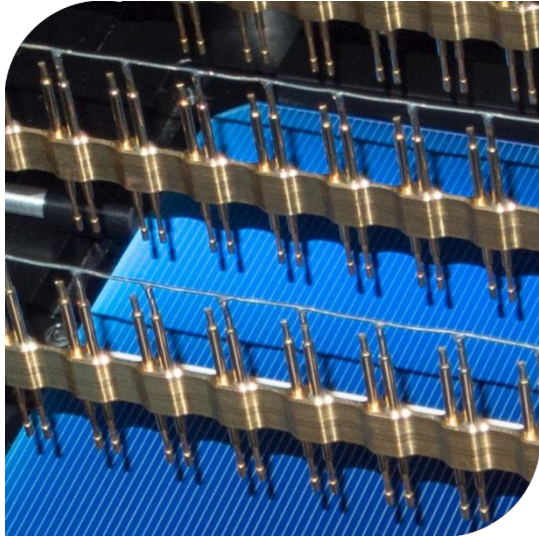




# Global Solar Technology Trends From Silicon to Modules

Dr. Radovan Kopecek, Andreas Halm et al.



International Solar Energy Research Center Konstanz

# Agenda

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## 1. ISC Konstanz R&D and technology ramp-up

## 2. c-Si PV tech

Market forecast (outside of China, in US)

Highest efficient modules

PV value chain

a. Material (Si, ingot, wafer)

b. Solar cells

c. Modules

d. Systems

Statements in PV arena

Hot R&D topics in PV arena





Employees at  
ISC Konstanz

70 ↗

Turnover  
2025

8 Mio€ ↗

Educated  
scientists

150 ↗

Achieved solar  
cell efficiency\*

24.6% ↗  
(Lab: 24.8%)

\*in industrial manufacturing

Transferred  
technology

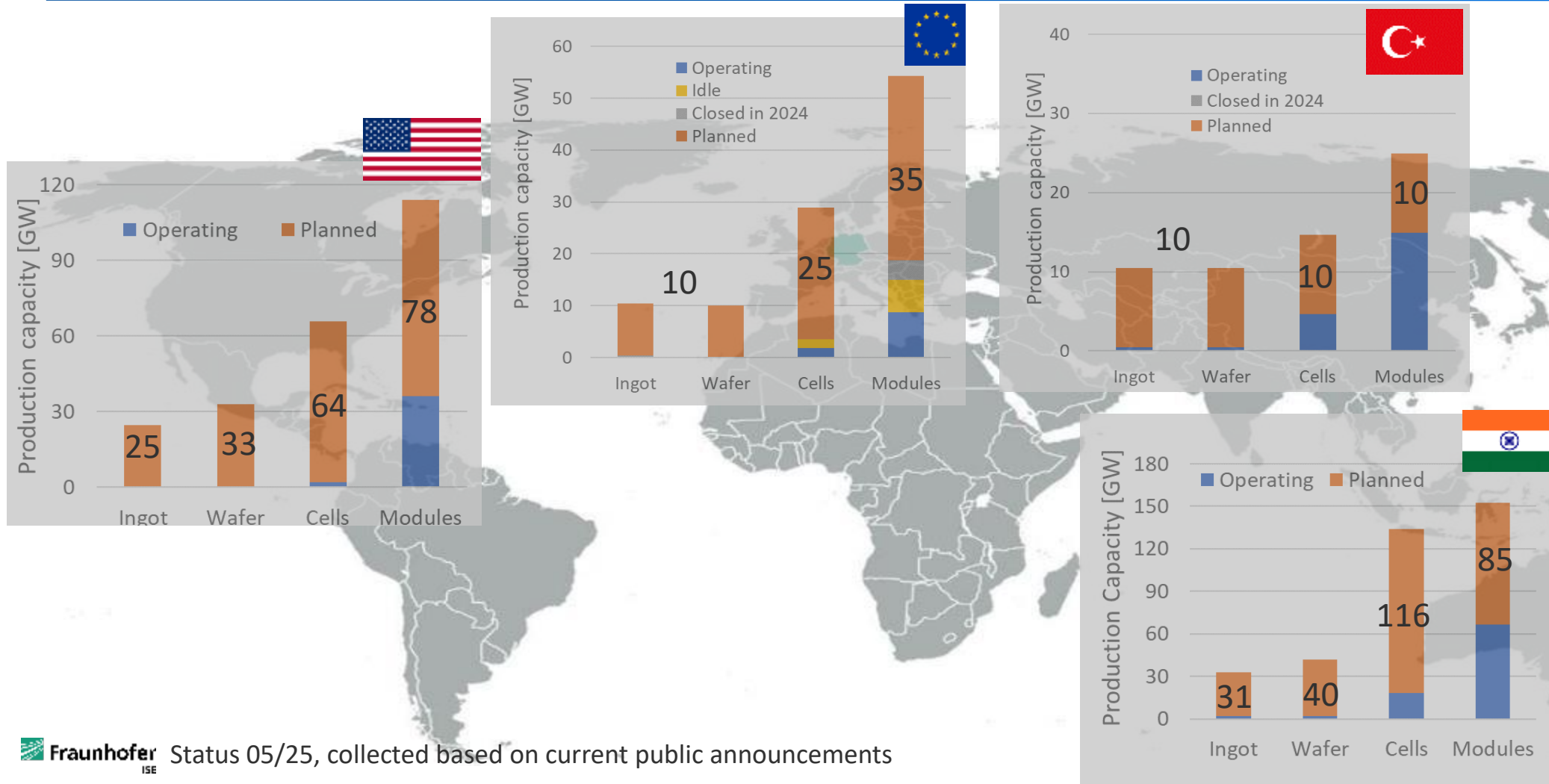
7GW ↗

# Technology transfer & Ramp-up service – track record

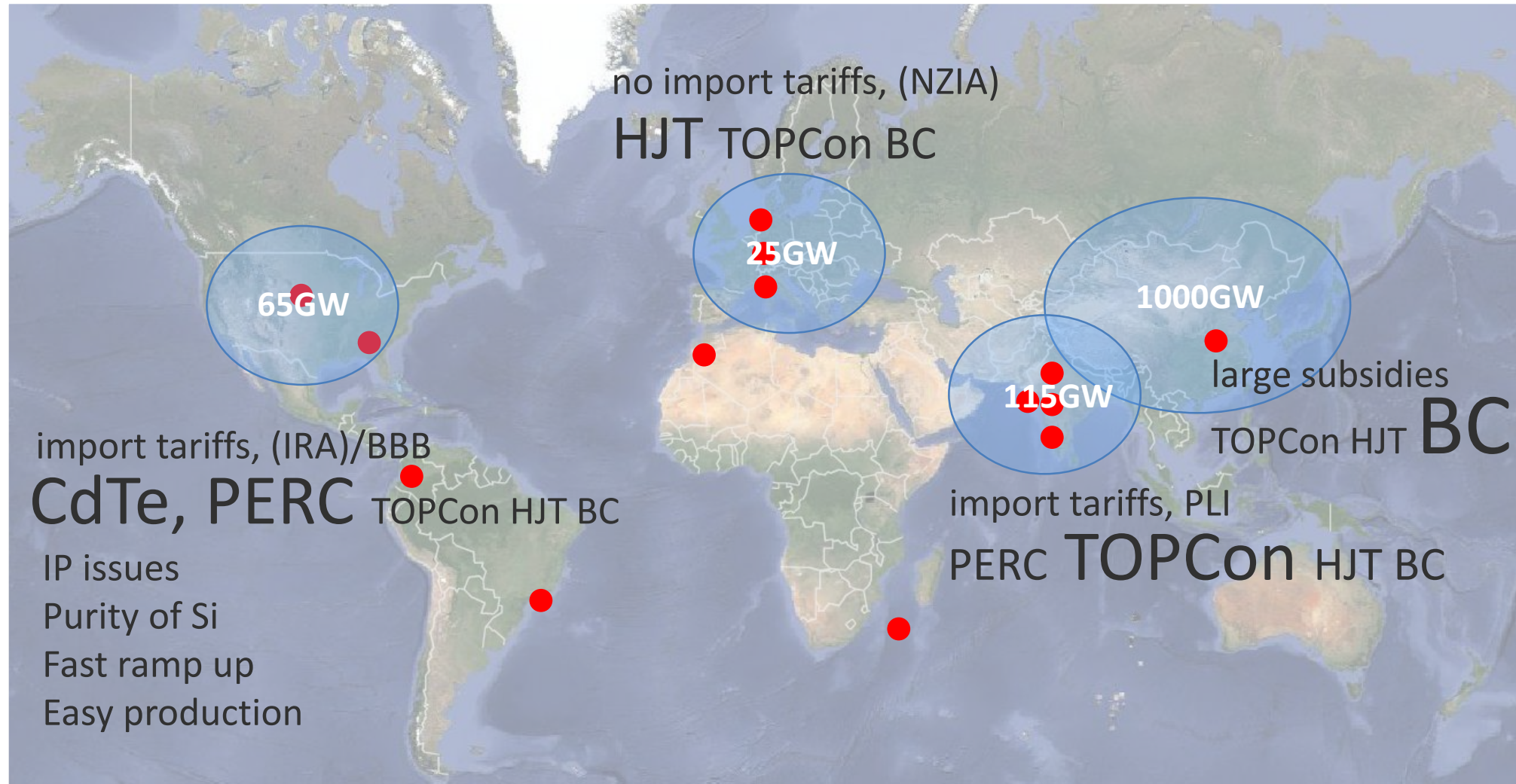
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- ISC Konstanz has **20 years of experience** in development and industrialization of n-type cells concepts
- **Successful process transfers into industry:**
  - 2015 @ MegaCell, Italy → BiSoN (40MW nPERT technology successfully transferred)
  - 2017 @ 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)
  - Ongoing @ Asian customer, India → TOPCon (1.2GW process optimisation on European process equipment)
  - Ongoing @ Suniva, US → PERC (1GW process optimisation on European process equipment)
  - Ongoing @ Asian customer, India → TOPCon (500MW > 4GW process optimisation on European process equipment)

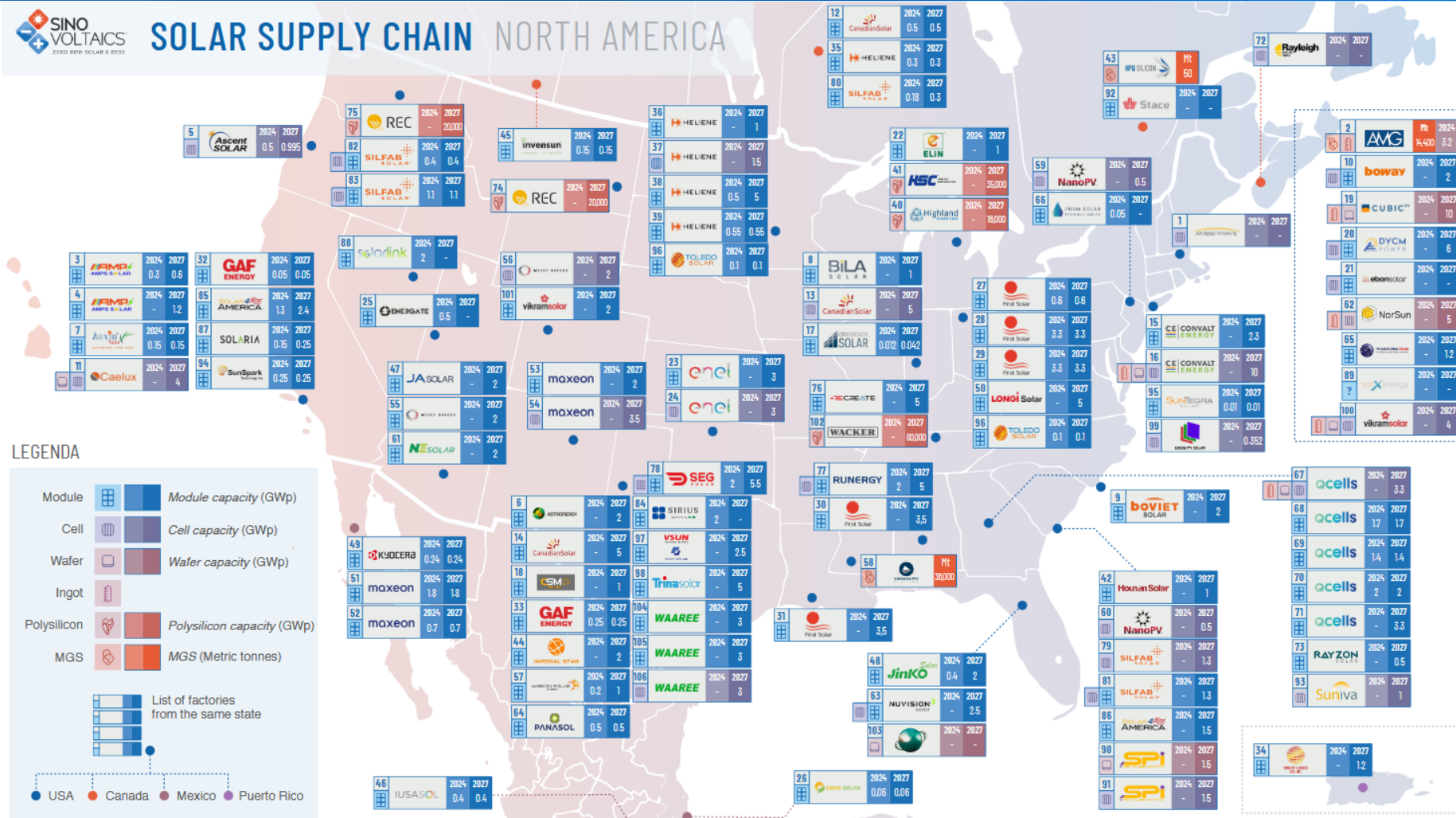
# Total production capacity and forecast



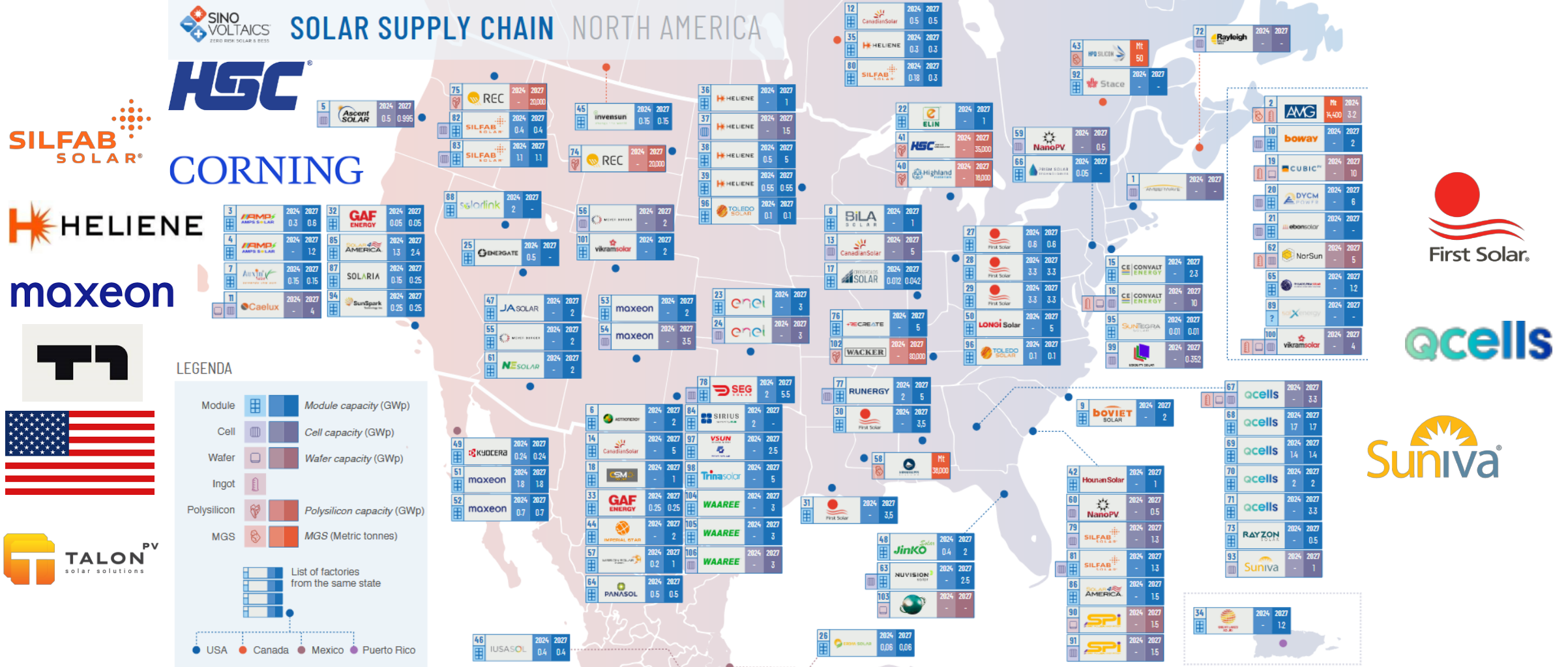
# Total cell production until 2027 and ISC's projects •



# Production landscape in NA



# Production landscape in NA





# c-Si technology

# Highest efficiency modules in August 2025

| <b>TAIYANGNEWS</b><br><small>ALL ABOUT SOLAR POWER</small> <b>TaiyangNews Top Modules: Highest Efficient Commercial Solar Modules 08-2025</b> |                       |                  |                        |            |           |           |           |                                        |           |                |
|-----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|------------------|------------------------|------------|-----------|-----------|-----------|----------------------------------------|-----------|----------------|
| Rank                                                                                                                                          | Company               | Series           | Model                  | Wafer type | Cell Size | Cells No. | Cell Tech | Module Technology                      | Power (W) | Efficiency (%) |
| 1                                                                                                                                             | <b>AIKO</b>           | Comet 2U         | AIKO-G660-MCH72Mw      | n-type     | 182       | 144       | ABC       | Half-cell, Back Contact                | 660       | 24.4           |
| 2                                                                                                                                             | <b>LONGi</b>          | Hi-MO 9          | LR8-66HYD 635-655M     | n-type     | 182       | 132       | HPBC      | Bifacial, Half-cell, Back Contact      | 655       | 24.2           |
| 3                                                                                                                                             | <b>Maxeon</b>         | Maxeon 7         | SPR-MAX7-445-PT        | n-type     | 125       | 112       | IBC       | Back Contact, Full-cell                | 445       | 24.1           |
| 4                                                                                                                                             | <b>HUASUN</b>         | Himalaya         | HS-210-B132DS730W      | n-type     | 210       | 132       | HJT       | Bifacial, Half-cell, MBB               | 730       | 23.5           |
| 5                                                                                                                                             | <b>Jinko</b>          | Tiger Neo        | JKM625-630N-66HL4M-BDV | n-type     | 210R      | 132       | TOPCon    | Bifacial, Half-cell, MBB               | 630       | 23.32          |
| 6                                                                                                                                             | <b>JA SOLAR</b>       | DeepBlue 4.0 Pro | JAM72D40 600/MB        | n-type     | 182       | 144       | TOPCon    | Bifacial, Half-cell, MBB               | 600       | 23.2           |
| 7                                                                                                                                             | <b>ASTROENERGY</b>    | Astro N7         | CHSM66RN(DG)/F-BH      | n-type     | 182       | 132       | TOPCon    | Bifacial, Half-cell, MBB               | 625       | 23.1           |
| 8                                                                                                                                             | <b>TrinaSolar</b>     | Vertex N         | TSM-NEG21C.20          | n-type     | 210       | 132       | TOPCon    | Bifacial, Half-cell, MBB               | 715       | 23.0           |
| 8                                                                                                                                             | <b>TW SOLAR</b>       | -                | TWMHF-66HD700-715W     | n-type     | 210       | 132       | HJT       | Bifacial, Half-cell, MBB               | 715       | 23.0           |
| 8                                                                                                                                             | <b>DMEGC</b>          | Infinity RT      | DM620G12RT-B66HSW      | n-type     | 210       | 132       | TOPCon    | Bifacial, Half-cell, MBB               | 620       | 23.0           |
| 11                                                                                                                                            | <b>Jetion Solar</b>   | Jeniüs           | JT SLk(B) 690-710W     | n-type     | 210       | 132       | HJT       | Bifacial, Half-cell, MBB               | 710       | 22.9           |
| 12                                                                                                                                            | <b>Grand Sunergy</b>  | -                | GSM-MH3/132-BHDG710    | n-type     | 210       | 132       | HJT       | Bifacial, Half-cell, MBB               | 710       | 22.86          |
| 13                                                                                                                                            | <b>TW SOLAR</b>       | -                | TWMND-72HS575-590W     | n-type     | 182       | 144       | TOPCon    | Half-cell, MBB                         | 590       | 22.8           |
| 13                                                                                                                                            | <b>SPIC</b>           | ANDROMEDA 3.0    | SPICN6(LDF)-60/BIH410W | n-type     | 166       | 120       | TBC       | Bifacial, Back Contact, Half-cell, MBB | 410       | 22.8           |
| 15                                                                                                                                            | <b>SolarSpace</b>     | Lumina II        | SS8-72HD-585N          | n-type     | 182       | 144       | TOPCon    | Bifacial, Half-cell, MBB               | 585       | 22.65          |
| 16                                                                                                                                            | <b>REC Group</b>      | Alpha®Pure-RX    | REC470AA Pure-RX       | n-type     | 210       | 88        | HJT       | Bifacial, half-cell, MBB               | 470       | 22.6           |
| 17                                                                                                                                            | <b>GCL</b>            | -                | GCL-NT12/66GDF         | n-type     | 210       | 132       | TOPCon    | Bifacial, half-cell, MBB               | 700       | 22.53          |
| 17                                                                                                                                            | <b>中東股份 JOLYWOOD</b>  | Niwa Pro         | JW-HD108N415-440W      | n-type     | 182       | 108       | TOPCon    | Bifacial, Half-cell, MBB               | 440       | 22.53          |
| 19                                                                                                                                            | <b>risen</b>          | Hyper-ion        | RSM132-B-700BHDG       | n-type     | 210       | 132       | HJT       | Bifacial, Half-cell, MBB               | 700       | 22.5           |
| 19                                                                                                                                            | <b>DASOLAR</b>        | -                | DAS-DH156NA-620-630W   | n-type     | 182       | 156       | TOPCon    | Bifacial, Half-cell, MBB               | 630       | 22.5           |
| 19                                                                                                                                            | <b>Canadian Solar</b> | TOPHiKu6         | CS6W-570-580T          | n-type     | 182       | 144       | TOPCon    | Half-cell, MBB                         | 580       | 22.5           |
| 19                                                                                                                                            | <b>Eging PV</b>       | STAR Pro         | EG-580NT72-HL/BF-DG    | n-type     | 182       | 144       | TOPCon    | Bifacial, Half-cell, MBB               | 580       | 22.5           |
| 19                                                                                                                                            | <b>RUNERGY</b>        | -                | HY-DH144N8             | n-type     | 182       | 144       | TOPCon    | Bifacial, Half-cell, MBB               | 580       | 22.5           |

3 x BC

24+%

HJT

23+%

TOPCon

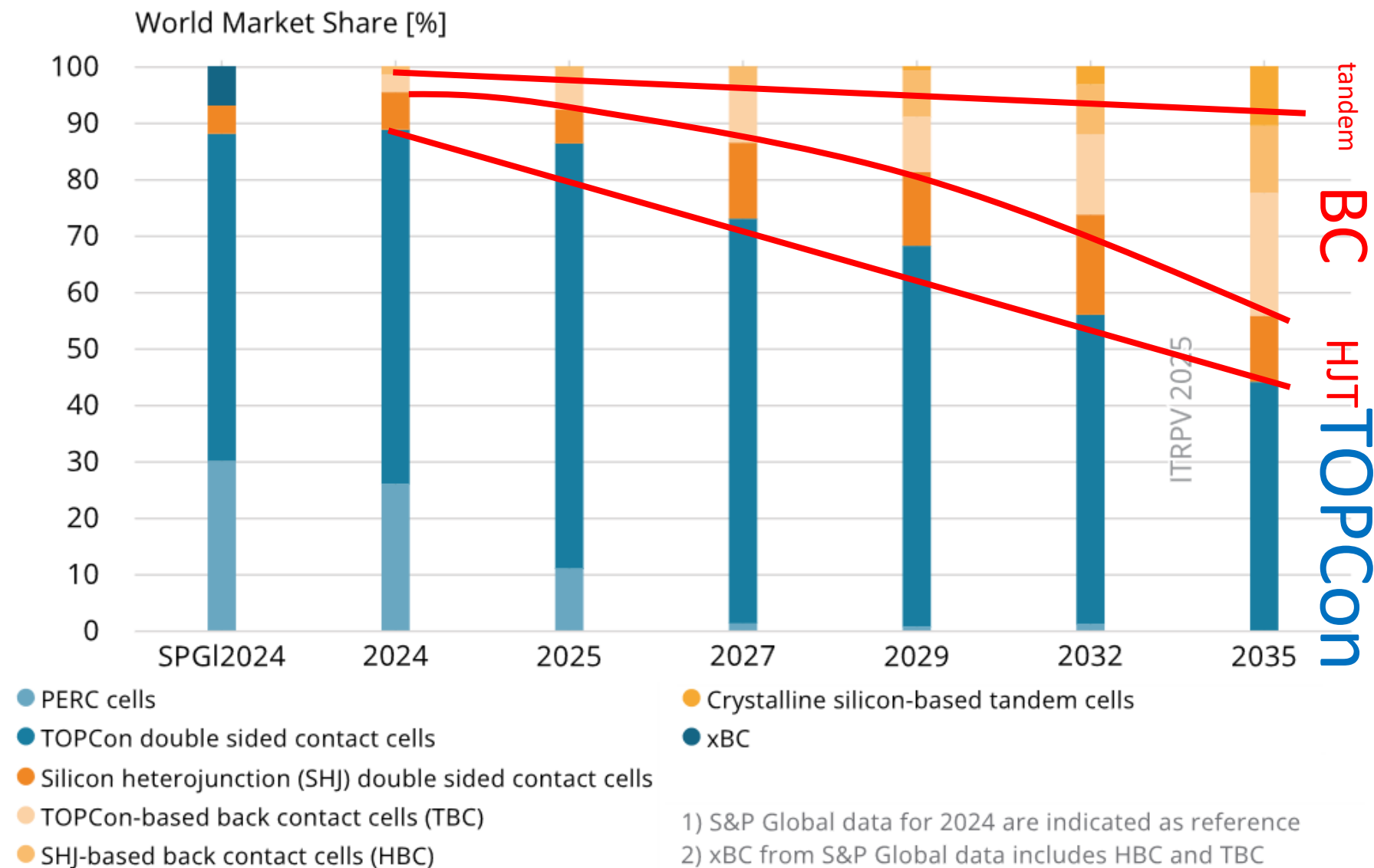
23+%

PERC

21.5-22%

## Different cell technologies

For GW-scale device and equipment manufacturers



28+%

25+%

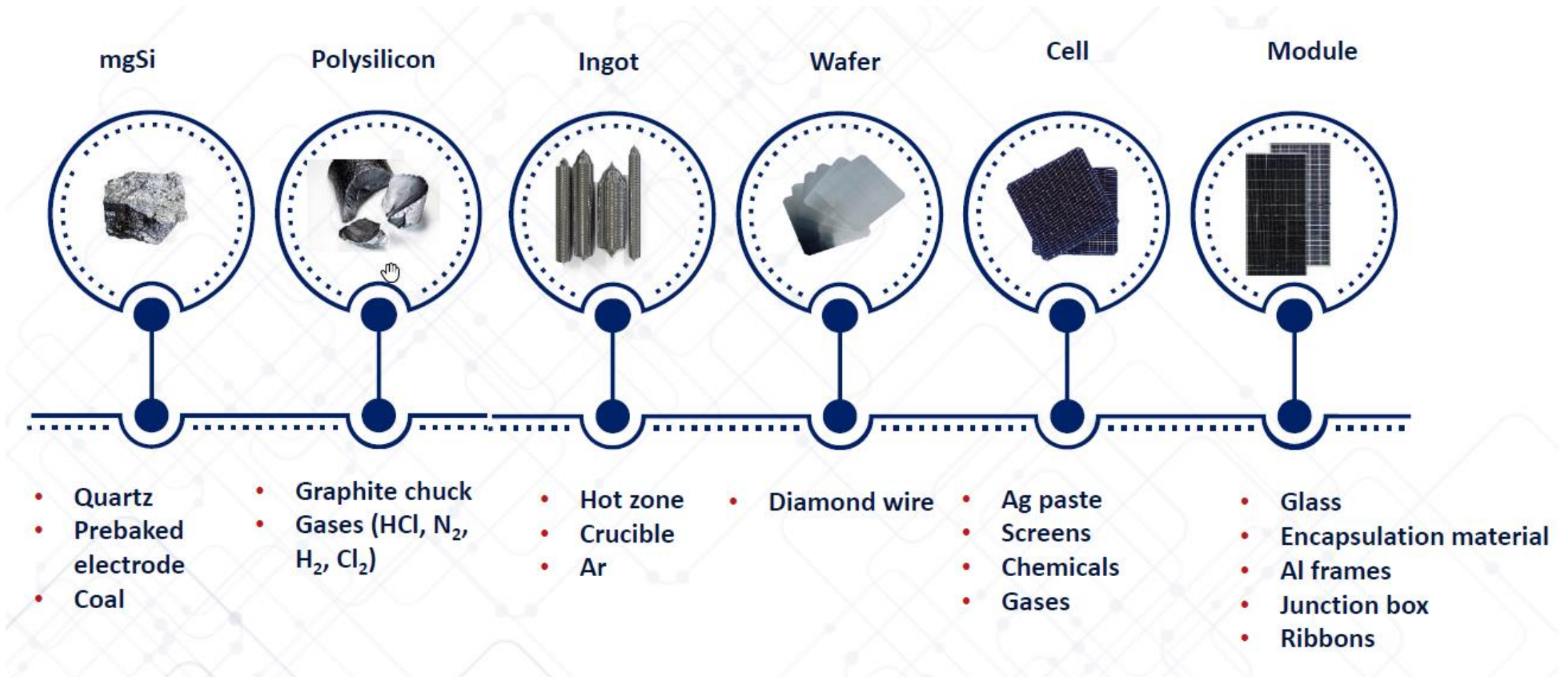
24+%

24+%

21.5-22%

1) S&P Global data for 2024 are indicated as reference  
2) xBC from S&P Global data includes HBC and TBC

# c-Si PV value chain



# Si material: from p-type to n-type

**Poly-Si:** Siemens, FBR and other (e.g. UMG-Si/Highland) > electronic grade purity necessary (10N+)

**Ingot:** Recharged Cz-Si, P, Sb (Tai Ray) doping, 2+ms (wafer) lifetime

**Wafer:** M10/G12 families, 130μm thickness direct wafer (NexWafe)

Silicon feedstock technology

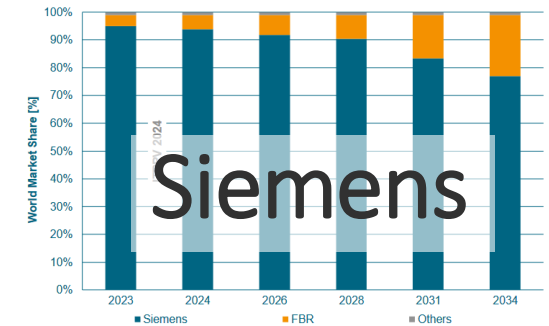


Fig. 2: Expected world market share of poly-Si feedstock technology.

Different mono-Si Crystallisation Methods

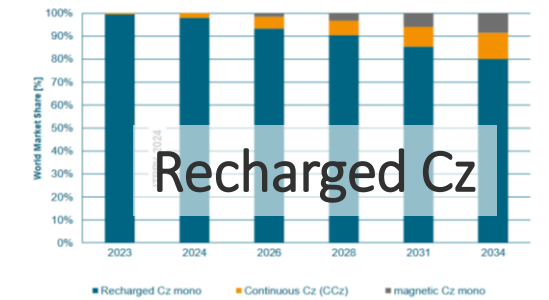


Fig. 5: Different mono-Si crystallization methods.

World market share of mono-Si wafer sizes

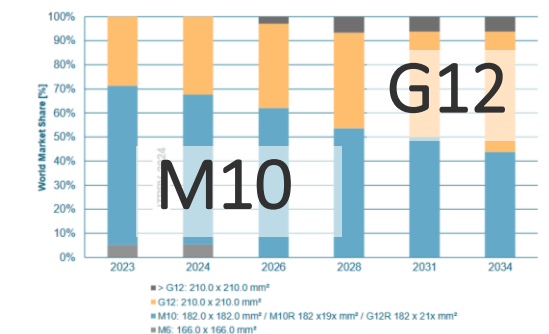
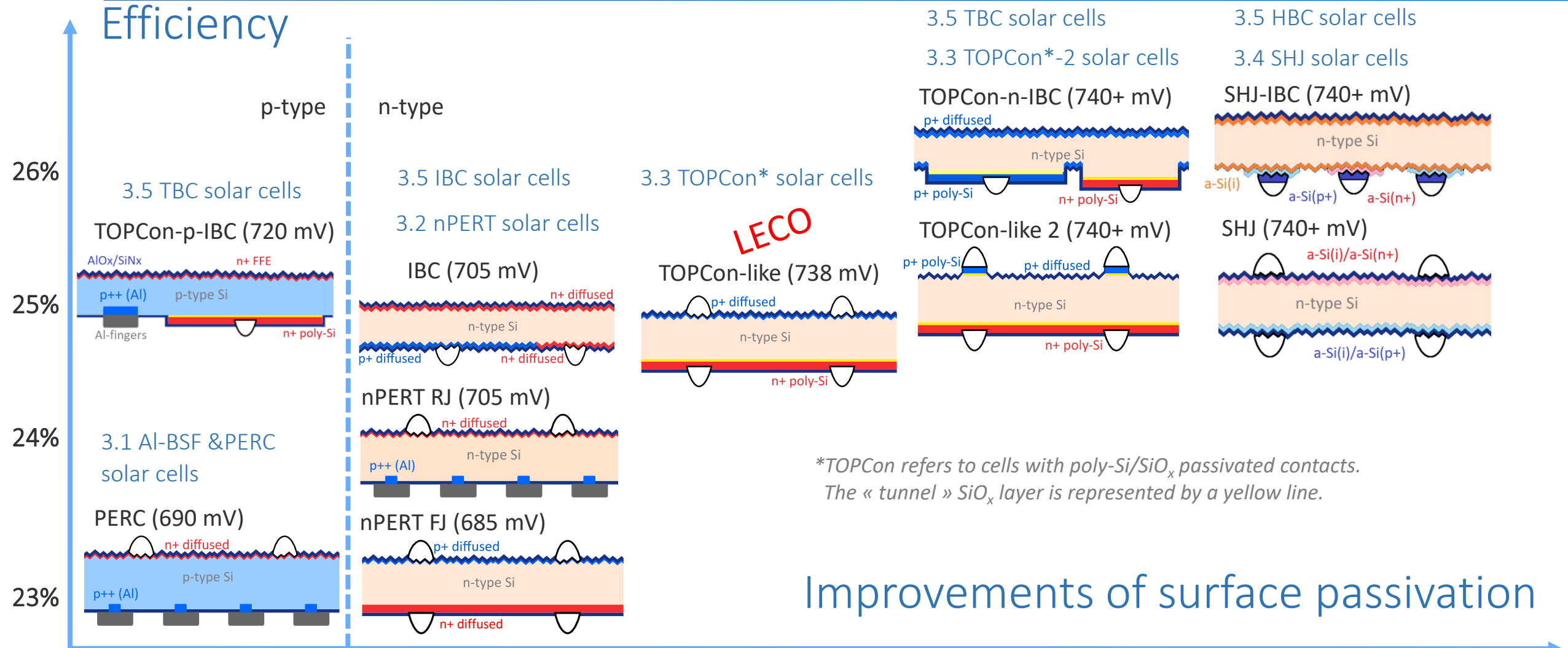
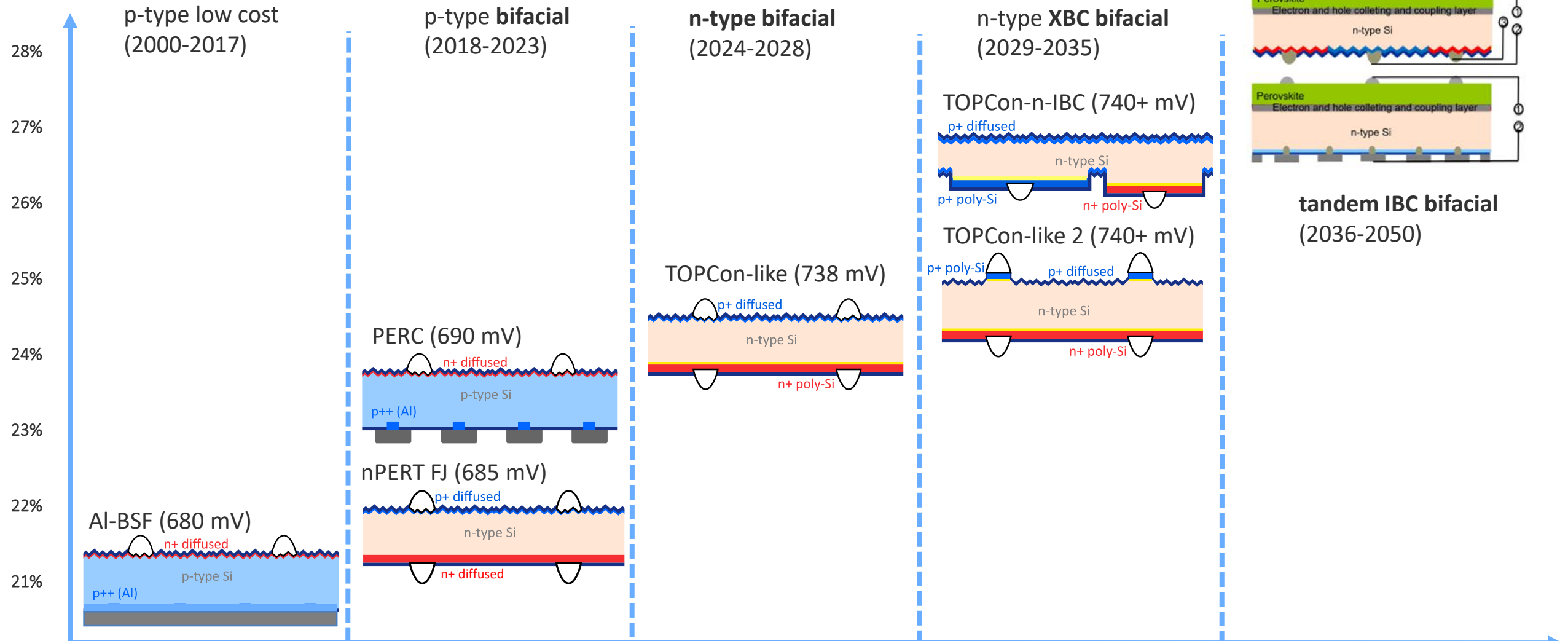


Fig. 10: Expected trend of Cz-mono-Si wafer size in mass production.

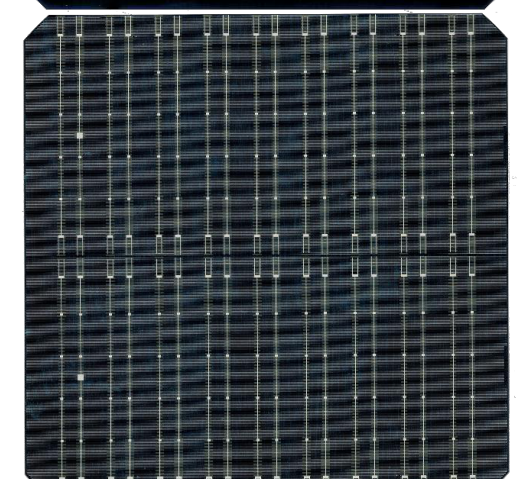
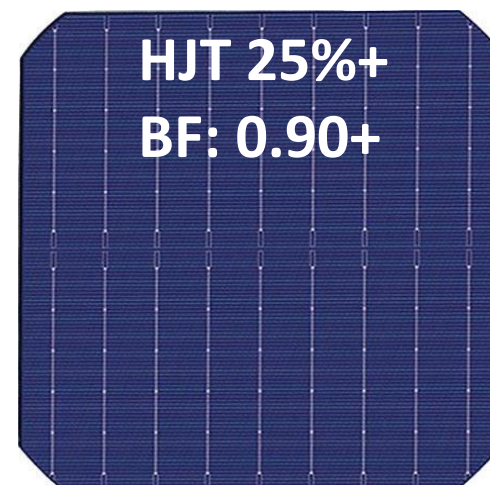
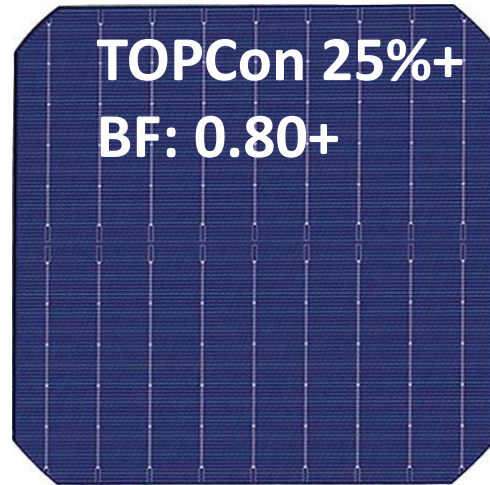
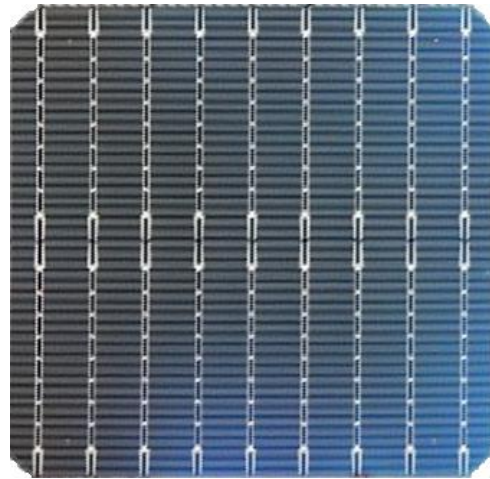
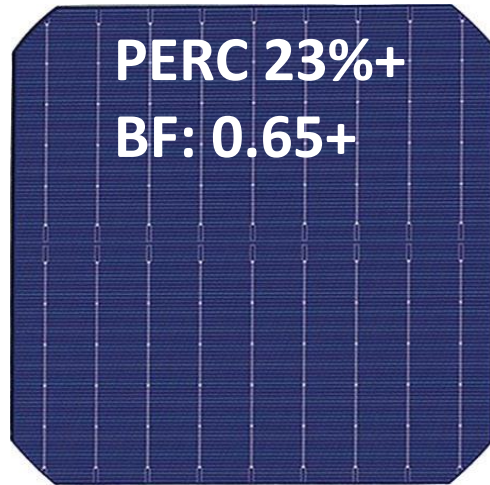
# Crystalline silicon solar cell technology



# Crystalline silicon solar cell technology



# Solar cell pictures of PERC, TOPCon, HJT and IBC



# Rear side module pictures of PERC, TOPCon, HJT and IBC



# Module technology: what is the trend?

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half cell, 1/3 cell technology

negative gap

OBB technology

bifacial BC

led free (gluing instead of solder)

Cu metallization

from 3mm to 2mm glass

Laser processing

smart modules

large “floppy” modules

steel frames

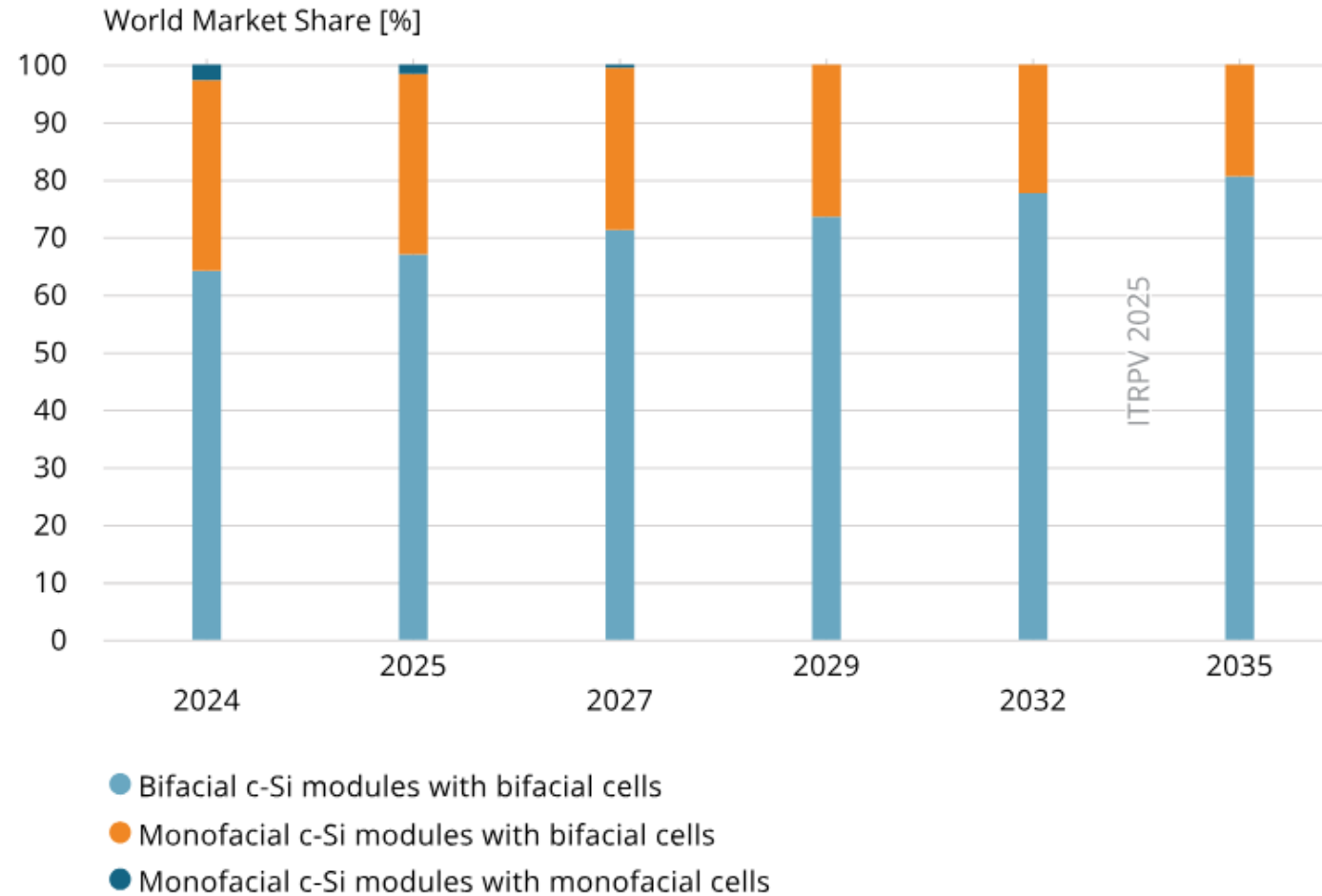
# PV systems: applications



# PV systems: applications



World Market Share of monofacial and bifacial modules



# PV systems: bifacial applications and gains

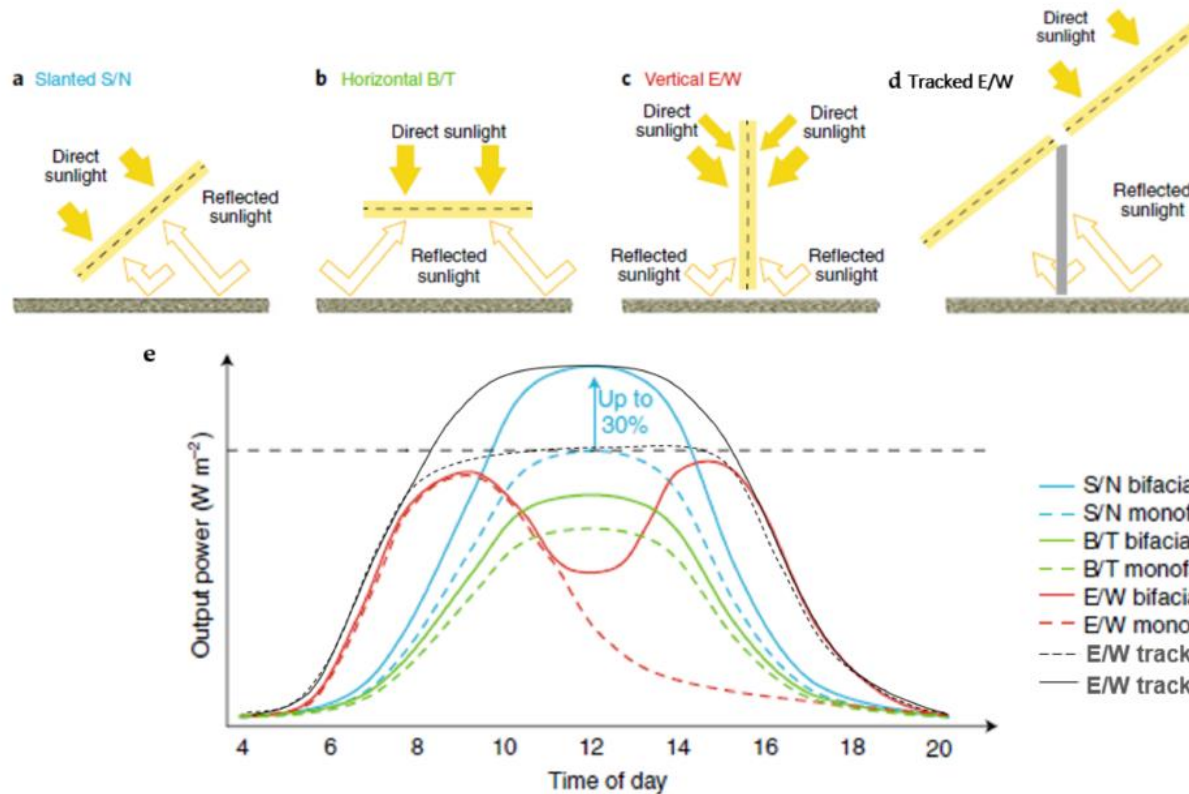


Table 2. Energy gains in systems using tracking and bifacial modules [20].

| Installation Geometry      | Monofacial [%] | Bifacial [%] |
|----------------------------|----------------|--------------|
| Fixed tilt (flat roof)     | 100            | 105–115      |
| Fixed tilt (utility scale) | 100            | 107–130      |
| Vertical (utility scale)   | 40–50          | 95–140 *     |
| HSAT                       | 110–122        | 117–145      |

\* comparison with monofacial fixed tilt.

bifacial gains of 5-30%

Figure 5. (a–d) possibilities for installations of bifacial modules and (e) comparison of power generation curves for monofacial and bifacial modules [16]. S/N means South/North, B/T is Bottom/Top and E/W is East/West.

R Kopecek; J Libal, Towards large-scale deployment of bifacial photovoltaics Nature Energy 3 (6), 443-446, **2018**

R Kopecek; J Libal, Bifacial Photovoltaics 2021: Status, Opportunities and Challenges, Energies, 14, 2076, **2021** <https://doi.org/10.3390/en14082076>

# Statements in PV arena

---

“For new cells Siemens and FBR material purity must be **electronic grade.**”

“TaiRay is the future!”

“**Laser** tech is the future.”

“PV developed from low cost Si-material and Al-BSF to **electronic grade material/wafers and selective processes.**”

“**LECO** killed HJT!”

“TOPCon with **LPCVD, PECVD, PVD** is similar.”

“The last step to **TBC as mainstream** is the development of low cost effective insitu p-poly!”

“Tandem will need much more time for large GW scale!”

“**Energy transition will be driven by c-Si tech** with 80TW total installations until 2050!”

“**AI** is the future.”

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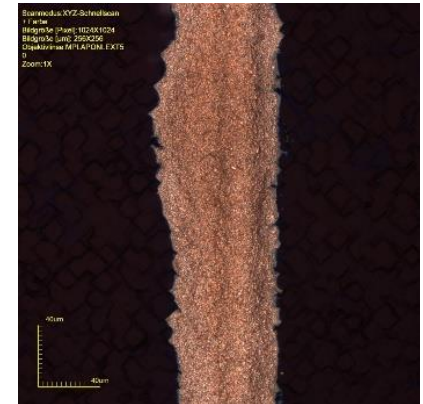
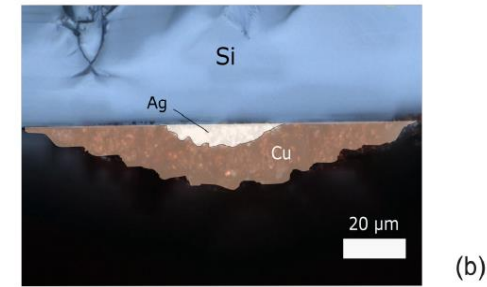
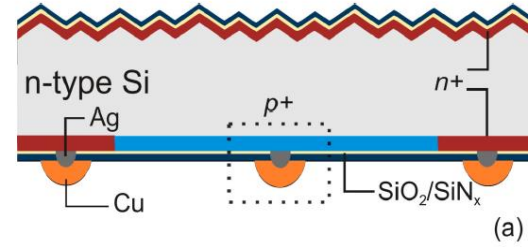
“**Energy transition will be driven by c-Si tech** with 80TW total installations until 2050!”

“**AI** is the future.”

**LOW COST BATTERY STORAGE IS A TOTAL GAME CHANGER!!!**

# Hot R&D topics in PV arena

- Direct wafer
- Edge passivation
- Additives for advanced chemistry
- Cu metallization
- Bifacial BC technology
- Tandem technology
- Shingling tech
- Conductive adhesives
- Laser module production
- **c-Si space cells and modules**



Thank you for  
listening



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