Hot topics and key questions for the solar industry in 2025

Solar Technology and Cost service – 2025 Q1 webinar

Agenda

- Today's Speakers
- Company Introductions
- Solar Technology and Cost
  - 2025 outlook for supply and demand
  - What to watch out for in the US market
- Module Tracker – new modules and technology trends
- Insights from CRU's Silicon Metal services
- UVID and module testing outlook for 2025
- Q&A

Today's Speakers

Presenters

Alex Barrows
Head of PV
CRU

Molly Morgan
Senior Analyst
CRU

Tristan Erion-Lorico
VP of Sales and Marketing
Kiwa PVEL

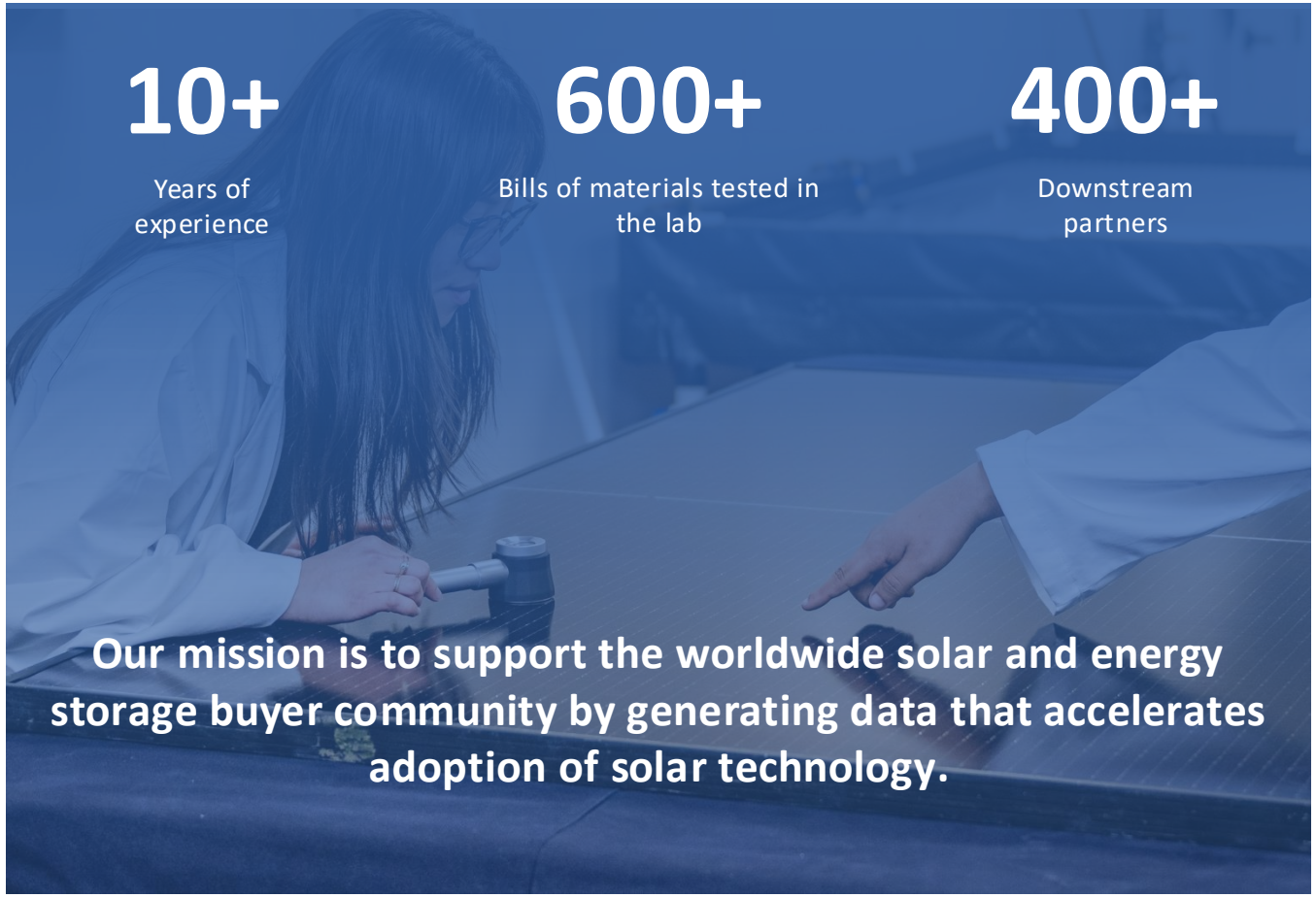
Moderator

Max Macpherson
Senior Program Manager
Kiwa PVEL

Guest Speaker

Jorn de Linde
Senior VP
CRU

Kiwa PVEL is the Independent Lab of the Downstream Solar Market



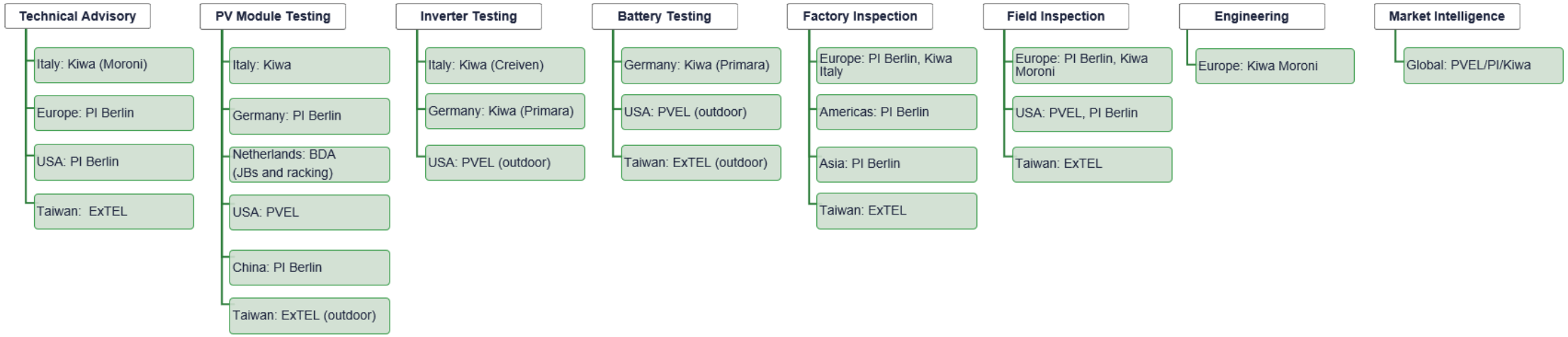
Services at a glance

- Extended reliability and performance testing for PV modules
- Batch testing of PV modules
- Outdoor testing at PVUSA, an iconic grid-connected research site
- Data services for PV buyers and investors

See more details at kiwa.com/pvel

Kiwa overview

- Kiwa is a global testing, inspection and certification (TIC) company, founded in 1948.
- Headquartered in Rijswijk, the Netherlands with more than 10,000 employees, working in over 37 countries. Kiwa is primarily active in renewable energy, construction, manufacturing, fire safety, medical devices, food & water.
- Kiwa's solar businesses at a glance:



- Kiwa's mission is to create trust by contributing to the transparency of the quality, safety and sustainability of products, services and organizations as well as of personal and environmental performance.

Market intelligence that empowers confident decision-making - today, tomorrow and for the future

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- In-depth analysis of global demand, production, trade and stocks for 50+ commodity markets
- Historical and forecast prices, news and analysis of commodity market developments
- Short, mid and long-term outlooks for production, demand, price outlook, scenario and risk analysis
- Independent cost information and analysis of cost drivers by asset
- 1000+ independently assessed prices
- Robust and transparent methodologies
- Compliance with IOSCO code of best practice
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- Strategy development
- Market assessment
- Due diligence
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Events

Connecting industry communities

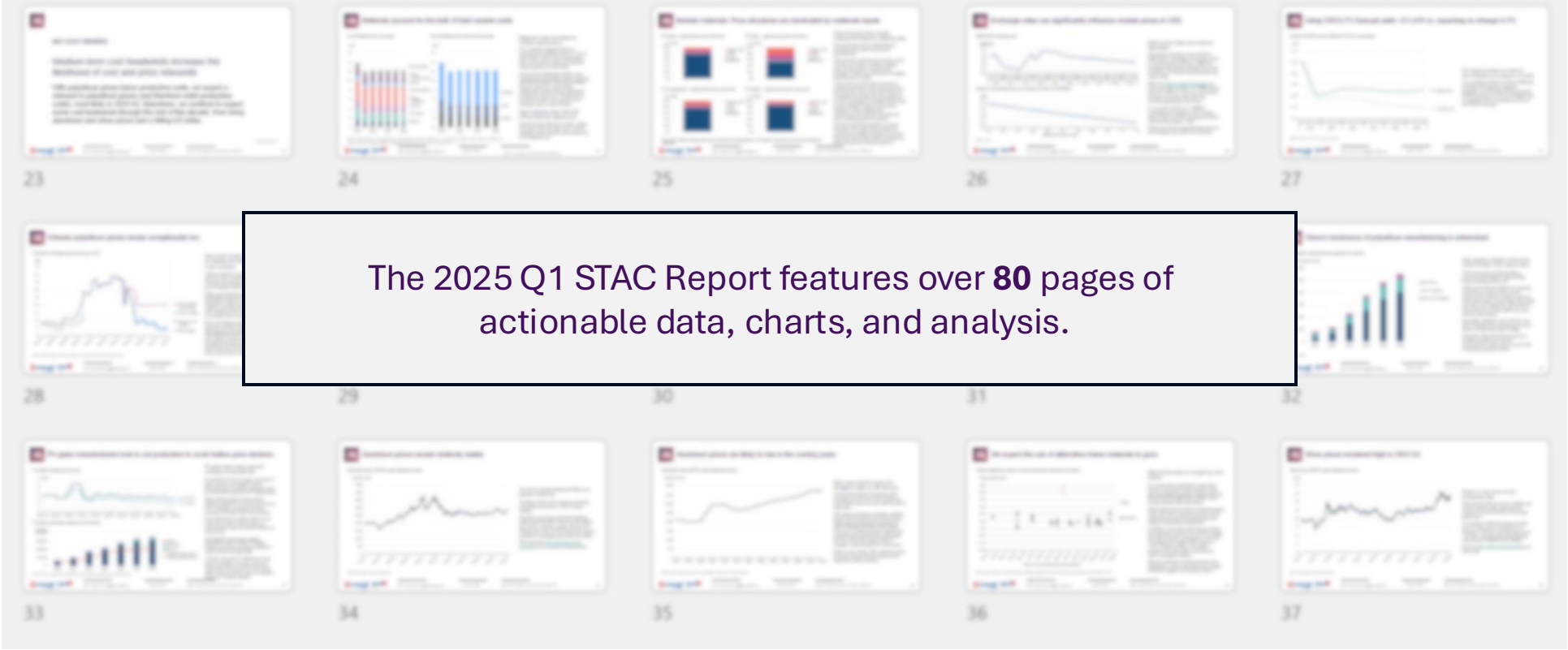
- Technical and commercial events and training
- Conferences and exhibitions
- Briefings
- Webinars

Sustainability

Advisory and analytics

- Analysis of carbon emissions through the value chain
- Policy and regulation assessment
- Forecast carbon prices
- Scenario planning
- Tailored advisory

STAC report overview



The 2025 Q1 STAC Report features over **80** pages of actionable data, charts, and analysis.

To learn more, or to subscribe to the STAC Report, email pvel@kiwa.com.

Solar Technology and Cost – key topics to watch in 2025

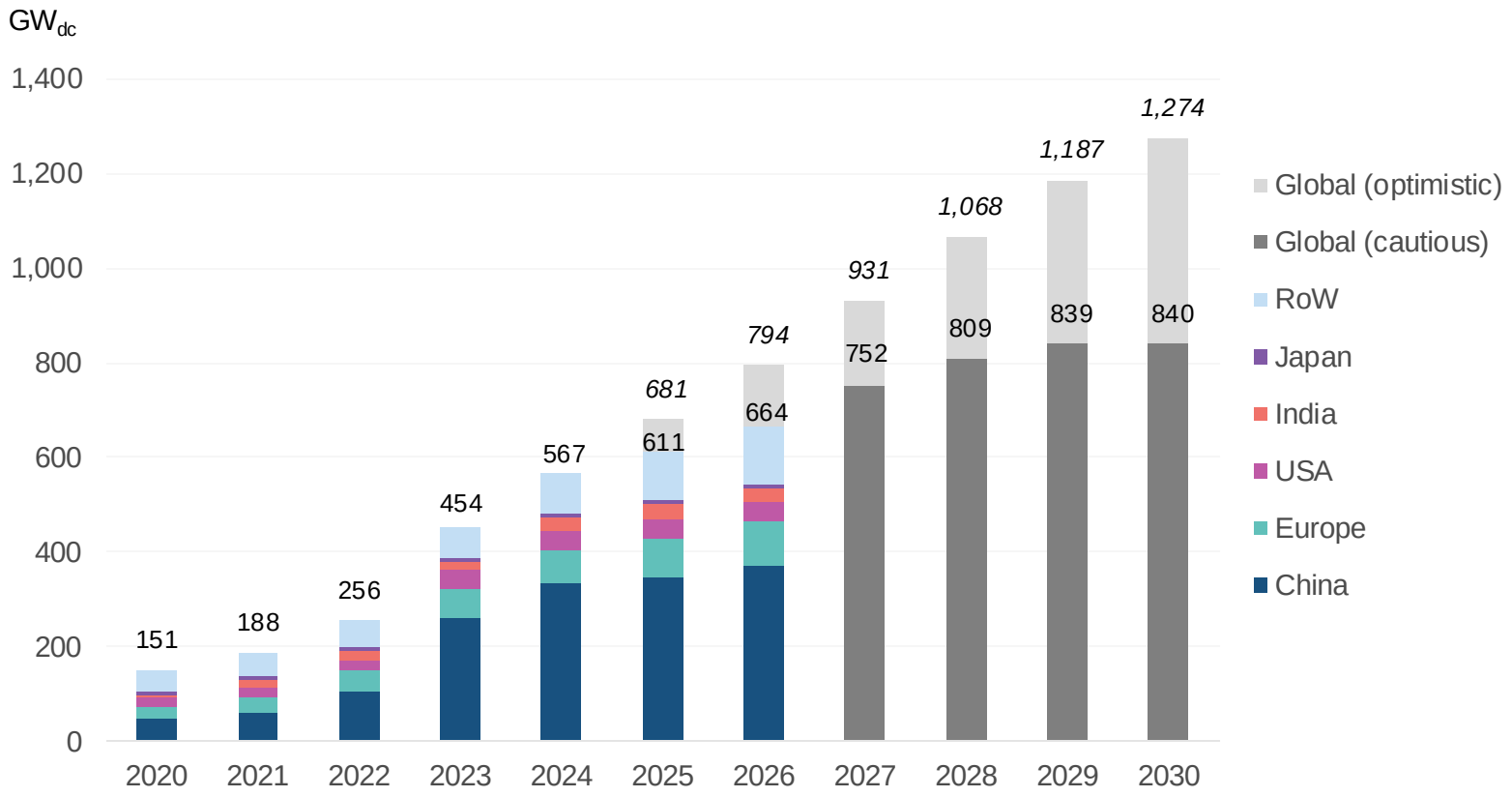
Demand: Growth in annual installations should continue, but at an increasingly subdued rate

Supply: Overcapacity will not be alleviated in 2025 – the success of exerting "self-discipline" on production volumes (via formal agreements or otherwise) will determine whether oversupply continues

US market: Cell imports will overtake module imports; key risks include new trade cases and Foreign Entity of Concern regulations

Demand remains solid, though 2025 growth is likely to be modest

Annual PV installations



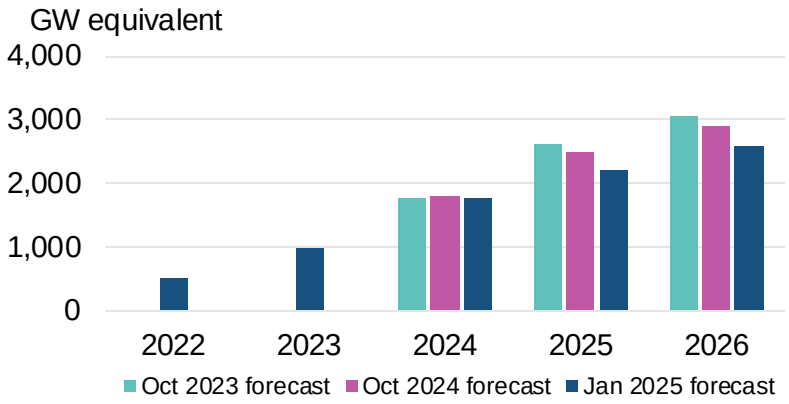
Annual PV installations exceeded 560 GW_{dc} in 2024

2025 installations like to reach 611-681 GWdc – 8-20% y/y growth

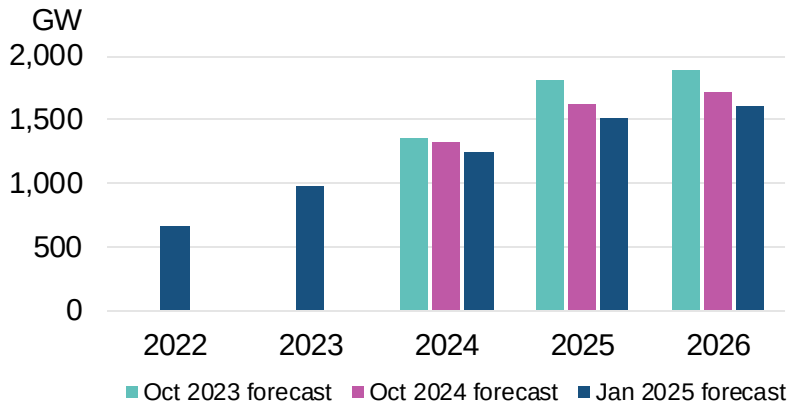
DATA: CRU

Reductions in capacity plans are not yet close to sufficient to solve overcapacity

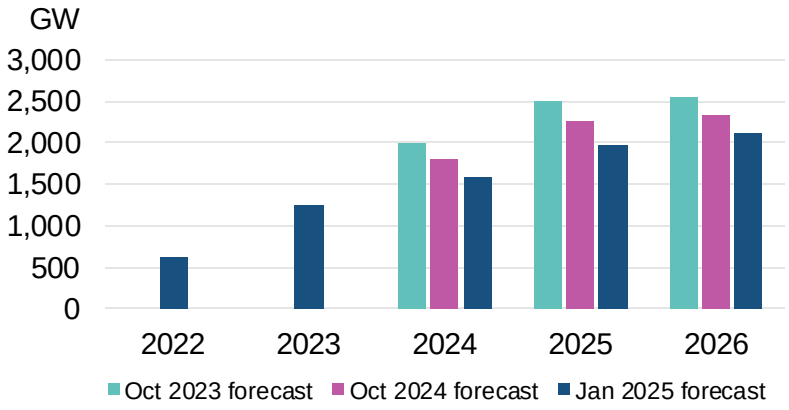
Polysilicon capacity



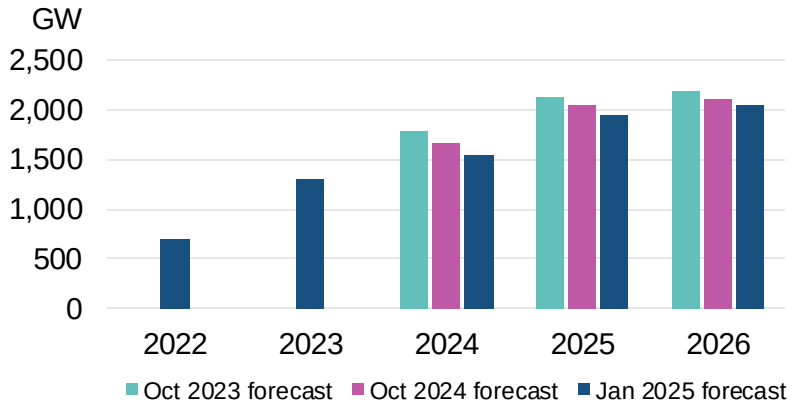
Wafer



Cell capacity



Module capacity



While capacity plans are no longer as aggressive as they were, the outlook remains for capacity growth

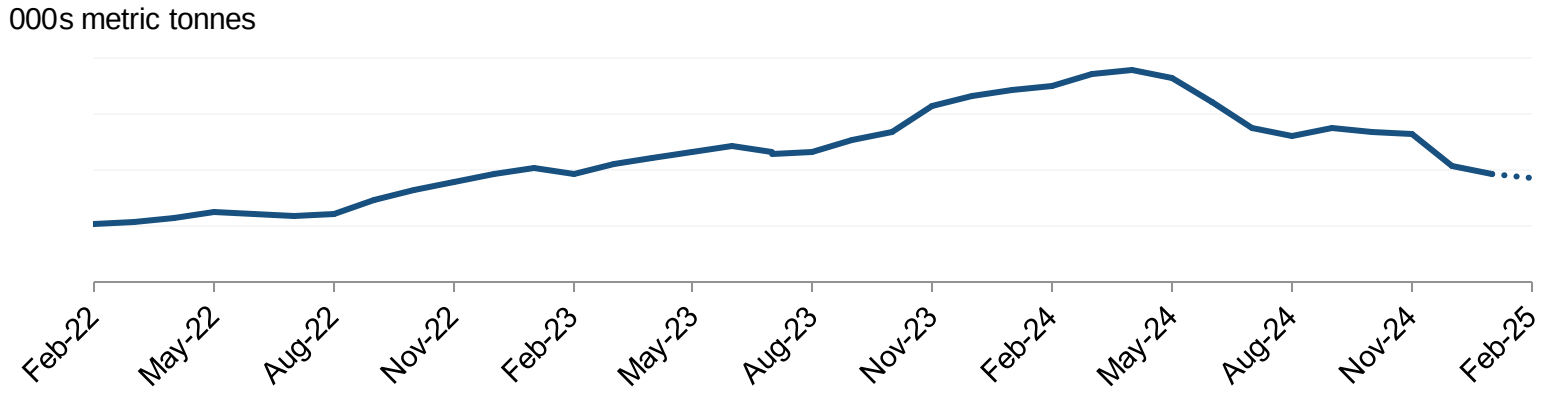
We expect 2026 installations to be 660-800 GW. Meanwhile, planned capacity through the value chain for the end of 2025 is 1.5-2.2 TW

A rebalancing of supply and demand will require a significant volume of capacity to exit the market, or for manufacturers to exert far more discipline in terms of utilization levels

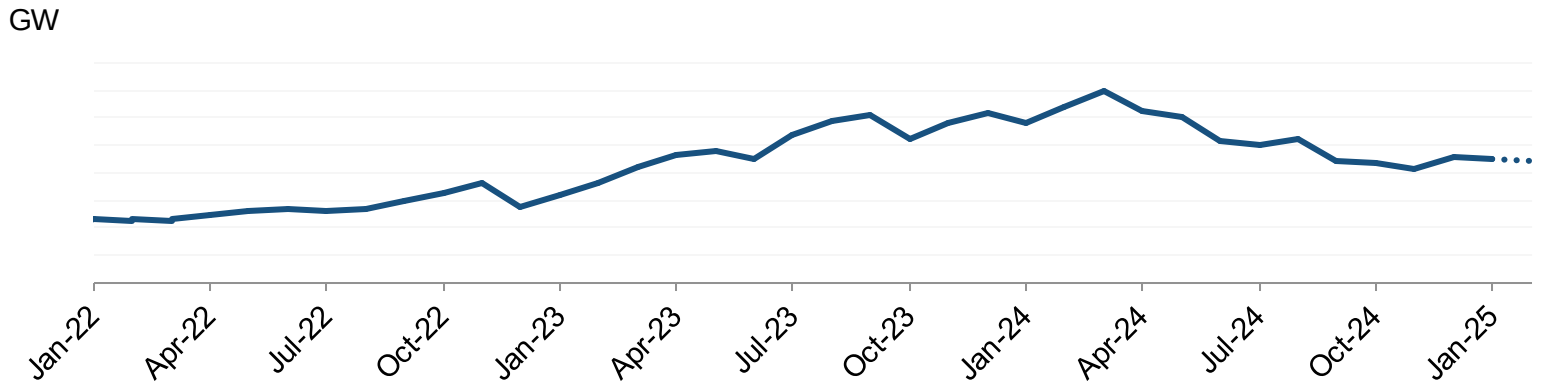
DATA: CRU Solar Technology and Cost Service

Chinese poly and wafer production cuts continue

Chinese monthly polysilicon production



Chinese monthly wafer production



Chinese production cuts have brought volumes down to sustainable levels

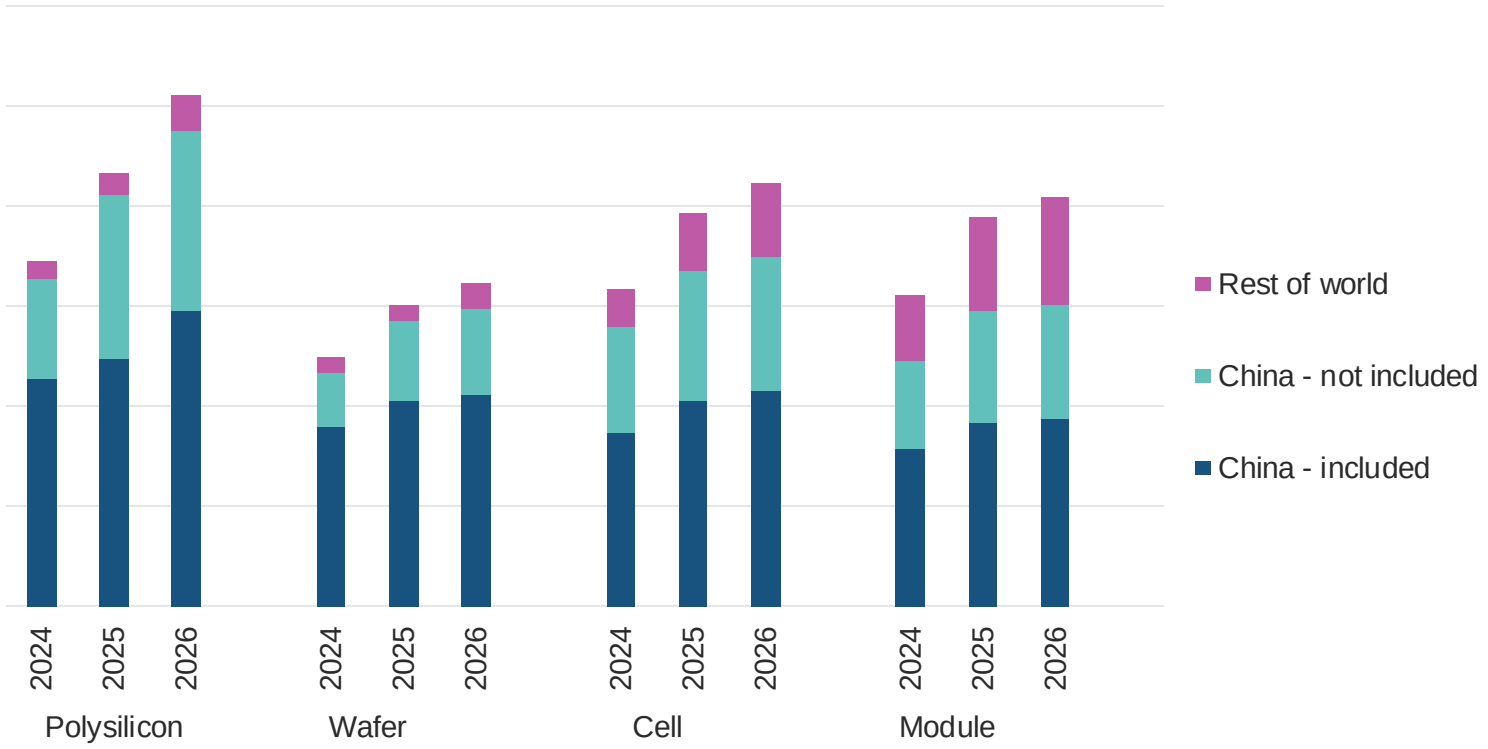
However, it will not be fast to work through inventory (~200 GW of excess modules!)

DATA: China Silicon Association

“Self discipline” agreement could usher in production quotas in China

Capacity included in the “self discipline” group

GW (or GW equivalent)



Self discipline agreement signed by 33 leading manufacturers in December 2024

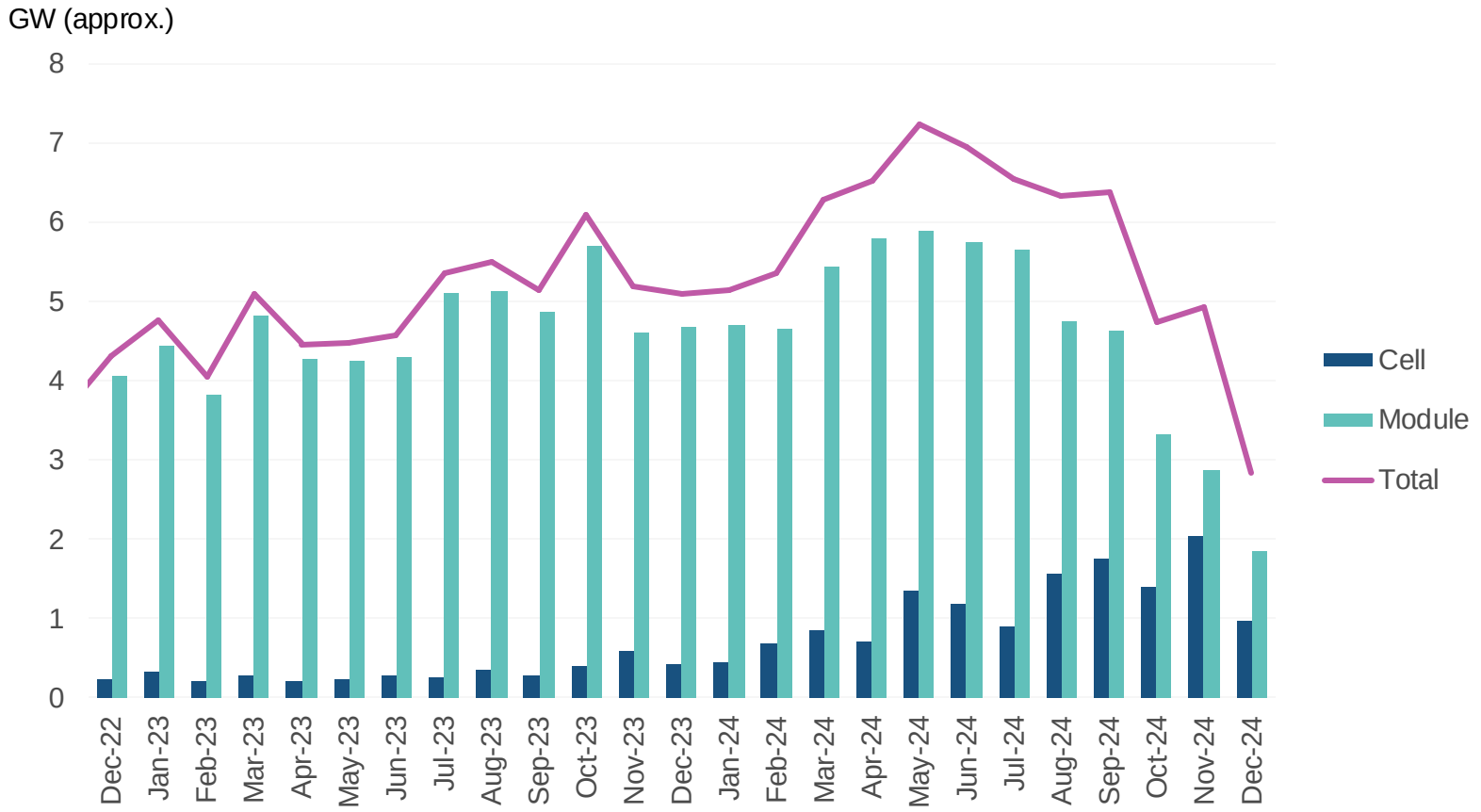
Proposed quota levels would be low enough to allow a significant depletion of global inventory if they covered all companies

However, signatories currently account for only 69%, 77%, 62% and 64% of total capacity in China for poly, wafer, cell and module

DATA: CRU

Module imports from Laos and Indonesia begin to grow

US monthly imports



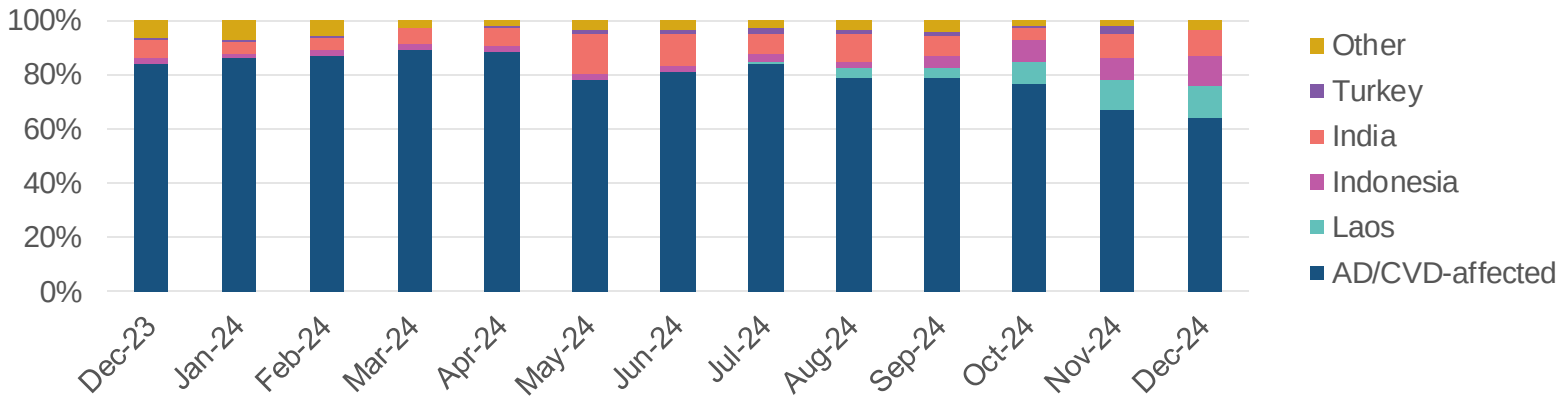
US cell and module imports declined significantly through 2024 H2, while US cell imports have climbed (unsteadily!)

Expect this to continue through 2025 as US module capacity continues to ramp up

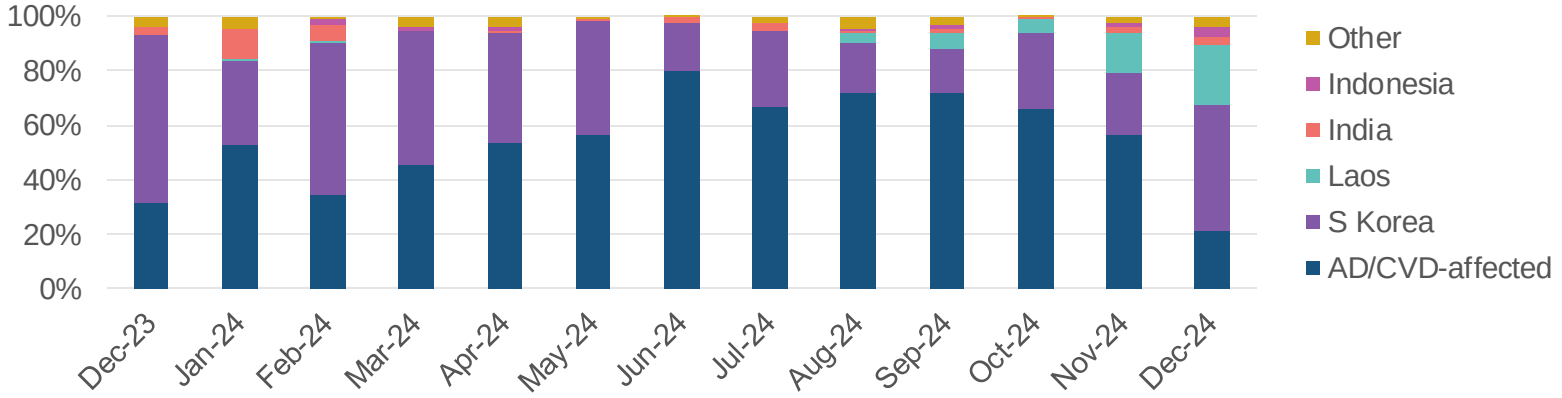
DATA: Kiwa PVEL analysis of data provided by the US Census Bureau and United States International Trade Commission

Module imports from Laos and Indonesia begin to grow

US module imports by country



US cell imports by country



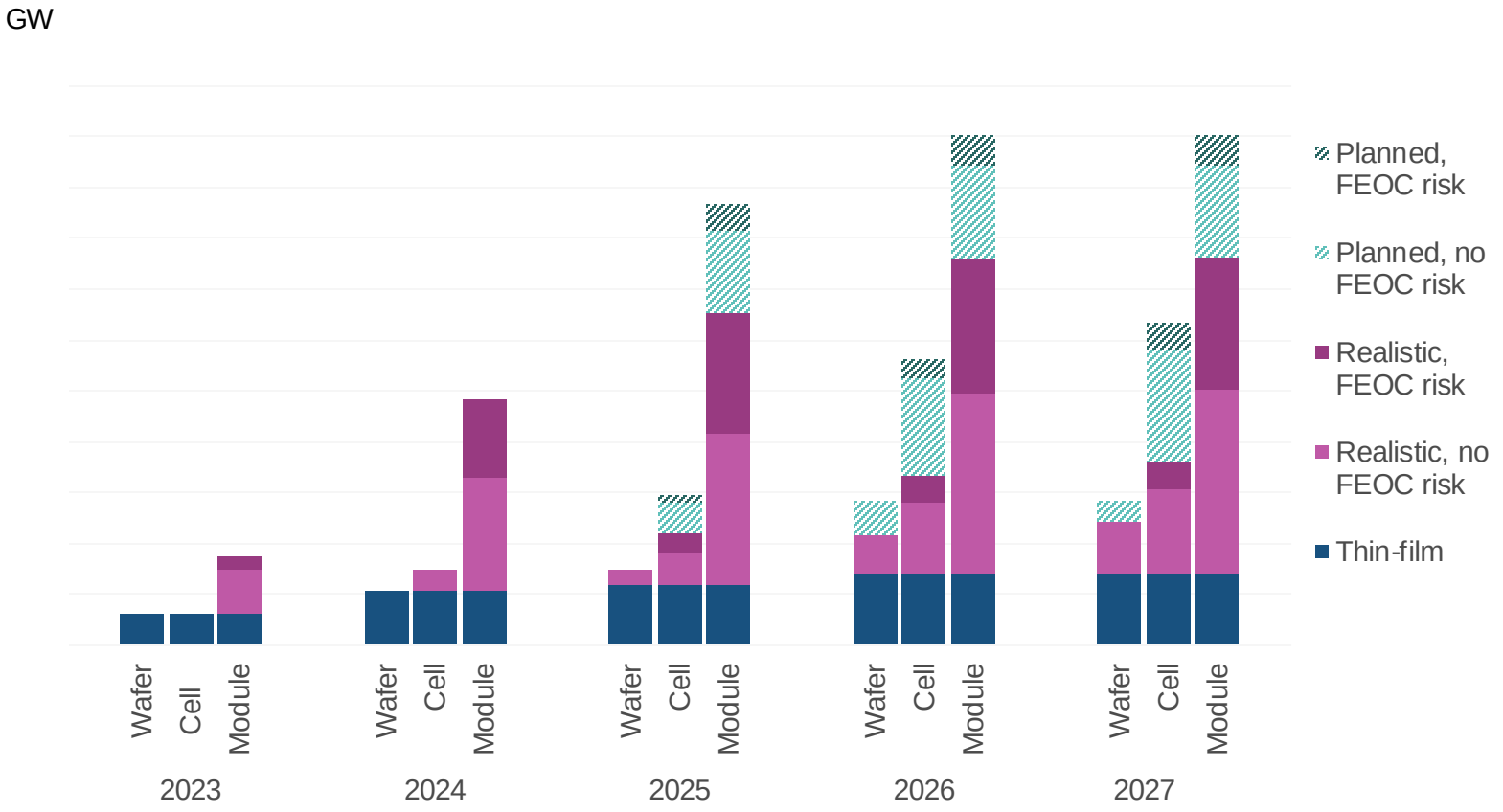
Imports from Laos and Indonesia are growing rapidly – up from 2% of imports in 2024 Q1 (0.3 GW) to 19% in Q4 (~1.5 GW)

Watch for AD/CVD cases on countries like Indonesia and Laos, as well as possible other trade cases (e.g., Section 232 investigation on polysilicon)

DATA: Kiwa PVEL analysis of data provided by the US Census Bureau and United States International Trade Commission

Foreign Entity of Concern rules are likely in 2025

US manufacturing capacity



A bill excluding Foreign Entities of Concern (FEOCs, including Chinese companies) from receiving Section 45X manufacturing tax credits is likely to be passed in 2025

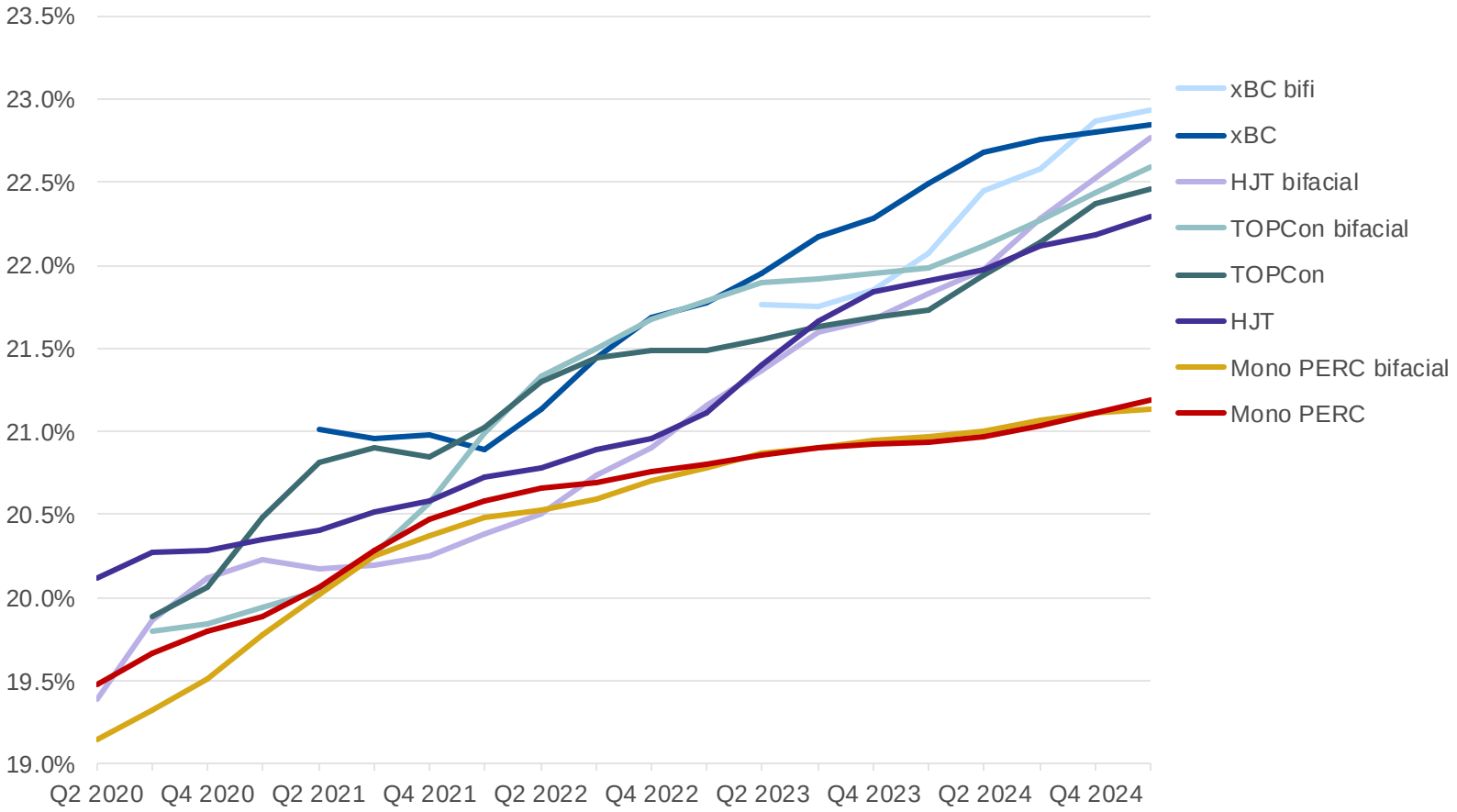
Around 40% of the c-Si module manufacturing capacity that we expect to be online by the end of 2025 could be impacted by FEOC rules

The impact of any bill will depend critically on the details

DATA: CRU

How has module efficiency evolved?

Production weighted mean (PWM) of efficiency by technology: three quarter rolling average



The advanced technologies are continually improving

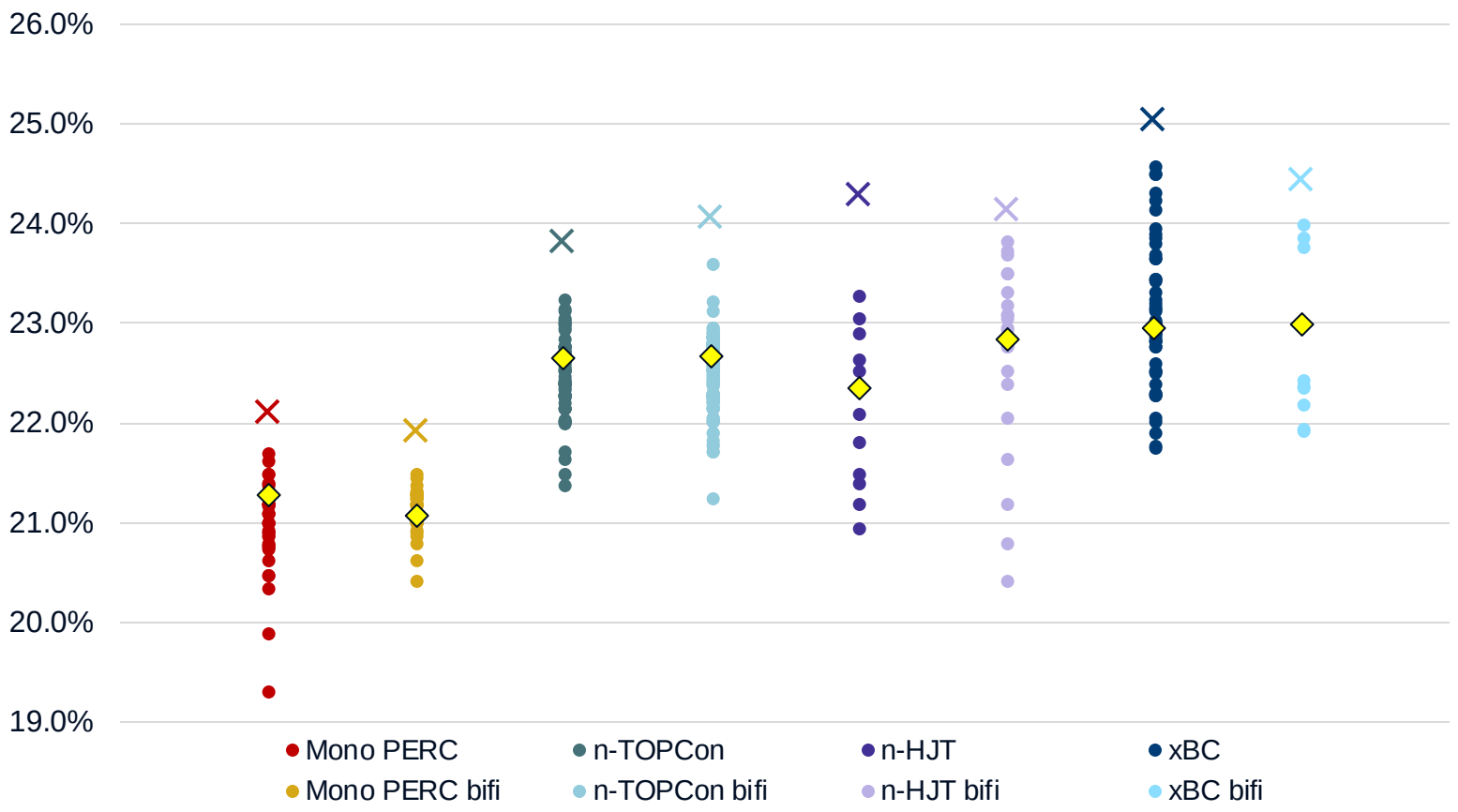
TOPCon and HJT technology efficiencies are neck-and-neck, with similar long-term maximum efficiency potentials

Back-contact technology continues its lead in both average and maximum efficiency

DATA: CRU

Where does module efficiency stand today?

Distribution of module series average efficiency by technology: Q1 2025



DATA: CRU

Mono PERC efficiency gains are well and truly a thing of the past

TOPCon and heterojunction technologies offer broadly similar efficiency ranges

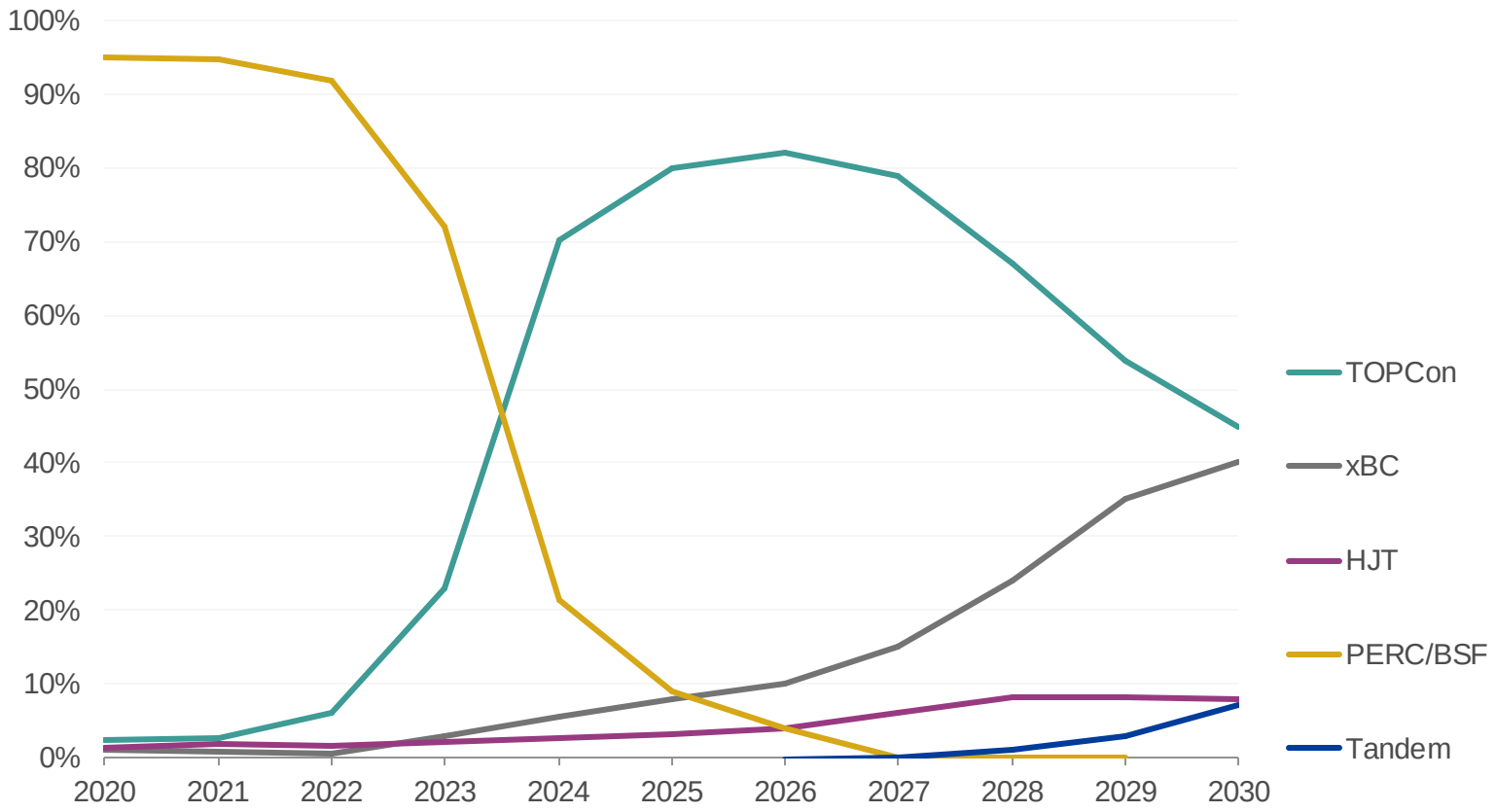
Back-contact leads the market in terms of maximum efficiencies, but with standard average efficiencies

Maximum efficiency

PWM average efficiency

Which PV technology will dominate the market in 2025 and beyond?

Market shares for mainstream PV technologies



Large-scale technology transitions can occur rapidly

TOPCon came to dominate market share though a rapid technology transition away from mono PERC

Market share will continue to be dominated by TOPCon in the near term, with tandem modules taking over in the 2030s

DATA: CRU

Silicon metal market and industry highlights

The market is currently characterised by significant imbalances that are weighing on silicon metal prices worldwide.

Current weak demand masks substantial long-term growth.

The solar industry will remain the principal driver of silicon metal consumption but other end-uses, notably batteries and semiconductors, will make significant contributions to future demand in certain markets.

After years of consistently rapid growth, China has established dominant supply positions in all segments of the silicon-value chain.

Although significant pockets of growth will emerge elsewhere, in large part linked to investments in solar value-chains, China will retain a central role in shaping the future trajectory of the global silicon metal market and industry.

Silicon metal market and industry highlights (cont.)

Silicon metal prices are principally shaped by the rate of demand growth, the resulting supply response, and the underlying production cost structure.

Existing plants will continue to provide additional capacity but there are significant constraints and ultimate limitations.

As lower-cost options are exhausted, a rising share of needed capacity will be in the form of brownfield and greenfield plants, increasingly located outside China.

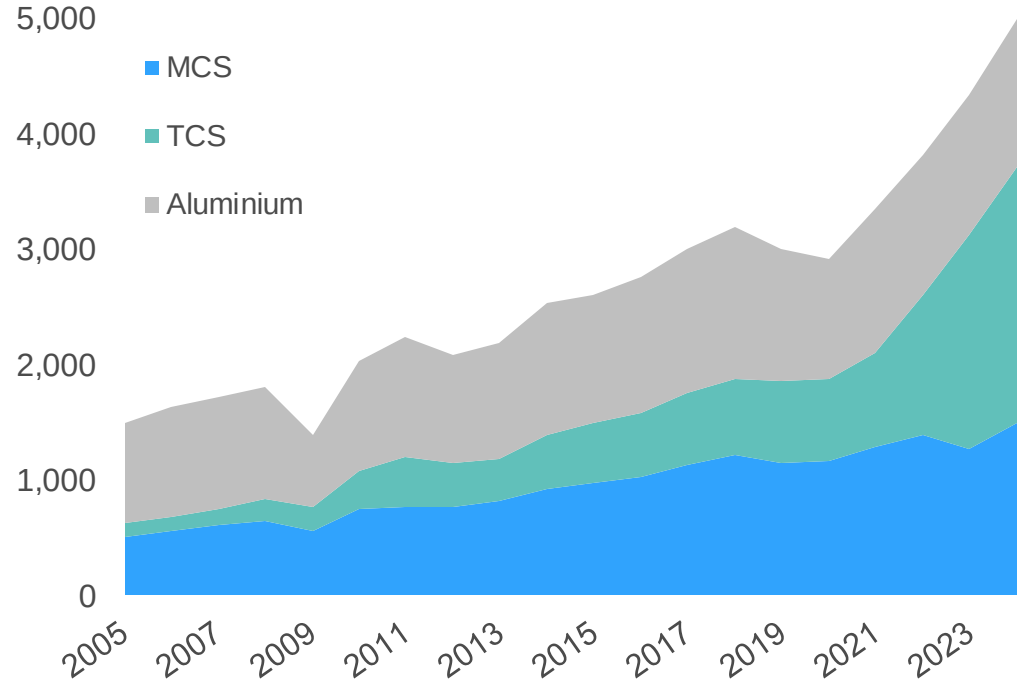
No single location offers the most attractive setting for new (greenfield) plants.

Affordable power remains a key consideration. Other important factors include access to raw materials, skilled labour, technology, and equipment; attractive logistics; carbon footprint; and in view of geopolitics and more restrictive trade policies, market access.

Solar energy is the key driver of silicon demand

Consumption is closely linked to polysilicon production and, by extension, China

Silicon metal demand by intermediate use, '000 t



DATA: CRU

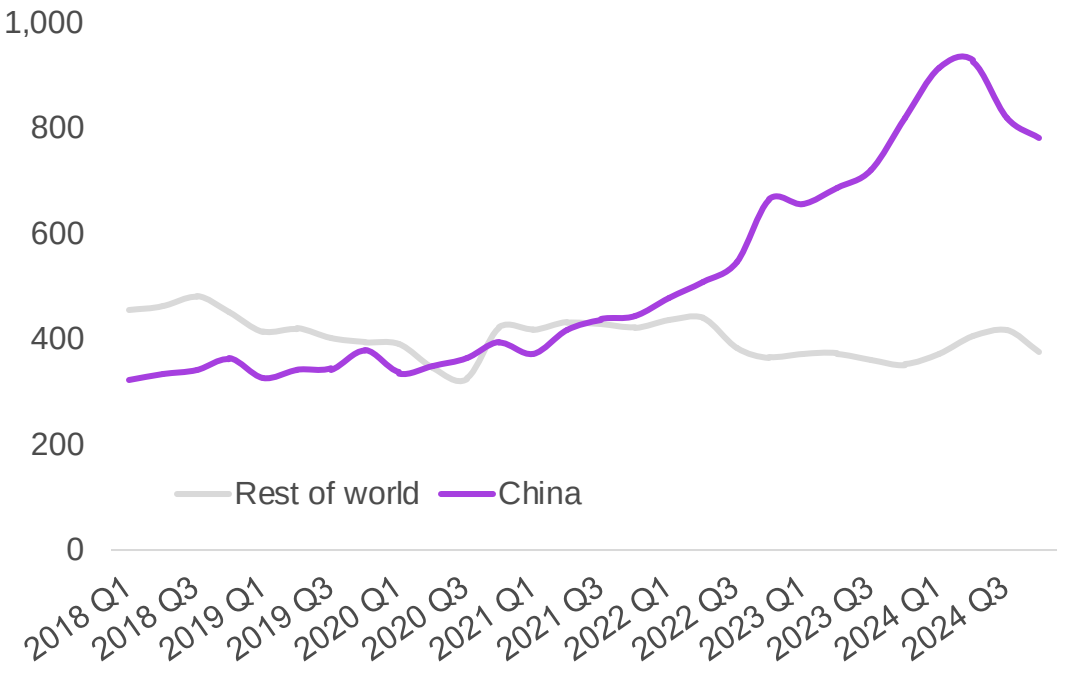
Although moderated by improved manufacturing efficiencies, the rapid expansion of solar-related polysilicon production has fueled large gains in silicon metal consumption.

Most of the growth in global silicon metal demand has occurred in China, facilitated by a massive build-up of local polysilicon and siloxane capacity, increasingly supported by captive silicon metal operations.

Global market conditions shaped by China

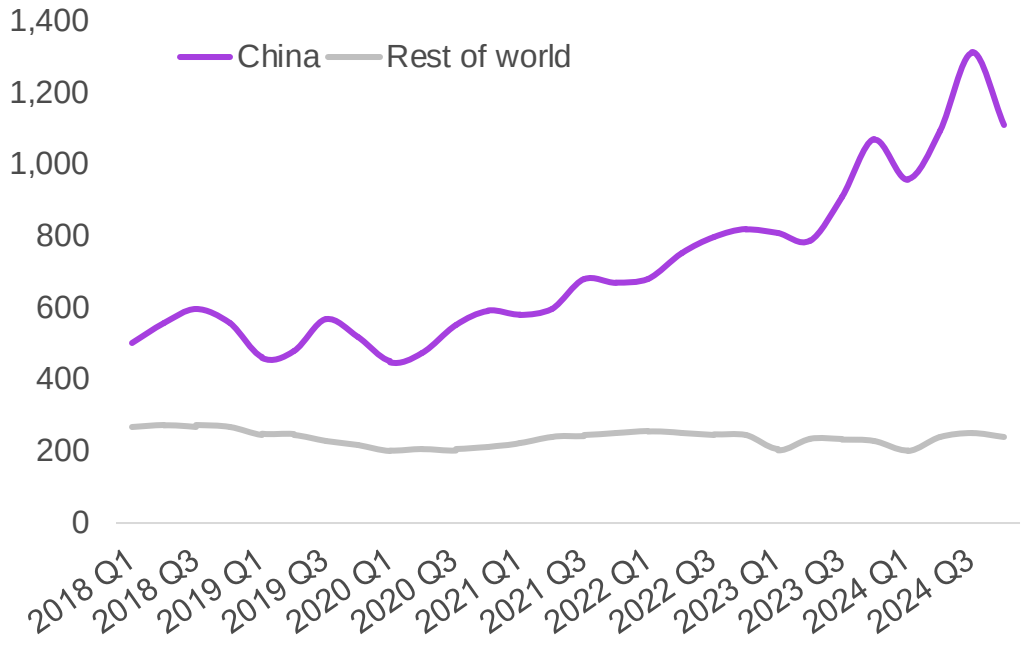
China has accounted for nearly all the variation in total demand and supply

Estimated silicon metal demand China vs. rest of world, '000 t



DATA: CRU

Estimated silicon metal production China vs. rest of world, '000 t

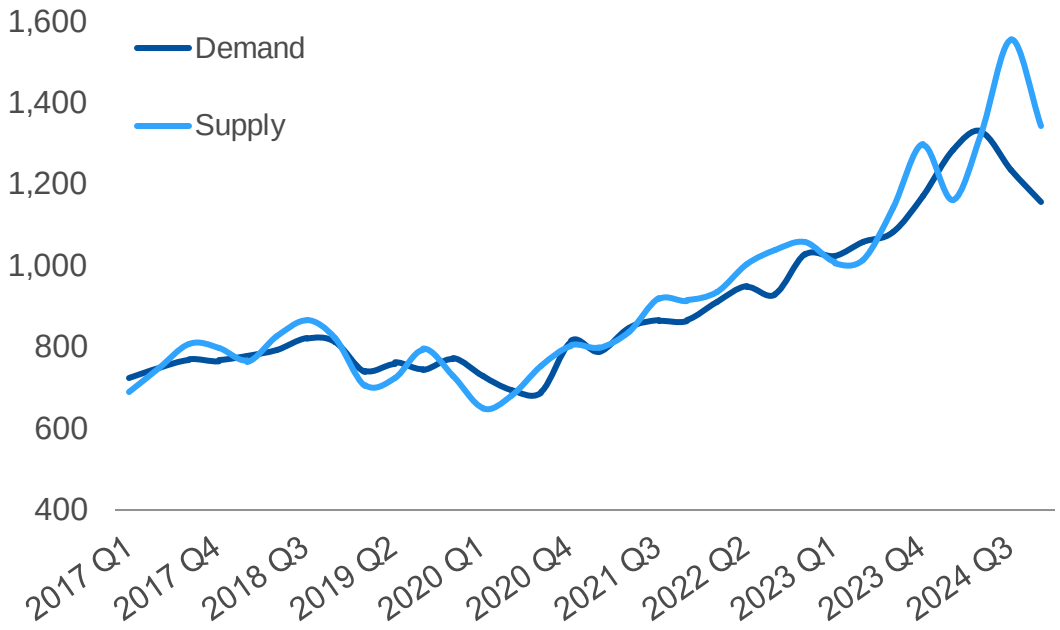


DATA: CRU

Uneven growth and significant imbalances

A large gap between total silicon metal supply and demand emerged in 2024 H2

Global silicon metal supply and demand by quarter, '000 t



DATA: CRU

The single biggest development in 2024 was a sharp contraction in Chinese silicon metal consumption caused by extensive curtailments in local polysilicon production.

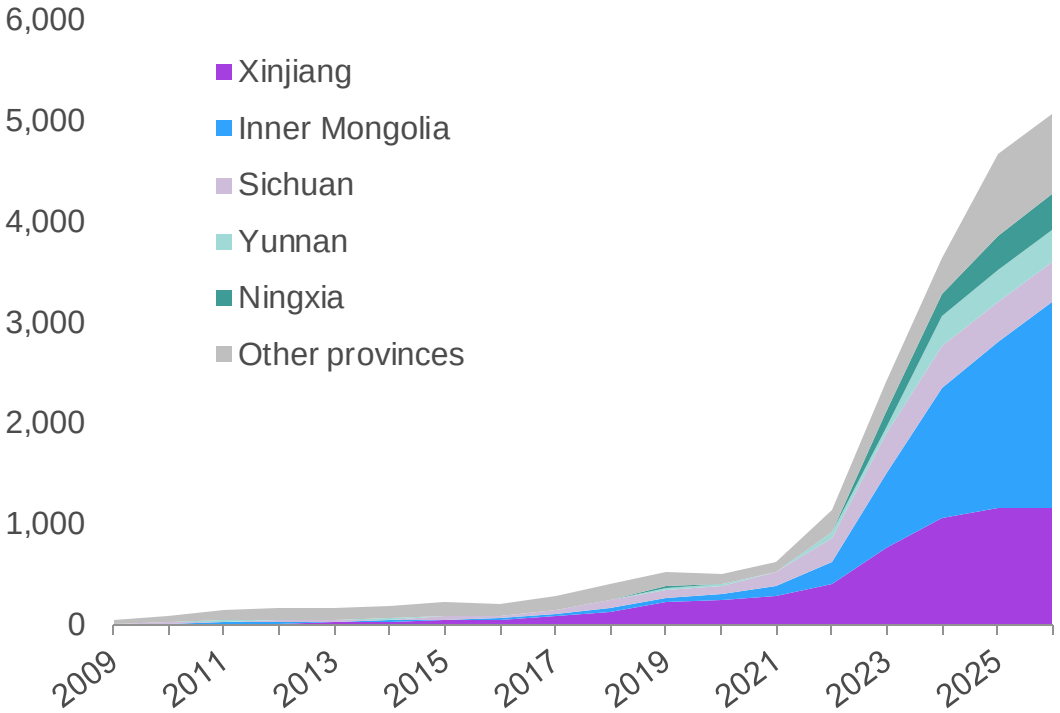
A delayed supply response led to a large build-up of silicon metal inventories in China in 2024 H2.

Meanwhile, rising Chinese exports of silicon-based products have curbed silicon metal consumption in most other major markets.

Silicon value chains are dominated by China

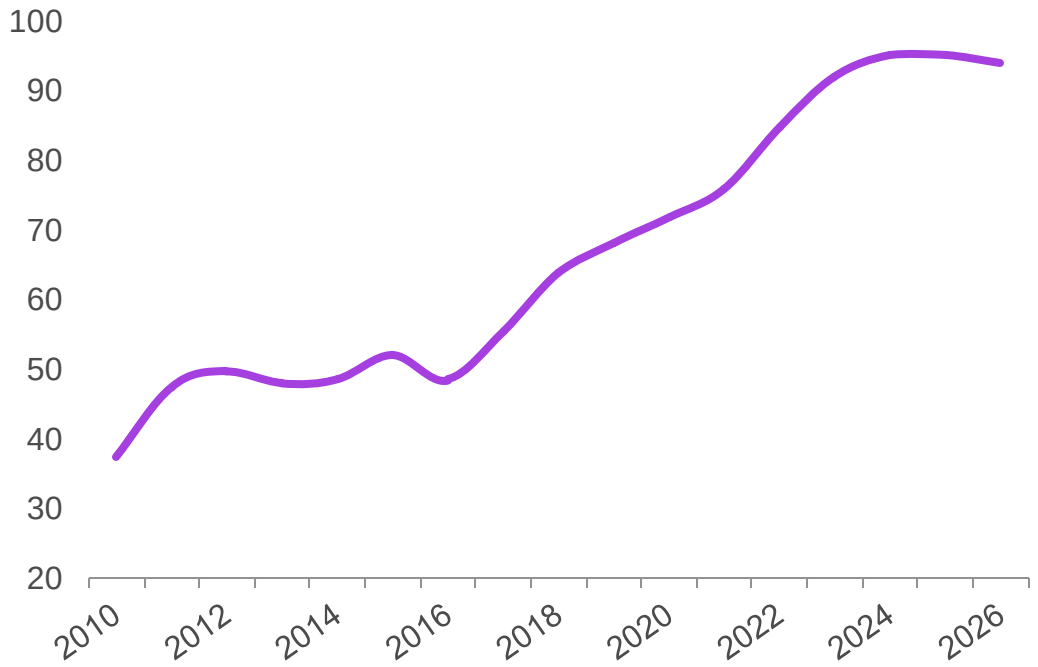
Build-up is slowing but China now controls >90% of global polysilicon capacity

Chinese polysilicon capacity at year-end, '000 t



DATA: CRU

China's share of total production capacity at year-end, %

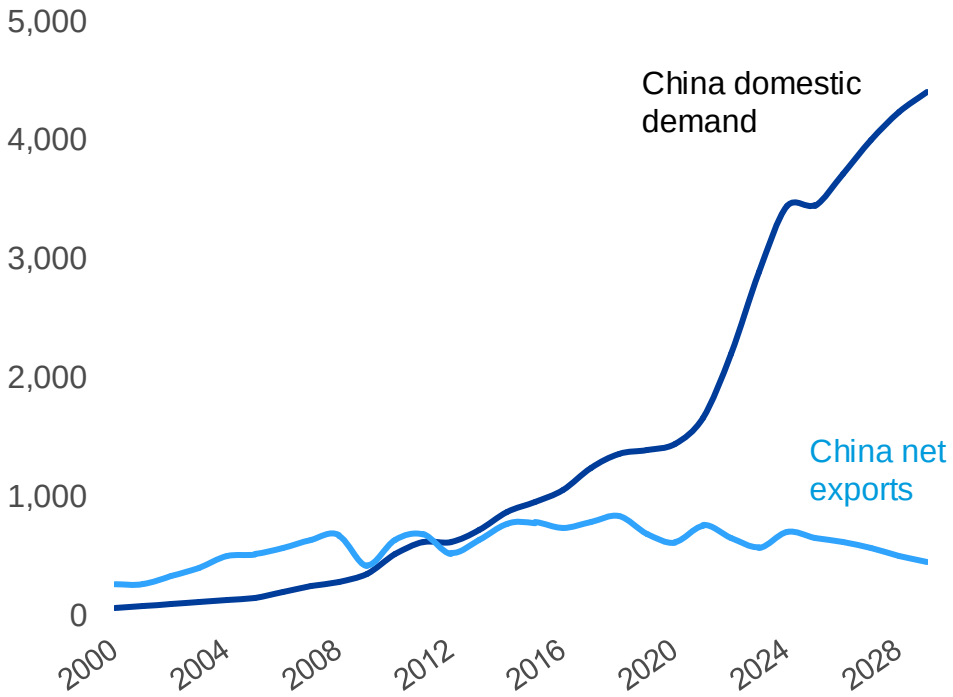


DATA: CRU

Market dynamics in China are changing

Other countries will account for a bigger share of future silicon metal supply

Silicon metal exports vs, domestic demand in China, '000 t



DATA: CRU

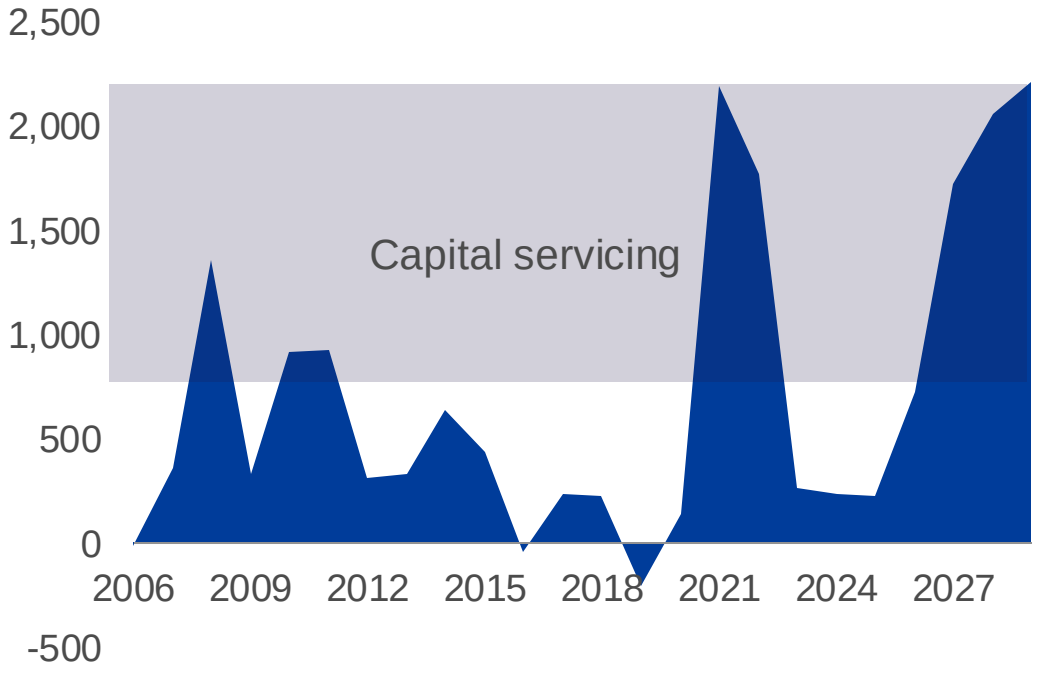
As China moves away from the manufacture of energy-intensive and polluting products for export towards value-added manufacture, a steadily larger portion of local silicon metal supply will be consumed within China.

A rising share of demand in the rest of the world will in turn be met by silicon metal plants located outside China. To maintain access to export markets, some Chinese consumers will also rely on external supply.

Greenfield investment requires higher prices

The rate of demand growth has major implications for future silicon metal prices

Difference between EU spot price and adjusted operating cost at plants outside China and the CIS, $/t



DATA: CRU

Depending on site and equipment-specific factors, a greenfield silicon metal plant can require a total investment in the order of 400-600 million USD or more than $10,000 /t of annual production capacity.

Unit capital costs in China are much lower, but this advantage may not be fully transferable when it comes to the construction of new silicon metal plants in other countries.

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MODULE TESTING

UVID testing shows a wide range of results

UVID results in BOMs submitted to Kiwa PVEL have displayed a variety of results, particularly for TOPCon. Meanwhile, a Y/Y comparison of BOMs submitted for testing in 2023 and 2024 illustrates technology consolidation.

UVID: mixed results, especially for TOPCon

UVID Sensitivity

UV 60 kWh/m² 60°C front

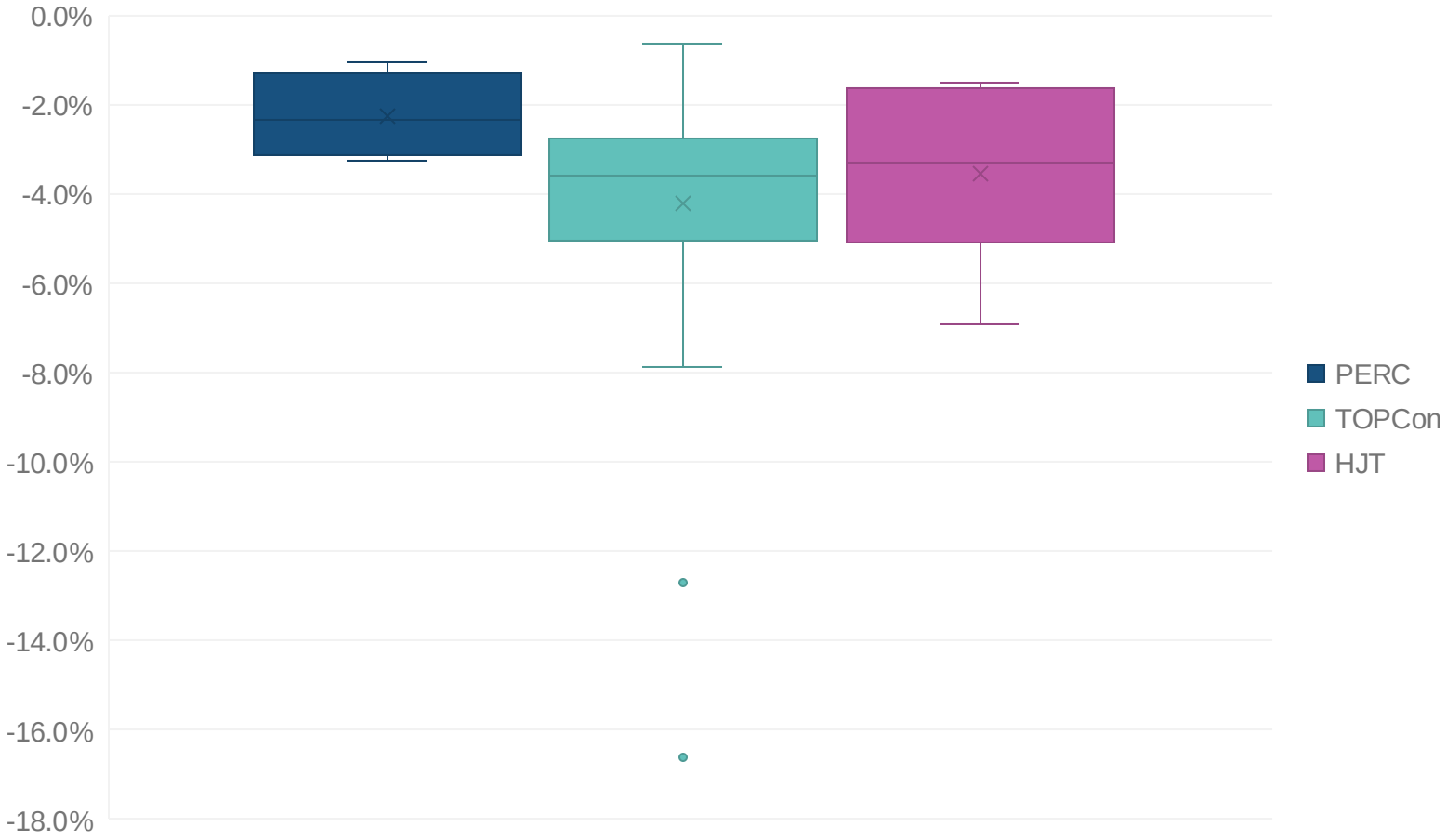
Characterization

UV 60 kWh/m² 60°C front

Characterization

UV

UVID in PERC, TOPCon, and HJT modules tested in 2023 and 2024



DATA: Kiwa PVEL

UVID testing

While the dataset for PERC is not large, the range of results is narrower than it is for TOPCon or HJT

	PERC	TOPCon	HJT
P10	-1.19%	-1.97%	-1.57%
P50	-2.31%	-3.57%	-3.27%
P90	-3.16%	-6.10%	-5.69%
P99	-3.23%	-14.07%	-6.79%
Count	**6**	**66**	**6**

Trends in testing: TOPCon and SMBB come to dominate year over year

BOMs submitted to Kiwa PVEL for testing, 2023 vs. 2024

		2023	2024
Technology	PERC	38%	13%
	TOPCon	51%	80%
	HJT	6%	7%
	Other	5%	0%
Busbars	Busbar	1%	0%
	MBB	45%	16%
	SMBB	50%	81%
	Other	5%	3%
Wafer	M6	5%	0%
	182	87%	71%
	182R*	2%	10%
	210	4%	13%
	210R*	3%	6%
Backsheet vs. glass-glass	Backsheet	47%	21%
	Glass-glass	53%	79%
Bifaciality (measured)	PERC	69.44%	67.94%
	TOPCon	75.47%	75.84%
	HJT	86.57%	84.51%

Trends in BOM submissions show the shift to TOPCon, SMBB and dual-glass

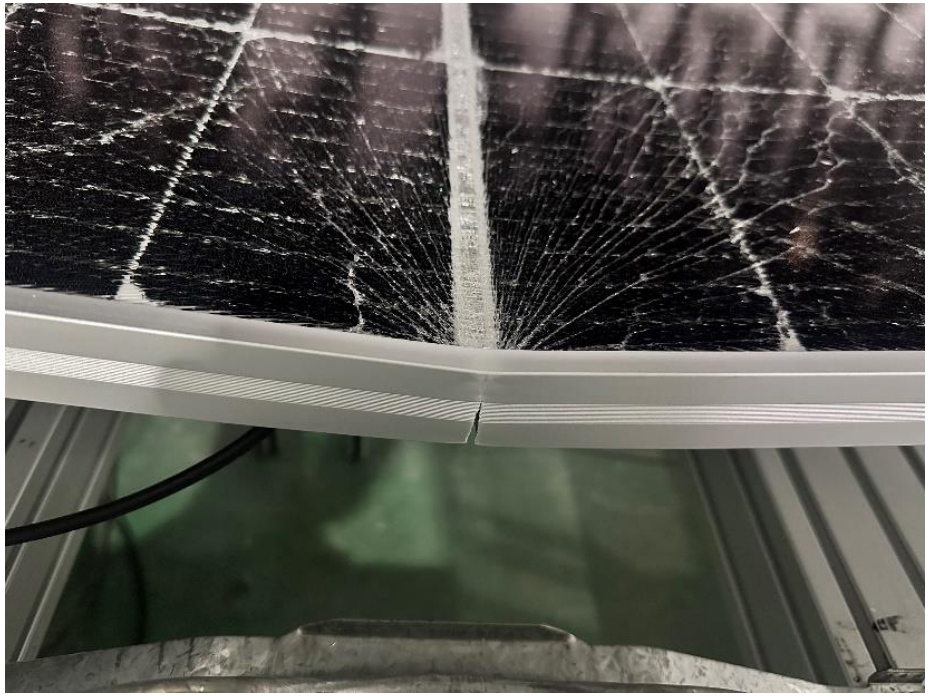
Some trends continued in 2024's BOM submissions, including: the shift from PERC to TOPCon; the shift from busbars and multi-busbar (MBB) to super multi-busbar (SMBB); and the shift from backsheet to rear glass.

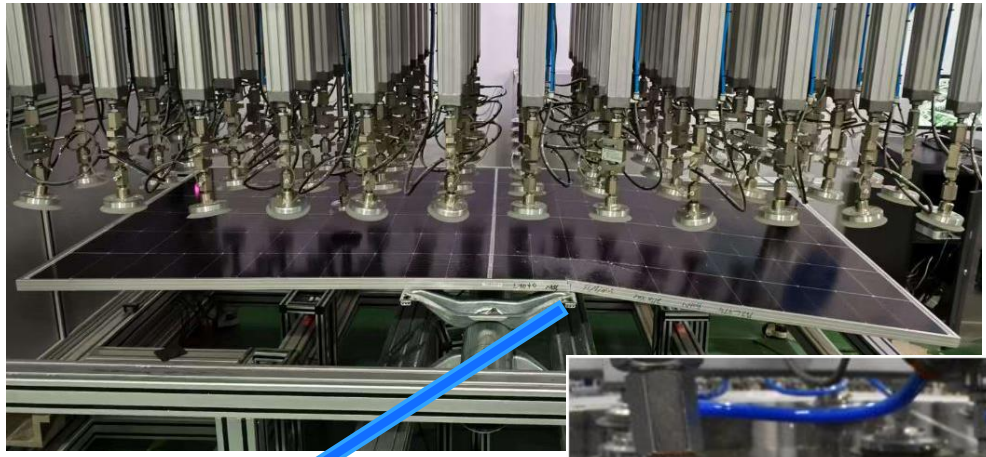
Wafer size has shifted remarkably, as M6 has dropped off completely and 182R and 210R are increasingly seen in the lab.

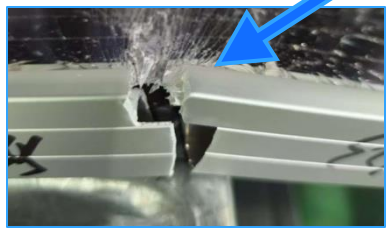
DATA: Kiwa PVEL; 182R covers rectangular wafers with one side length ~182 mm and the other anything other than 210 mm. 210R covers 182*210 mm wafers.

Trends in testing: modules are breaking at an alarming rate

Kiwa PVEL is seeing an increasing number of modules breaking during tracker-mounted MSS testing





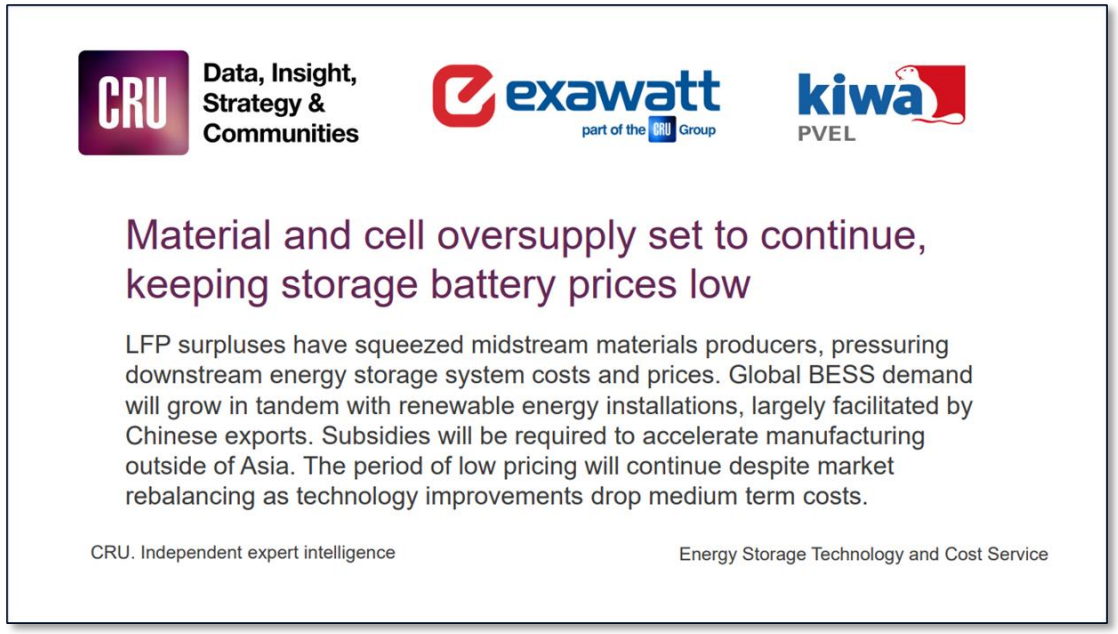


DATA: Kiwa PVEL.

Thank you!

Q+A

Please submit your questions now!



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