Degradation patterns of module packaging materials across length scales: global, local, sub-module

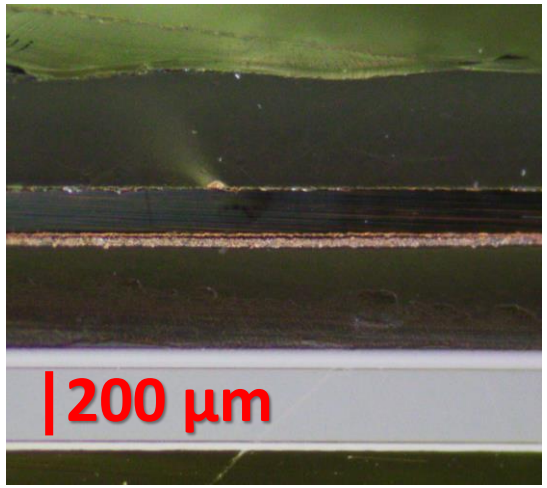
Andrew Fairbrother

1st SOPHIA PV-Module Reliability Webinar
28-29 May 2020

PV-lab IMT NEUCHATEL
NIST National Institute of Standards and Technology U.S. Department of Commerce
EPFL

PV module packaging

Structure of c-Si PV module



Superstrate (glass)

Encapsulant (EVA)

Cell (Si), metallization (Ag)

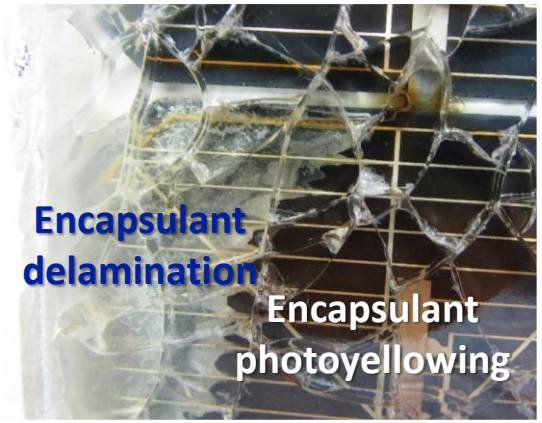
Encapsulant (EVA)

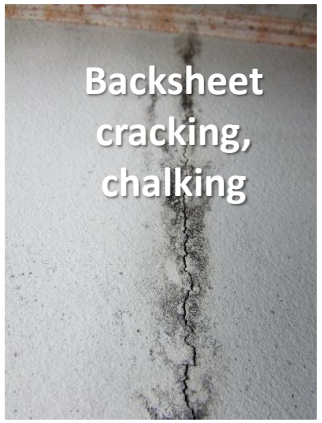
Backsheet (FPE, PPE)

Glass and polymeric materials for:

- Electrical insulation
- Environmental isolation
- Mechanical support
- Optical coupling

Degradation of PV module packaging

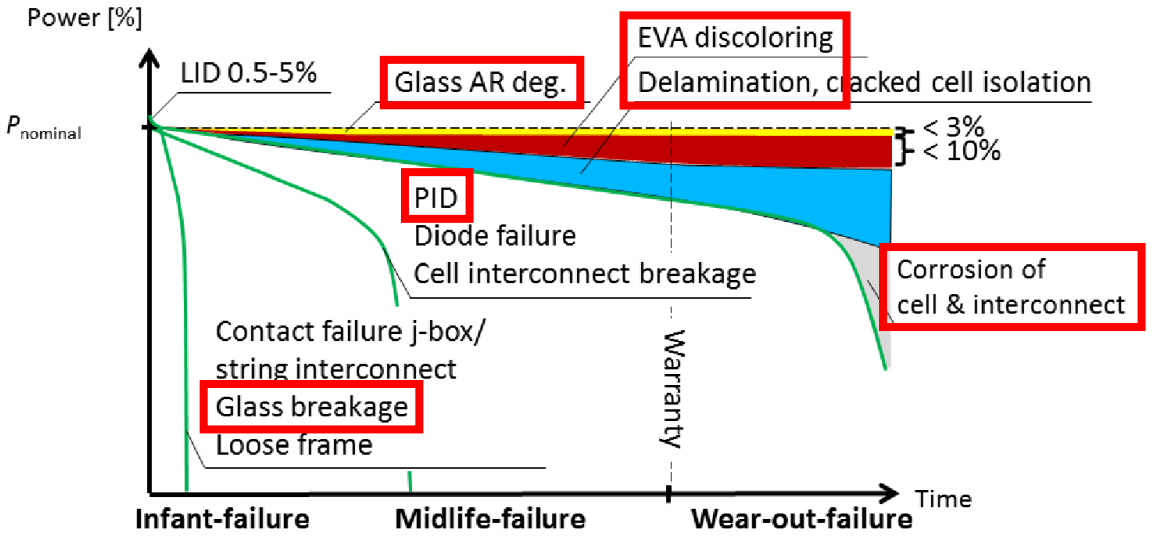




End-of-life failure commonly linked to packaging degradation or interactions

- 90% of installed modules <10 years old
- 90% reduction in module cost in past 10 years

Increasing use of new materials with little field history

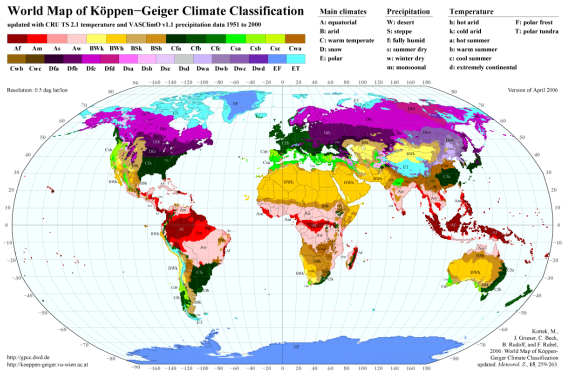


Fairbrother A, et al. Degradation analysis of field-exposed photovoltaic modules with non-fluoropolymer-based backsheets, Proc. of SPIE 10370, **2017**, pp. 1037003
Köntges M, et al. Review of failures of photovoltaic modules, IEA PVPS Task 13 Report, **2014**
Li J and Hsi E, Solar panel code of practice, Swiss Re, **2018**

Degradation patterns across length scales

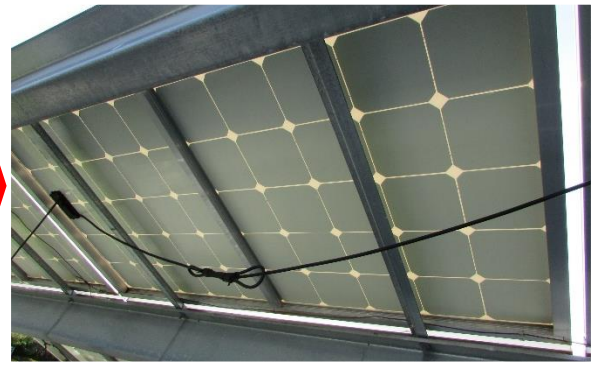
km — m — mm — µm

Global (climate)

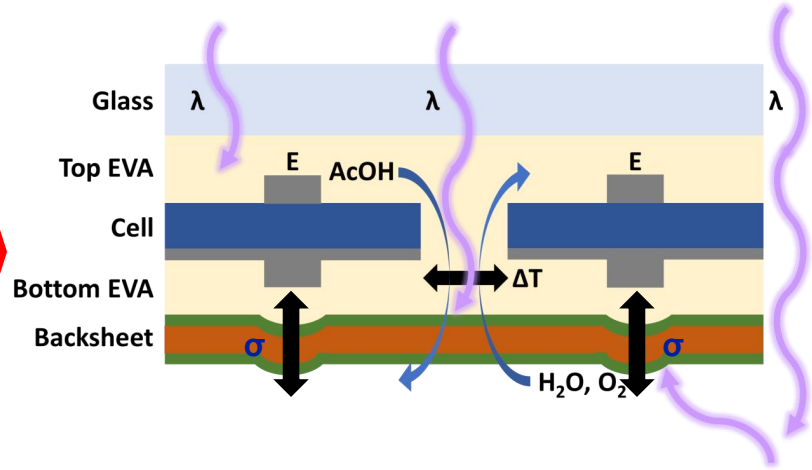


Array

Module



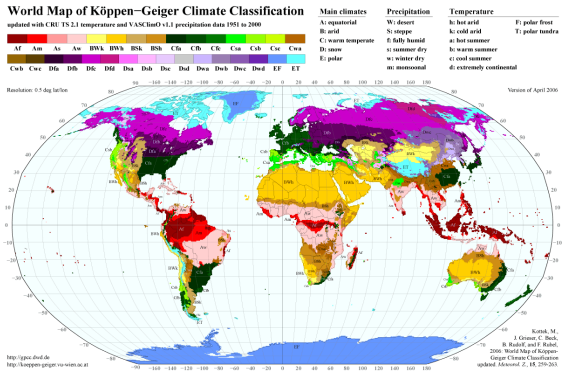
Sub-module

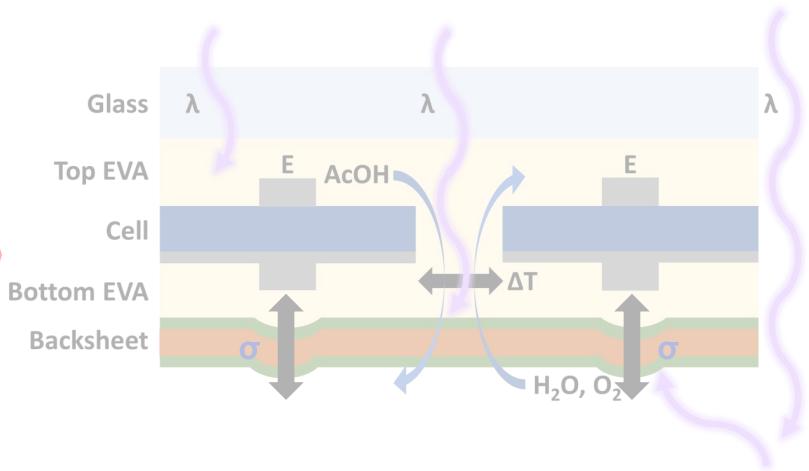


Degradation patterns: global

km — m — mm — µm

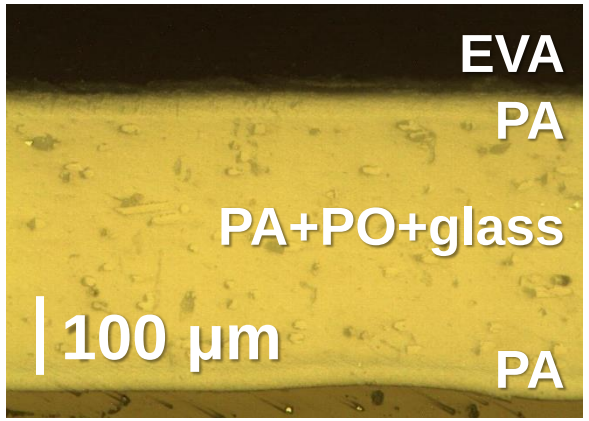
Global (climate) | Array | Module | Sub-module

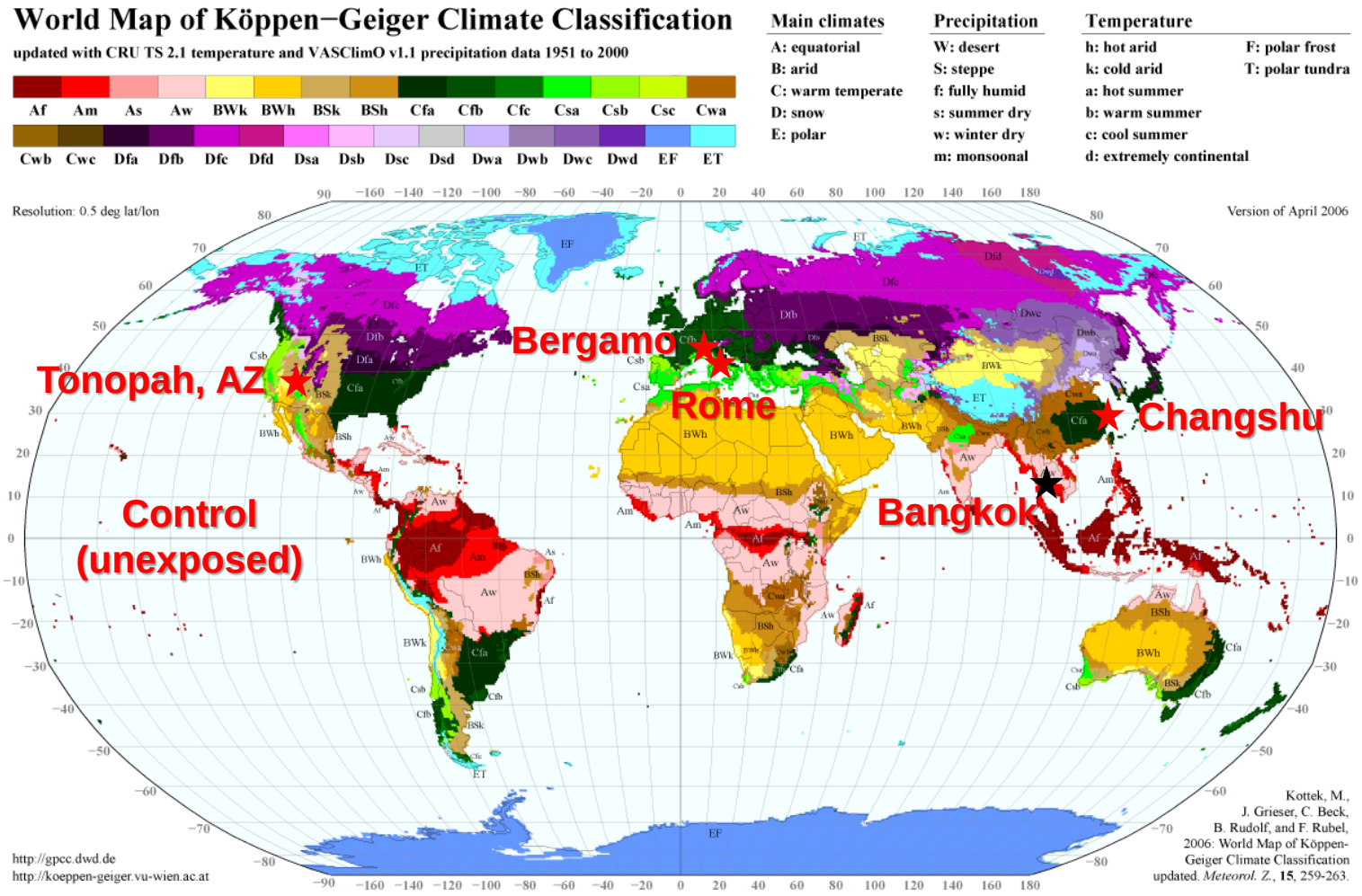




Global degradation patterns: backsheet

Complete failure of PA/PA/PA backsheet in between cells



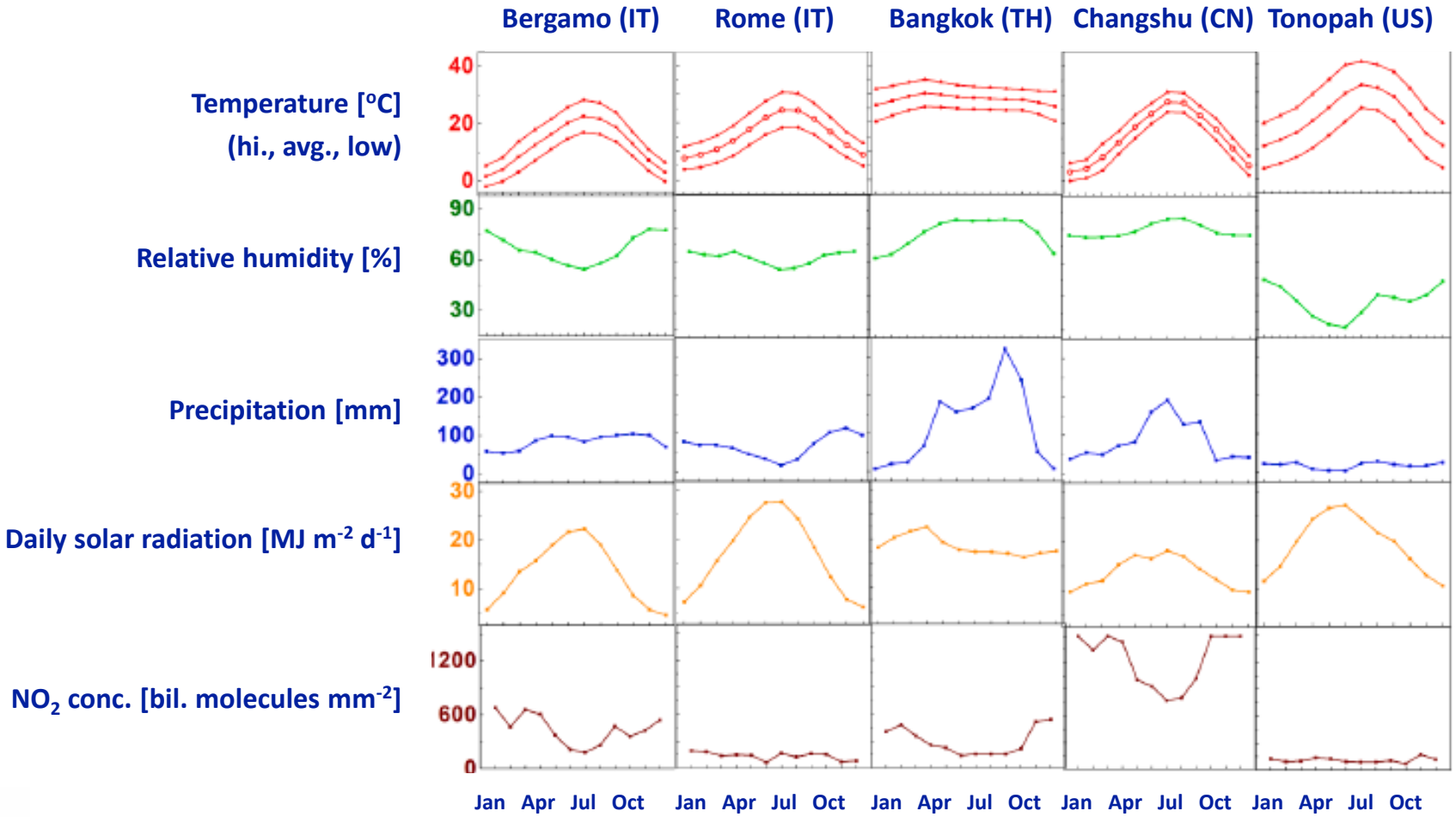


Fairbrother A, et al. Degradation analysis of field-exposed photovoltaic modules with non-fluoropolymer-based backsheets, Proc. of SPIE 10370, **2017**, pp. 1037003

Lyu Y, et al. Impact of environmental variables on the degradation of photovoltaic components and perspectives for the reliability assessment methodology, Sol. Eng. 199, **2020**, pp. 425-436

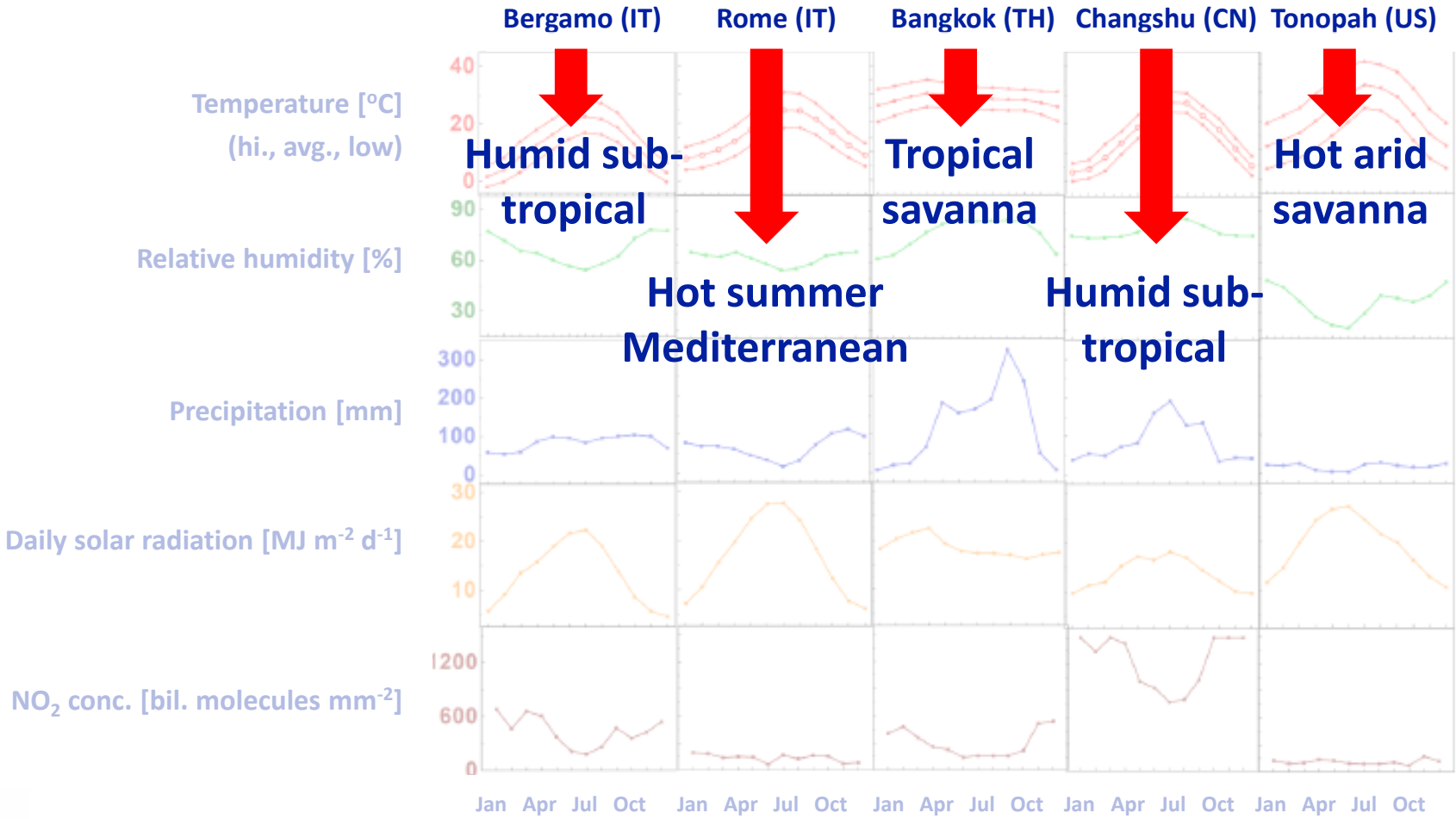
Global degradation patterns: backsheet

Climatic conditions:



Global degradation patterns: backsheet

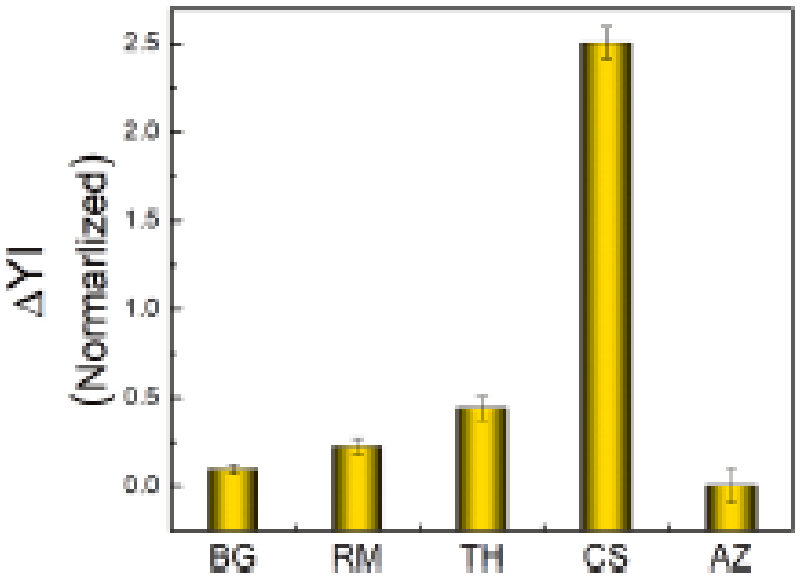
Climatic conditions:



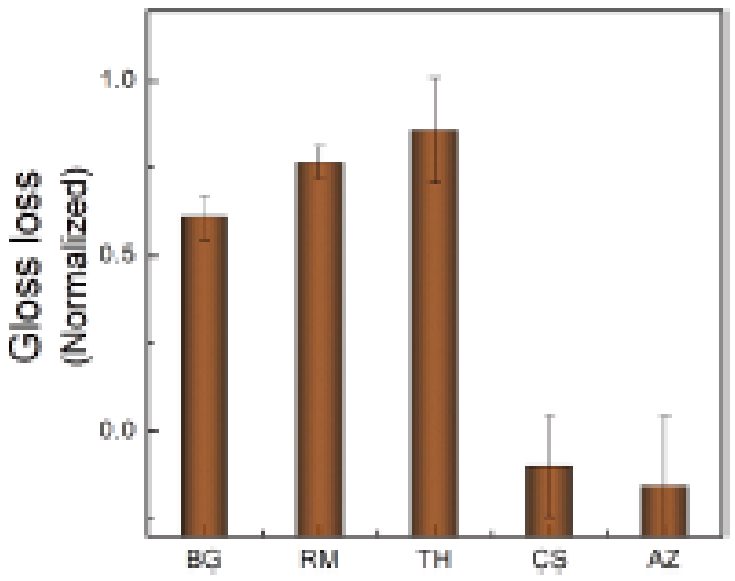
Global degradation patterns: backsheet

Backsheet degradation indicators:

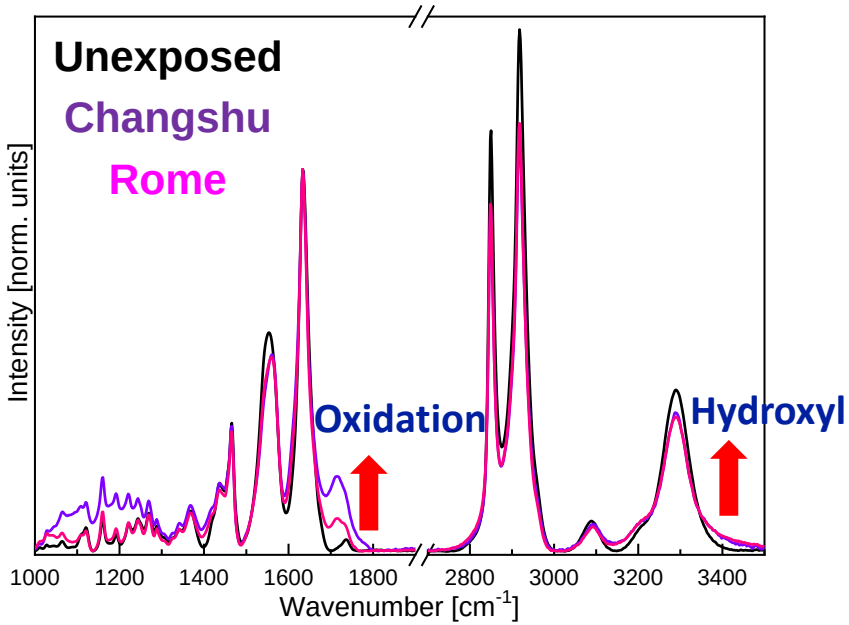
Yellowing



Gloss-loss



Oxidation, hydroxyl



Fairbrother A, et al. Degradation analysis of field-exposed photovoltaic modules with non-fluoropolymer-based backsheets, Proc. of SPIE 10370, **2017**, pp. 1037003

Lyu Y, et al. Impact of environmental variables on the degradation of photovoltaic components and perspectives for the reliability assessment methodology, Sol. Eng. 199, **2020**, pp. 425-436

Global degradation patterns: backsheet

Principle component analysis shows strong correlation between…

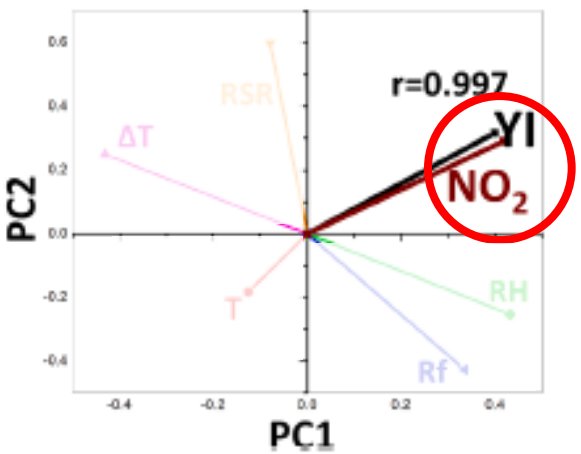
… yellowing and NO_2 concentration

… oxidation and reflected solar radiation

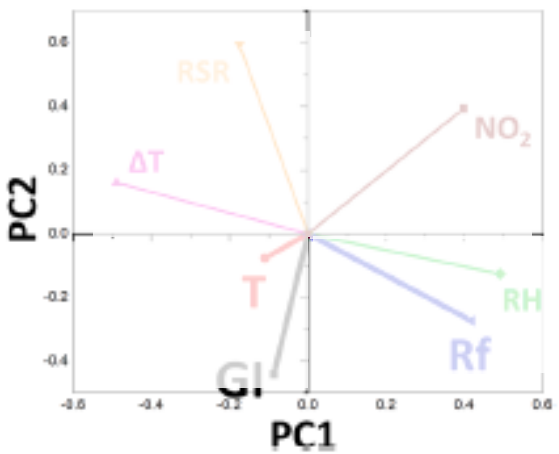
… hydroxyl formation and temperature

Proximity of parameters indicates strength of correlation

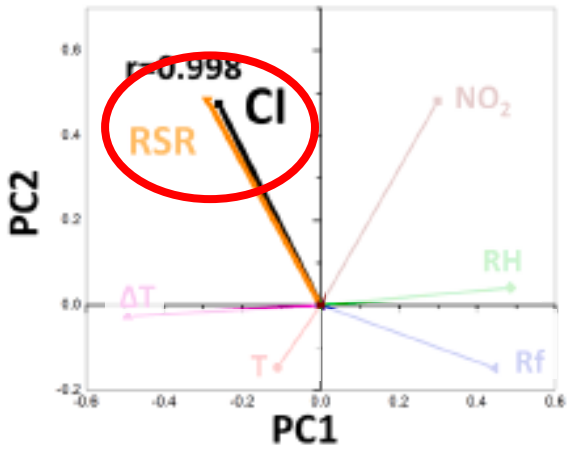
Yellowing



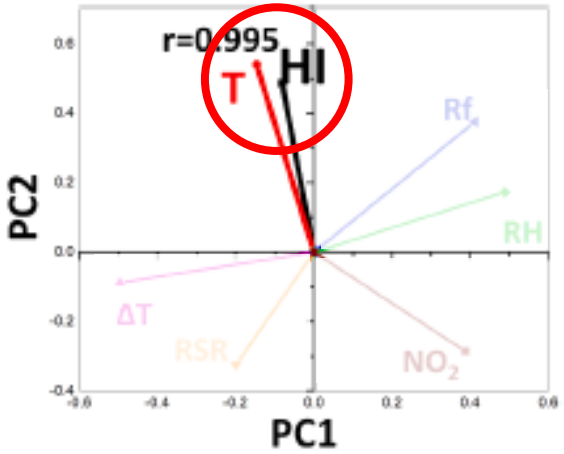
Gloss-loss



Oxidation



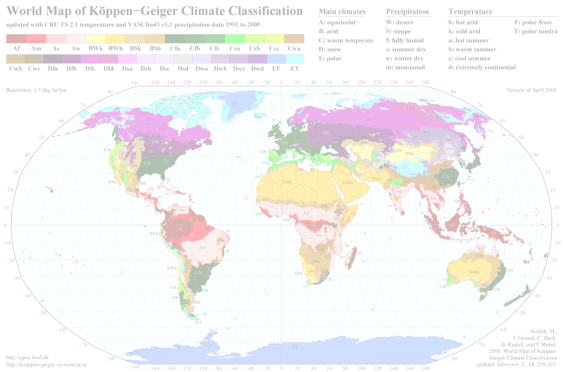
Hydroxyl



Degradation patterns: local

km — m — mm — µm

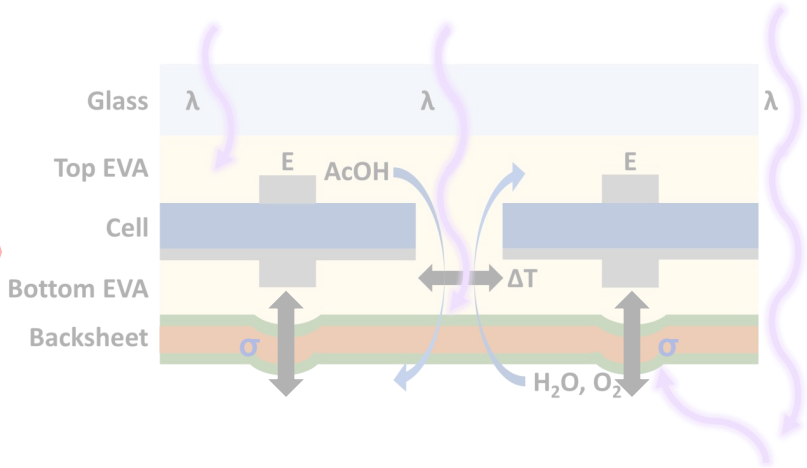
Global (climate)



Array

Module

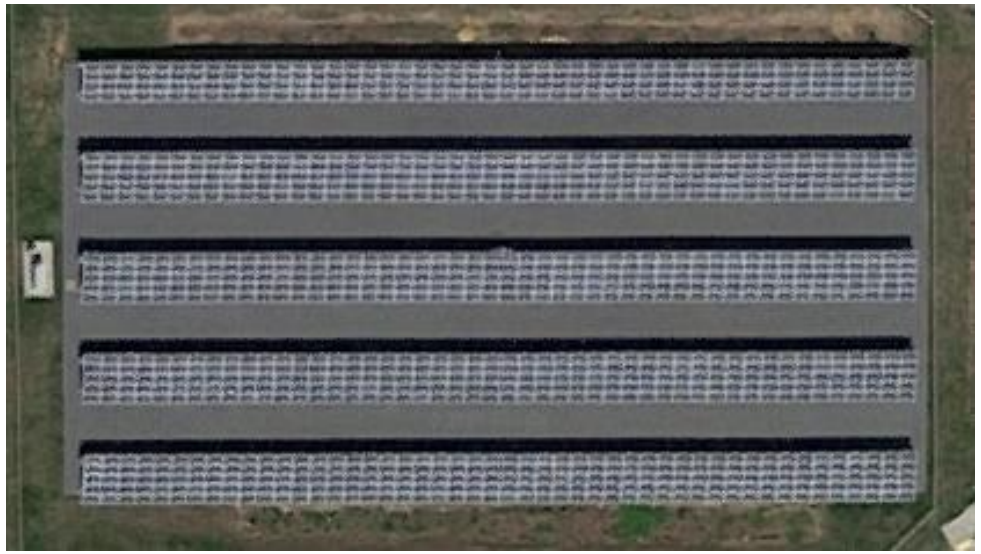
Sub-module



Array-level degradation patterns: backsheet

Utility scale array in Maryland (US):

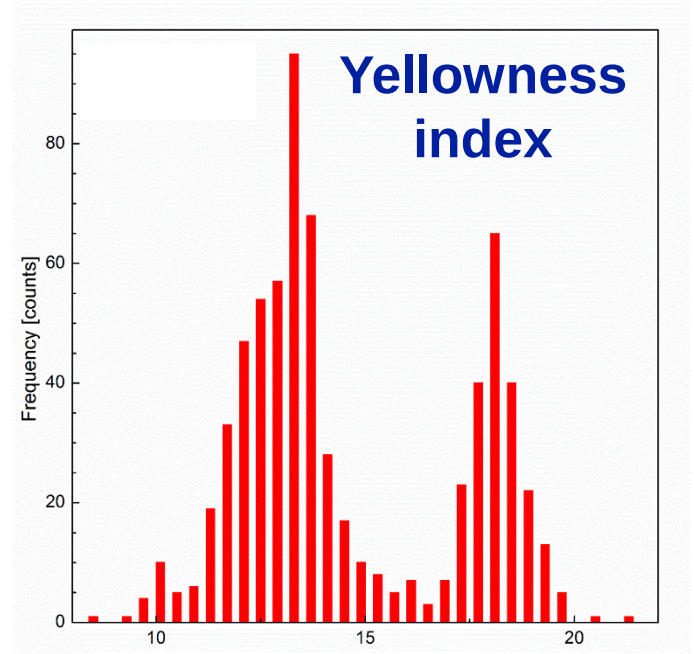
- Commissioned: 2014
- Rated production: 271 kWp (1152 modules)
- Backsheet: PEN-based

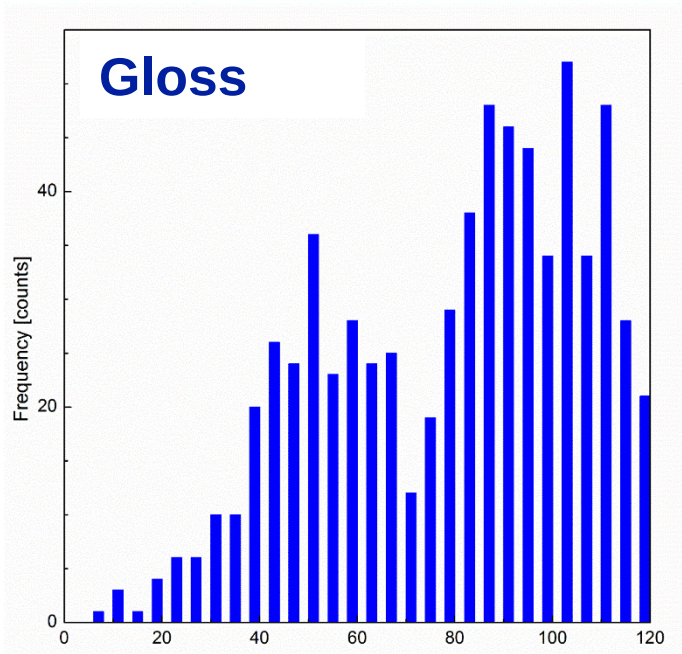


Fairbrother A, et al. Differential degradation patterns of photovoltaic backsheets at the array level, Sol. Eng. 163, **2018**, pp. 62-69

Array-level degradation patterns: backsheet

Backsheet degradation indicators for the array:



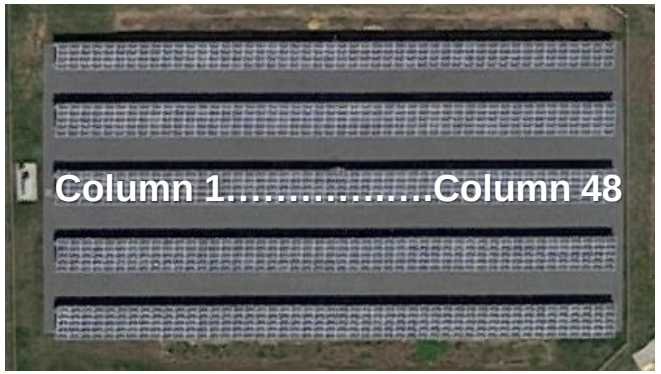


Fairbrother A, et al. Differential degradation patterns of photovoltaic backsheets at the array level, Sol. Eng. 163, **2018**, pp. 62-69

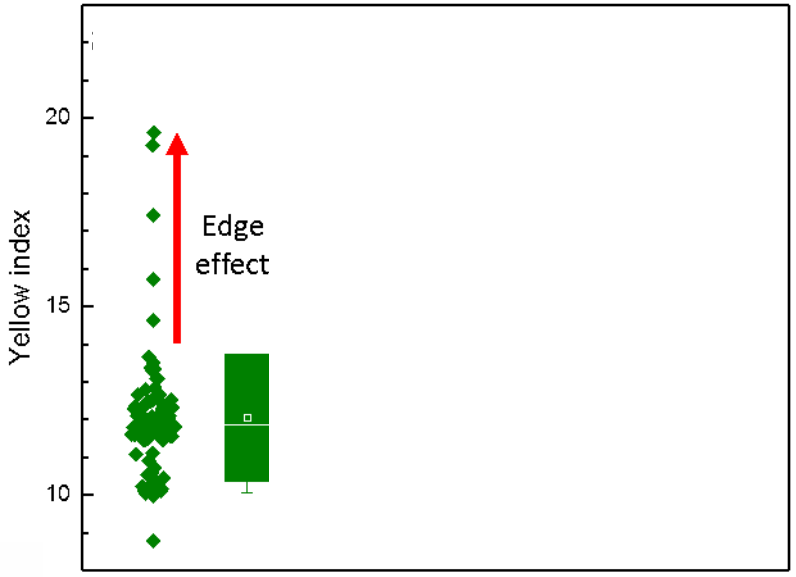
Array-level degradation patterns: backsheet

More advanced degradation in modules situated…

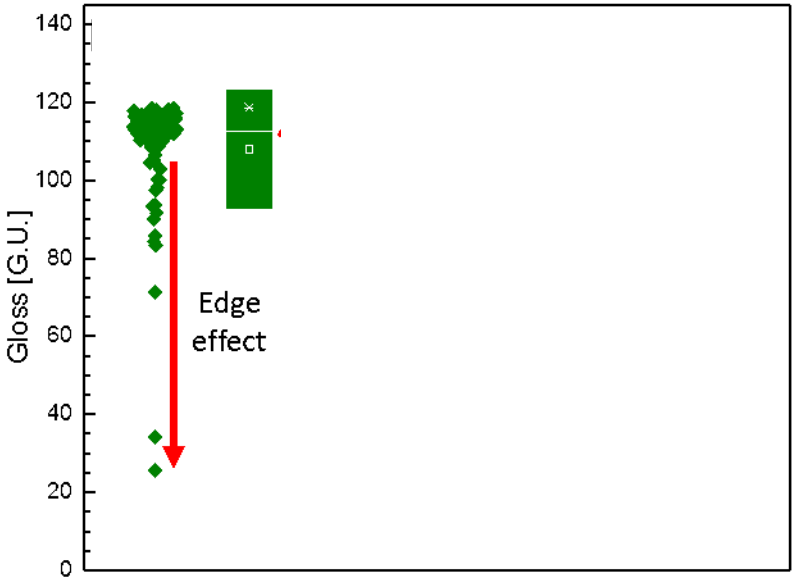
… closer to edges of array



Yellowness index



Gloss



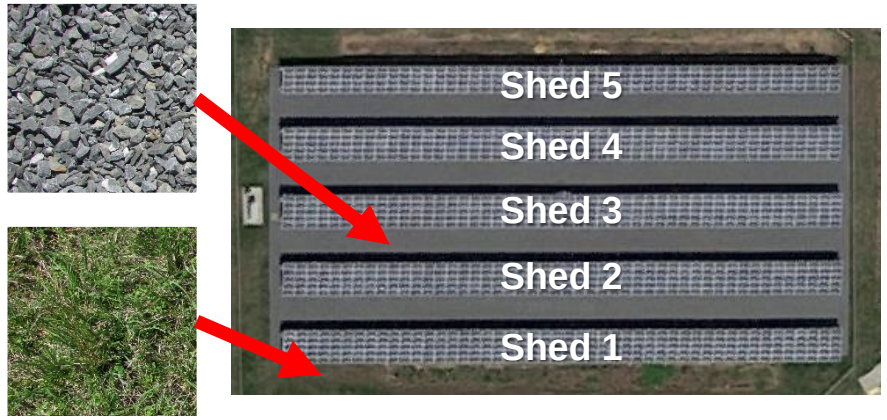
Fairbrother A, et al. Differential degradation patterns of photovoltaic backsheets at the array level, Sol. Eng. 163, **2018**, pp. 62-69

Array-level degradation patterns: backsheet

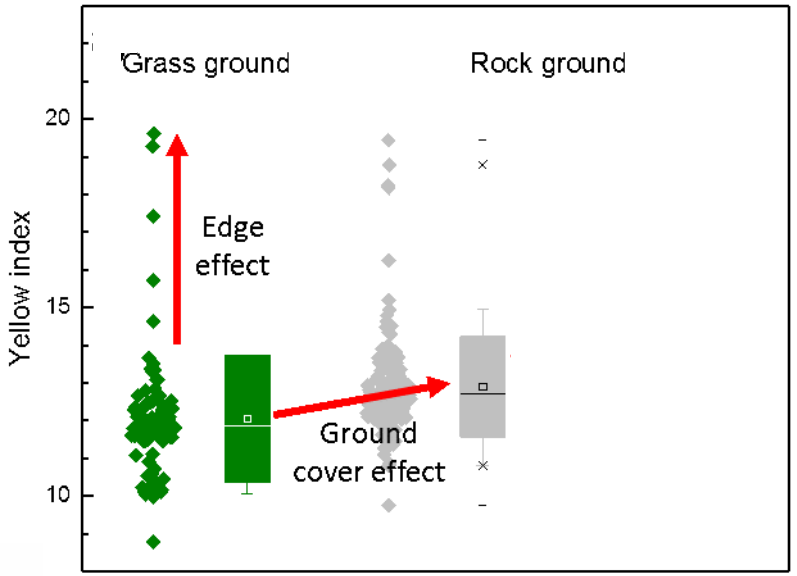
More advanced degradation in modules situated…

… closer to edges of array

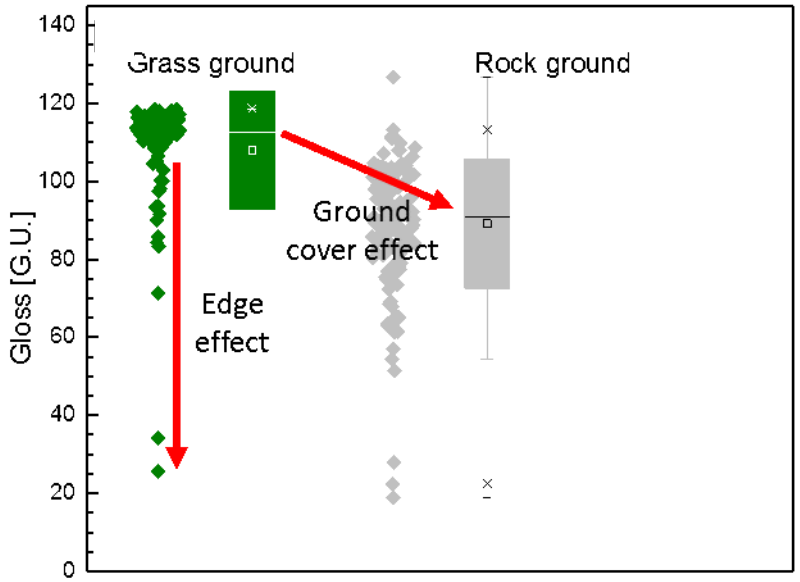
… above certain types of ground



Yellowness index



Gloss



Fairbrother A, et al. Differential degradation patterns of photovoltaic backsheets at the array level, Sol. Eng. 163, **2018**, pp. 62-69

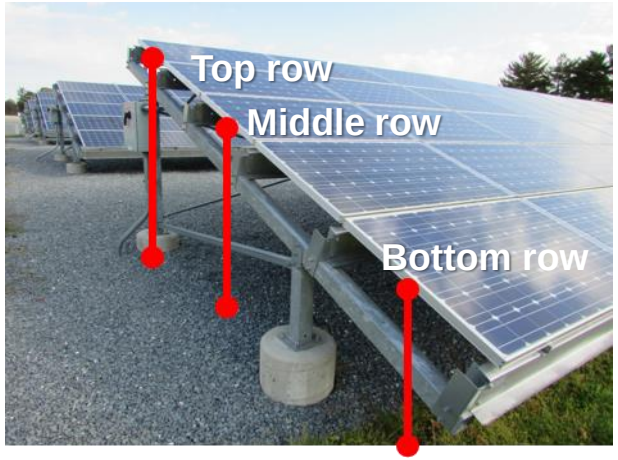
Array-level degradation patterns: backsheet

More advanced degradation in modules situated…

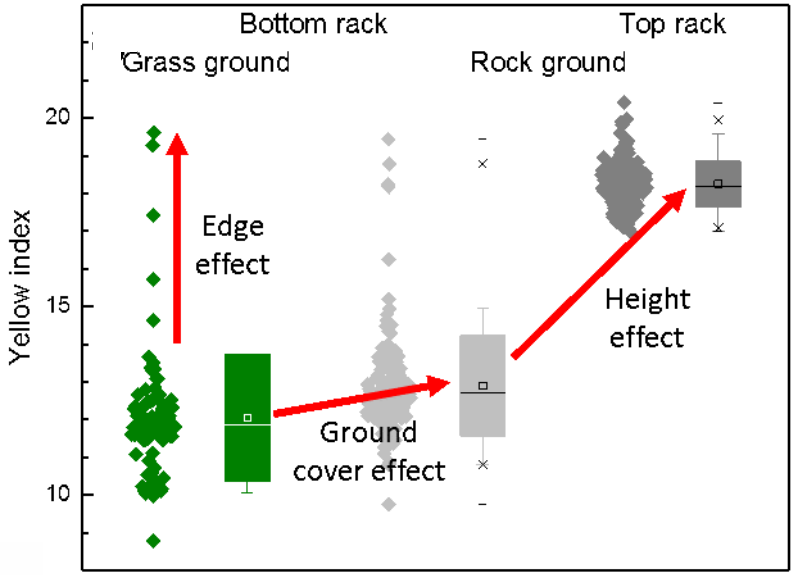
… closer to edges of array

… above certain types of ground

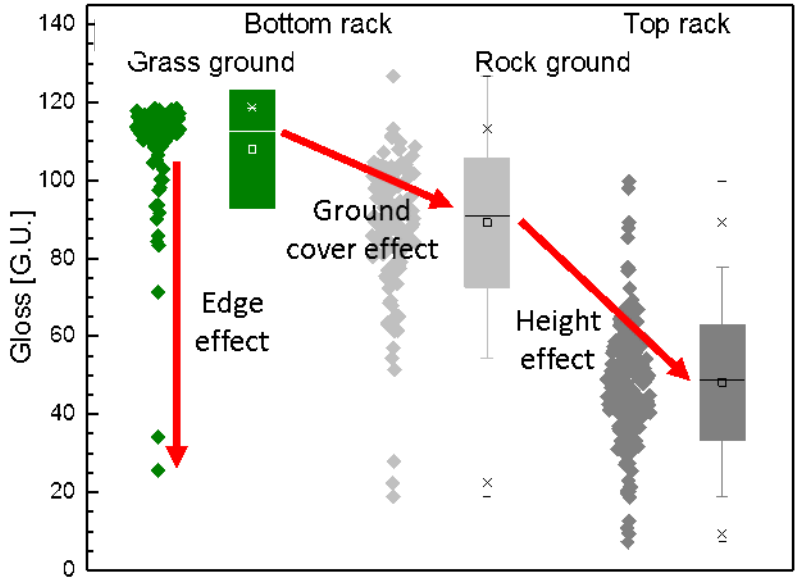
… with higher elevation



Yellowness index



Gloss



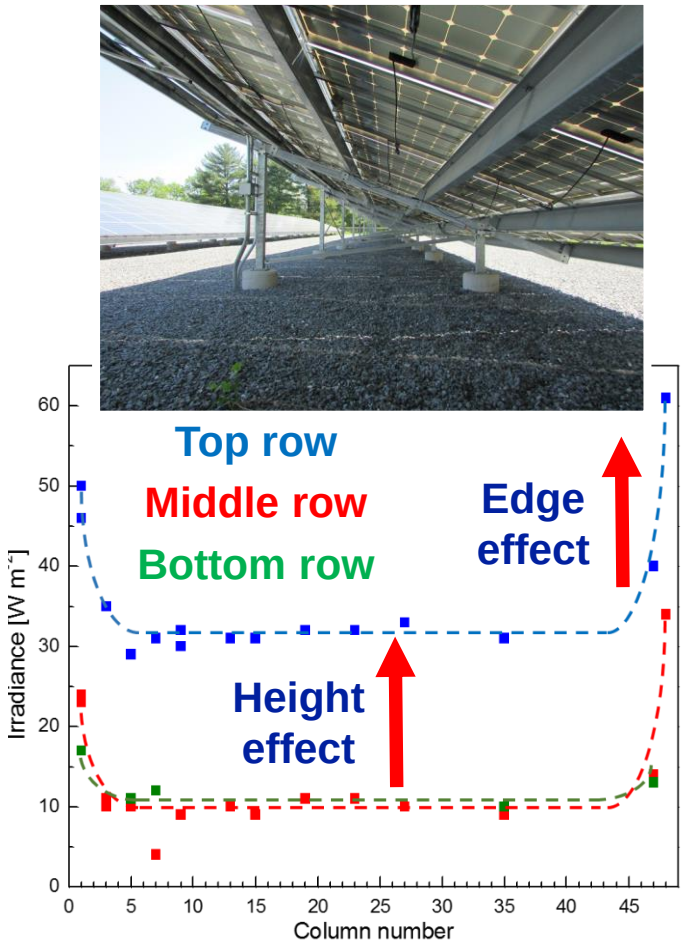
Fairbrother A, et al. Differential degradation patterns of photovoltaic backsheets at the array level, Sol. Eng. 163, **2018**, pp. 62-69

Array-level degradation patterns: backsheet

Backside irradiance varies by module position:

Environmental factors: ground albedo

Structural factors: light-blocking structures



Array-level degradation patterns: backsheet

Backside irradiance varies by module position:

→ environmental, structural

Other local exposure variables:

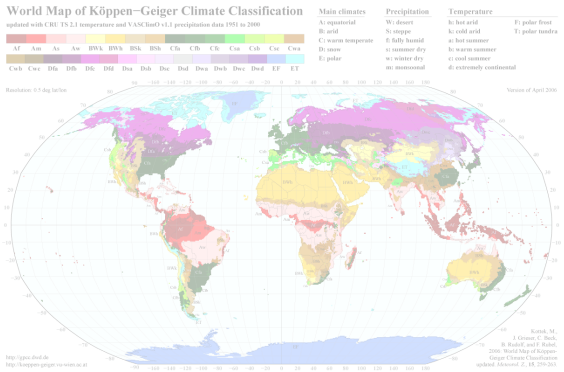
- Temperature → wind, BIPV v. rack-mount
- Mechanical loads → wind, vibrations
- Moisture → waterfront
- Pollutants, soiling → industrial zones, roadside, roof exhaust

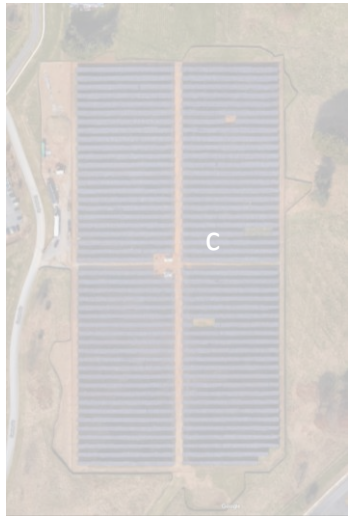
Fairbrother A, et al. Differential degradation patterns of photovoltaic backsheets at the array level, Sol. Eng. 163, **2018**, pp. 62-69

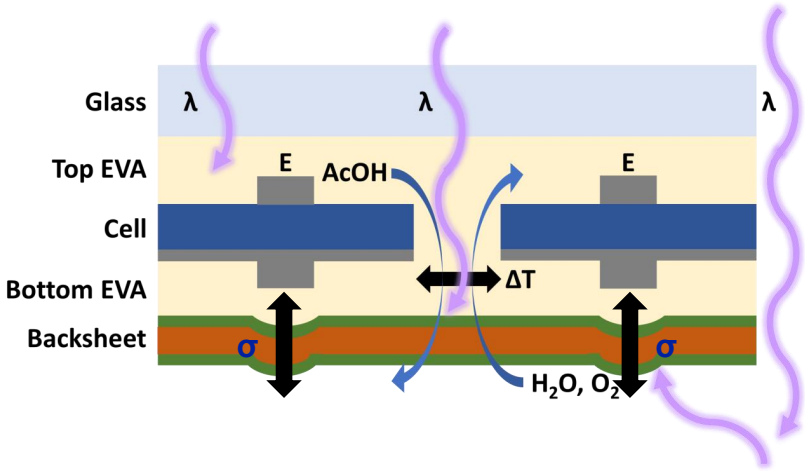
Degradation patterns: sub-module

km — m — mm — µm

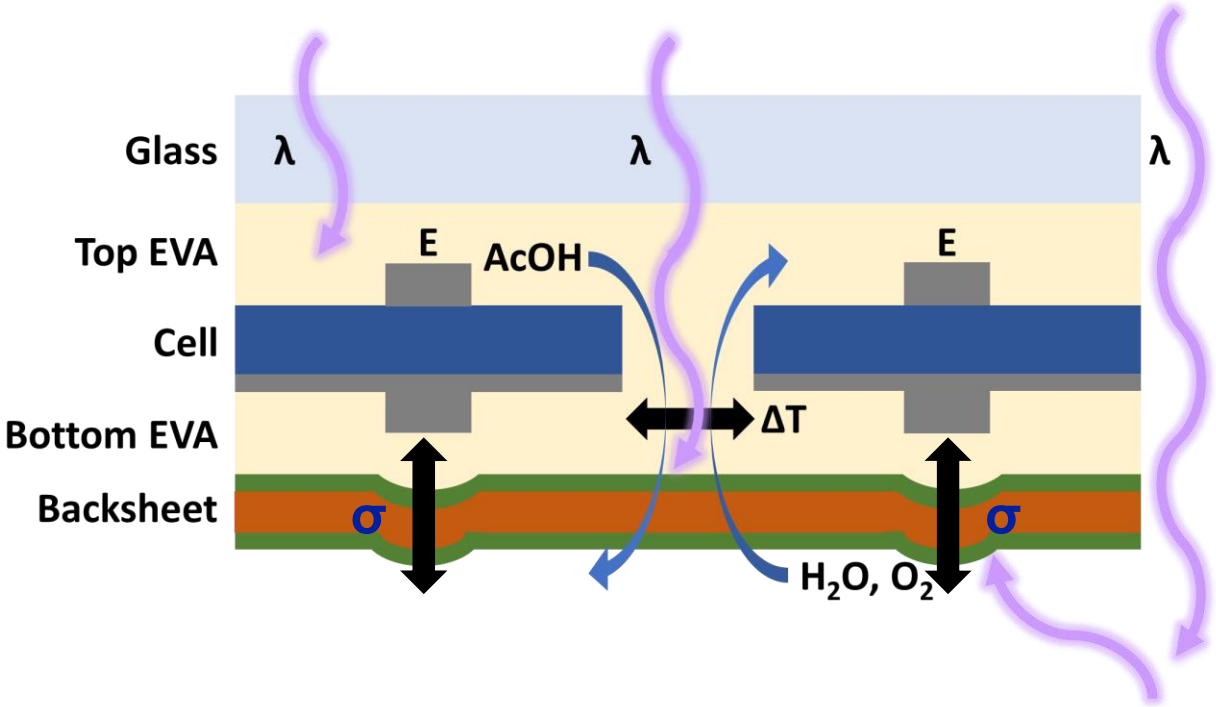
Global (climate) | Array | Module | **Sub-module**

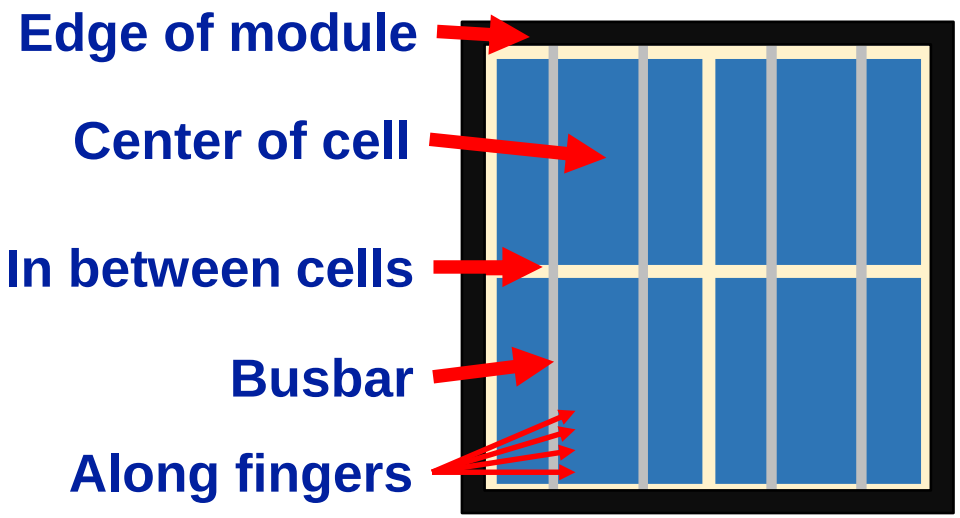






Degradation patterns: sub-module

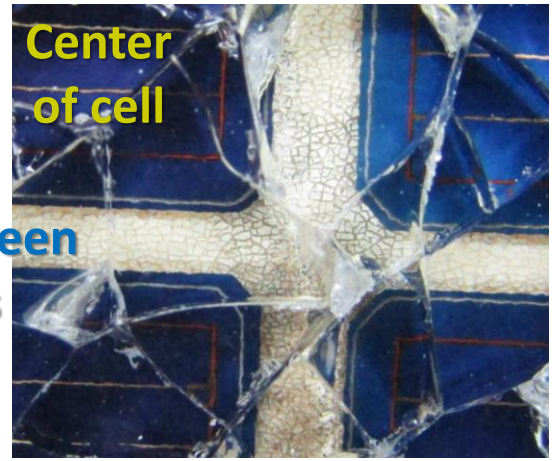


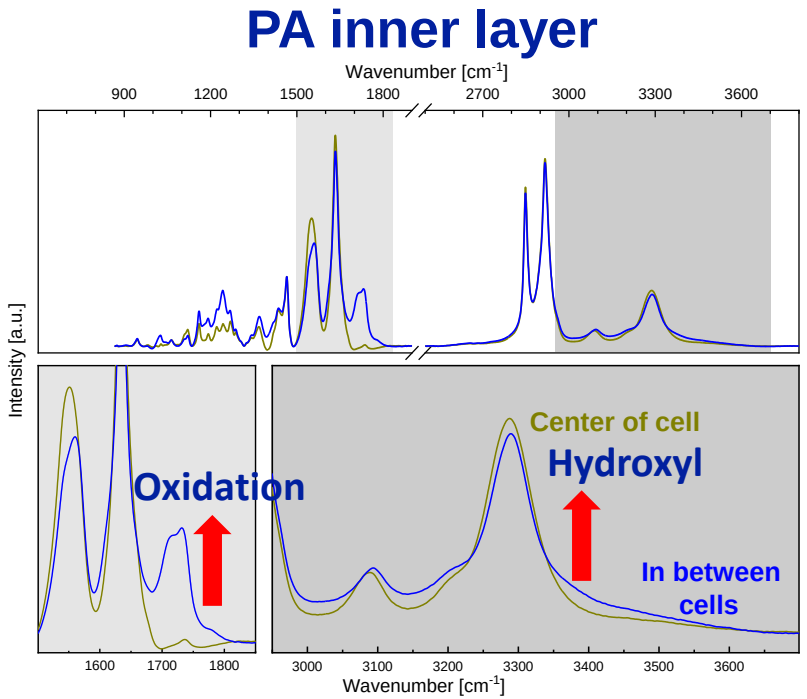


Component tests often fail to fully replicate real-world conditions

Sub-module degradation patterns: backsheet

PA/PA/PA backsheet cracking initiated by inner layer degradation



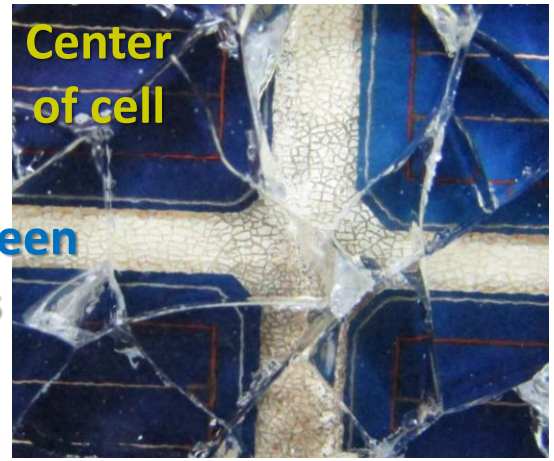


UV, heat, humidity not sufficient to reproduce this degradation

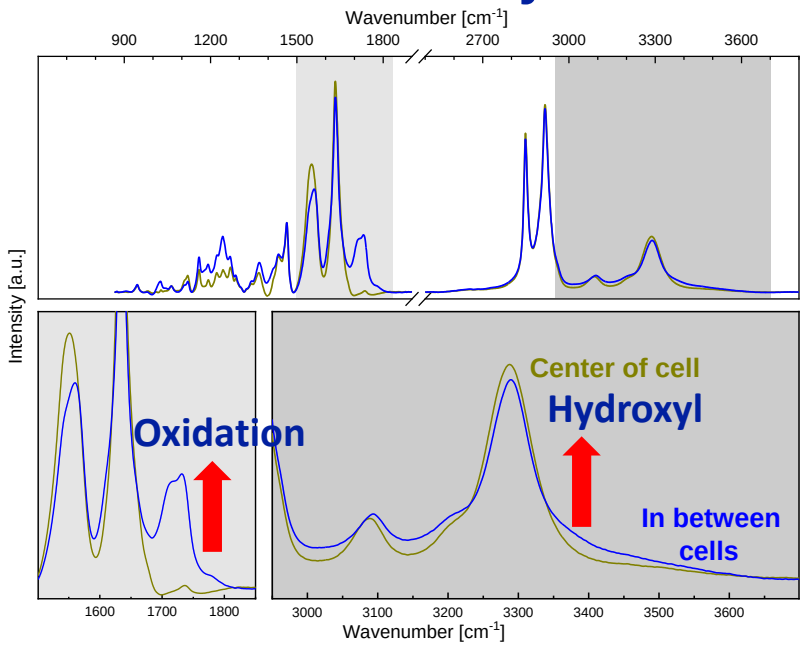
Lyu Y, et al. Drivers for the cracking of multilayer polyamide-based backsheets in field photovoltaic modules: In-depth degradation mapping analysis, Prog. Photovolt. **2020**, pp. 1-13

Sub-module degradation patterns: backsheet

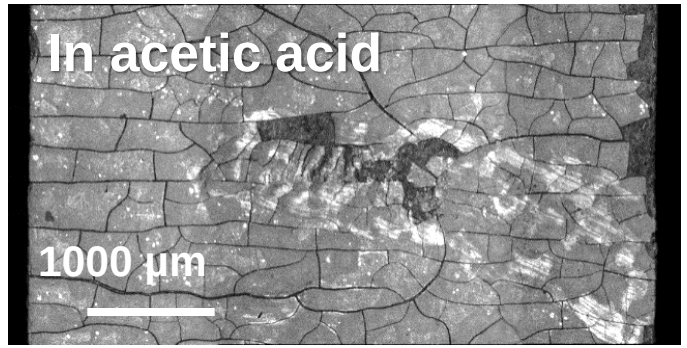
PA/PA/PA backsheet cracking initiated by inner layer degradation

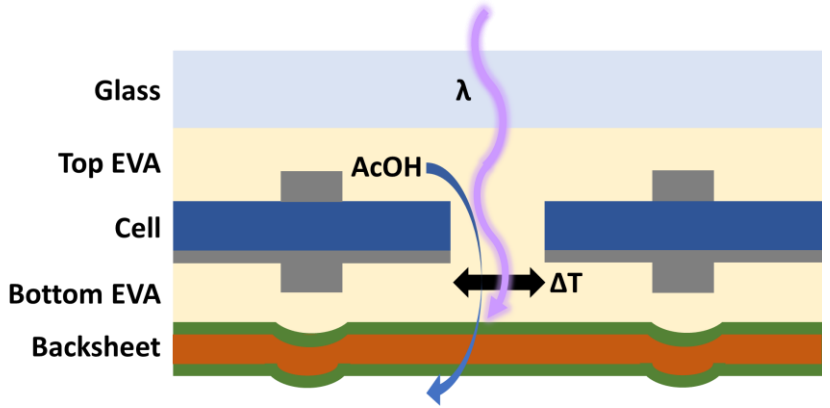


PA inner layer



Outdoor exposure

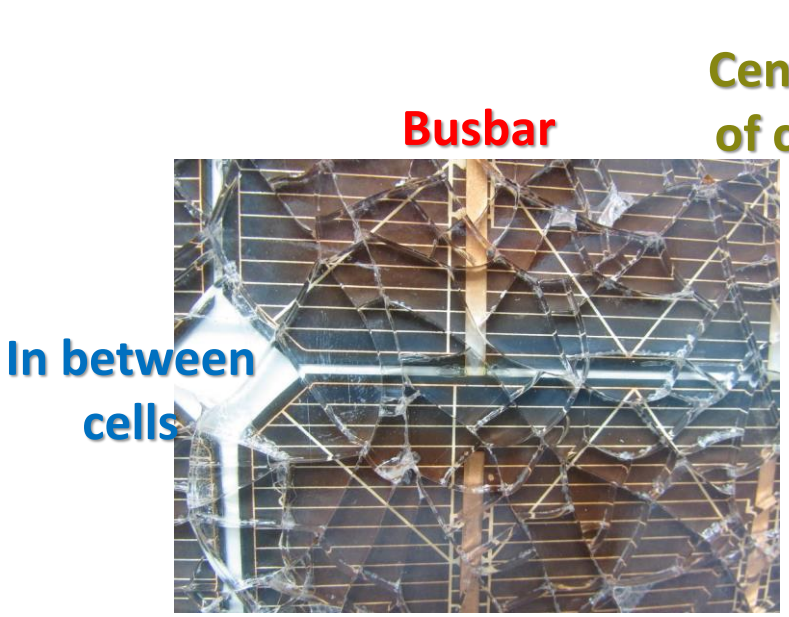


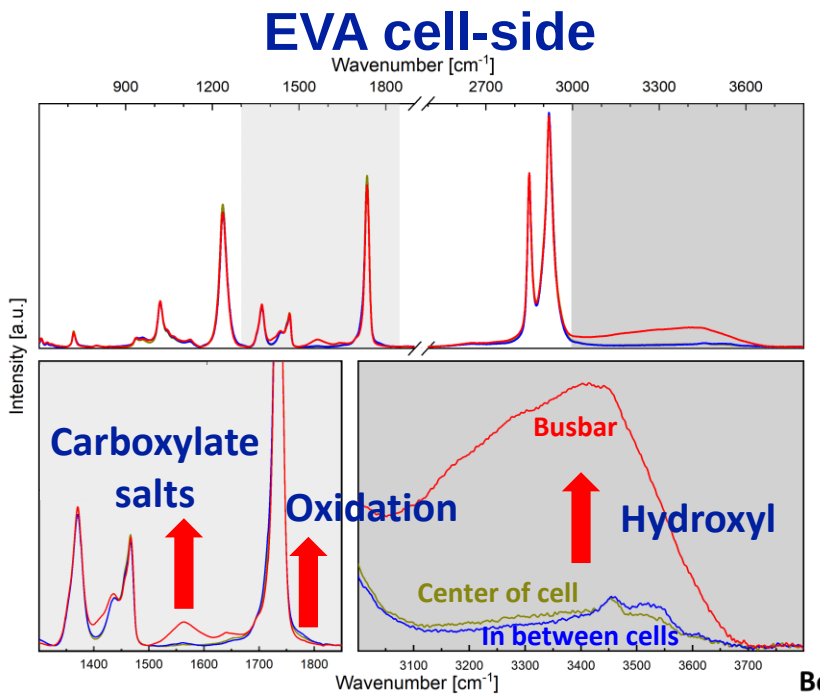


Lyu Y, et al. Drivers for the cracking of multilayer polyamide-based backsheets in field photovoltaic modules: In-depth degradation mapping analysis, Prog. Photovolt. **2020**, pp. 1-13

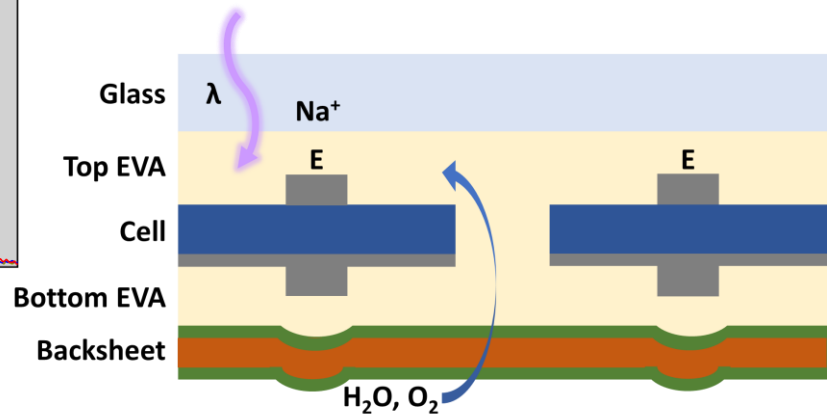
Sub-module degradation patterns: encapsulant

EVA encapsulant





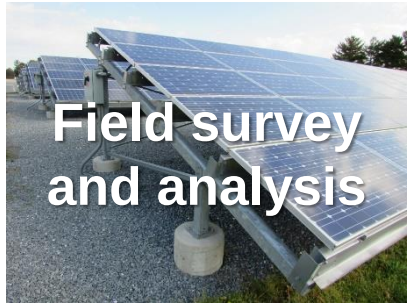
Interfacial degradation products lower adhesion



Improving test, module, and array design

Continuous feedback between field and laboratory:

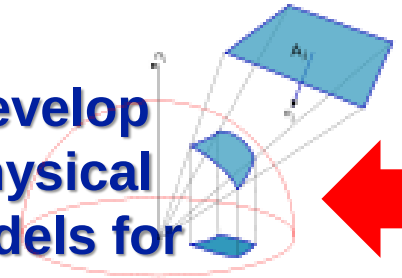
Consider…material interaction in BOM
…local factors in PV plant design



Define real service conditions

Identify key environmental stressors

Accelerated testing with appropriate stress levels



Develop physical models for degradation

Validate with field data

Acknowledgements

Xiaohong Gu, Yadong Lyu, Brian Dougherty, Matthew Boyd…

Michael Kempe…

Laura Bruckman, Roger French, Yu Wang…

Funding: US DOE SunShot PREDICTS 2: Backsheets (DE-EE0007143)