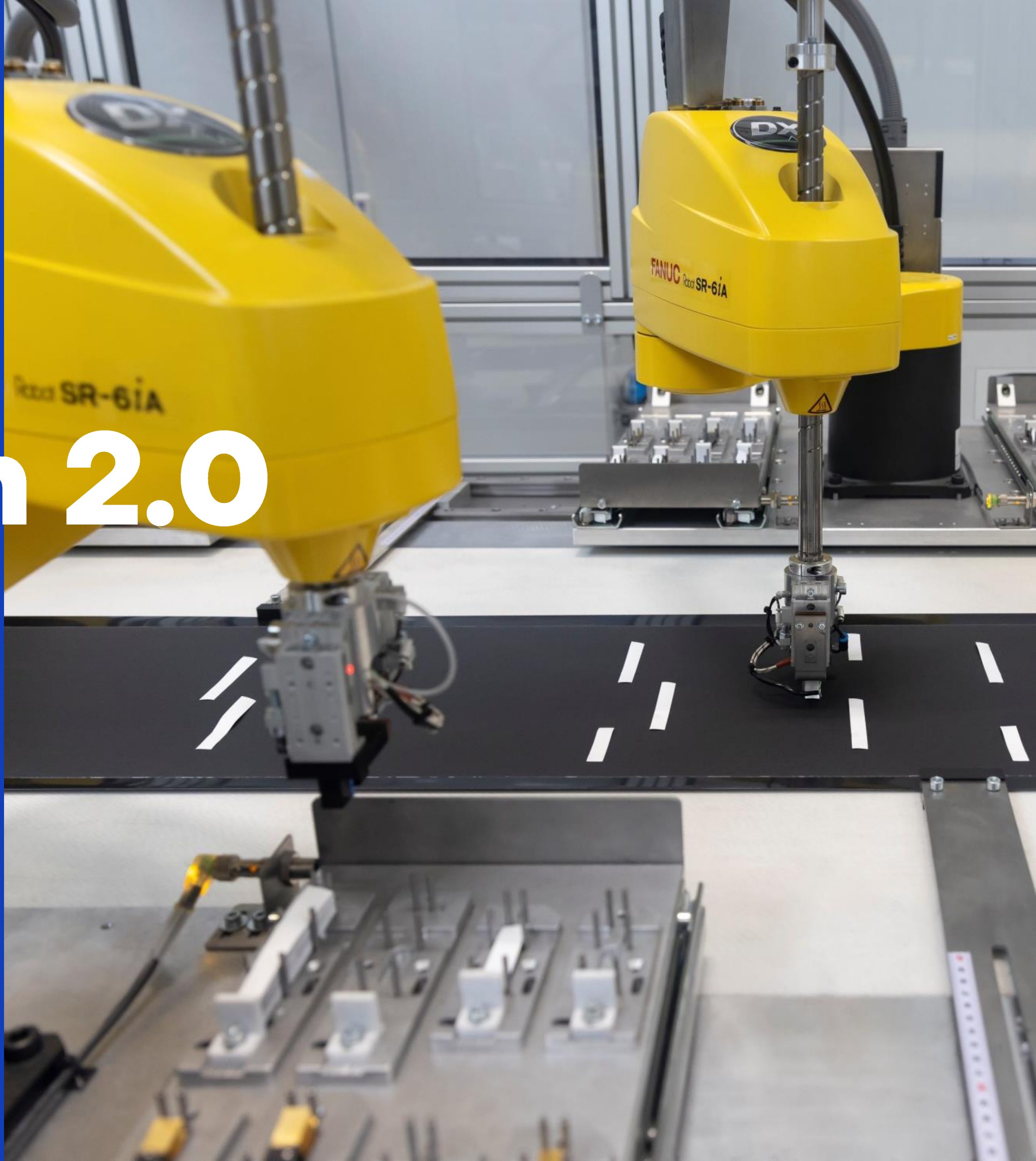
Mass Customization 2.0

Reliability aspects of PV semi-fabricates

Aldo Kingma, Marc Koetse |
Sophia Workshop Hasselt 25/04/2023



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MCL team:

- Bart van de Vorst, Erik Smedts, J-P Garcia, Monique van de Nieuwenhof, Niels van Loon.

Partners in MC2.0:

- Roartis (Anja Henckens, Jochen Schuermans);
  PCCL: Petra Christöfl, Eric Helfer, Sonja Feldbacher, Gernot Oreski

MC2.0

Provincie Noord-Brabant

SOLARNL CIRCULAR INTEGRATED HIGH-EFFICIENCY SOLAR PANELS

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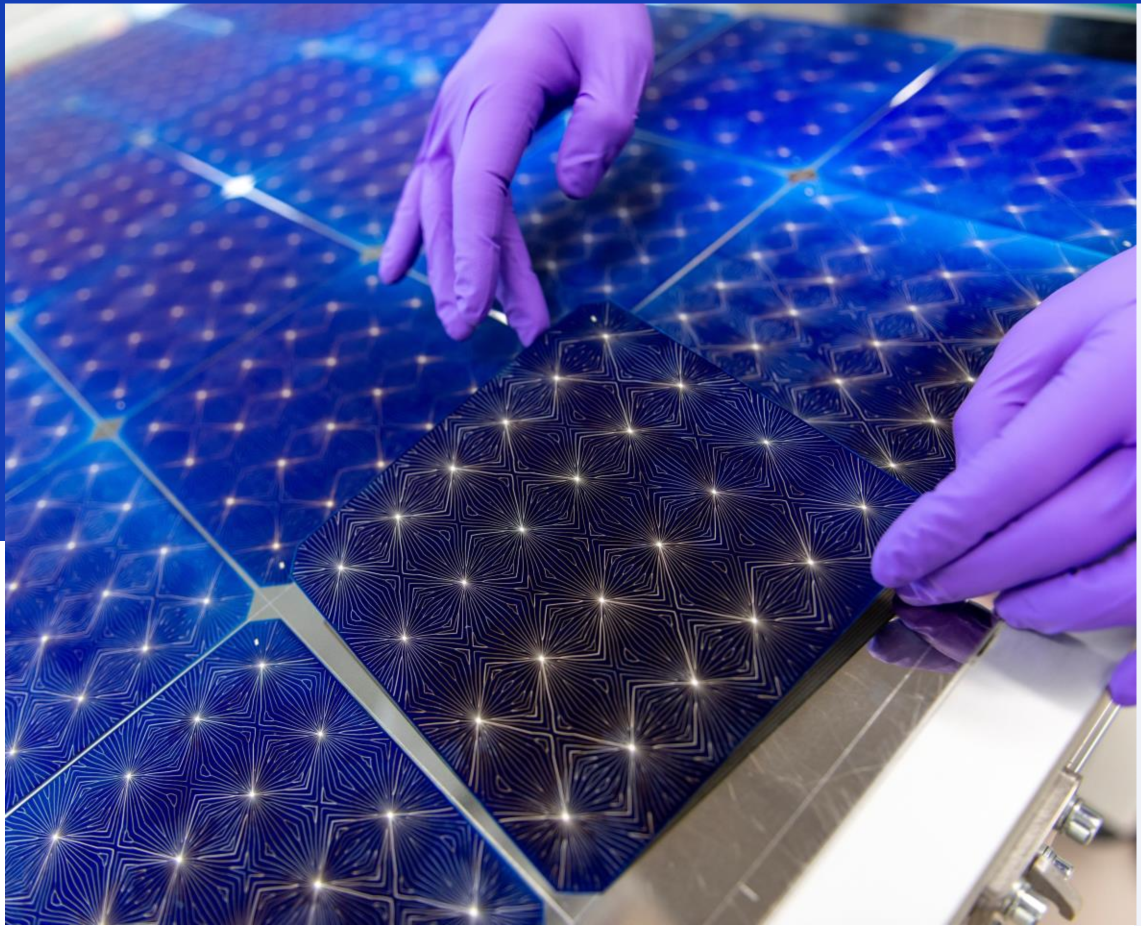
Agenda



1. Introducing the project MC2.0
2. Reliability of PV semi-fabricates
3. Towards back-contacting of cells
4. Resume and outlook

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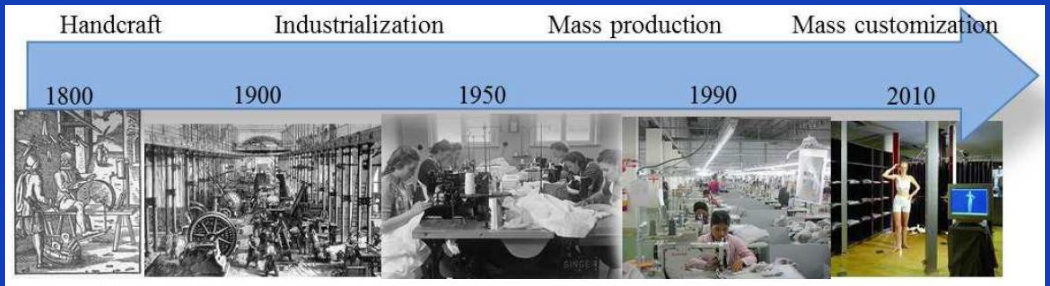
Mass Customisation

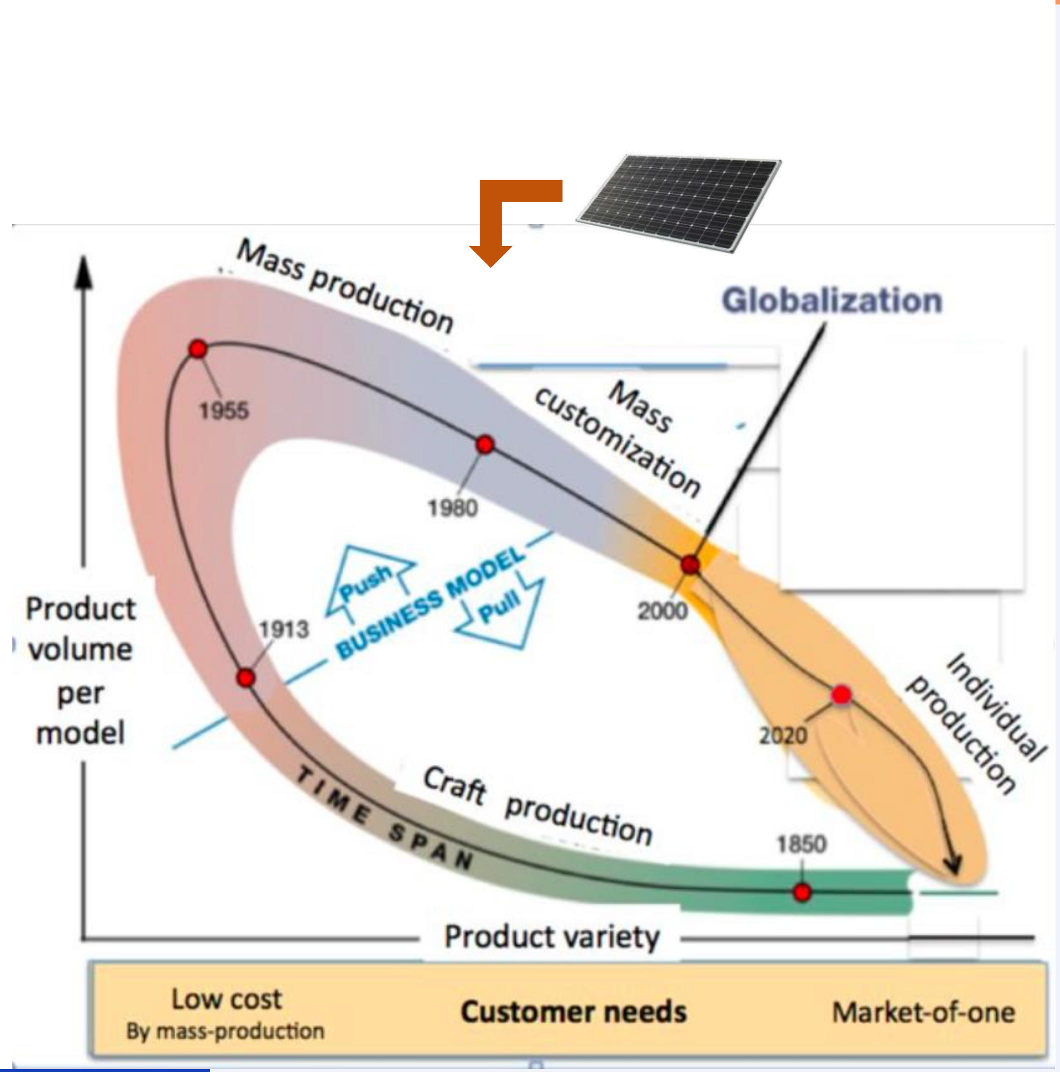
Definition (Piller, 2004)

- … “a strategy that combines customized products and services in compliance with the efficiency of mass production”
- … “a perfect bridge for connecting cost pressures and customer-specific requirements”

individualization



Development of production condition.



Source: Yoram Koren “The Local Factory of the Future for Producing Individualized Products.”

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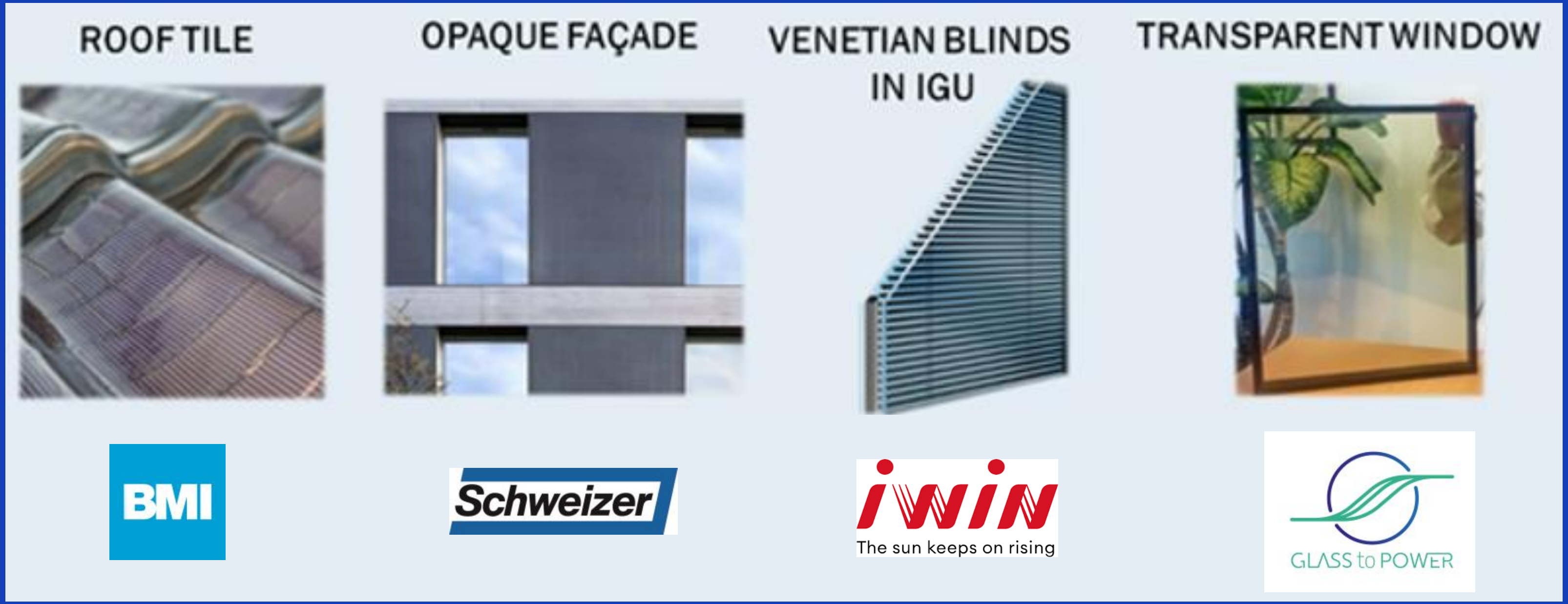
Ambition

- Make PV available for every available surface(IPV)

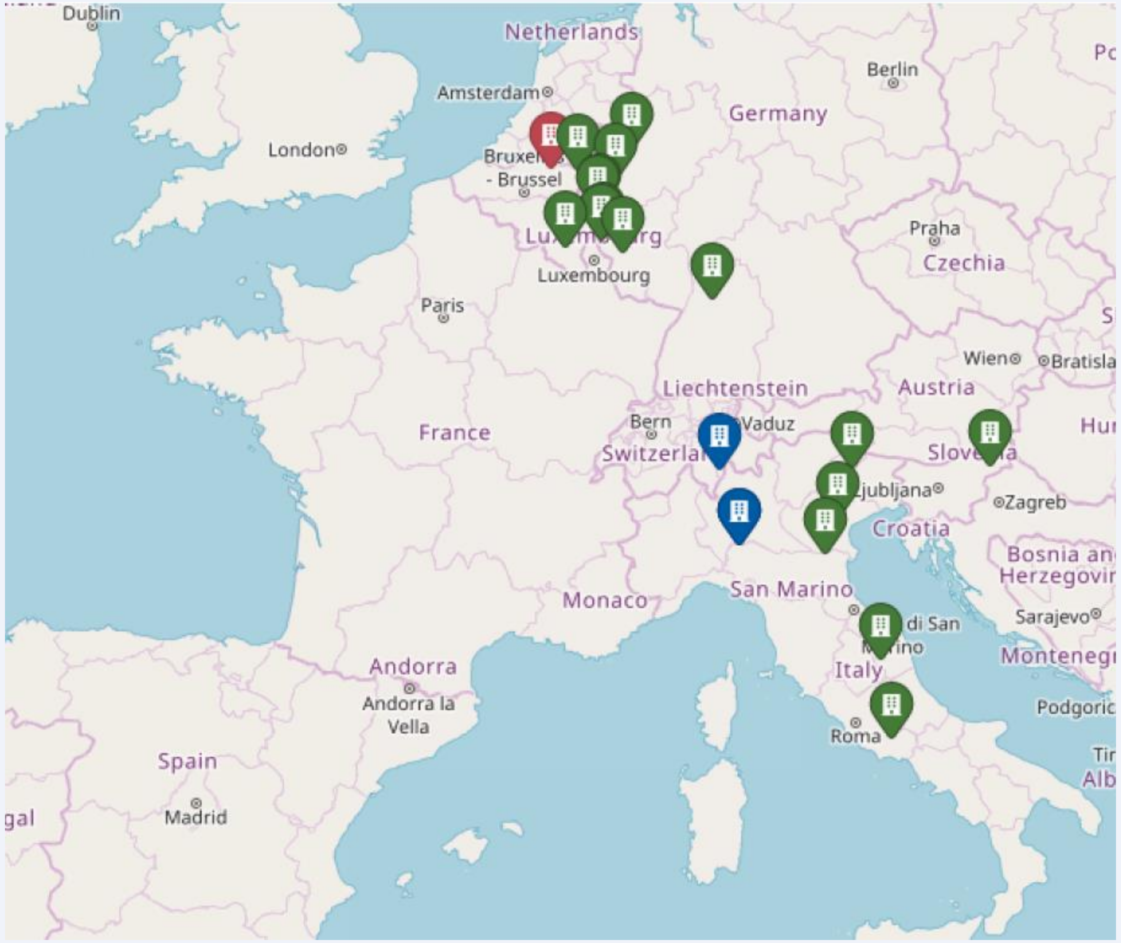
- Demonstrate a cost breakthrough for IPV by means of an advanced manufacturing approach, referred to as “mass customization”.



Horizon Europe project MC2.0

- 20 partners
  - 5 institutes; 15 companies
  - 6 EU countries

eurac research · University of Applied Sciences and Arts of Southern Switzerland SUPSI · PCCL Polymer Competence Center Leoben · TNO innovation for life · imec · Applied Materials make possible · BouwhulpGroep advies en architectuur · Duflex Mechatronics · EnFoil · Focchi since 1914 · Glass to Power · MAAN Engineering · I40MC Industrie 4.0 Maturity Center · iWin The sun keeps on rising · Roartis IQ-Bond · Schweizer · sunplugged · VDL ETG Projects · Vitronic · BMI



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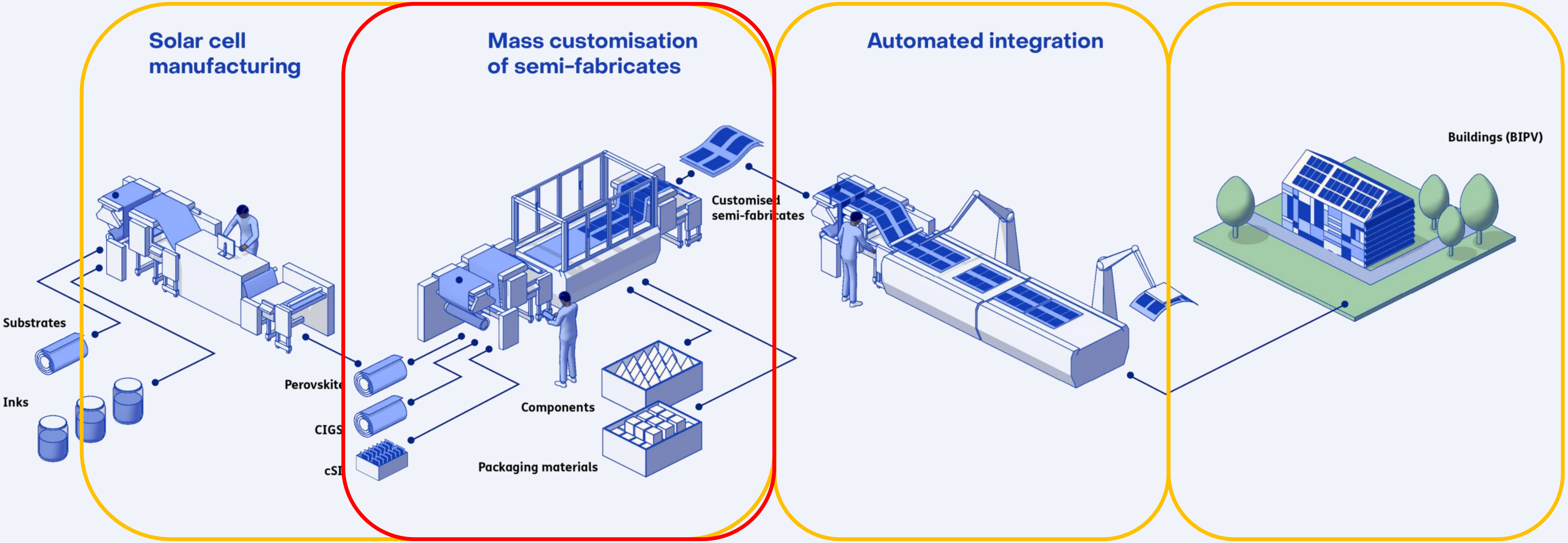
Mass-customization concept

Front end | Back end | Demonstration



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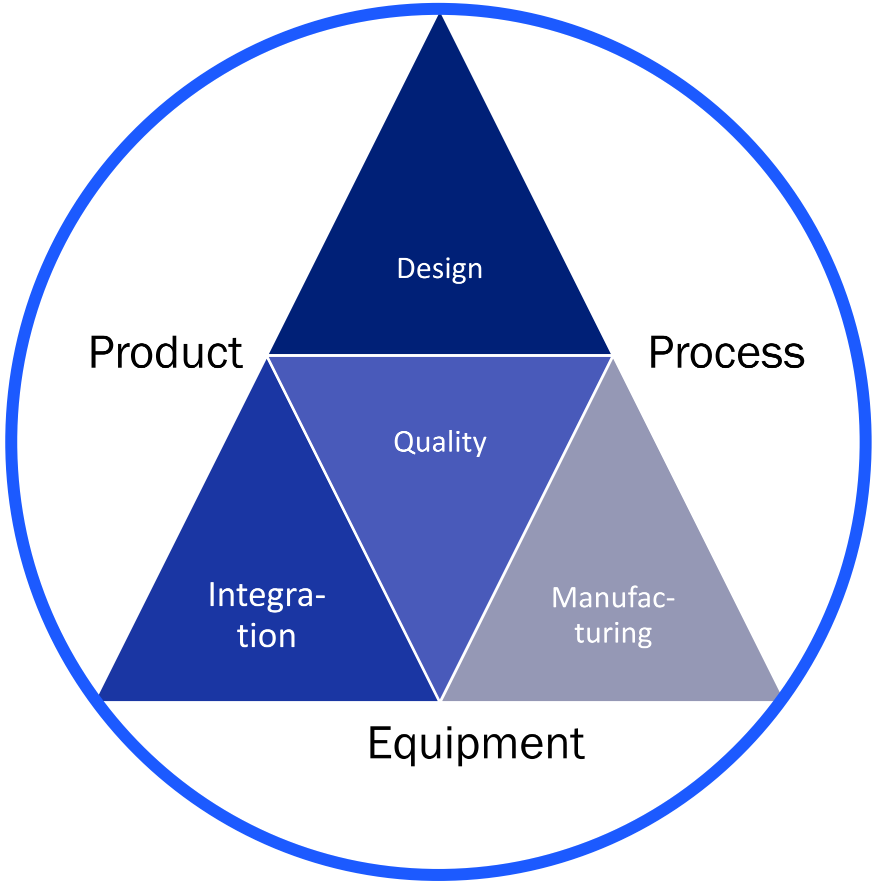
Reliability in MC2.0
Front End

- Reliability testing of semi fabricates

- **Main task**: ensuring reliability for semi-fabricates made using new processes, new materials and for novel applications.

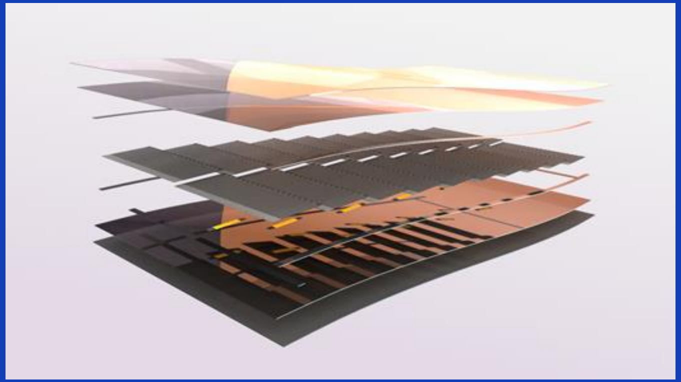
- Semi-fabricates and PV integrated products are not standard panels.

- Certifiable vs certification?



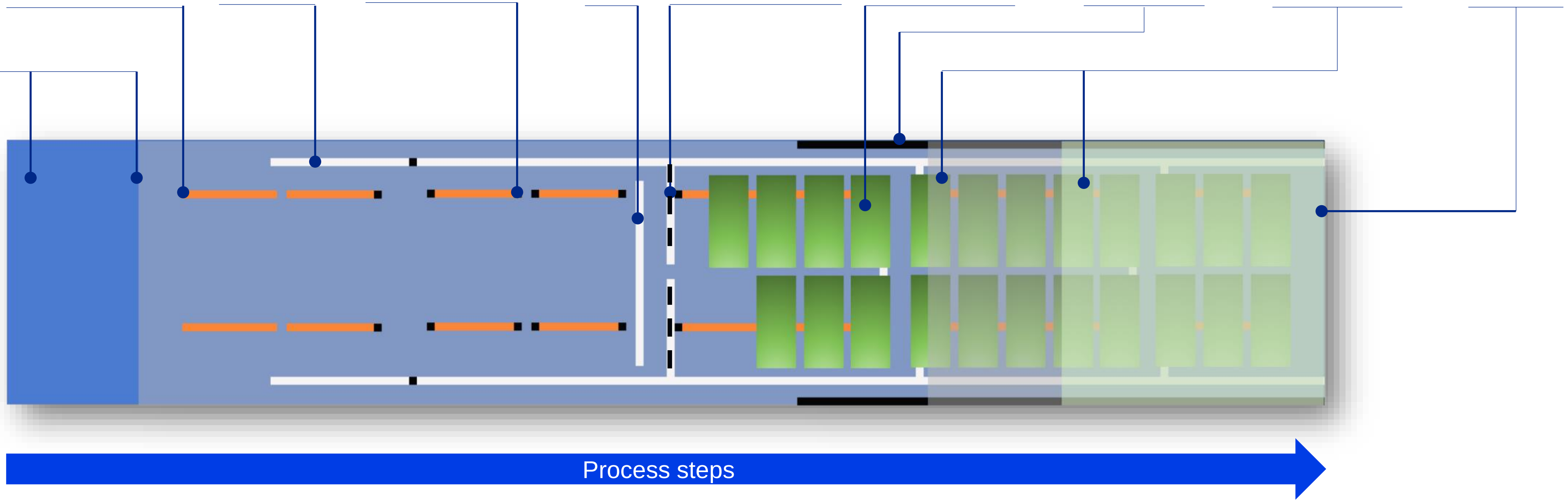
Semi-Fabricate

- The solar laminate or PV semi-fabricate consists of those elements that are minimally required to provide durable and reliable PV performance to the product
- Cell technology, Aesthetics, Weather resistance…



Baseline process MC-line

Pre-lamination	Pick & Place	Pick & Place	Dispensing	Pick & Place	Dispensing	Pick & Place	Tape application	Roll Lamination	Cut to size
• Encapsulant • Back sheet	• Diodes	• Bus bars	• Conductive paste	• Ribbons	• Conductive paste	• PV Cells	• Edge sealant	• Encapsulant • Front sheet	• Fly-cut • Slitting



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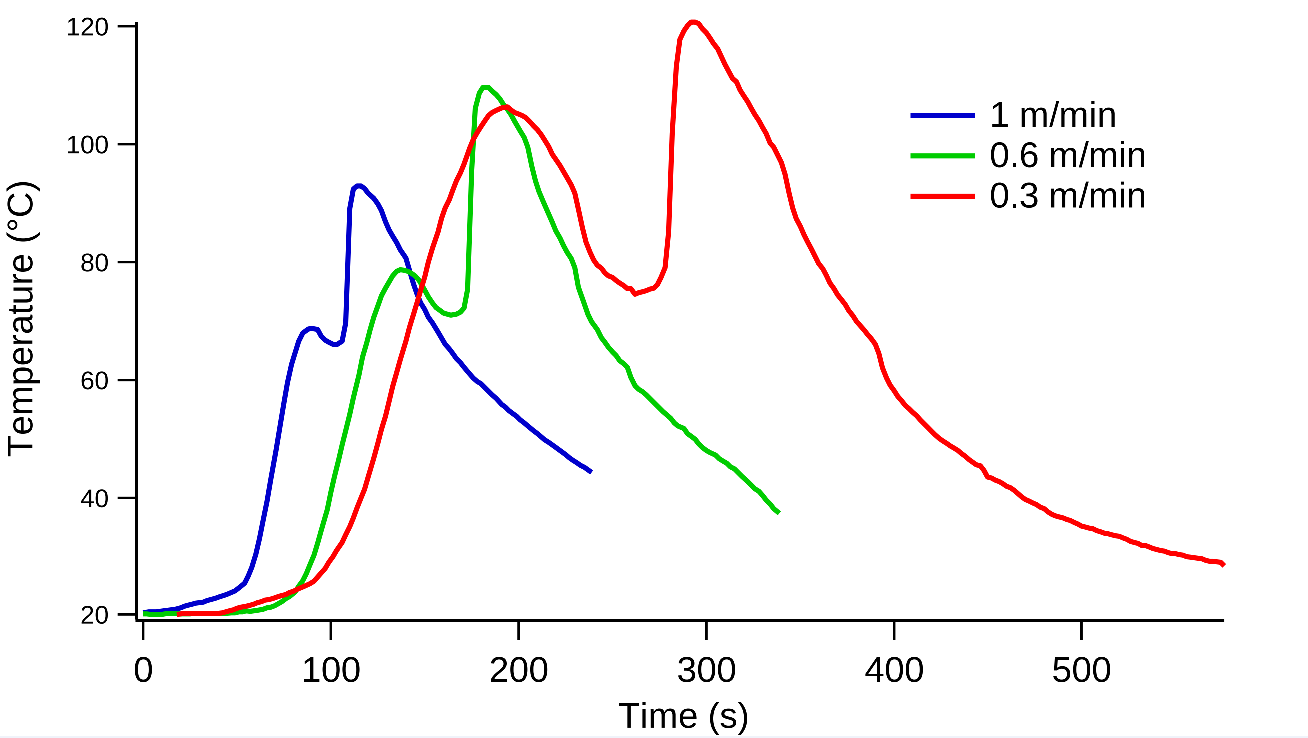
Roll vs. Vacuum Lamination

- Short dwell time has important implications on bill of materials.
- Tuning of materials, process and equipment
  - Encapsulant
  - Isotropic Conductive Adhesive
  - Edge seal
  - Front and back sheet



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MC2.0

Reliability of PV Semi-Fabricates

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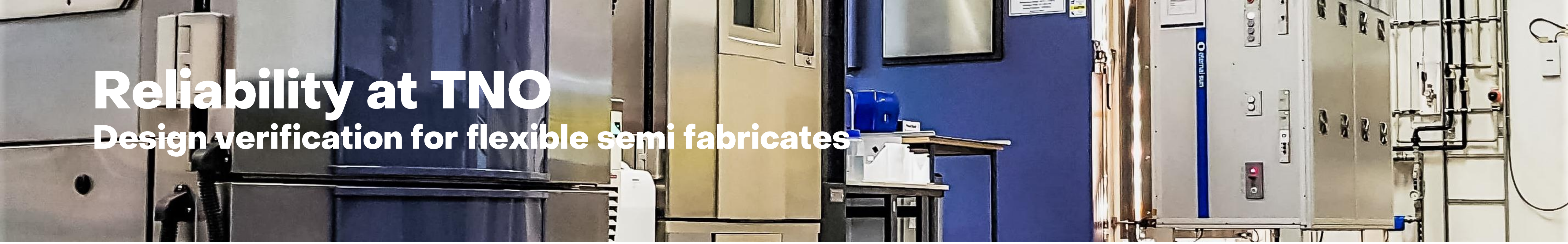
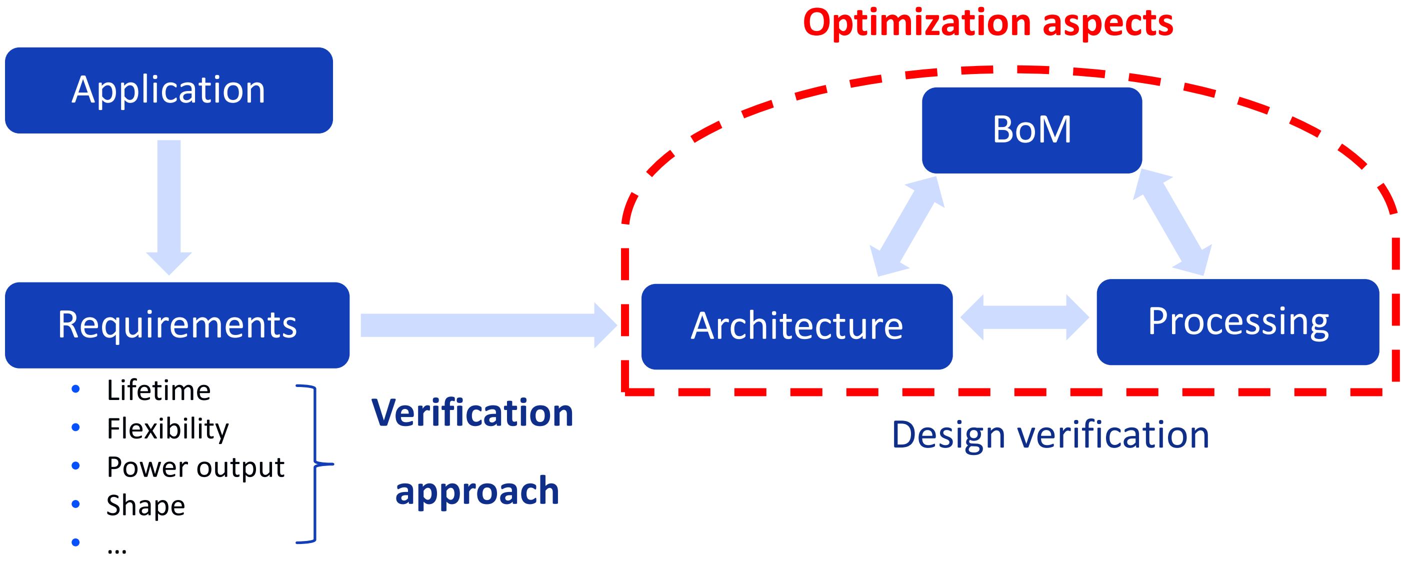


Reliability at TNO

Design verification for flexible semi fabricates

- **At this stage in the project focus on optimization aspects**



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Reliability at TNO
Design verification for flexible semi fabricates

- **Optimization aspects:**
  - BoM, processing, architecture

- **Lifetime is usually the limiting requirement**

- **Accelerated lifetime tests**
  - Standard tests from IEC (61215, 61730)
  - (Non-standard) application specific testing

- **Failure mode/post-mortem analysis**

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Approach

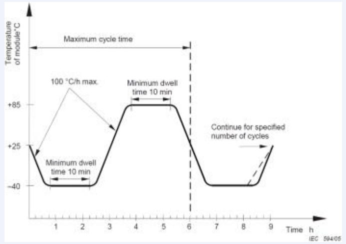
Standard IEC tests

- Selection of tests depends on application
  - Damp heat, Temperature Cycle, Sequential test
- Starting point is always the semi-fabricate
- DH/TC tests generally 3x IEC requirements
- Test results give ‘weak points’
  and possible aspects for optimization

-40°C +85°C

Thermal Cycling (TC)

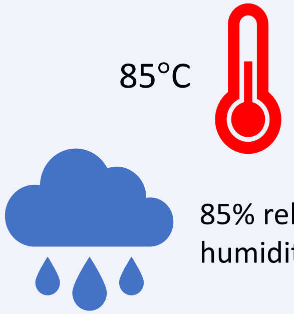
200 x



Delamination due to CTE mismatch

Damp Heat (DH)

85°C



85% relative humidity (RH)

Moisture protection

UV exposure

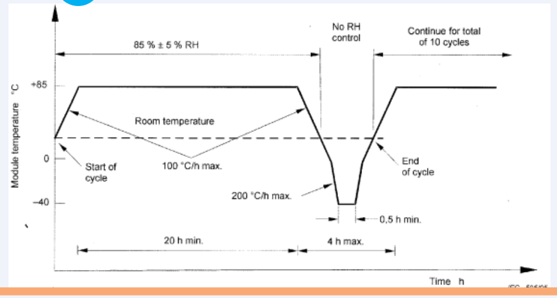
15-60 kWh/m^2

Discolouration
Embrittlement

DH -40 °C

Humidity Freeze (HF)

10X



Moisture ingress + freezing

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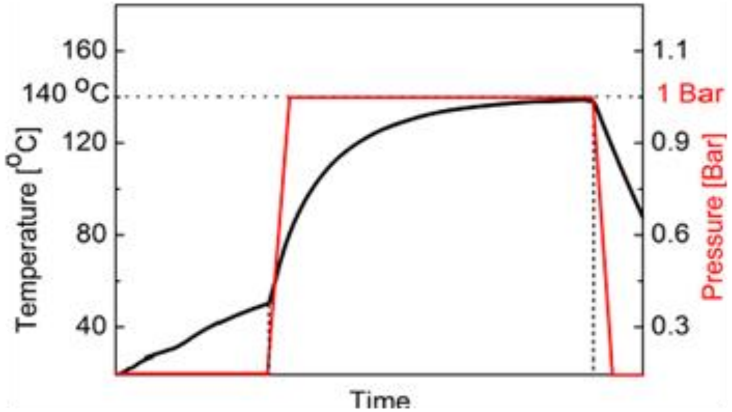
State of the Art BoM + Process

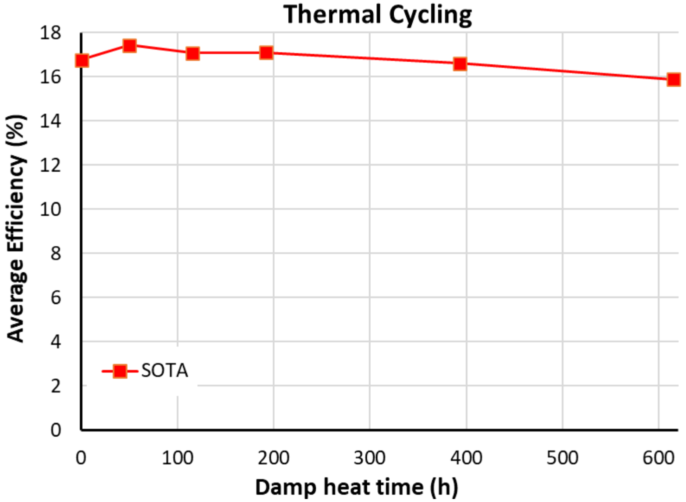
Current "State of the Art" (SOTA) identified with ALT (3x IEC):

- 'Commercial barrier' front sheet
- Krempel back sheet
- MiaSolé CIGS cells
- PO (PO3)
- ICA (A)
- Edge seal

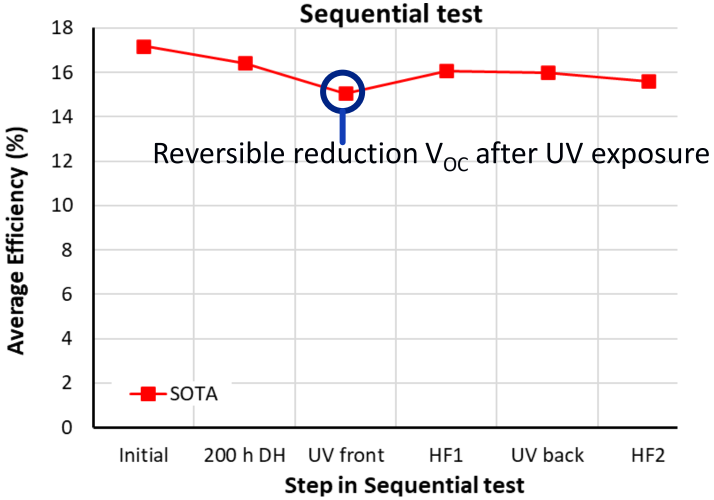
Large impact on cost
Thickness increases temp. budget in R2R

Designed for S2S
Melting/curing temperature not reached in R2R

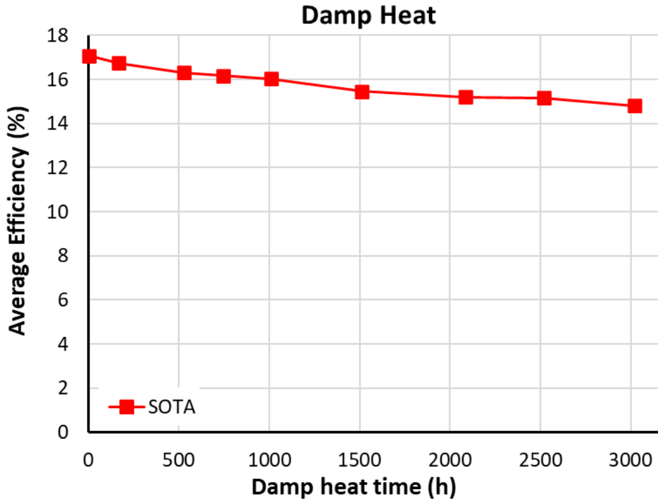




~95% initial efficiency after TC test



~91% initial efficiency after Seq test



~87% initial efficiency after DH test

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Encapsulant selection (PCCL)

Sample	Partner	Melting peak [°C]	Crosslinking peak [°C]	Crosslinking onset [°C]	material	Softening [°C]	Melting [°C]	Heating plate
PO1	TNO	92			Ethylene ethyl acrylate copolymer	71	97	
PO2	TNO	75	166	144	Ethylene α-olefin copolymer	74	93	warps
PO3	TNO	74			Ethylene based coploymer	75	93	warps
PO4	TNO	72			Ethylene based coploymer	66	93	warps
PO5	TNO	60	157	148	Ethylene α-olefin copolymer	60	78	
PO6	TNO	91			Ethylene ethyl acrylate copolymer	72	93	
PO7	PCCL	73			Ethylene α-olefin copolymer	71	110	
PO8	PCCL	103			Ethylene α-olefin copolymer	67	101	
PO9	PCCL	121			Ethylene α-olefin copolymer	54	76	

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Encapsulant selection process

- **Internship Casper van Kessel:** tests on 6 encapsulants (POs) for R2R compatibility
- Mechanical properties
- R2R processed
- Mechanical testing and DH/TC on laminates

	Tm [°C]	Crosslink onset [°C]	WVTR @38°C,90% RH [g/m²*day]	Stress [MPa]	Strain [%]	Peel FS R2R [N]	Peel BS R2R [N]
PO1	93,5	N.a.	109,0	6,25	690	80	20
PO2	78,2	144,87	5,1	5,25	380	N.A.	N.A.
PO3	76,4	N.A.	4,5	5,4	500	12	5
PO4	74,1	N.A.	5,2	7	320	13	7
PO5	**64,8**	131,54	7,5	4,4	**780**	**10**	**25**
PO6	91,8	N.A.	26,1	7,1	670	12,5	25

- PO5 found to have most favourable material properties for R2R on average

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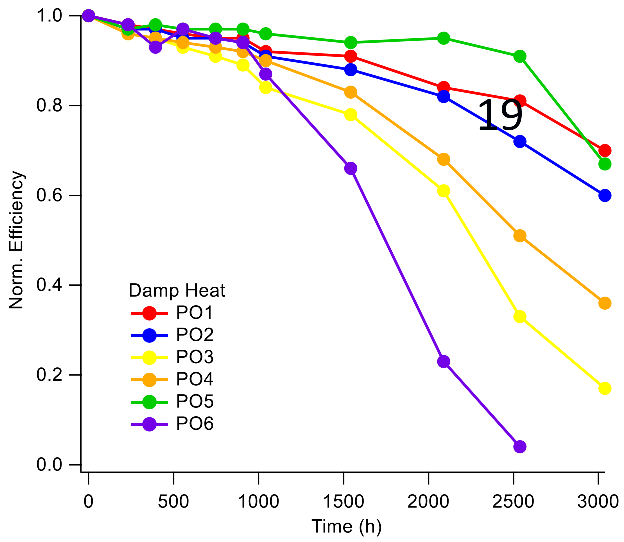
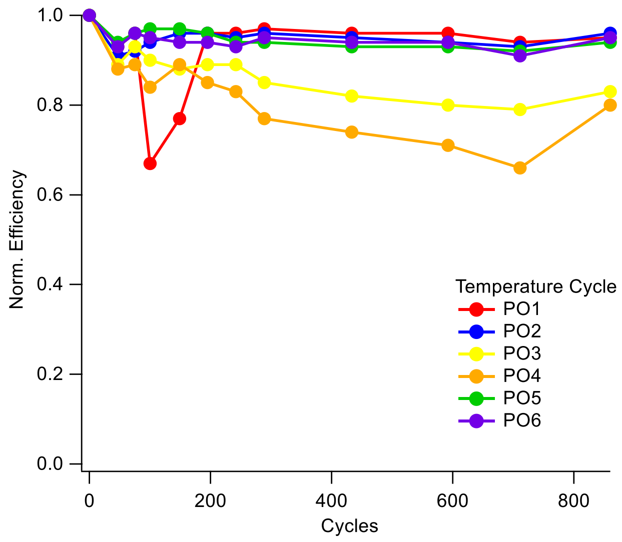
Material selection: encapsulants

Internship Casper van Kessel: tests on 6 encapsulants (POs) for R2R compatibility

- **Material tests:** melting point (onset cross-linking), WVTR, tensile testing, peel tests (and more)
- **DH + TC** with functioning devices: PO5 also performs best





R2R lamination, 135°C
0.1 m/min

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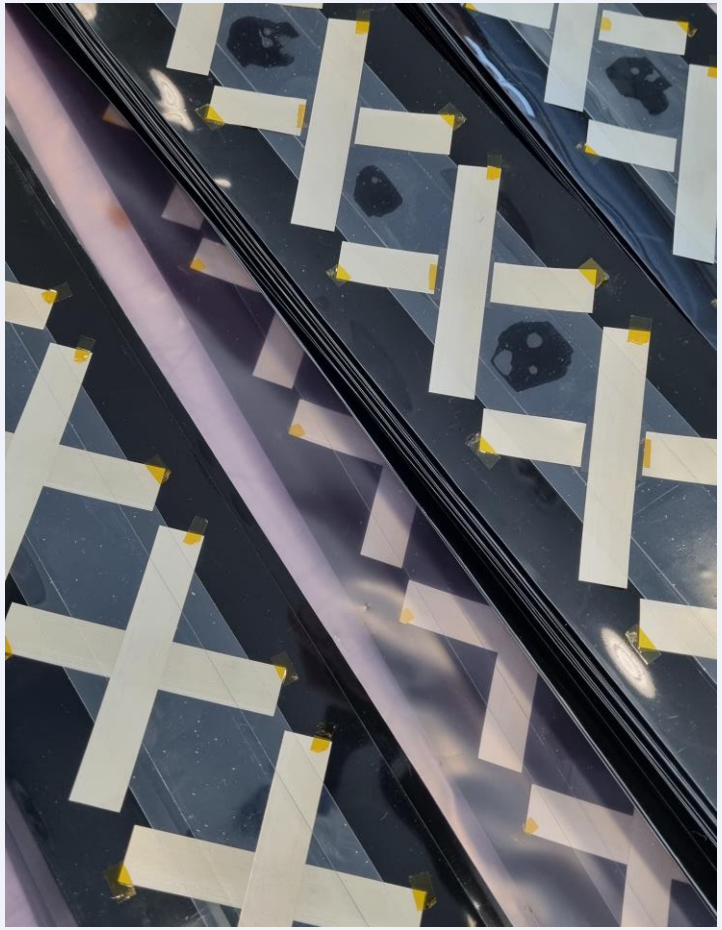
Material selection: ICAs

Internship Bart Vos: tests on conductive adhesives (ICAs)

- 7 ICA’s tested (DOE)
  - Difference in composition and curing behaviour
  - Varying chemistry
  - 4 point resistance measurements

- ICA A Current standard S2S
- ICA B Current standard **R2R**
- ICA C & D Alternatives for **R2R** (supplier 1)
- ICA E & F Alternatives for S2S (supplier 1)
- ICA G Alternative for **R2R** (supplier 2)



- Meeting 16-04-2024

Material selection: ICAs

Internship Bart Vos: tests on conductive adhesives (ICAs)

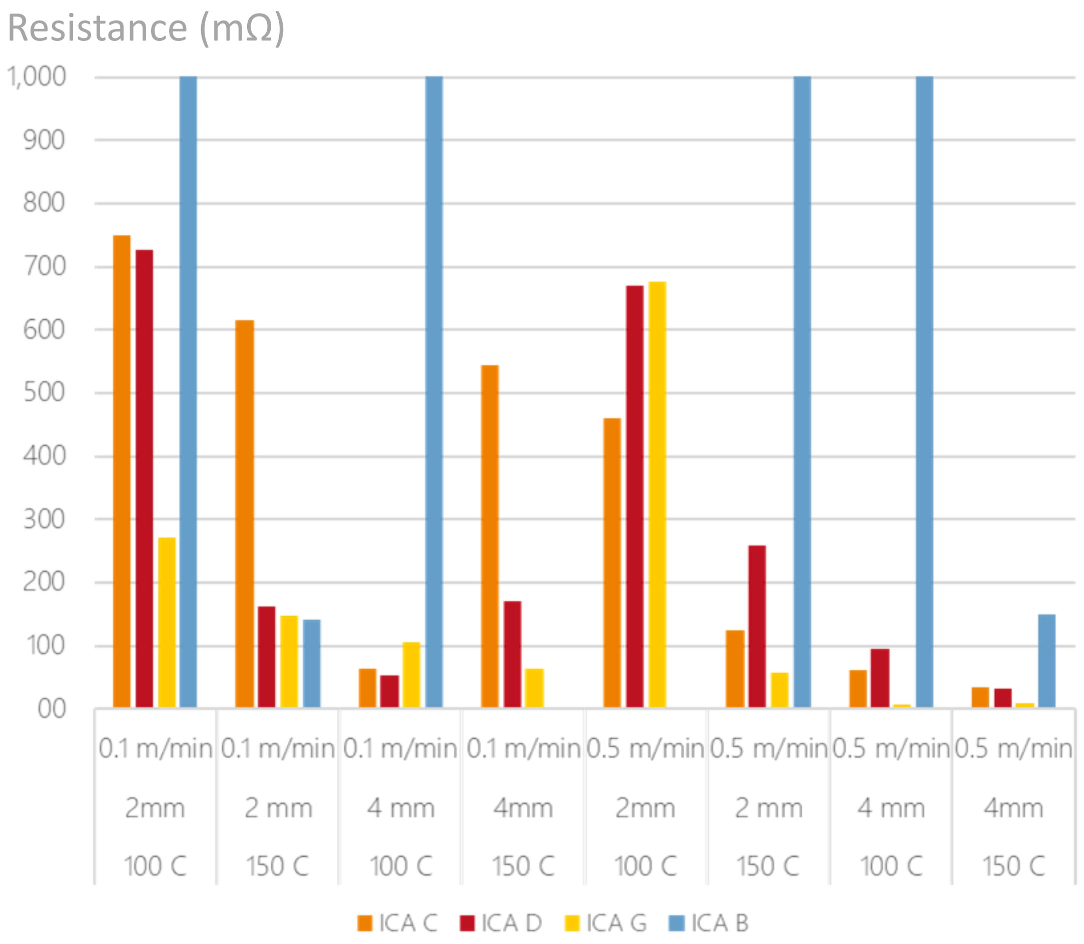
- ICAs developed for R2R processing live up to their promise

- ICA B performs poorly in R2R lamination

- Lower curing temperatures are not necessarily better
  - Crust formation before pressure can applied

- All tested parameters are of importance

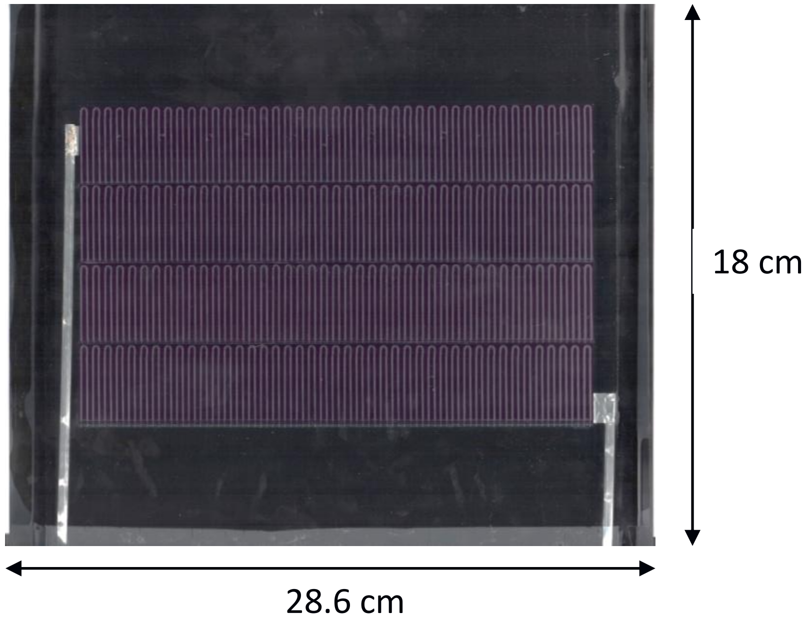
- For each ICA there is a setting that leads to (usable/ acceptable) low resistance values



*Lowest temperature for ICA B is 120 °C

Reliability on MCL samples

- Typically 25 samples in one run.
- Standardized samples suited for solar simulator and climate chambers
- Results from first runs!



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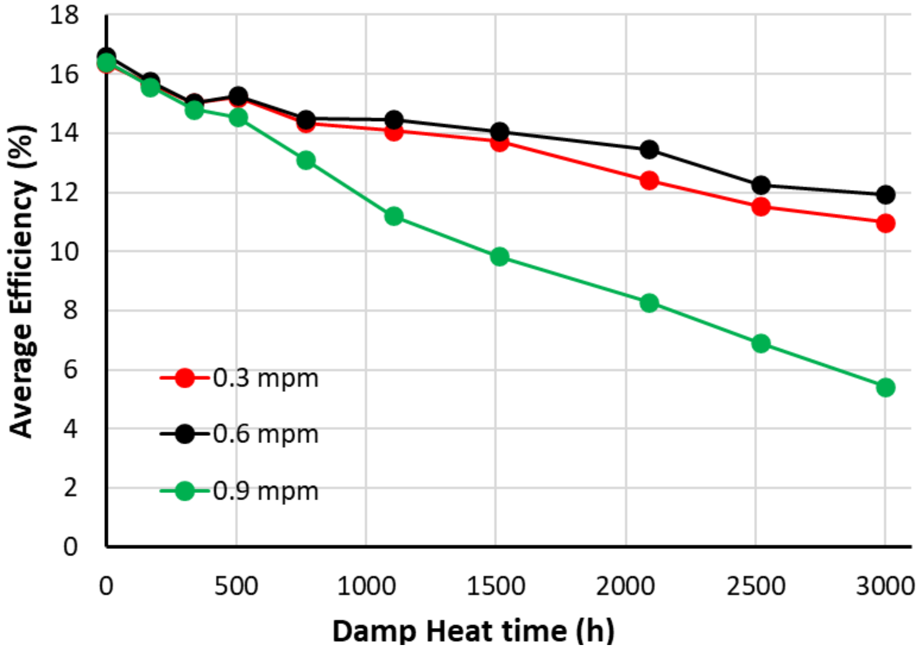
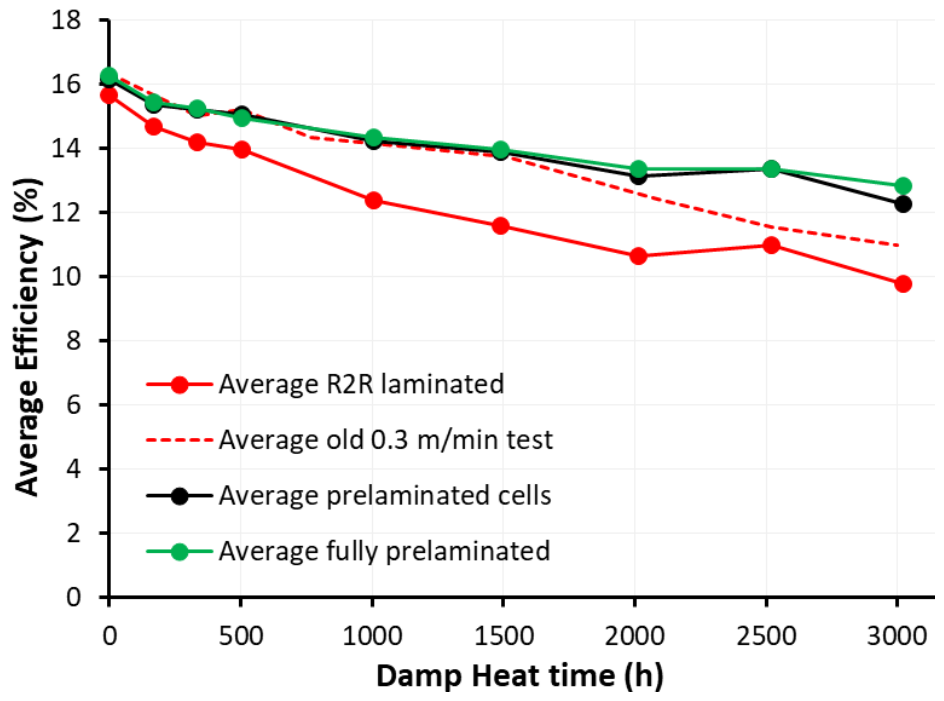
Lamination Speed

- Lower speeds still necessary to reach stable laminate
- Degradation rate still too high (~70% initial performance 0.3 and 0.6 mpm)



Prelamination Strategies

- Prelamination greatly improves stability in performance
- Challenge: obtaining good contact cell/grid
- Still large variations between 0.3 mpm processing



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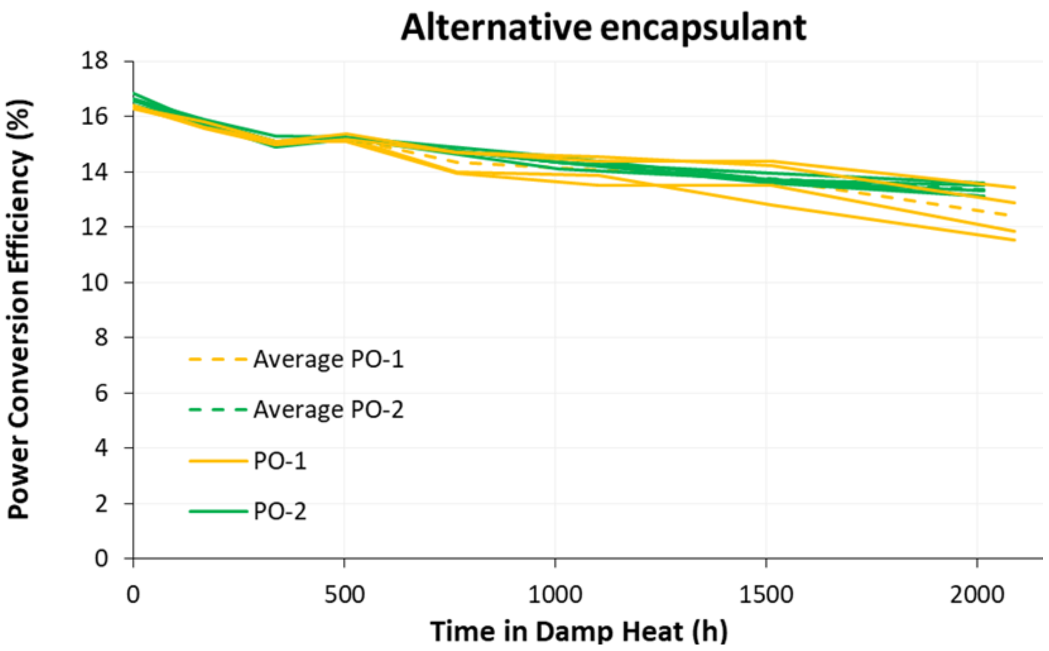
Alternative Encapsulants

- Comparison encapsulants developed for S2S and R2R (PO2 and PO3 from the previous experiment)

- No significant difference



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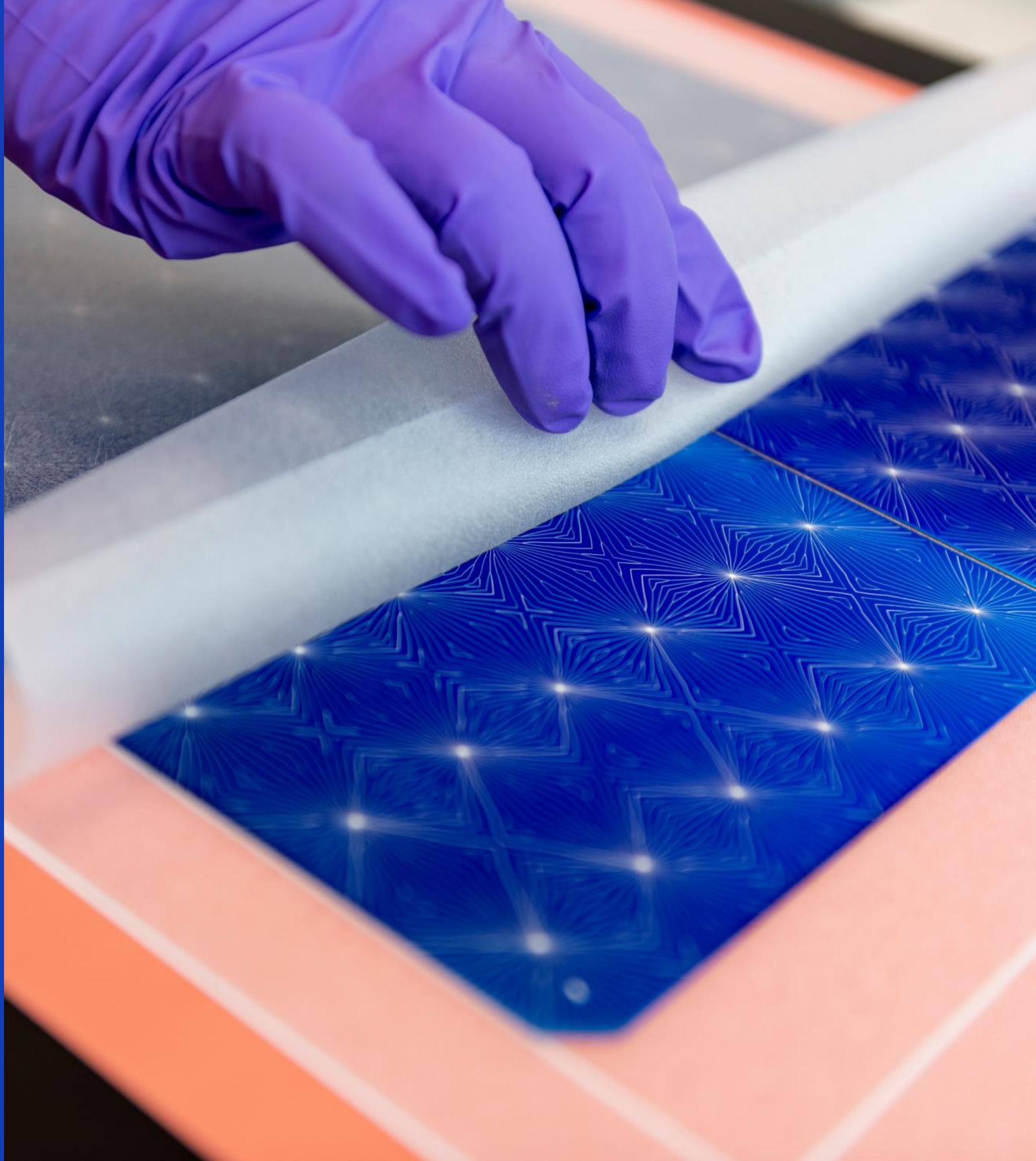
Back Contact in MC2.0



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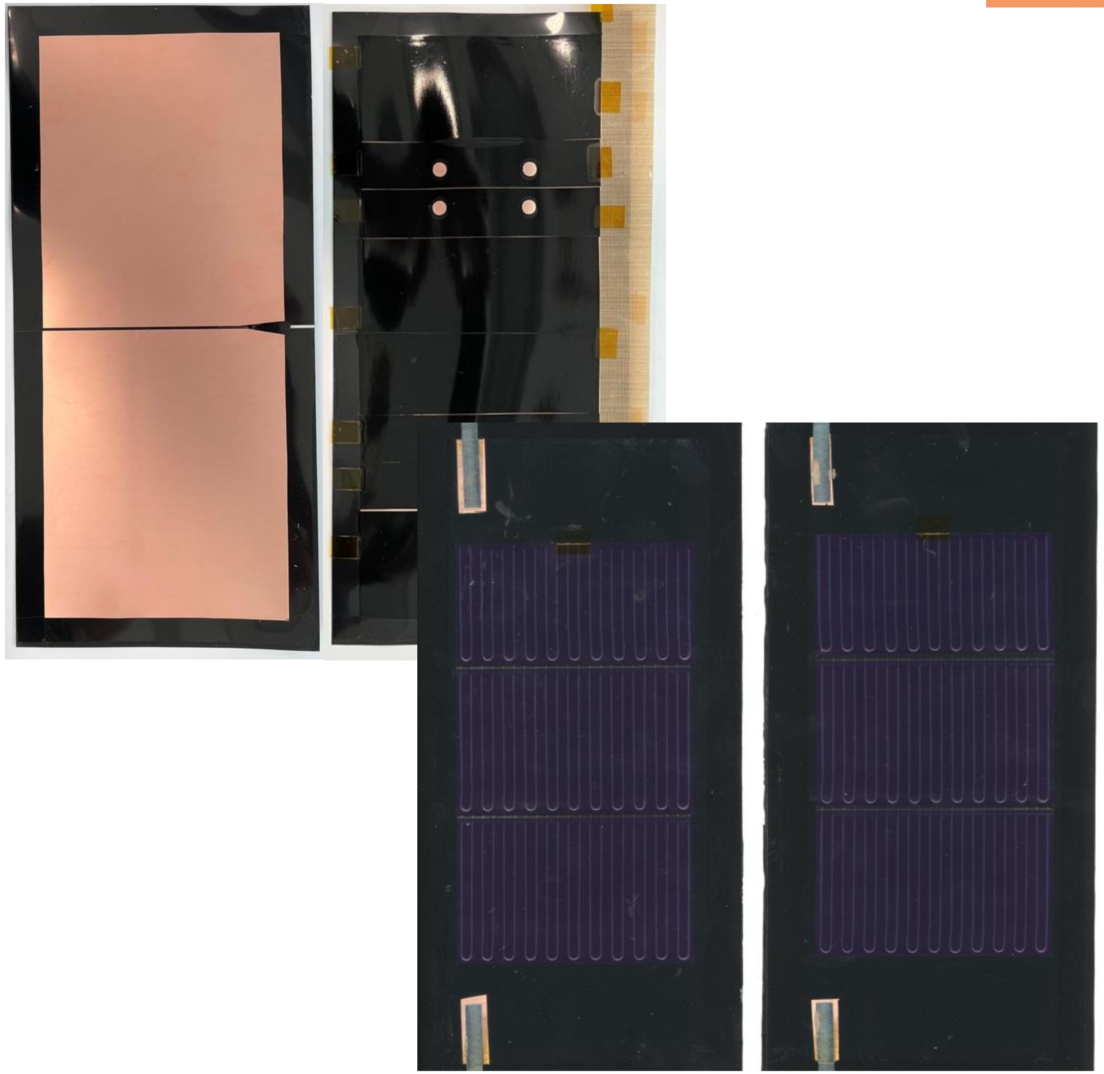
Towards back-contact in MC2.0

- Copper clad back foil with moisture barrier
- Milled pattern in copper
- Black encapsulant
- ICA dispensed in laser patterned holes
- 2 Miasolé cells in series
- S2S and R2R processed



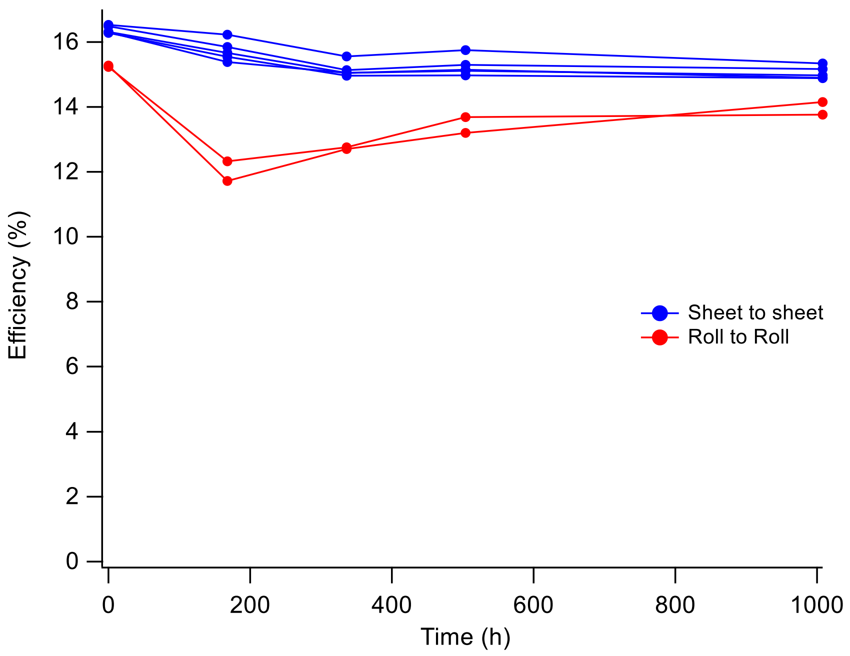
Towards back-contact

Preliminary result!

- comparing back-contact in S2S and R2R
  - Cu clad back sheet with barrier
  - EPE lasered encapsulant

- Back contact feasible on lab scale R2R

- Milling of copper does not affect moisture barrier



Summary and outlook

- The Mass customisation concept, especially roll lamination requires the development of new materials, processes and equipment.
- Process windows for various materials can be found, matching these is the next challenge.
- Next chapter is to develop back-contact processes for inline manufacturing.
- Accelerated lifetime testing is an important tool for optimization. IEC tests can be applied for PV semi-fabricates
- **How to characterise reliability of integrated PV products?**

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Thank you very much for your attention!

TNO innovation for life