (20%) | × | | |
| Sulfuric Acid (20%) | × | | |
| Sulfuric Acid (30%) | | | × |
| **Bases** | | | |
| Ammonium Hydroxide (12% & 39%) | × | | |
| Ammonium Hydroxide (10%) | | | × |
| Sodium Hydroxide (10%) | × | × | |
| Sodium Hydroxide (10% & 54%) | | | × |
| **Solvents** | | | |
| Acetone | × | × | |
| Benzene | × | × | |
| Benzyl Alcohol | | | × |
| Dioxane (14) | | | × |
| Ethyl Acetate | | | × |
| Ethyl Alcohol | | | × |
| n-Heptane | × | | |
| Kerosene | × | | |
| Methyl Ethyl Ketone | | | × |
| Toluene | | | × |
| Trichloroethylene | | | × |
| **Miscellaneous** | | | |
| Phenol | × | | |
| Phenol (5%) | | | × |
| Sodium Chloride (10%) | × | | |
| Sodium Sulfide (9%) | | | × |
| Tricresyl Phosphate | | | × |

Tedlar® PVF has superior resistance to chemical, contamination, and solvent

# Over Water Application Requires High Quality Materials to Resist Corrosion, Humidity, Salty and Mechanical Stresses

Location: Suzhou, Anhui province, CECEP project (coal mining subsidence area)
Project size: 70MW
Installation time: 2017
Backsheet: Tedlar®-based backsheet

Location: Huai'an, Jiangsu province, SPIC Golden lake project
Project size: 40MW
Installation time: 2016 Q4 - 2017 Q1
Backsheet: Tedlar®-based backsheet

# Thank You