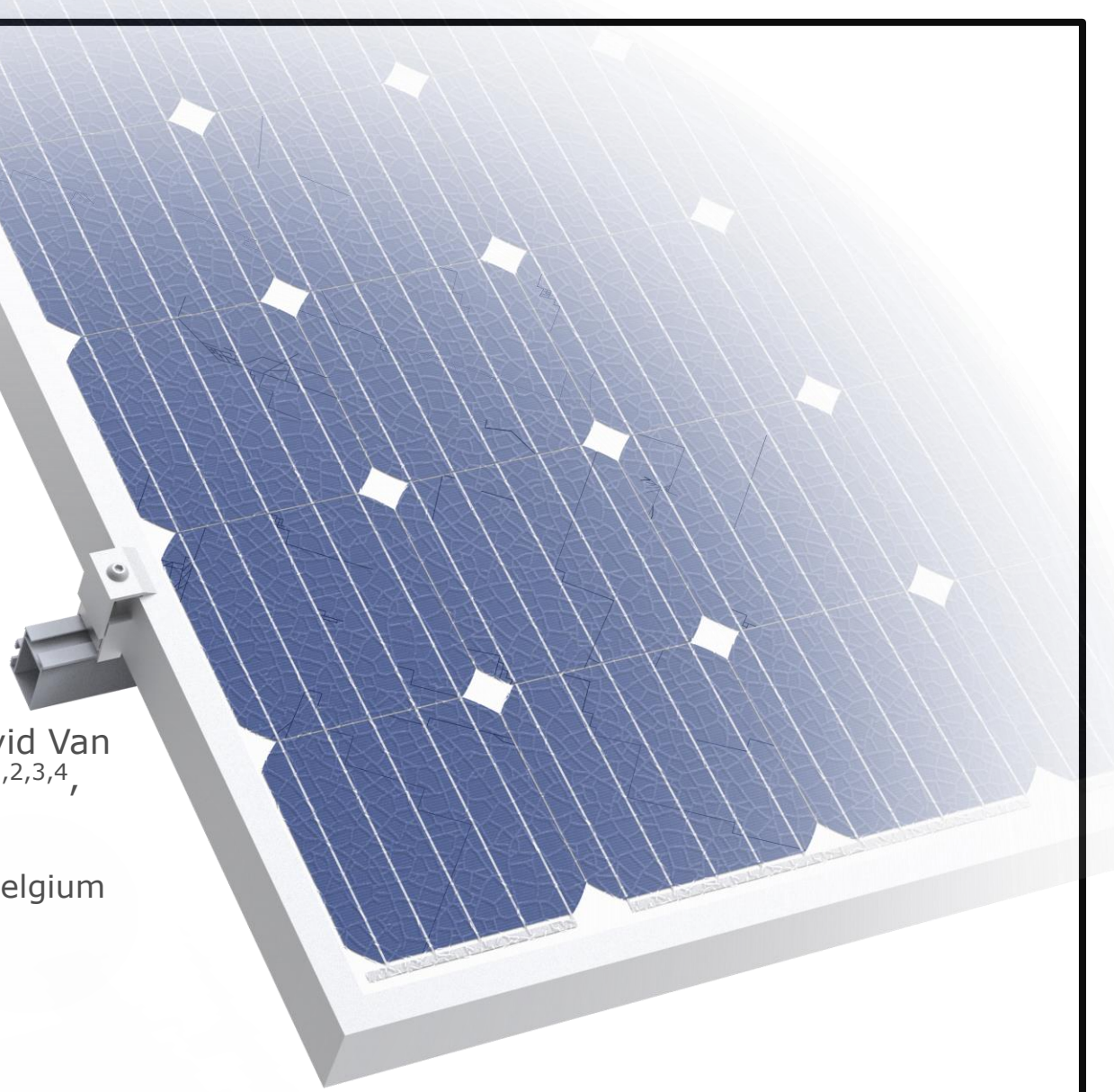
Multi-scale multi-physics modelling of photovoltaic systems: a co-development approach



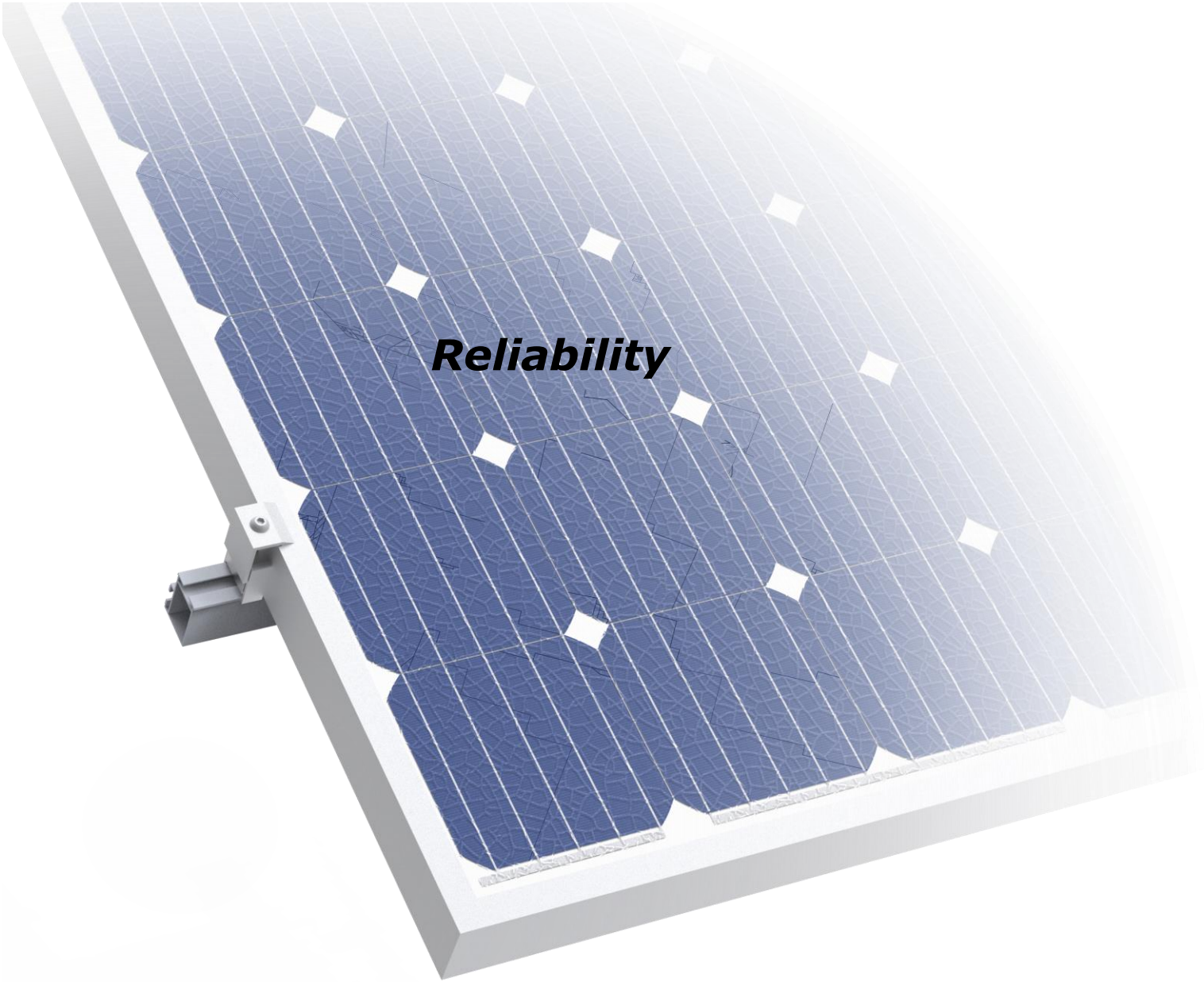
Philippe Nivelle[1,2,3], Tom Borgers[1,2,3], Jonathan Govaerts[1,2,3] , Arvid Van der Heide[1,2,3] , Tine Engelen[1,2,3], Jan Mertens[1,2,3], Jef Poortmans[1,2,3,4], Michaël Daenen[1,2,3]

[1] Hasselt University, imo-imomec, Martelarenlaan 42, 3500 Hasselt, Belgium
[2] Imec, imo-imomec, Thor Park 8320, 3600 Genk, Belgium
[3] EnergyVille, imo-imomec, Thor Park 8320, 3600 Genk, Belgium
[4] KULeuven, Oude markt 13, 3000 Leuven, Belgium

Overview

- ✓ Motivation
- ✓ Multi-scale nature of reliability
- ✓ Multi-scale Multiphysics reliability framework
- ✓ A case-study: PV module clamping/mounting systems
- ✓ Moving from indirect to direct validation
- ✓ PV-sense
  - ✓ Working principle
  - ✓ Investigating lamination
  - ✓ Investigating thermal cycling
  - ✓ Full size field monitoring
- ✓ A co-development approach
- ✓ Acknowledgements

Motivation



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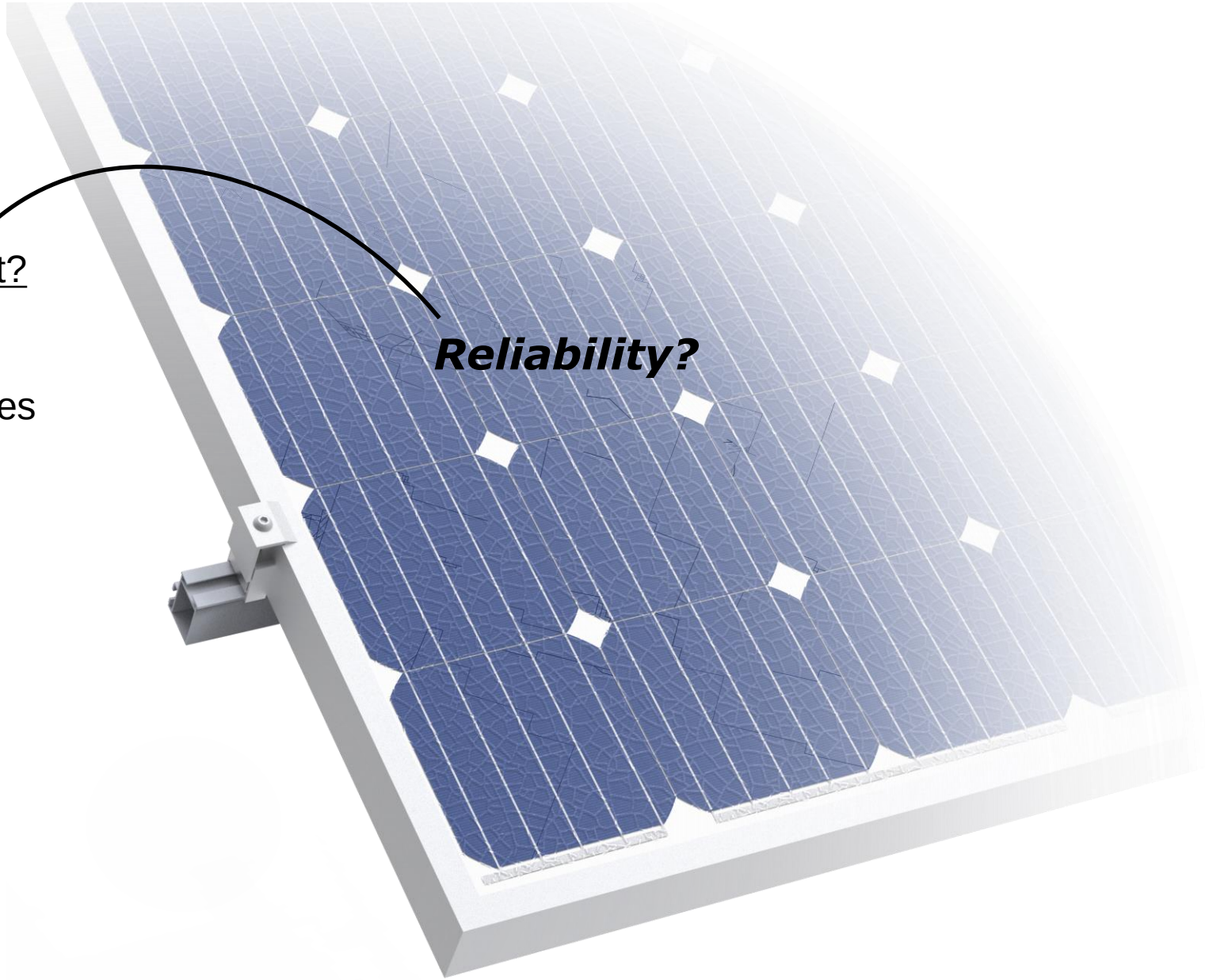
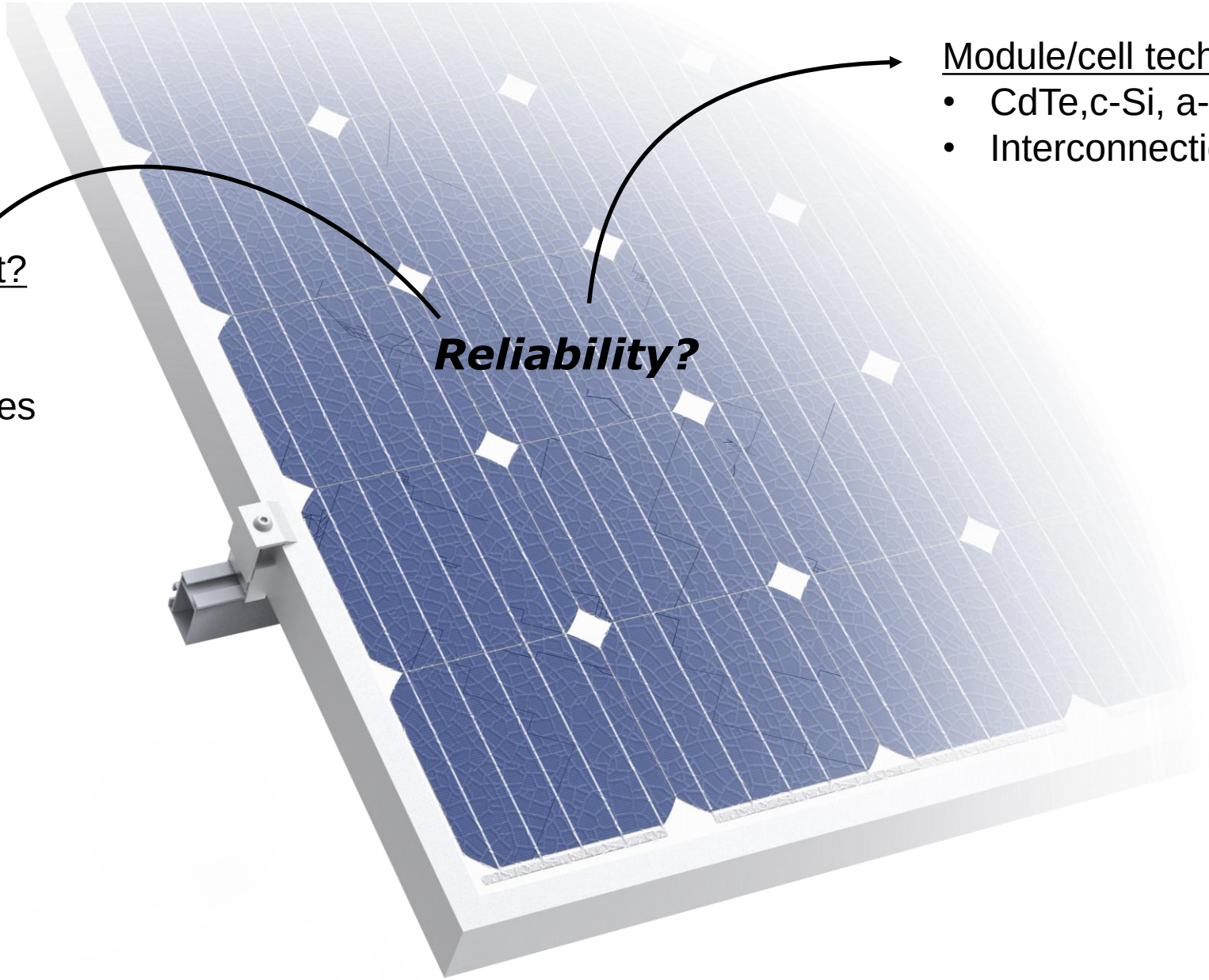


Climate/Environment?

- Irradiation
- Wind speeds
- Ambient temperatures
- Soiling
- Shading
- Hail

Motivation



Module/cell technologies?

- CdTe,c-Si, a-Si, GaAs, CiGS,…
- Interconnection technology

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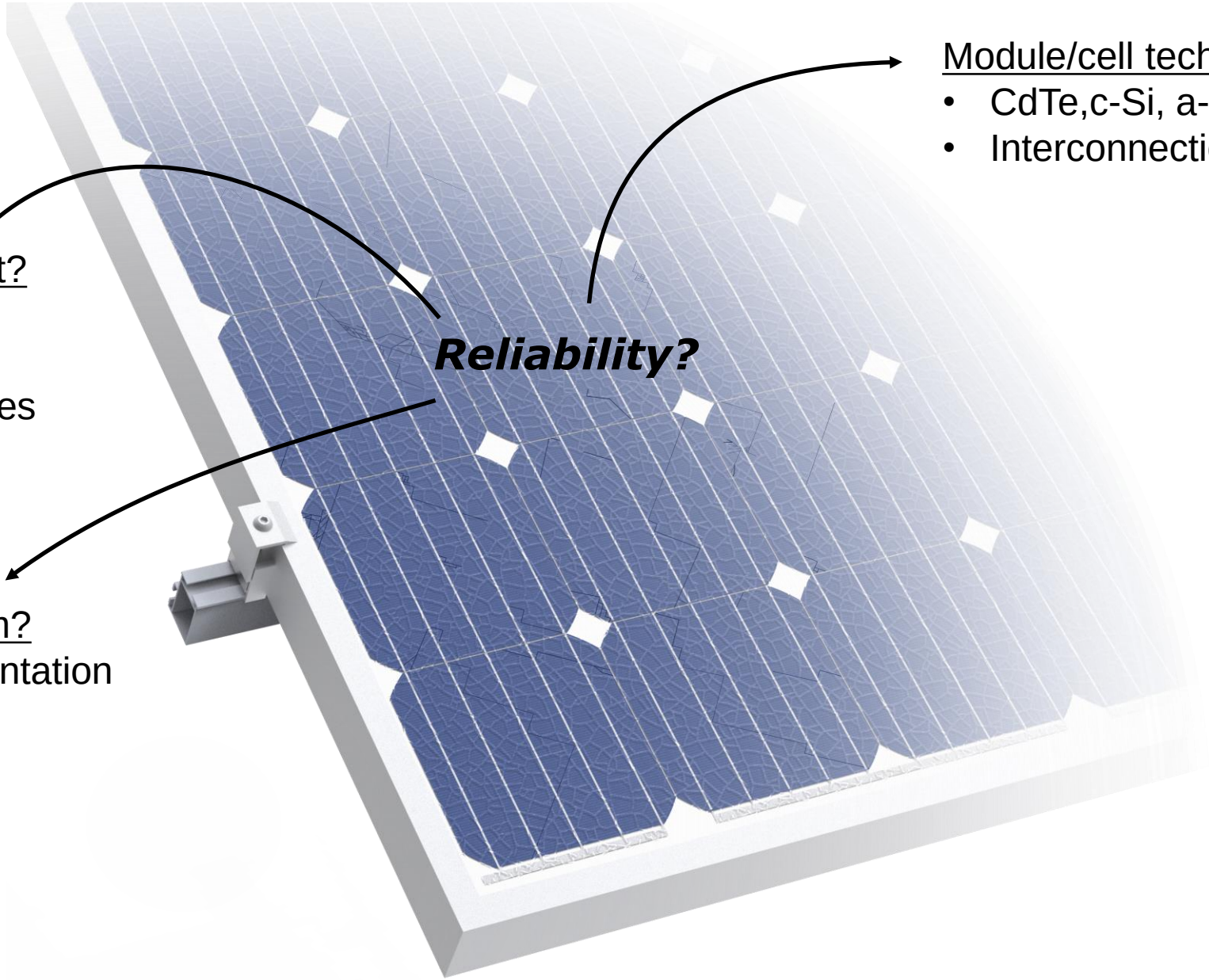

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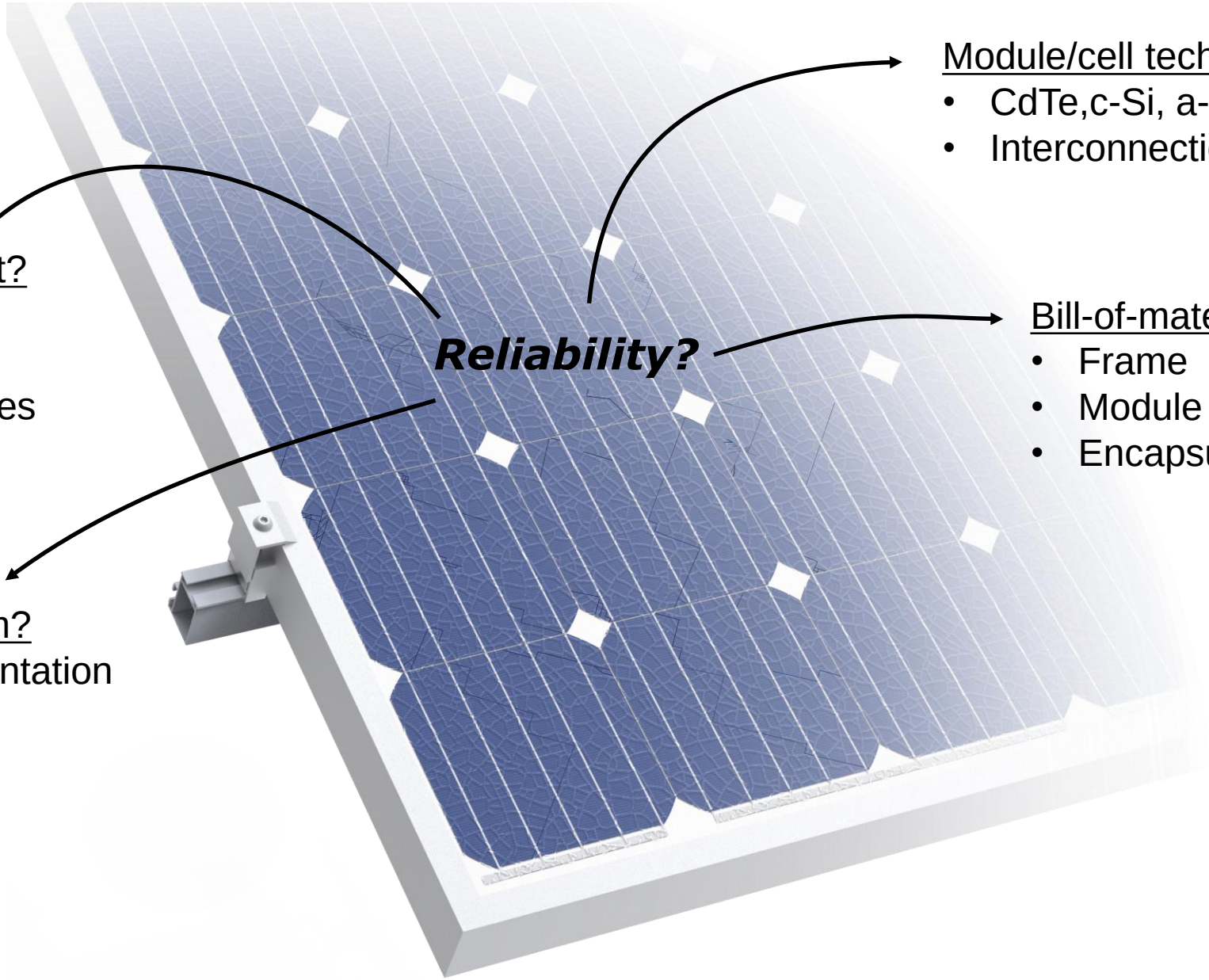
System?

- Module orientation
- Clamping

Motivation



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Bill-of-materials/dimensions?
- Frame
- Module size
- Encapsulant material

System?
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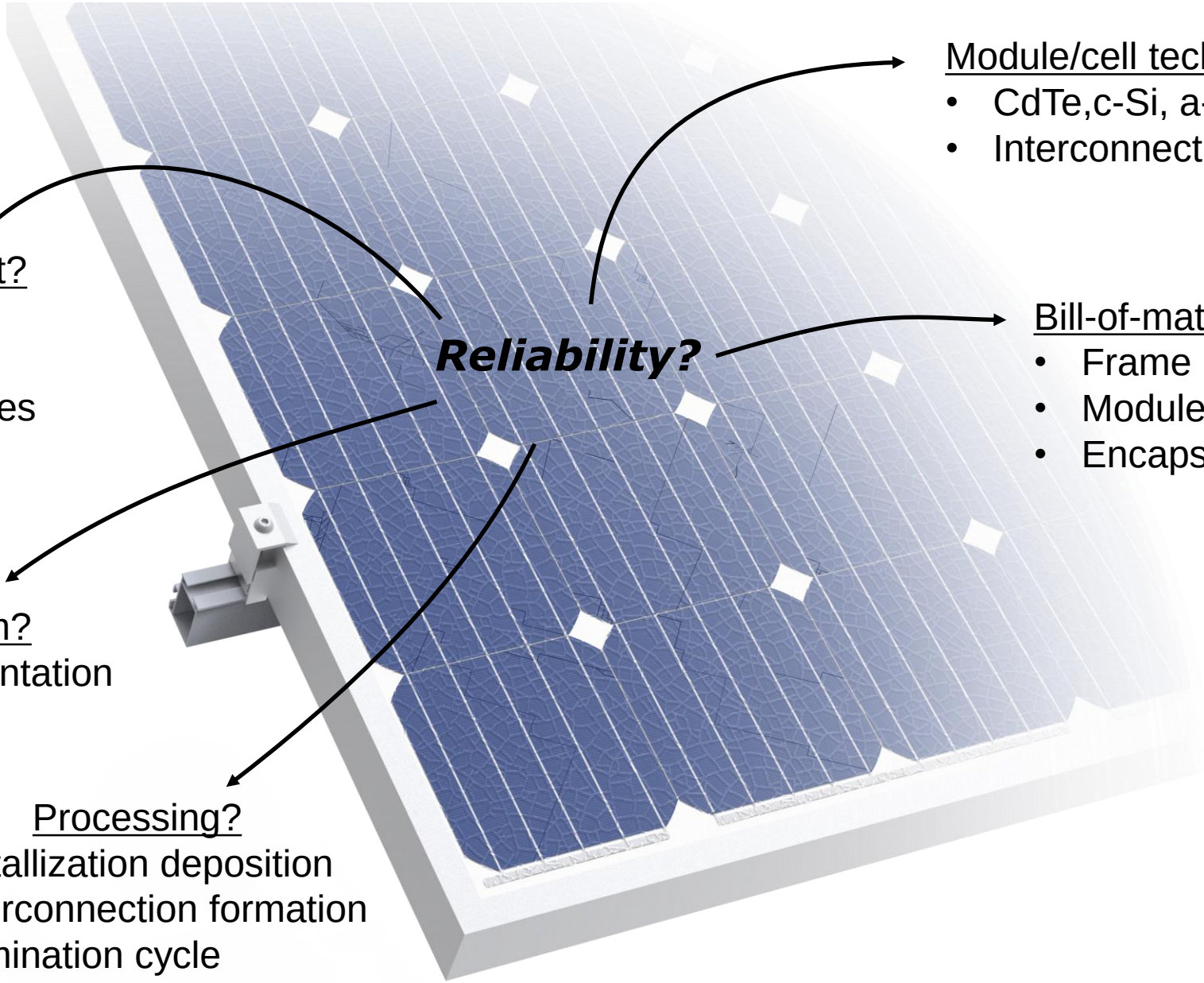
- Clamping

Motivation



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Bill-of-materials/dimensions?
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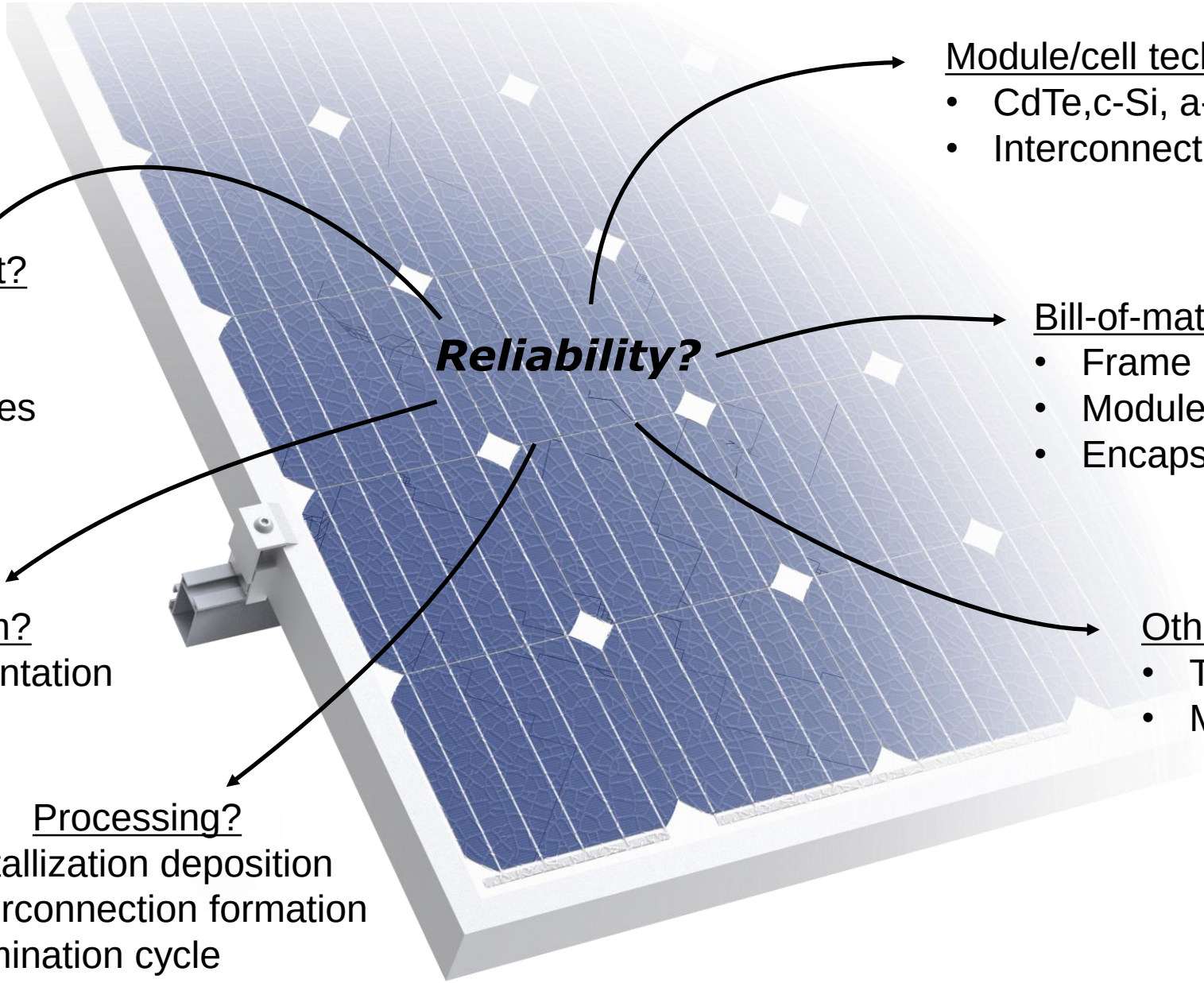
System?
- Module orientation
- Clamping

Processing?
- Metallization deposition
- Interconnection formation
- Lamination cycle

Motivation



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Climate/Environment?
- Irradiation
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- Shading
- Hail

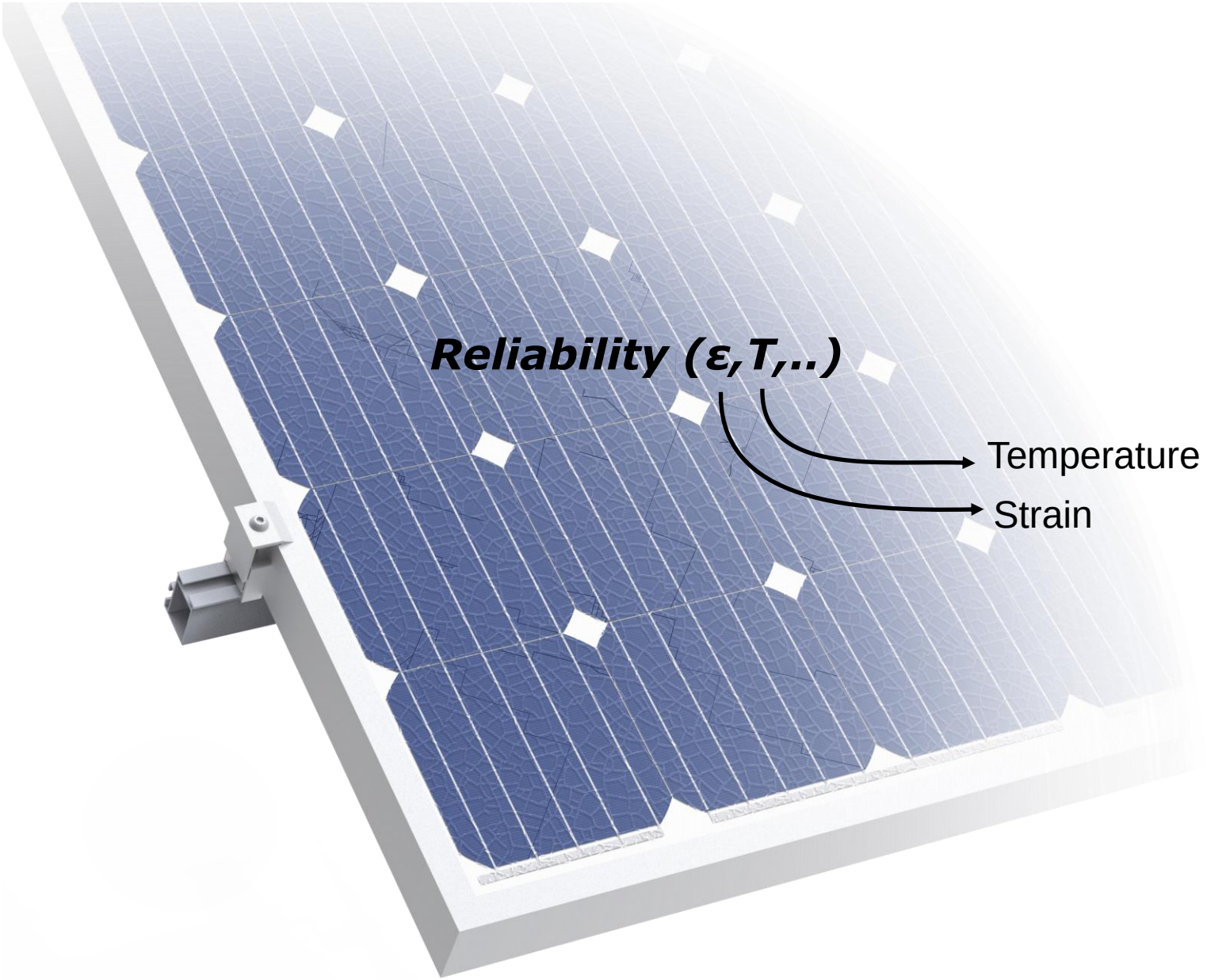
Bill-of-materials/dimensions?
- Frame
- Module size
- Encapsulant material

System?
- Module orientation
- Clamping

Others?
- Transport conditions
- Maintenance

Processing?
- Metallization deposition
- Interconnection formation
- Lamination cycle

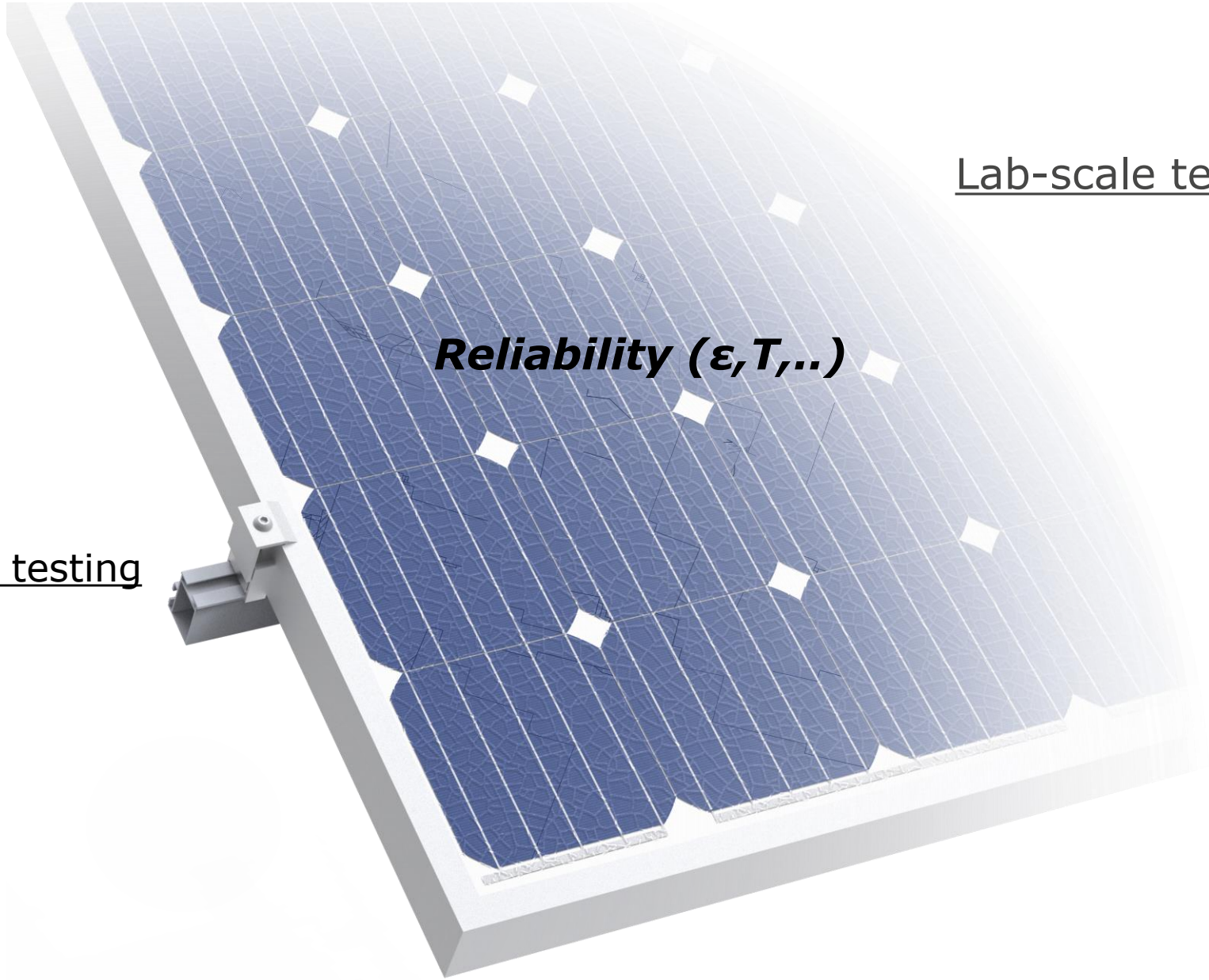
Motivation



Motivation

Field testing

Accelerated stress testing



Lab-scale testing

Reliability (ε,T,..)

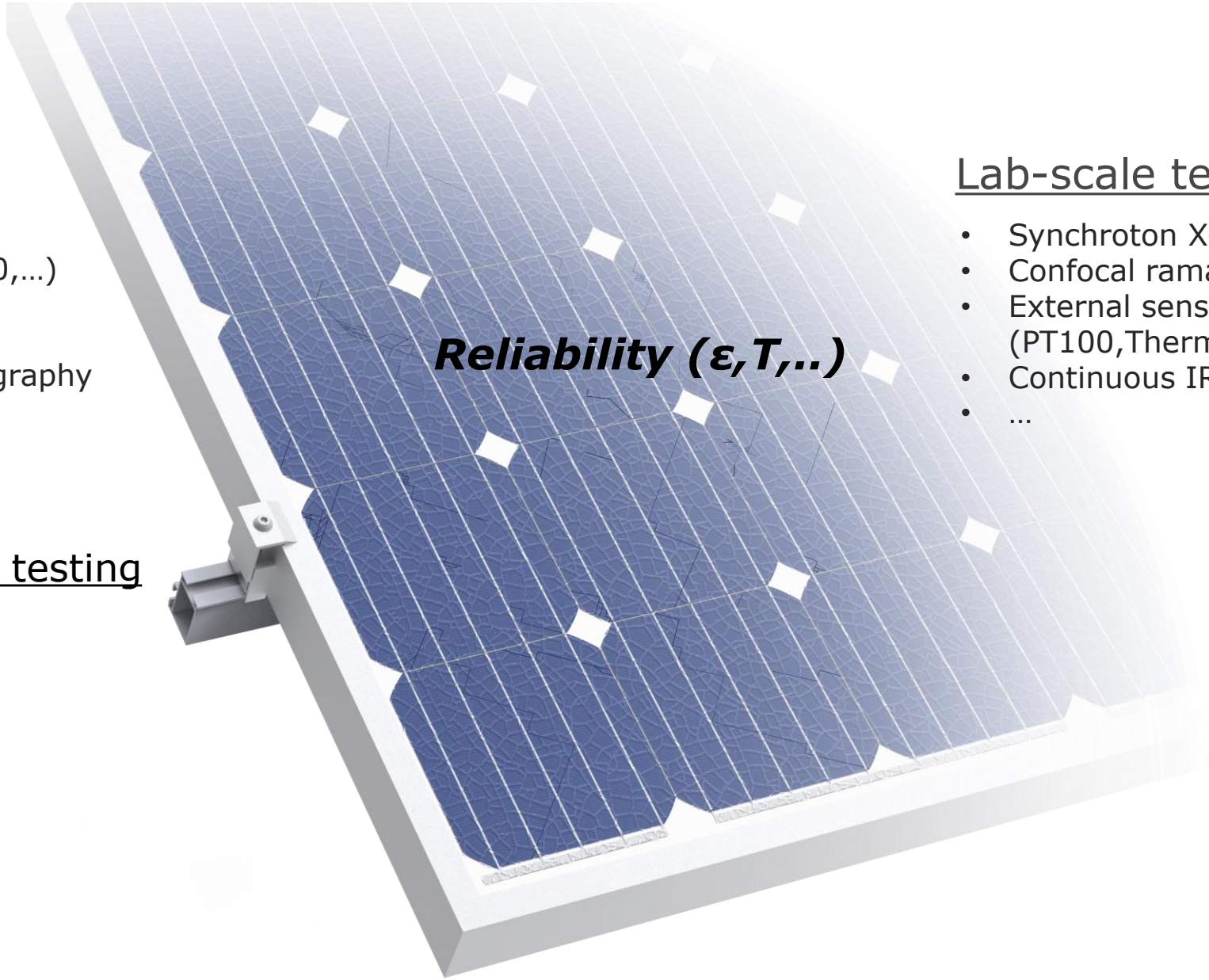
Motivation

Field testing

- External sensors (PT100,…)
- Intermittent I/V tracing
- Intermittent EL
- Intermittent IR thermography
- …

Accelerated stress testing

- Intermittent I/V tracing
- Intermittent EL
- Displacement sensors
- …



Lab-scale testing

- Synchroton X-ray microdiffraction
- Confocal raman microscopy
- External sensors (PT100,Thermocouple)
- Continuous IR thermography
- …

Motivation

Field testing

- External sensors (PT100,…)
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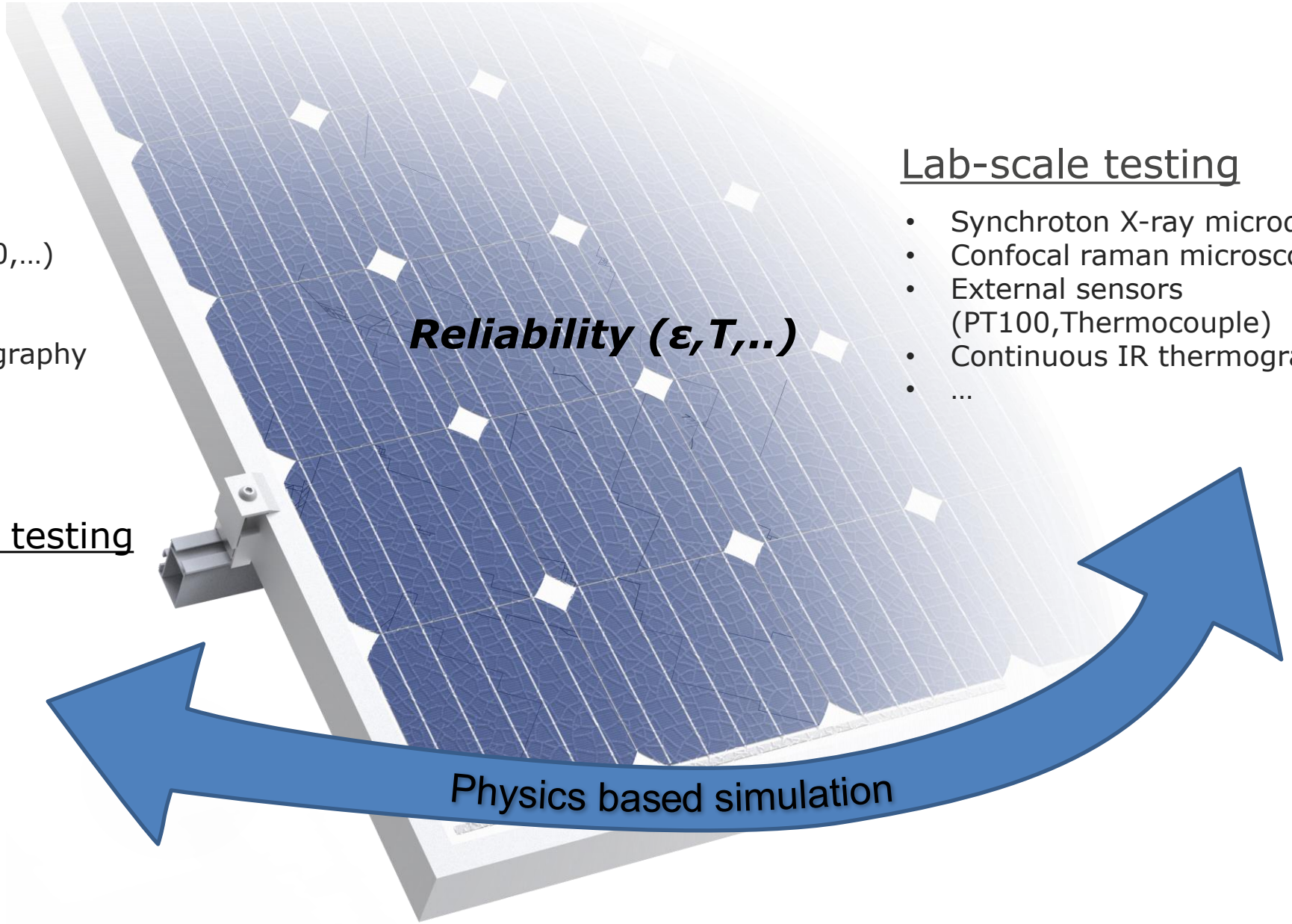

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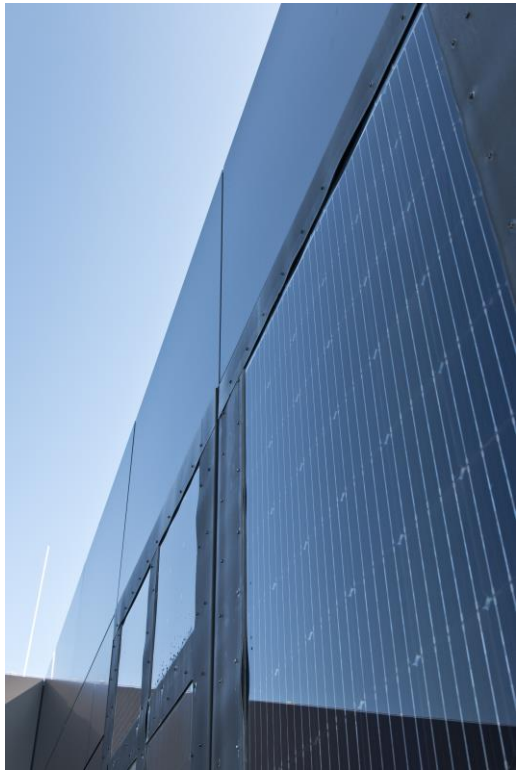
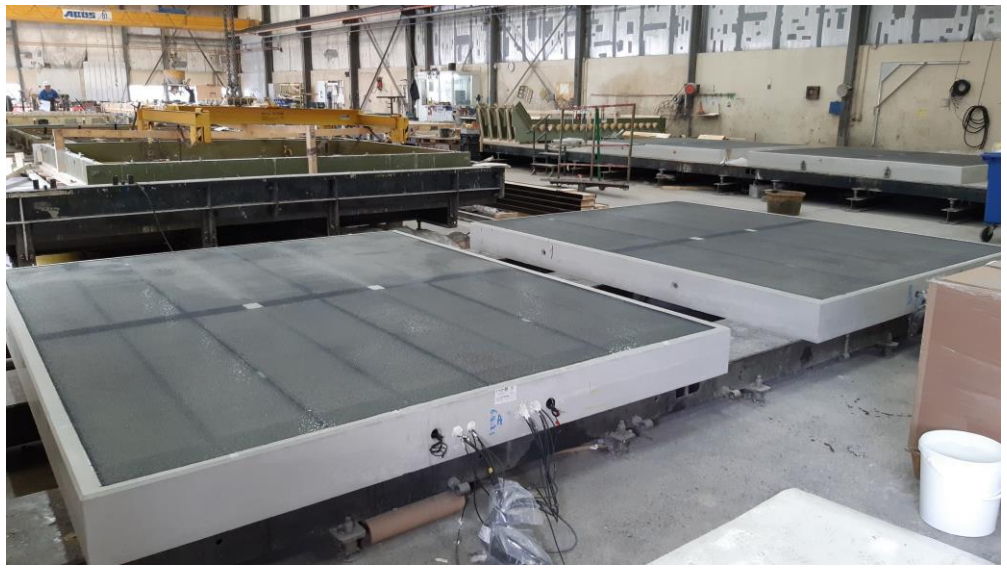


Building-integrated PV @ Energyville site

New applications pose additional challenges from a simulation and validation perspective

- Commonly used assumptions from BA PV are not longer valid
- Use of new (laminate) materials/structures
- Increased interactions between the module and surrounding structures



Road elements with integrated PV

Infrastructure-integrated PV @ Energyville site

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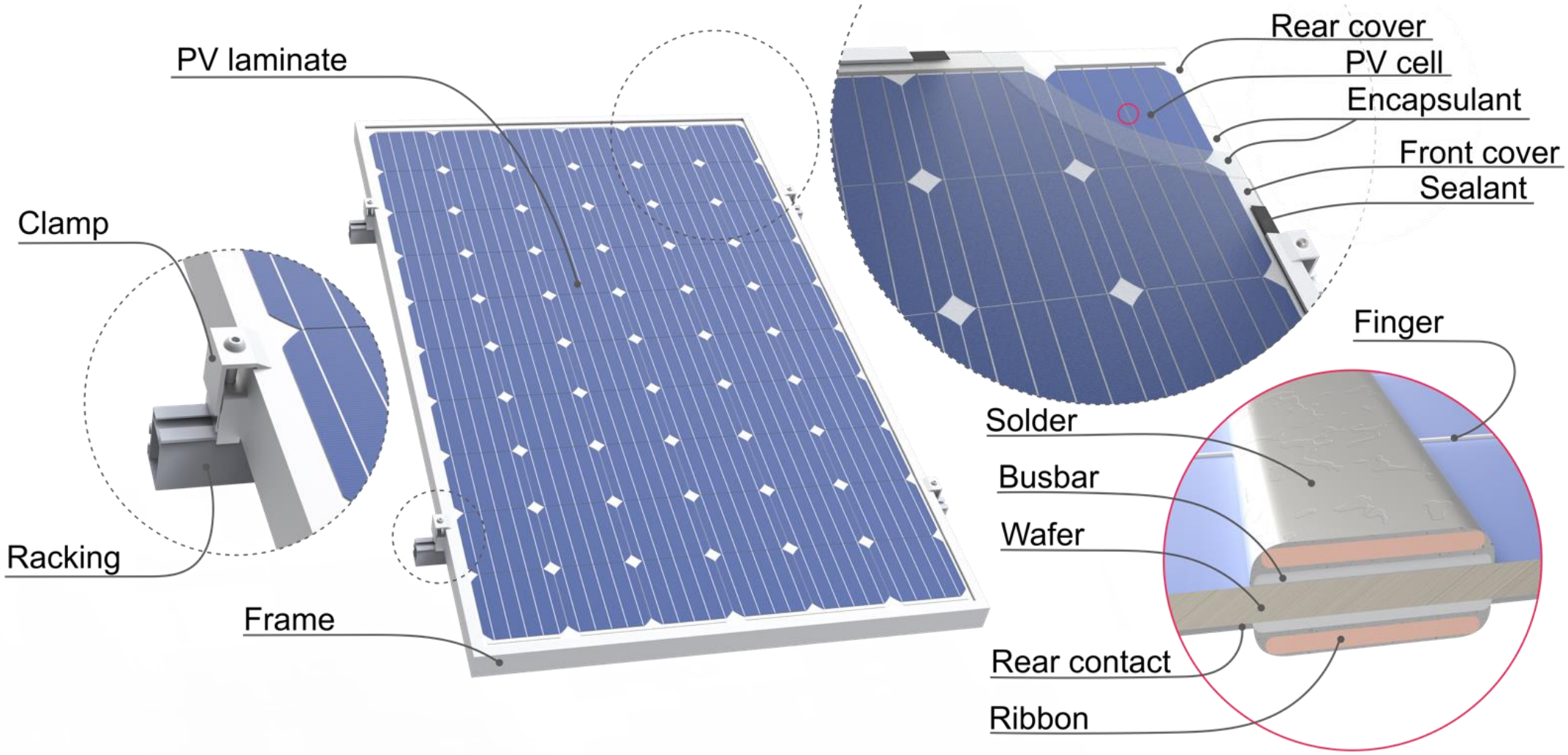
Multi-scale nature of reliability



[1]An industry-standard PV module and all its constituents, reliability is largely determined by the scale regarded

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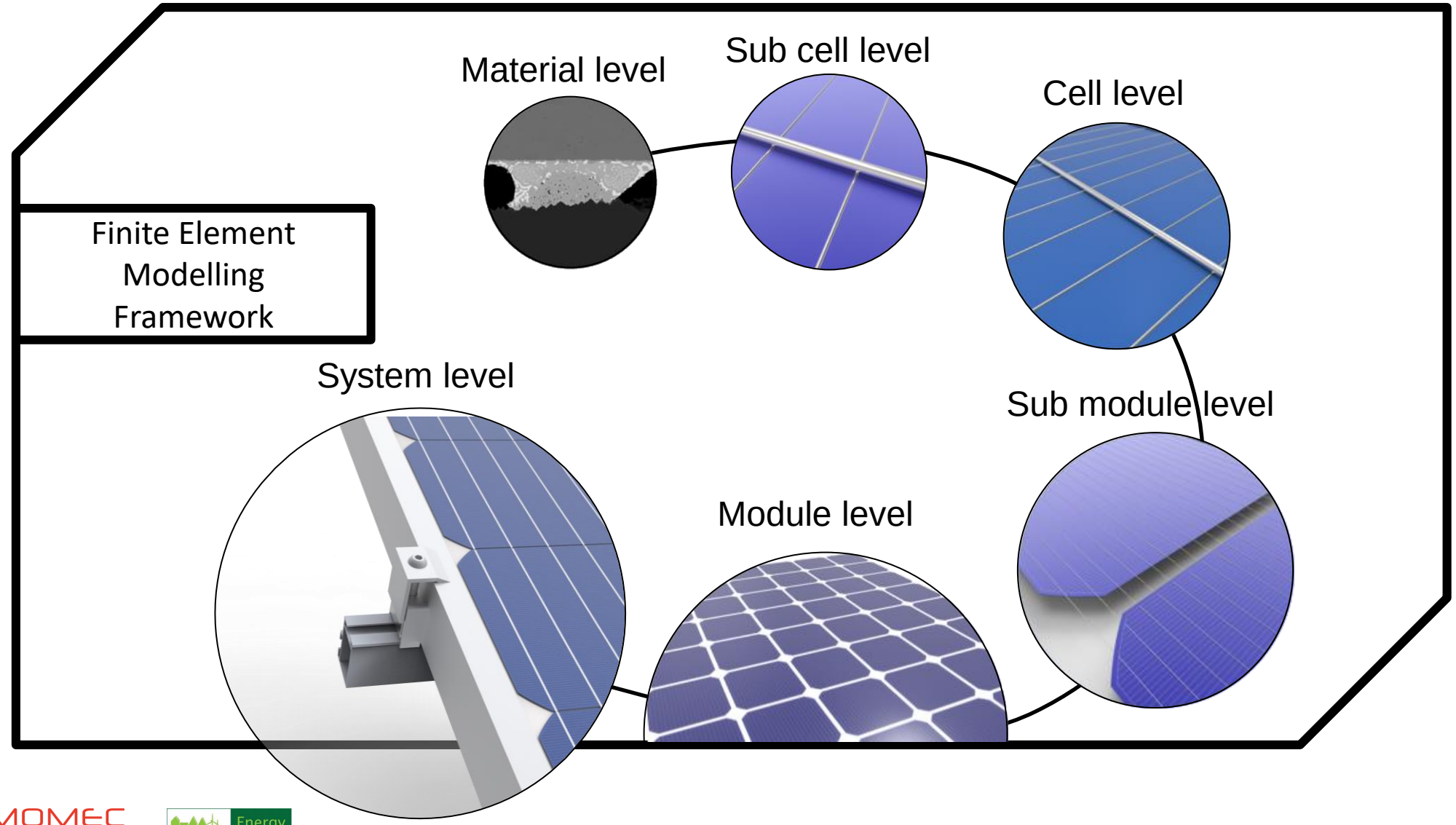
[1]Figure adopted with permission from P. Nivelle et al - Stress and strain within photovoltaic modules using the finite element method: A critical review, Renewable sustainable energy reviews, 2021

Multi-scale multi-physics reliability framework

In submission*



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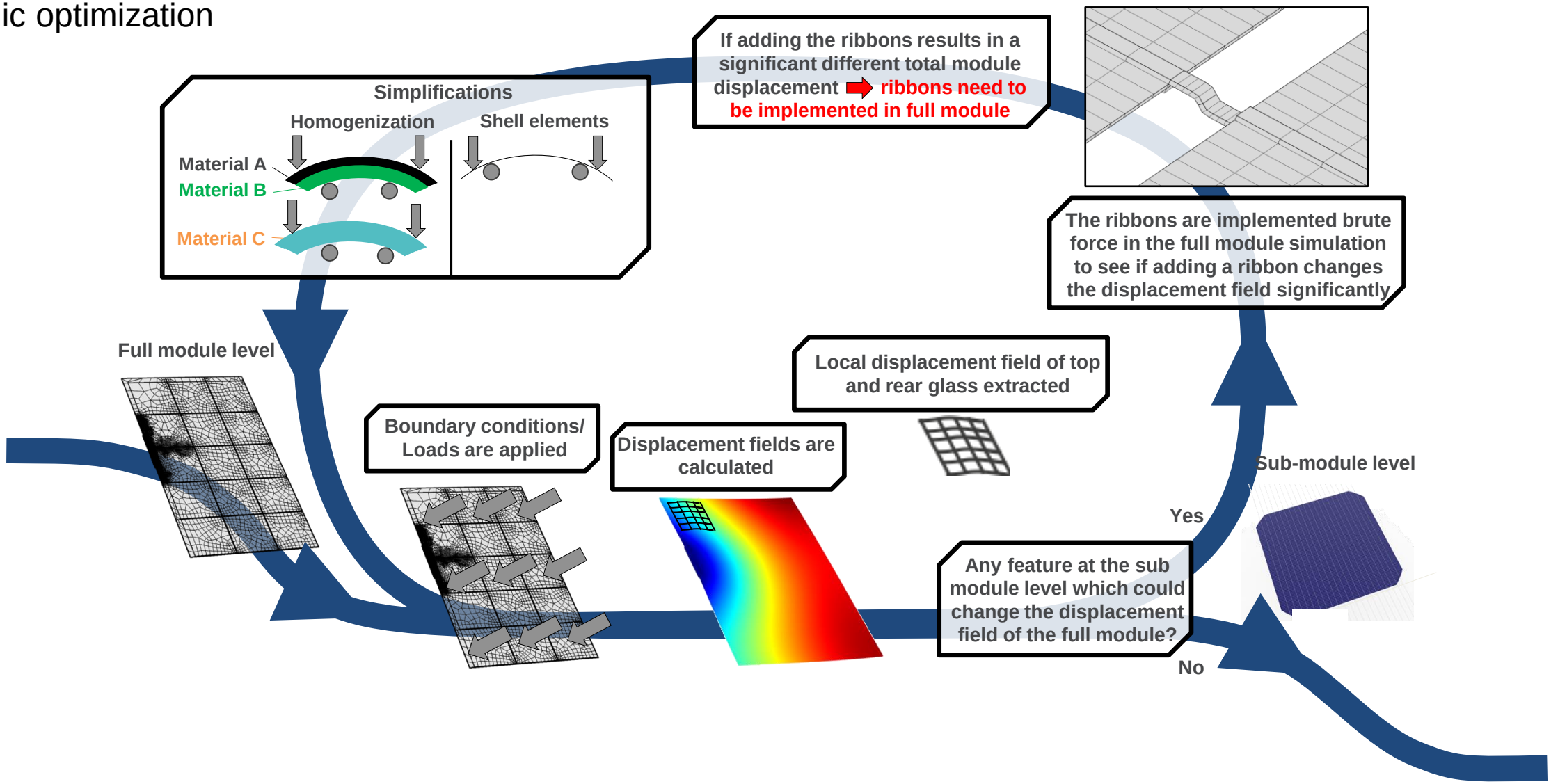
Multi-scale multi-physics reliability framework

Cyclic optimization

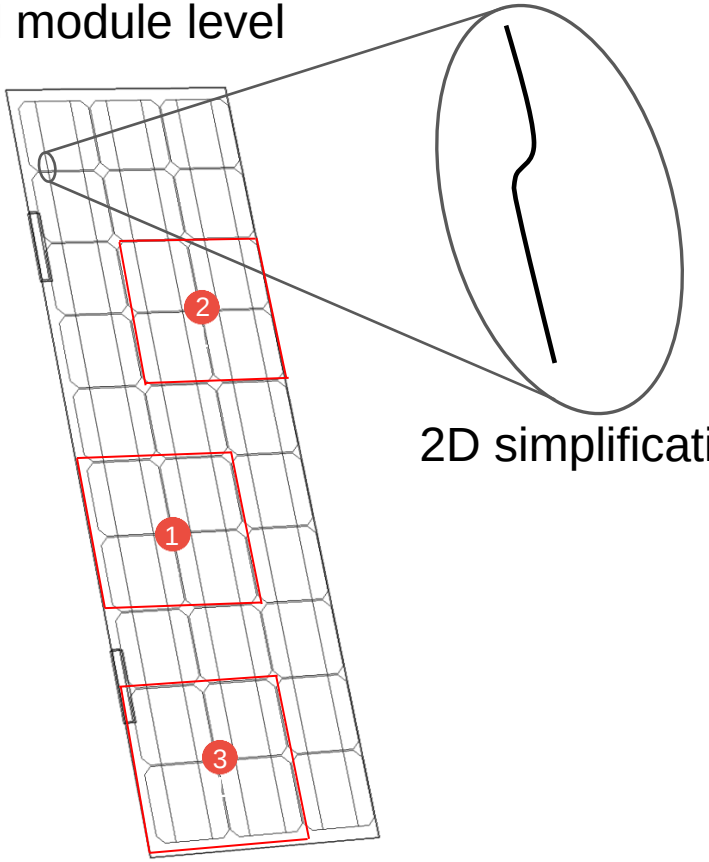


Multi-scale multi-physics reliability framework

In submission*

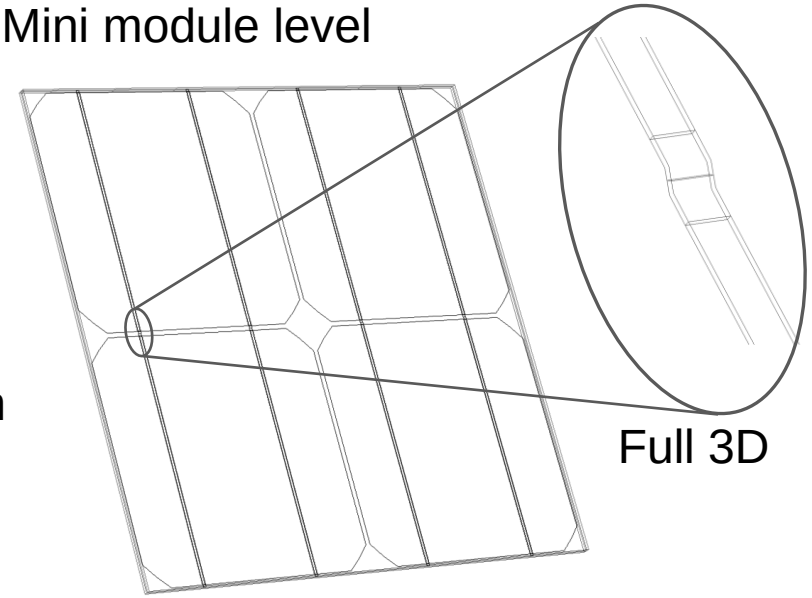
Multi-scale coupling – key features

Full module level

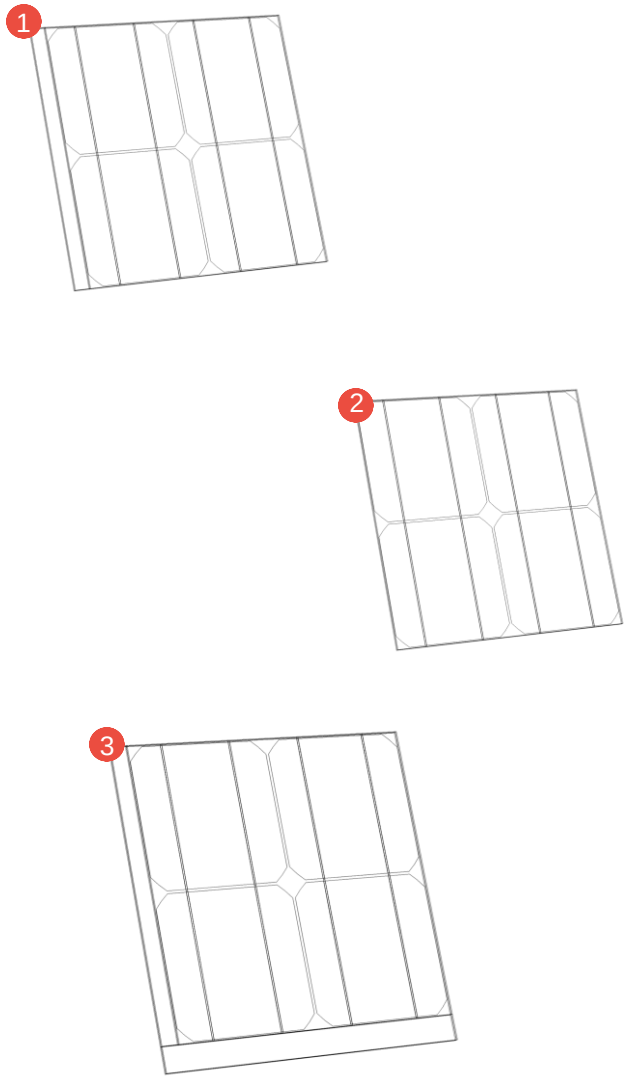


2D simplification

Mini module level



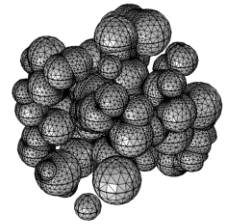
Full 3D

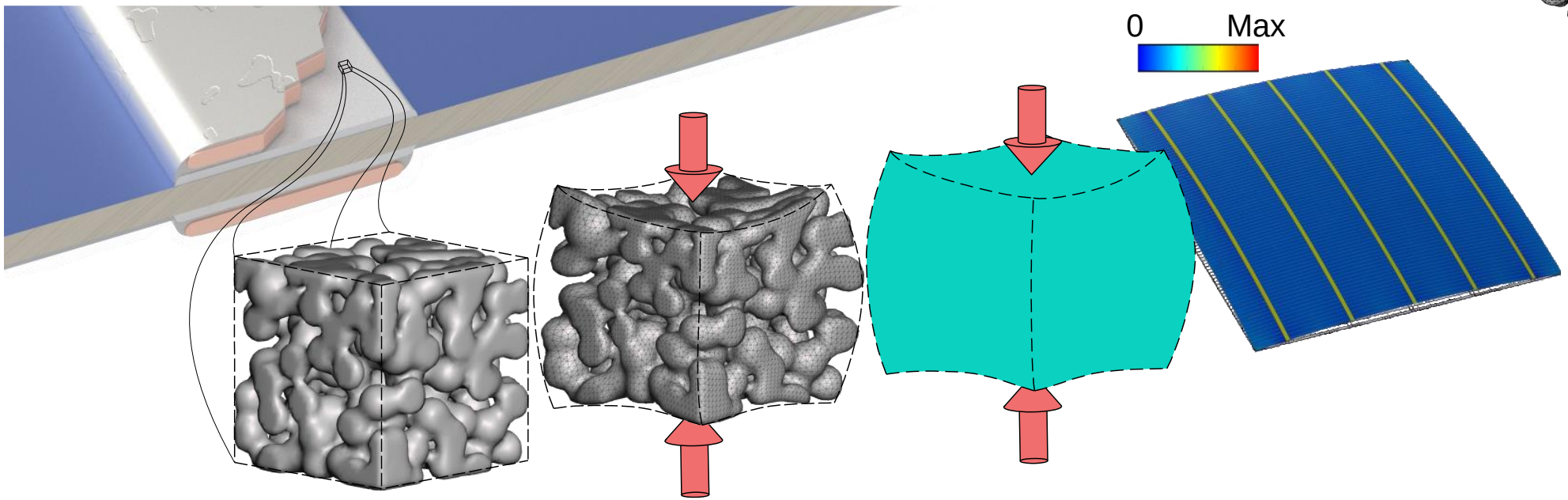


Multi-scale multi-physics reliability framework

Material level

Material level





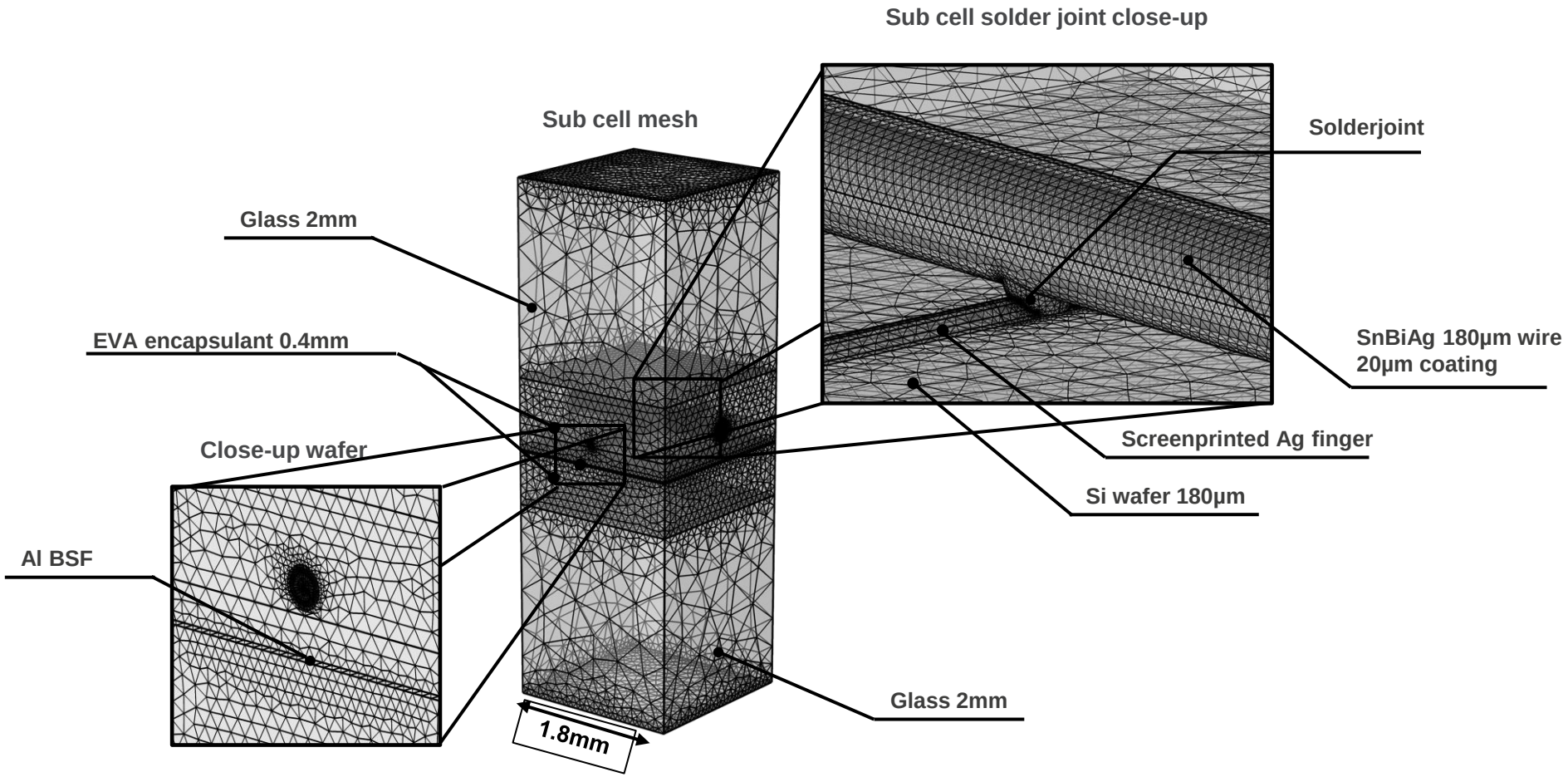
[1]Homogenization of complex materials such as Ag paste[2] or Solder alloys

[1]Figure adopted with permission from P. Nivelle et al - Stress and strain within photovoltaic modules using the finite element method: A critical review, Renewable sustainable energy reviews, 2021

[2] Van Amstel T, Popovich V, Bennett IJ. A multi-scale model for the aluminium layer at the rear side of a solar cell. Eur. Photovolt. Sol. Energy Conf. Exhib. 2009: 21–5.

Multi-scale multi-physics reliability framework

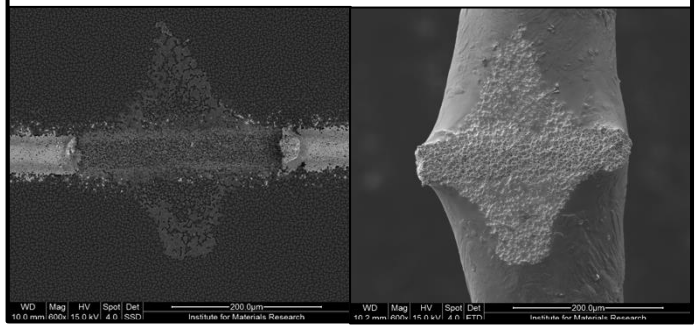
Sub-cell level



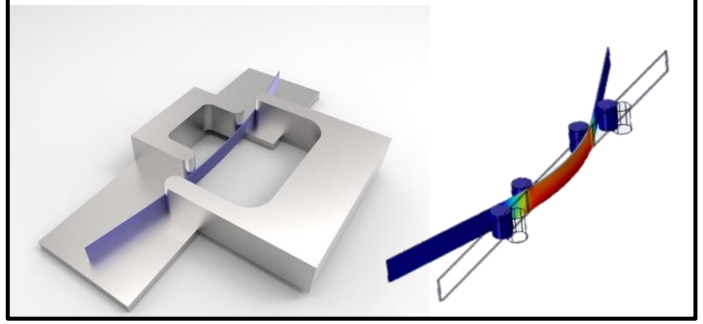
Multi-scale multi-physics reliability framework

Characterization as input

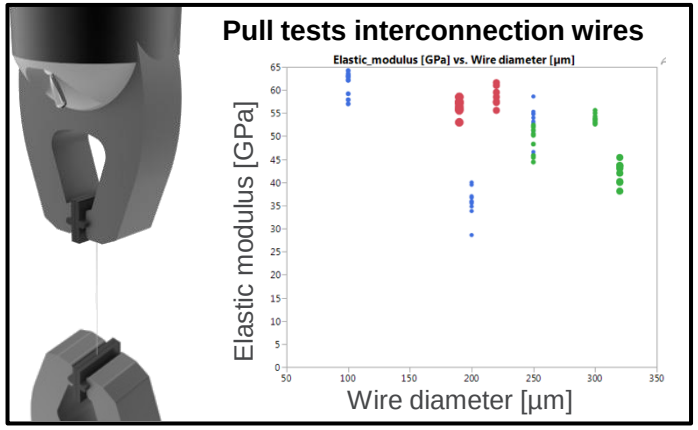
Solder joint investigations



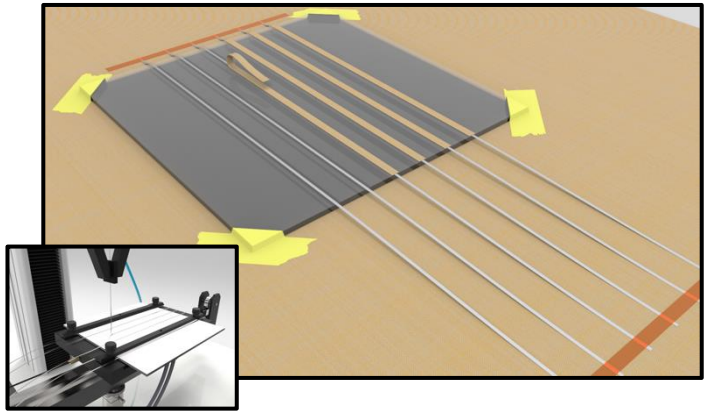
Four point flexural tests



Pull tests interconnection wires

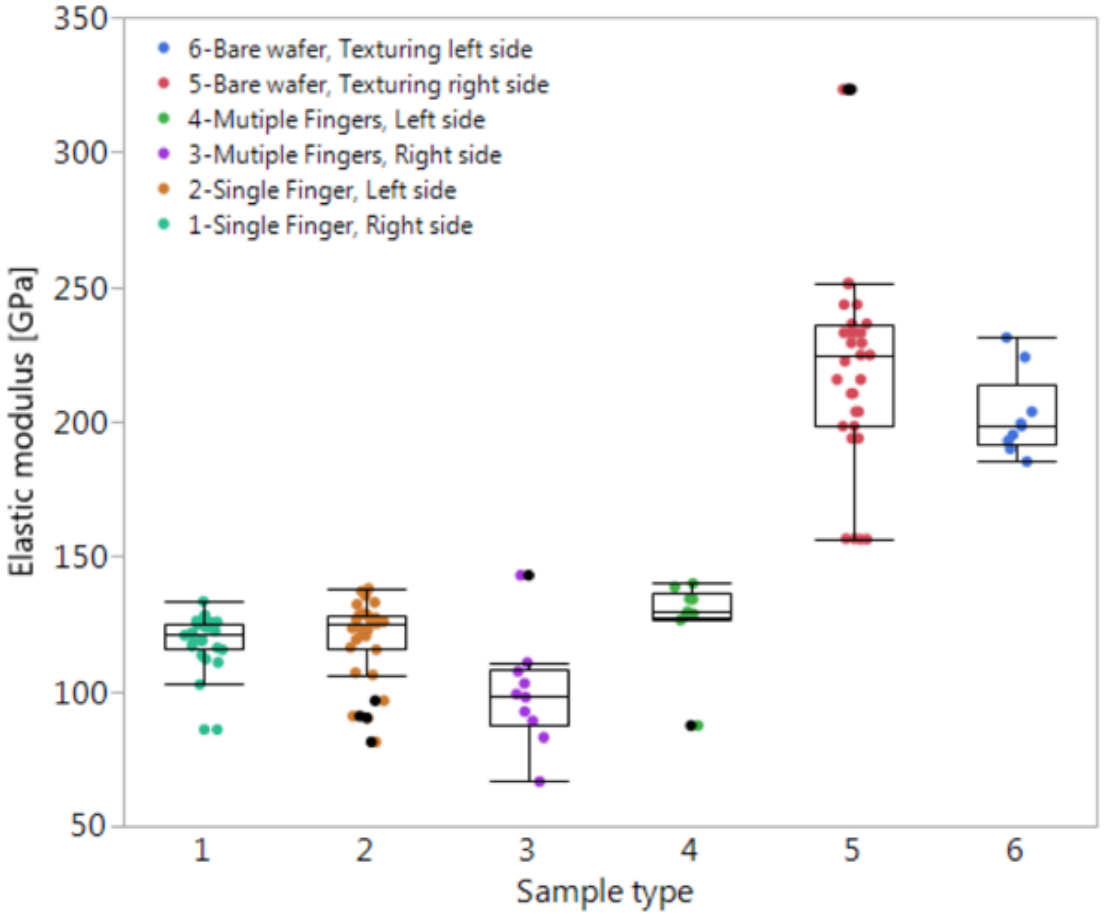


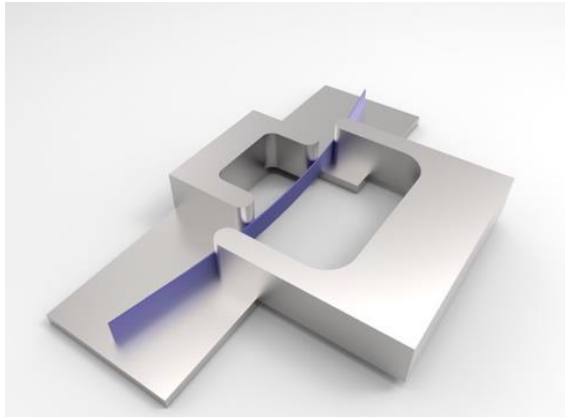
Interface investigations

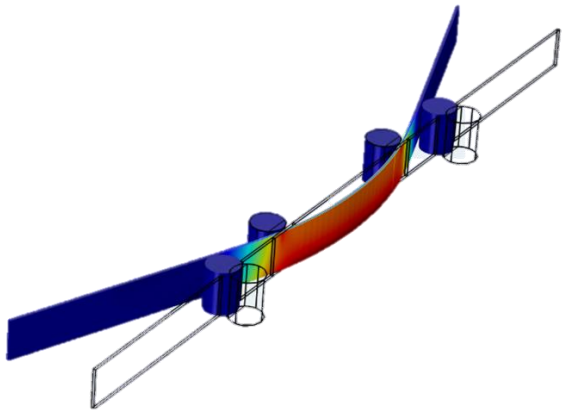


Multi-scale multi-physics reliability framework

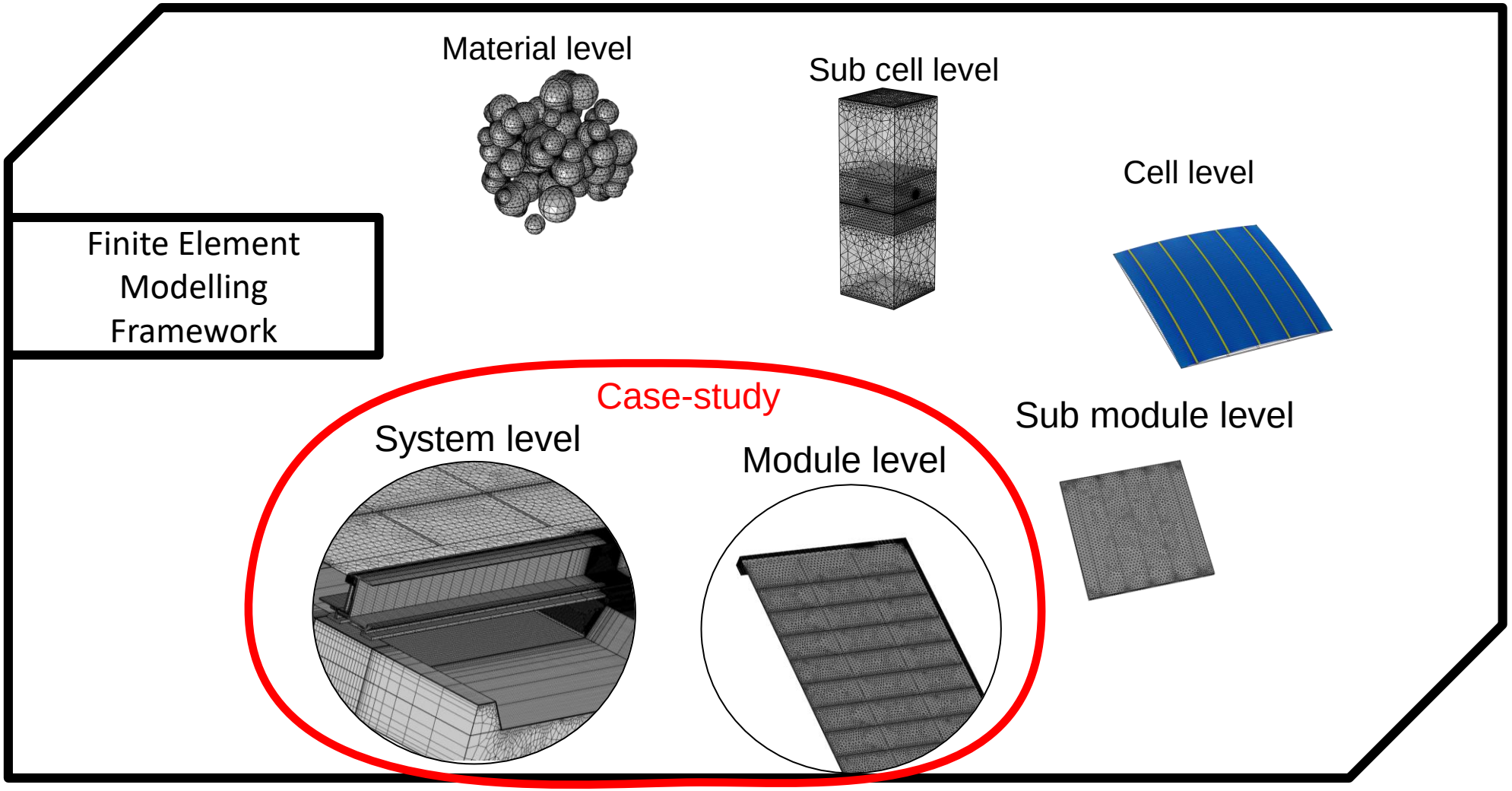
Abstraction method for various levels determined through characterization







Multi-scale multi-physics reliability framework



Multi-scale multi-physics reliability framework

In submission*

A case study on how roofing and mounting affects module behaviour

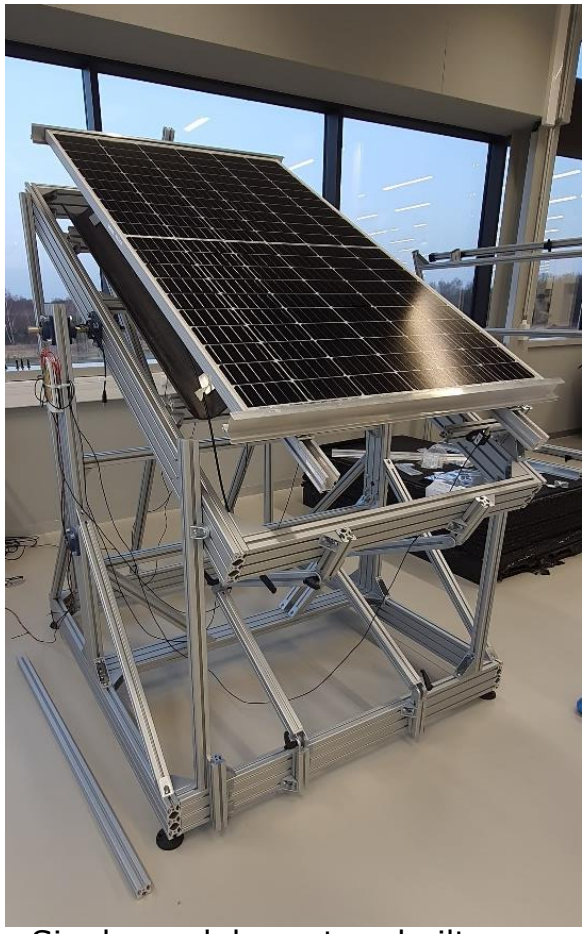
Mounting system for corrugated rooftiles

Mounting system for steeldeck rooftiles

A case study

In submission*

Mechanical deformation testing using custom mechanical test setup



Single module system built on mechanical stress tester

Mechanical load performed test at 30º angle

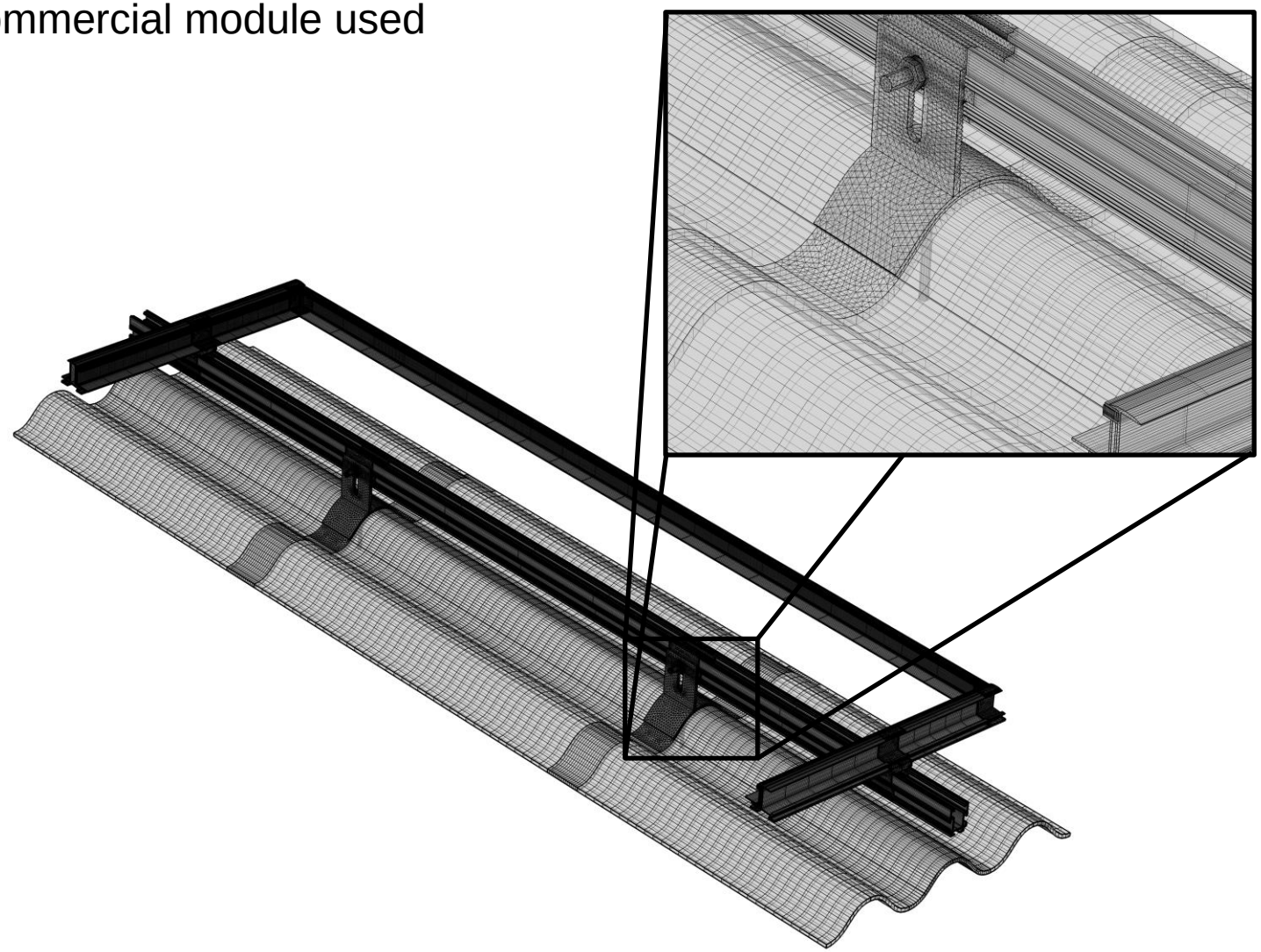
Contactless displacement sensors mounted on framing and modules

A case study

In submission*

Calibrating module level simulation due to commercial module used

Calibrating module model (ran about 3k variations)

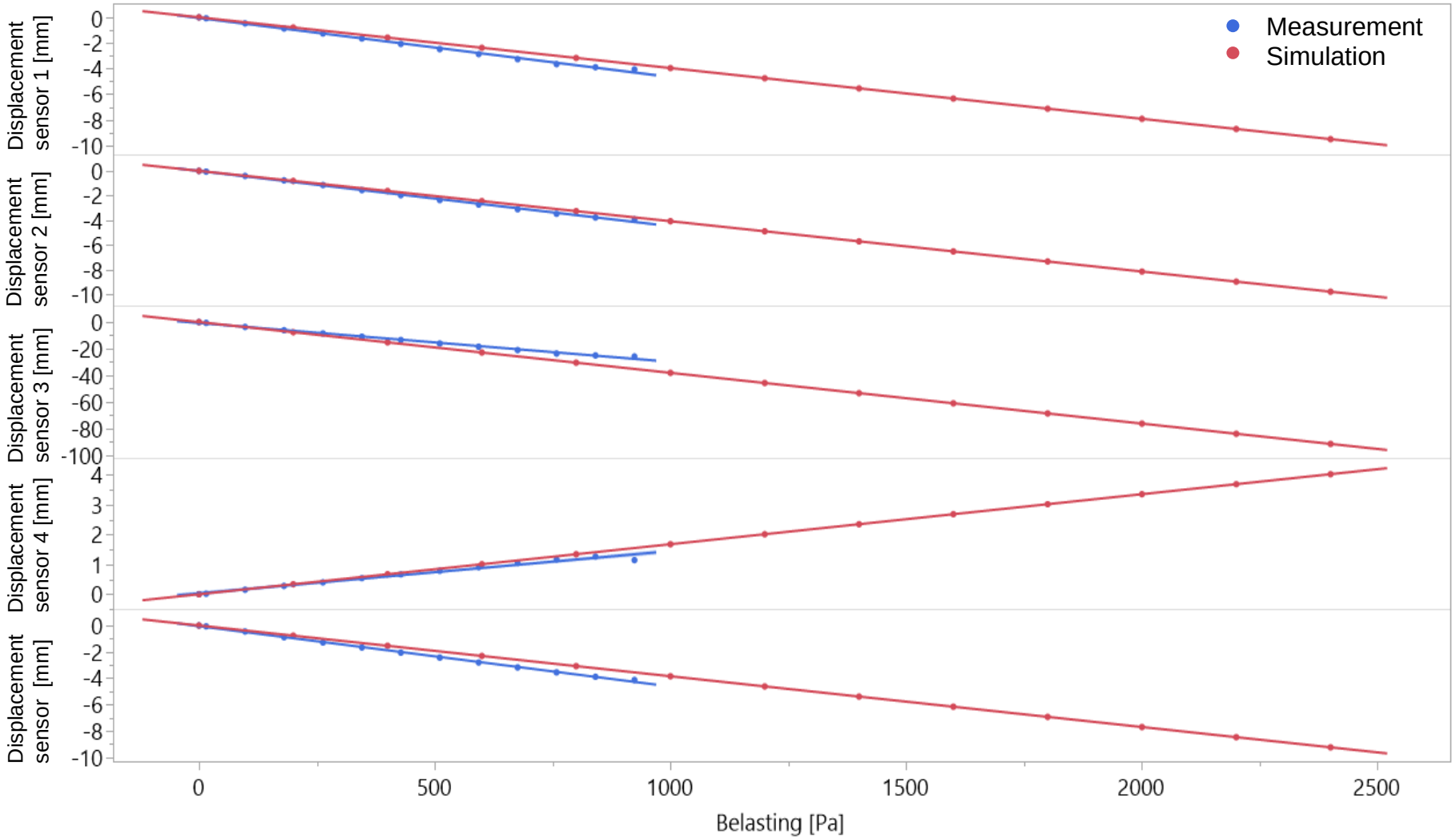


Creating system level model

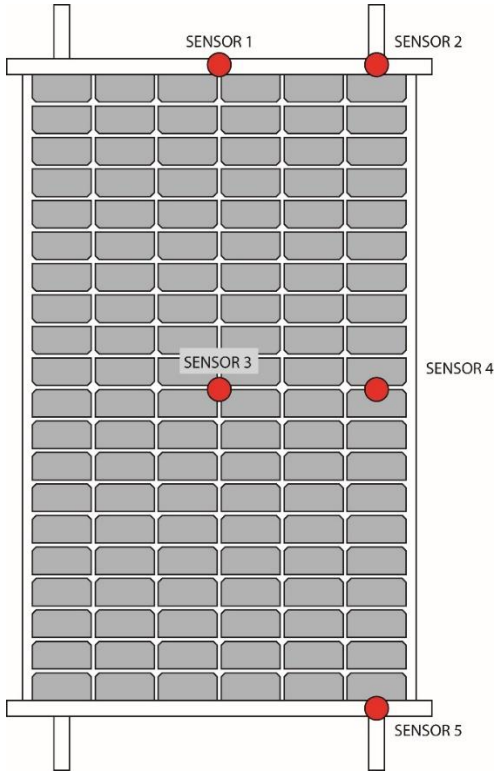
A case study

In submission*

Validation using system and module deformation



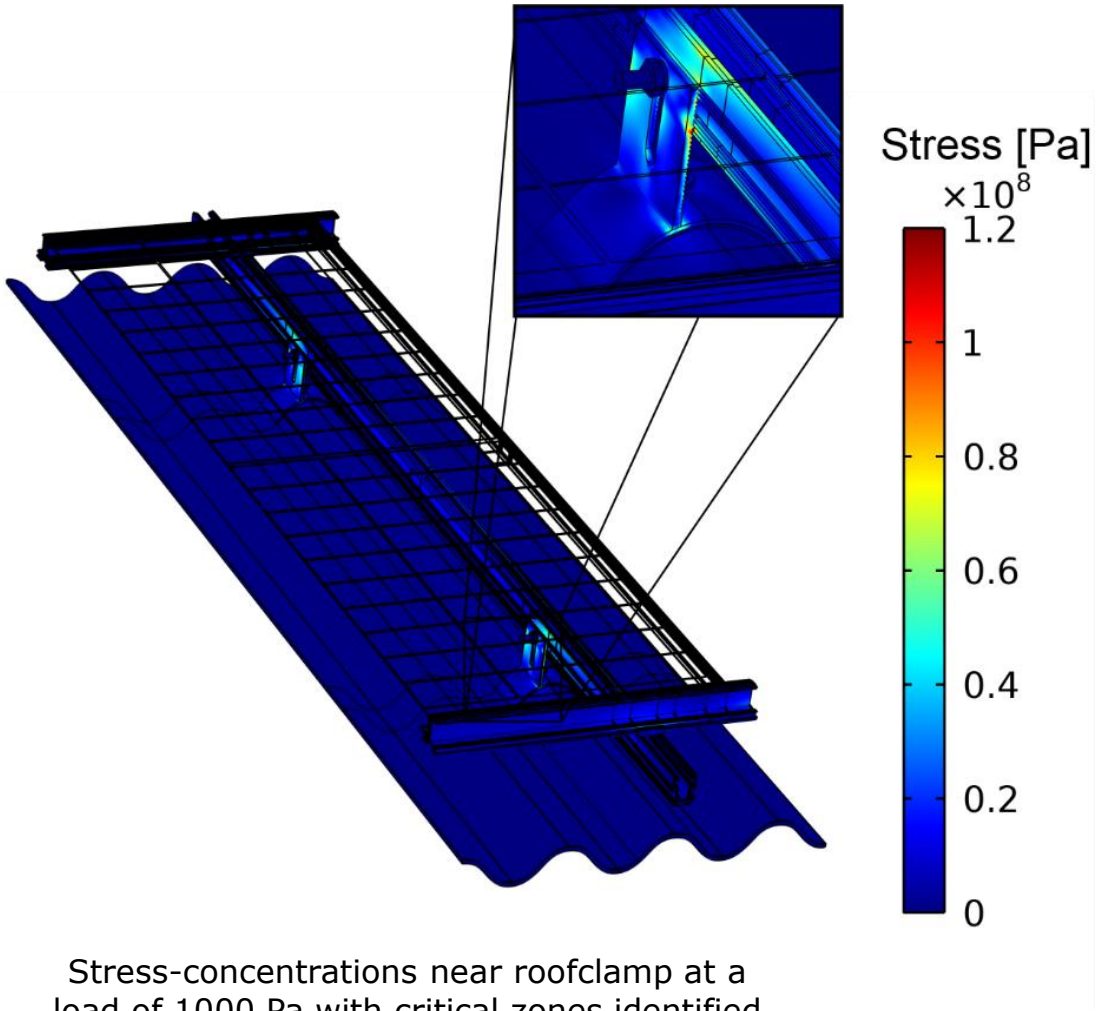
Sensor layout top view



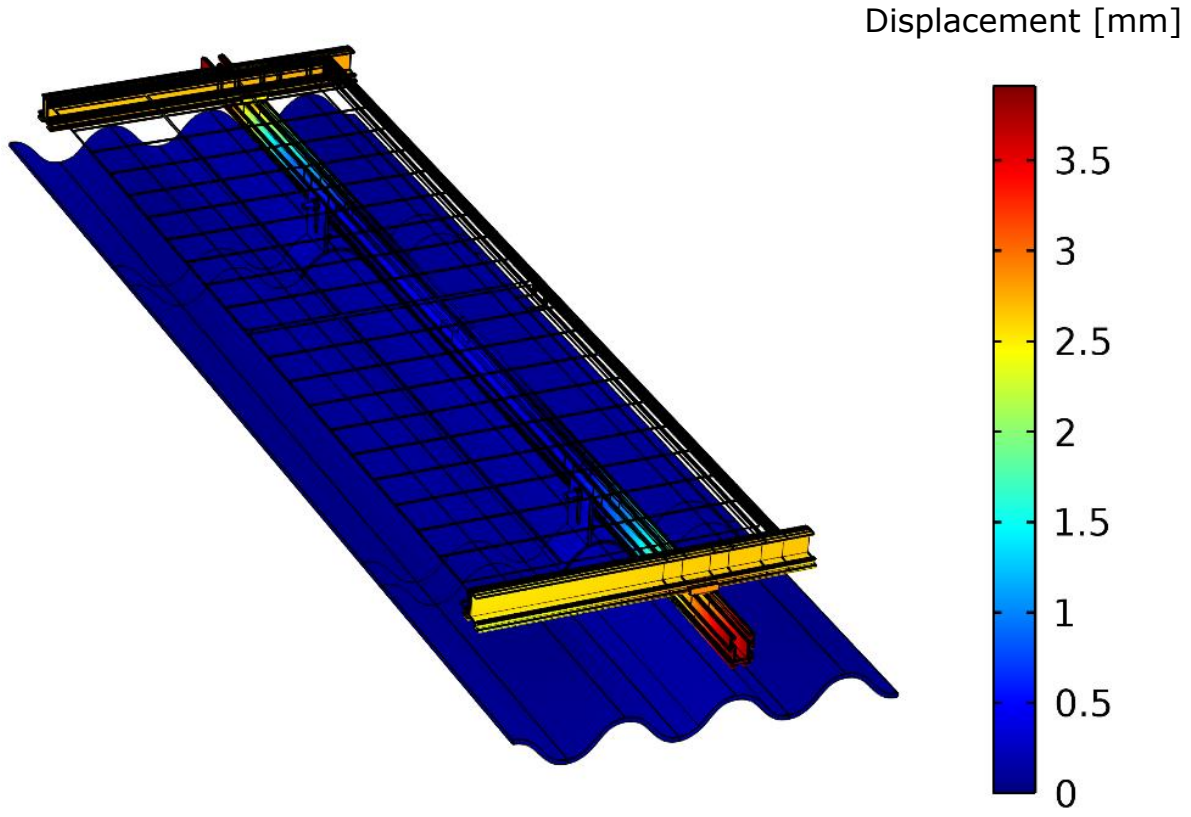
A case study

In submission*

Simulation results



Stress-concentrations near roofclamp at a load of 1000 Pa with critical zones identified



Displacement of racking structure at 1000 Pa homogeneous load

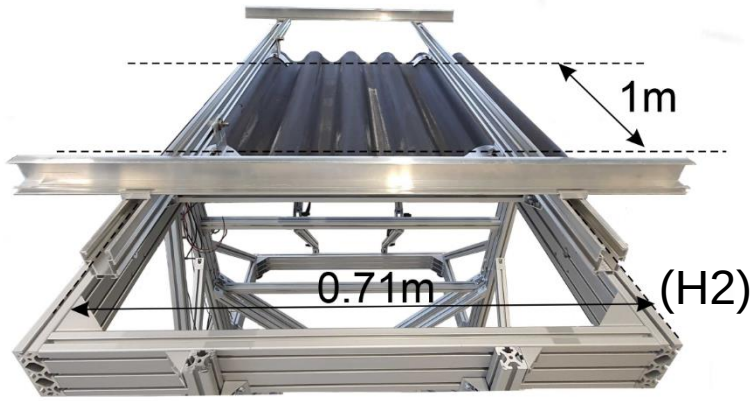
A case study

In submission*

Value for industry

H2 713 mm	Load [Pa]													
Mounting angle [°]	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000
0	31 %	44 %	56%	68%	81%	93%	105%	117%	130%	142%	154%	166%	179%	191%
5	31 %	43 %	55%	68%	80%	92%	104%	116%	128%	140%	153%	165%	177%	189%
10	31 %	42 %	54%	66%	78%	90%	102%	114%	126%	138%	150%	162%	174%	185%
15	30 %	41 %	53%	65%	76%	88%	99%	111%	123%	134%	146%	157%	169%	181%
20	29 %	40 %	51%	62%	74%	85%	96%	107%	118%	130%	141%	152%	163%	174%
25	27 %	38 %	49%	60%	70%	81%	92%	102%	113%	124%	135%	145%	156%	167%
30	27 %	38 %	48%	59%	69%	79%	90%	100%	111%	121%	131%	142%	152%	163%

H2 1068 mm	Load [Pa]													
Mounting angle [°]	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000
0	37%	52%	66%	81%	95%	110%	124%	138%	153%	167%	182%	196%	211%	225%
5	37%	51%	65%	80%	94%	108%	123%	137%	151%	166%	180%	194%	209%	223%
10	36%	50%	64%	78%	92%	106%	120%	134%	149%	163%	177%	191%	205%	219%
15	35%	49%	63%	76%	90%	104%	117%	131%	145%	158%	172%	186%	199%	213%
20	34%	47%	60%	74%	87%	100%	113%	126%	140%	153%	166%	179%	193%	206%
25	32%	45%	58%	70%	83%	96%	108%	121%	134%	146%	159%	172%	184%	197%
30	31%	43%	55%	67%	79%	91%	103%	115%	127%	139%	151%	162%	174%	186%



Indirect validation

Field testing

- External sensors (PT100,…)
- Intermittent I/V tracing
- Intermittent EL
- Intermittent IR thermography
- …

Accelerated stress testing

- Intermittent I/V tracing
- Intermittent EL
- Displacement sensors
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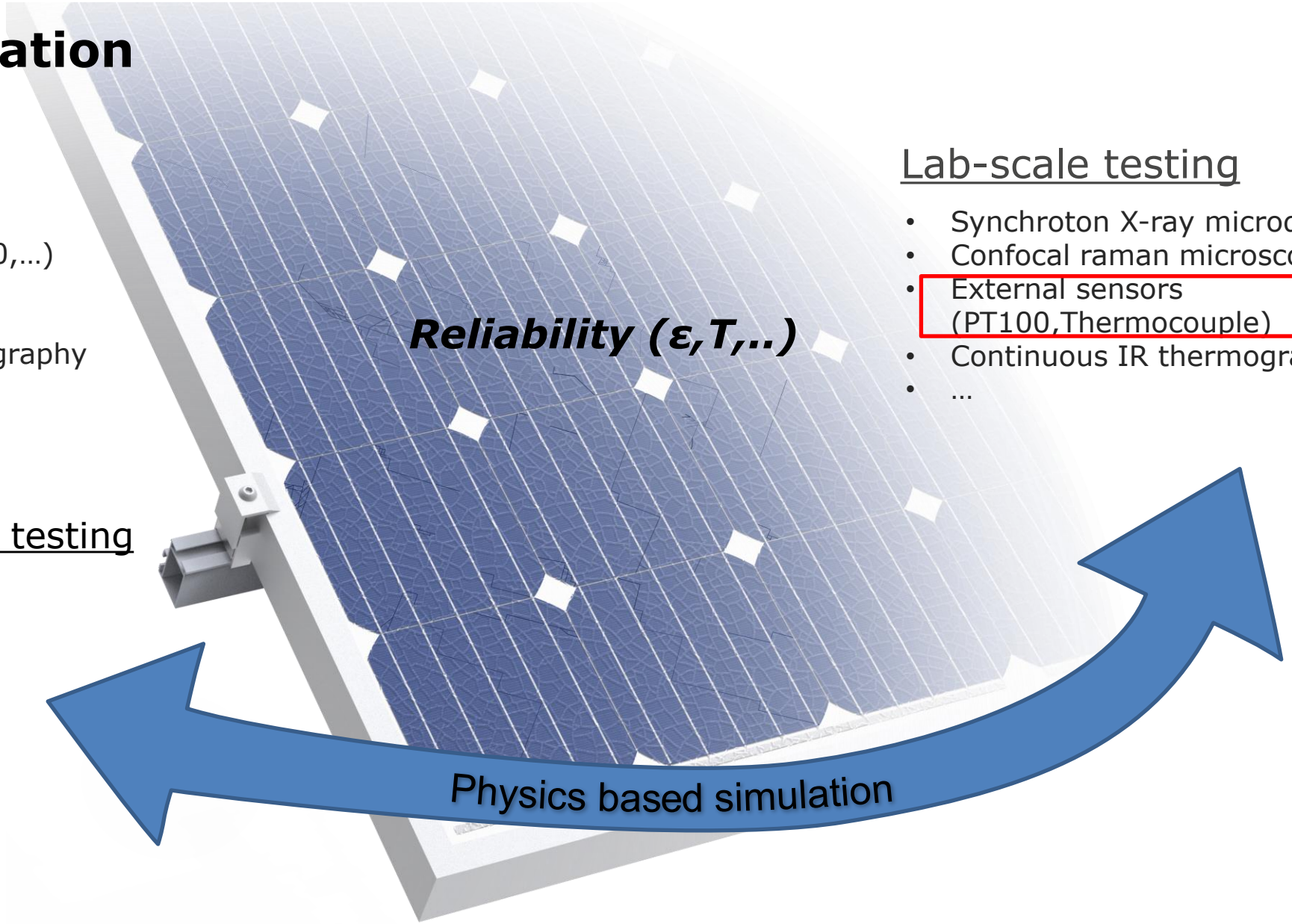

Lab-scale testing

- Synchroton X-ray microdiffraction
- Confocal raman microscopy
- External sensors (PT100,Thermocouple)
- Continuous IR thermography
- …

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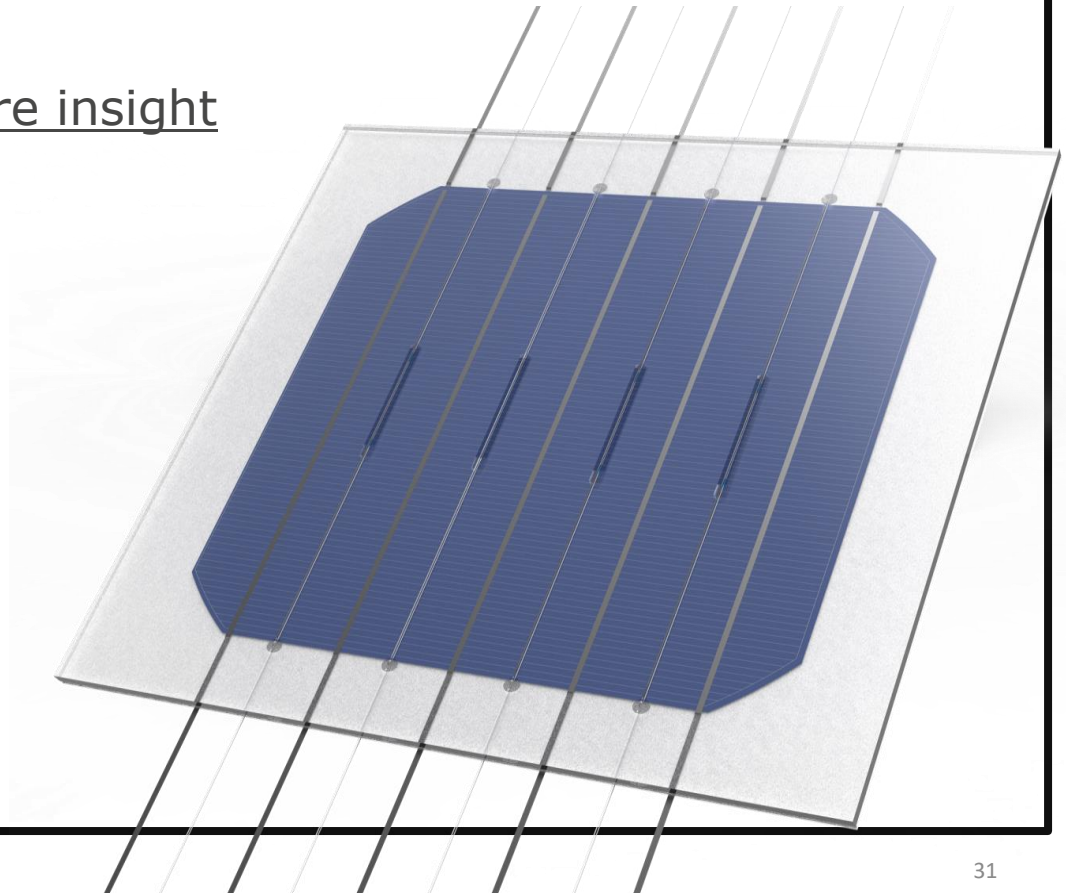
Optical in-situ thermo-mechanical sensing solution

PV-sense [2]

- The use of embedded optical sensors enables in-situ characterization ***ε,T*** at various stages in the development process
- Using these sensors, simulations can be validated for both lab and field conditions on a quantitative basis.
- Accelerated stress tests using the sensors provides more insight on internal deformation mechanisms and can thereby accelerates novel PV technology development as well



[2] P. Nivelle et al., Optical Strain and Temperature Sensing within Photovoltaic Laminates, EUPVSEC 2020

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PV-sense

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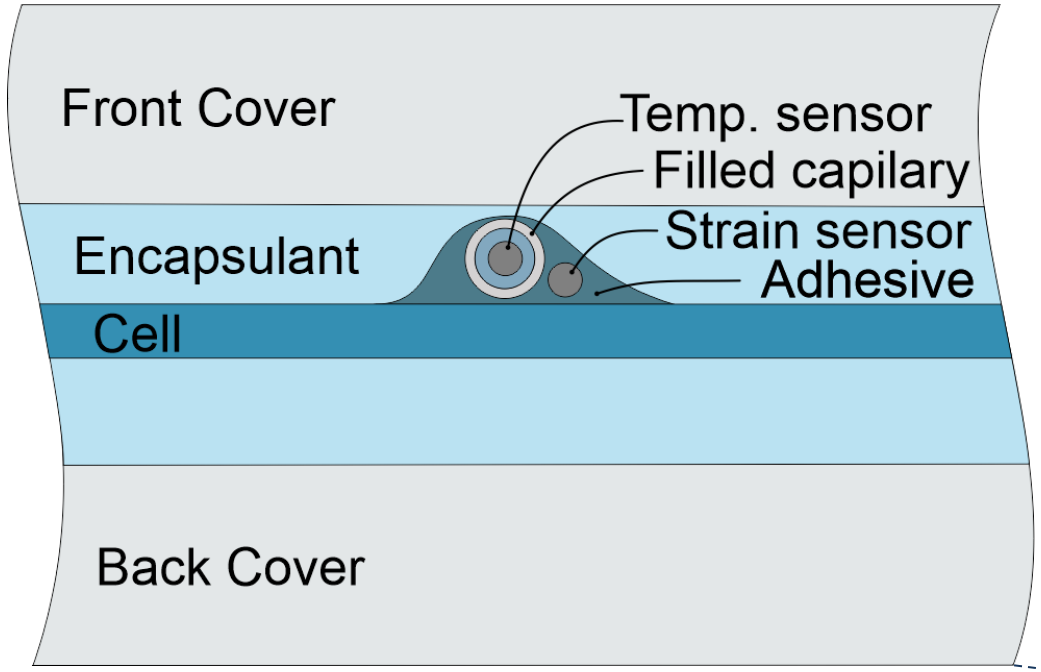
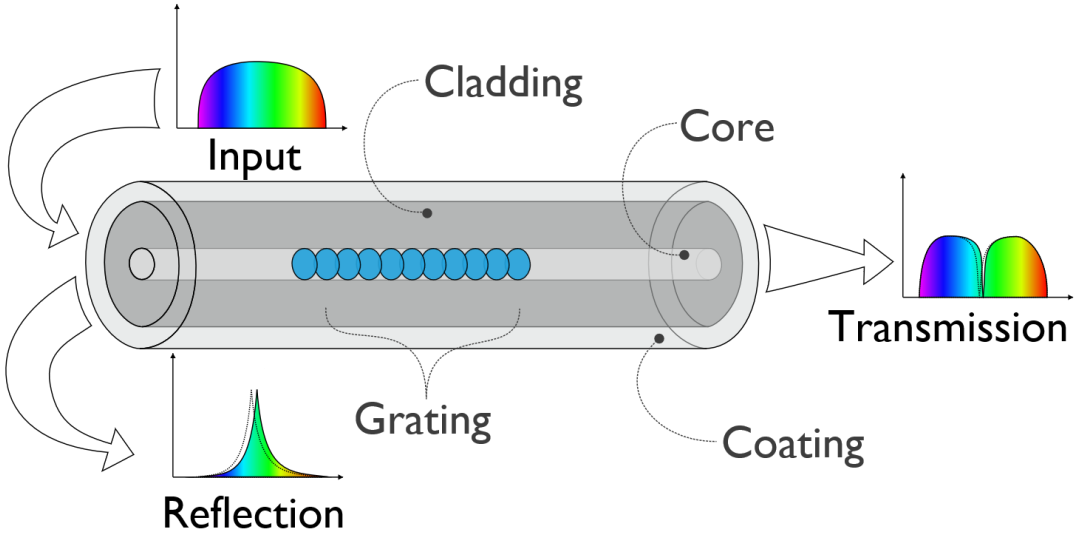
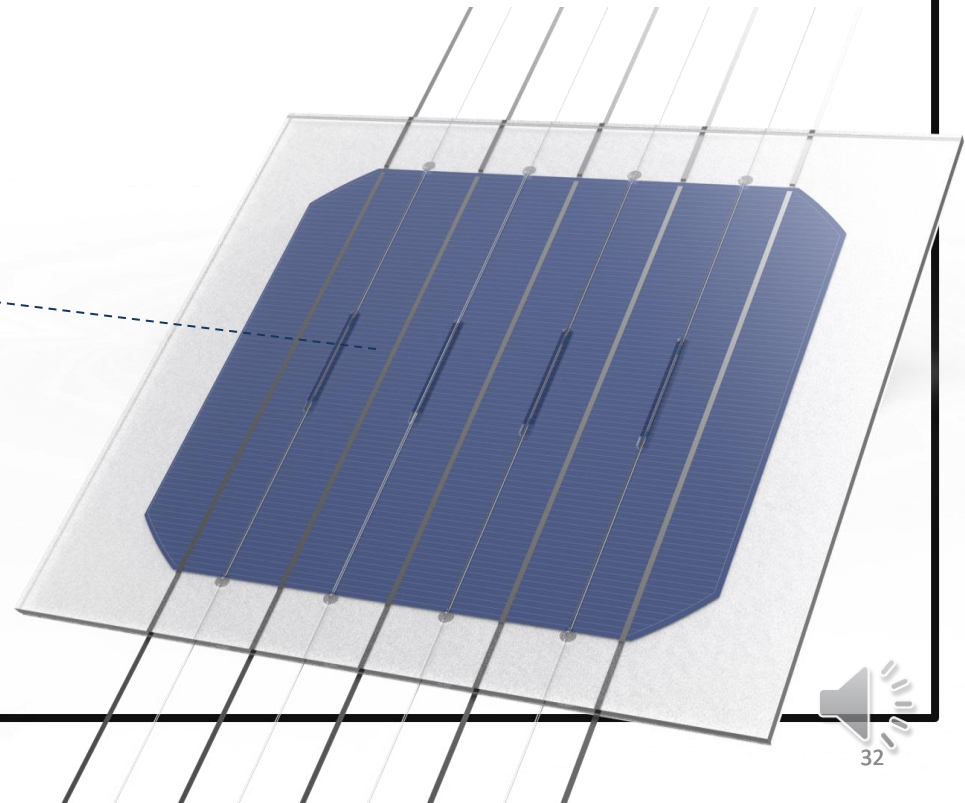




$$ln\left(\frac{\lambda}{\lambda_0}\right) = (1 - Pe) \cdot \varepsilon + (\alpha + \eta) \cdot \Delta T$$

Elasto-optic coefficient

Thermo-optic coefficient



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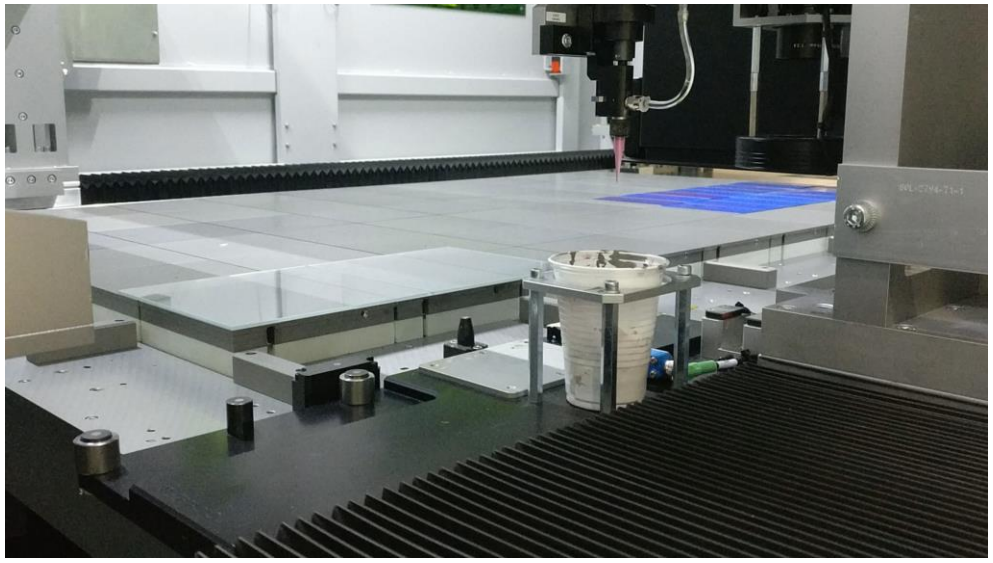
Expanding automation for integration



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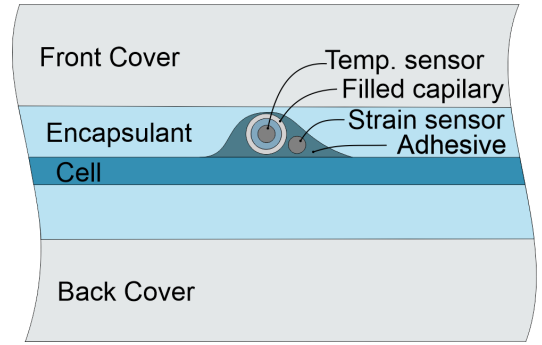
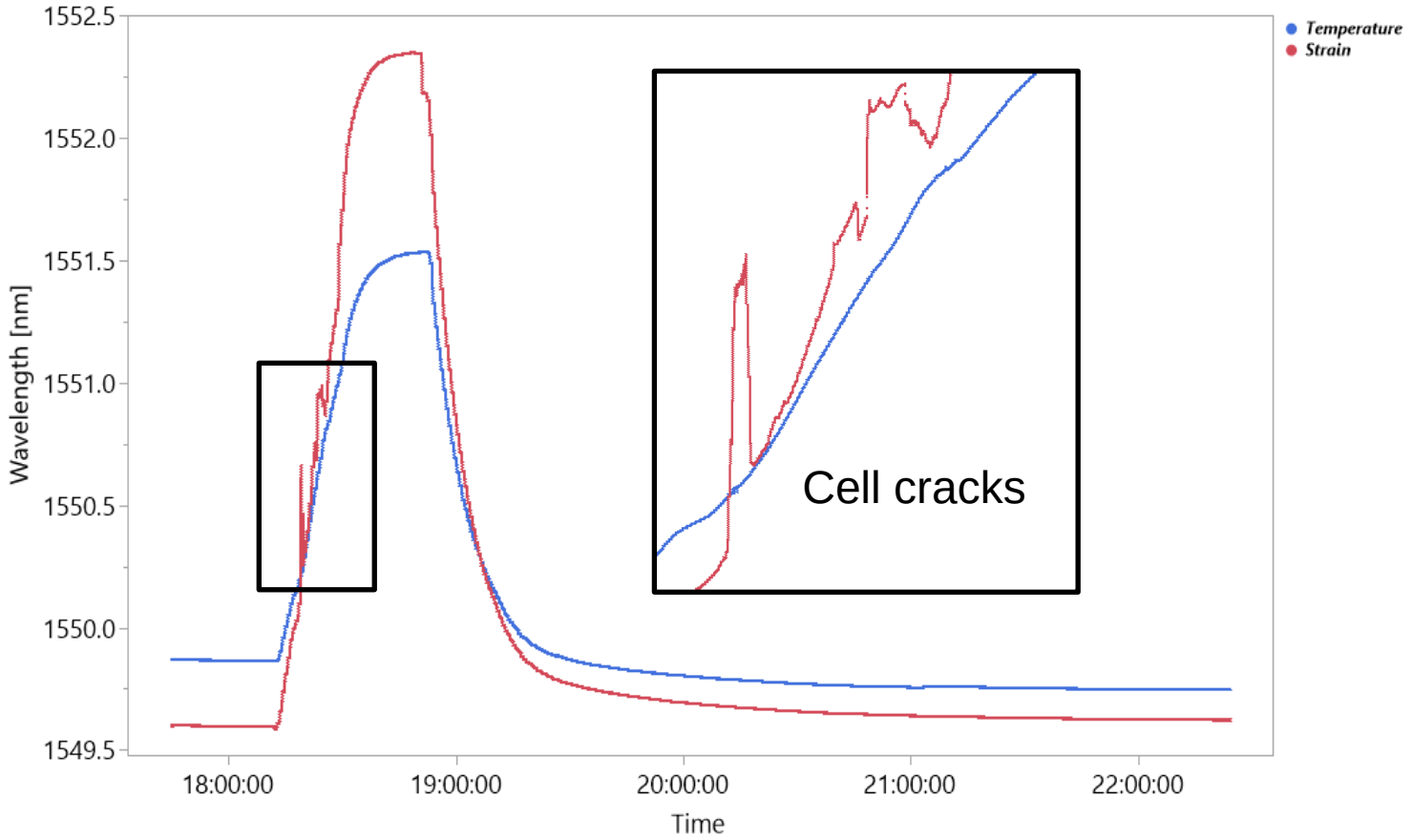
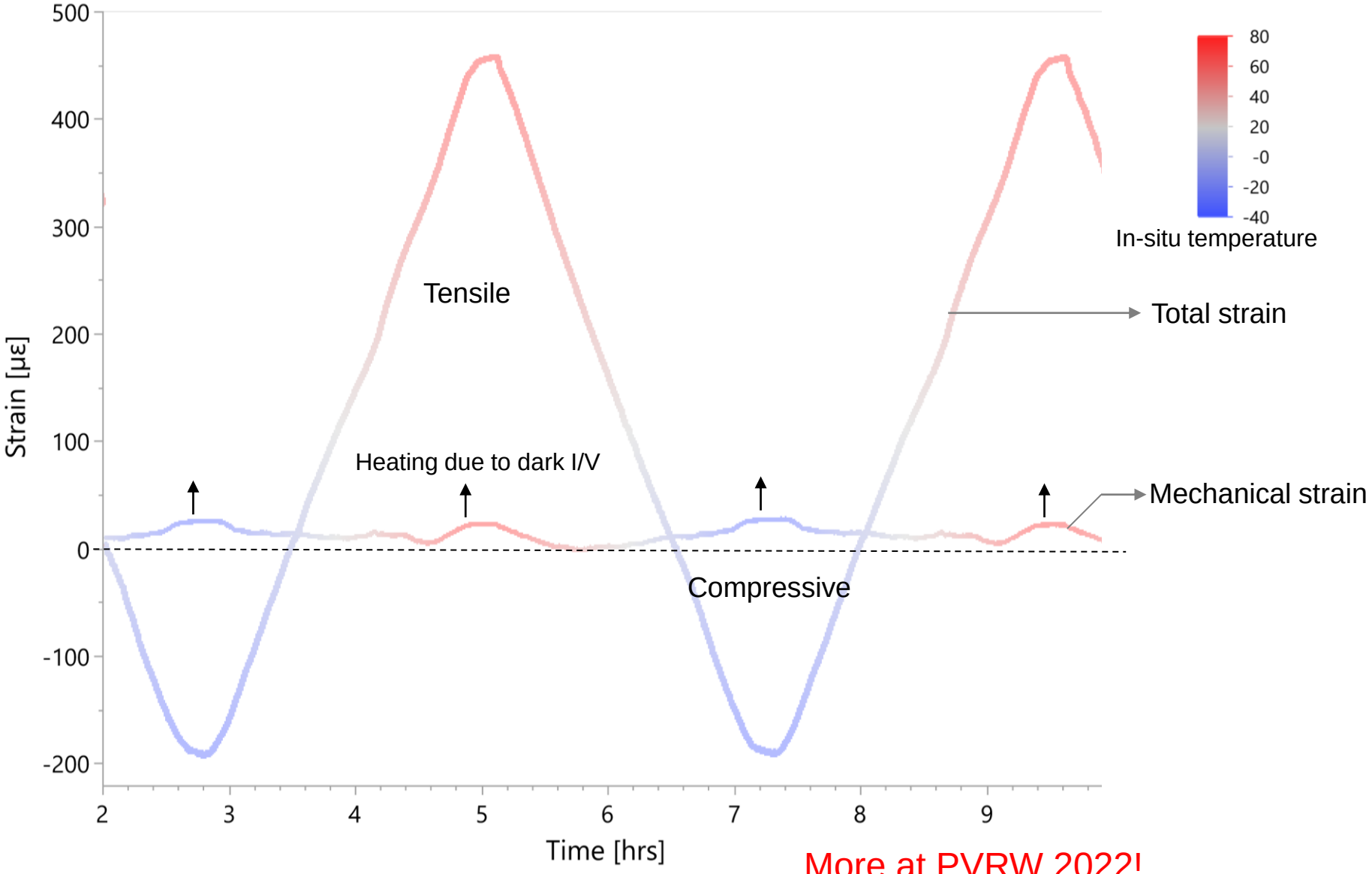
Investigation lamination





More at WCPEC 2022!

PV-sense: investigating thermal cycling



More at PVRW 2022!

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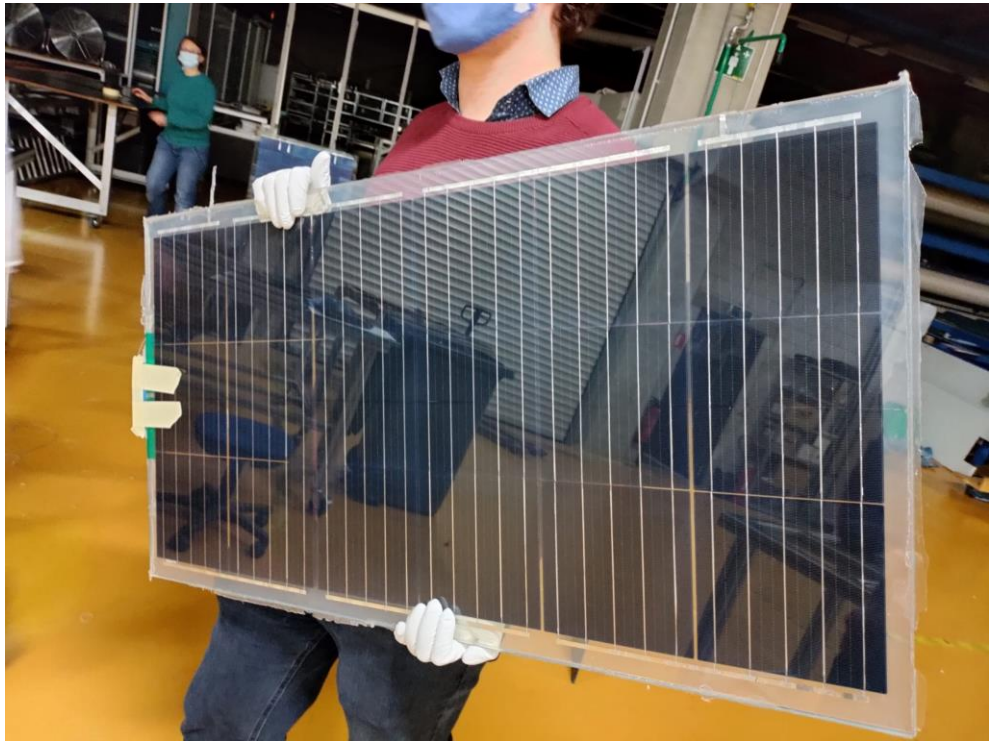
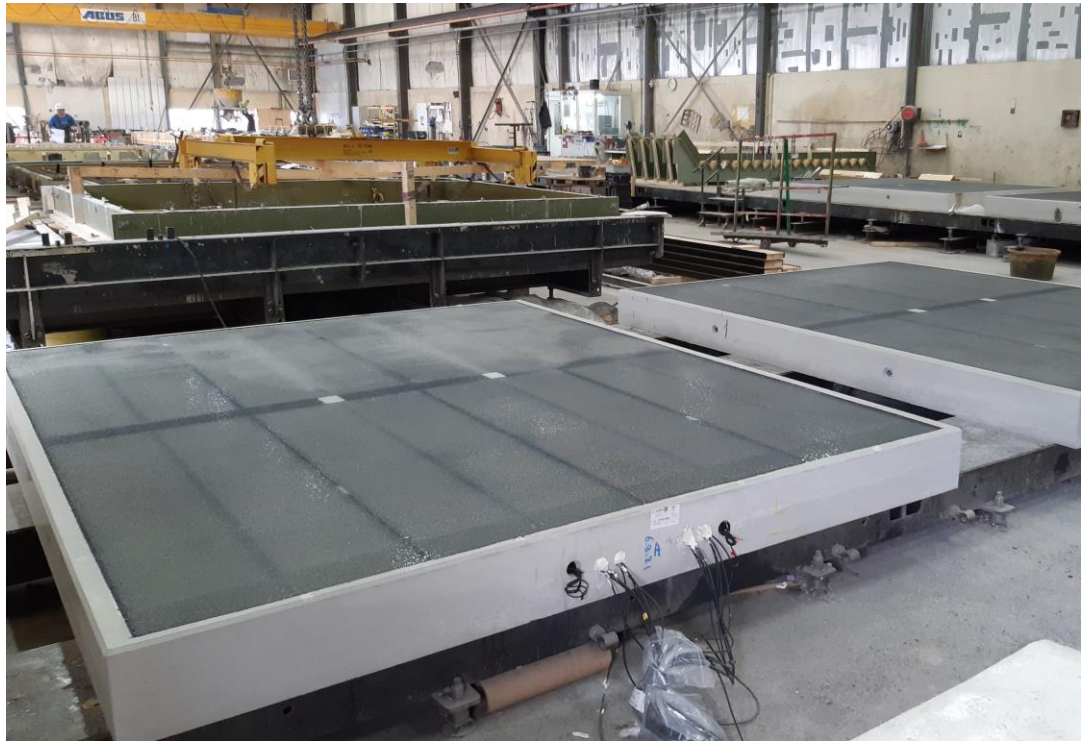
Scaling up, full size demonstrators with in-field testing capabilities



BIPV module with thermal packaging to monitor lamination behaviour and thermal effects in the field



Road elements are monitored real-time using thermo-mechanical packaging to study the load of passing vehicles

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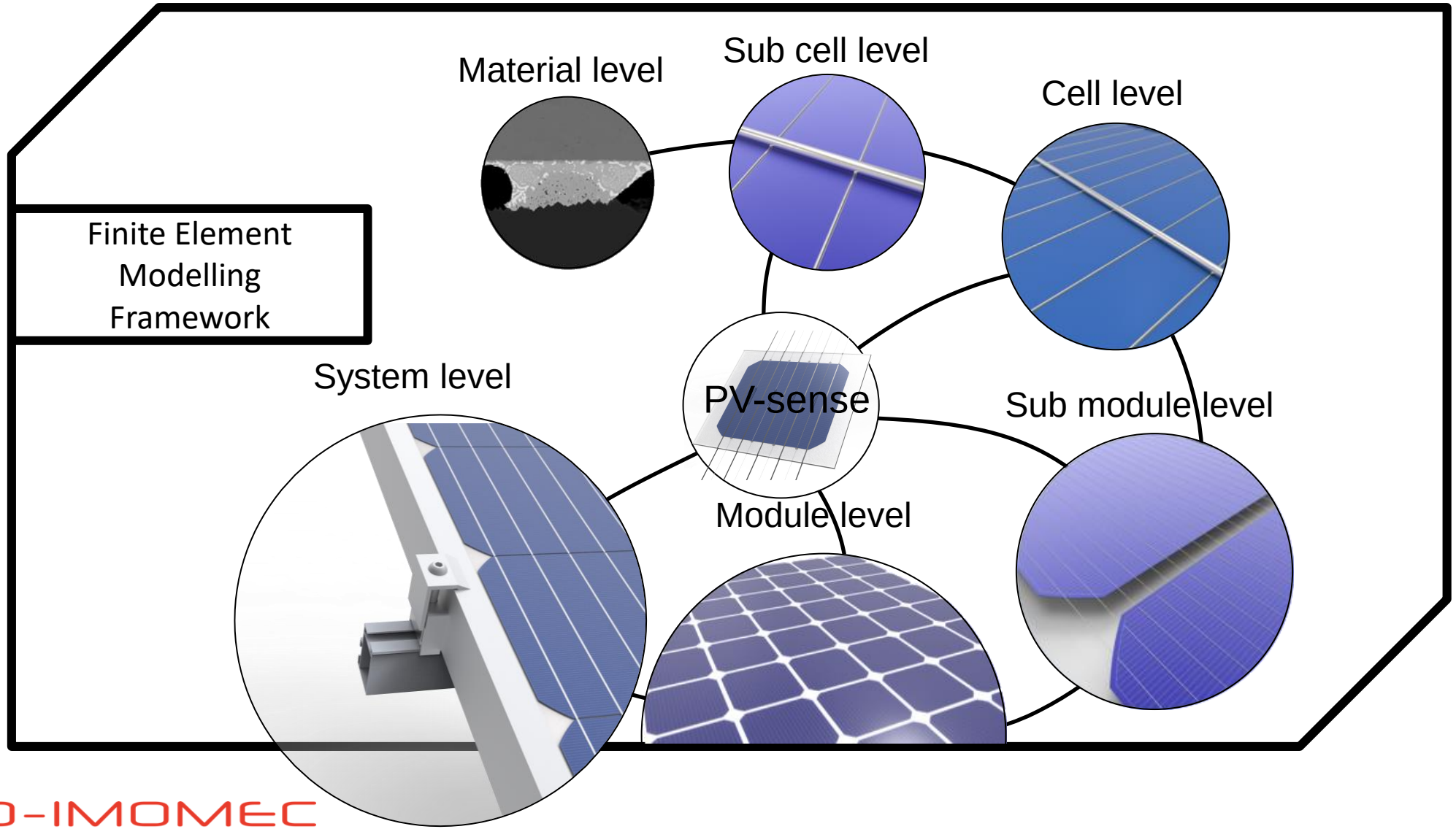
A co-development approach



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Interreg Euregio Maas-Rijn
EUROPESE UNIE

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