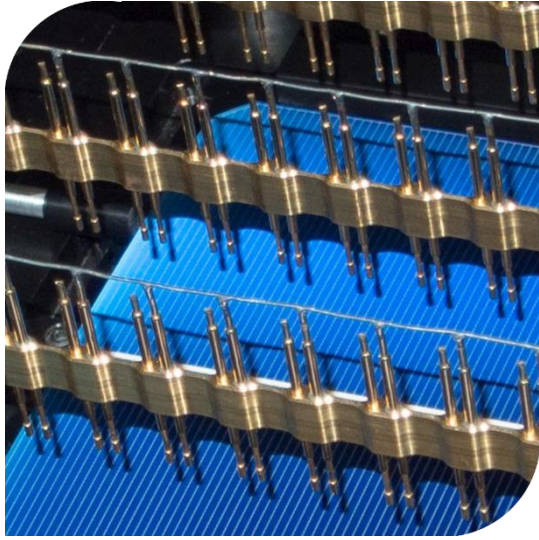




Quo vadis PV cell technology ?



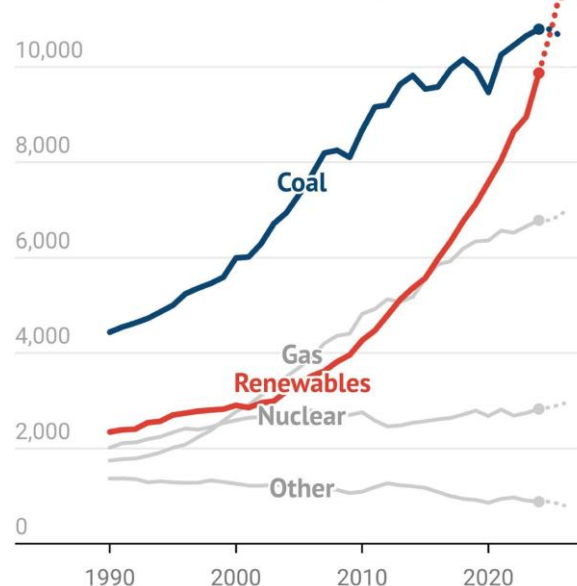
Dr. Radovan Kopecek, Dr. Kristian Peter, Lejo Joseph, Tobias Messmer, Jan Lossen, Dr. Jan Hoss, Dr. Florian Buchholz, Dr. Joris Libal, Dr. Valentin Mihailetschi, Rudolf Harney et al.

Milestones from 1954 over 2026 to 2050



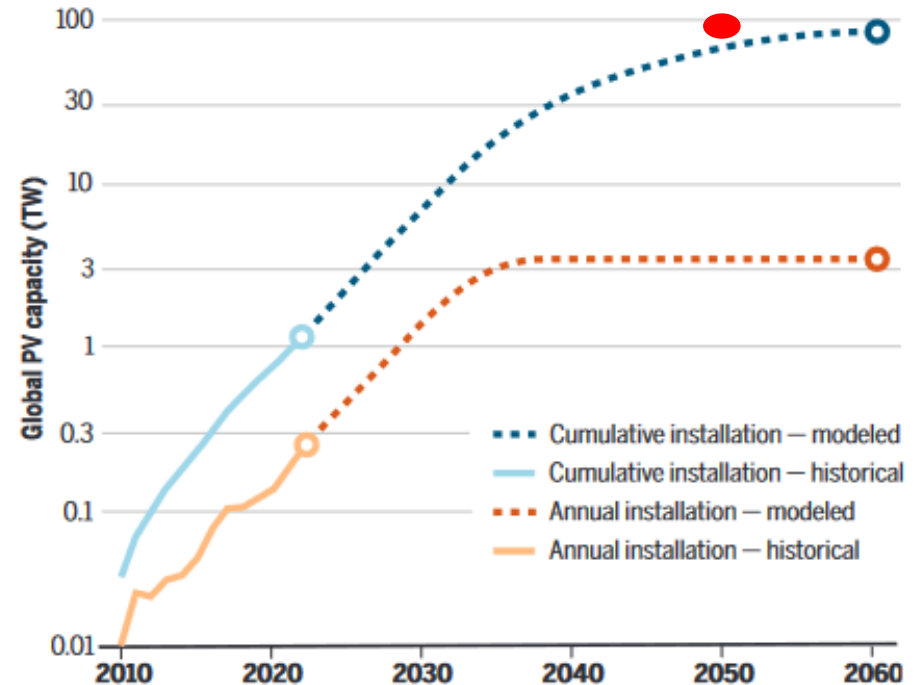
IEA: Renewables will be world's top power source 'by 2026'

Global electricity generation by source, TWh



Source: International Energy Agency

CarbonBrief



1954: 6% cell efficiency (n-type BC)

2026: 25% stable module efficiency (n-type BC)

2050: 28% stable module efficiency
100TW (n-type BC)

By 2050 70-80% of global energy demand will be powered by PV

Agenda

1. **ISC2.0** technology, transfer
2. **GLOBAL PV MARKET CELL TECHNOLOGY**
3. **German Turnkey Alliance** partners, advantages
4. **ISC Workshops and Summary**





1. ISC 2.0

ISC Konstanz: 20 years

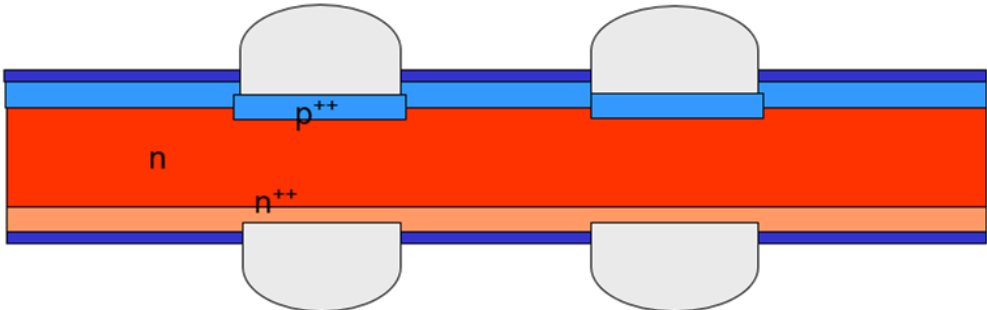




International Solar
Energy Research
Center, Konstanz

sub 100





Main advantages

- elimination of bow
- improved rear side passivation
- less paste used
- increased power output
- applicable for p and n-type Si
- simplified module interconnection

ISC Advisory Board Meeting, 1st December 2006

R. Kopecek *et al.*



Employees at
ISC Konstanz

75 ↗

Turnover
2025

8 Mio€ ↗

Educated
scientists

150 ↗

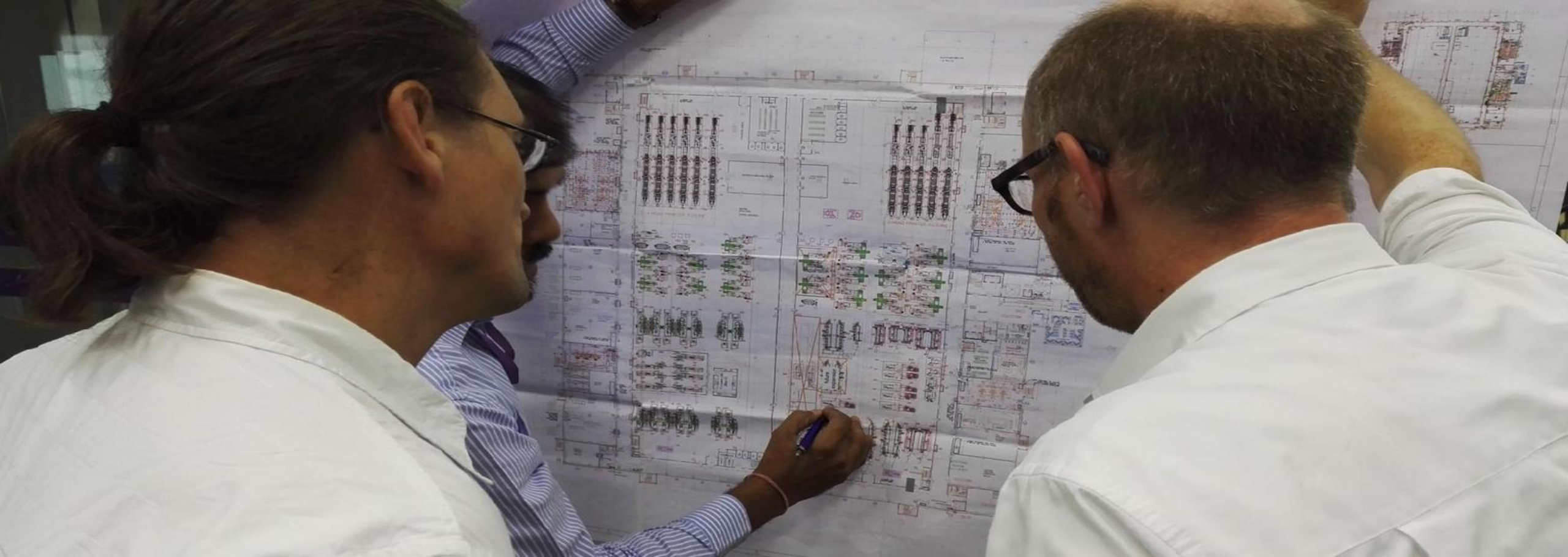
Achieved solar
cell efficiency*

25.4% ↗

Transferred
technology

10 GW ↗

*in industrial manufacturing **2028 25 GW!**



Technology Transfer, Ramp-up, Line Optimisation and R&D support

ISC Cell and Module Process Integration Expert Pool

Process Integrator



Pirmin Preis



Dr. Jan Hoß



Jan Lossen



Dr. Joris Libal



Lejo Joseph

Wet Chemistry



Dr. Florian
Buchholz



Dr. Tom
Kollek



Rafael
Marczak



Melike
Eren



Apoorva
Gattu

Thermal & PECVD



Dr. Valentin
Mihailetchi



Dr. Jonathan
Linke



Dr. Lazhar
Rachdi



Dr. Vaibhav
Kurugati



Dr. Saman
Sharbaf



Tanju Eren



Stephan
Eisert



David
Bäurle

Metallisation & Characterisation



Christoph
Peter



Mertcan
Comak



Sebastian
Veerman



Dominik
Rudolph



Justus
Carsten

Modules



Dr. Gerhard
Mathiak



Ignacia
Devoto



Raphael
Shanmugam



Tobias
Messmer



Dr. Tudor
Timofte



Dr. Daniel
Tune



Karl
Wienands



Prof. Dr. Andreas
Schneider

Technology transfer & Ramp-up service – track record

- ISC Konstanz has **20 years of experience** in development and industrialization of n-type cells concepts

- Successful Process transfers and Integration into industry:**

- 2008-2015 @ Sunways, @ Qcells, @ SolarWorld, @ BOSCH Solar
- 2015 @ MegaCell, Italy → BiSoN (40MW nPERT technology successfully transferred)
- 2017 @ Adani, India → BiSoN (80MW nPERT technology successfully transferred)
- 2018 @ undisclosed Asian customer → BiSoN converted to !!TOPCon!!
- 2020 @ SPIC, China → ZEBRA (200MW IBC technology transferred and in mass production)
- 2021 @ Valoe Solar, Lithuania → ZEBRA (60MW IBC technology, ramp-up service)
- 2023 @ Asian customer, India → PERC (2GW process optimisation on Asian process equipment)
- 2024 @ Asian customer, India → PERC (450MW process optimisation on European process equipment)
- 2024 @ Asian customer, India → TOPCon (2GW process optimisation on Asian process equipment)
- 2025 @ Asian customer, India → TOPCon (2.9GW process optimisation on European process equipment)
- 2025 @ Asian customer, India → TOPCon (500MW process optimisation on European process equipment)
- 2025 - Present @ Suniva, USA → PERC (1GW process optimisation on European process equipment)
- Ongoing @ ISC Konstanz → R&D Pilot line (European equipment)

Module Process

- 2024 @ TATA, India → PERC Module line audit for process optimisation
- 2025 @ European customer, Lithuania → IBC Module process optimisation
- 2025 @ Heliene, USA → PERC Module process audit for optimisation
- 2026 @ SolX, USA → PERC Module process audit and training



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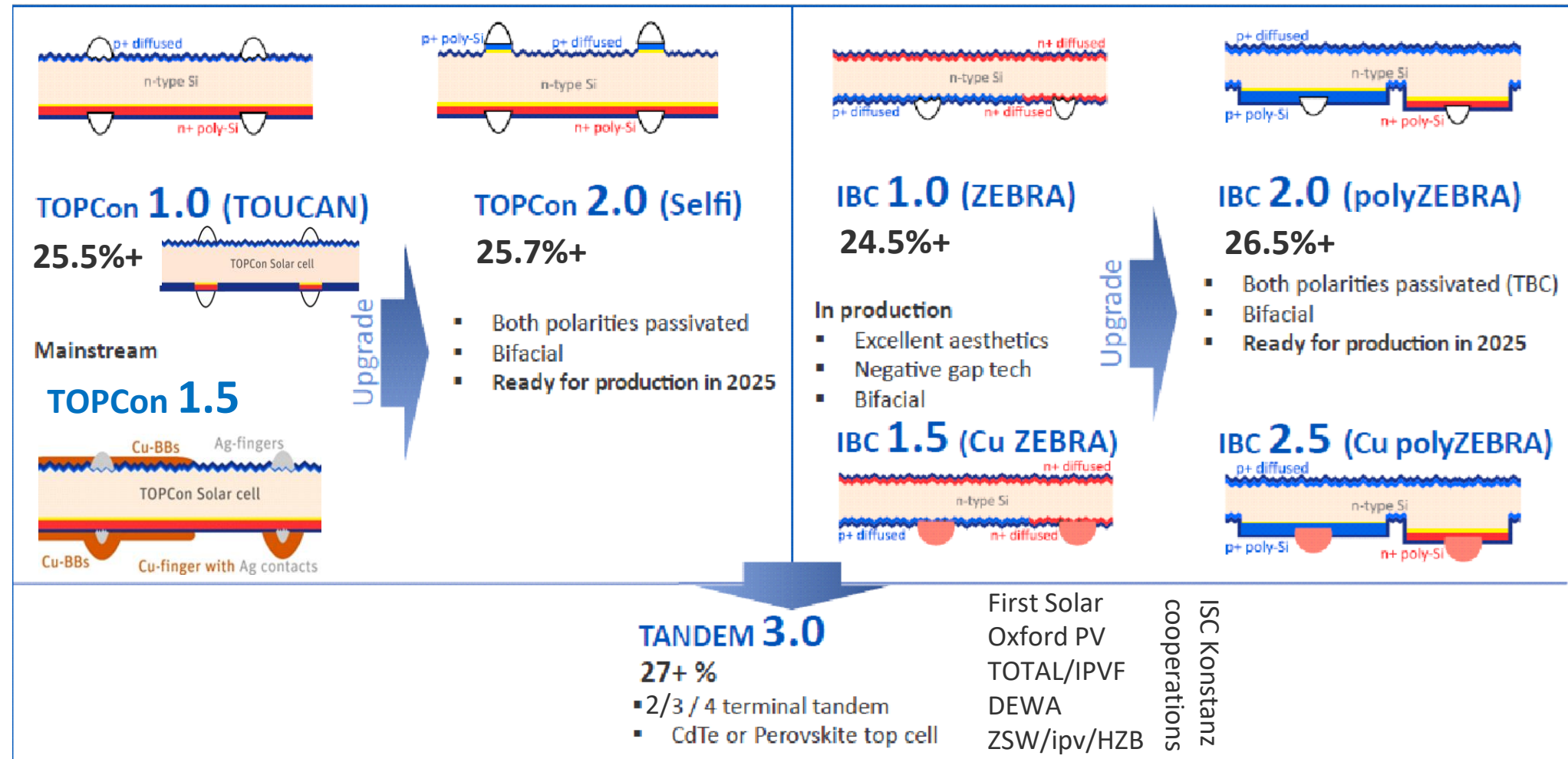
INDIA'S TOP SOLAR CELL MANUFACTURERS 2026

***RANKED BY AVERAGE CELL EFFICIENCY**

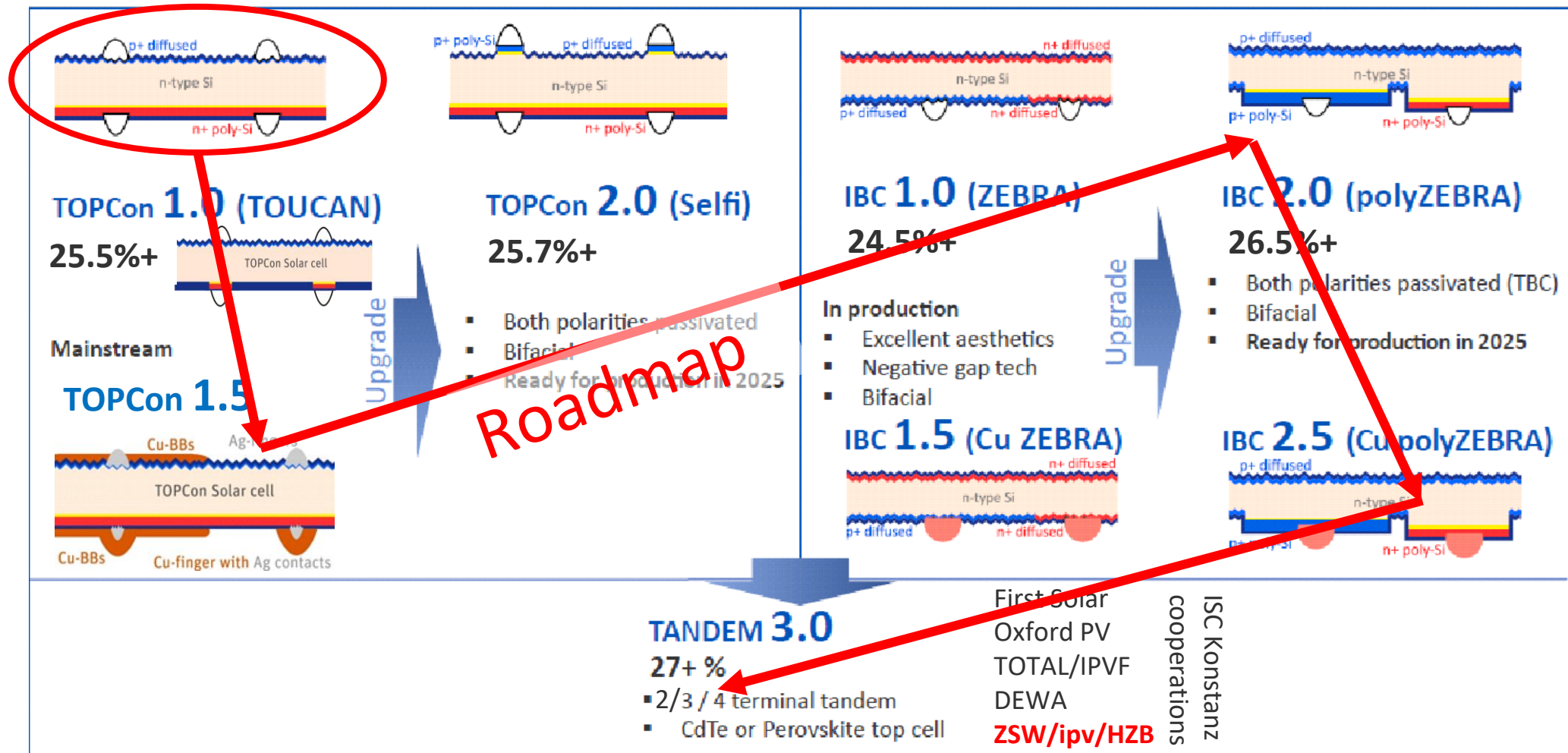
Based on ALMM (Approved List of Models & Manufacturers) List-II, Revision 9 dated 21 August 2026, issued by **MNRE**.

RANK	MANUFACTURER	MAIN TECHNOLOGY	CELL EFFICIENCY (%)	
			AVERAGE	MAXIMUM (RANGE)
1	AVAADA Avaada Electro Ltd.	n-type TOPCon (Half-cut & Full Cell)	25.83% / 25.71%	26.3% (24.5% – 26.3%)
2	EMMVEE EMMVEE Energy Pvt. Ltd.	n-type TOPCon	25.60%	26.0% (24.0% – 26.0%)
3	Reliance Industries Limited	HJT	25.40%	26.6% (23.8% – 25.0%)
4	WAAREE Waaree Energies Ltd.	n-type TOPCon + Mono-PERC	25.39%	26.0% (24.0% – 26.0%)
5	PREMIER ENERGIES Premier Energies Photovoltaic	n-type TOPCon	25.37%	25.0% (24.0% – 25.7%)
6	MUNDRA SOLAR PV Mundra Solar PV Ltd.	n-type TOPCon	25.35%	25.7% (24.5% – 25.7%)
7	ReNew POWER ReNew Photovoltaics Pvt. Ltd.	PERC TOPCon (Si-Wafer module addition)	23.35%	23.3% (23.4% – 25.5%)
8	TATA TP Solar Ltd. (Tata)	PERC Mono-PERC	23.25%	23.8% (22.4% – 23.8%)
9	MUNDRA SOLAR Mundra Solar Energy Ltd.	PERC Mono-PERC	23.15%	23.5% (22.0% – 23.5%)

ISC Konstanz's technology for GW PV production



ISC Konstanz's technology for GW PV production



ISC 2.0 >> Start September 2026



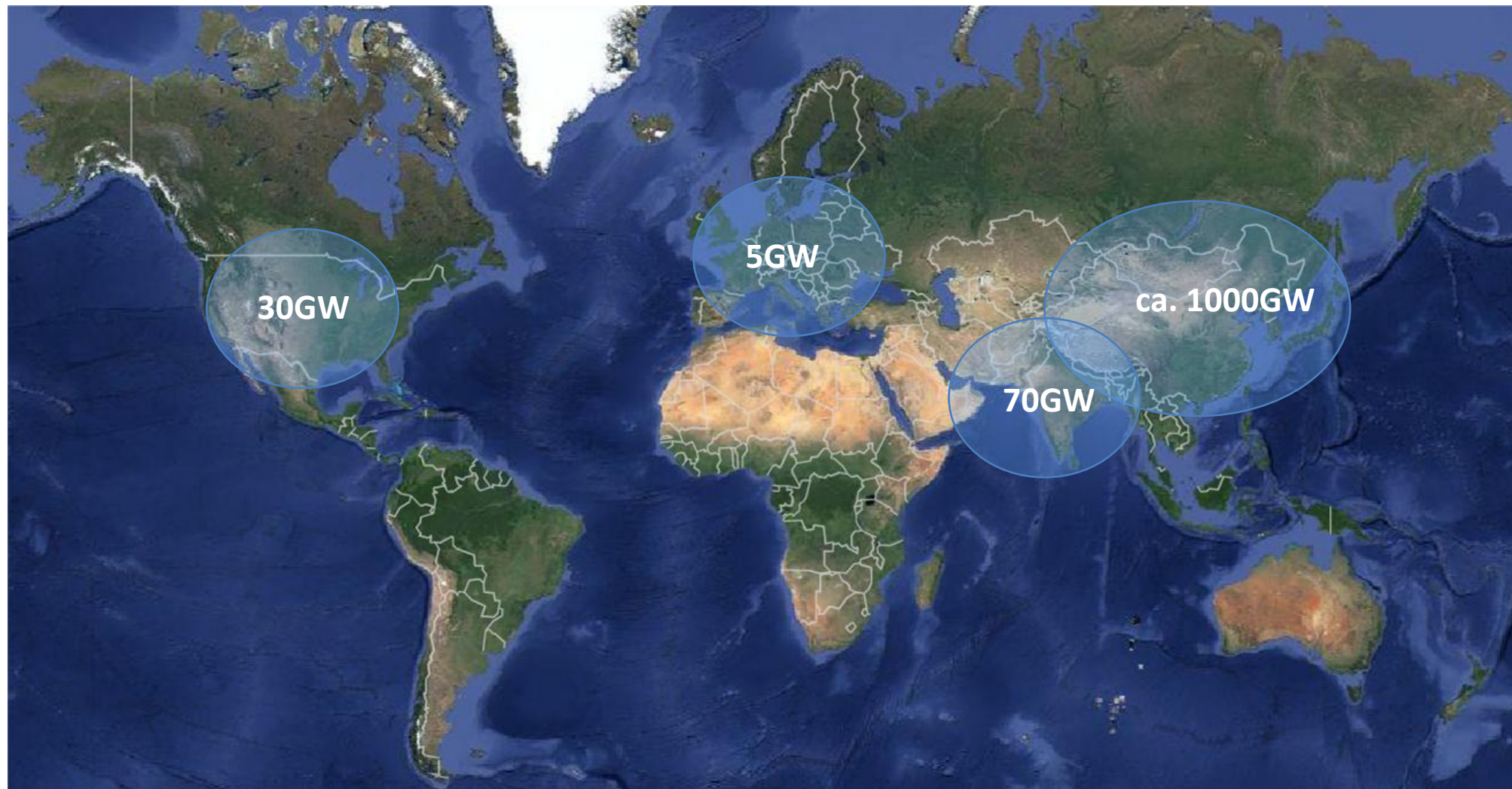
ISC 2.0 >> M10/G12/G12R Automation



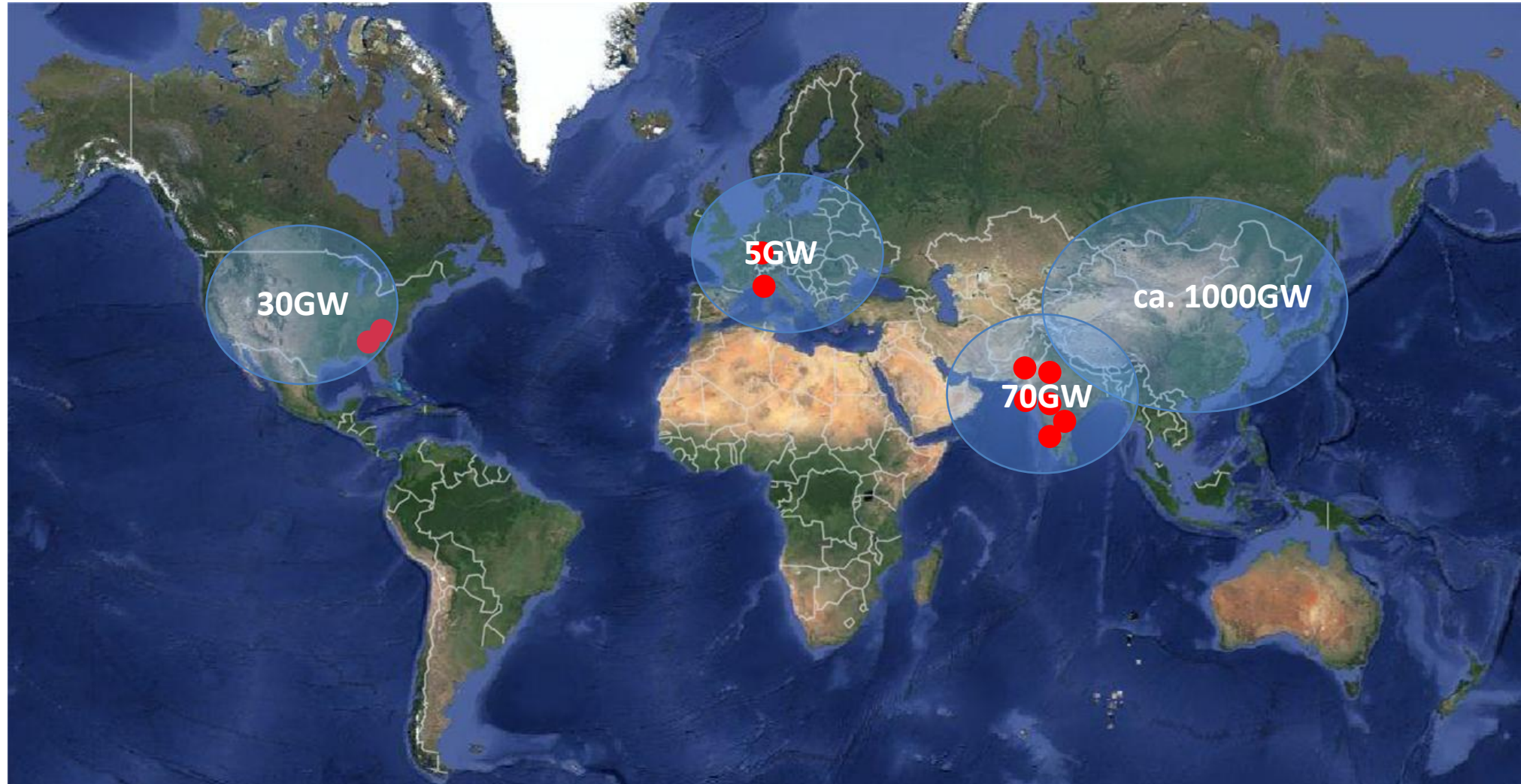


2. Global PV market tech: status and outlook

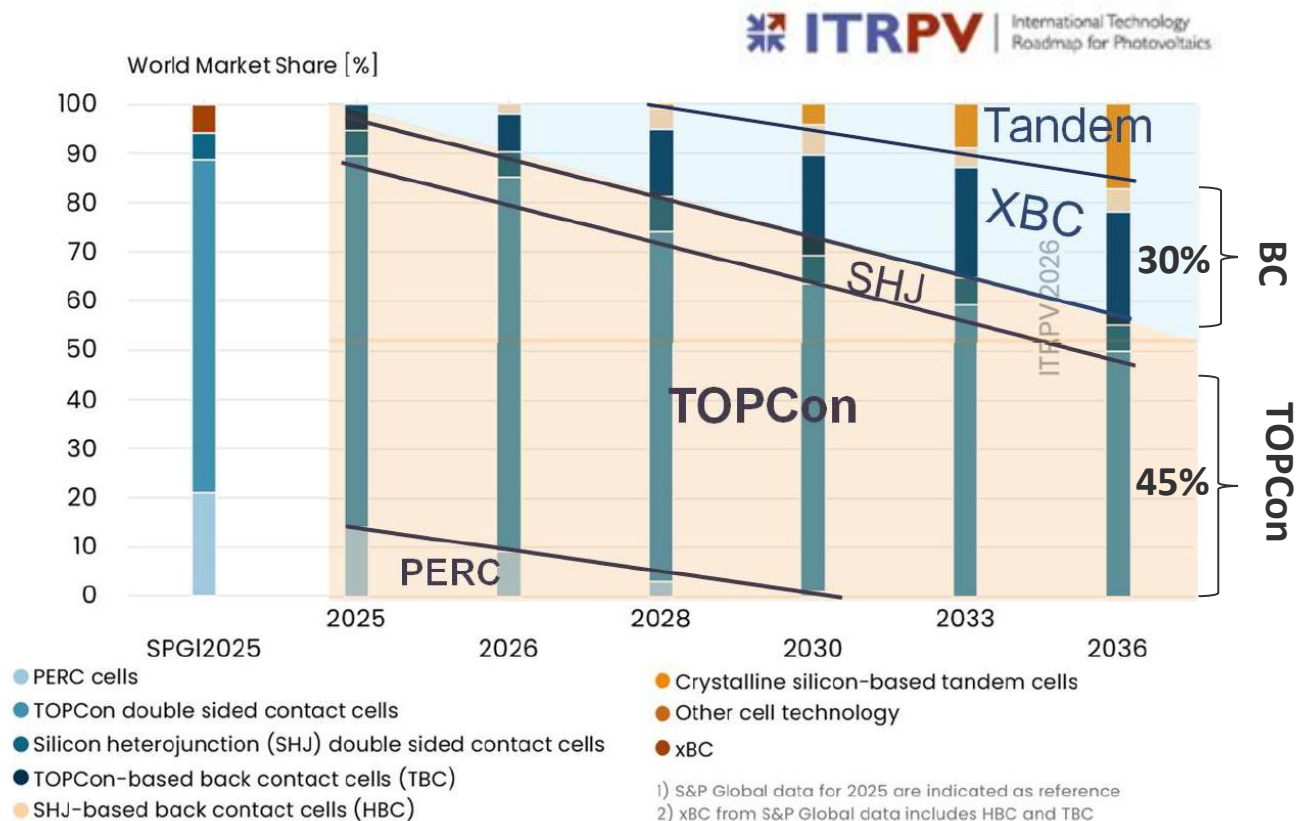
Total cell production until 2028



Total cell production until 2028 and ISC's projects



Share in production until 2028 and beyond



CLEAN ENERGY REVIEWS [2] Most Efficient Residential Solar Panels 2026 * V6 Feb 2026

Manufacturer	Model	Power Rating	Cell Technology	Efficiency
AIKO	Neostar 3P54	500W	N-Type ABC (Back Contact)	25.0 %
RECOM TECHNOLOGIES	Black Tiger Series	495W	N-Type BC (Back Contact)	24.8 %
LONGi Solar	Hi-MO X10 Explorer	495W	N-Type HPBC 2.0 Hybrid Back Contact	24.3 %
moxeon	Moxeon 7	445W	N-Type IBC (Back-contact)	24.1 %
Jinko Solar	Tiger NEO III	520W	N-Type TOPcon	24.0 %
SUNTECH	Ultra BC	480W	N-Type BC (Back-contact)	24.0 %
Trinasolar	Vertex S+	475W	N-Type TOPCon	23.8 %
WINAICO	WST-485BDX54-B2	485W	N-Type BC (Back-contact)	23.8 %

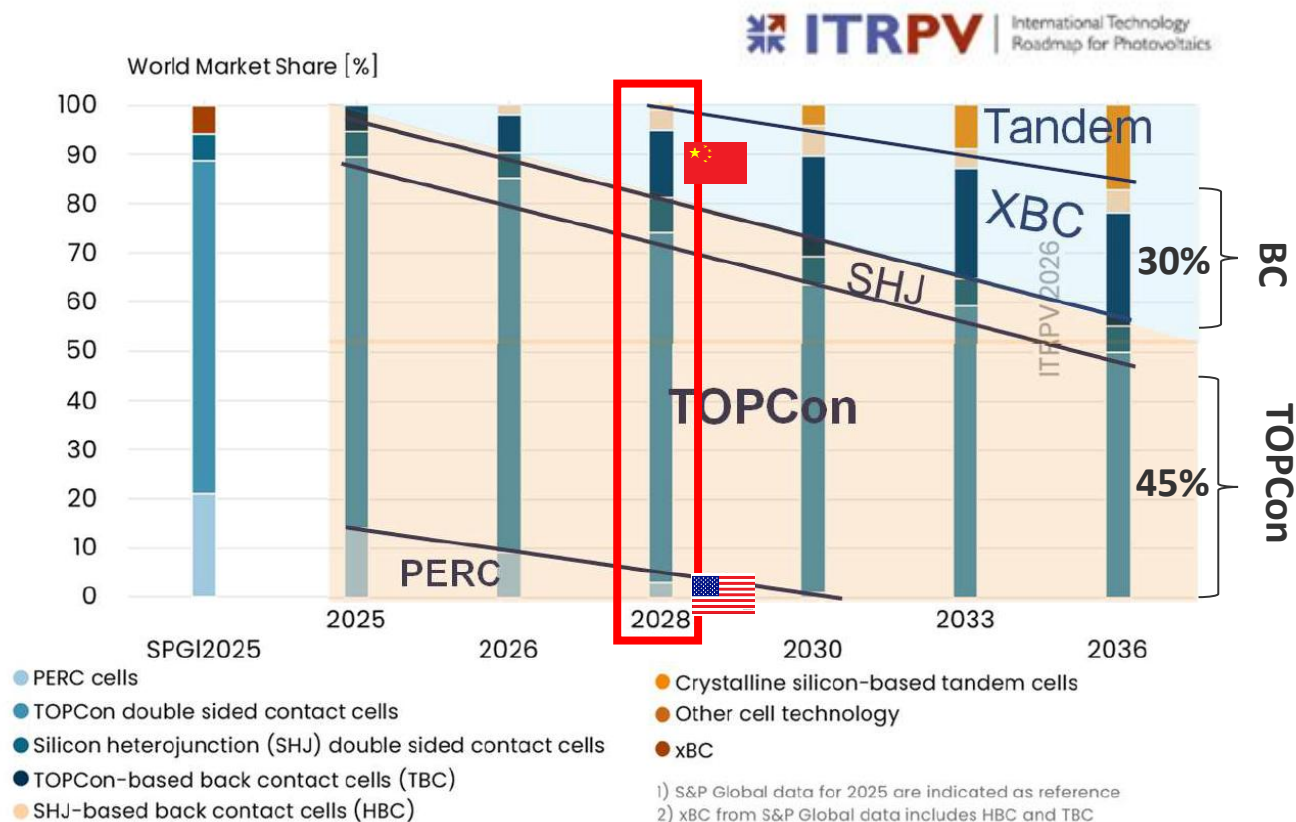
Group	Cell details	Eta (%)
LONGi	n-type HTBC	28.29% [3]

[1] ITRPV, 17th edition, June 2026

[2] Clean Energy Reviews, "Most Efficient Residential Solar Panels 2025," Feb. 2026

[3] LONGi, "28.29% HIBC solar cell efficiency record," Sept. 24, 2026

Share in production until 2028 and beyond



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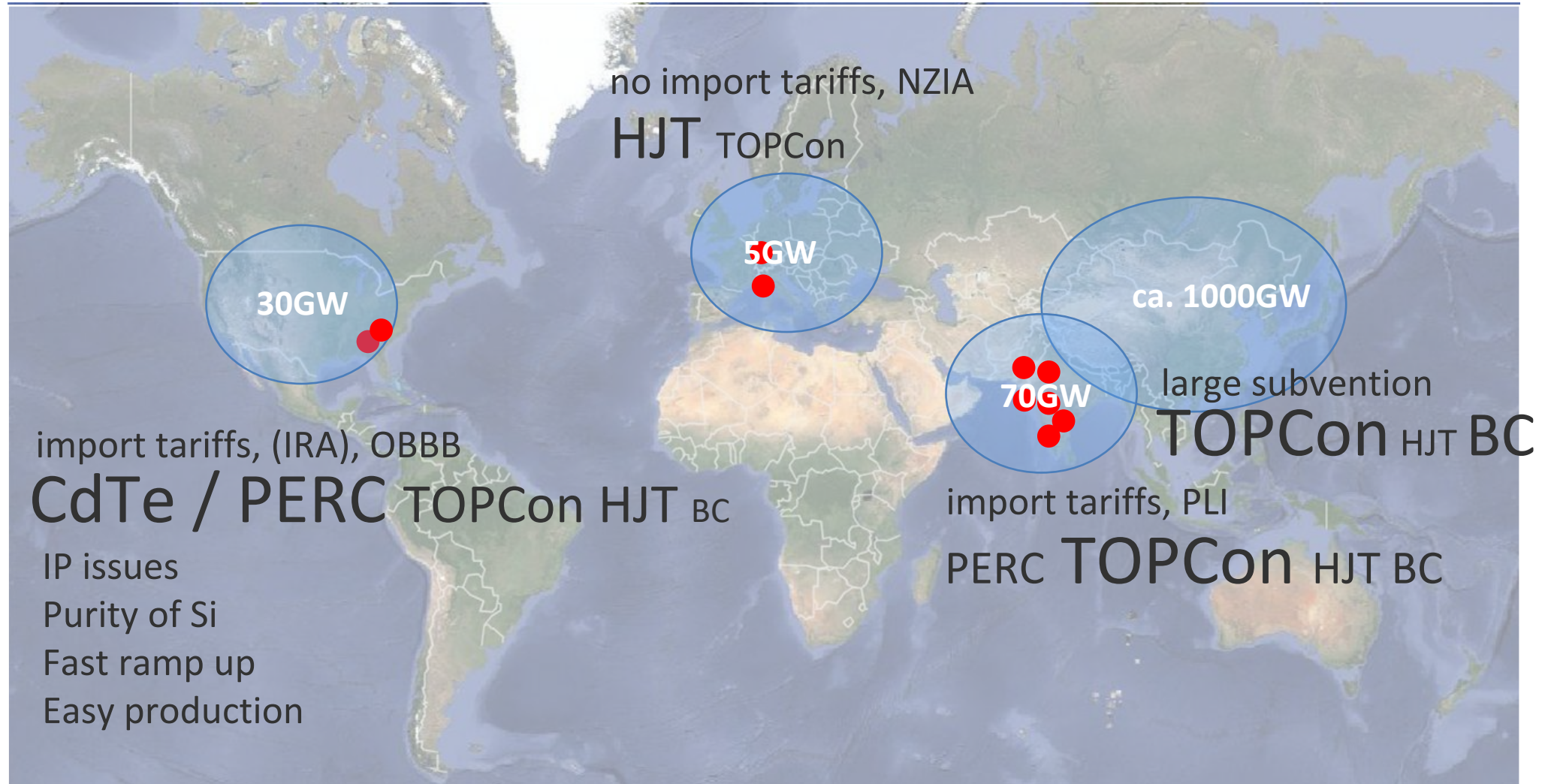
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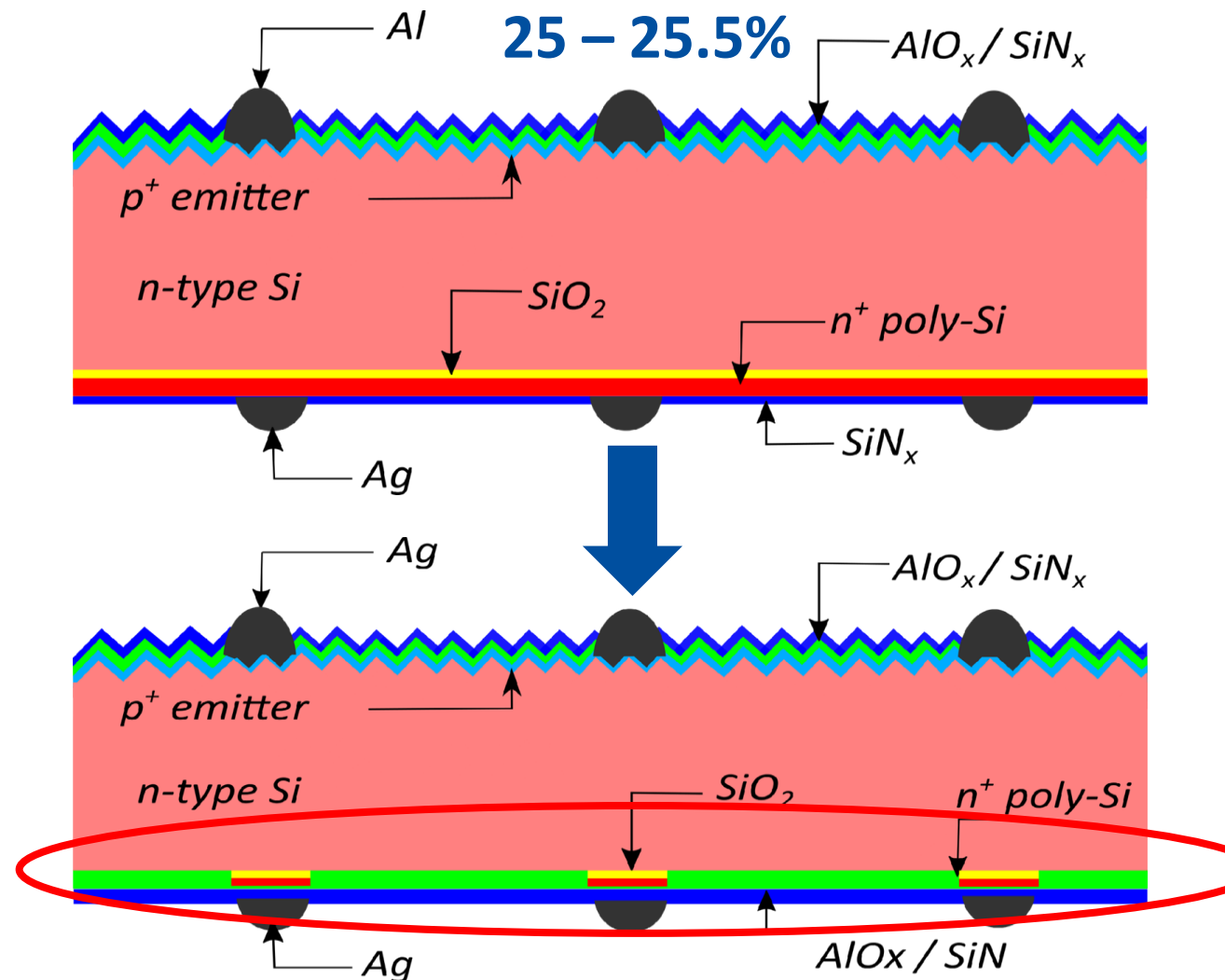
Total cell production until 2028 and ISC's projects





TOPCon upgrades

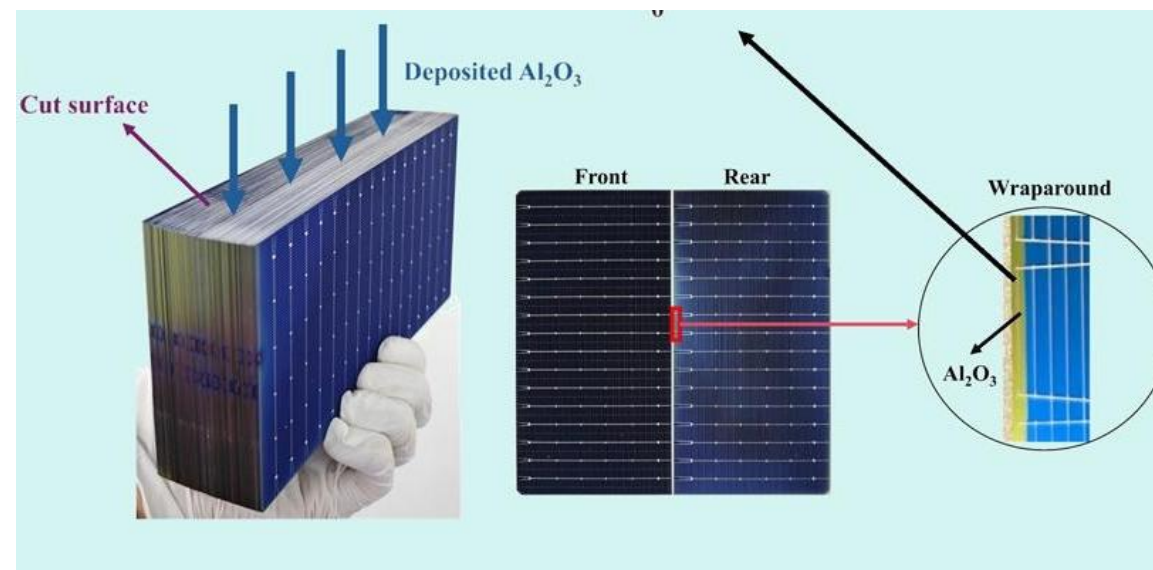
- TOPCon upgrades
 - **Polyfingers**
 - Adding one laser step and one ALD passivation step
 - **0.1 – 0.2 % efficiency gain**
 - Higher bifaciality





TOPCon upgrades

- TOPCon upgrades
 - Polyfingers
 - **Edge passivation**
 - Additional ALD deposition after cell cutting (half, third, quarter)
 - Passivating the cut edge
 - **3 – 6 W gain in module power**

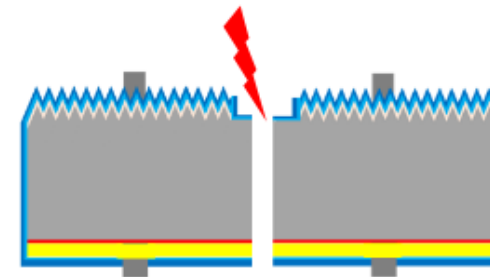
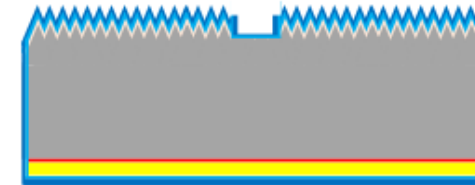
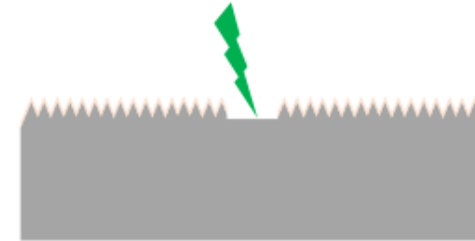


W.Li et al.:Preparation of Al_2O_3 thin films by RS-ALD and edge passivation application for TOPCon half solar cells



TOPCon upgrades

- TOPCon upgrades
 - Polyfingers
 - Edge passivation
 - **Laser assisted edge isolation**
 - Adding one laser tool to locally remove junction on the front side early in TOPCon process
 - No laser cut through the junction
 - Blocks carrier transport to the cut edge
 - **3 W gain in module power**

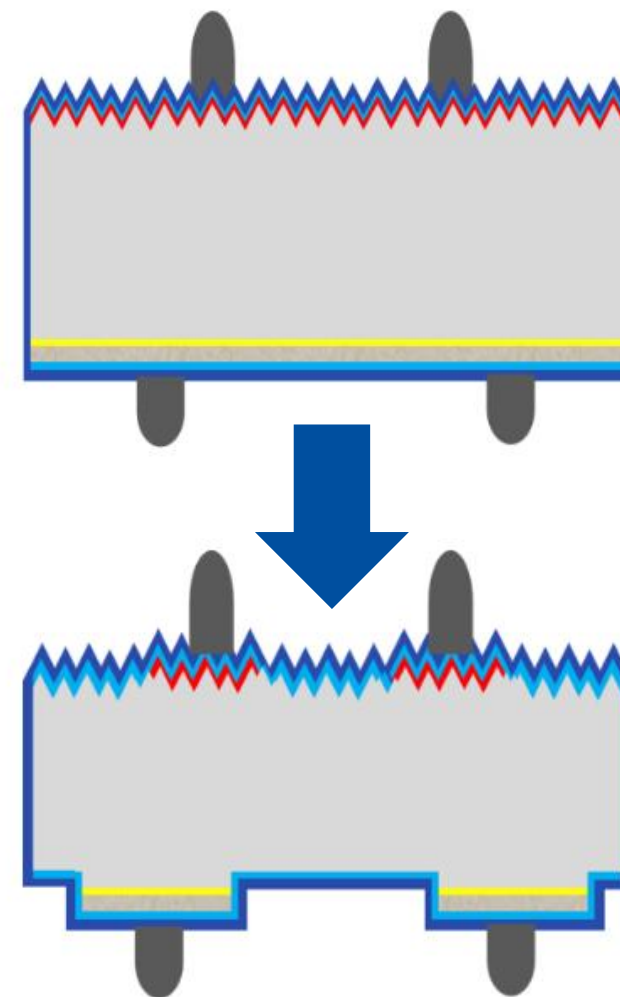
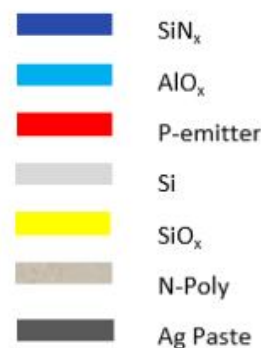


DR Laser: Leading-edge Laser Technologies Empower the Performance of c-Si Solar Cells



TOPCon upgrades

- TOPCon upgrades
 - Polyfingers
 - Edge passivation
 - Laser assisted edge isolation
 - **Potentially selective front side diffusion**
 - Localized front side junction
 - Adding one laser and one additional texturing step
 - **0.1 – 0.2 % efficiency gain**
 - UV stability of non diffused surface has to be kept in mind
 - So far only in piloting phase

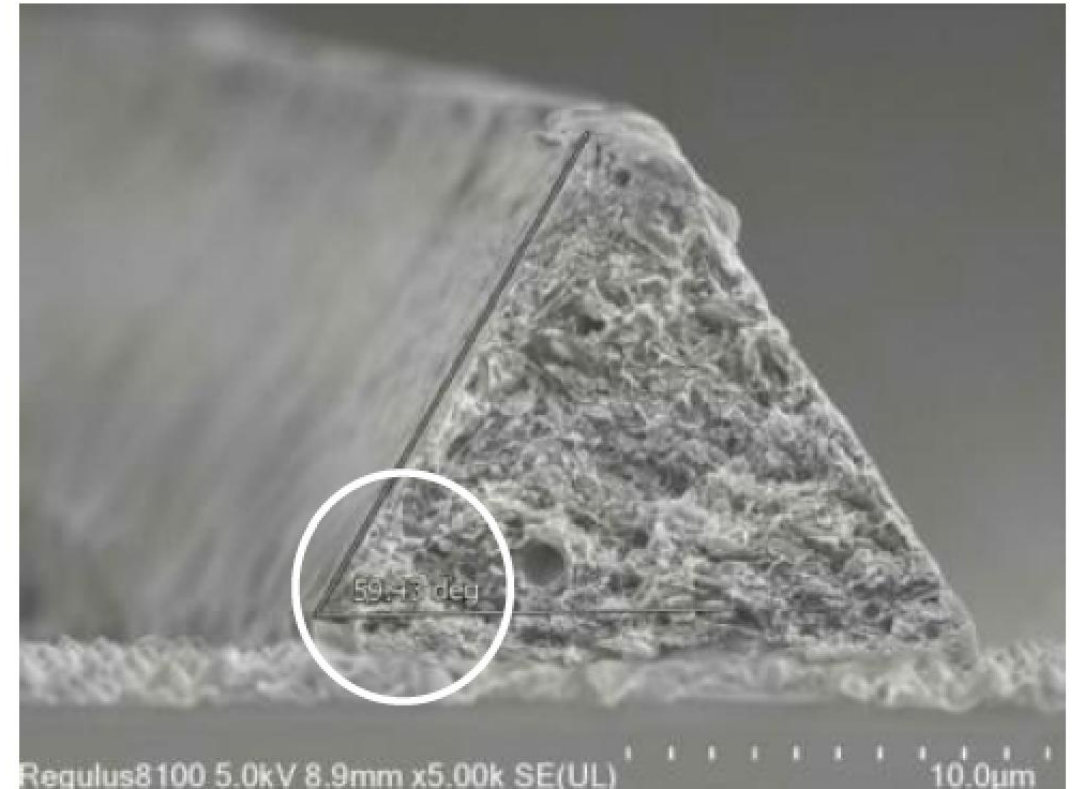


DR Laser: Leading-edge Laser Technologies Empower the Performance of c-Si Solar Cells



TOPCon upgrades

- TOPCon upgrades
 - Polyfingers
 - Edge passivation
 - Laser assisted edge isolation
 - Potentially selective front side diffusion
 - **Metallization optimization**
 - Low cost metallization based on Cu or Al
 - Zero Busbar
 - Triangle shaped front contact

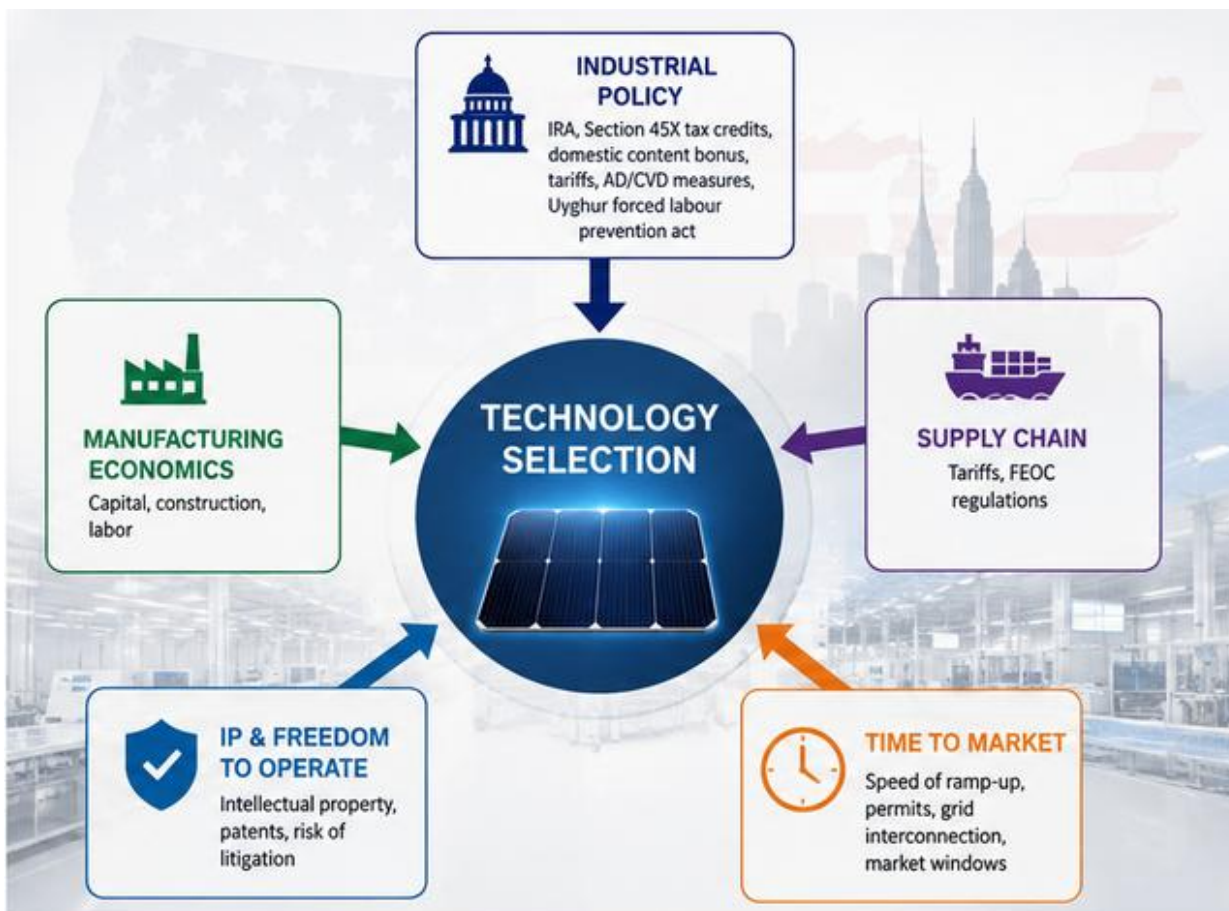


M. Xiajie (Tongwei): Industrial TOPCon Solar Cell with super sheet resistance, Silicon PV 2026, Ankara



US market

- What impacts technology selection in the US
 - Industrial policies
 - Manufacturing economics
 - Supply chain
 - IP and freedom to operate
 - Time to market



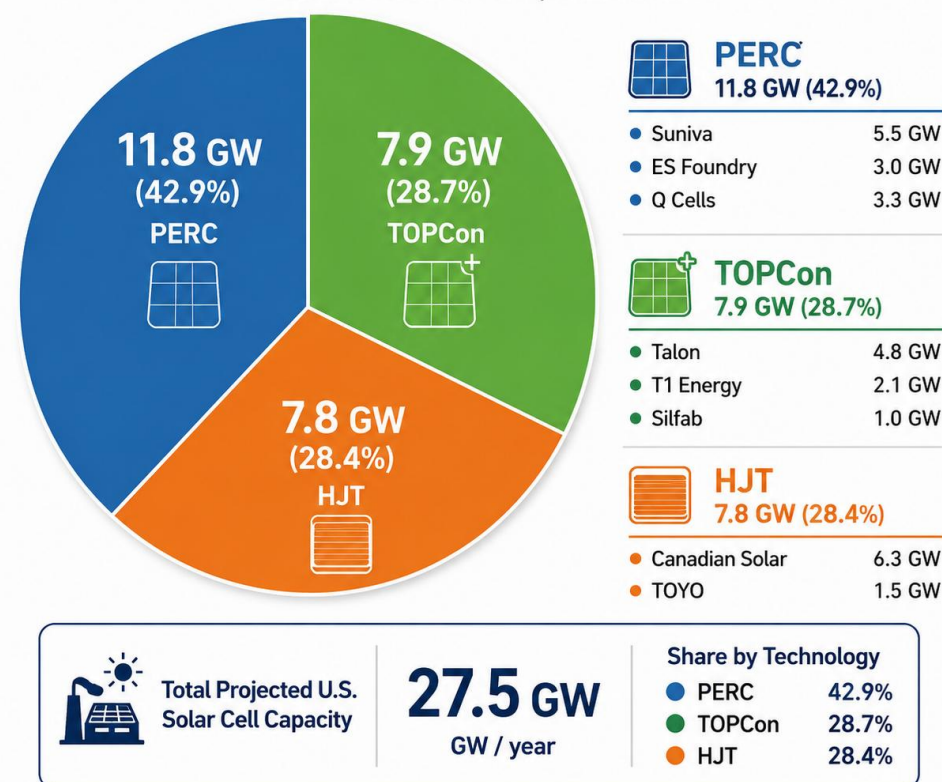


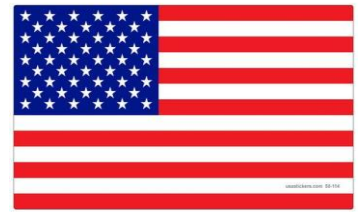
US market

- No converging into one single technology
- Further TOPCon additions in the US may depend on evolution of TOPCon IP landscape
- Independently of the technology further addition will depend on availability of mature manufacturing equipment and process know-how (EU)
- BC could become an attractive U.S. technology pathway:
 - premium efficiency
 - evolutionary upgrade from TOPCon manufacturing
 - potentially reducing exposure to the current TOPCon IP landscape

Projected U.S. Solar Cell Manufacturing Capacity by Technology (End of 2027)

Crystalline silicon solar cell manufacturing capacity based on announced U.S. production lines.





TECHNOLOGY & PRODUCTS

- **The elephant in the room: TESLA**
 - 100 GW vertical integrated manufacturing ambition
 - Technology: TOPCon
 - Uncertainty of manufacturing equipment
 - This technology decision may significantly influence the future direction of the US PV industry

Tesla advances plan to build 100 GW of U.S. PV manufacturing capacity by 2028

Job advertisements on Tesla's website outline the 100 GW ambition and follow reports the company is in talks with Chinese firms for the purchase of \$2.9 billion worth of equipment for solar manufacturing.



By Patrick Jowett | Mar 25 2026

<https://pv-magazine-usa.com/2026/03/25/tesla-advances-plan-to-build-100-gw-of-u-s-pv-manufacturing-capacity-by-2028/>

China weighs curbs on exports of solar manufacturing equipment to US

By Reuters

April 15, 2026 9:50 AM GMT+2 · Updated April 15, 2026

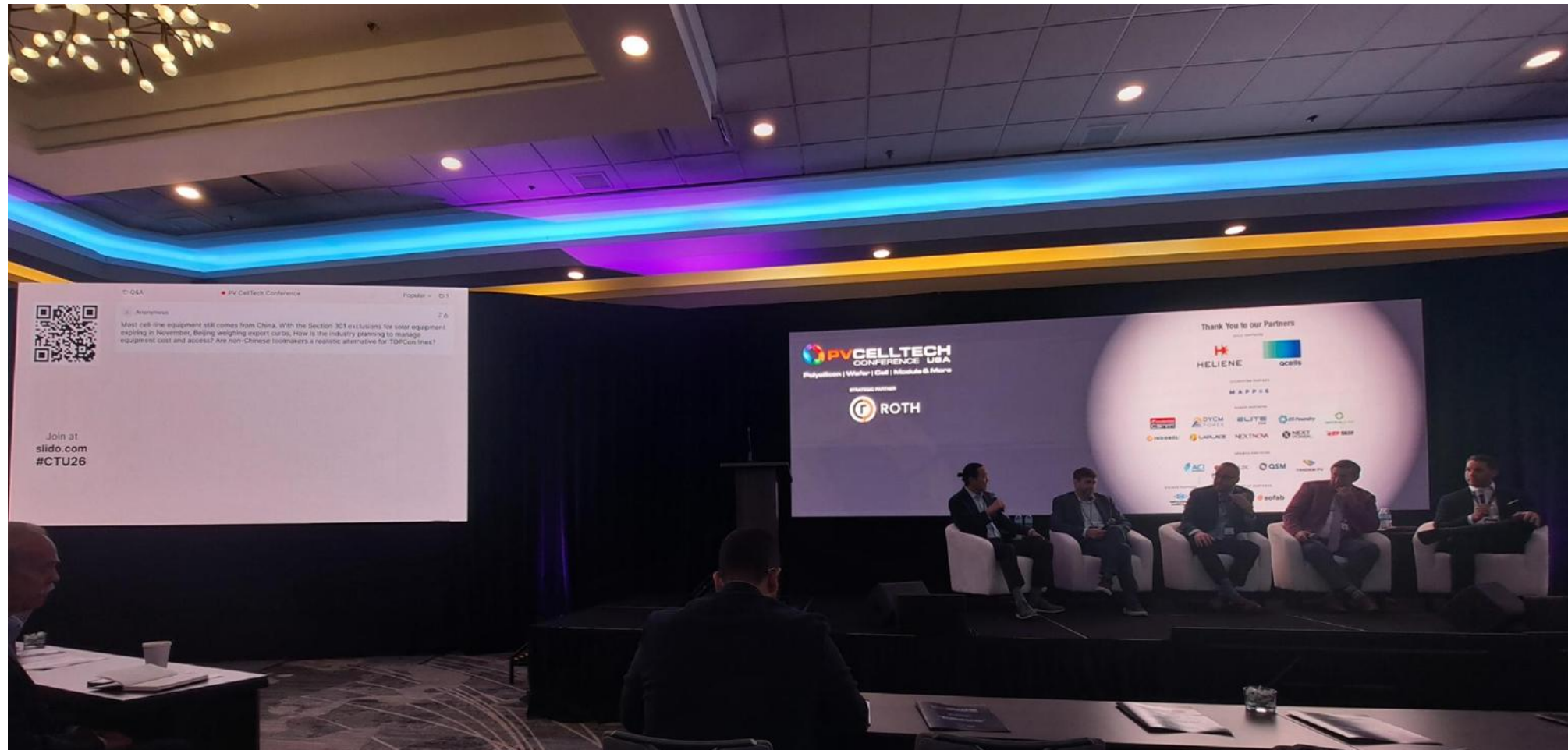


<https://www.reuters.com/legal/litigation/china-weighs-curbs-exports-solar-manufacturing-equipment-us-2026-04-15/>

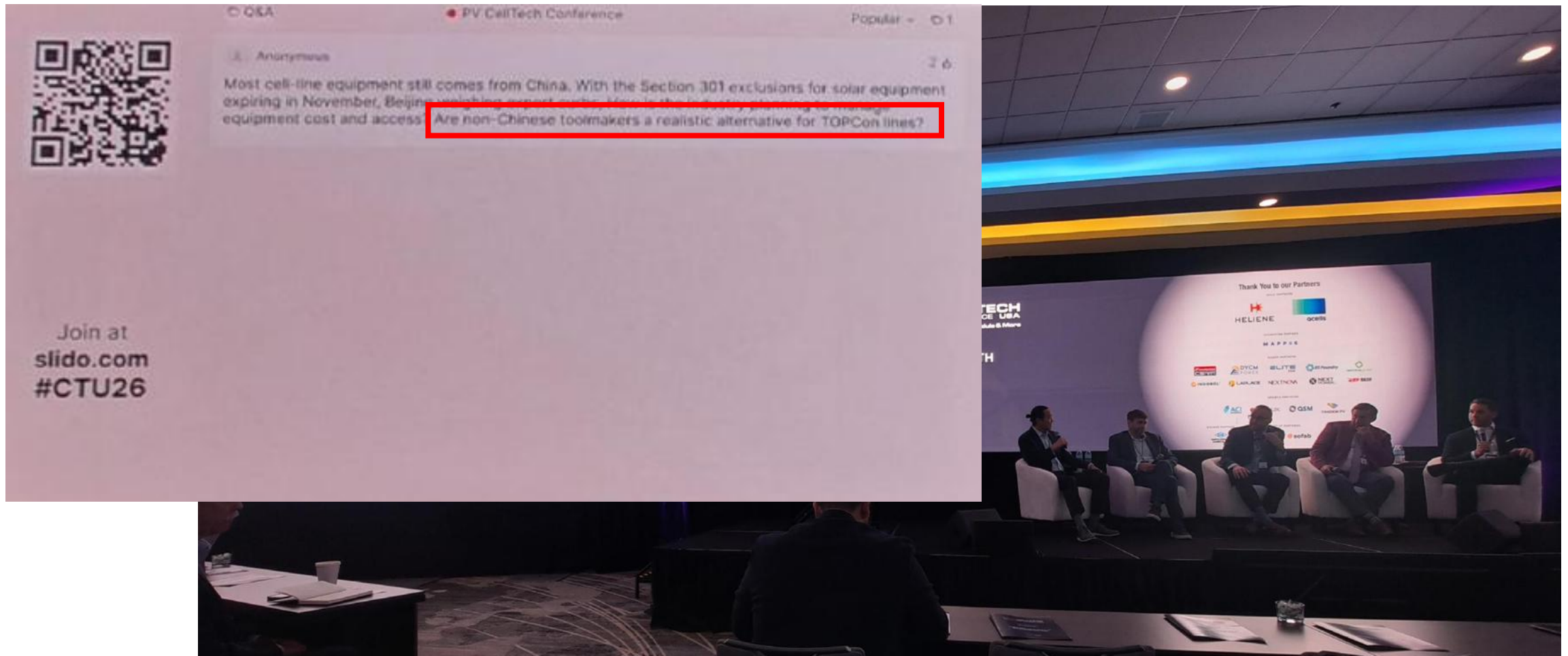


German Turnkey Alliance

PVCellTech2026: yesterday's panel

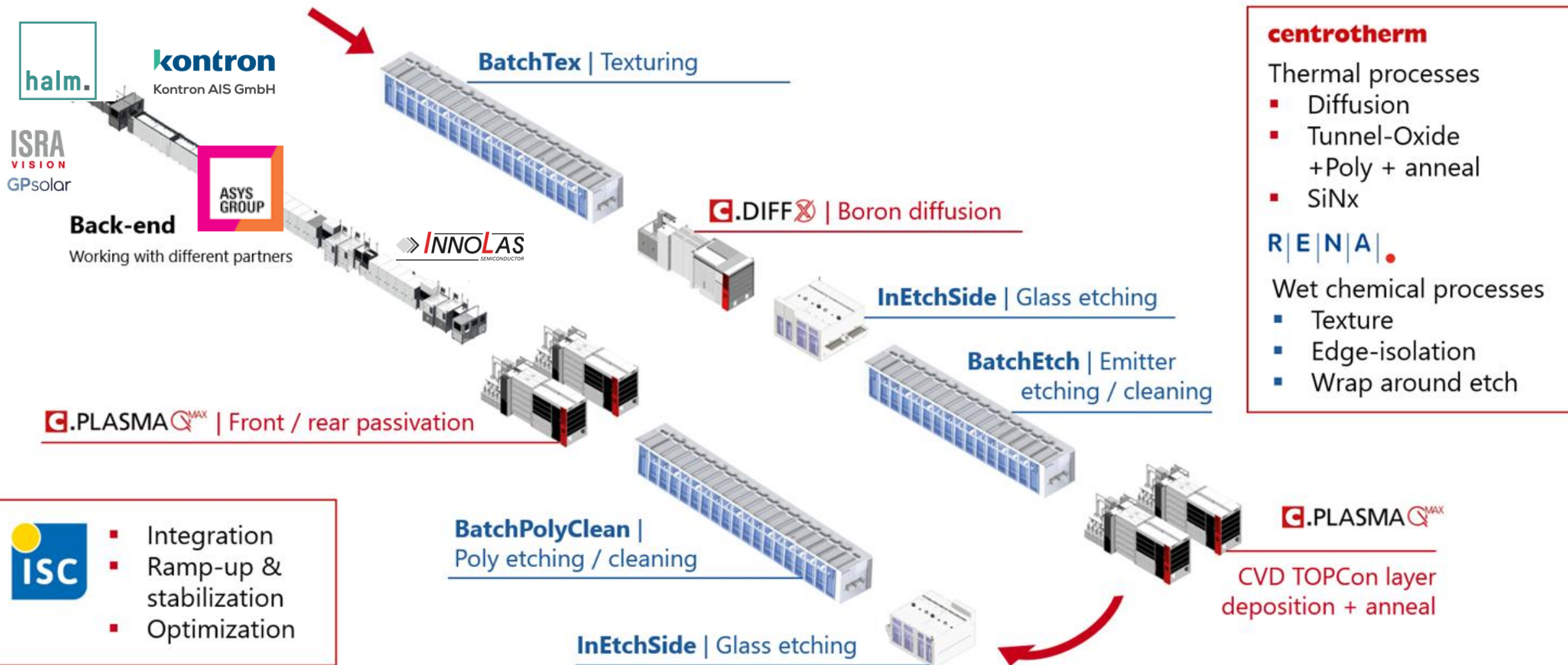


PVCellTech2026: yesterday's panel





PRODUCTION LINE DESIGN





COST OF OWNERSHIP

centrotherm

- New PECVD platform
- - 50 % lower gas consumption
- - 35 % lower footprint
- low maintenance

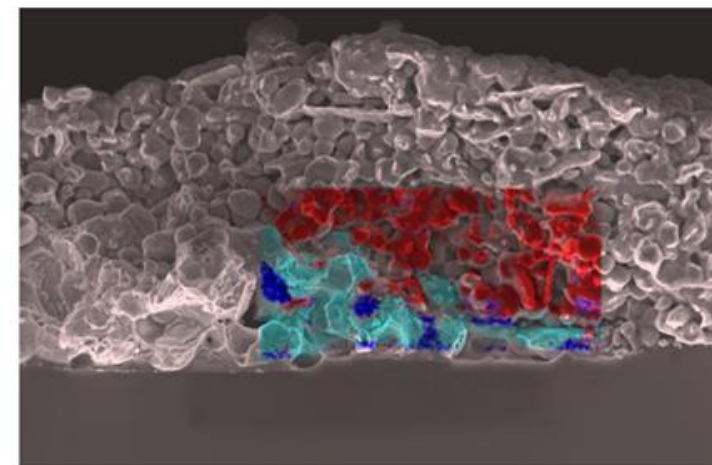


R | E | N | A | .

- Up to 50% lower CoO
- Low opex ⇔ profit optimization
- Key drive O3-clean



- TOPCon process optimization
- Ag reduction by Cu screen printing
- TOPCon to BC / tandem concepts



Cross section of screen-printed Cu-finger

Novel Multitrack Matrix-based Screen Printing Solution for Metallization

Key Advantage: 1 Tool for 1.2 GW Throughput



Higher

Cell-Level Cycle Time, Wider Process Window

Up to **+87%**



Reduced

Number of Operators

Up to **-40%**



Reduced

Downtime for Screen Exchanges

Up to **-75%**



Reduced

Operating Power

Up to **-20%**



Reduced

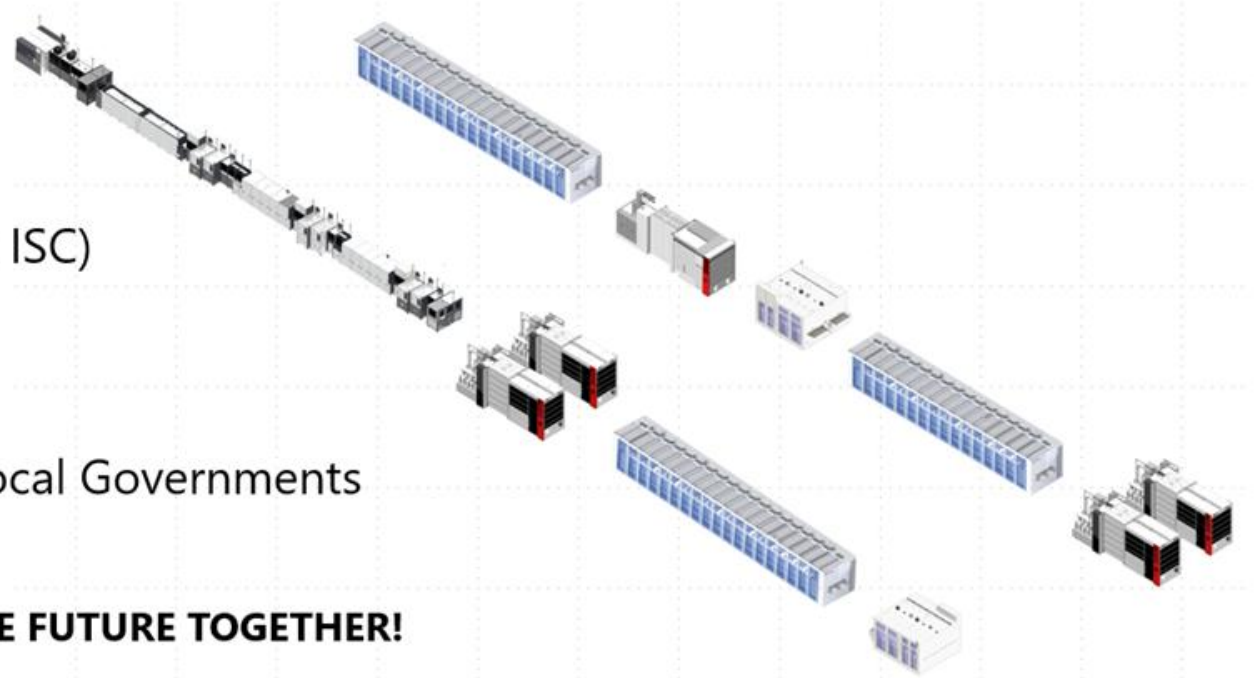
Footprint

Up to **-30%**

centrotherm / RENA / ISC offer complete solution for PERC, TOPCon & BC

- Focus on superior cost of ownership
- On-site support through fully localized teams
- Training of personnel (also possible prior ramp up at ISC)
- R&D support for future upgrades
- Long term partnership with support of federal and local Governments

LET US BUILD THE RENEWABLE FUTURE TOGETHER!





4. Upcoming workshops from ISC Konstanz

Upcoming “ISC events” in 2026



Bringing together Indian Producers, EU
Machine Builders and Academia

GWPVtech

Bangalore, October 26/27 2026



TAIYANGNEWS
ALL ABOUT SOLAR POWER

OCT



NOVEMBER 16-18:
FULL CONFERENCE EDUCATION

NOVEMBER 17-19:
EXHIBITS & SHOW FLOOR

SAVE THE DATE

LAS VEGAS, NV

POWERED BY  **SEIA** Solar Energy Industries Association

 **Smart Electric Power Alliance**

NOV



🕒 8–10 December 2026
📍 Berlin, Germany



GLOBAL BC SUMMIT
BERLIN 2026



www.globalbcsummit.com/

DEC

MIW 2027 – Call for Abstracts



14th edition of the **Metallization and Interconnection Workshop (MIW)** will take place on **9-10 March 2027 in Konstanz**

Fields of special interest are:

- Metallization fundamentals: insights, limits, understanding, modelling
- Progress and understanding of screen and stencil printing
- Advanced Metallization and Interconnection Techniques
- Interconnection: Performance and Reliability
- Zero busbar interconnection (0BB) and shingling technology
- Low temperature metallization and interconnection for Si-Pk tandem solar cells

Deadline for abstract submission is **October 23rd**

All infos on <https://miworkshop.info/>

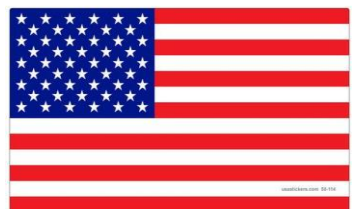
Summary



- Global technology leader
- TOPCon established as standard, clear shift towards BC
- Technology selection is driven by cost-performance



- Rapid TOPCon expansion
- Technology roadmap follows China
- Likely transition to BC after TOPCon matured



- No clear technology convergence
- Regional drivers outweigh pure cost considerations
- First GW-scale manufacturing investments may shape future technology adoption

☐ Technology adoption is increasingly determined by regional manufacturing ecosystems rather than technology performance alone



© ISC Konstanz
e.V.

R. Kopecek, Quo vadis
PV cell technology ?

Radovan.Kopecek@isc-konstanz.de

More information: www.isc-konstanz.de



We look forward to
our cooperation

Thank you