

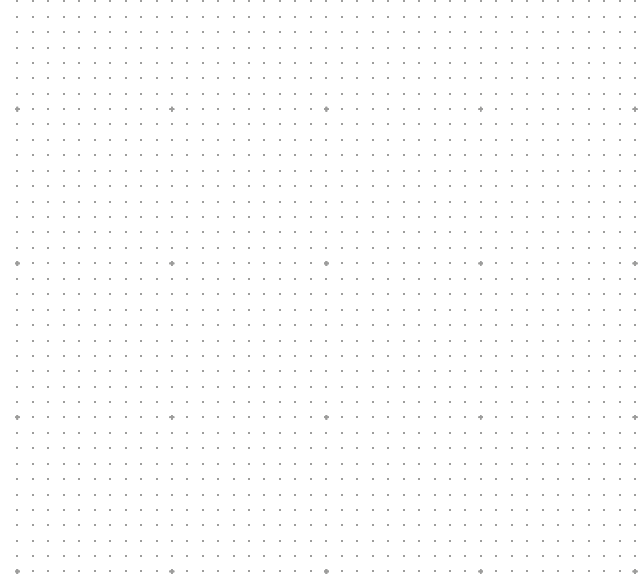
# Steel decarbonization

The scale of the challenge

Dr. Kwasi Ampofo

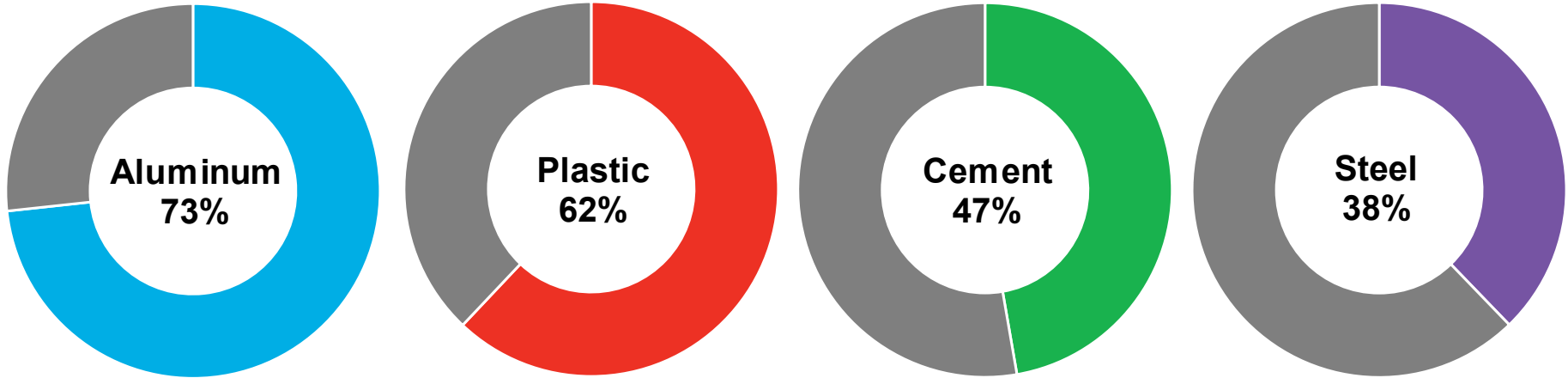
September 12, 2023

# The state of the industry



# Steel was an early mover in decarbonization, but others have now made major commitments

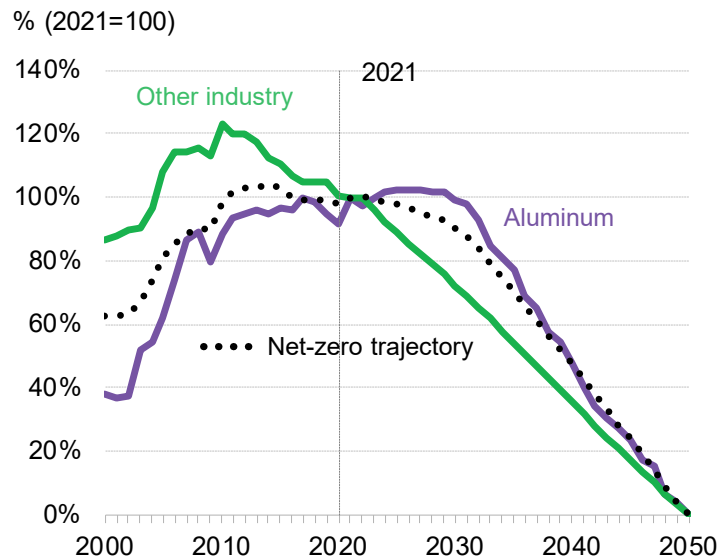
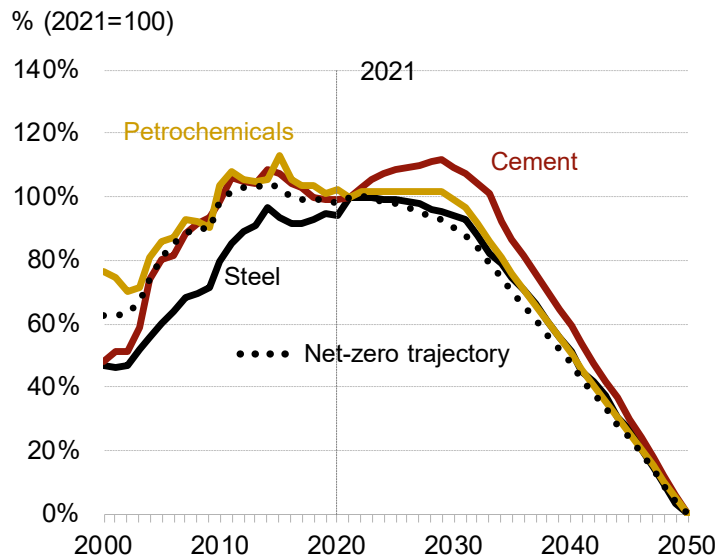
Tracked capacity covered by a corporate net-zero target, by material (Jan 2023)



Source: BloombergNEF. Note: Plastics include polyolefins and PET.

# Steel is still expected to decarbonize faster than its peers

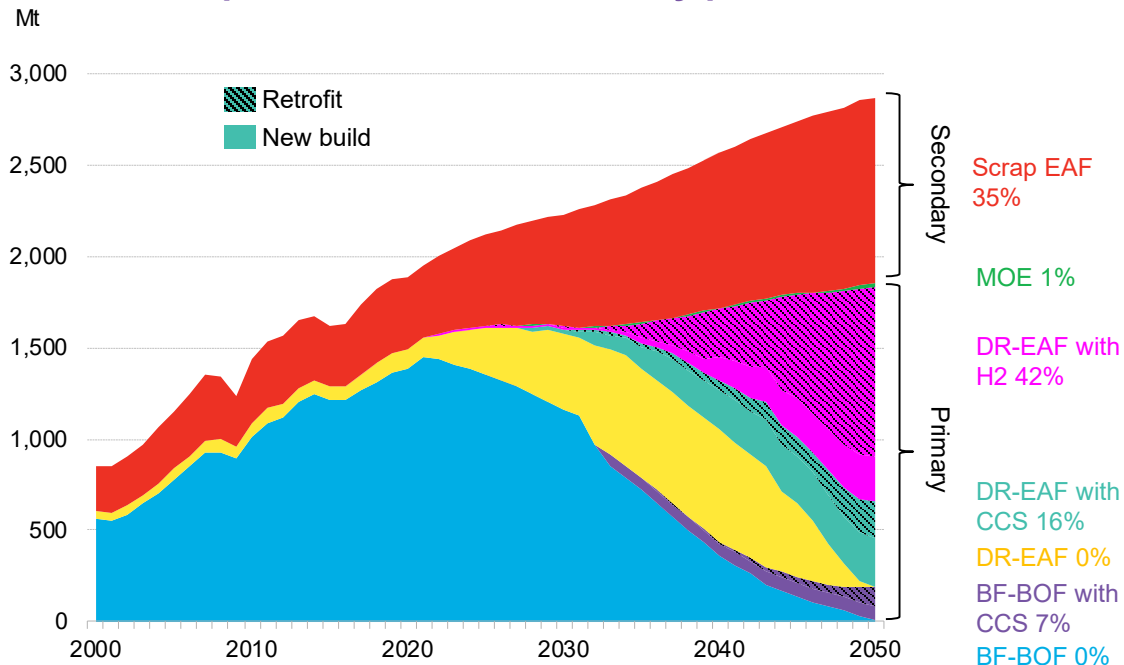
## Direct CO2 emissions by sector relative to 2021



Source: BloombergNEF

# Steelmaking will shift to direct reduction and electrification

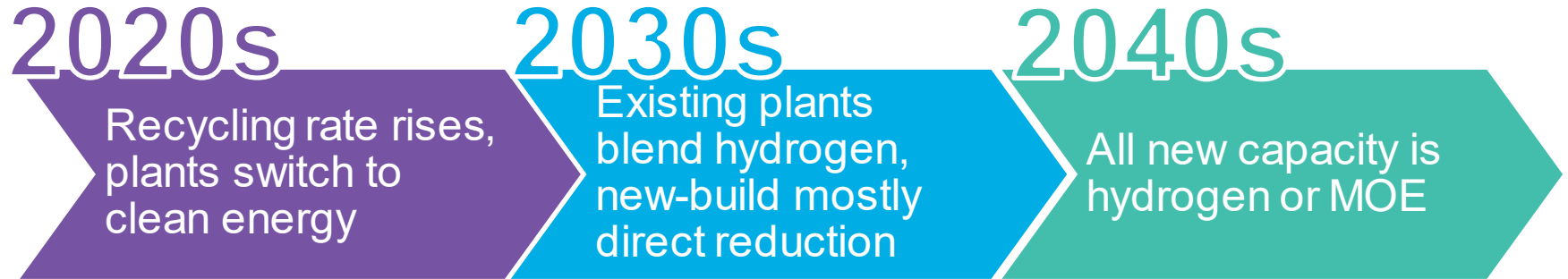
## Global steel production for net-zero, by process



Source: BloombergNEF. Note: Mt is million tons, MOE is molten oxide electrolysis, DR-EAF is direct reduction paired with an electric arc furnace, BF-BOF is a blast furnace paired with a basic oxygen furnace. Percentages may not sum to 100% due to rounding.

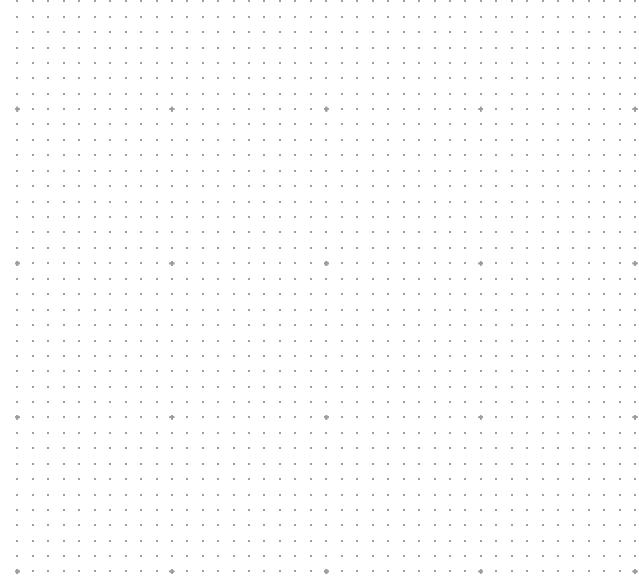
# Changes need to happen right away

## Transformation pathway for the steel sector



Source: BloombergNEF

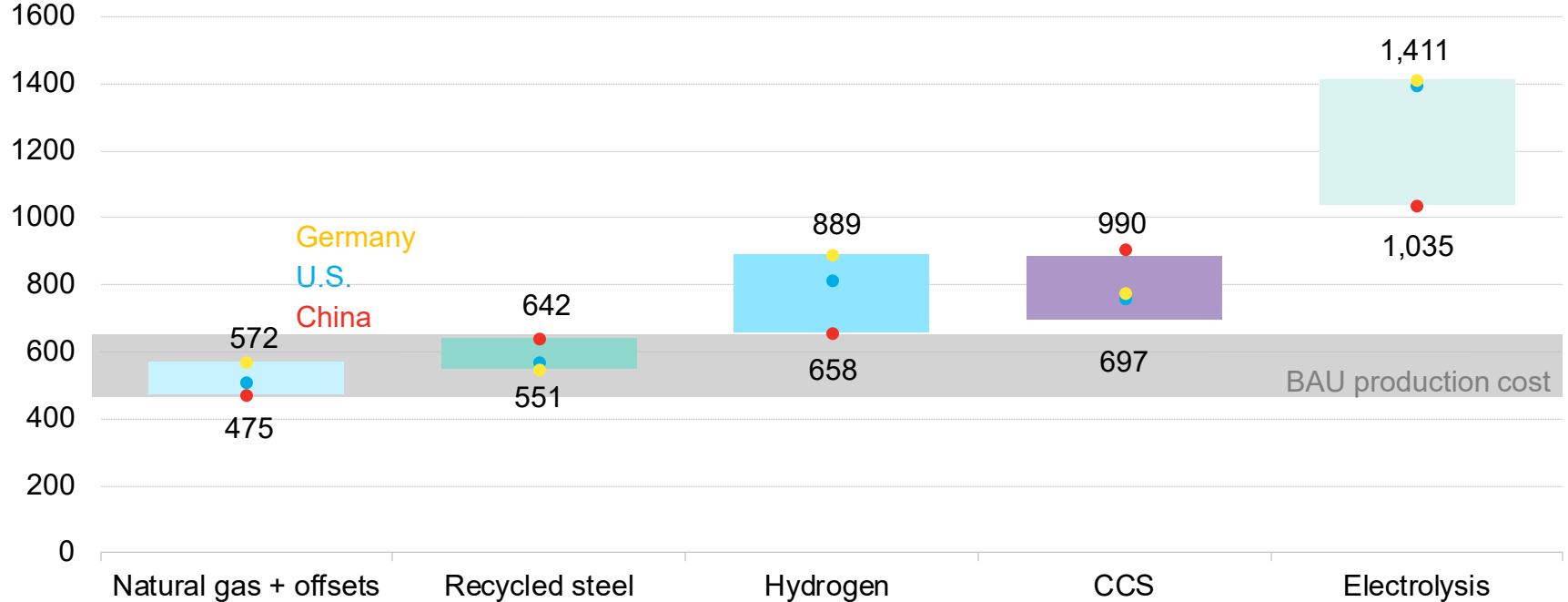
# Recycling and hydrogen lead the way



# Net-zero steel costs are high for now

## Cost of net-zero steel, by technology, 2021

Levelized cost of steel (\$/t crude steel)



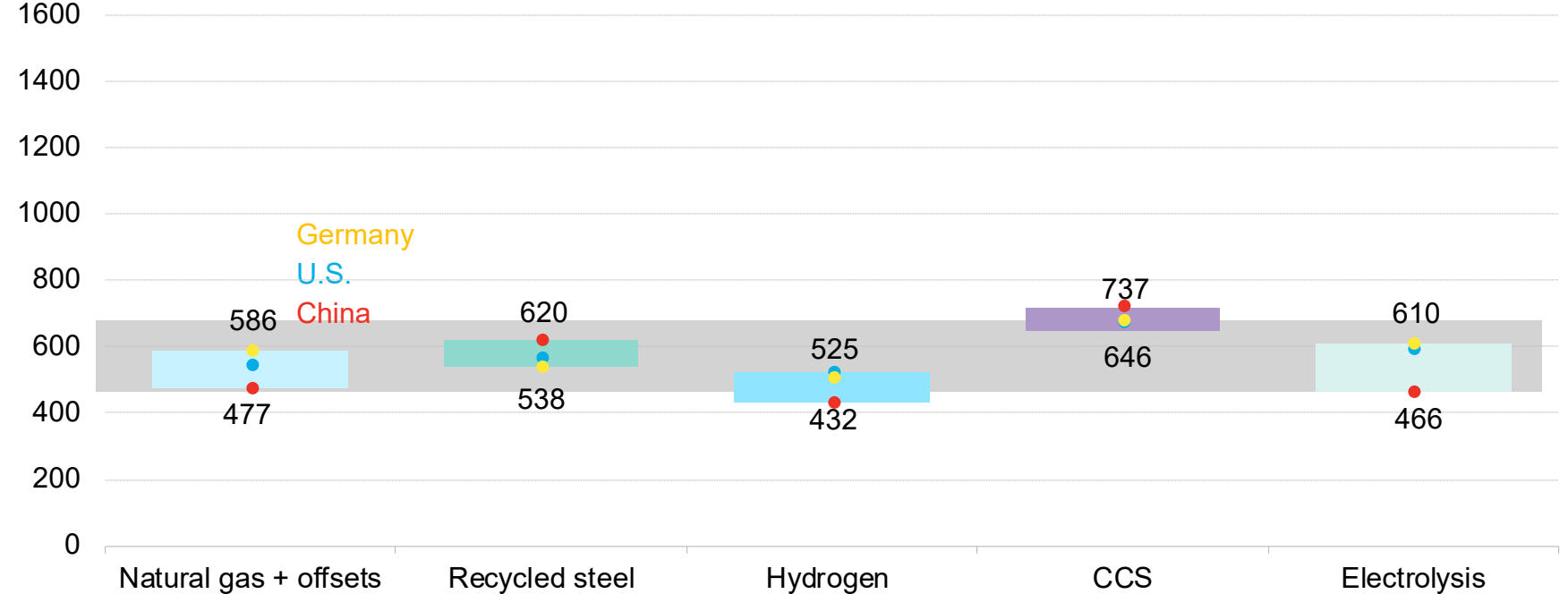
Source: BloombergNEF



# But could be competitive by 2050

## Cost of net-zero steel, by technology, 2050

Levelized cost of steel (\$/t crude steel)

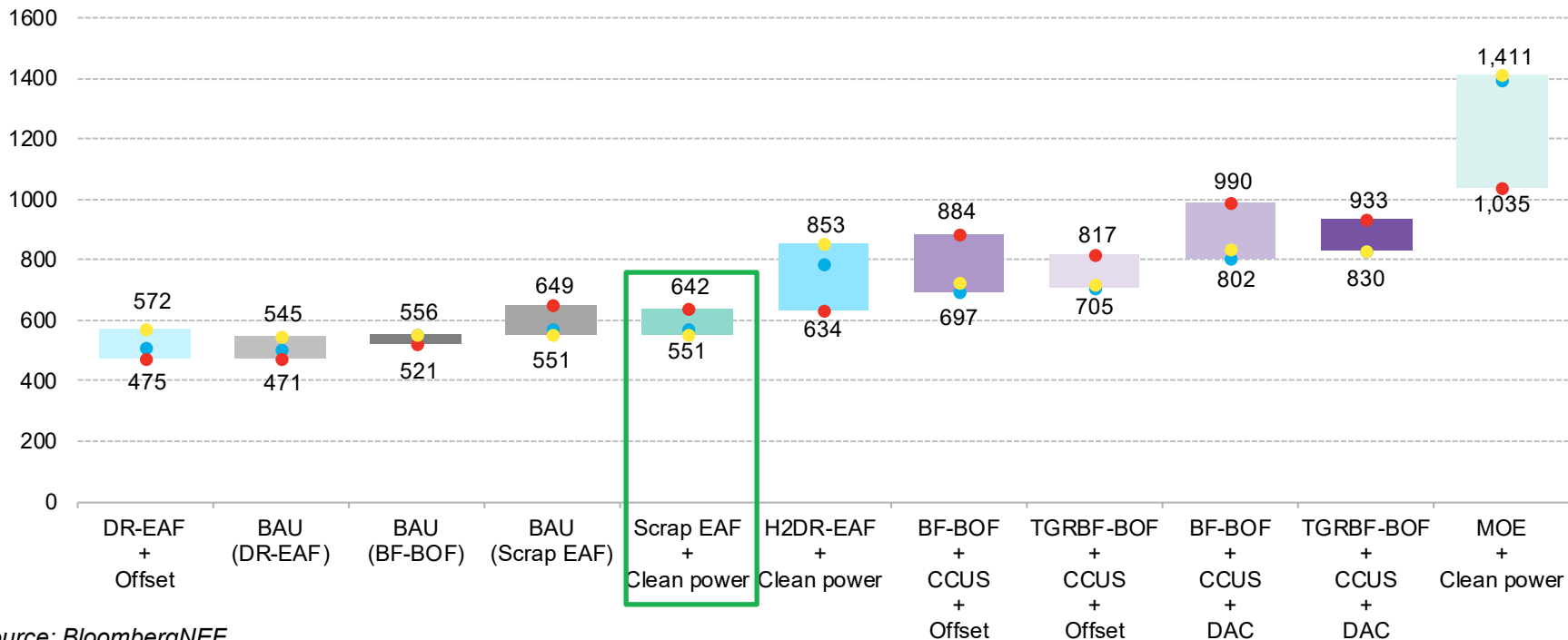


Source: BloombergNEF

# Net-zero production options

## Levelized cost of steel, 2021

Levelized cost of steel (\$/t crude steel)

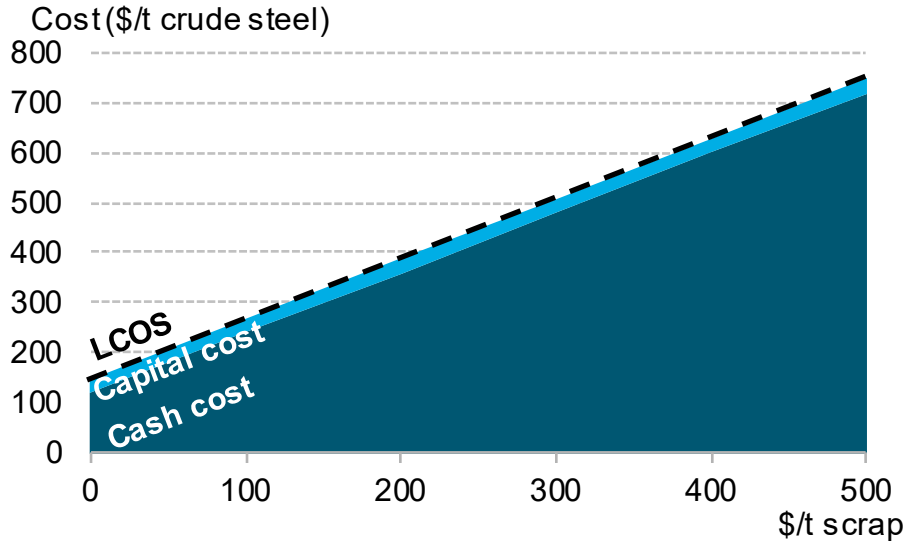


Source: BloombergNEF

## Recycling

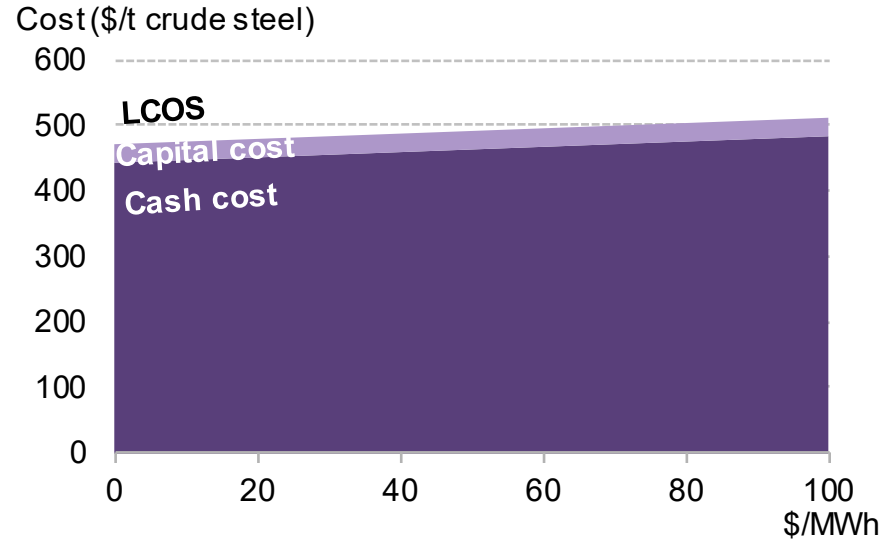
# Scrap prices dictate recycled steel costs

LCOS of net-zero recycling over scrap prices, U.S. 2021



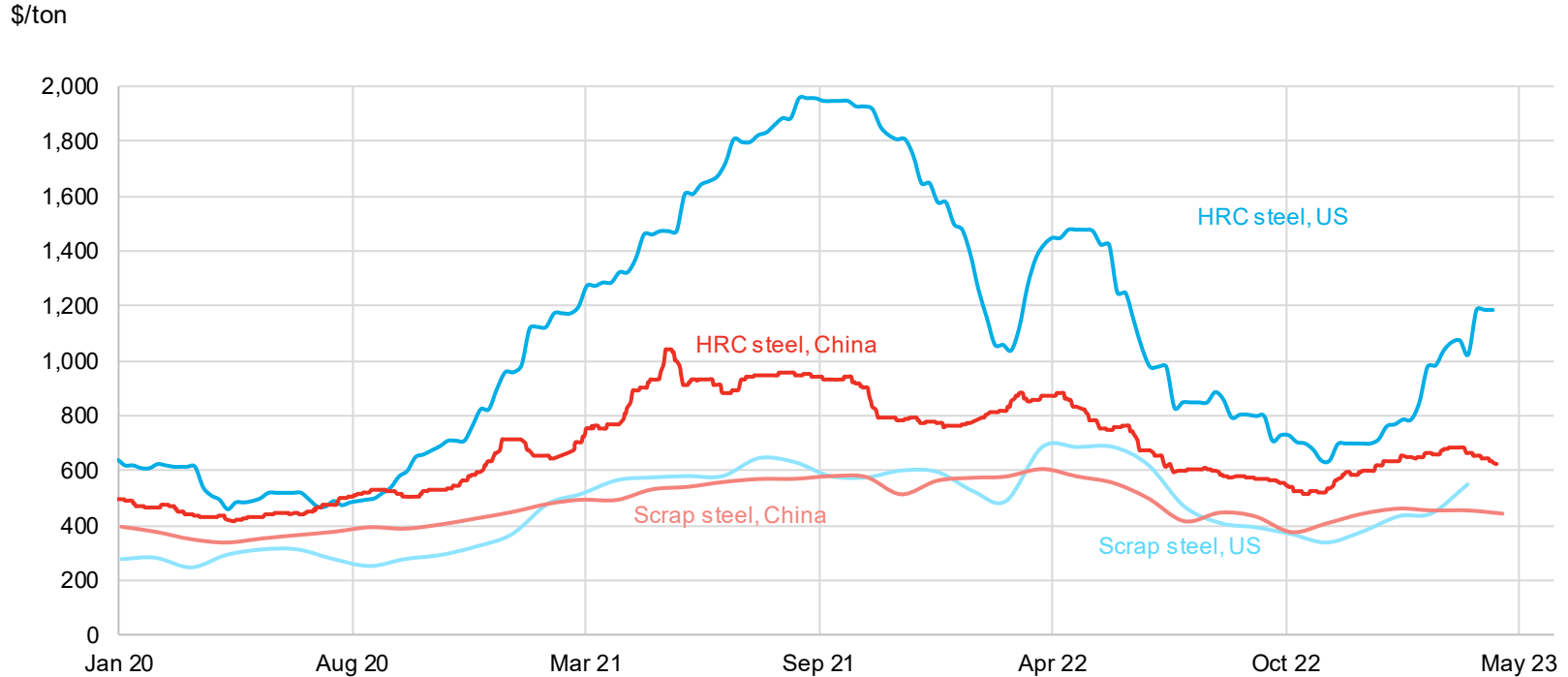
Source: BloombergNEF

LCOS of net-zero recycling over renewable electricity prices, U.S. 2021



# Steel scrap is following the super-cycle

## Steel scrap and virgin price change since January 2020

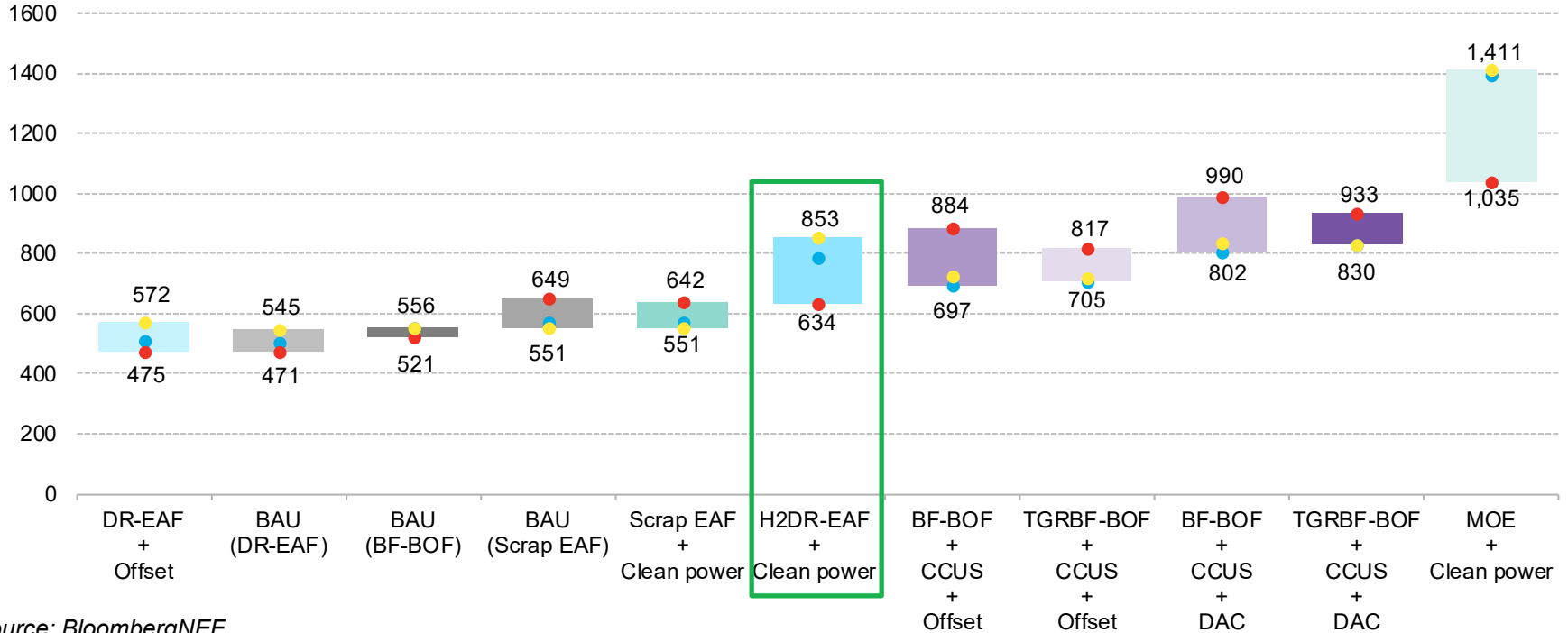


Source: BloombergNEF, Kallanish, Scrap Monster, CU Steel

# Net-zero production options

## Levelized cost of steel, 2021

Levelized cost of steel (\$/t crude steel)

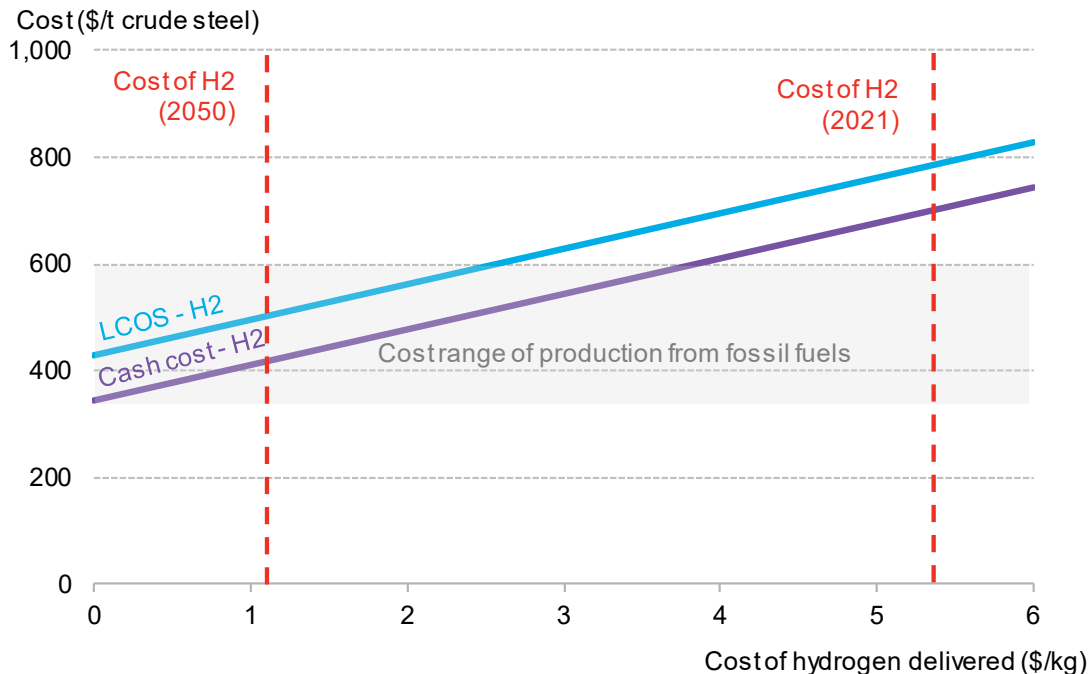


Source: BloombergNEF

## Hydrogen

# Hydrogen-made steel can compete

## LCOS with hydrogen prices, 2050

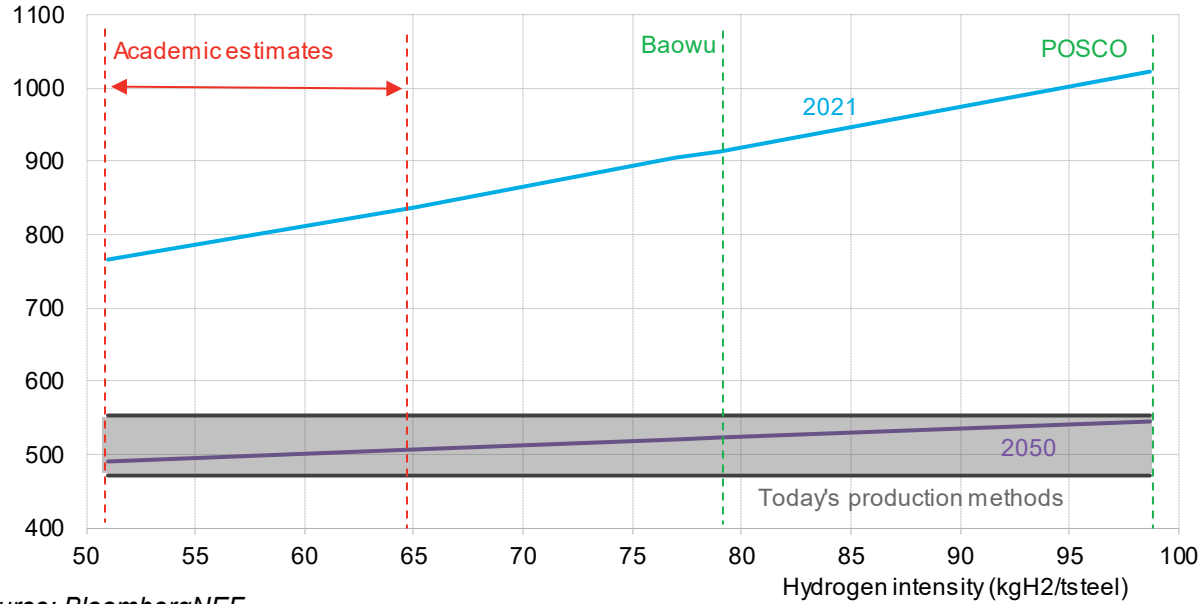


Source: BloombergNEF. Note: H2 is hydrogen. Capex, opex and hydrogen price assumptions are based on Germany. For more on our assumptions for LCOS costs for CCUS, see Appendix B. The cost range of production from fossil fuels represents costs for new-build steel plants.

# The amount of H2 needed to make steel is the greatest uncertainty

## Hydrogen intensity's impact on green steel costs

Levelized cost of steel (\$/tsteel)

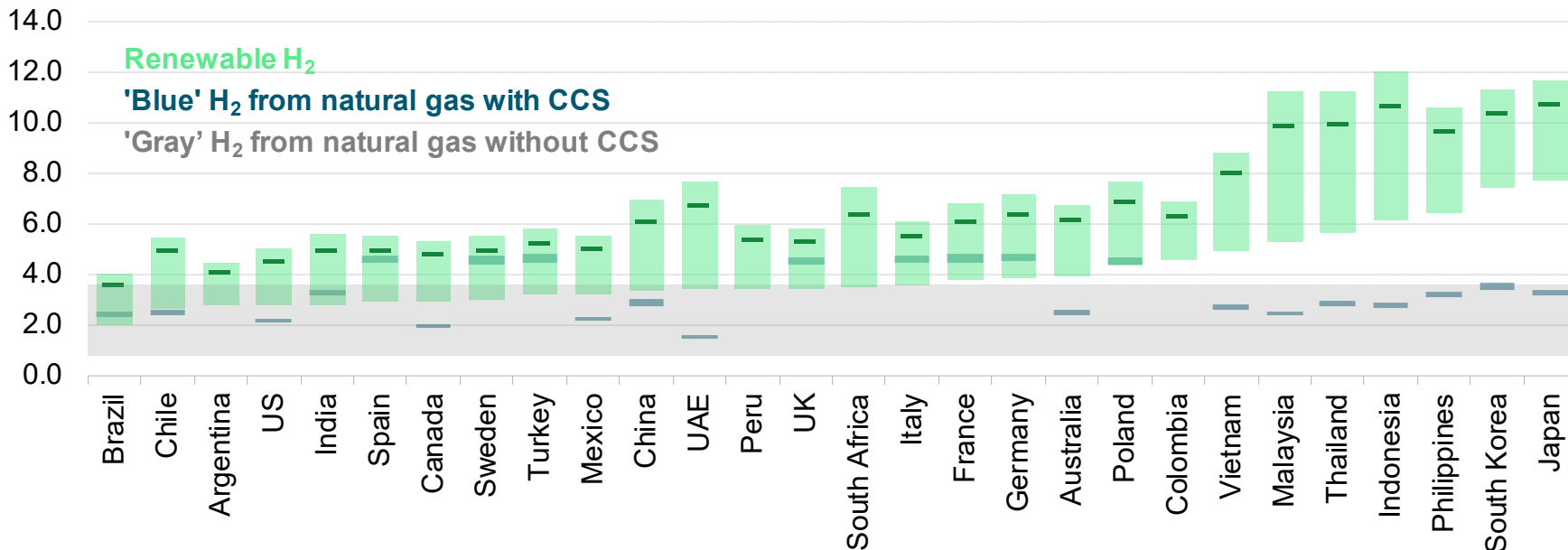


Source: BloombergNEF

# Blue and green are competing today

## Global range of green and blue LCOH<sub>2</sub> in 25 countries, 2022

\$/kg (real 2021)



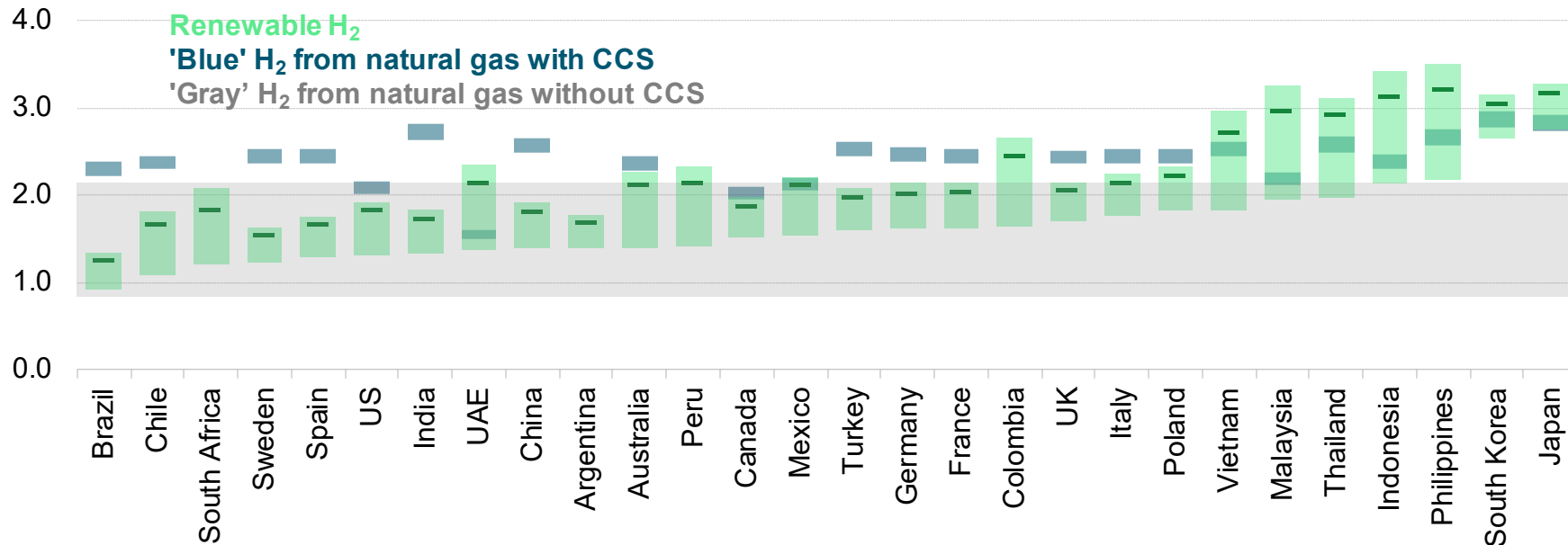
Source: BloombergNEF, NETL. Assumes our optimistic electrolyzer cost scenario. Renewable LCOH<sub>2</sub> range reflects a diversity of electrolyzer type, Chinese alkaline (low) to PEM (high). The electrolyzer's electricity is sourced from the cheaper renewable resource. Capital and operational costs for blue hydrogen are sourced from the [National Energy Technology Laboratory](#). Gas prices derived from BloombergNEF's New Energy Outlook ([web](#) | [terminal](#)). Grid electricity prices assumed at \$75 (real 2021) for all modeled markets.



# Green overtakes blue by 2030

## Global range of green and blue LCOH<sub>2</sub> in 25 countries, 2030

\$/kg (real 2021)

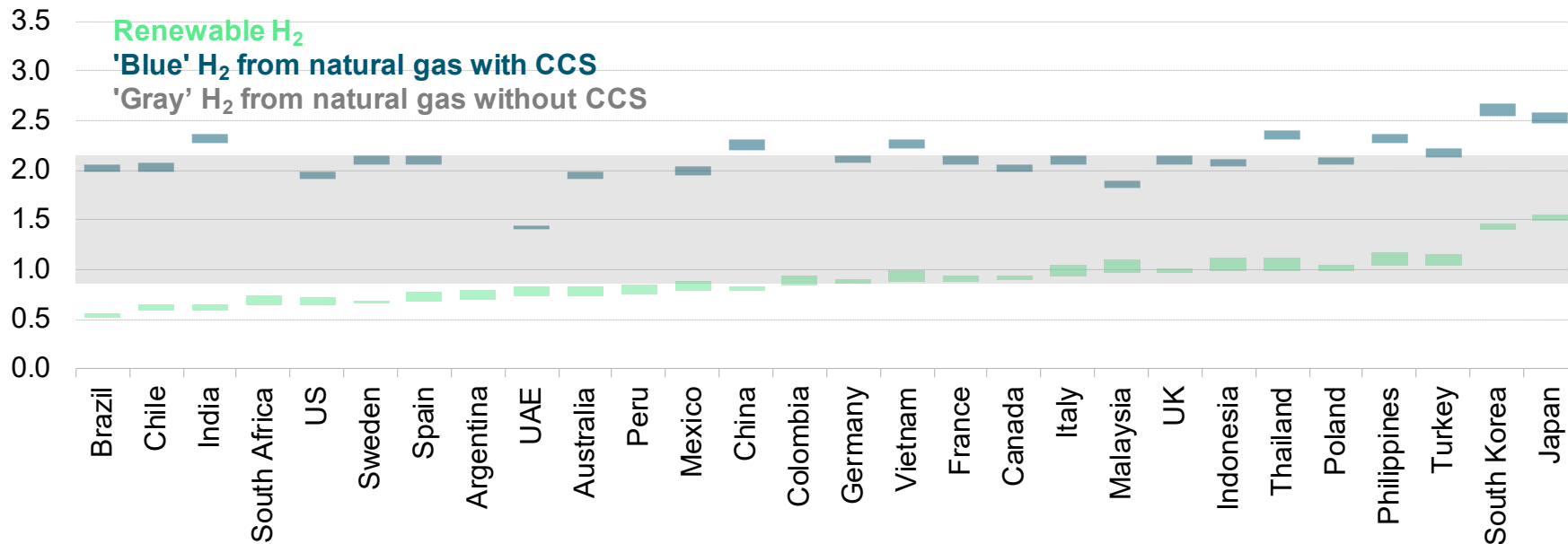


Source: BloombergNEF, NETL. Assumes our optimistic electrolyzer cost scenario. Renewable LCOH<sub>2</sub> range reflects a diversity of electrolyzer type, Chinese alkaline (low) to PEM (high). The electrolyzer's electricity is sourced from the cheaper renewable resource. Capital and operational costs for blue hydrogen are sourced from the [National Energy Technology Laboratory](#). Gas prices derived from BloombergNEF's New Energy Outlook ([web](#) | [terminal](#)). Grid electricity prices assumed at \$75 (real 2021) for all modeled markets.

# Green is cheapest in the long run

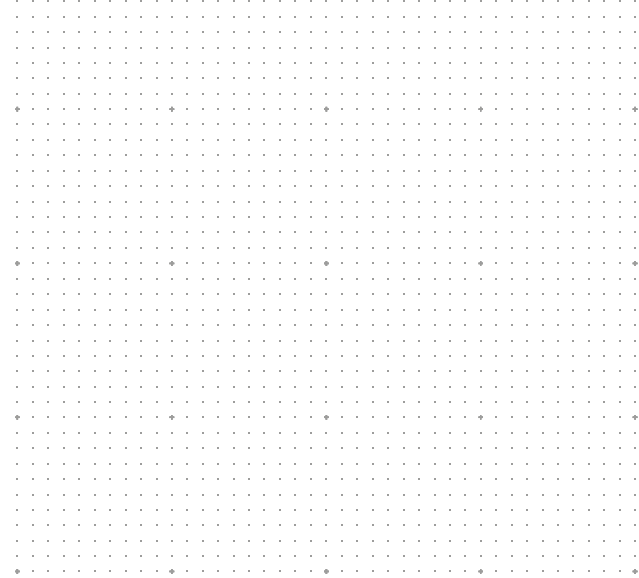
## Global range of green and blue LCOH<sub>2</sub> in 25 countries, 2050

\$/kg (real 2021)



Source: BloombergNEF, NETL. Assumes our optimistic electrolyzer cost scenario. Renewable LCOH<sub>2</sub> range reflects a diversity of electrolyzer type, Chinese alkaline (low) to PEM (high). The electrolyzer's electricity is sourced from the cheaper renewable resource. Capital and operational costs for blue hydrogen are sourced from the [National Energy Technology Laboratory](#). Gas prices derived from BloombergNEF's [New Energy Outlook \(web | terminal\)](#). Grid electricity prices assumed at \$75 (real 2021) for all modeled markets.

# Corporate commitments



# There is no consensus on a net-zero technology route

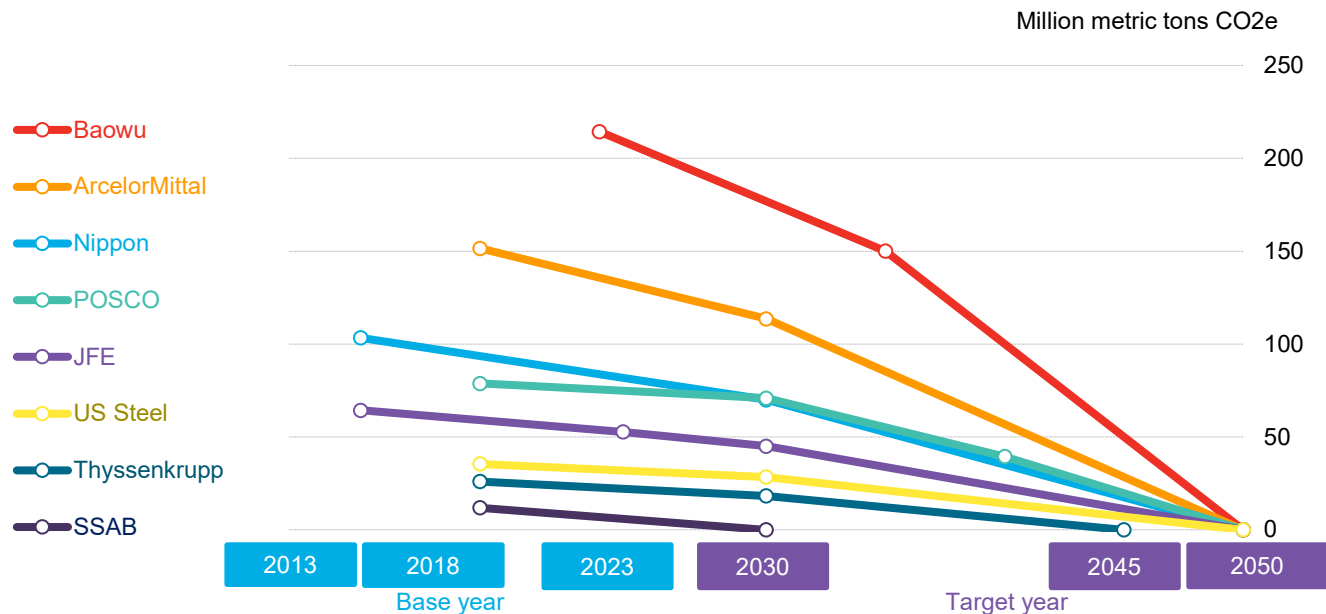
## Net-zero corporate strategies, by technology

Scope	Tech route	Option	BAOWU	ArcelorMittal	NIPPON STEEL	posco	IFF	Uss	thyssenkrupp	SSAB
Scope 1	Mature EAF-based	Increase EAF production	Green	Green	Green	Green	Green	Green	Grey	Green
	Mature BF-based	Energy efficiency	Purple	Purple	Purple	Purple	Purple	Purple	Purple	Purple
		Feedstock/raw material	Purple	Purple	Purple	Purple	Purple	Purple	Purple	Purple
	BF-BOF based	H2 injection	Purple	Purple	Purple	Light Purple	Purple	Grey	Purple	Grey
		Top-gas-recycling	Purple	Purple	Light Purple	Grey	Purple	Grey	Grey	Grey
	DR-based	H2 direct reduction	Blue	Blue	Light Blue	Blue	Light Blue	Light Blue	Blue	Blue
	CCUS	Carbon capture	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Grey
		Carbon utilization	Yellow	Yellow	Yellow	Yellow	Yellow	Grey	Yellow	Grey
		Carbon transport and storage	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Grey	Grey
	Others	Others	Yellow	Yellow	Grey	Yellow	Grey	Grey	Grey	Yellow

Source: BloombergNEF

# Most steelmakers are aiming for net-zero in 2050, with two exceptions

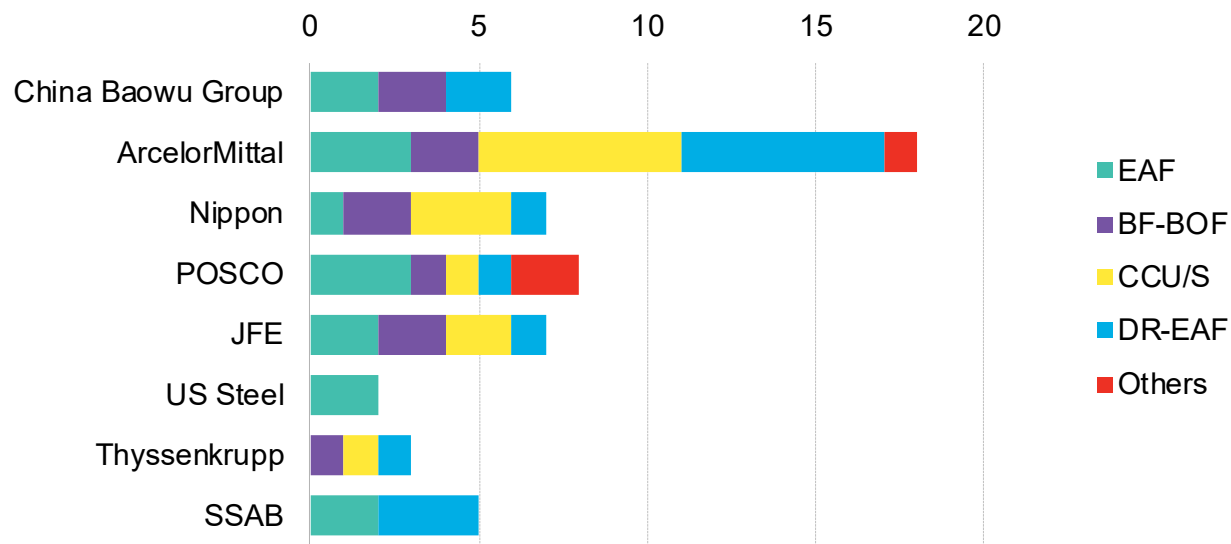
Net-zero pathway for select steelmakers, for absolute scope 1 & 2 emissions reduction



Source: Company filings, BloombergNEF. Note: Emissions pathway begin with base year. The lines are illustrative only and do not necessarily indicate that corporates follow a linear emissions reduction pathway. For individual company assumption, see attached excel file.

# ArcelorMittal leads in low-carbon project announcements

## Low-carbon steel project count of steelmakers, by technology routes



Source: Company announcements, BloombergNEF. Note: EAF is building electric arc furnace. BF-BOF is emissions reduction based on blast furnace. CCU/S is carbon capture and utilization or storage. DR-EAF is hydrogen-based direct reduction. Others include electrolysis and FINEX. Projects include large demo and commercial projects.

# Customers and policy are pushing steelmakers to net-zero

1. Countries go towards net-zero



2. Carbon pricing kicks in



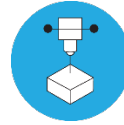
3. Investors demand ESG effort








4. Market demands green products



5. Industry competes to upgrade tech and product



Policy landscape for steel industry decarbonization in selected countries, by **push** and **pull** factors

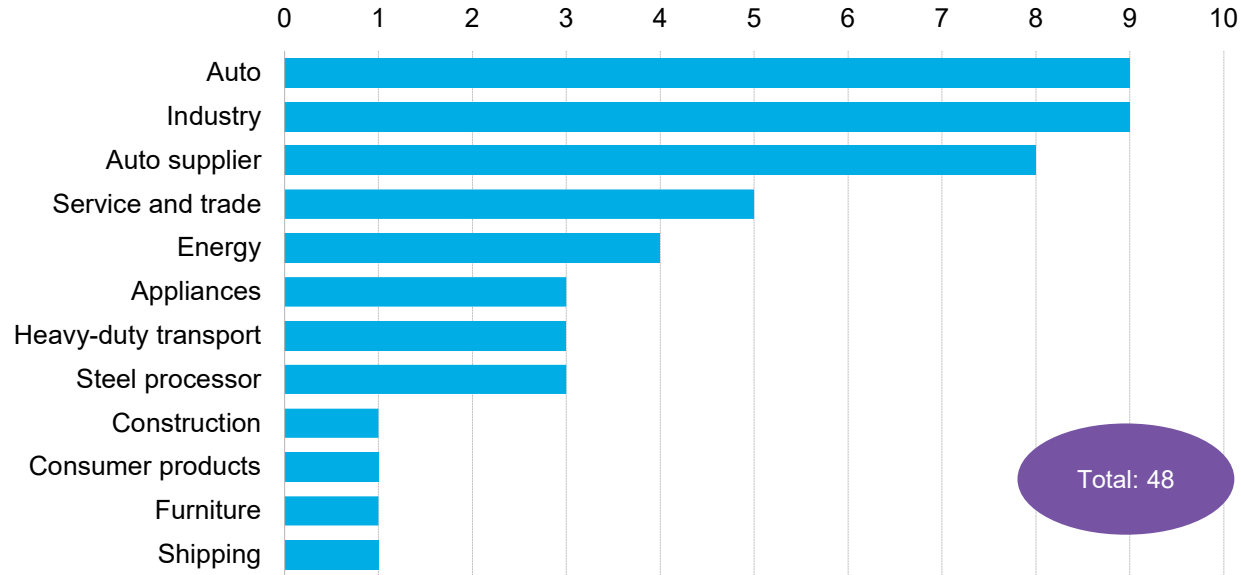
Country/ region	Operating companies	Official target for industry	Carbon market / tax	Subsidies or grants for low- carbon steel	Support for hydrogen	Support for CCUS	Green public procurement	Access to low- cost clean energy
EU-27								
US					Recent	Recent	Recent	
China								
Japan								
Korea								

Source: BloombergNEF. Note: Access to low-cost clean energy only considers the high-level policies and may not reflect the regional reality most relevant to the current and planned operation sites of the steelmakers. The policies marked "Recent" were rolled out during the writing of this report, the effect of which may yet be shown on the analyzed steelmakers. **Green**= strong policy and clear; **yellow**= somewhat effective policy/policy pending, **red**=does not exist/ineffective.

# Customers are already signing contracts for green steel

## Count of supply agreements for green steel

Count of supply agreements

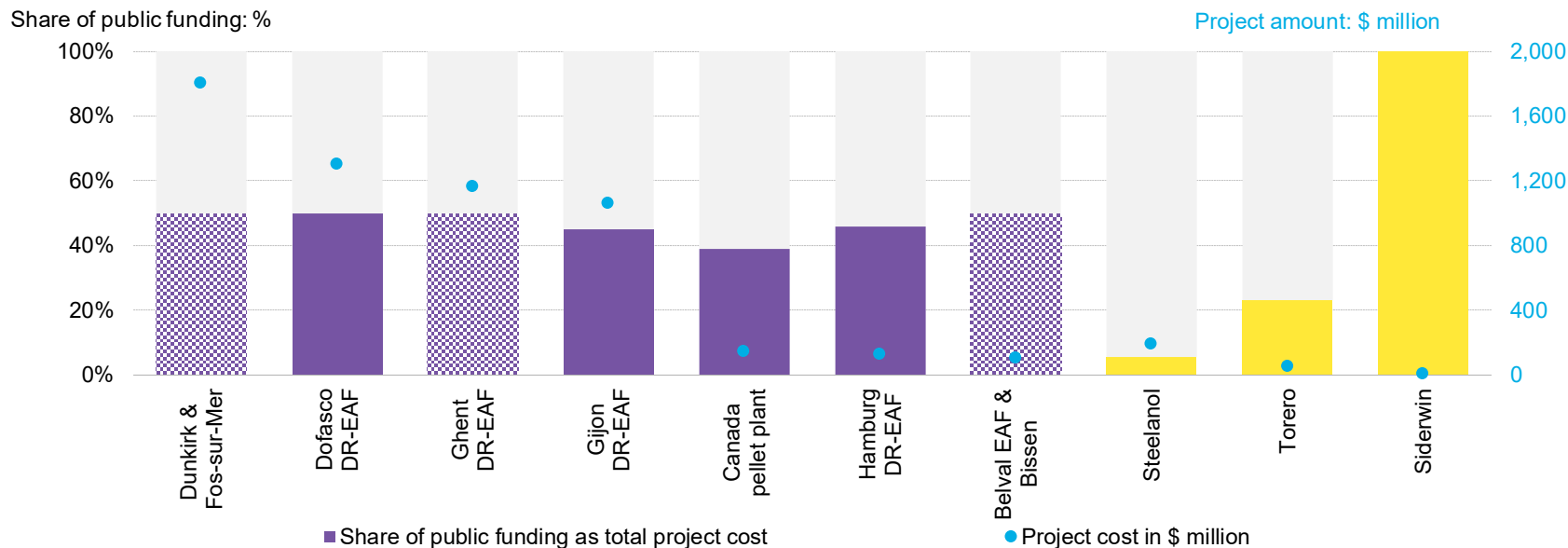


Source: BloombergNEF, company announcements



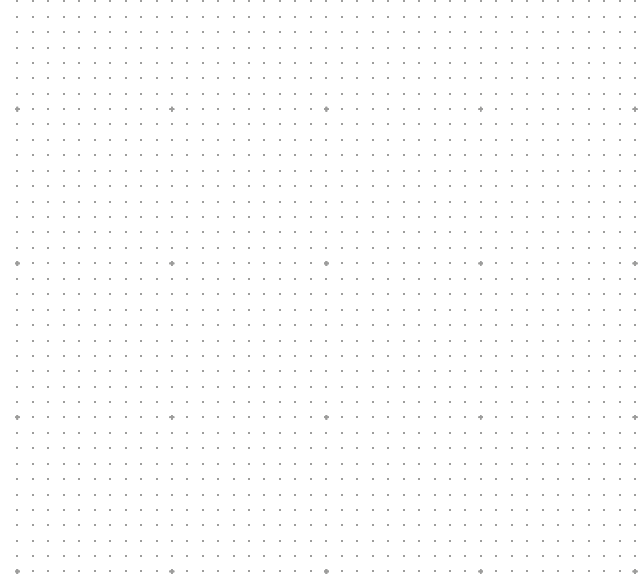
# Early green steel projects rely heavily on public funding

## ArcelorMittal's steel projects with disclosed government support



Source: Company announcements, BloombergNEF. Note: The shaded projects are supported by local government, but the exact amount of government funding was not disclosed. BNEF estimates these to be around 50% of project cost.

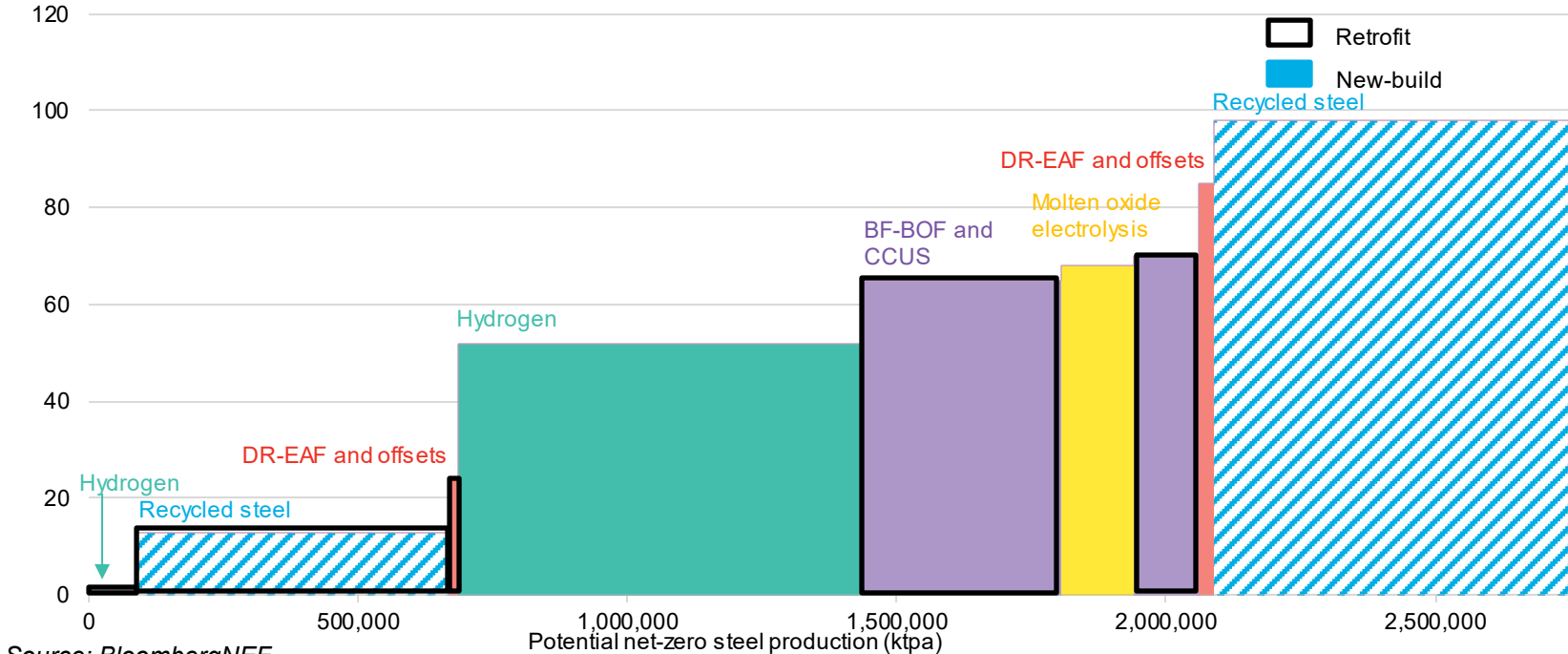
# A helping hand from policymakers



# Incentives needed for net-zero

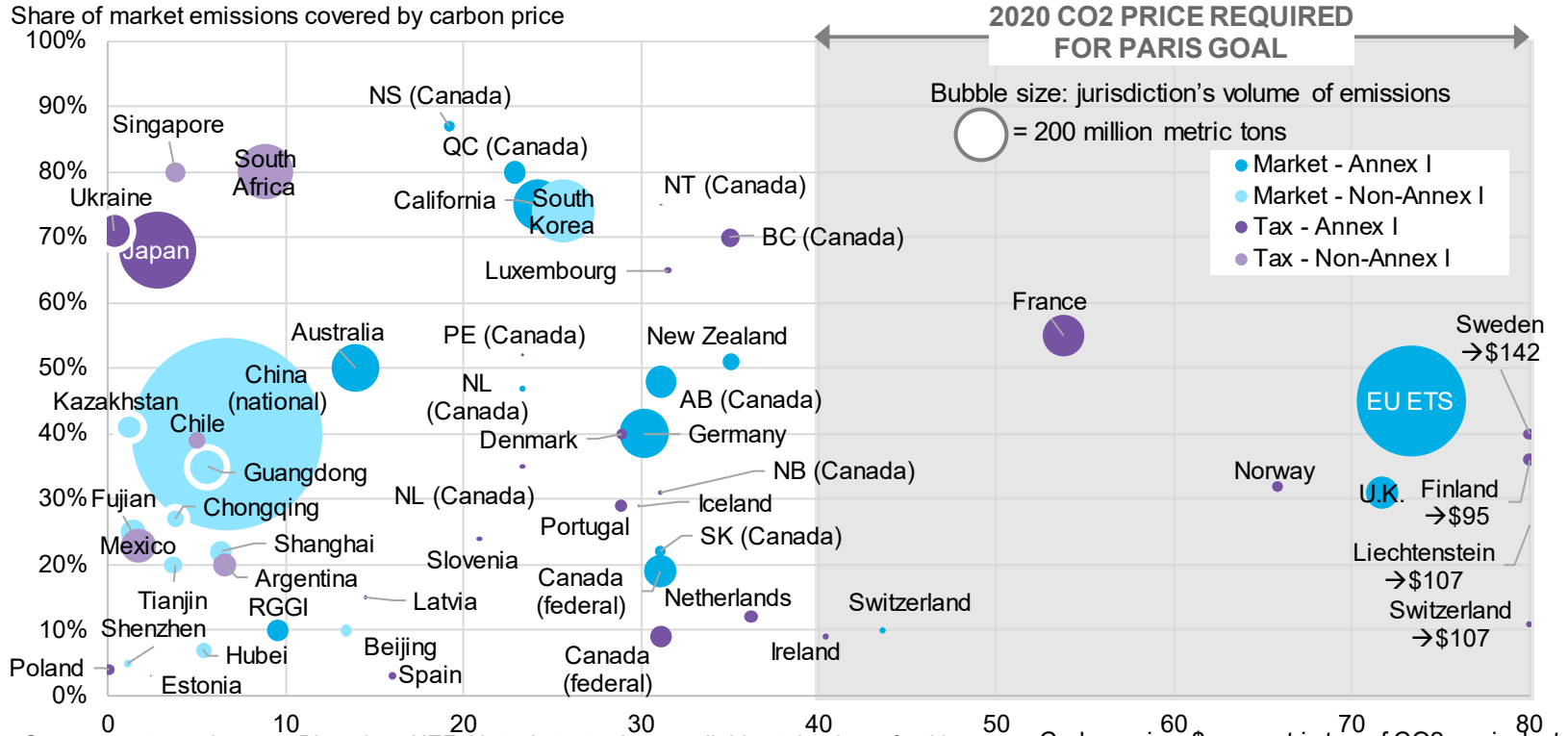
## Carbon prices required to support net-zero steel making (at NOAK costs)

Carbon price (\$/tCO<sub>2</sub>)



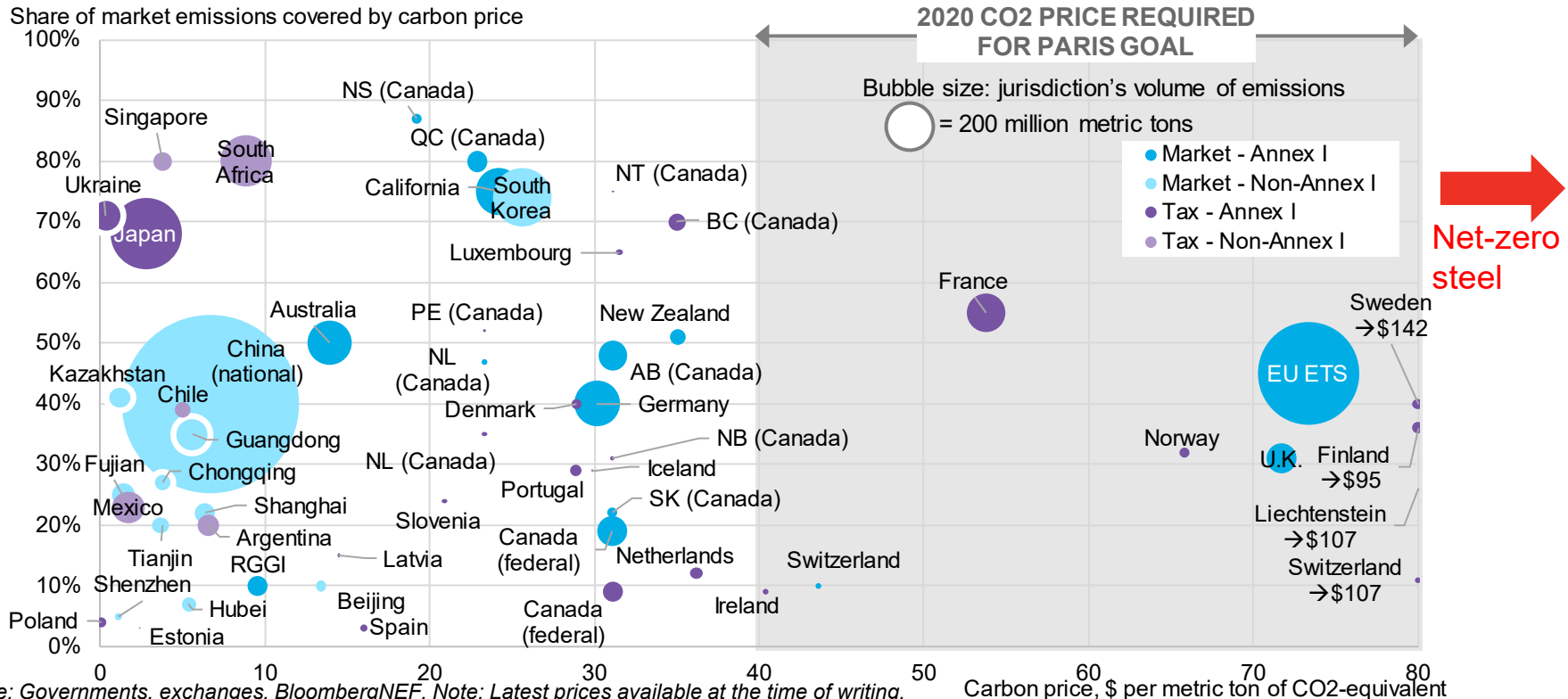
Source: BloombergNEF

# Carbon-pricing programs by price and emissions covered



Source: Governments, exchanges, BloombergNEF. Note: Latest prices available at the time of writing. Where tax rates vary across fuels, sectors and greenhouse gases, figure uses median.

# Carbon-pricing programs by price and emissions covered

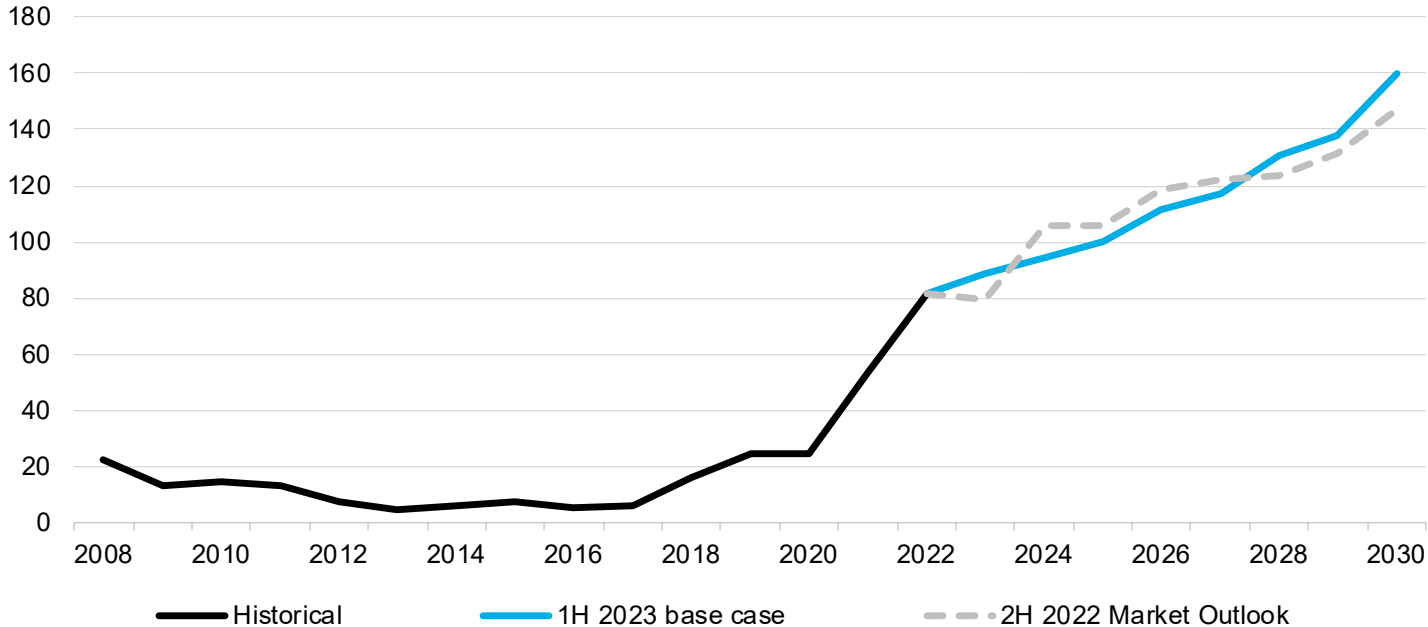


Source: Governments, exchanges, BloombergNEF. Note: Latest prices available at the time of writing. Where tax rates vary across fuels, sectors and greenhouse gases, figure uses median.

# EU carbon prices are set to rise, but industry gets a pass

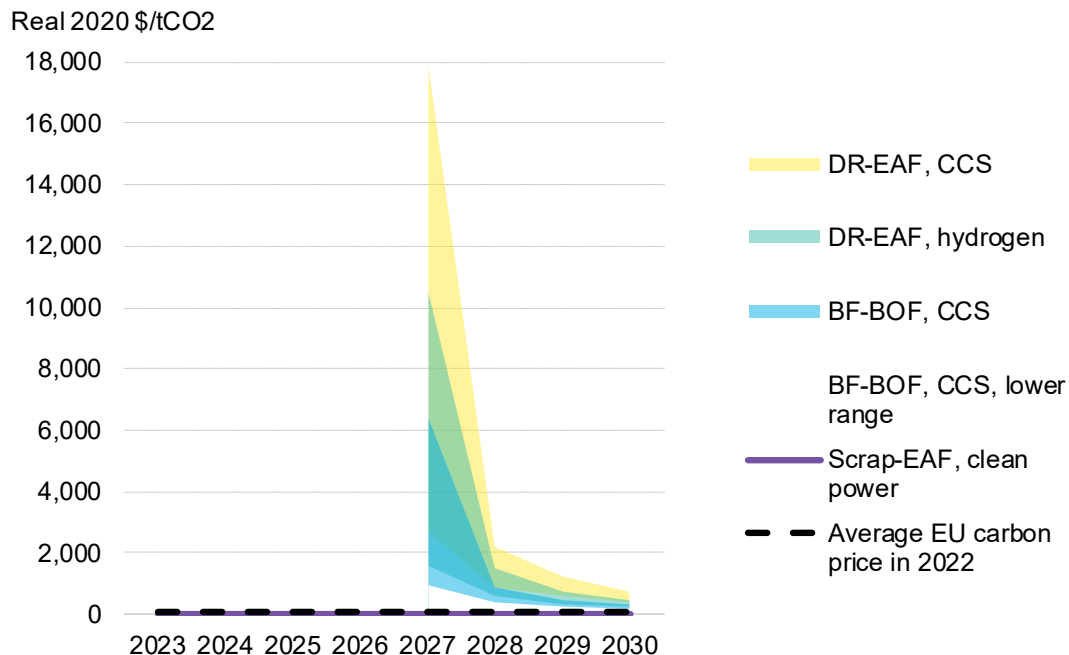
## Historical and forecast EU emissions allowance price

€/t, nominal



Source: BloombergNEF

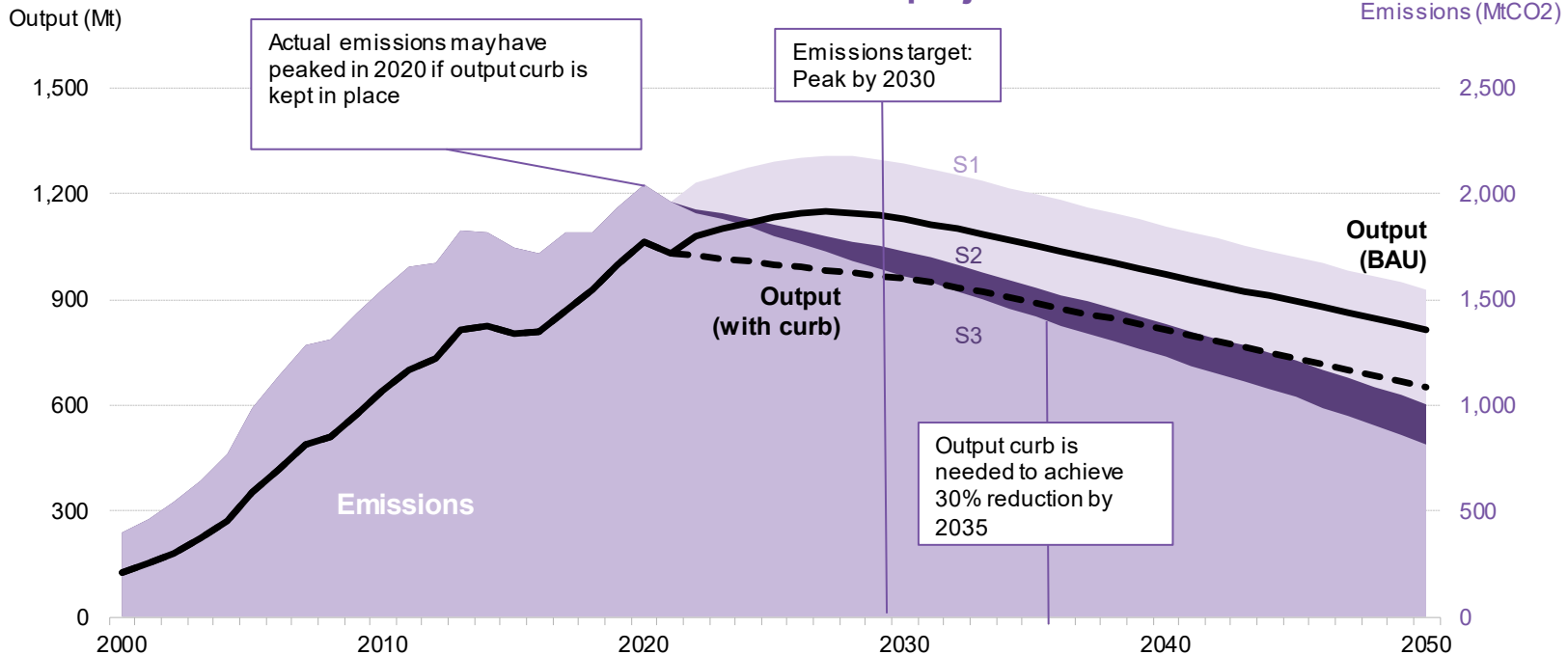
# With free allowances in place, steel needs a price of thousands of dollars per ton



Source: BloombergNEF. Note: From 2026 to 2030, the upper range assumes a linear phase-out of free allocation from 2026 to 2032, while the lower range assumes a linear phase-out of free allocation from 2026 to 2036.

# China's emissions may already have peaked

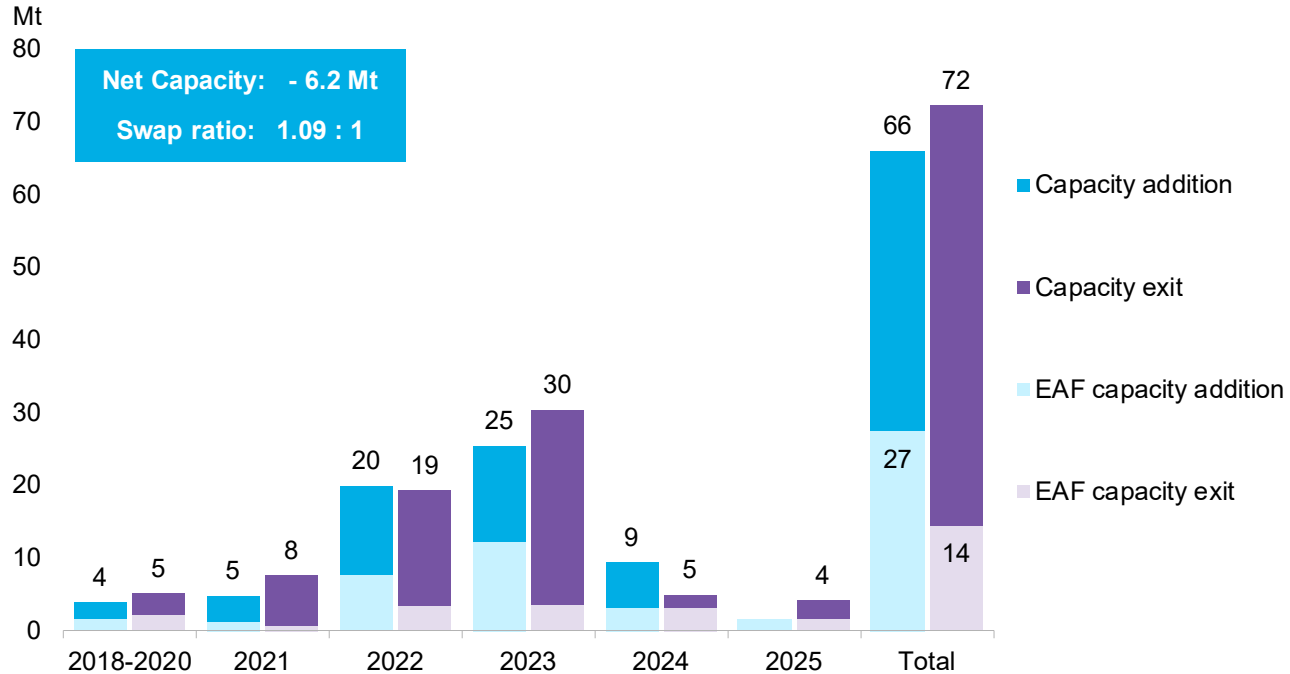
## BNEF estimate of China's steel sector historical and projected emissions



Source: BloombergNEF, Chinese government, World Steel Association. BloombergNEF, Chinese government, World Steel Association, Shangguan, F, et al, *Climate Change and decarbonization development of Steel Industry*, 2021.



# Capacity swapping makes EAFs more attractive

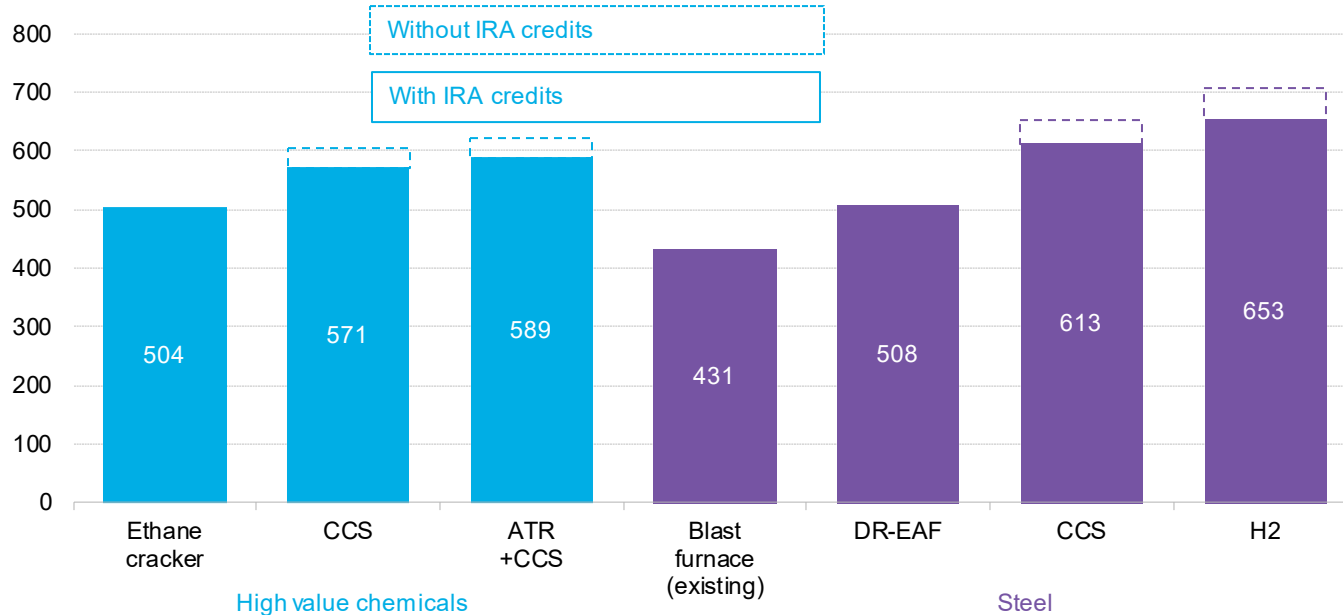


Source: BloombergNEF, Provincial government websites. Note: Data include only announcements made in 2021. The total amount includes plans without completion dates.

# Green materials get a bit cheaper with the US's IRA subsidies

## Reduction in green chemical and steel costs with 45Q and hydrogen subsidies

Levelized cost (\$/t material)



Source: BloombergNEF. Note: ATR is autothermal reforming, DR-EAF is a direct reduction furnace paired with an electric arc furnace. H2 is hydrogen. Blast furnace cost is for an existing, coal-fired plant. Ethane cracker costs are for a new-build plant.

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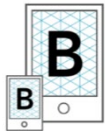
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