Latest generation of eco-designed PV module packaging materials and highly accelerated testing methods

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INSTITUT NATIONAL DE L'ENERGIE SOLAIRE

AGENDA

Introduction

- Presentation of CEA INES
- Environmental footprint of PV modules manufacturing

Selection of non cross-linked encapsulants and non fluorinated backsheets

- State of the art
- Material characterization
- Highly accelerated test for humidity ingress
- Highly accelerated testing sequence

Novel formulation of frontsheet as glass alternatives

- Material characterization
- Mini-modules ageing in DH test
- Conclusions and large module manufacturing
- Eco-designed backsheet proposition

Conclusions and perspectives

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Conclusions and perspectives

20,000 employees
5.4 B€ budget
700 patents a year

REUTERS
Most innovative organisations

1st european

3rd global

Clarivate™
Top 100 Global Innovators™ 2022
9x Winner
2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020

LOW CARBON ENERGY & ENVIRONMENT

MICROELECTRONICS & DIGITAL ECONOMY

HEALTHCARE

INSTITUT NATIONAL
DE L'ENERGIE SOLAIRE
Born in 2005

22 000 sqm

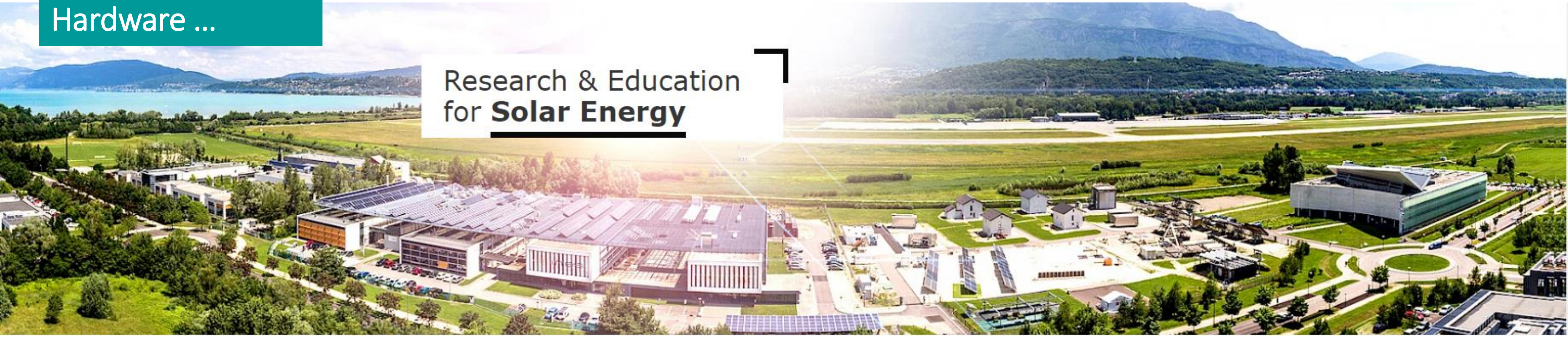
120 M€ Equipment

500 employees

50 M€ Annual Budget

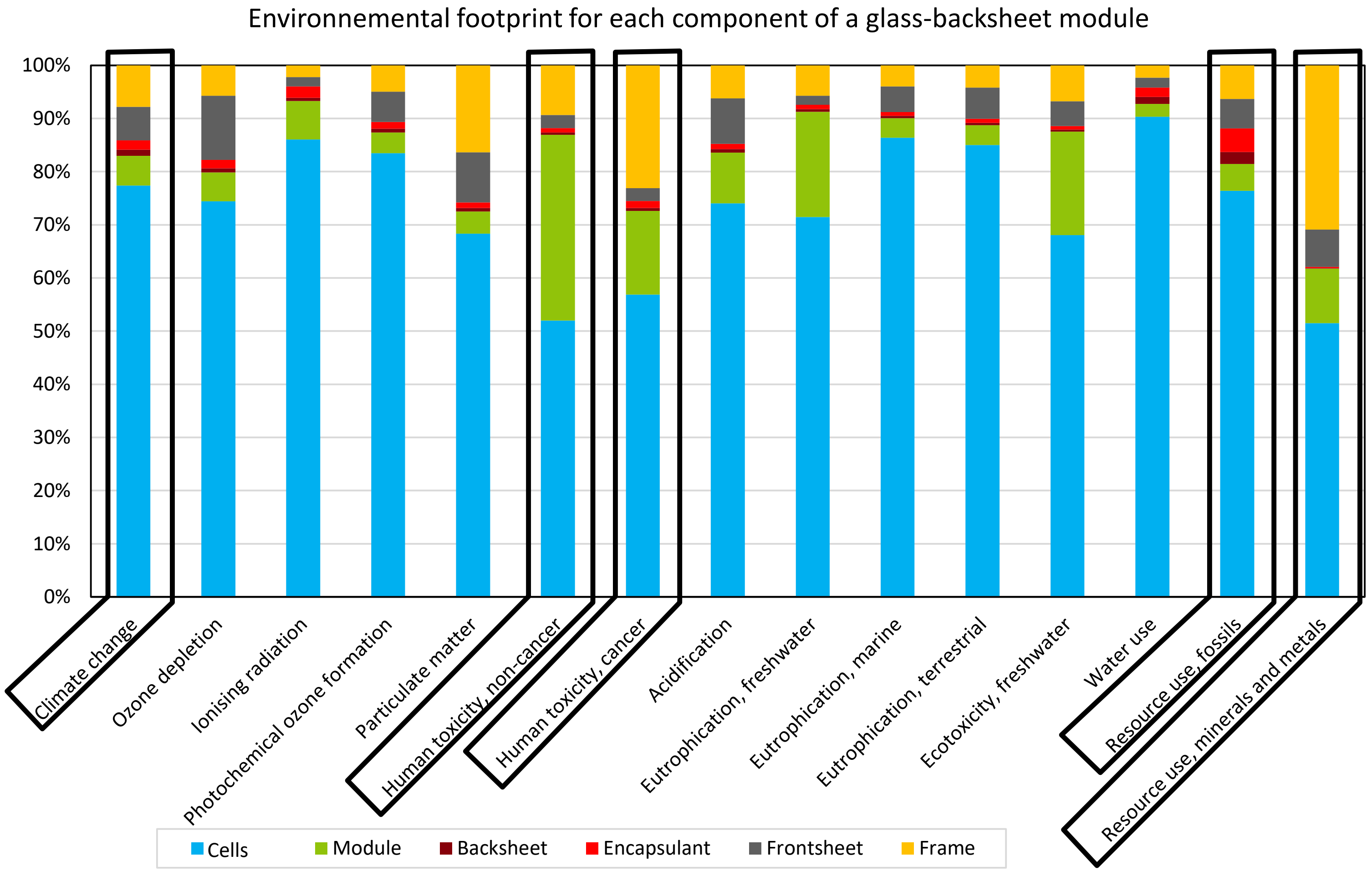
Premium PV Cells and modules I Process & equipment I X-IPV I Power electronics I Plants Architectures

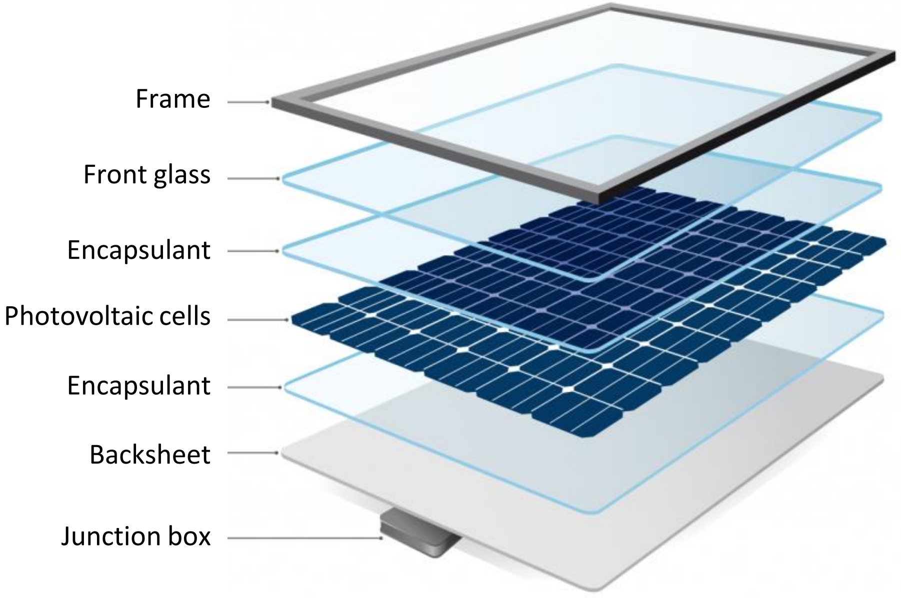
Hardware …



Grid integration I Diagnosis & Data I Energy management systems I Storage I **Smart grids & Smart cities**

ENVIRONMENTAL FOOTPRINT OF PV MODULES MANUFACTURING

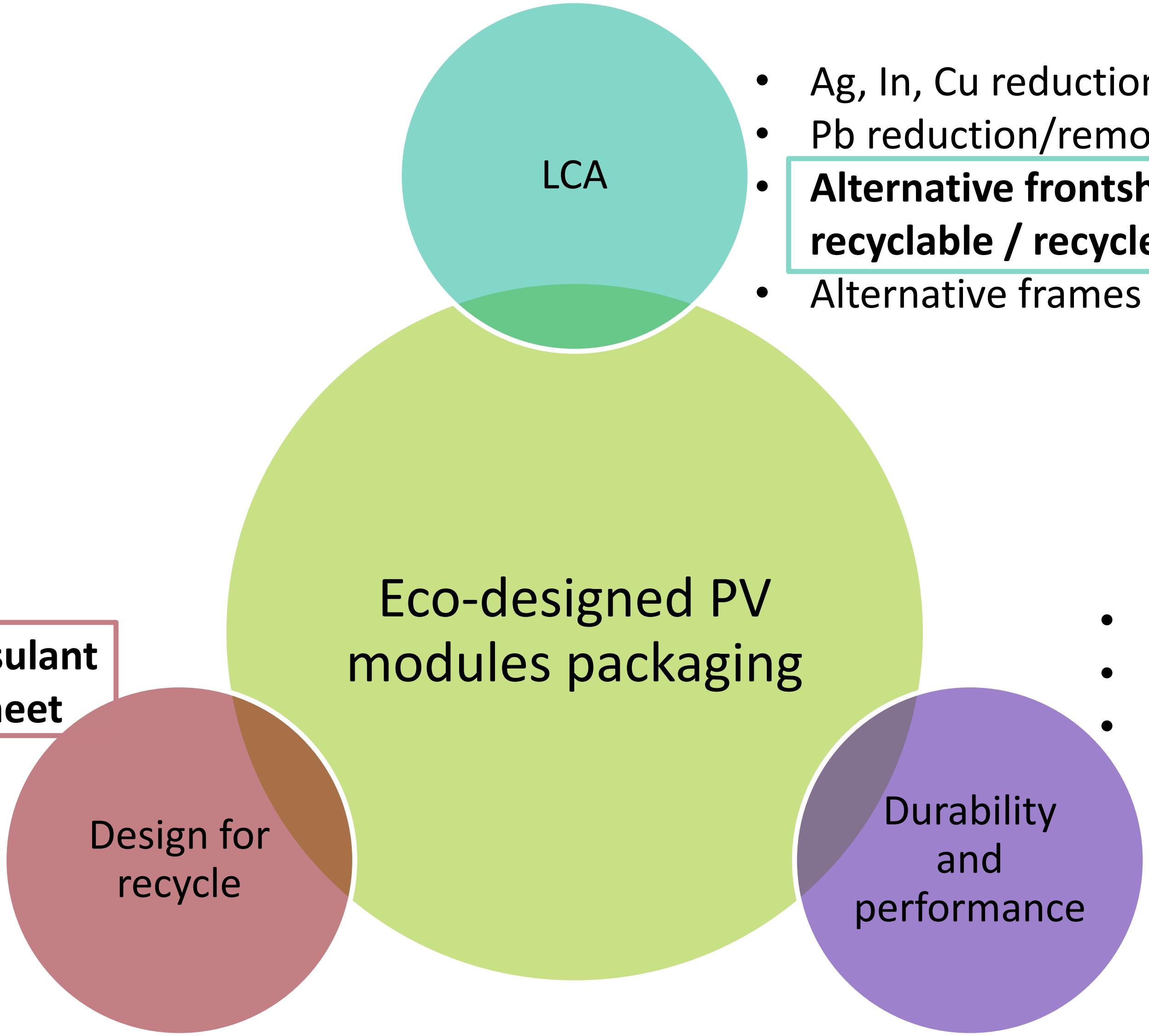




N. Gazbour, CEA-INES, 2022
Database : Ecoinvent 3.6
Data Source : CEA INES
Software : Sima Pro 9.1 /ECO PV
Method : ILCD2011 Midpoint +V1,10

➢ **Polymeric materials does not have the greatest impact on LCA analysis but they represent a key point for recyclability and durability**

BEYOND LCA (AND CO_2 FOOTPRINT)



- Ag, In, Cu reduction
- Pb reduction/removal
- **Alternative frontsheets to glass (biobased / recyclable / recycled polymers)**
- Alternative frames to aluminium

- **Non crosslinked encapsulant**
- **Non fluorinated backsheet**

- High gas barrier properties (O_2, H_20)
- UV resistance
- Good optical properties (transparency/reflectivity)

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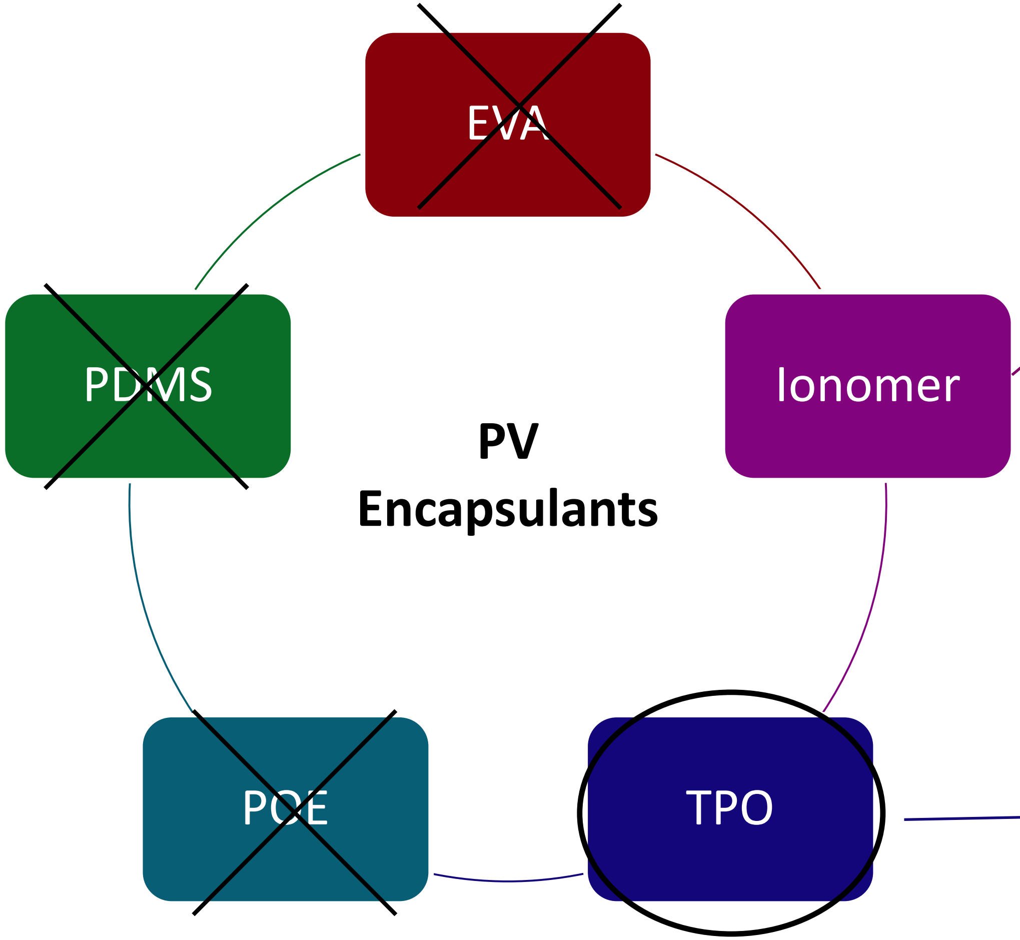
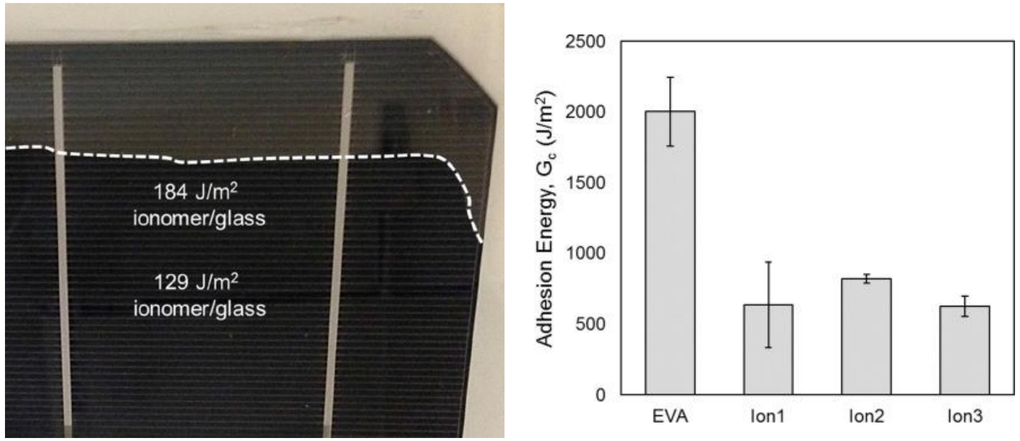
NON CROSSLINKED ENCAPSULANT - STATE OF THE ART



Adhesion of ionomers with glass is generally low compare to EVA *(Tracy et al., Solar Energy Mat. and Solar Cells, Vol. 208, 2020)*

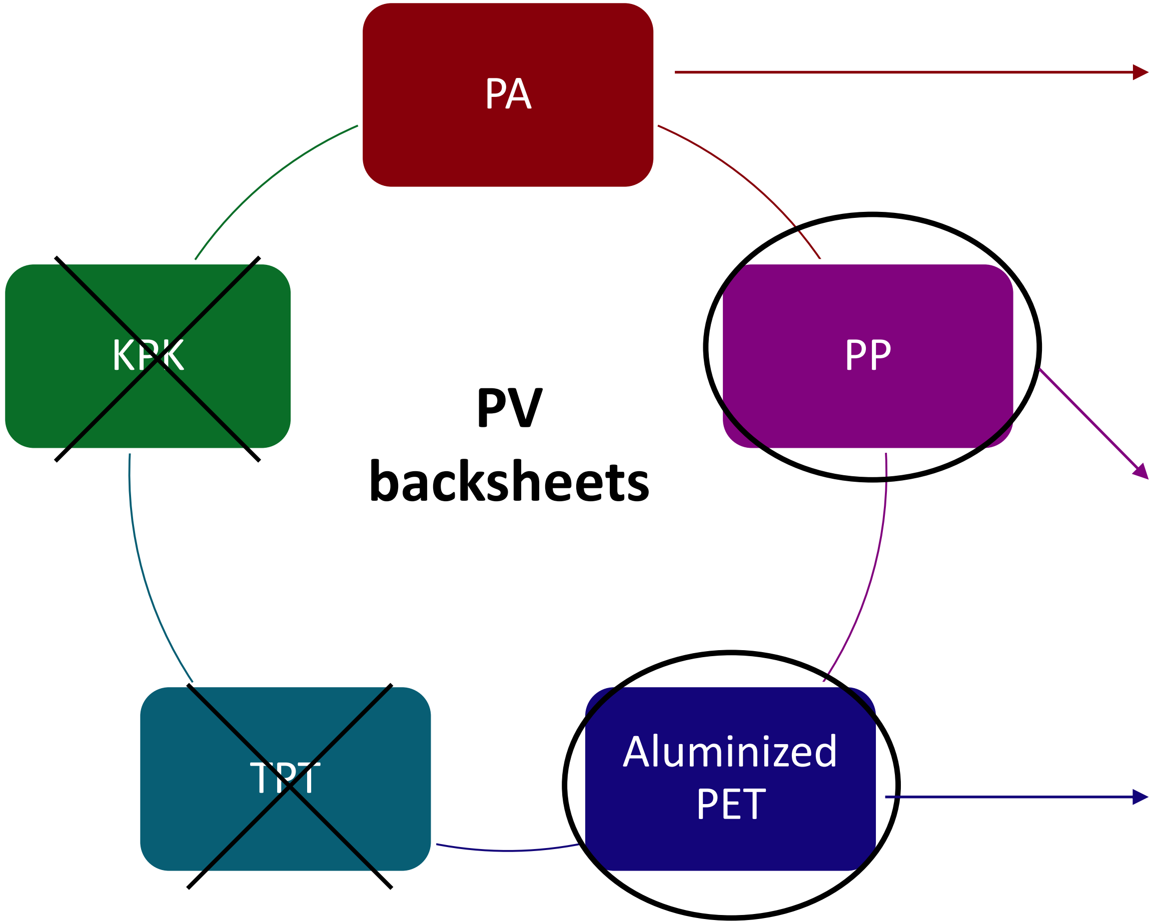


TPO cannot produce acetic acid as they do not have vinyl acetate moieties (*C. Barretta et al., Polymers, Vol. 13, 271, 2021*)

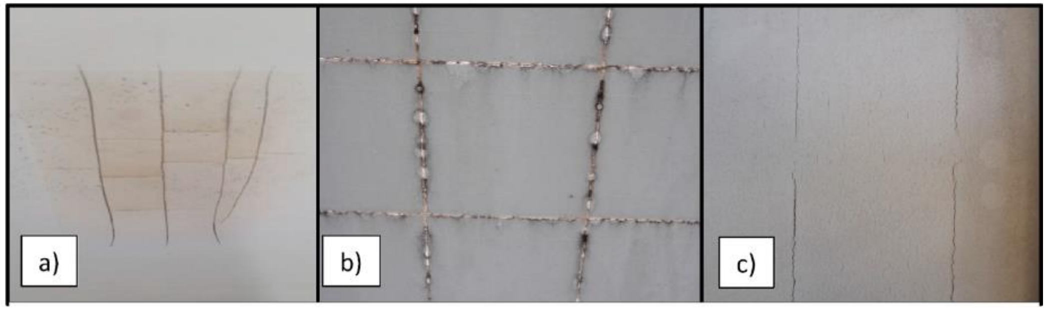
TPO encapsulants present a higher stability versus UV exposure than EVA (*B. Adothu et al., Polymer Degradation and Stability, Vol. 201, 2022*)

➢ **TPO meet all the requirements to encapsulate PV cells with non crosslinked encapsulant**

NON FLUORINATED BACKSHEET – STATE OF THE ART

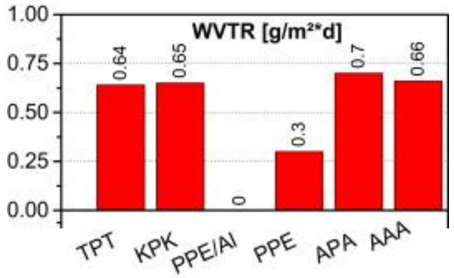


Cracking backsheets phenomena are observed for PA backsheet modules (*G. C. Eder, Solar Energy Mat. and Solar Cells, Vol. 203, 2019*)



PP backsheets is equivalent to PET as humidity barrier and allow for diffusion of acetic acid out of the PV module (*G. Oreski et al., Solar Energy Mat. and Solar Cells, Vol. 223, 2021*)

Aluminium insert allow a significant decrease in the WVTR (*G. Oreski et al., Polymer Testing, Vol.60, pp 374-380, 2017*)



➢ **PP and aluminized PET based materials are interesting candidates for more eco-friendly backsheet**

MATERIAL QUALIFICATION PROTOCOL – BACKSHEET AND ENCAPSULANTS

Thermal Analysis
Aim: Assess the fusion and crosslinking temperatures as well as the crosslinking rate
Method: S. Ogier et al., Polym. Sci., Part B: Polym. Phys. Vol. 55, 2017

Optical measurement
Aim: Determine the effective transmission of encapsulant
Method: Spectrophotometer, in short wavelength (280-1250 nm)

Water absorption
Aim: Measure the mass variation due to water uptake
Method: Submerging laminated samples into deionized water, ISO 62:2008

Tensile stress - strain
Aim: Assess the material behaviour
Method: According to ISO 527-3:2018 standard.

Peel strength
Aim: Assess the adhesion by peeling (180°) before and after 200h DH
Method: DH according to IEC 61215 standard.

Shrinkage in lamination conditions
Aim: Asses the material behaviour after 10 min of 160°C temperature exposure
Method: According to IEC 61215 standard

T. BEJAT's talk at WCPEC 2022 about backsheet characterization

H. Gauthier, A. Derrier, BPI Project, INES.2S

DIFFERENT TEMPERATURE TRANSITIONS FOR EVERY ENCAPSULANT FAMILY

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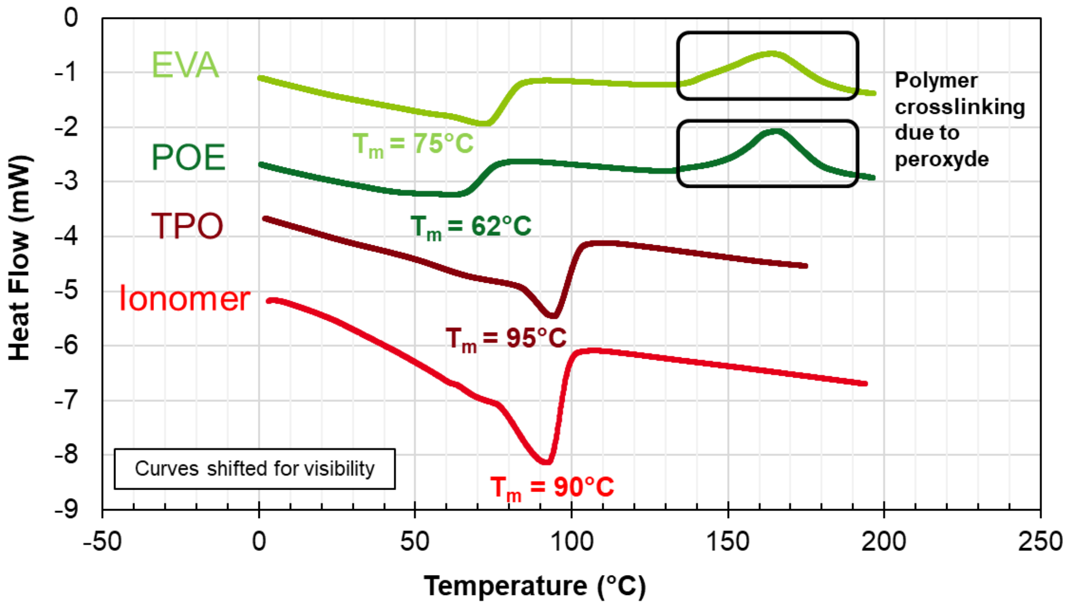

- Ionomer and TPO do not crosslink ➔ No need to measure the crosslinking rate after lamination + possible decrease of lamination process time
- Ionomer and TPO encapsulants melt at higher temperatures ➔ Necessity to adapt the lamination recipe in accordance

DIFFERENT OPTICAL PROPERTIES FOR EVERY ENCAPSULANT DEPENDING ON FORMULATION (UV ADDITIVES)

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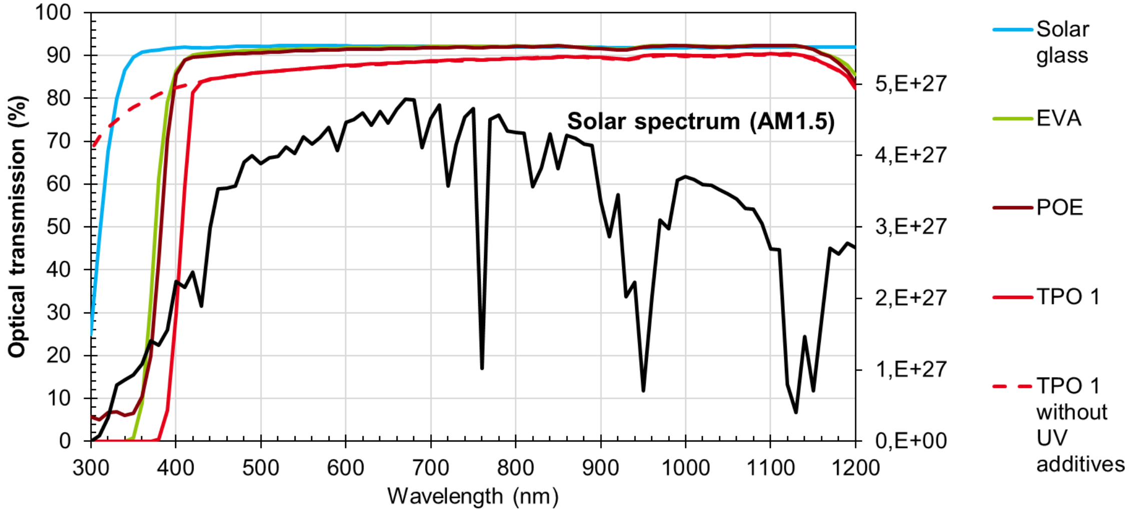

- Transmission is generally higher for EVA than others polyolefin encapsulant (POE, TPO) due to a lower crystallinity rate *(G. Oreski et al., Progress in PV, Vol. 28, 12, pp 1277-1288, 2020)*
- Different formulation of encapsulant are possible in order to tune the UV cut off value

ENCAPSULANT ADHESION ON GLASS

Thermal Analysis
Aim: Assess the fusion and crosslinking temperatures as well as the crosslinking rate
Method: S. Ogier et al., Polym. Sci., Part B: Polym. Phys. Vol. 55, 2017

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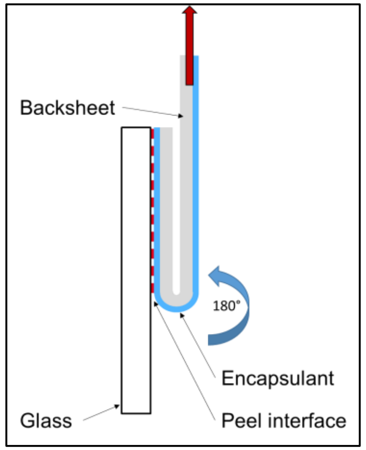
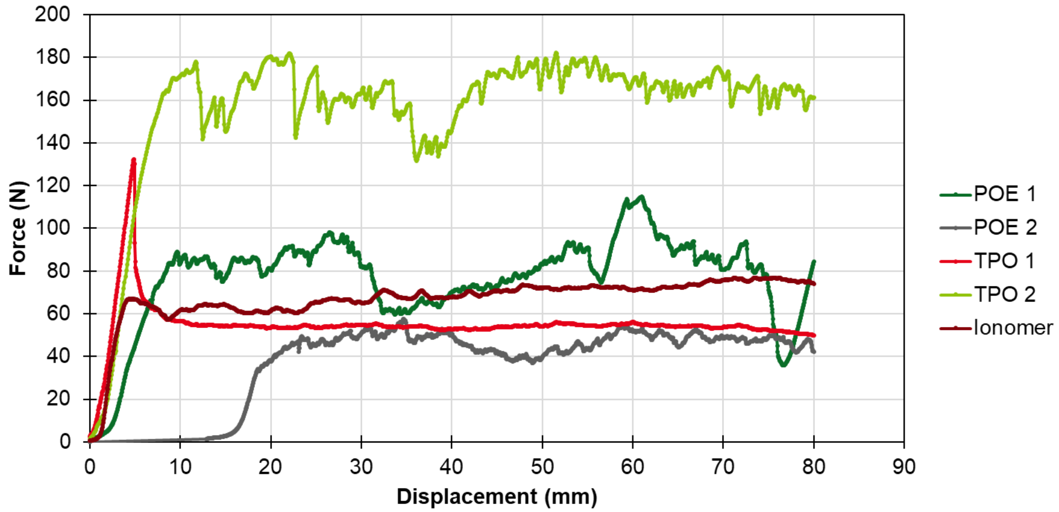


Peel test schema in the Instron machine



- With same lamination parameters, adhesion on glass can be very different for each encapsulants
- Recommended minimum value is 80 N/cm

HIGHLY ACCELERATED TEST FOR HUMIDITY INGRESS

IEC 61215 – MQT 13: Damp Heat test

- ➔ 1000h 85°C / 85%RH = 42 days is too long

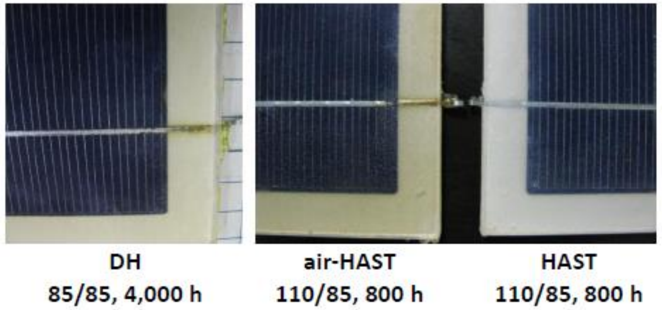
To be substituted by HAST test from literature

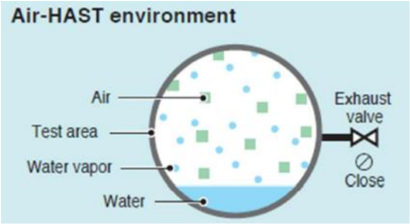
- *S. Suzuki et al., Jap. Jour. of App. Ph., Vol. 55, 2, 2016*
- 110°C / 85%HR + Pressure for only 250h (11 days)

➔ Testing of commercially available non fluorinated backsheet and next generation encapsulant

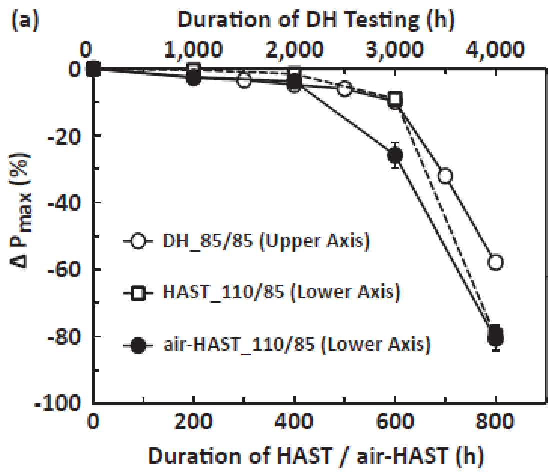
TPO 1	PP Backsheet	Stack 1
TPO 1	Aluminized backsheet	Stack 2
TPO 2	PP Backsheet	Stack 3
TPO 2	Aluminized backsheet	Stack 4
POE 1	PP Backsheet	Stack 5
POE 1	Aluminized backsheet	Stack 6

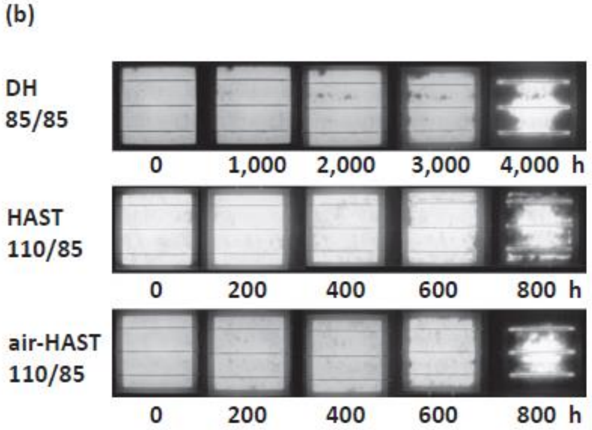
Design Of Experiment





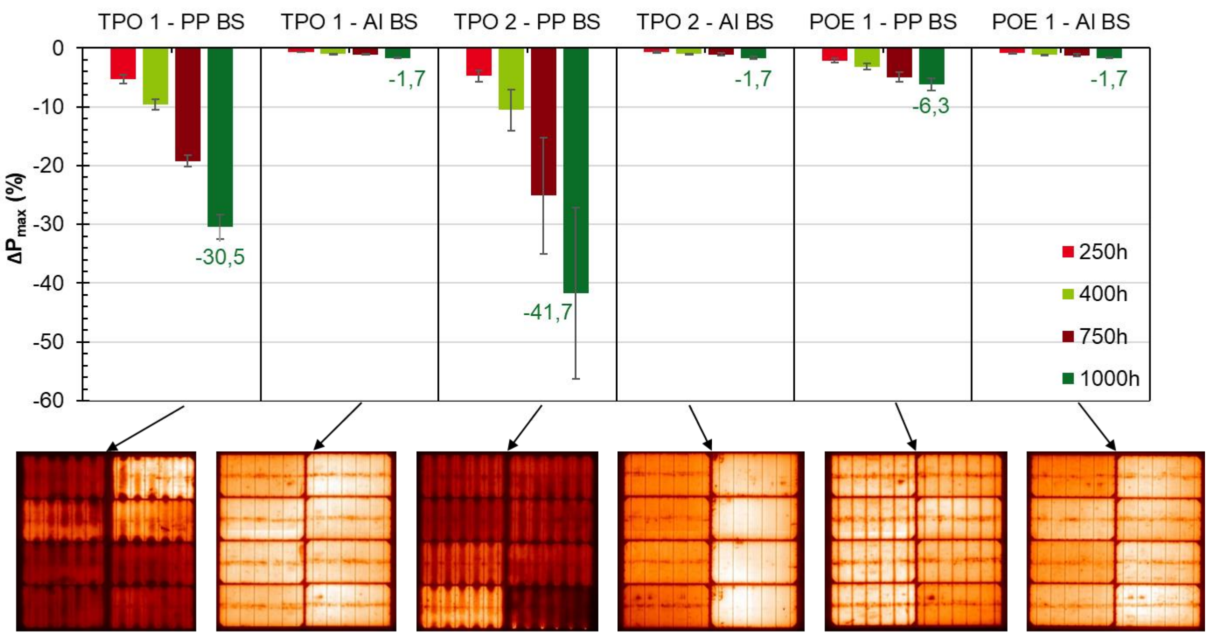
air-HAST generates the same oxydation than DH



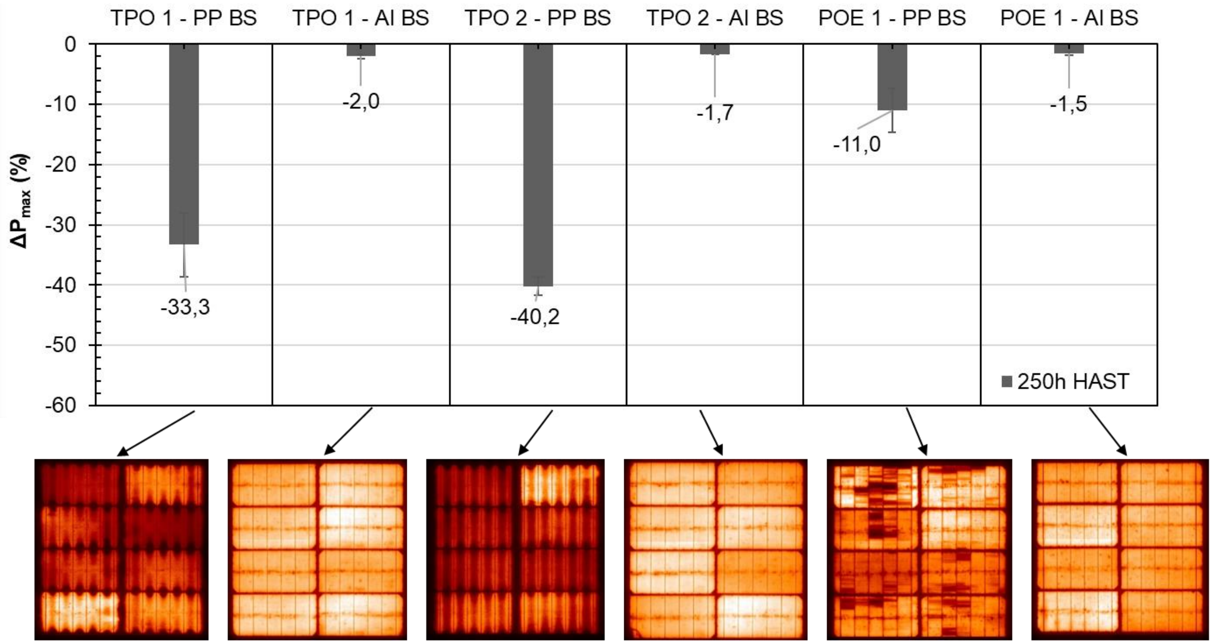


HIGHLY ACCELERATED TEST FOR HUMIDITY INGRESS

Testing of different combinations in DH test (85°C – 85%RH) and HAST test (110°C – 85%RH)



Electroluminescence images after 1000h of DH for each stack



Electroluminescence images after 250h of HAST for each stack

- **Both tests give similar results and same degradation mechanisms are observed on most of the EL images**
- **Current TPO encapsulant should be used with aluminized backsheet to pass DH test ($\Delta P_{max} < -2\%$), and coupling with PP backsheet is possible for less humidity sensitive technologies**

HIGHLY ACCELERATED TESTING SEQUENCES - STATE OF THE ART

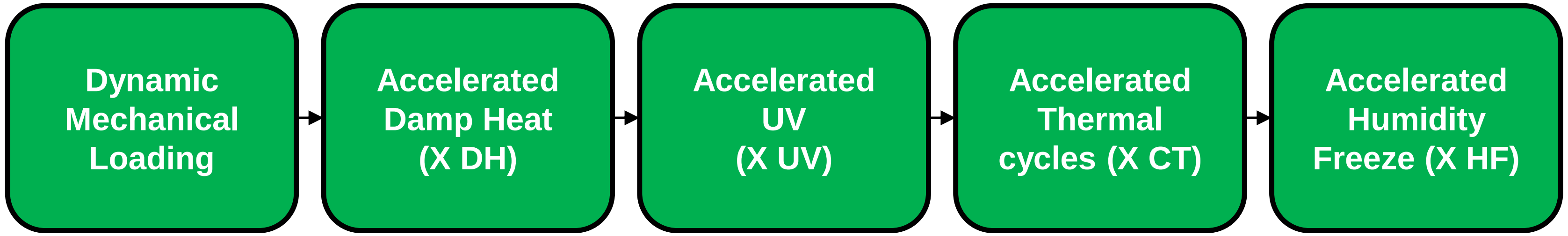
Current practices impose qualification by 2-3x IEC61215 testing BUT too long and not adapted to detect new failure modes

➔ Introduction of sequential, combined stress testing with strong UV included after DH

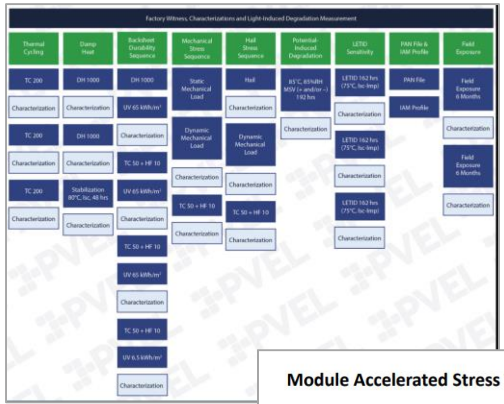
J. F. Lelievre et al., Solar Energy Materials and Solar Cells, Vol. 236, 2022

Jean-Patrice Rakotoniaina, et al. Poster presentation, IEEE 2022

A. Derrier, BPI Project, INES.2S

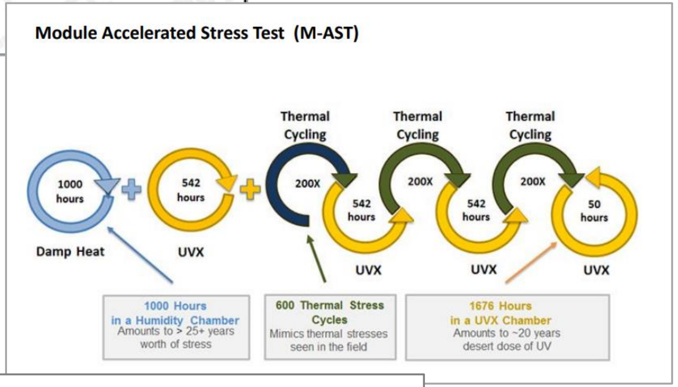


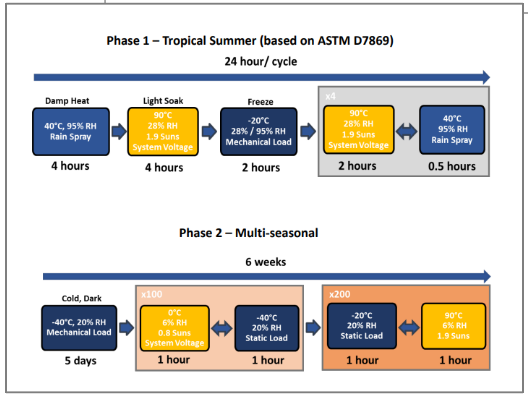
STROKE CEA testing sequence



PVEL

MAST by Dupont





CAST by NREL

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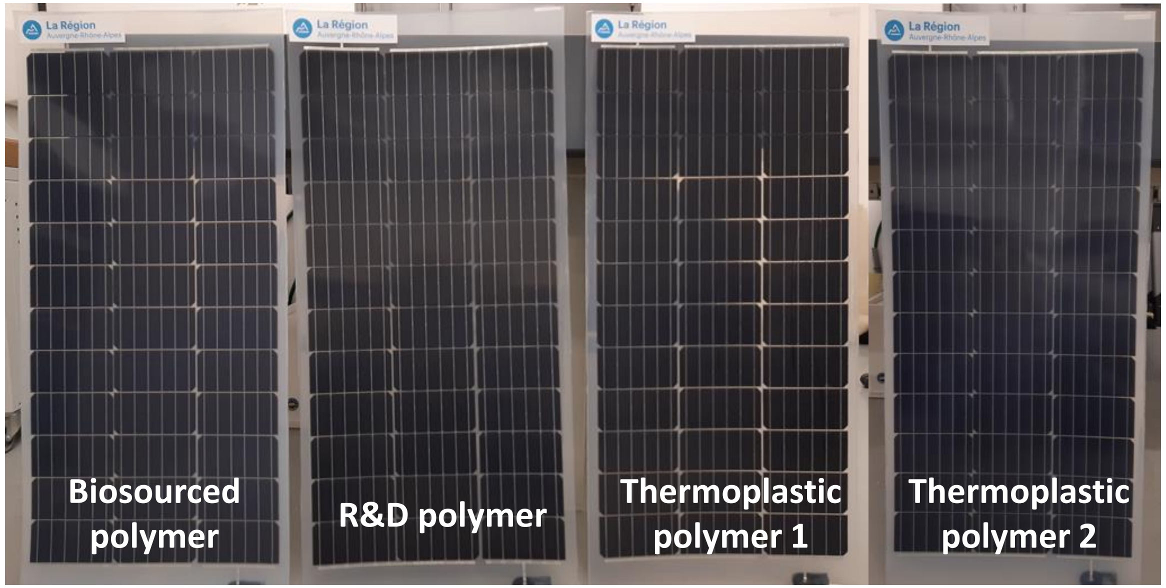
CONCLUSIONS ON TESTED POLYMER FRONTSHEET AS GLASS ALTERNATIVES

Four different polymers were tested in material characterization and mini-module DH ageing

- Thermoplastic polymer 2 to be forgotten (due to high UV and water sensitivity)
- All three others studied polymers are promising but:
  - R&D polymer only adheres with one TPO encapsulant (small versatility on encapsulant choice)
  - Necessity to find better humidity barrier encapsulants as 1000h DH tests on first mini-modules realized give P_{max} loss between 3 and 8 %

Large module manufacturing is possible in double plate laminator →



Large bifacial modules (1100 x 510 mm) manufactured with different polymers

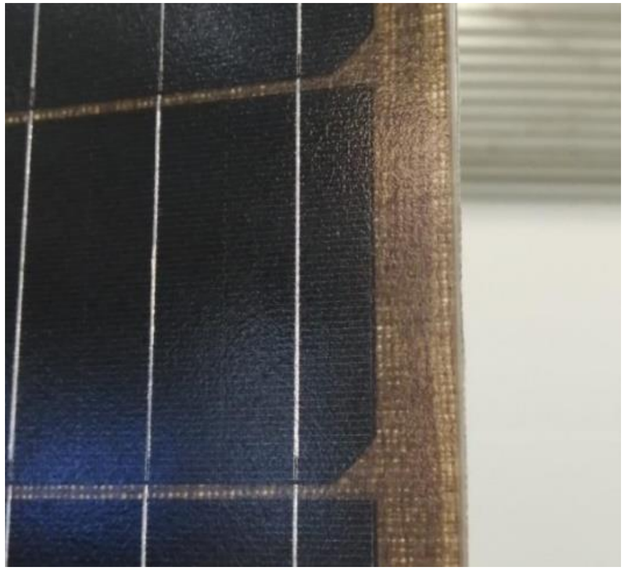
Perspectives:

- Selection of best combinations materials (encapsulant, backsheet)
- Ageing of modules in UV, CT, HF => Stroke
- Mechanical resistance to be improved (hail test): work on going with material & BOM optimization

INNOVATIVE ECO-DESIGNED MODULE WITH THE USE OF CEA RECYCLING PROCESS AND FLAX FIBERS

Innovative eco-designed module BOM proposition

- Flax fiber – epoxy composite as backsheet
- Reused glass frontsheet
- Thermoplastic encapsulant
- Initial performance : 78.3 Wp (vs GBS ref 79.9 Wp)



Esthetic aspect of the PV module

Innovative ecodesigned module

https://www.pv-magazine.com/2022/06/17/solar-panels-based-on-biosourced-materials/

CONCLUSIONS AND PERSPECTIVES

Non X-linked encapsulants and fluorine-free backsheets:

- Replacing EVA with new polyolefin encapsulants is necessary for new generations cells (perovskites, tandem…)
- Non crosslinked encapsulant and not fluorinated backsheet are preferred for recycling
  - Qualification of TPO and PP backsheet in various combinations
  - Highly accelerated and sequential stress testing method allow material selection for increase PV module lifetime

Polymer frontsheet:

- The environmental footprint of glass frontsheet is important
- Replacing glass with non fluorinated polymer frontsheet for eco-design and/or lightweight PV modules
  - Thorough material qualification (e.g. adhesion level, high barrier properties, high optical transparency)
  - First module prototypes

Eco-design decision making tool

- Eco-design integrating **both** manufacturing and recycling processes to develop for next generation modules
- Increased/Updated material database

Thank you for your attention

SPECIAL thanks to
all the heterojunction and module
teams at CEA-INES!

Thanks for funding!