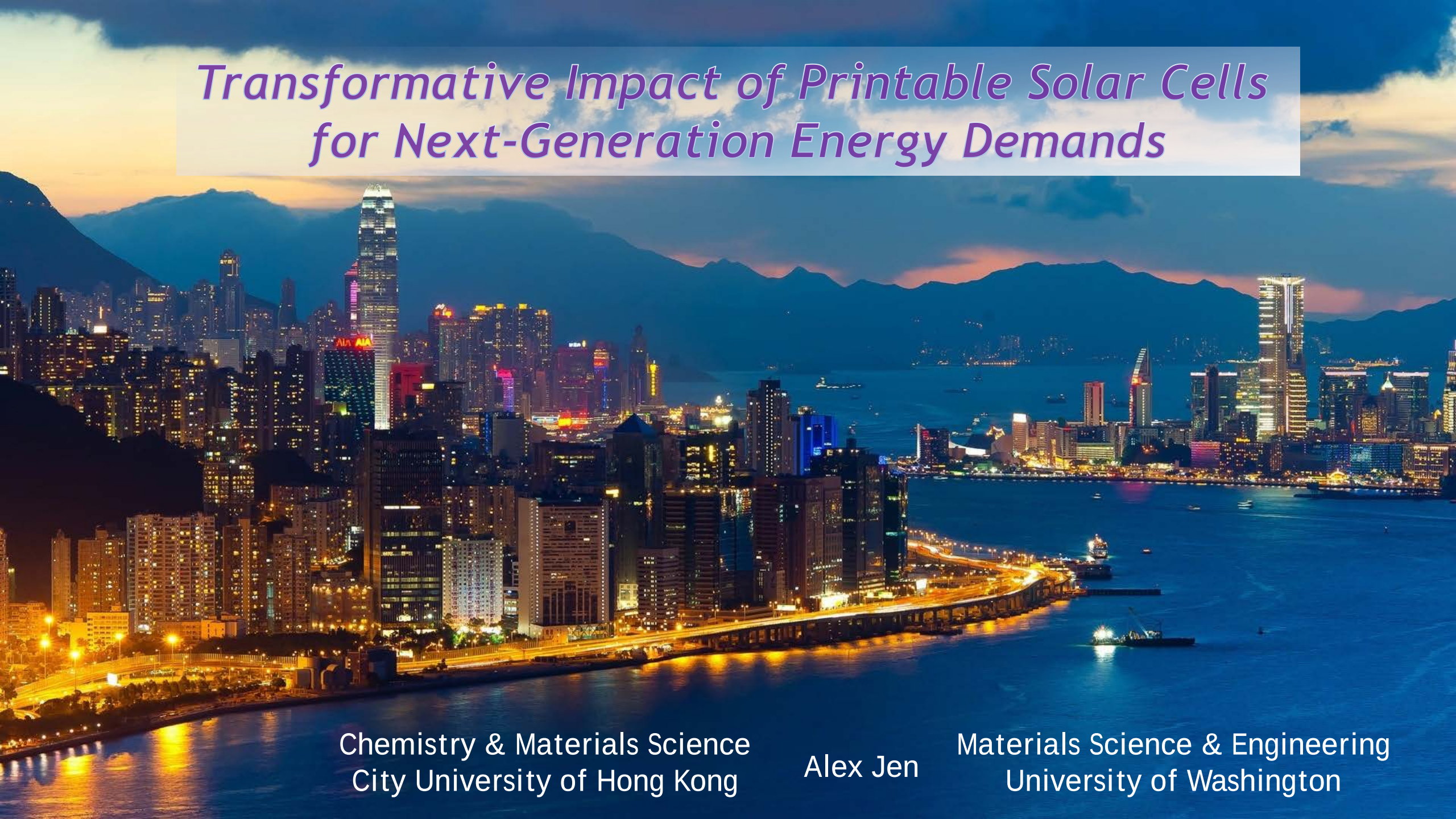
Transformative Impact of Printable Solar Cells for Next-Generation Energy Demands

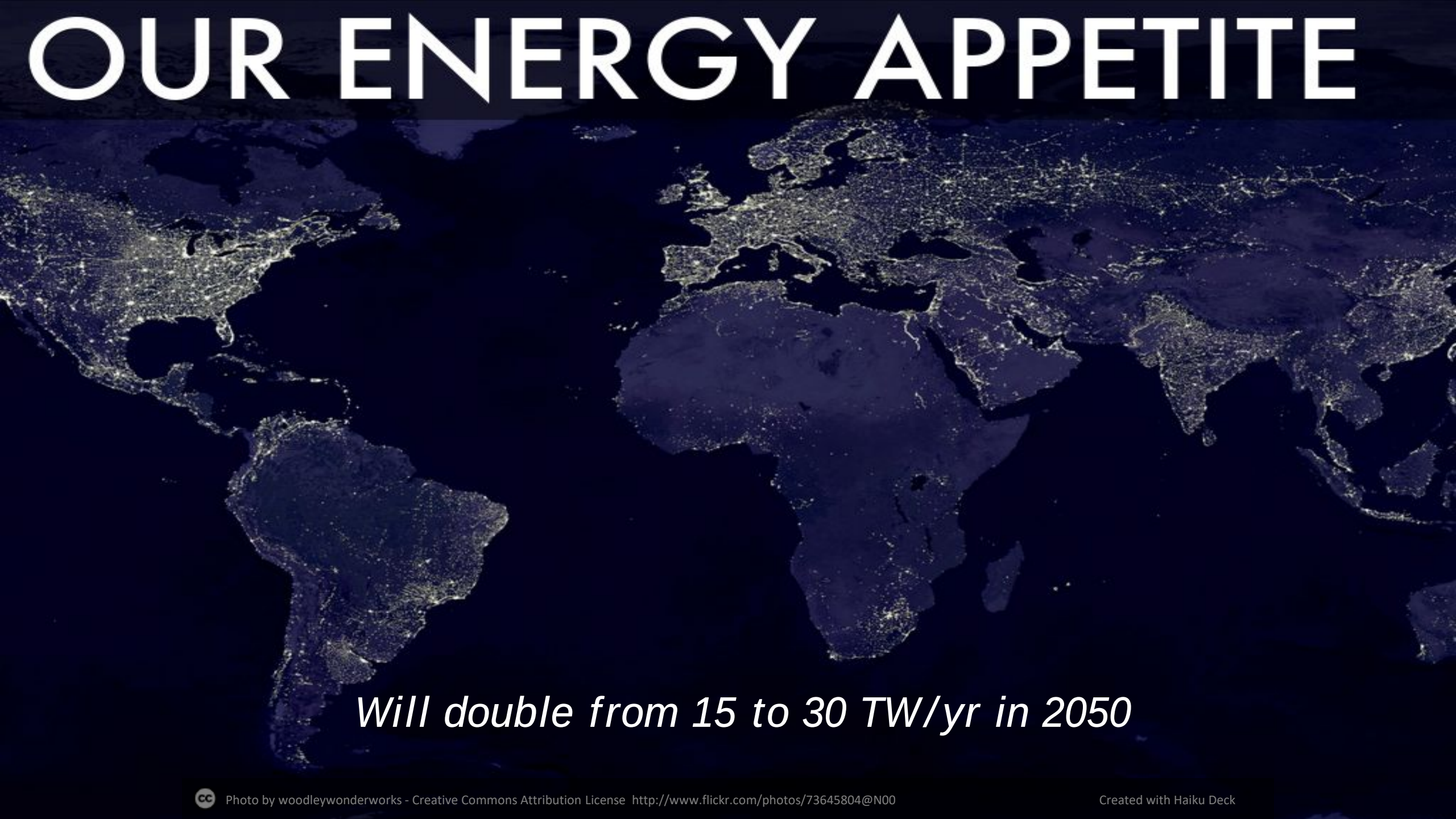


Chemistry & Materials Science
City University of Hong Kong

Alex Jen

Materials Science & Engineering
University of Washington

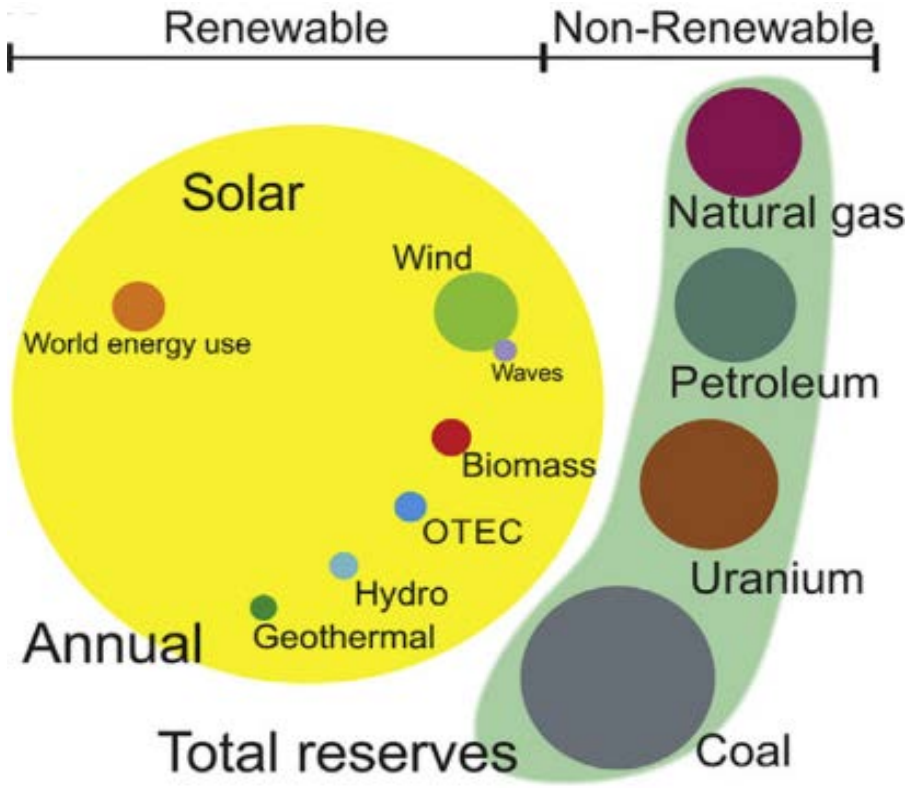
OUR ENERGY APPETITE



Will double from 15 to 30 TW/yr in 2050

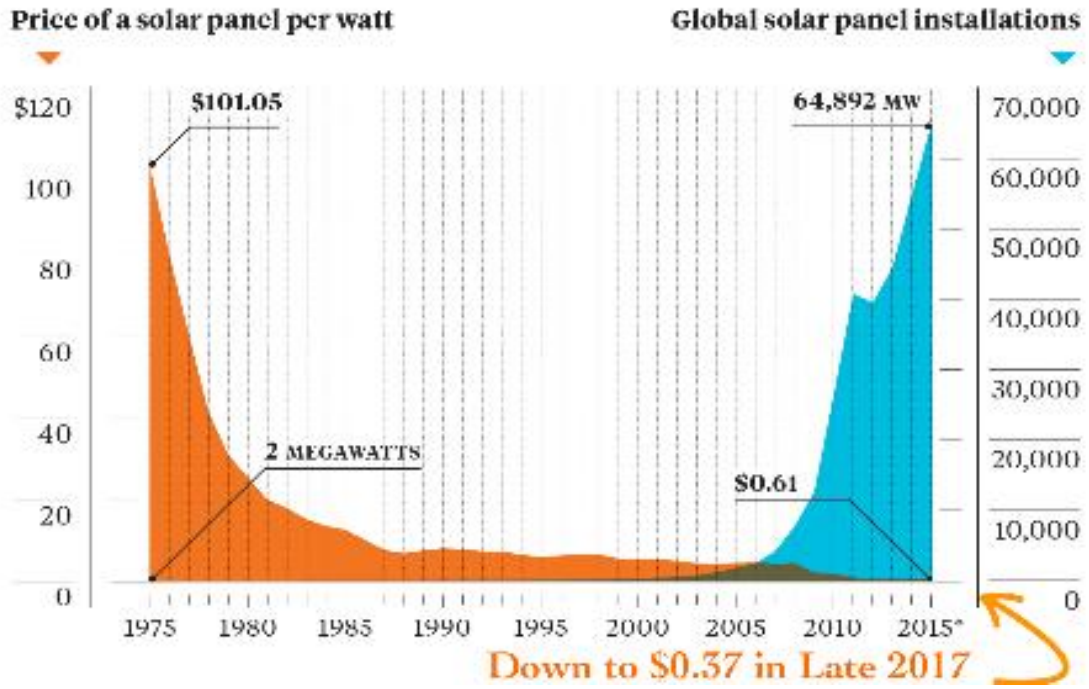
Solar Power for Global Energy Needs

Global Energy Sources



IEA-SHC Solar Update **2015**
Miguez et al. *Joule* **2017**

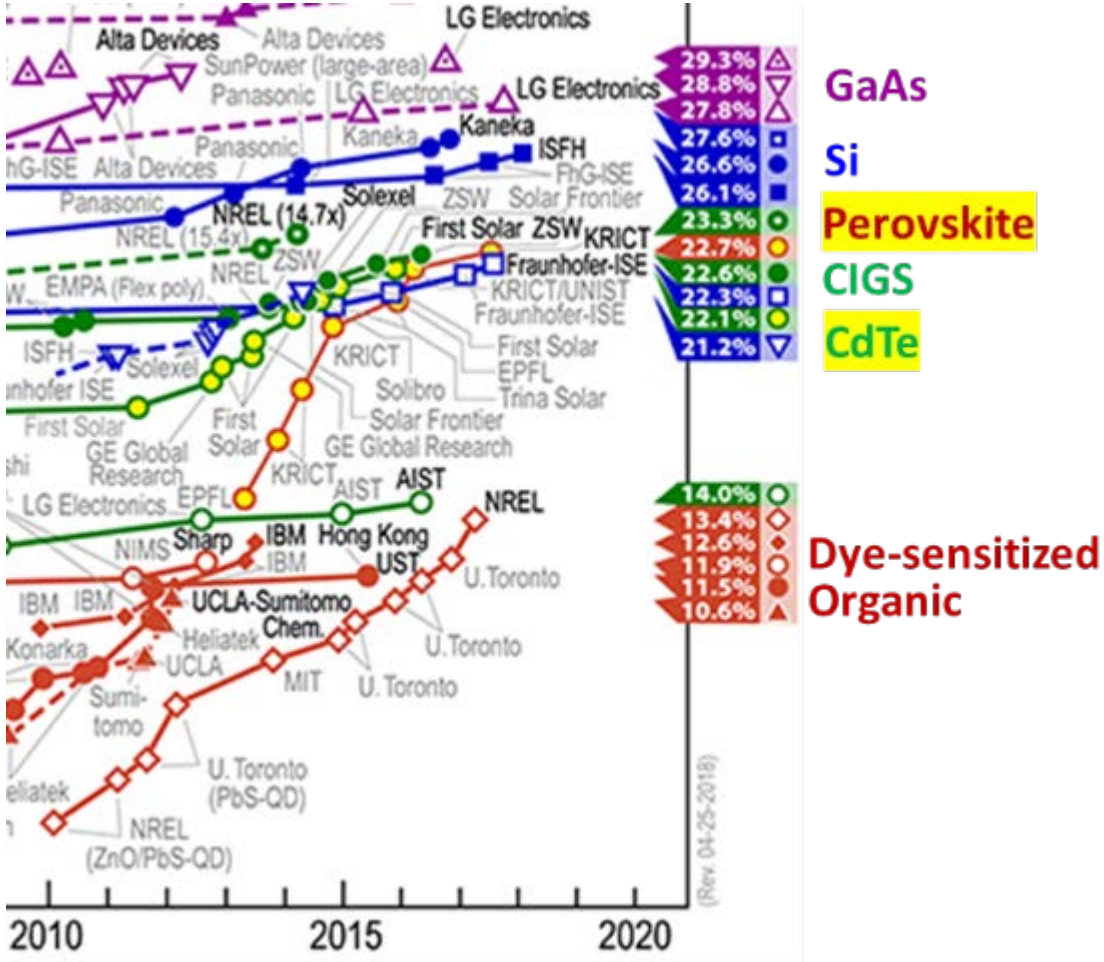
Solar Installations



Bloomberg, Earth Policy Institute
www.earth-policy.org

Advantages of Perovskite Solar Cell Technology

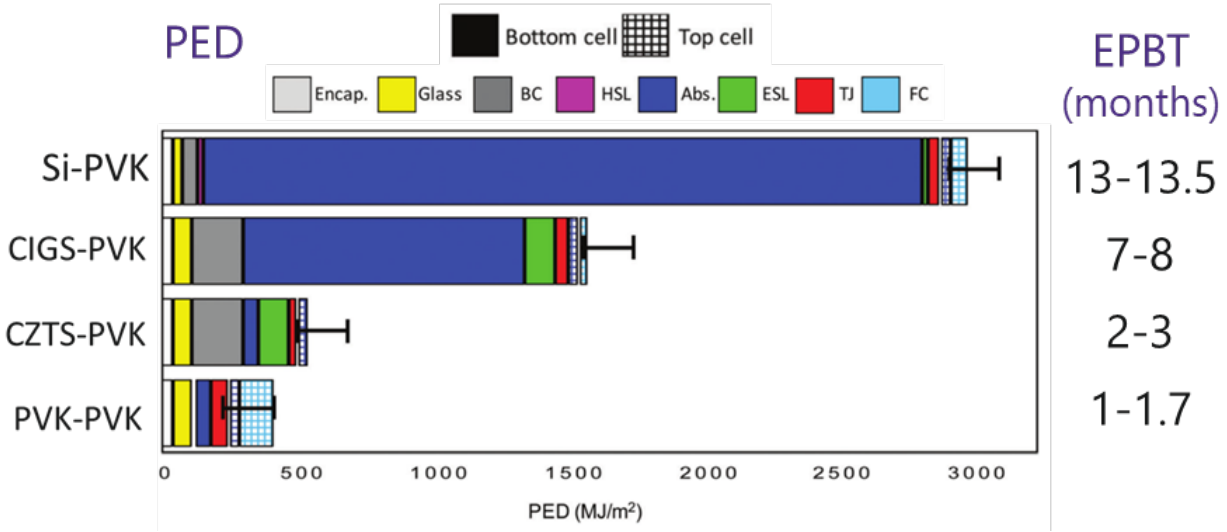
High Efficiency



NREL Efficiency Chart

Low Primary Energy Demand & Payback Time

- Primary Energy Demand (PED): Energy consumed in manufacturing process
- Energy Payback Time (EPBT): Time required for generating back primary energy consumed



Apul et al. *Energy Environ. Sci.* **2017**

PVSC was Identified as the ***Game Changer*** in Renewable Energy

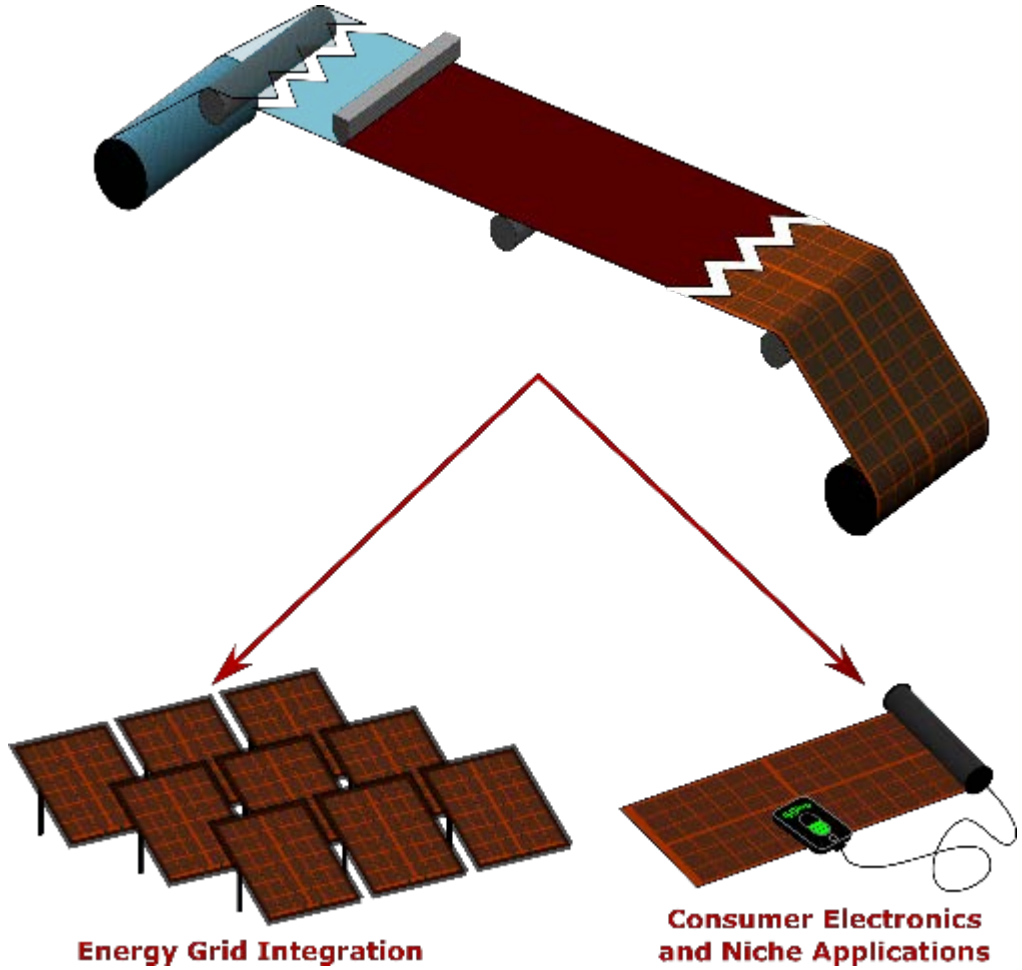
Perovskite Solar Cells: A new generation of solar-cell materials, cheaper and easier to produce than those in traditional silicon cells, garnered plenty of attention this past year. ***Science, top 10 breakthrough of 2013***

EU has funded 45 perovskite projects: including ***six "EUR 5 million" projects***: CHEOPS, ESPResSo, APOLO, GotSolar, MAESTRO, PERTPV etc.

Perovskite solar cell is listed as a strategic project by National Natural Science Foundation of China for 2017. **国家自然科学基金 2017 重大项目**

Perovskite solar cell is Listed as a ***strategic project in the National Energy Technology Plan for 2016-2020***. **国家能源局 《能源技术创新"十三五"规划》**
-- 钙钛矿太阳能电池 被列为集中攻关项目

Potential for Printable Perovskite Solar Cells



Low Manufacturing Costs
High throughput processing

Tunable Material Properties
Molecular and composition engineering

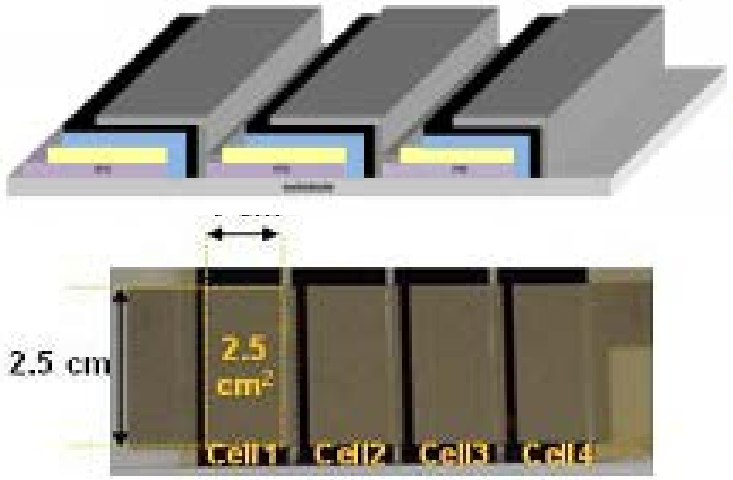
Low Environmental Impact
Benign processes with low energy intake

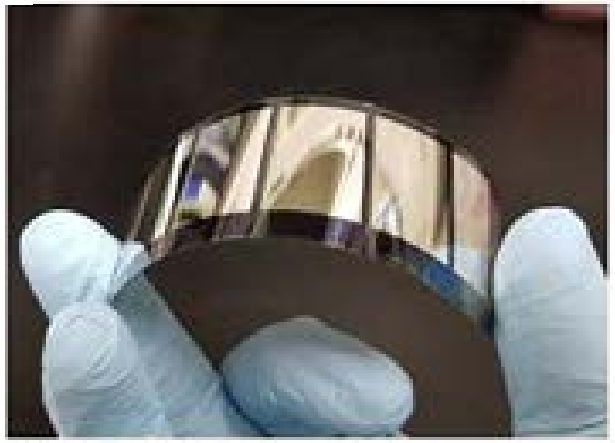
Versatile Form Factor
Lightweight, flexible and portable

Multiple Applications
Building-integrated and semi transparent

Jen et al. *J. Phys. Chem. Lett.* **2016**

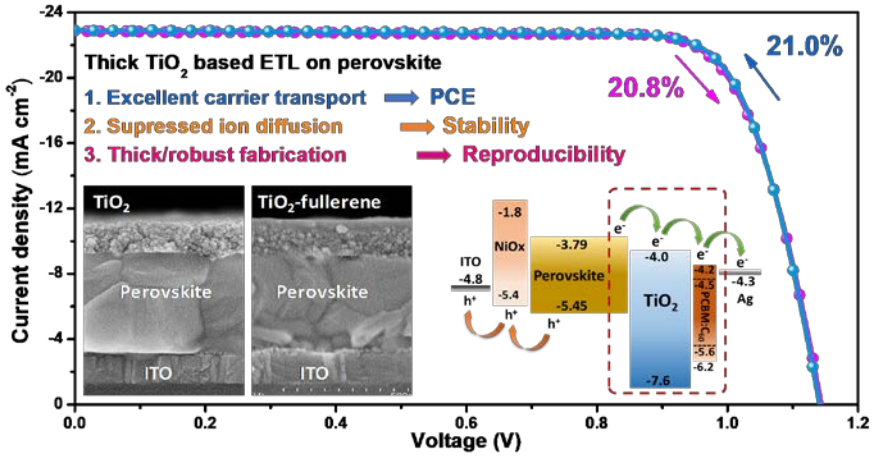
Semi-Transparent Solar Cells for Building Integration PV



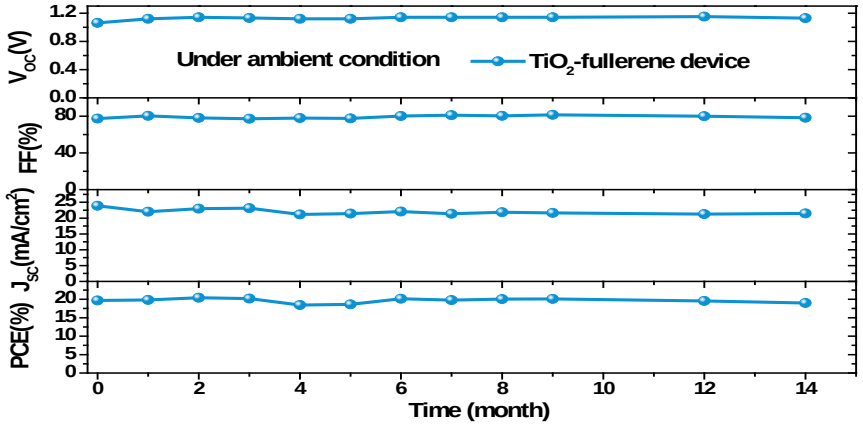


Highly Efficient and Stable PVSC

High PCE without Hysterisis



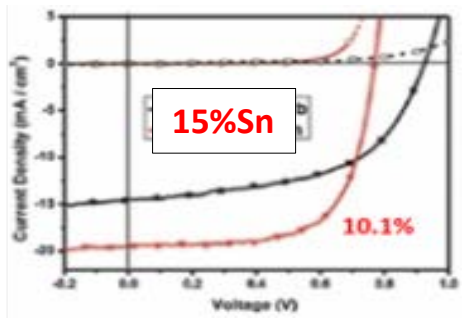
Long-Term Device Stability



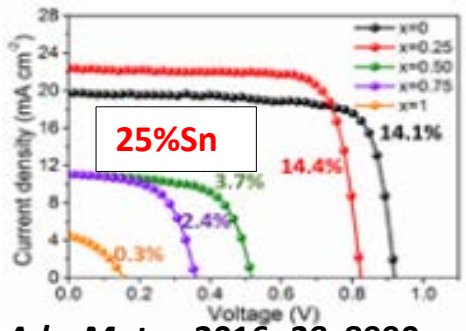
Jen & Choy *et al*, submitted

Pb-Free PVSC

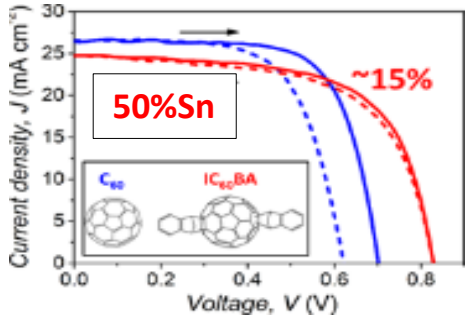
Replace Pb to Address Toxicity Concern



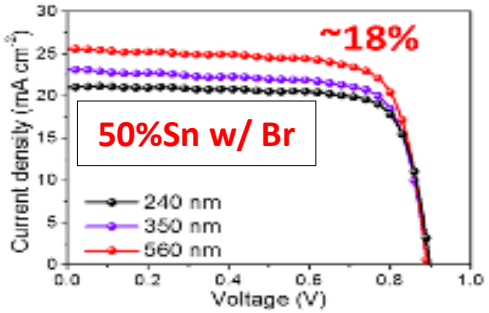
Adv. Mater. 2014, *26*, 6454



Adv. Mater. 2016, *28*, 8990

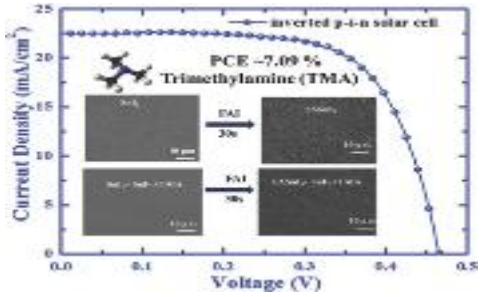


Adv. Mater. 2017, *29*, 1702140



Adv. Mater. 2017, *29*, 1704418

Pure Sn

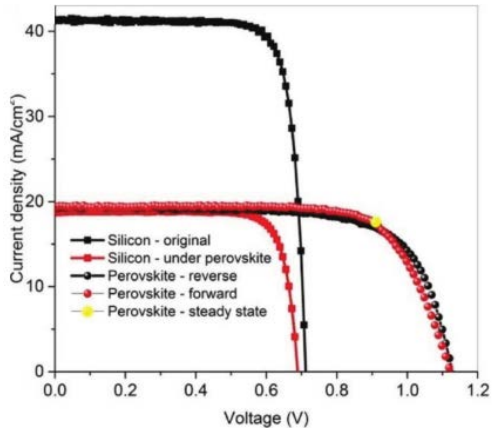


Adv. Mater. 2017, *30*, 1703800

Jen Group

Prospects of Perovskite Tandem Solar Cells

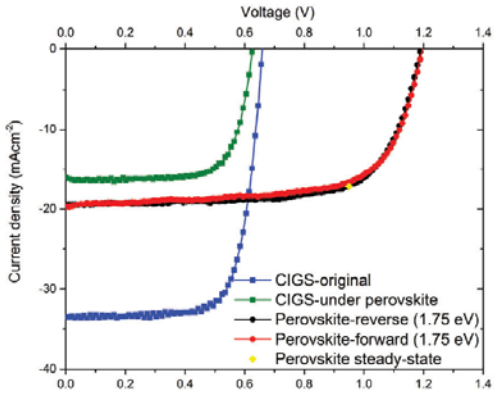
Silicon-Perovskite Multi Junction



	PCE (%)
Silicon Single Junction	23.9
Perovskite Single Junction	16.0
Silicon-Perovskite Multi Junction	**26.4**

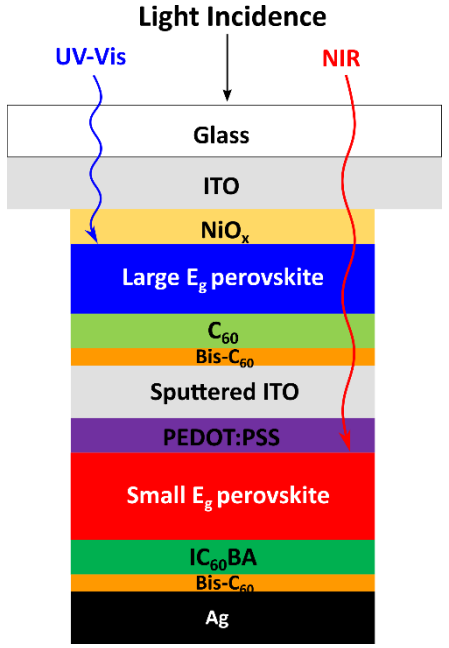
Catchpole *et al.*, *Adv. Energy Mater.* **2017**

CIGS-Perovskite Multi Junction

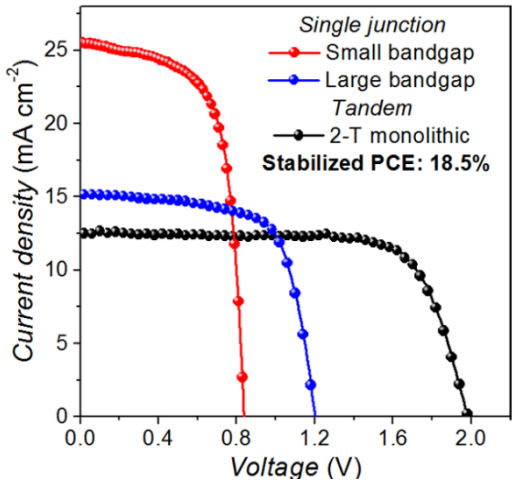


	PCE (%)
CIGS Single Junction	16.5
Perovskite Single Junction	16.0
CIGS-Perovskite Multi Junction	**23.4**

Catchpole *et al.*, *Energy Environ. Sci.* **2017**



Perovskite-Perovskite Multi Junction



Jen *et al.*, *Adv. Mater.* **2017**

$V_{oc}/V_{oc,SQ}$	**0.92**	**0.87**

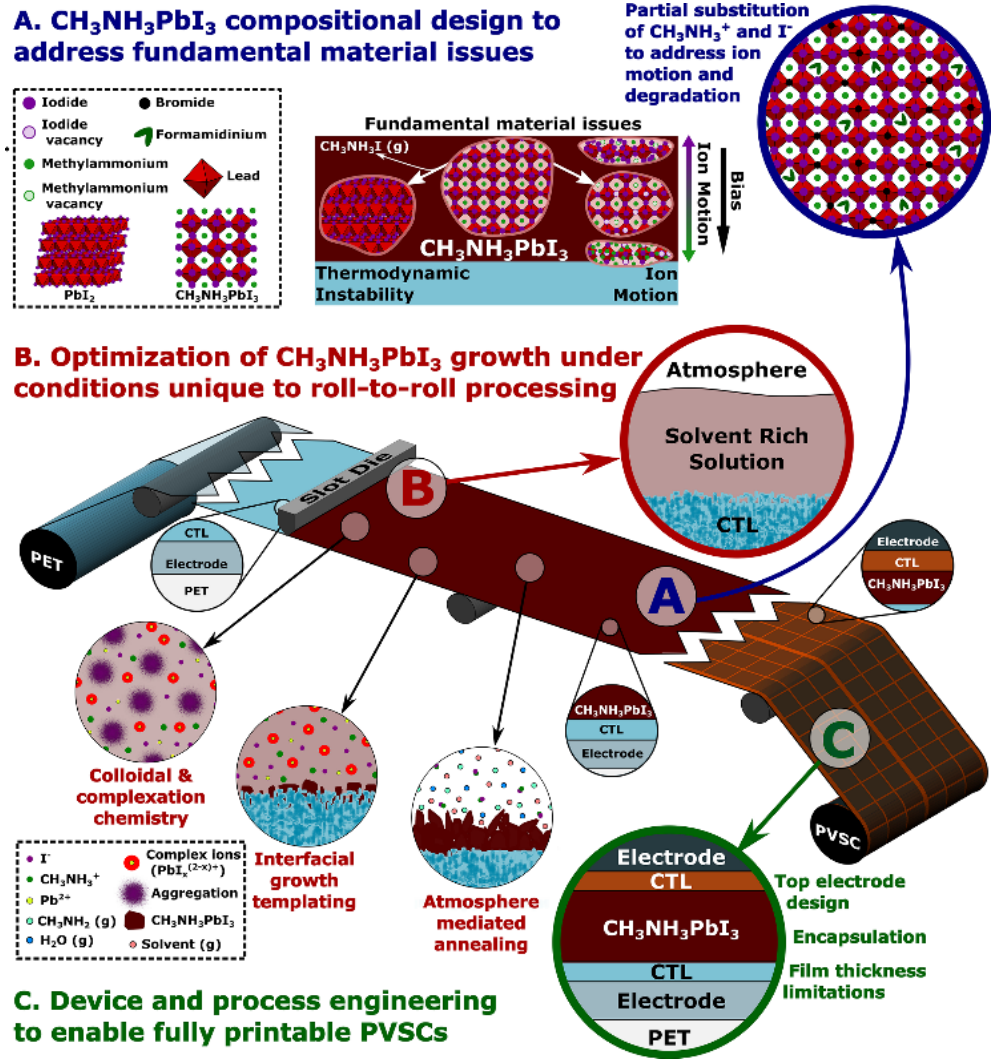
Jen *et al.*, *Nano Lett*, **2018**

2-T Perovskite-Perovskite Tandem Performance. Using V_{oc}'s achieved and best reported J_{sc} & FF:

V_{oc} * J_{sc} * FF = 2.19 * 15 * 0.73 **~24% PCE**

Challenges and Considerations in Commercializing Printable Solar Cells

- **Scalability**
  - Large scale R-2-R printing in ambient
- **Durability**
  - Encapsulation
  - IEC Tests
    - -40°C to +85°C for 200 cycles
    - -40°C to +85°C & 85% RH for 10 cycles
    - +85°C & 85% RH for 1000 h
- **Sustainability**
  - Environmental Toxicity
  - Green Solvent Processing
  - Material Utilization
  - Recycling and End-of-life



Jen *et al. J. Phys. Chem. Lett.* **2016**

Application Landscape for OPVs and Perovskite PVs

OPV – New Form Factor, Non-Toxic

Automobile and Building Integrated PV (BIPV)

Wearable, Portable Power Source

Best Application: ST-OPV

Solar Farm On-Grid Power

Perovskite PV or Perovskite/Si, CIGS Tandem
- **High PCE**
- **Rural area**

Target : PCE >30%

Performance

1-100 W

100W – MW

10 MW - GW

Power Generation