Field study and analysis of backsheet degradation in 450MW+ PV installations

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DuPont Photovoltaic Solutions

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…

Agenda

- DuPont Global Field Assessment Program

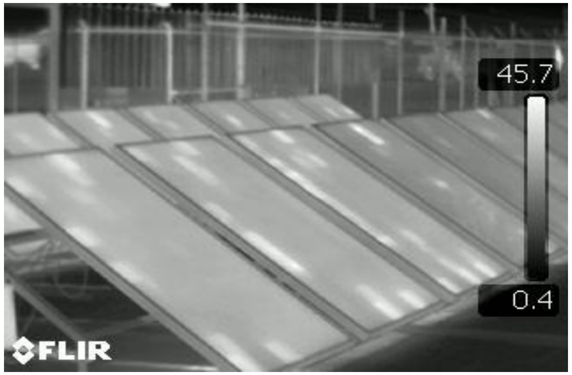
- Solar panel defects observed in the field
  - By component
  - By climate
  - By roof vs ground mounting
  - By age and backsheet type

- Field examples of backsheet defects
  - Frontside yellowing
  - Airside Yellowing and mechanical loss
  - Cracking
  - Busbar corrosion and glass breakage
  - Tedlar® PVF field results

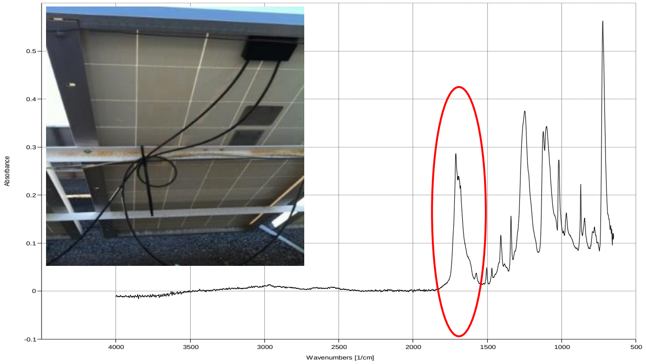
- Conclusions

DuPont Global Field Assessment Program

By end of 2016, surveyed >190 global installations in NA, EU, and AP
45 module manufacturers, 450MW, 1,900,000 modules, newly commissioned to 30+ years in service



Thermal Imaging IR camera identifying hot spots in modules



Backsheet identification and degradation using FTIR spectrometer

Multi-step Inspection Protocol

- Documentation of location, age, climate, module, energy production, visual & thermal imaging, IR spectroscopy
- Defect categorization

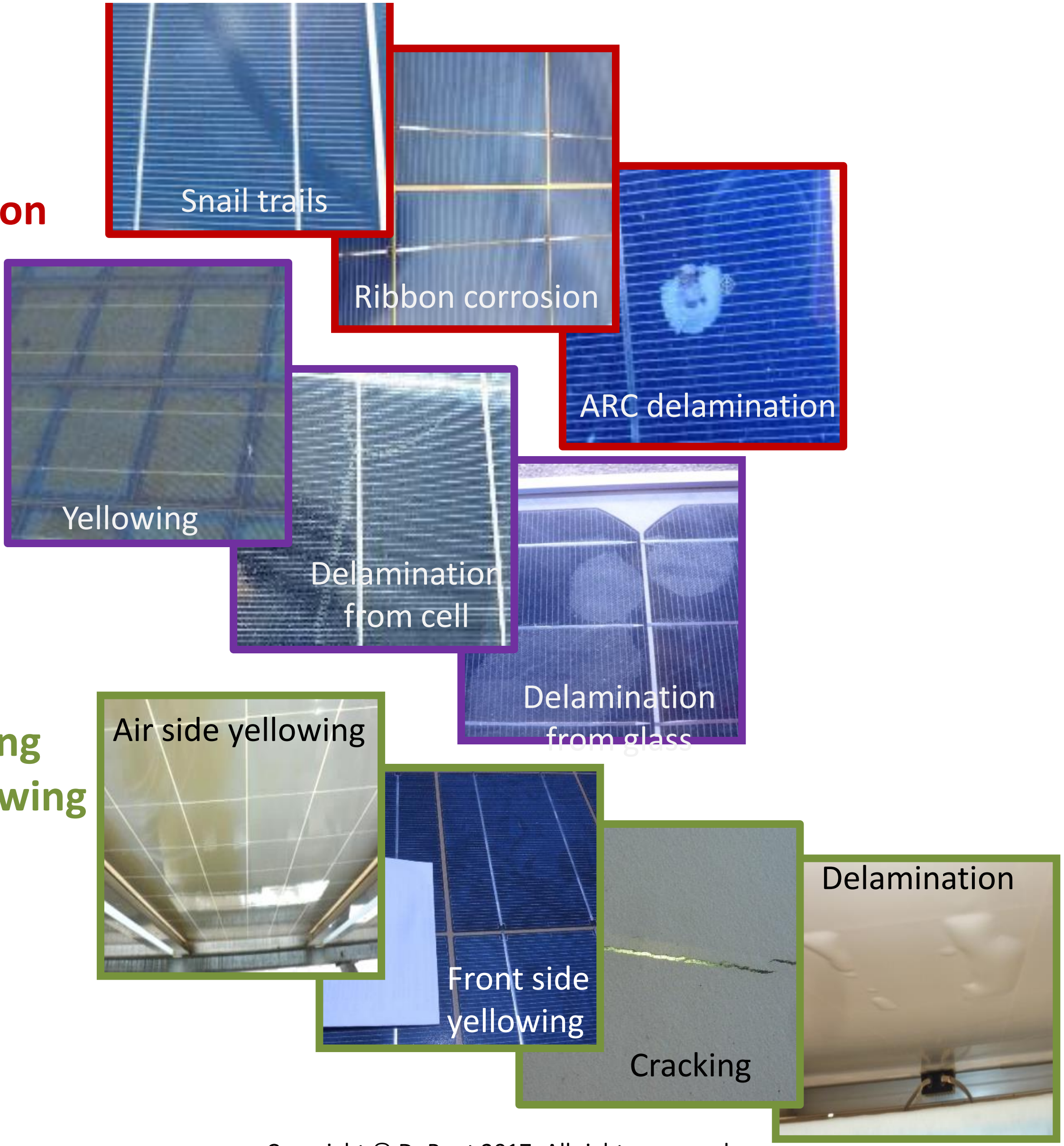
Defect Analysis (FMEA) and Statistics
Working with many partners globally

Field Degradation and Defect Categories

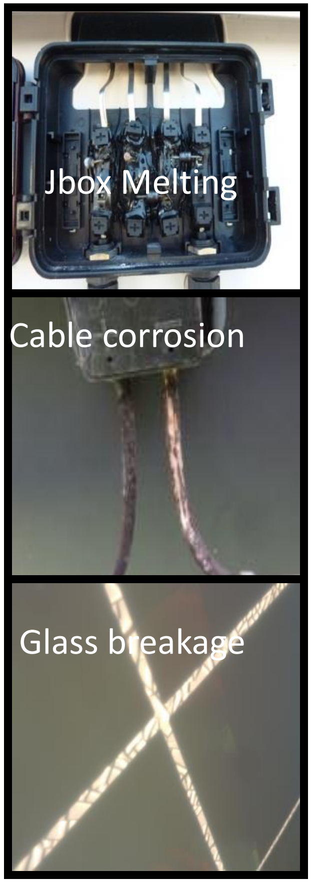
Cell defects
- **Snail Trails**
- **Corrosion**
- **ARC Delamination**

EVA defects
- **Yellowing**
- **Delamination**

Backsheet defects
- **Air Side Yellowing**
- **Front Side Yellowing**
- **Cracking**
- **Delamination**
- **Bubbling**
- **Other**



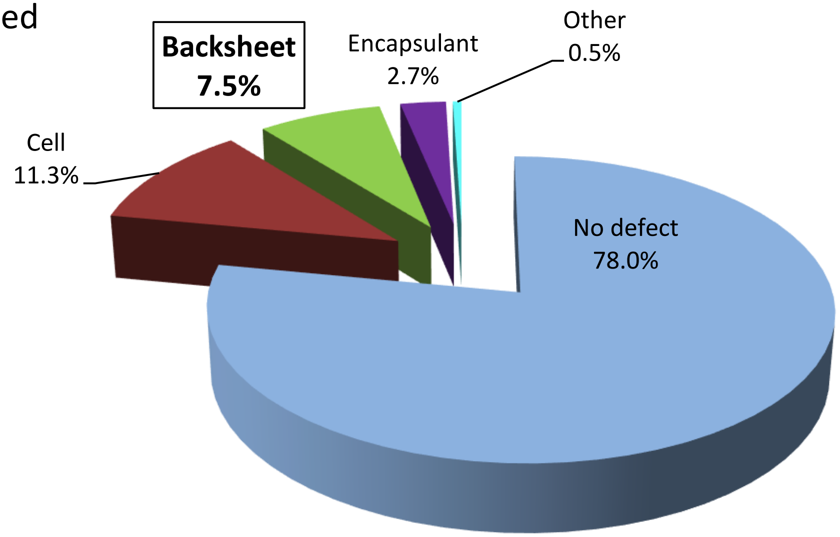
Other defects



DuPont 2016 Field Analysis and Database - Overview

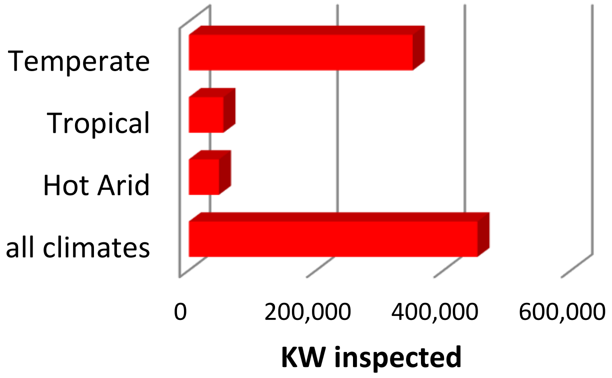
2016 Analysis

453MW inspected



	2016
Installations	197
Number of panels	1,919,000
Average age (years)	3.4
MW	453

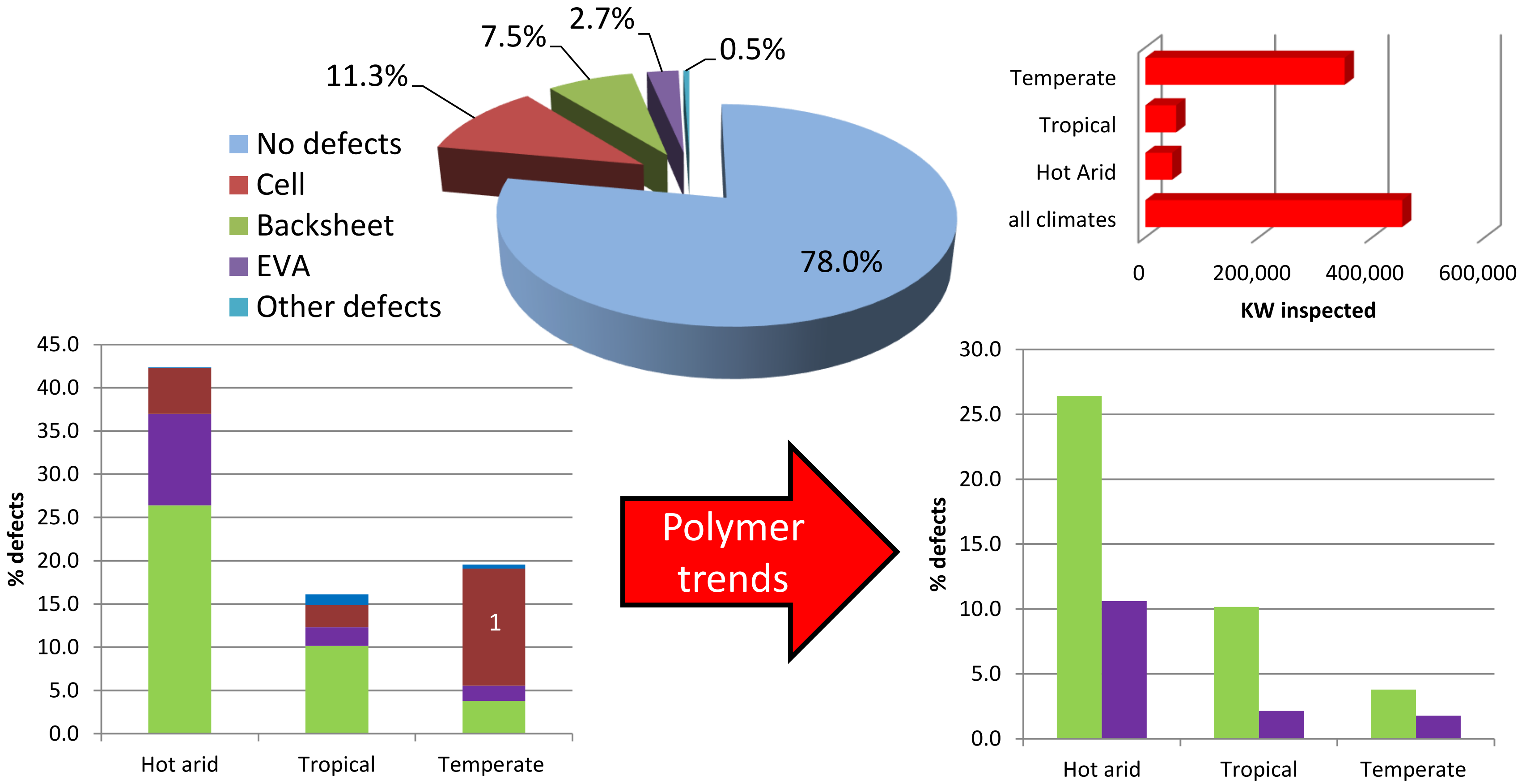
Climate sample sizes 2016



Data size more than doubled from 2015 to 453 MW

- All defects 22%
- Cell related defects 11.3%
- Backsheet defects 7.5%

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 factor is likely Temperature, then UV

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

Analysis of Defect Rates for Roof vs Ground Mounted Systems

Roof mounted, 11.7MW

Ground mounted, 441MW

Overall Higher defect rates for roof vs ground installations

- Backsheet defects are > 3X 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^{o}C higher than Ground Mounted[1]
- This trend with temperature is similar to the effect seen in climates

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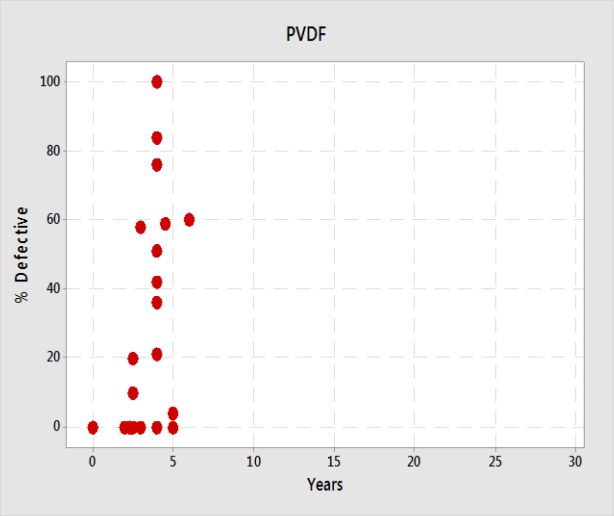
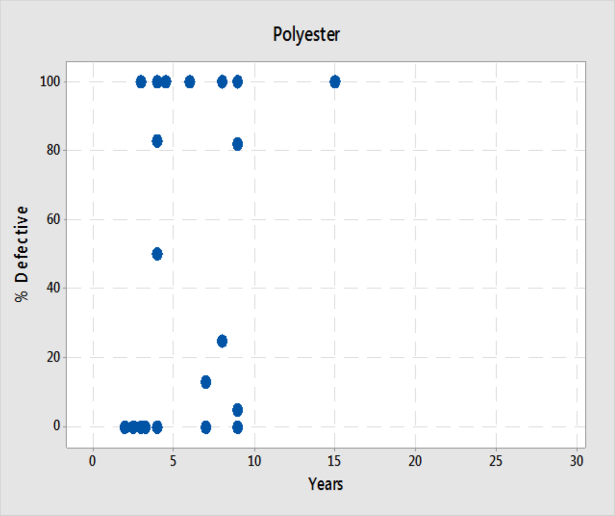
1 Creep in Photovoltaic Modules: Examining the Stability of Polymeric Materials and Components (2010) 35th IEEE Photovoltaic Specialists Conference (PVSC '10) Honolulu, David C. Miller, Michael Kempe

Analysis of Backsheet Defects vs Age

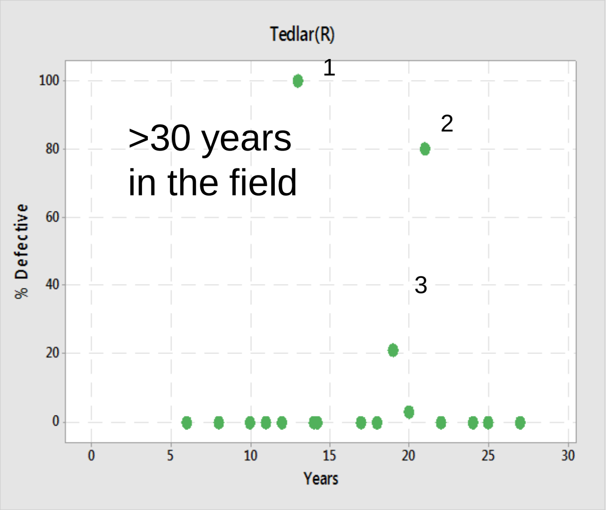
PVDF



PET



PVF



>30 years
in the field

Defect Rates by Backsheet

Material (av. age in years)	Defect rate (MW basis)
Tedlar® (5.4)	0.1%
PVDF (2.3)	7%
Polyester(3.0)	8.6%

Tedlar®-oldest installations, lowest defect percentage

- Defect rate is low and not increasing over time

PVDF and Polyester, highest defect percentages

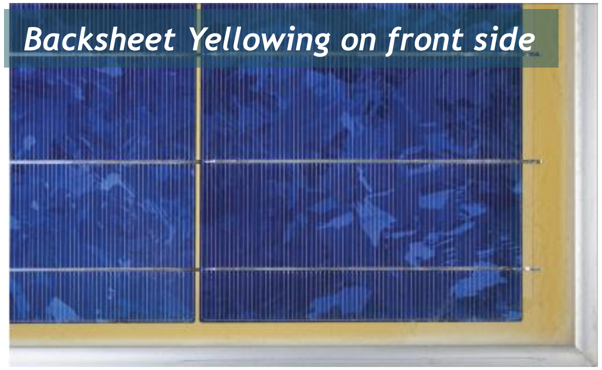
- Defect rate is increasing with time

[1] Front side yellowing due to inner layer chemical treatment

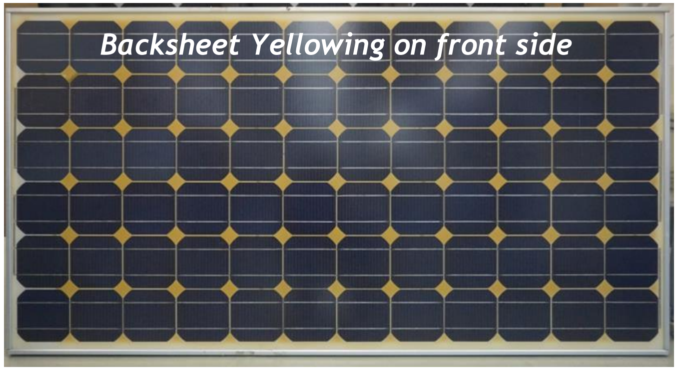
[2] TPE, Weak inner layer adhesion led to delamination

[3] Slight Front side yellowing

Field Examples of Backsheet Inner Layer Yellowing

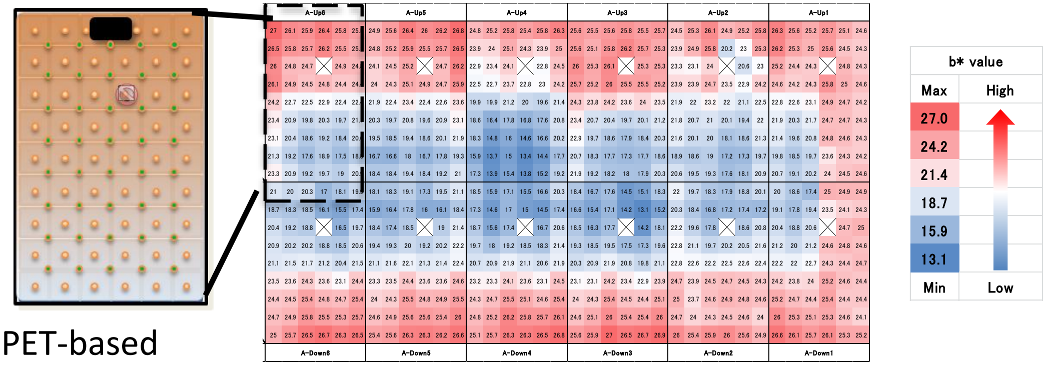


2 year old fielded module in a desert region in USA- PVDF-based backsheet



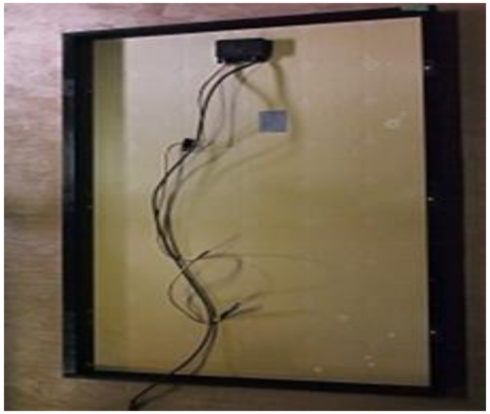
9 year old fielded module in Tibet- PET-based backsheet-100% modules yellowed in 10kW field

Field examples of Backsheet Outer Layer Yellowing



PET-based Backsheets

Yellowness measured on 12 rooftop modules deployed 15 years in Japan.
Significant yellowing even on the interior of array (b* of 13-20)
Highest yellowing is along edges with highest UV exposure (b* up to 27)

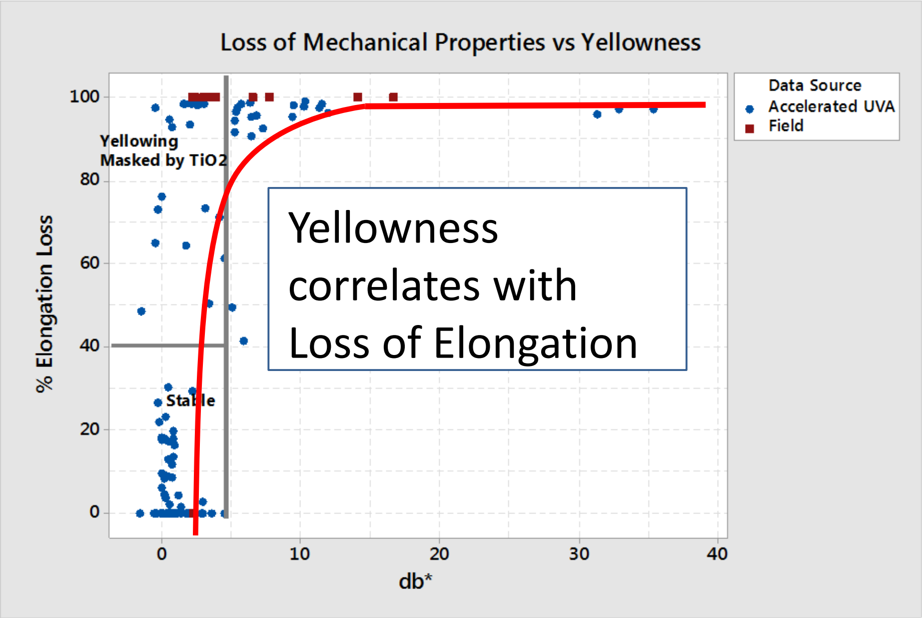


Detail of module from the installation shown on left

Source: Modules provided by AIST; DuPont analysis

<u>Yellowing:</u> Indicates Polymer Degradation
Correlates with loss of Mechanical Properties

- Yellowing is often observed on the backsheet air side in the field.
- An extensive study comparing yellowing with elongation loss showed a correlation
- Loss of elongation can lead to cracking



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

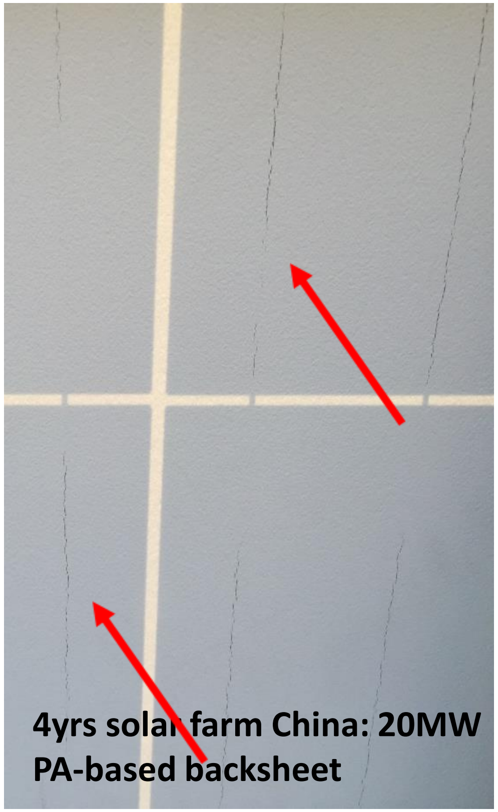
Cracking: Backsheet Loses Insulation and Places Modules at High Risk for Failure and Safety


9yrs rooftop Arizona: 35kW
PET-based backsheet

PET-based Backsheet cracking with ~15-20% of modules cracked. 80% power loss


4yrs solar farm NA: 40kW
PVDF-based backsheet

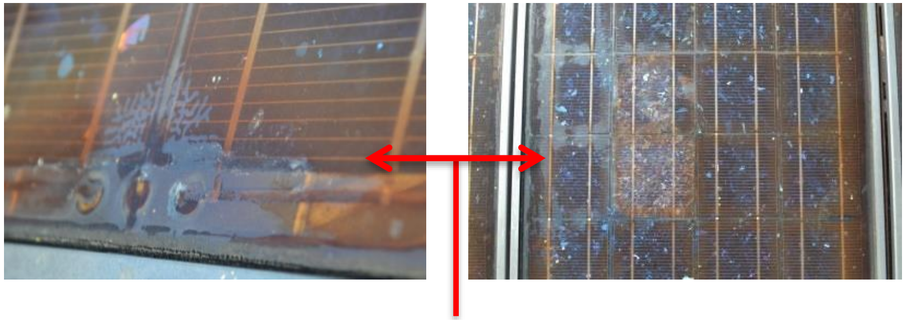
PVDF-based Backsheet cracking & delamination 57% of modules cracked


4yrs solar farm China: 20MW
PA-based backsheet

PA-based Backsheet large amount of cracking with ~40% of modules cracked.

Backsheet cracking observed in 3 classes of backsheets

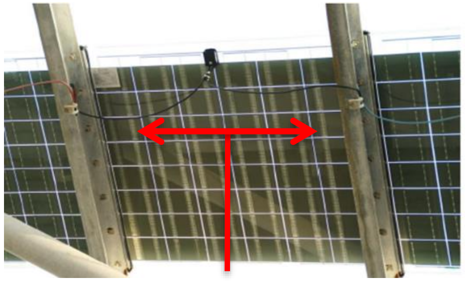
Breakage, busbar corrosion, and power loss in glass-glass modules



Observation: Bus bar Corrosion, EVA browning

Power loss

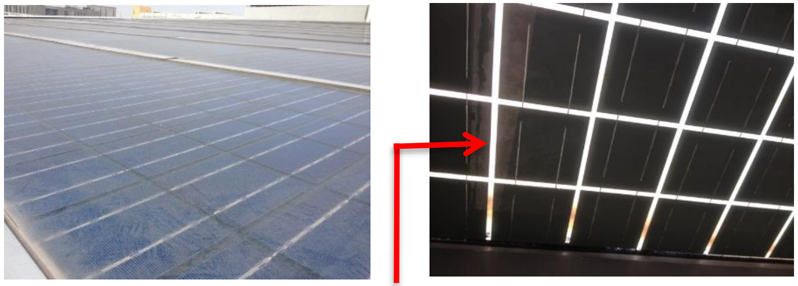
Location: Danzhou (China), Time: 15 years



Observation: Bus Bar Corrosion,

Power loss

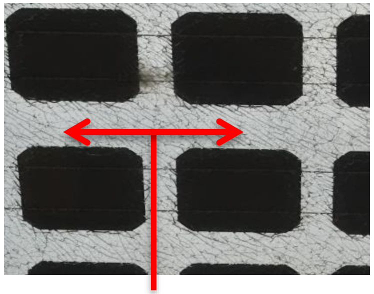
Location: Okinawa (Japan), Time:11 years



Observation: Bus bar Corrosion

Power loss

Location: Shanghai (China), Time: 5 years



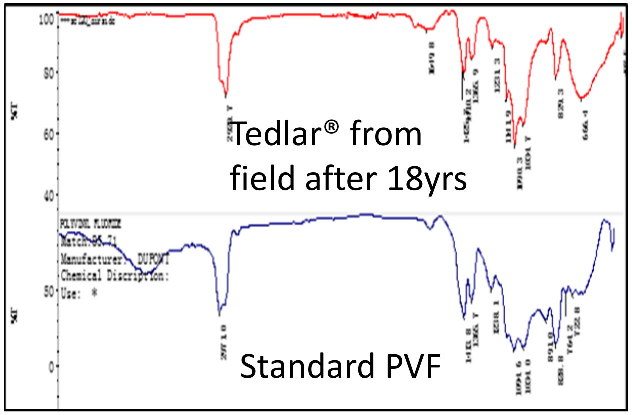
Observation: Extensive breakage

Location: Yannan (China), Time: 10 years

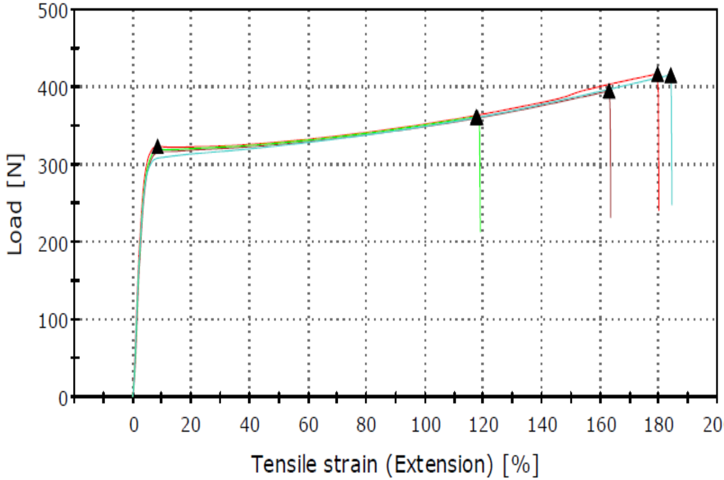
- Multiple failures: Power Loss & Breakages across regions, applications (roof+ground)
- Believed higher corrosion rates are due to trapping of acetic acid by the glass backsheet

Tedlar® Field Case: 18yrs Old Tedlar® TPT Installation in Beijing Low Power Loss and No Sign of Degradation

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



Tedlar® film shows no degradation after 18yrs field service



TPT backsheet maintains 160.8% elongation and 92.1 Mpa tensile strength, excellent retention of properties

Tedlar® Protecting Modules for over 35 years

SUPSI, Switzerland 1982

Nara, Japan 1983

SMUD, USA 1984

Vermont, USA 1985

SYSU, China 1985

Mt Soleil, Switzerland 1992

Tamil Nadu, India 1995

Beijing, China 1999

Conclusions

- Results of >190 site inspections shows 22% of modules have defects

  - Cells (11.3%) and backsheets (7.5%) are the leading categories
  - Hot arid climate shows greatest polymer defect frequency
  - No climate trend for cells and metallization
  - Backsheet defects are 3X greater frequency on roof vs ground mount

- Backsheet defect analysis

  - Defect rates are
    - 7% for PVDF backsheets
    - 8.6% for PET-based backsheets
    - 0.1% for PVF-based backsheets

  - Defects rates for PVDF and PET-based backsheets are increasing with time, rate is not increasing for PVF
  - Yellowing is observed on both front and airsides of backsheets
  - Backsheet airside yellowing is correlated with backsheet cracking
  - Glass breakage, bus bar corrosion, and power loss is seen in glass-glass modules
  - Tedlar® PVF stable

- Tedlar® PVF offers the best protection for PV modules photovoltaics.dupont.com

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