Flexible and printed photovoltaics for integration applications

rapid.tech 3D

Michael Wagner

14.05.2025

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PV yesterday

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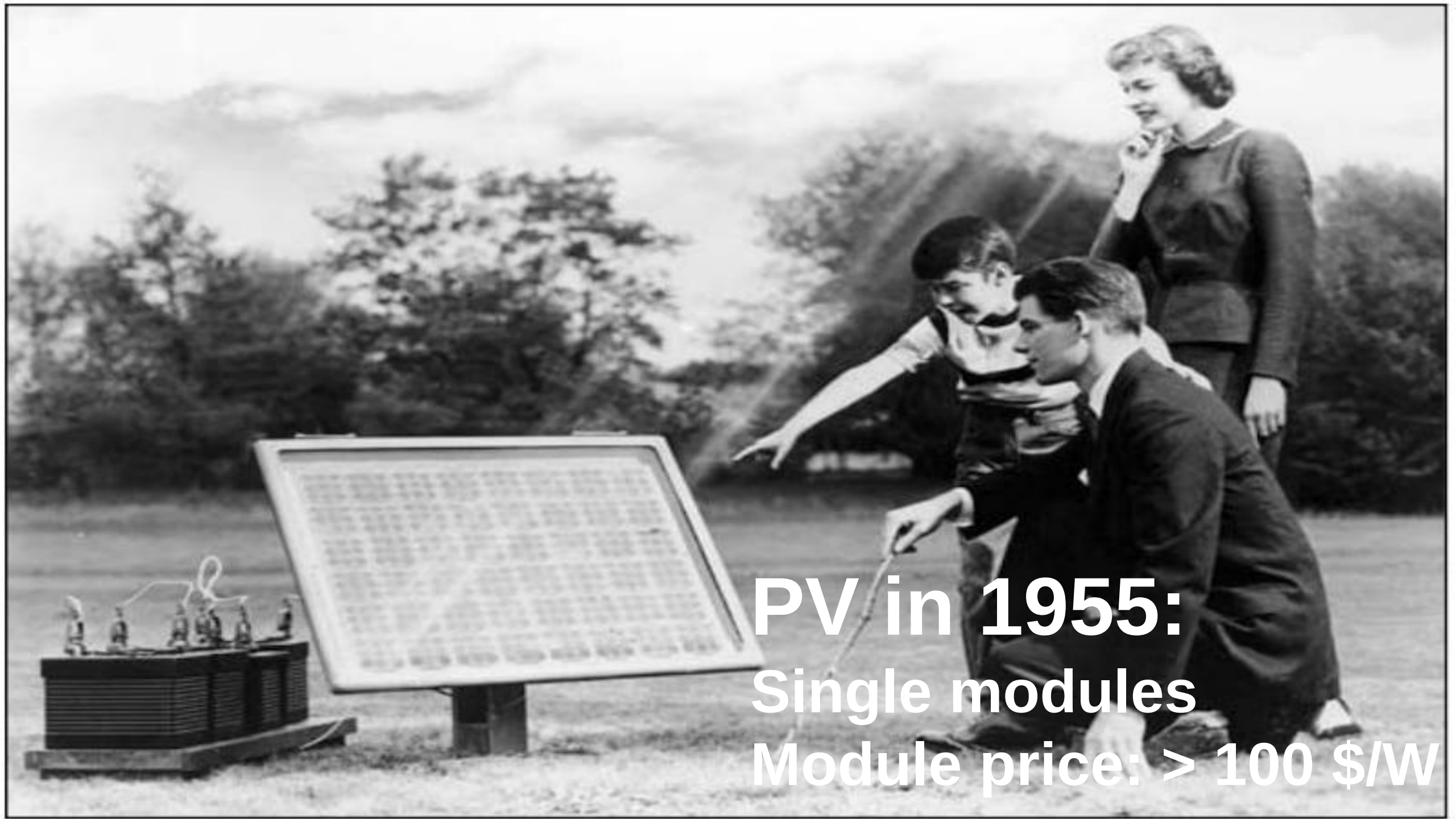
PV in 1955:
Single modules
Module price: > 100 $/W

PV in 1980:

5 MW installed – 100.000 modules
Single sites with 250 modules
Module price: 30 $/W
Electricity price: .....

Staiß, F. (1996). Entwicklung des Photovoltaik-Marktes in den 80er und 90er Jahren. In: Photovoltaik. Vieweg+Teubner Verlag. https://doi.org/10.1007/978-3-322-83122-4_1

PV in 2004:

3GW installed – 10.000.000 modules

Single sites with 33.500 modules

Module price: 3.7 $/W

Electricity price: 40 ct/kWh

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PV today

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PV today:

2.2 TW installed – 6.000.000.000 modules

Single sites with up to 10.000.000 modules

Module price: 0.13 $/W

Electricity price: 3.5 ct/kWh

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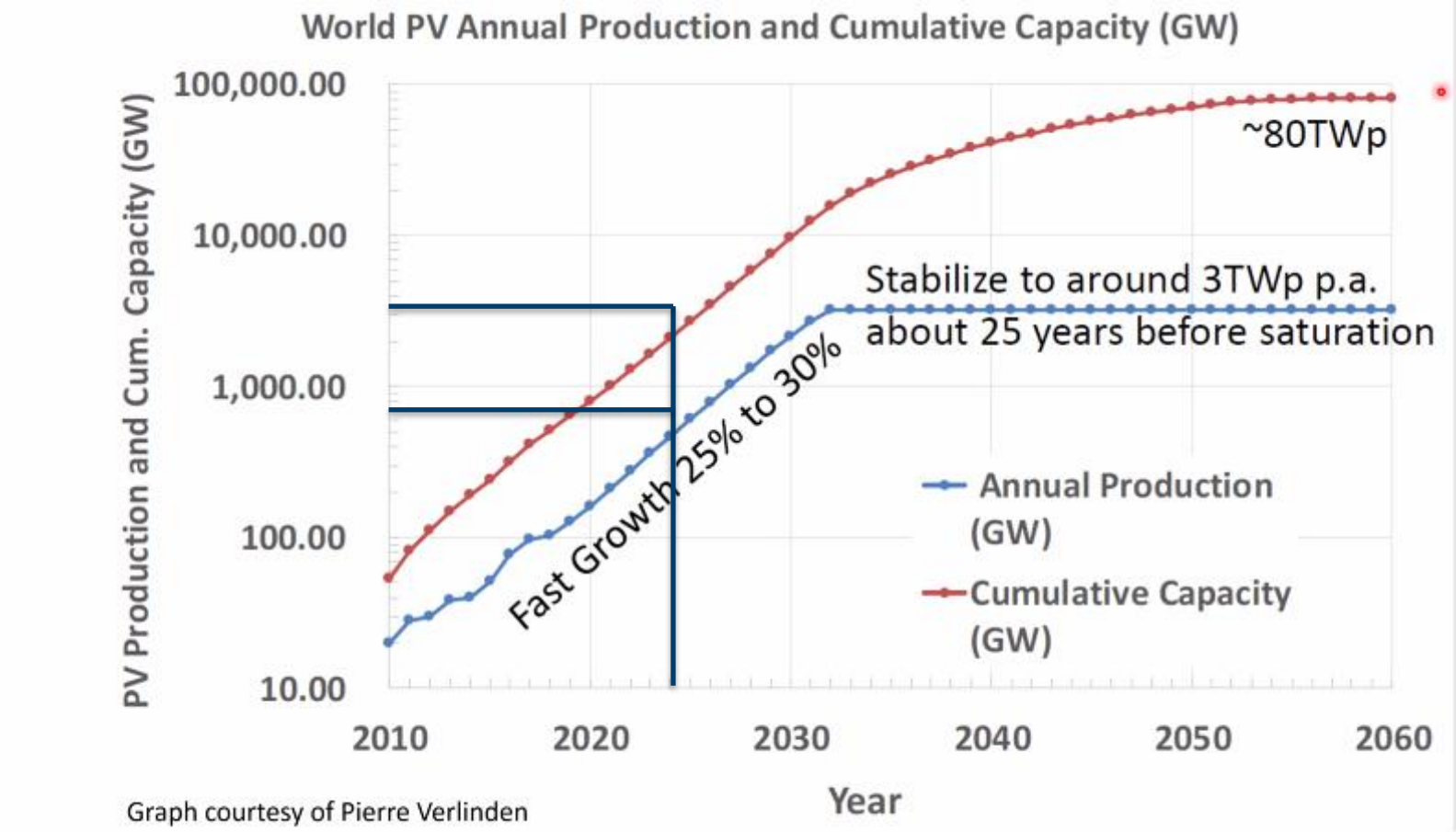
PV tomorrow – growth

PV will continue to grow! Why? Because it produces electrical power cheaper than any other technology



Industry has to grow by a factor of 30 – 50!

PV has to cover an area of > 500.000 km2

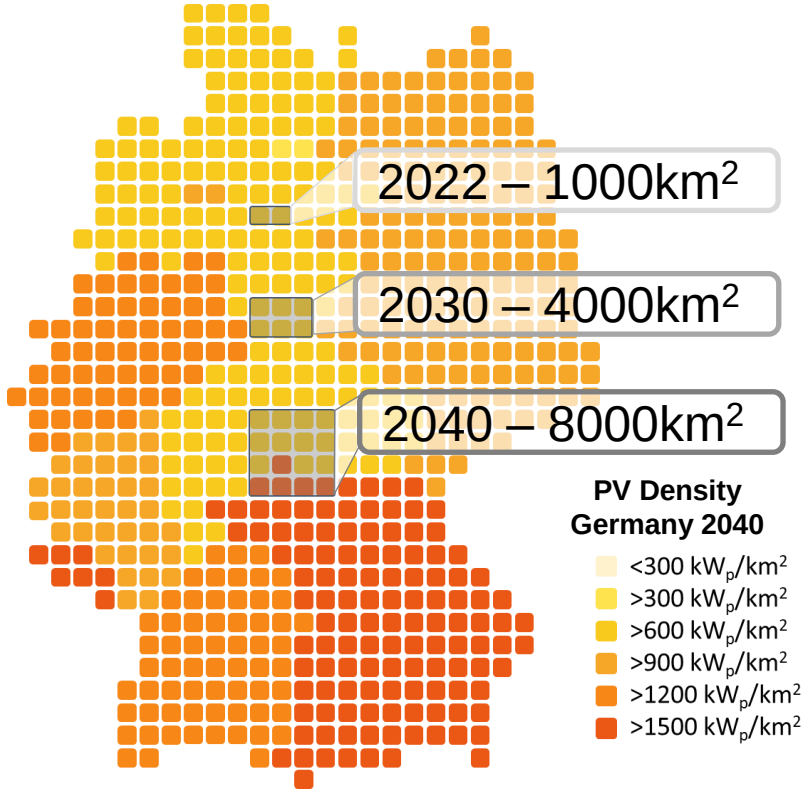
P. Verlinden, *Journal of Renewable and Sustainable Energy* 12, 053505 (2020), https://doi.org/10.1063/5.0020380

PV tomorrow – space management

Better use of available area for PV to meet EU Green Deal and German Osterpaket 2050 Goals!

- 100 GW PV in 2024
- 215 GW PV in 2030
- 400 GW PV in 2040

- PV has lowest area footprint among all renewables.
- PV alone requires about 2 % space in Germany.
- Integration into agriculture, buildings and mobility infrastructure must be a success
  → **Mulit-Beneficial PV**



Deutscher Bundestag Drucksache 20/1630 20. Wahlperiode 02.05.2022

PV tomorrow – multi-benefit applications

Huge technical potential, but current technologies can not exploit the economic and pratical potential

	Agriculture PV	Building PV	Mobility Infrastructure PV
			
Tech. Potential	~ 3 TW	~ 1TW	~ 0.3 TW
Usage 2022	< 0.001 %	< 0.1 % of facades	< 0.1 %

H. Wirth, *Report, aktuelle Fakten zur Photovoltaik in Deutschland, 1.03.2023*

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What´s the status of printed PV?

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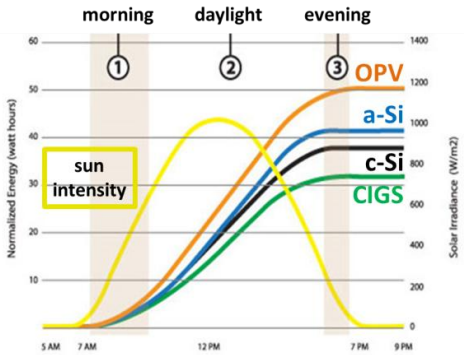
Advantages of printed PV

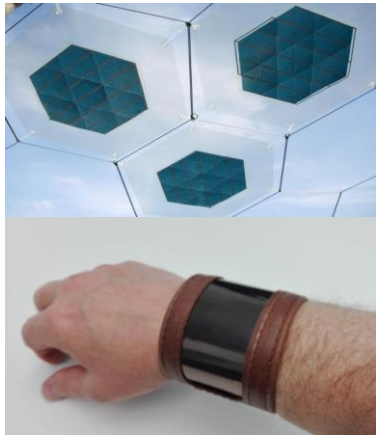
Design:

- Transparency
- Color
- Freeform



Technology:

- Shadow-tolerant
- Good low and diffuse light behavior
- Neutral temperature coefficient



Integration:

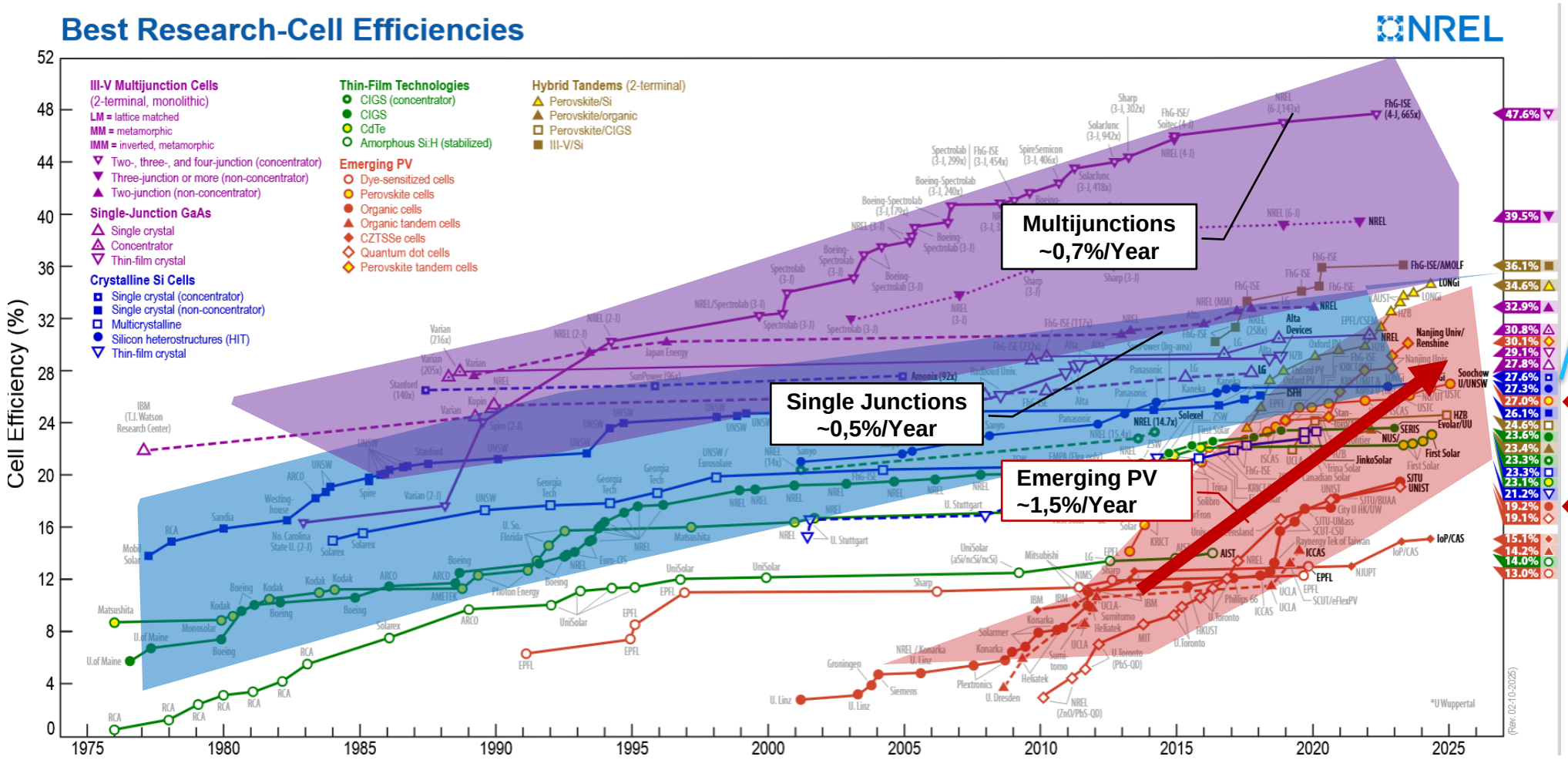
- Thin
- Light
- Flexible

Manufacturing:

- Roll-to-Roll printable
- Other types of printing possible
  - Ink jet, Aerosol jet, spray coating
- High throughput
- Low energy consumption → Lowest CO2 footprint

Emerging-PV are catching up with silicon

Perovskites, Organics, … – it is about the low temperature solution processing



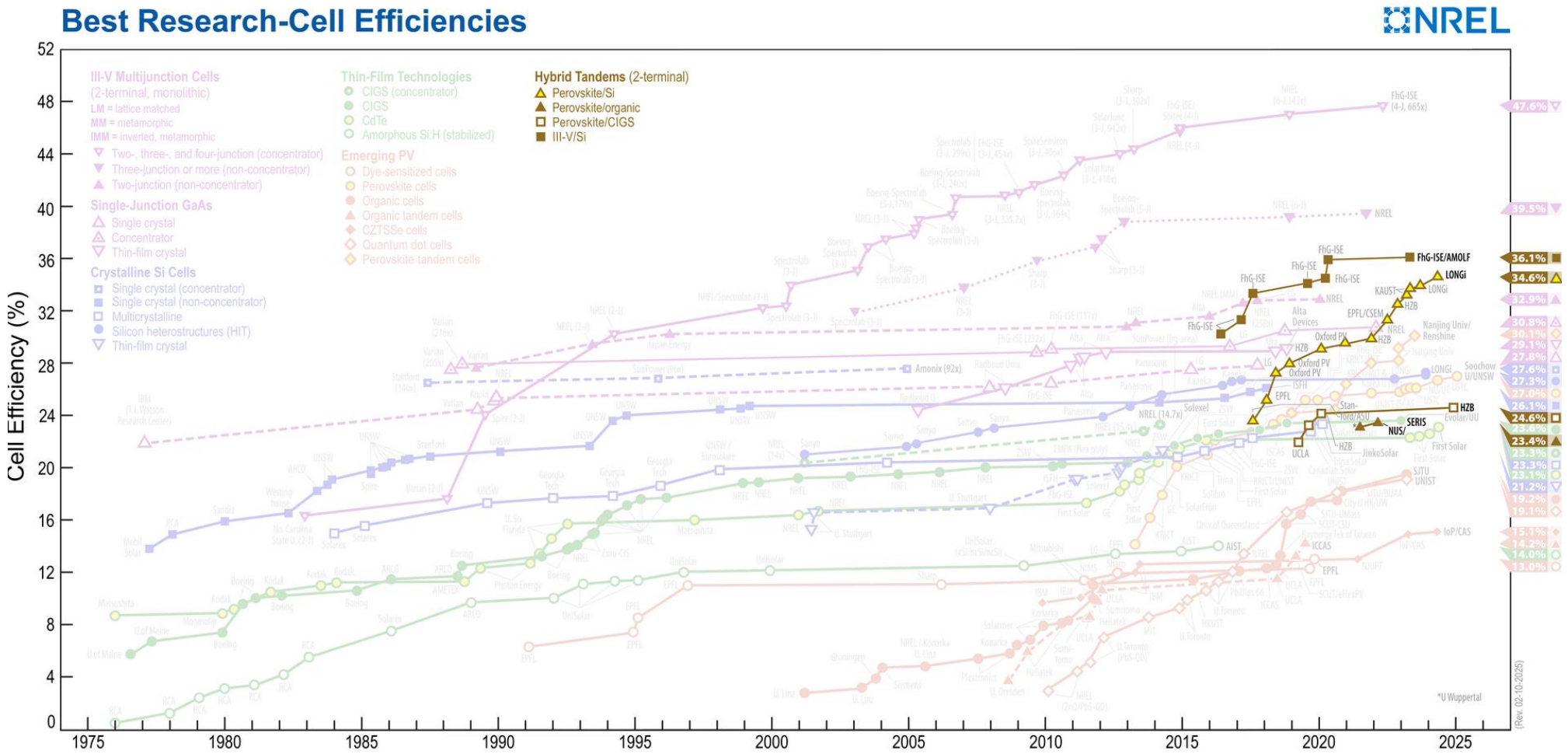
Silicon heterojunction 27.3 %

Solution Processed

- Perovskites (27 %)
- Organic PV (19.2 %)

NREL, efficiency charts, https://www.nrel.gov/pv/cell-efficiency.html,

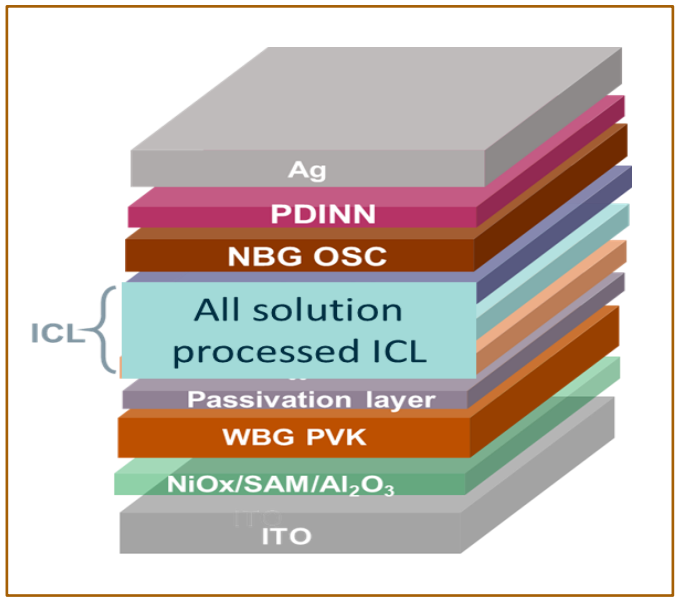
Tandem Solar Cells



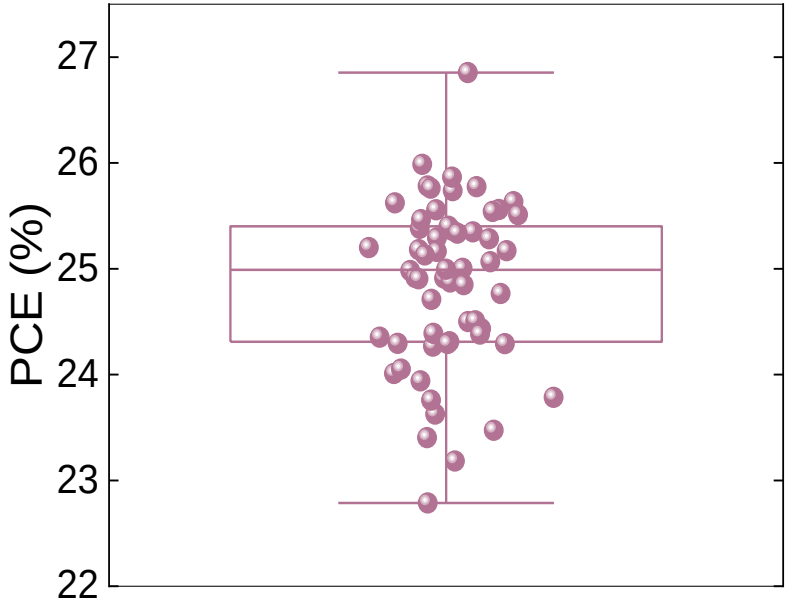
- Perovskite/Si (34.6%)
- Perovskite/OPV (23.4%)

NREL, efficiency charts, *https://www.nrel.gov/pv/cell-efficiency.html*,

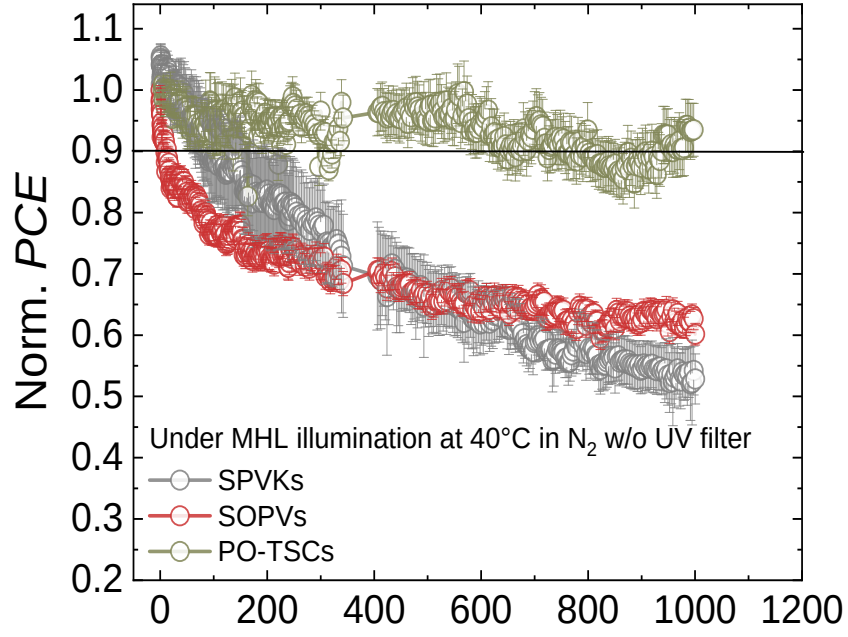
Tandem Solar Cells



ICL with no Ag, solution processed



60 cells, processed in multiple campaigns



Stable for > 1000 hrs

A „+25 % “ organic – perovskite tandem cell. Suppressing interface degradation by a metal free recombination layer

Chao Liu & Kaicheng Zahng, … & CJB, 2024; in submission

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Upscaling of printed PV

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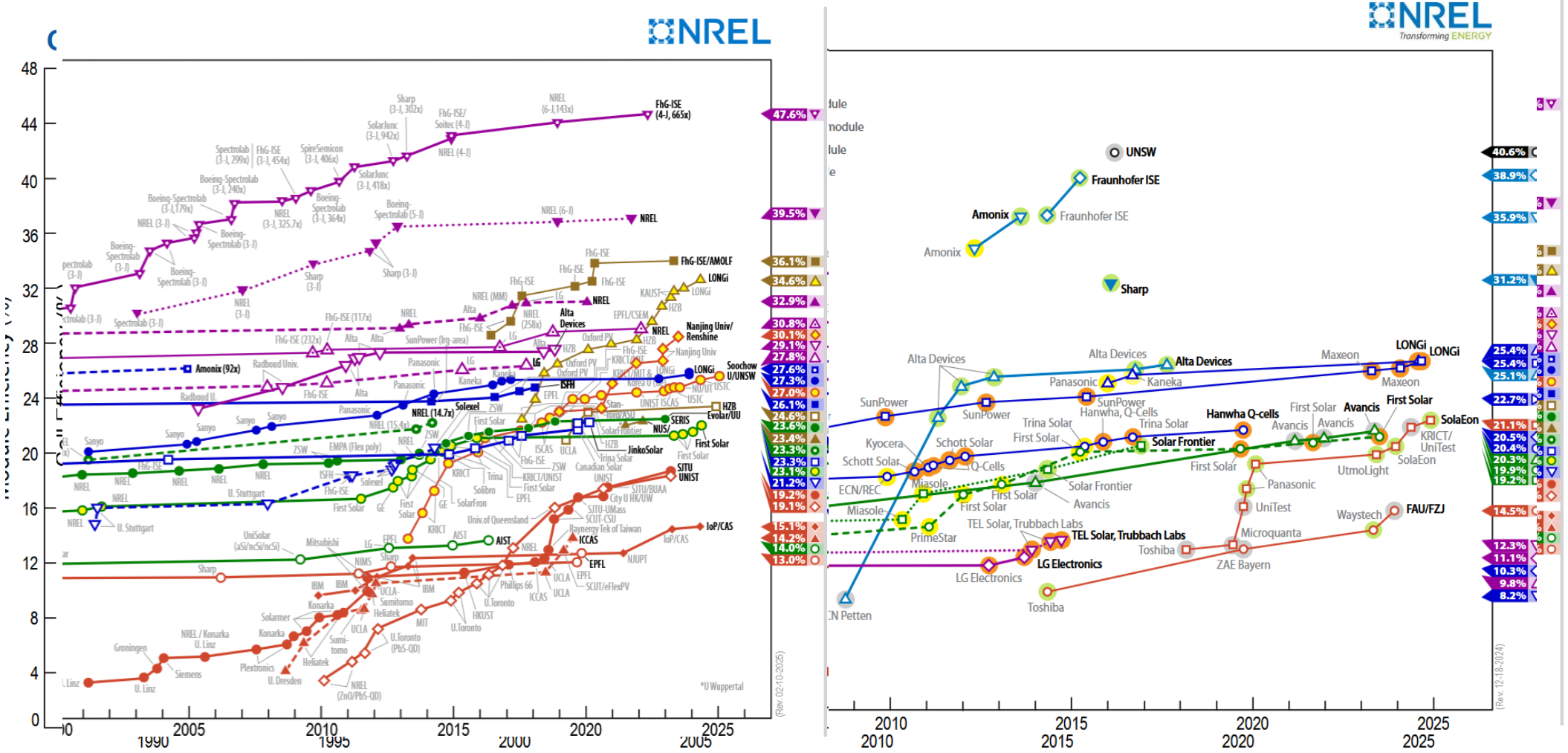
Upscaling of printed PV



Upscaling of printed PV

PV-Technology	Record Efficiency (Labcells)	Record Efficiency (Module)	Discrepancy
1. Generation (Silicon):			
- Polycrystalline Si	23.3%	20.4%	- 14%
- Monocrystalline Si	26.1%	25.4%	- 3%
2. Generation (Thin film):			
- Amorphous Silicon (a-Si)	14.0%	12.3%	
- CdTe-Solarcells	23.1%	19.9%	
- CIGS-Solarcells	23.6%	19.2%	
- GaAs-Solarcells	29.1%	25.1%	
3. Generation (printable):			
- Dye sensitized (DSSC)	13.0%	-	
- Organic Photovoltaic (OPV)	19.2%	14.5% (HIERN/FAU)	- 32%
- Perovskite Photovoltaic	27.0%	21.1%	- 28%

What is the prerequisite for upscaling

Solvents

Halogenated?
Reformulation possible?
Exchange of the materials possible?

Process

Fully printable?
Processable in air?
What atmosphere can be tolerated?

Temperature

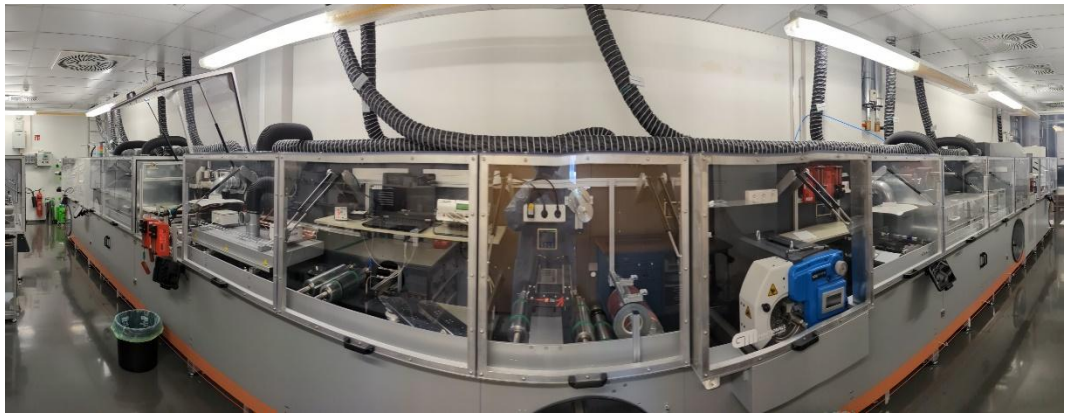
Temperature < 140°C?
Annealing time R2R compatible?

Stability

Pass accelerated stability tests?
Pass outdoor tests?

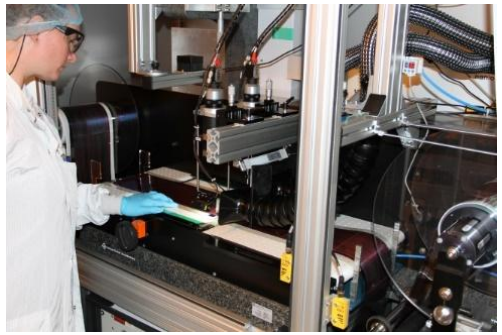
Reproducibility

Upscaling equipment



Roll to Roll printing, 3 Stations, 13 m Ovens, Screen printer
Inline on-the-fly laser

Roll to Roll printing for Perovskite



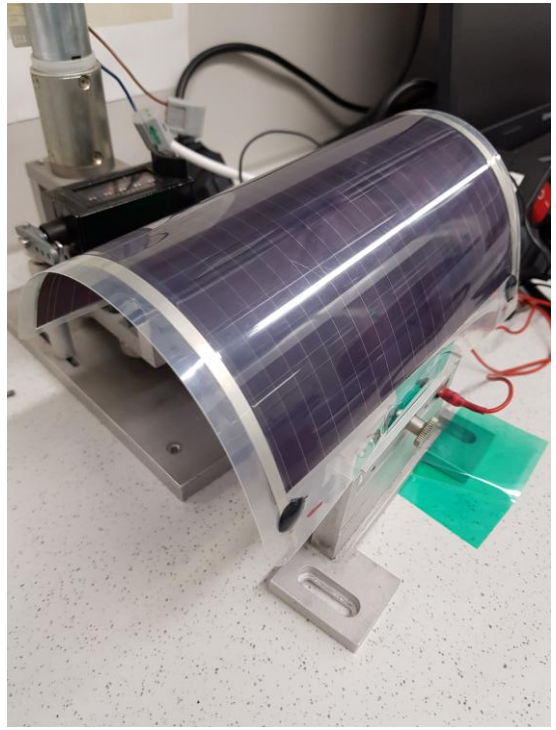
Standalone R2R Laser

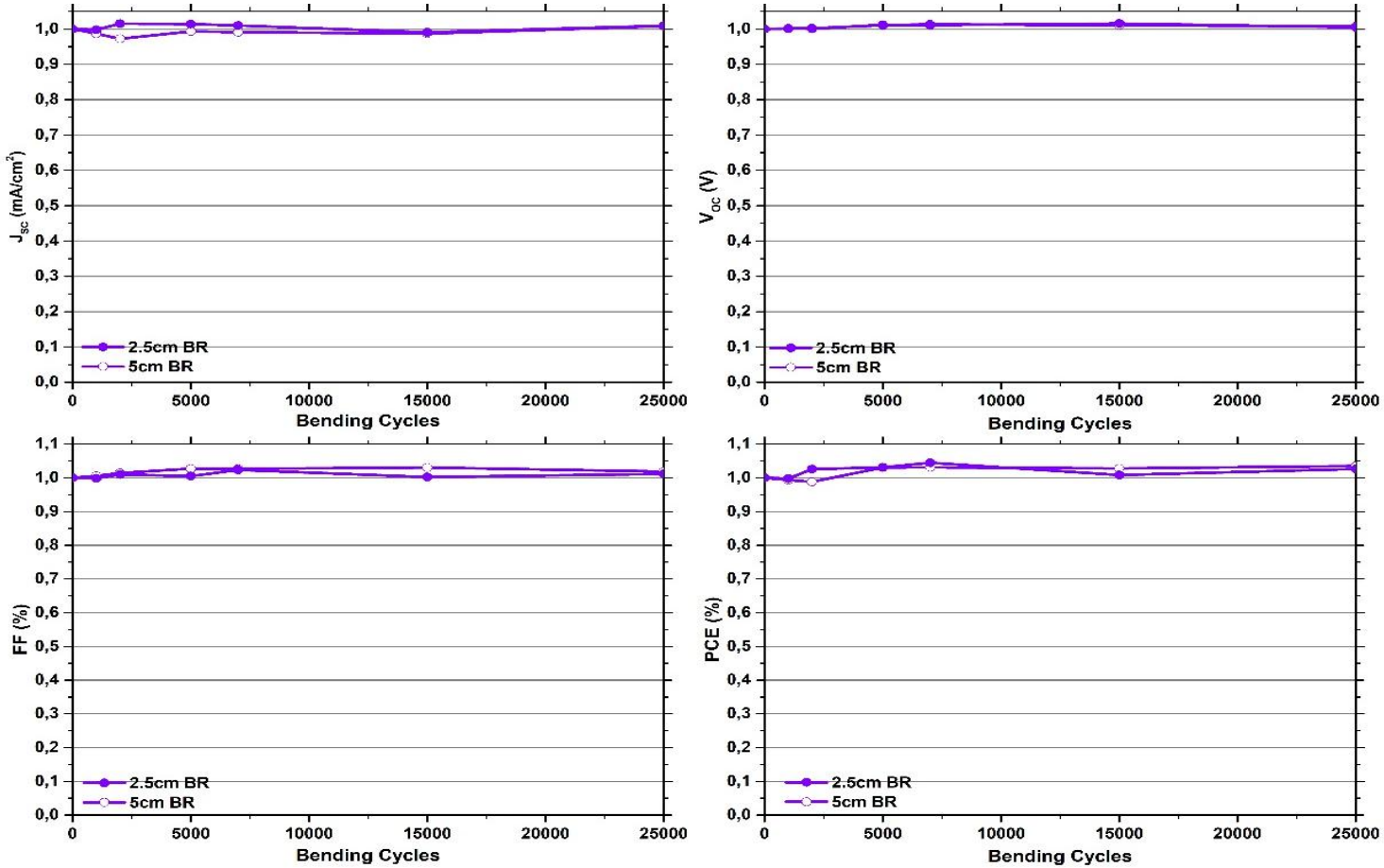
R2S Lamination

R2R Bus Bar lamination

Stability tests

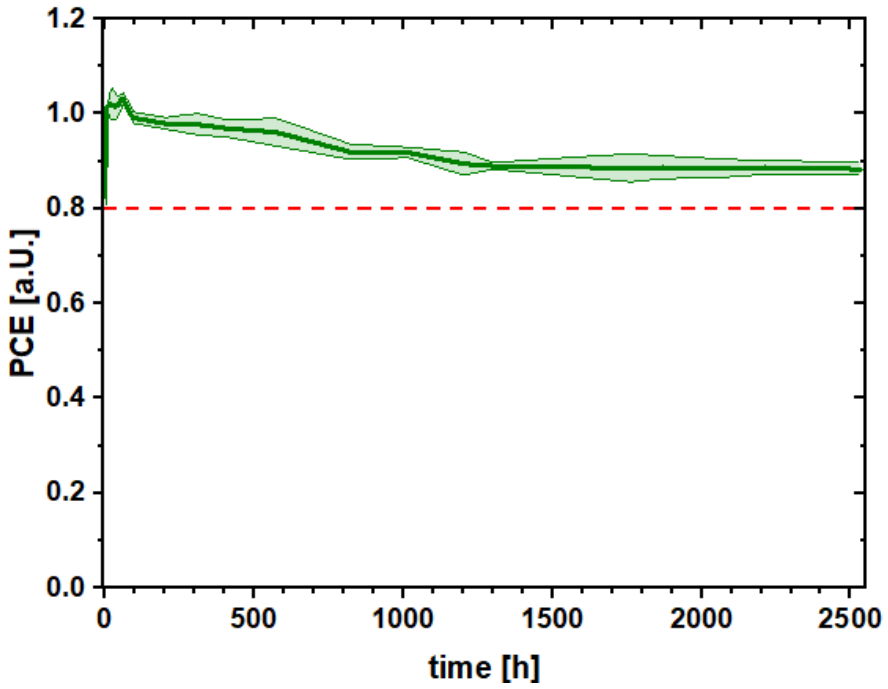
Bending test over a bending radius of 2.5 and 5cm respectively

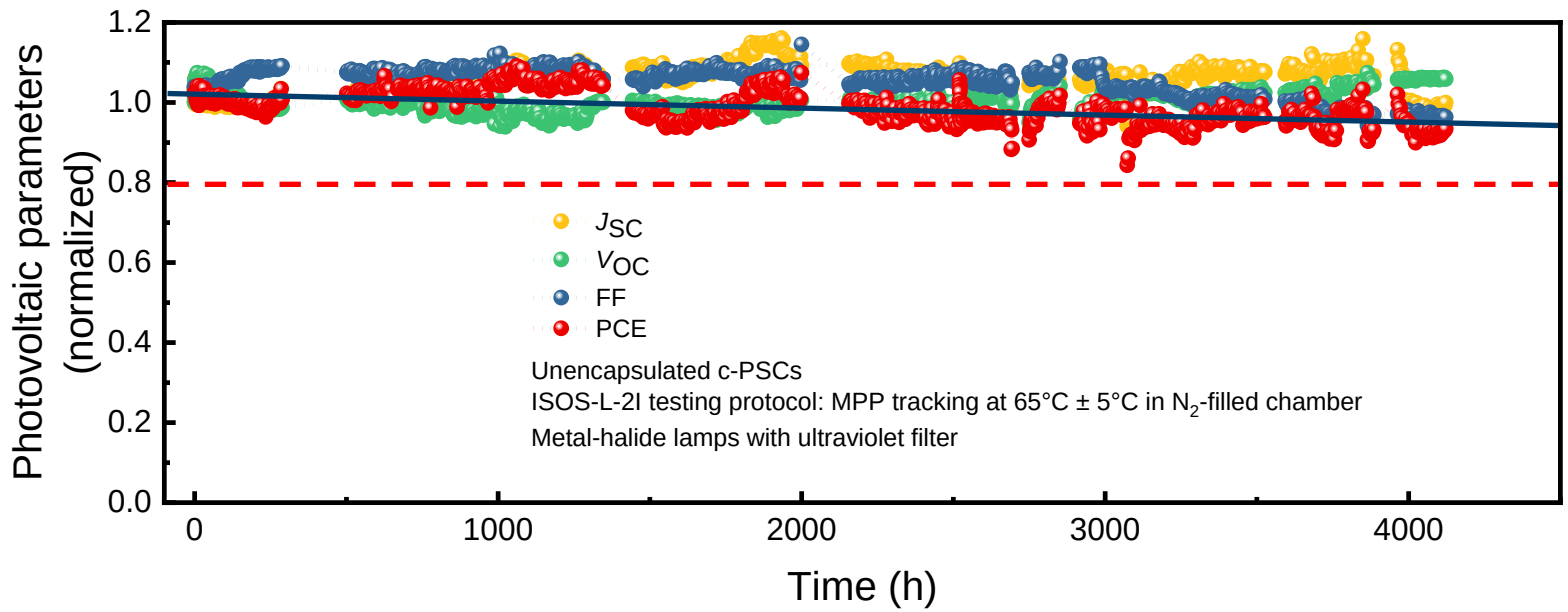




25000 bending cycles without loss

Accelerated lifetime test (sun degradation)





OPV lifetime > 2500 h

According to ISOS-L-2 > 4.5 years

Perovskite lifetime > 4000 h

According to ISOS-L-2 > 7.5 years

Zhang Y., et. Al. Current status of outdoor lifetime testing of organic photovoltaics, advanced science

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What is the market (at the moment)?

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Main selling points

Transparency & Design

- BIPV
- AgriPV / Greenhouse

Flexibility & Light weight

- Mobility
- Low light applications

Tandem Glass/Glass Modules

- Powerplants

Transparency & Design

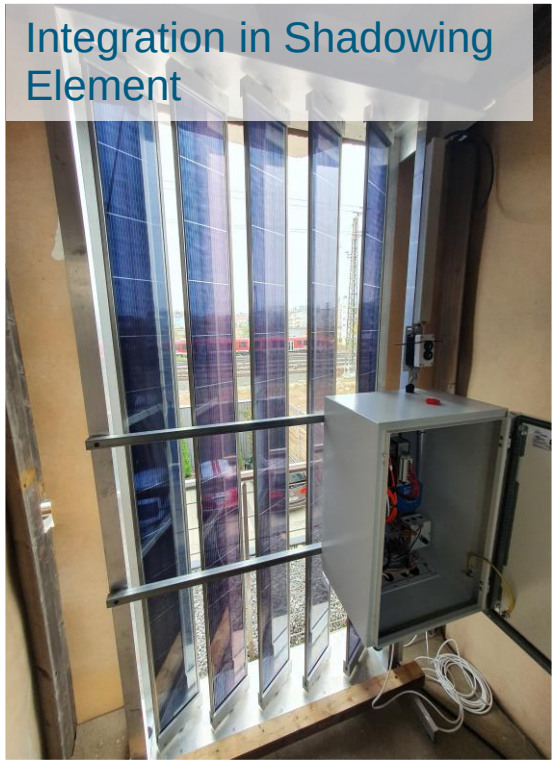
BIPV

Integration in Canopies

25 m² OPV
Development mulitbeneficial
Facade element

Fassade3

Integration in Shadowing Element



Development of controllable shading element

Transparency & Design

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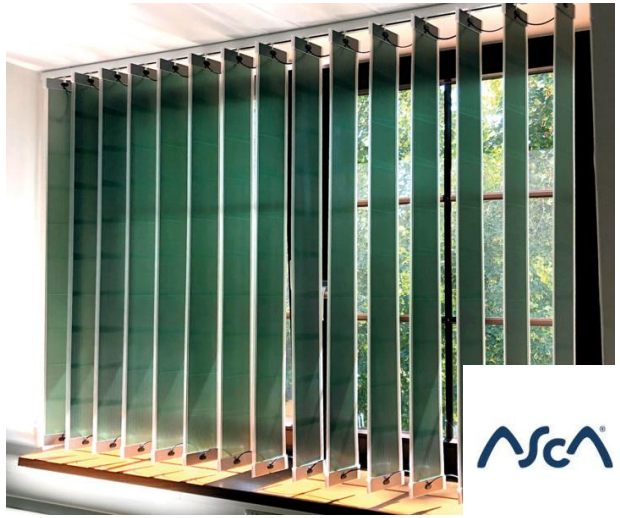
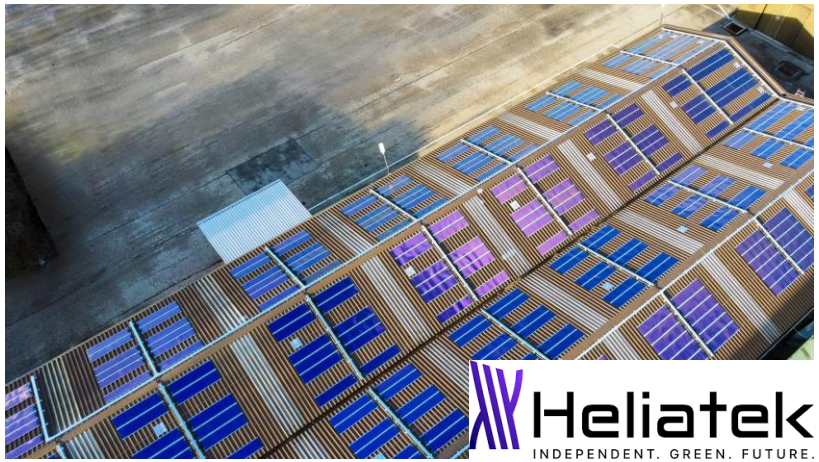
BIPV





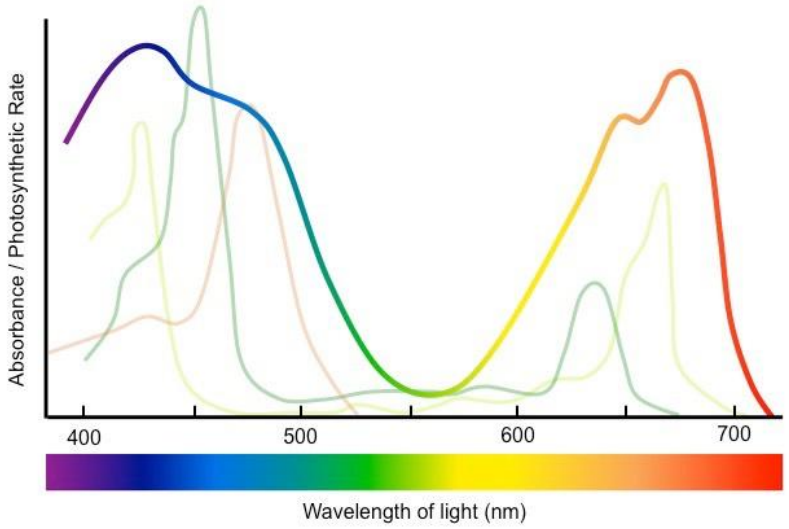
Heliatek
INDEPENDENT. GREEN. FUTURE.

Transparency & Design

AgriPV / Greenhouse integration

Opportunities: Photovoltaics is the solution

- Develop ultra light weight photovoltaics
- Develop truly transparent / colored photovoltaics
- Develop modules suitable to protect plants, provide water and help regulating local climate

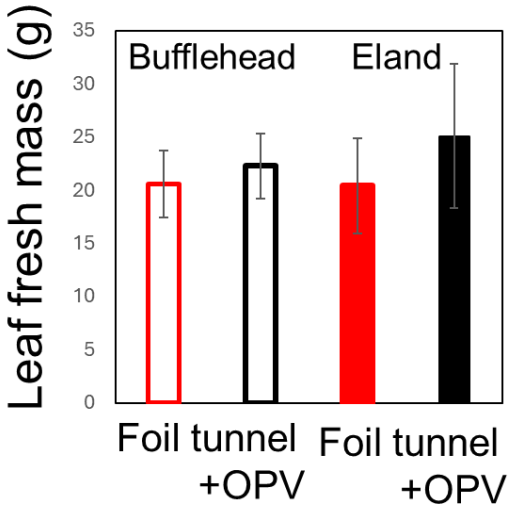


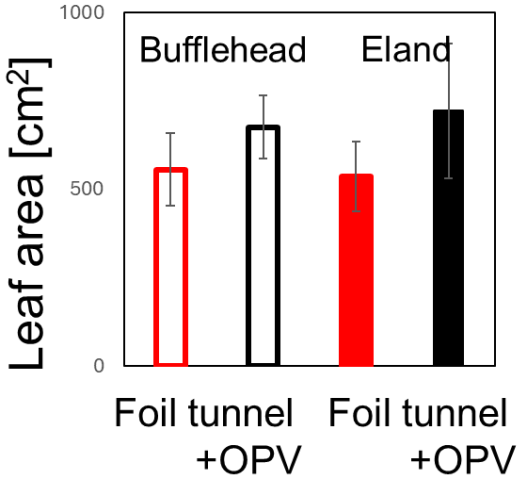
world of technology: http://mytechnologyworld9.blogspot.com/2013/09/the-greenhouses-of-almeria.html

PCE 7.3 %, AVT 47 %

Transparency & Design

AgriPV / Greenhouse integration





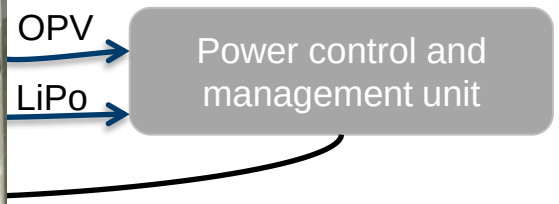
Dr. Matthias Meier, IBG-2

Flexibility & Lightweight

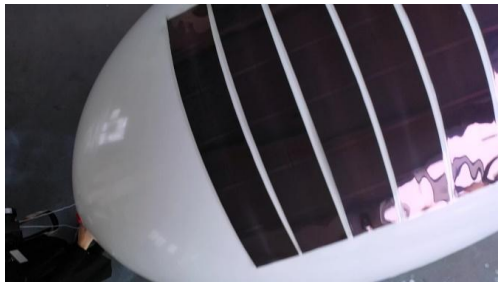
Mobility

Problem: Flight time limited by batteries

Solution (kind of…): OPV + Power Management



OPV modules:
Power: 41 Wp
weight: 500 g

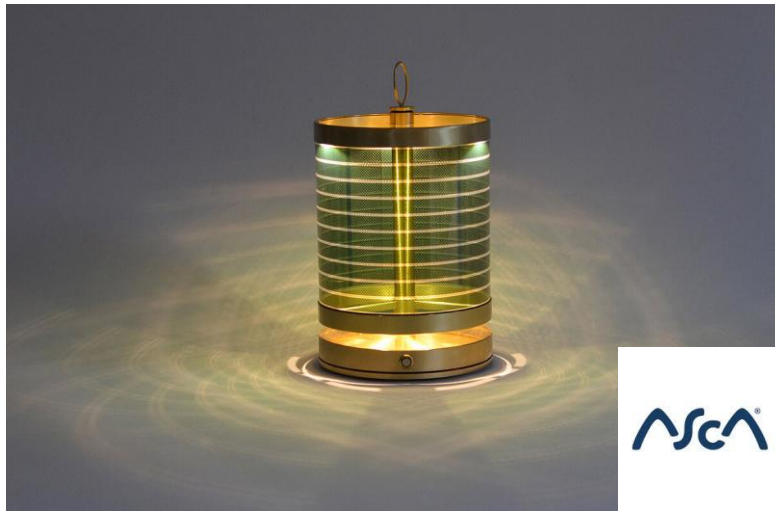


In cooperation with IBG-2 and

WINDREITER

Flexibility & Lightweight

Low light applications



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The Possibilities

Helmholtz Labs | **Solar TAP** | **Applications & Industry**

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KIT Karlsruher Institut für Technologie

Transfer Innovation (from lab to fab)

State-Gate Process

Demonstrate technology (with industry)

Roadmap Process

Define objectives (with end users)

Solar TAP

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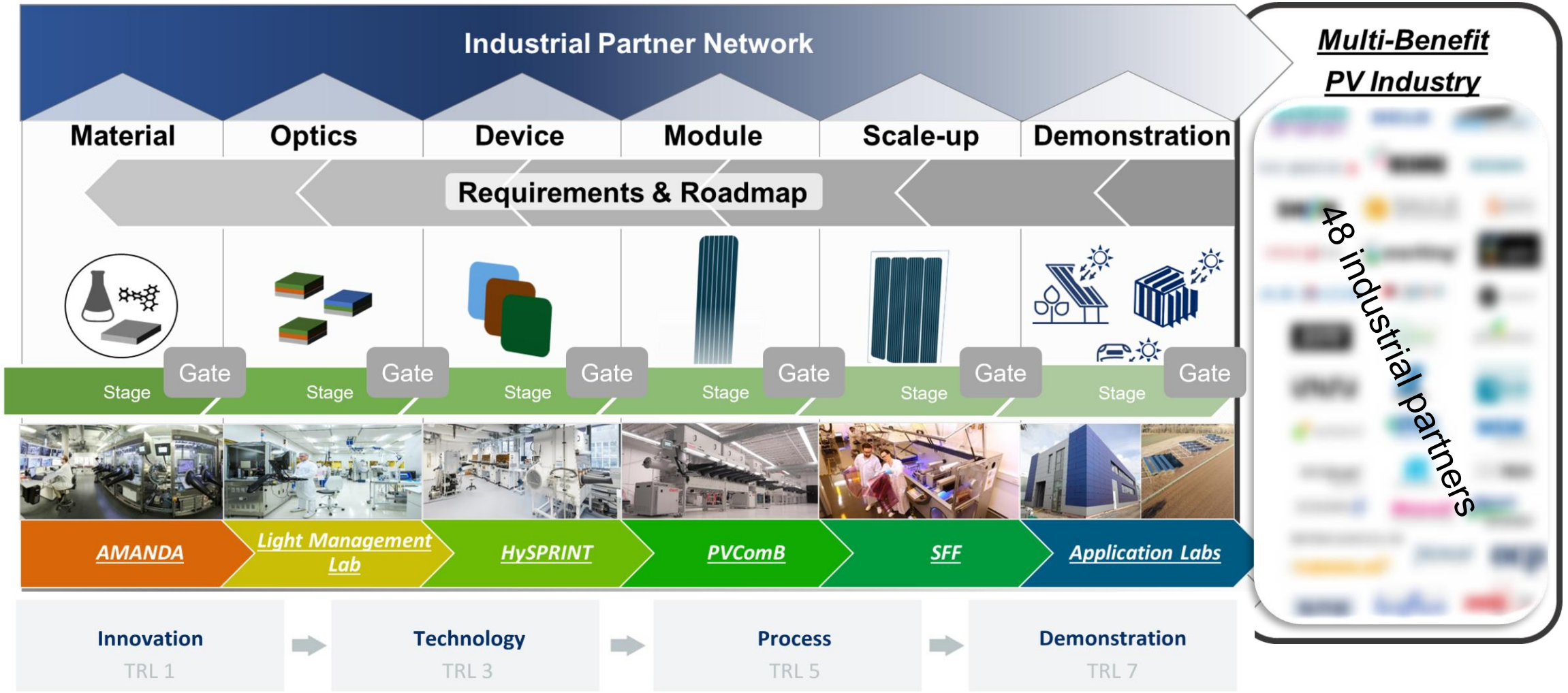
TRANSFERRING TECHNOLOGIES ALONG THE FULL VALUE CHAIN



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Thank you for your attention!

Michael Wagner

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