LIGHTWEIGHT PV MODULES:
CHALLENGES AND POSSIBLE SOLUTIONS FOR RELIABLE DESIGNS

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SOPHIA PV-Module Reliability WEBINAR 2021

LEICHTBAU PV SONDERMODULES:
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GER: **leicht** → ENG: easy, light

Light weight modules →

Easy to build special modules →

PV Sondermodule

Design requirements
- special shape and size (2D, 3D)
- weight limitations
- easy to built to customer specifications (e.g. color)
- Mechanical requirements

Longevity requirements
- for min. useful life time
- Aesthetics
- E.o.L, recycling
- …

Challenge triangle

Markets:

BiPV

ViPV

Rail-PV

Floating

Agri-PV

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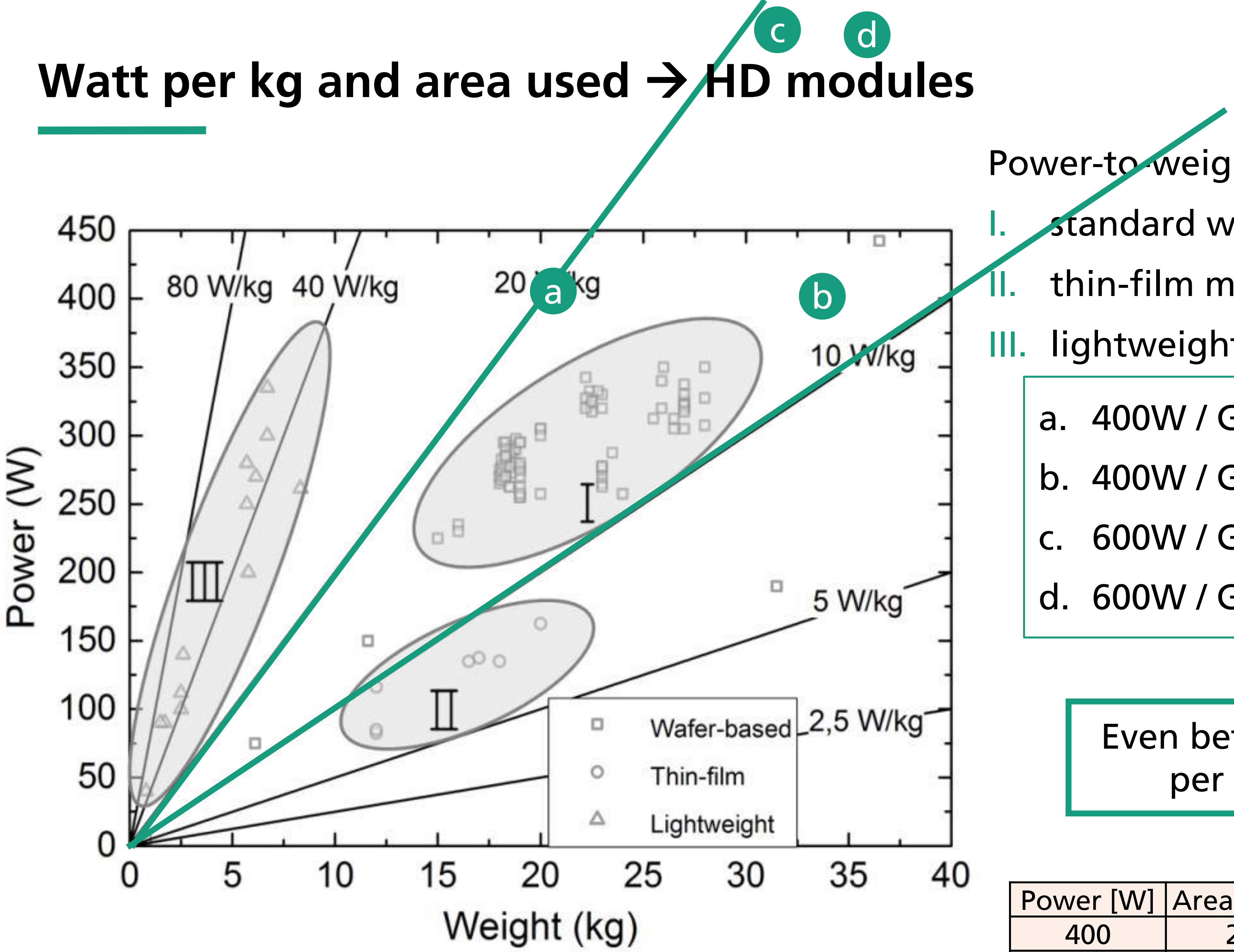
Watt per kg and area used → HD modules



Power-to-weight ratio of

I. standard wafer-based (glass-foil, glass-glass)
II. thin-film modules
III. lightweight modules

a. 400W / G/F / ~2m²/ ~20 kg → 20W/kg
b. 400W / G/G / ~2m²/ ~34 kg → 11,8W/kg
c. 600W / G/F / ~2,9m²/ ~ 31kg → 19,4W/kg
d. 600W / G/G / ~2,9m²/ ~ 36kg → 16,7W/kg

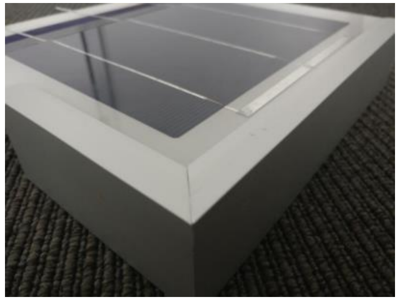
Even better: Area specific Watt per weigh [W/(kg*m²)]

Power [W]	Area [m²]	Weight [kg]	W/m²	W/kg	W/(m²*kg)
400	2	20	200,0	20,0	10,00
400	2	34	200,0	11,8	5,88
600	2,9	31	206,9	19,4	6,67
600	2,9	36	206,9	16,7	5,75

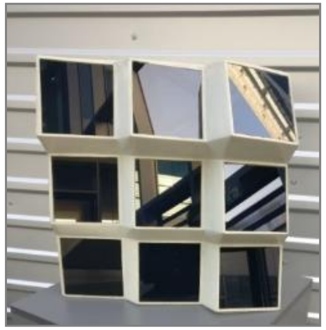
Schindler et al, "Beyond Watt per Module and Costs Per Watt – New Weight Related Parameters for Photovoltaic Modules", EU PVSEC 2018
Schindler et al, "Lightweight PV Module Approach - Field Test Study and Yield Evaluation", EU PVSEC 2019
Jäckel et al, „Filling in the gaps: The evolution of high-density module design ", Webinar PV Magazine 2020

Components and Parameters to consider

Module part	Standard	"Heavy"	Lightweight	Challenge
Front sheet				
Encapsulation front				
Solar cell				
Encapsulation back				
Back sheet				
Electrical contacts				

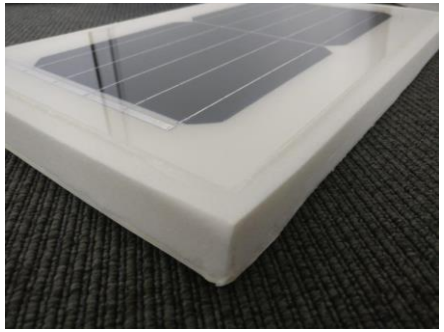


Standard module with Al-Frame



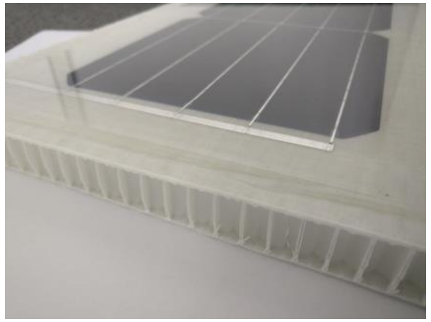
Concreate façade Prototype

Semi-lightweight roof integration



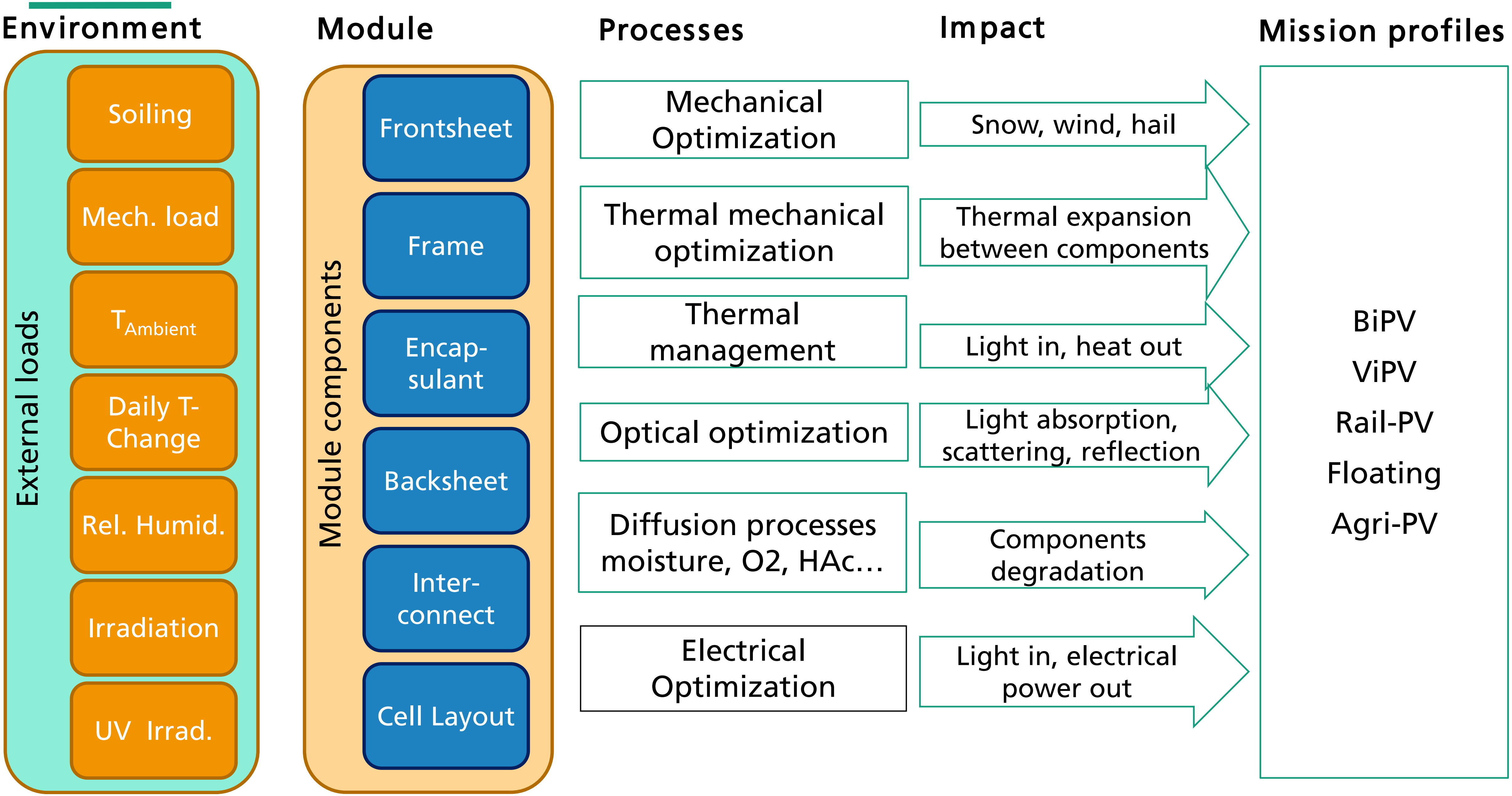
Glass/Foam prototype

Polymer/Foam full size prototype

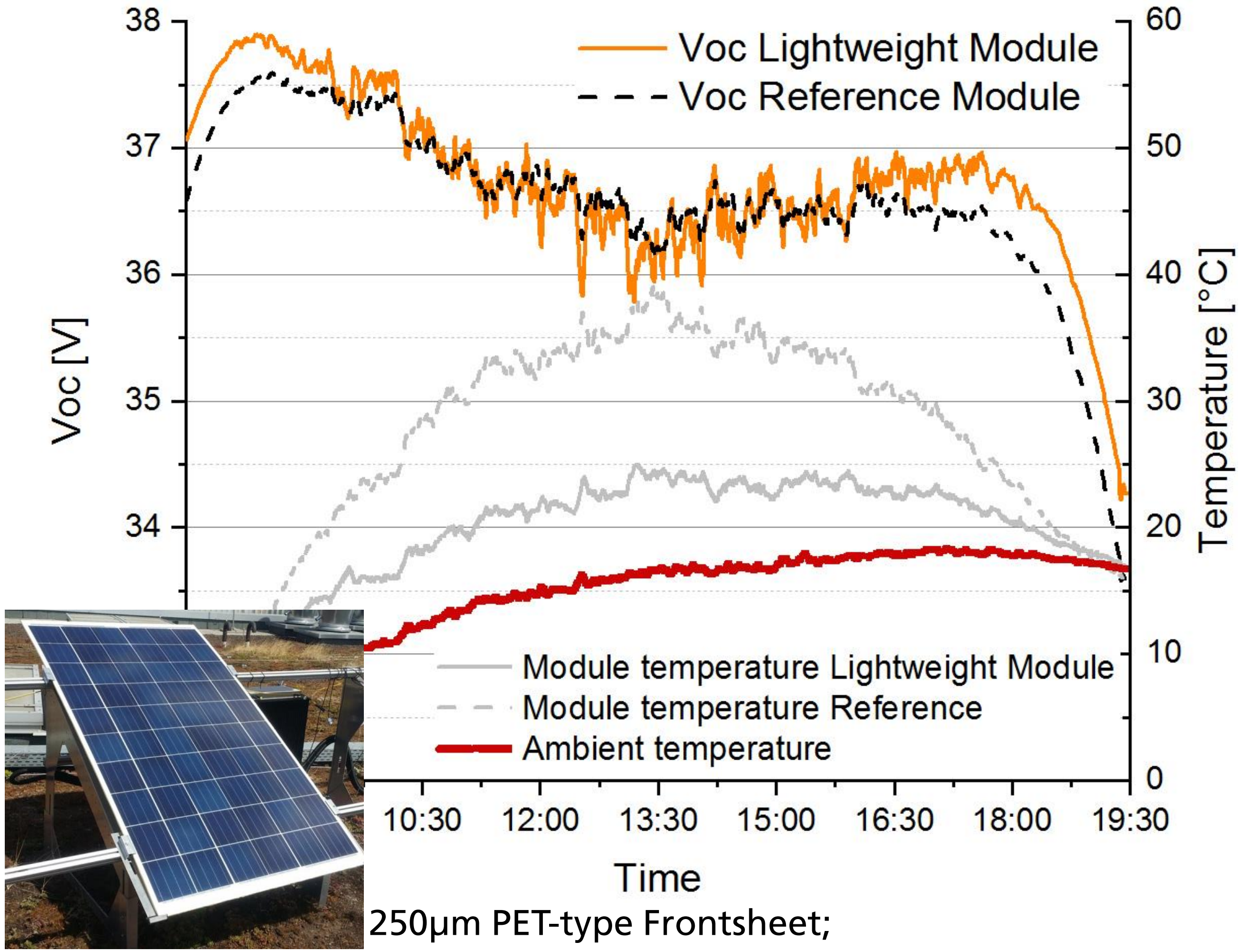


Glass/ honeycomb structure prototype

Resulting Design and Reliability Challenges



Challenge I: Module operational performance



250µm PET-type Frontsheet;

10mm Foamy Backsheet

- Module temperature (Tmod) measured direct at **rear side** of the modules (rear side temperature)
- Temperature at the **rear cooler** as for standard module (rear side material isolates the back side, by foam baking structure)
- Some drop in Voc → **increase in cell temperature**, but actually less than expected (probably quite good heat dissipation through thin front sheet)

Challenge:

Light structures vs. mechanical stability vs. heat dissipation

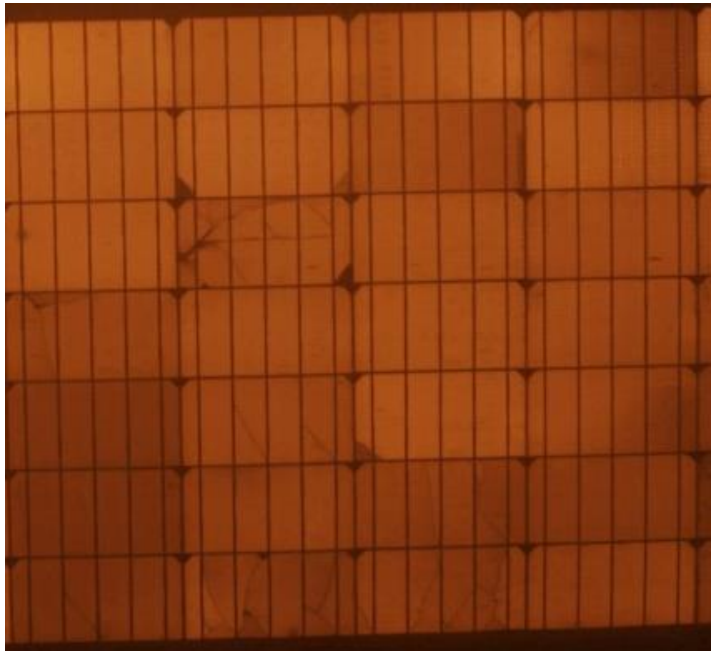
Impact: Energy production

Fraunhofer CSP

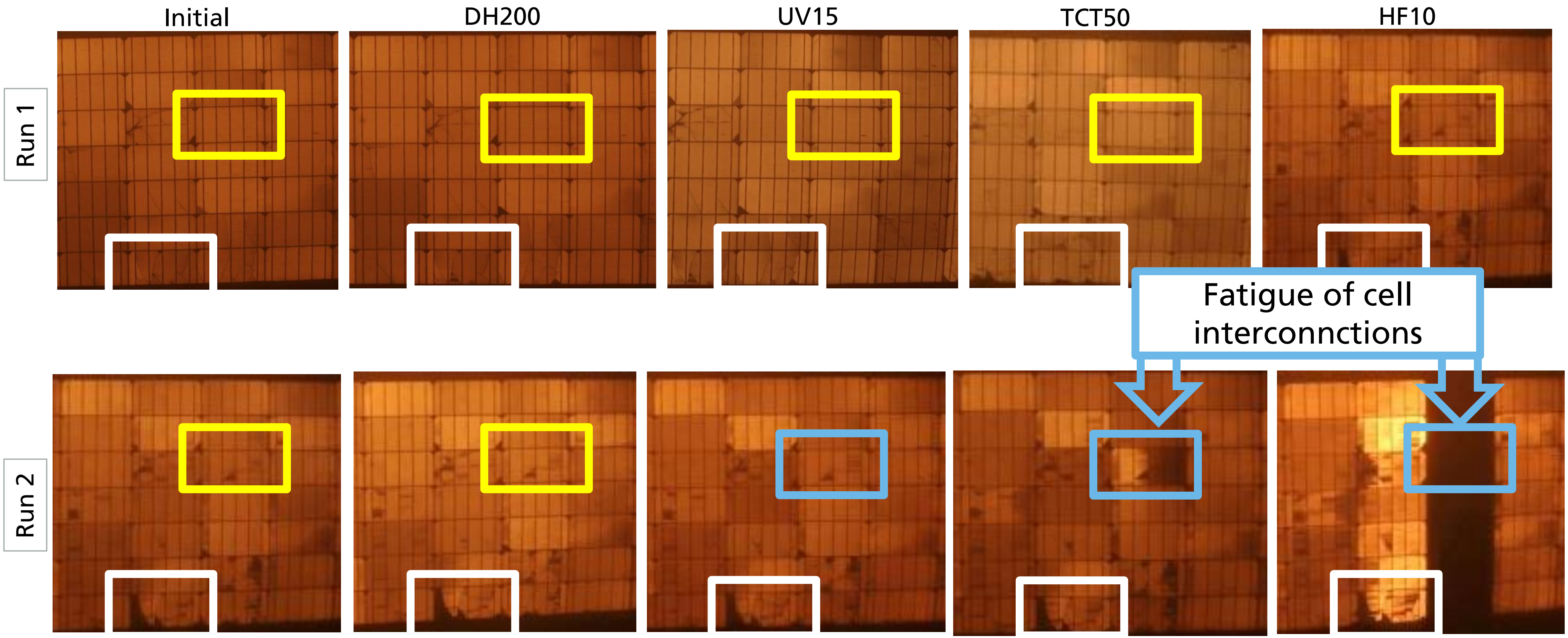
Challenge II: Module Reliability / durability

- Example of **Polymer-Polymer** module with slightly **curved surface**
  - 5BB half cut cells
  - Standard cell interconnection
- Testprotocol: Sequencial Testing
  - Combining humidity, UV and Thermal cycles
  - Repeat: DH, UV, TCT, HF to fail

Some lamination and transportation damage



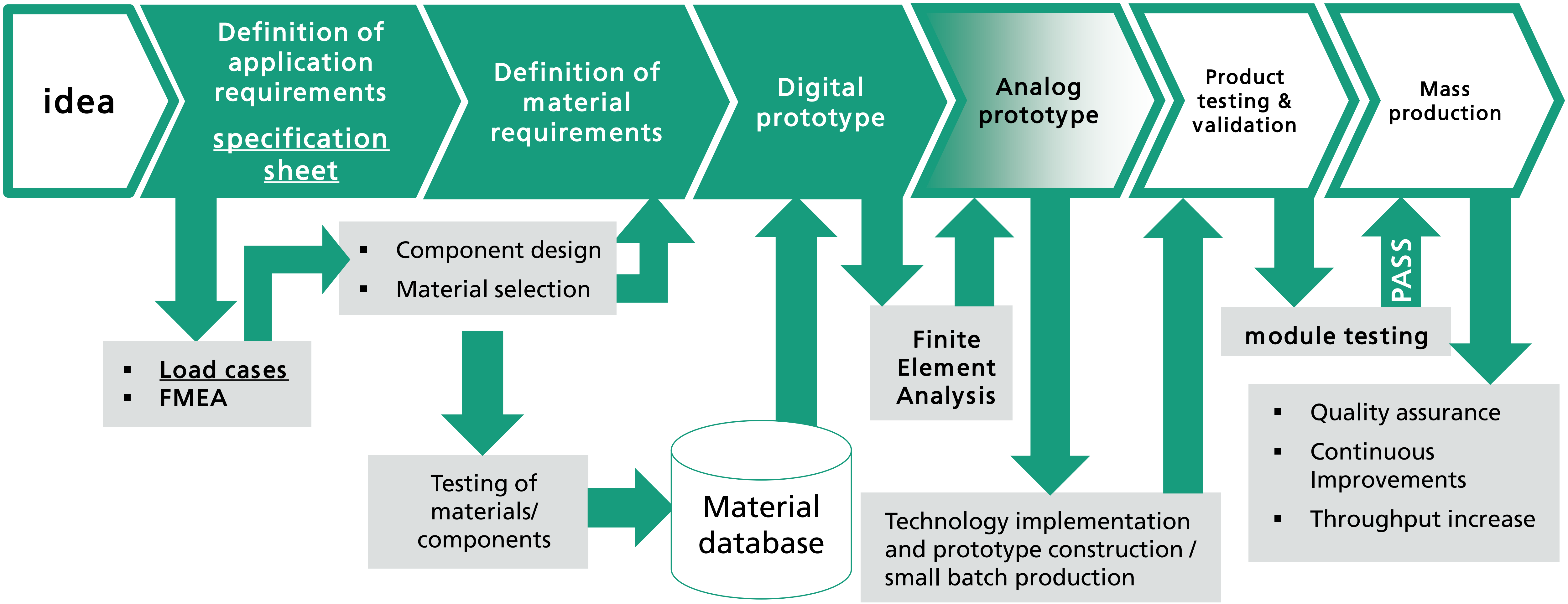
Challenge II: Module reliability / durability



How can we better understand such failures?

How to prevent them in the future?

From idea to mass production: Leichtbau → digital design to minimise development cost



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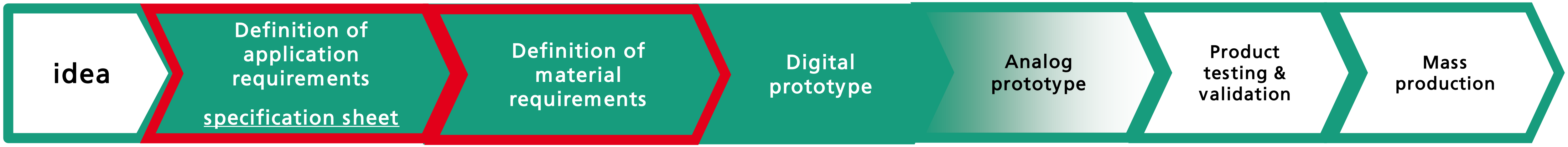
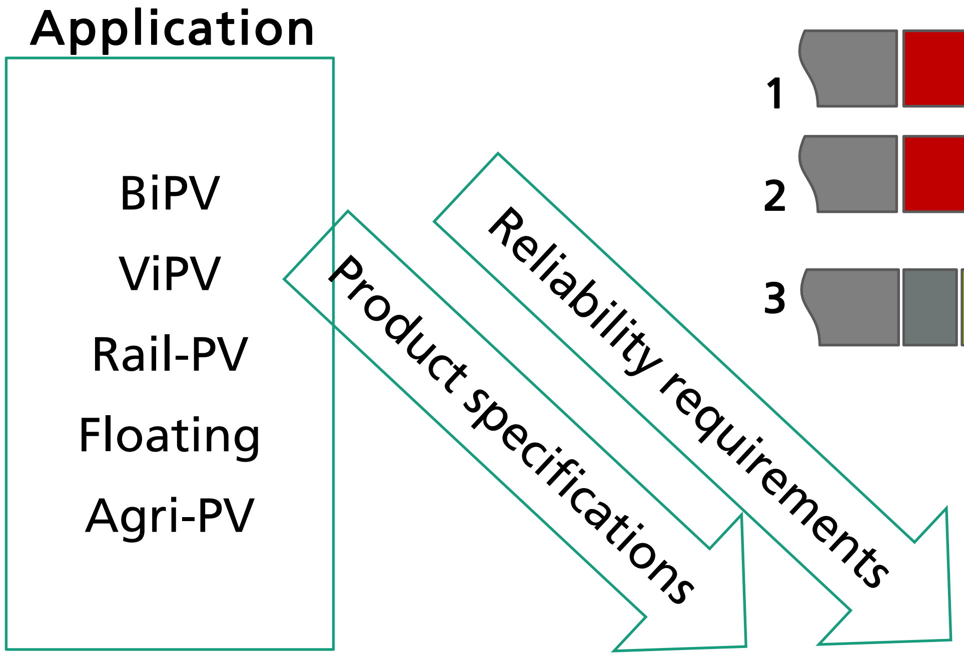
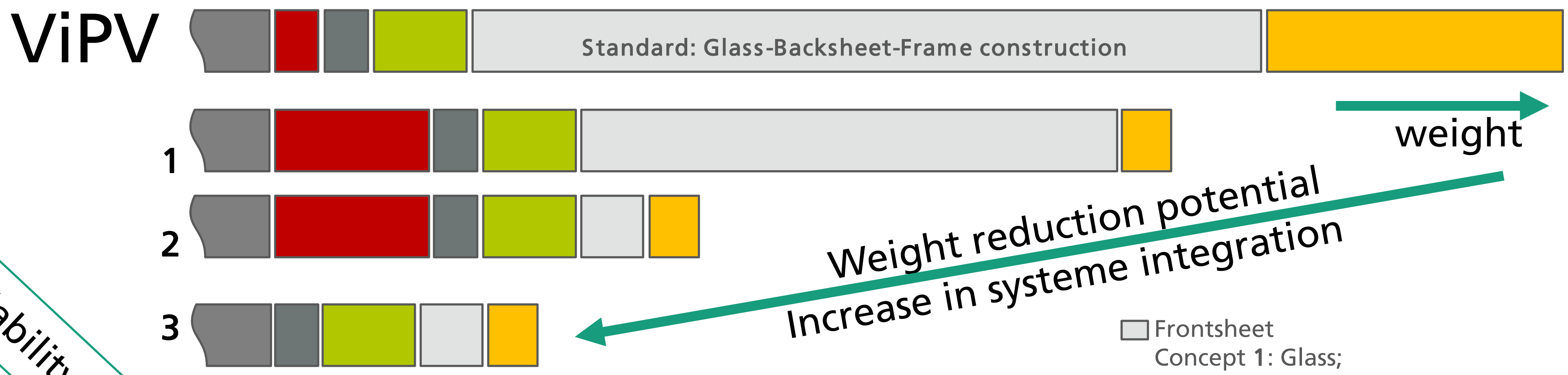
Application and load profile



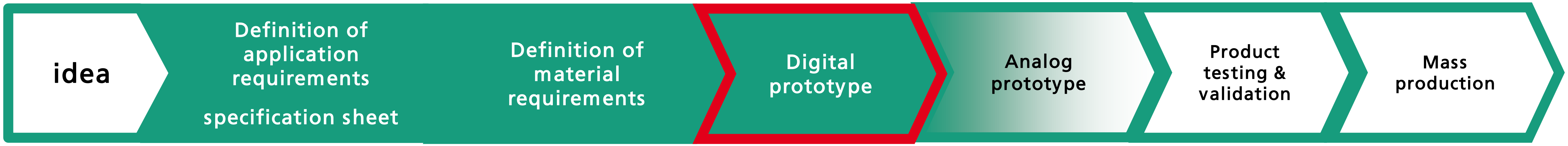




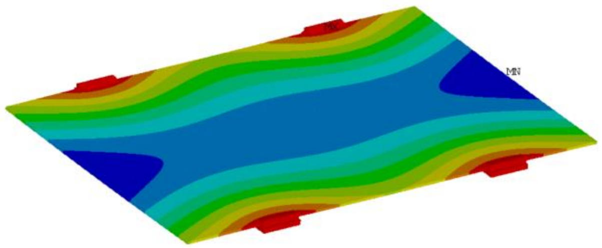
- Reference: Glass-Backsheet setup (not nice but probably functional): ~10-12kg/m²
- concept 1: Glass-Foam-Laminate: ~7,5 kg/m²
- concept 2: Foil-Foam-Laminate: ~3,5 kg/m²

Frontsheet
Concept **1**: Glass;
Concept **2**: Polymer
Encapsulant
Solar cells & electrical conections
Backsheet: Polymer or stiff foam
J-Box, frame
Vehicle

Digital prototype of modules

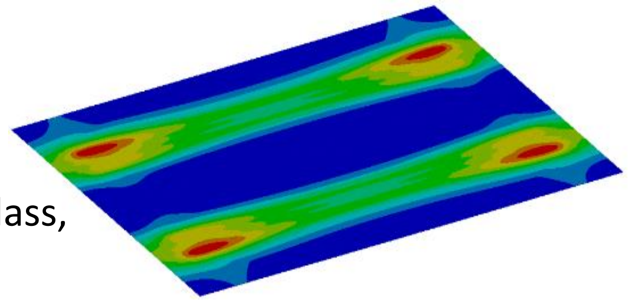


- **BOM:** Mechanical modell of materials, components, specimen and modules
- Material data and **properties of materials** and componds needed
- Challenges: different thermal **coefficient of expansion**, hail test, area moment of inertia (Young modulus and height)
- Different **support conditions** can be calculated
- Different mission / **load profiles** can be applied



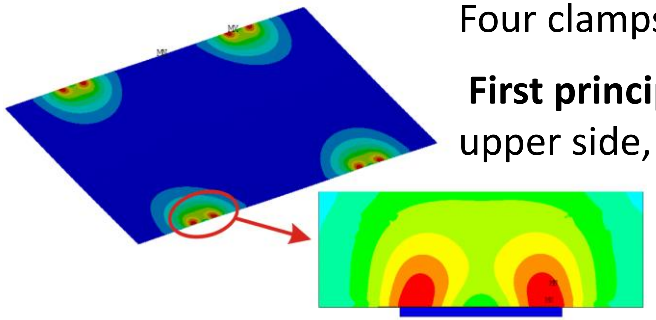
Four clamps:

Deformation under wind pressure (vertical Load)



Back rail:

First principal stress, back glass, upper side, vertical load



Four clamps:

First principal stress, front glass, upper side, vertical load

Pander et al, “Cell Strength Test in Laminates – Findings and Practical Relevance”, EU PVSEC 2017

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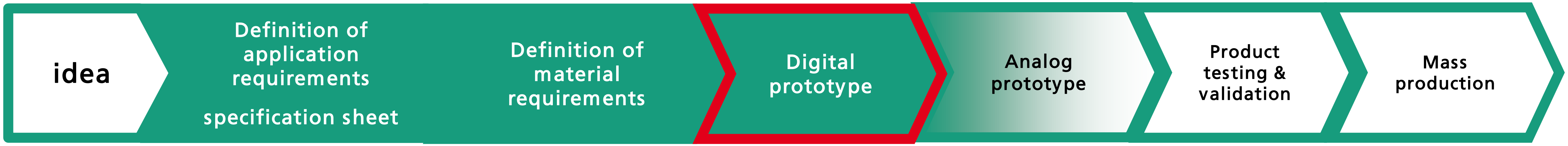
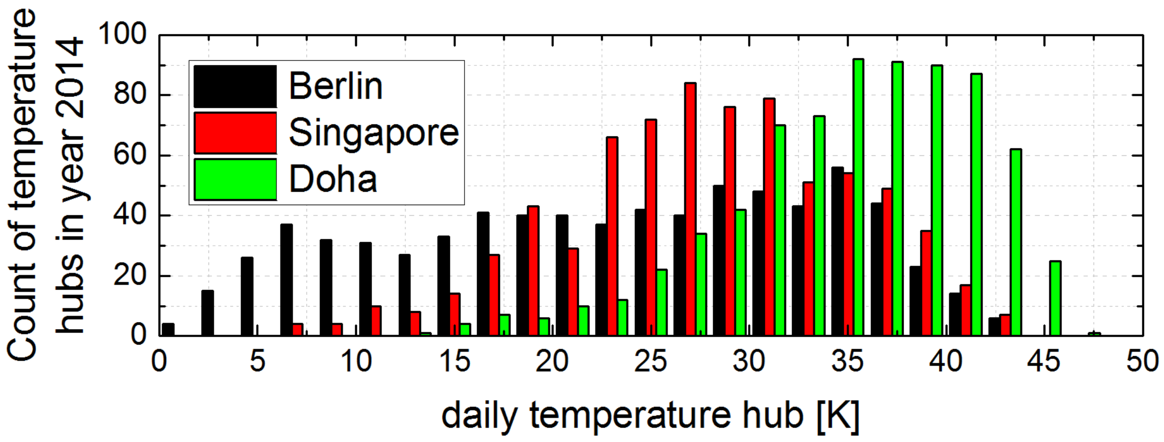
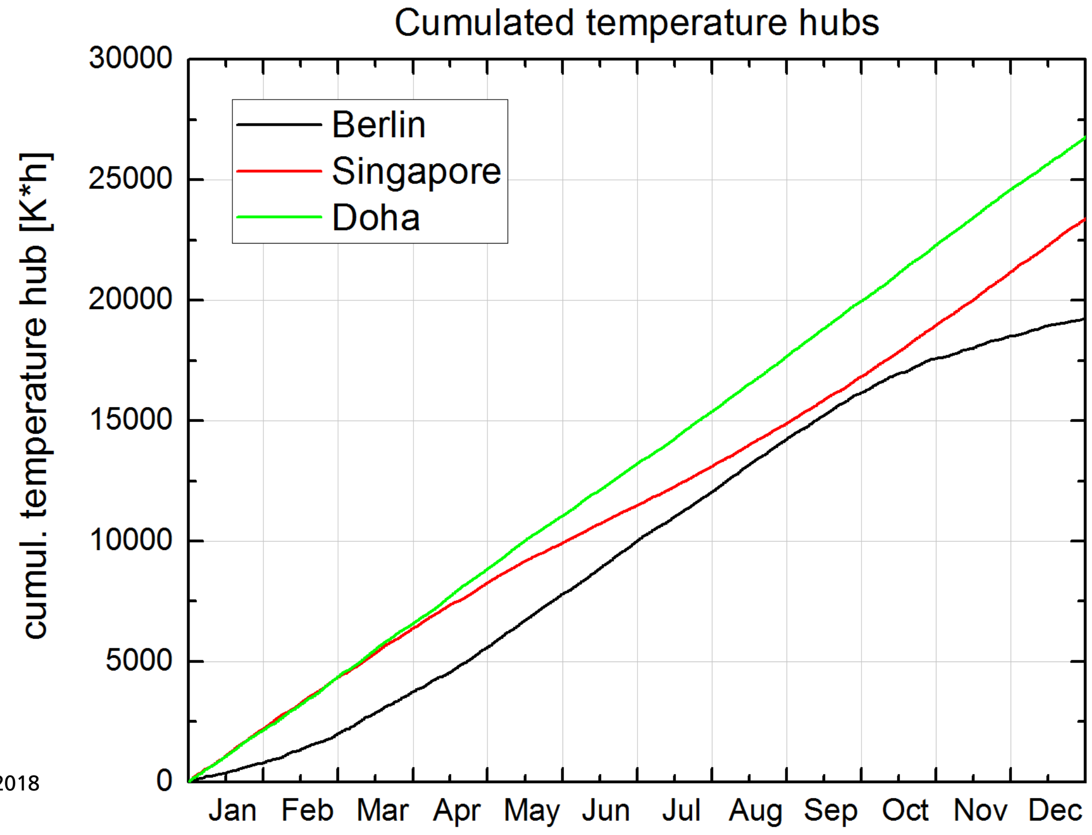
Digital prototype testing for thermal fatigue



- Example for Berlin, Singapore and Doha
- Fokus on Thermal stress





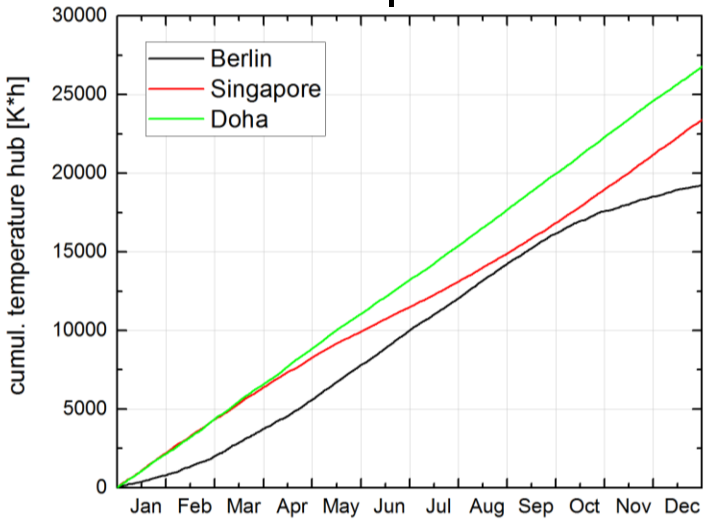
Zeller, et al "Digitalization in PV – Virtual Application of Real Weather Data on PV Modules for Lifetime Prediction", EU PVSEC 2018
Pander et al, „Digital Prototyping – Application of Numerical Methods in Module Development", EU PVSEC 2019

Digital prototype testing

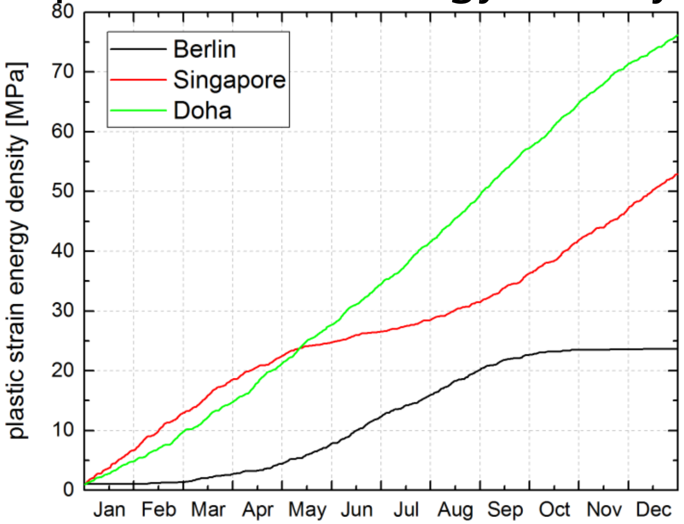
idea → Definition of application requirements (specification sheet) → Definition of material requirements → **Digital prototype** → Analog prototype → Product testing & validation → Mass production

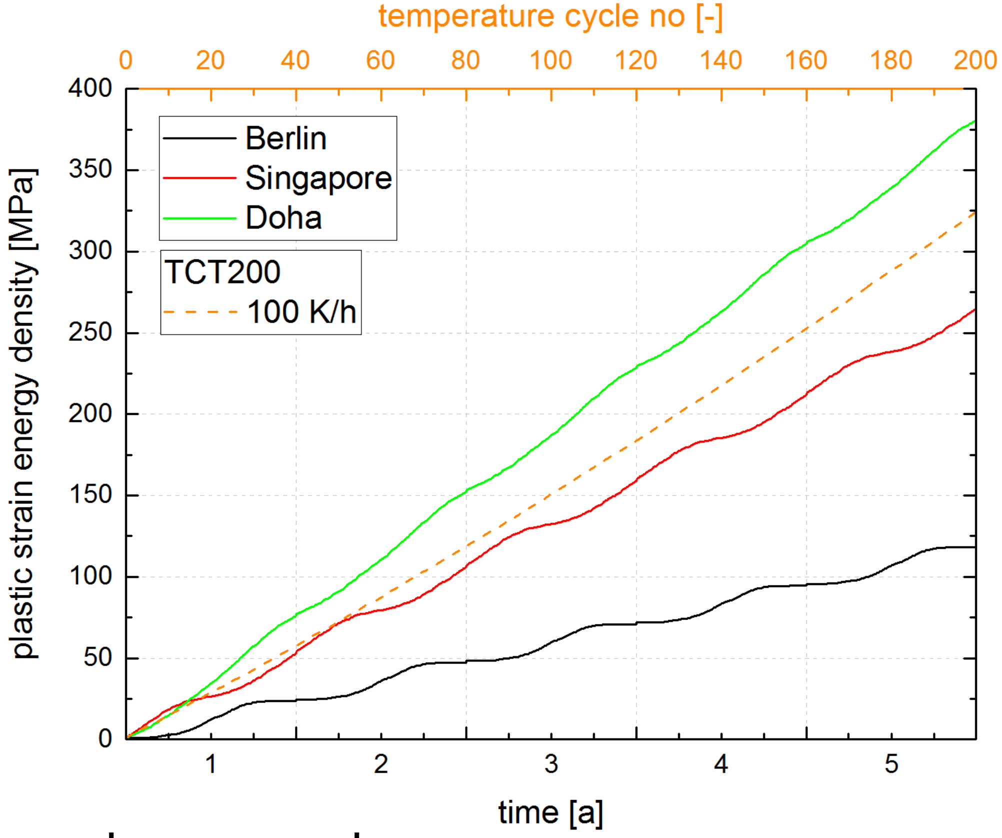
- Failure fatigue criterion: plastic strain energy density

Cummulated temperature hubs



plastic strain energy density



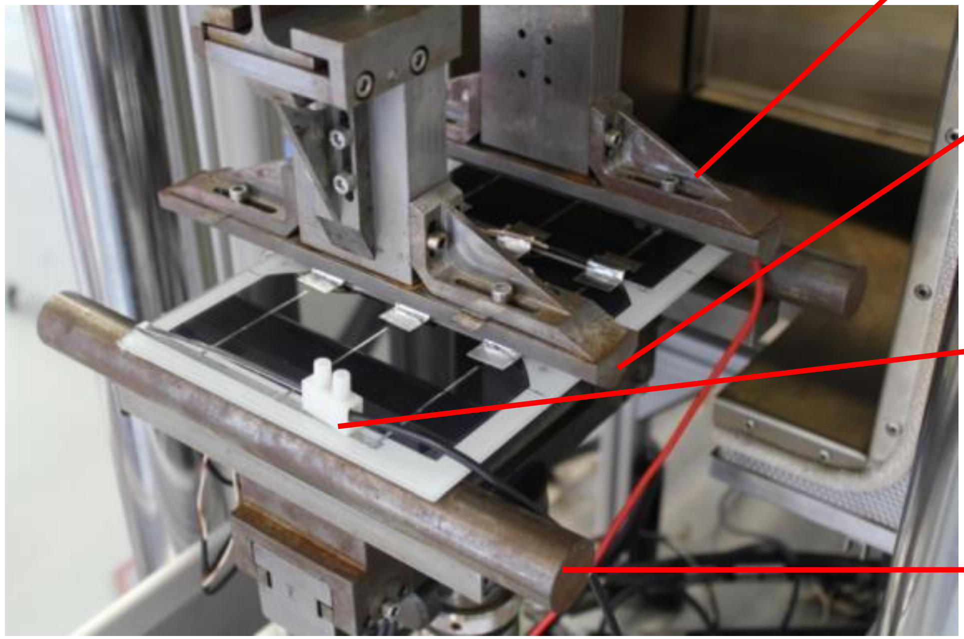


- Extreme climates 2 – 3x more severe than moderate climate
- **Special applications** like use of thermal insulating material (foam, honey comb structures) cause e.g. electrical interconnections to fail significant earlier even in a moderate climate → the see there on **stressful "micro climate"**

Material and sample testing: Temperature dependent fatigue test

idea → Definition of application requirements (specification sheet) → Definition of material requirements → Digital prototype → **Analog prototype** → Product testing & validation → Mass production

- Four point bending experiments with tempering chamber for small samples (750 mm x 200 mm w/o temperature, 280 mm x 200 mm with temperature
- Dynamic experiments for fatigue investigations
(bis 5 Hz, 2 kN, Amplitude ~5 mm)
- In-situ interconnector breakage detection
- Result: Temperature dependent number of cycles till failure → temperature accelerated fatige process



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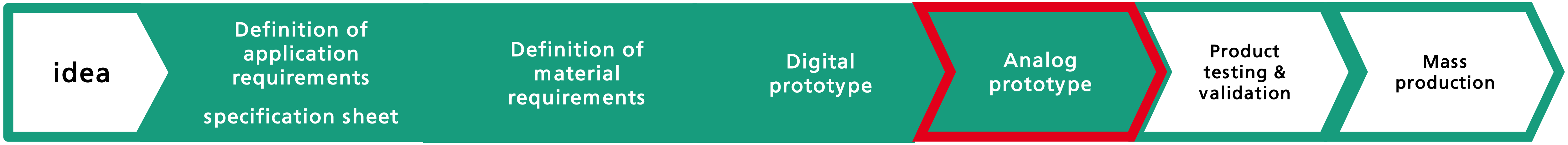
Prototype testing: Thermal cycling

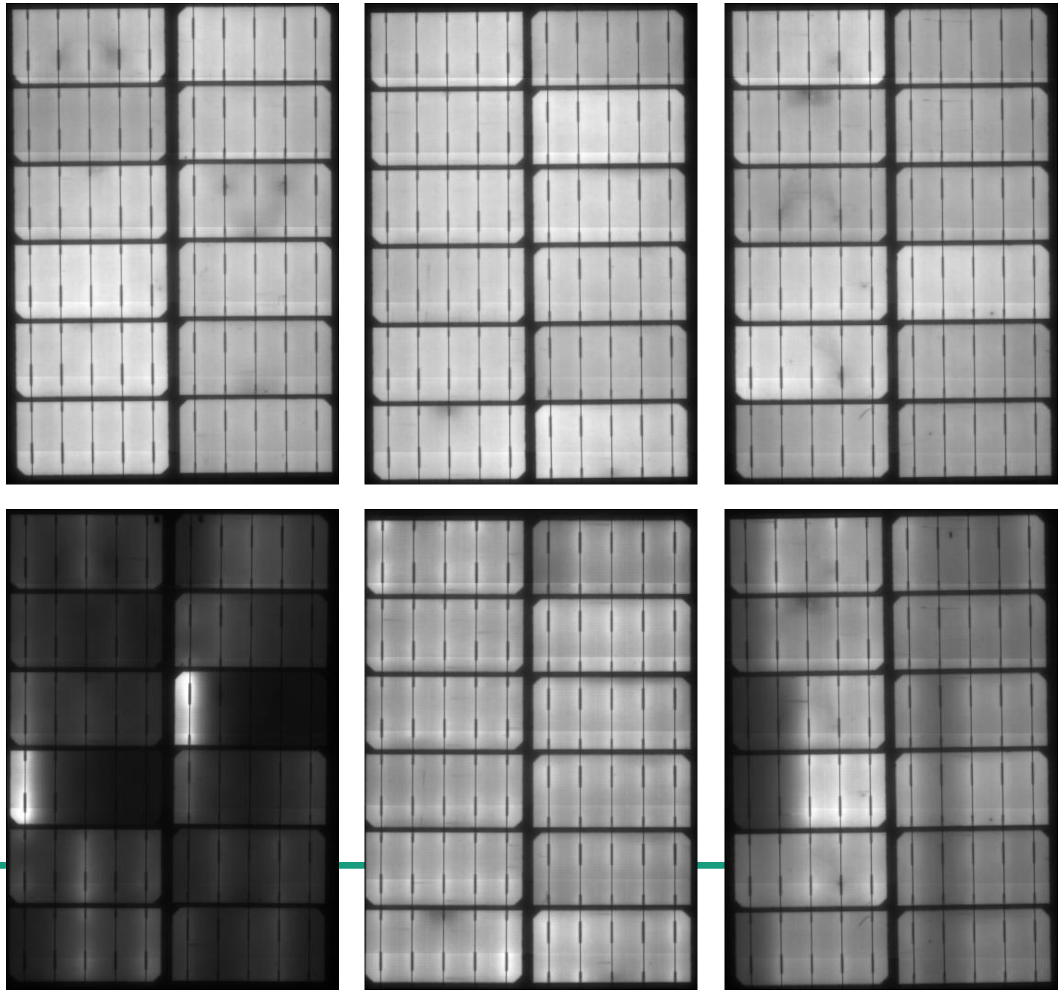


- Tests with combination of different encapsulation materials
- Half Cell specimen
- Example for failure after TC Tests

- Result: Breakage of interconnectors strongly **depends on encapsulation material** and thermal stress applied by the different materials

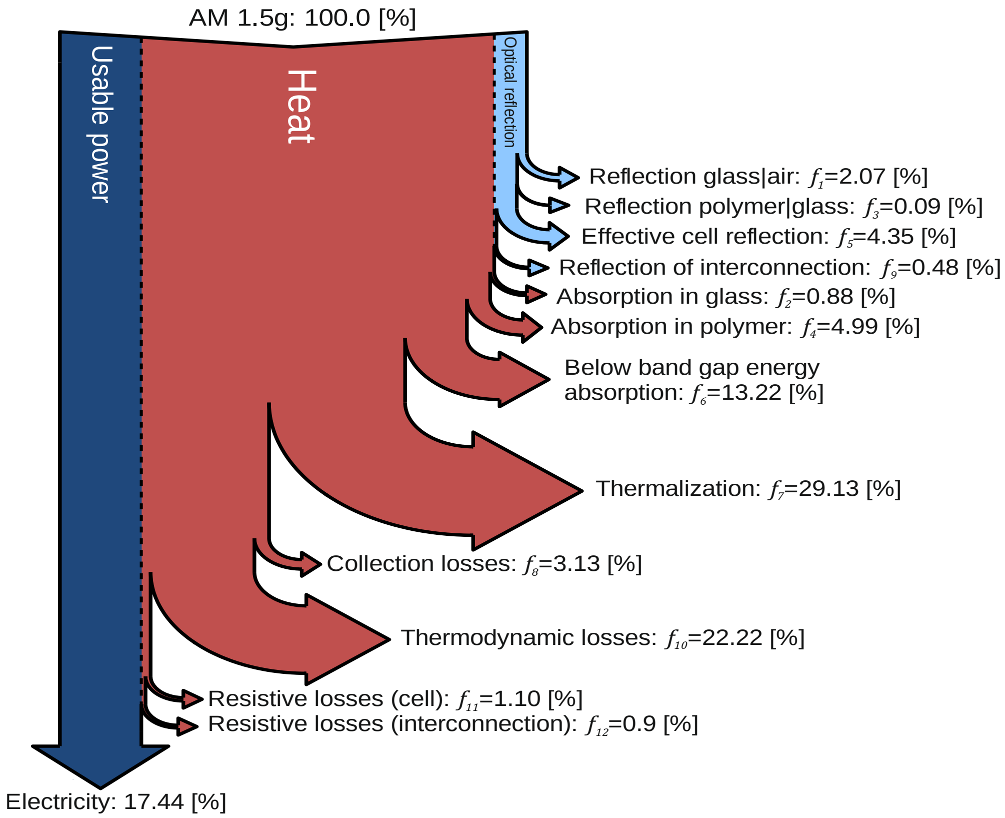
Initial

TCT50



Summary Leichtbau modules

- Wp → Wp/kg --> Wp/(kg*m²) ➔ **“Light”**
- Modules for special applications like BiPV and ViPV require new development approaches ➔ **“Easy / Simplified”**
- Simulations can support
  - Material selection
  - Dimensioning
  - Do fast „pre-testing“ for selected designs
- Thermal management:
  - Modules with foam, honey comb or similar structures need to be evaluated beyond STC conditions
  - **Wp/(kg*m²) under STC** does not represent light weight & integrated PV modules in e. g. ViPV application
  - heat transfer and quite different and variable light levels have to be considered for reasonable Energy yield calculation but also for **Reliability understanding and testing**



Sankey-Diagram of different energy loss mechanism of a PV module:

- Optical losses
- Thermal losses
- Usable power → kWh

Acknowledgement & Thank You !

- TEC: Sebastian Schindler, Dominik Götz (now with Sunovation), Jens Schneider (now with HTWK)
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