

# Ink-jet printed perovskite photovoltaics: from laboratory to industry

Dr. David Forgacs



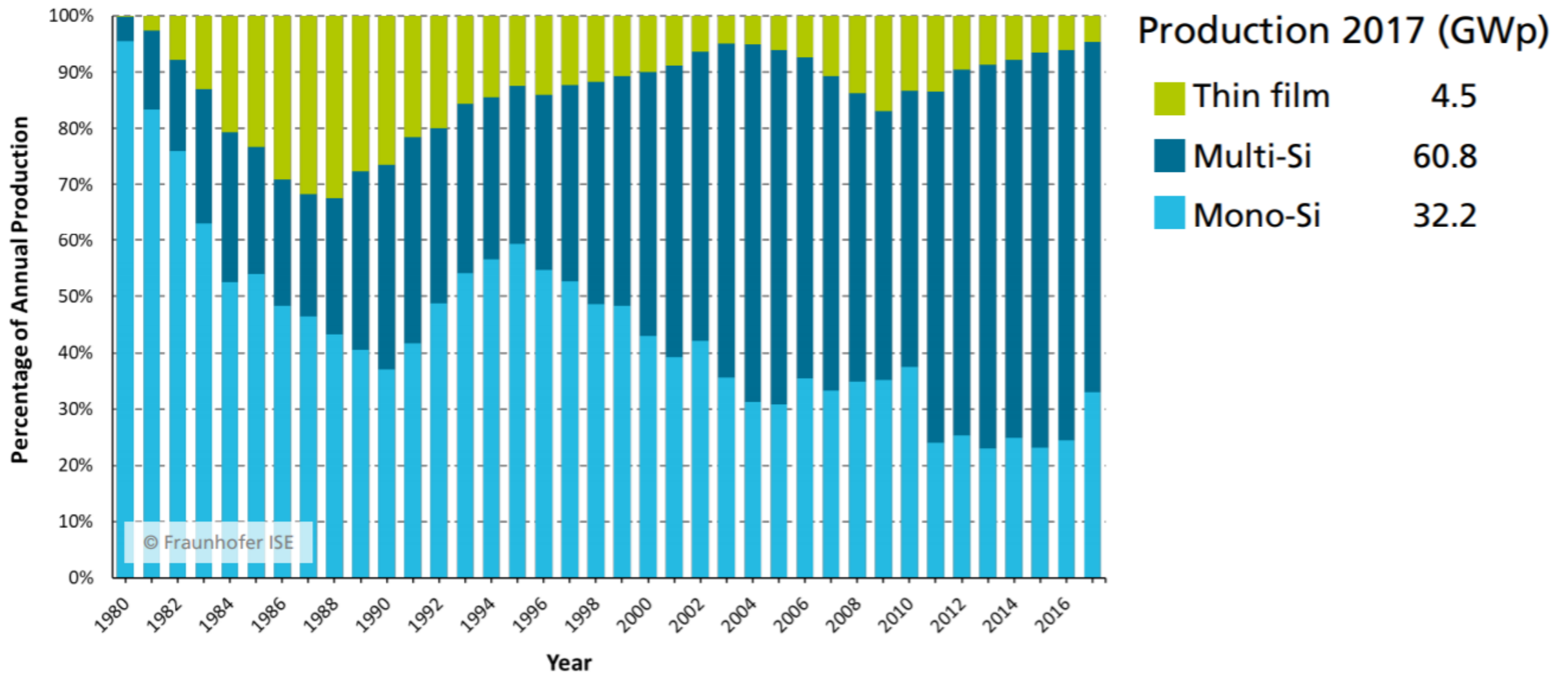
**EuroNanoForum**  
2019

**2019.06.12**

[WWW.SAULETECH.COM](http://WWW.SAULETECH.COM)

# PHOTOVOLTAIC TECHNOLOGIES

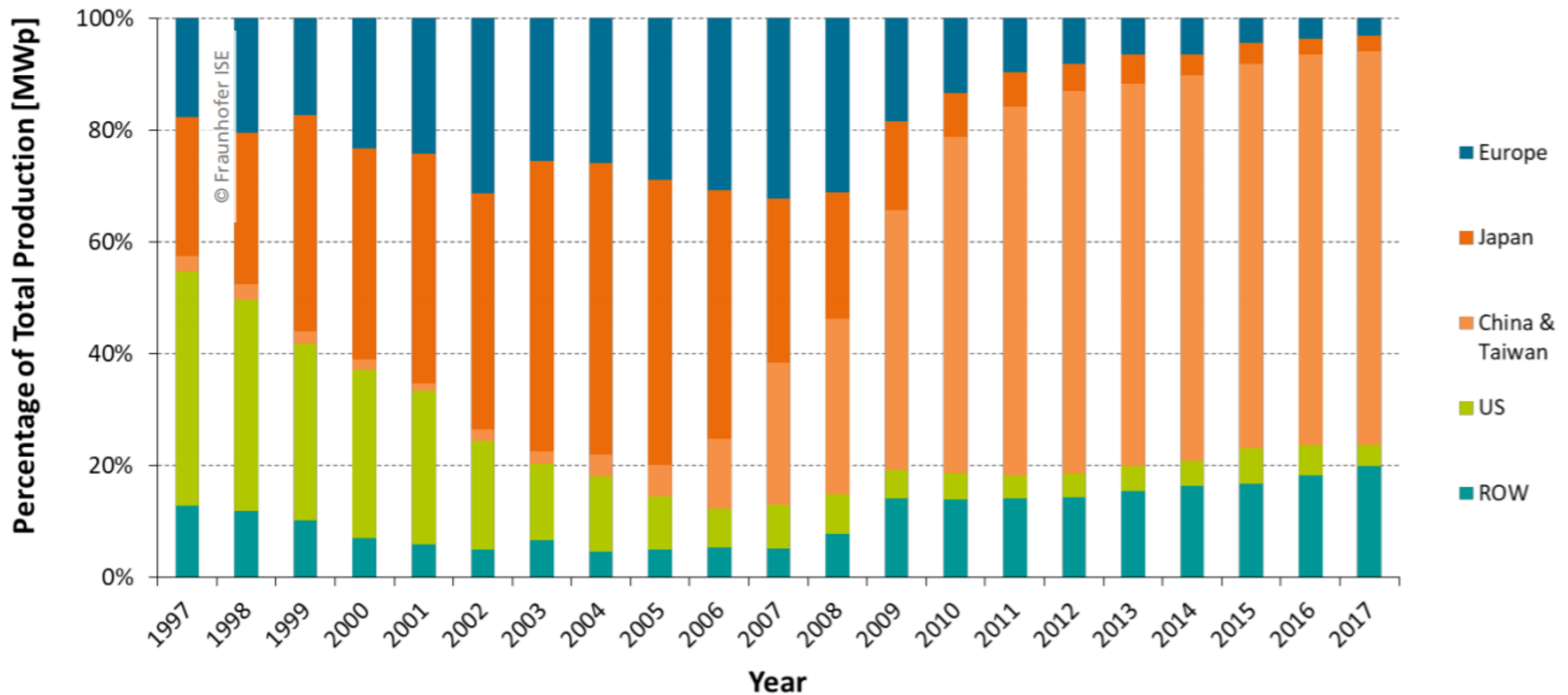
## PV Production by Technology Percentage of Global Annual Production



Source: <https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf>

# PHOTOVOLTAIC TECHNOLOGIES

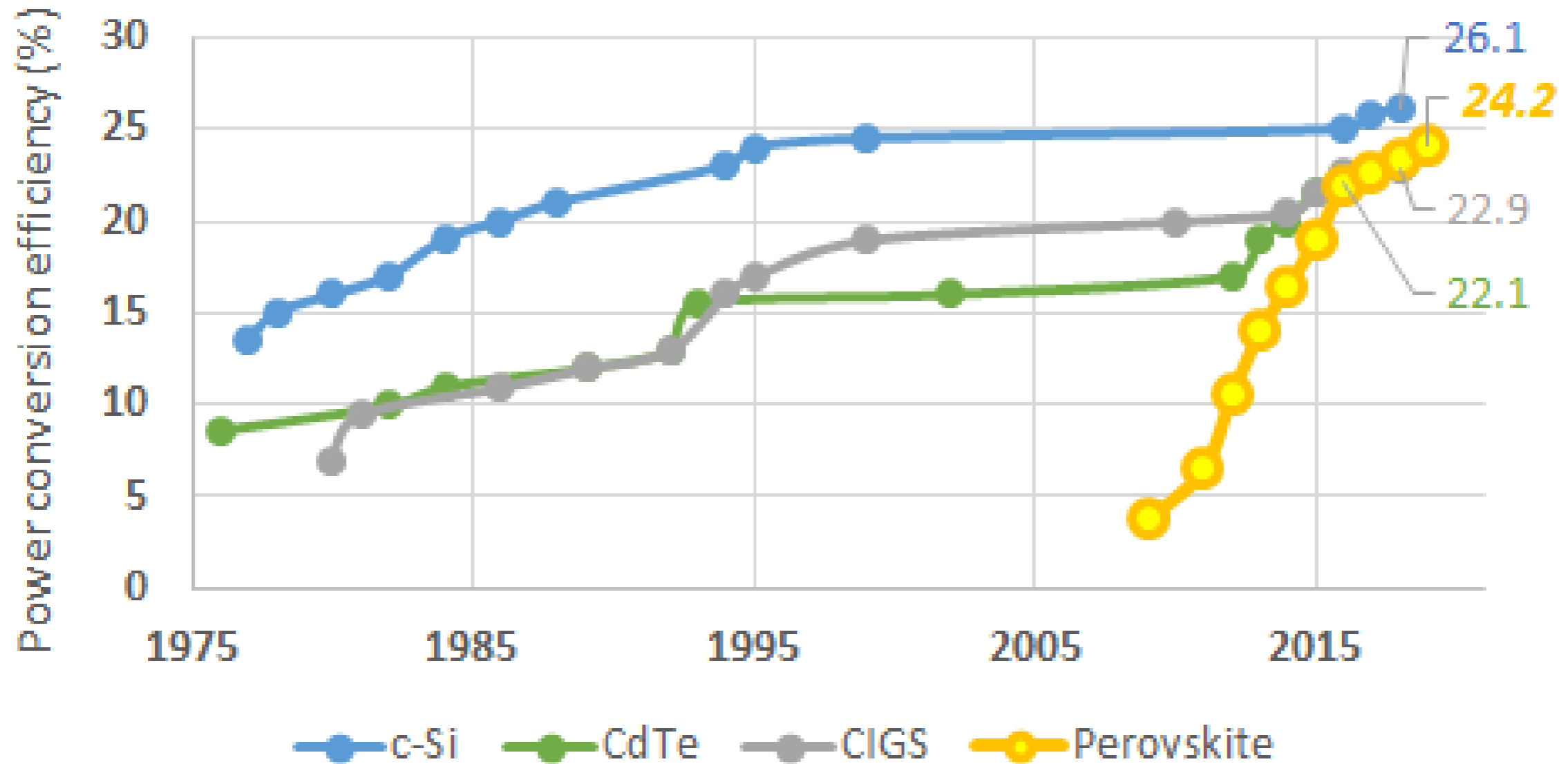
## PV Module Production by Region 1997-2017 Percentage of Total MWp Produced



Source: <https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf>

# PEROVSKITE: EFFICIENCY

## Solar cell efficiency records



Data source: <https://www.nrel.gov/pv/assets/images/efficiency-chart.png>



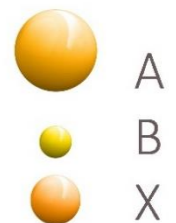
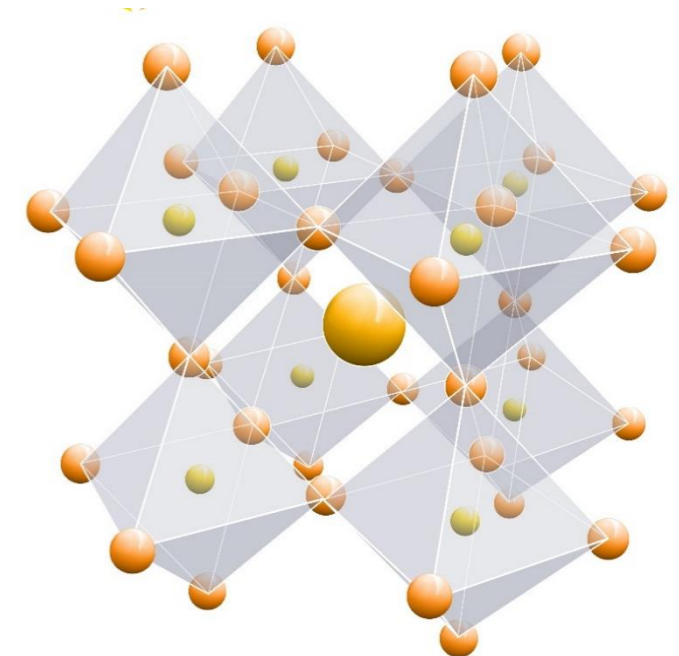
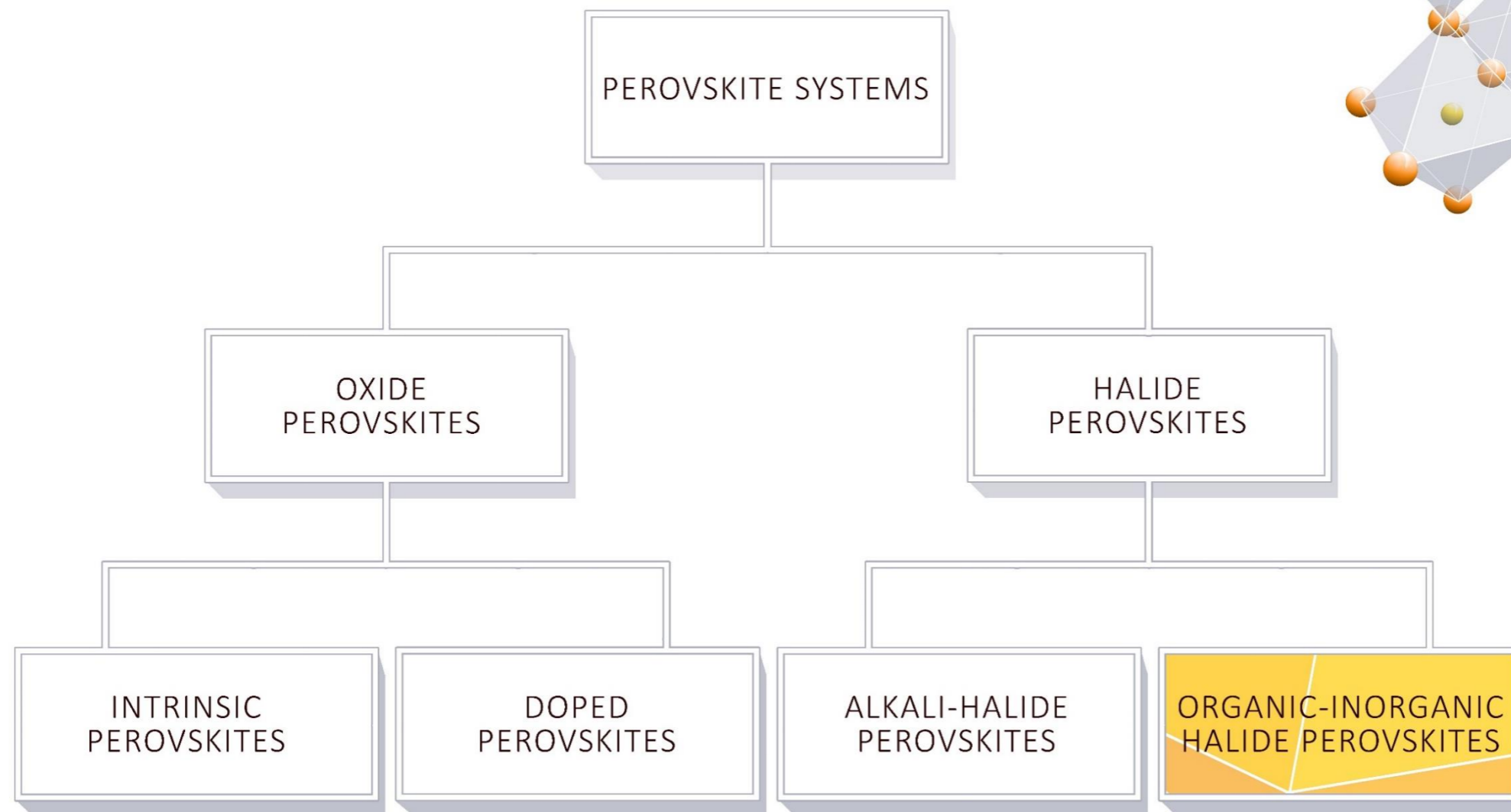
SAULE  
TECHNOLOGIES



# WHAT ARE PEROVSKITES?

[WWW.SAULETECH.COM](http://WWW.SAULETECH.COM)

# PEROVSKITE: ABX<sub>3</sub>

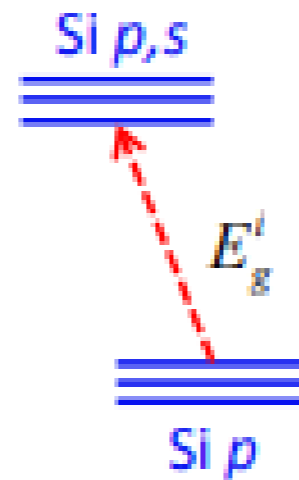


**A: 1+ / 2+**  
**B: 2+ / 4+**  
**X: 1- / 2-**

## Perovskite in solar cells:

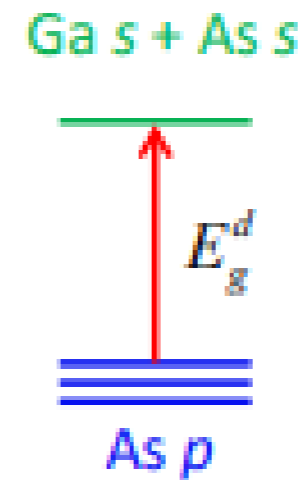
1. High absorption coefficient

(a) 1st Generation



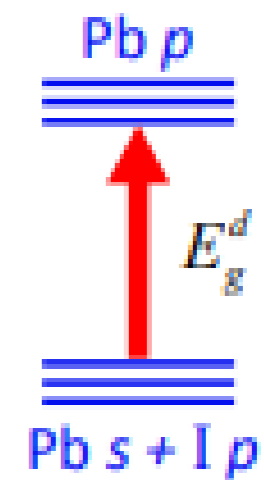
**weak**  
 Indirect  
 $p \rightarrow p$  transition

(b) 2nd Generation



**moderate**  
 direct  
 $As\ p \rightarrow Ga\ s$  transition  
 $As\ p \rightarrow As\ s$  transition

(c) Perovskite halide



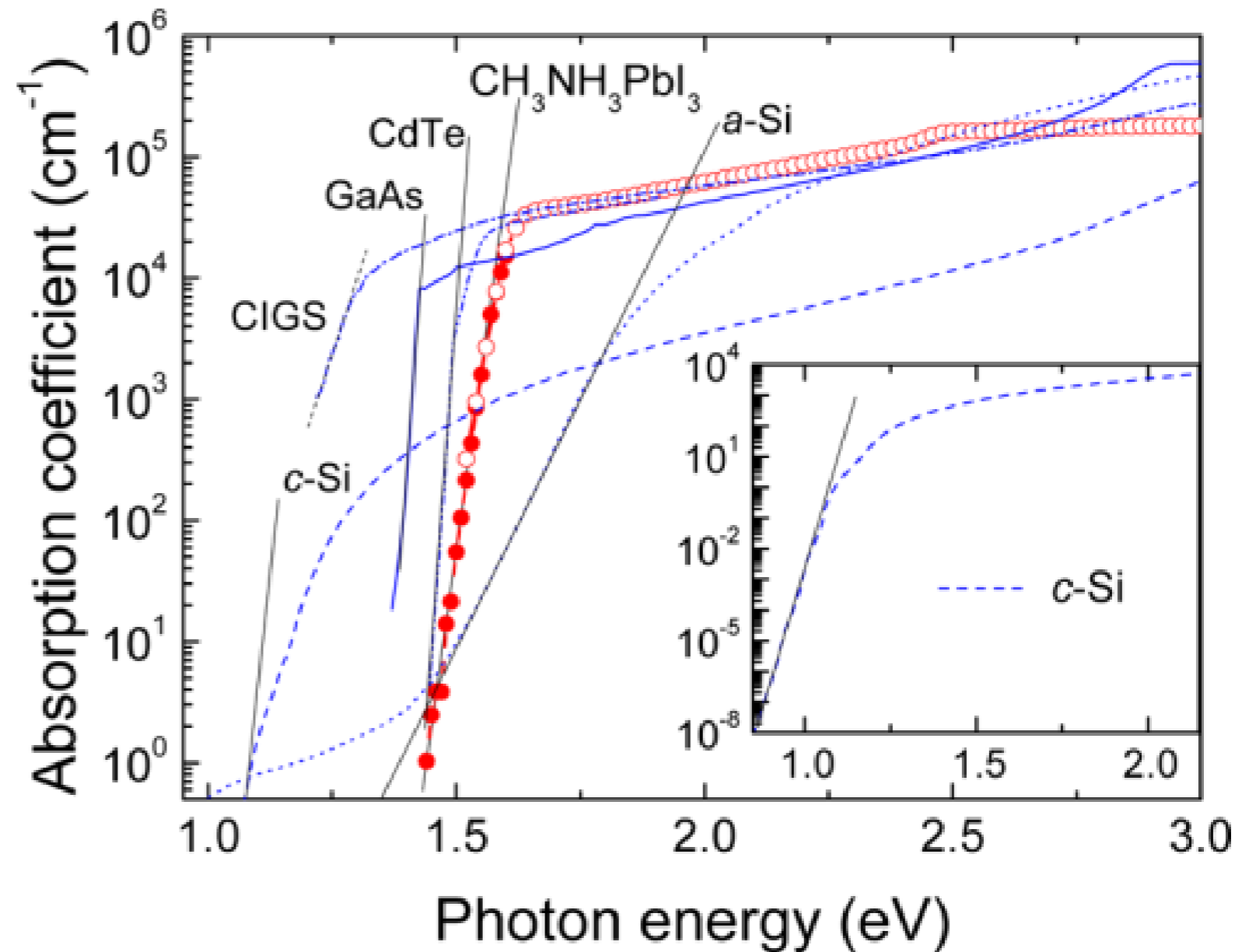
**strong**  
 direct  
 $I\ p \rightarrow Pb\ p$  transition  
 $Pb\ s \rightarrow Pb\ p$  transition

*J. Mater. Chem. A*, 2015,3, 8926-8942

WWW.SAULETECH.COM

## Perovskite in solar cells:

1. High absorption coefficient
2. Close to optimal bandgap (VIS&NIR)



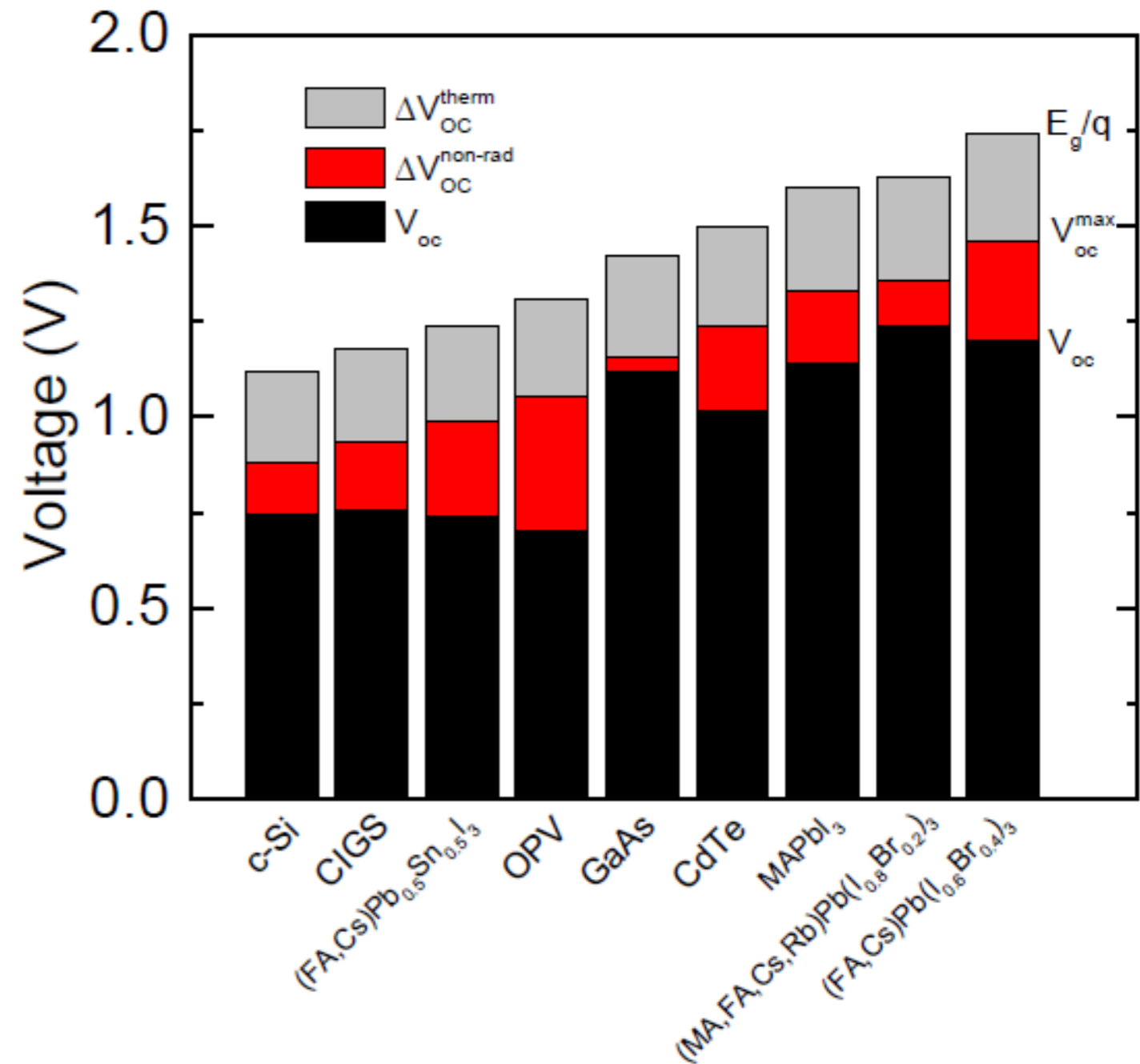
*J. Phys. Chem. Lett.* 2014, 5, 1035-1039

WWW.SAULETECH.COM



## Perovskite in solar cells:

1. High absorption coefficient
2. Close to optimal bandgap (VIS&NIR)
3. Low  $qV_{oc}$  losses

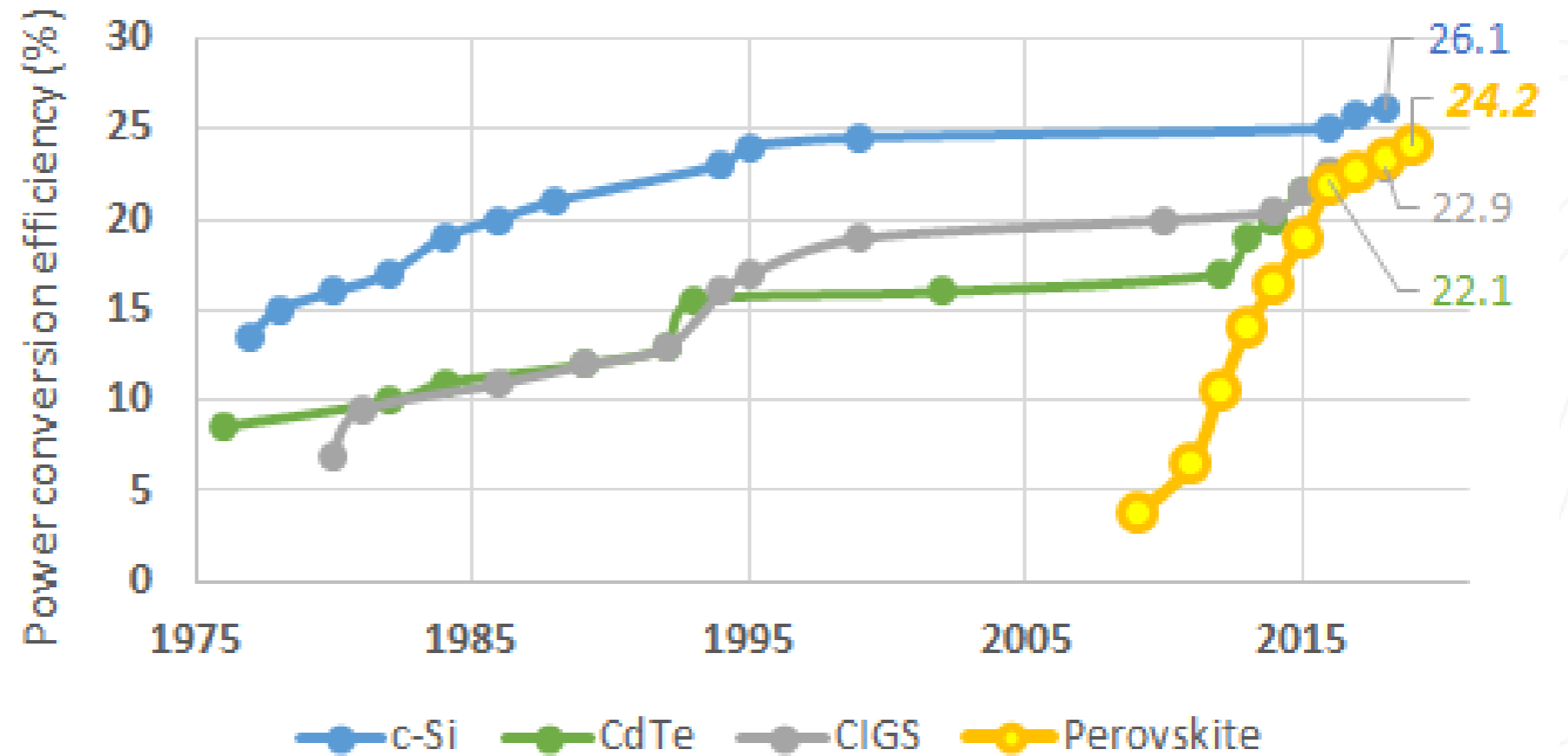


Stranks et al. *ACS Energy Letters* 2 (2017)

## Perovskite in solar cells:

1. High absorption coefficient
2. Close to optimal bandgap (VIS&NIR)
3. Low  $qV_{oc}$  losses
4. High performance

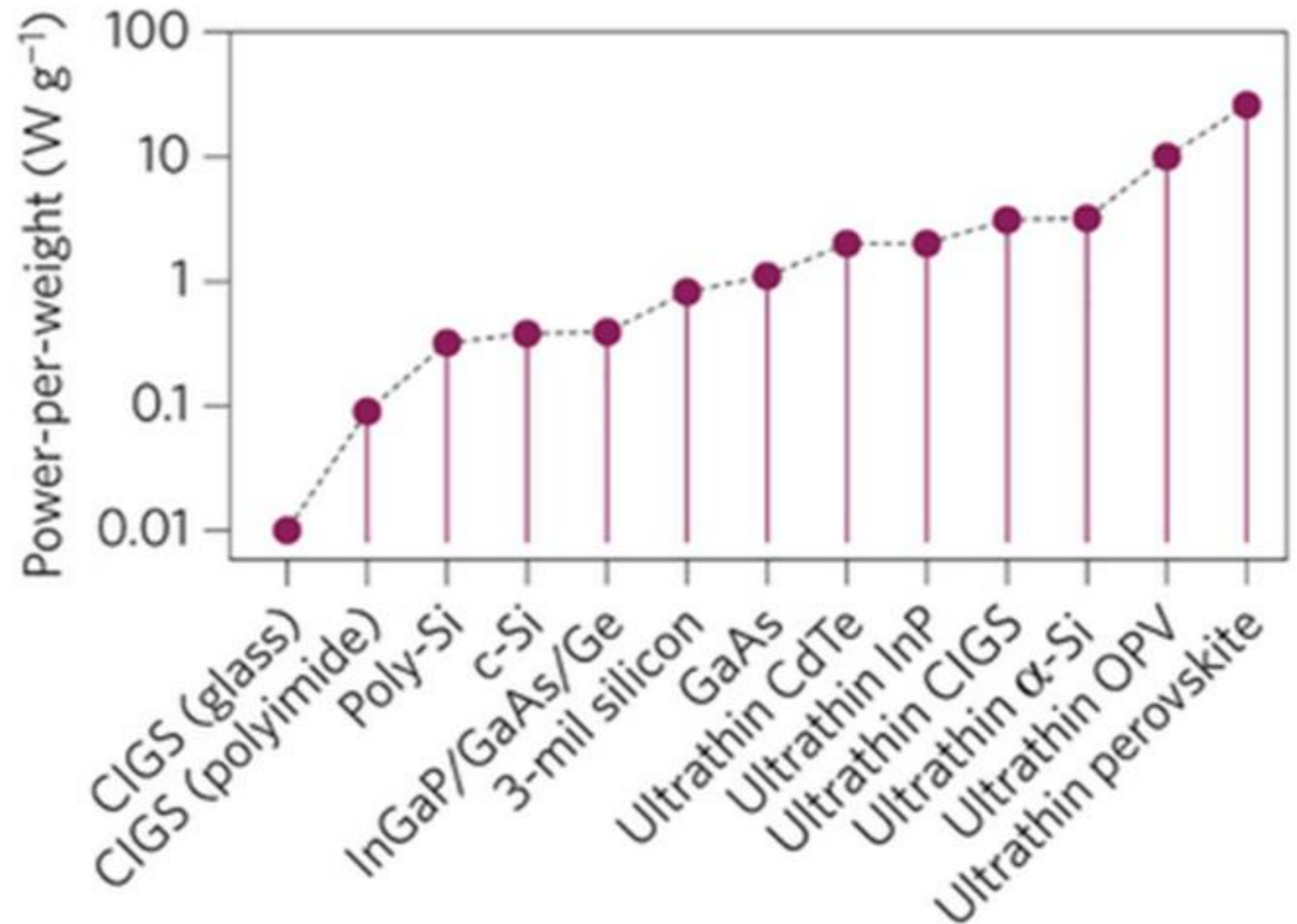
### Solar cell efficiency records



Data source: <https://www.nrel.gov/pv/assets/images/efficiency-chart.png>

## Perovskite in solar cells:

1. High absorption coefficient
2. Close to optimal bandgap (VIS&NIR)
3. Low  $qV_{oc}$  losses
4. High performance
5. High specific power



for ultra-thin (1.3 μm) parylene foil and 12% device efficiency  
*Nature Materials 14, 1032-1039, (2015)*

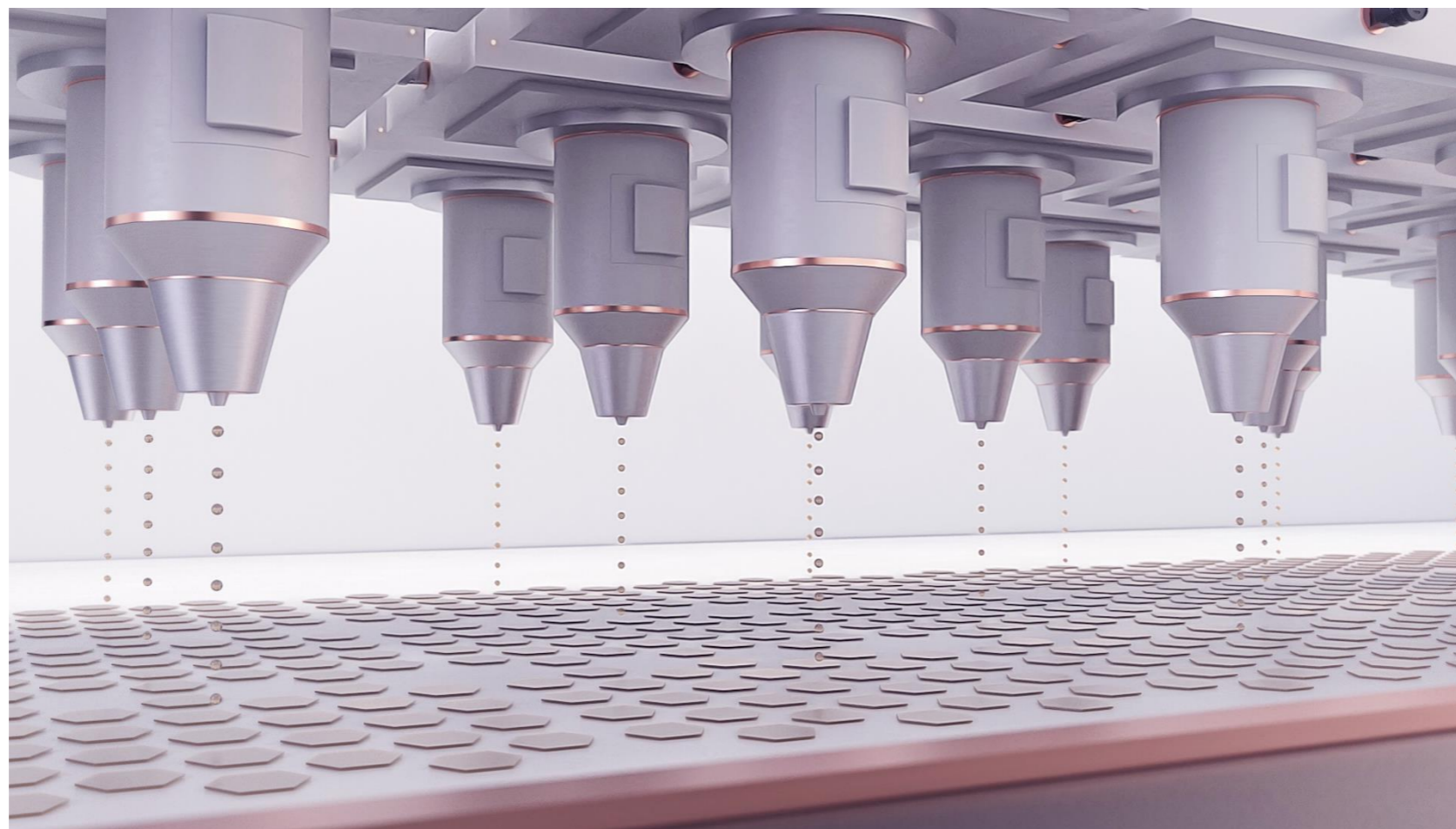


SAULE  
TECHNOLOGIES



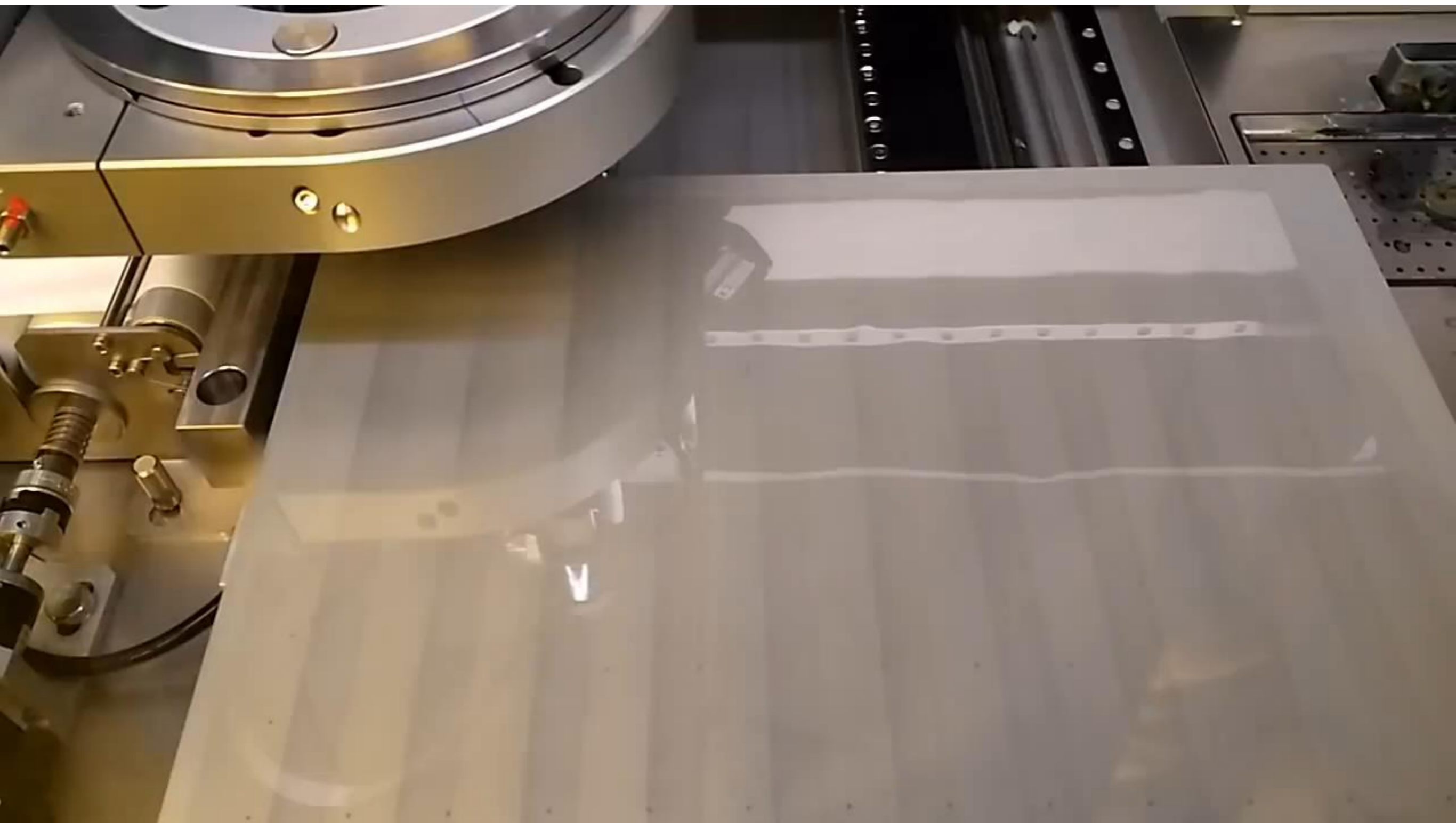
# INK-JET PRINTING BY SAULE

[WWW.SAULETECH.COM](http://WWW.SAULETECH.COM)



- ✓ Ambient processing
- ✓ Low material waste
- ✓ Straightforward scaling
- ✓ Custom design
- ✓ Substrate independence
- ✓ High resolution

# INK-JET PRINTED PEROVSKITE





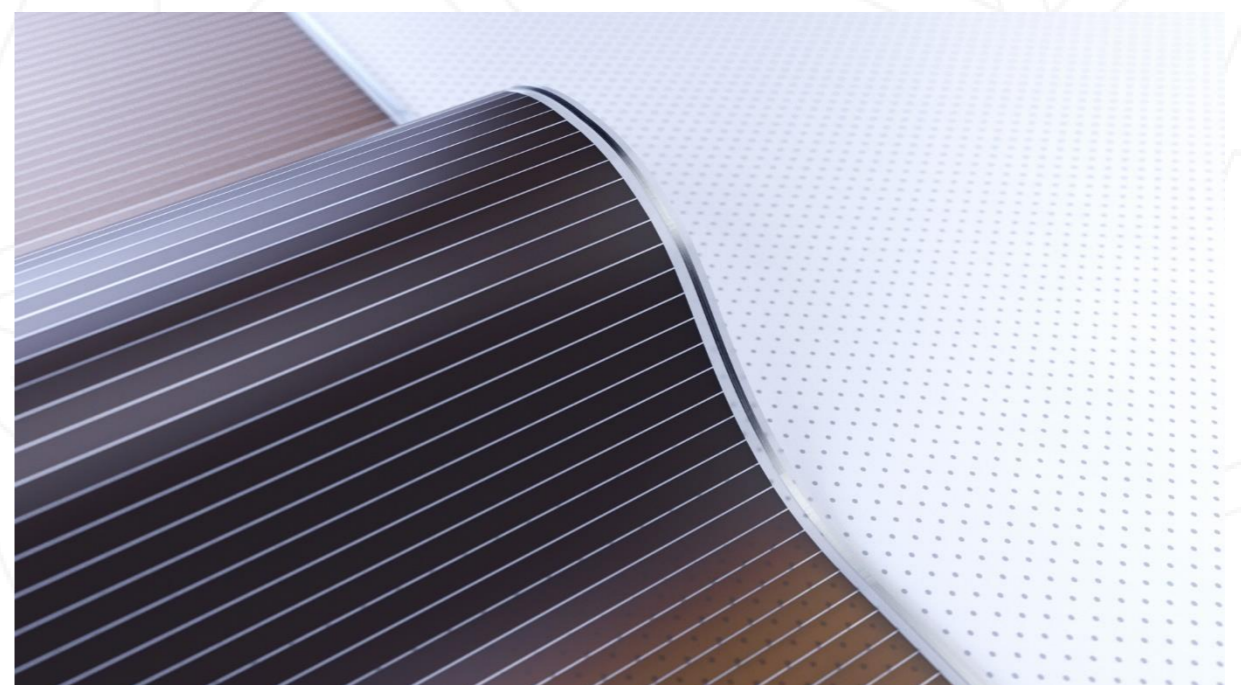
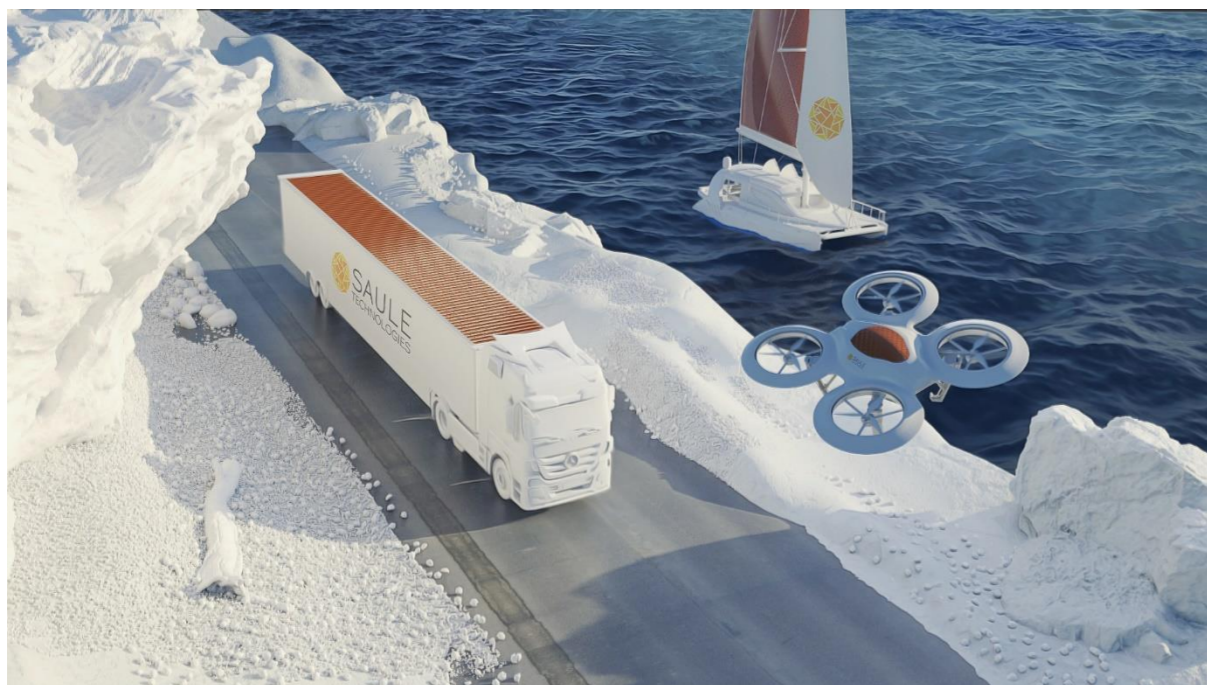
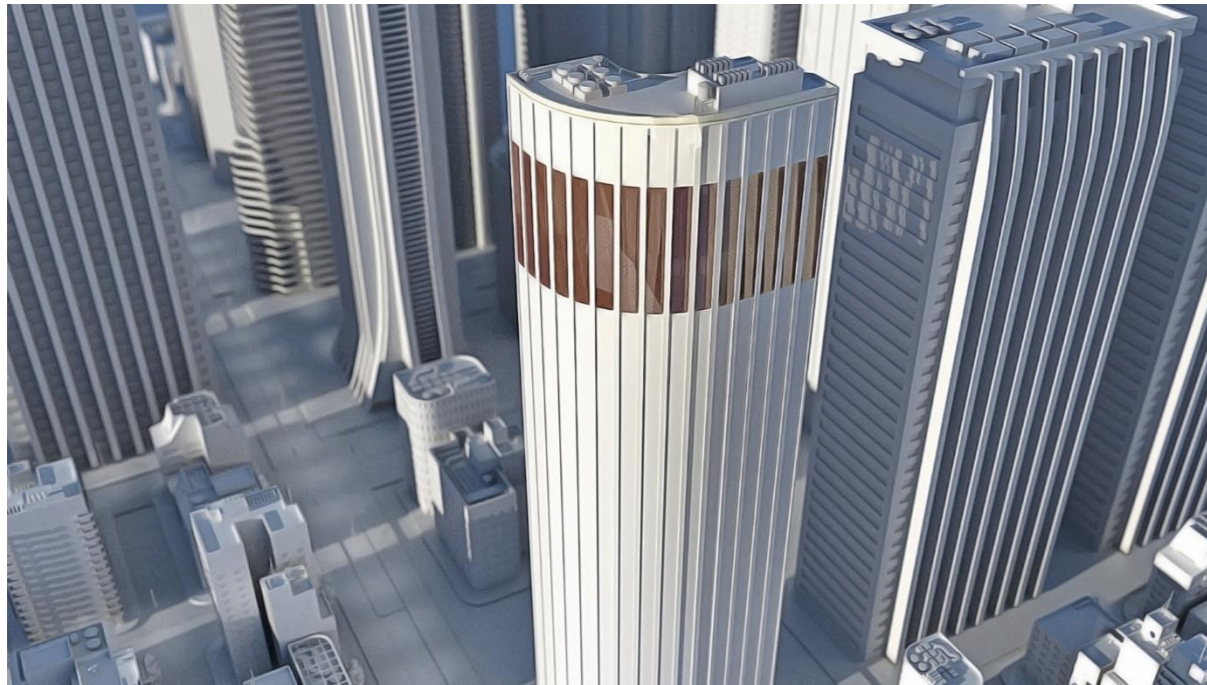
SAULE  
TECHNOLOGIES



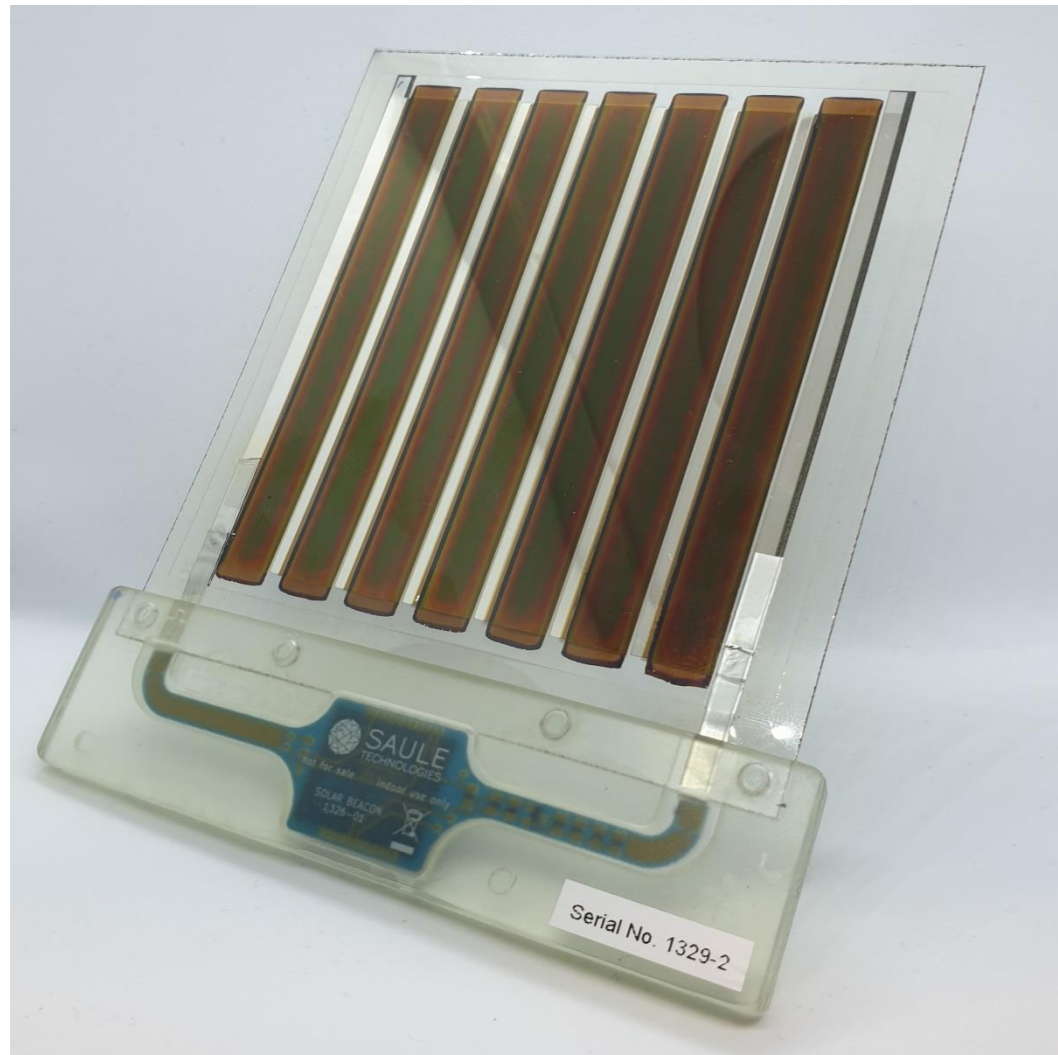
# APPLICATIONS

# Creating the PV technology of the future...

*Flexible perovskite cells can be used in solar generation, construction, space technology & consumer goods*





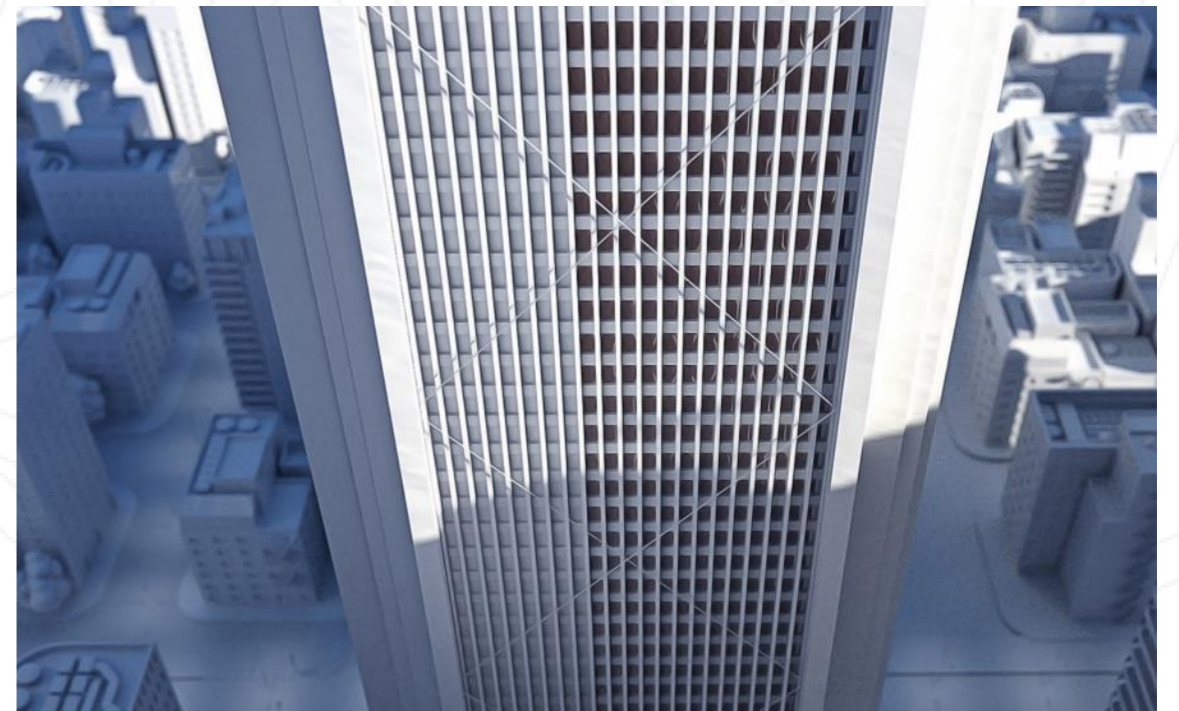
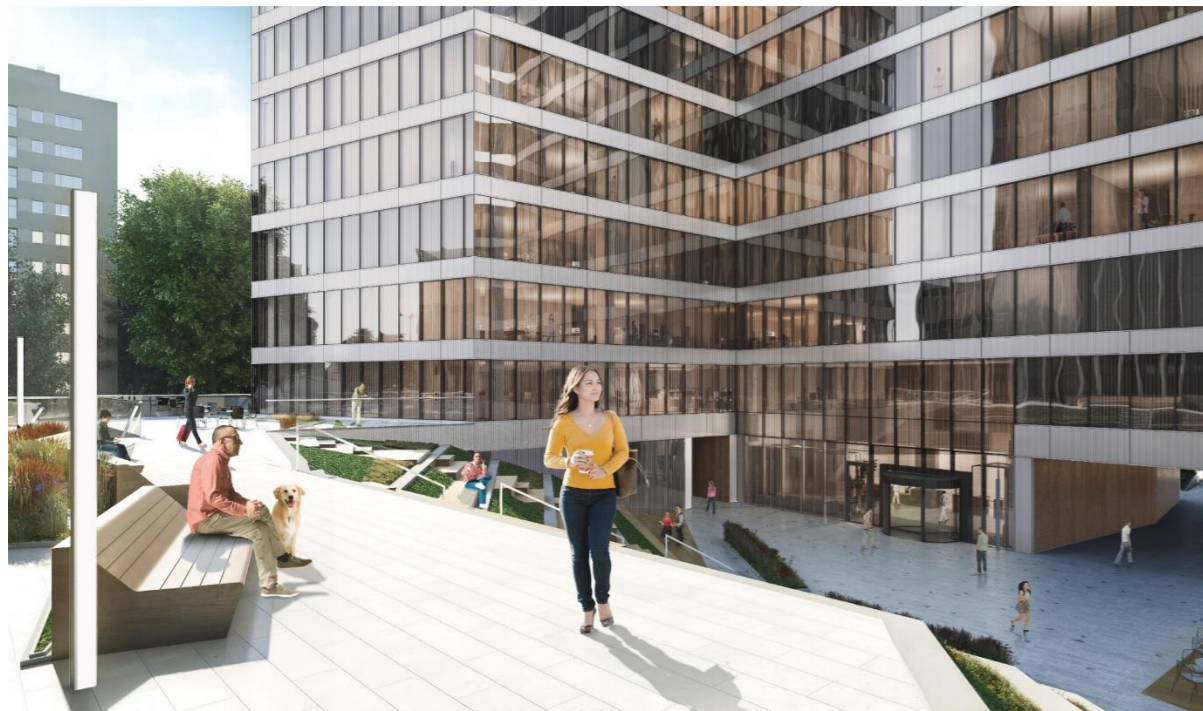
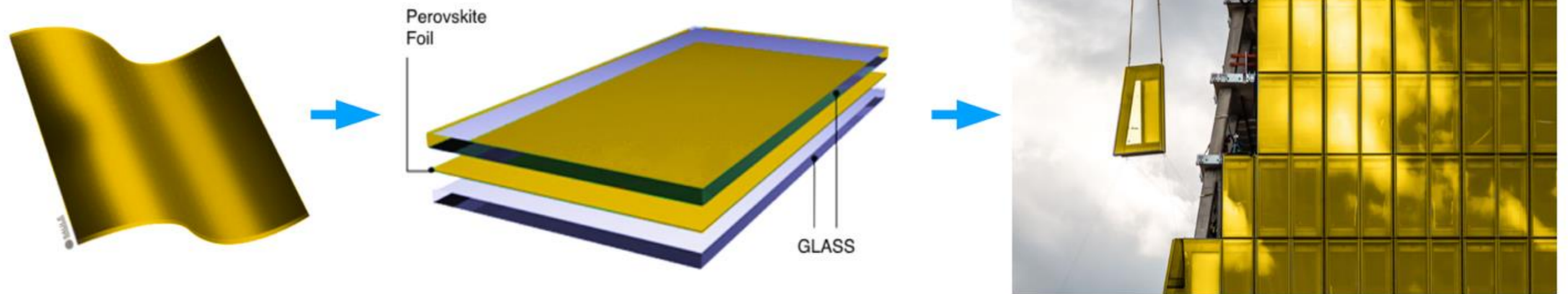


**Autonomous Bluetooth beacon powered by Saule's perovskite**

“The key issue for **[Confidential]** is the **reduction of energy consumption** for IT and Networks. The carbon footprint should be decreased by 20% by 2020...The emergence of and rapid growth of IoT require the development of **efficient methods for indoor & outdoor dim-light energy harvesting** (...) In most cases these objects interacting via wireless communication necessitate **off-grid power supply**. Harvesting the indoor dim-light could provide a sustainable power source for these objects. Medium life time (5-10 years) should be a mass market for Perovskite solar cells...”

– **source: Internal Memorandum from potential JDA Telco Partner.**

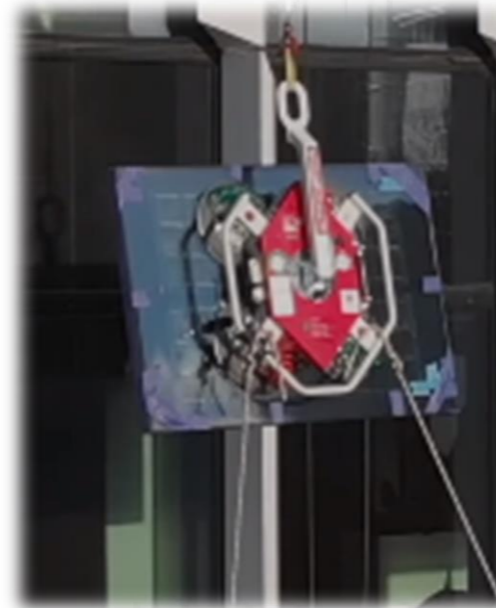
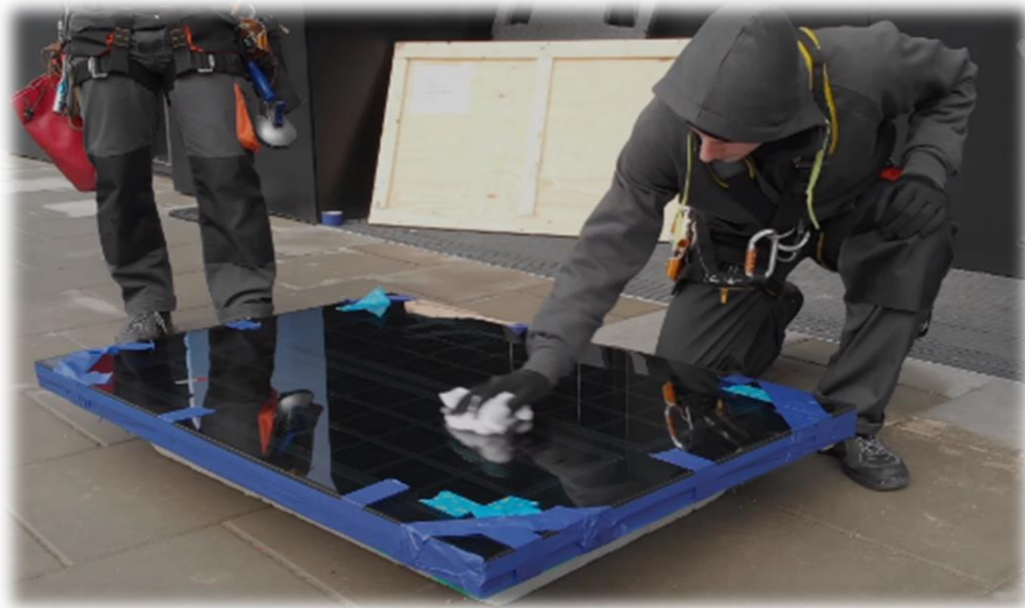
# BIPV: applications



# BIPV: technology demonstrator (1/2)

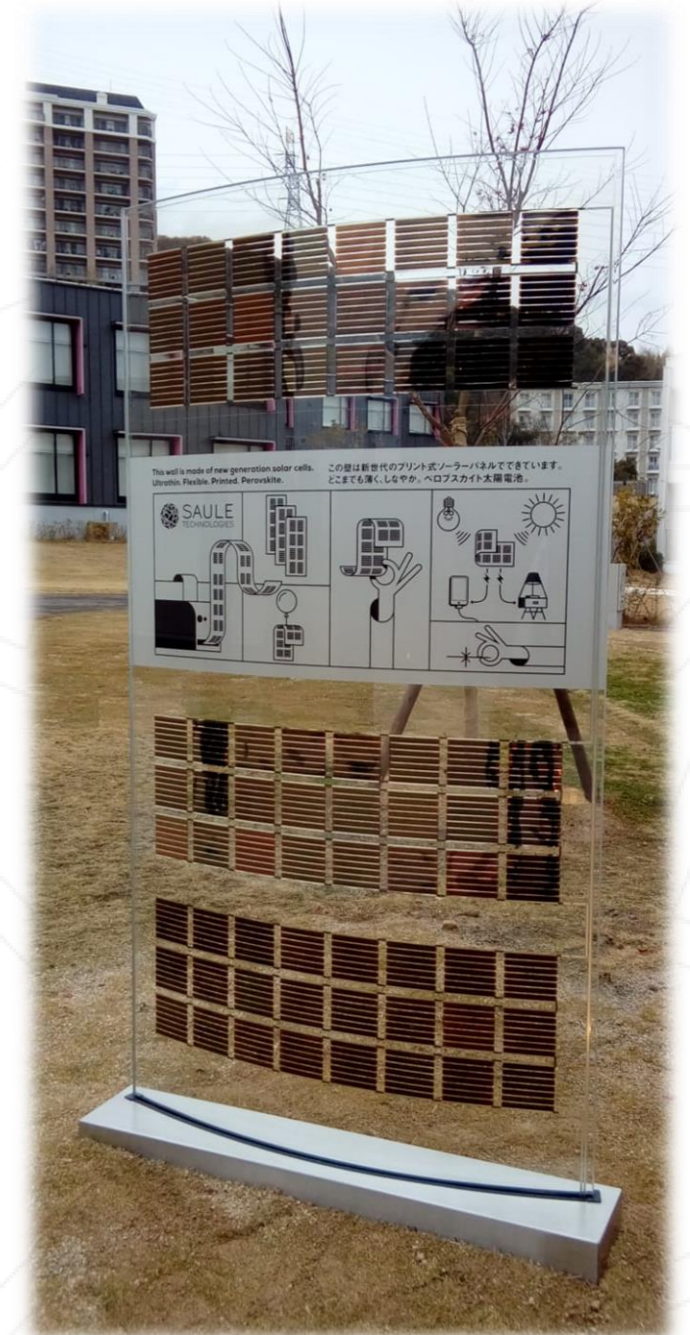
Technology demonstrators: Spark building (Warsaw, Poland)

- SKANSKA** ■ **building façade** (SKANSKA) with integrated perovskite modules.  
■ Size 1.3 x 0.9 m<sup>2</sup>. **52 printed perovskite modules**



# BIPV: technology demonstrator (2/2)

- **Perovskite photovoltaic wall (in bended glass).** Demonstration of technology readiness for mass production. Wall consist of **72 printed perovskite modules**. Active area ca. 0.4m<sup>2</sup>. Deliver up to 20W power, which correlates to a 5% efficiency (active area).
- **Coffee table** with integrated screen and PV modules. Demonstration of technology for indoor applications. Artificial light from hotel lobby charge a tablet integrated with a table. Tablet is connected to the internet, uploading and showing news on the screen. **30 printed perovskite modules**.



# TEAM OVERVIEW



Small, efficient,  
interdisciplinary  
team



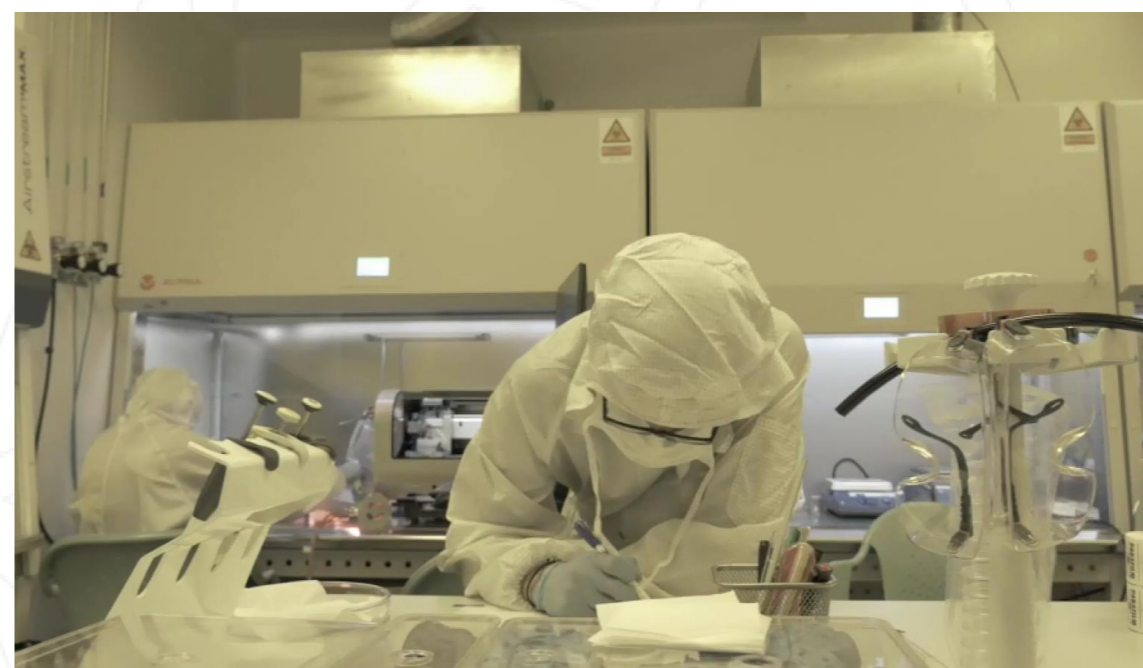
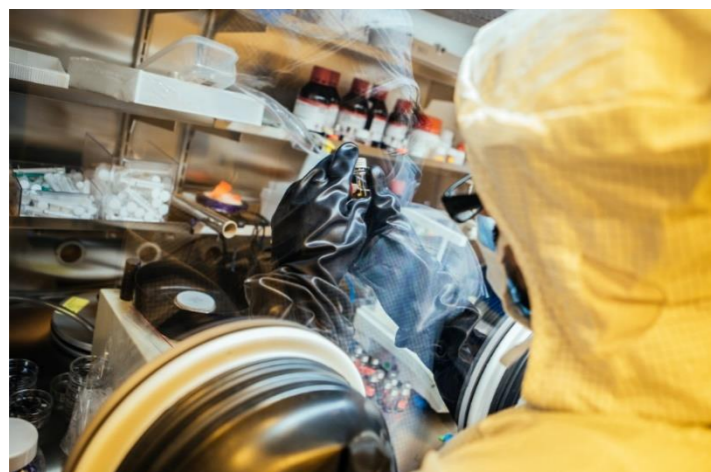
Multicultural  
work  
environment



Talented scientists  
sharing knowledge  
& experience

Interested in joining us? Send your CV to: [job@sauletech.com](mailto:job@sauletech.com)

# One of the most advanced optoelectronics laboratories in Europe




Interested in joining us? Send your CV to: [job@sauletech.com](mailto:job@sauletech.com)

## CONTACT

Dr. David Forgacs

Director of Knowledge Management

david.forgacs@sauletech.com

 sauletech

 sauletech

 saule-technologies



**SKANSKA**



**WPT**  
WROCLAWSKI PARK TECHNOLOGICZNY



**GRUPA ERGIS**



**European Funds**  
Smart Growth



Republic  
of Poland



The National Centre  
for Research and Development



**European Union**  
European Regional  
Development Fund

