Assessing end-of-life failure modes in PV modules

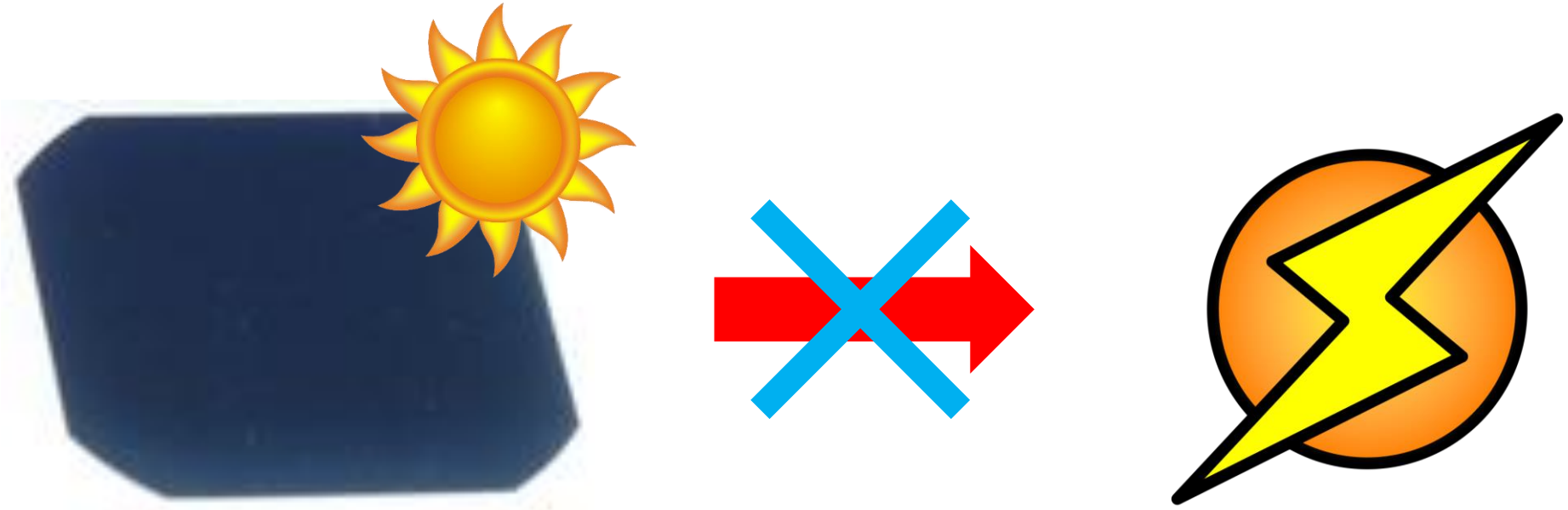
Andrew Fairbrother

PEARL PV WG2 webinar – 2 February 2020

PV-lab
IMT NEUCHATEL
EPFL

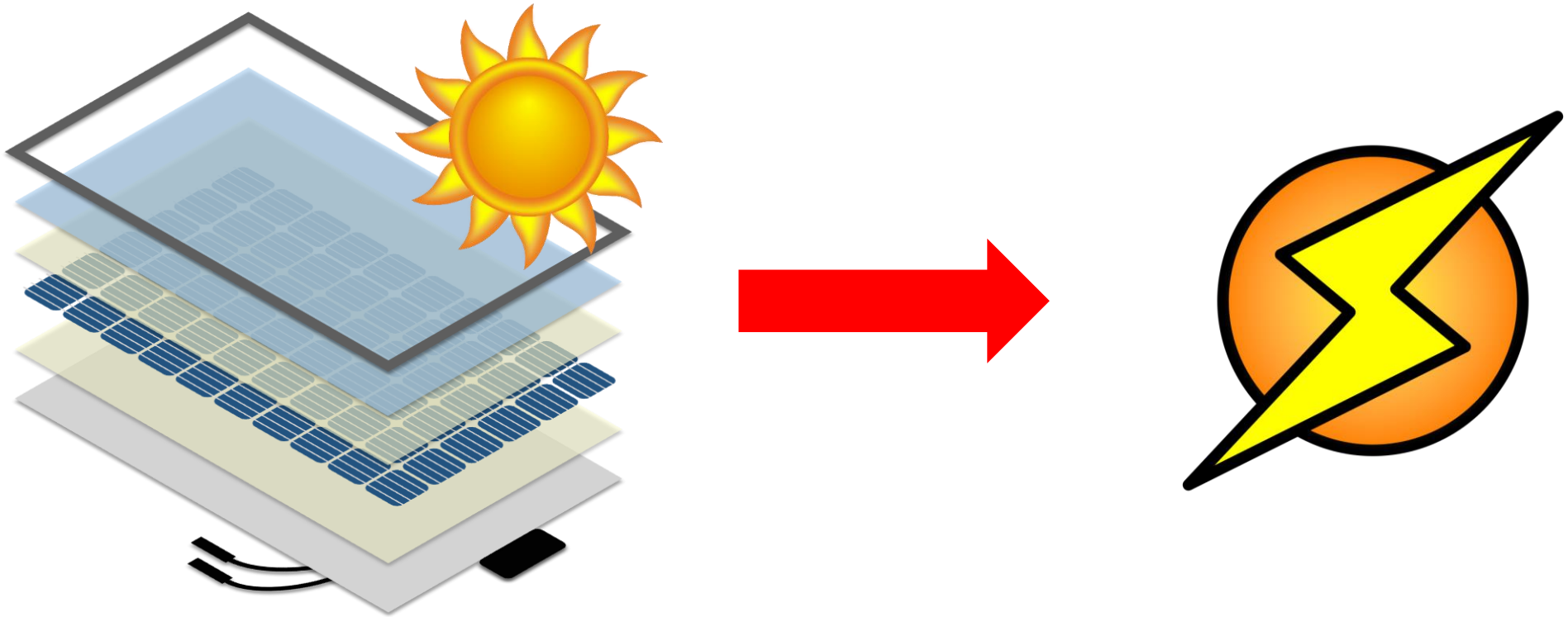
PV modules

Modules are more than silicon

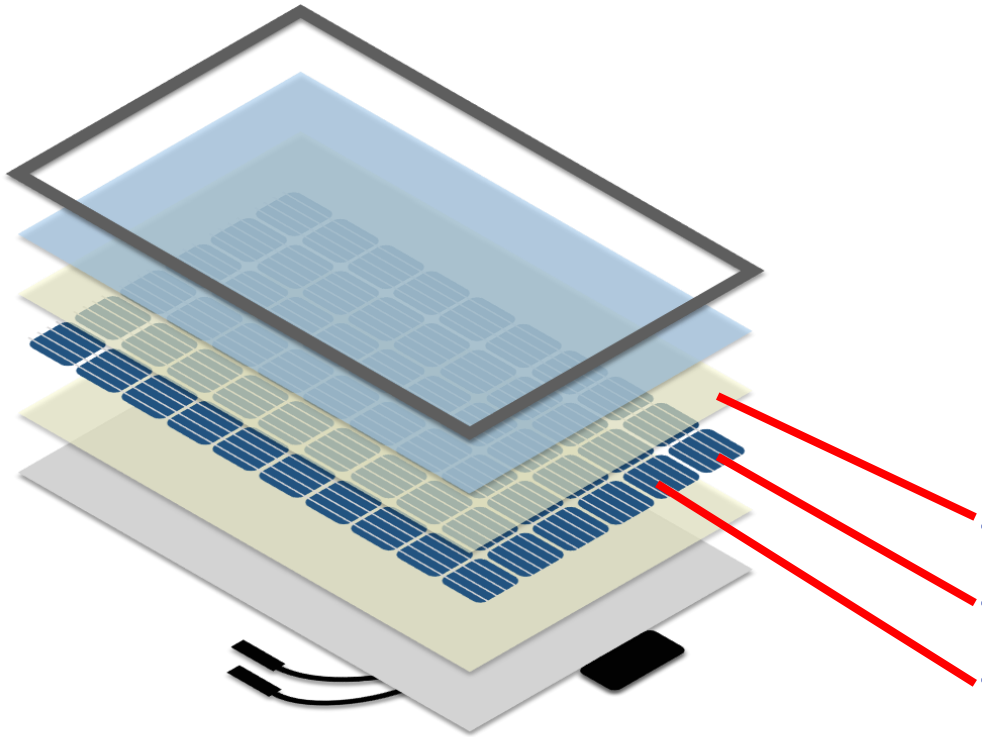


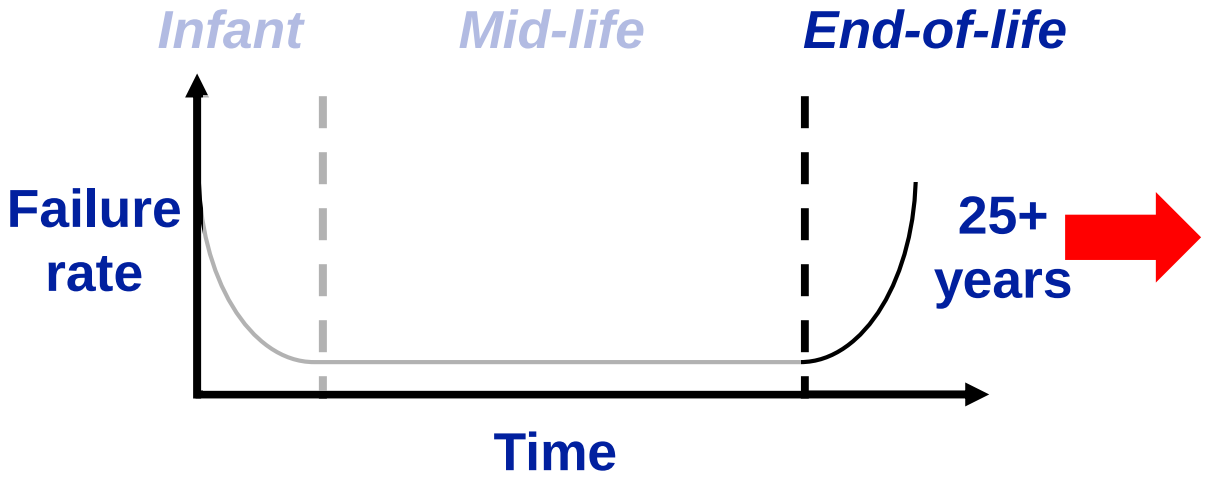
PV modules

Modules are more than silicon



Module end-of-life failure





- Packaging delamination
- Cell and interconnect corrosion
- Cracked cell isolation

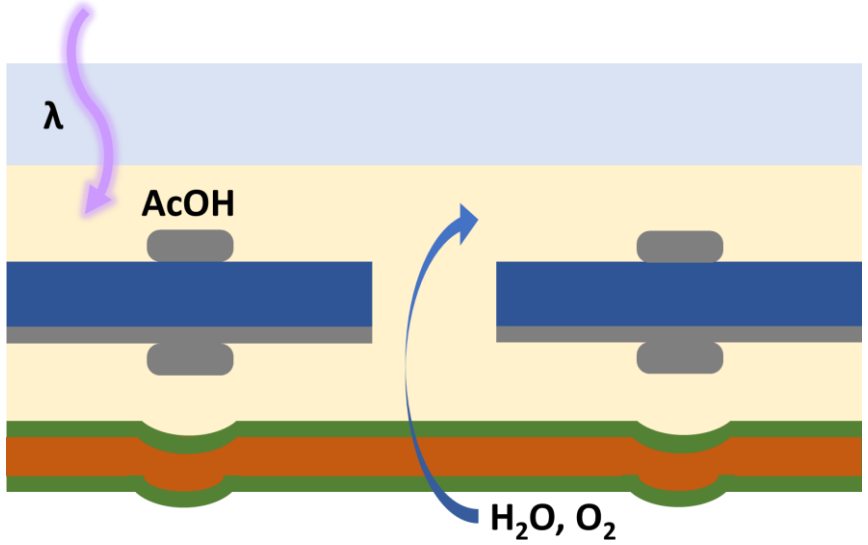
Risk factors for end-of-life failure

Delamination:

- BOM quality, compatibility
- Process (lamination) quality
- Interface degradation

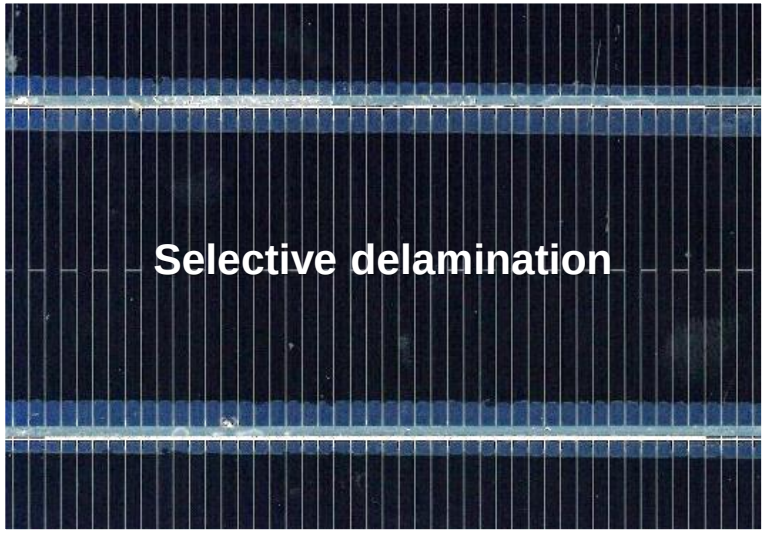
Corrosion:

- Moisture ingress
- EVA degradation (acetic acid generation)
- Electrical currents

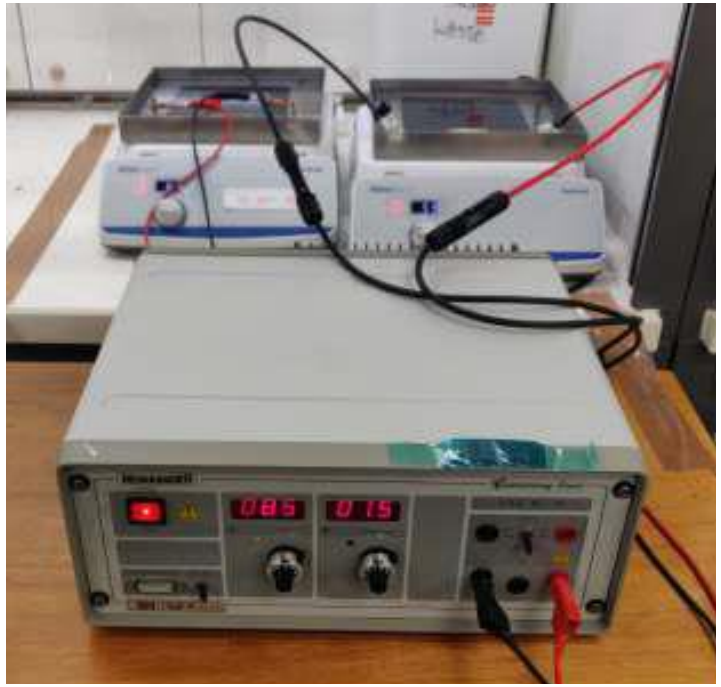


Test to failure

1. Accelerated delamination tests

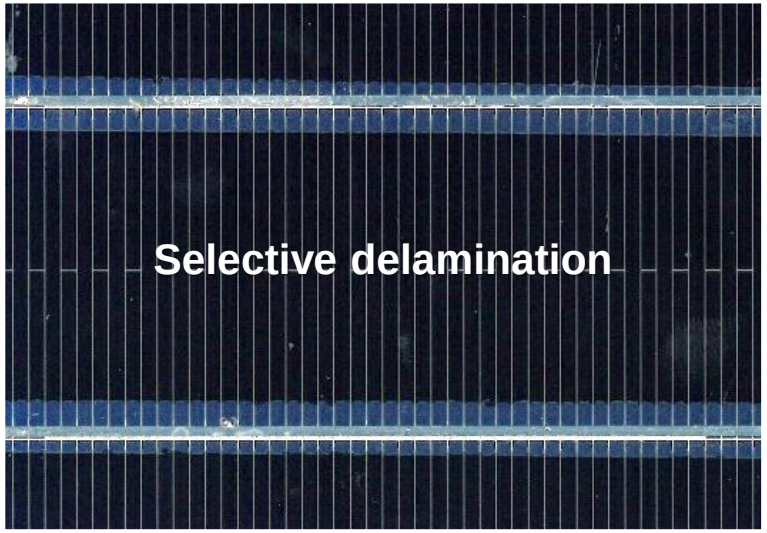


2. Accelerated acid corrosion tests

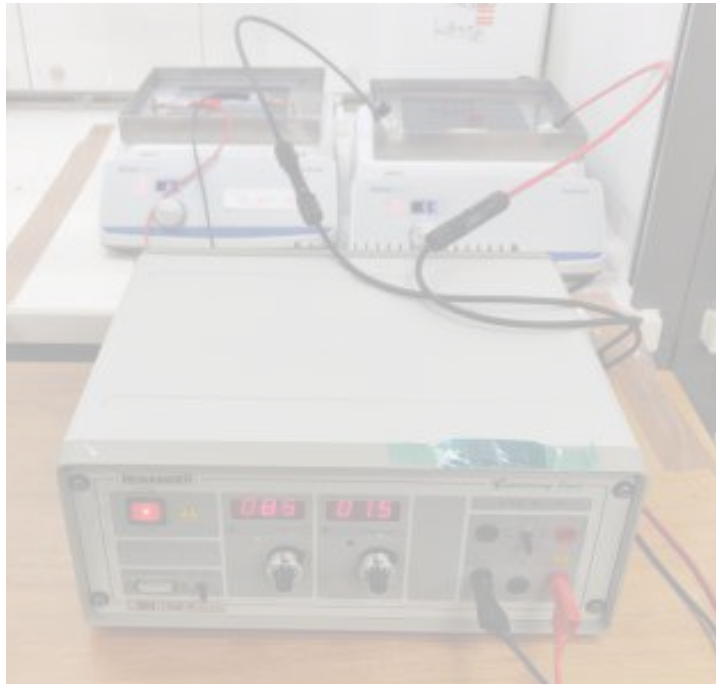


Test to failure

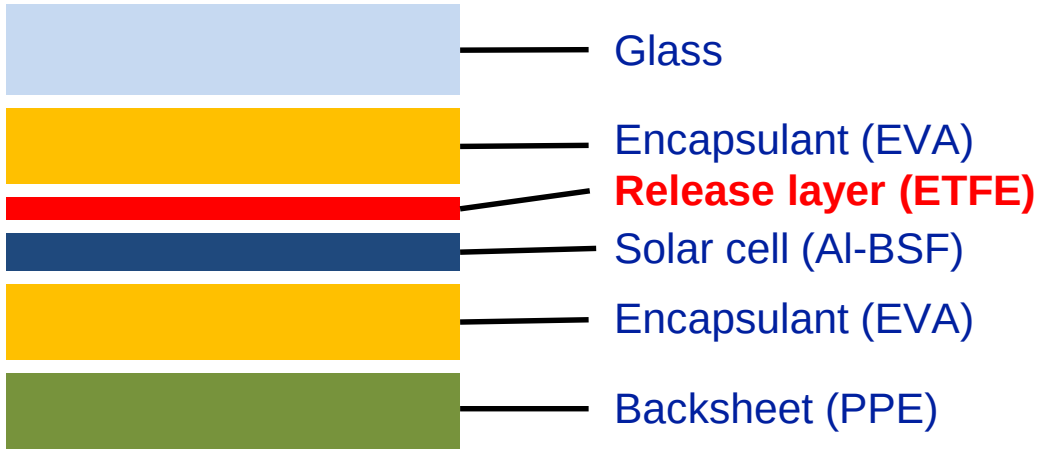
1. Accelerated delamination tests



2. Accelerated acid corrosion tests

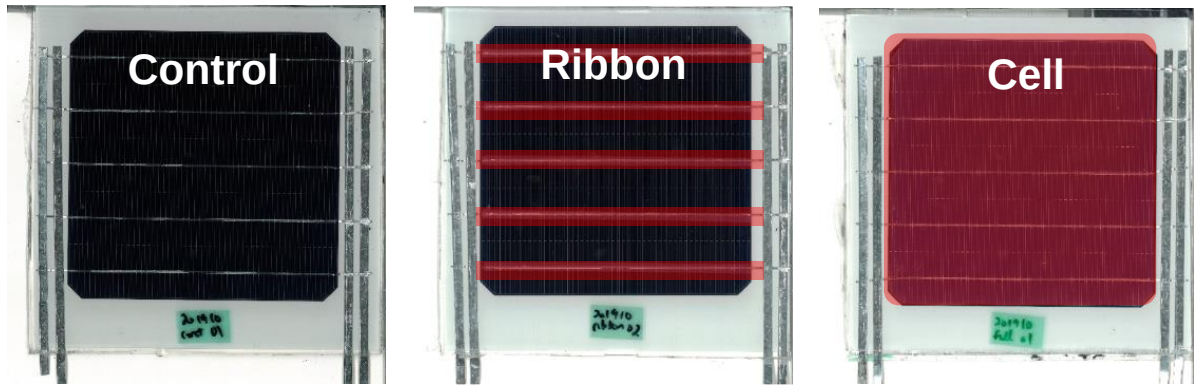


Accelerated delamination tests



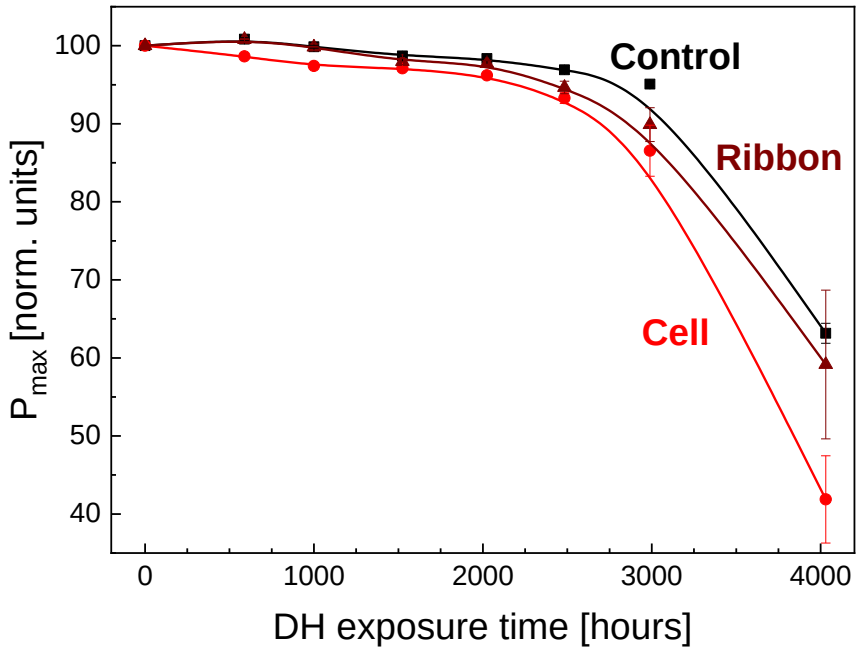
Weathering test	Conditions
Damp heat	**85°C/85% RH**
Thermal cycling	-40°C to 85°C
UV	UVA fluor. 0.7 W m^{-2} (@340 nm), 65°C
Outdoor	Neuchâtel, CH

Increasing delamination area

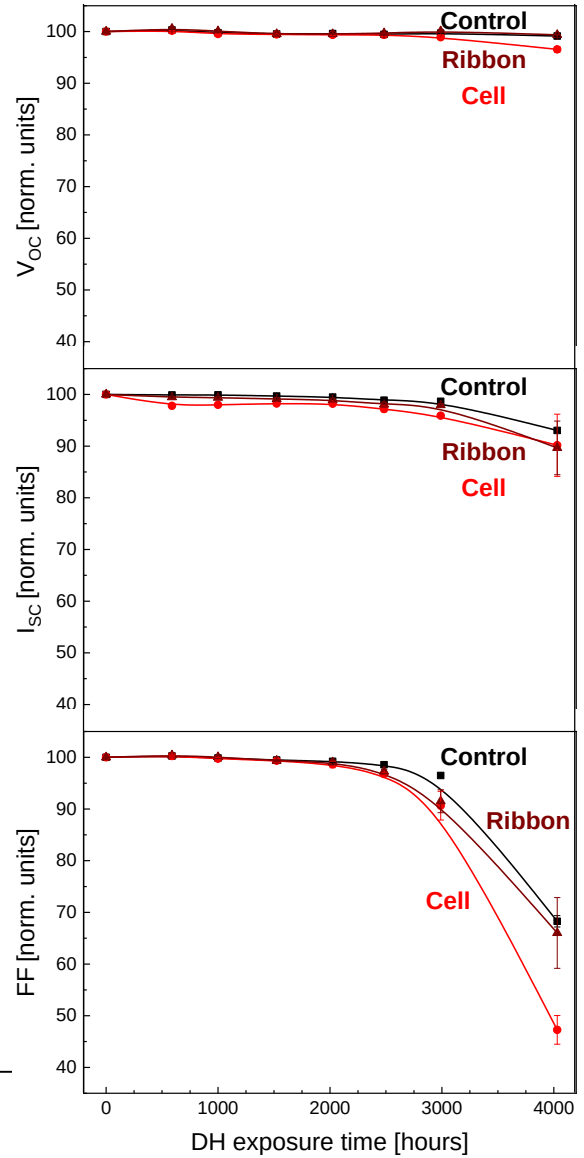


Delamination: module performance

>2 times rate of power loss for full cell delamination in damp heat



Increasing delamination area



Open circuit voltage

Short circuit current

Fill factor

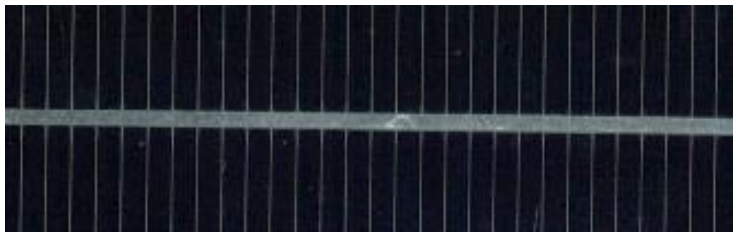
PV-lab
IMT NEUCHATEL

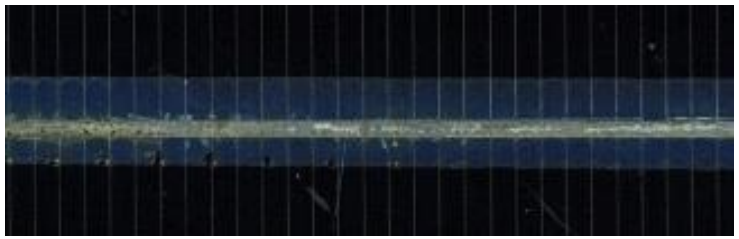
Delamination: degradation mechanism

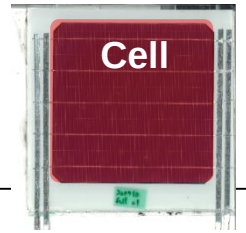
Delamination facilitates corrosion

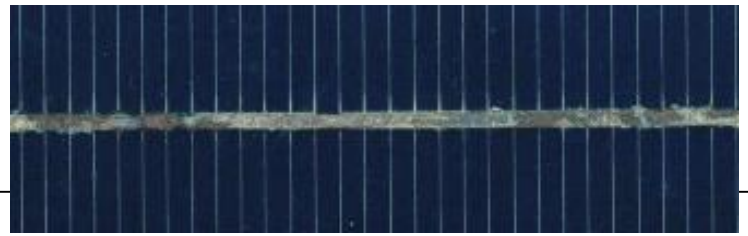
Damp heat 3000 hours

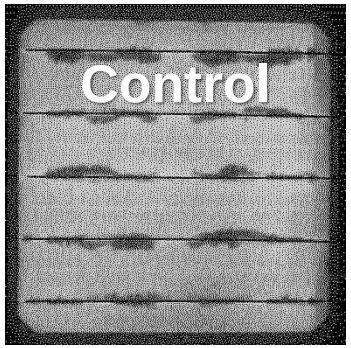
Increasing delamination area

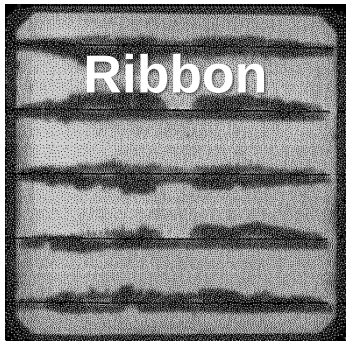


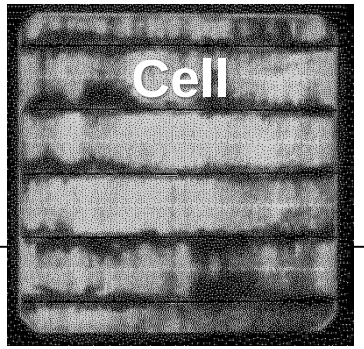






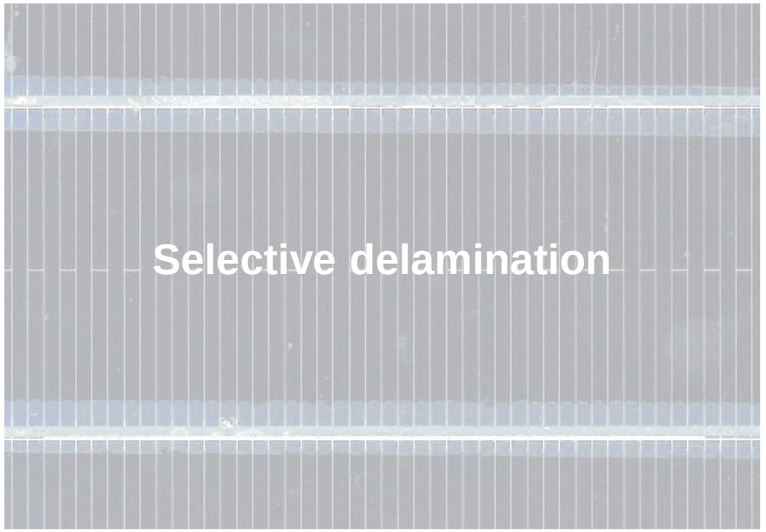




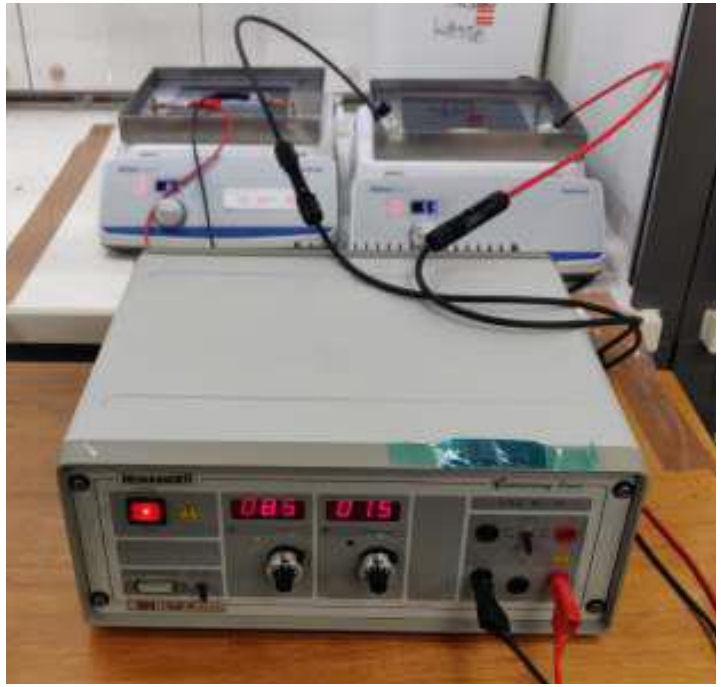


Test to failure

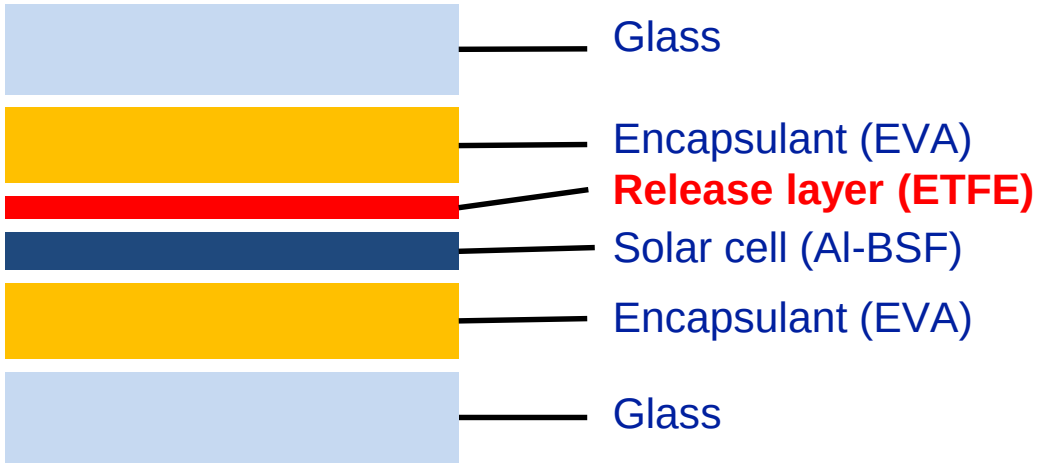
1. Accelerated delamination tests

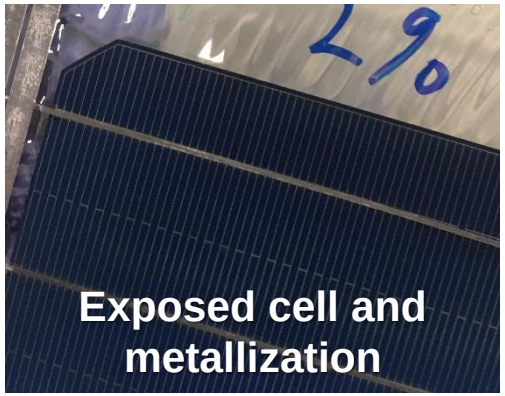


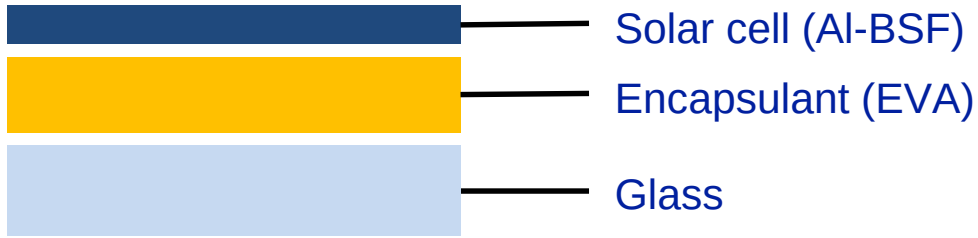
2. Accelerated acid corrosion tests

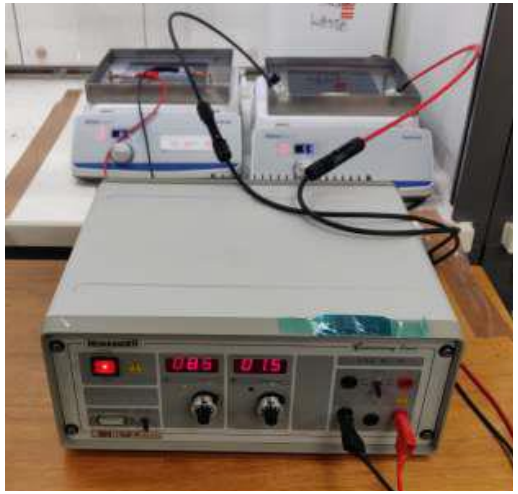


Accelerated acid corrosion tests









Acid conc. [v/v%]		Temperature [ºC]	Electrical bias [A]
Acetic acid	0	20	0
	***0.1**	40	***8.5**
	1.0	***60**	
	2.0	***80**	
	5.0		
	10.0		

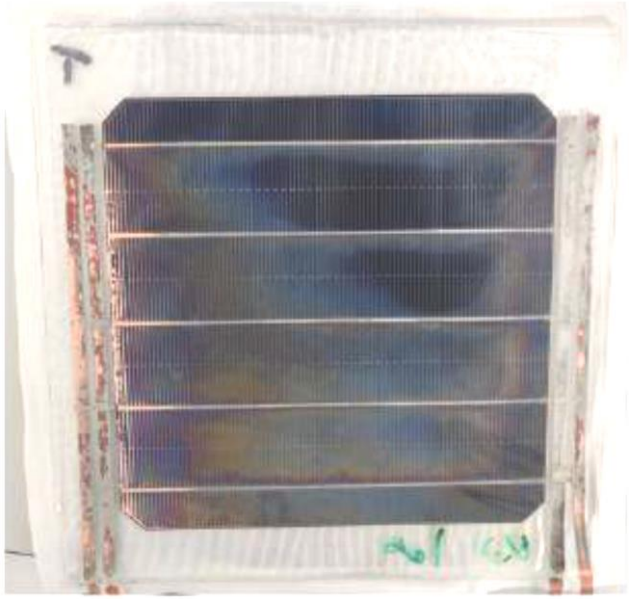
***Realistic worst-case field conditions**

PV-lab IMT NEUCHATEL

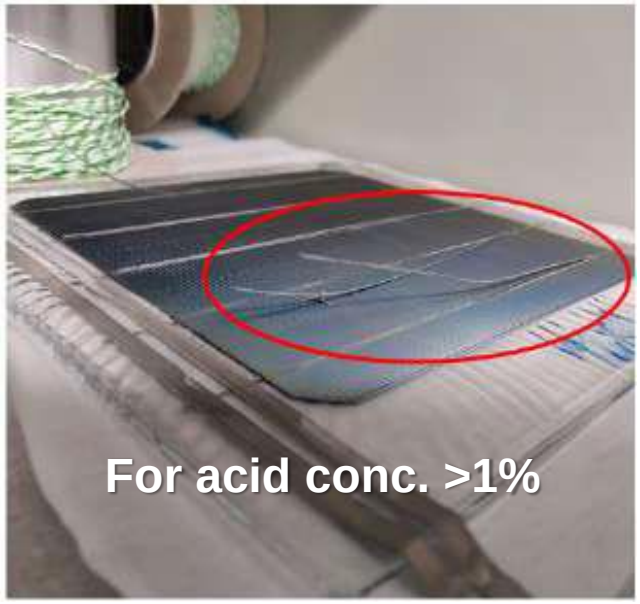
EPFL

Corrosion: visual evidence

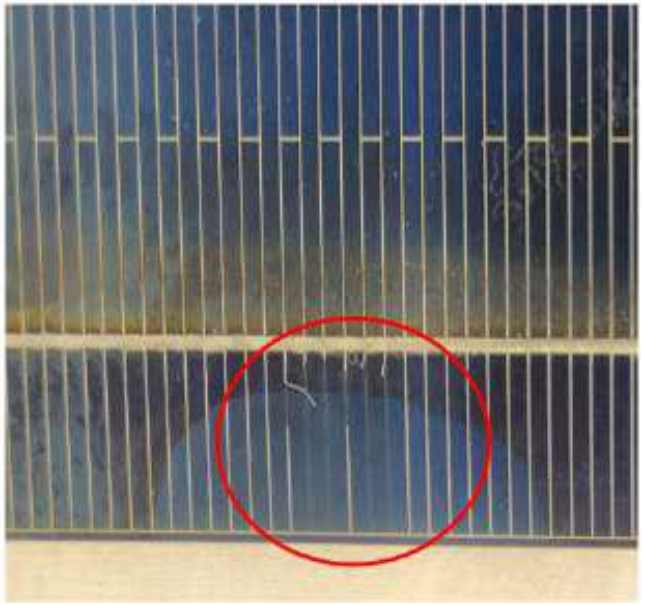
Discoloration



Ribbon detachment



Finger detachment

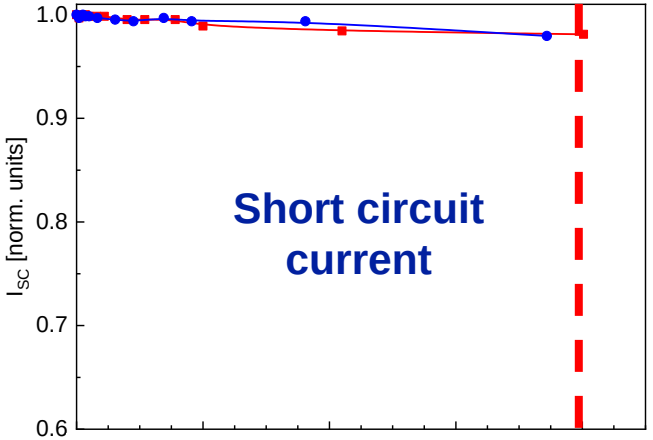


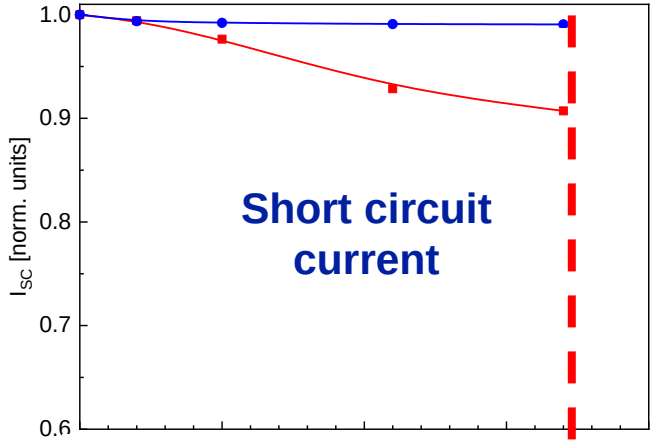
Tests with >1% acid too aggressive

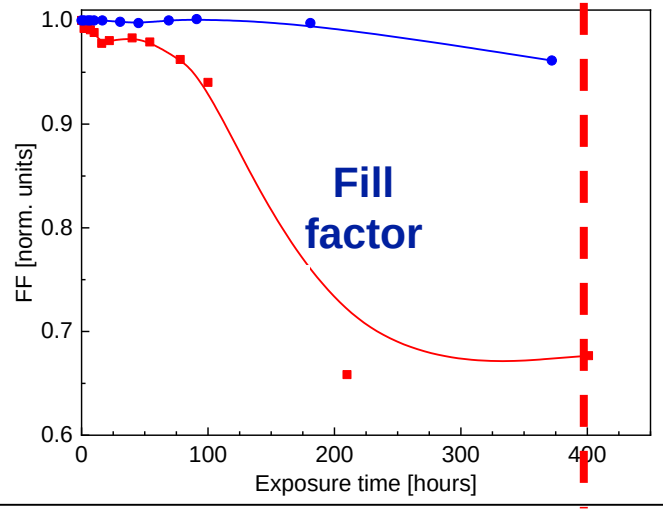
Corrosion: module performance

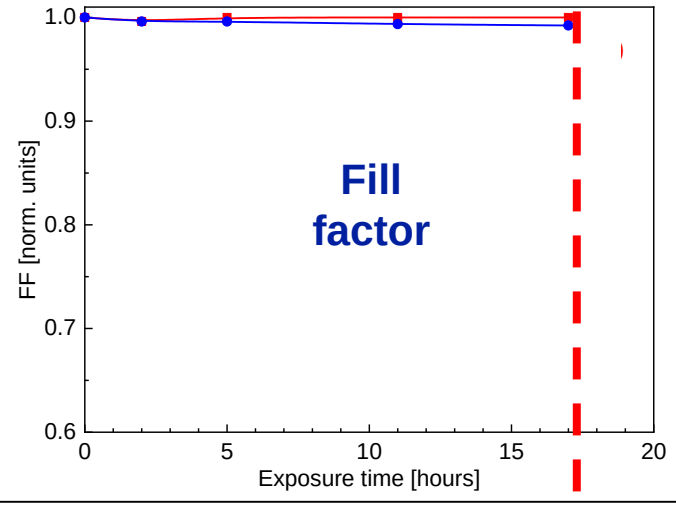
Application of bias accelerates corrosion, alters loss mechanism

Water
1% acid
60ºC
No bias

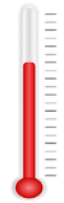








Water
1% acid
60ºC
8.5 bias



FF loss dominates

I_{SC} loss dominates

400 hours

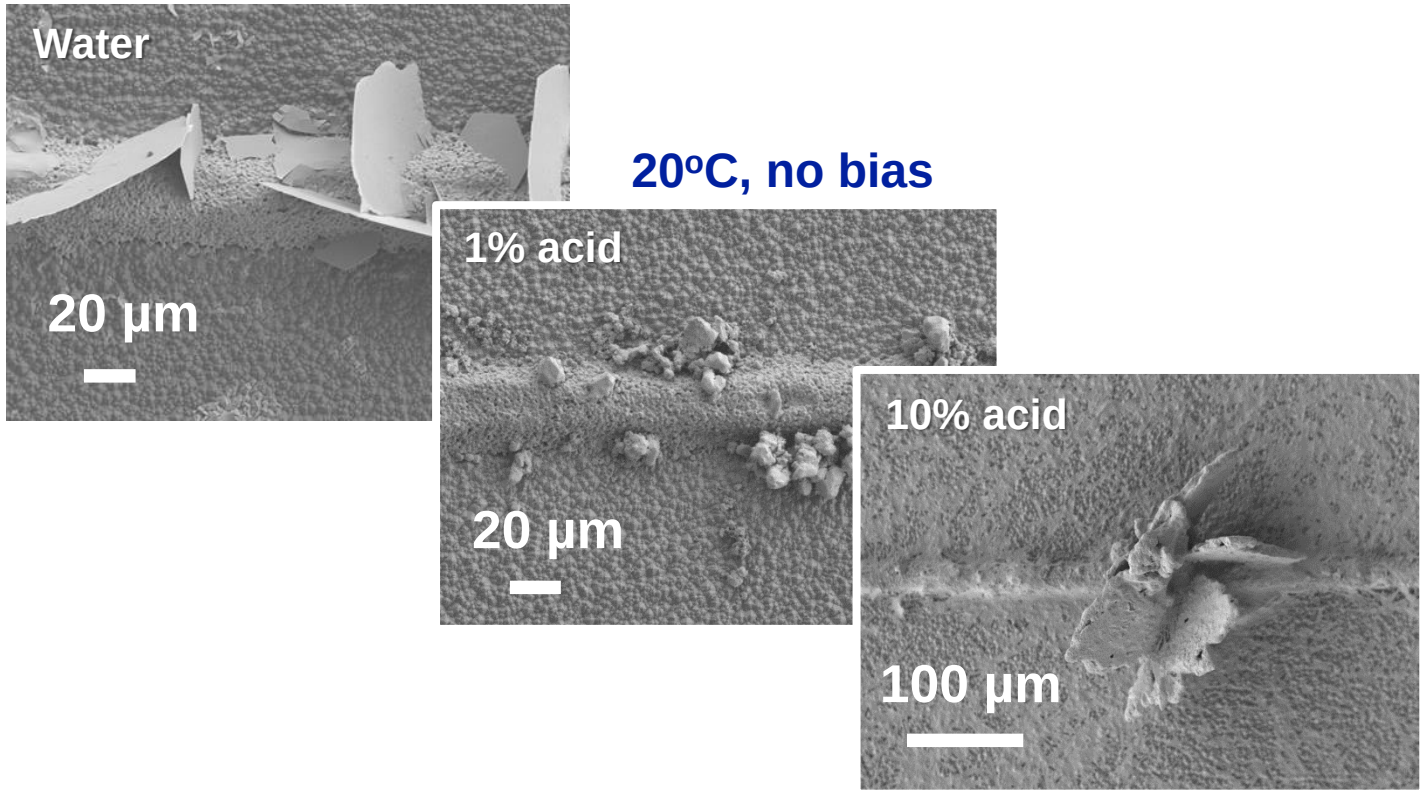
17 hours

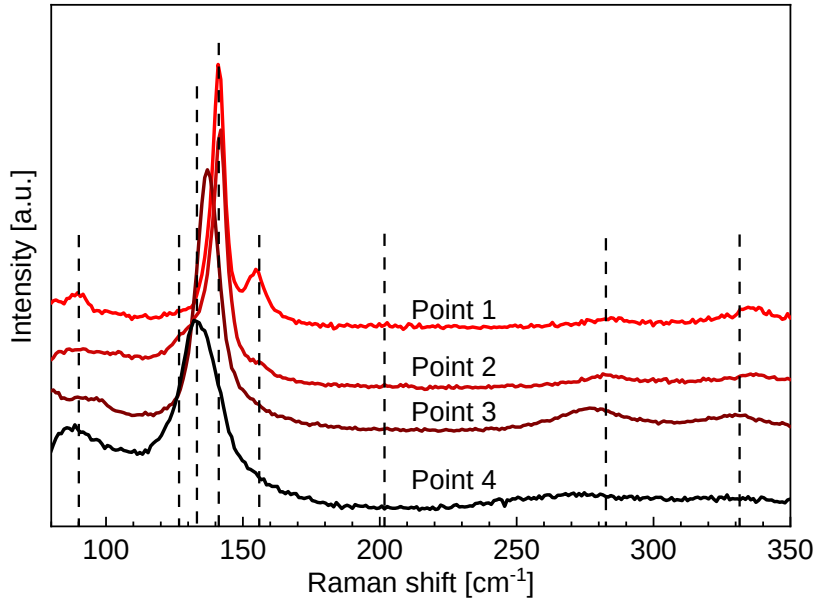
PV-lab
IMT NEUCHATEL

EPFL

Corrosion: degradation products

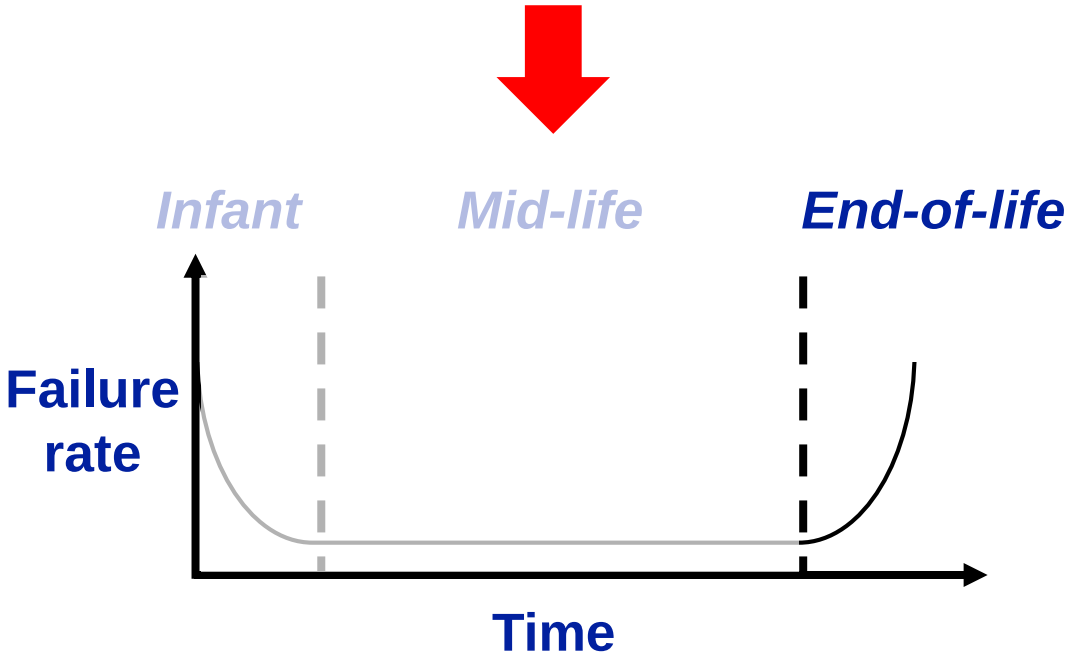
PbO_2 main corrosion product for all conditions, accumulation along fingers, busbar





Conclusions

Isolate degradation/failure mode for test with non-conventional specimen and test design



Targeted testing for failure to expose weaknesses in product design

PV-lab IMT NEUCHATEL

Acknowledgements: H2020 Be-Smart (#818009) and SNF REBI-PV (GDB 16627)

EPFL