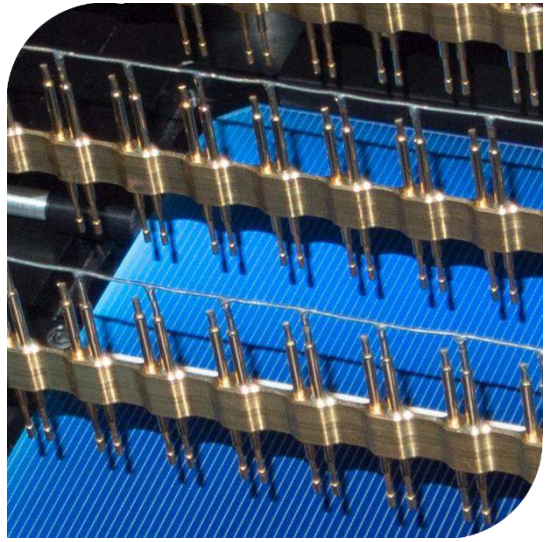



IBC Technology Targeting Fast and Effective Silver Reduction Applying Advanced Screen Printing

Radovan Kopecek[1], Florian Buchholz[1], Valentin D. Mihailetchi[1], Joris Libal[1], Ning Chen[1], Haifeng Chu1, Christoph Peter[1], Dominik Rudolph[1], Thomas Buck[1], Tudor Timofte[1], Andreas Halm[1], Yonggang Guo[2], Xiaoyong Qu[2], Xiang Wu[2], Jiaqing Gao[2], Peng Dong[2]

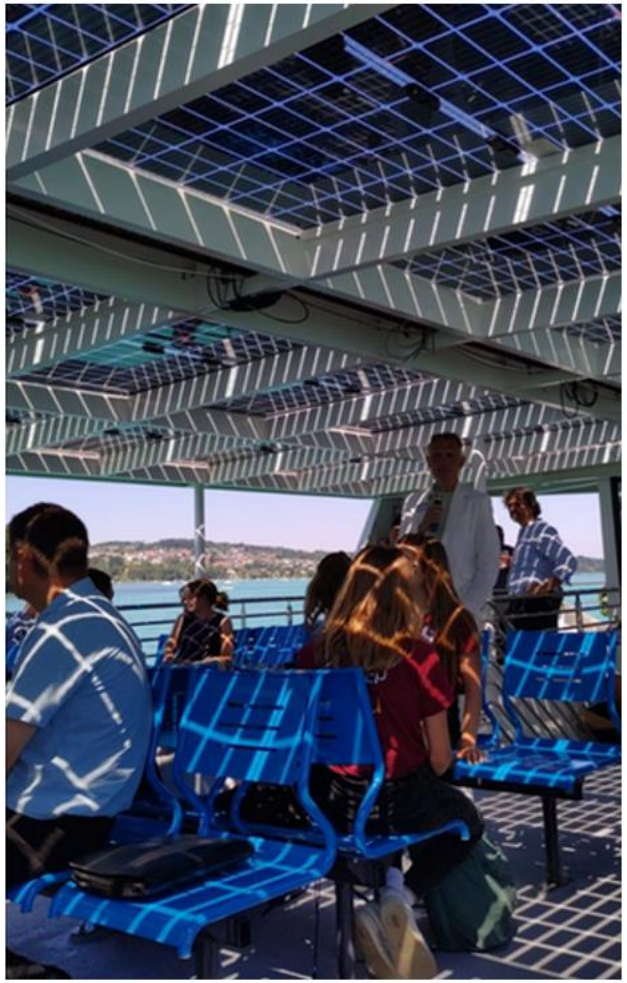
ISC research for a sunny future

[1]International Solar Energy Research Center Konstanz, Konstanz, Germany.

[2]SPIC Solar, Xining, China

SPIC

What is the presentation about? Beauty with high efficiency **at low cost**.










- VIPV
- BIPV
- Balcony
- Roof
- Utility

Agenda

1. ISC Konstanz/SPIC Solar / 2 min
2. Entering the bifacial nPV era / 4min
3. **ZEBRA IBC tech and beyond / 8min**
4. Summary/ 1 min

Employees at ISC Konstanz	Turnover 2022	Educated scientists	Achieved solar cell efficiency*
65	5.8 Mio €	75+	24.6%

*in industrial manufacturing

ISC Konstanz: who we are

- **International Solar Energy Research Center e.V.**
- a nonprofit organization
- Founded in 2005
- R&D on c-Si solar cells, modules and systems
- **Technology transfer: TOPCon (TOUCAN)/IBC (ZEBRA)**

- Track record: 8 transfers from 2015
- 10 transfers planned for 2023-2026
- India, Africa, US now- EU from 2025

SPIC Solar: world´s larges PV system owner

85GW Thermal Power

24GW Hydropower

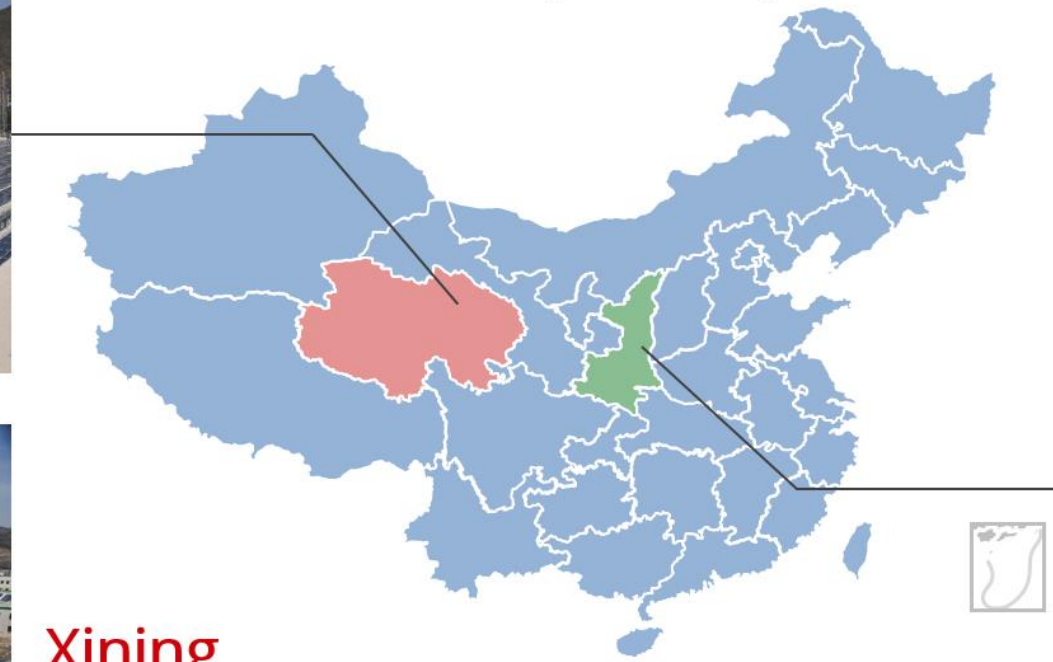
35GW Solar Power Rank 1st

8GW Nuclear Power

35GW Wind Power

SPIC Solar: producer of 3 major technologies

SPIC Solar develops and produces 3 major PV technologies



Xining

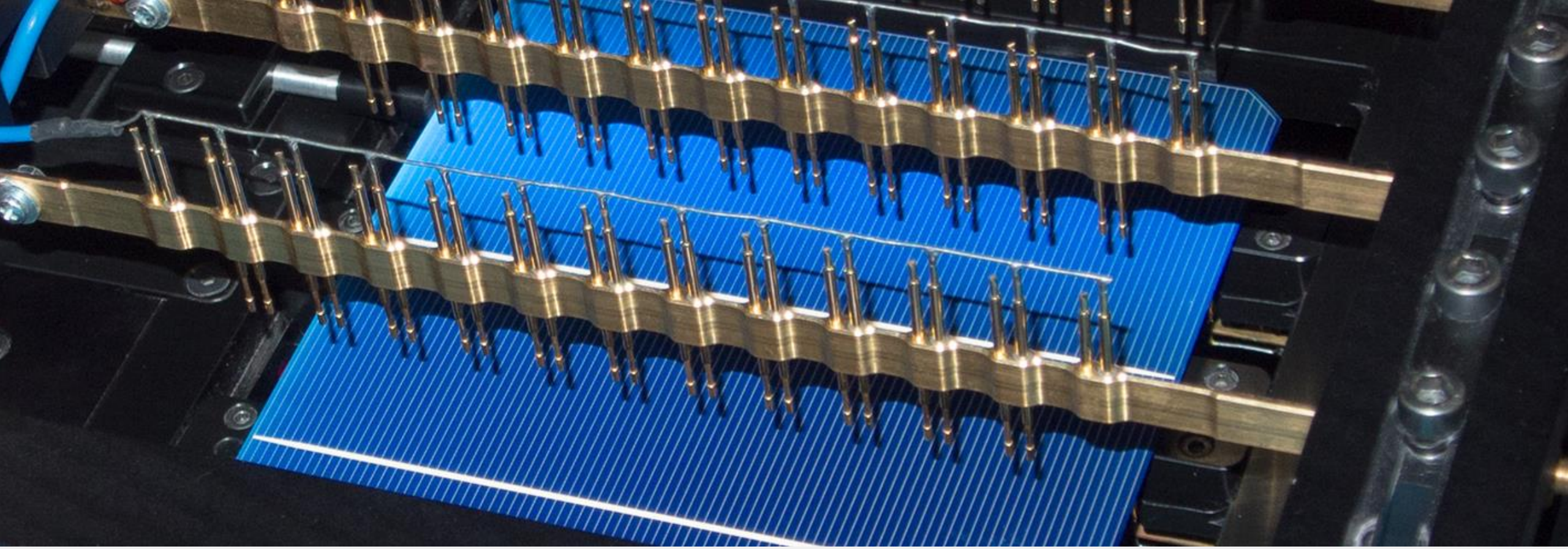
500MW **p-PERC** cell

200MW **n-IBC** cell & module

Xi'an

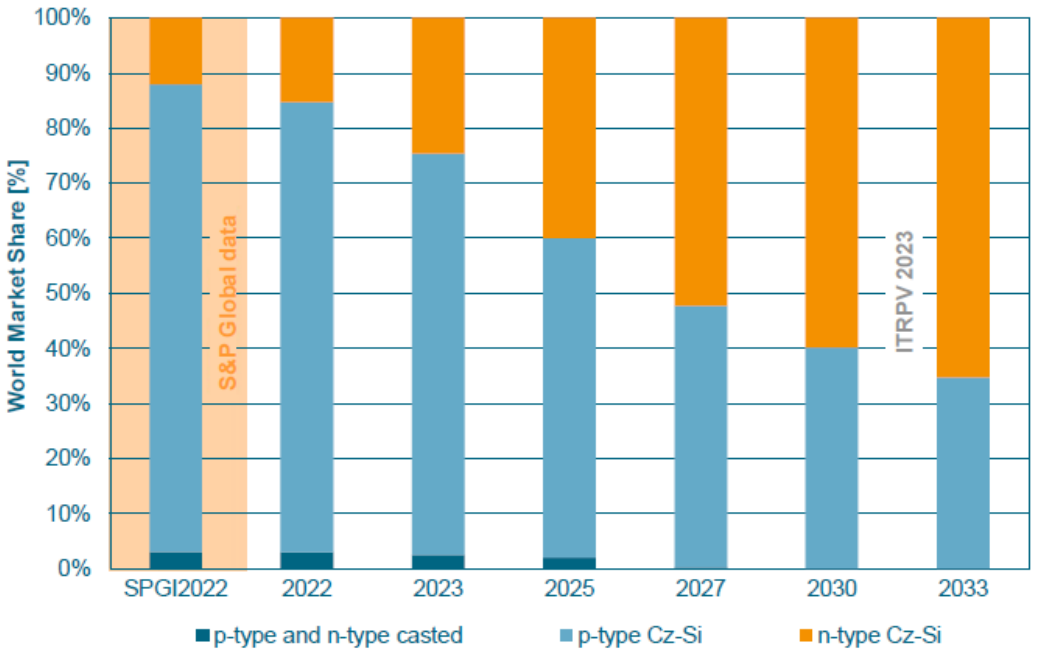
400MW **n-TOPCon** cell

SPIC at Intersolar Munich 2022 and 2023

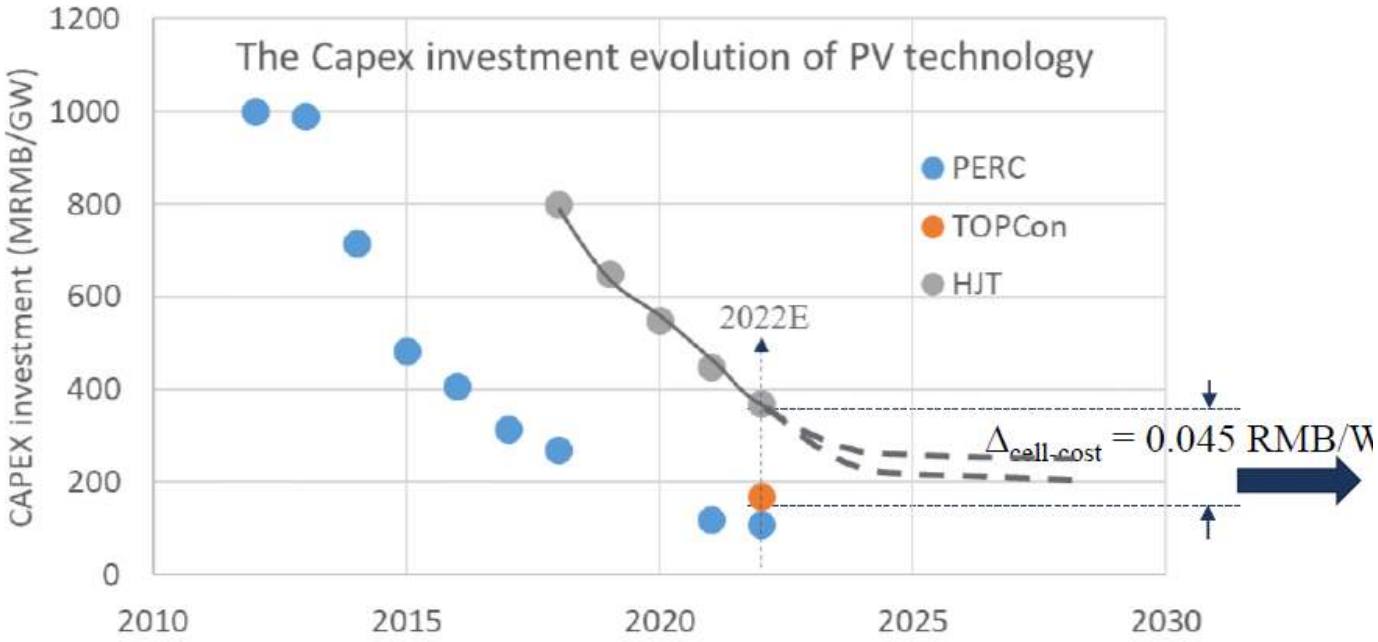


2. Entering the bifacial nPV era

nPV technology and CAPEX: market forecast



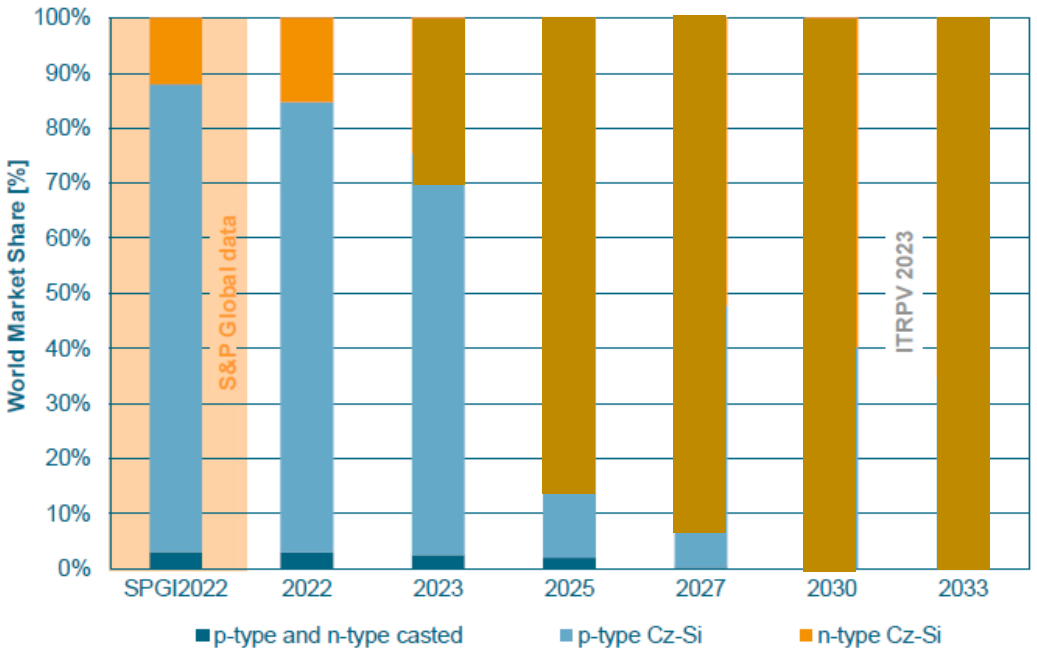
ITRPV 2023



3 years-50% law [1]:
The CAPEX/manufacturing cost (throughput related) of by 50% every 3 years (by 75% every 6 years).

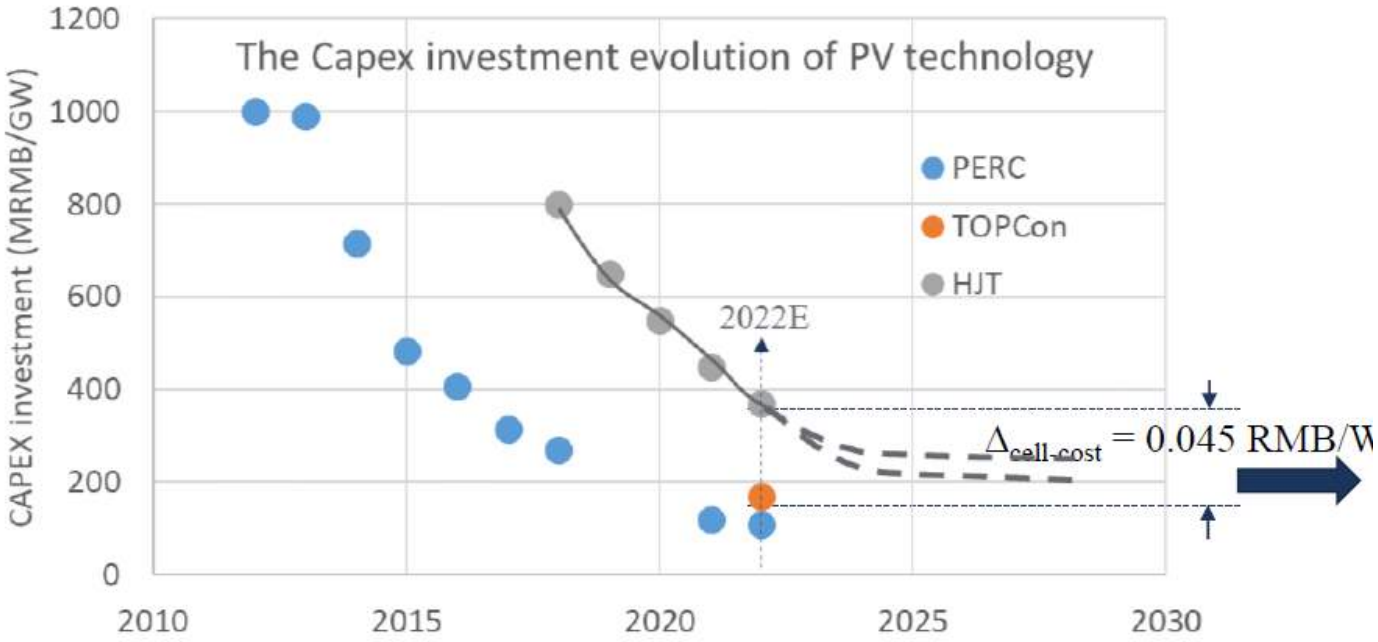
Trina nPV workshop 2023

nPV technology and CAPEX: market forecast



ITRPV 2023

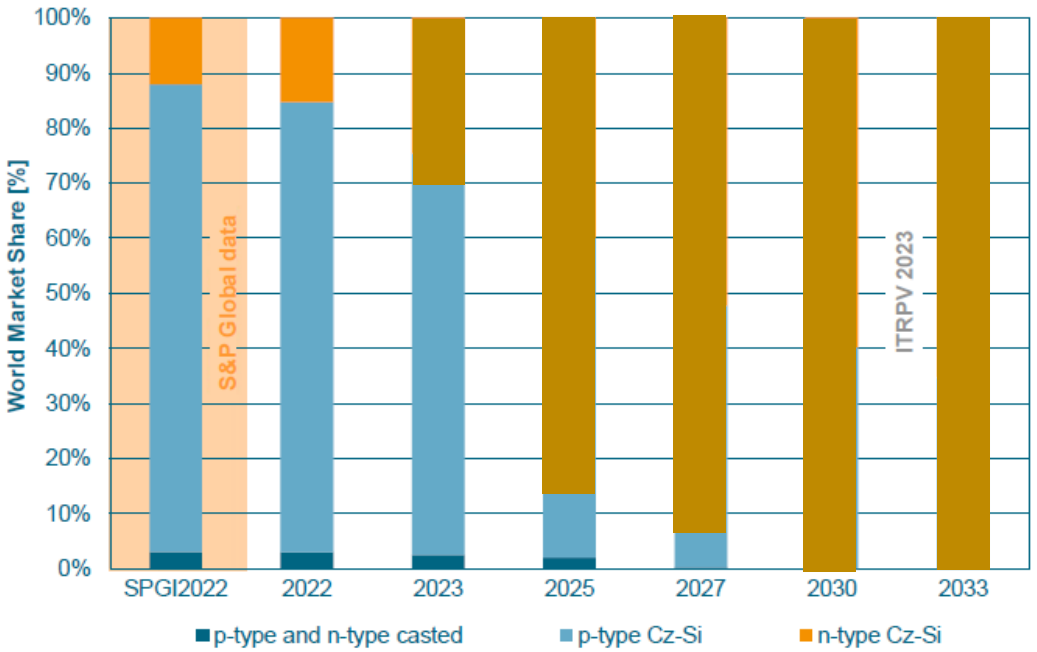
PV Infolink



3 years-50% law [1]:
The CAPEX/manufacturing cost (throughput related) of by 50% every 3 years (by 75% every 6 years).

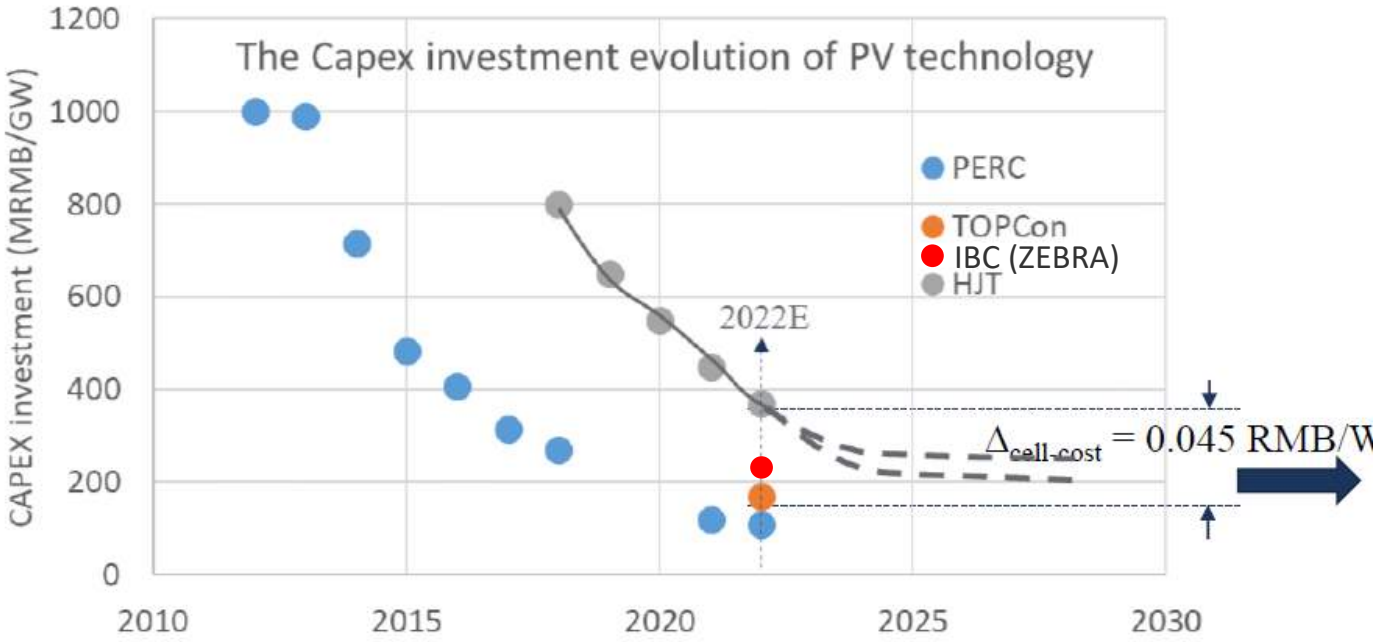
Trina nPV workshop 2023

nPV technology and CAPEX: market forecast



ITRPV 2023

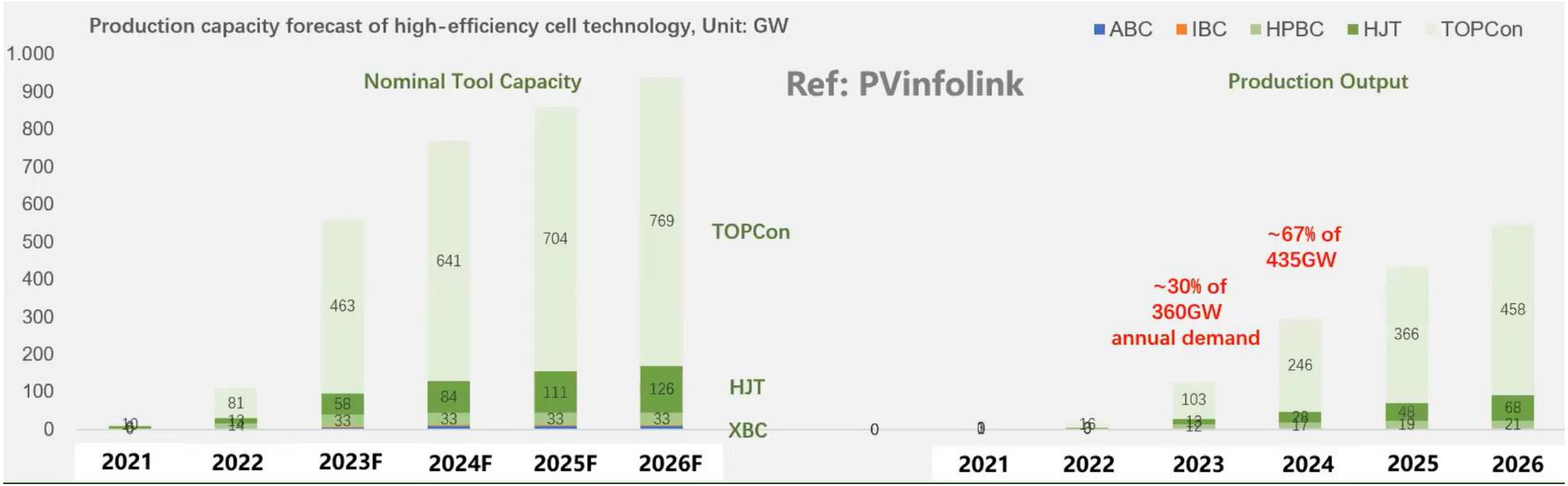
PV Infolink



3 years-50% law [1]:
The CAPEX/manufacturing cost (throughput related) of by 50% every 3 years (by 75% every 6 years).

Trina nPV workshop 2023
and IBC added by R. Kopecek in this presentation

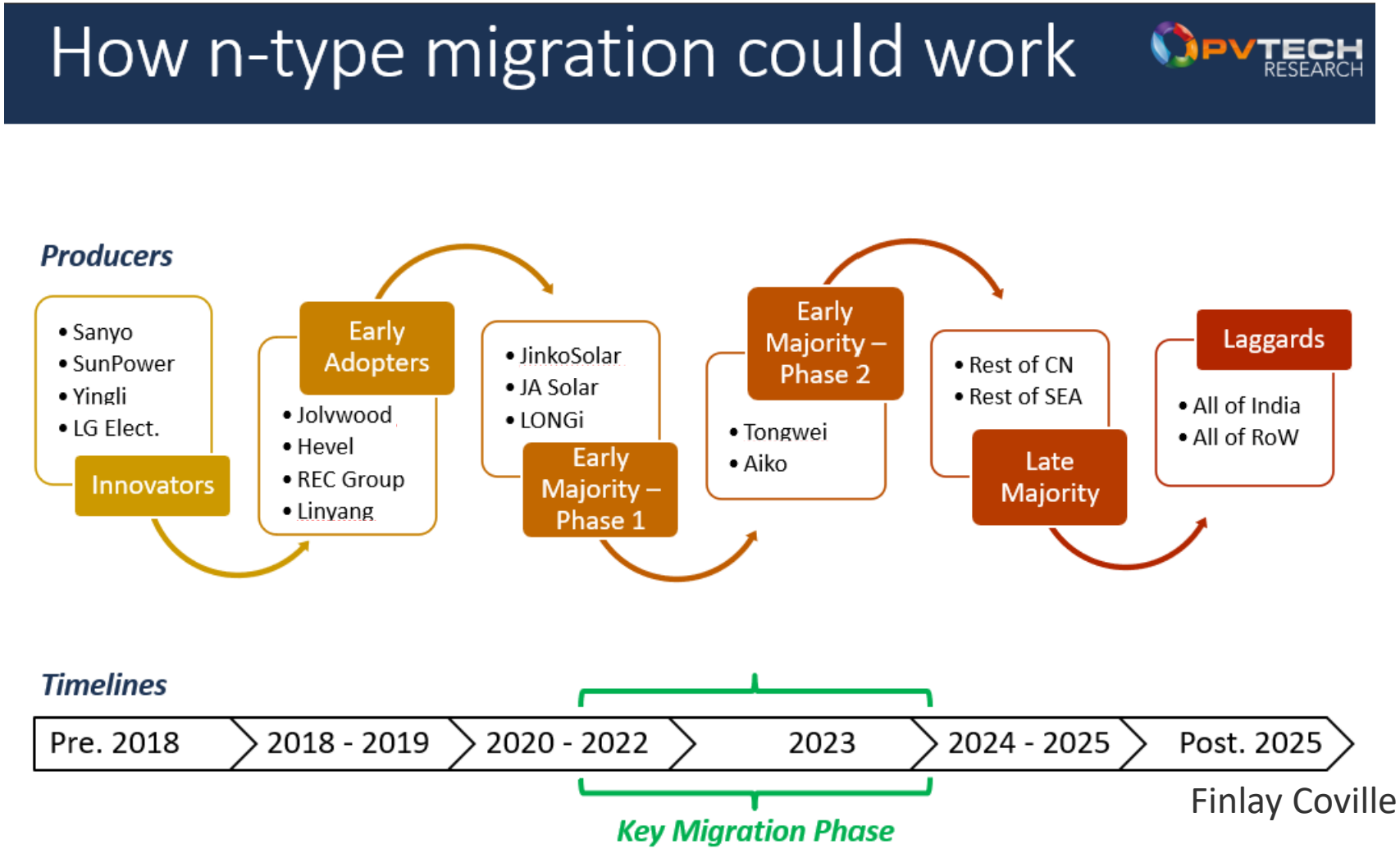
nPV technology: market forecast



AstroEnergy´s presentation

TOPCon modules at SNEC offered at 17USct/Wp

PVTECH Research

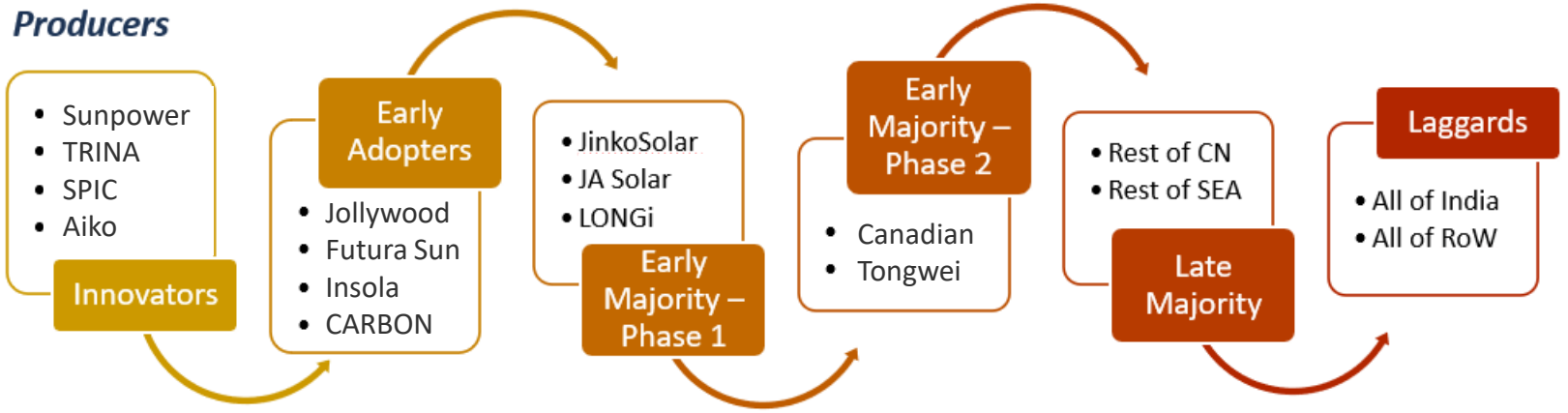


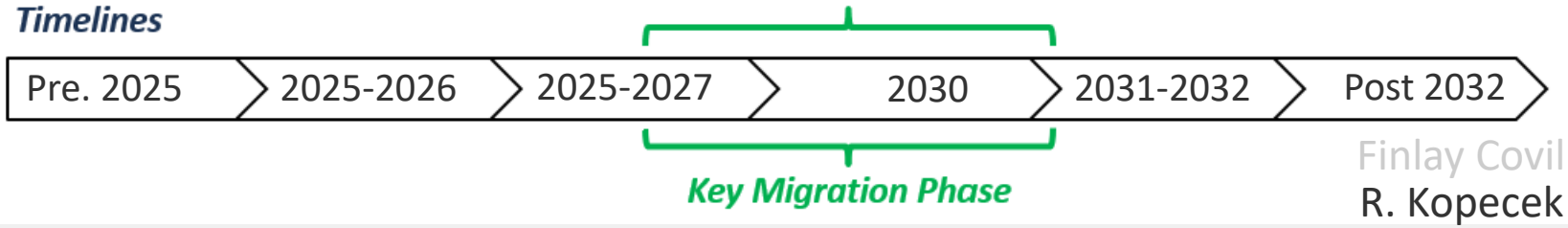
Finlay Coville (PV Cell Tech 2023)

ISC Konstanz Research

How TBC migration could work

isc research for a sunny future





Finlay Coville (PV Cell Tech 2023)

R. Kopecek (this presentation)

Highest efficiency modules March 2023

TAIYANGNEWS ALL ABOUT SOLAR POWER

TaiyangNews Solar Facts: Highest Efficient Commercial Solar Modules 03-2023

Rank	Company	Series	Model	Wafer type	Cell Size	Cells No.	Cell Tech	Module Technology	Power (W)	Efficiency (%)
1	Aikosolar	ABC White hole	AIKO-A610-MAH72Mw	n-type	182	144	ABC	Halfcell, Back Contact	610	23.6
2	LONGi	Hi-MO 6	LR5-72HTH-590M	-	182	144	HPBC	Halfcell, Backcontact	590	22.8
2	Maxeon	Maxeon 6	SPR-MAX6-440-E3-AC	n-type	-	66	IBC	Halfcell, Back Contact	440	22.8
4	JinKO Solar	Tiger Neo	JKM585N-72HL4-V	n-type	-	144	TOPCon	Halfcell, MBB	585	22.65
5	HUASUN	Himalaya	HS-210-B132	n-type	210	132	HJT	Bifacial, Halfcell, MBB	700	22.53
5	中来股份 JOLYWOOD	Niwa Light	JW-HT108N	n-type	182	108	TOPCon	Halfcell, MBB	440	22.53
7	Canadian Solar	HiHero	CS6R-440H-AG	n-type	182	108	HJT	Halfcell, MBB	440	22.5
8	ASTRONERGY	Astro N5	CHSM78N(DG)/F-BH	n-type	182	156	TOPCon	Bifacial, halfcell, MBB	625	22.4
8	JA SOLAR	DeepBlue 4.0	JAM78D40 600-625/GB	n-type	182	156	TOPCon	Bifacial, Halfcell, MBB	625	22.4
8	TW Solar	-	TH405-430TMBG 54ZDDF	n-type	-	108 (2x54)	TOPCon	Bifacial, Shingle	430	22.4
11	Canadian Solar	TOPBiHiKu6	CS6W-575TB-AG	n-type	182	144	TOPCon	Bifacial, Halfcell, MBB	575	22.3
11	SPIC	ANDROMEDA 2.0	SPICN6(LAR)-66/IH	n-type	166	132	IBC	Halfcell, MBB	440	22.3
11	REC	Alpha Pure-R	RECxxxAA Pure-R	n-type	210	80	HJT	Halfcell, SWCT	430	22.3
14	Akcome	Ak iPower	SKA611HDGDC	n-type	210	132	HJT	Bifacial, halfcell, MBB	690	22.22
15	DASOLAR	DAON	DAS-DH144NA	n-type	182	144	TOPCon	Bifacial, halfcell, MBB	570	22.1
16	Eging PV	Aurora Pro	EG-685NT66-HU/BF-DG	n-type	210	132	TOPCon	Bifacial, halfcell, MBB	685	22.05
17	Qcells	Q.TRON	Q.TRON BLK-G1+	n-type	-	120	TOPCon	Halfcell, MBB, Zero Gap	395	22
18	Trinasolar	Vertex S+	TSM-NEG9.28	n-type	210	120	TOPCon	Halfcell, MBB	425	21.9
19	Meyer Burger	Meyer Burger Glass	Heterojunction Bifacial	n-type	-	120	HJT	Bifacial, halfcell, SWCT	390	21.8
20	Canadian Solar	HiKu7	CS7N-645-675MS	p-type	210	132	PERC	Halfcell, MBB	675	21.7
20	LONGi	Hi-MO 5m	LR5-72HPH 540 - 560M	p-type	182	144	PERC	Halfcell, MBB	560	21.7
20	risen	TITAN	RSM130-8-450M	p-type	210	130*	PERC	1/3 cells, MBB	450	21.7
20	TW Solar	-	TH400-430PMB7 44SCS	p-type	-	305 (61x5)	PERC	Shingle	430	21.7

4 x IBC

10 x TOPCon

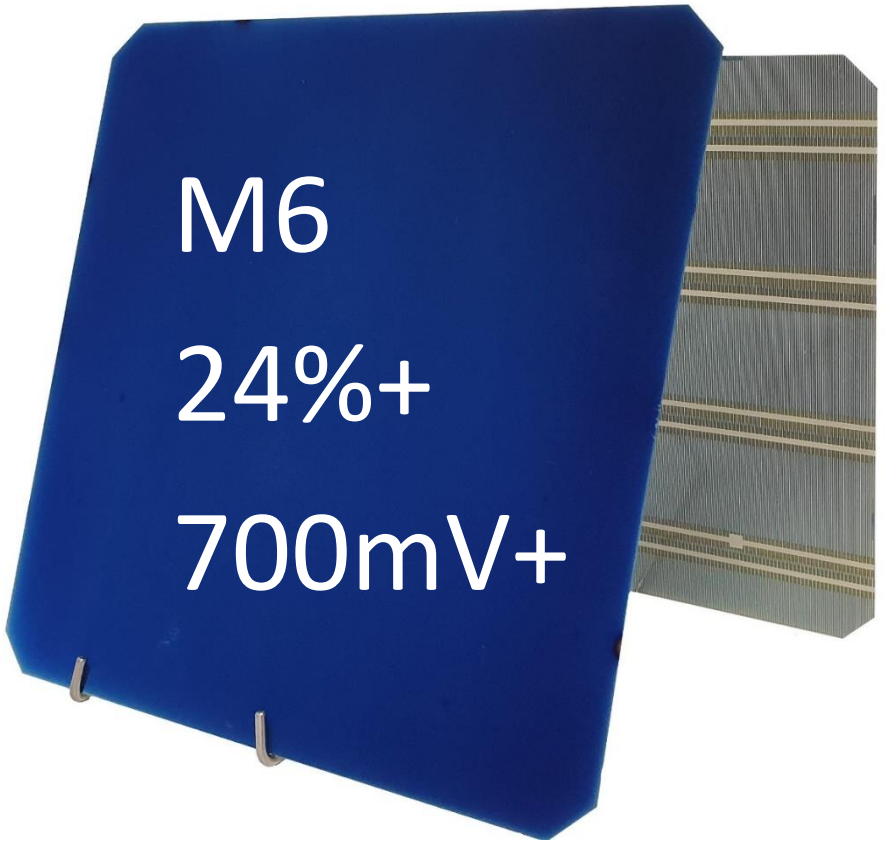
5 x HJT

3. ZEBRA technology and beyond

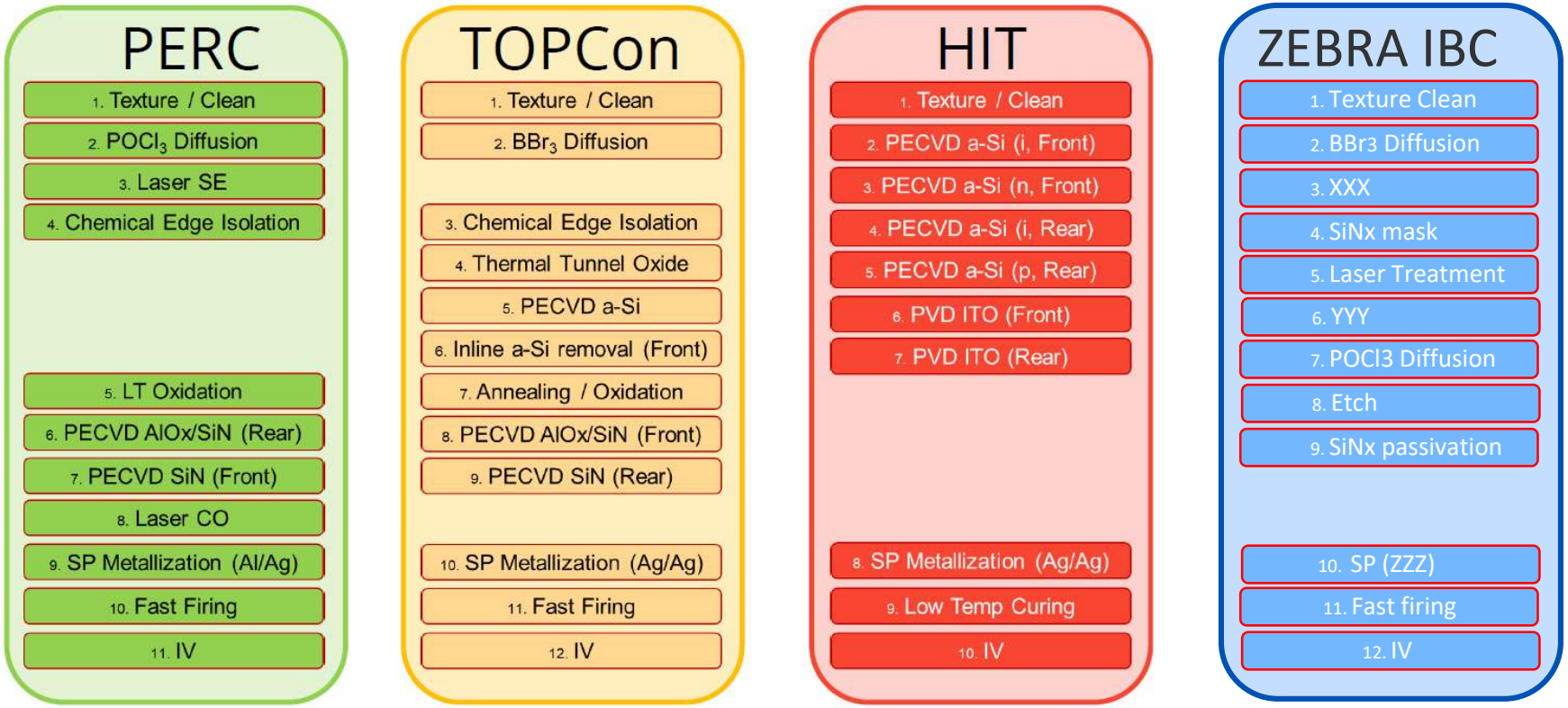
ZEBRA cell technology: properties

A low-cost, high efficiency, n-type back contact back junction solar cell

- No metallization on front side
- Regular stripes of n+ and p+ doping on the rear
- Screen printed (SP) Ag-paste metallization
- Busbars on flexible positions
- Developed by ISC Konstanz in 10+ years of R&D



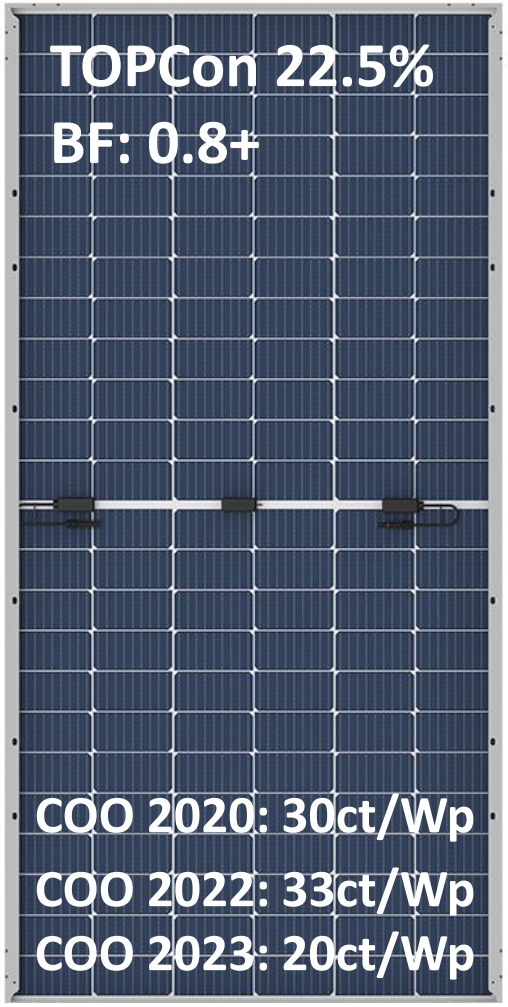
ZEBRA cell technology: process sequence

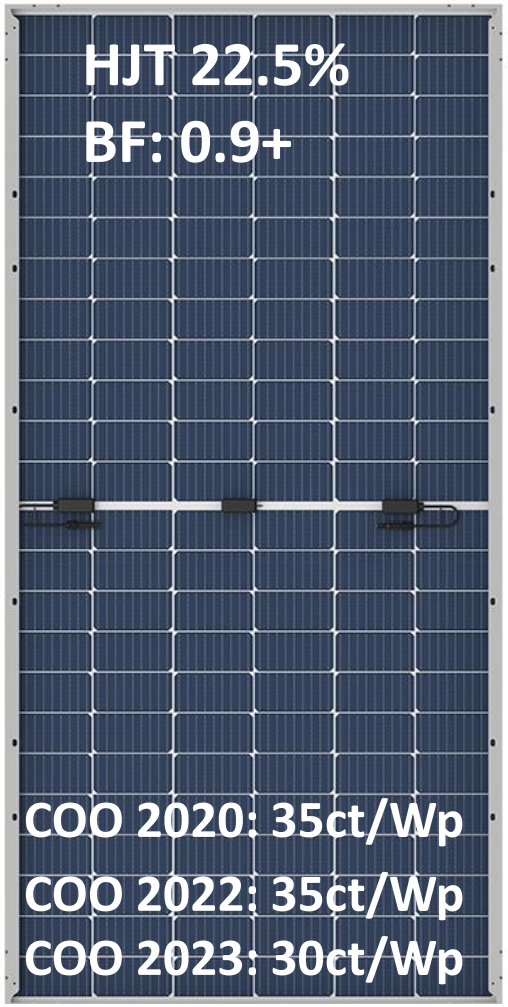


- Efficiency
- Complexity
- Throughput
- Yield
- Module implementation

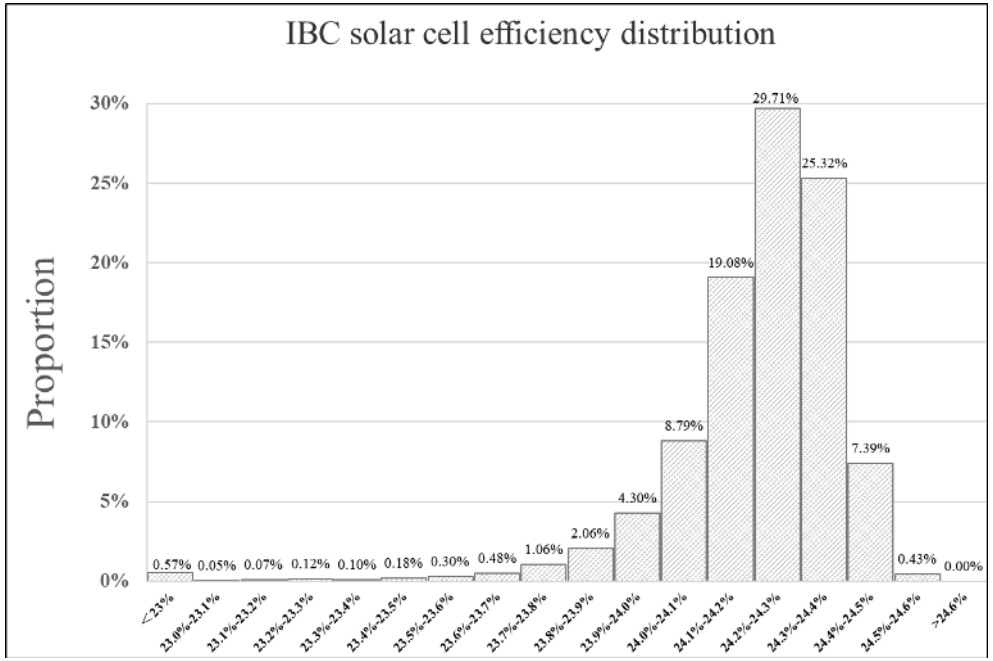
- Bifaciality
- Temperature coefficient
- Degradation

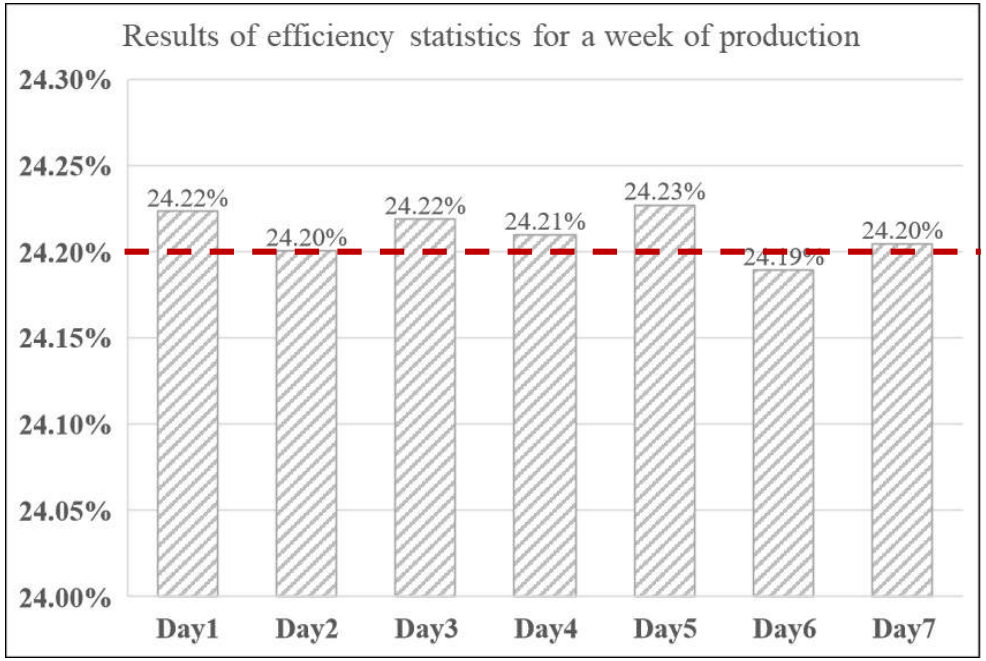
ZEBRA technology: bifacial module





ZEBRA cell technology: cell parameters from production



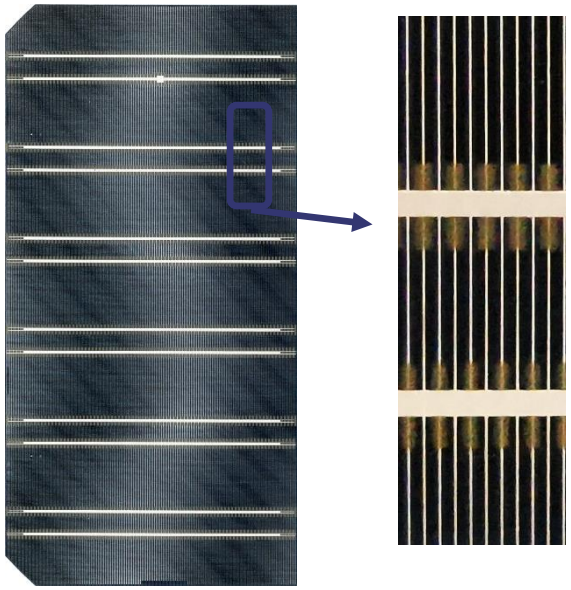


	Voc (mV)	Isc(A)	FF(%)	Eta(%)
average	700	11.83	80.15	24.21
Best cell	704	11.86	80.64	24.60

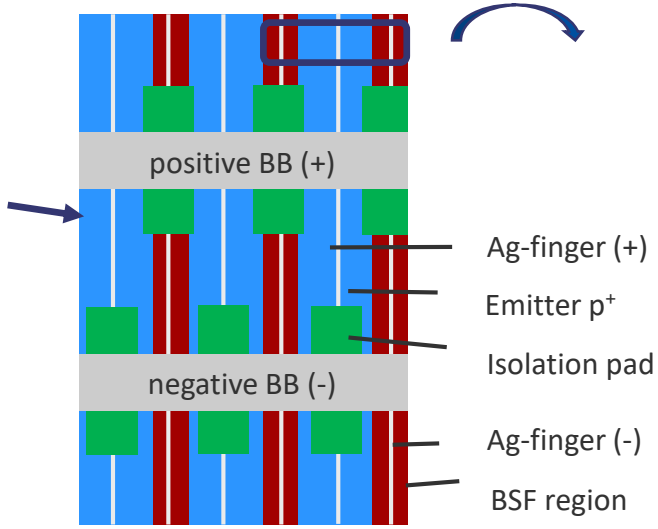
IV data for a week of production, 4/2022

ZEBRA cell technology: 3D SP device architecture

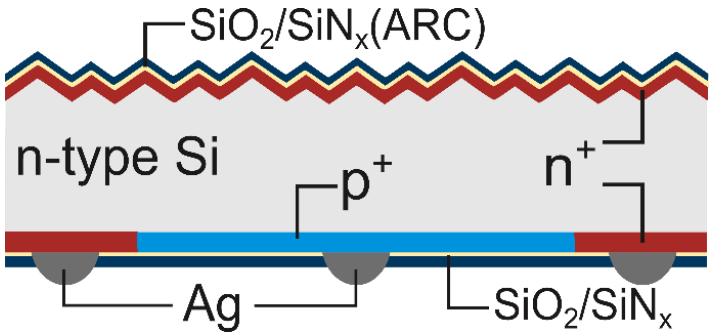
Photo of rear side



Schematic drawing



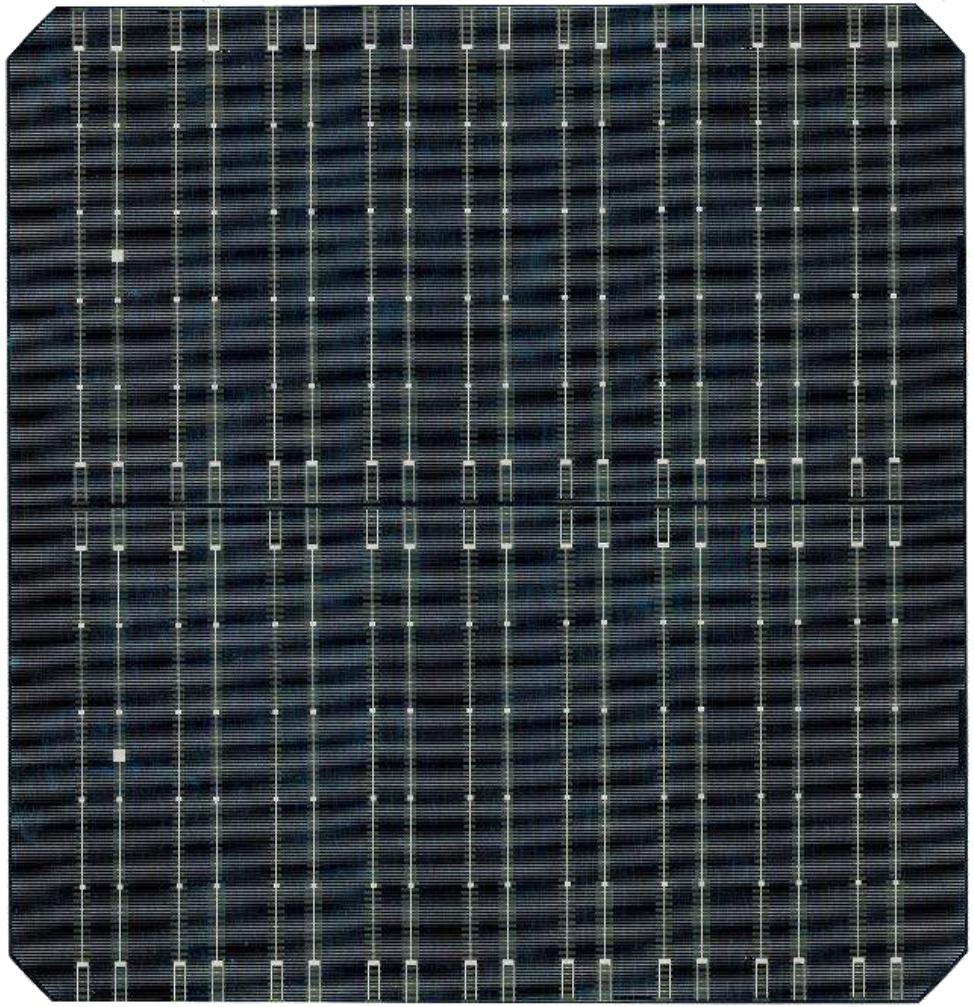
Drawing cross section



The stripes are p+ and n+ doped regions of optimum width

20mg Ag/W

ZEBRA cell technology: Ag SP properties



- M6 wafers >> G12 possible
- 9 BB technology
- No passivating contacts
- No AlOx passivation
- Simple module interconnection
- No PID, No LeTID, No UV degradation

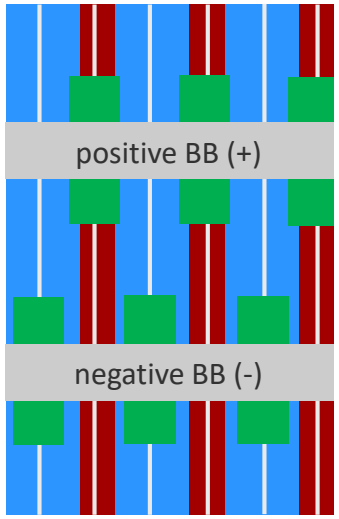
Future:

- Lean upgrade to poly-ZEBRA
- Easy implementation of Cu and Al

SPIC

ZEBRA cell technology: SP with Ag, Cu and Al

3D printed IBC

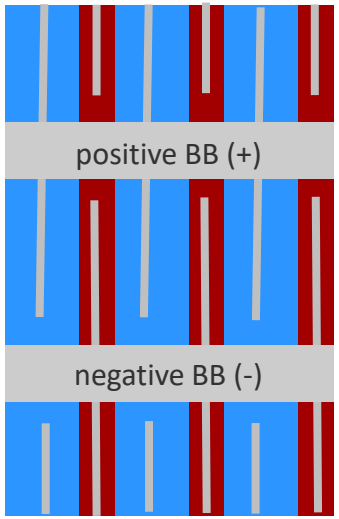


PROPERTIES
- Isolation paste
- 5 prints (2 times IP)
- Complex process
- Shallow fingers

CELL PARAMETERS
- High voltage of 700+mV
- Efficiency of 24%+
- High BF of 0.75+

Ag, Cu

2D printed IBC



PROPERTIES
- No isolation paste
- 2 prints only
- Lean process
- Broad fingers

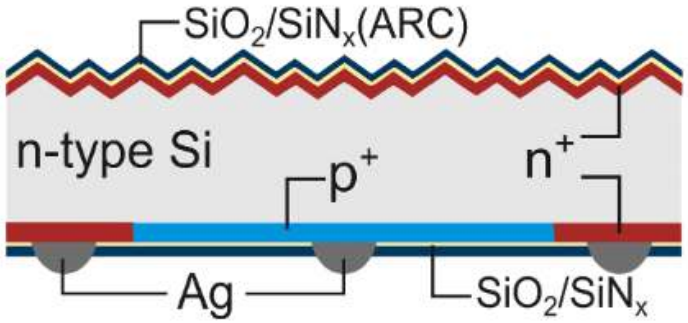
CELL PARAMETERS
- Voltage below 700mV
- Efficiency of 23%+
- Moderate BF of 0.65

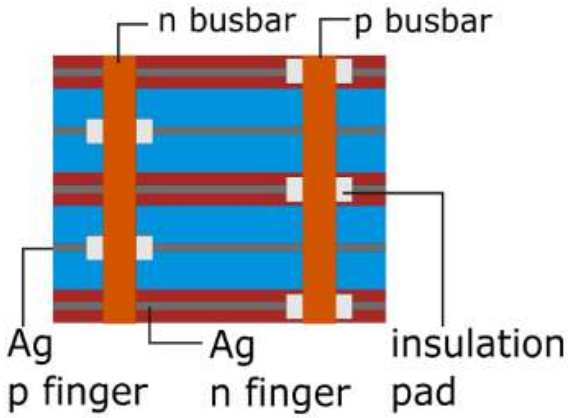
Al

4 mg Ag/W

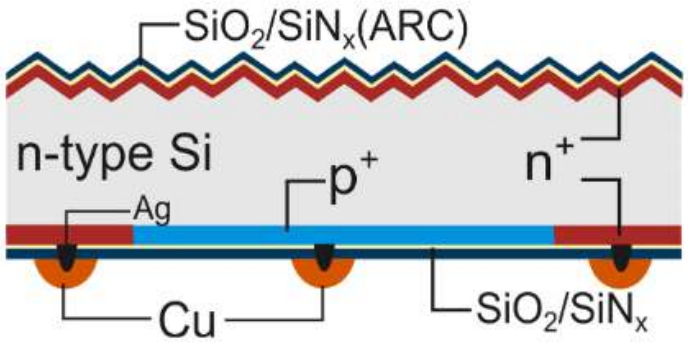
Cu SP ZEBRA cell technology

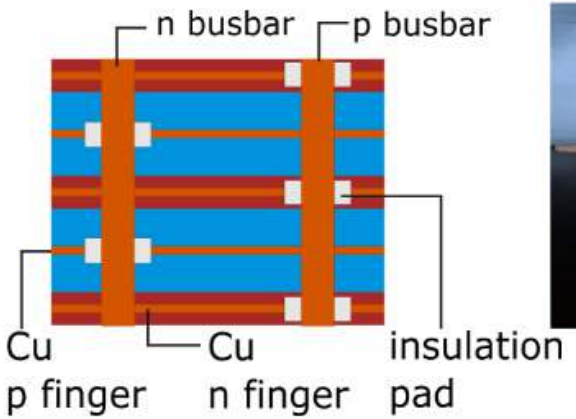
1) Replacement of **BBs** in ZEBRA

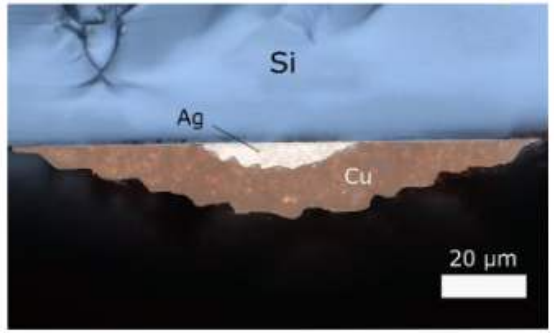




2) Replacement of **fingers** in ZEBRA







[7] N. Chen, et al., Screen printed copper paste for metallization of IBC solar cells, SiliconPV, 2022

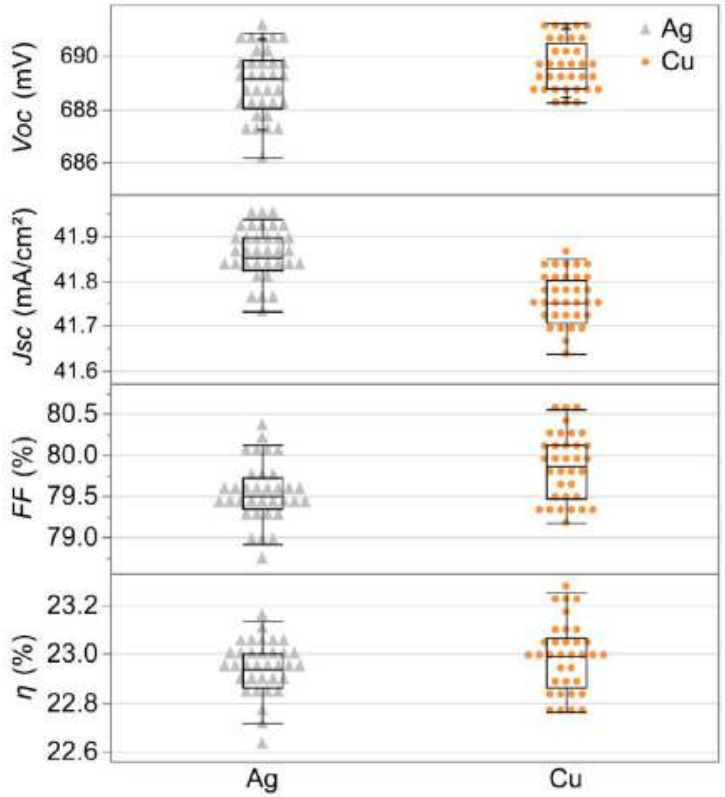
Copprint

4 mg Ag/W

Cu SP ZEBRA cell technology

- Comparable V_{OC}, pFF and cell efficiency η
- Lower J_{SC} of 0.1 mA/cm²
- Better FF of 0.3 $\%_{abs}$ but not statistically significant

Paste	Data type	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF (%)	η (%)
Ag	Best cell	687.2	41.92	80.32	23.14
	Avg. of 34 cells	688.9±1.2	41.85±0.05	79.54±0.36	22.94 ±0.11
Cu	Best cell	690.2	41.80	80.56	23.25
	Avg. of 34 cells	689.6±0.9	41.75±0.06	79.81±0.41	22.98±0.13



[9] N. Chen, et al., "Thermal stable high efficiency copper screen printed back contac[illegible]" solar cells, Solar RRL, 2022

Copprint

4 mg Ag/W

Cu SP ZEBRA cell technology

• High throughput process capability	➢Screen printing & short drying/curing ✓
• **No contamination** of the cell	➢pFF & Climate chamber tests ✓
• Series resistance	➢Line resistance & FF ✓
• Long time durability and reliability	➢Climate chamber tests ✓
• Solderability	➢Stringer ✓
• Adhesion	➢Peel force ✓

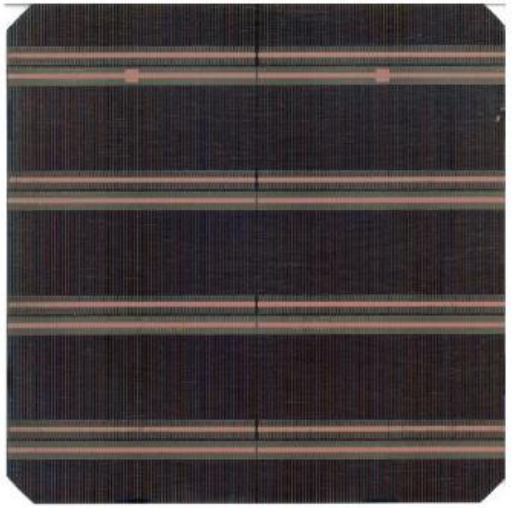
Presentation from D. Rudolph at MIW 2023 in Lausanne
https://miworkshop.info/wp-content/uploads/2023/05/4_ZEBRA-Interconnection-d-rudolph.pdf

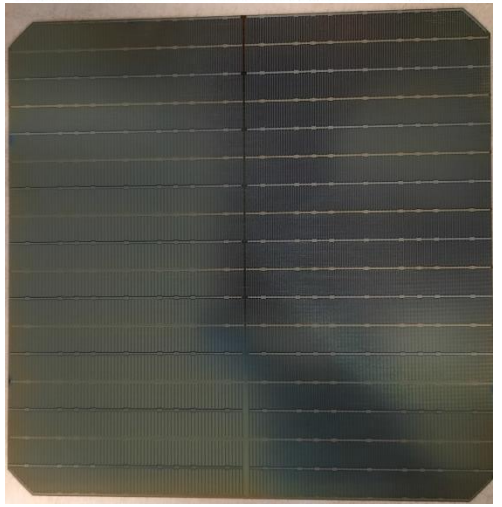
Copprint

ZEBRA cell technology: cell parameters for SP Ag, Cu and Al device

	Ag cons. [mg/Wp]	Voc [mV]	Jsc [mA/cm^2]	FF [%]	Eta [%]
Ag best	25	687	41.9	80.3	23.1
Ag ave.		689	41.9	79.5	22.9
Cu best	4	690	41.8	80.6	23.2
Cu ave.		690	41.8	79.8	23.0
Ag ave.	25	690	41.5	80.3	23.0
Al ave.	9	690	41.4	79.0	22.5

- Same efficiency for CuZEBRA as for Ag SP ref.
- AlZEBRA needs some optimisation

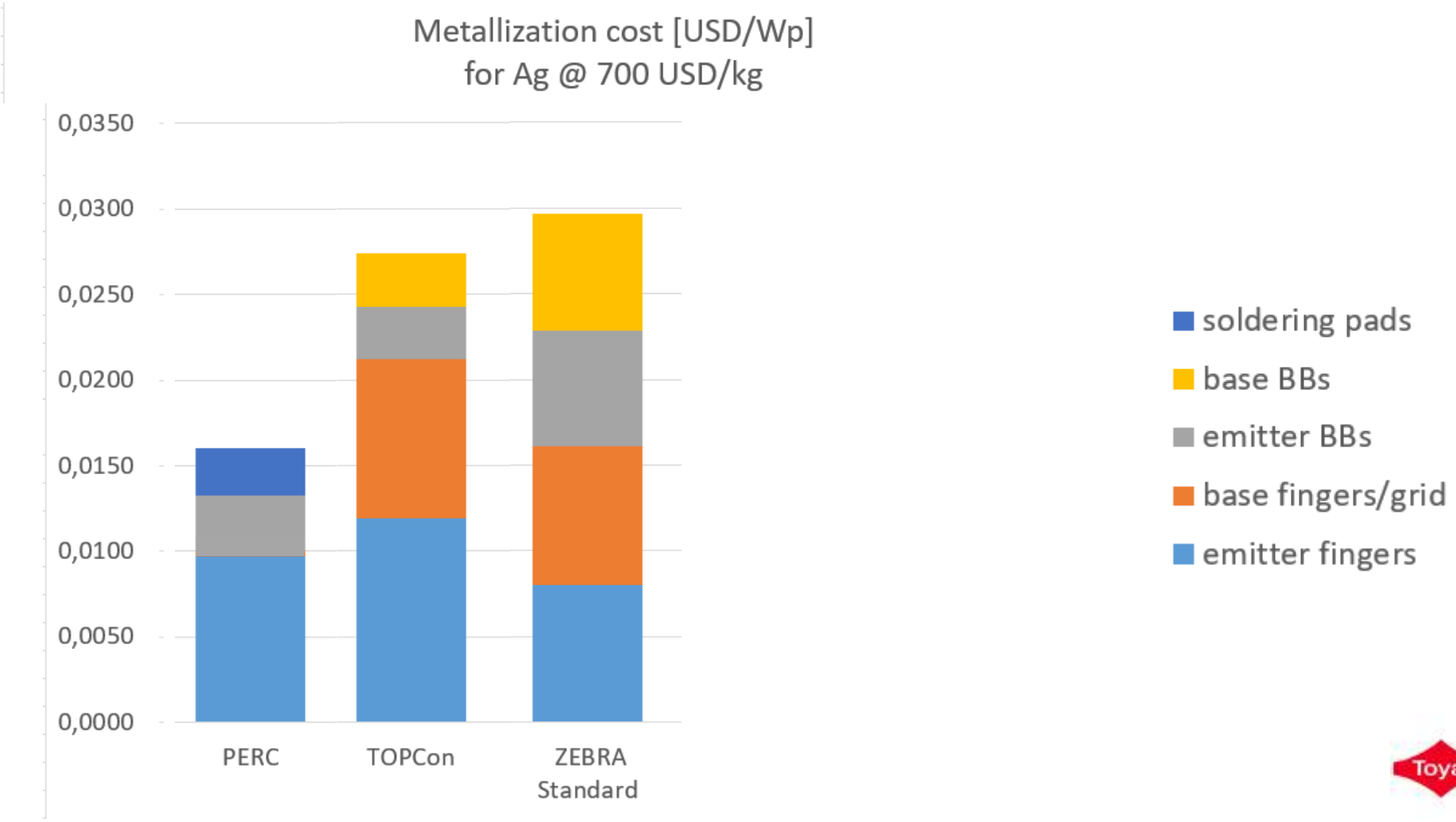




Copprint

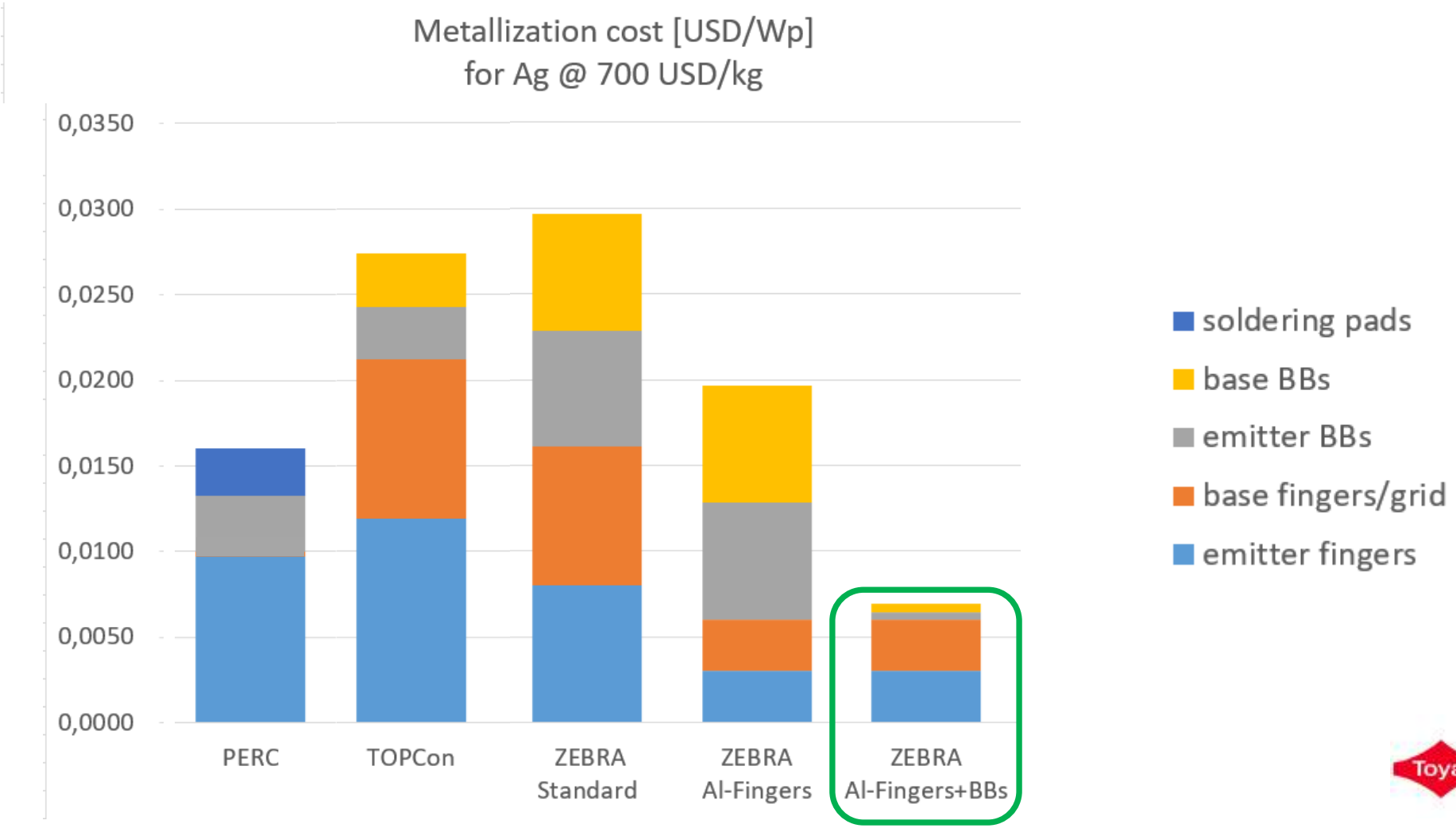
Toyal 東洋アルミ

ZEBRA cell technology with SP Al: COO



4 mg Ag/W

ZEBRA cell technology with SP Al: COO



IBC4EU (Horizon Europe project with 13.5Mio funding)

EURECA: EUropan REar Contact Alliance

EURECA

R|E|N|A | centrotherm | LPKF | Toyal

NorSun | VALOE | kalyon | FuturaSun anticipate tomorrow | ENERGYRA

ISC research for a sunny future | ISFH | TNO innovation for life | imec | Copprint

protech | BECQUEREL INSTITUTE | WIP | cea | ines INSTITUT NATIONAL DE L'ENERGIE SOLAIRE | HIGHLINE TECHNOLOGY | LuxChemtech

IBC4EU

Piloting novel cost-competitive bifacial IBC technology for vertically integrated European GW scale PV production value chain

Call: HORIZON-CL5-2021-D3-03
(Sustainable, secure and competitive energy supply)

Topic: HORIZON-CL5-2021-D3-03-13

Type of Action: HORIZON-IA

Proposal number: 101084259

Proposal acronym: IBC4EU

Type of Model Grant Agreement: HORIZON Action Grant Budget-Based

STARTED
1.11.2022-31.10.2025

IBC4EU (Horizon Europe project with 13.5Mio funding)

EURECA: EUropan REar Contact Alliance

EURECA

R|E|N|A centrotherm LPKF Toyal

NorSun VALOE kalyon FuturaSun anticipate tomorrow ENERGYRA

ISC research for a sunny future ISFH TNO innovation for life imec Copprint

protech BECQUEREL INSTITUTE WIP cea ines HIGHLINE TECHNOLOGY LuxChemtech

IBC4EU

Piloting novel cost-competitive bifacial IBC technology for vertically integrated European GW scale PV production value chain

Call: HORIZON-CL5-2021-D3-03
(Sustainable, secure and competitive energy supply)

Topic: HORIZON-CL5-2021-D3-03-13

Type of Action: HORIZON-IA

Proposal number: 101084259

Proposal acronym: IBC4EU

Type of Model Grant Agreement: HORIZON Action Grant Budget-Based

STARTED
1.11.2022-31.10.2025

Summary

- nPV technology is coming fast to the PV market
- For TW/a market replacement of Ag by Cu and/or Al is key
- IBC, as the holy grail and will substitute TOPCon from 2028 on because of
  1) easy implementation of poly-Si
  2) easy implementation of Cu/Al-contacts

Al/Cu IBC are very good candidates for a sustainable PV future

BCworkshop2023 in Hameln