Perovskite solar cells on flexible substrates: up-scaling and applications

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Introduction

smArt designed full Printed flexible rObust efficient organic haLide perOvskite solar cells

Reliable & fully printable

22% of efficiency

90% of performance after ageing tests

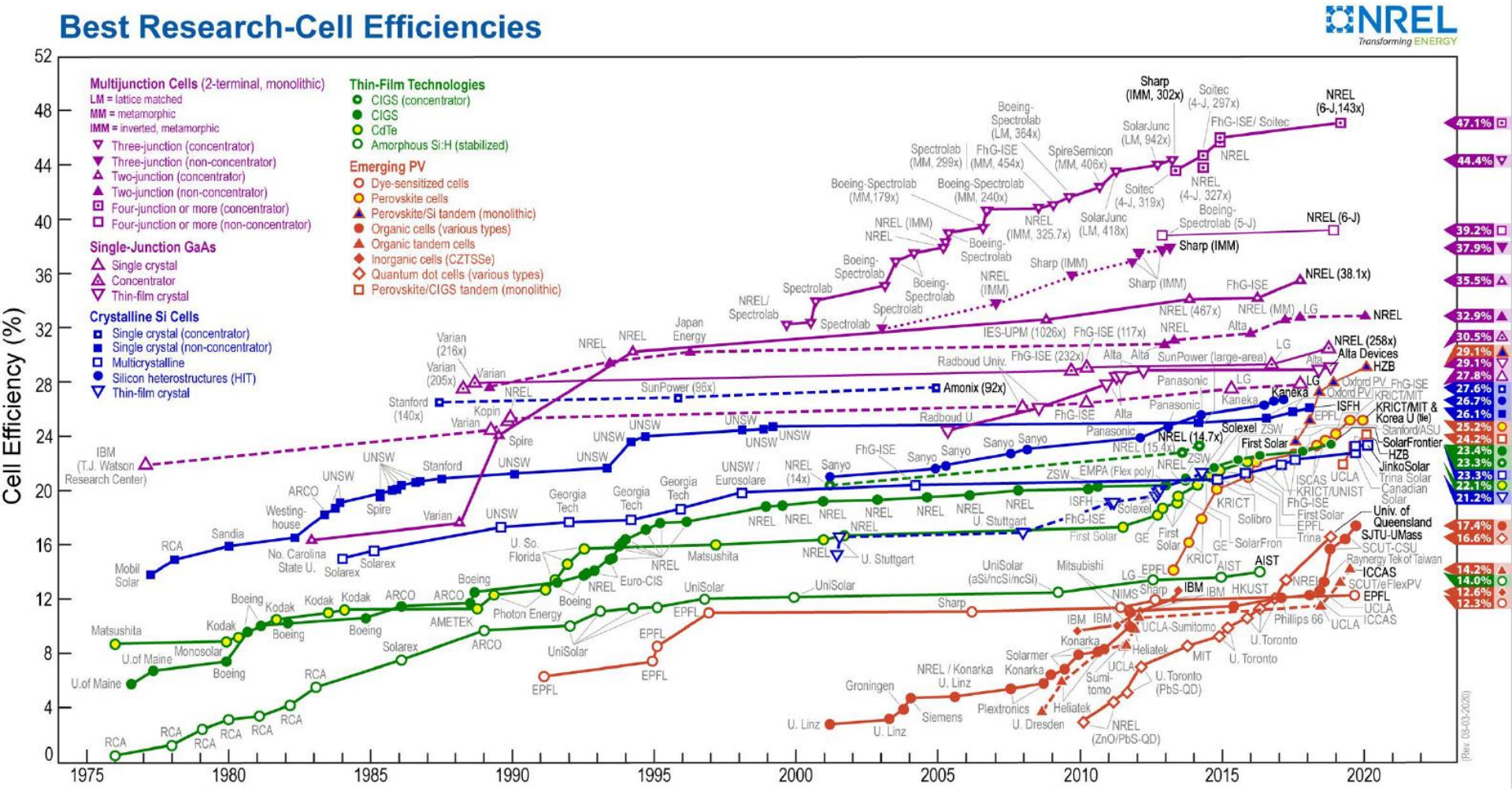
Reduce module cost below 0.40€/Wp

Utilization of innovative green processes.

Integration into buildings and other new markets.

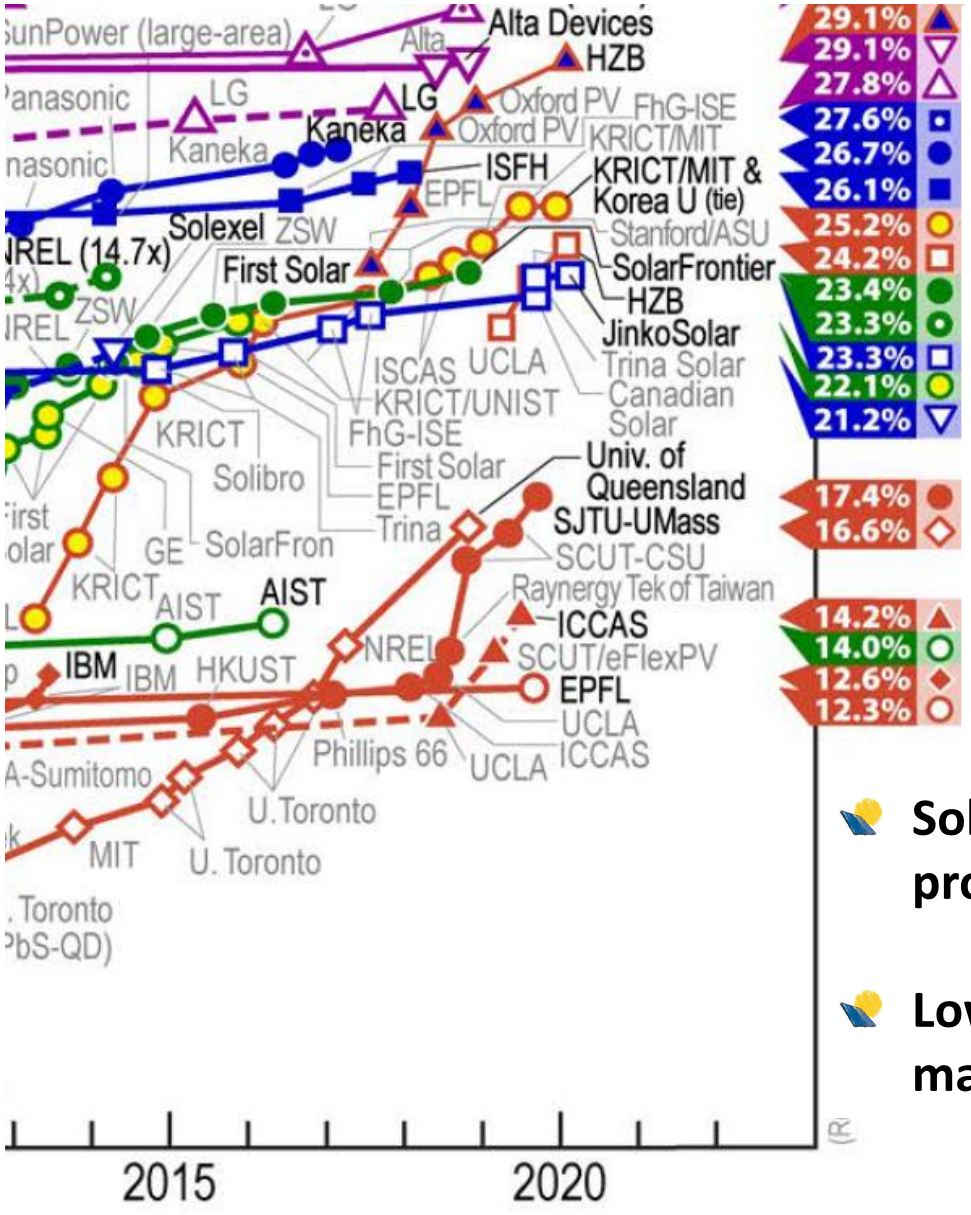
Significant cost reduction for market entry

Why perovskite solar cells (PSC)?



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

Why perovskite solar cells (PSC)?



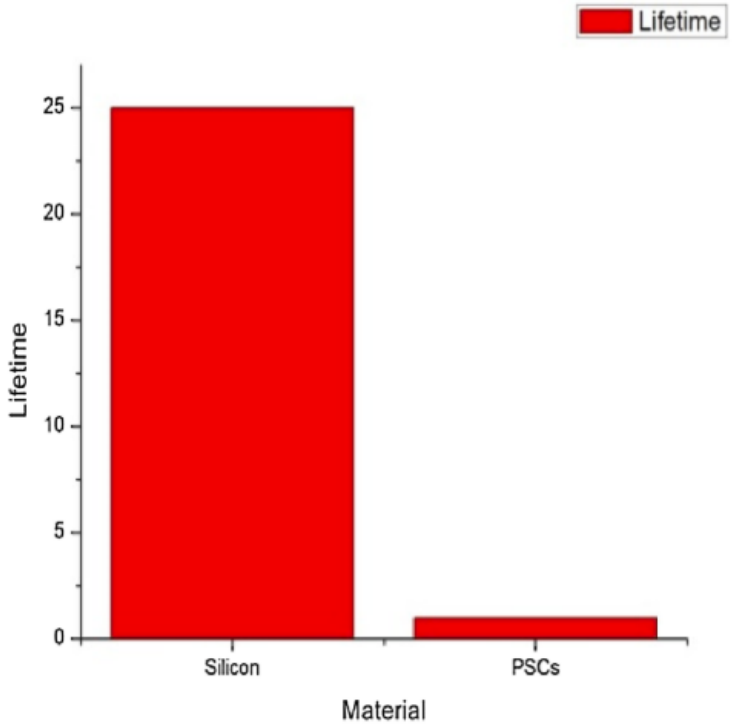
PSC/Si

PSC

- Solution processability
- Low-cost manufacturing

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

Huge challenge for the community: stability



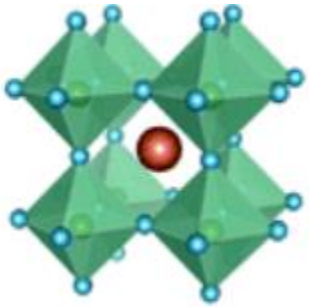
P. Roy, et al. Solar Energy 198 (2020) 665–688

Huge challenge for the community: stability

Moisture
Hydration of perovskite in presence of water

Temperature
Decomposition of perovskite due to structural phase transition

Light (UV)
Light-activated metastable traps create inhomogeneous electric field, UV light can trigger surface defects in metal oxides

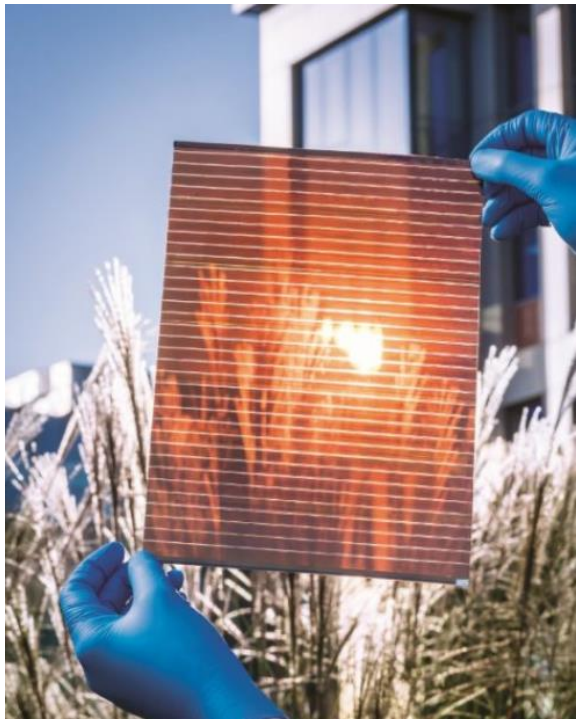


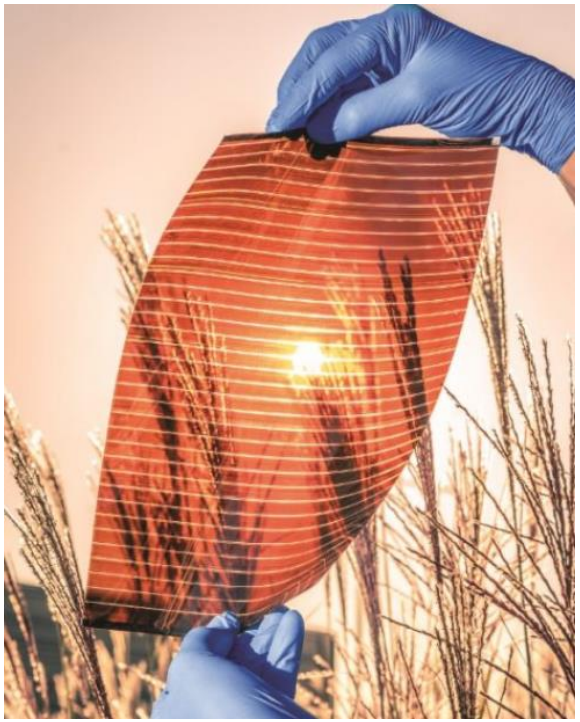
Oxygen
Perovskite reacts with O_2 and decomposes if electron transfer at the interface is not efficient

Intrinsic
Interfacial degradation, corrosion with back contact, perovskite composition…

Y Zhou, et al. *Energy & Environmental Science* 12.5 (2019): 1495-1511

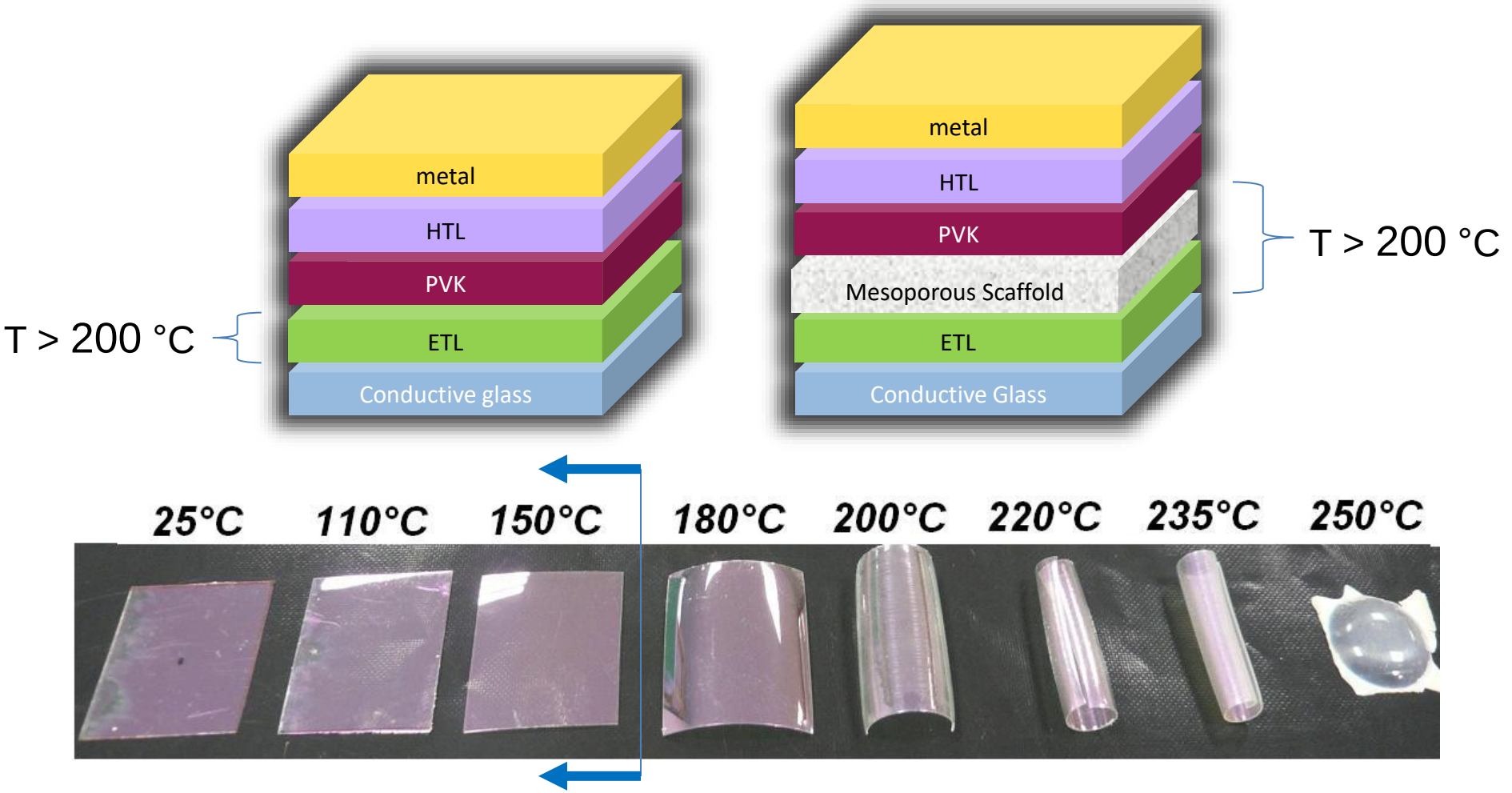
APOLO 1st challenge: flexible





- thin
- light-weight
- conformable
- roll-to-roll compatible
- lower embedded energy

APOLO 1st challenge: flexible



Low Temperature processing!

APOLO 2nd challenge: full printed

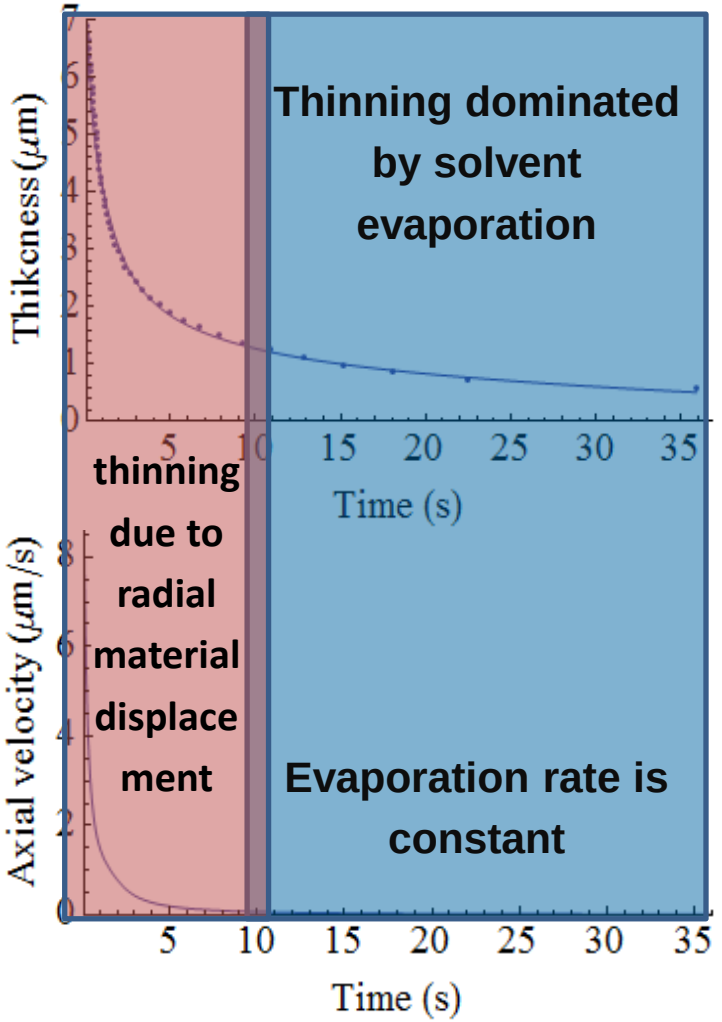
>150 ml/m²

Spin coating

Wet Film formation

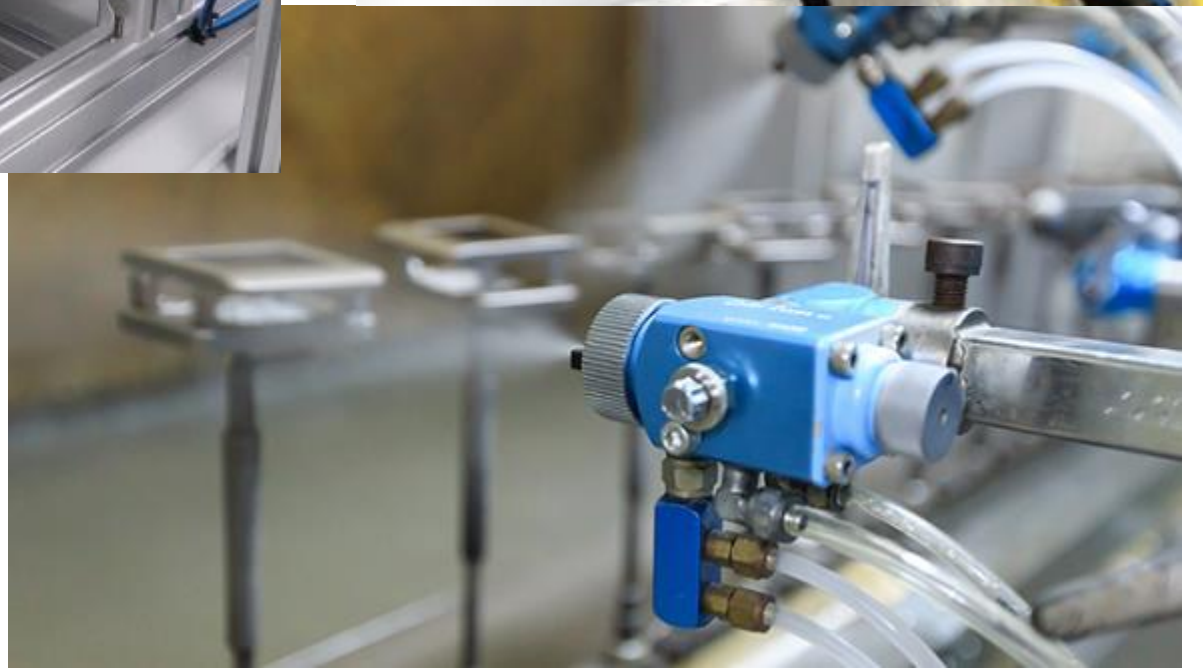
Solvent evaporation

Max substrate size 5 x 5 cm²



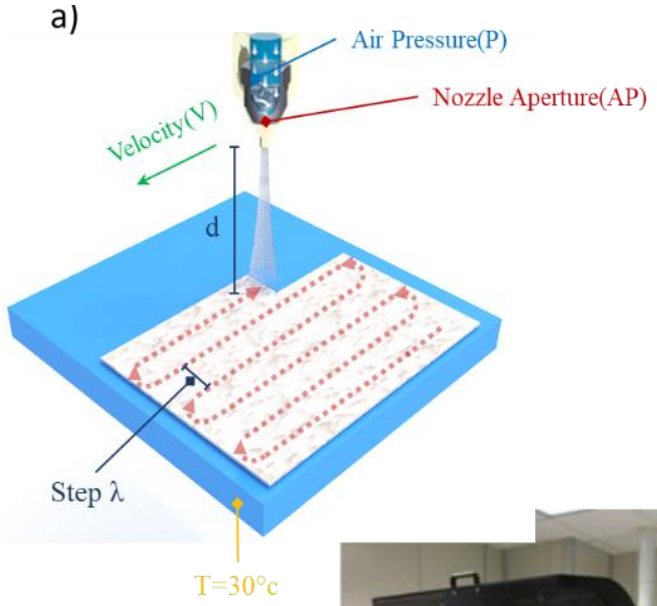
Y. Mouhamad, J. Appl. Phys. 116 (2014) 123513. doi:10.1063/1.4896674.

APOLO 2nd challenge: full printed



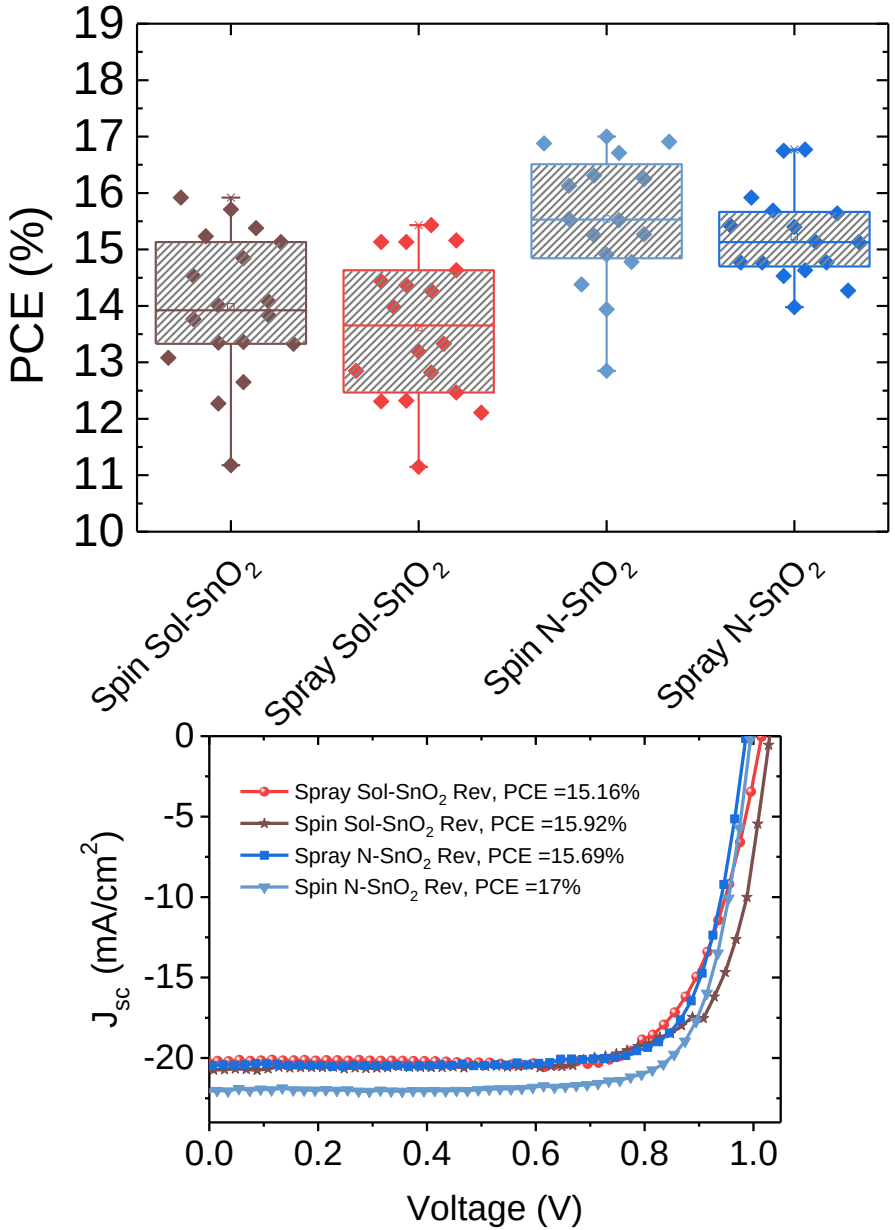
Automated spray coating

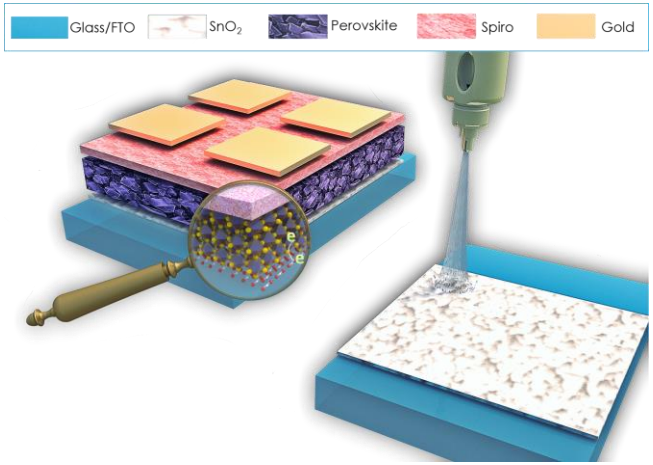
- Automated Process
- Low temperature deposition (< 50 °C) in air
- Uniform and very thin (tens of nm) film on large area (6 x 6 cm^2)
- Scalable up to 20 x 20 cm^2
- Environmentally friendly solvents for SnO_2 solutions/dispersions



B. Taheri et al., Energy Technology 8.5 (2020) 1901284

Automated spray coating





- $SnCl_2$ solution in IPA
- SnO_2 NPs dispersed in water
- Active area = 0.1 cm^2

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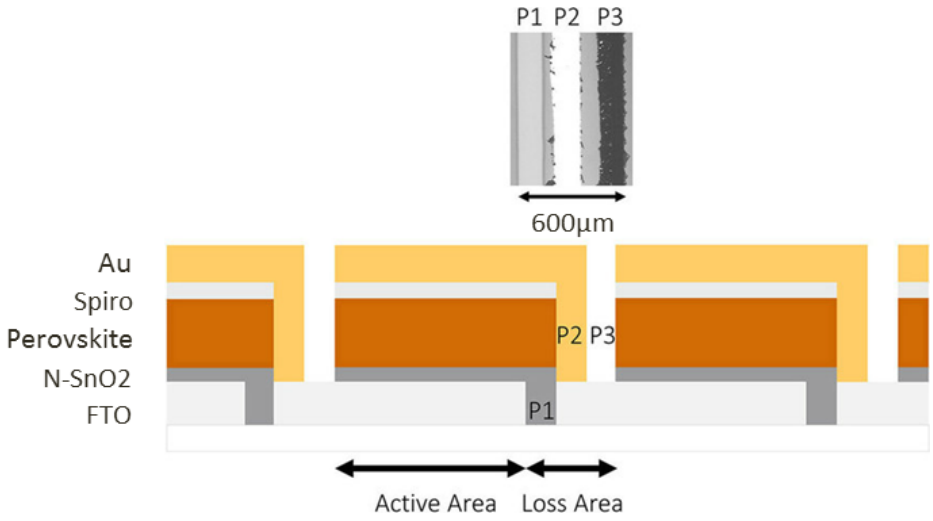
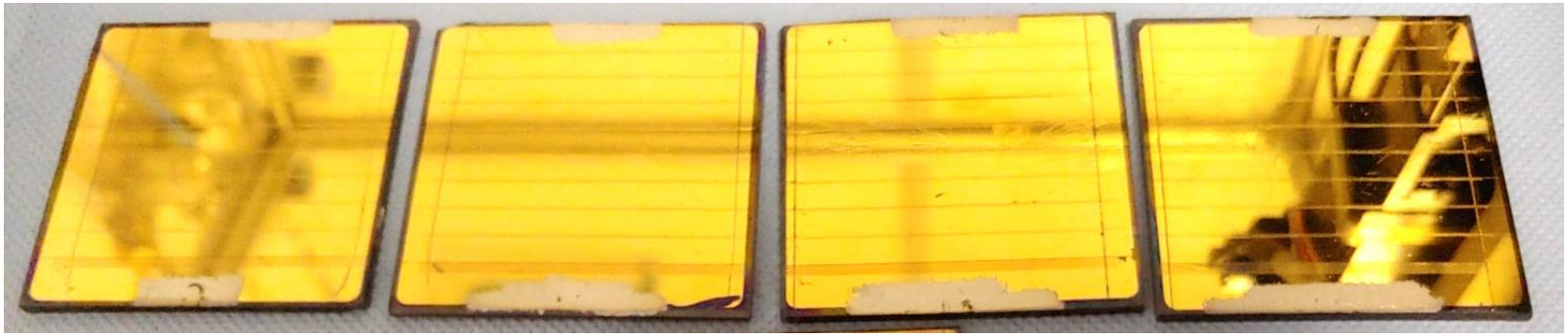
From small to large area



One more challenge: laser patterning



6 x 6 cm^2 glass substrates
8 cells in series

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Modules on glass

Before optimisation of laser patterning settings

ETL	structure	PCE (%)	V_{OC} (mV)	J_{SC} (mA/cm2)	FF (%)	Active Area
Module SnO_2 Spin	FTO/SnO_2 NPs/MAPI/Spiro/Au	**4.6**	4880	16	48	15 cm^2
Module SnO_2 Spray	FTO/SnO_2 NPs/MAPI/Spiro/Au	**3.2**	5320	13	37	15 cm^2

After optimisation of laser patterning settings

ETL	structure	PCE_{max} (PCE_{avg}) (%)	V_{OC} (mV)	J_{SC} (mA/cm2)	FF (%)	Active Area
Ref cell spin	*FTO/SnO2 NPs/MAPI/Spiro/Au*	***13.9***	*962*	*18.5*	*77*	*0.1 cm^2*
Module SnO_2 Spin	FTO/SnO_2 NPs/MAPI/Spiro/Au	**10.6 (9.5)**	7720	15.2	72	15 cm^2
Module SnO_2 Spray	FTO/SnO_2 NPs/MAPI/Spiro/Au	**9.4 (9.0)**	6820	14.6	73	15 cm^2

Spray coating gives similar results as spin coating

Laser patterning settings make the difference!

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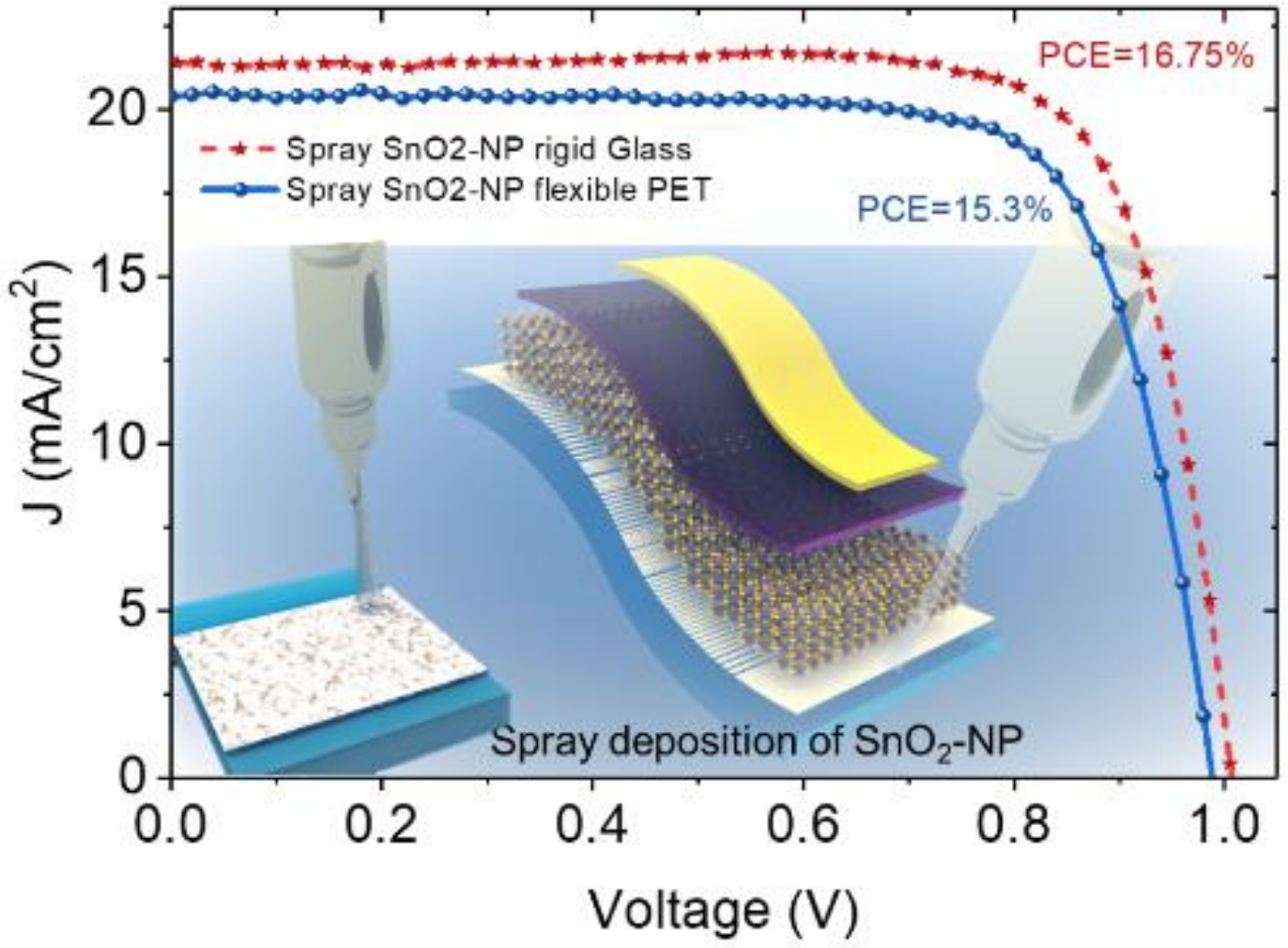
Cells on flexible PET



...and modules

B. Taheri et al., manuscript in preparation

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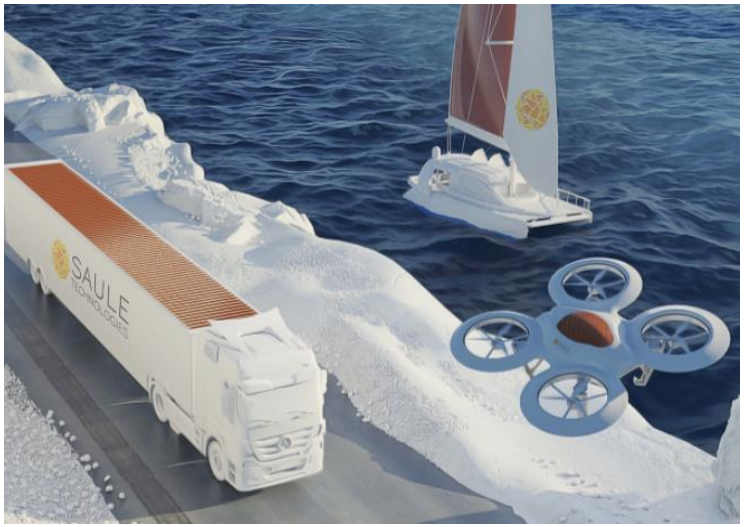
Building-Integrated Photovoltaics (BIPV)

Figure 5. Flexible perovskite solar modules laminated into a glass facade element and integrated into the Skanska's Spark building in Warsaw, Poland. The system consists of 52 perovskite modules, and its performance is monitored by a maximum power point tracker. Reproduced with permission. Copyright 2019, Skanska and Saule Technologies.[32]

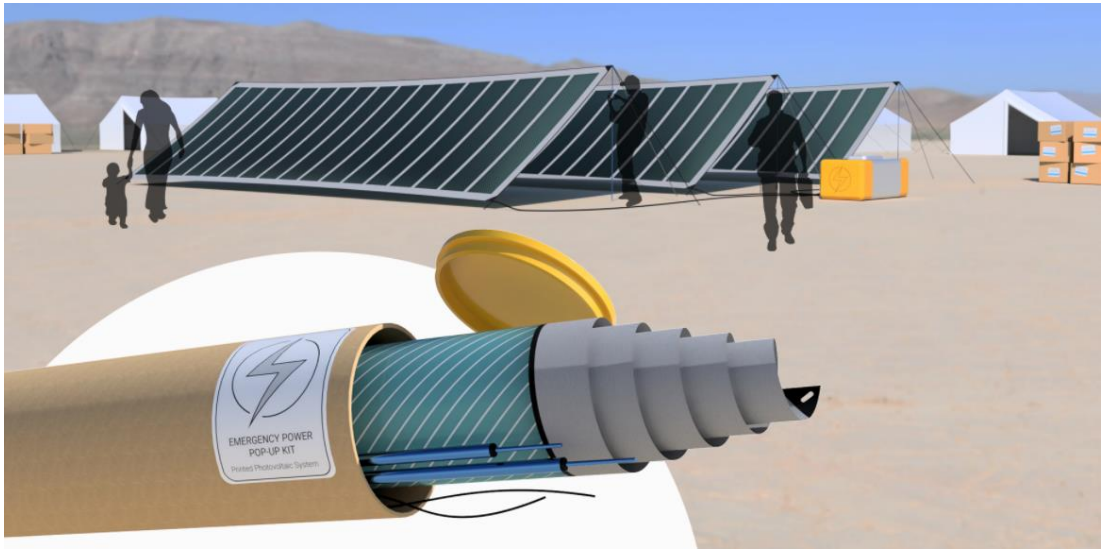
Building-Applied Photovoltaics (BAPV)

K. Wojciechowski et al., Sol. RRL 2019, 1900144



Smart furniture
Transportation
Space

https://sauletech.com/



Credit: Rowan Muller

https://blog.csiro.au/flexing-our-solar-muscle-solar-for-everyone-everywhere/

Portable Electronic Devices

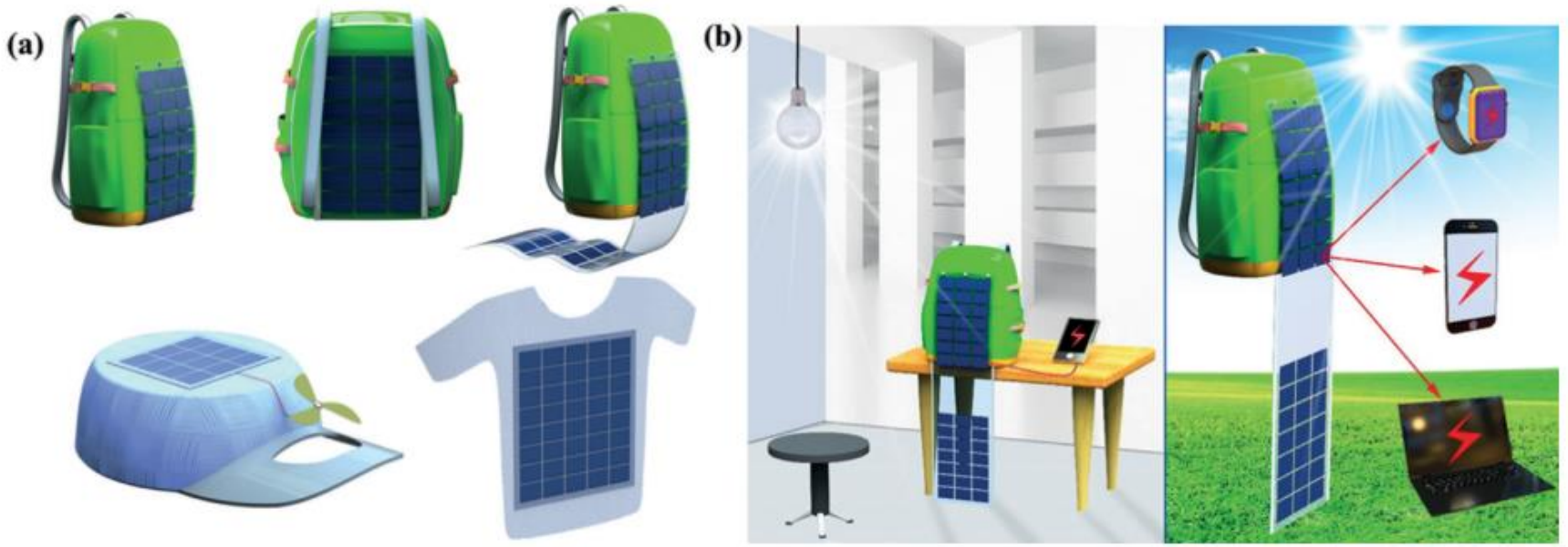
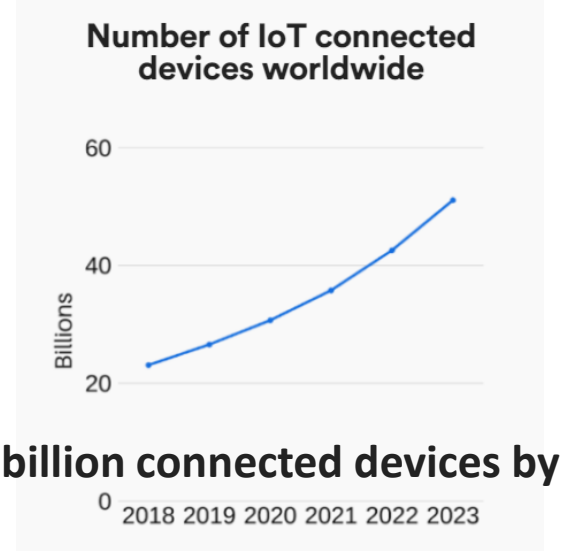
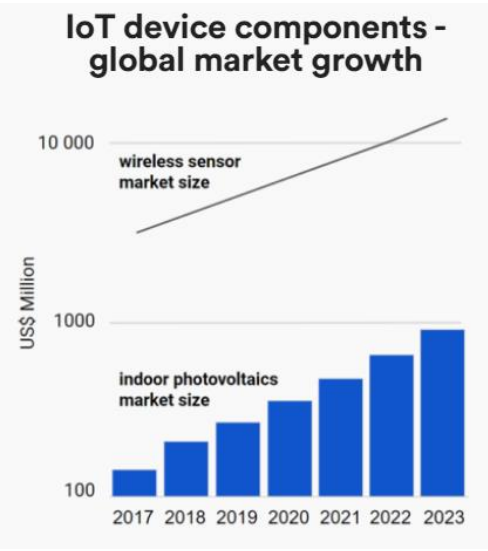


Figure 5. Illustration of flexible PSCs integrates with some wearable devices. a) Bag with both sides covered by flexible perovskite devices, and wearable devices for flexible PSCs provide the power in hat and clothes. b) Cases of indoor and outdoor situations for the perovskite-based flexible solar-cell-covered bag to charge smart phones, smart watches, and laptops.

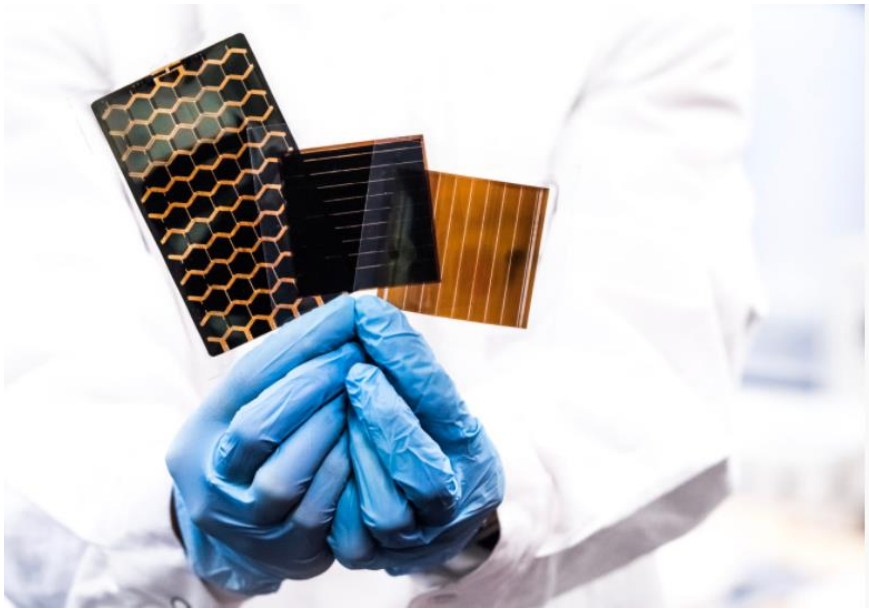
Indoor Light Harvesting for IoT

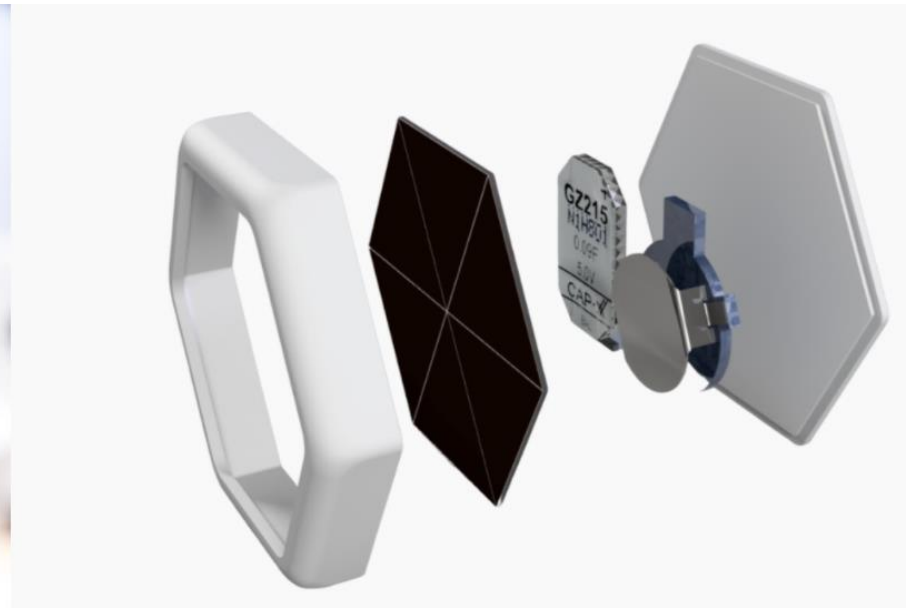


over 51 billion connected devices by 2023



almost $1 billion for indoor PV and over $10 billion for wireless sensors by 2023





Conclusions

- Flex PSCs very appealing for several reasons
- Vast number of applications

- Small cells on glass substrates ~ **17% PCE**
- Modules on glass substrates ~**10% PCE**

  *via **low T automated spray coating** of SnO_2*
- Small cells on **plastic** substrates > **15% PCE**

  *via **low T automated spray coating** of SnO_2*
- Modules on plastic substrates need some optimisation of the laser process

Many thanks to

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TOR VERGATA
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Macroarea di Ingegneria

Funds

ASI
Agenzia Spaziale Italiana

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