Printable Solar Cells for Transformative Clean Energy and Sustainable Society

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ENERGY IMPACTS MANY THINGS

ENVIRONMENT


CLEAN WATER
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ECONOMY

THE WALL STREET JOURNAL.

BUSINESS

Tesla Plans $5 Billion Battery Factory

HUMAN HEALTH

SECURITY

OUR ENERGY APPETITE

Will double from 15 to 30 TW/yr in 2050

An Integrated Energy Solution Should Include:

Clean Energy Sources

Better Energy Storage

Efficient Energy Usage

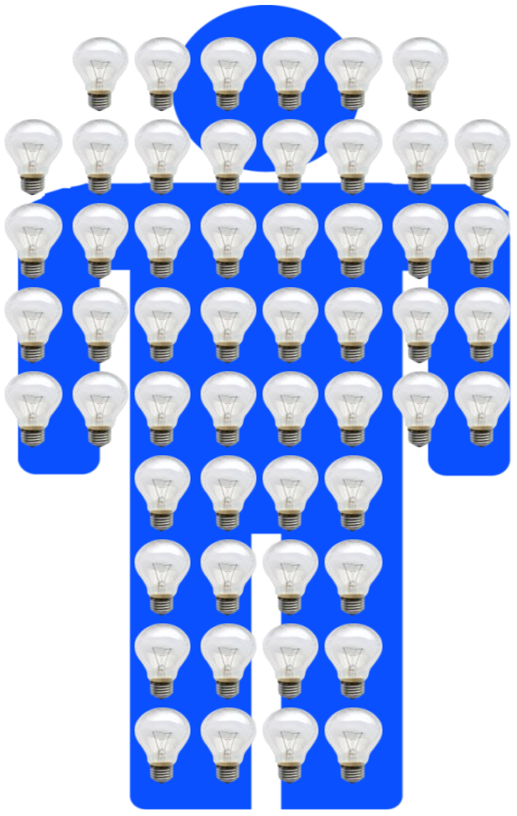
Better Distribution

Need to Balance Energy Demands and Environmental Sustainability

China is #1 in energy consumption in the world: 6.88TW (1.44 billion people)

Per person, this corresponds to:

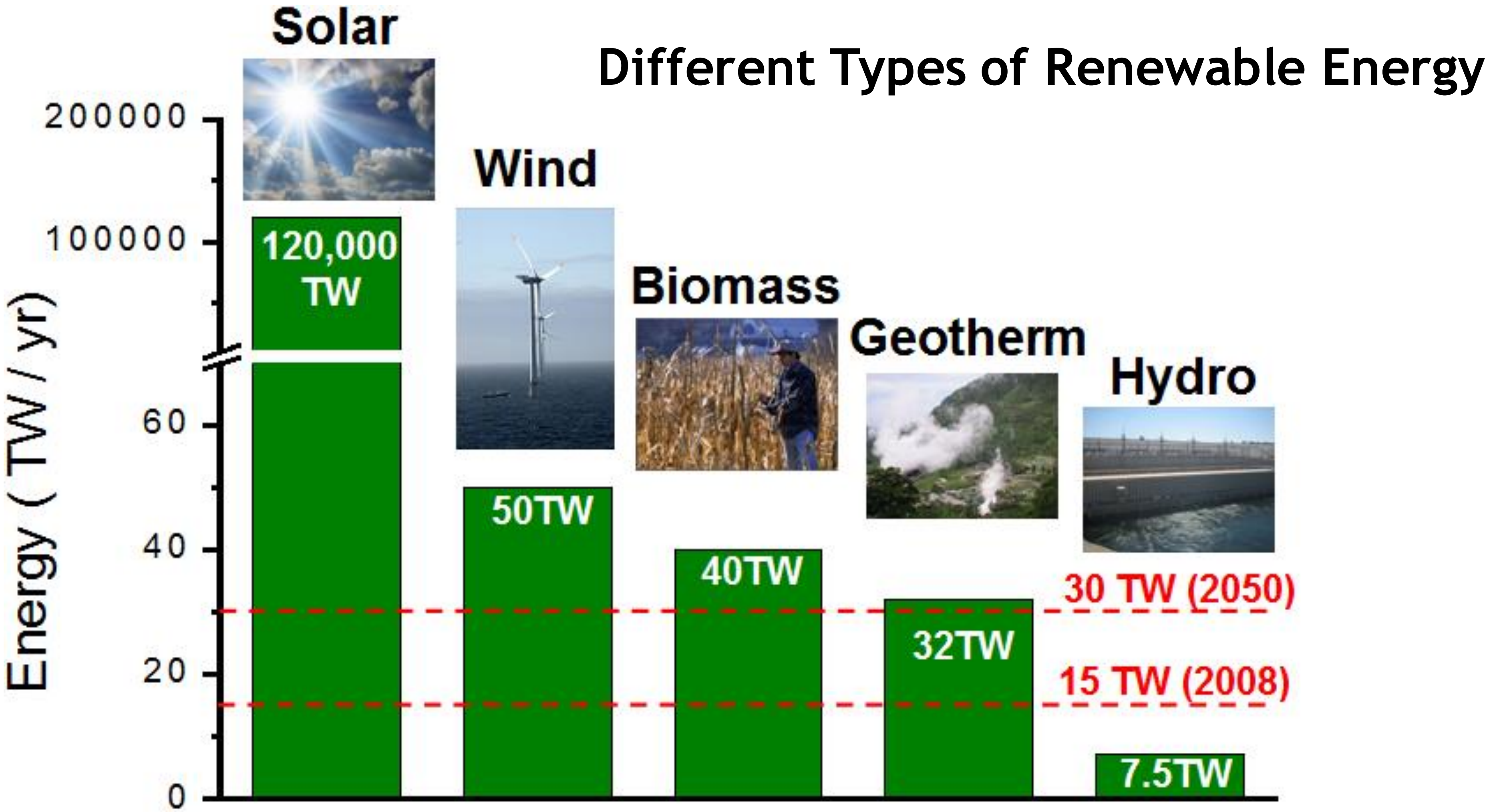
- 53 100-Watt incandescent light bulbs on continuously....or
- 1,436 gallons of oil....or
- 12,920 lbs of coal



This translates to 10,432,751,400 tons of CO_2 emission (29.2% in the world and 7.38 tons per person) !

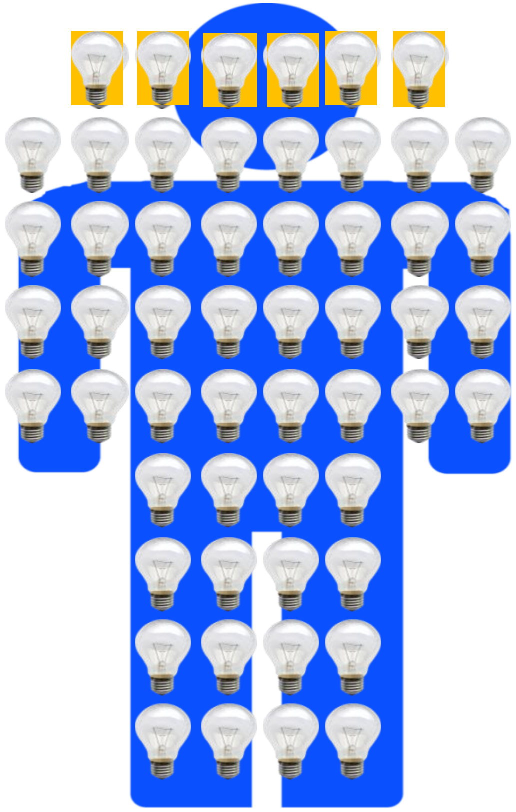
What are the Potential Solutions to Meet the Carbon Neutral Demand in 2050 ?

Energy in 1 hr of sunlight is ~14 TW. There is ≈600 TW solar energy potential

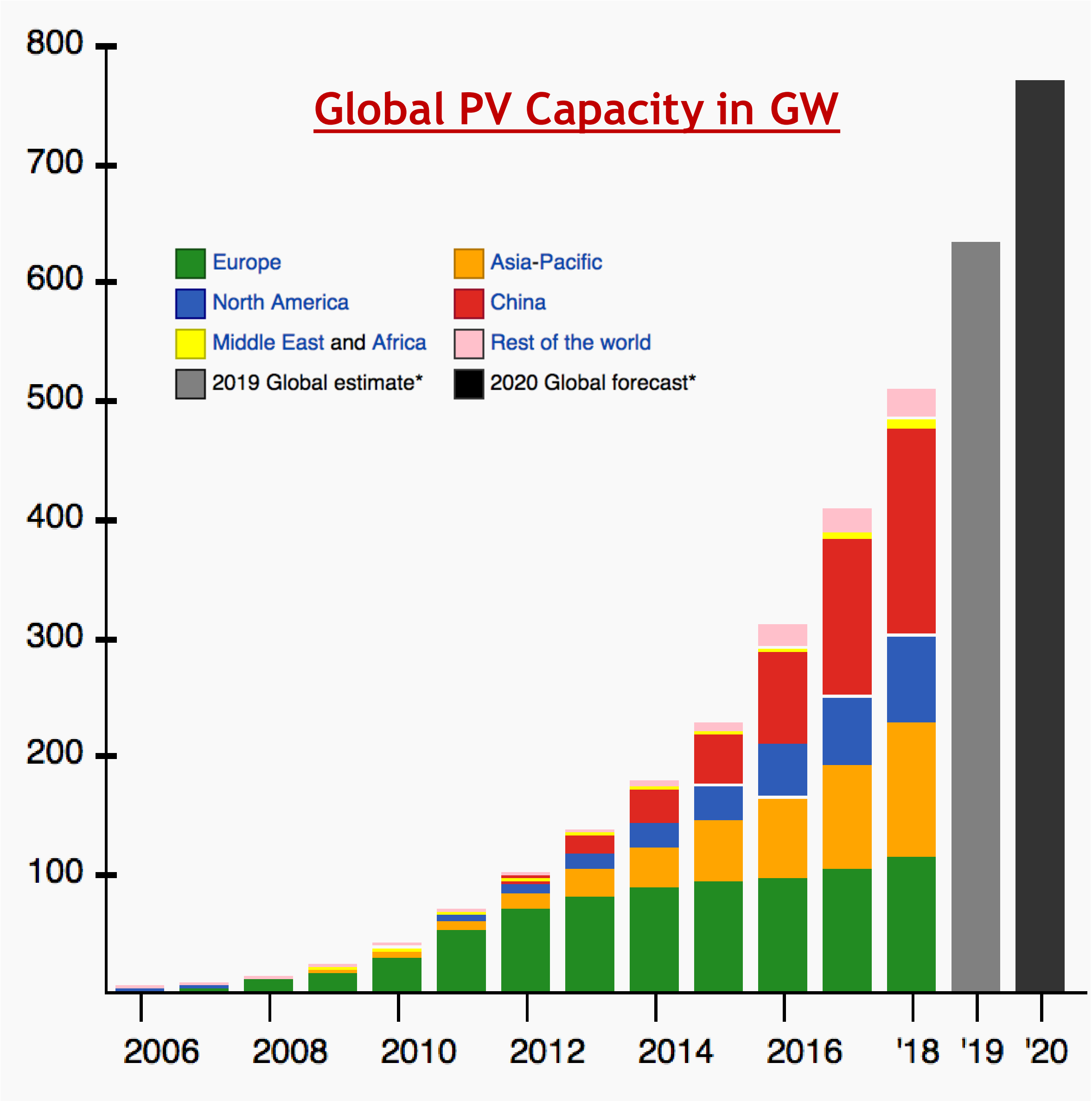


Most of China's Current Renewable Energy Comes from Hydropower, Solar, and Wind

- China is ***#1*** in the world in electricity production (***790 GW***) from renewable energy sources (more than twice that of US), which is account for ***11.5%*** of total energy it consumed.
- Hydropower capacity: 356 GW
- Solar power capacity: 240 GW
- Wind power capacity: 224 GW
- ***China's renewable energy sector is growing faster than its fossil and nuclear power.***



Worldwide PV Deployment is Rapidly Growing



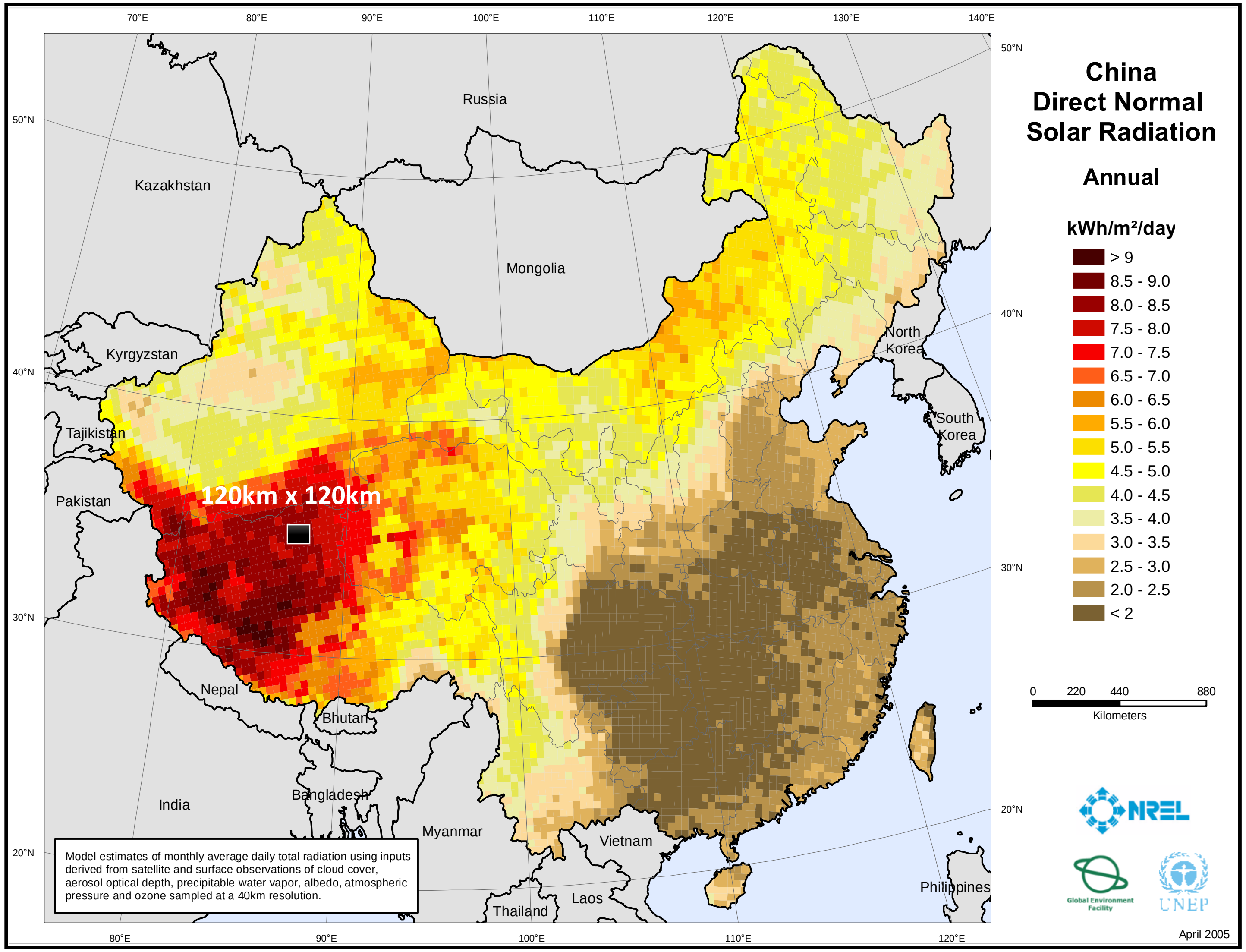
- By 2030, worldwide PV market ~ *1700 GW* (1.7 TW)
- In 2020 alone, China added ***48 GW*** PV capacity
- By 2030, China will reach ***650 GW*** solar PV
- In HK, the installed PV capacity is *~6.3 MW* in 2017, which is ***~0.01%*** of its total energy consumption
- It can reach *1% (~500 MW)* if all the available rooftops in HK are installed with PV panels

Solar Cells (10% Efficiency) Covering (120 km)^2 of Land Would Provide 6.88 TW Energy for the Whole China

5 kWh per square meter per day of incoming solar energy.

At 10% efficiency, energy contained in 60 square meters could power the utilities of a house (30 kWh).

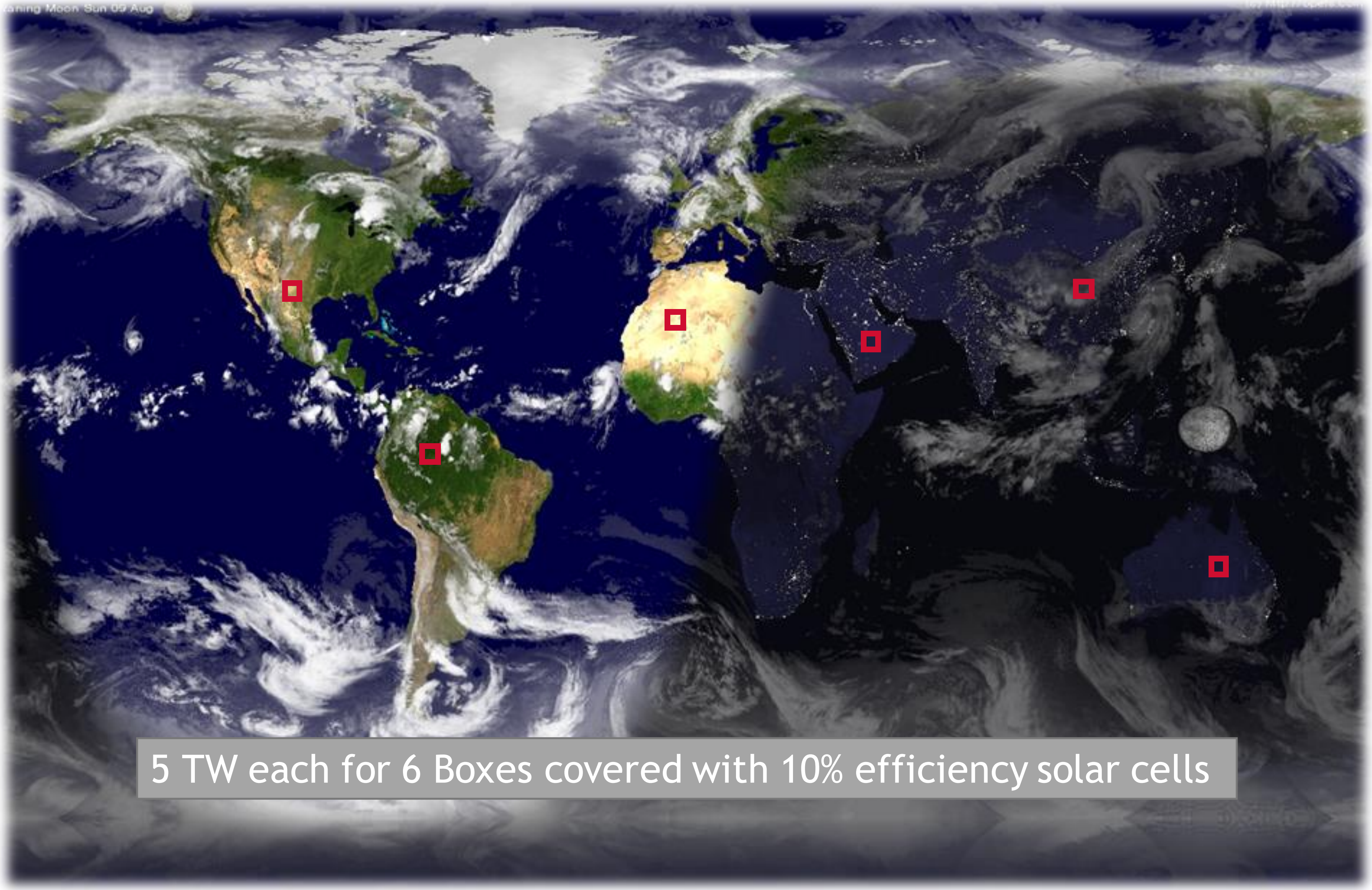
Solar energy falling on the total area of rooftops and roads meets total energy demand for China!



http://en.openei.org/wiki/File:NREL-china40kmdir.pdf

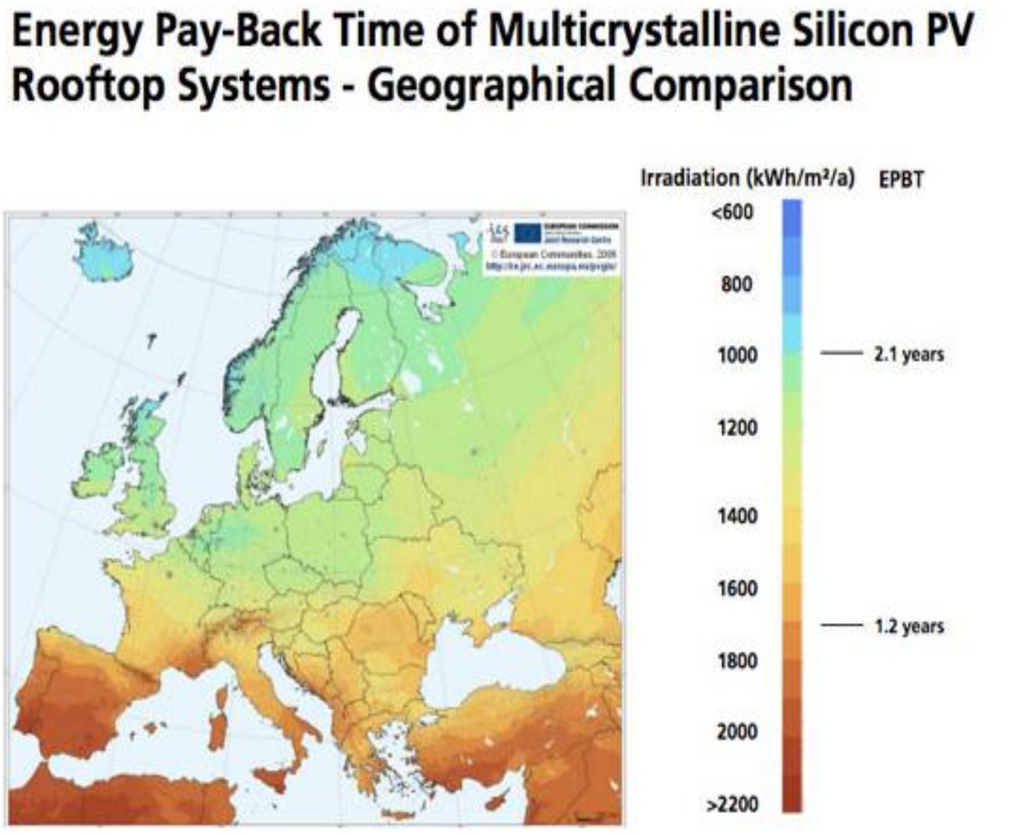
Potential Land Required for 30 TW Solar Power

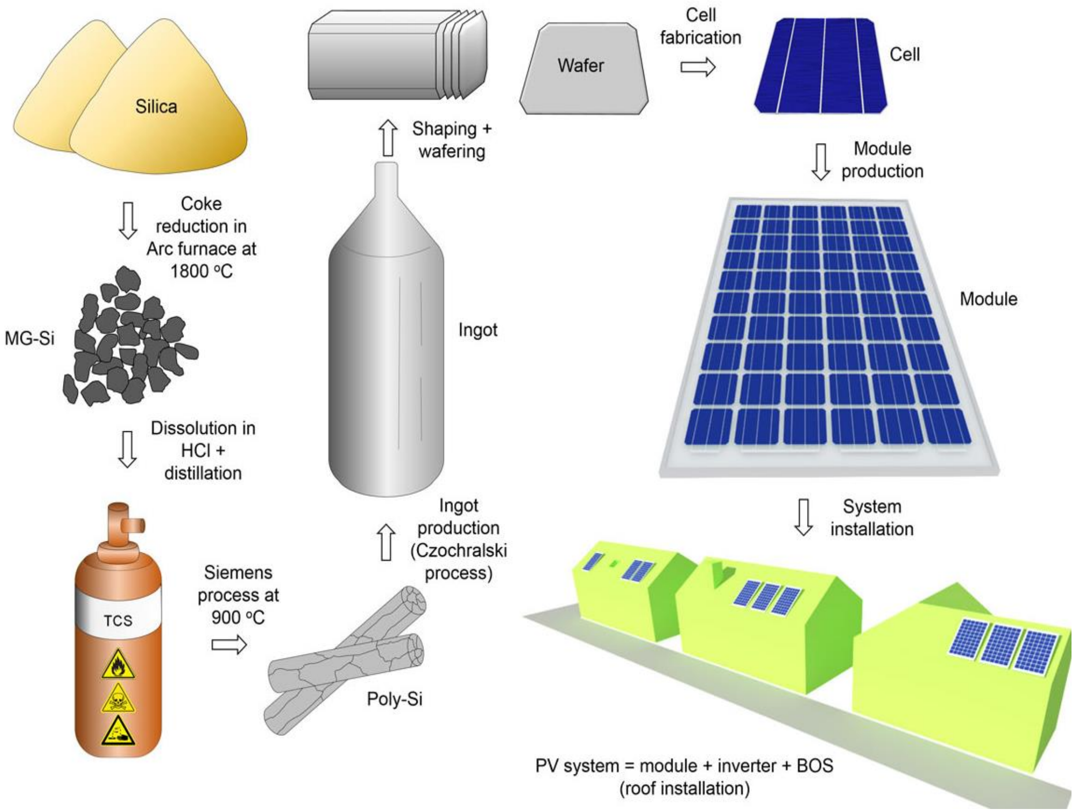
CityU
香港城市大學
City University of Hong Kong



Unfortunately, to achieve Tera Watt scalability we need to burn more fossil fuels in order to make enough silicon solar modules

***Energy payback time (EPBT)** of a power generating system is the time required to generate as much energy as is consumed during production and lifetime operation of the system*





(Good News!) New Discoveries Beyond Silicon Semiconductor

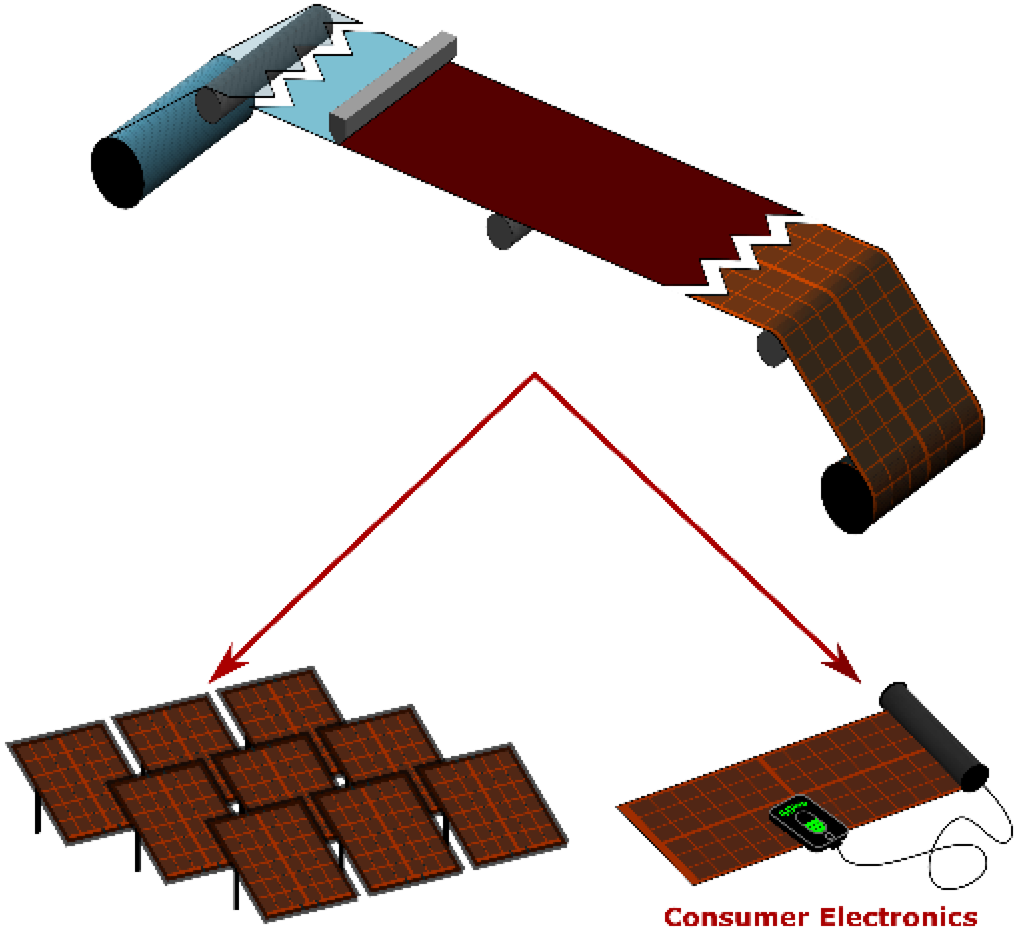
Organic and Perovskite Semiconductors

Advantages:

- Low temperature solution/vapor processible
- Low cost
- Flexible form factors
- Broad applications in **LEDs**, ***displays***, FETs, ***lighting***, ***PV***, ***BIPV***, detectors, sensors, ***integrated photonics*** for ultrafast information processing, hybrid silicon photonics, THz
- Potential billion/trillion dollars industry

Potential for Printable Solar Cells

Organic Solar Cells - Perovskite Solar Cells



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

Low Manufacturing Costs
High throughput processing

Tunable Material Properties
Molecular and composition engineering

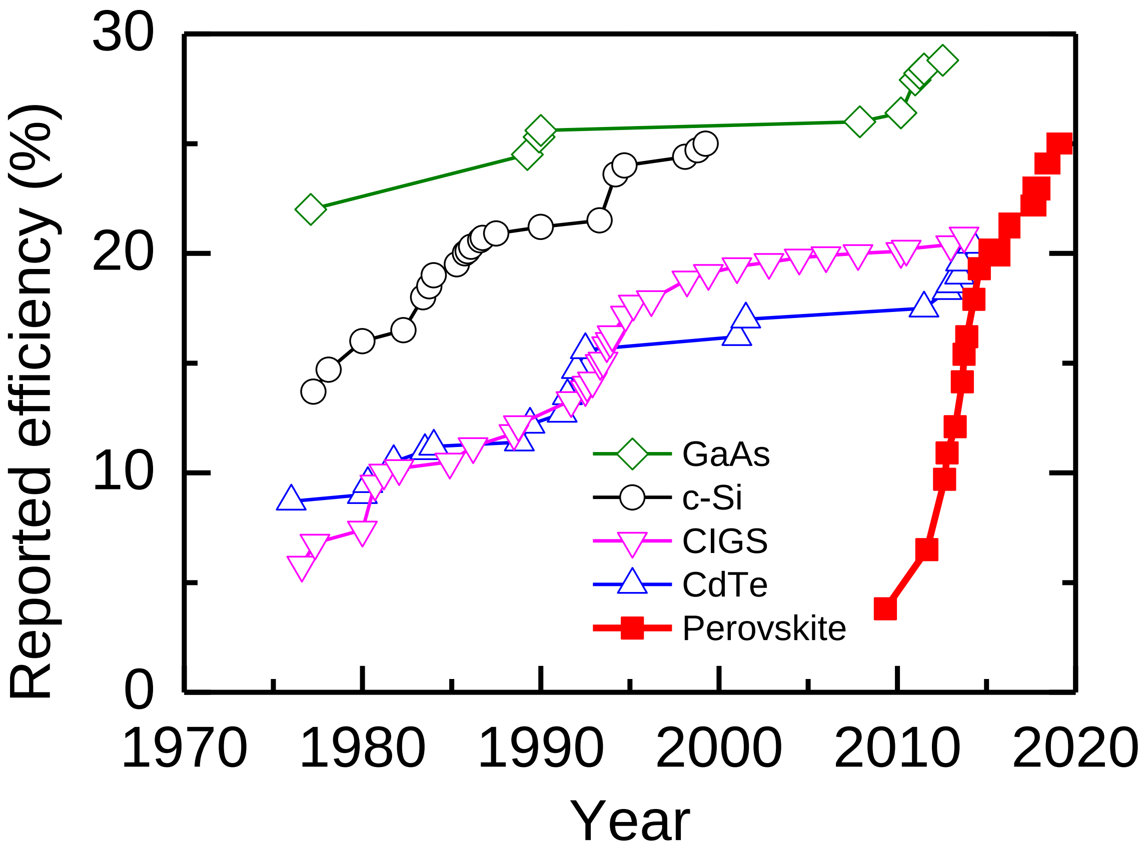
Low Environmental Impact
Benign processes with low energy intake

Versatile Form Factor
Lightweight, flexible and portable

Multiple Applications
Building-integrated and semi transparent

Rapidly Developing Perovskite Solar Cell Technology

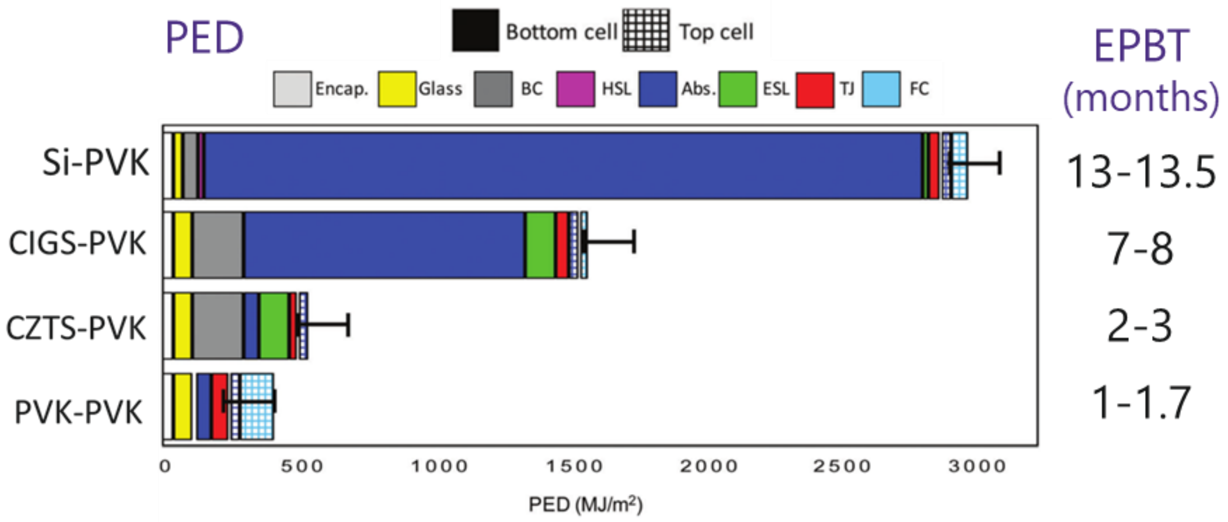
High Efficiency



Courtesy from H. Snaith

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

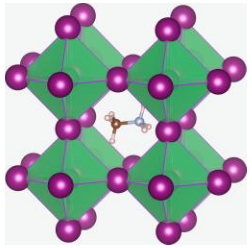


Apul et al. *Energy Environ. Sci.* **2017**

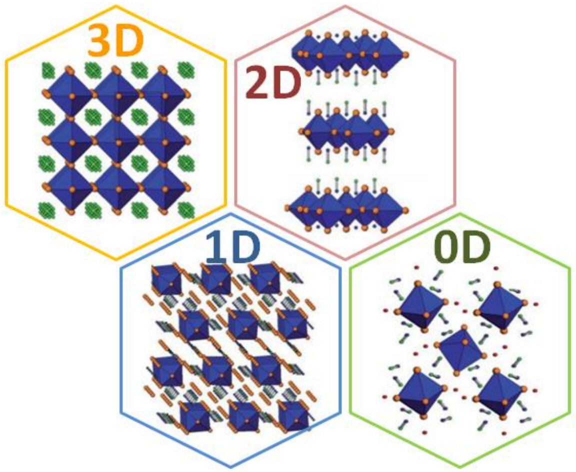
Hybrid Perovskites: A Nearly Perfect Family of Semiconductors

Superior Properties of Perovskites

- Tunable bandgap with a diverse range of composition
- Long carrier life time (up to μs)
- Superior carrier mobility (about 40 cm^2/Vs for $MAPbI_3$)
- Wide range of absorption (375-1150 nm)
- Light-weight
- Easy-processing and low cost



Structure of Perovskite

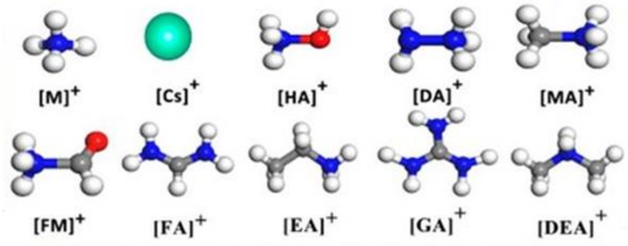


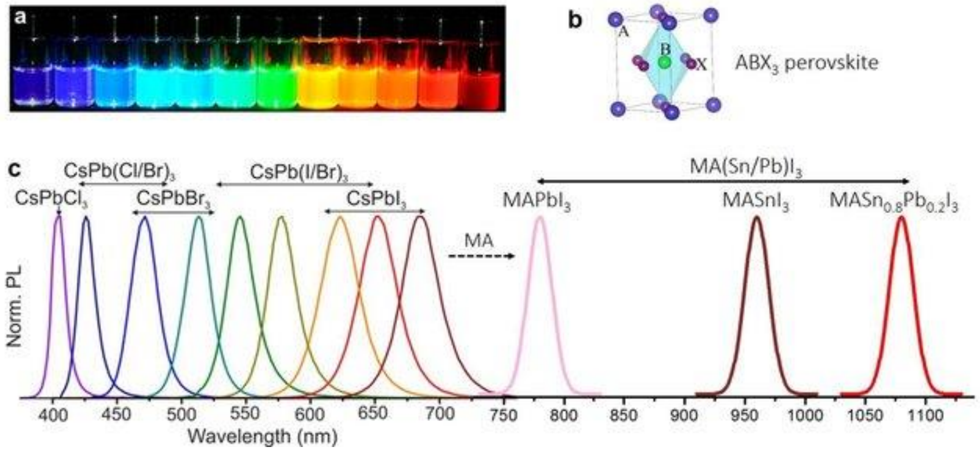
ABX_3

A= $CH_3NH_3^+$, $NH_2CHNH_2^+$, Cs^+…

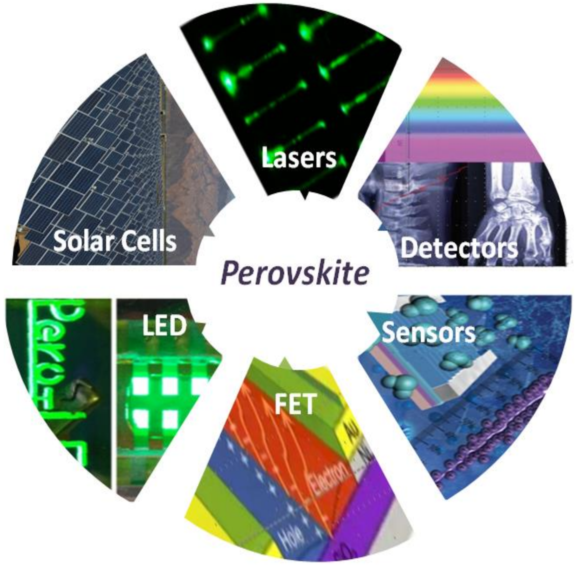
B= Ge^{2+}, Sn^{2+}, Pb^{2+}…

X= I^-, Br^-, Cl^-…





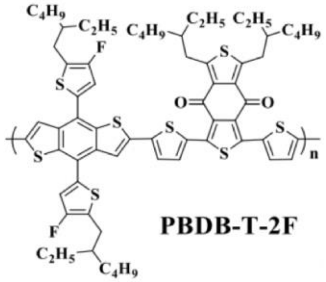
Applications



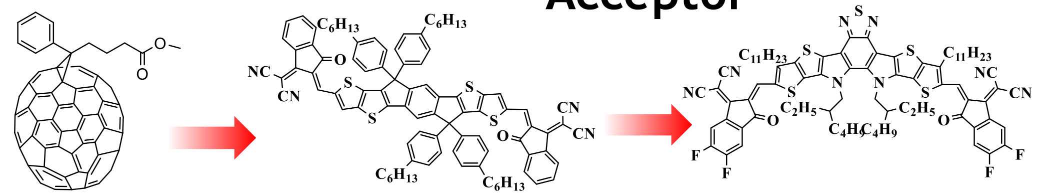
Rajagopal & Jen, *Adv. Mater.* **2018**, *30*, 1800455
(Review in the **Hall of Fame** Special Issue)

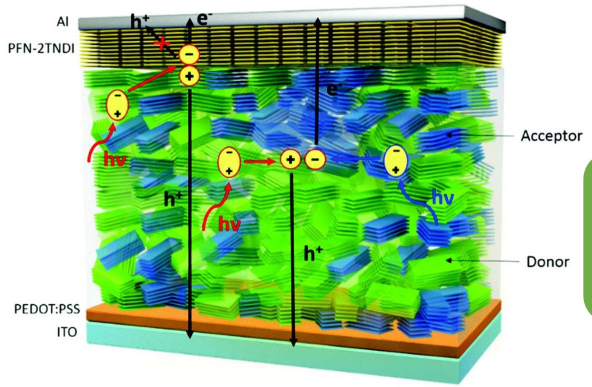
Donor-Acceptor Based Organic Solar Cells

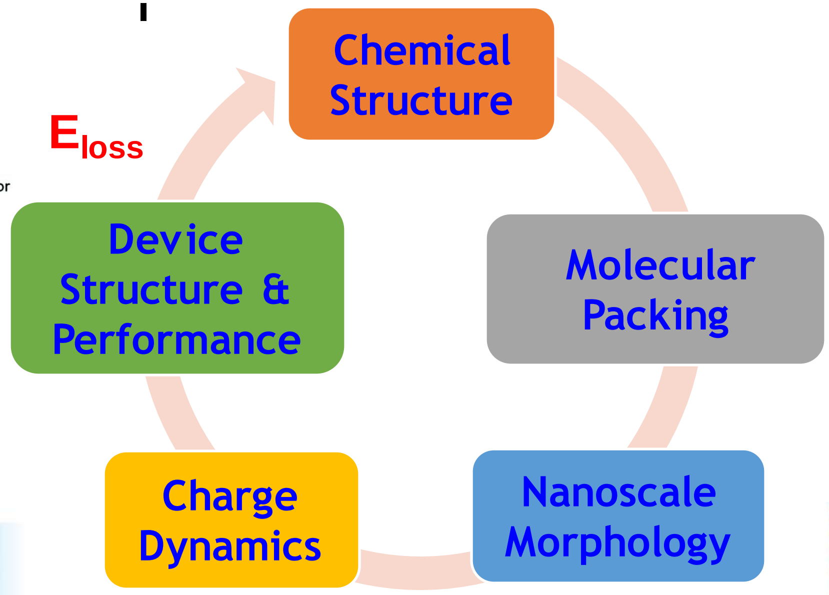
Donor



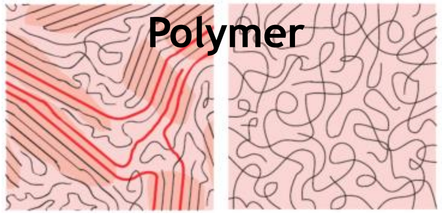
Acceptor

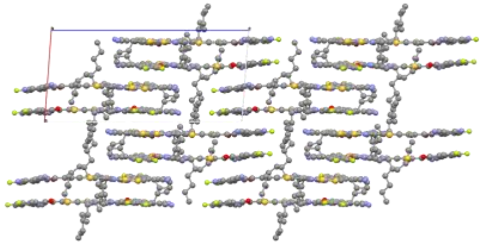


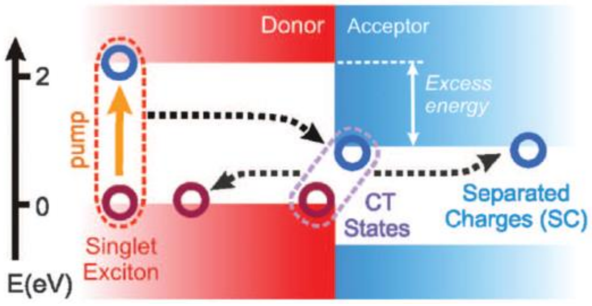


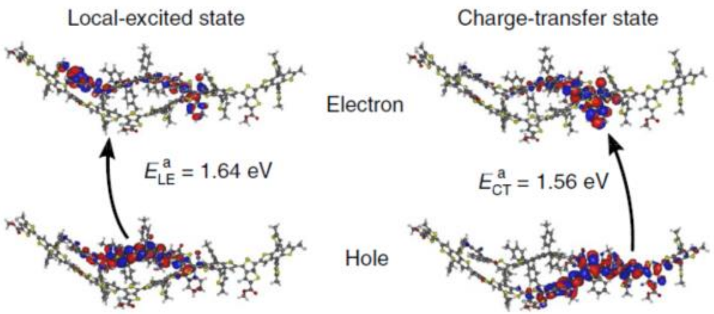


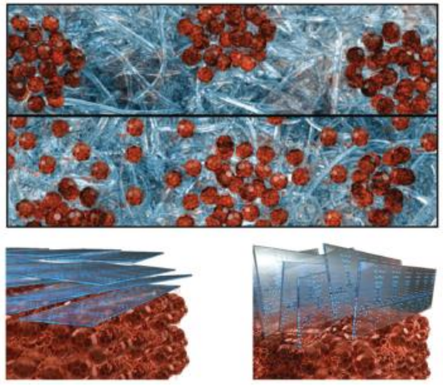
Polymer





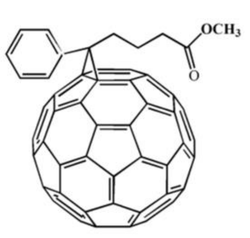






Yip @ CityU

1st Generation



PCBM

- **Fullerene Acceptor**

✓ Last 20 Years (PCE ~11%)

✓ Isotropic/High electron mobility

✓ Limited absorption and energy level

✓ Morphological stability and lifetime

2nd Generation

- **Non-Fullerene Acceptor**

✓ Recent ~5 Years (PCE: ~18%)

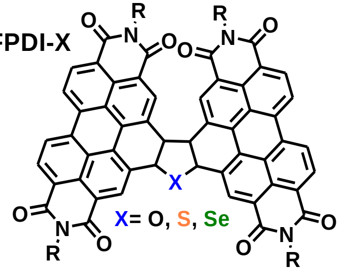
✓ Rational Molecular Design

✓ Device Engineering

✓ Interfacial Modulation

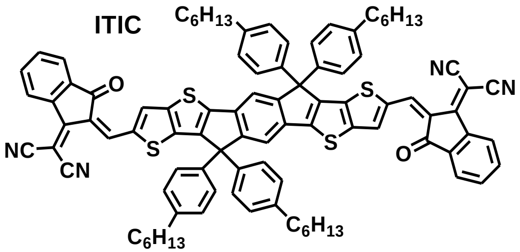
Typically Chemical Structures for Non-Fullerene Acceptors

FPDI-X



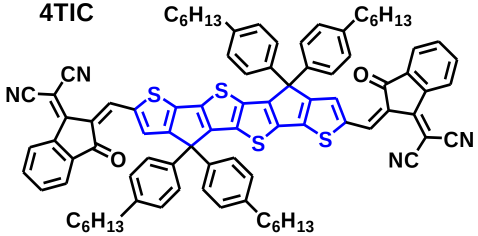
PCE: 6.72% A. Jen., Adv. Mater. 2016, 28, 951.

ITIC

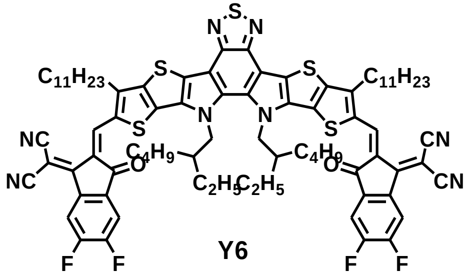


PCE: 6.8% X. Zhan, Adv. Mater. 2015, 27, 1170.

4TIC

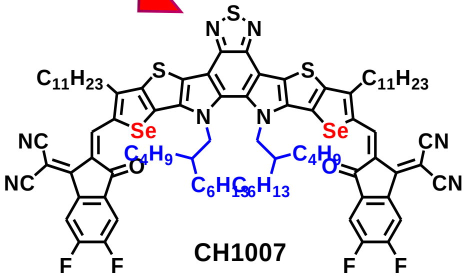


PCE: 10.43% A. Jen, Chem. Mater. 2017, 29, 8369.
PCE: 11.07% A. Jen, Adv. Energy Mater. 2018, 8, 1702831.
PCE: 13.20% A. Jen, Chem. Mater. 2018, 30, 5429.



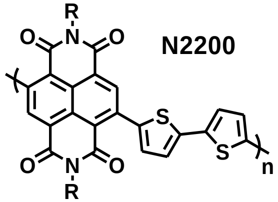
Y6

PCE: 15.7% Y. Zou, Joule, 2019, 3, 1140.



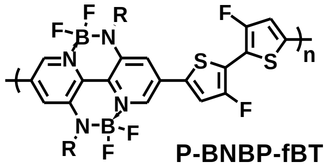
CH1007

PCE: 17.08% A. Jen., J. Am. Chem. Soc. 2020, 142, 36, 15246.



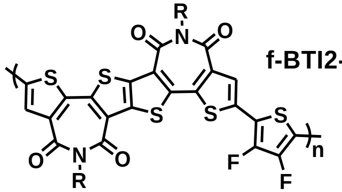
N2200

A Facchetti, Nature, 2009, 457, 679.
PCE: 8.27% Y. Li, Adv. Mater. 2016, 28, 1884.
PCE: 9.16% F. Huang, Energy Environ. Sci. 2017,10, 1243.
PCE: 9.27% F. Huang, Sci. China. Chem. 2018, 61, 427¨C436.



P-BNBP-fBT

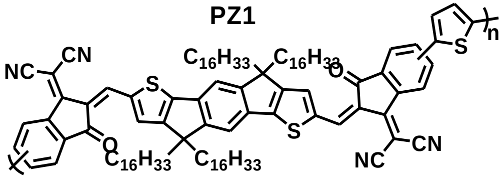
PCE: 6.26% J. Liu, Adv. Mater. 2016, 28, 6504.



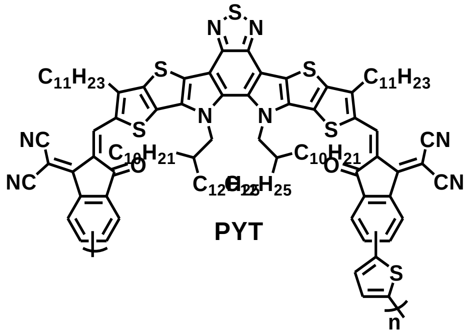
f-BTI2-FT

PCE: 6.85% X. Guo, Angew. Chem. Int. Ed. 2017, 56, 15304.

PZ1



PCE: 9.19% Z. Zhang, Angew. Chem. Int. Ed. 2017, 56, 13503.



PYT

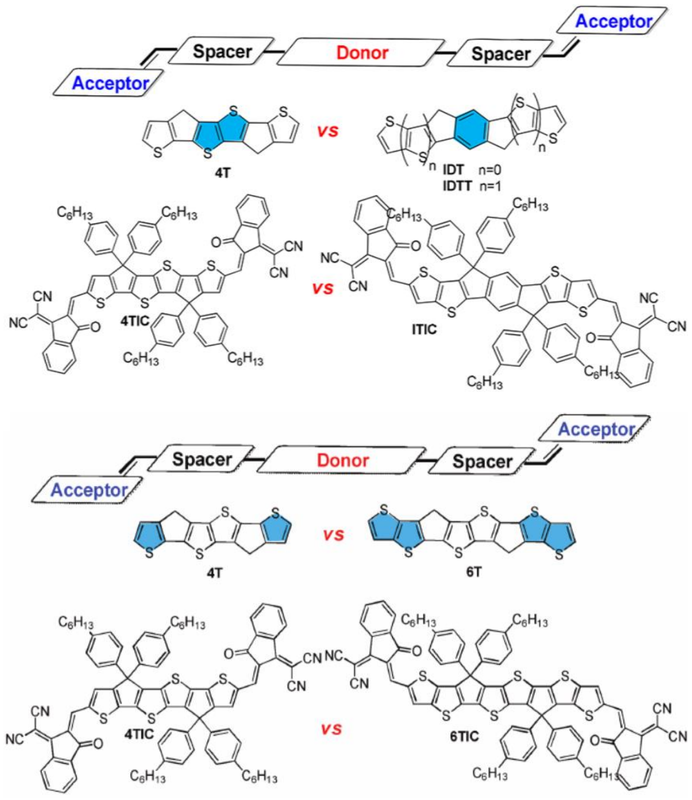
PCE: 14.4% F. Huang, Nano Energy, 2020, 72, 104718.
PCE: 13.4% J. Min, Joule, 2020, 4, 1-17.

Yan, Marder, Wang, Jen, & Zhan *et al. Nature Rev. Mater.* **2018**, *3*, 18003.

Ladder/Fused Aromatics for Small Molecule NF-Acceptors

香港城市大學
City University of Hong Kong

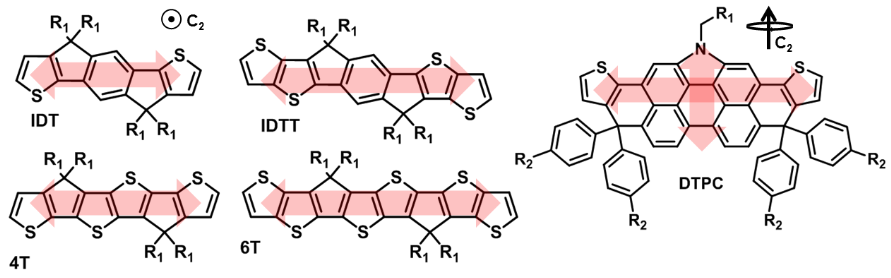
Molecular Design: 1D Rigidified & Fused Central-Ring Extension to Pseudo-2D

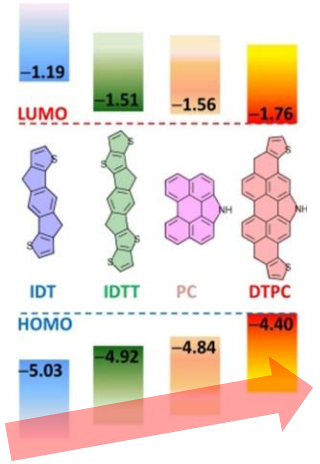


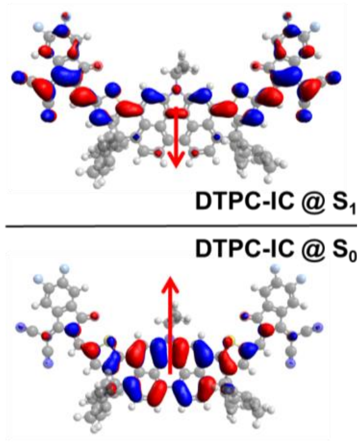
PTB7-Th:4TIC, PCE=10.43%

PTB7-Th:6TIC, PCE=11.07%

Shi & Jen., *Chem. Mater.* **2017**, *29*, 8369.
Shi & Jen., *Adv. Energy Mater.* **2018**, *8*, 1702831.





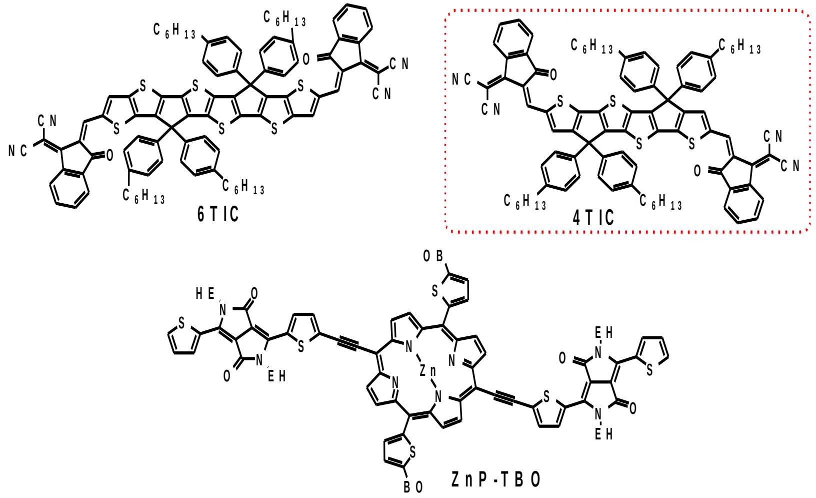


- *1D and 2D extension of D units for ICT*
- *2D extension of the conjugation off the long-axis (A-D-A) could reduce the ICT without directly affecting the bandgaps*

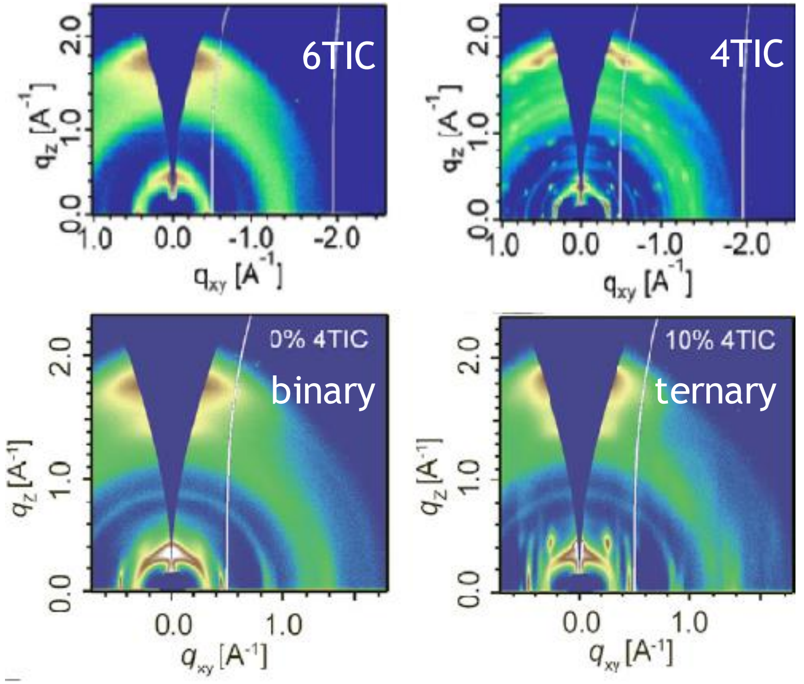
Yao & Jen, *J. Am. Chem. Soc.* **2018**, *140*, 2054.
Nian, Gao & Jen, *Joule*, **2020**, *4*, 2223.

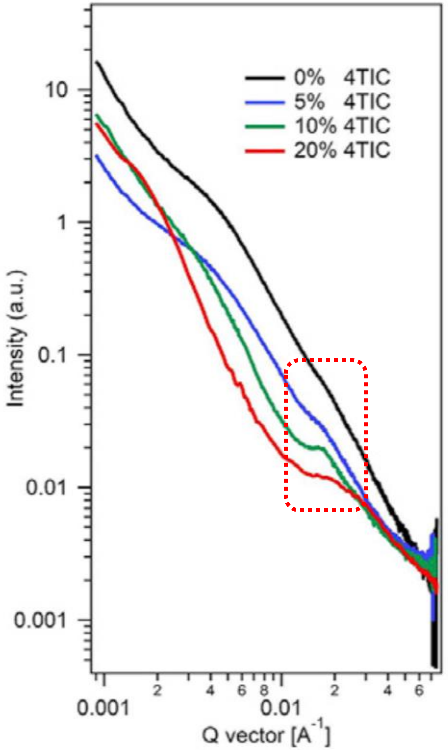
Achieved a Record-High ~16% PCE in All-SM Ternary OSCs

When 10% of the highly crystalline 4TIC is added to 6TIC as additive, it significantly enhances the crystallinity of the blend and maintains the face-on orientation in a proper multi-length scale morphology to improve both charge extraction and recombination in devices, resulting in ***a record-high PCE of 15.9% in all-SM OSCs.***



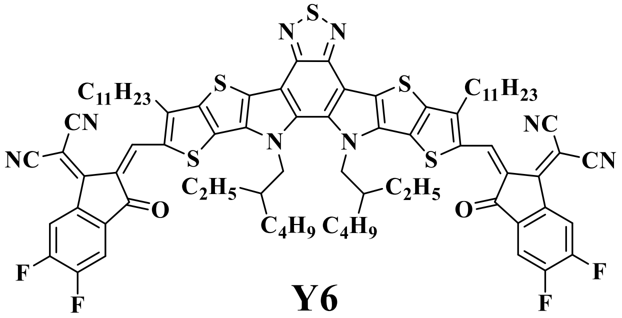
	Voc (V)	Jsc (mA cm^{-2})	FF (%)	PCE (%)
Binary	0.81	23.14	72.23	13.54
Ternary	0.81	25.95	75.57	15.88



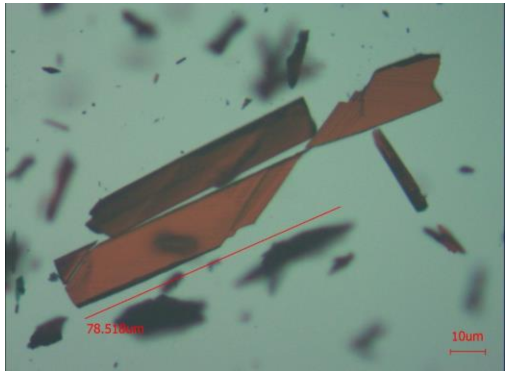


Nian, Gao & Jen, *Joule*, **2020**, *4*, 2223.

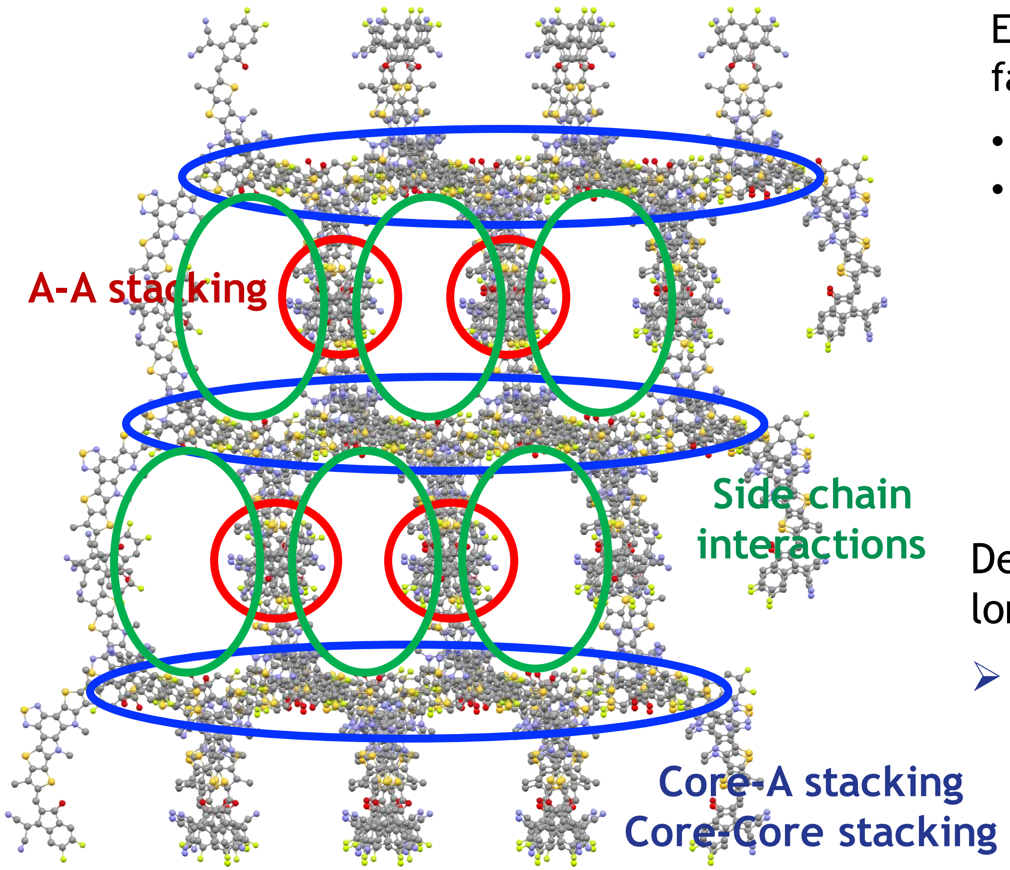
Y6 Crystal Structure - Property Relationship



Y6



Y6 crystal structure



3D ambipolar transport network

Efficient HOMO & LUMO delocalization facilitate ambipolar charge transport

- Electron coupling: max~ 81 meV
- Hole coupling: max~ 74 meV

Pure Y6 film mobilities:

SCLC : μ_e ~ 1x10^{-4} cm^2/Vs
μ_h ~ 6 x10^{-4} cm^2/Vs

Delocalization of exciton enables long exciton lifetime.

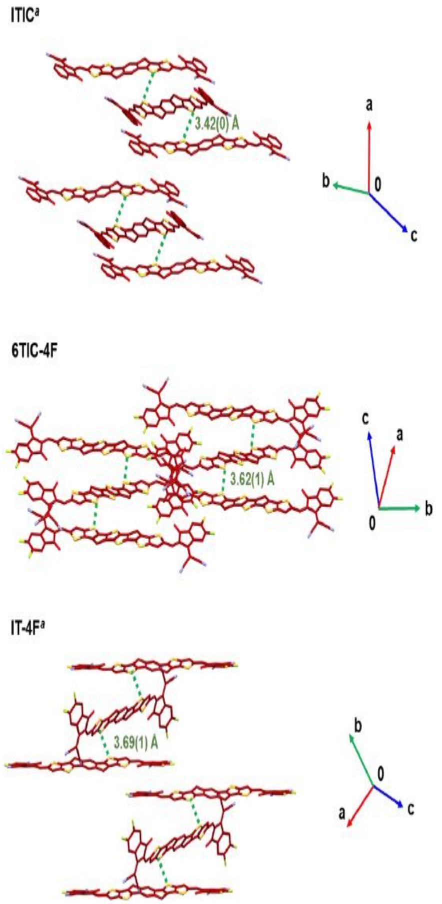
➢ ***Reduced non-radiative loss which will enhance Voc***

Lead to 15.7% PCE

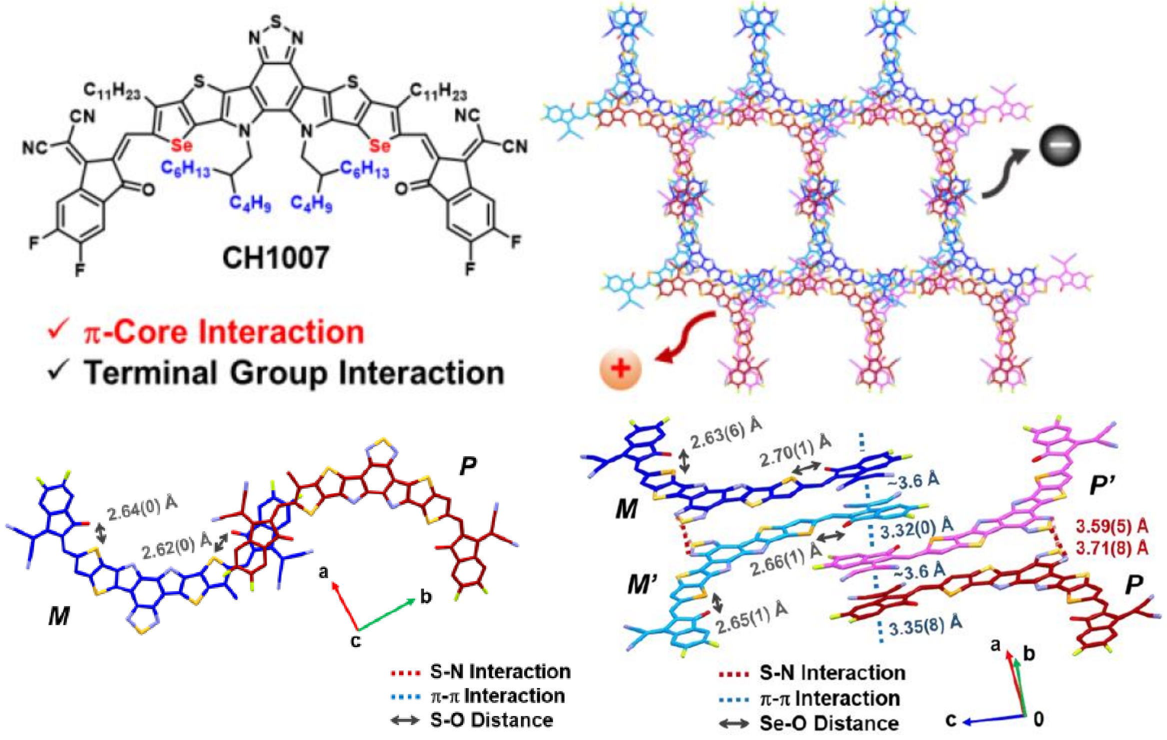
Extended 2D/3D crystal structure

Zhang, Chen, Chow, Zou, Bredas, Yip, et al *Nat. Commun.*, **2020**, *11*, 3943

A Selenium-Substituted Y6 Analog Non-Fullerene Acceptor



The crystallographic study of Y6 and CH1007

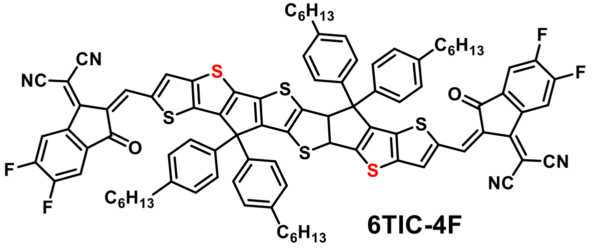


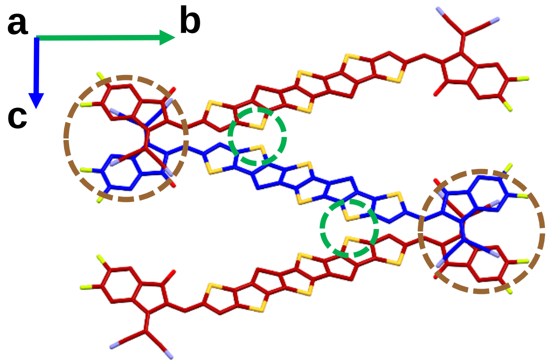
- Achieved **17.08% PCE** based on this narrow bandgap acceptor CH1007 **(1.3 eV)**
- Single crystals help reveal the packing behaviors of this family of acceptors (compare to ITIC)
- A 3D interpenetrated network *(π-π core interactions and terminal group interactions)*

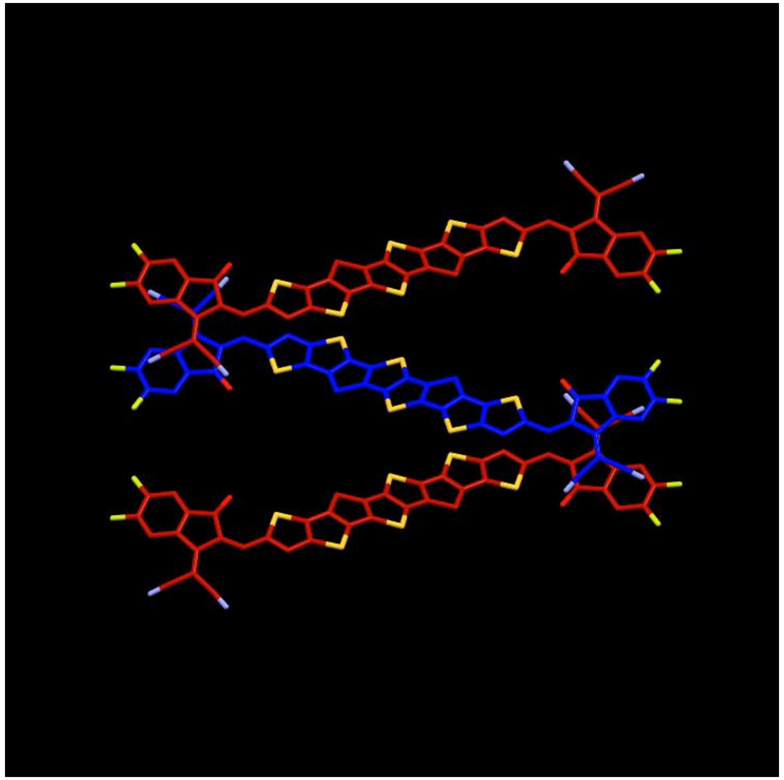
Lin, Zhu & Jen, *J. Am. Chem. Soc.*, **2020**, *142*, 15246.

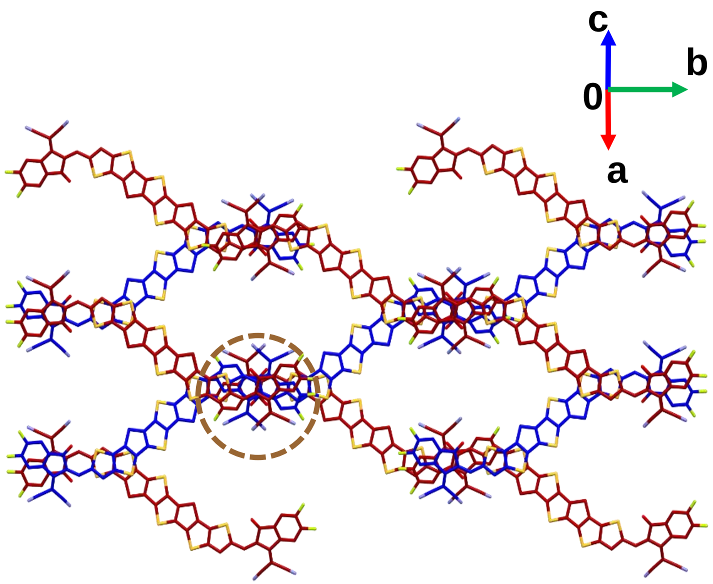
Lesson Learned From Single Crystals of NFAs

The A-D-A linear 6TIC-4F has only one molecular conformation in single crystal









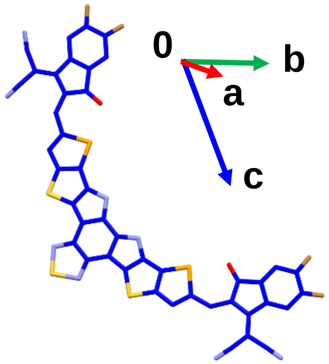
- 3 **6TIC-4F** molecules self-assemble into a "Z-shape" unit.
- **S-S distance** of 3.62(1) Å between the interior thienyls.
- **π-π distance** of ~3.52 Å between indanone terminal groups.

In bulk crystal, the Z-shape units stack through indanone terminal groups, with a **π-π distance** of ~3.52 Å.

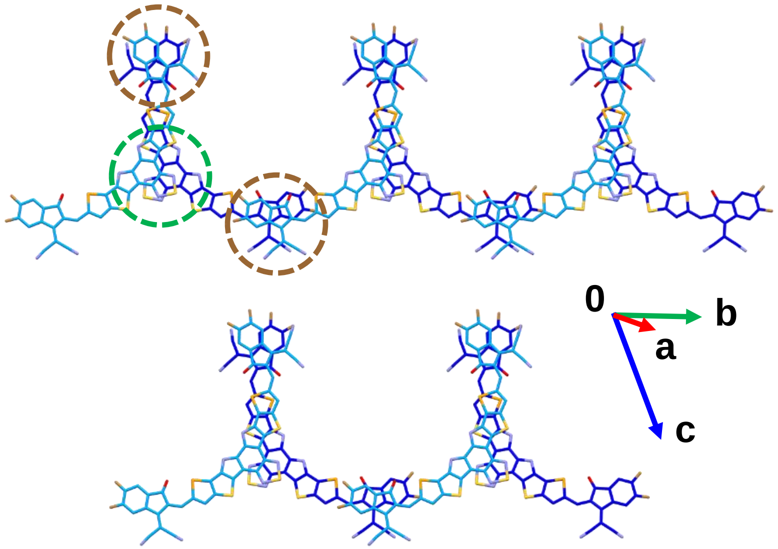
Shi & Jen *et al.*, *Adv. Funct. Mater.* **2018**, *28*, 1802324.
Gao, Lin, Jen & Liu, *Nature Commun.*, **2021**, submitted.

2D Packing of Molecular Engineered NFA

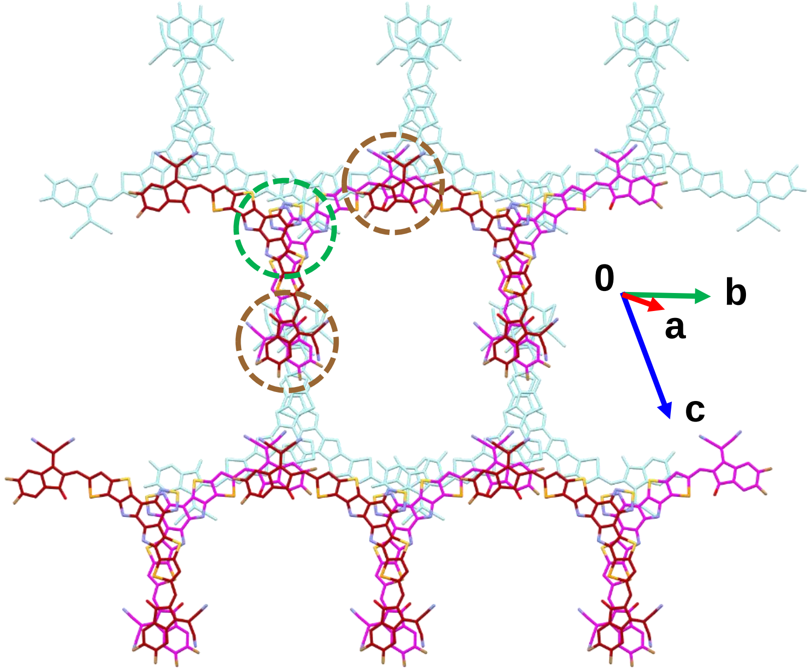
4 molecular conformations in single crystal (M, M’, P’, P)



Single molecule with *M* conformation.



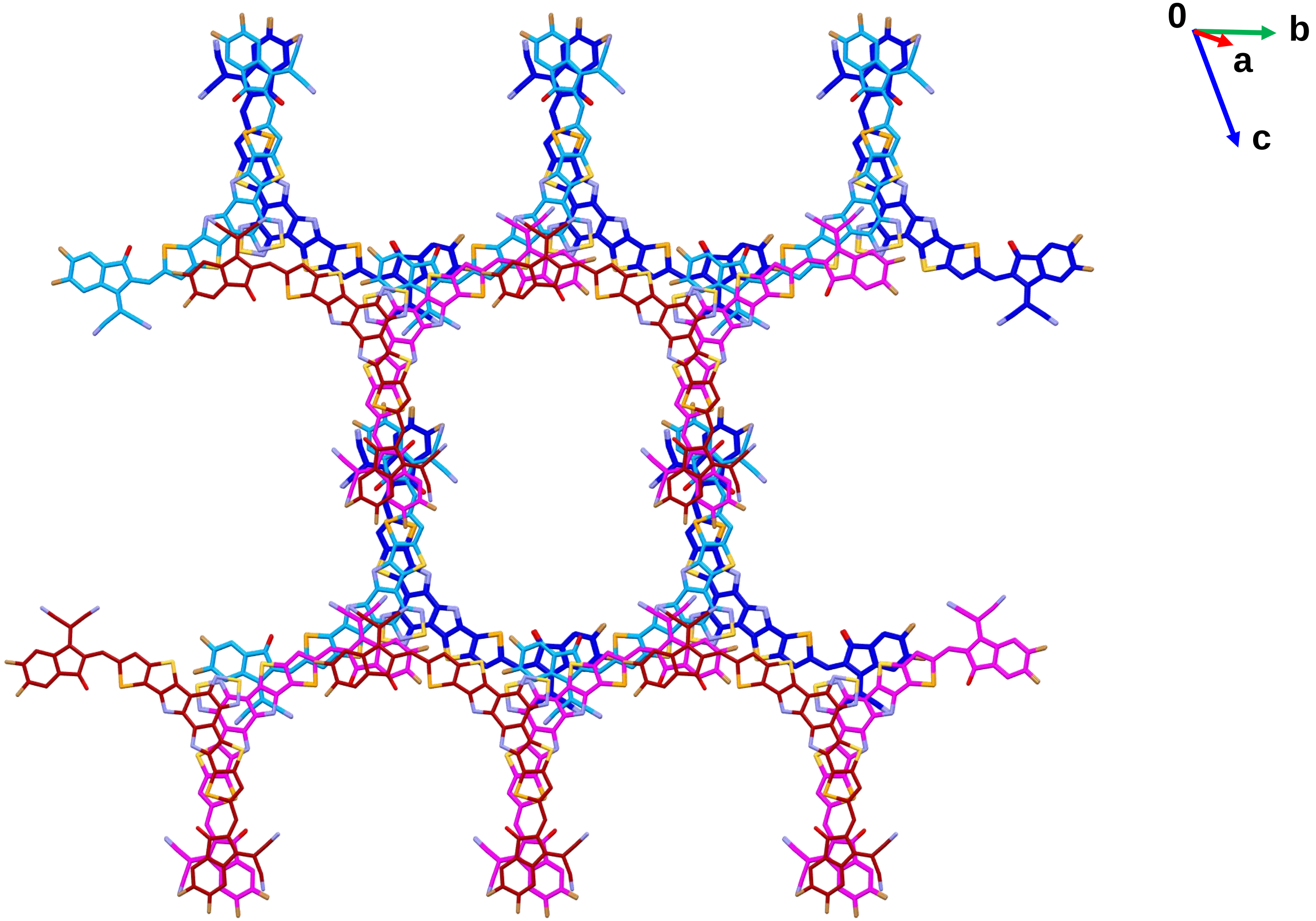
Molecules with *M’* conformation stack on top of those with *M* conformation to form **<u>1D channels</u>** through **terminal group stacking** and **π-core stacking**.



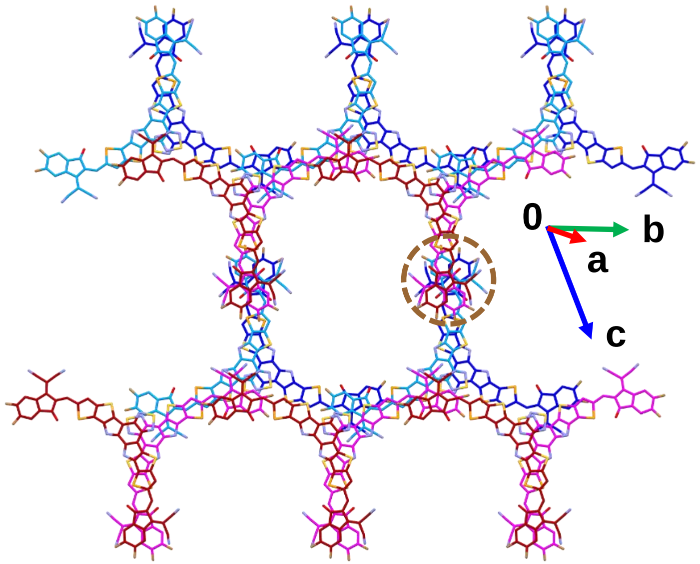
Stacking of molecules with *P’* and *P* conformations on top of those with *M* and *M’* conformations (faded for clearance), forming the **<u>2D plane</u>**.

Newly Molecular Engineered NFA

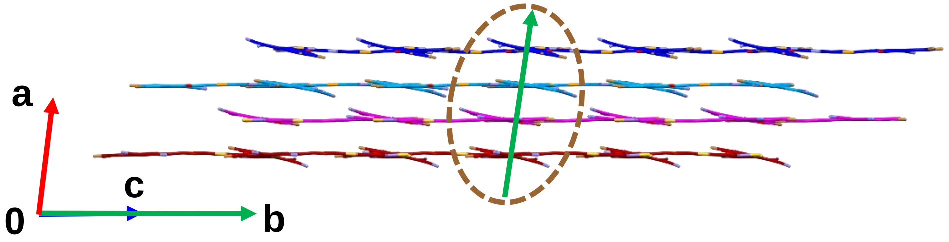
4 molecular conformations in single crystal (M, M', P', P)



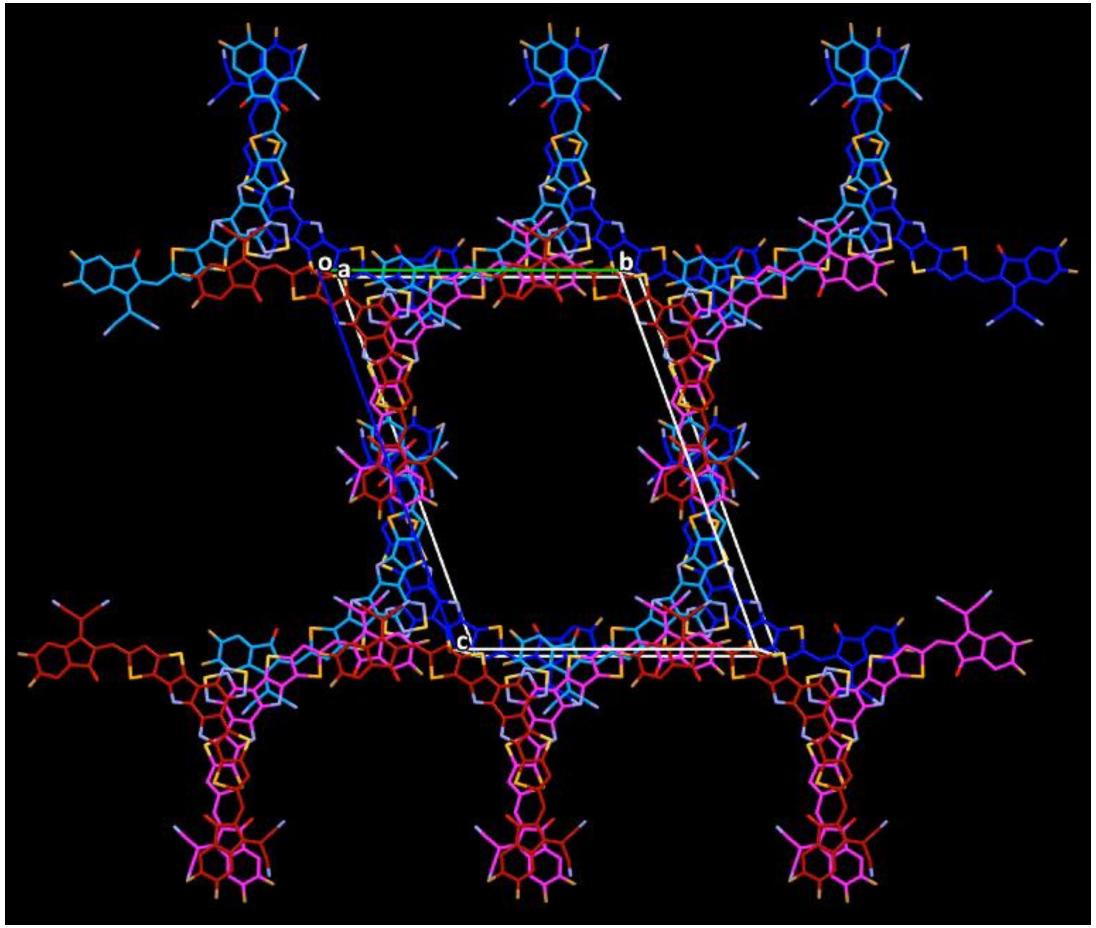
Newly Molecular Engineered NFA



3D packing viewing from top, the stacking of indanone terminal groups forms an out-of-plane channel connecting molecules with different conformations.



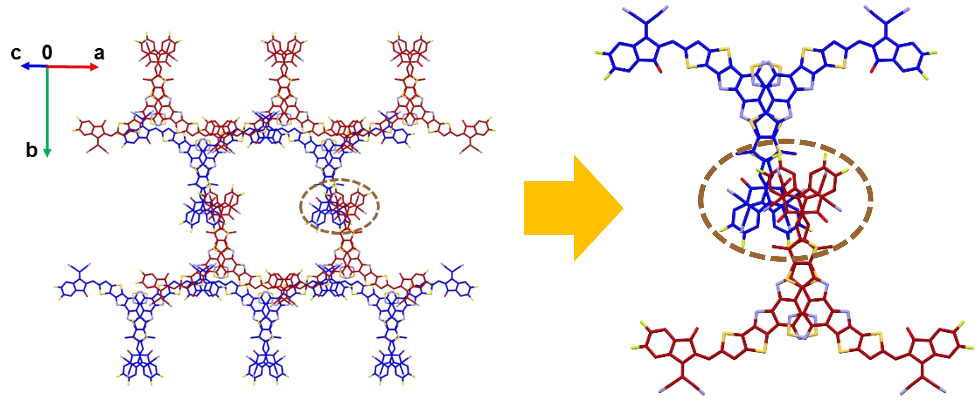
3D packing viewing from side, the stacking of indanone terminal groups is *less tilted* toward the molecular plane.

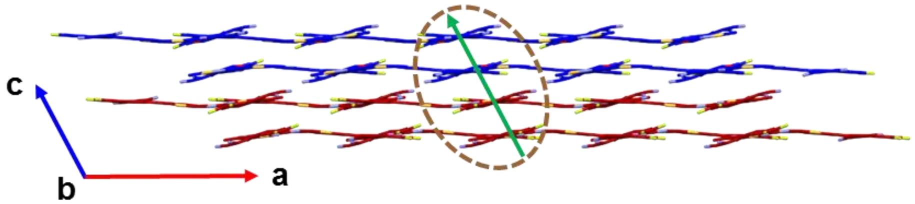


Lin, Jiang, Qi, Zhu & Jen, (manuscript in preparation)

Better Molecular Packing Improves Charge Transport

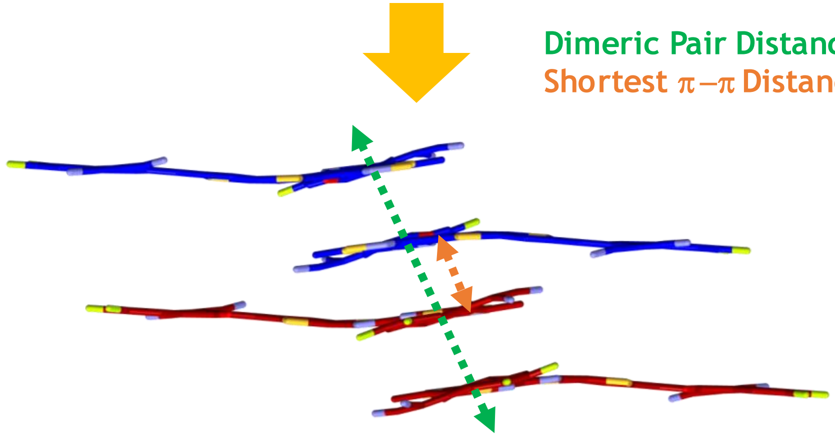
Y6



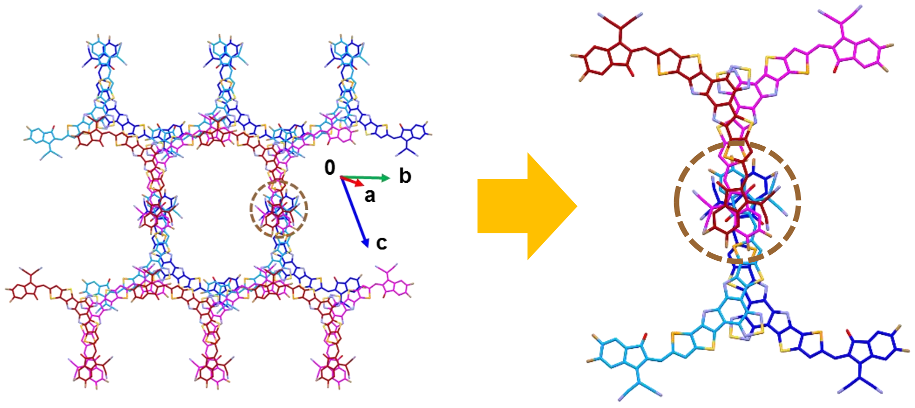


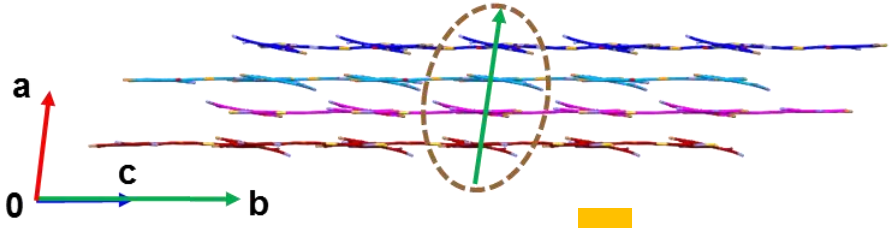
Dimeric Pair Distance 14.05(4) Å

Shortest $\pi-\pi$ Distance 3.64(7) Å



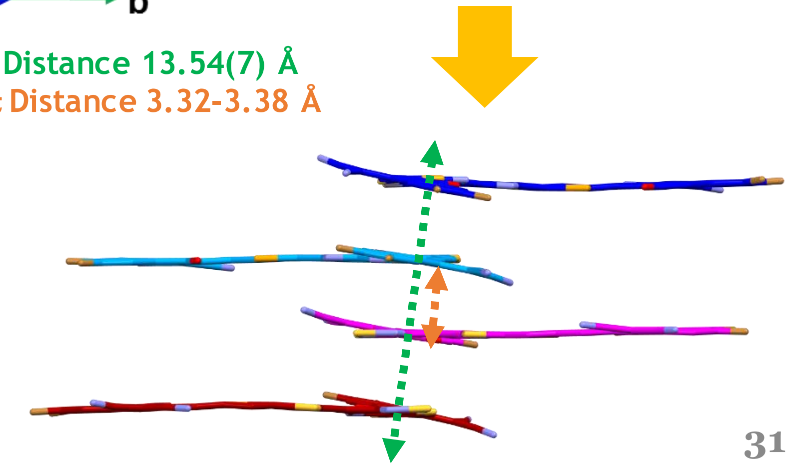
Newly Designed Structure





Dimeric Pair Distance 13.54(7) Å

Shortest $\pi-\pi$ Distance 3.32-3.38 Å



- Planarized NFA backbone
- Closer packing

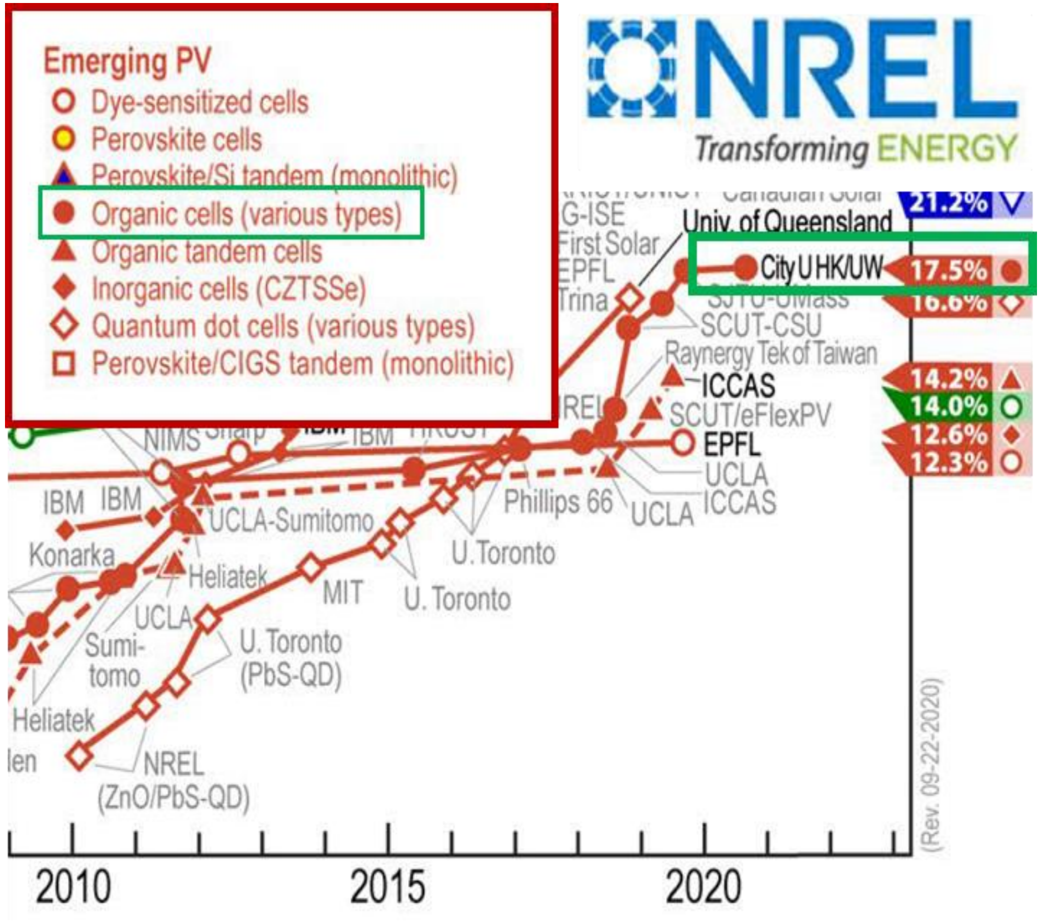
Approaching Theoretical Voltage Limits in OPV & PVSC

With the design of new NFAs, we have successfully reduced non-ideal losses without sacrificing photocurrent generation (>70% EQE_{Max}, >10% PCE)

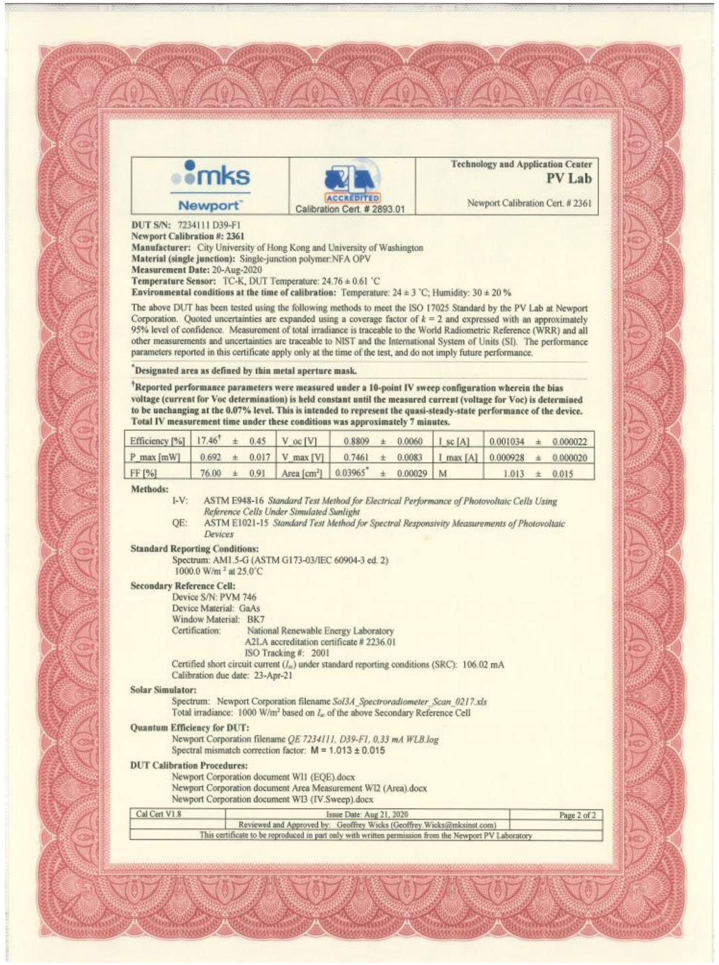
Type of Solar Cell	Bandgap	qV_{OC}	ΔE_{total}	$q\Delta V_{OC,SQ}$ (SQ-limit)	$q\Delta V_{OC}$ (Non-ideal)	$q\Delta V_{OC,rad}$ (non-ideal radiative)	$q\Delta V_{OC,non\text{-}rad}$ (non-radiative)
GaAs[1]	1.42	1.11	0.31	0.27	0.04	<0.01	0.04
Perovskite[3]	1.34	0.95	0.39	0.27	0.12	-	-
CIGS[1]	1.18	0.74	0.44	0.22	0.22	<0.01	0.21
c-Si[1]	1.12	0.68	0.44	0.25	0.18	<0.01	0.18
PCE10:DTPC-DFIC[7]	**1.26**	**0.77**	**0.49**	**0.26**	**0.22**	**0.03**	**0.19**
Perovskite[2]	1.82	1.32	0.50	0.3	0.2	0.08	0.12
Perovskite[3]	1.61	1.08	0.53	0.28	0.25	0.01	0.25
Perovskite[8]	**1.50**	**1.17**	**0.33**	**0.27**	**0.06**	**<0.01**	**0.06**
PDCBT-2F:IT-M[4]	1.67	1.13	0.54	0.29	0.25	0.04	0.21
PBDB-T:Y1[5]	1.44	0.87	0.57	0.27	0.3	0.05	0.25
PCE10:FIDTT-2PDI[6]	1.65	1.06	0.59	0.29	0.30	0.06	0.30
PBDB-T : mixed ITIC/4TIC	1.52	0.90	0.62	0.29	0.33	0.05	0.28
PM6 : mixed ITIC-4F/6TIC-4F[9]	**1.36**	**0.81**	**0.55**	**0.28**	**0.27**	**0.02**	**0.25**
PM6 : mixed ITIC/6TIC-4F[9]	**1.38**	**0.86**	**0.52**	**0.27**	**0.25**	**0.04**	**0.21**
★ **PM6:Y11 (150 °C, Champion)[10]**	**1.32**	**0.83**	**0.49**	**0.26**	**0.23**	**0.03**	**0.20**
PM6 : mixed ITIC/Y6[9]	**1.47**	**0.93**	**0.54**	**0.28**	**0.27**	**0.03**	**0.22**
Certified System AJ1	**1.42**	**0.87**	**0.55**	**0.26**	**0.29**	**0.10**	**0.18**
Certified System AJ2	**1.39**	**0.85**	**0.56**	**0.26**	**0.30**	**0.09**	**0.21**
PCE10:PCBM	1.63	0.81	0.82	0.29	0.53	0.12	0.39

[1] J. Nelson and coworkers, *Phys. Rev. Appl.* **2015**, 4, 014020
[2] A. Jen and coworkers, *Nano Lett.* **2018**, 18, 3985
[3] A. Jen and coworkers, *Adv. Mater.* **2018**, 30, 1800455
[4] F. Gao and coworkers, *Nat. Mater.* **2018**, 17, 703
[5] Y. Yang and coworkers, Nat. Commun. **2019**, 10, 570
[6] D. Ginger & A. Jen and coworkers, J. Am. Chem. Soc. **2018**, 140, 9996
[7] Yao & Jen and coworkers, J. Am. Chem. Soc. **2018**, 140, 2054.
[8] Li & Jen and coworkers, J. Am. Chem. Soc. **2020**, *DOI*: 10.1021/jacs.0c09845.
[9] Zuo, Jo & Jen, submitted.
[10] Wu, *Nat. Photon.* **2020**, *13*, 300.

Achieved NREL Certified World Record PCE for OPV



https://www.nrel.gov/pv/assets/pdfs/best-research-cell-efficiencies.20200925.pdf



mks Newport | ACCREDITED Calibration Cert. # 2893.01 | Technology and Application Center PV Lab Newport Calibration Cert. # 2361

DUT S/N: 7234111 D39-F1
Newport Calibration #: 2361
Manufacturer: City University of Hong Kong and University of Washington
Material (single junction): Single-junction polymer:NFA OPV
Measurement Date: 20-Aug-2020
Temperature Sensor: TC-K, DUT Temperature: 24.76 ± 0.61 °C
Environmental conditions at the time of calibration: Temperature: 24 ± 3 °C; Humidity: 30 ± 20 %

The above DUT has been tested using the following methods to meet the ISO 17025 Standard by the PV Lab at Newport Corporation. Quoted uncertainties are expanded using a coverage factor of $k = 2$ and expressed with an approximately 95% level of confidence. Measurement of total irradiance is traceable to the World Radiometric Reference (WRR) and all other measurements and uncertainties are traceable to NIST and the International System of Units (SI). The performance parameters reported in this certificate apply only at the time of the test, and do not imply future performance.

***Designated area as defined by thin metal aperture mask.**

†Reported performance parameters were measured under a 10-point IV sweep configuration wherein the bias voltage (current for Voc determination) is held constant until the measured current (voltage for Voc) is determined to be unchanging at the 0.07% level. This is intended to represent the quasi-steady-state performance of the device. Total IV measurement time under these conditions was approximately 7 minutes.

Efficiency [%]	17.46† ± 0.45	V_oc [V]	0.8809 ± 0.0060	I_sc [A]	0.001034 ± 0.000022
P_max [mW]	0.692 ± 0.017	V_max [V]	0.7461 ± 0.0083	I_max [A]	0.000928 ± 0.000020
FF [%]	76.00 ± 0.91	Area [cm²]	0.03965* ± 0.00029	M	1.013 ± 0.015

Methods:
I-V: ASTM E948-16 *Standard Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight*
QE: ASTM E1021-15 *Standard Test Method for Spectral Responsivity Measurements of Photovoltaic Devices*

Standard Reporting Conditions:
Spectrum: AM1.5-G (ASTM G173-03/IEC 60904-3 ed. 2)
1000.0 W/m ^{2} at 25.0°C

Secondary Reference Cell:
Device S/N: PVM 746
Device Material: GaAs
Window Material: BK7
Certification: National Renewable Energy Laboratory
A2LA accreditation certificate # 2236.01
ISO Tracking #: 2001
Certified short circuit current (I_{sc}) under standard reporting conditions (SRC): 106.02 mA
Calibration due date: 23-Apr-21

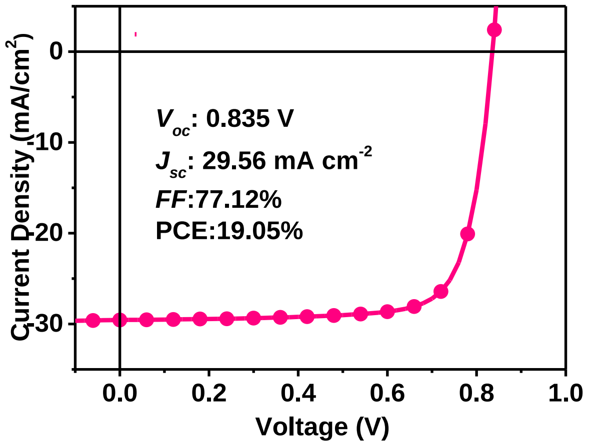
Solar Simulator:
Spectrum: Newport Corporation filename *Sol3A_Spectroradiometer_Scan_0217.xls*
Total irradiance: 1000 W/m² based on I_{sc} of the above Secondary Reference Cell

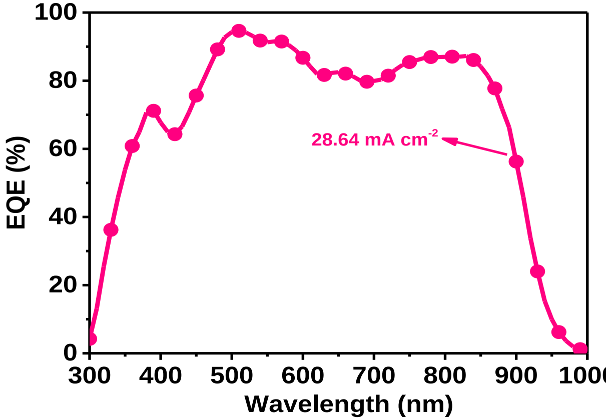
Quantum Efficiency for DUT:
Newport Corporation filename *QE 7234111, D39-F1, 0,33 mA WLB.log*
Spectral mismatch correction factor: M = 1.013 ± 0.015

DUT Calibration Procedures:
Newport Corporation document WI1 (EQE).docx
Newport Corporation document Area Measurement WI2 (Area).docx
Newport Corporation document WI3 (IV.Sweep).docx

Cal Cert V1.8	Issue Date: Aug 21, 2020	Page 2 of 2
	Reviewed and Approved by: Geoffrey Wicks (Geoffrey.Wicks@mksinst.com)	
This certificate to be reproduced in part only with written permission from the Newport PV Laboratory		

Jiang, Lin, Zhu & Jen,
Nature Commun, **2021**, *12*, 468.



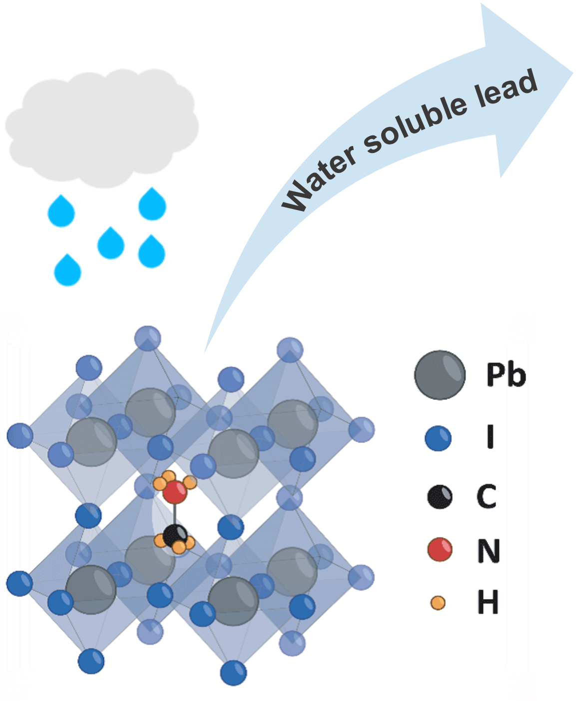


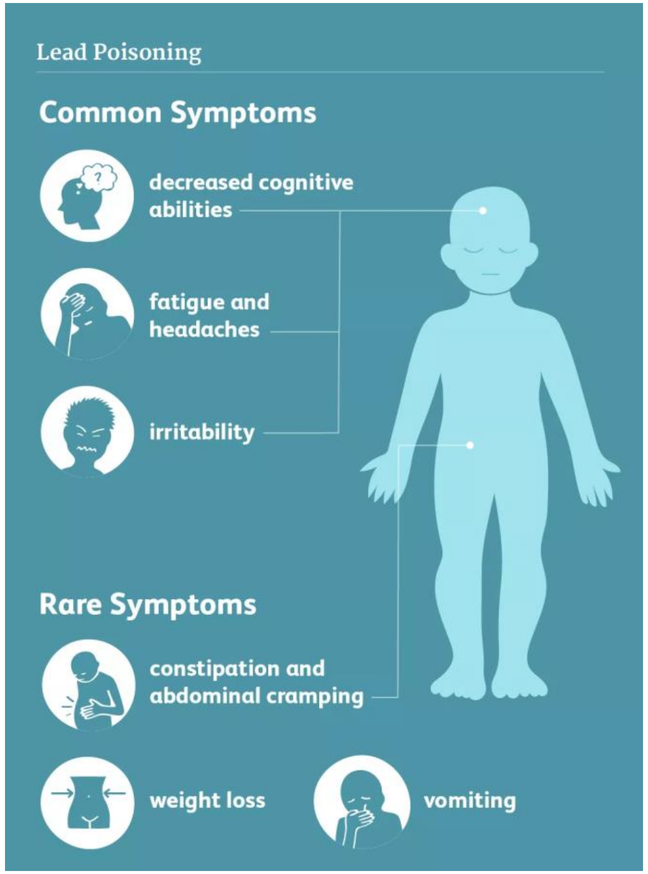
Jiang, Lin & Jen,
(manuscript in preparation)

Printing solar cells like printing newspapers (fast & cheap)

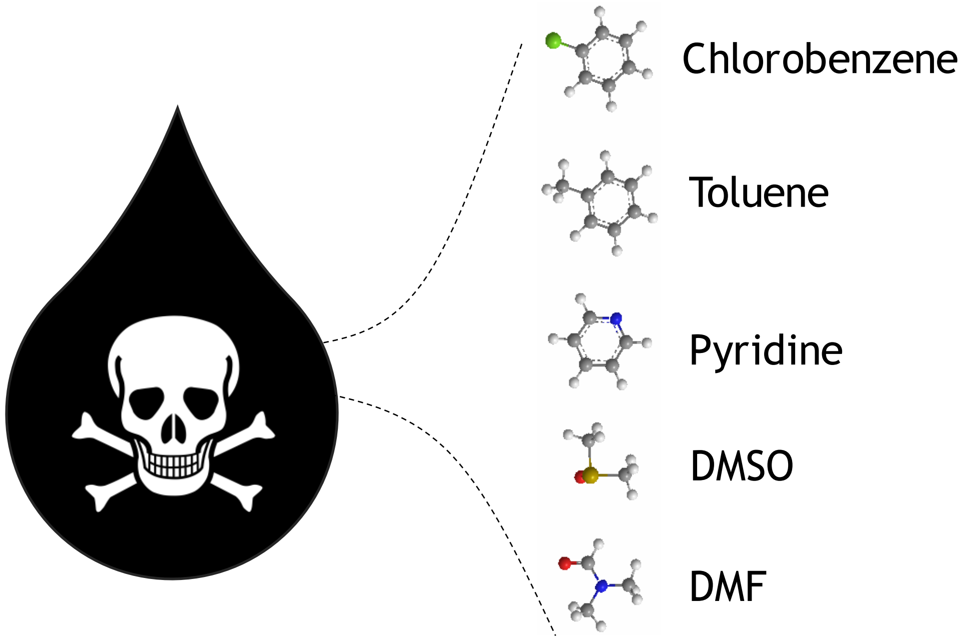
Environmental Concerns for Perovskite Solar Cells: Lead Leakage and Solvent Toxicity

- **Lead Poisoning in PVSCs**



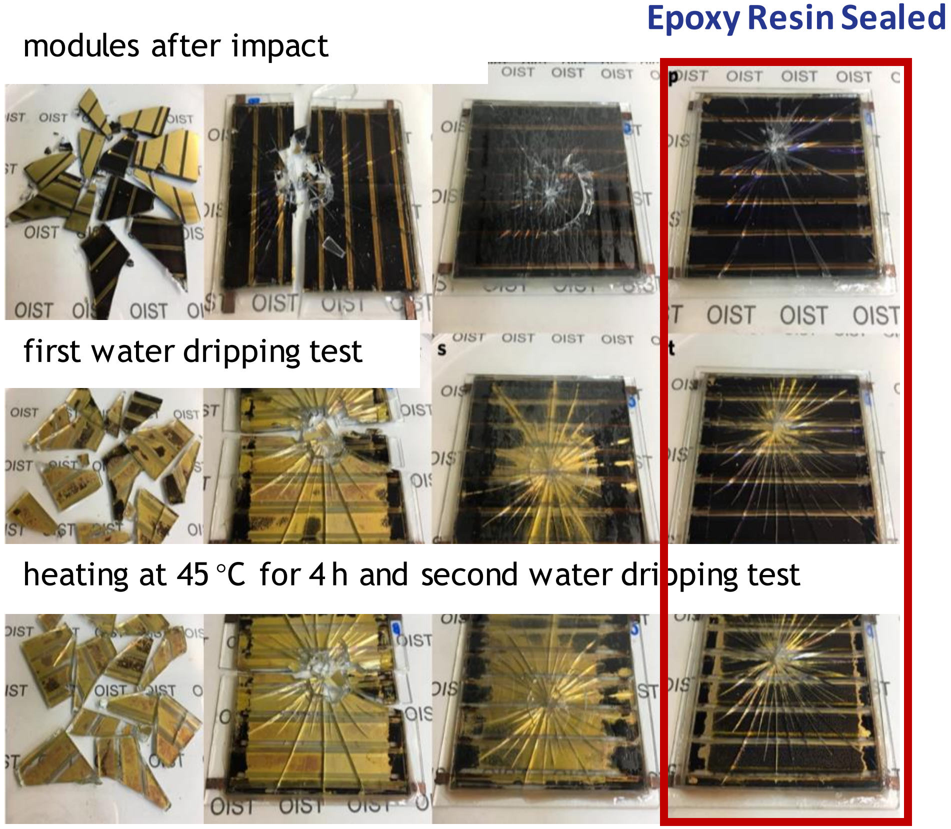


- **Solvent Toxicity**



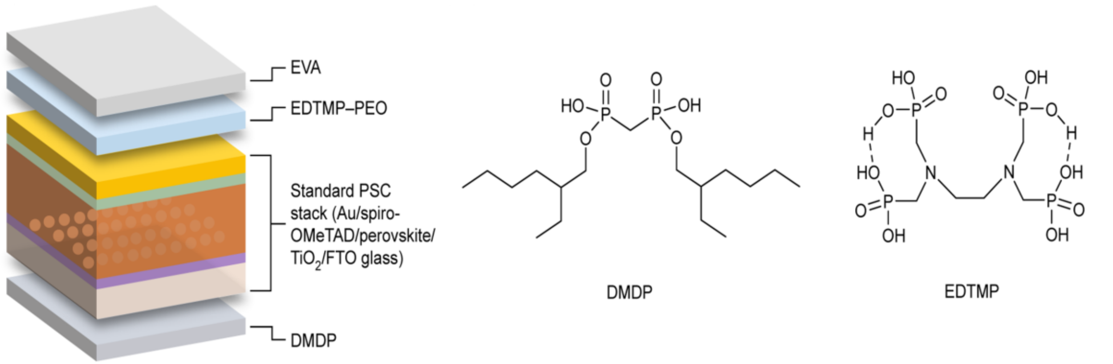
Reduce Lead Leakage through Innovative Encapsulation

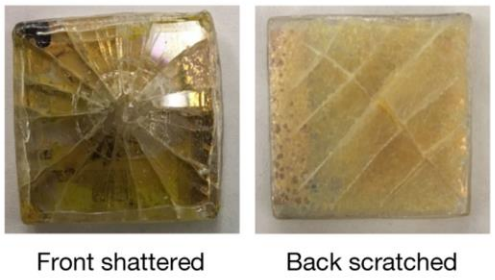
Reduce lead leakage with ***self-healing polymer***-based encapsulation

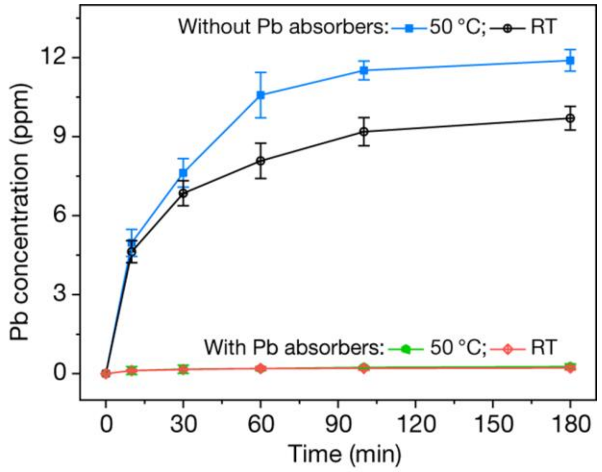


Jiang & Qi, Nat. Energy **2019**, *4*, 585.

Coat ***lead-absorbing material*** on both sides of the device stack for preventing Pb ions leakage due to severe device damage



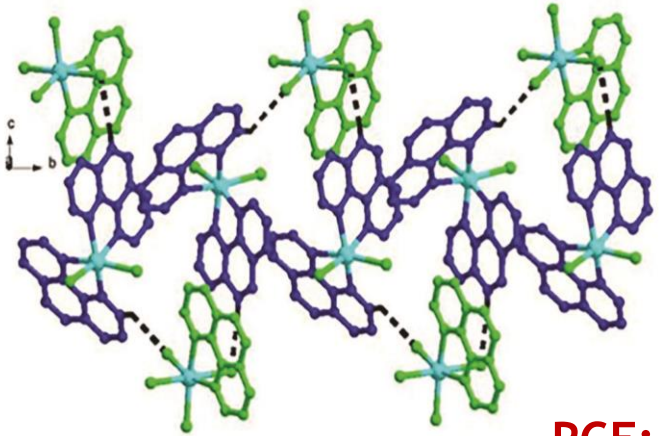




Li , Zhu & Xu, *Nature* **2020**, *578*, 555.

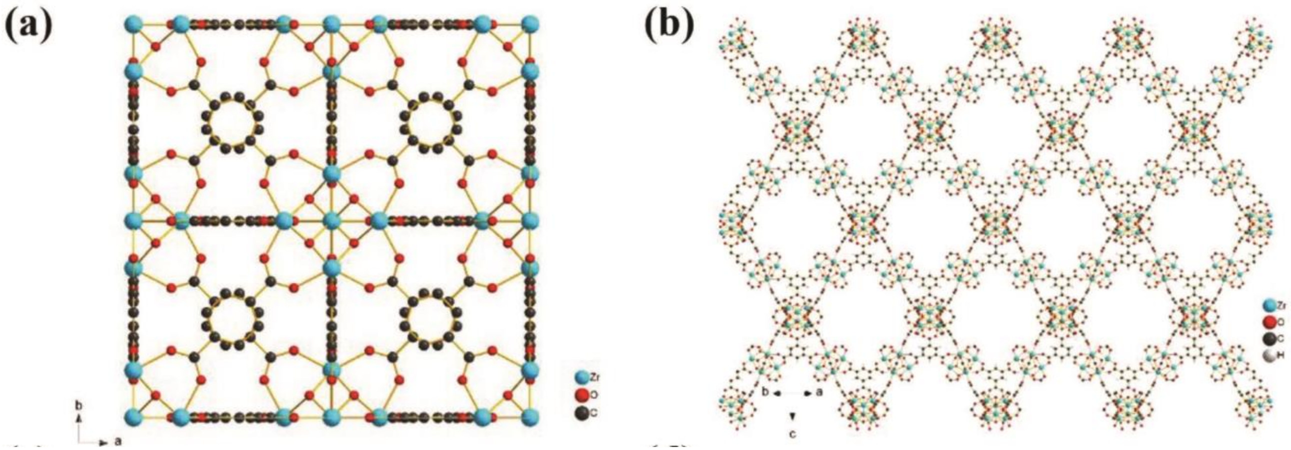
Metal-Organic Frameworks (MOF) for Perovskite Solar Cells

- MOFs are 3D porous crystalline materials consisting of multipodal organic linkers, like terephthalic acid and trimesic acid, and secondary building units (SBUs) based on high-valent ions/clusters
- MOF porous scaffolds can be used to facilitate perovskite growth
- ***3D MOFs*** usually possess good moisture and chemical stabilities, but they have relatively poor charge transporting properties due to charge localization. ***Need to be doped.***



PCE:15.8

3D structure of In2



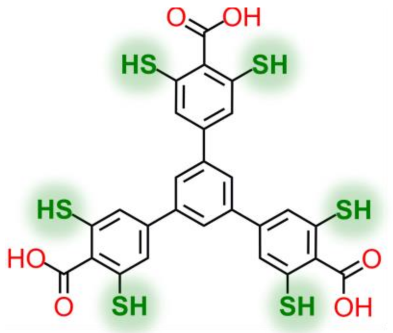
PCE:16.6

Li & Fan, *Adv. Energy Mater.*, **2018**, *8*, 1702052

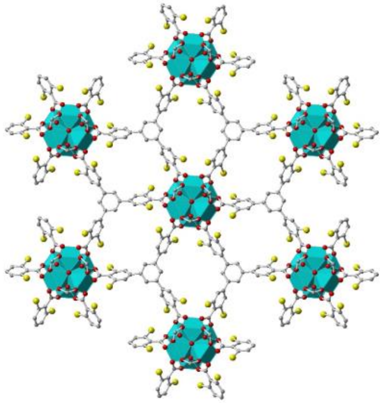
Wu & Chueh, *Adv. Sci.* **2019**, *6*, 1801715

2D-MOF for Enhancing Device Stability and Lead Capturing

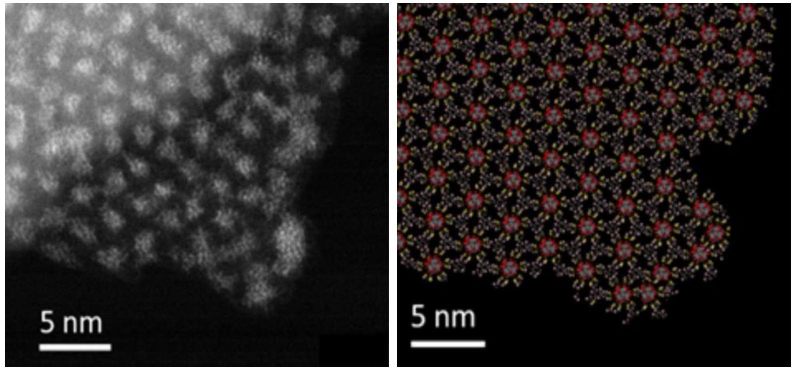
- Excellent thermal stability which can maintain structural integrity in ***boiling-water for 24h.***
- Thiol groups on MOF can form ***Ag−S*** bonds at the MOF-electrode interface to ***improve contact*** and resist detrimental stimuli under ambient atmosphere and light irradiation.
- ***Thiol groups*** can also ***capture the leaked*** $\boldsymbol{Pb^{2+}}$ ***ions*** from degraded perovskites to prevent contamination of the environment through forming ***insoluble Pb-MOF products.***

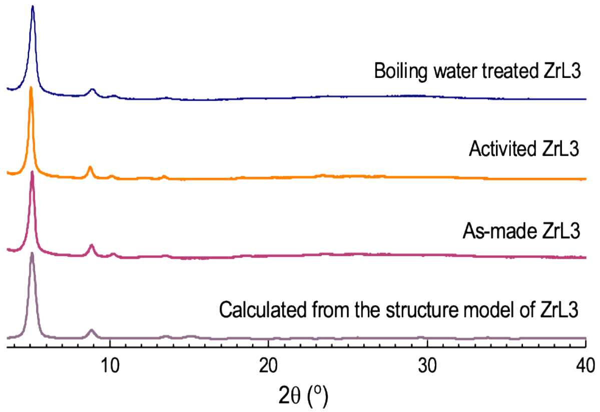


H_3**L3**



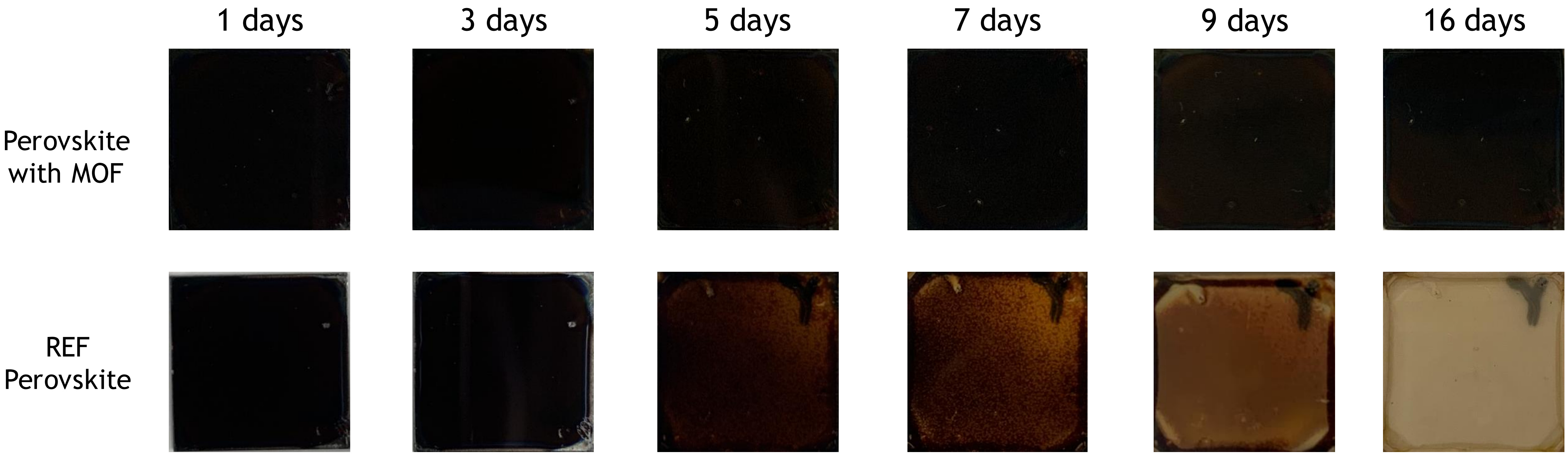
Zr**L3**





Wu, Xu, Zhu & Jen, *Nature Nanotech.* **2020**, *15*, 934.

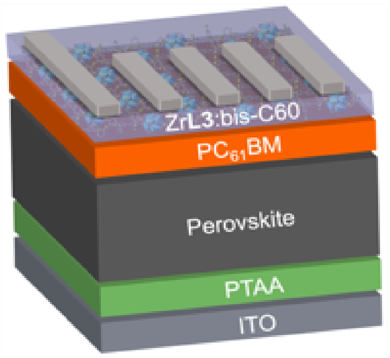
MOF Covered Perovskites Show Excellent Ambient Stability

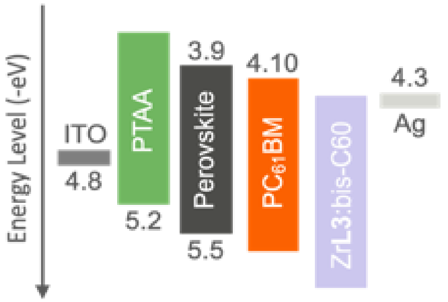


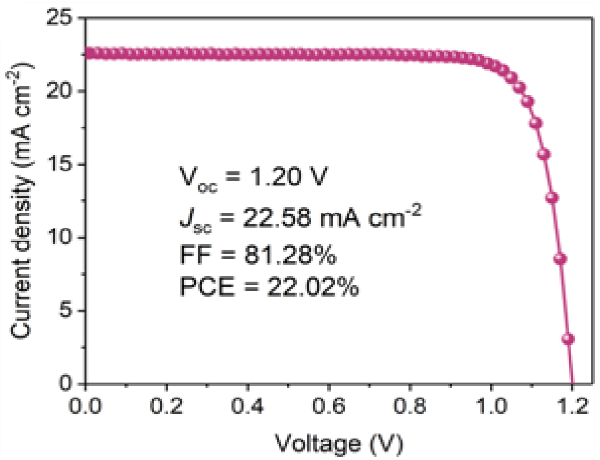
Stored in ambient with RH of 75-80% @ RT

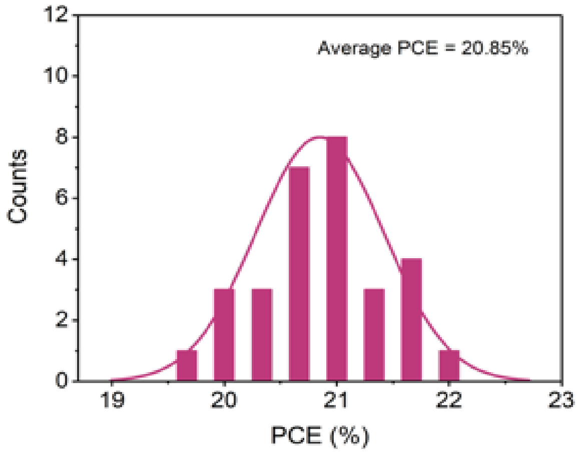
Wu, Xu, Zhu & Jen, *Nature Nanotech.* **2020**, *15*, 934.

Device Performance of 2D-MOF EEL-Based PVSCs









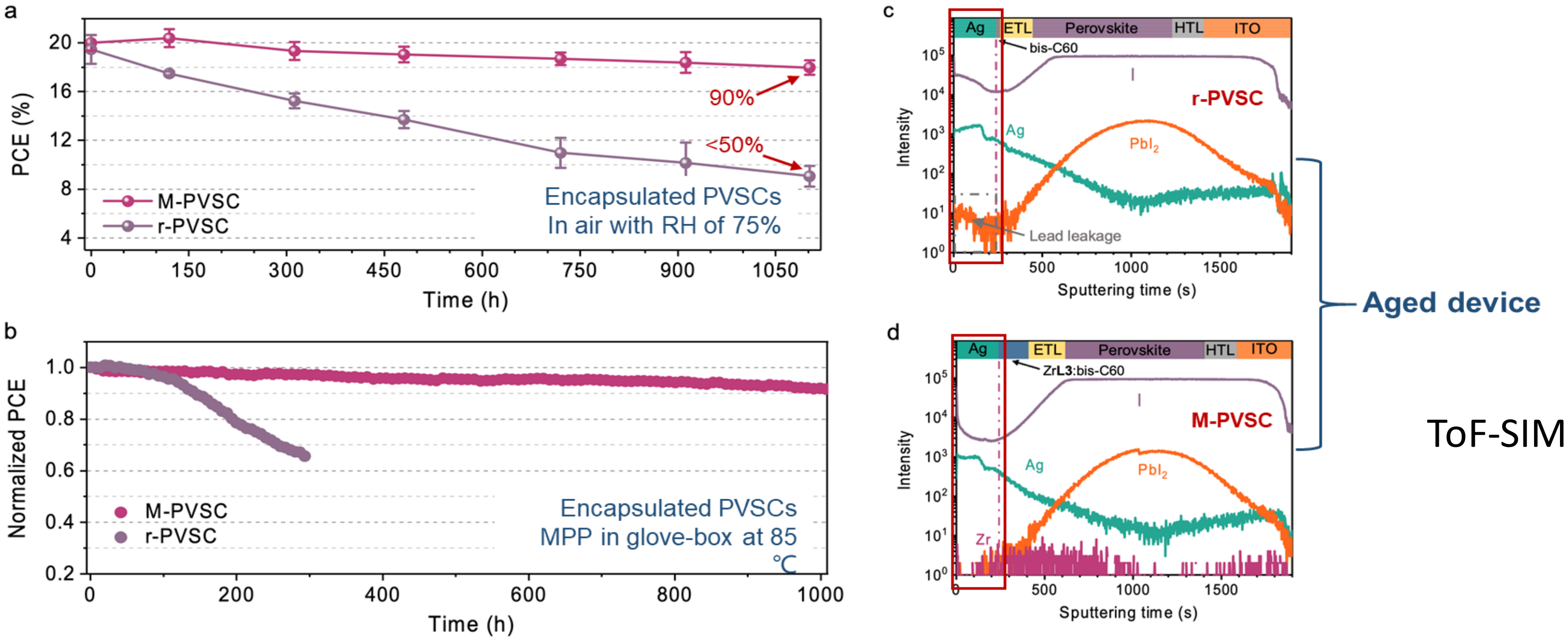
High PCE of ***22.02%*** can be achieved with 2D MOF interlayer at perovskite/cathode interface, which is among the highest values for the inverted PVSCs.

Wu, Xu, Zhu & Jen, *Nature Nanotech.* **2020**, *15*, 934.

2D-MOF Enhanced Device Stability and Lead Capturing

香港城市大學
City University of Hong Kong

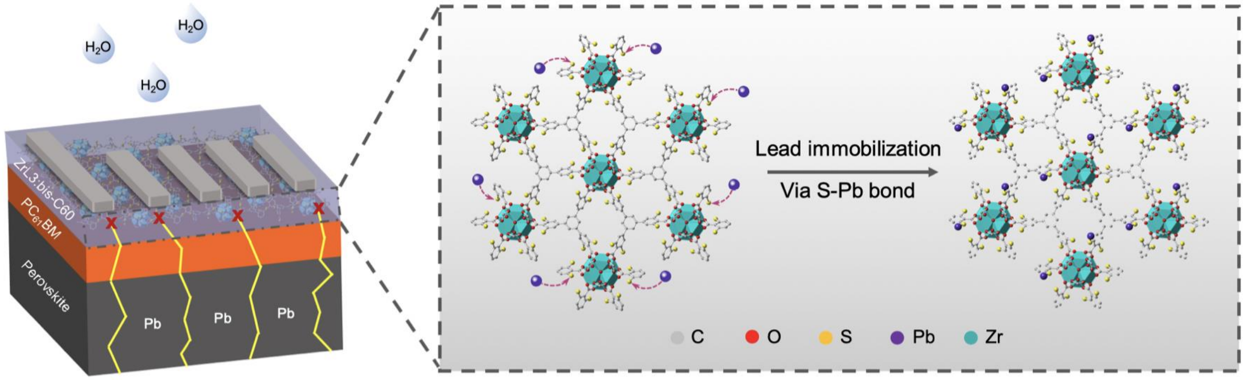
- The encapsulated M-PVSC exhibited ***superior shelf stability and long-term operational stability.***
- The leaked Pb ions from the degraded PVSC can be ***"trapped"*** *by* the Zr**L3**:bis-C_{60} EEL due to the dense thiol and disulfide groups in Zr**L3**, which can strongly interact with Pb^{2+} by ***S-Pb bond***.

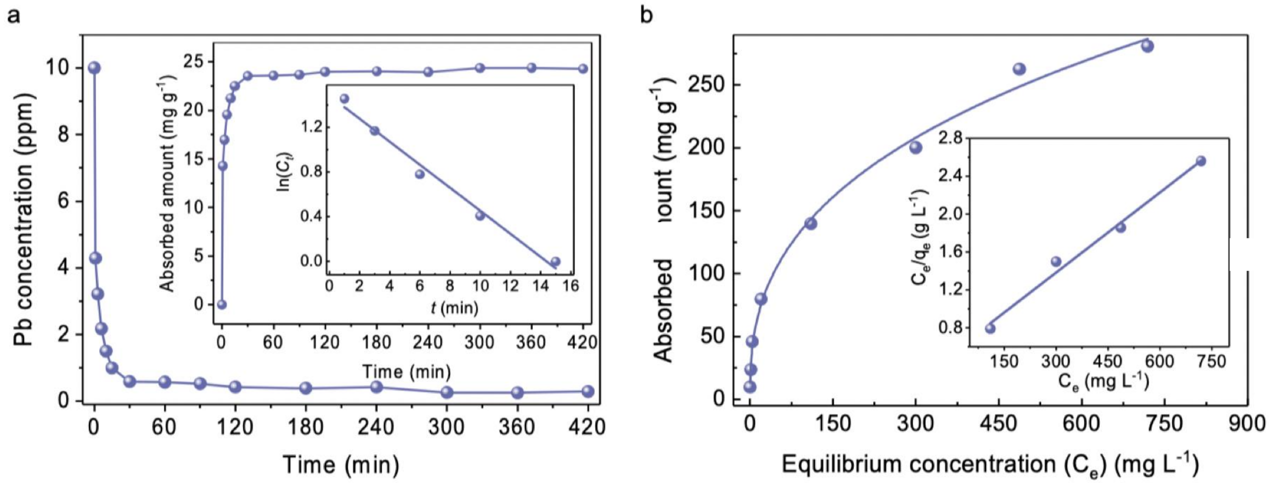


ToF-SIMS

Wu, Xu, Zhu & Jen, *Nature Nanotech*. **2020**, *15*, 934.

Ability of 2D-MOF in Adsorbing Lead Ions



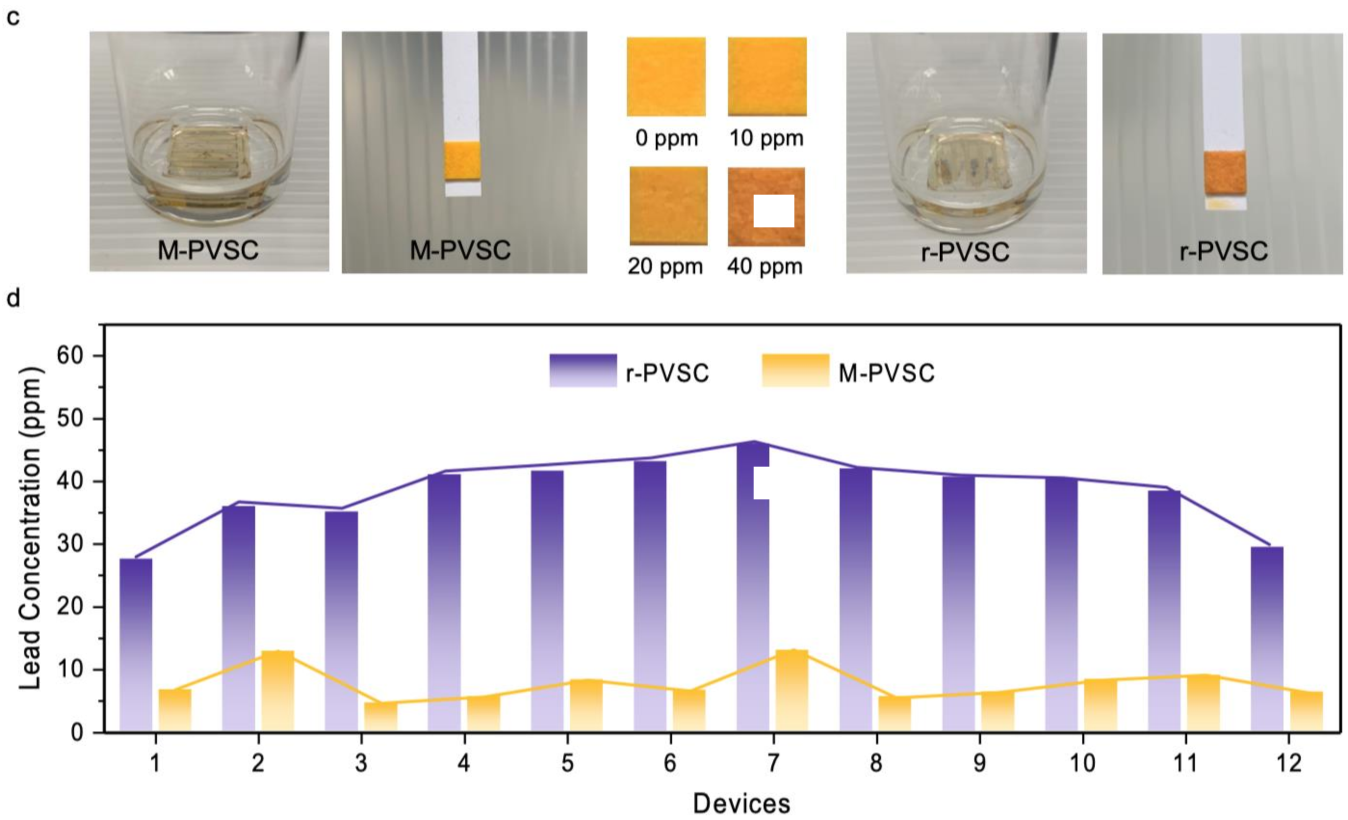


A distribution coefficient K_d of around 105 ml g^{-1} and the substantial value of ***355 mg g^{-1}*** for the Pb adsorption capacity strongly support that Zr**L3** EEL can effectively adsorb Pb^{2+}.

Wu, Xu, Zhu & Jen, *Nature Nanotech.* **2020**, *15*, 934.

2D MOF Interlayer for Capturing Lead Products

Lead adsorption capability of ZrL3 interlayer



Tested in acidic water (pH:5.6) to simulate acid rain

ICP-OES: Inductively coupled plasma-mass spectroscopy

Pb^{2+} concentration decreased to *7.6 ppm for M-PVSCs and 38.4 ppm for r-PVSCs*, which means 80% of the leaked Pb^{2+} ions from the degraded perovskite could be captured by Zr**L3**.

Wu, Xu, Zhu & Jen, *Nature Nanotech*. **2020**, *15*, 934.

Press Coverage

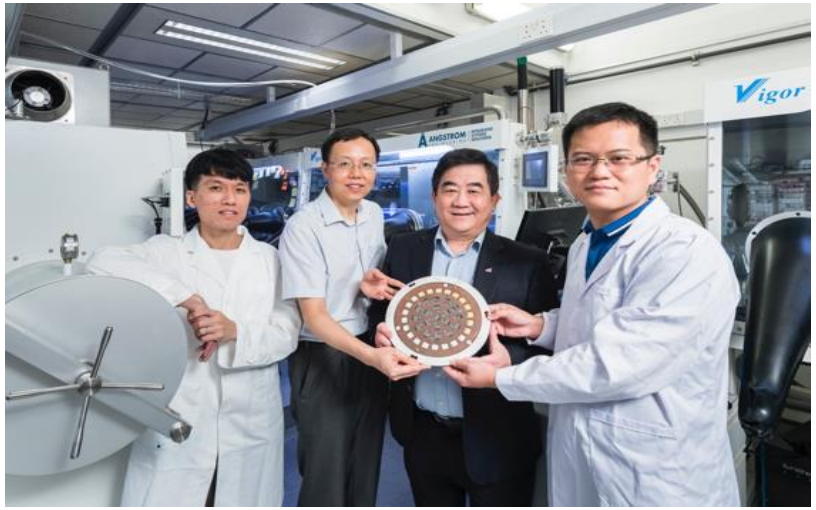
News Release 21-Sep-2020

Highly efficient perovskite solar cells with enhanced stability and minimised lead leakage

City University of Hong Kong

Perovskite solar cell based on metal-organic framework with 22.02% efficiency

Scientists in Hong Kong have developed a cell they say retains more than 90% of its initial efficiency under accelerated testing conditions. The device is based on two-dimensional metal-organic frameworks. September 22, 2020 *Emiliano Bellini*



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PV Challenge in HK: Dense Urban City, Limited Land Space

*Just like "**location**" is very important for real estate, "**efficiency**" and "**flexibility of use**" are critical for the successful deployment of solar technology*

- Needs to develop innovative PV solutions to fully utilize existing surface areas like roofs, windows, curtains, walls, and cars for generating electricity
- Develop a low-cost and scalable PV technology with very high efficiency and new form factors that allow to be better integrated with buildings

Perovskites can increase Si Solar Cell Efficiency by ~40% !

Tandem PV Concept Towards 30% PCE

PVTECH

Power Plants | Features | Industry Updates | Market Research | Eve

NEWS

Oxford PV pushes tandem SHJ/perovskite cell conversion efficiency to record 29.52%

By Mark Osborne

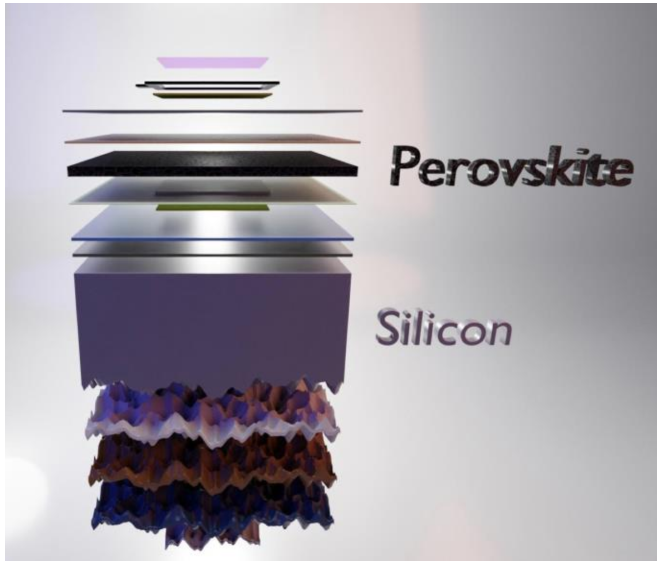
December 21, 2020

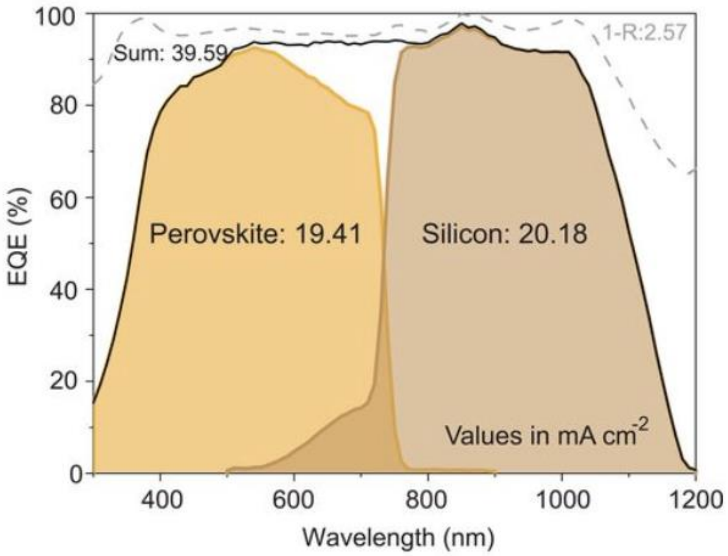
Cell Processing, Manufacturing, Materials

Europe

Facebook | Twitter | LinkedIn | Reddit | Email

Perovskite solar cell developer Oxford Photovoltaics (PV) has smashed its previous industry cell efficiency record for a tandem silicon heterojunction/perovskite 2T (Terminal) solar cell, which has been certified by the US National Renewable Energy Laboratory (NREL) at 29.52%.

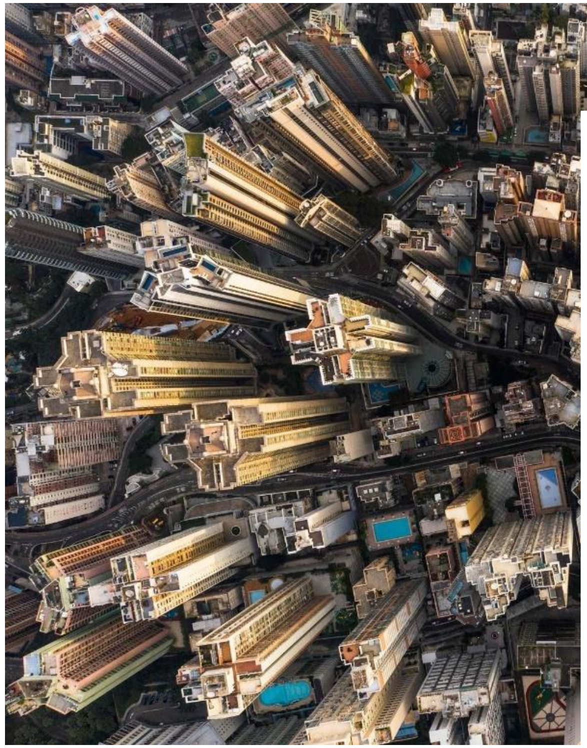




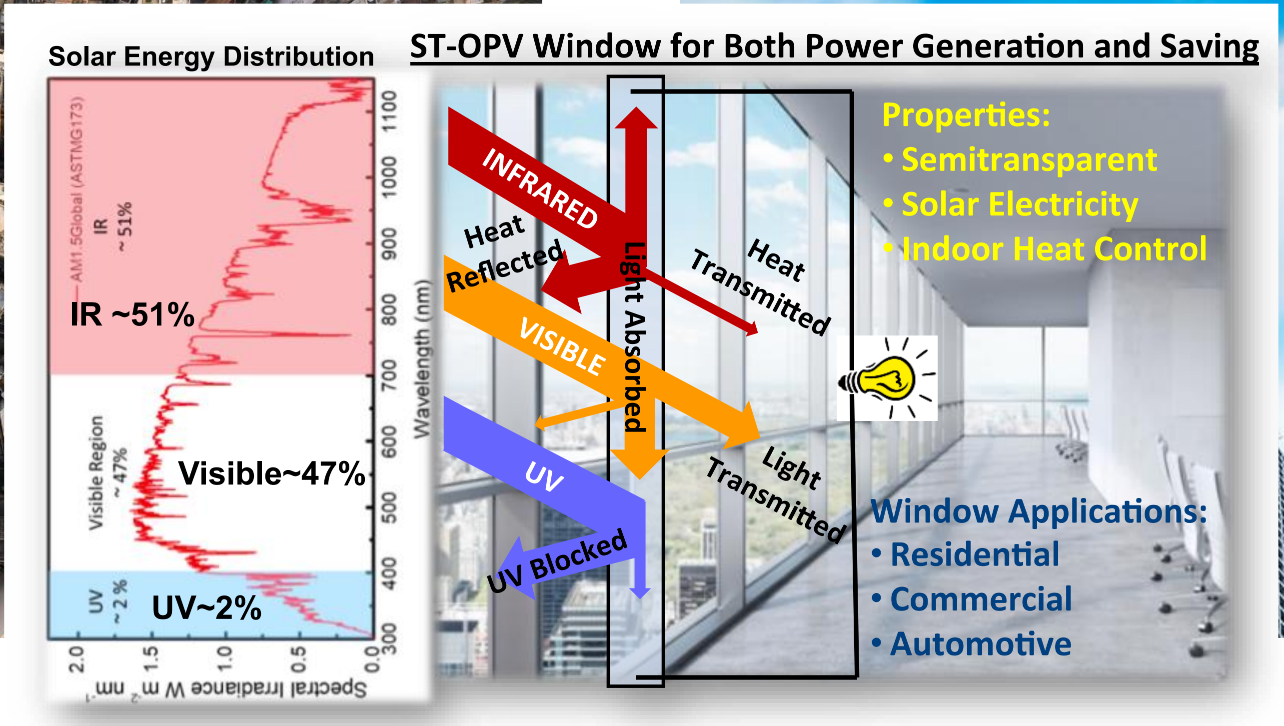
Albrecht *et al*, *Science* **2020**, *370*, 1300

With Innovation, Solar Can Be Everywhere!

Limited space for direct sunlight irradiation in HK.



BIPV - Turn the skyscrapers into solar farms.



Will be working with:

南玻集团

天地綠色能源 MONDO GREEN ENERGY

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香港城市大學
City University of Hong Kong

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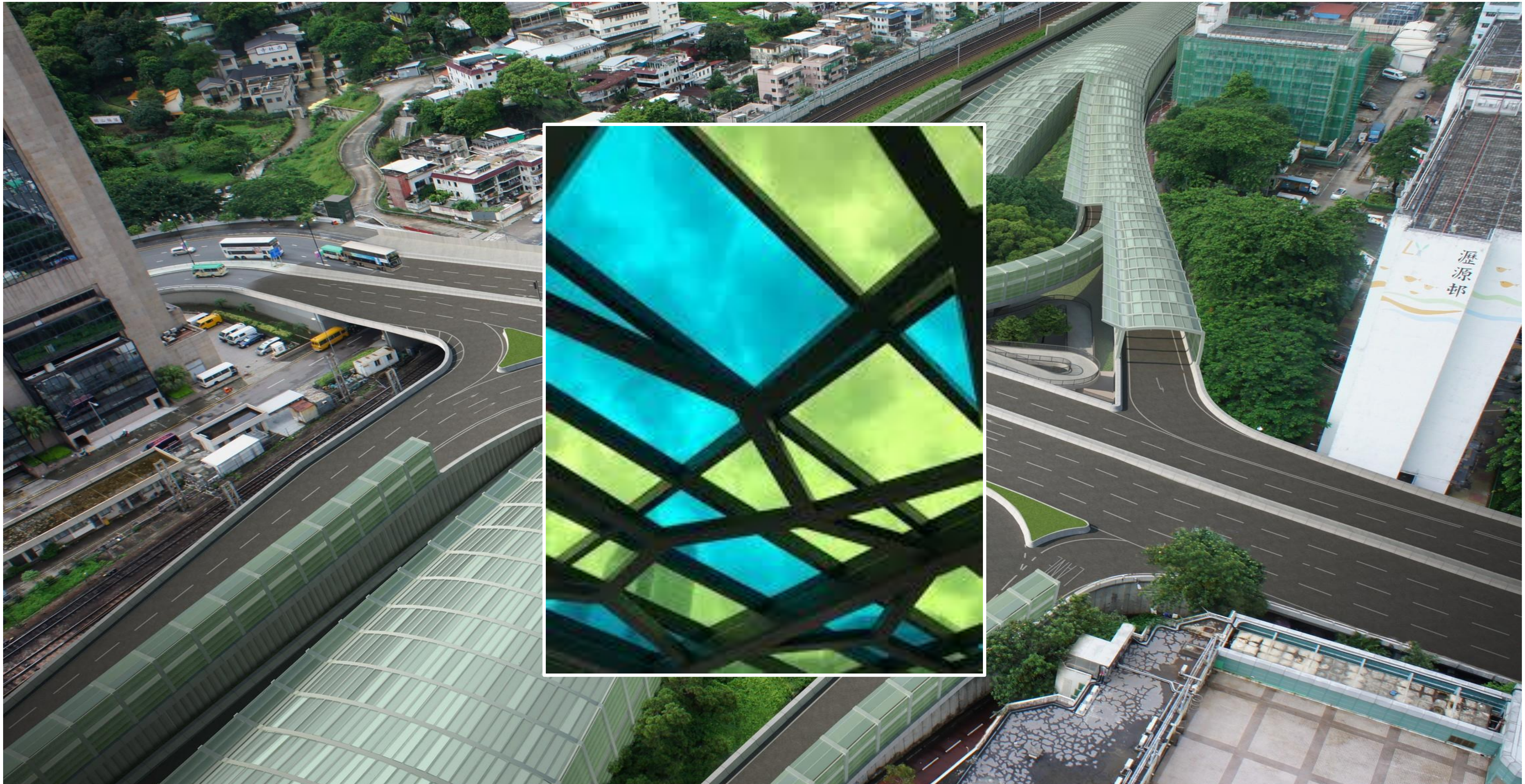

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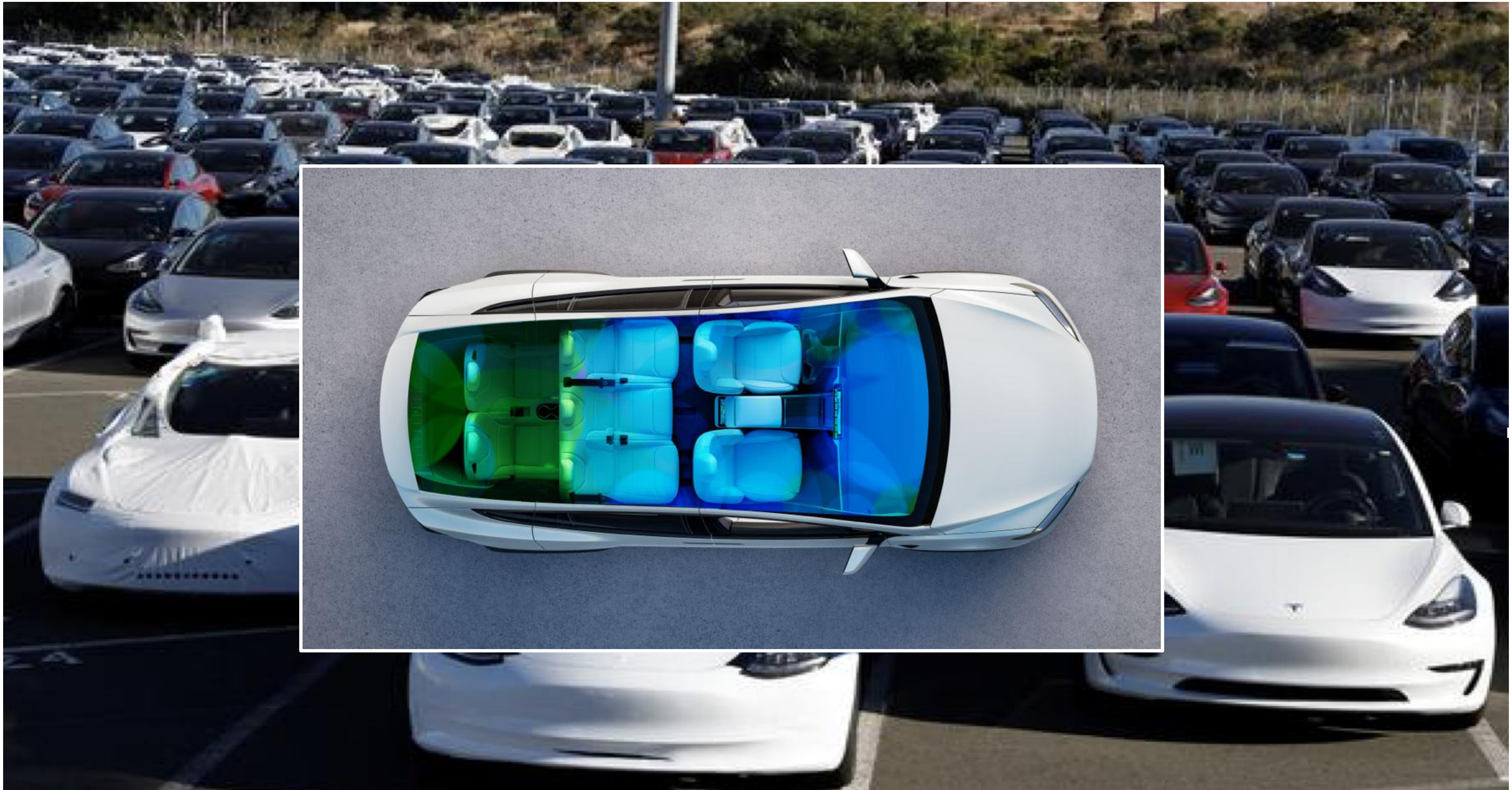

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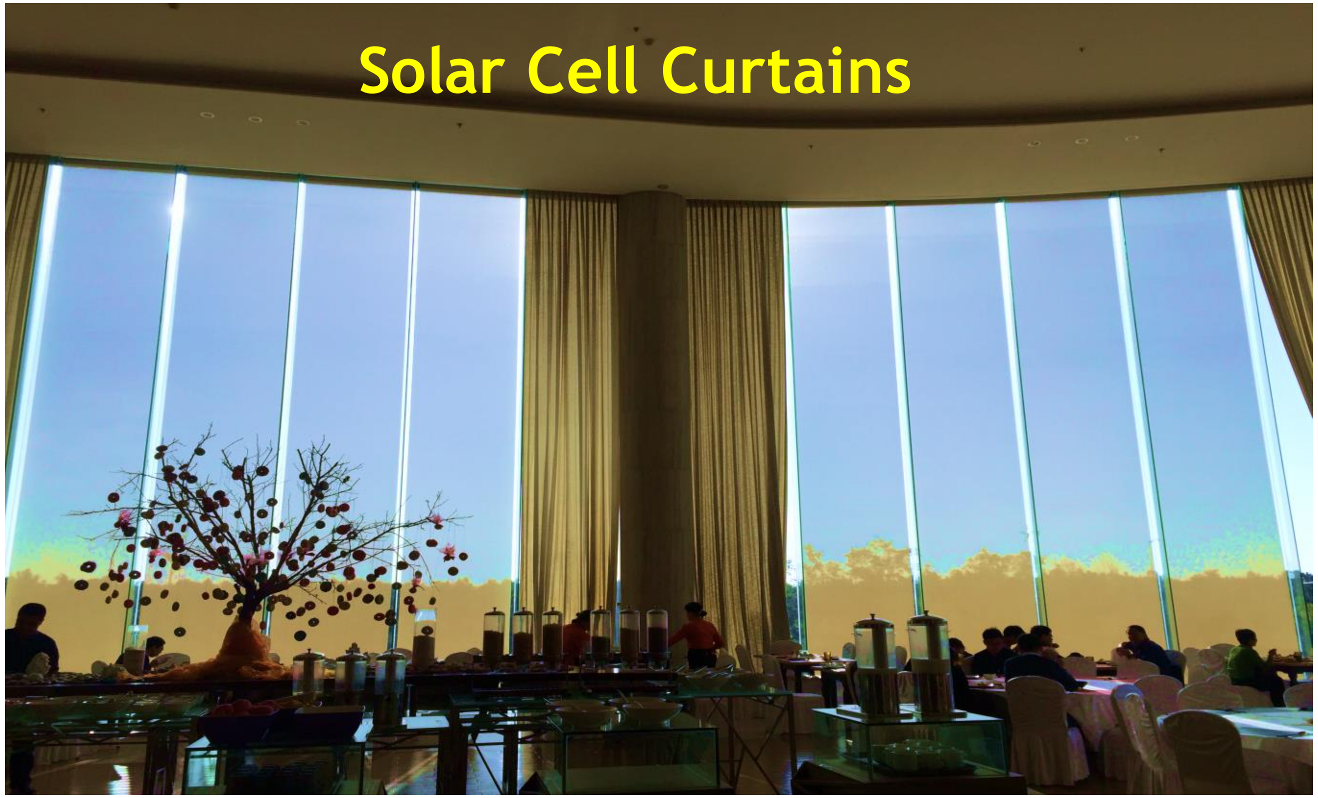

Indoor (IoT), AI, Wearable, Portable Power Source

With Innovation, Solar Can be Everywhere !

Last 4 years at CityU is a very productive time in my career

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International Recognition in Perovskite Solar Cells

Alex Jen was selected as one of the top 10 researchers in perovskite solar cell field by the Times Higher Education (THE)

TIMES HIGHER EDUCATION WORLD UNIVERSITY RANKINGS

PROFESSIONAL JOBS SUMMITS RANKINGS STU

Top universities and researchers in perovskite solar cell research

In the first of a regular series looking at who is producing highly cited research in different areas, *THE* explores a subject currently deemed the 'most prominent' by Elsevier metrics

February 6, 2018

The Jen Group @ City University of Hong Kong

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