KEEP COOL AND DISTRIBUTE STRESS

A recipe for improved performance

26 APRIL 2021

WEBINAR OVERVIEW

Questions to answer:

1. What determines degradation, output and lifetime?

Simon Meijer
COOLBACK Company

2. Can COOLBACK® new module technology reduce degradation?

Alex Masolin
COOLBACK Company

3. What about mechanical stress, new cells and larger modules?

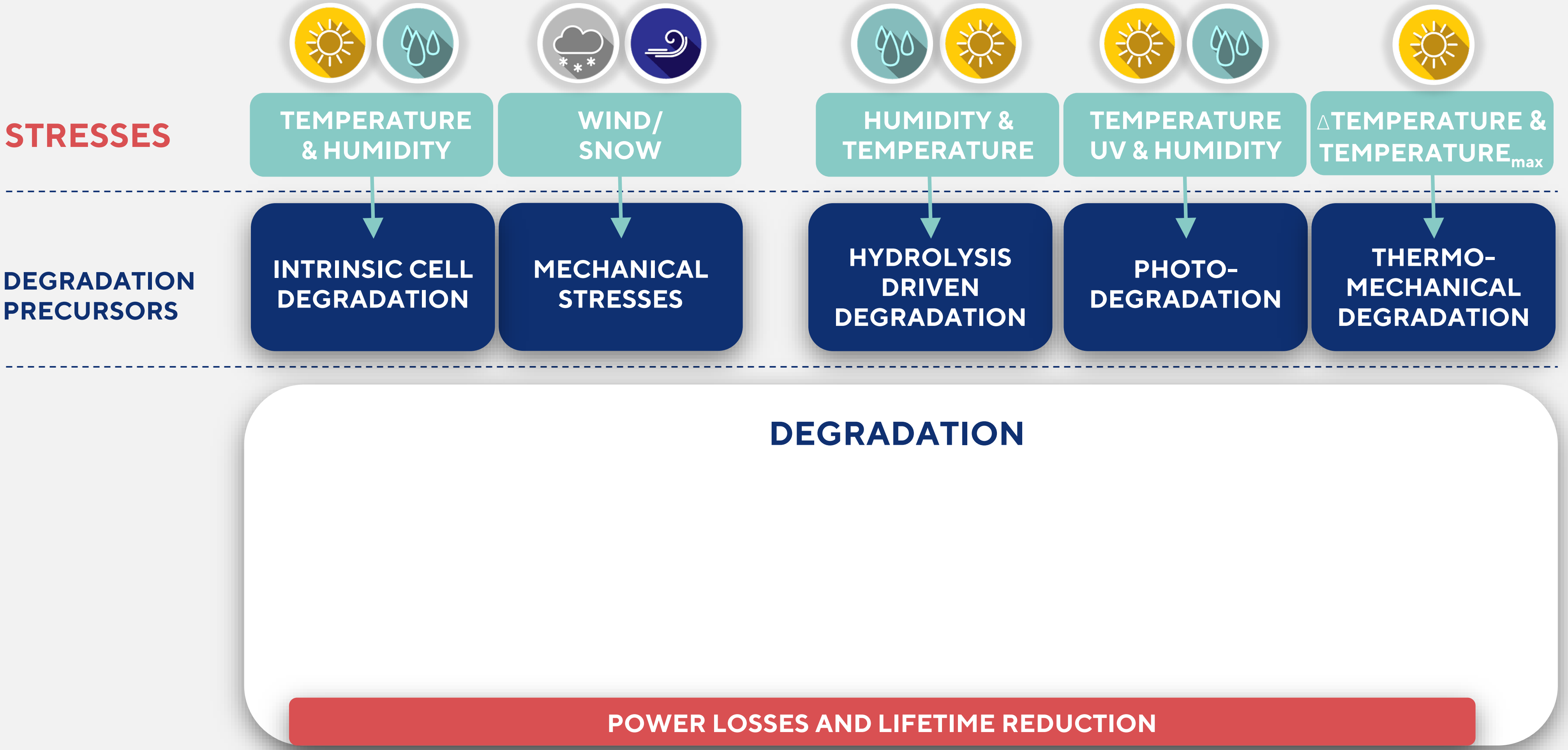
Andreas Beinert
Fraunhofer Institute for Solar Energy Systems ISE

4. How can we quantify the effects of using COOLBACK® ?

Simon Meijer
COOLBACK Company

1 What determines degradation, output and lifetime?

1 DEGRADATION MECHANISMS



Adapted from : I. Kaaya, et al., "Modeling Outdoor Service Lifetime Prediction of PV Modules: Effects of Combined Climatic Stressors on PV Module Power Degradation," in IEEE Journal of Photovoltaics, vol. 9, no. 4, pp. 1105-1112, July 2019

① DEGRADATION MECHANISMS

STRESSES	TEMPERATURE & HUMIDITY	WIND/ SNOW	HUMIDITY & TEMPERATURE	TEMPERATURE UV & HUMIDITY	∆TEMPERATURE & $TEMPERATURE_{max}$
DEGRADATION PRECURSORS	INTRINSIC CELL DEGRADATION	MECHANICAL STRESSES	HYDROLYSIS DRIVEN DEGRADATION	PHOTO-DEGRADATION	THERMO-MECHANICAL DEGRADATION

DEGRADATION

➡ **TEMPERATURE** is involved in almost every degradation mechanism

POWER LOSSES AND LIFETIME REDUCTION

Adapted from : I. Kaaya, et al., "Modeling Outdoor Service Lifetime Prediction of PV Modules: Effects of Combined Climatic Stressors on PV Module Power Degradation," in IEEE Journal of Photovoltaics, vol. 9, no. 4, pp. 1105-1112, July 2019

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➡ **MOISTURE** is involved in hydrolysis, corrosion and photo-degeneration

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DEGRADATION

TEMPERATURE is involved in almost every degradation mechanism

MOISTURE is involved in hydrolys, corrosion and photo-degeneration

MECHANICAL FORCES cause of load stress and thermal stress degradation

POWER LOSSES AND LIFETIME REDUCTION

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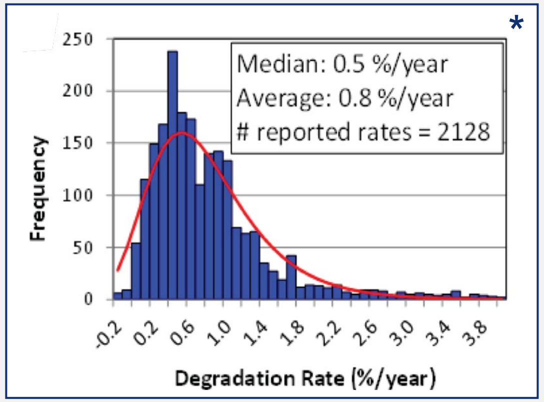
COOLBACK®

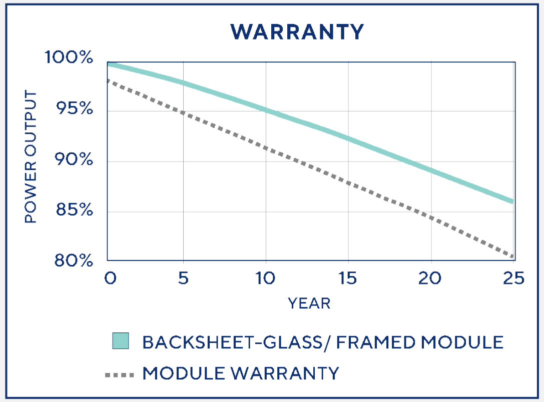
① DEGRADATION IN PV INDUSTRY

How the PV industry deals with degradation

DEGRADATION IS INTEGRATED IN THE PRODUCT RELIABILITY WITH:

- **Degradation Rate**
  Linear behavior, average **0,8%/year**
- **Power Output decline**
  Range 0,2 – 2% /year





BUT SEVERAL FACTORS ARE NOT INCLUDED:

- **Climate**
  Higher degradation when **hot & humid**
- **Cell Technology**
  Higher vulnerability of **high efficiency** cells
- **Module materials**
  Longlasting materials are available, but more expensive
- **Module type**
  Lower Degradation Rate for glass-glass (~0,4%/year)

THIS RESULTS IN:

- **Warranties**
  Normal 25 years on mono-facial backsheet-glass module and 30 years for glass-glass, excluding several "harsh" situations

* Source: NREL/CP-5200-56485, 2012

1 POLL QUESTION 1

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QUESTION

In order of magnitude, what is the ranking of the 3 dominant degradation precursors affecting module output & lifetime?

1	2	3
TEMPERATURE	HUMIDITY	MECHANICAL FORCE

a. 1, 2, 3

b. 2, 3, 1

c. 3, 2, 1,

d. 3, 1, 2

1 POLL QUESTION 1 - ANSWER

QUESTION

In order of magnitude, what is the ranking of the 3 dominant degradation precursors affecting module output & lifetime?

1	2	3
TEMPERATURE	HUMIDITY	MECHANICAL FORCE

a. 1, 2, 3

b. 2, 3, 1

c. 3, 2, 1,

d. 3, 1, 2

ANSWER

a. 1, 2, 3

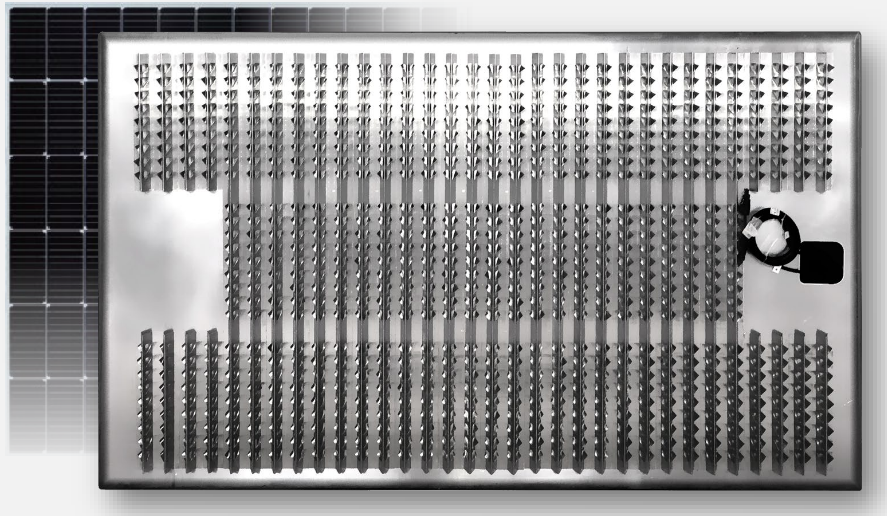
Precursors contributing to degradation:

Temperature	**40%**
Humidity	**30%**
Mechanical Force	**20%**
Other	**10%**

2 Can COOLBACK® new module technology reduce degradation?

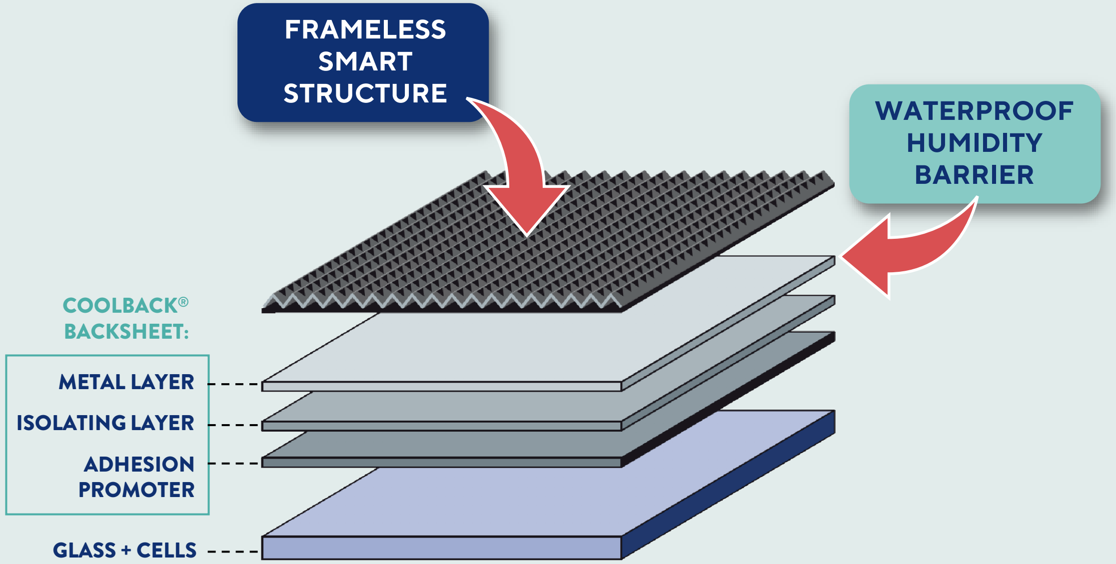
② COOLBACK® = ⬇ DEGRADATION

COOLBACK® module technology increases output and reduces degradation:



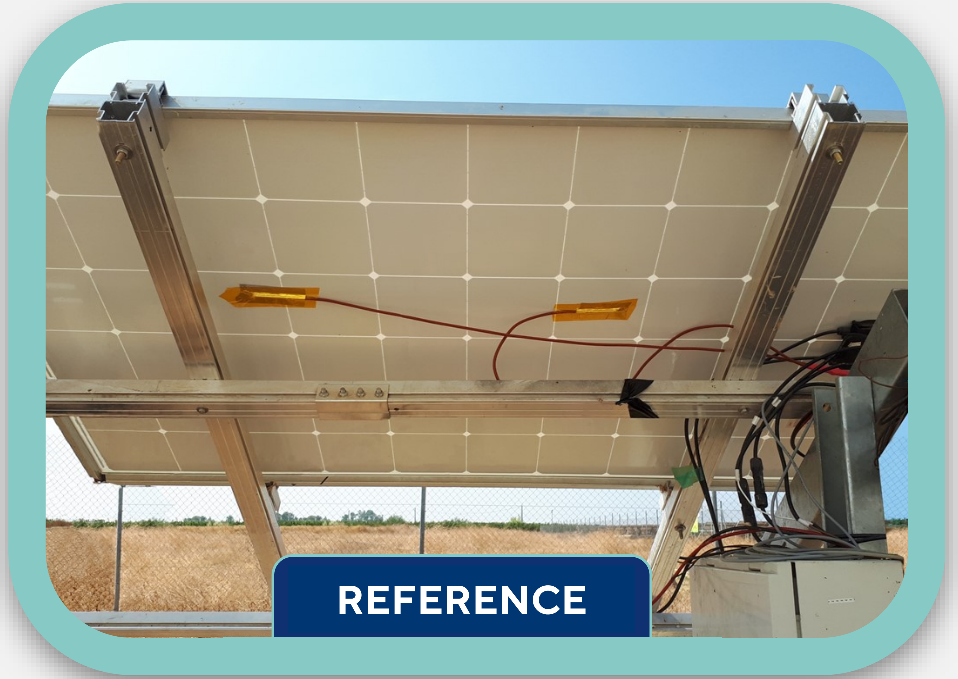
Same costs, weight and size

COOLBACK® replaces original frame and backsheet during production



② TEMPERATURE EFFECTS (1)

Operating temperature: lower temperature increases output

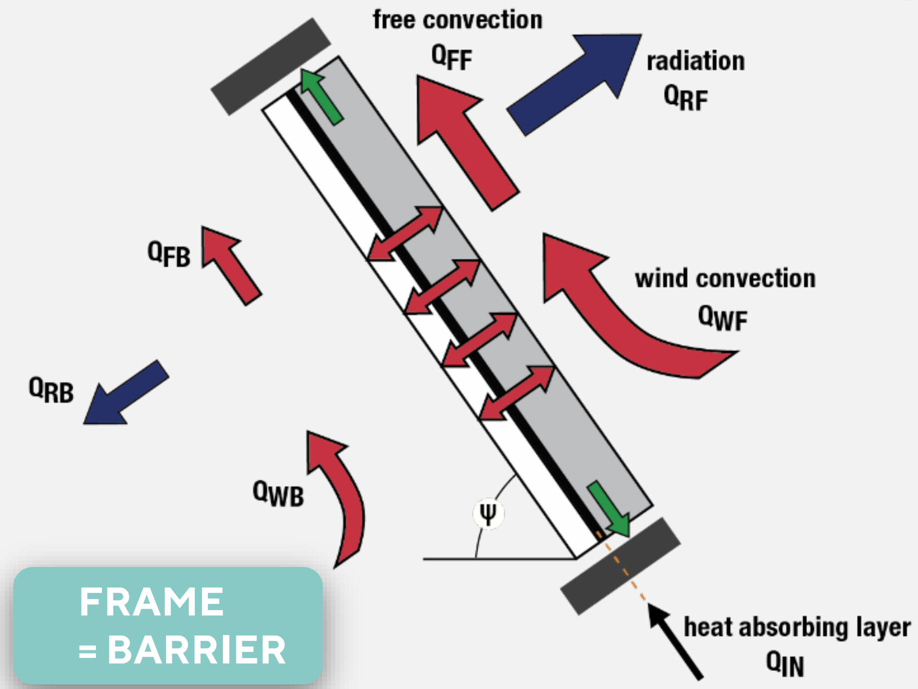


Higher operating temperature

Lower operating temperature

② TEMPERATURE EFFECTS (2)

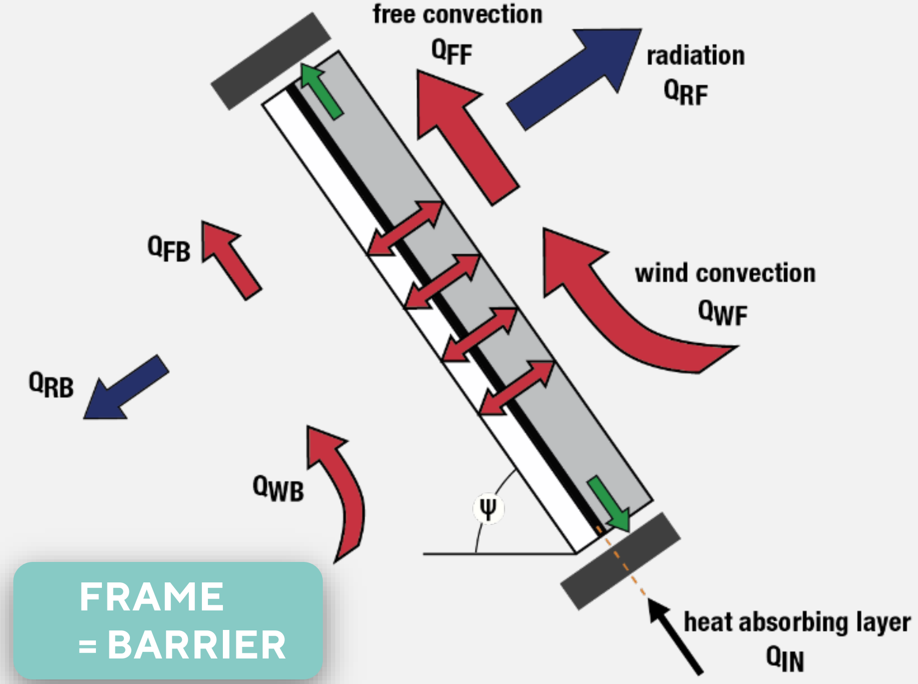
Standard framed PV modules suffer from low heat dissipation due to blocked airflows and non heat-transmitting materials.



FRAME = BARRIER

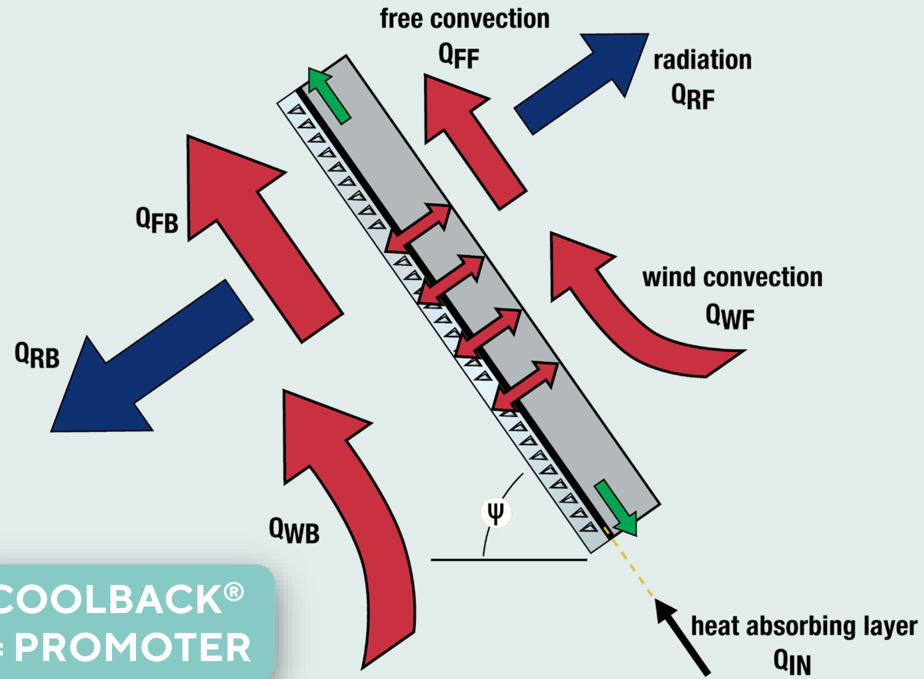
② TEMPERATURE EFFECTS (3)

Standard framed PV modules suffer from low heat dissipation due to blocked airflows and non heat-transmitting materials.



FRAME = BARRIER

COOLBACK® Profiles dramatically increase heat dissipation by means of higher natural convection cooling.



COOLBACK® = PROMOTER

② ↓ TEMPERATURE = ↑ OUTPUT

Lower operating temperature increases energy yield

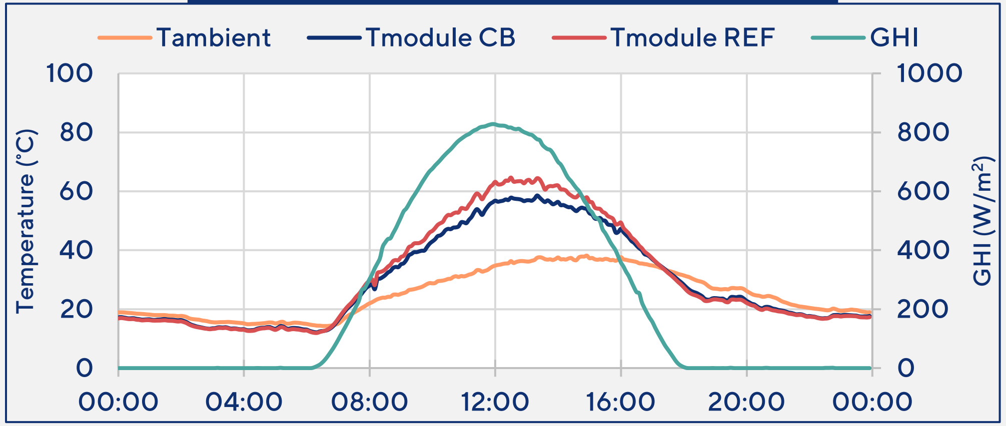
Representative daily average:

- Maximum module temperature gain: **- 7°C**

Annual average:

- Module operating temperature: **- 7.3°C**

DAILY PERFORMANCE



The results were confirmed in several climates at third-party test sites in Spain, Italy, Qatar, UAE and Thailand, and also at PV module makers' test sites in China. Wind and irradiation, as major drivers, can cause slightly different outcomes.

2 TEMPERATURE = OUTPUT

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Lower operating temperature increases energy yield

Representative daily average:

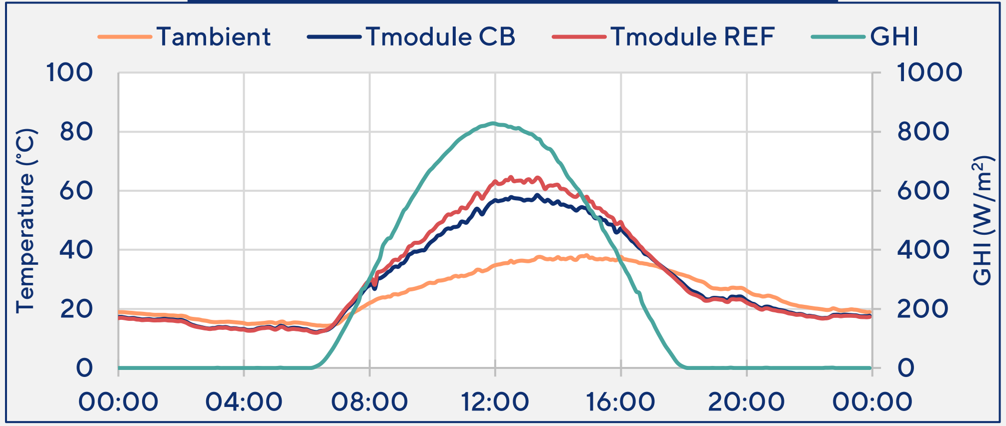
- Maximum module temperature gain: **- 7°C**
- Maximum power generation gain: **+ 12%**

Annual average:

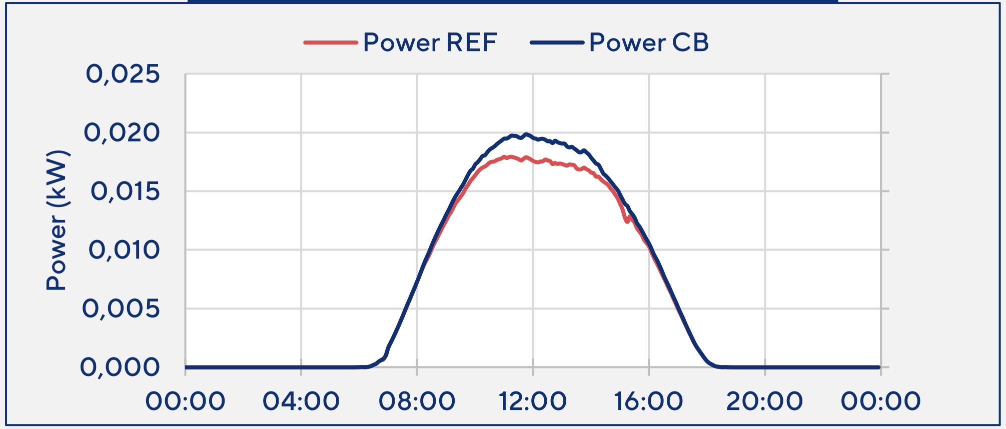
- Module operating temperature: **- 7.3°C**
- Energy yield gain: + **3.0%**

The results were confirmed in several climates at third-party test sites in Spain, Italy, Qatar, UAE and Thailand, and also at PV module makers' test sites in China. Wind and irradiation, as major drivers, can cause slightly different outcomes.

DAILY PERFORMANCE



ENERGY YIELD ON SPECIFIC DAY



② MATERIAL CHOICE EXTENDS LIFETIME

Ideal humidity barrier

MOISTURE PENETRATION - BACKSHEET

BACKSHEET TYPE	WVTR[1] (g/ m² * DAY)	5% PERFORMANCE DROP UNDER 85°C / 85% (damp heat)
SUB-STANDARD (sub-tier 1)	> 4	< 1000 hours
STANDARD (Tier-1 manufacturer)	3	1000 hours
	2	< 3000 hours
COOLBACK®	< 0,0001	> 4000 hours

[1] WVTR = Water Vapor Transmission Rate

② MATERIAL CHOICE EXTENDS LIFETIME

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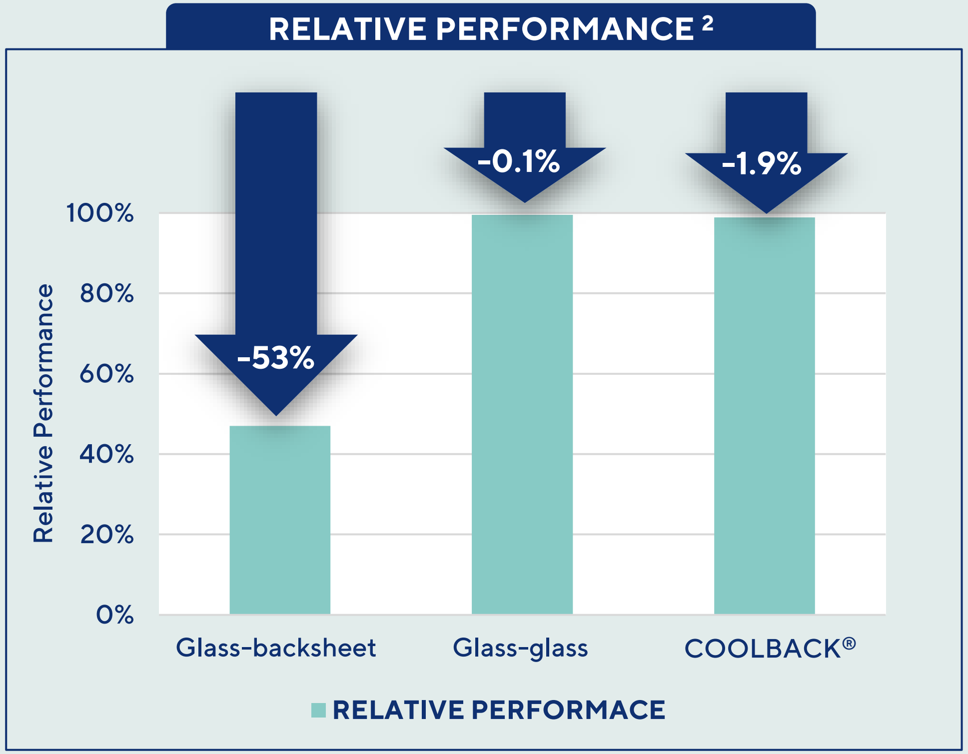
SUB-STANDARD (sub-tier 1)	> 4	< 1000 hours
STANDARD (Tier-1 manufacturer)	3	1000 hours
	2	< 3000 hours
COOLBACK®	< 0,0001	> 4000 hours

Damp Heat Test – 4.000 hours

TEMPERATURE: 85°C | RELATIVE HUMIDITY: 85%

COOLBACK® provides outstanding performance and is as good as sealed glass-glass.



Fraunhofer ISE

1 **WVTR = Water Vapor Transmission Rate**

2 Koehl, M., Hoffmann, S., and Wiesmeier, S. (2017) Evaluation of damp-heat testing of photovoltaic modules. Prog. Photovolt: Res. Appl., 25: 175– 183. doi: 10.1002/pip.2842.

COOLBACK®

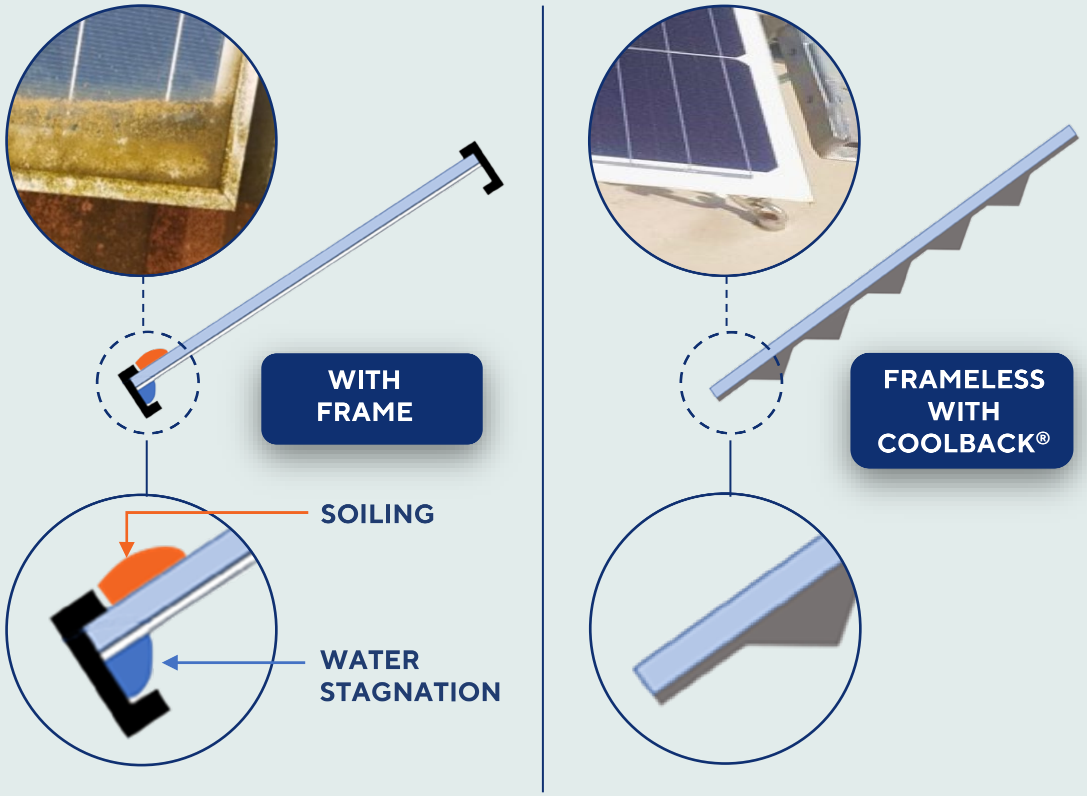
② FRAMELESS DESIGN EXTENDS LIFETIME

Ideal humidity backsheet edge

MOISTURE PENETRATION - BACKSHEET EDGE

In humid climates and floating installations, frames cause water to stagnate. This is the primary cause of water penetration from the edges, especially where small sealing defects are present.

Frames affect humidity and soiling



② NEW DESIGN LOWERS DEGRADATION!

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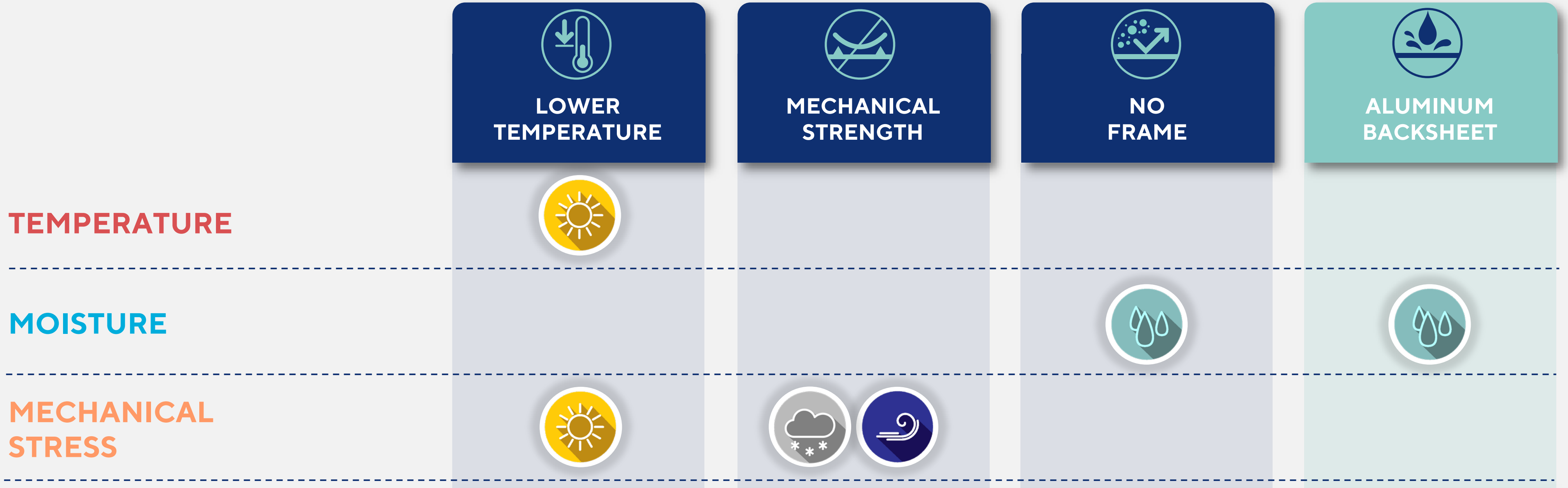
STRESS

IMPACT OF THE COOLBACK® SMART STRUCTURE & BACKSHEET



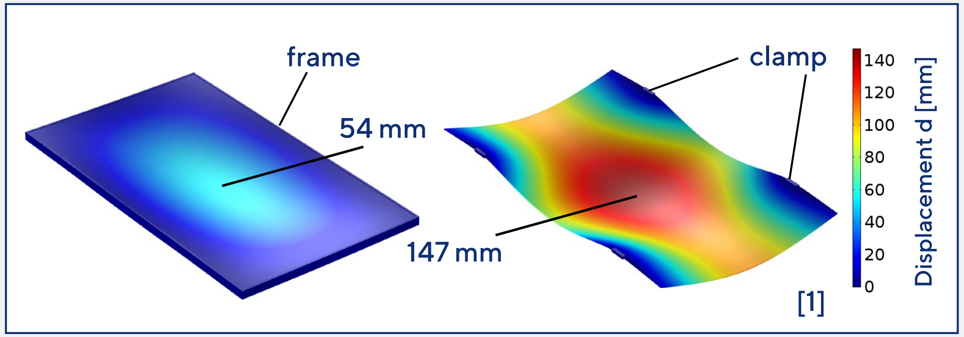
COOLBACK® LOWERS DEGRADATION PRECURSORS, RESULTING IN HIGHER POWER AND LONGER LIFETIME

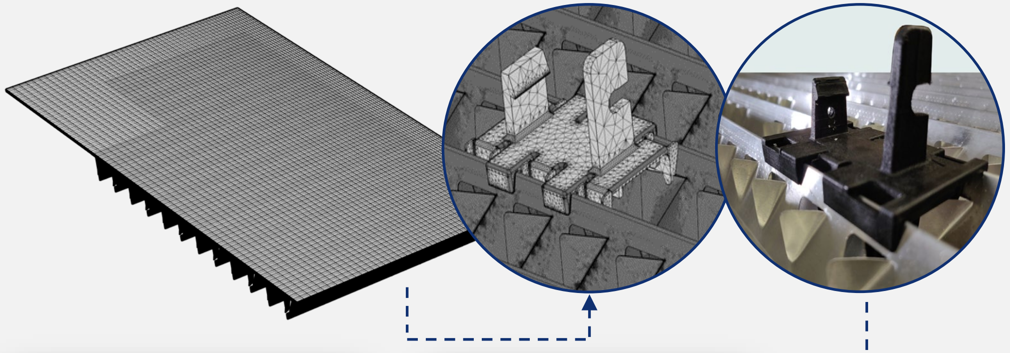
3 What about mechanical stress, new cells & larger modules?

③ FEM SIMULATION OF COOLBACK®

FEM simulation method:

- Mounting Structure crucial for PV module mechanics
  - High deflection = high stress
- Digital prototyping by FEM model based on previously published FEM model [2]
- Simulation of deflection and stress in cells
  - Pull load (-2400 Pa)
  - Push load (2400 Pa or 5400 Pa)
- COOLBACK® comparison to conventional framed module of same dimension





SYMMETRY ELEMENT OF COOLBACK® MODULE WITH FEM MESH

DETAILED MESH OF PROFILES AND CLAMP

COOLBACK® CLAMP

[1] A. J. Beinert *et. al.*, Influence of photovoltaic module mounting systems on the thermo-mechanical stresses in solar cells by FEM modelling, EU PVSEC 2016, pp. 1833-1839

[2] A. J. Beinert *et. al.*, Thermomechanical evaluation of new PV module designs by FEM simulations, pp EU PVSEC 2019, pp. 783-788

Fraunhofer ISE

POLL QUESTION 2

QUESTION

By how much does COOLBACK® improve bending (deflection) at the center of a module?

a. 5%

b. 20%

c. 60%

d. 70%

3 POLL QUESTION 2 - ANSWER

QUESTION

By how much does COOLBACK® improve bending (deflection) at the center of a module?

a. 5%

b. 20%

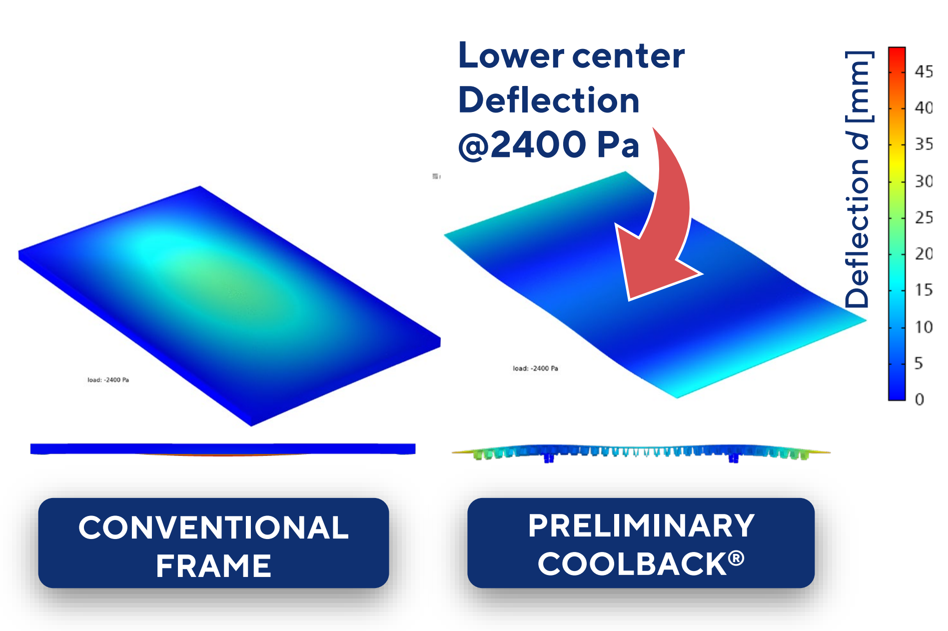
c. 60%

d. 70%

ANSWER

d. 70% less bending at the center with COOLBACK®

Preliminary results (prior to clamp optimization):



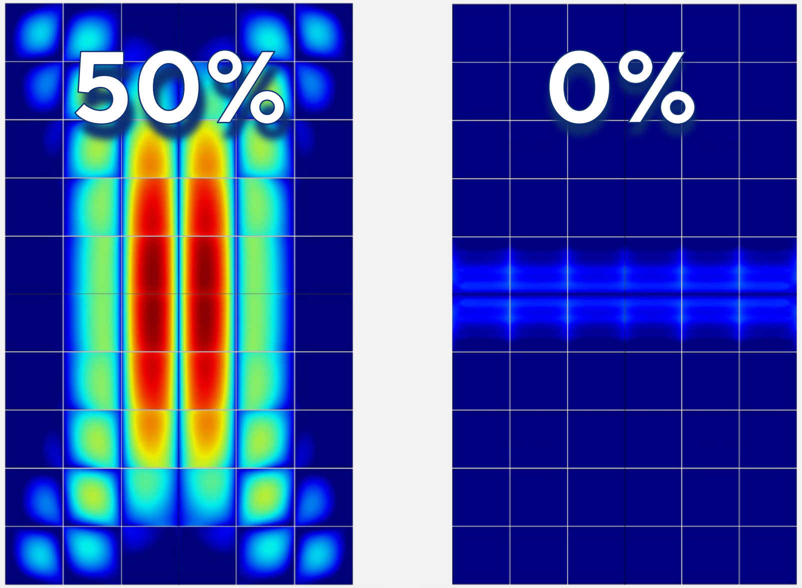
③ FEM SIMULATION OF COOLBACK®

COOLBACK® effect:

- Full surface support by better clamp positioning, avoiding trampoline effect. Optimization based on simulation results.
- Lower deflection all over → lower stress
- In comparison enormous reduction of cracks in normal size cells and modules expected

STRESS @ 5400 Pa PUSH

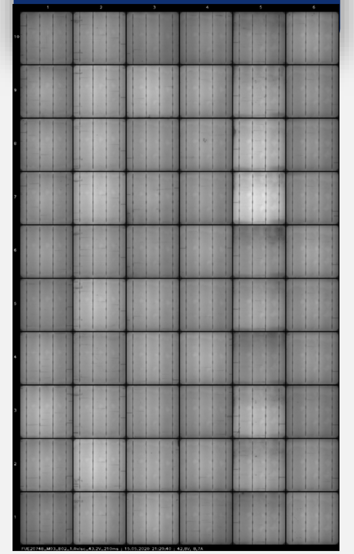
Cell fracture probability :



CONVENTIONAL FRAME | **COOLBACK®**

③ STATIC MECHANICAL IEC LOAD TEST

INITIAL



FULL TEST
IEC 61215-2:2016
(additional
push/pull to failure)

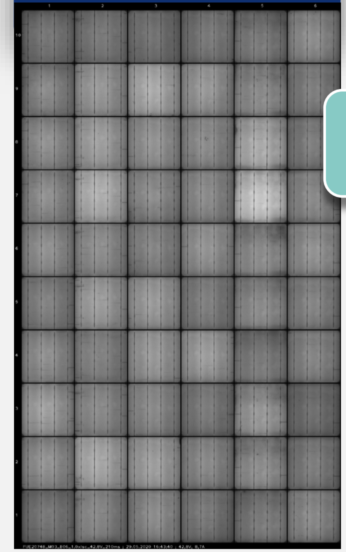
MODULE

Characterization:
MQT 01 - Visual inspection
MQT 06.01 - Performance at STC
Electroluminescence Image

Static Mechanical Load Test:
MQT 16 – Mechanical Load Test
(additionally **push/pull** to failure)

Characterization:
MQT 01 - Visual inspection
MQT 06.01 - Performance at STC
Electroluminescence Image

AFTER
7650 Pa PUSH



< 2.0% POWER LOSS

Maximum push load: 7650 Pa (8 clamps)
Maximum pull load: -5500 Pa (10 clamps)

3 DYNAMIC MECHANICAL IEC LOAD TEST

MODULE

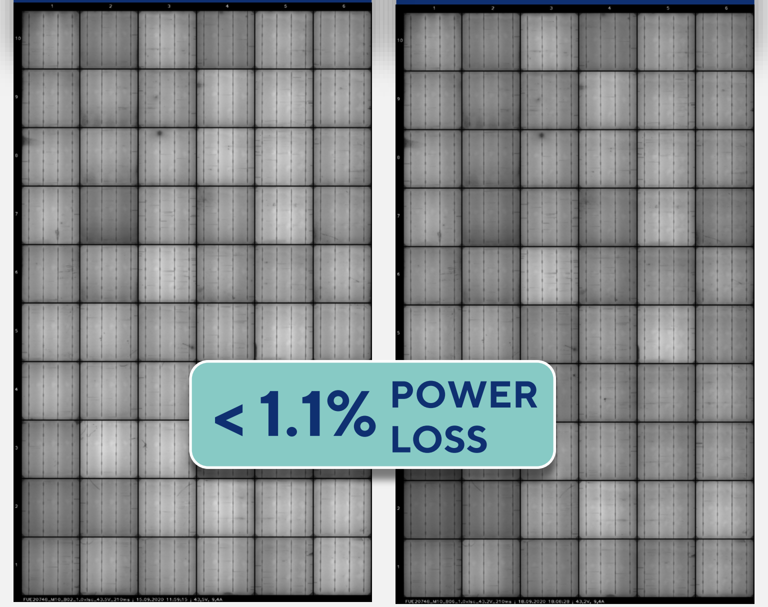
Characterization:
MQT 01 - Visual inspection
MQT03 – Insulation test
MQT15 – Wet leakage current test
MQT 06.01 - Performance at STC
Electroluminescence Image

Dynamic Mechanical Load Test:
1000 cycles
+1000 Pa / -1000Pa

Characterization:
MQT 01 - Visual inspection
MQT03 – Insulation test
MQT15 – Wet leakage current test
MQT 06.01 - Performance at STC
Electroluminescence Image

IEC TS 62782-2:2016

INITIAL | **AFTER TEST**



< 1.1% POWER LOSS

- 10 clamps
- 1000 cycles +1000 Pa / -1000 Pa
- Insulation test passed initially and after ML

③ INDUSTRY TREND: LARGER & HJT CELLS

Trend: larger and new cell types lead to higher degradation at module level

LARGER CELLS

CELL SIZE

- **Larger cells**
- Cell cutting
- Thinner cells

LEADS TO

MODULE

- **Larger panel/ glass size**
- Plus 20%, to 2,20 meters in length and 1,2 meters in width
- Extra weight and larger glass surface
- More power per module

FRAME

- **Heavier and larger frames**
- Higher material costs,
- Higher transport costs
- Larger CO2 footprint

\+

NEW CELLS

CELL TYPE

Sensitive cells:

New high efficiency cell technologies (i.e. HJT) require 10–3g/m^2*day of WVTR (Vapour barrier), but general backsheet shows 2g/ m^2*day

=

EFFECTS

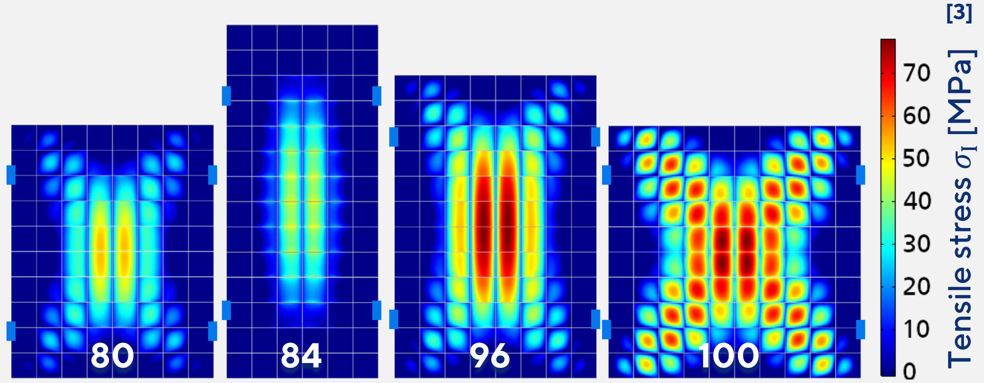
VULNERABILITIES:

- TEMPERATURE
- MOISTURE
- MECHANICAL STRESS
- COSTS

③ IMPACT ON LARGER MODULES

The impact of increased module size

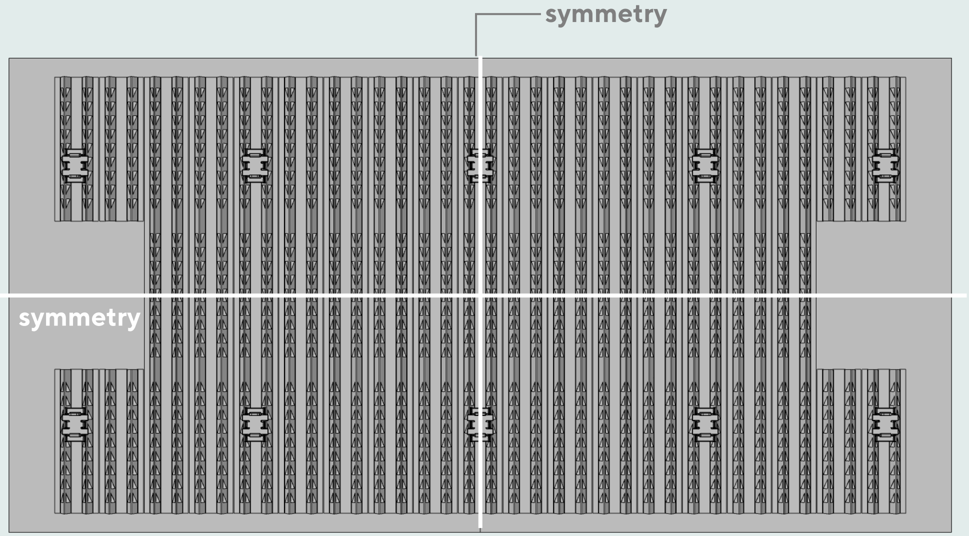
- More cells = higher deflection = higher stress
- Mounting on the long side is disadvantageous for bad aspect ratios



Frames must be stronger to handle the same load

How about COOLBACK®?

- 144 half-cells
- Comparison to conventional framed module of same dimension
- Optimized symmetric clamp setup (10 clamps)

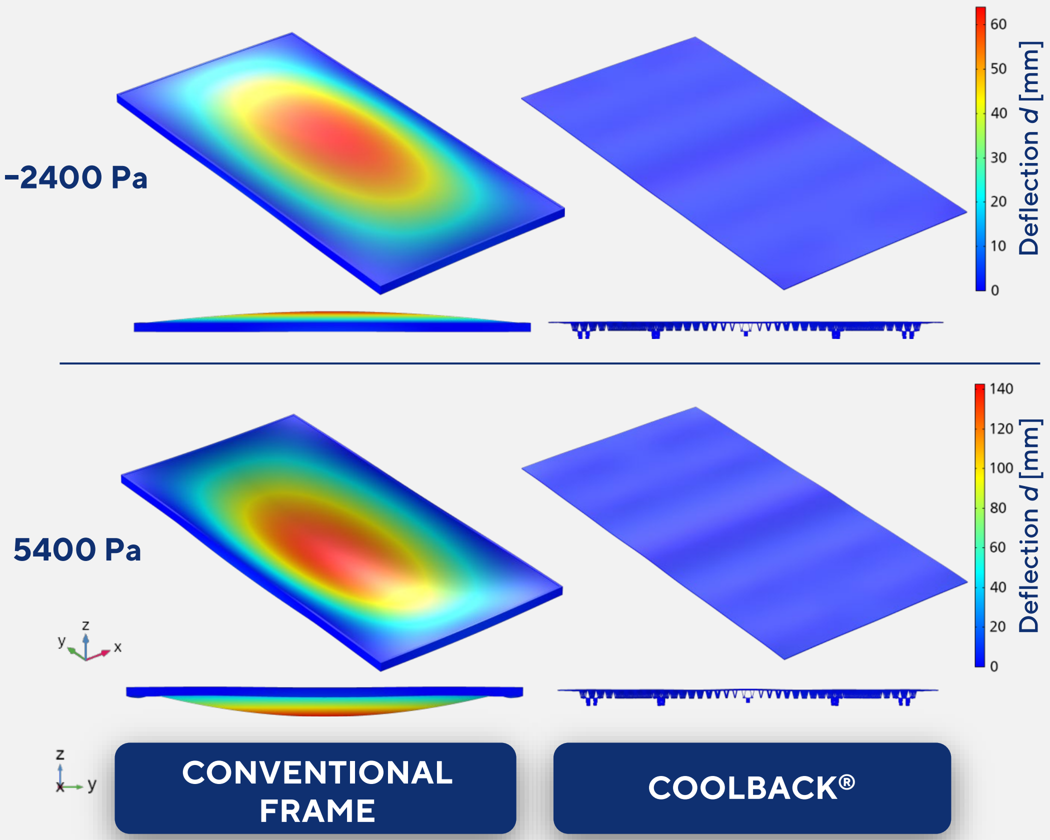


www.ise.fraunhofer.de/module-fem

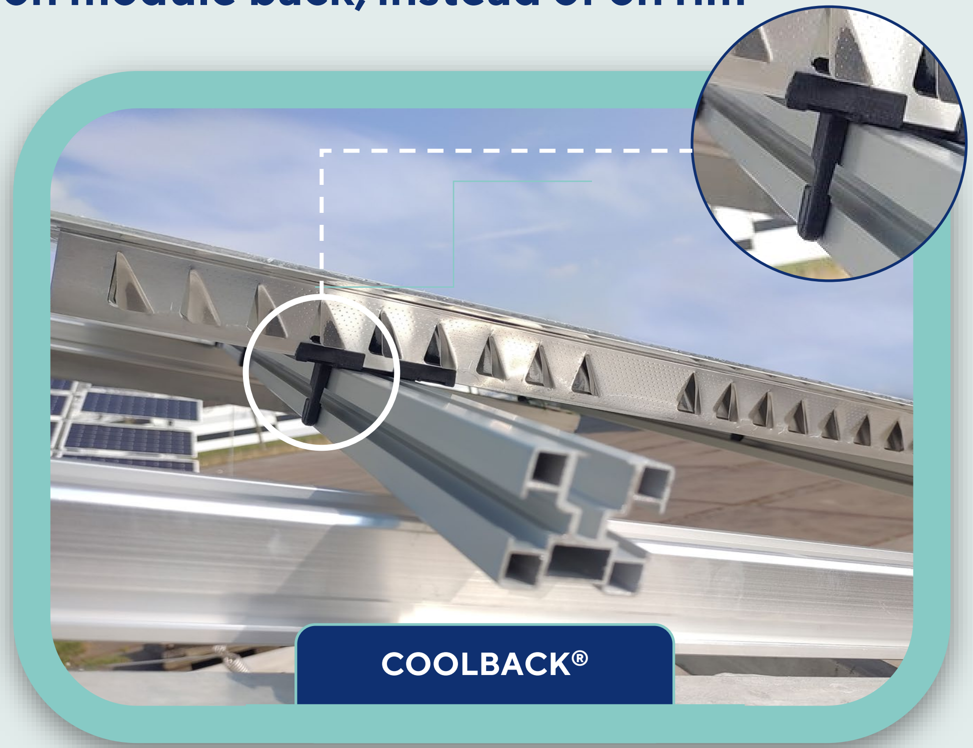
[3] A. J. Beinert *et. al.*, The Effect of Cell and Module Dimensions on Thermomechanical Stress in PV Modules, IEEE J. Photovoltaics, vol. 10, no. 1, 2020, pp. 70-77

③ COMPARISON ON THE 144 HALF-CELL

Almost NO deflection for COOLBACK®



Optimal support and substantially less stress is achieved by positioning clamps on module back, instead of on rim

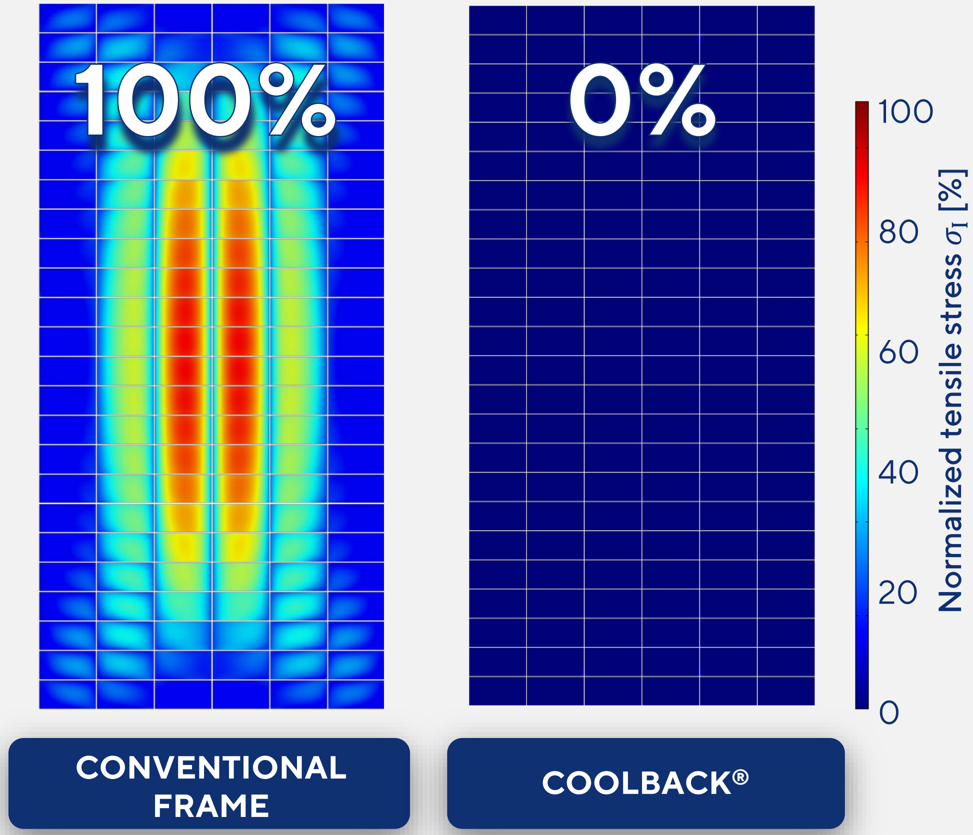


③ RESULTS OF SIMULATIONS AND IEC TESTS

Conclusion:

- Successful digital prototyping by FEM simulations by Fraunhofer ISE
- PV modules with COOLBACK® passed mechanical-load test in accordance with IEC 61215-2:2016 at TestLab PV modules
- Test at maximum load :
  - 16 mm deflection @ 7650 Pa push load
  - 13 mm deflection @ -5500 Pa pull load
- COOLBACK® provides additional rigidity to the rear side of PV modules, reducing deflection and stress
- COOLBACK® modules are more robust against mechanical load

Cell fracture probability at 5400 Pa push load:



4 How can we quantify the effects of using COOLBACK®?

4 ENERGY & FINANCIAL GAIN CALCULATION

PROJECT PARAMETERS FOR SIMULATION

200 MWp SYSTEM

- Module reference (400Wp)

- compared with -

- Module reference (400Wp) + COOLBACK®

LOCATION

- Sevilla, Spain
- Irradiation: 1875 kWh/m²

FINANCIAL

POWER PURCHASE AGREEMENT (PPA):

- 25 years, no residual value
- Income AT € 0,03 /kWh

NO additional costs for COOLBACK®

FINANCING

- Market conform finance

PVSYST PHOTOVOLTAIC SOFTWARE

PVsyst:
state-of-the-art analytical tool to calculate energy yield, LCOE and ROI

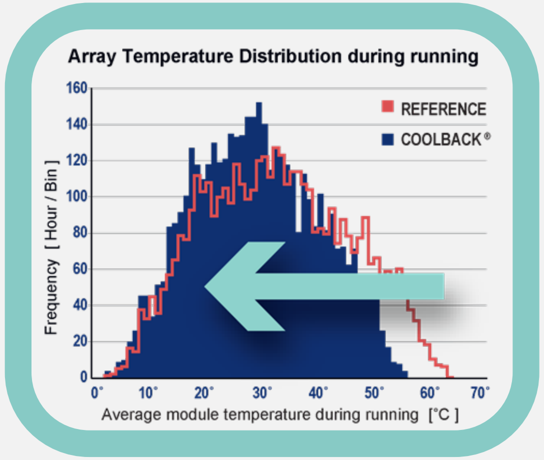
INPUT DATA CHANGE BY USING COOLBACK®

COOLER	STRONGER
Constant loss factor Uc	Module average degradation
29 => 42,5 W/m²k	**0,40 => 0,34%/year**

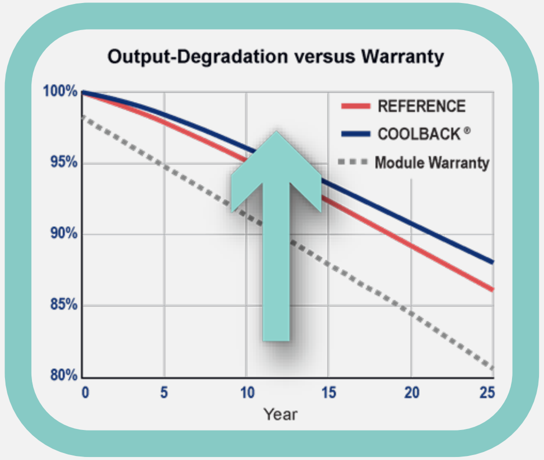
④ SUBSTANTIALLY BETTER PERFORMANCE

LOWER TEMPERATURE + LONGER LIFETIME = HIGHER PERFORMANCE

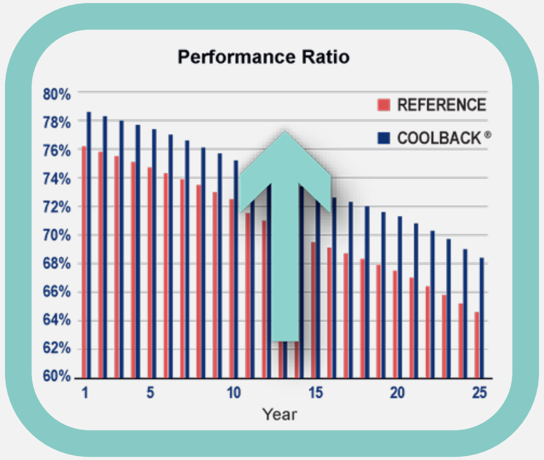
LOWER TEMPERATURE



LONGER LIFETIME



HIGHER PERFORMANCE



YEAR 1		YEAR 25	PROJECT	PROJECT	PROJECT
+ ↑ 3.2% ENERGY	>	+ ↑ 10.6% ENERGY	+ ↑ 8.0% NPV	+ ↑ 14.1% POINT ROI	+5 YEARS

1 Determining factors of degradation, output and lifetime

2 How COOLBACK® new module technology reduces degradation

3 Mechanical stress, new cells and larger modules

4 The quantified effects of using COOLBACK®

4 PHYSICS & FINANCE - COOLBACK® EFFECTS

KEEP COOL AND DISTRIBUTE STRESS

What we've learned:

1 Determining factors of degradation, output and lifetime

- In order of magnitude: temperature, humidity and mechanical forces cause PV module degradation and decreases output and lifetime
- PV industry is not very specific on degradation

2 How COOLBACK® new module technology reduces degradation

- Achievement of lower temperature, better moisture barrier for backsheet and the advantage of a frameless design for less soiling
- Mechanical forces better distributed

3 Mechanical stress, new cells and larger modules

- New cells request more expensive materials, but cracks and humidity problems increase
- COOLBACK® outperforms all issues with ease

4 The quantified effects of using COOLBACK®

- At same costs, a substantially higher output in energy and a longer lifetime is available
- Higher project ROI without higher investment

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Keep cool and distribute stress: A recipe for improved performance

Q&A

26 April 2021

11:00 am – 12:00 pm | CEST, Berlin
1:00 pm – 2:00 pm | GST, Dubai
5:00 pm – 6:00 pm | CST, Beijing/ Singapore

Mark Hutchins
Editor
pv magazine

Simon Meijer
Founder & CEO
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