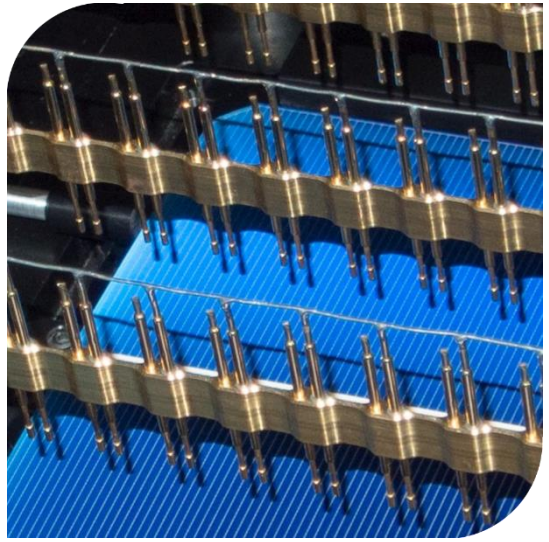



Current trends in cell and module technology

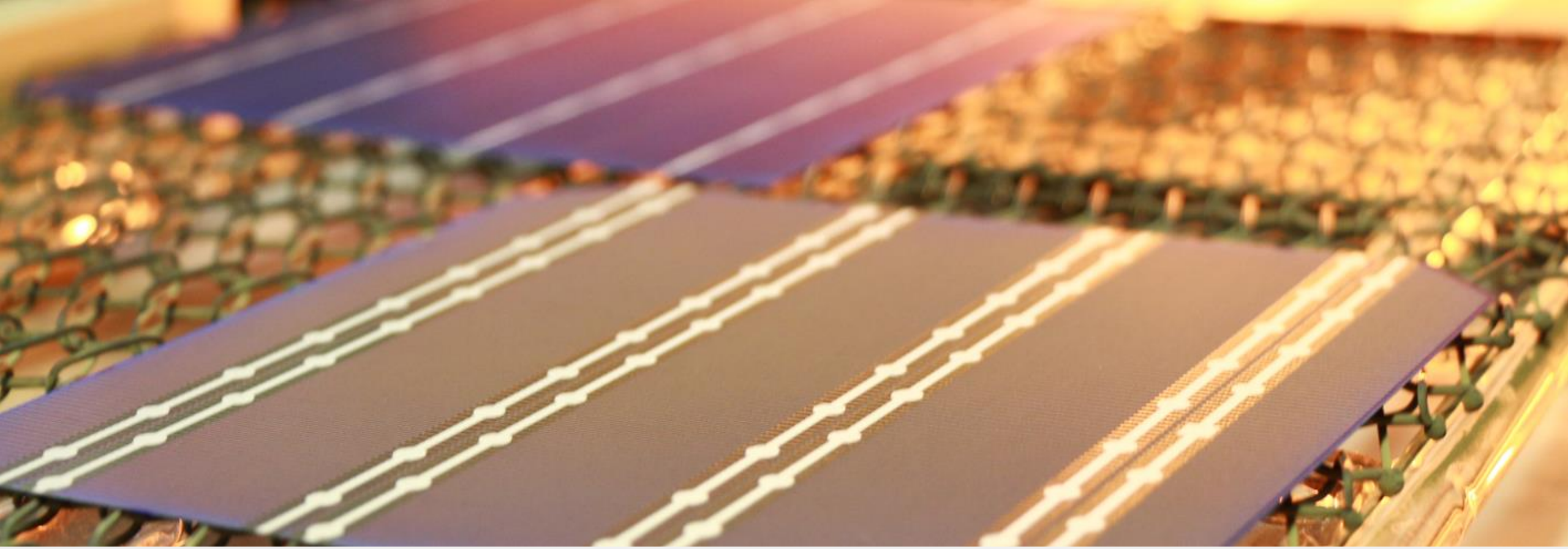
ISC research for a sunny future

Dr. Florian Buchholz, Andreas Halm, Dr. Radovan Kopecek, Dr. Kristian Peter, Lejo Joseph, Tobias Messmer, Dr. Tudor Timofte, Dr. Joris Libal, Dr. Valentin Mihailetchi et al.

International Solar Energy Research Center Konstanz e.V.

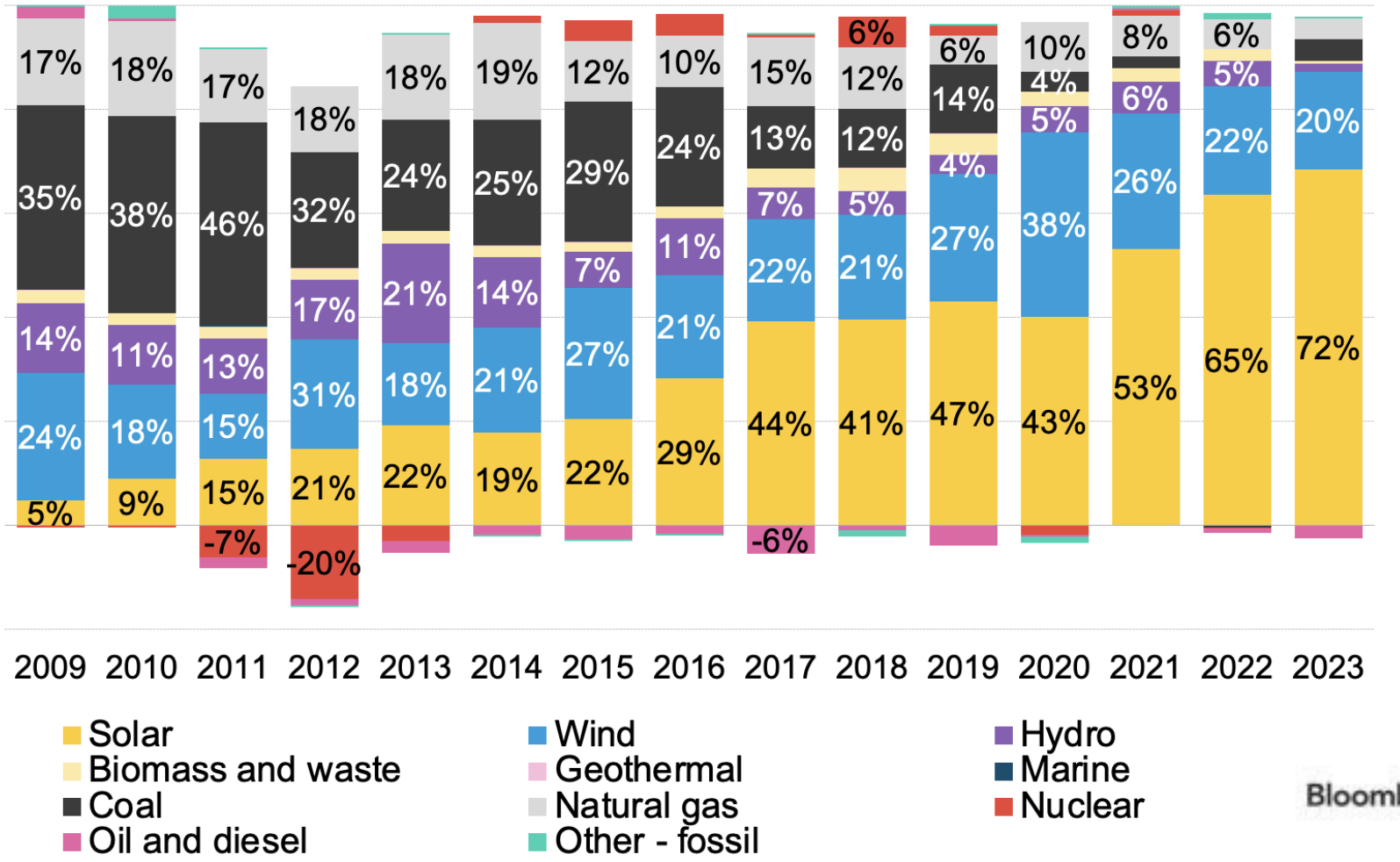
Agenda

1. **Status PV deployment**
2. **cell and module technology**
3. **Technology trends module**
4. **Summary**



1. Status PV deployment

Yearly new installed capacity by **Bloomberg**



PV 2023 / 400+GW

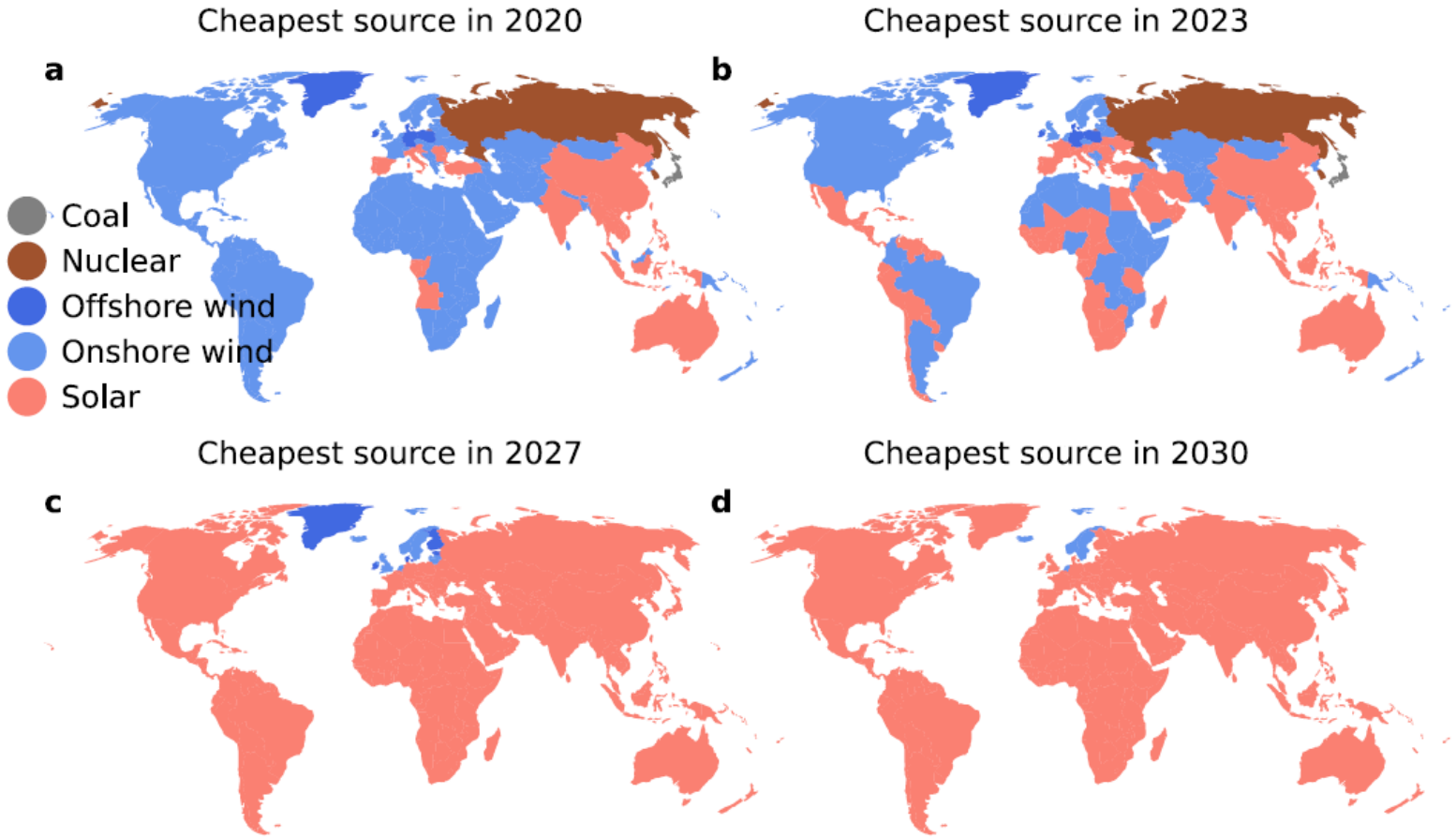
PV 2024 / 550+GW

PV 2025 / 700+GW

PV 2027 / 1000+GW

BloombergNEF

LCOE calculations by **Nijsse**

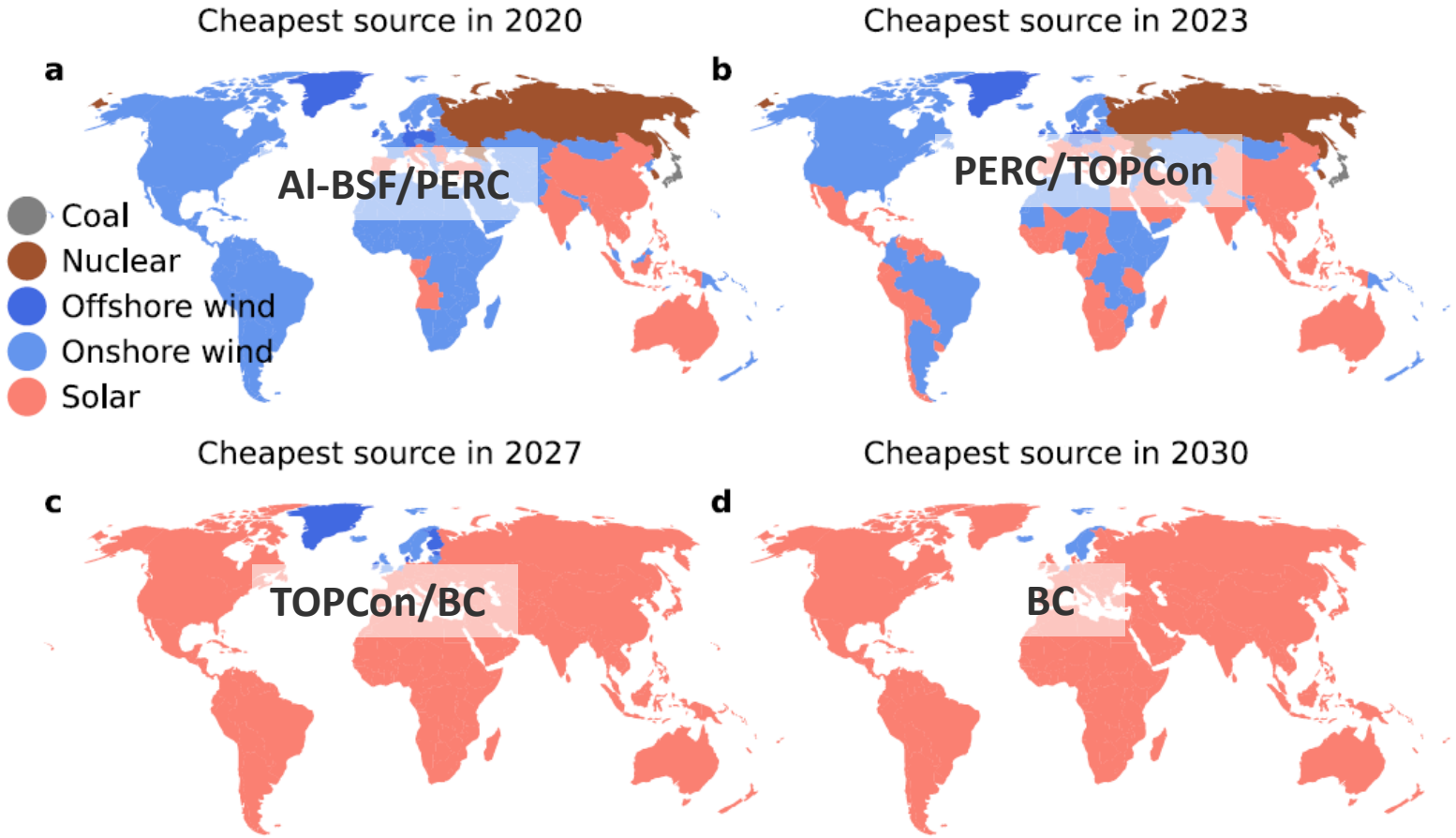


Nijsse, F.J.M.M., Mercure, JF., Ameli, N. et al. The momentum of the solar energy transition. Nat Commun. 14, 6542 (2023). https://doi.org/10.1038/s41467-023-41971-7

PV WITH storage will be the cheapest energy globally

- c-Si is still on a steep learning curve
- Average module efficiency: 22.5%
- With BC tech we reach average of 25.5% in 5-6 years from now
- 1TW PV annually will be installed

LCOE calculations by **Nijsse**

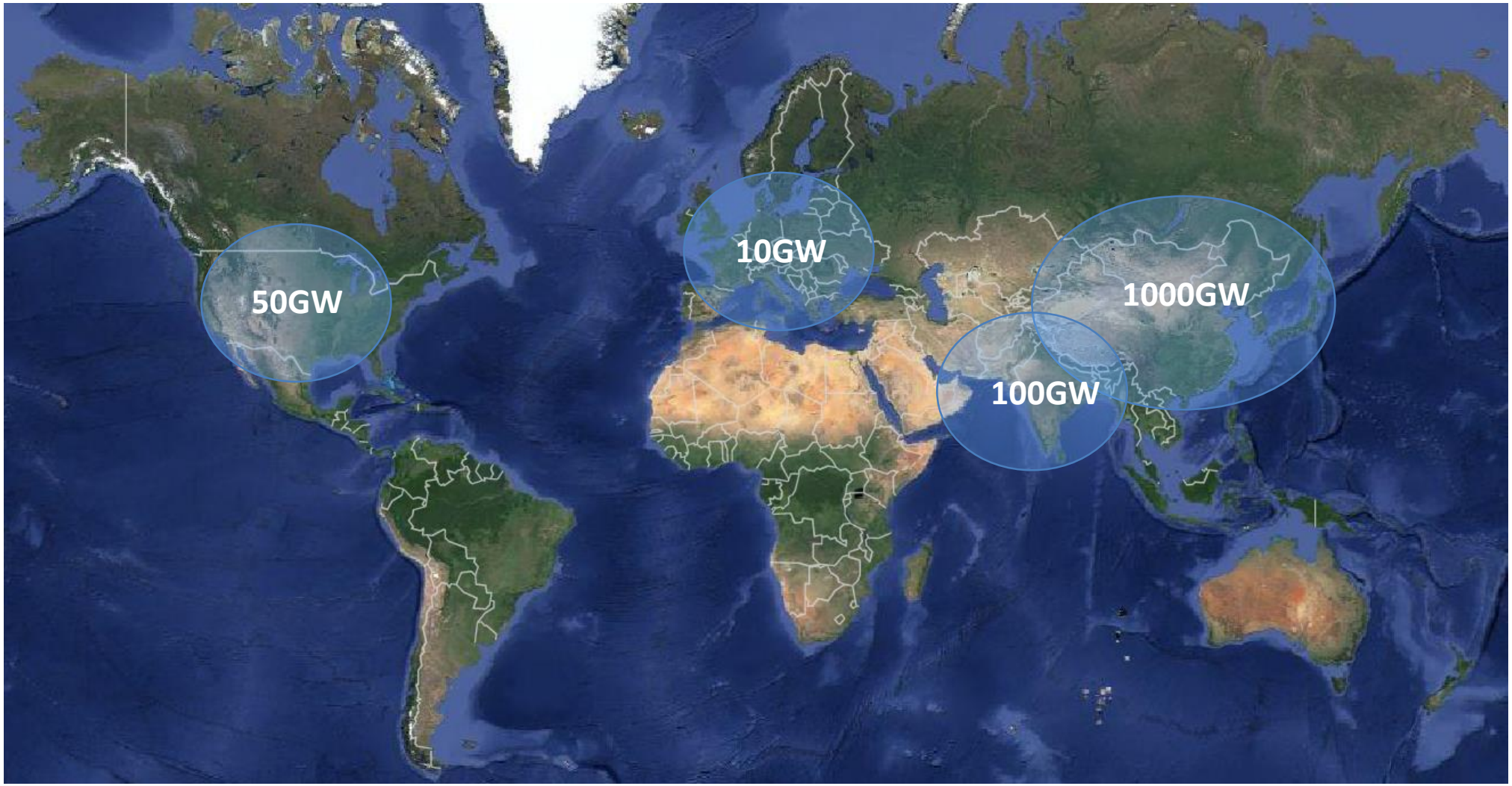


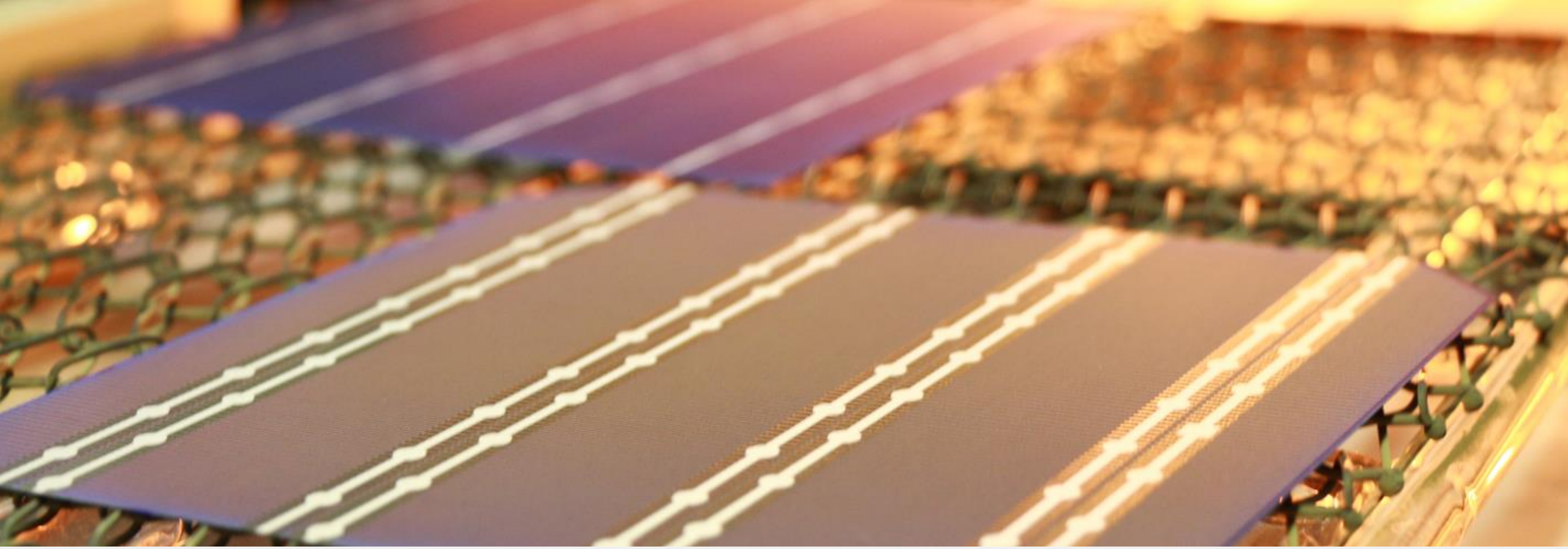
PV WITH storage will be the cheapest energy globally

- c-Si is still on a steep learning curve
- Average module efficiency: 22.5%
- With BC tech we reach average of 25.5% in 5-6 years from now
- 1TW PV annually will be installed
- **Bifacial BC tech will be the winner**

Nijsse, F.J.M.M., Mercure, JF., Ameli, N. et al. The momentum of the solar energy transition. Nat Commun. 14, 6542 (2023). https://doi.org/10.1038/s41467-023-41971-7

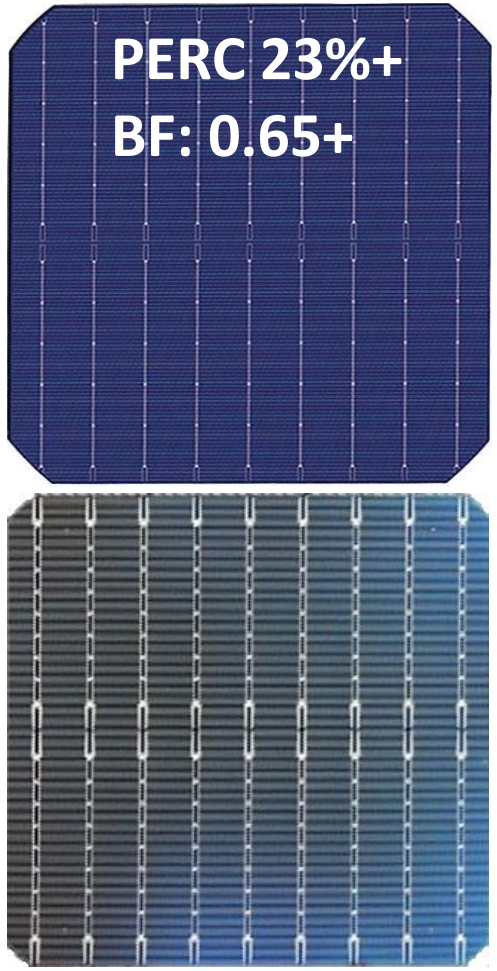
Total production until 2027

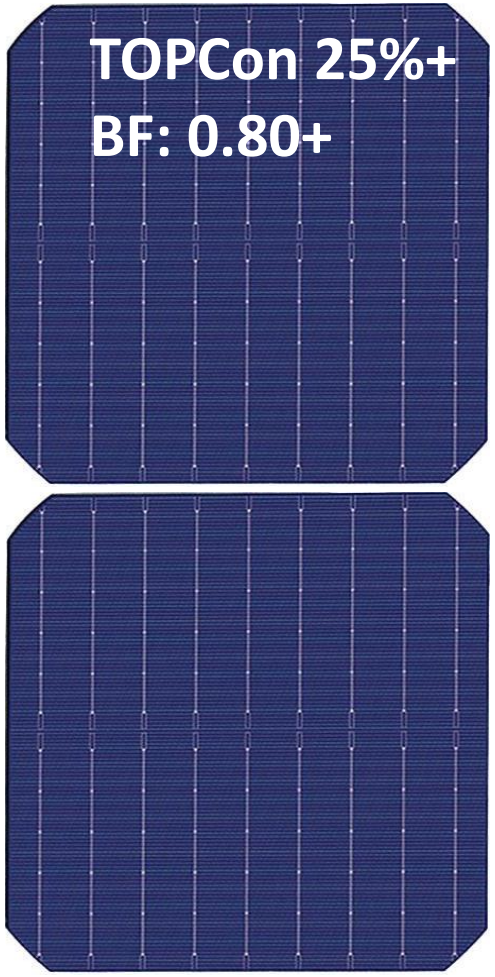


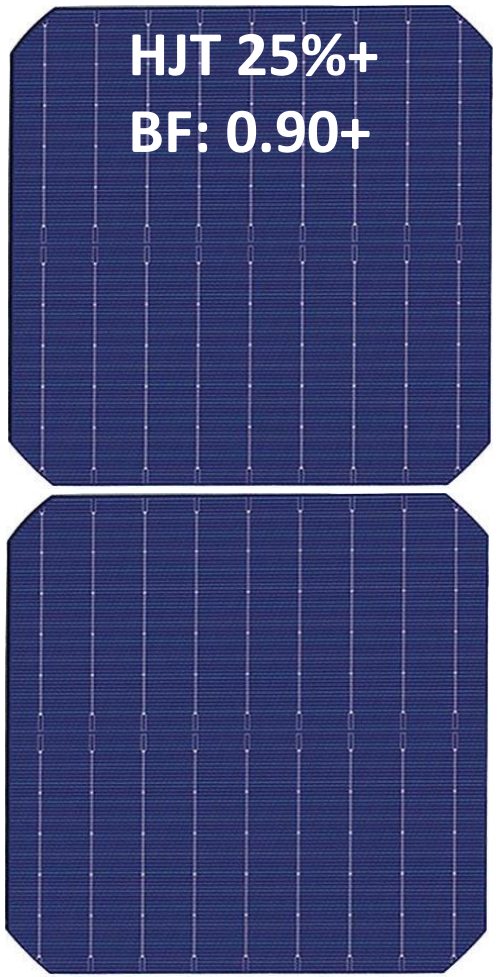


2. Cell and module technology

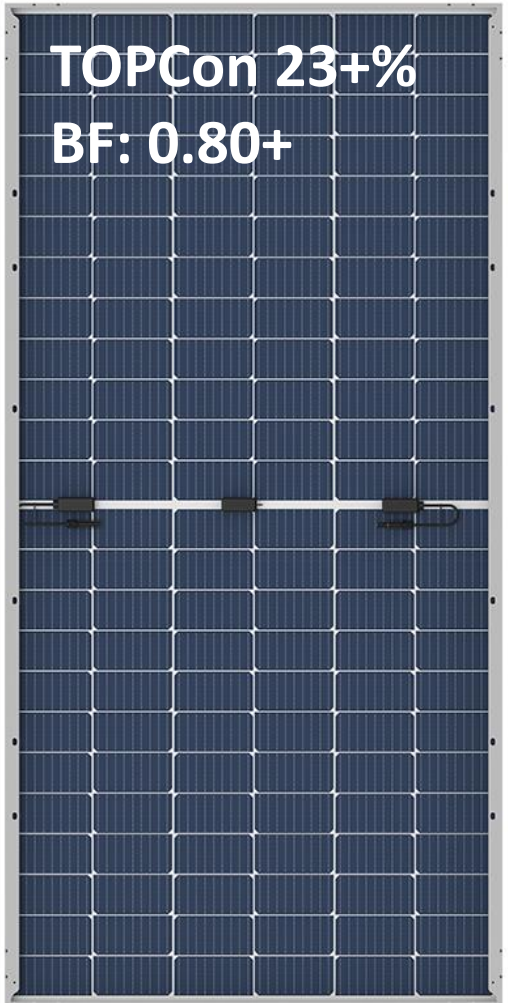
Solar cell pictures of PERC, TOPCon, HJT and IBC

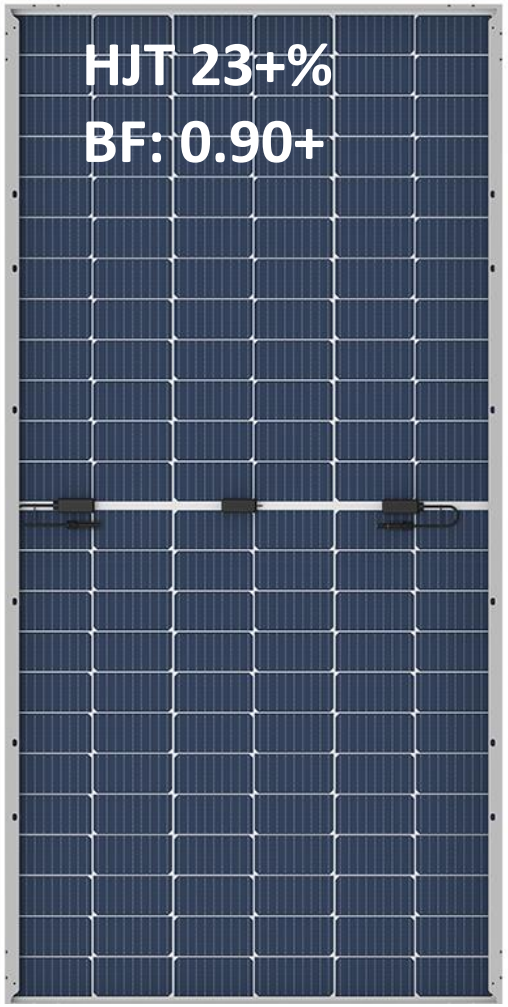


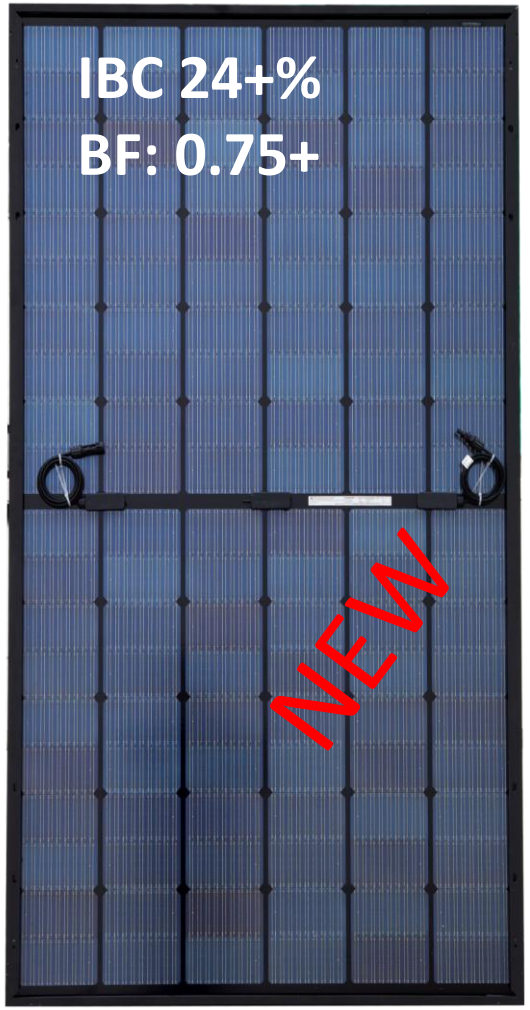




Rear side module pictures of PERC, TOPCon, HJT and IBC





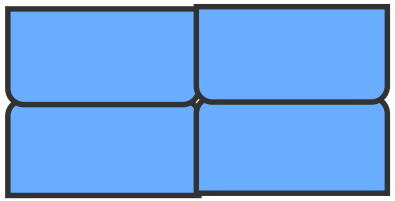


Gapless stringing for IBC to maximize active module area

- Small cell to cell overlap during stringing (0.5 to 1mm)
- Shadowing of cut edge reduces edge cutting losses
- No ribbon visible in cell gap
- Maximized active area
- Fully IEC 61215 certified product available from SPIC solar, Aiko

R&D approach for maximized module area

Zebra module with maximized active area



gapless module layup

22.4% efficiency
on aperture area

Highest efficiency modules in April 2025

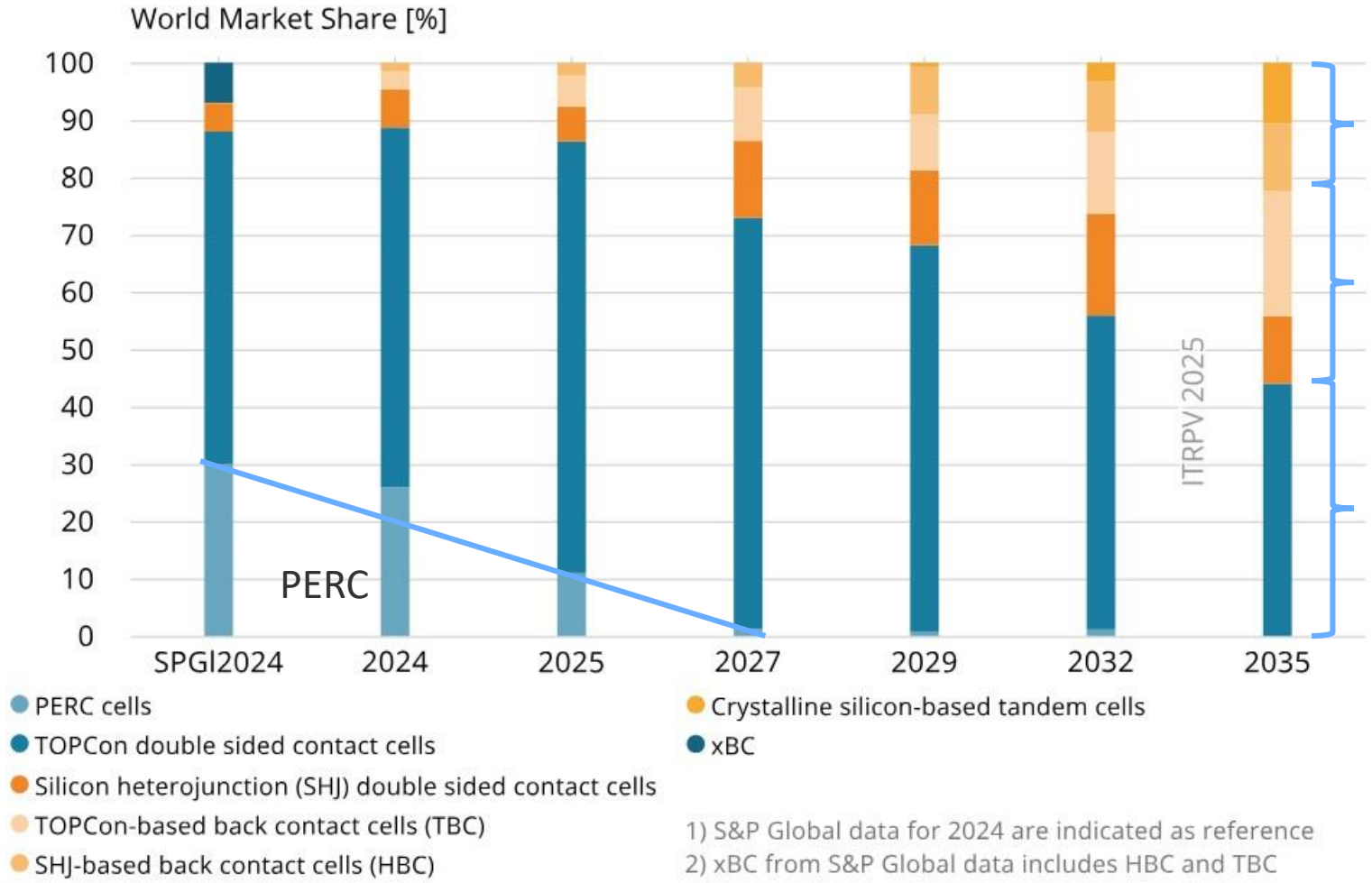
TAIYANGNEWS ALL ABOUT SOLAR POWER

TaiyangNews Top Modules: Highest Efficient Commercial Solar Modules 04-2025

Rank	Company	Series	Model	Wafer type	Cell Size	Cells No.	Cell Tech	Module Technology	Power (W)	Efficiency (%)
1	AIKO	Comet 2U	AIKO-G655-MCH72Mw	n-type	182	144	ABC	Half-cell, Back Contact	655	24.2
2	LONGi	Hi-MO 9	LR7-72HYD 625-650M	n-type	182	144	HPBC	Bifacial, Half-cell, Back Contact	650	24.1
2	Maxeon	Maxeon 7	SPR-MAX7-445-PT	n-type	125	112	IBC	Back Contact, Full-cell	445	24.1
4	HUASUN	Himalaya	HS-210-B132DS720W	n-type	210	132	HJT	Bifacial, Half-cell, MBB	720	23.18
5	TW SOLAR	-	TWMHF-66HD700-715W	n-type	210	132	HJT	Bifacial, Half-cell, MBB	715	23.0
5	ASTRONERGY	Astro N7	CHSM66RN(DG)/F-BH	n-type	182	132	TOPCon	Bifacial, Half-cell, MBB	620	23.0
5	DMEGC SOLAR	Infinity RT	DM620G12RT-B66HSW	n-type	210	132	TOPCon	Bifacial, Half-cell, MBB	620	23.0
5	JA SOLAR	DeepBlue 4.0 Pro	JAM72D40 595/MB	n-type	182	144	TOPCon	Bifacial, Half-cell, MBB	595	23.0
9	Grand Sunergy	-	GSM-MH3/132-BHDG710	n-type	210	132	HJT	Bifacial, Half-cell, MBB	710	22.86
10	TW SOLAR	-	TWMND-72HS585-590W	n-type	182	144	TOPCon	Half-cell, MBB	590	22.8
10	SPIC	ANDROMEDA 3.0	SPICN6(LDF)-60/BIH410W	n-type	166	120	TBC	Bifacial, Back Contact, Half-cell, MBB	410	22.8
12	JinkoSolar	Tiger Neo	JKM585N-72HL4-BDV	n-type	-	144	TOPCon	Bifacial, Half-cell, MBB	585	22.65
12	SolarSpace	Lumina II	SS8-72HD-585N	n-type	182	144	TOPCon	Bifacial, Half-cell, MBB	585	22.65
14	REC Group	AlphA®Pure-RX	REC470AA Pure-RX	n-type	210	88	HJT	Bifacial, half-cell, MBB	470	22.6
15	JOLYWOOD	Niwa Pro	JW-HD108N415-440W	n-type	182	108	TOPCon	Bifacial, Half-cell, MBB	440	22.53
16	risen	Hyper-ion	RSM132-8-700BHDG	n-type	210	132	HJT	Bifacial,Half-cell, MBB	700	22.5
16	Trinasolar	Vertex N	TSM-NEG21C.20	n-type	210	132	TOPCon	Bifacial, Half-cell, MBB	700	22.5
16	DASOLAR	-	DAS-DH156NA-620-630W	n-type	182	156	TOPCon	Bifacial, Half-cell, MBB	630	22.5
16	Canadian Solar	TOPHiKu6	CS6W-570-580T	n-type	182	144	TOPCon	Half-cell, MBB	580	22.5
16	Eging PV	STAR Pro	EG-580NT72-HL/BF-DG	n-type	182	144	TOPCon	Bifacial, Half-cell, MBB	580	22.5
16	RUNERGY	-	HY-DH144N8	n-type	182	144	TOPCon	Bifacial, Half-cell, MBB	580	22.5
22	Qn-SOLAR	-	QNN182-HG-72	n-type	182	144	TOPCon	Bifacial, Half-cell, MBB	580	22.45
22	URECO	GLORY	FBF580B8D	n-type	182	144	TOPCon	Bifacial, Half-cell, MBB	580	22.45

3 x BC	24+%
HJT	23+%
TOPCon	23+%
PERC	21.5-22%

ITRPV cell technology forecast



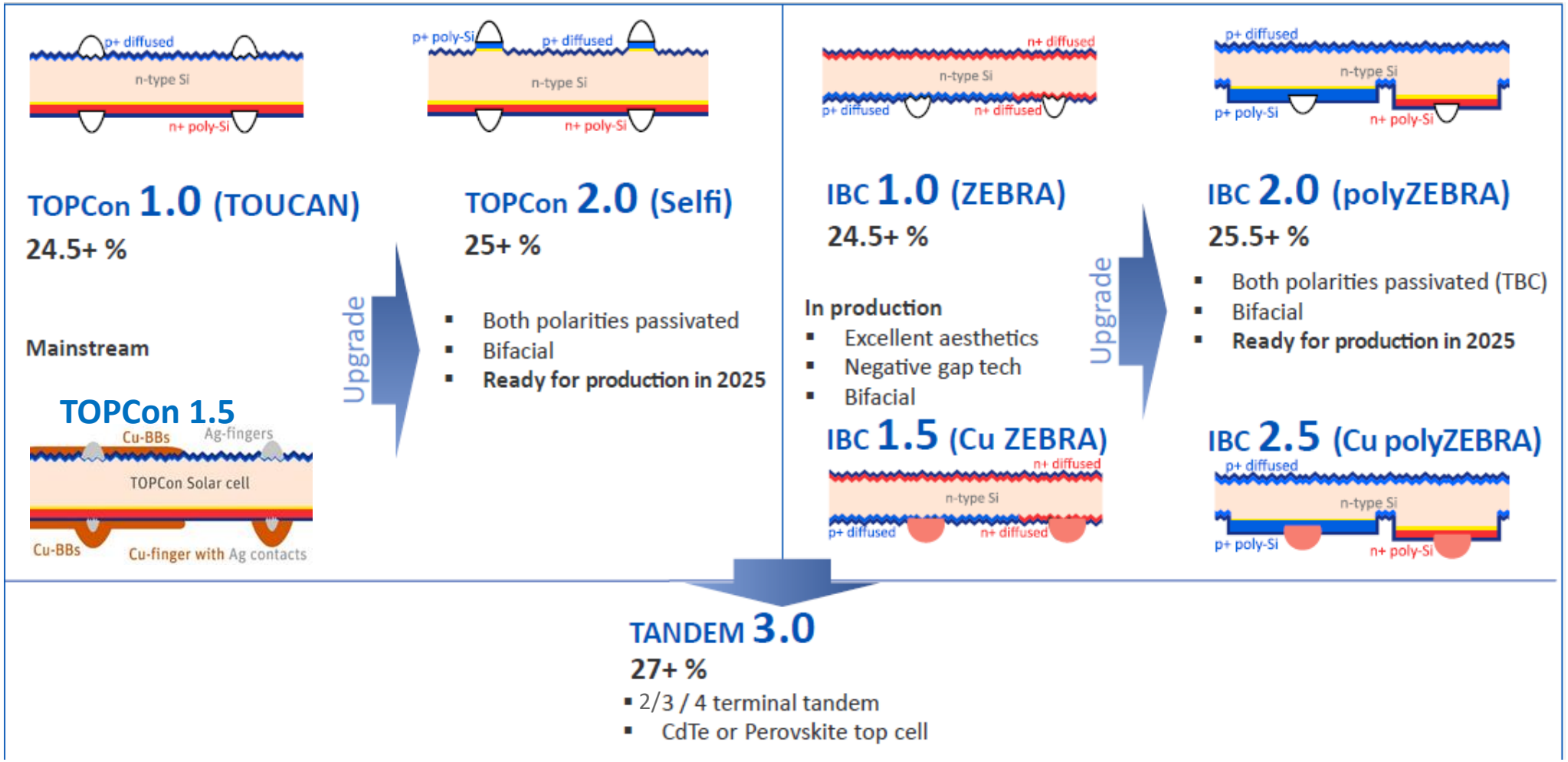
HJT + Tandem ~ 22 %

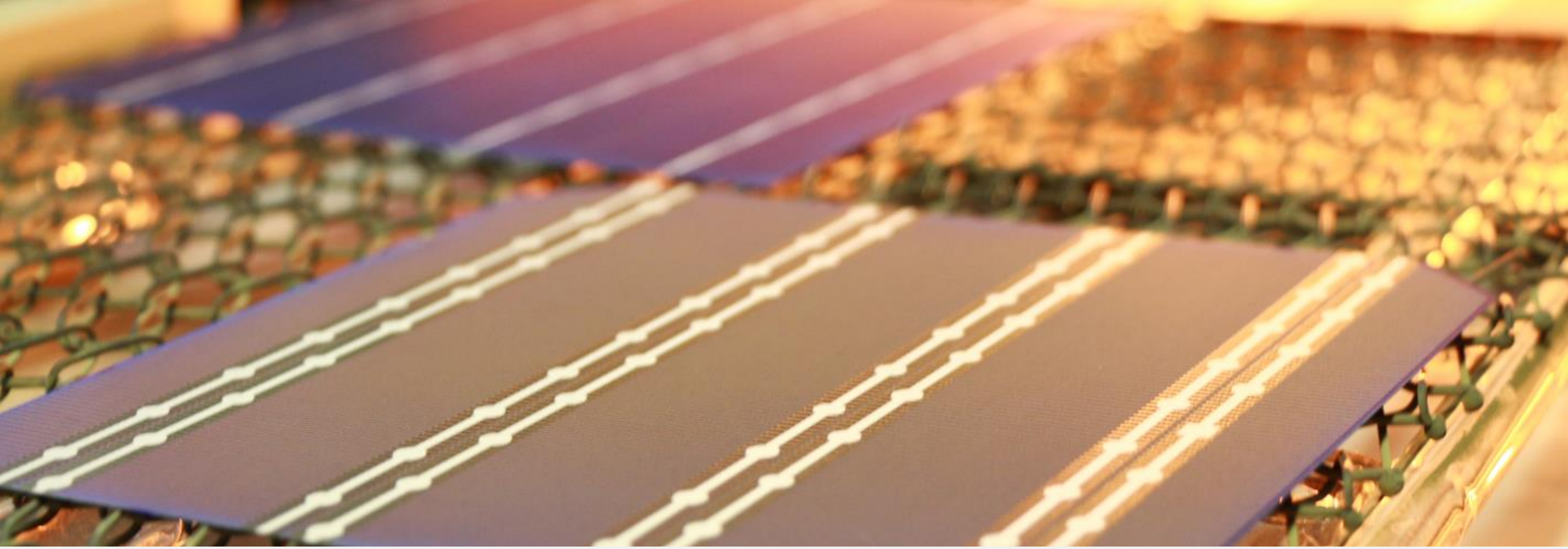
Back contact ~ 35 %

TopCon ~ 43 %

https://www.vdma.org/international-technology-roadmap-photovoltaic

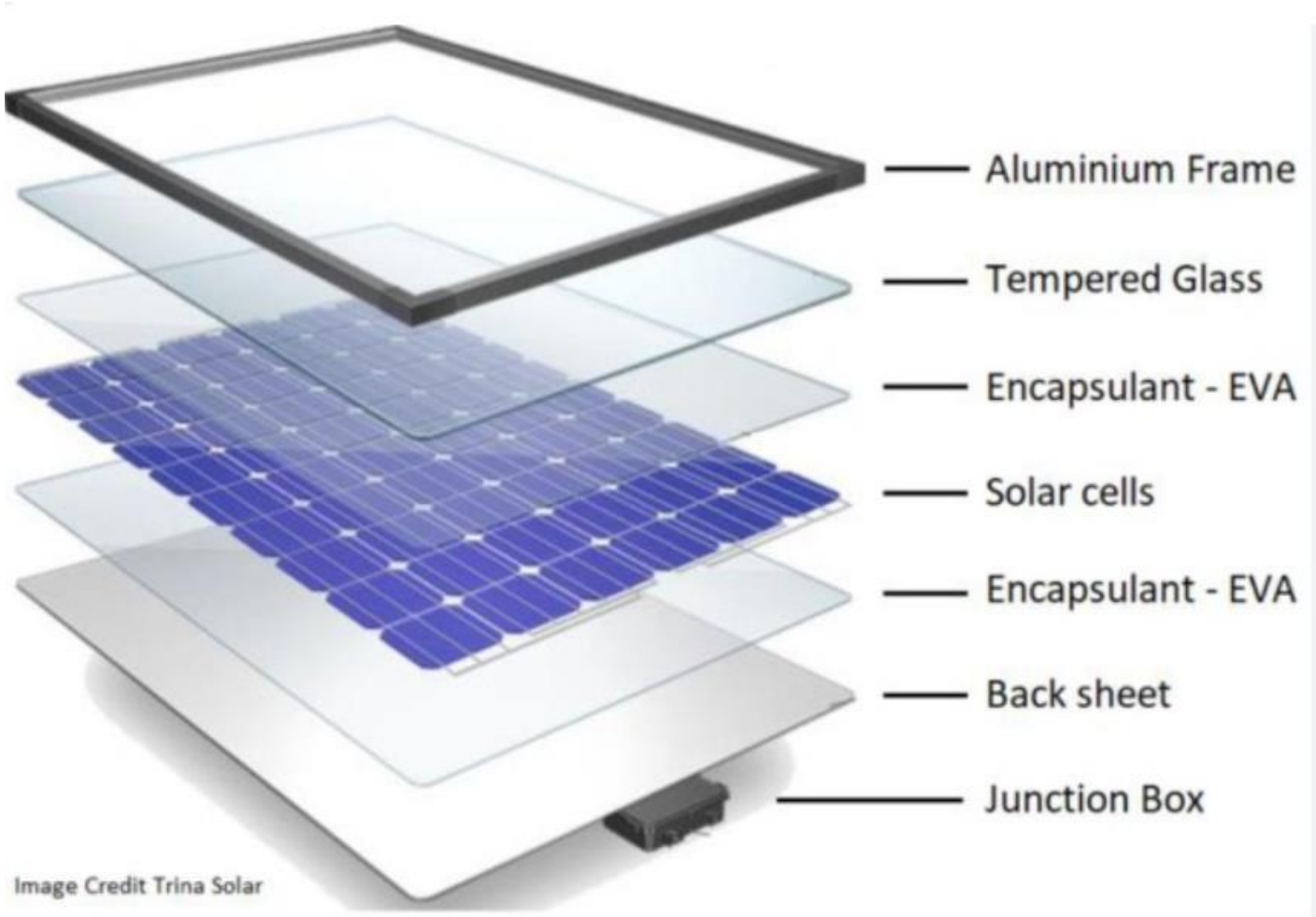
ISC Konstanz´s technology for PV production





3. Technology trends module

Quick review on module architecture



China photovoltaic industry association on wafer sizes

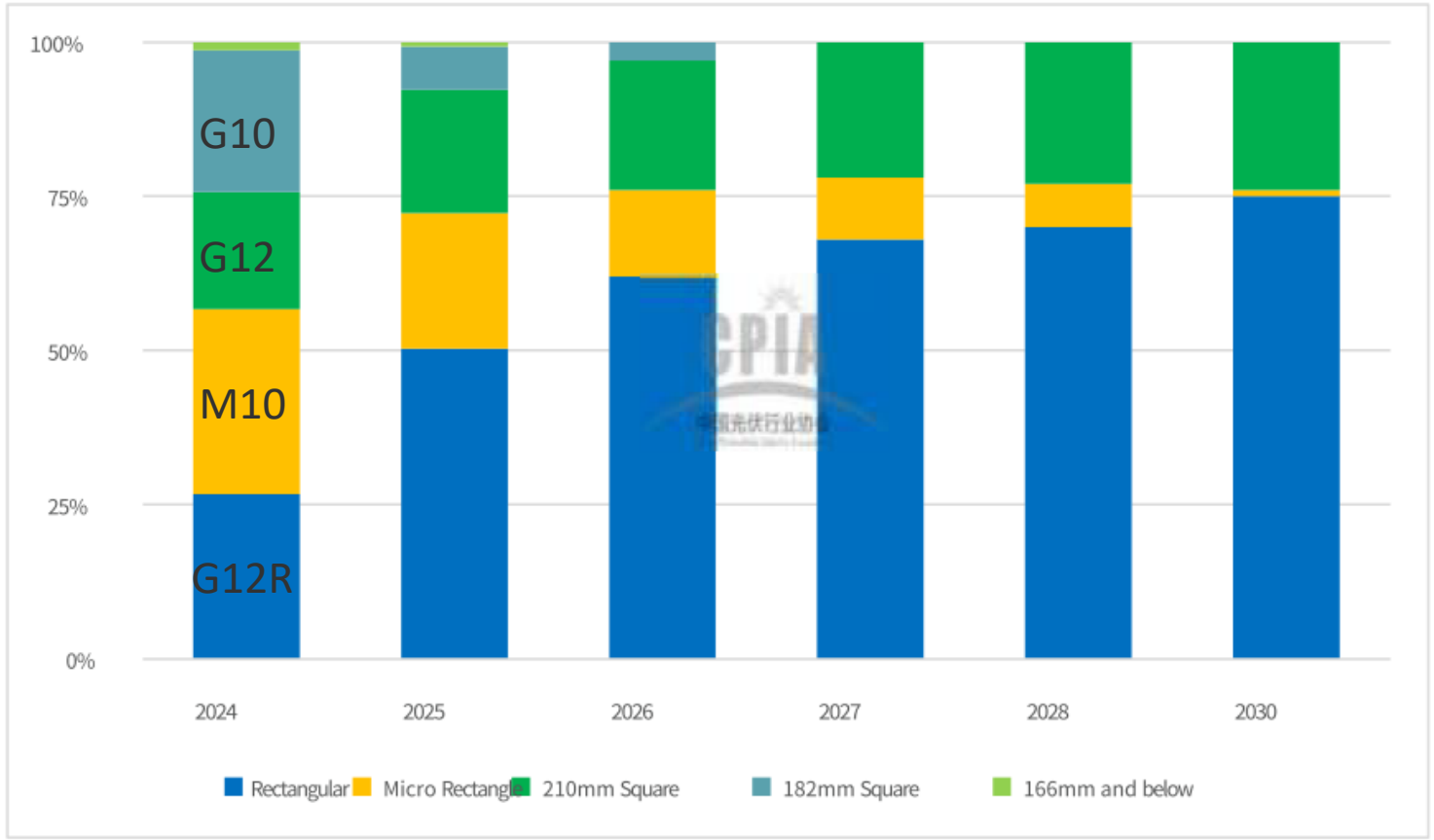


Figure 32 Trend of Wafer Market Share by Size, 2024-2030

https://english.www.gov.cn/news/202502/27/content_WS67c01568c6d0868f4e8f018b.html

G: full square

M: chamferd corner

G12R and G12 to remain

No adaption in modul sizes to be expected in near future

Current module sizes

Rectangular wafers Format		48pcs module format	54pcs module format	66pcs module format	72pcs module format	Company	Note
Margin 1	Margin 2						
182.2	182.2	-	1722*1134	-	2278*1134	-	
182.3	183.5		1722*1134	-	2278*1134	Astronergy	
182.2	183.75	-	1722*1134	-	2278*1134	LONGi, DAS Solar, Tong	
182.2	183.75	-	1722*1134	-	2278*1134	LONGi, Jinko, T	
182.2	185.3	-	1722*1134	-	2278*1134		
182.2	186.8	-	1762*1134	-	-		
182.1	187.75	-	1747*1134	-	2323*1134		
182.2	188		1762*1134		2333*1134		
182.2	191.6	-	1800*1134 (up to manufacturers)	-	2382*1134	LONGi,	
182.2	192.5	-	-	-	2382*1134		ell-count modules
182.2	199	-	1762*1134	2382*1134	2333*1134 2465*1134		-
182.2	210	1762*1134	-	2382*1134	-	Trina, Jinko ingwei, Astronergy, etc.	-

1134 mm as new std. width

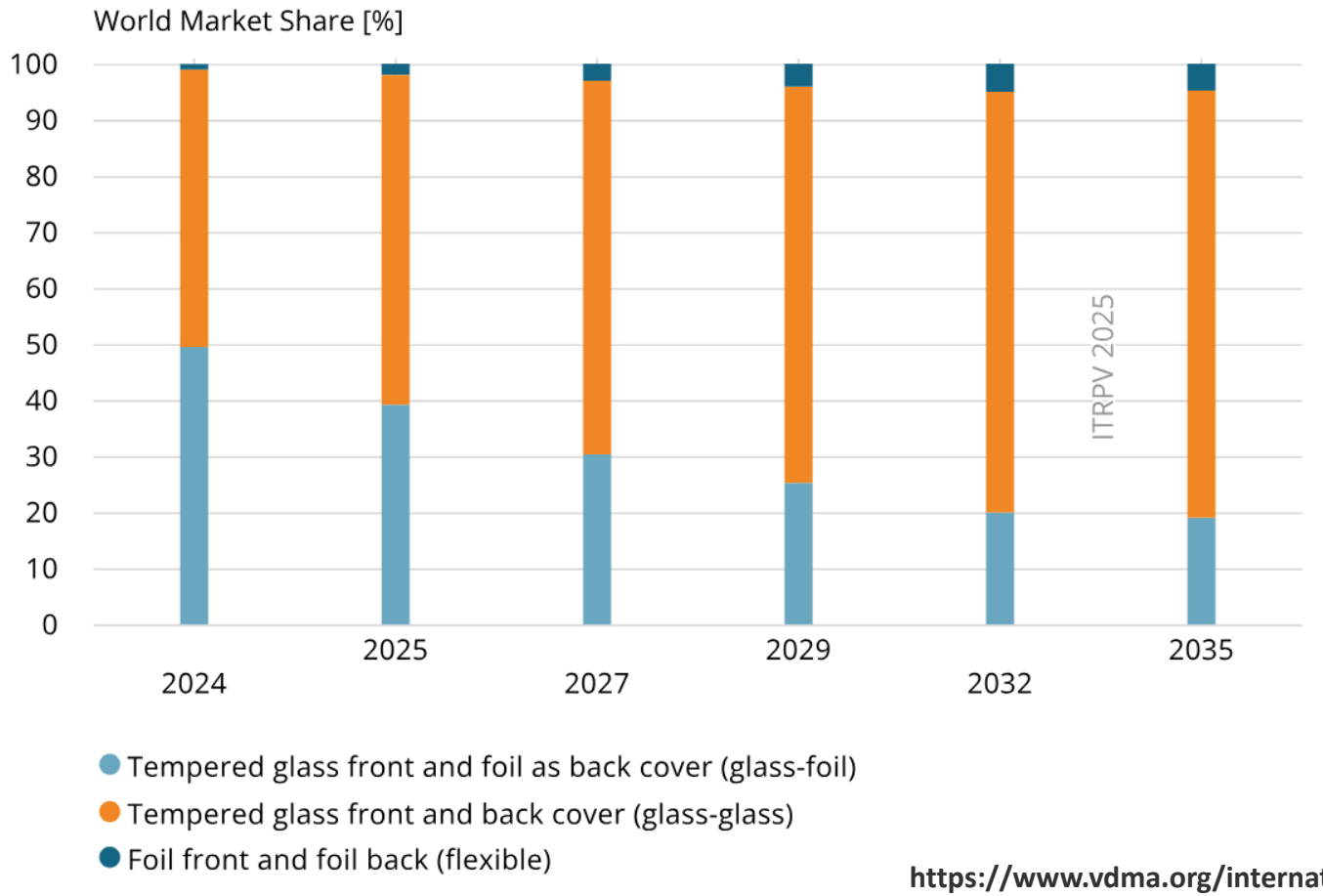
1722 mm to 2382 (2464) mm module length

-> no issue in Germany since 2m² rule is obsolete

https://www.infolink-group.com/energy-article/solar-topic-trends-prospects-for-rectangular-module

Module front and rear sheet

Market share of different front and back cover materials

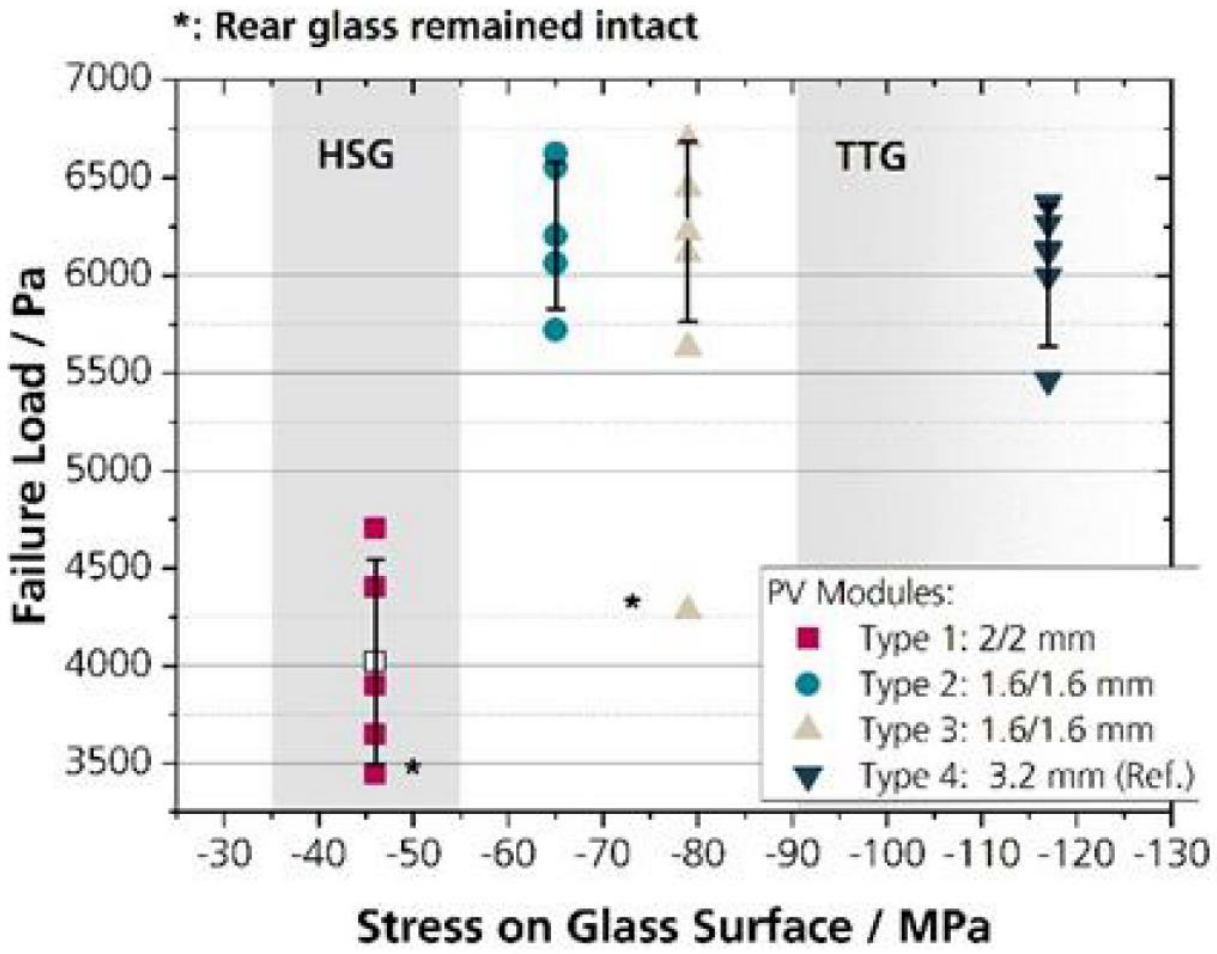


- Glass-glass configuration @ ~ 55 % market share and increasing

- Framed are standard
- Frame width reduces to 30 mm
- frameless only for special applications

https://www.vdma.org/international-technology-roadmap-photovoltaic

Module glass thickness



https://doi.org/10.52825/pv-symposium.v1i.1237

-> glass thickness is secondary

-> most relevant is the toughening process

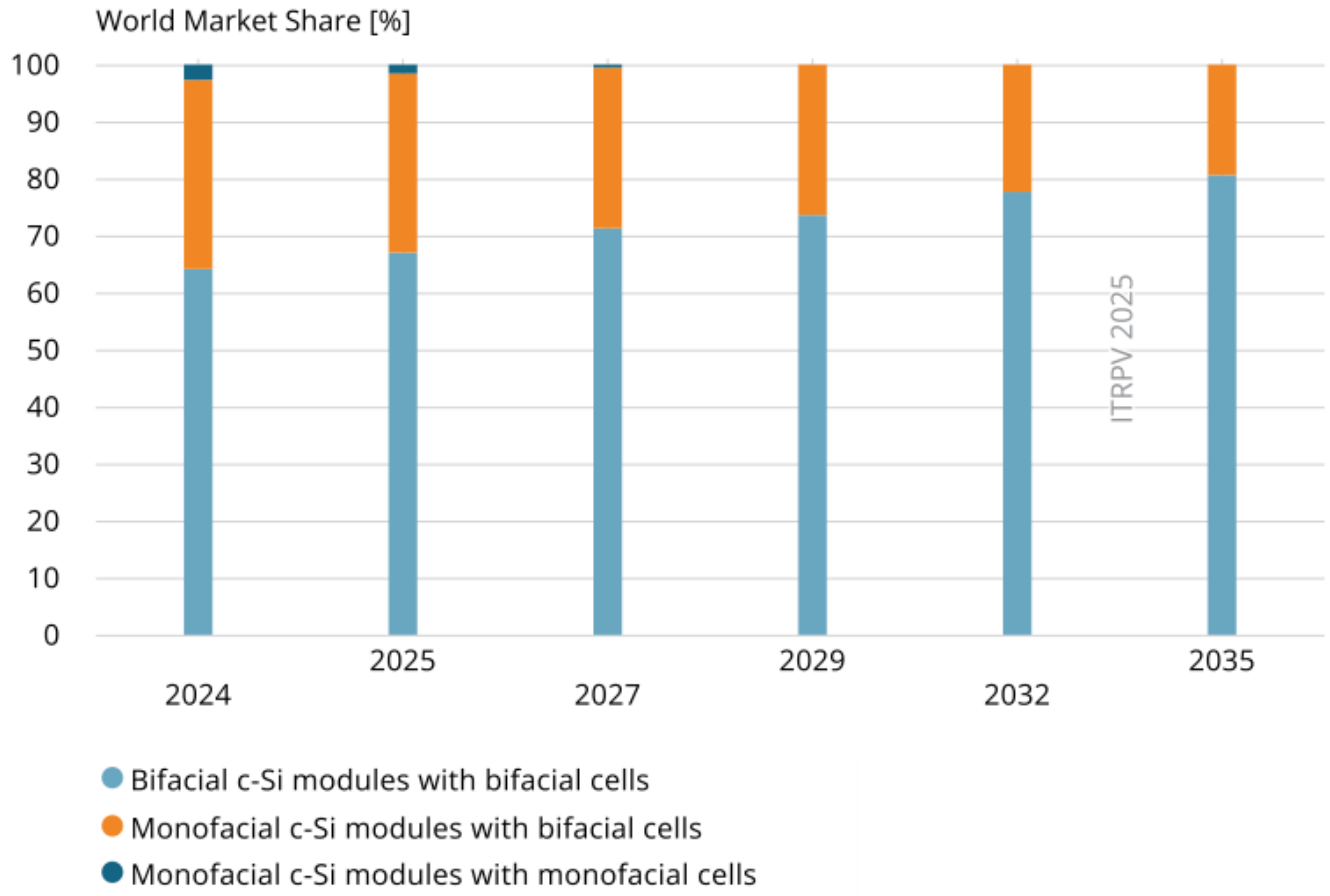
-> 2 and 2.5 mm glass for gg and 3.2 mm for glass foil modules are dominat

HSG: Heat strengthened glass

TTG: Thermally toughened safety glass

Module bifaciality

World Market Share of monofacial and bifacial modules



Bifacial module market share keeps growing

-> bifacial gain relevant in all utility scale configurations

bifiPV: bifacial applications and gains

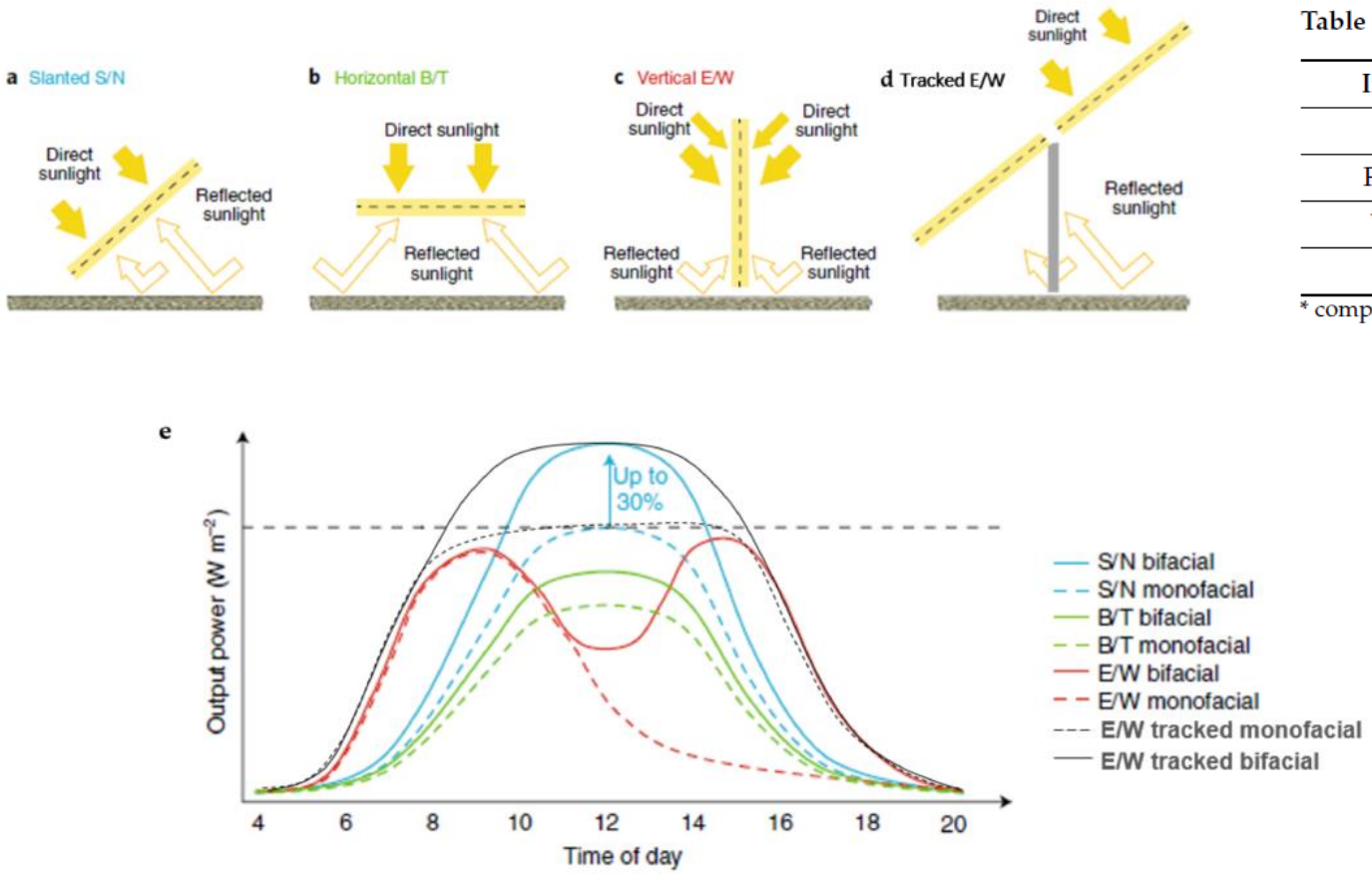


Figure 5. (a–d) possibilities for installations of bifacial modules and (e) comparison of power generation curves for monofacial and bifacial modules [16]. S/N means South/North, B/T is Bottom/Top and E/W is East/West.

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.

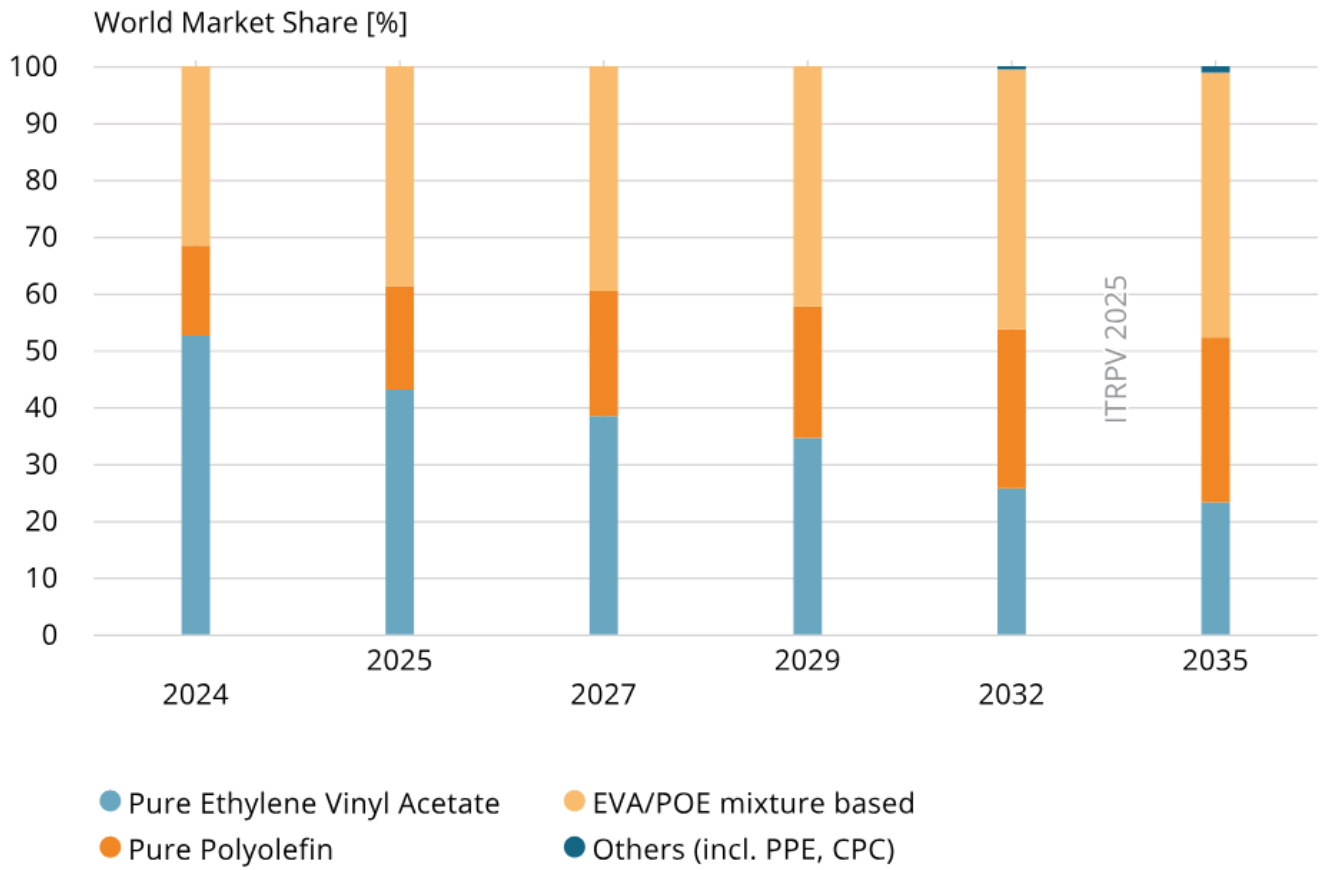
R Kopecek; J Libal, Bifacial Photovoltaics 2021: Status, Opportunities and Challenges, Energies 2021, 14, 2076. https://doi.org/10.3390/en14082076

bifacial gains of 1-30%

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

Module encapsulation

Different encapsulation material



EPE is gaining market shares due to:

- Price structure
- Properties in module

Module encapsulation: EPE

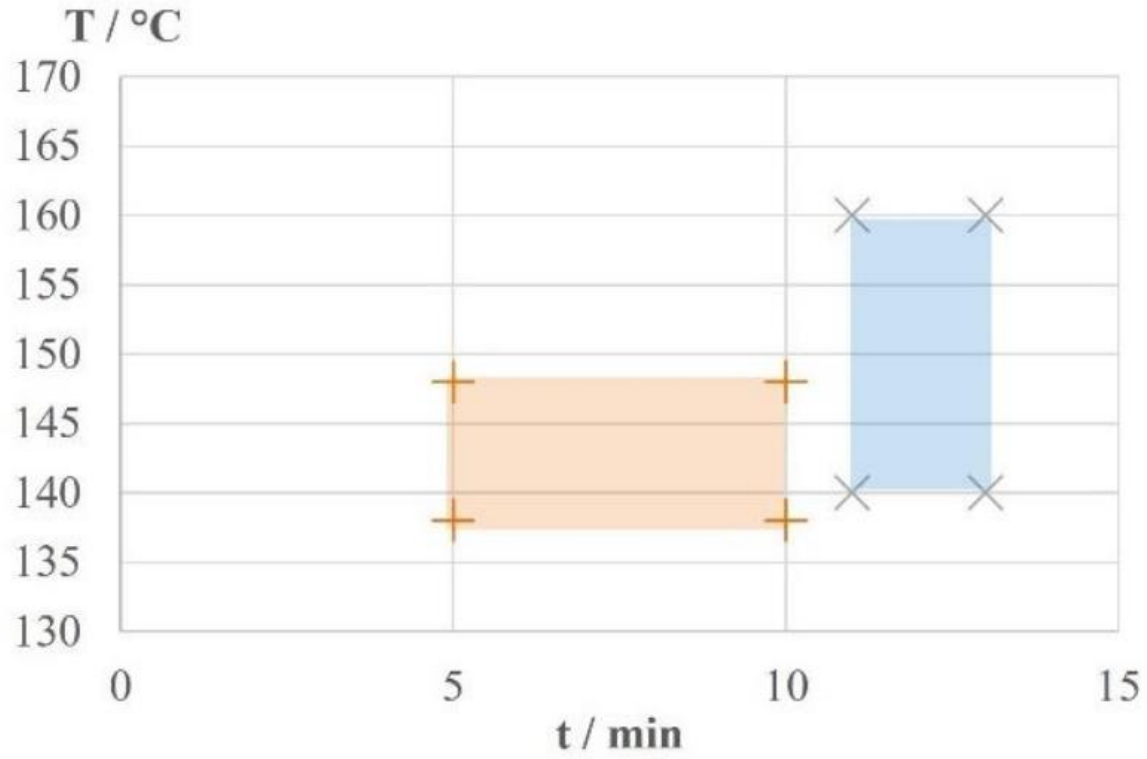


Figure 1: Lamination process windows recommended for the two encapsulant materials (front and rear) of a commercially available solar module.

- EPE is a co-extruded film of EVA and POE
- Quality control for EPE is important and still not fully solved (gel test)
- Process window smaller to fit both, EVA and POE

S. Lust et al., EUPVSEC 2023: 10.4229/EUPVSEC2023/3DO.19.3

Module interconnection: busbars

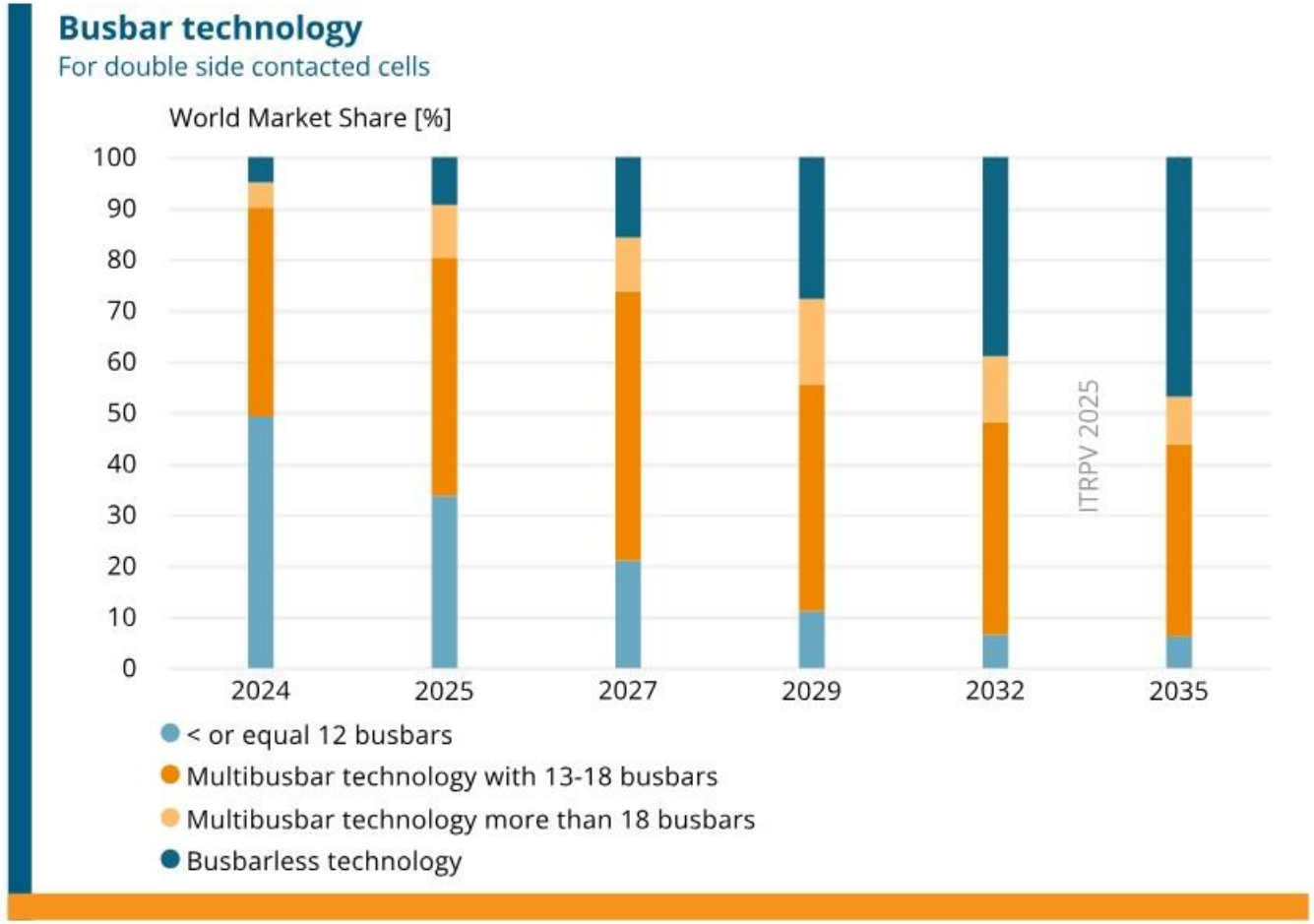
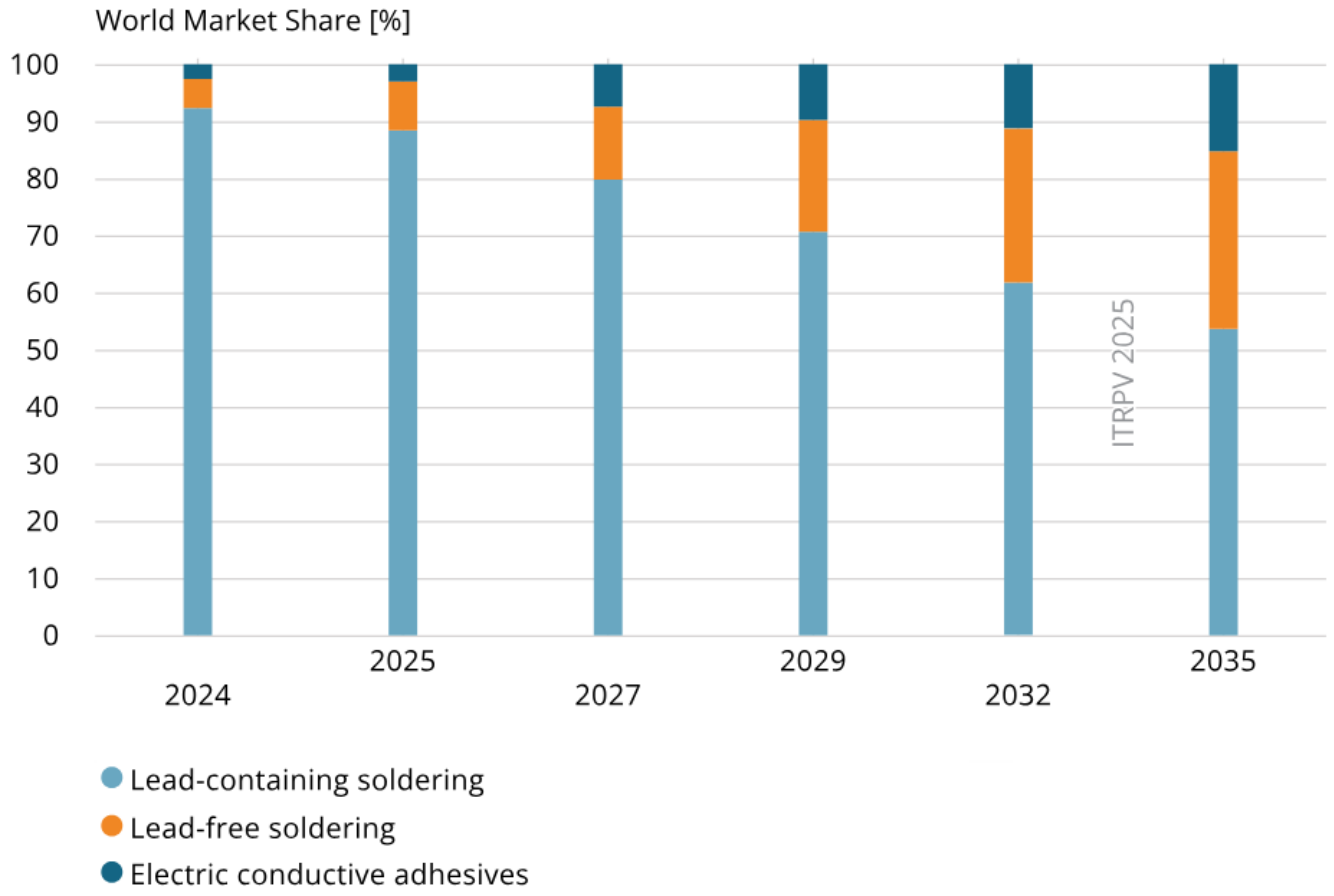


Fig. 36: Market share for different busbar technologies.

- Round wire is std. for both side contacted cells
- 0 BB tech will gain traction in future

Module interconnection: technology

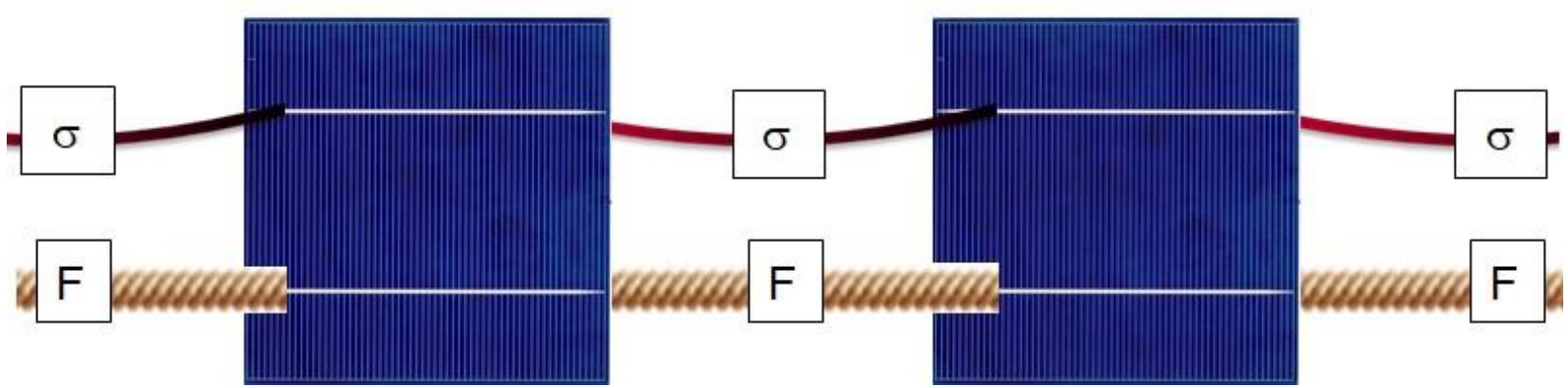
Different technologies for cell interconnection



- IR based solderin with leaded (SnPb) wire coating remains standard
- Lead free apporaches gaining market share

0 BB stringing for Zebra: Indifiduell process

Requirements for cell to cell connection

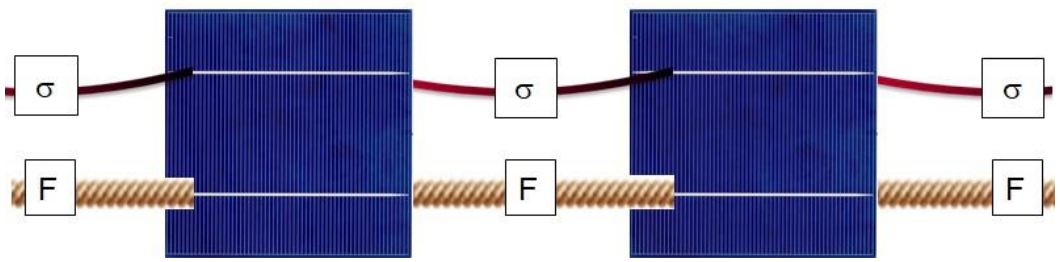


Electrical connection

Mechanical connection

0 BB stringing for Zebra: Indifiduell process

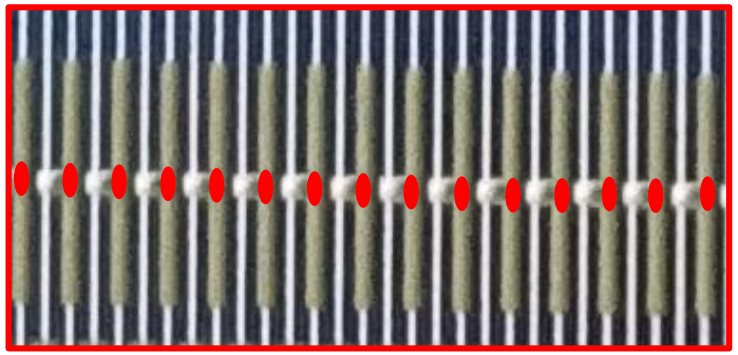
Requirements for cell to cell connection



Electrical connection

Mechanical connection

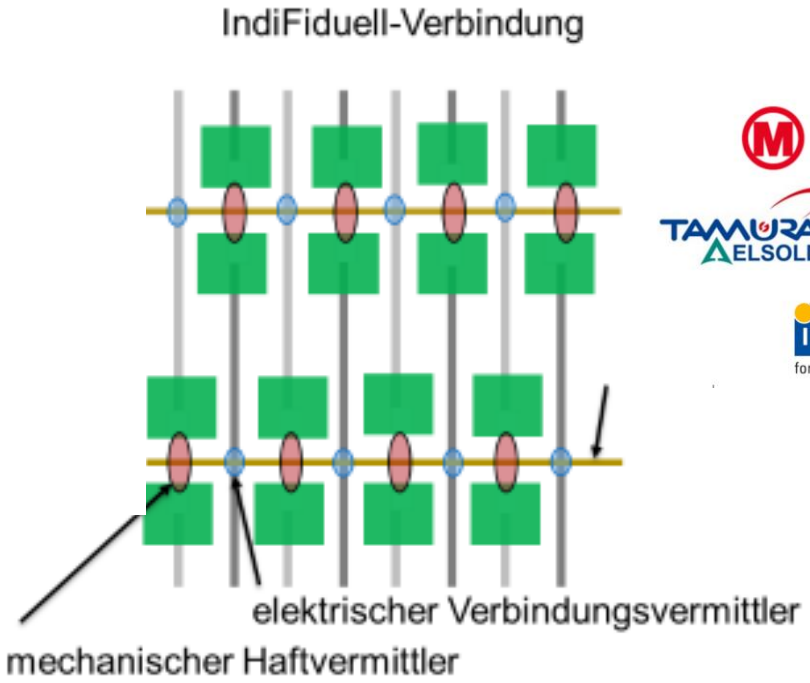
Mechanical connection supported by NCA (non conductive adhesive)

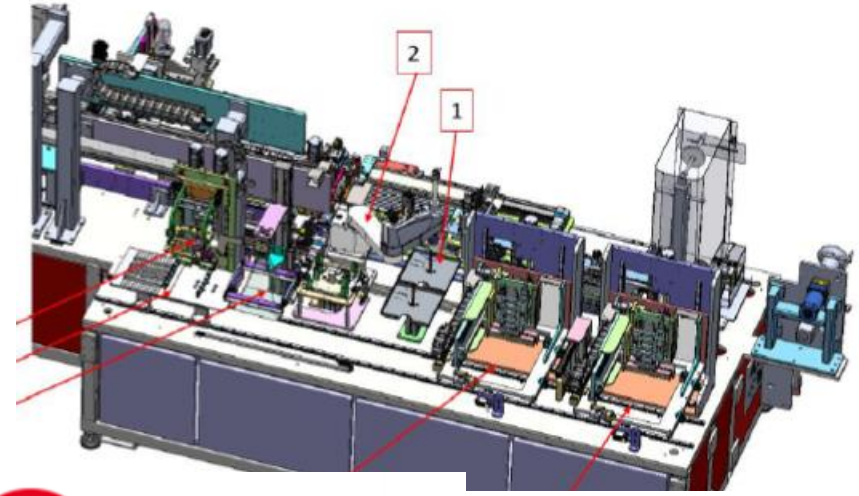


Reduced material deposition of electrical contact agent (ECA or solder paste)

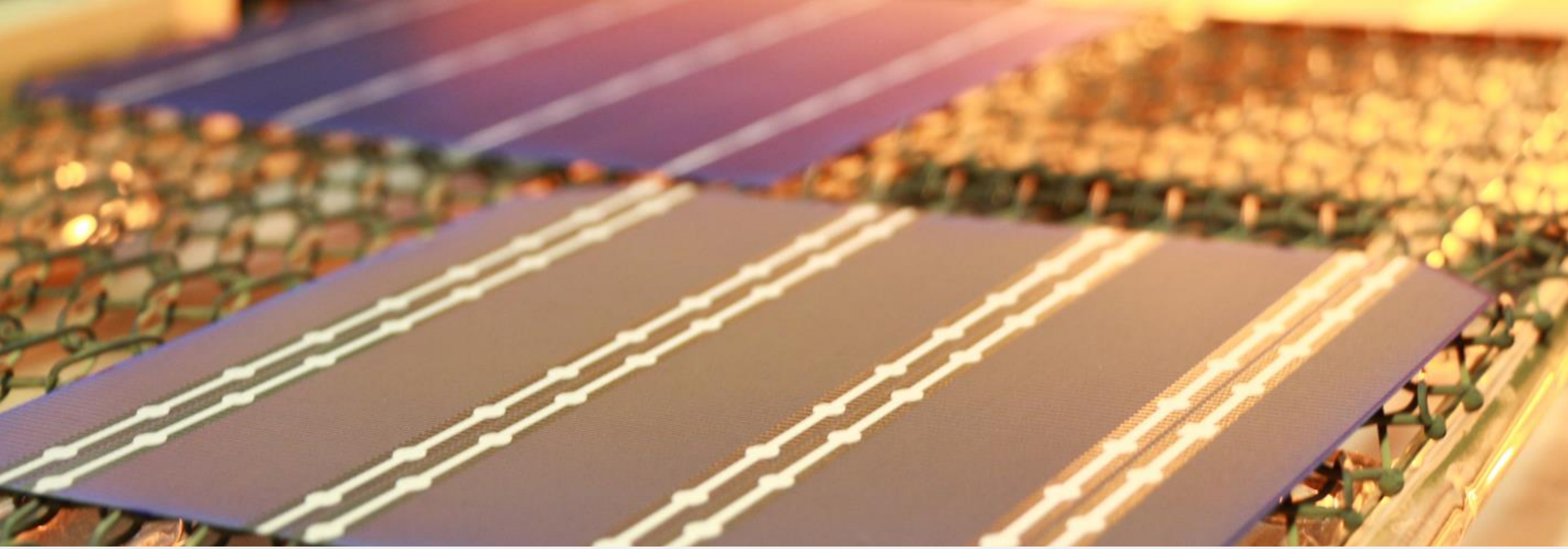
0 BB stringing for Zebra: Indifiduell project

0 busbar interconnection with ECA/NCA or solder paste/NCA for classic





New flexible stringer tool specified and ordered !
IR soldering and deposition of 2 media possible !



4. Summary

Summary: 3 takeaways

1) Module technology develops evolutionary.

> sizes, materials and technology are further developed, no disruptive changes

> For all technologies, reliable products can be found

2) Bifacial nPV is the new emperor.

> TOPCon and HJT are used for utility scale. Quality is good when the process is under control.

3) BC is at the moment entering utility scale as well.

> Bifacial BC will dominate the market form 2027/2028. Bifaciality will reach 80%.

ISC research
for a sunny future

Thank You for Your kind attention