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TOPCon’s time to shine

28 March 2023

11:00 am - 12:00 pm | CEST, Berlin
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S&P Global
Commodity Insights

PV Module Technology Trends

TOPCon's time to shine – Webinar

Karl Melkonyan

Senior Analyst
Clean Energy Technology

28.03.2023

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$1.7B	15K	60%	135K	6.5M	15K
Annual revenue	Customers in 150+ countries, including the 50 largest energy companies	Of the world's crude oil trade estimated to be priced using the Platts Dated Brent™ benchmark	Renewable energy projects with detailed information	E&P data records for oil wells and fields	Daily Platts price assessments published

Market overview

S&P Global
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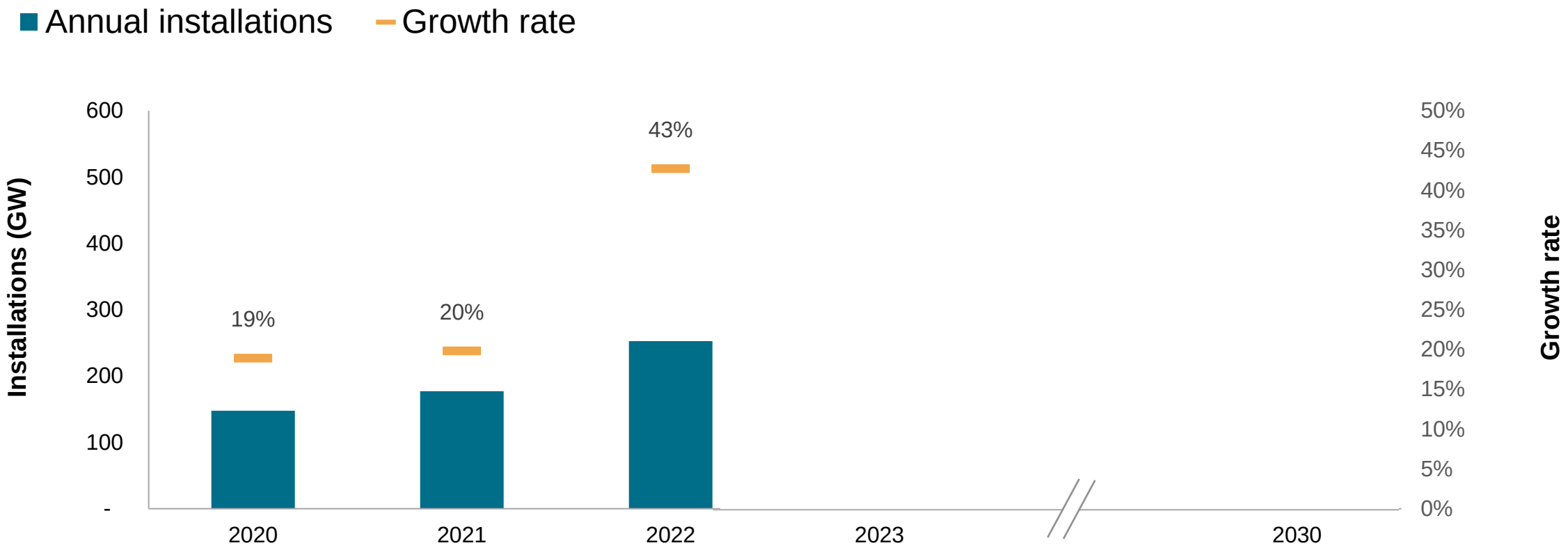
Global PV installation forecast

In 2022, annual PV market growth is estimated to have reached 43%



Source: S&P Global Commodity Insights.

Global PV installation forecast

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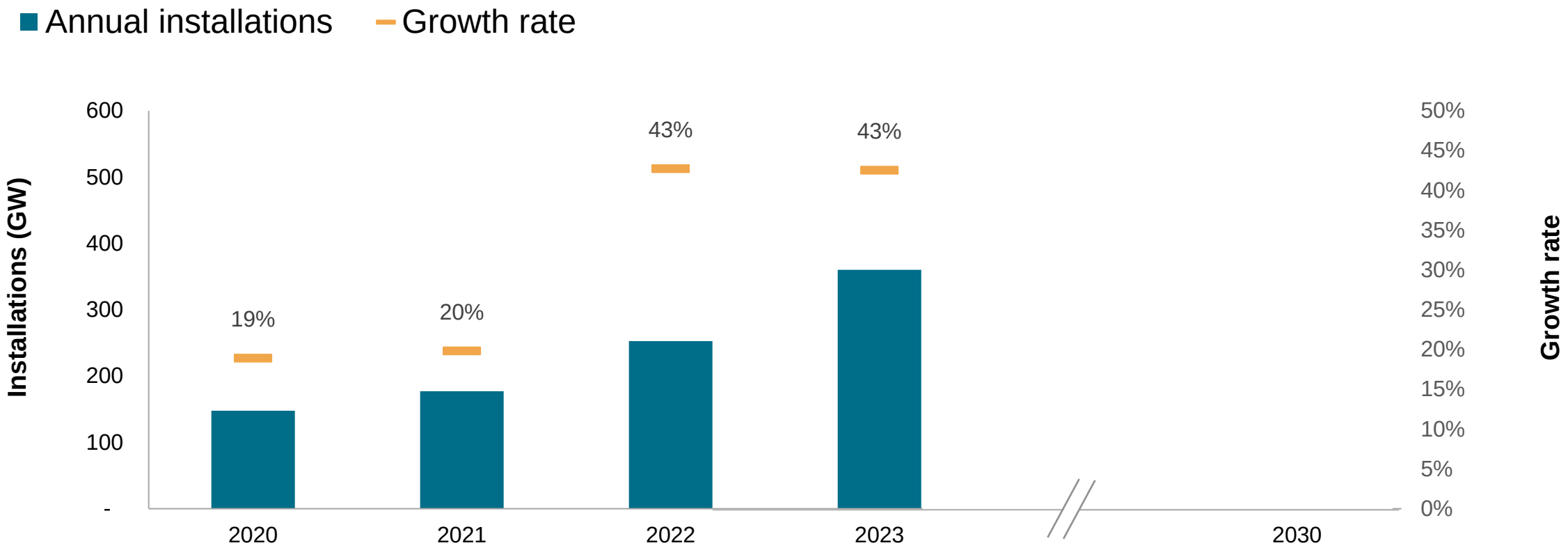

Note: includes preliminary forecast data
Source: S&P Global Commodity Insights.

Global PV installation forecast

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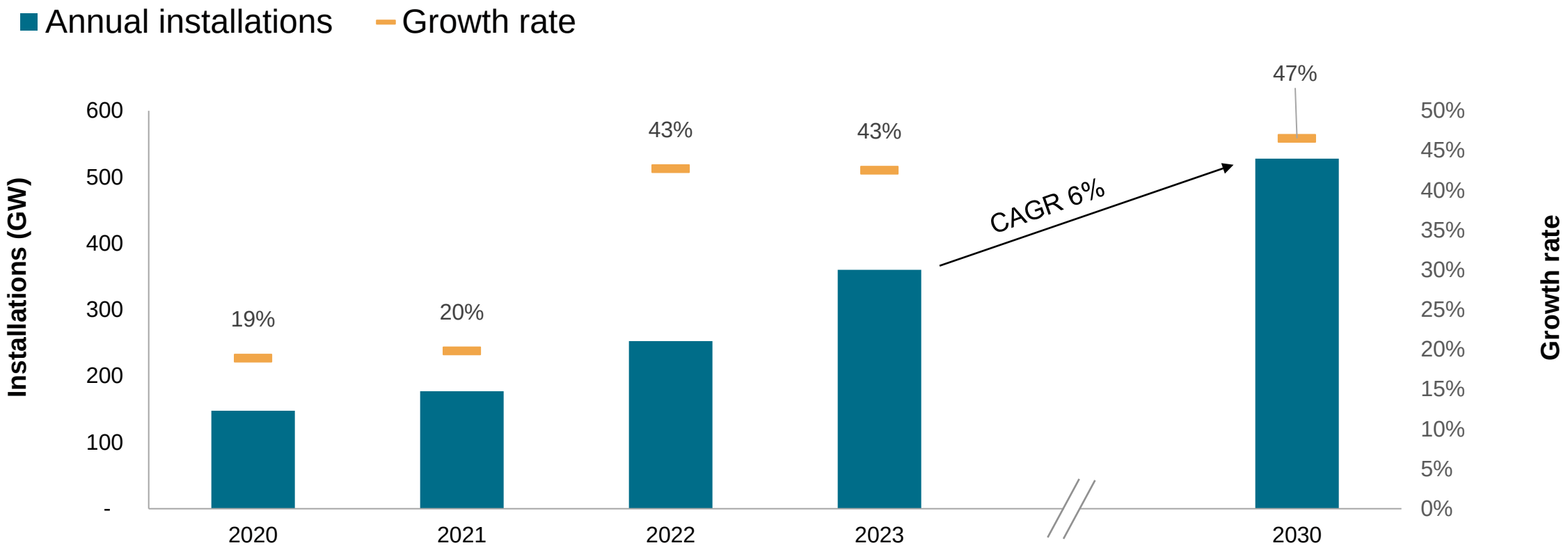
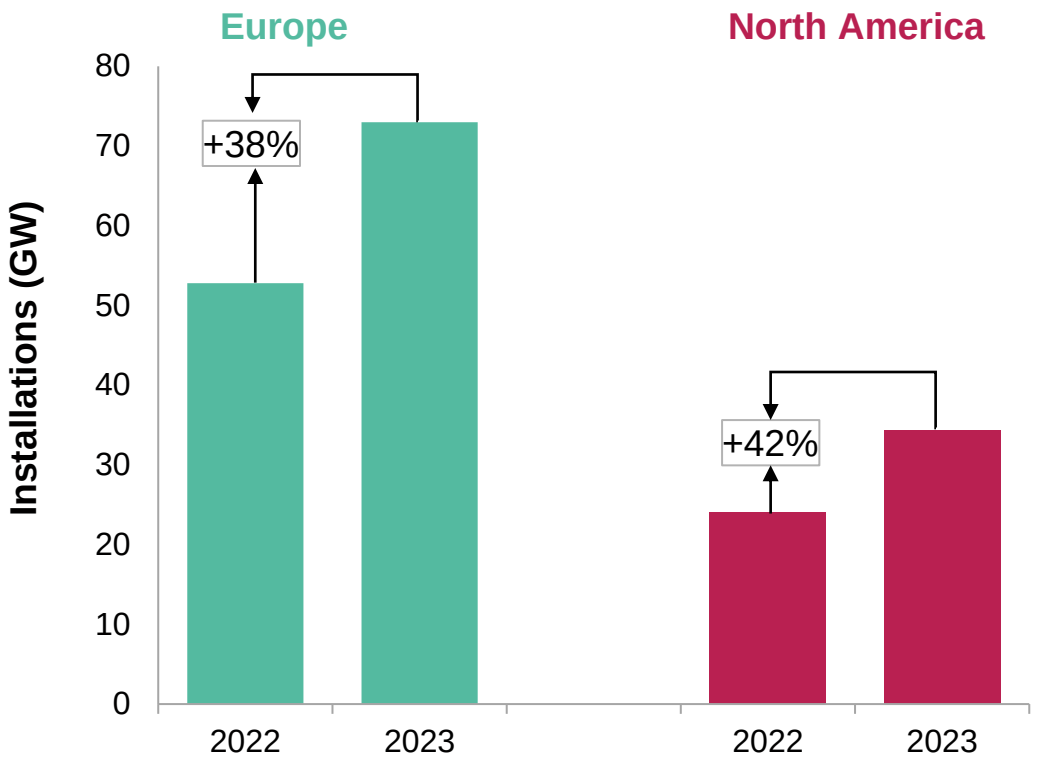
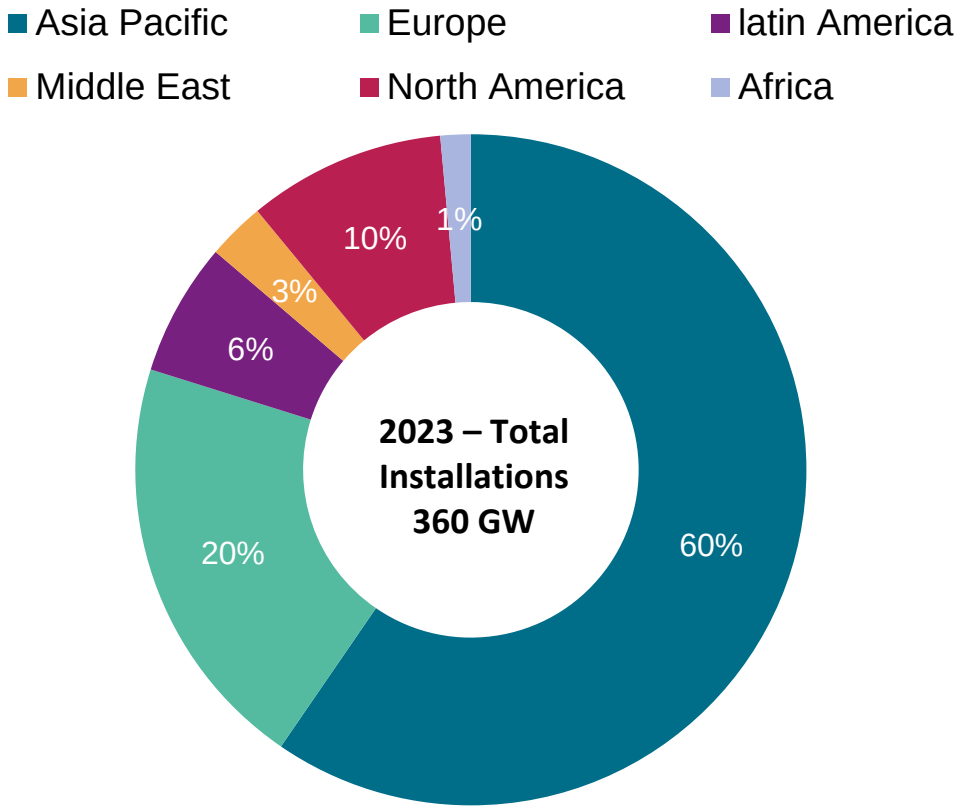


Note: includes preliminary forecast data
Source: S&P Global Commodity Insights.

In 2023, global PV market is forecast to reach 360 GW

Strong demand also in Europe and the United States





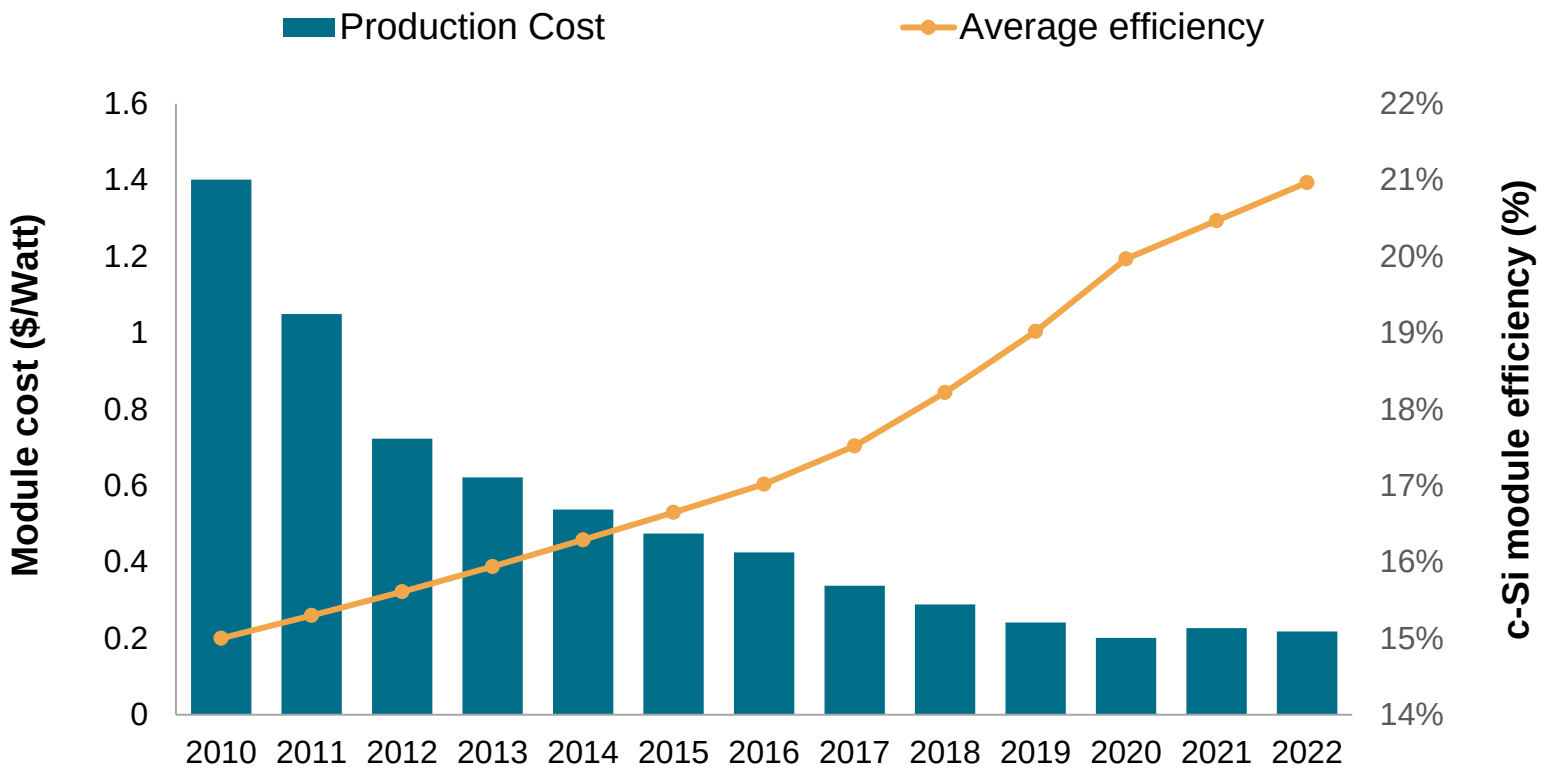
Note: includes preliminary forecast data
Source: S&P Global Commodity Insights.

Module market overview

S&P Global
Commodity Insights

Continued technology advances and cost improvements

Module production costs have fallen from 2010 to 2020 by more than 85%



Conversion efficiency

The persistent increase of efficiencies plays a very important role to keep growing the market share of the renewable energy sector in the energy mix.

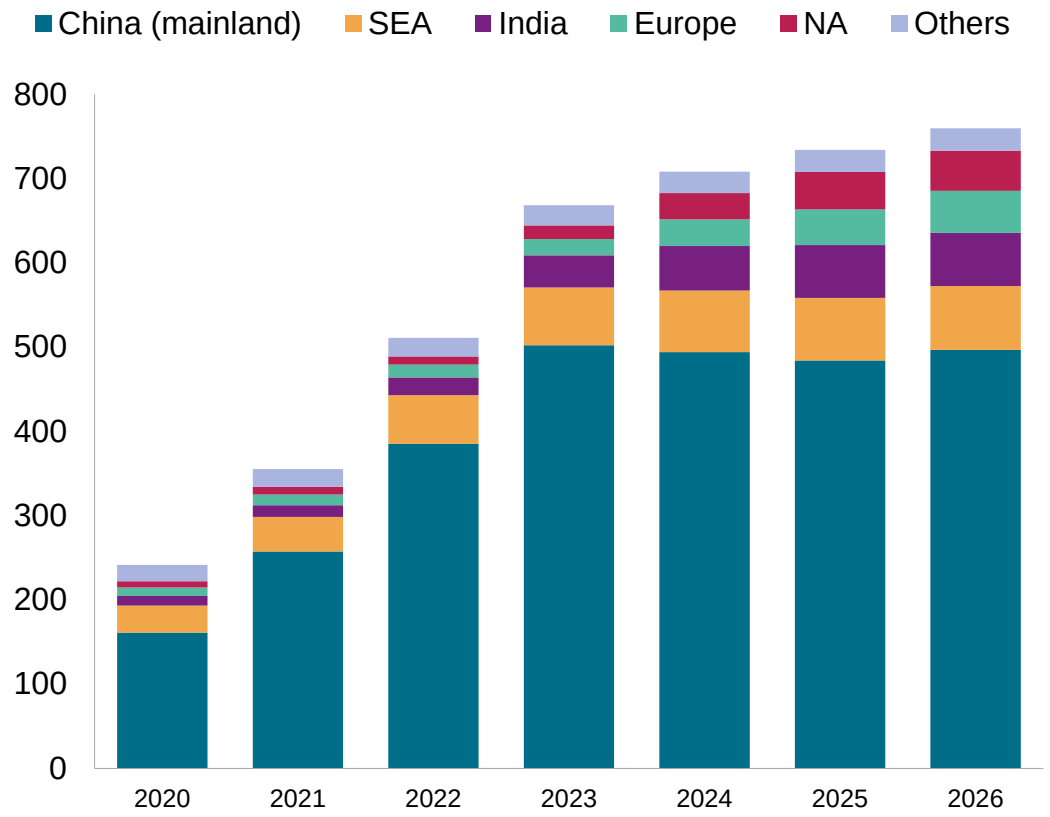
Module Cost

Technological innovation has taken place in a context of extreme price competition among solar manufacturers, where module production costs have fallen more than 80% in the past 10 years.

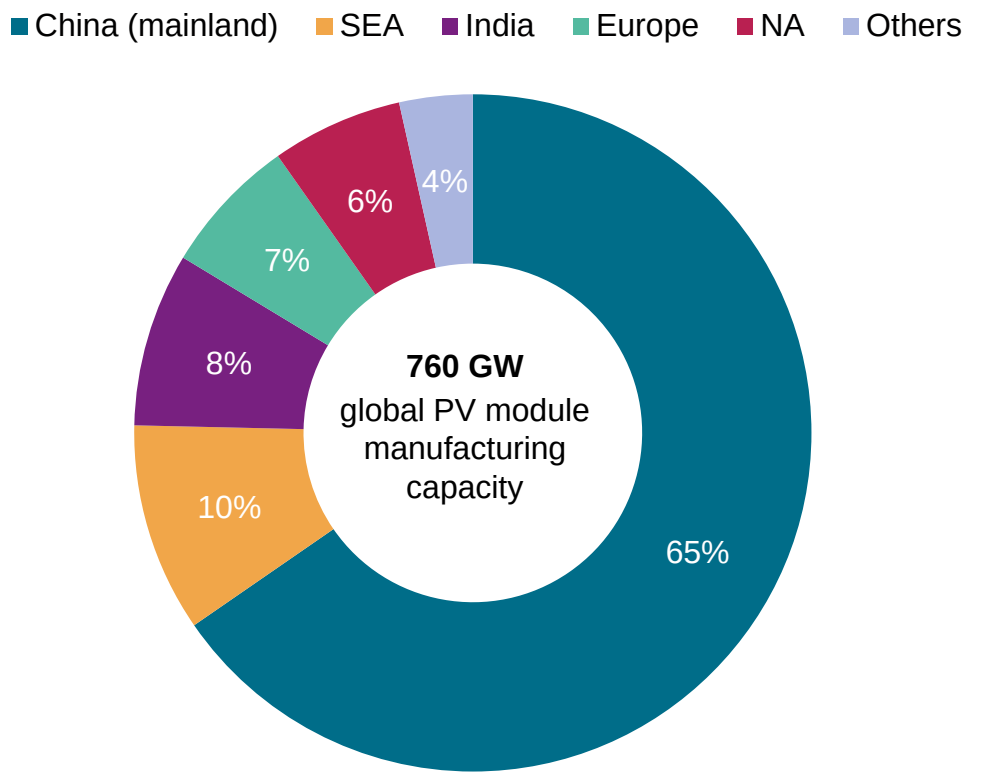
Source: S&P Global Commodity Insights

Falling system costs, increasing demand, and a global subsidy race lead to global module manufacturing capacity reaching 760GW by 2026

Evolution of global PV module production capacity (GW)

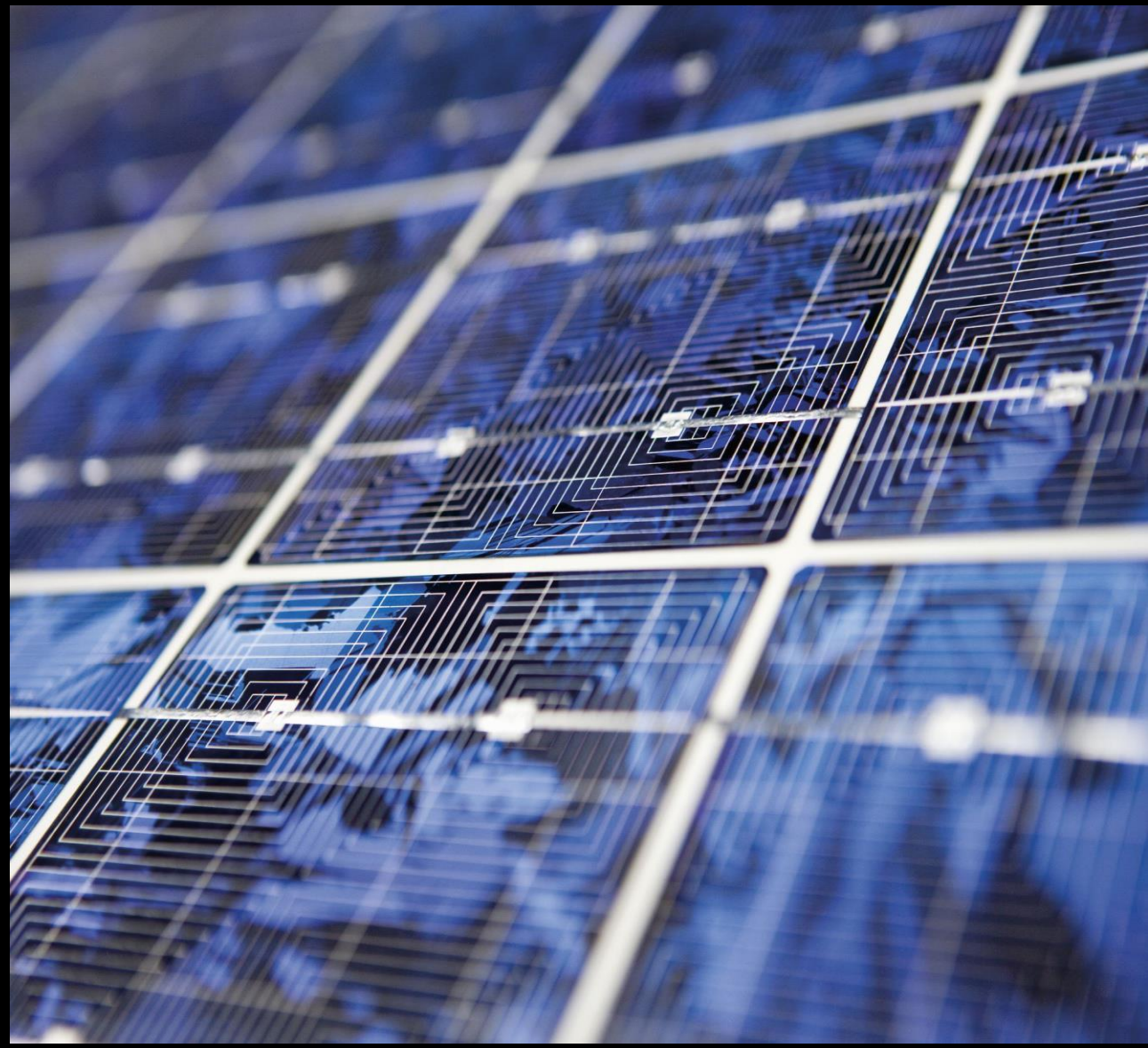


Share of installed global PV module capacity by region (2026)



Source: S&P Global Commodity Insights

Technology trends



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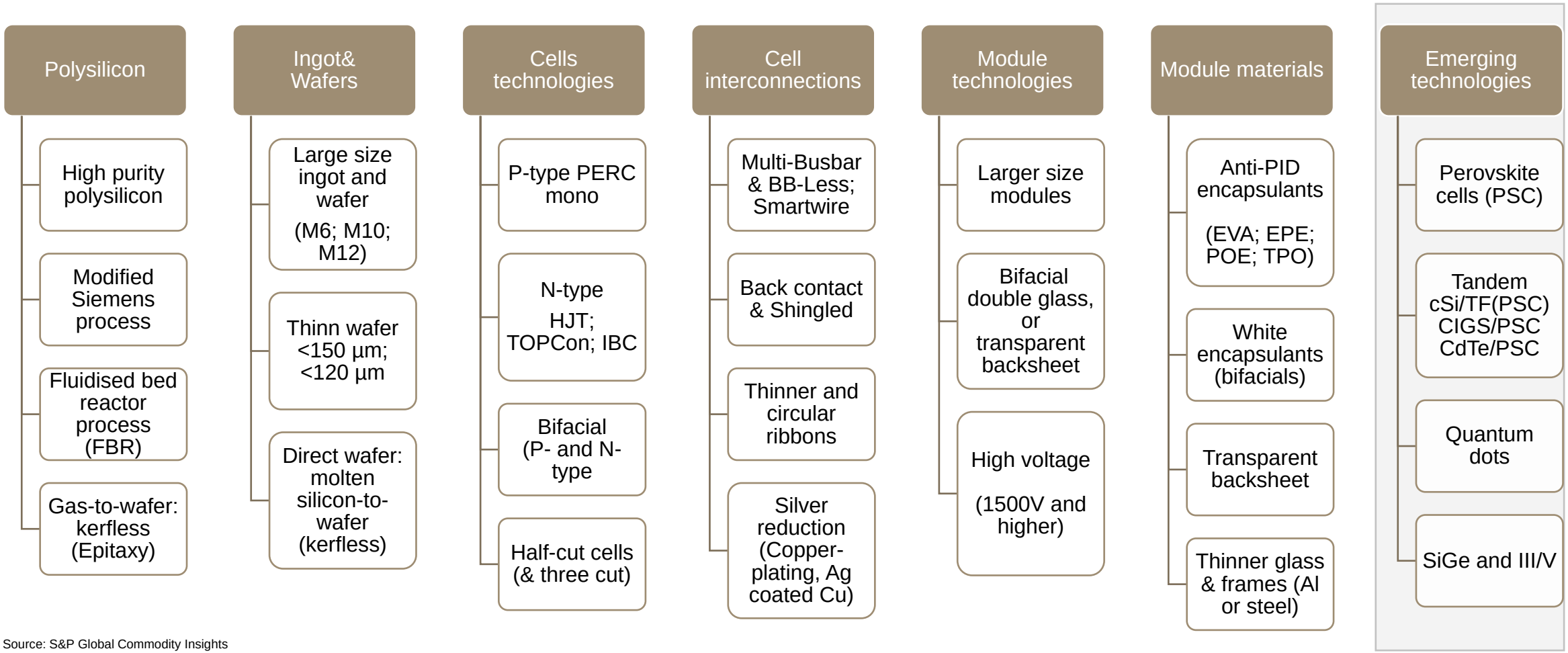
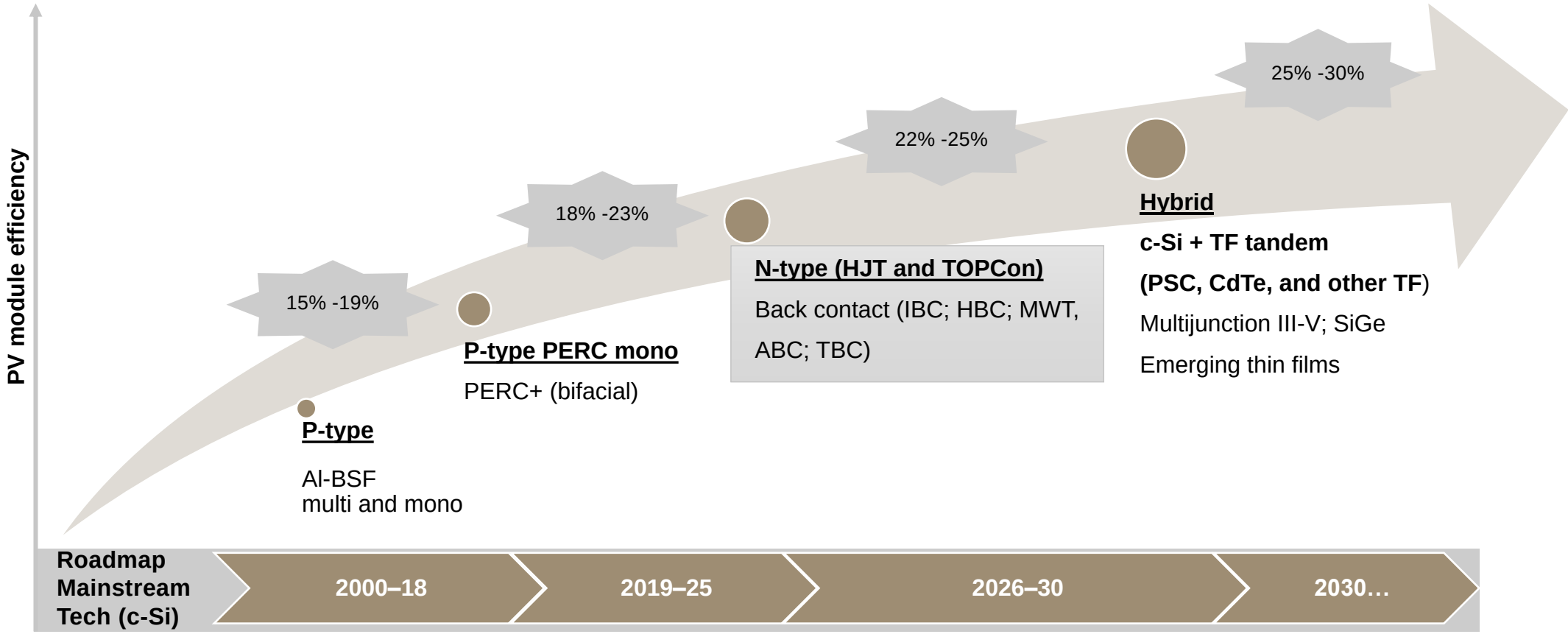
Efficiency increase, working lifetime, and cost reduction are the three most important factors for any PV technology to become mainstream



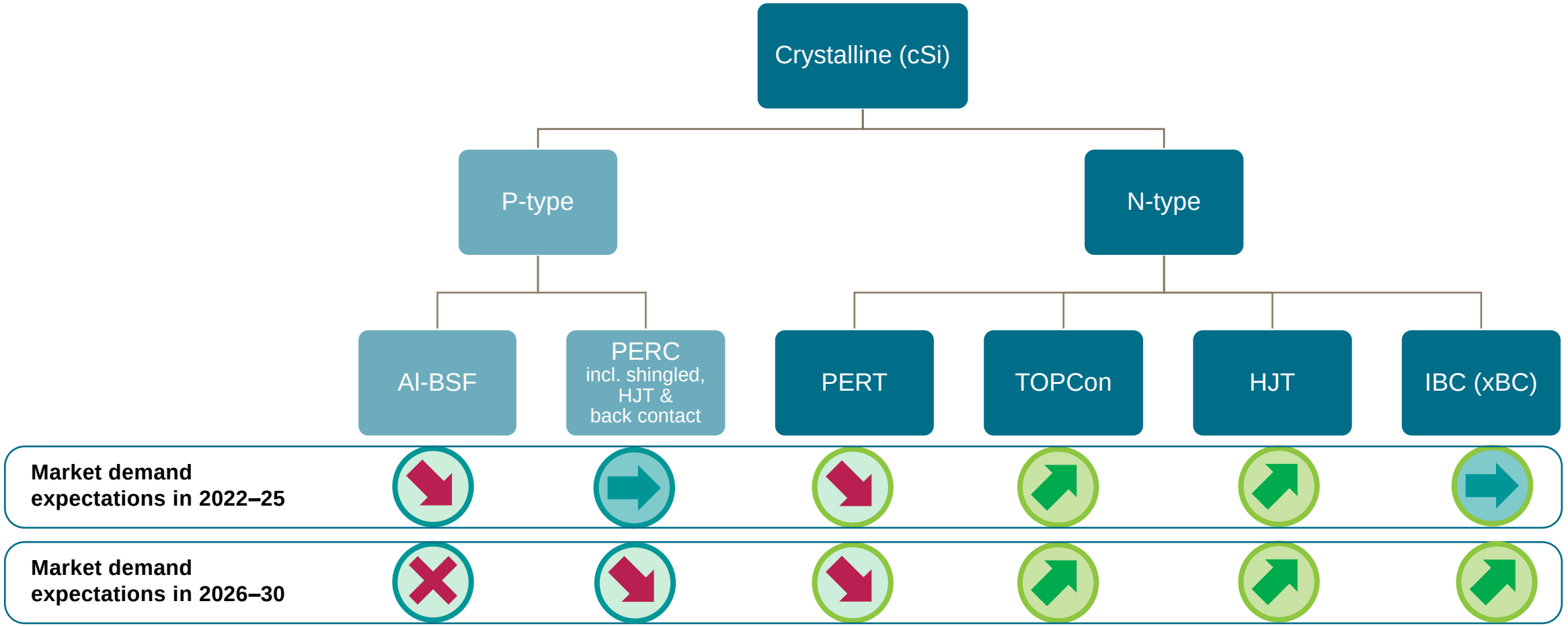
Source: S&P Global Commodity Insights

Crystalline silicon mainstream modules and technology roadmap



Source: S&P Global Commodity Insights

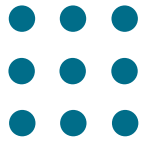
Crystalline cell technology classifications, and market expectations



Source: S&P Global Commodity Insights

Crystalline cell technologies—Benchmark and review of key parameters

Comparison of crystalline cell technology

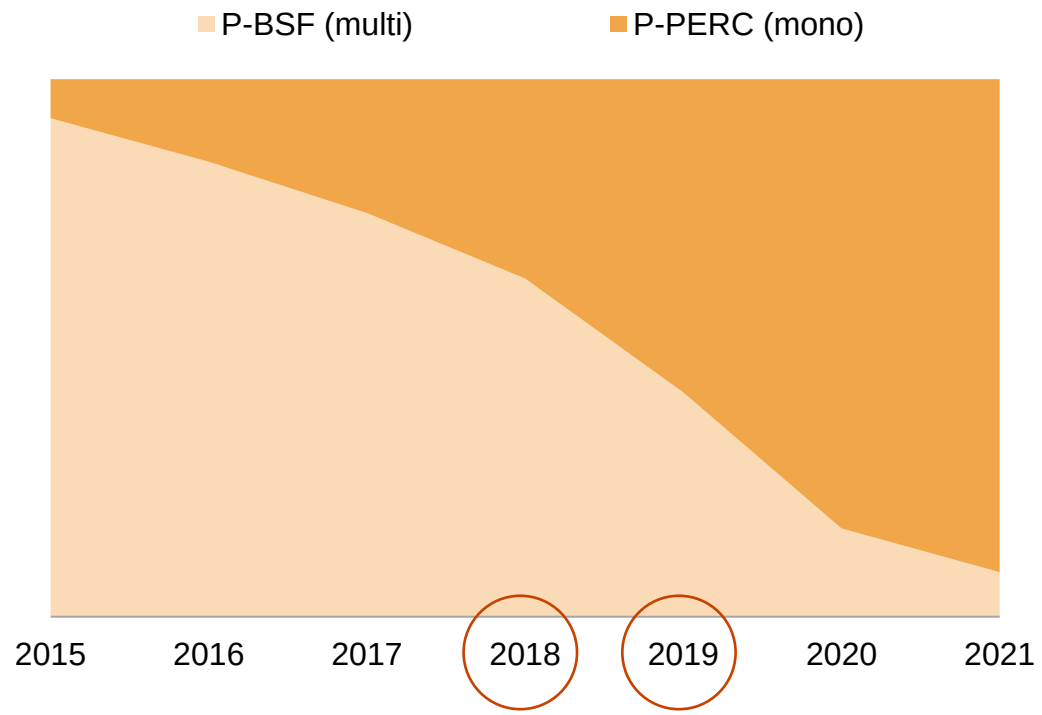
	PERC (benchmark)	N-PERT/PERL	N-TOPCon	N-HJT	N-IBC
Level of difficulty					
Processing steps					
Cost of investment					
Compatibility with existing equipment	N/A	Applicable to upgrade	Applicable to upgrade	No	No
Bifaciality factor	>75%	>85%	>85%	>95%	>70%
Efficiency record in 2022	25.4%	25.5%	26.4%	26.6%	26.7%
Key producers	Most cell producers	Jolywood, LG*	Jinko Solar, Jolywood, REC Solar, LG*, LONGi, Trina, CSI	Meyer Burger, ENEL, Jinergy, Tongwei, REC Solar, Risen	Maxeon (SunPower), Futurasun, SPIC, Aico
Comments	- Mainstream - Limited potential to increase efficiency	- Better performance on bifacial than PERC but worse cost performance - Limited improvement to represent the next generation of technology	- Theoretic highest efficiency is 28.7%,Compatible with existing PERC production lines - Lower efficiency and yield than HJT on mass production, compatibility limitations with future technologies	- A hybrid of crystalline and thin film technologies - Compatible to combine with the future technology, Perovskite - Equipment is still expensive	- Highest efficiency in mass production - Most difficult technology of the five - Most expensive of the five

Note: *LG Electronics has stopped solar panel manufacturing as of Q2 2022*
Source: S&P Global Commodity Insights

Previous cell technology transitions occurred in only a few years

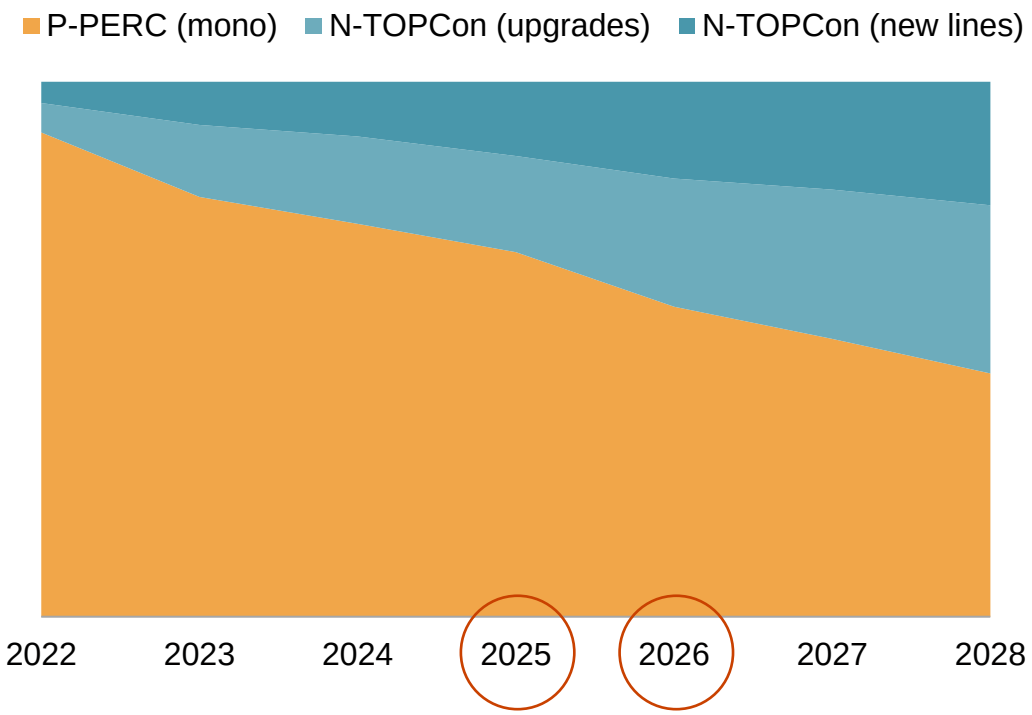
Technology shift from P-BSF multi to P-PERC Mono

PERC capacity increased strongly
–Both upgrades from BSF and new lines



Technology shift from P-PERC Mono to N-TOPCon

N-TOPCon capacity expanding
- Both new lines and upgrades from PERC

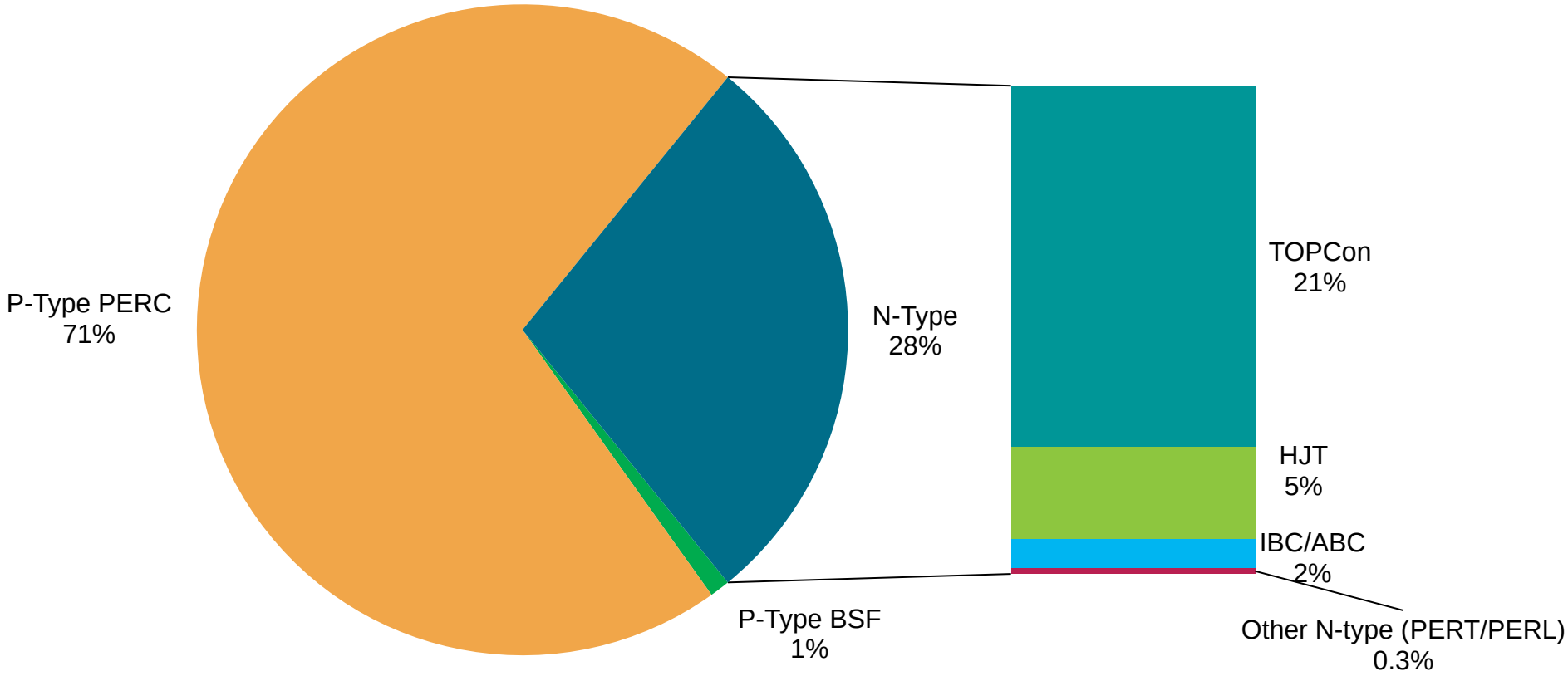


Source: S&P Global Commodity Insights

TOPCon cell capacity aggressively expands from 2022, achieving 74% of total n-type cell capacities

PV cell capacity by technology in 2023

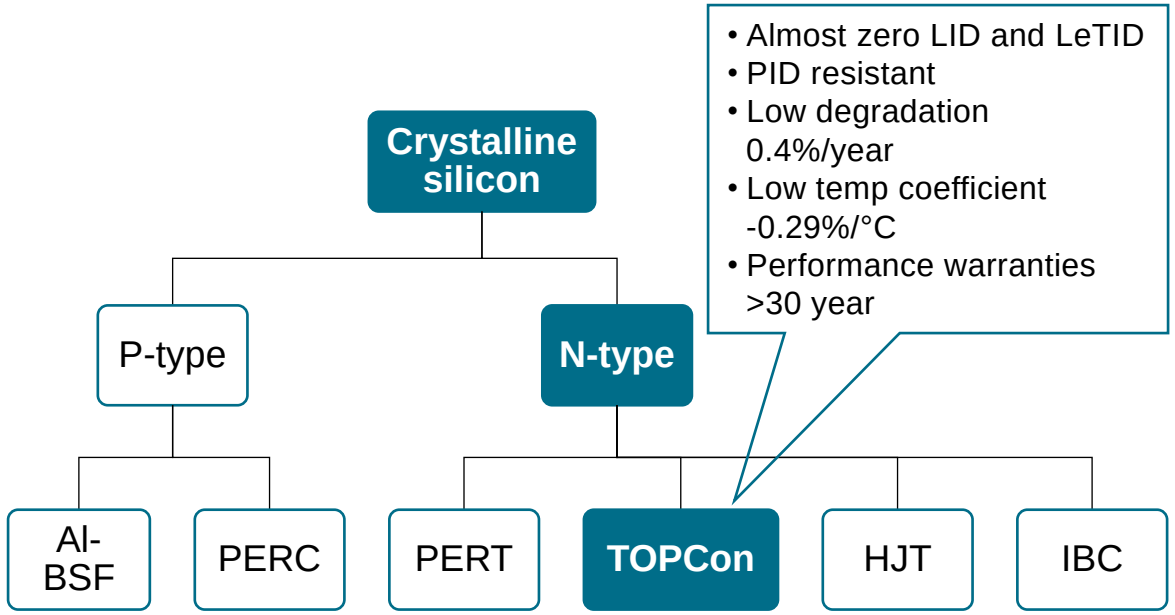
Total: 650 GW



Source: S&P Global Commodity Insights

TOPCon will be soon ready to become a mainstream technology, with most of the leading P-type producers upgrading their PERC lines

TOPCon is a very fast emerging technology that offers a relatively easy and low-cost option to upgrade the existing PERC lines



The concept consists in adding a thin tunnelling silicon dioxide and a doped polysilicon layer between the silicon substrate and the rear metal contact, which prevents electrons from recombining, thus reducing internal losses and further increasing efficiency.

Source: S&P Global Commodity Insights

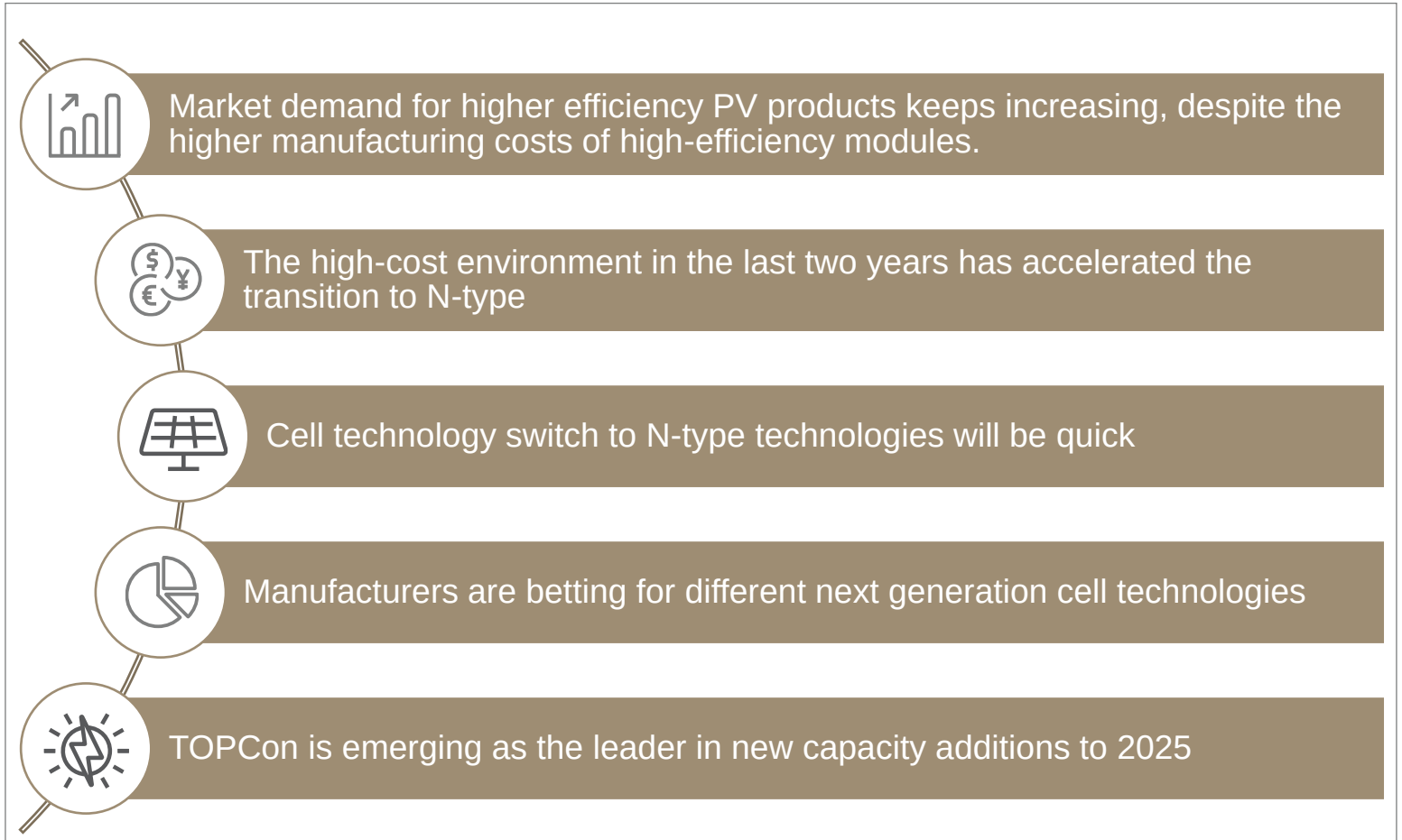
Drivers and outlook

- Similar properties and efficiencies such HJT, but with a lower equipment investment cost
- Easy to upgrade from existing PERC lines by adding two to three manufacturing tools
- Costs are starting to decline given technology advancements and increase in manufacturing scale
- Optimization of deposition tolls and technologies would allow increased throughput
- Optimizations and improvement of metallization techniques would allow the reduction of silver requirements

Barriers and improvement potential

- Equipment cost is higher than for standard PERC
- Technical difficulties of the complex multistage process, which may result in low production yields and higher labor cost
- Cell metallization requires 50% more silver than PERC

Key takeaways



Source: S&P Global Commodity Insights.

Thank You for your attention!

Karl Melkonyan

Senior Research Analyst – Clean Energy Technology

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All data and insight from:

S&P Global Commodity Insights

Global Clean Energy Technology service

TOPCon Technology: Going Mainstream

Mohammed Saady Al-Dweik
Head of Technical Services - MENA

TOPCon Technology: Concept

No.1 Shipment

for 4 Consecutive Years

130GW+
Delivered

14%
Market Share

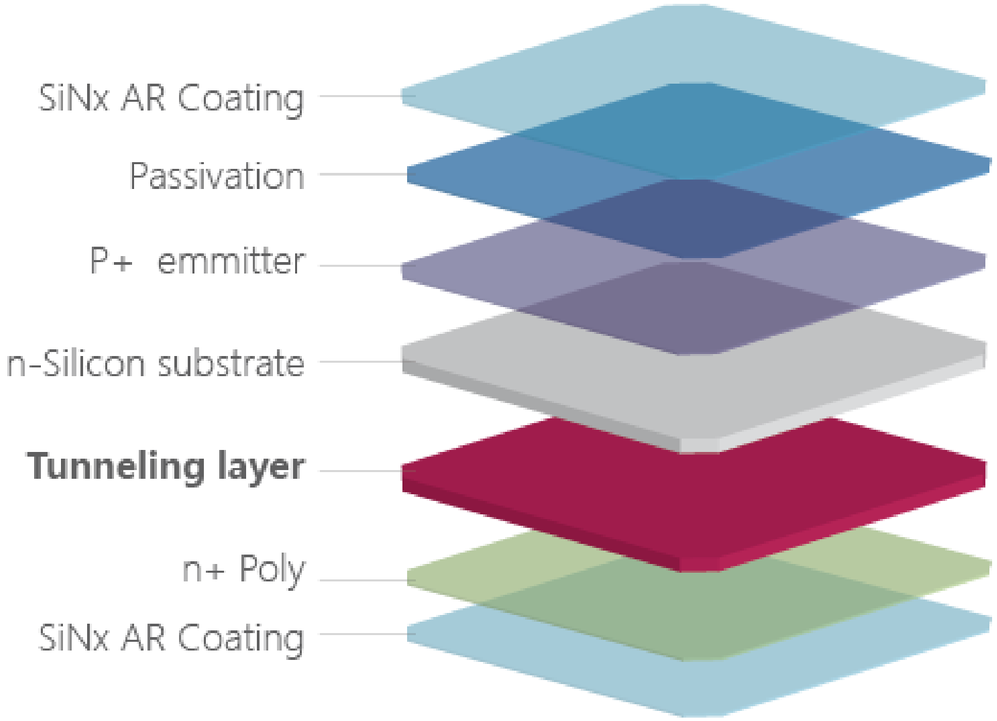
22
World Records

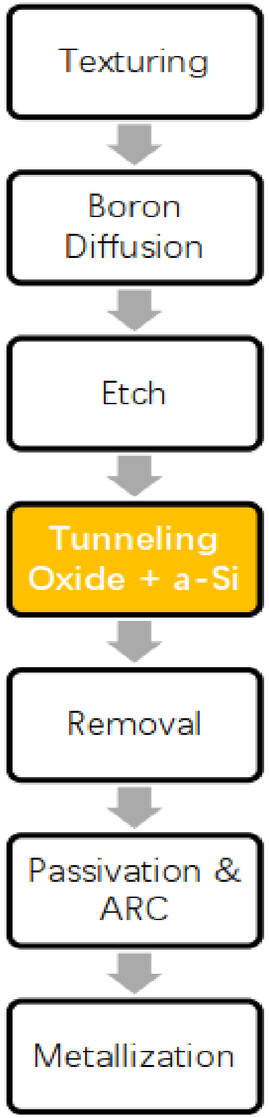
70GW
Cell capacity

TOPCon Technology Background

Passivation

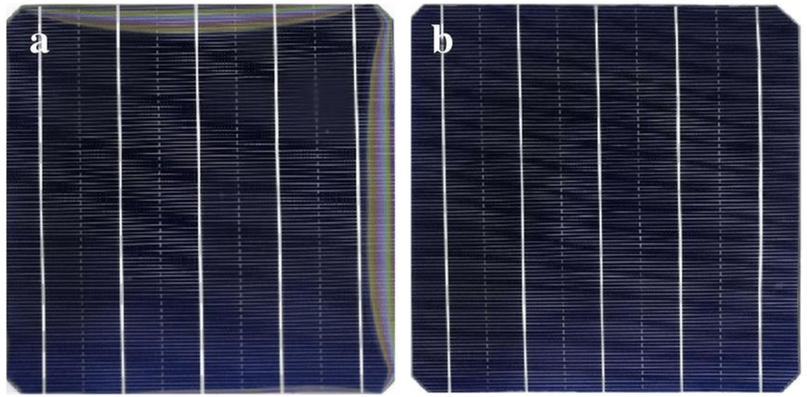
- Majority carrier pass → Resistance loss → J_0
- Minority carrier restrain → Carrier recombination → ρ_c





Wrap-around Poly Cleaning

- Requires more control during deposition process.
- Reduces the cell efficiency
- Increases the production costs and complexity.

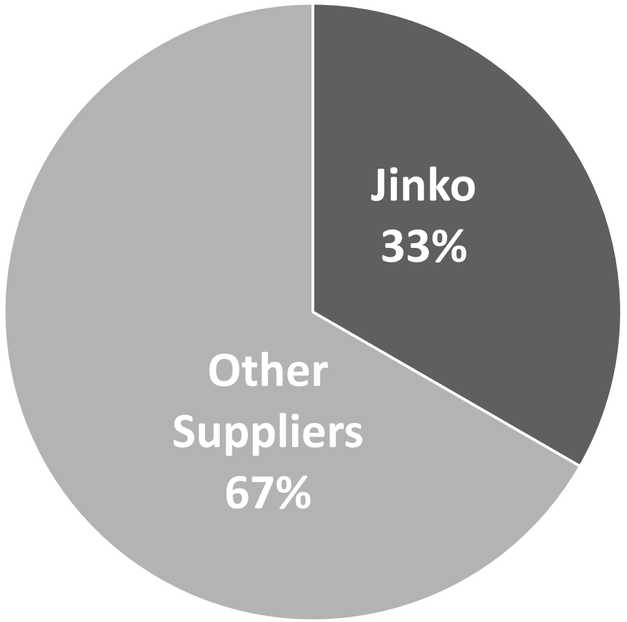


How To Become A Mainstream PV Technology?

Performance Improvement

Cost Effective

Reliable



- **More than 10 major PV suppliers announced TOPCon capacity in 2023/2024 and most of the new expansions are based on TOPCon.**
- **The total TOPCon capacity in 2023 is 150GW compared to 72GW in 2022.**

Polycrystalline
2016/2017

Mono-PERC
2023/2024

Monocrystalline
Poly-PERC

TOPCon

PERT
HJT
IBC

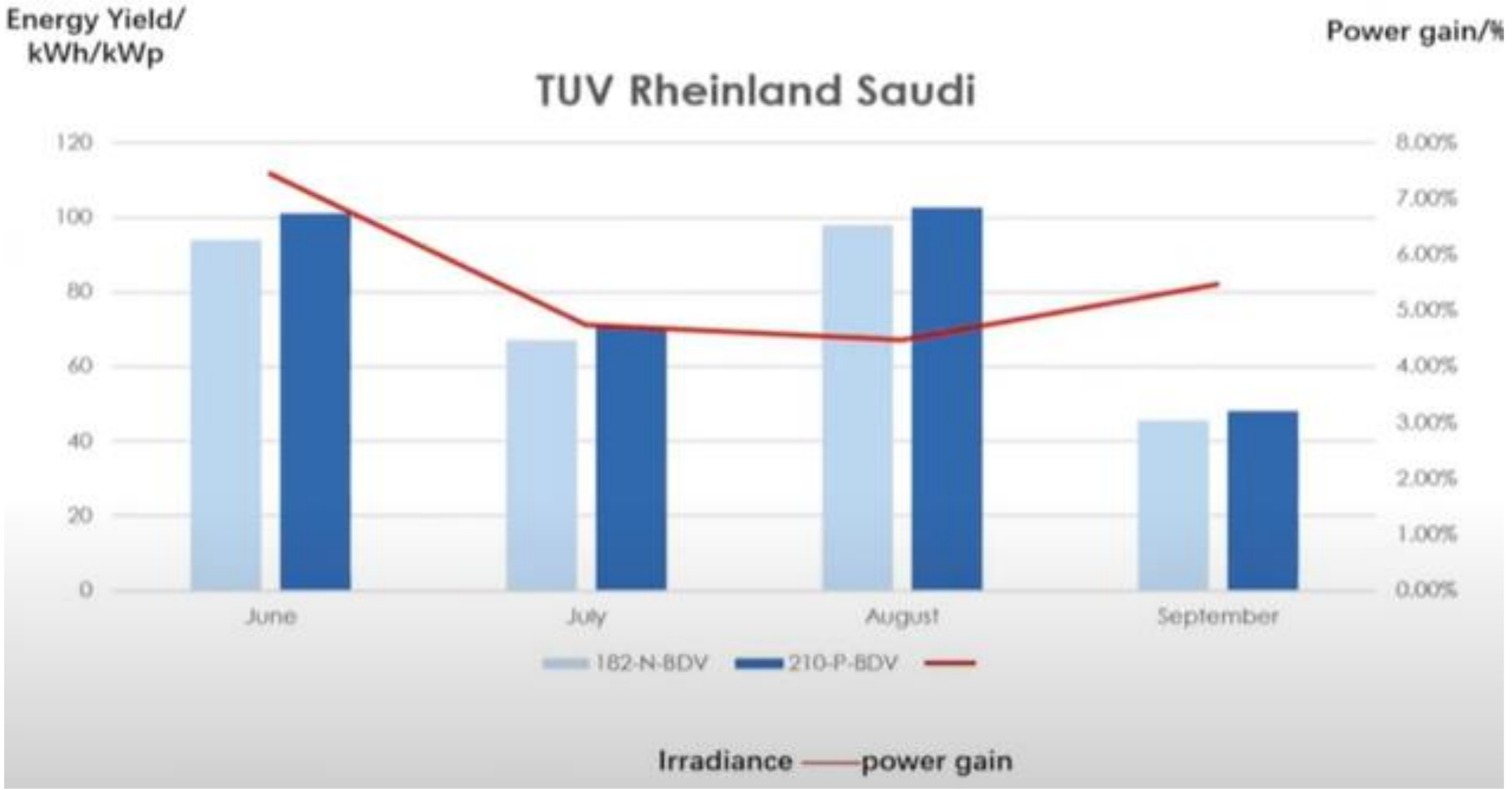
Technical Potential of TOPCon Technology

TOPCon Field Study

- **Location**
  Thuwal, Saudi Arabia
- **Climate type:**
  Tropical desert climate
- **Climate features:**
  High temperature, high irradiance
- **Longitude & latitude:**
  22°18'N; 39°06'E
- **Monitoring period:**
  2022/6/01~2022/9/30
- **Modules compared:**
  JKM550N-72HL4-BDV
  XXX-645DEG XXXX

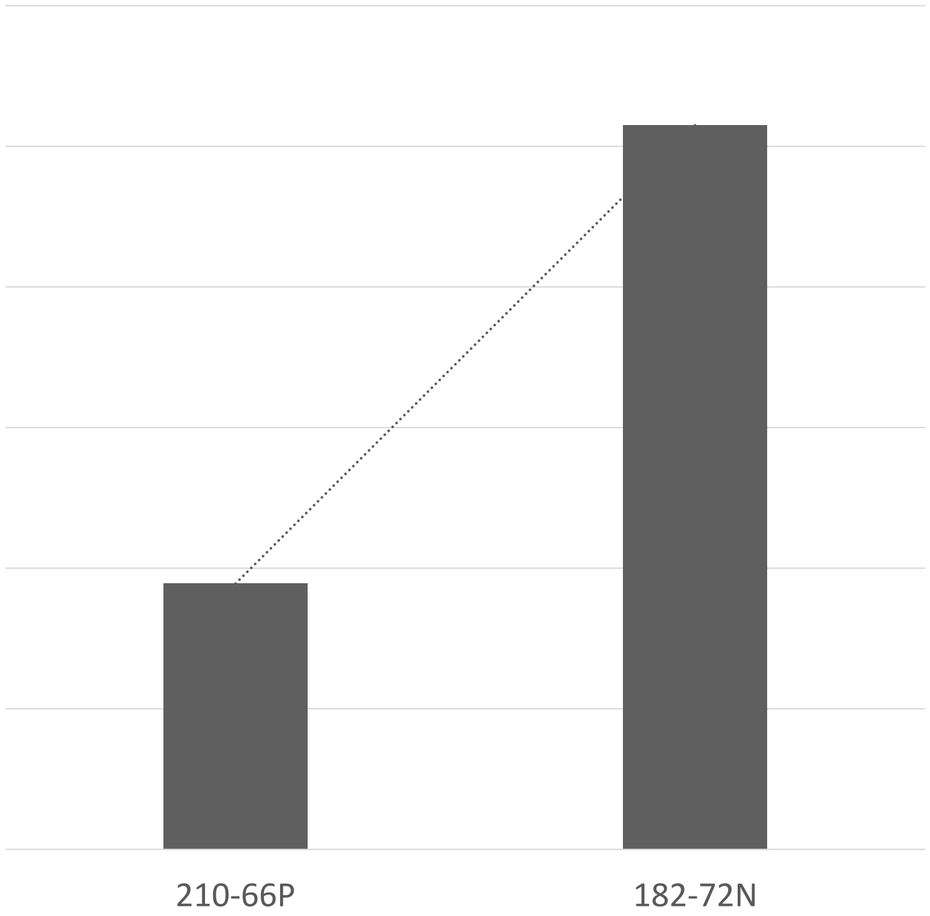
Module type	Power	Amount (pcs)	Installation	Ground type	Location	Tilt angle	3rd-party body
Tiger Neo 72 Dual glass	550W	1	Fixed structure	Soil (15%~)	Saudi	25°	TÜV Rheinland
XXX 210-66 Dual glass	645W	1					

TOPCon Field Study

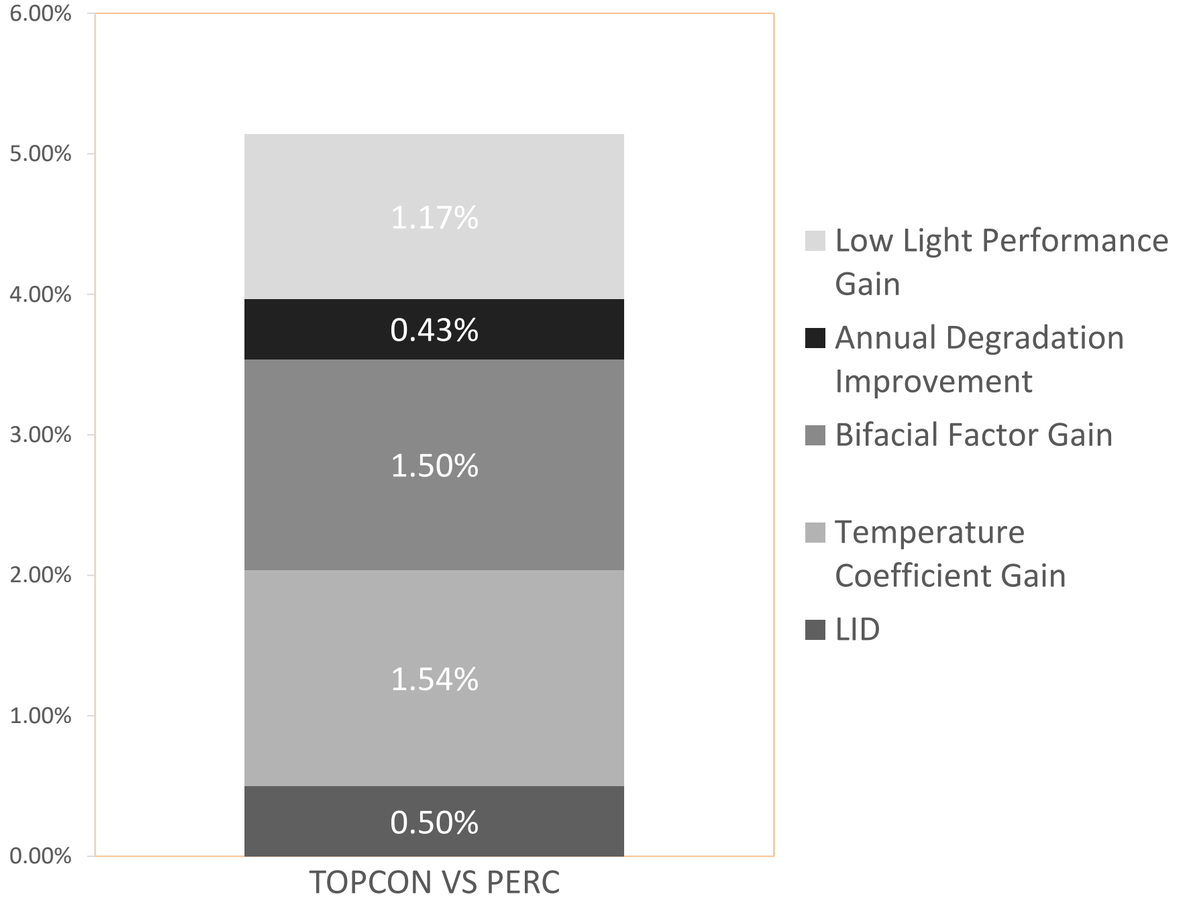


TOPCon Field Study

Energy yield



Energy Gain Contributors

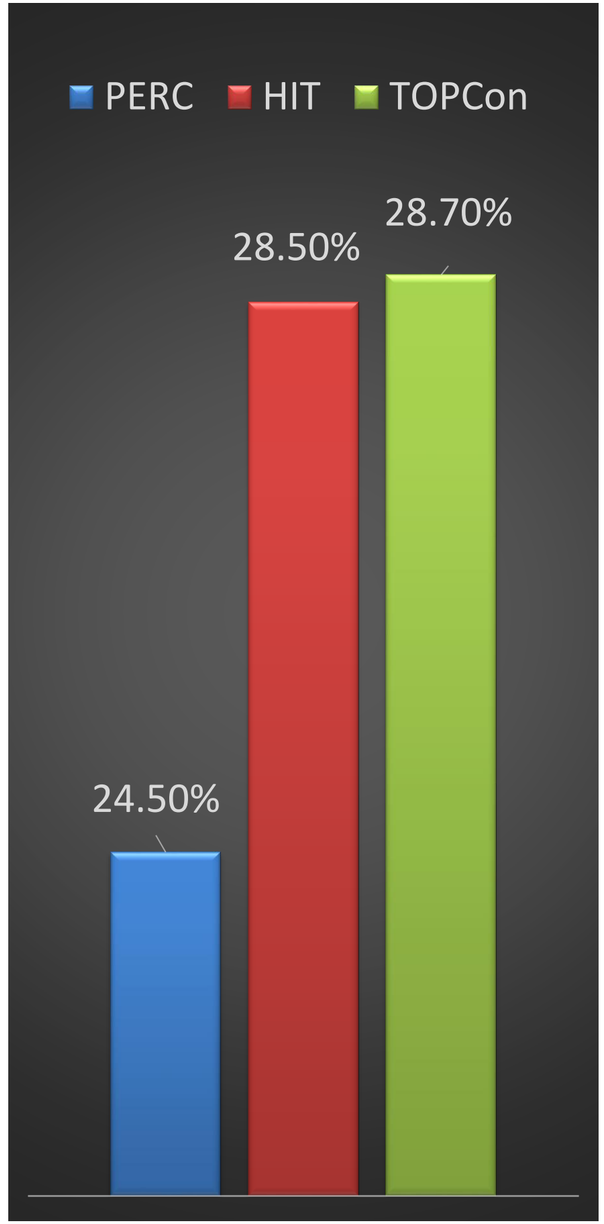


Technical Potentials of TOPCon

- TOPCon has the biggest theoretical cell efficiency limit compared to HJT & PERC.

	Electron selective		P-diffused n+		a-Si:H(i)/a-Si:H(n)		Thermal/PECVD SiO_x/poly-Si(n+)		Thermal/LPCVD SiO_x/poly-Si(n+)		Chemical/LPCVD SiO_x/poly-Si(n+)	
Hole selective			$J_{0,e}$	$\rho_{c,e}$	$J_{0,e}$	$\rho_{c,e}$	$J_{0,e}$	$\rho_{c,e}$	$J_{0,e}$	$\rho_{c,e}$	$J_{0,e}$	$\rho_{c,e}$
			109	0.26	2	0.017	5	0.016	2.7	0.0013	10	0.0001
Al-doped p+	$J_{0,h}$	550	11.7	56.5%	12.9	34.6%	12.8	23.4%	12.9	8.5%	13.0	1.2%
	$\rho_{c,h}$	0.005	3.5%	24.5	1.2%	27.0	1.2%	26.9	1.2%	27.1	1.2%	27.1
a-Si:H(i)/a-Si:H(p)	$J_{0,h}$	2	11.9	45.6%	14.0	24.4%	14.0	14.9%	14.6	5.5%	14.6	0.8%
	$\rho_{c,h}$	0.055	97.9%	24.9	43.9%	28.5	27.6%	28.6	26.2%	28.9	26.0%	28.9
Chemical/PECVD SiO_x/poly-Si(p+)	$J_{0,h}$	16	11.9	46.7%	14.0	23.0%	13.8	15.5%	14.2	5.7%	14.2	0.8%
	$\rho_{c,h}$	0.008	21.4%	24.9	5.9%	28.5	6.1%	28.4	5.8%	28.7	5.7%	28.7

PERC p-TOPCon HJT n-TOPCon Bi-facial TOPCon



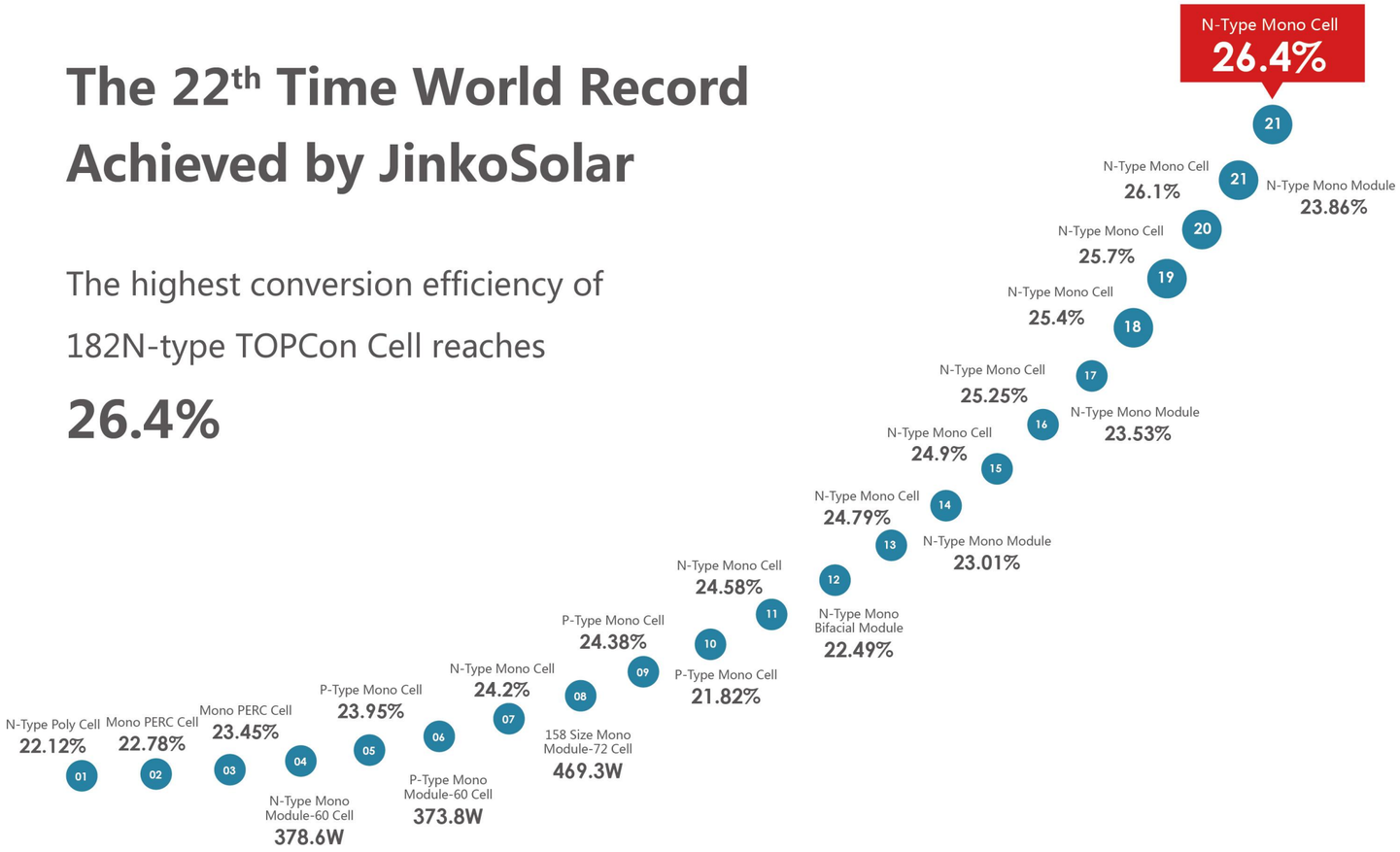
Source: Surface passivation of crystalline silicon solar cells: Present and future, Jan Schmidta, Robby Peibst, Rolf Brendela,2019, PV silicon Conference

Technical Potentials of TOPCon

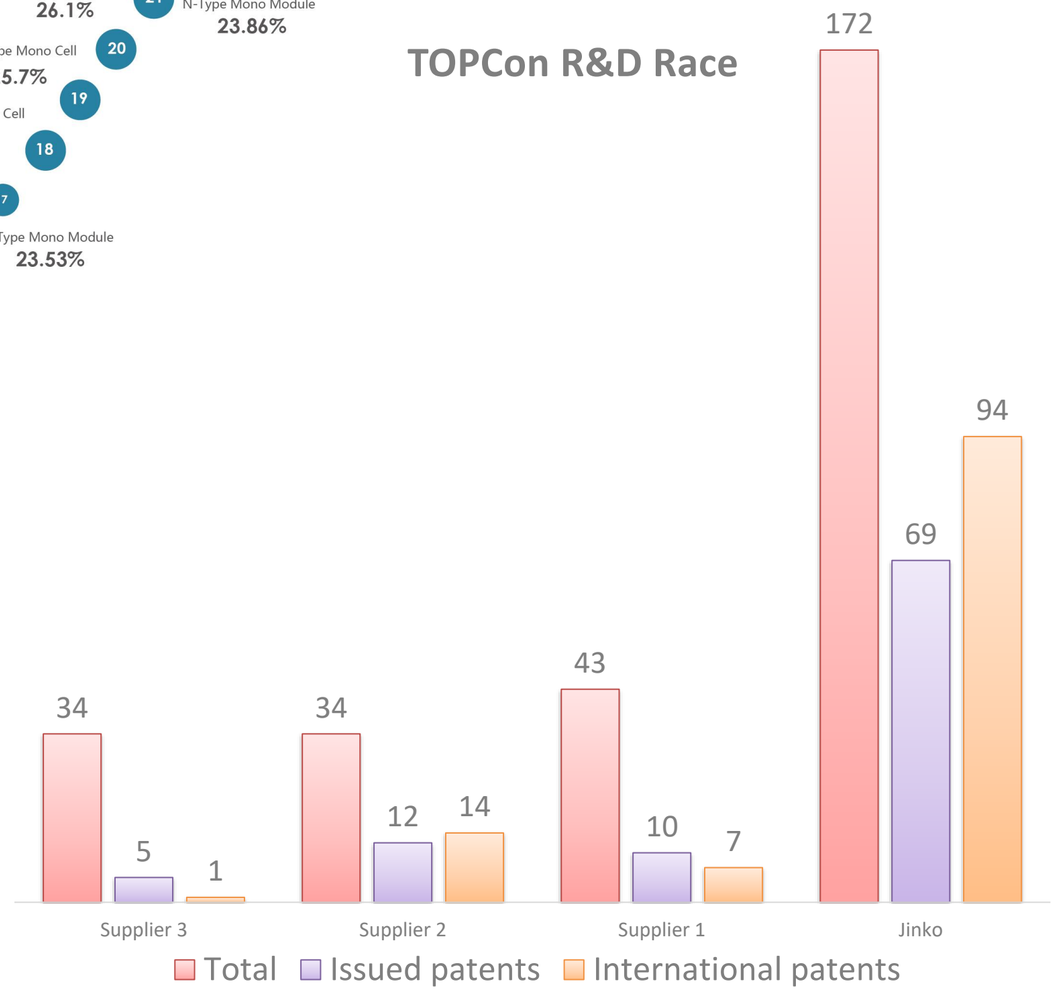
The 22th Time World Record Achieved by JinkoSolar

The highest conversion efficiency of 182N-type TOPCon Cell reaches

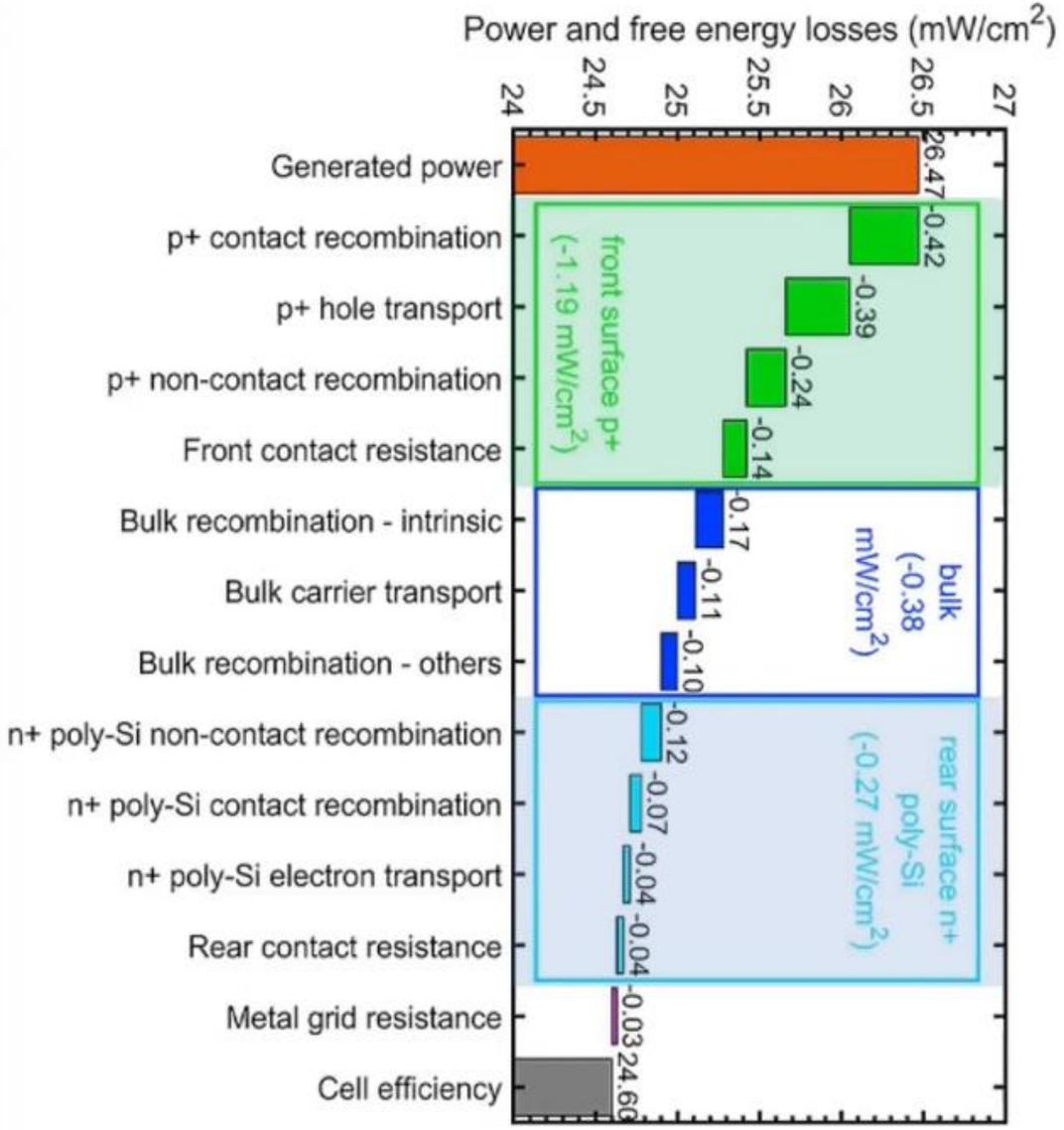
26.4%



Jinko Solar broke the cell efficiency world record 5 times in the last 24 months



Technical Potentials of TOPCon



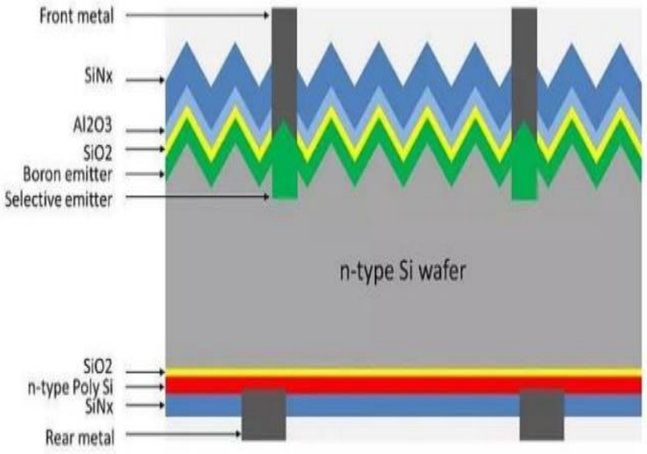
PolySi Optimization

Passive Film Optimization

Hydrogen Passivation

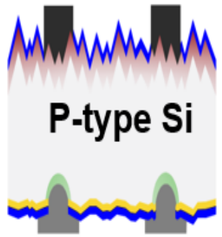
Selective Emitter SE

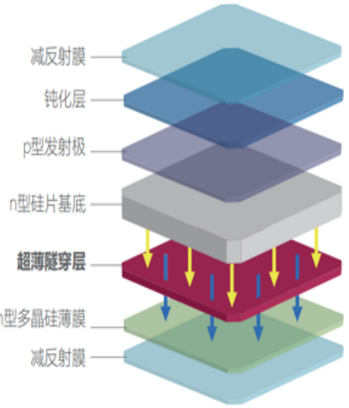
SE cell reduces **the contact resistance** between electrode and silicon wafer by doping high concentration of phosphorus in the contact area between busbar and silicon wafer.

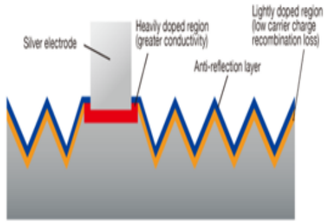


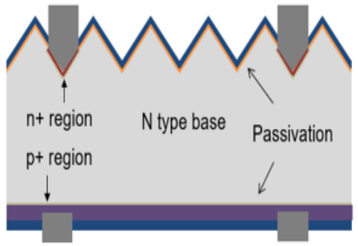
Technical Potentials of TOPCon

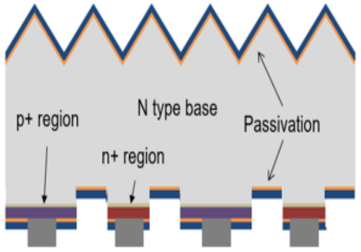
BSL 23.45%	2022 25~25.2%	2023 25.5~25.8%	2024 26.2-26.5%	2025 26.8~27.0%	2026 Expected Max Eff. >32.0%
0	1	2	3	4	5
PERC P-type Cell	TOPCon N-type Cell	TOPCon+ Selective Emitters	TOPCon Full Passivated 1.0	TOPCon Full Passivated 2.0	TOPCon Tandem Cell

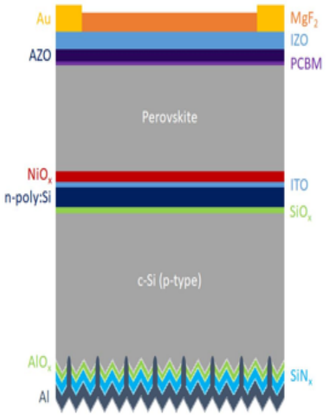








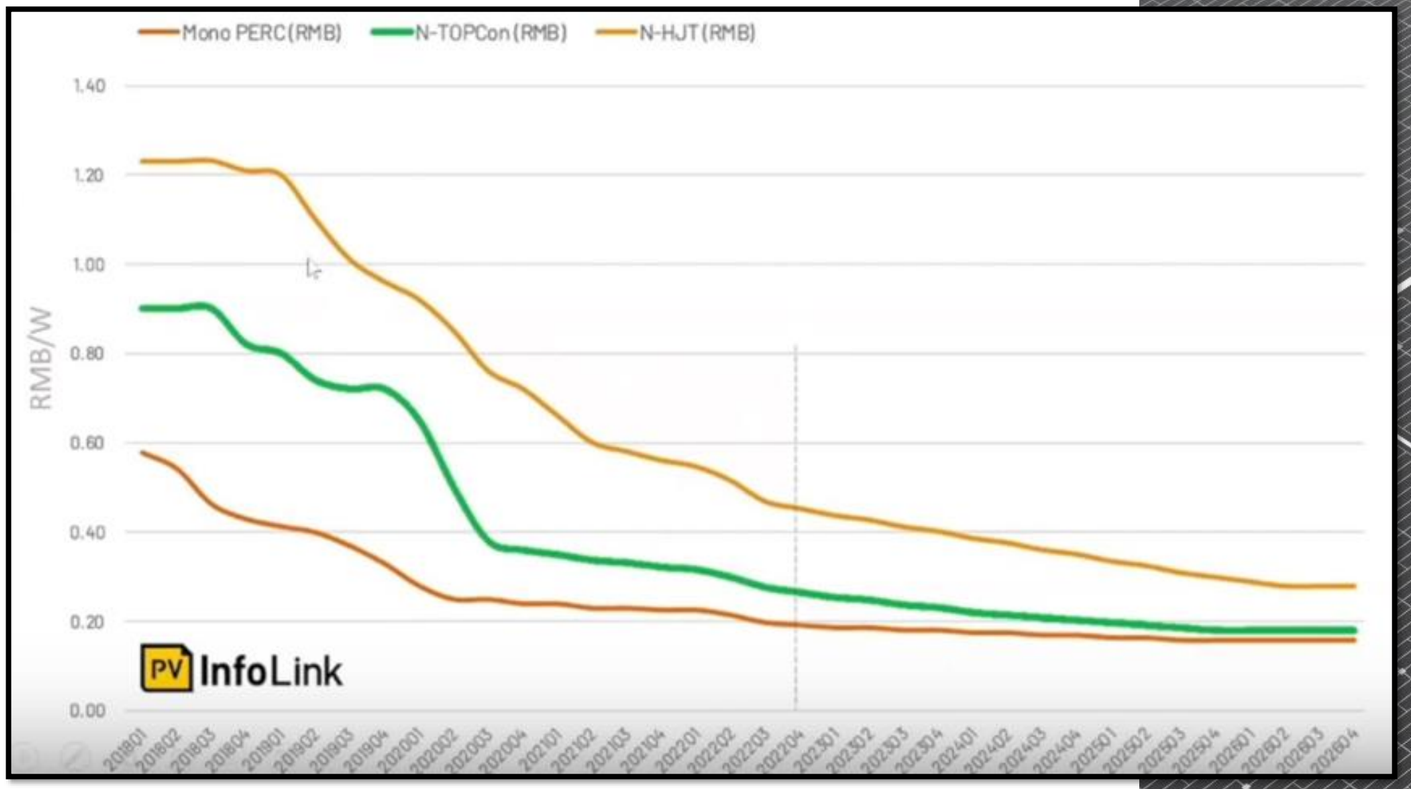




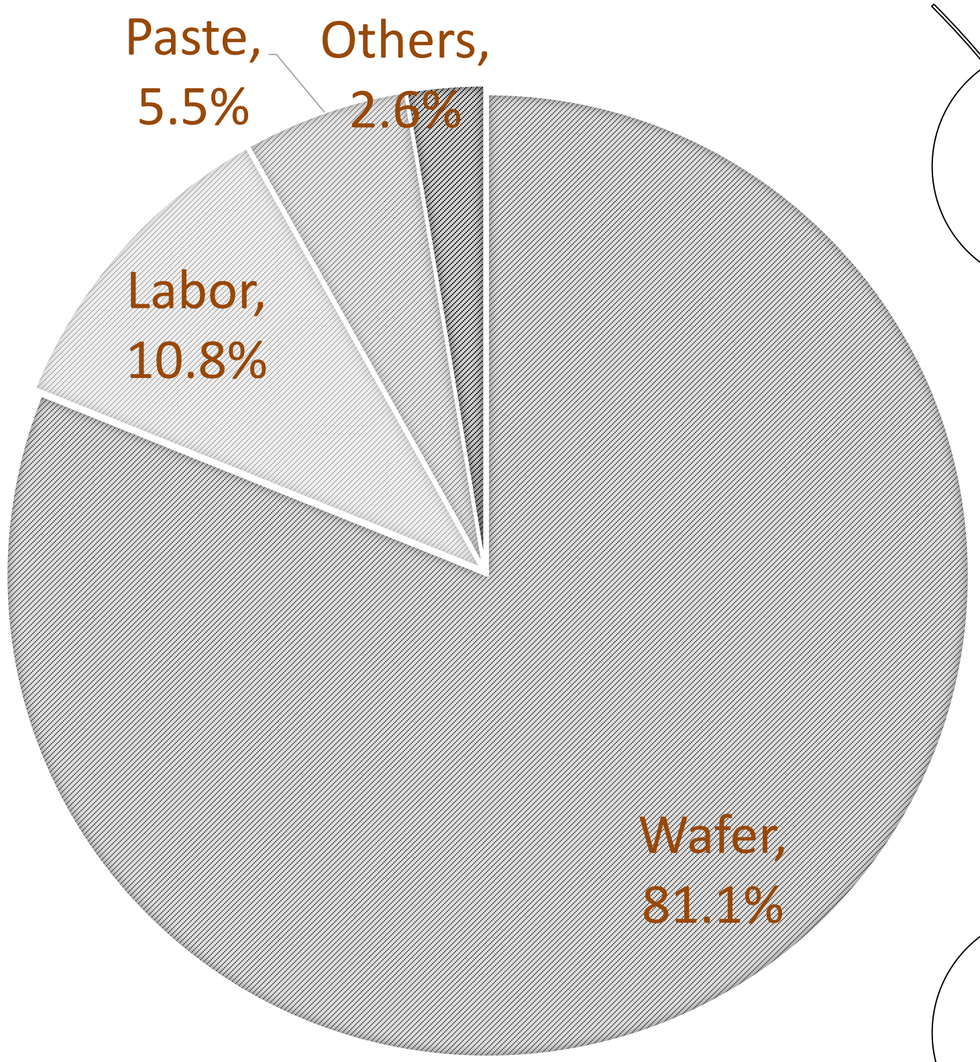
Cost Effectiveness of TOPCon

TOPCon Cost Reductions

- The price of TOPCon has reduced significantly in the last two years and it became very competitive.
- According to PV InfoLink projection, the price of TOPCon cells will continue to drop and it may reach PERC levels in the near future.
- The price of improving PERC production line into TOPCon is about $7Mil/GW, and the price for new TOPCon production line is $27Mil/GW, while the price of new HJT production line is around $63Mil/GW.
- Due to small price gap between PERC and TOPCon, TOPCon offers better LCOE by around 5%, and because of this many projects in MENA switched to TOPCon modules.



TOPCon Cost Reductions



Metallization

- Development of modern MBB technology
- Materials optimization (silver)

Process

- Develop more optimized passivation and doping technology.

Silicon Cost

- Reduce wafer thickness
- Wafer cutting optimization

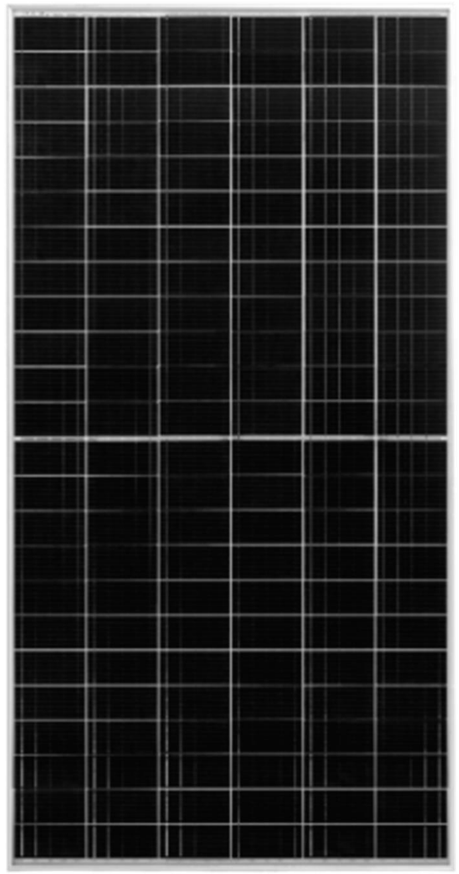
Production Capacity

- Improve manufacturing tools
- Large modules

Reliability of TOPCon Technology

TOPCon Reliability

Tiger Neo
Bifacial Dual Glass 72 cells
N-Type TOPCon



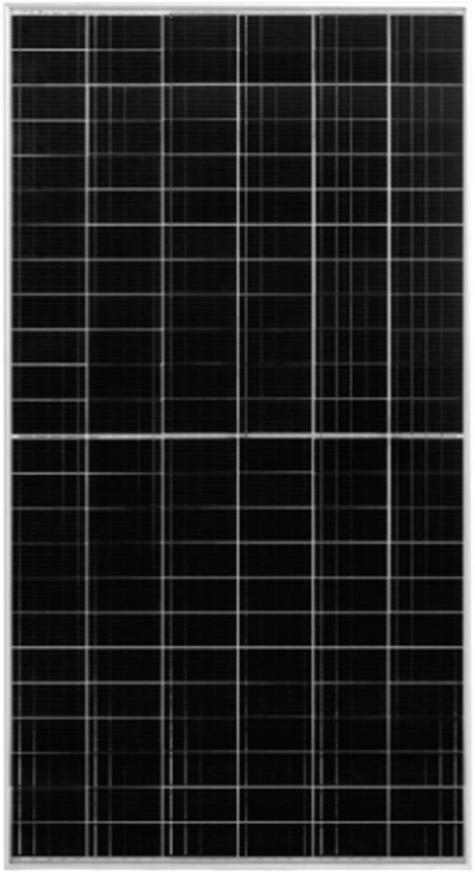
Same BOM

Same Dimensions

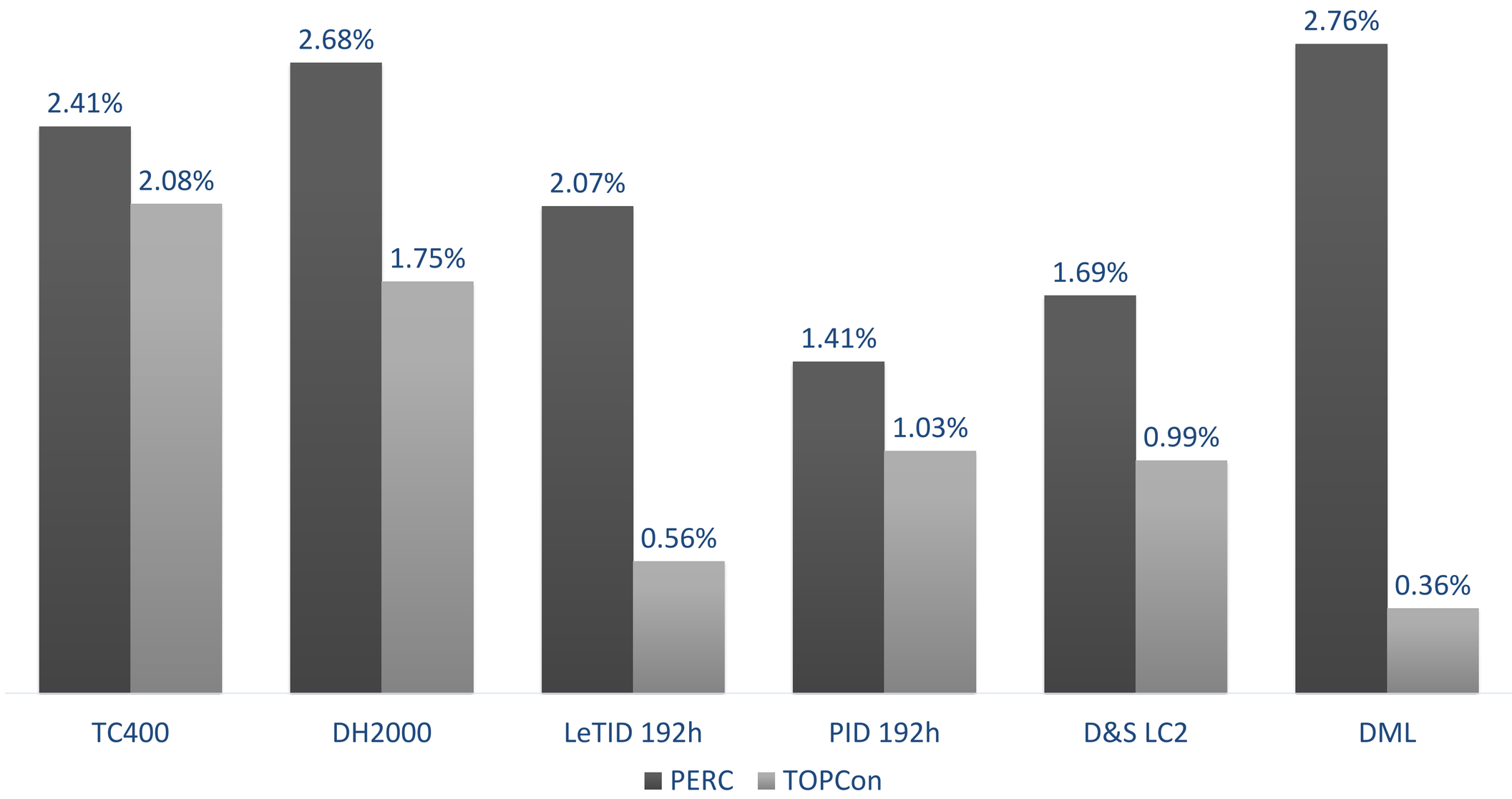
Same Cell Size

Different Cell Technology

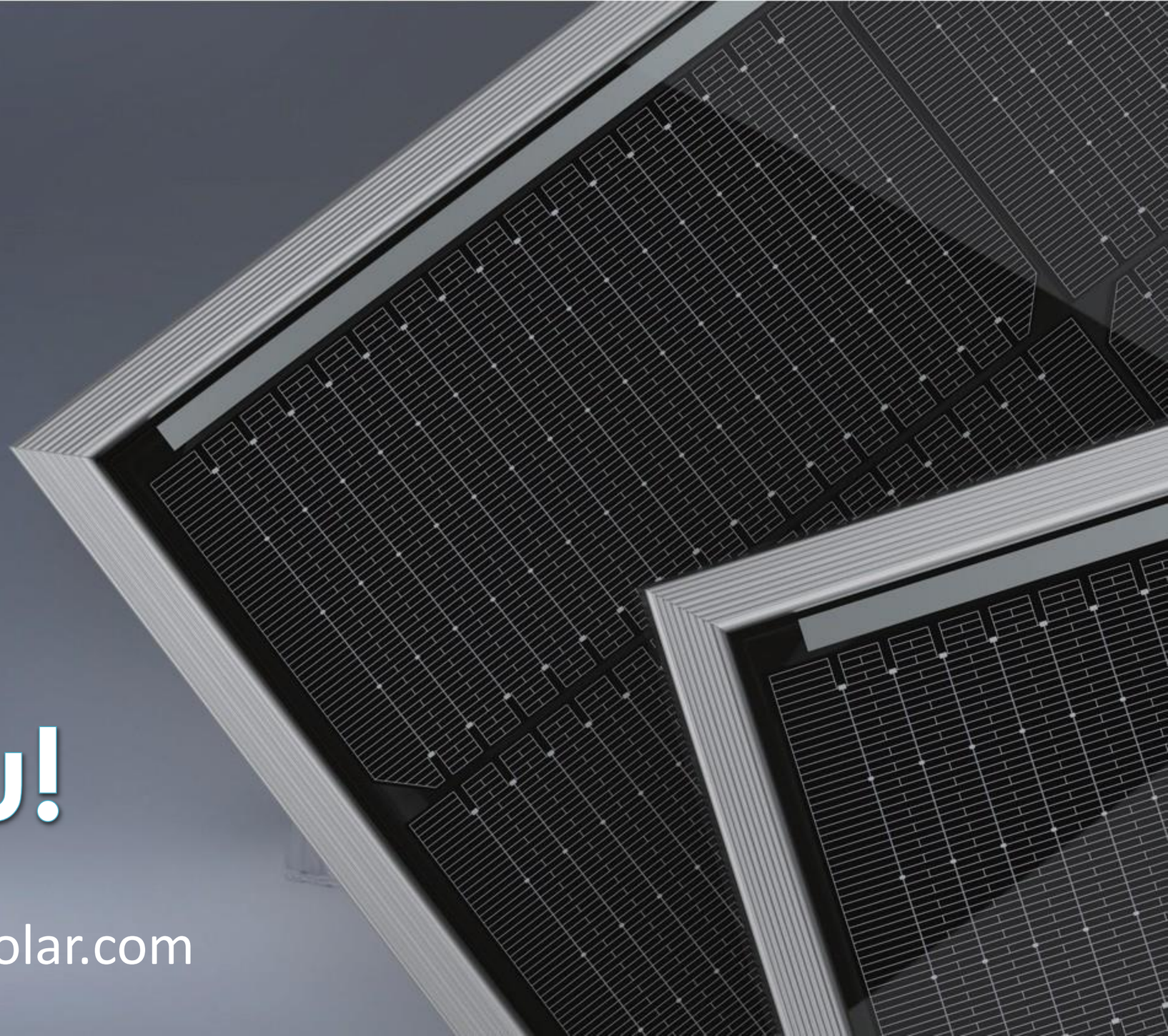
Tiger Pro
Bifacial Dual Glass 72 cells
P-Type PERC



TOPCon Reliability



Solar
JinKO
Building Your Trust in Solar



Thank You!

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TOPCon's time to shine

Q&A

28 March 2023

11:00 am - 12:00 pm | CEST, Berlin
12:00 pm – 1:00 pm | AST, Riyadh
1:00 pm – 2:00 pm | Dubai

Mark Hutchins
Editor
pv magazine

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Thursday, 6 April 2023
11:00 am – 12:00 pm CEST, Berlin, Paris, Madrid
5:00 pm – 6:00 pm CST, Beijing

Transparent advantage – Why transparent backsheet bifacial modules can beat out the cumbersome competition

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