



**NUS**  
National University  
of Singapore



SERIS  
Solar Energy Research  
Institute of Singapore



# Progress with perovskite-silicon tandem solar cells at SERIS

2<sup>nd</sup> Solar Technology Conference India (SCT.I 2026), New Delhi, 5-6 February 2026

Selvaraj Venkataraj and Armin Aberle, NUS-SERIS

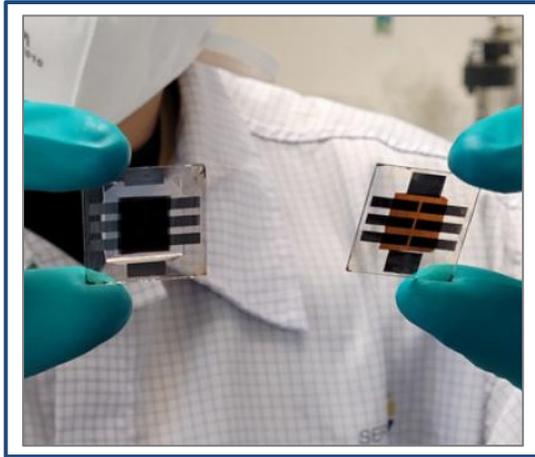
# SERIS

## Solar Energy Research Institute of Singapore

- ❑ National Lab founded at NUS in 2008; a global leader in solar research & development
- ❑ SERIS is supported by NUS, NRF, EMA & EDB
- ❑ Focuses on applied solar energy research (solar cells, PV modules, PV systems)
- ❑ ~ 110 staff, adjuncts & PhD students; state-of-the-art labs, ISO certified (9001, 17025)
- ❑ Close collaborations with companies & government agencies

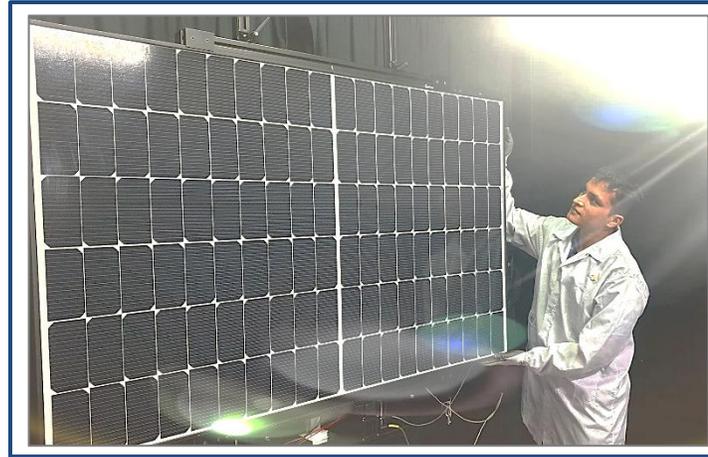


# Main R&D areas of SERIS



## Solar cells:

- Perovskite-silicon tandem solar cells
- Next-generation industrial solar cells
- Characterisation & simulation



## PV modules:

- Module testing (indoor & outdoor)
- Module development
- Building integrated PV (BIPV)
- Characterisation of optical properties
- Module reliability
- Recycling
- PV for vehicles



## Solar PV systems:

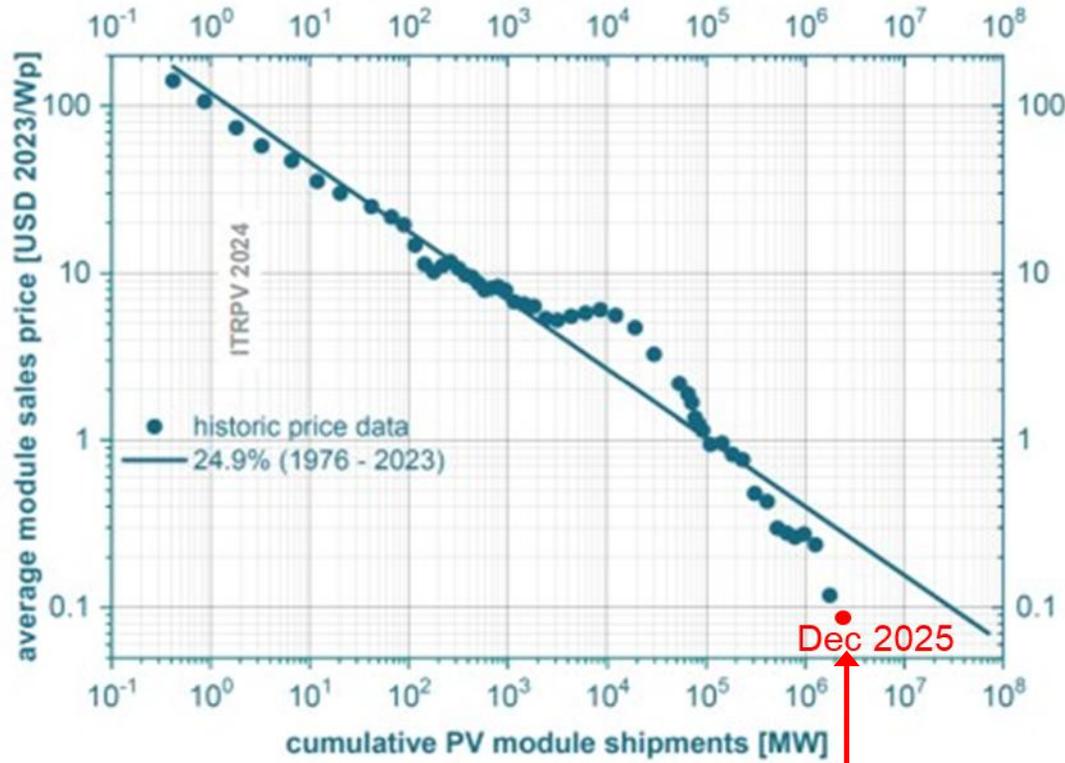
- System technologies, incl. Floating solar
- Innovative deployment concepts
- Urban Solar, incl. agrivoltaics
- PV grid integration
- Solar potential & energy meteorology (solar forecasting)
- Quality assurance of PV systems
- Solarisation of Singapore

# Learning curve for PV modules (\$/W)

Prices of c-Si PV modules

**“Race to the bottom for prices”**

Learning curve for module price as a function of cumulative shipments

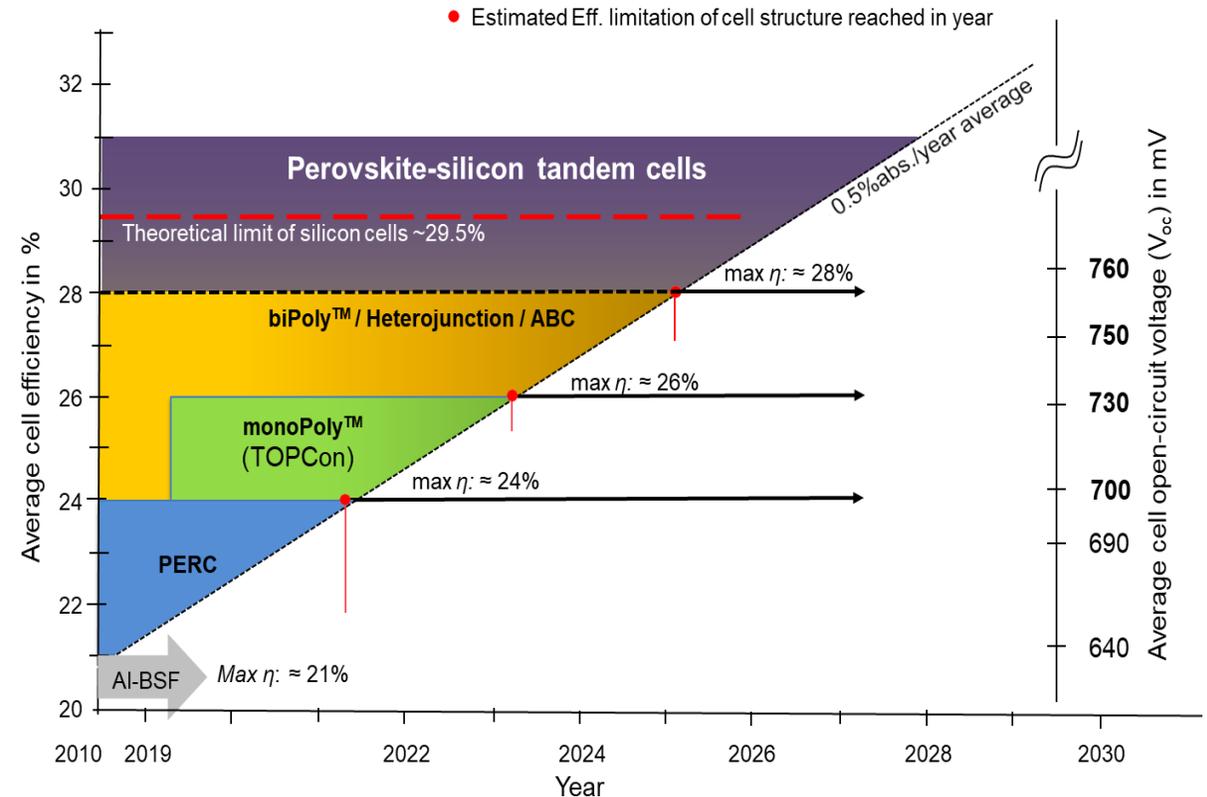


**Limit for c-Si modules  $\approx 10$  c/W<sub>p</sub>**

□ PV has fastest learning rate of all energy technologies!

ITRPV = International Technology Roadmap for Photovoltaic

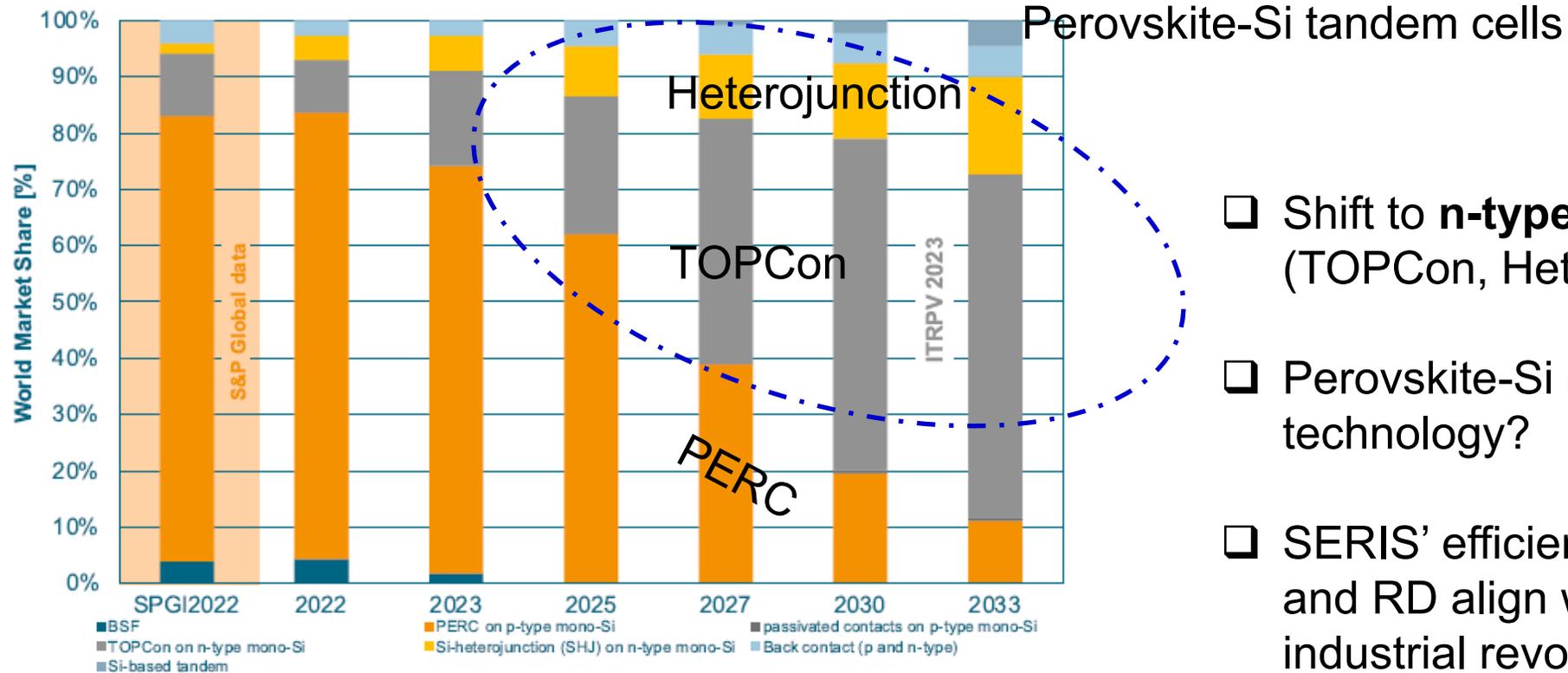
## SERIS' solar cell technology roadmap



# Expected evolution of industrial c-Si solar cells

## Different cell technologies

ITRPV = International Technology Roadmap for Photovoltaics



- Shift to **n-type** mono-Si cells! (TOPCon, Heterojunction)
- Perovskite-Si is the future technology?
- SERIS' efficiency road map and RD align with the industrial revolutions and market trends

Fig. 36: Market shares for different cell technologies. S&P Global (SPGI) data for 2022 are indicated as reference [20].

# Silicon Solar Cell Lab

## Next-Gen Industrial Solar Cells & Modules Cluster

- ❑ **1400 m<sup>2</sup>** cleanroom lab
- ❑ Versatile R&D **pilot lines** for mono c-Si and Thin Film solar cells
- ❑ **Large-area** silicon solar cells (> 200 cm<sup>2</sup>), high throughput
- ❑ Testbed for **industry collaboration**

### PECVD for HJT



### PECVD & Firing furnace



### In-line wet bench / Batch Tex



### GB for Perovskite

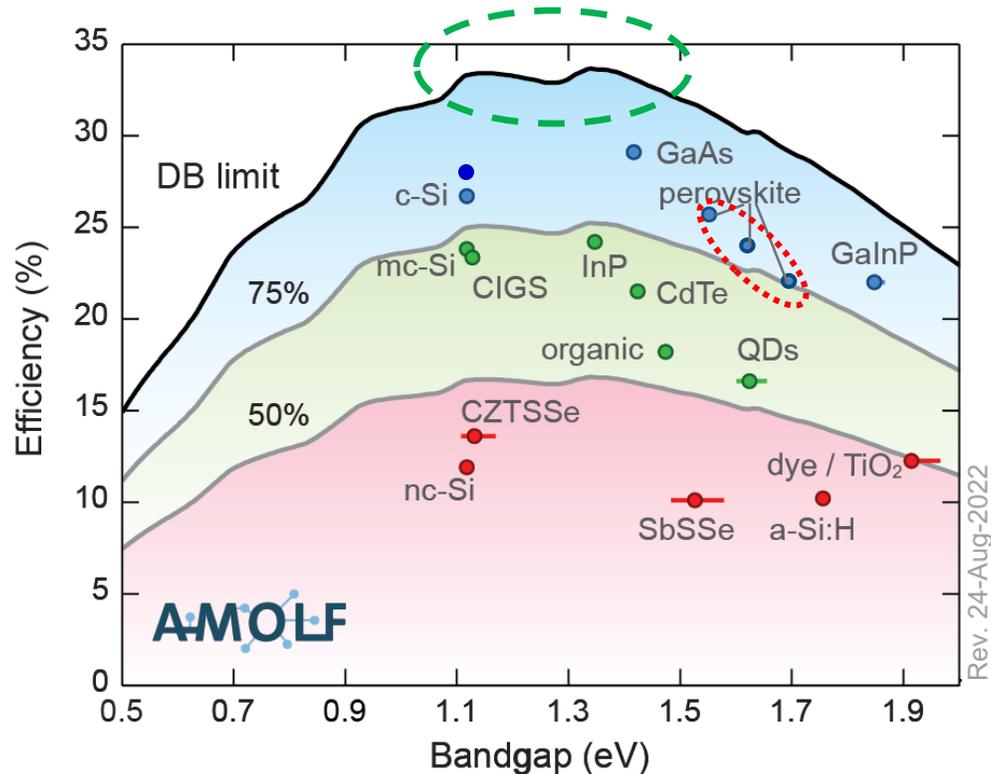


### In-line sputter machine



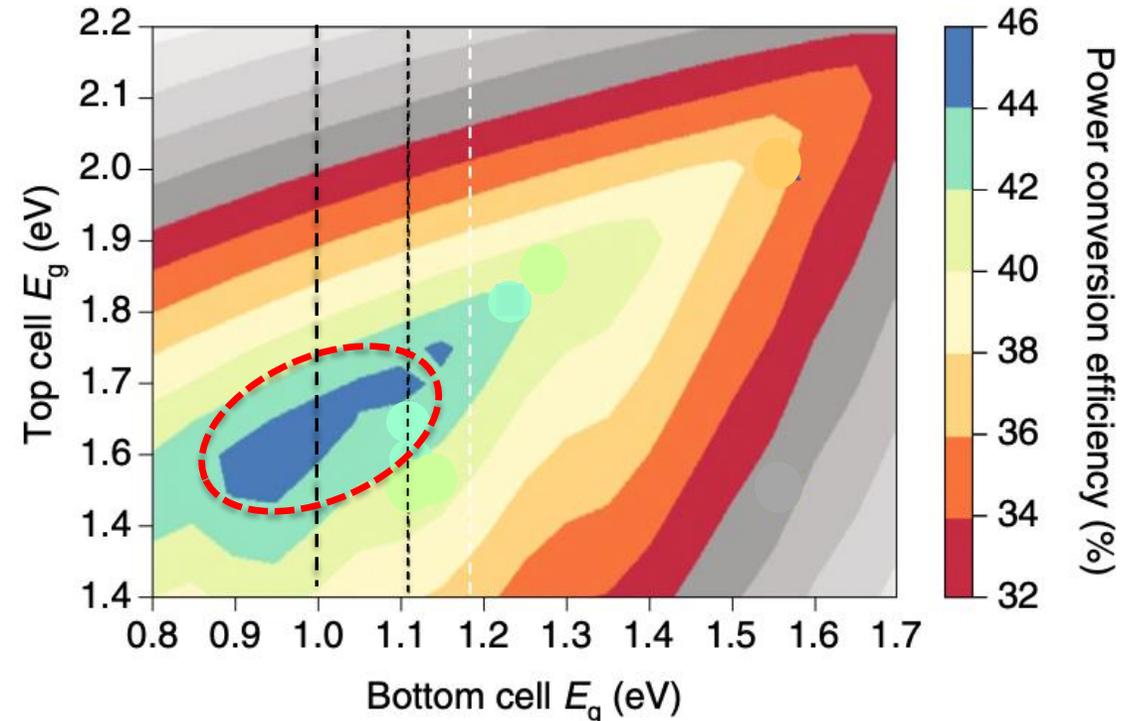
# Why 2 junctions? 45%!

## 1 junction: Efficiency limit ~34%



- ❑ Ideal bandgap: In the range of 1.0-1.5 eV
- ❑ Best materials: Si (27.8%) & GaAs (29.1%)

## 2 junctions: Efficiency limit ~45%

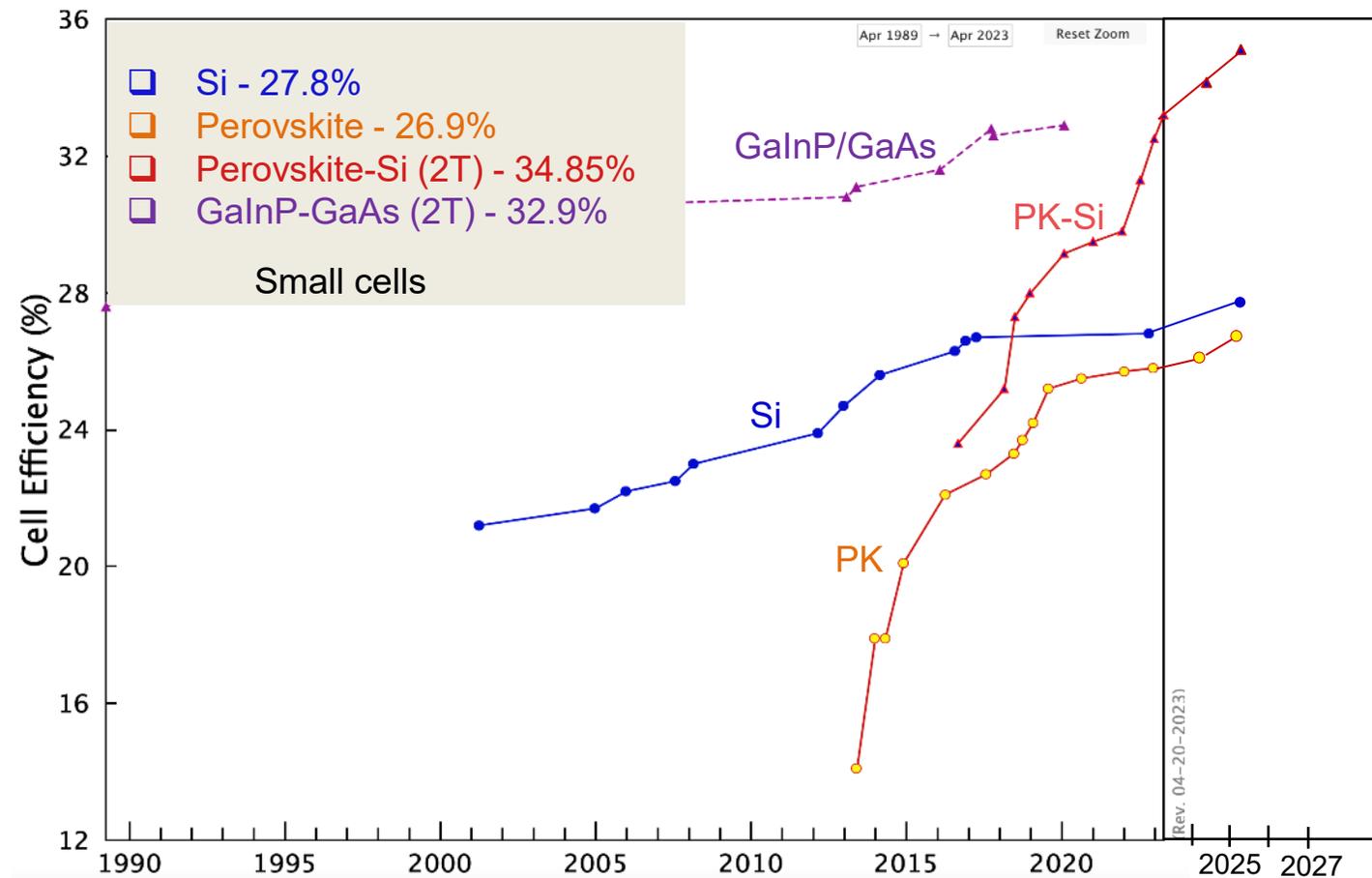
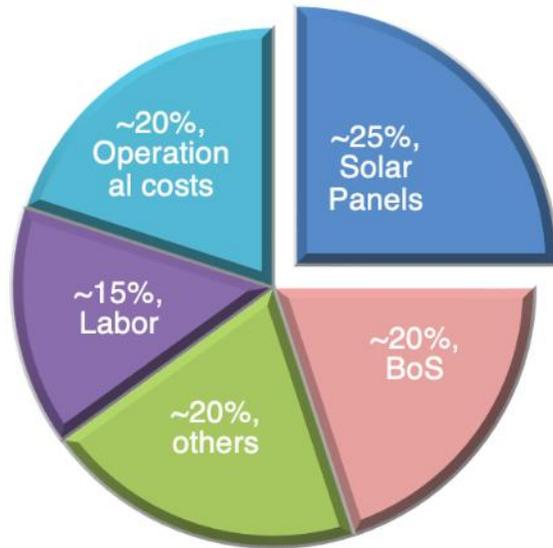


- ❑ Ideal bandgaps: ~1.65-eV top on ~1.0-eV bottom
- ❑ Si (1.1 eV) needs top cell with ~1.7 eV → **Perovskite**

Source: *Nature Energy* 3, 828 (2018), <https://www.impv.nl/db>

# Are 2 junctions cost-effective (LCOE)?

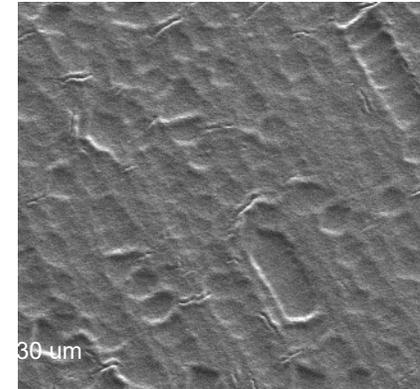
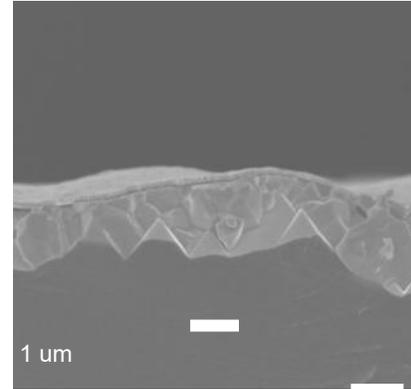
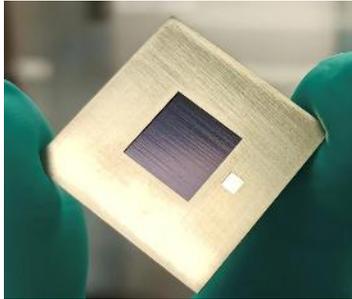
Cost breakdown (\$/W) of PV systems:



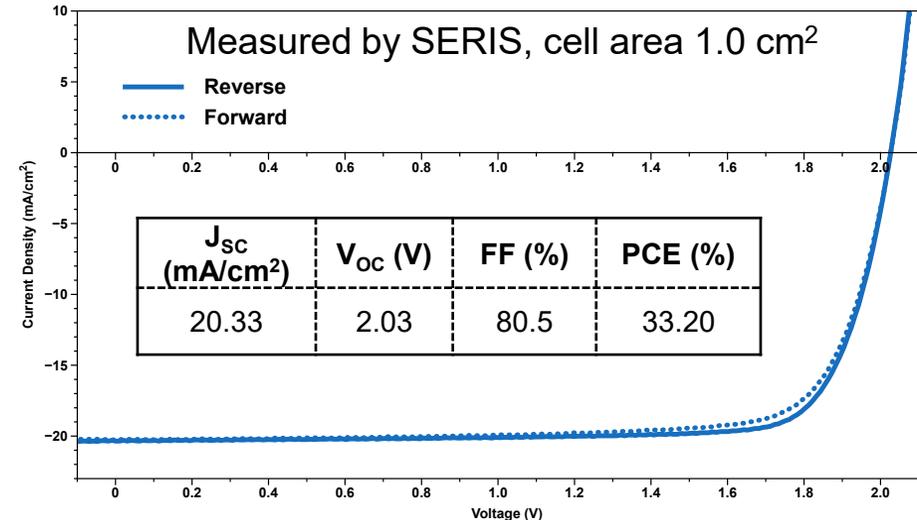
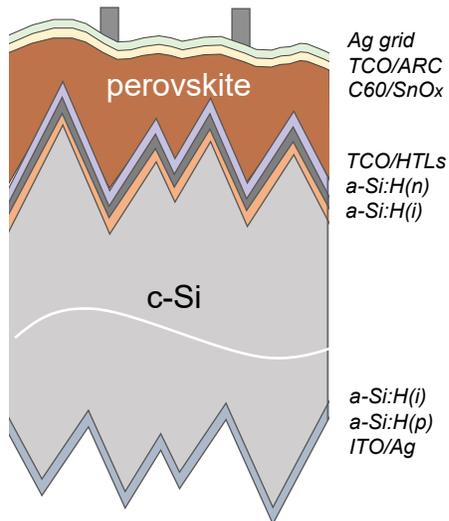
❑ Cost effectiveness (LCOE) requires PV modules with high efficiency, low cost (\$/W) & a long life on the roof.

# 33.2% perovskite-Si tandem cell (1 cm<sup>2</sup>)

NPVC Cluster, Asst Prof HOU Yi's group

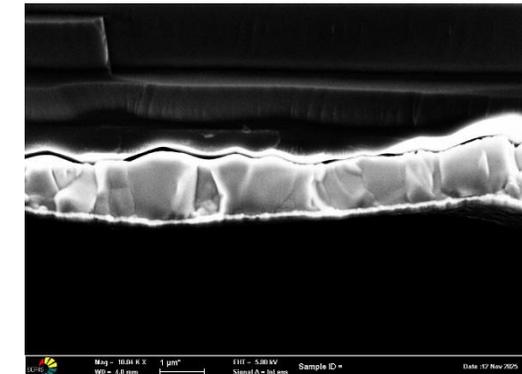
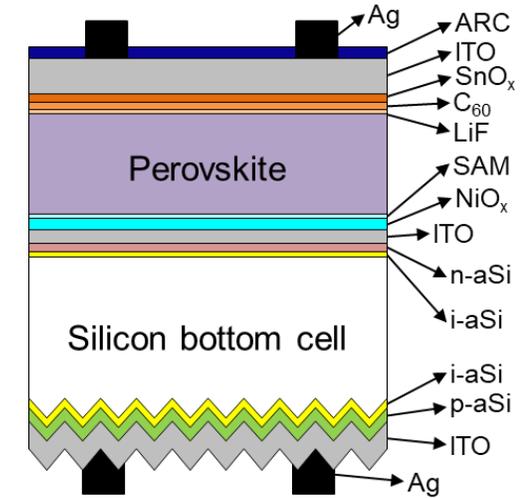
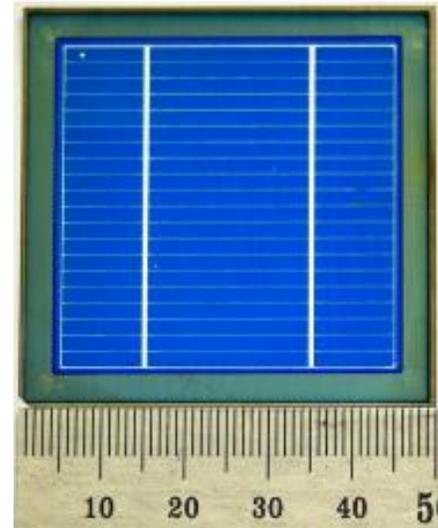
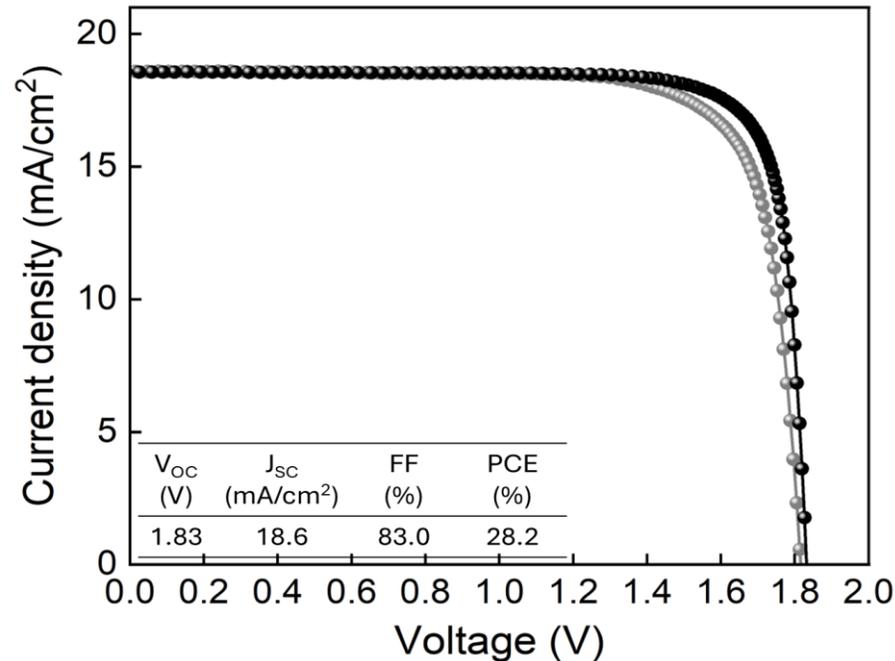


Fully solution-processed perovskite on industrial Si wafer (1 cm<sup>2</sup> aperture area)



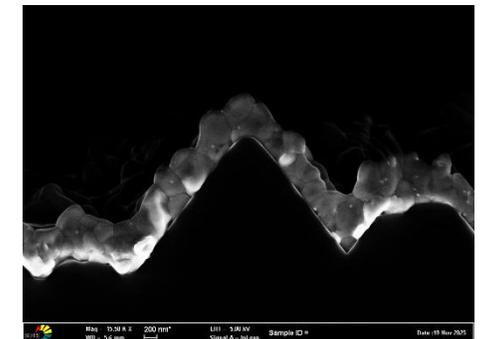
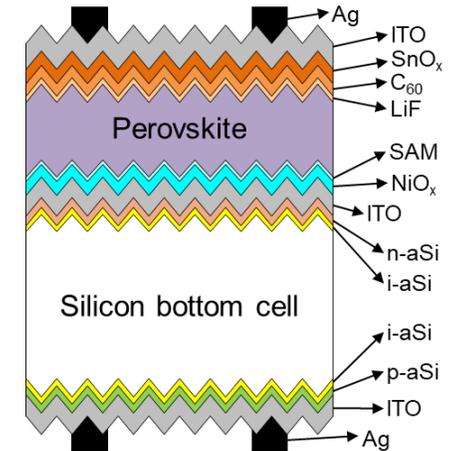
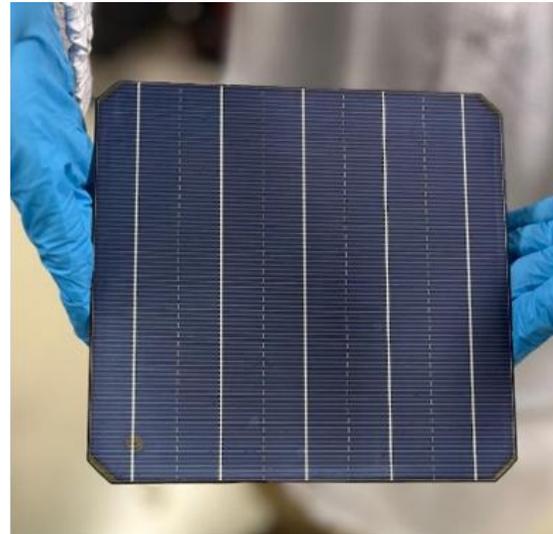
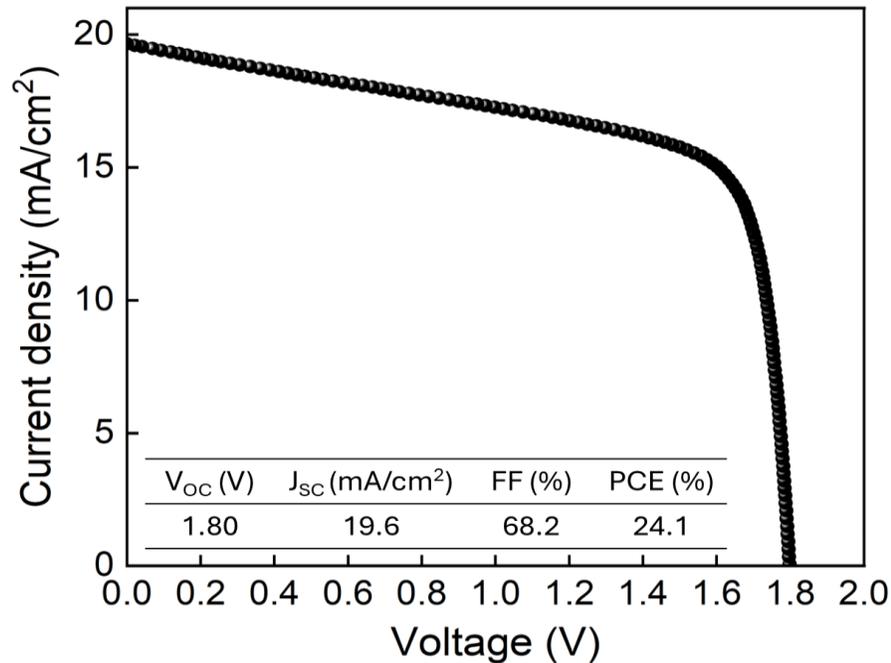
- ❑ 33.2% tandem cell (1 cm<sup>2</sup>) using industry standard Cz Si wafer (130 μm thick, bottom cell from industry)
- ❑ V<sub>oc</sub> of 2.026 V (**world record**), measured in-house.

# 28.2% perovskite-Si tandem cell (16 cm<sup>2</sup>)



- ❑ 28.2% perovskite-Si tandem cell (16 cm<sup>2</sup>) using industry standard Cz Si wafer cell from SERIS (smooth top surface)
- ❑ Fully solution-processed perovskite top cell with bandgap ~ 1.67 eV
- ❑ Industry relevant screen-printed metal contacts

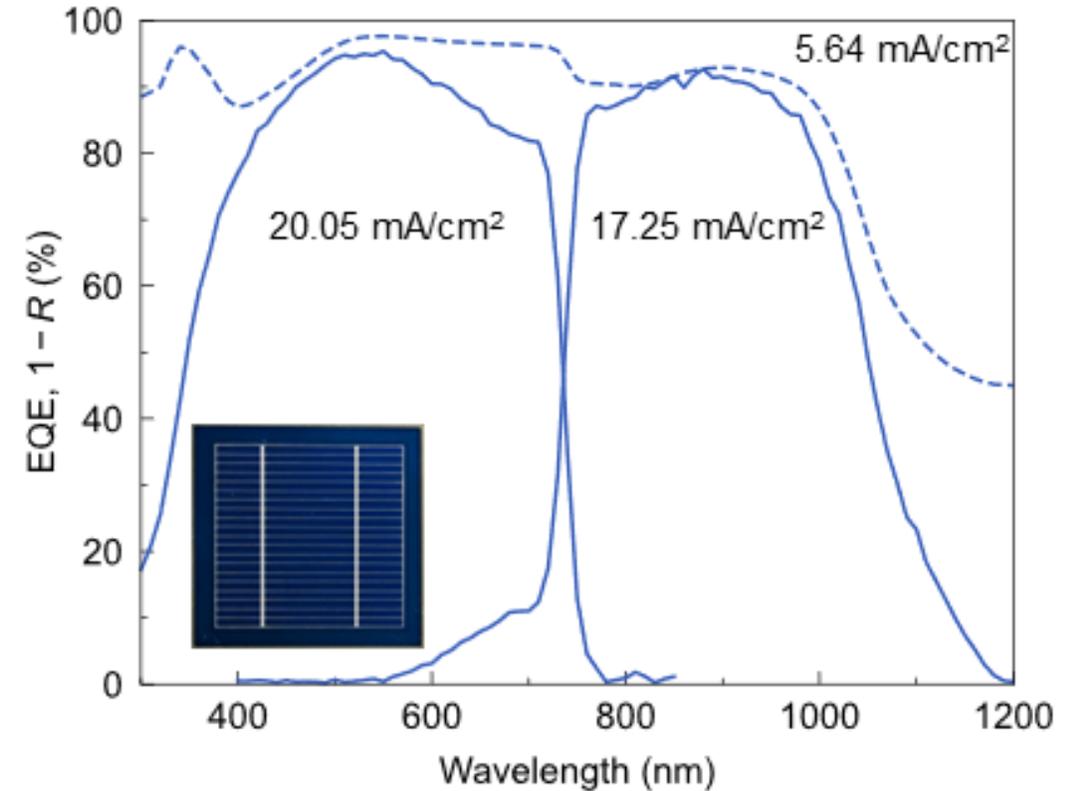
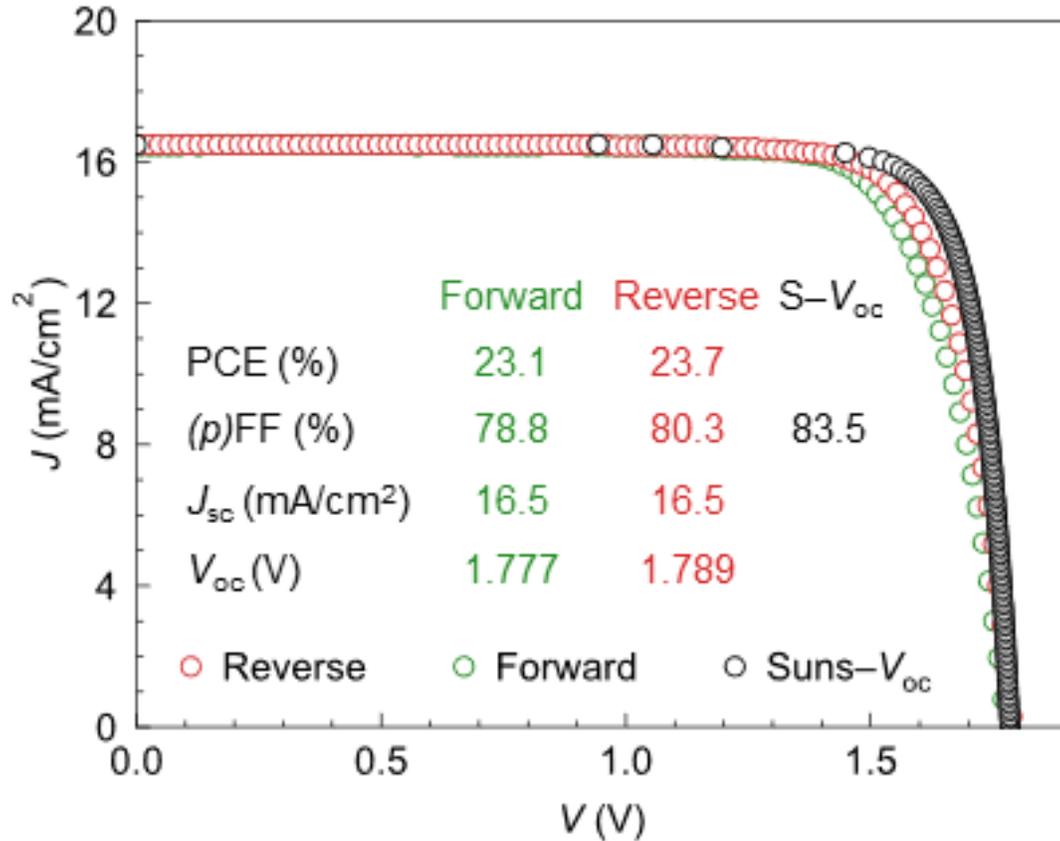
# 24% large perovskite-Si tandem cells (244 cm<sup>2</sup>)



- ❑ Developed **M2-size (244 cm<sup>2</sup>) tandem cells** with heterojunction bottom cells
  - Inhouse HJ bottom cells / SERIS process → Tailored for 2T development
  - Achieved **24.1% efficiency** (measured in-house)
- ❑ 2T efficiency → FF limited
  - Challenge: Minimise shunting issues
- ❑ Ambitious target to achieve in 2026: > 28%

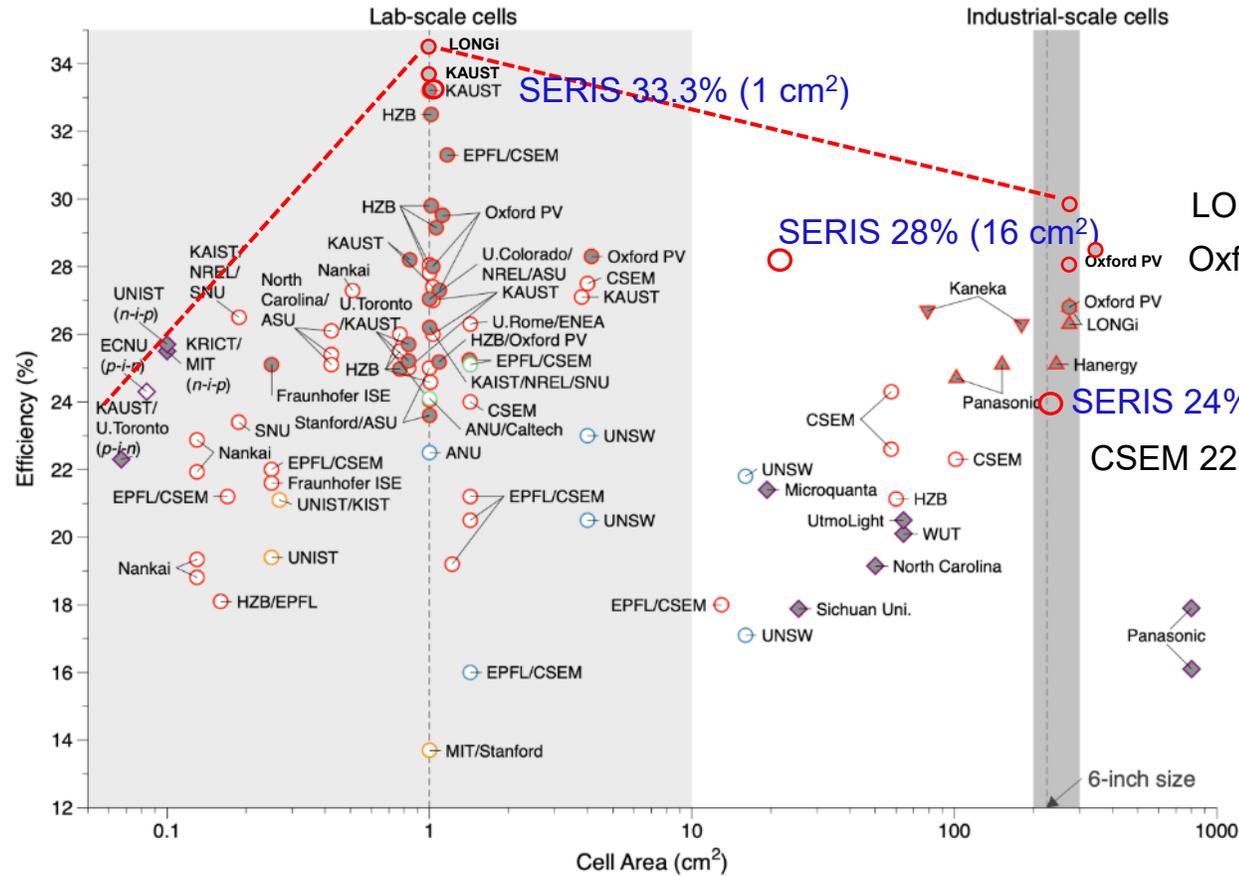
# 23% large perovskite-Si tandem cells (16 cm<sup>2</sup>)

BiPoly (TOPCon) concept bottom cells

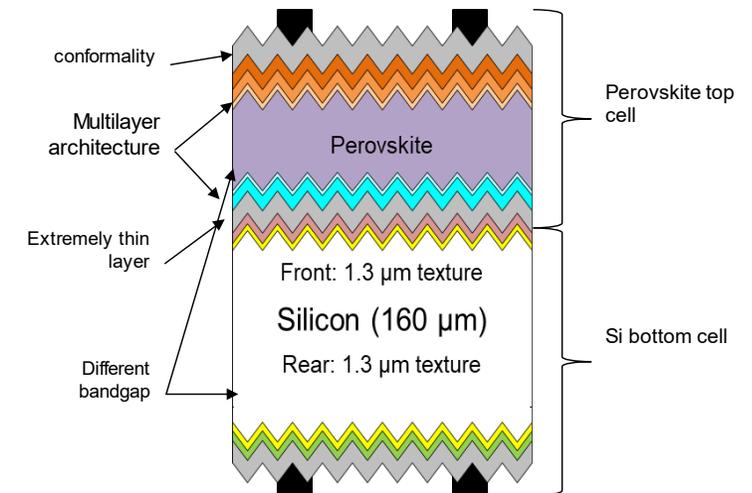


□ SERIS is looking for industrial partners for further development of perovskite on TOPCon bottom cells

# Perovskite-silicon tandem cells (2T, ○●)



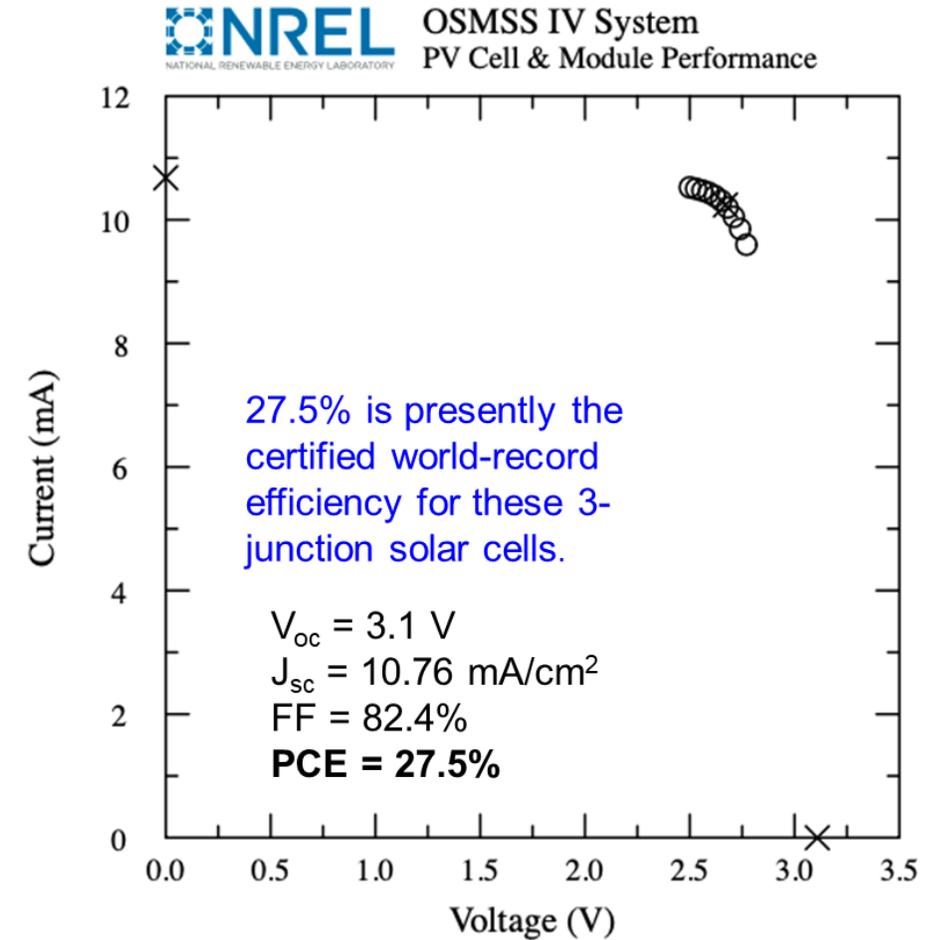
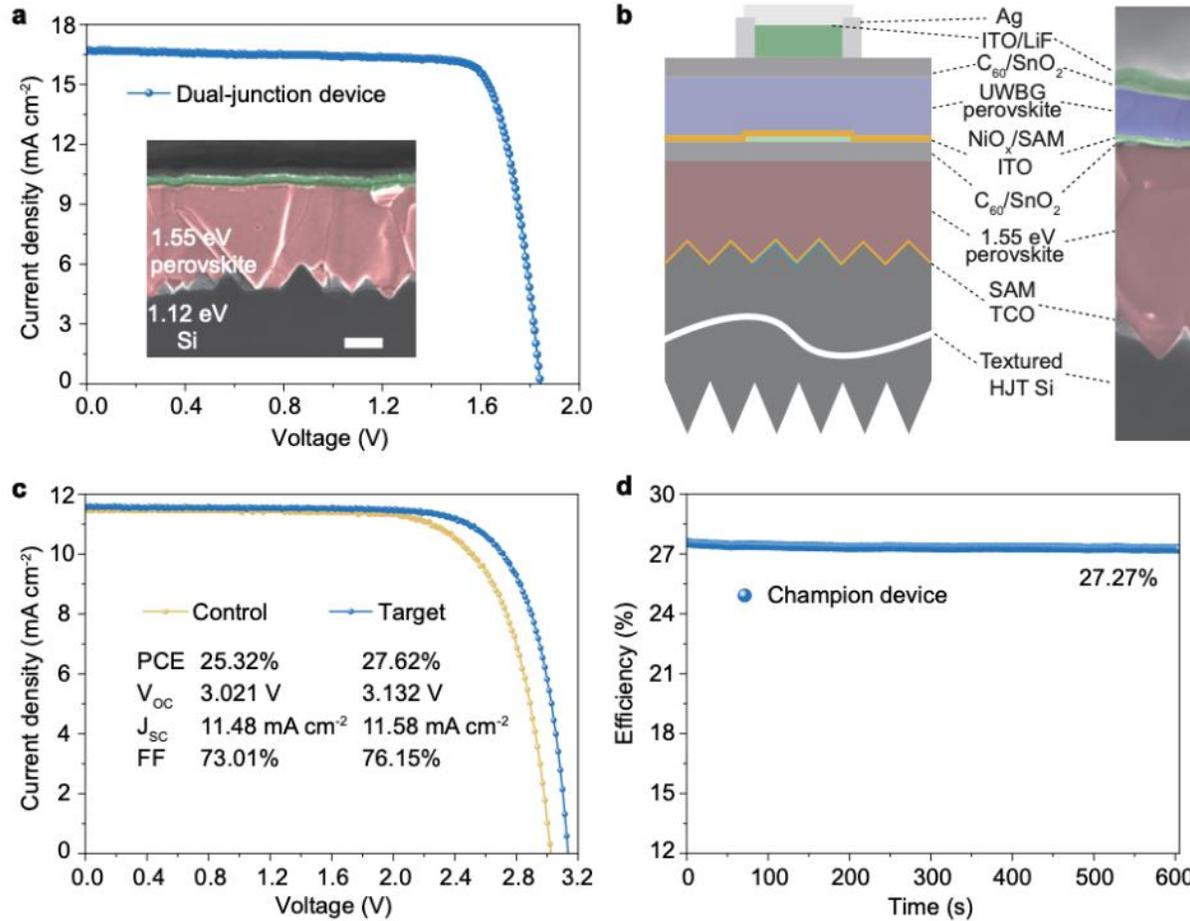
LONGi, 30.1% (M6)  
 Oxford PV 28.5% Hanwha Qcells 28.6% (M10, Nov 2024)



◇ Perovskite (SJ)	▲ SHJ (SJ, certified)	○ SHJ (tandem)	○ Al-BSF (tandem)	○ Passivating contact technology using doped polysilicon (POLO, TOPCon, etc.)
◆ Perovskite (SJ, certified)	▼ SHJ-IBC (SJ, certified)	● SHJ (tandem, certified)	○ PERC (tandem)	

# 27.3% perovskite-perovskite-Si cell (1 cm<sup>2</sup>)

NPVC Cluster, Asst Prof HOU Yi's group

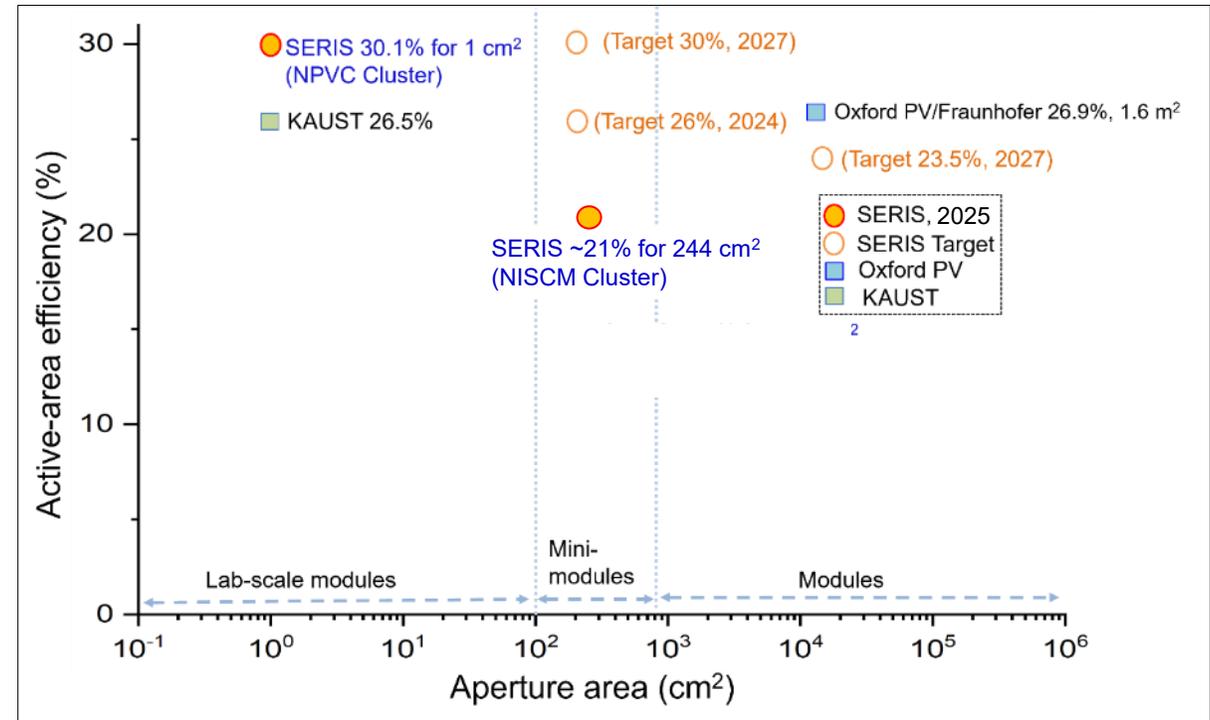
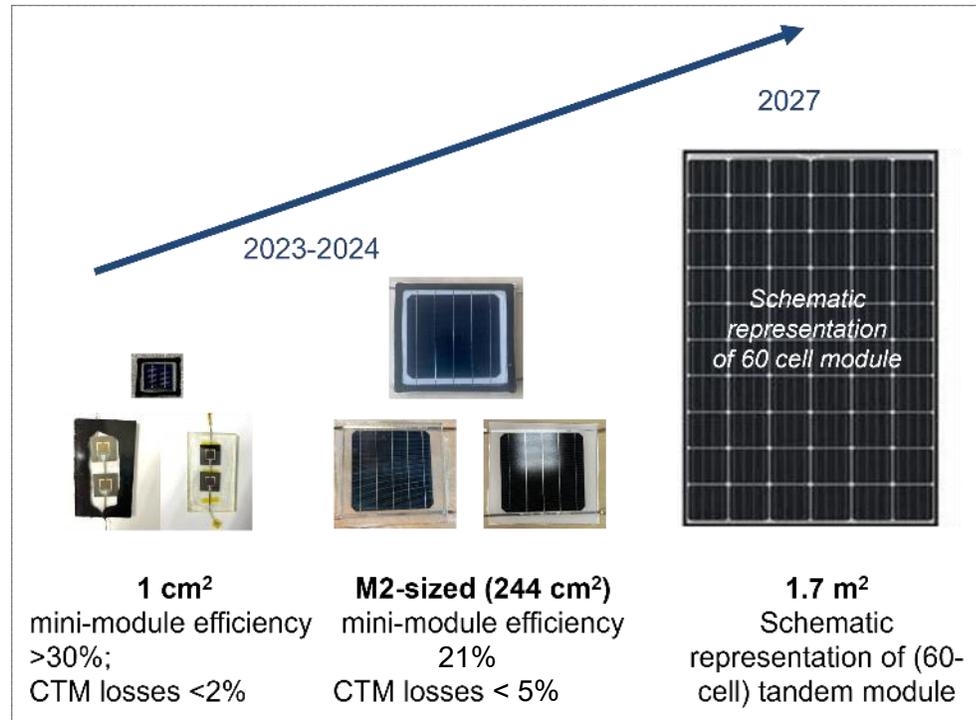


Source: S. Liu, Y. Lu, ..., and Yi Hou, *Nature* 628, 306 (2024), Triple-junction solar cells with cyanate in ultrawide-bandgap perovskites.

# Perovskite-silicon tandem mini-modules

## □ Next steps:

- By Dec 2026: Further improve the efficiency of perovskite-silicon mini-modules to ~30% for active area of > 200 cm<sup>2</sup>.
- Fabricate a large 60-cell perovskite-Si module (1.7 m<sup>2</sup>) by Jan 2027.

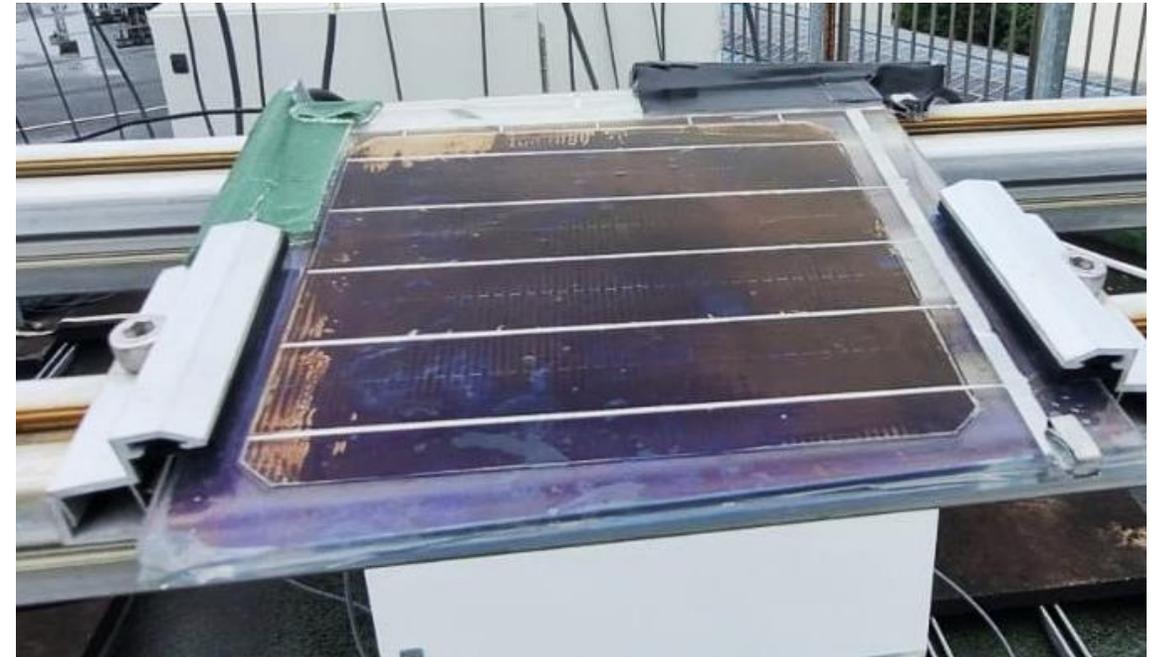


# Performance losses: Moisture ingress

Moisture penetration at module edges after 5 months outdoors



With edge sealant



Without edge sealant

# Summary

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- ❑ Upgrading single-junction **silicon solar cells** to tandem cells using a low-cost **perovskite top cell** is presently the most realistic option to achieve 30% efficient industrial PV modules at low cost (\$/W)
- ❑ SERIS' solar cell R&D is focused on perovskite-silicon tandem cells & modules
- ❑ SERIS has achieved world-class efficiencies for small, medium & large perovskite-silicon tandem solar cells, and is one of the leading public R&D institutes for this emerging PV technology
- ❑ Our work in 2026 & 2027 focusses on:
  - (i) improving the efficiency of large perovskite-silicon tandem cells to  $> 30\%$ ,
  - (ii) developing  $\sim 30\%$  tandem mini-modules with active area of at least  $200 \text{ cm}^2$ , and
  - (iii) developing  $1\text{-cm}^2$  triple-junction perovskite-perovskite-silicon cells with  $> 36\%$  efficiency

## Acknowledgements:

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- SERIS is a research institute at the National University of Singapore (NUS). SERIS is supported by NUS, the National Research Foundation Singapore (NRF), the Energy Market Authority of Singapore (EMA) and the Singapore Economic Development Board (EDB).

Thank you for your attention!

Contact: [s.venkataraj@nus.edu.sg](mailto:s.venkataraj@nus.edu.sg)

More information at [www.seris.sg](http://www.seris.sg)

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