



Technology Developments: TOPCon Era

Johanna Bonilla
Head of Technical Product Management EU

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01 Trends in the past decade

Wafer/Cell/Modules

Wafer Technology

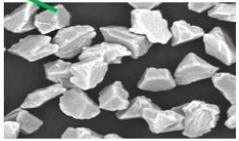
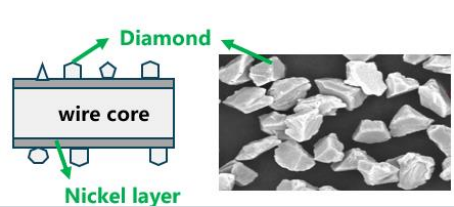
Czochralski (Cz) Si Growth

- **Higher Growth Efficiency:** Pulling rate improved from 0.8 to 1.9 mm/min; thermal field expanded from 22 to 36 inches.
- **Material Enhancements:** Increased purity (6N → 9N) and reduced oxygen content (14 → 9 ppma).

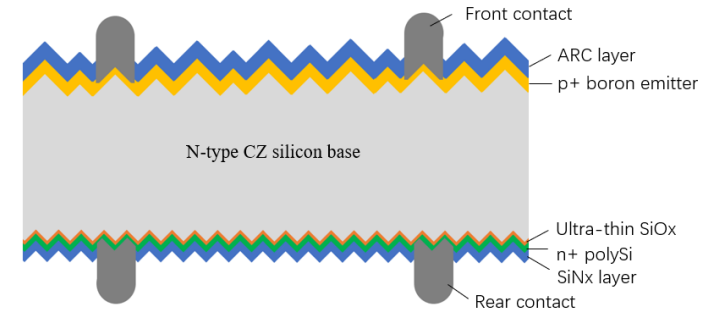
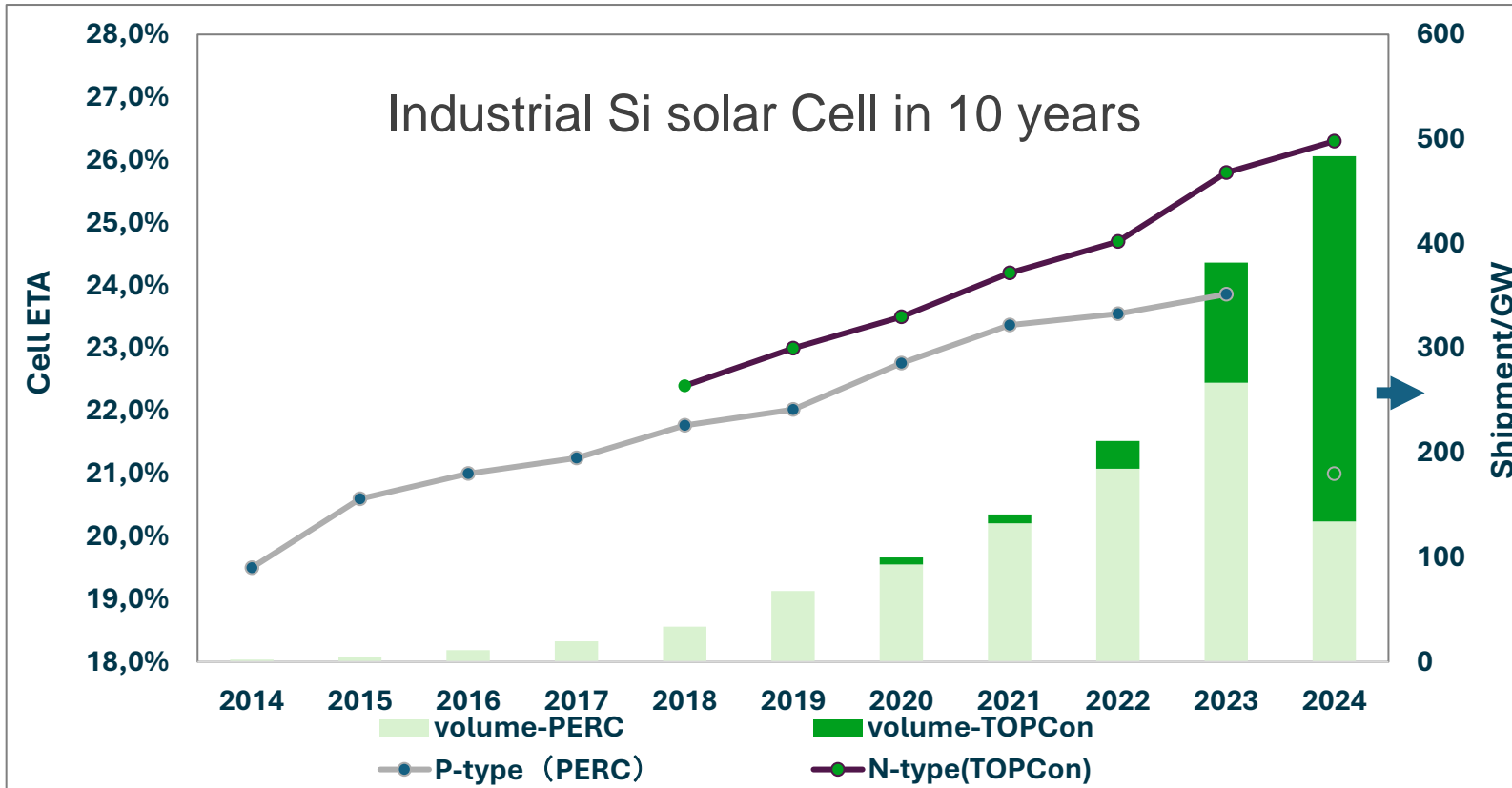


Wafer Cutting

- **Wire Core Optimization:** Transition to tungsten wire cores increased durability and reduced breaking force.
- **Efficiency Gains:** Diamond wire saw reduced material consumption by 33%



Solar Cell N-type TOPCon the current mainstream



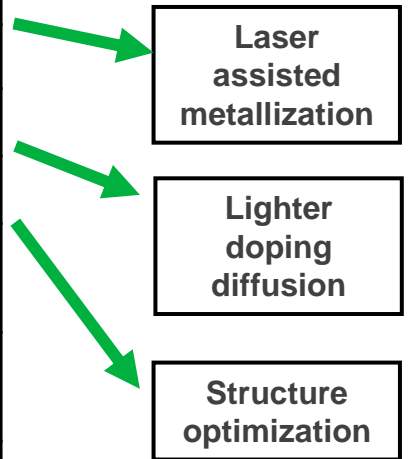
N-type TOPCon mono-c-Si cell

Mass Production Efficiency
> 26%
Wafer Size
182-210 mm
Cell Voc
~740mV

Solar Cell TOPCon has undergone accelerated developments

		PERC	TOPCon (~2019)	TOPCon (2024)
Optical system	reflectivity	~2.2%	~2.2%	~1.6%
	proportion of metal shading	~3%	~2.5%	~2.3%
	wafer thickness	150 um	180 um	120-130 um
	poly-Si parasitic absorption	/	~0.8 mA/cm ²	~0.4 mA/cm ²
Passivation system	front side passivation	$J_0 \sim 50 \text{ fA/cm}^2$	$J_0 \sim 15 \text{ fA/cm}^2$	$J_0 \sim 6 \text{ fA/cm}^2$
	rear side passivation	$J_0 \sim 5 \text{ fA/cm}^2$	$J_0 \sim 4 \text{ fA/cm}^2$	$J_0 \sim 3 \text{ fA/cm}^2$
	front metal recombination	$J_0 \sim 700 \text{ fA/cm}^2$	$J_0 \sim 1500 \text{ fA/cm}^2$	$J_0 \sim 100 \text{ fA/cm}^2$
	rear metal recombination	$J_0 \sim 400 \text{ fA/cm}^2$	$J_0 \sim 100 \text{ fA/cm}^2$	$J_0 \sim 50 \text{ fA/cm}^2$
Electrical system	front electrode contact resistance	~ 0.5 mΩ.cm	~ 1.5 mΩ.cm	~ 1.0 mΩ.cm
	rear electrode contact resistance	~ 1.0 mΩ.cm	~ 0.5 mΩ.cm	~ 0.5 mΩ.cm
	wafer resistivity	0.5-1.5 Ω.cm	1-3 Ω.cm	0.5-1.5 Ω.cm

TOPCon solar cell also experienced multiple technical optimizations and even structure updates.



Solar Cell **Summary of TOPCon Upgrading**

Bulk Quality

- Wafer thinning
- Resistivity optimization
- Hydrogenation technology (light anneal)

Optics

- Small-size pyramid texturing technology
- N-poly thinning technology
- ARC layer with gradient n

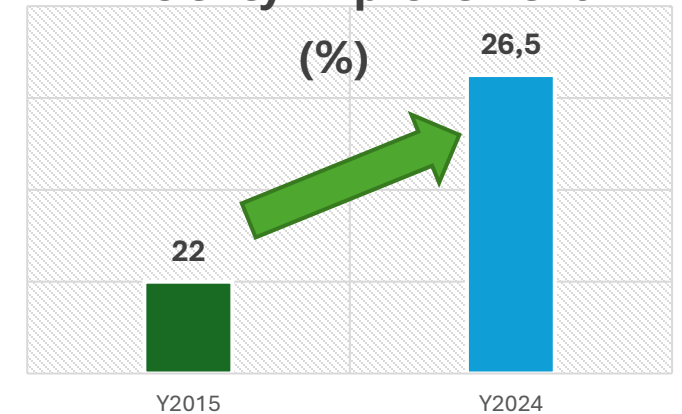
Passivation

- Front passivation improvement (high emitter sheet resistance)
- Rear passivation improvement (passivating contact)

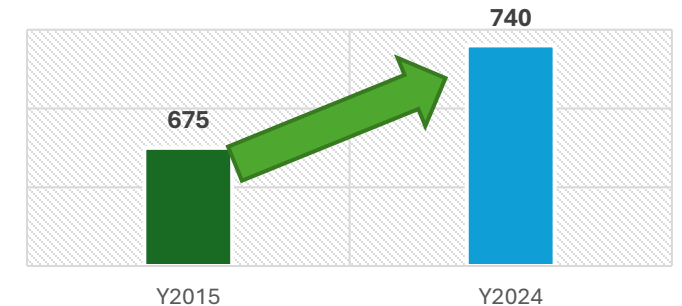
Metallization

- Evolution of Ag paste recipe
- SMBB/OBB technology
- Knotless screen printing
- ME technology

Efficiency Improvement



Voc Improvement (mV)

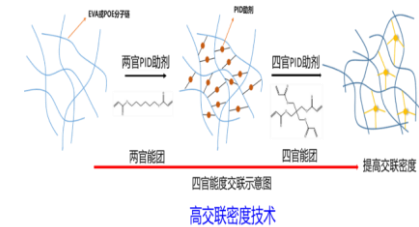
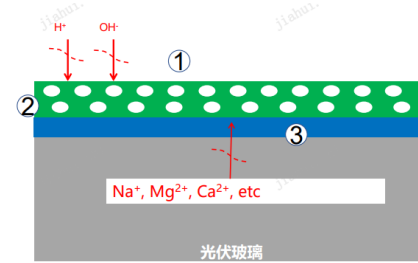


Module Technology- Customer Driven Developments

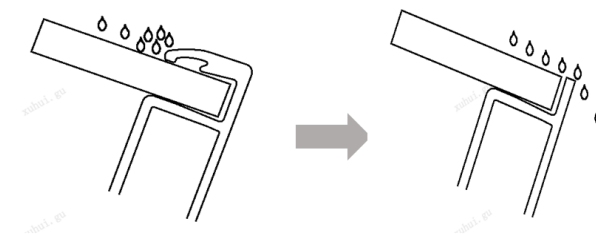
Environmental Scenarios Require Different Module Design.

Anti-humidity encapsulation materials

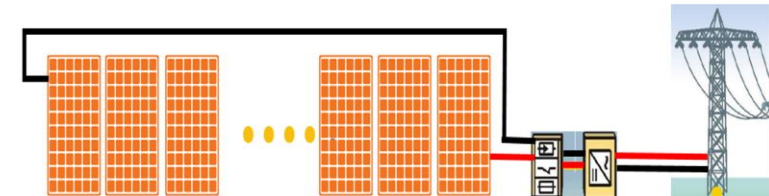
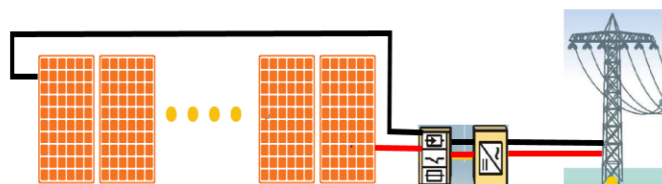
Offshore PV
(High humidity)



Soil accumulation
reduction



High voltage
2000V



02 Outlook of Silicon PV Technology

TOPCon Room for **Upgrading**

Si Wafer: Higher Ingot Quality

- **Co-Doping:** better uniformity & longer minority carrier lifetime
- **Cusp Magnetic Field:** less impurities & improving resistivity uniformity.
- **Machine Learning:** Process optimization via growth data enhances crystal yield & ingot quality.

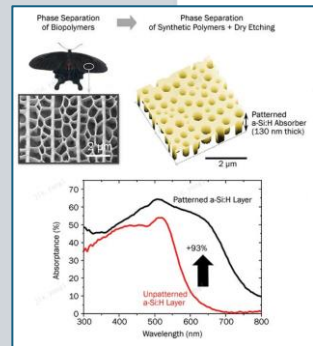


Passivation Contact Development

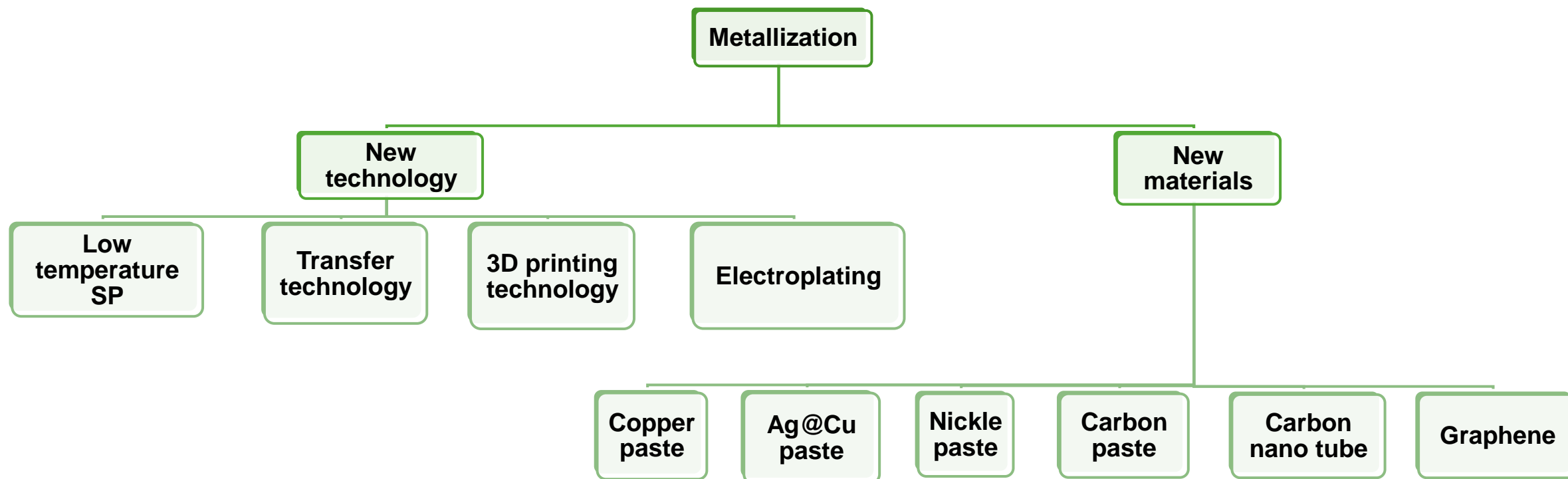
- **Future Focus:** Passivating contacts isolate metal electrodes from the silicon surface, significantly reducing recombination and increasing efficiency.
- **Material Innovation:** Thin films like SiO_x, SiN_x, and AlO_x enhance anti-reflection and contact performance.

Si-Cell

- **p+ Poly Optimization:** Thermal oxidation and pre-annealing processes enhance poly-Si film quality
- **Optical Improvements:** photonic crystals & refractive index improvements.
- **Metallisation:** many material options emerging



Outlook of Cell Metallization

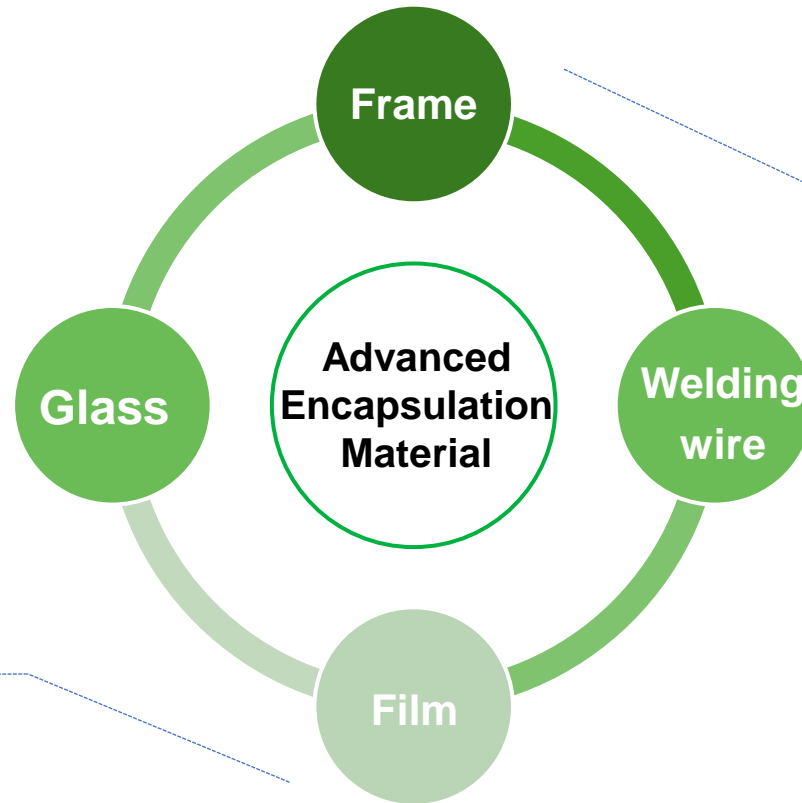


Outlook of Module Technology

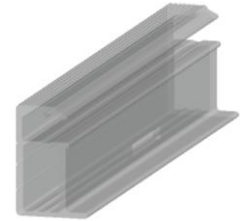
Glass material
Glazed → non-glazed
Glass thinning
2.0 → 1.8 → 1.6
Improve glass stress



Film material
POE → EPE/EP
Film gram
390 → 370 → 330
Developing new film



No C border frame
Frame cavity optimization
Optimization of excessive glue

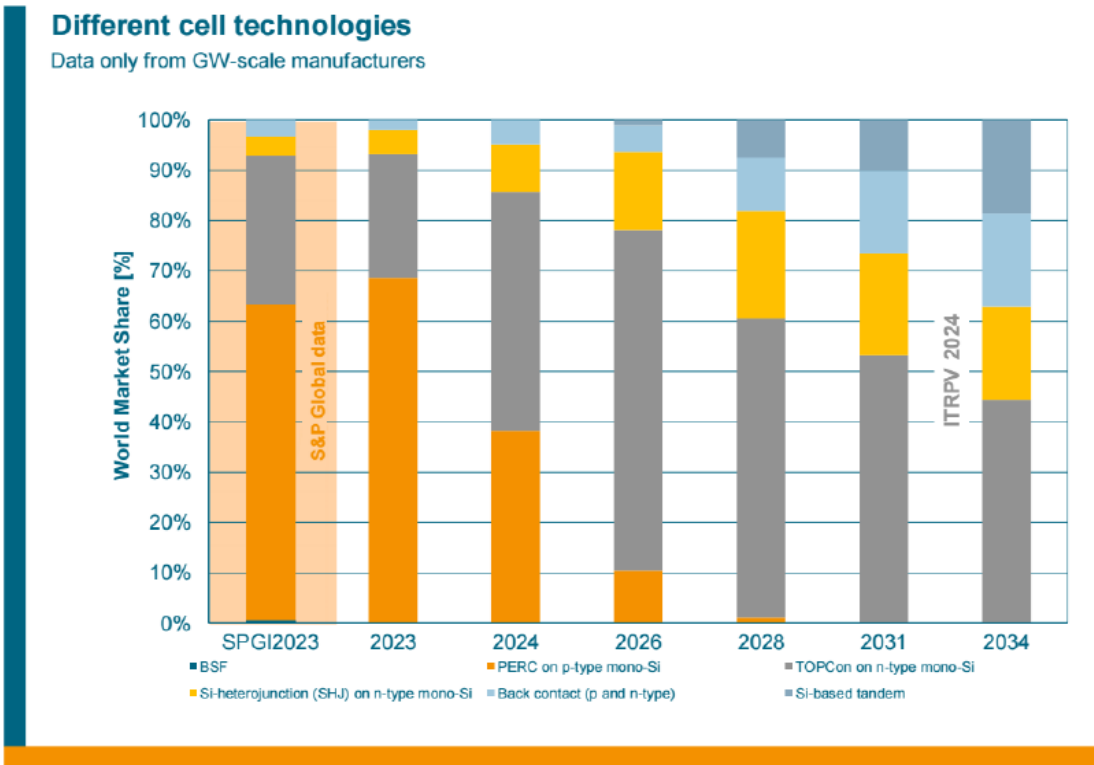


Welding wire thinning
0.29*10BB → 0.26*16BB → 0.24 → 0.20
Welding wire for BC/0BB

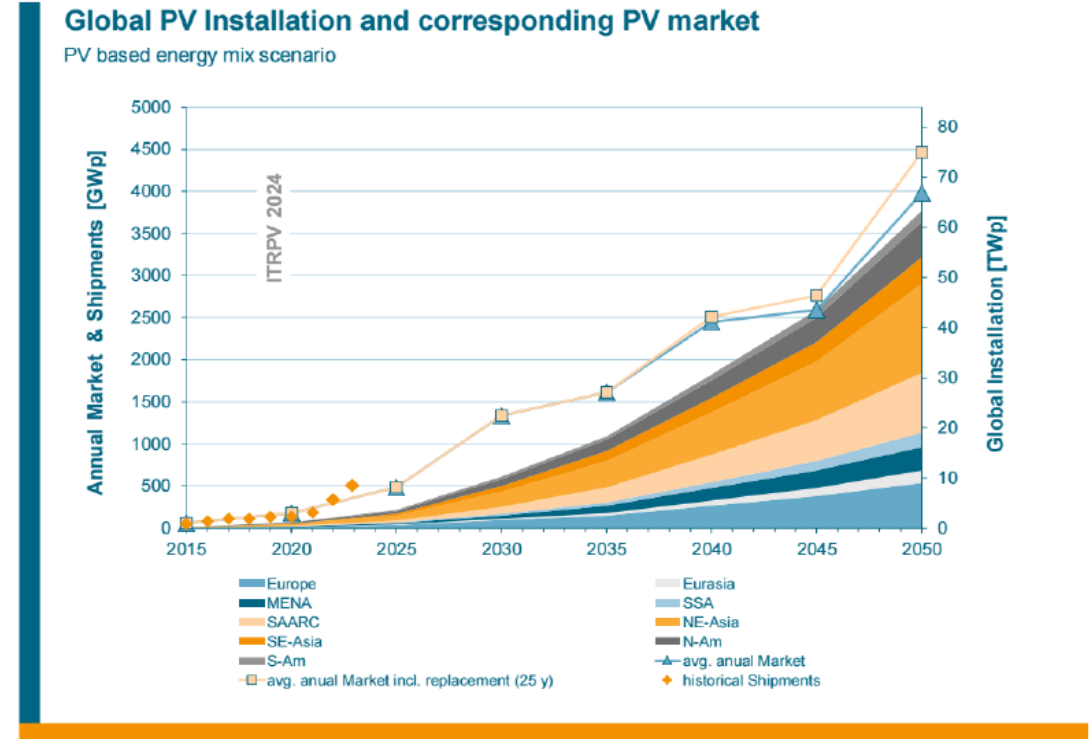


03 PV Industry

The Sun will Shine Again



Market shares for different cell technologies from GW-scale manufacturers.

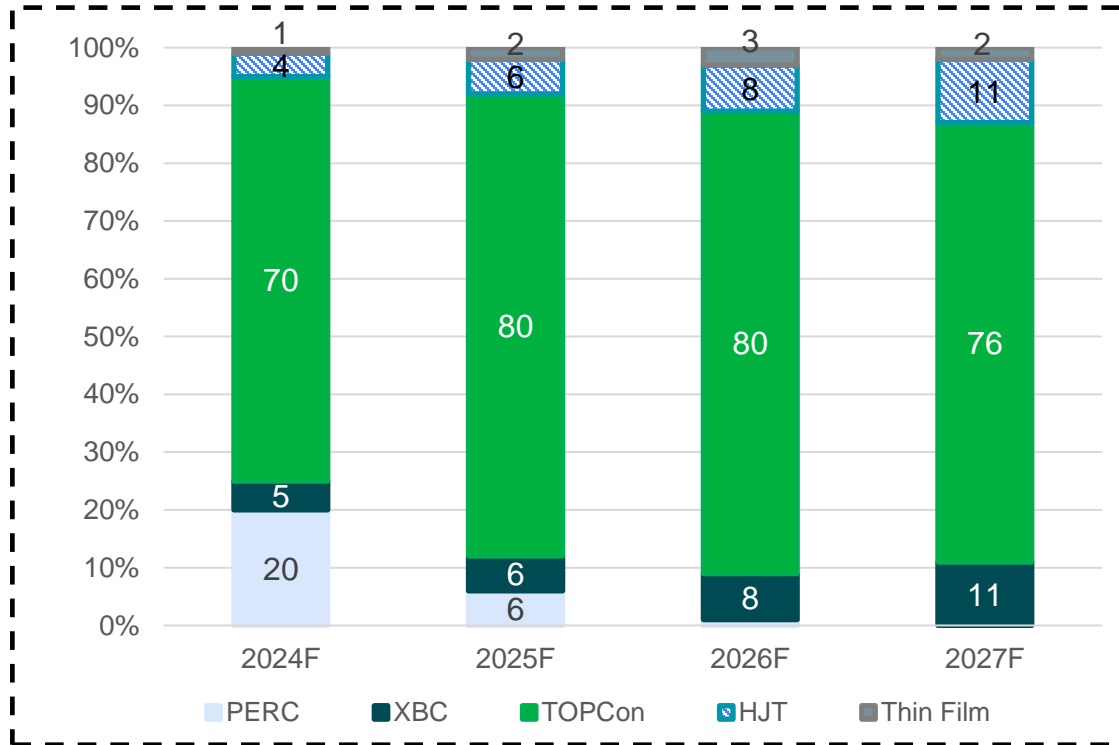


Cumulative installed PV module power and 5-year average annual market for global PV module installation of 63.4 TWp in 2050 in a zero-greenhouse gas emission economy.

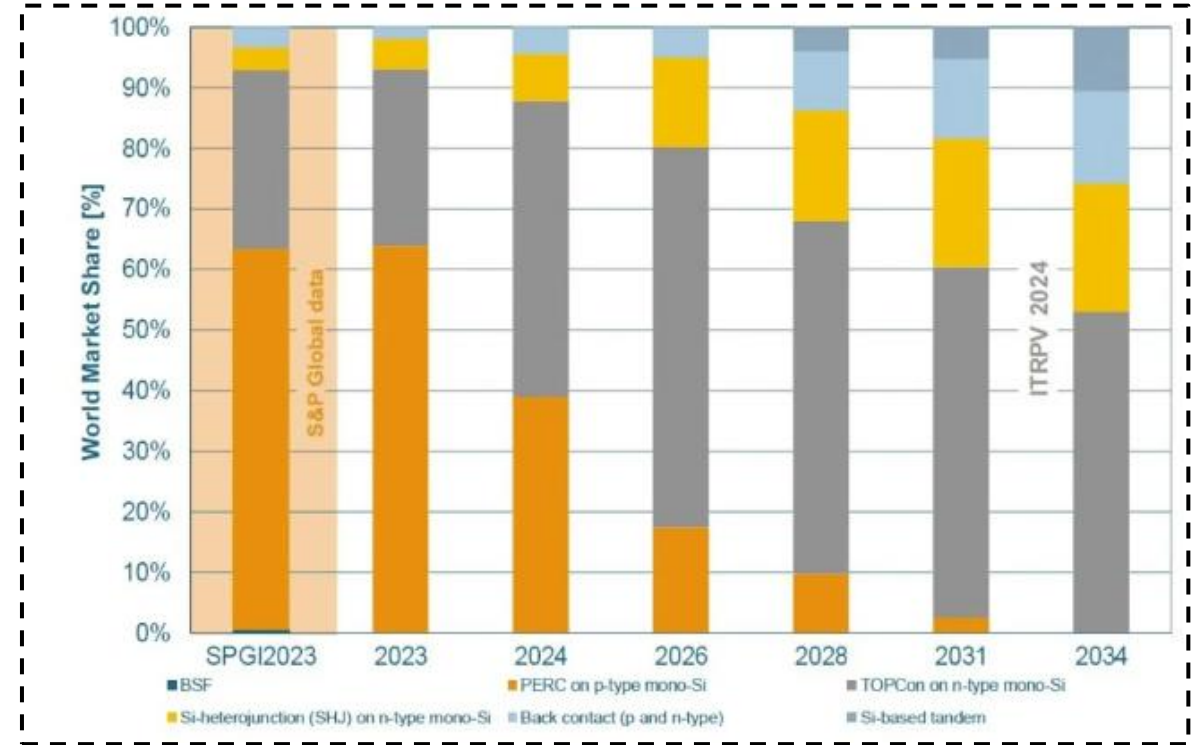
Module Technology Market Trends

- TOPCon will dominate for the next 4 years.

- TOPCon will lead from 2024, exceeding 50% market share by 2034.

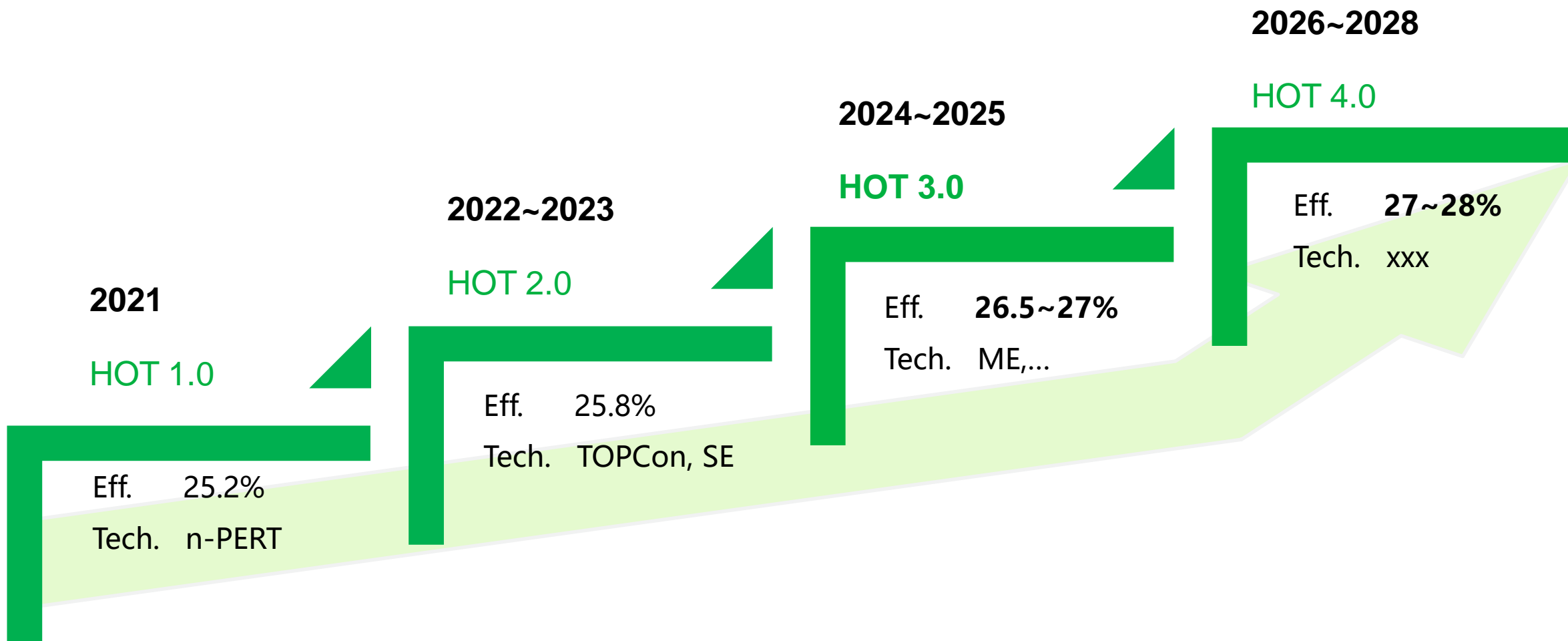


Source: InfoLink

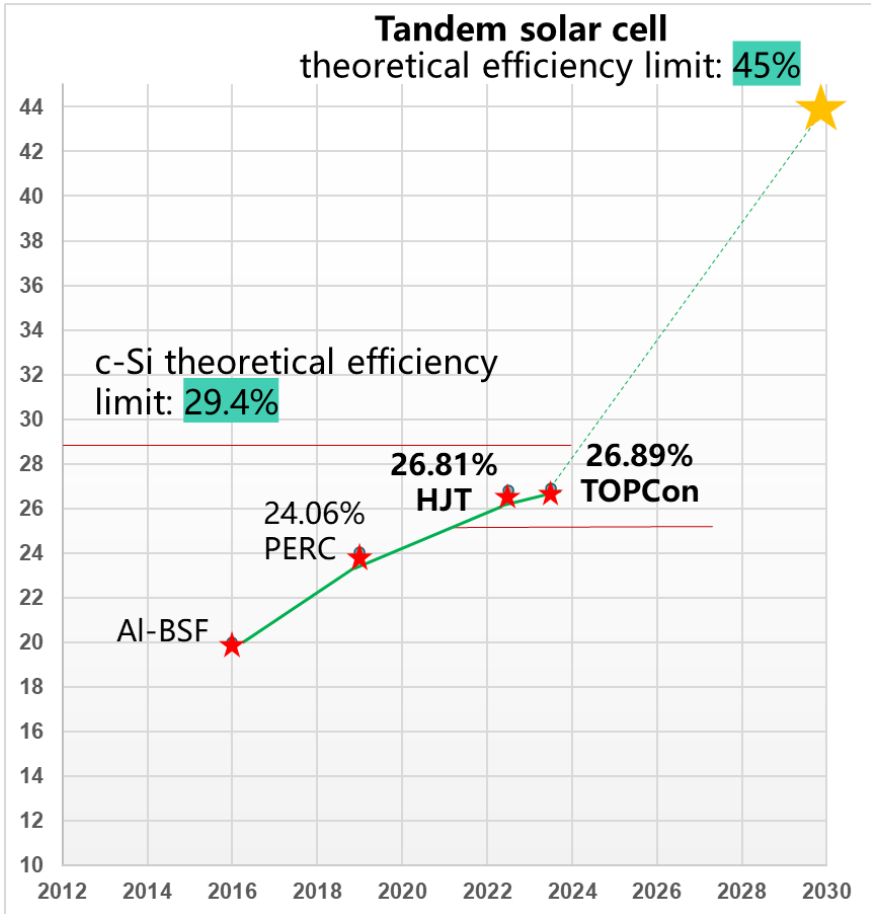


Source: ITRPV 2024

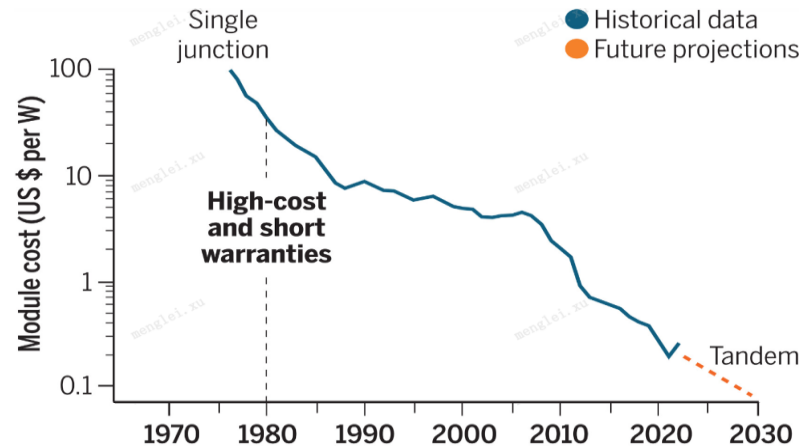
Jinko Development



Outlook Cell Concepts- Tandem (Perovskite)



- Advantage of tandem cell
 - high **theoretical efficiency of up to 45%**
- Challenge and opportunities
 - **challenge:** reliability, stable scaling process of perovskite, economic cell-to-module/system design
 - **opportunities:** large-scale tandem PV products enter market around 2030



Leading Edge Technology

26 times break the world record.

The 182 **N-type TOPCon cell** reaches **26.89%** maximum conversion efficiency, setting two new world records in **N-type TOPCon tandem** with **32.33%** and **33.24%**



4200+
Patent
Application

2800+
Granted
Patents

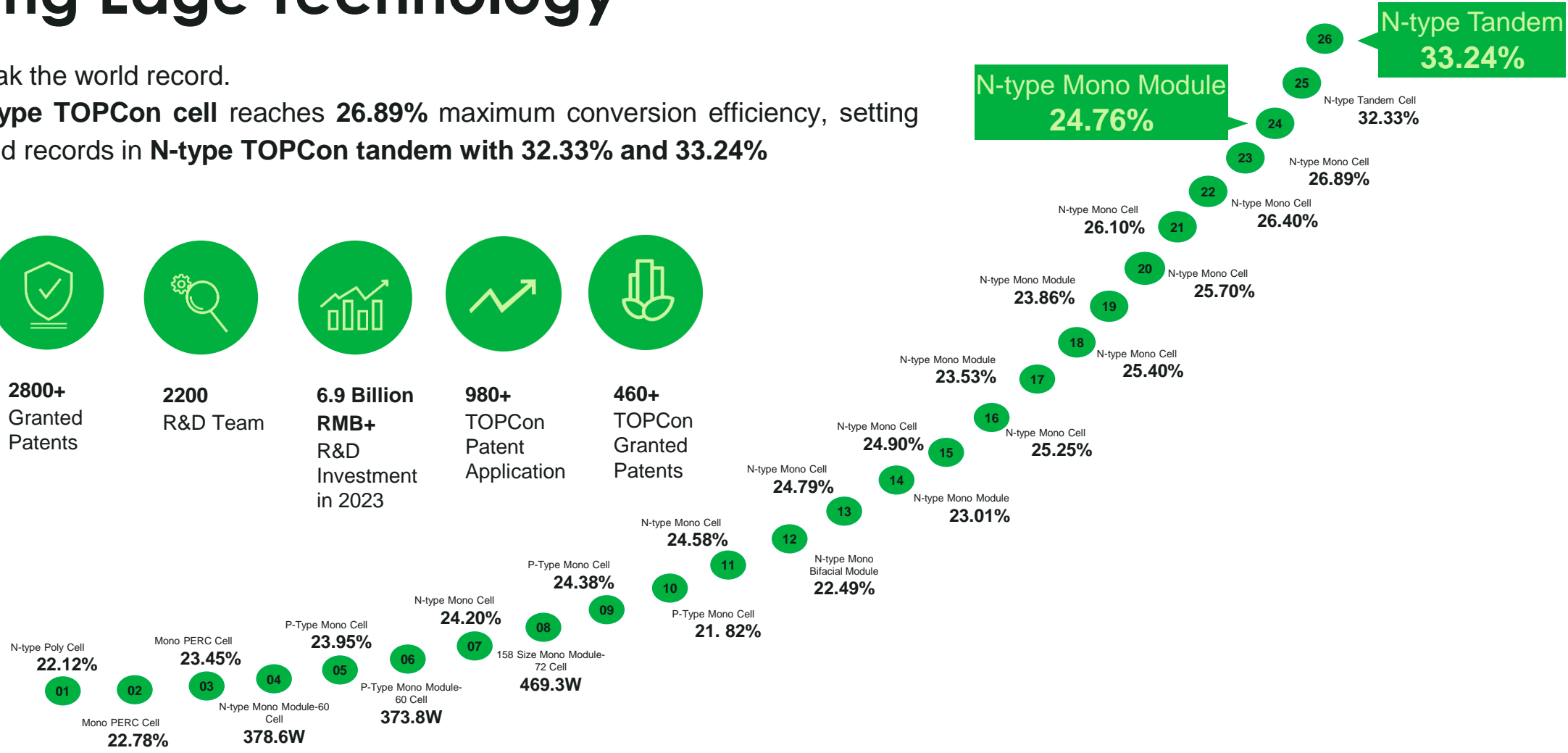
2200
R&D Team

6.9 Billion
RMB+
R&D
Investment
in 2023

980+
TOPCon
Patent
Application

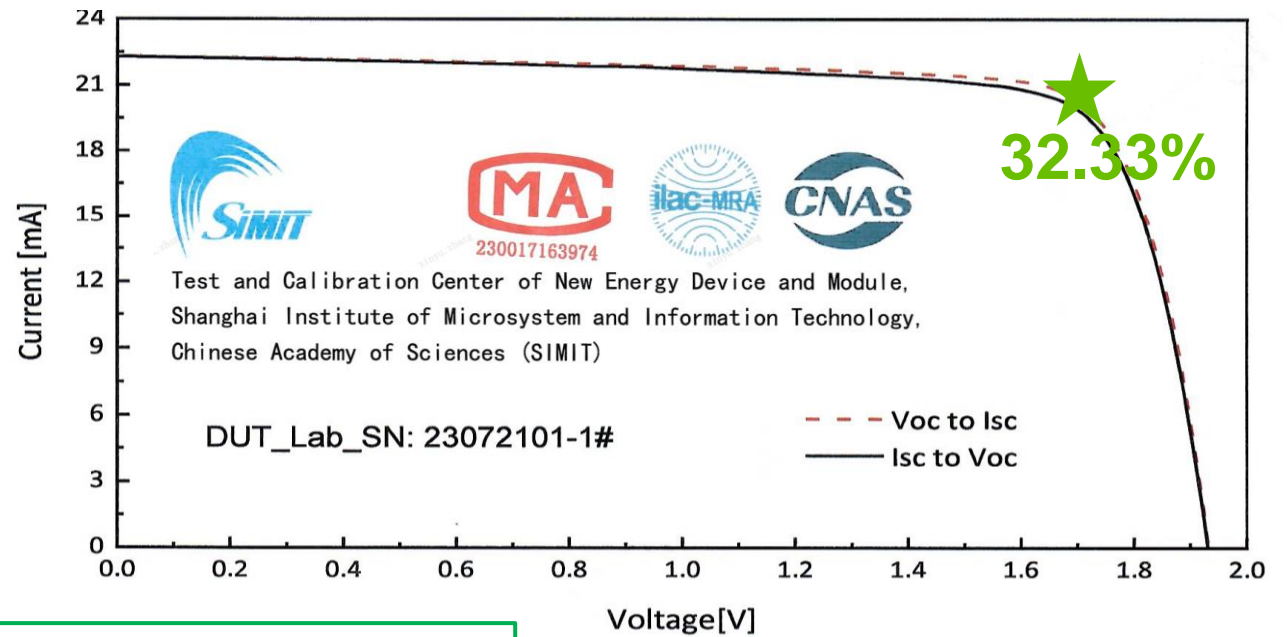
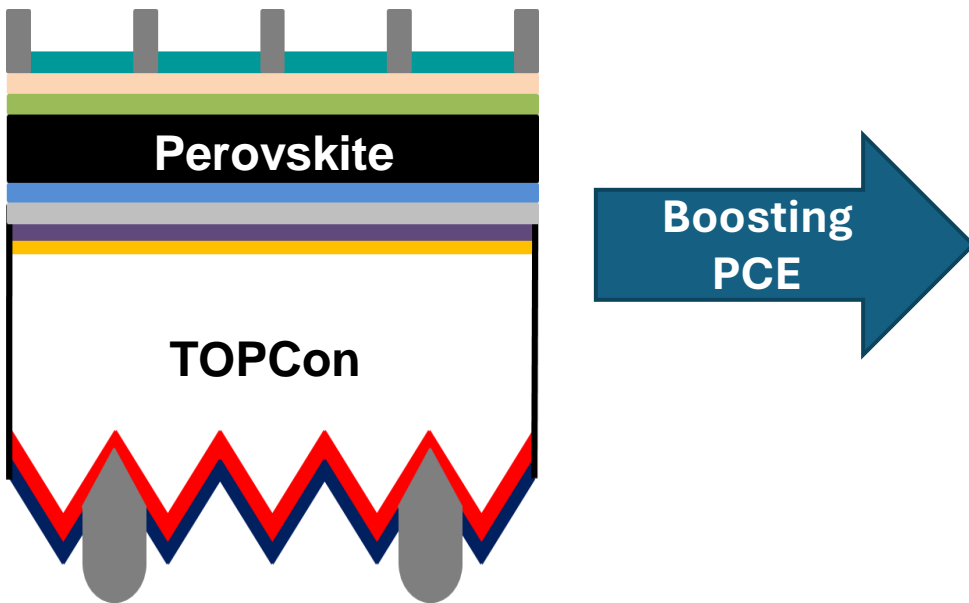
460+
TOPCon
Granted
Patents

2024Q2



Jinko Tandem

JinkoSolar's **Record of 32.33%** achieved on perovskite/TOPCon tandem



- ① **Surface passivation:** optimization of the passivation layer
- ② **Bulk passivation:** additive engineering to lower the hysteresis effect
- ③ **Recombination layer optimization:** high quality TCO with low resistance

