Energy Transitions Commission

Abundant clean energy for all: the electric future

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Chair, Energy Transitions Commission

ARUP

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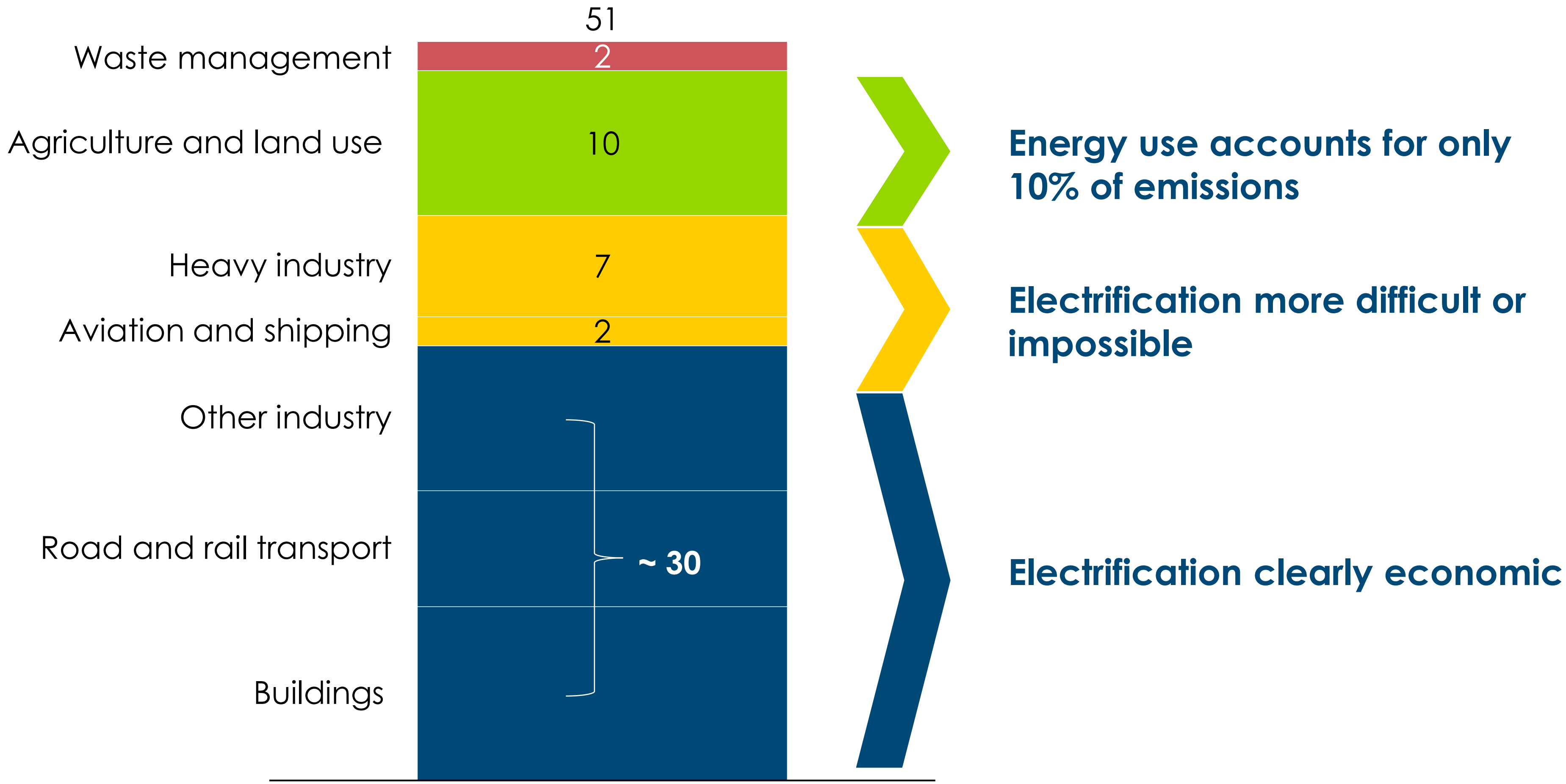
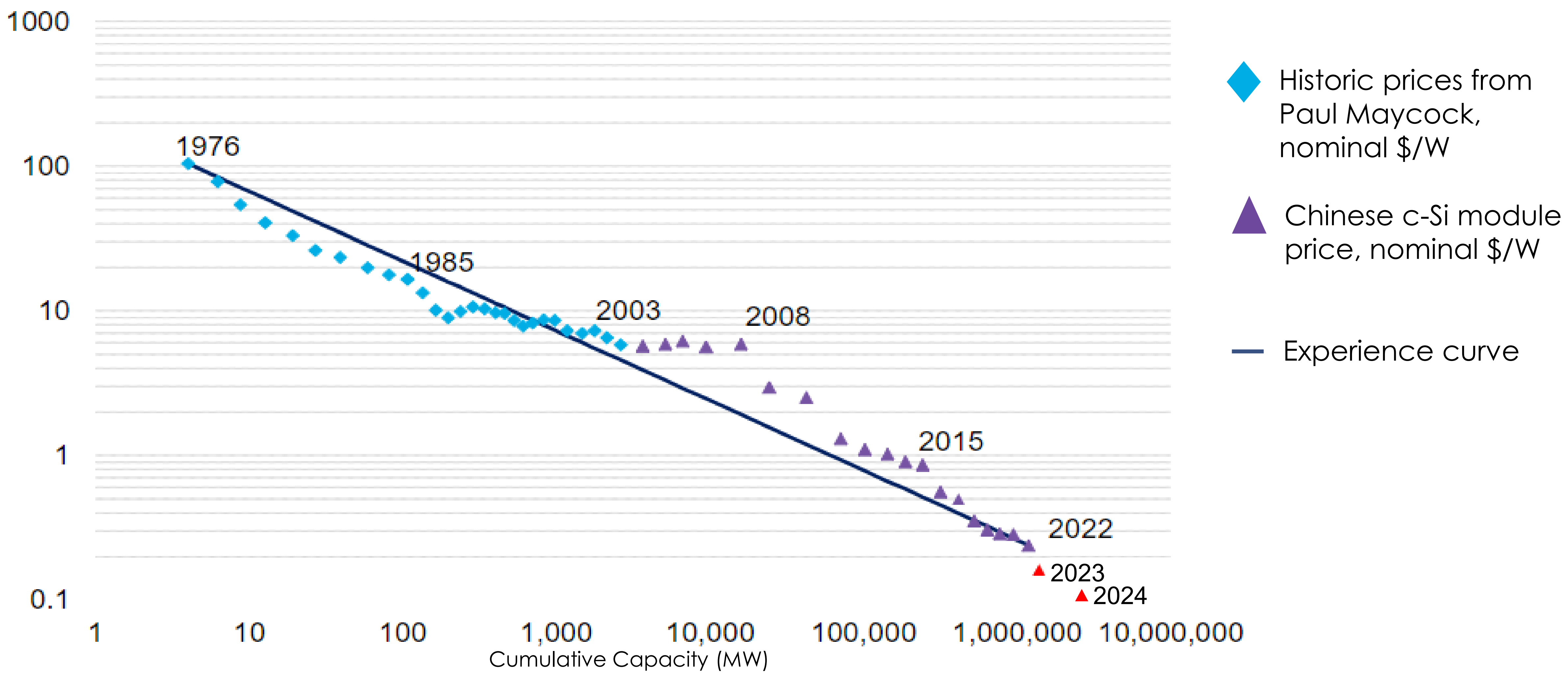
GHG emission by broad sector

Gt CO_{2eq}



Price of solar PV panels

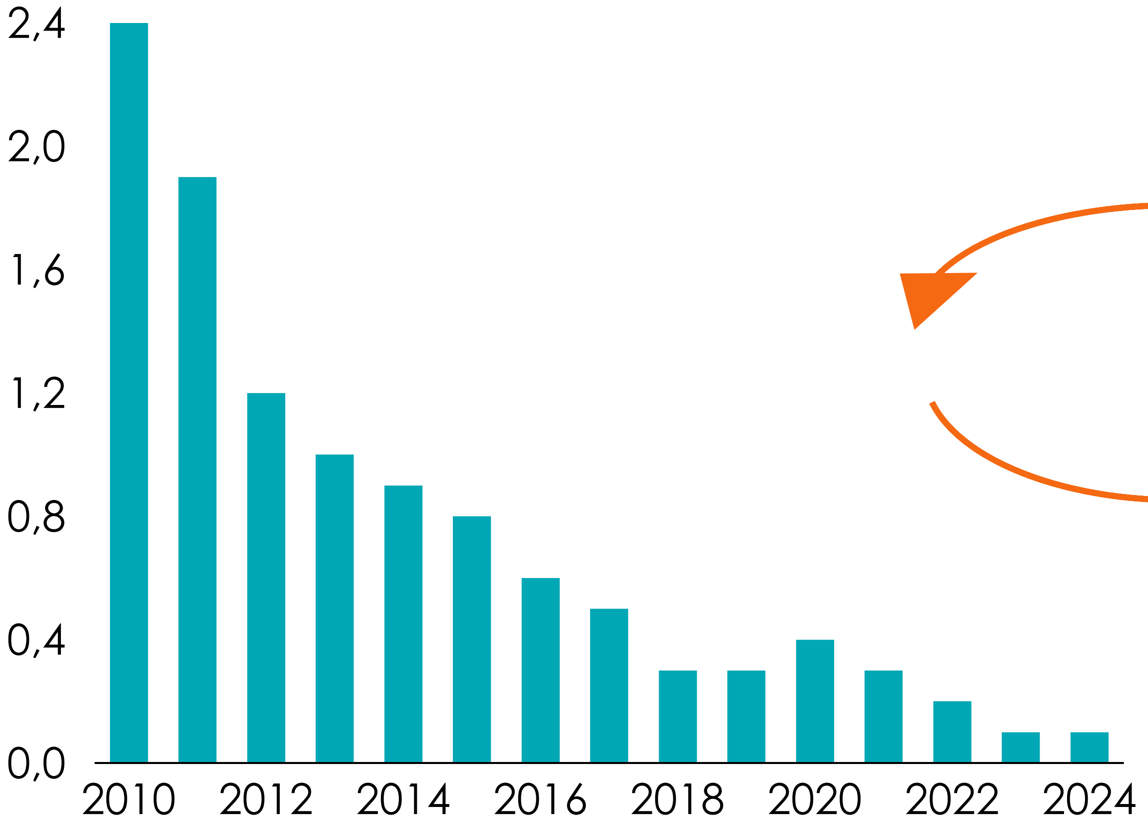
$ per peak watt; real 2023 $



Source: BNEF

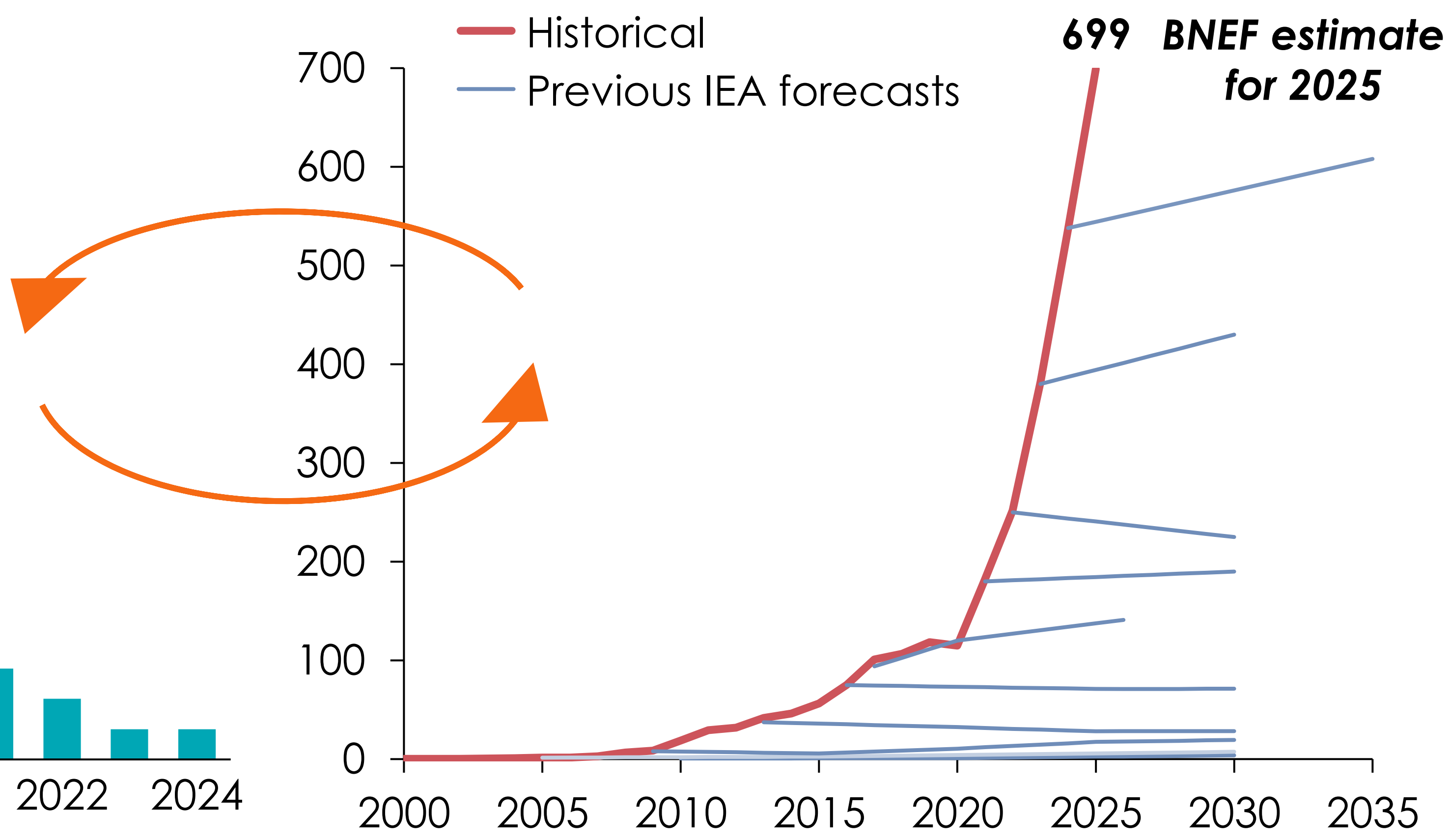
Benchmark capex for a typical module fixed-axis utility-scale photovoltaic power project

$ per Watt



Annual solar PV installations compared to IEA forecasts

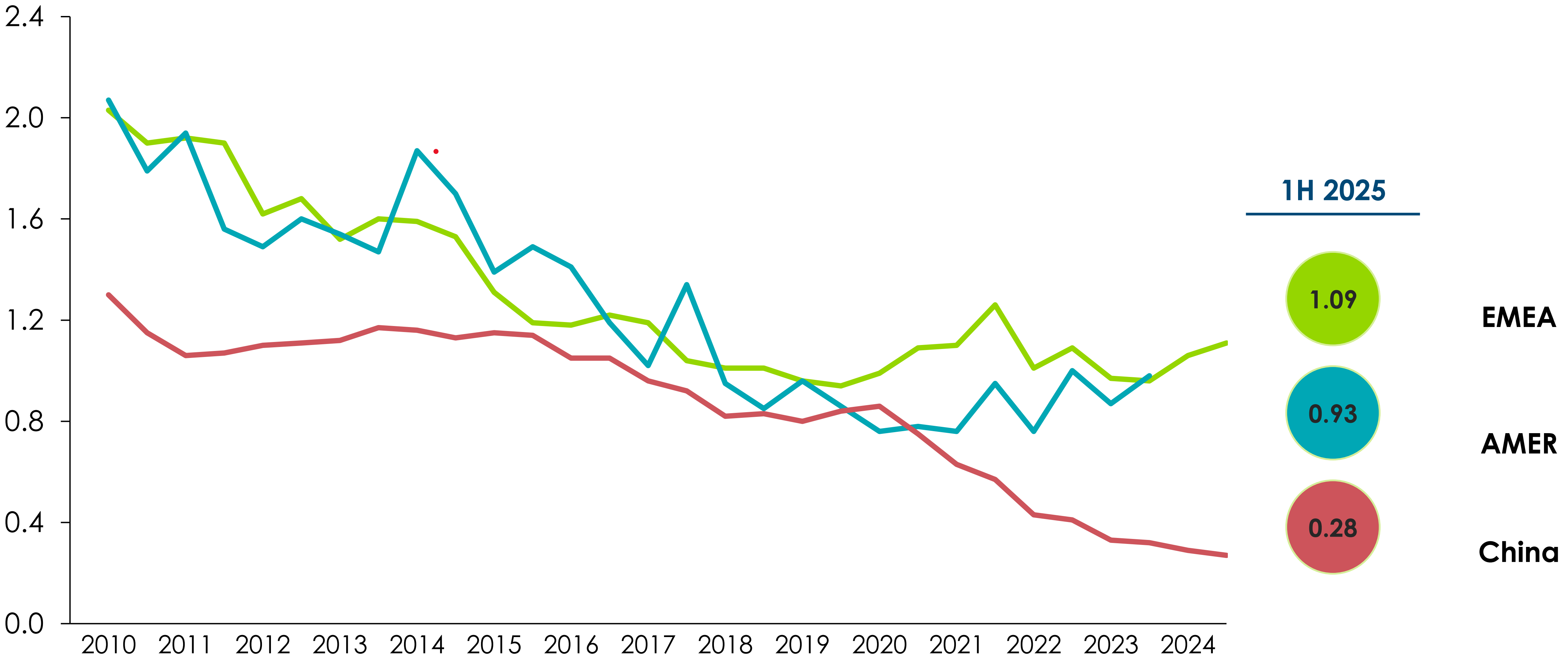
GW



Source: BNEF, Solar Modules Are Cheap and Will Become Even Cheaper. March 2025 https://www.bnef.com/shorts/ssej7bt1um0w00; IEA World Energy Outlook, multiple years of publication

Wind turbine prices by region, 2010-2025

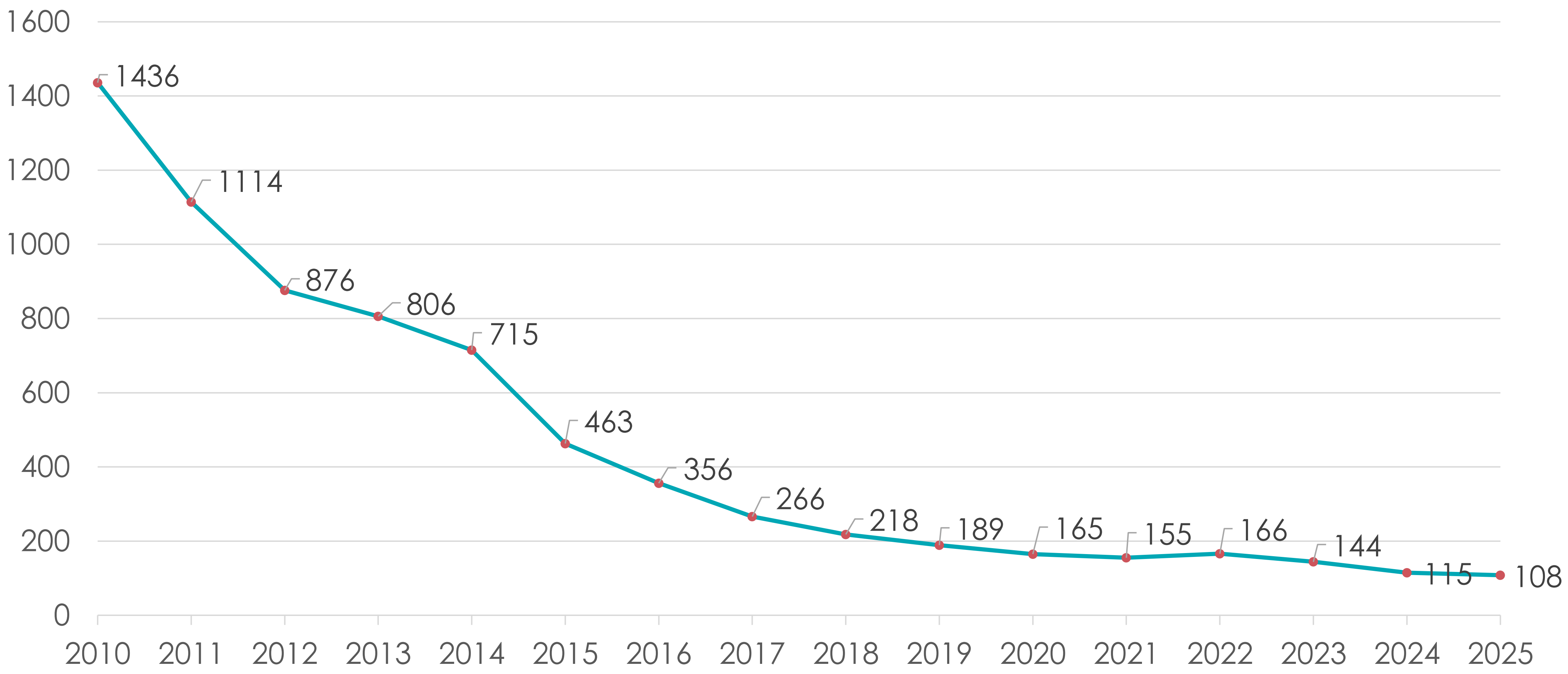
$ million/MW, 2025 real



Source: BNEF (2025) *Wind Turbine Price Index 1H 2025: Still on the Rise*; U.S. Bureau of Labor Statistics (2025), *Consumer Price Index for All Urban Consumers (CPI-U), All Items,U.S. City Average, Not Seasonally Adjusted.*

Lithium-ion battery price survey results: global average pack price

$/kWh, real 2024



Source: *BNEF Lithium-ion battery price survey* December 2025

Range: 190-250 miles

Price in China: ~ $9800
Fully competitive with ICE vehicles

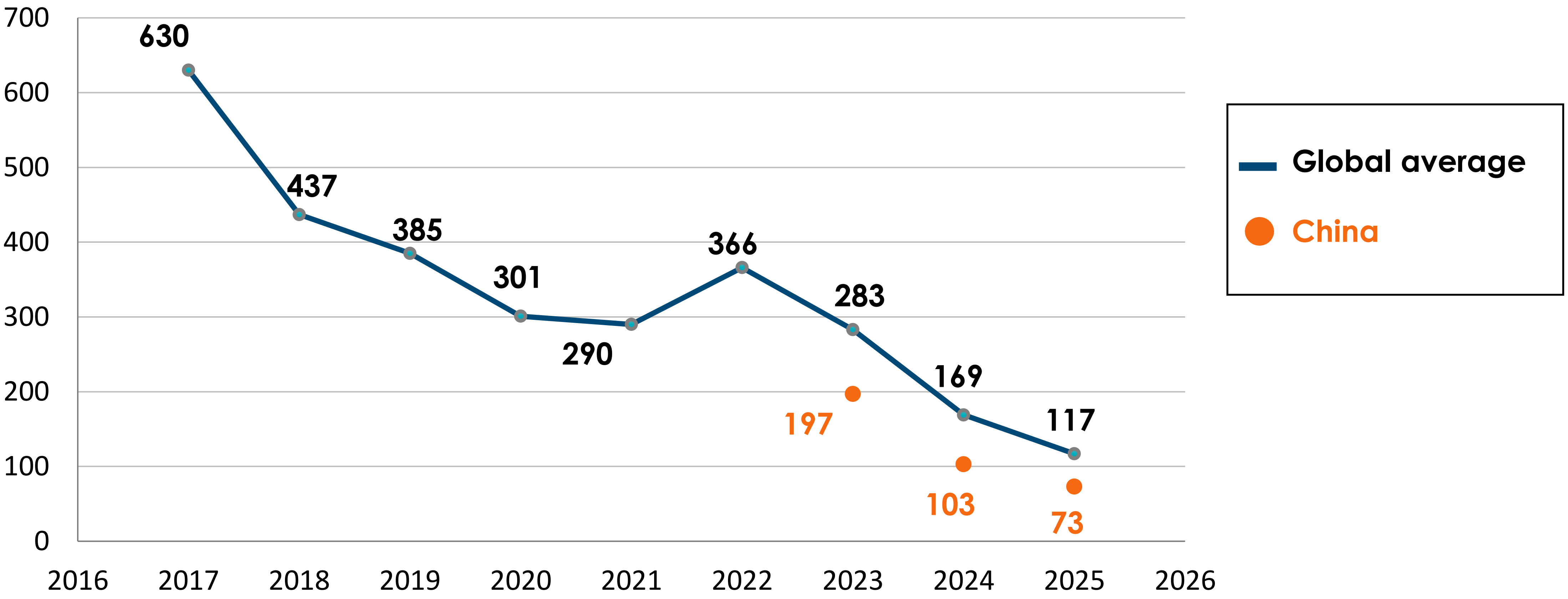
Launching in UK 2025
Price around £10000?

On average, EVs in China now 10% cheaper than equivalent ICEVs

Source: Our World in data (Accessed Jan 2025); Carbon dioxide concentrations in the atmosphere

Prices for turnkey energy storage systems 2016 –25

$ per kilowatt-hour, usable (real 2025)



Source: BNEF EnergyStorageSystems CostSurvey 2025, https://www.bnef.com/insights/38229/view

Falling solar costs

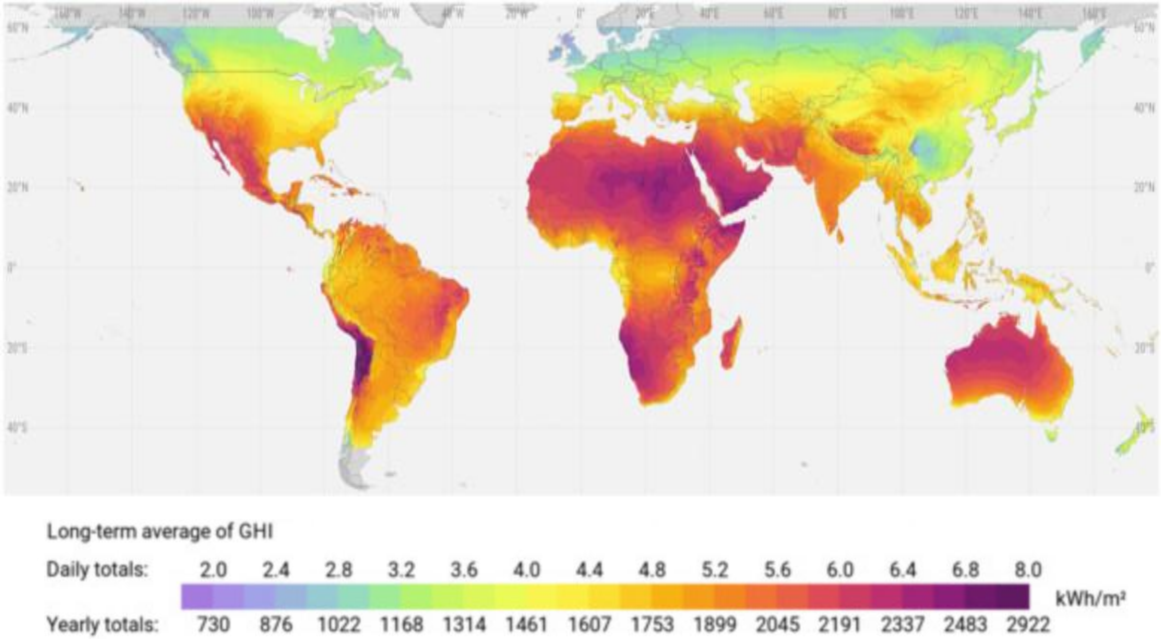
+

Falling battery costs

The global sunbelt and the high latitude wind belt

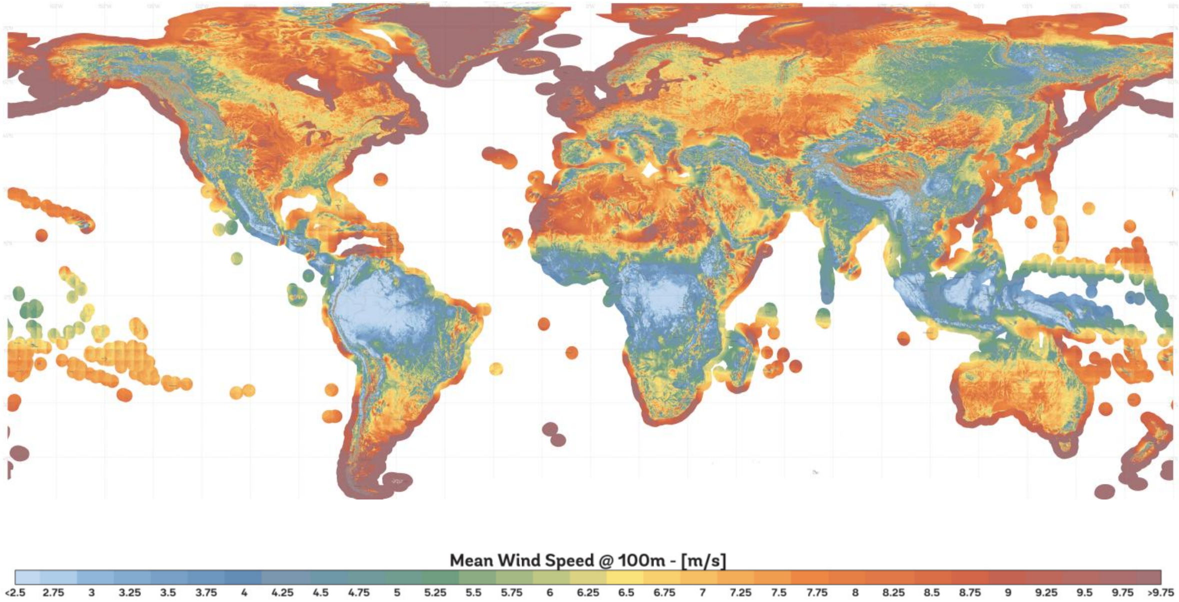
Solar irradiation intensity

Long-term yearly average of daily and yearly GHI totals



Wind power density

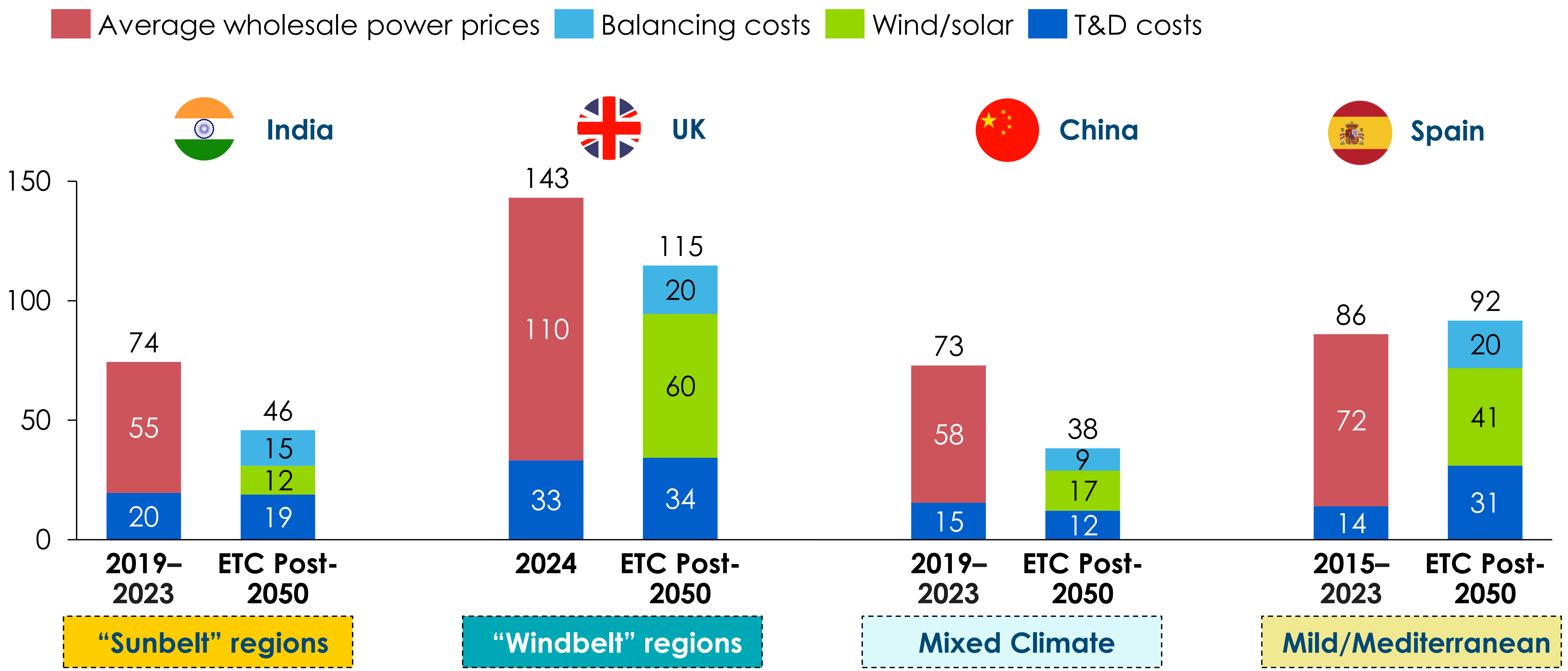
Mean wind power density at 100 m above surface level



Note: GHI refers to Global Horizontal Irradiance - the total amount of solar radiation received on a horizontal surface.
Source: World Bank (2023), *Global Solar Atlas*, available at https://globalsolaratlas.info/map?c=11.609193,8.4375,3. [Accessed 10/01/2025]; World Bank (2023), *Global Wind Atlas*, available at https://globalwindatlas.info/en/. [Accessed 10/01/2025].

Total system costs (generation, balancing, and grids), recent vs post-2050

$/MWh (real 2024$)

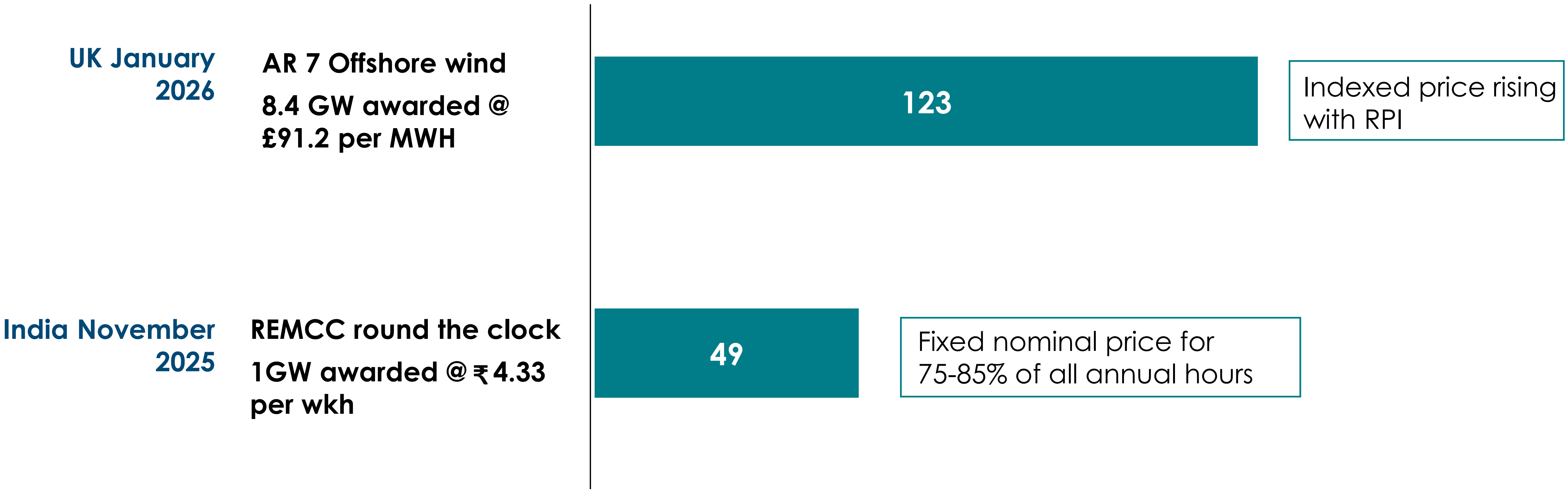


Note: T&D = Transmission and distribution.

Source: ETC (2025) Power Systems Transformation: Delivering Competitive, Resilient Electricity in High-Renewable Systems

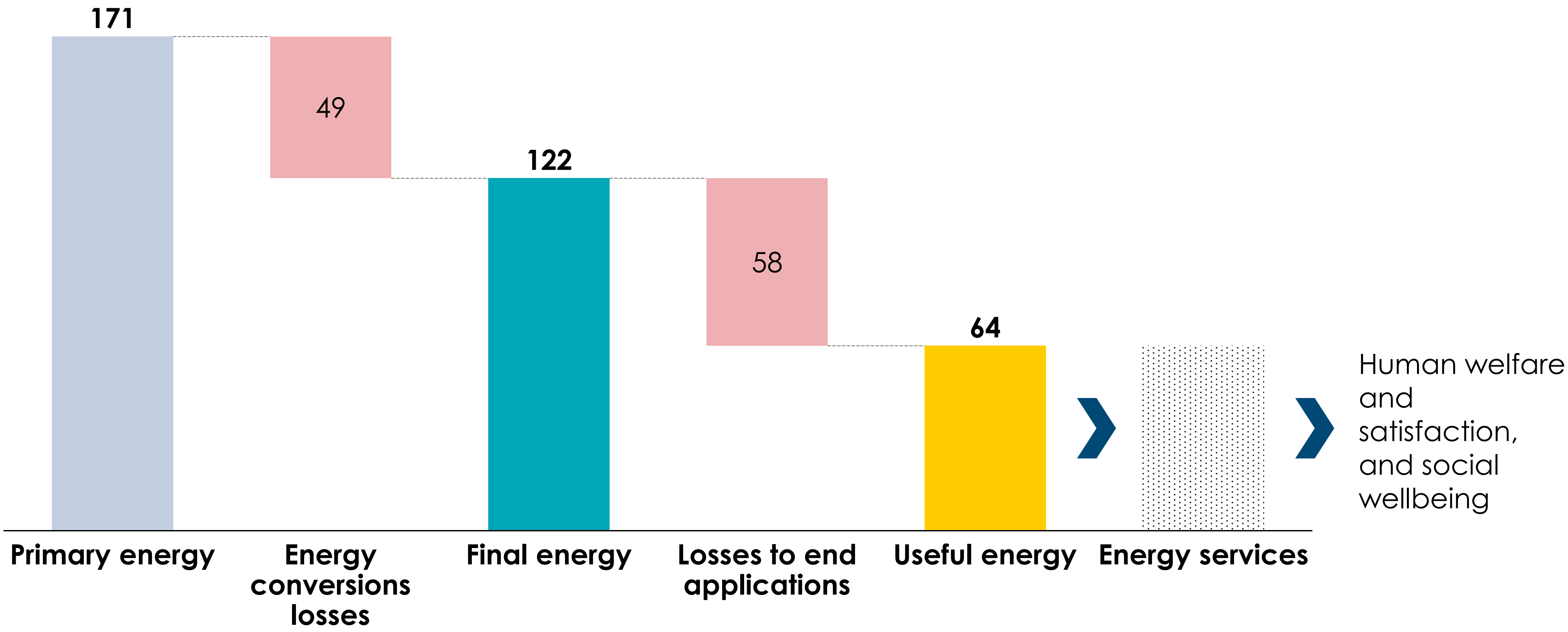
Clean power auctions in UK and India

$ per MWH price

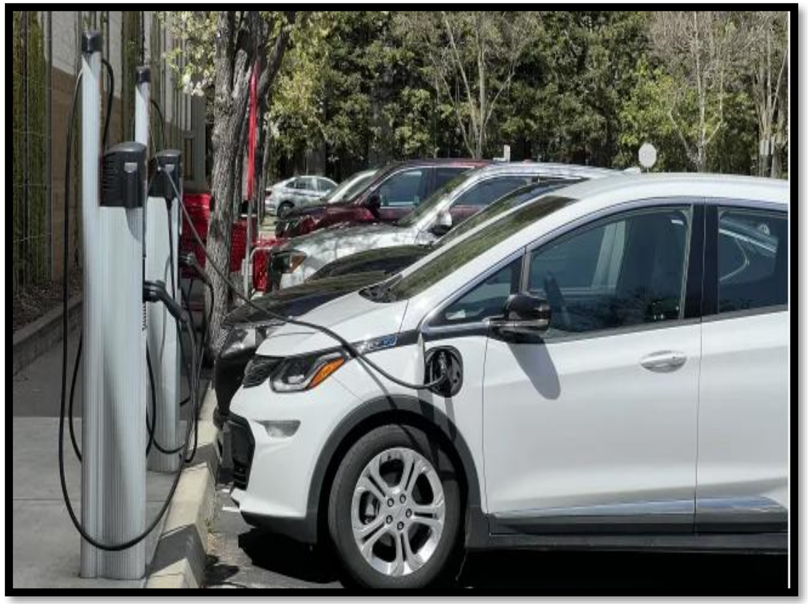


Global energy flows

000 TWh, 2023



Source: ETC (2025) Energy productivity: Increasing efficiency in an expanded, electrified energy system



3 to 4 times more efficient than ICEs in converting energy in the battery/ fuel tank into kinetic energy in the wheels

… Because of hugely reduced heat energy losses

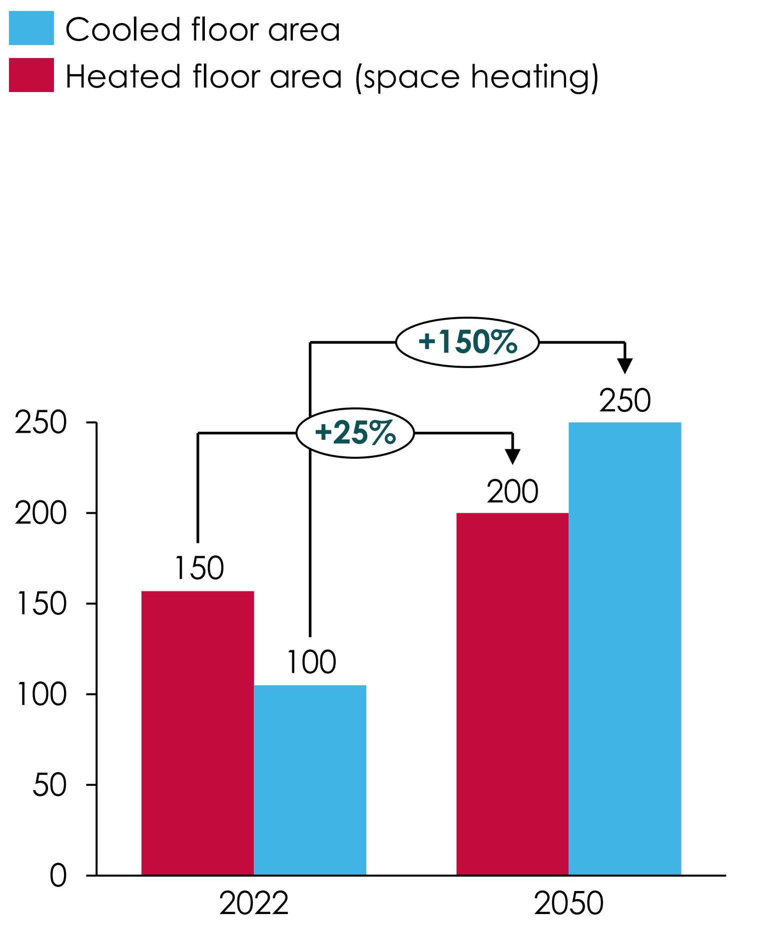
3 to 4 times more efficient than gas boilers in converting input energy heat within the home

- Gas boiler 70-90% efficiency
- Heat pump 300-400% COP, since extracts heat from the air

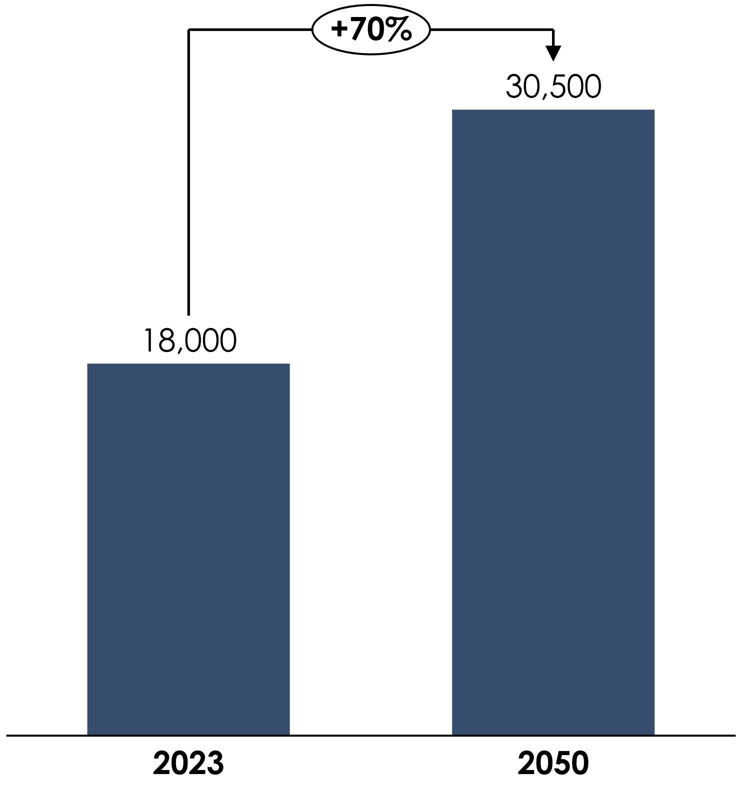
…and heat pump efficiencies will increase

Likely growth in energy services

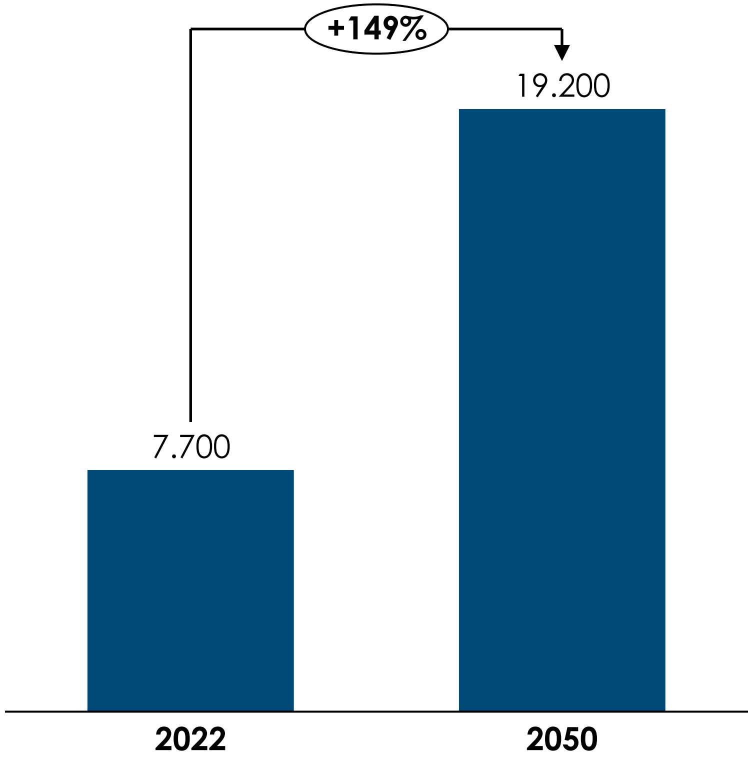
Heated and cooled floor area demand
Billion m2;



Passenger road transport demand
Billion km;



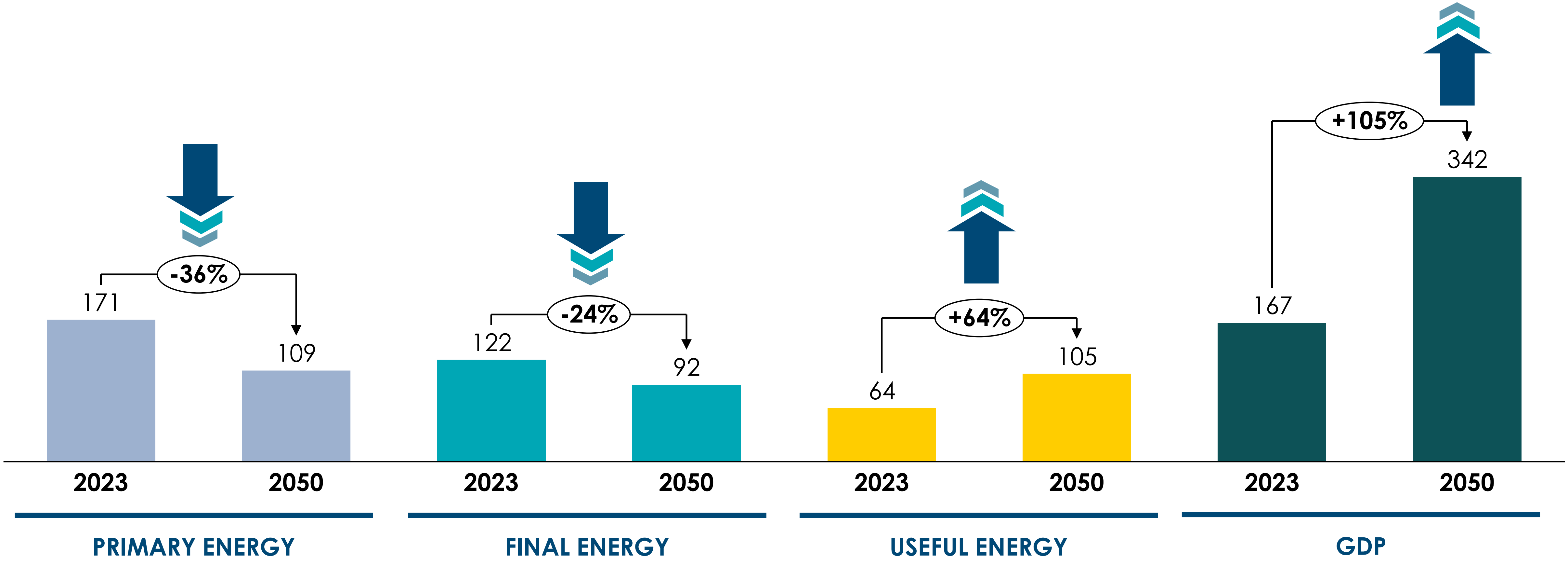
Aviation demand
Billions revenue passenger km (RPK)



Note: Revenue passenger km represents the number of paying passengers carried on scheduled flights multiplied by the number of km those seats were flown.
Source: ETC (2025) Energy productivity: Increasing efficiency in an expanded, electrified energy system

Rising energy services with falling inputs – the electrification effect

Energy in 000 TWh; GDP in constant 2021 Tn.US$



Source: ETC (2025) Energy productivity: Increasing efficiency in an expanded, electrified energy system

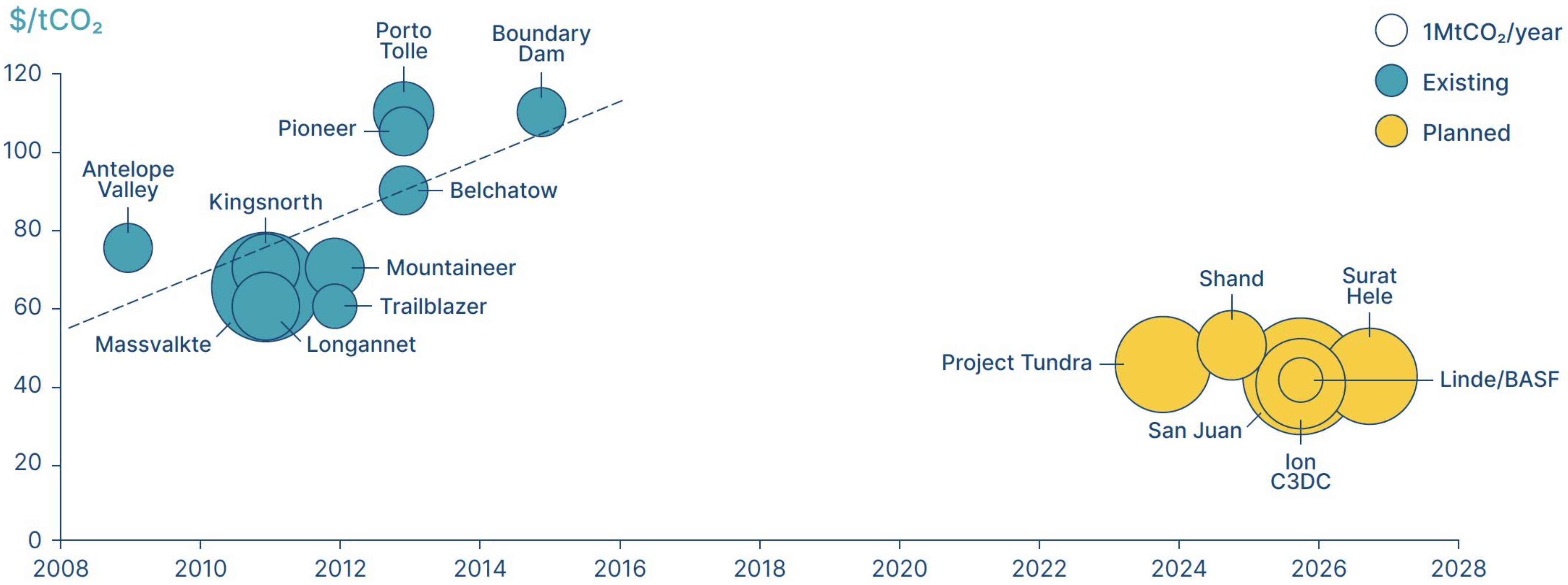
Fastest cost reduction

Solar PV, EVs and batteries	▪ Mass produced in large-scale, replicable factories ▪ Easily transported ▪ Easily deployed / installed
Heat pumps	▪ Mass produced in large factories ▪ Easily transported ▪ Complex installation
Wind	▪ Turbines supply chains very complex, scale of production is orders of magnitude smaller than PV/batteries ▪ Higher degree of customisation for projects ▪ Transport and installation more complex
Electrolyser and green H_2	▪ Can be mass produced, but balance of system costs and specific project complexities important
CCUS	▪ Customised engineering design and deployment
Large-scale nuclear	▪ Hugely complex large-scale systems

Slower/nil cost reduction

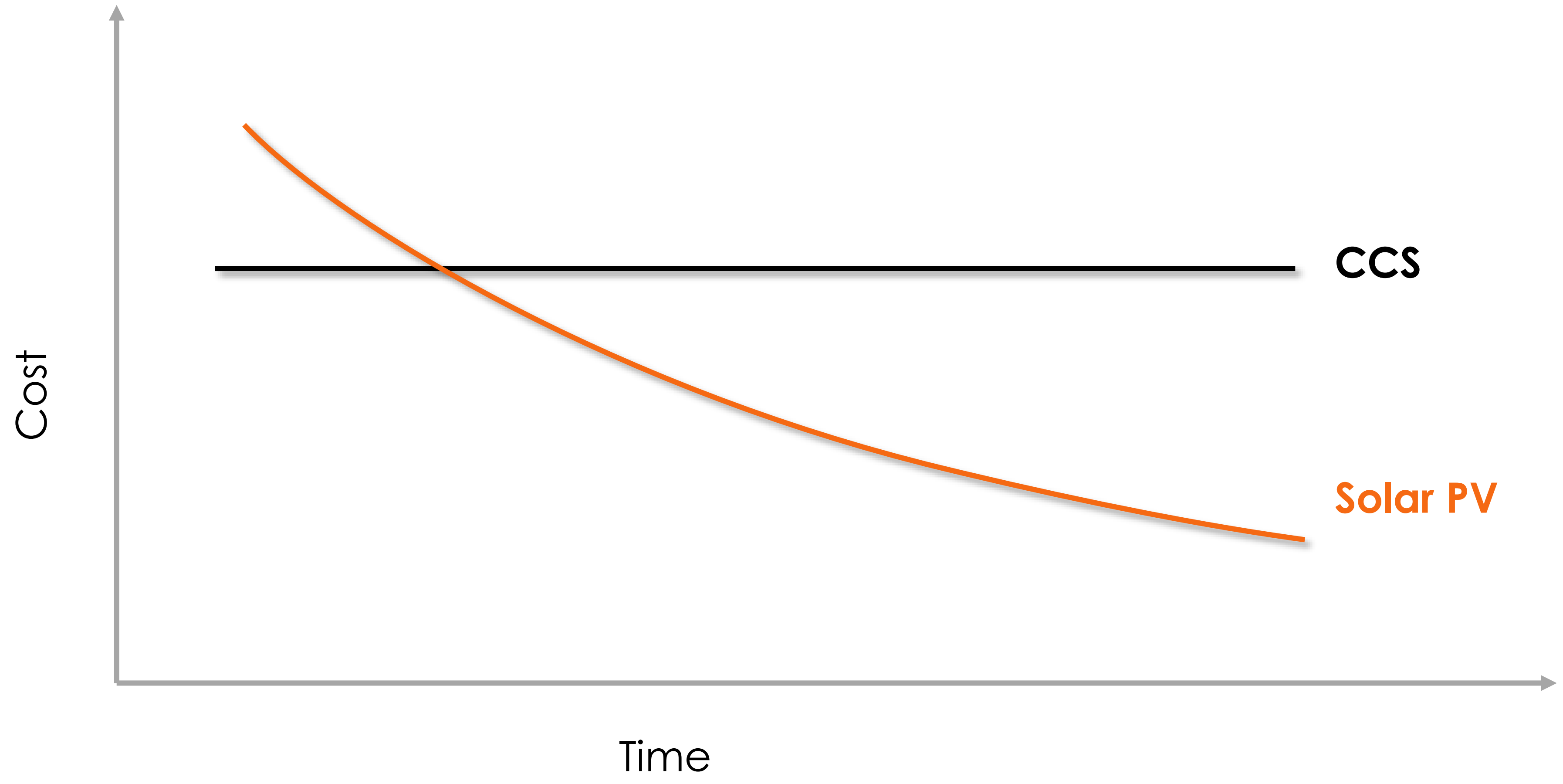
CCUS project costs: 2008-25

$/tCO$_2$

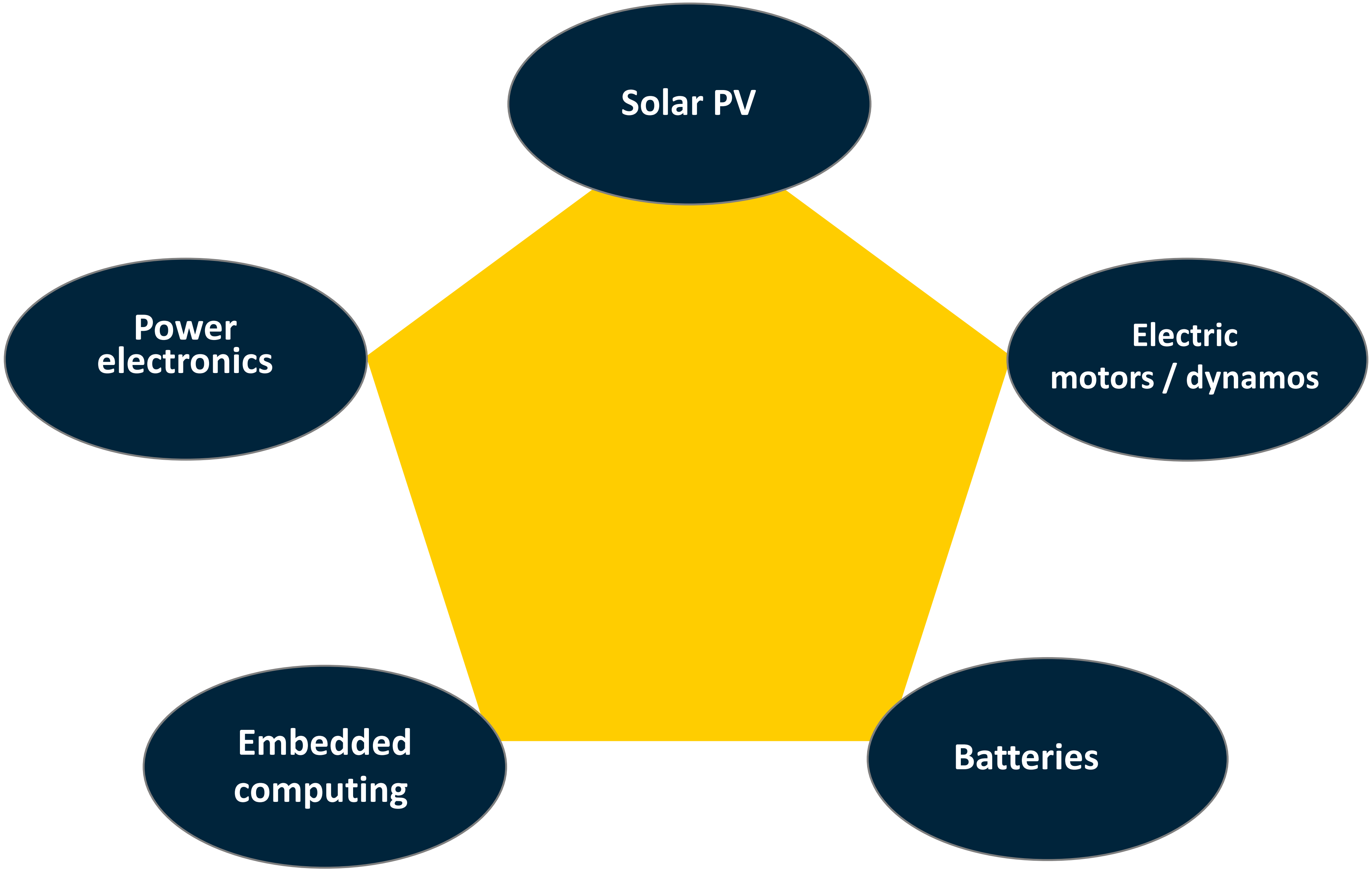


Source: ETC (2022) Carbon Capture, Utilisation and Storage in the Energy Transition: Vital but Limited

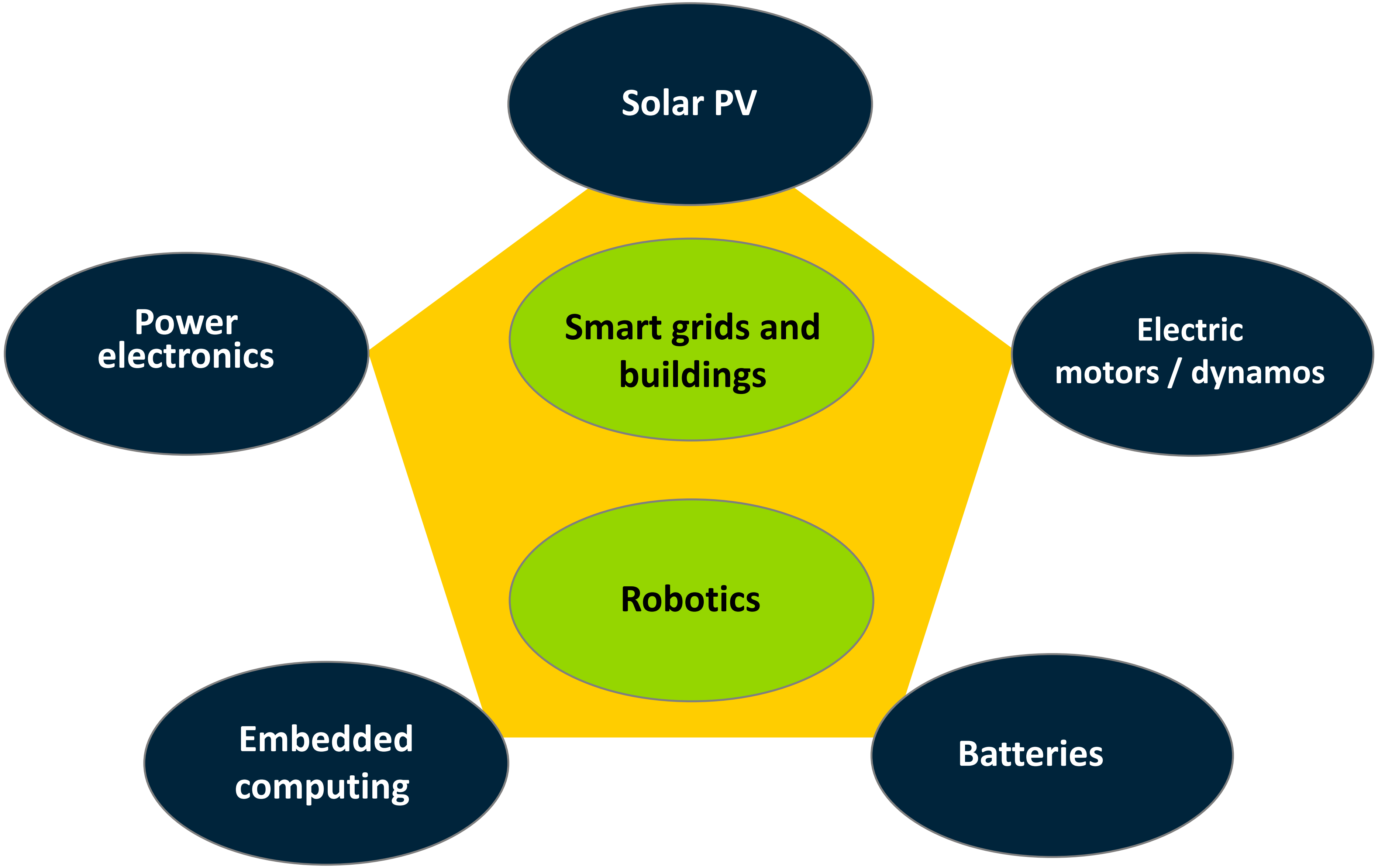
Solar PV vs carbon capture costs: 2008-25



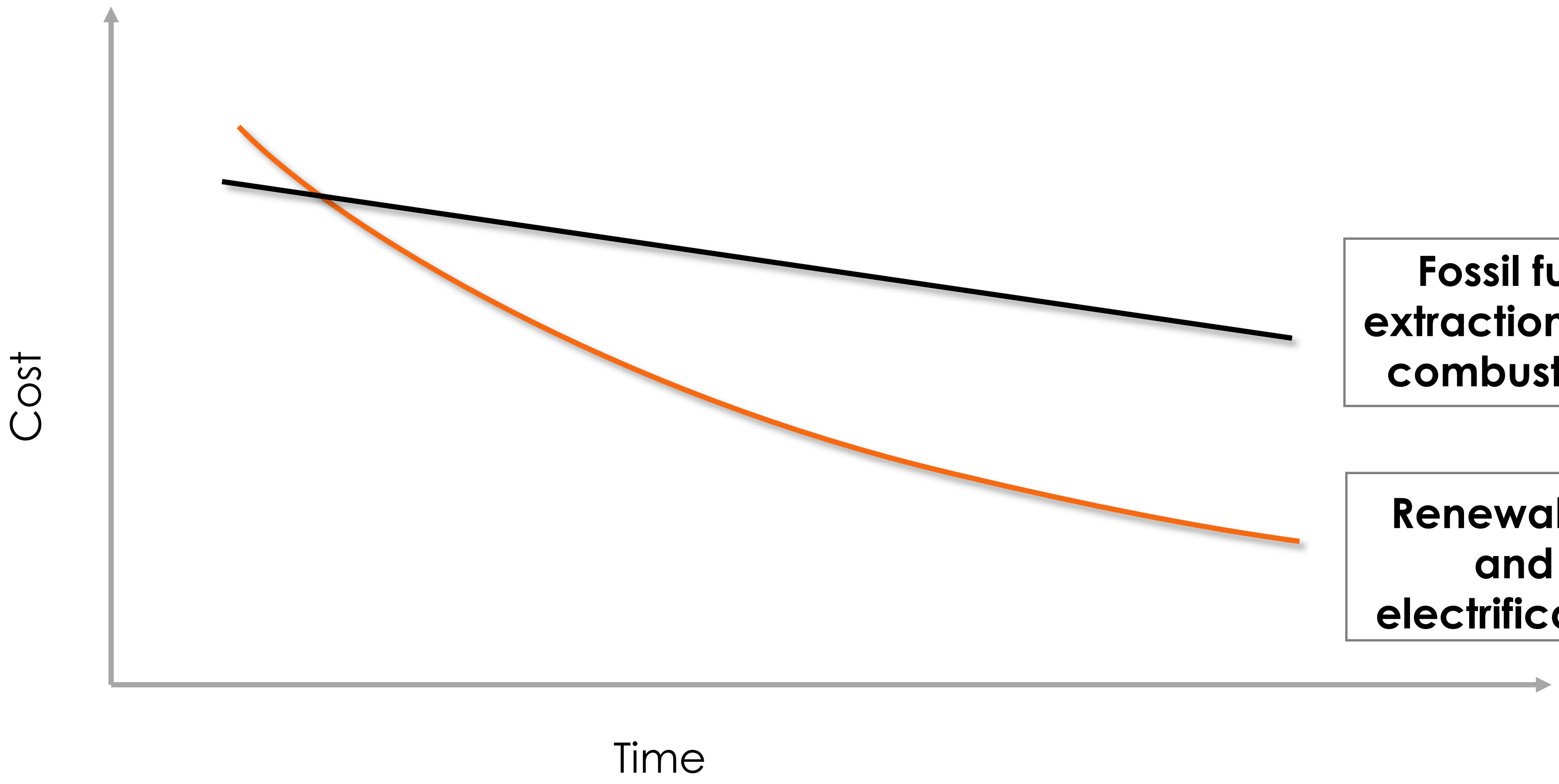
The electro tech stack



The electro tech stack

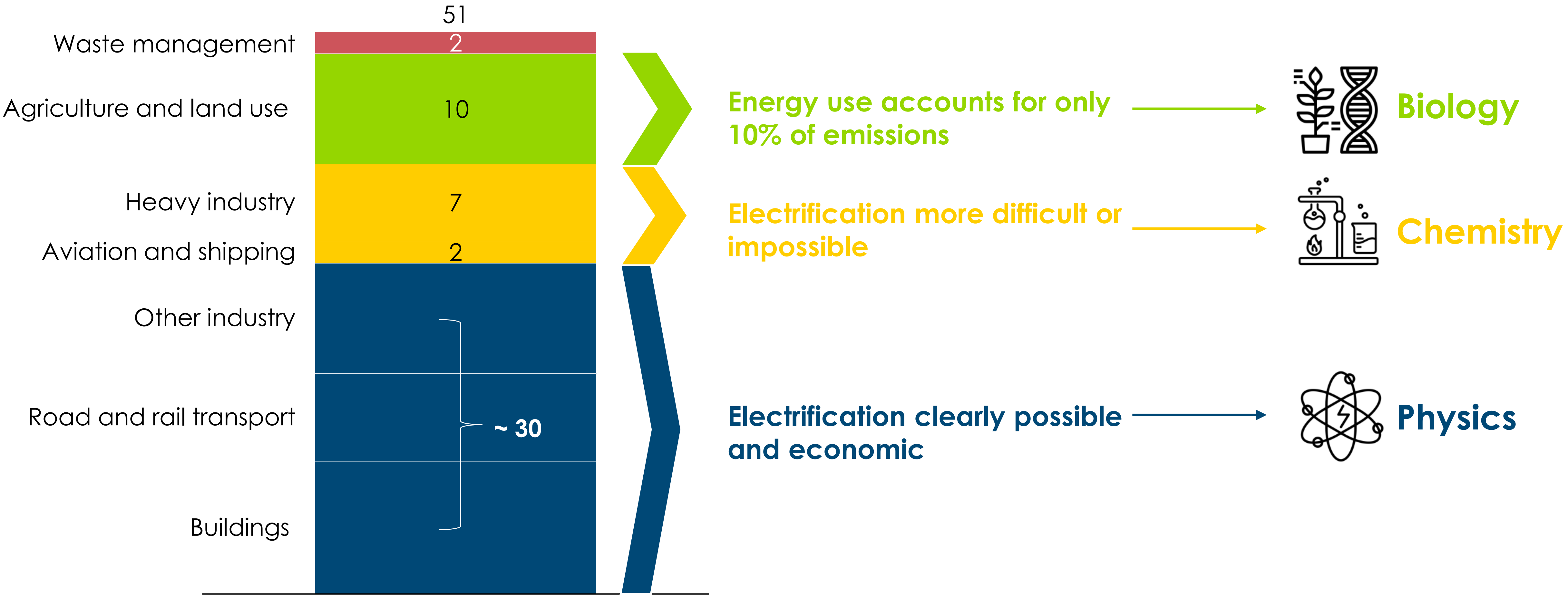


Electro tech vs fossil fuels



Greenhouse gas emissions by broad sector

Gt CO_{2eq}



Peak warming in the 21st century and key mitigation areas

°C

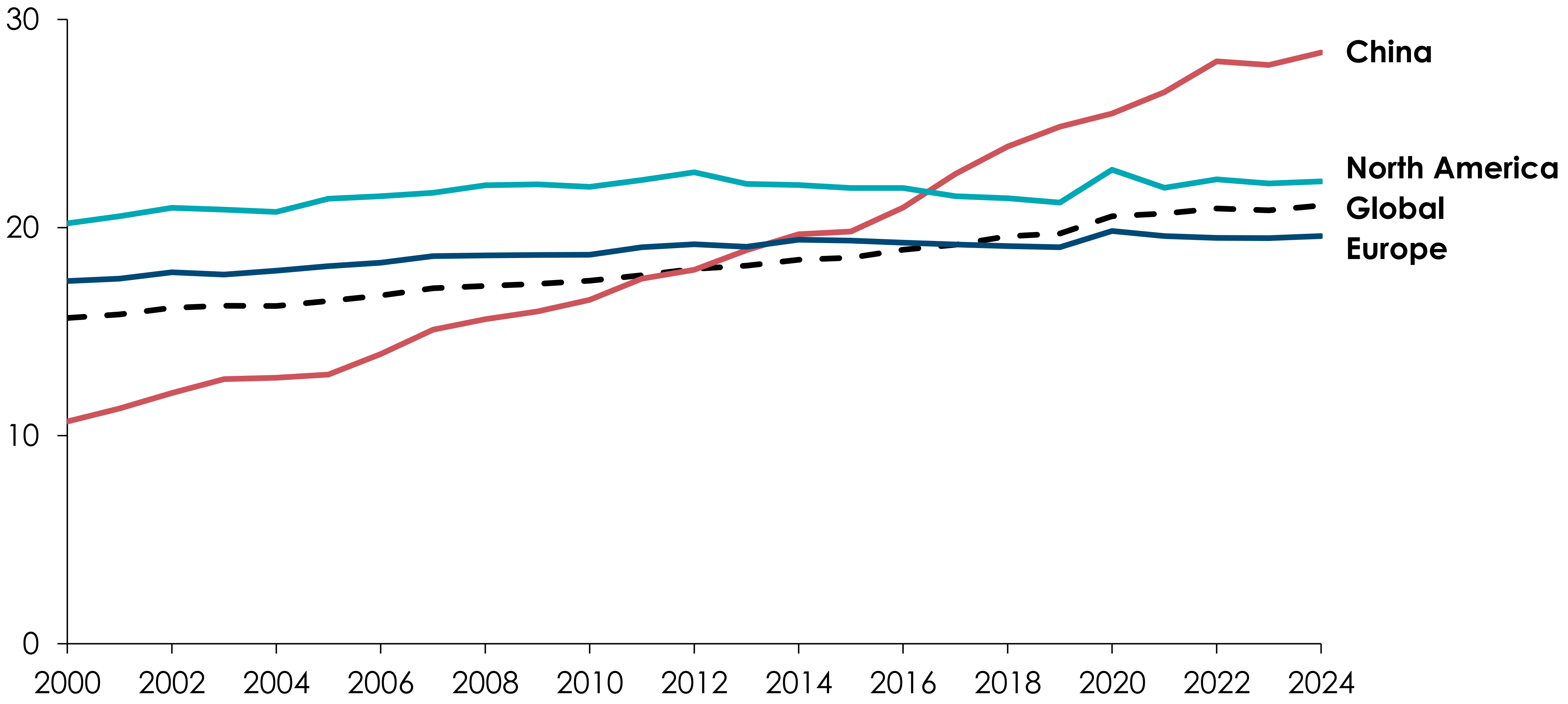
		Relative cost of action
	Economic transition, assuming no additional policy action (2.6°C)	
Clean electrification	AI **Turbocharging electrification**	Relatively costless – although heat pumps and industrial electrification uptake will need policy support
Clean electrification	AII **Accelerating clean power**	Renewables based system same or lower cost than fossil
Clean electrification	AIII **Early coal phase out**	Some cost for decommissioning or CCS
Other critical actions	BI **Accelerating action across HTA sectors**	Green premium will require carbon price on HTA
Other critical actions	BII **Reducing methane and $N_2$0 emissions**	Mix of costless/some cost
Other critical actions	BIII **Reducing emissions in LULUCF**	Mix of costless/some cost
	Removals	Costly, with limited material economic benefit
	Net-zero scenario (Well Below 2°C)	

Key

No cost or cheaper than alternative
Some cost
Clear cost

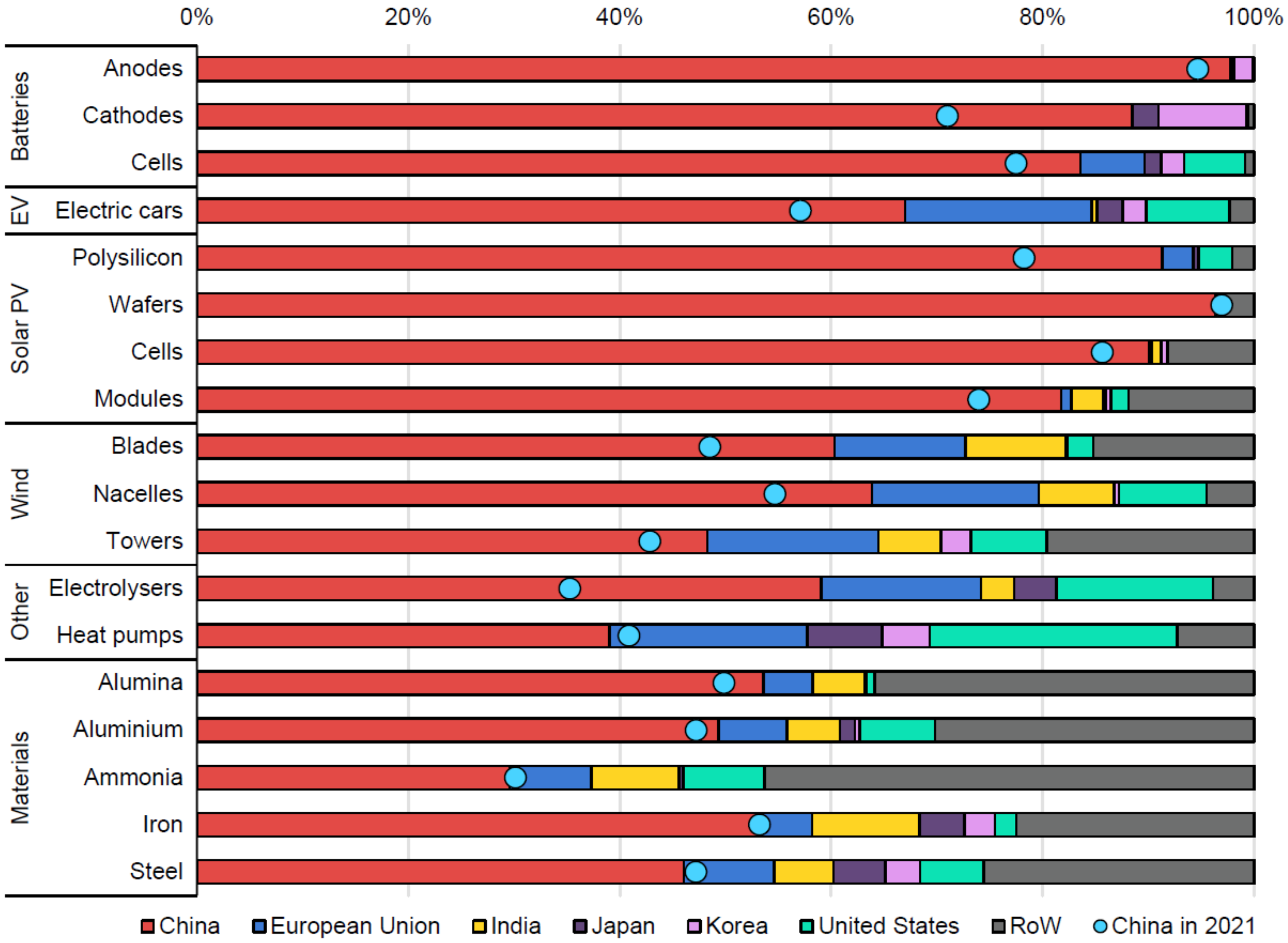
Electricity share of final energy demand

%



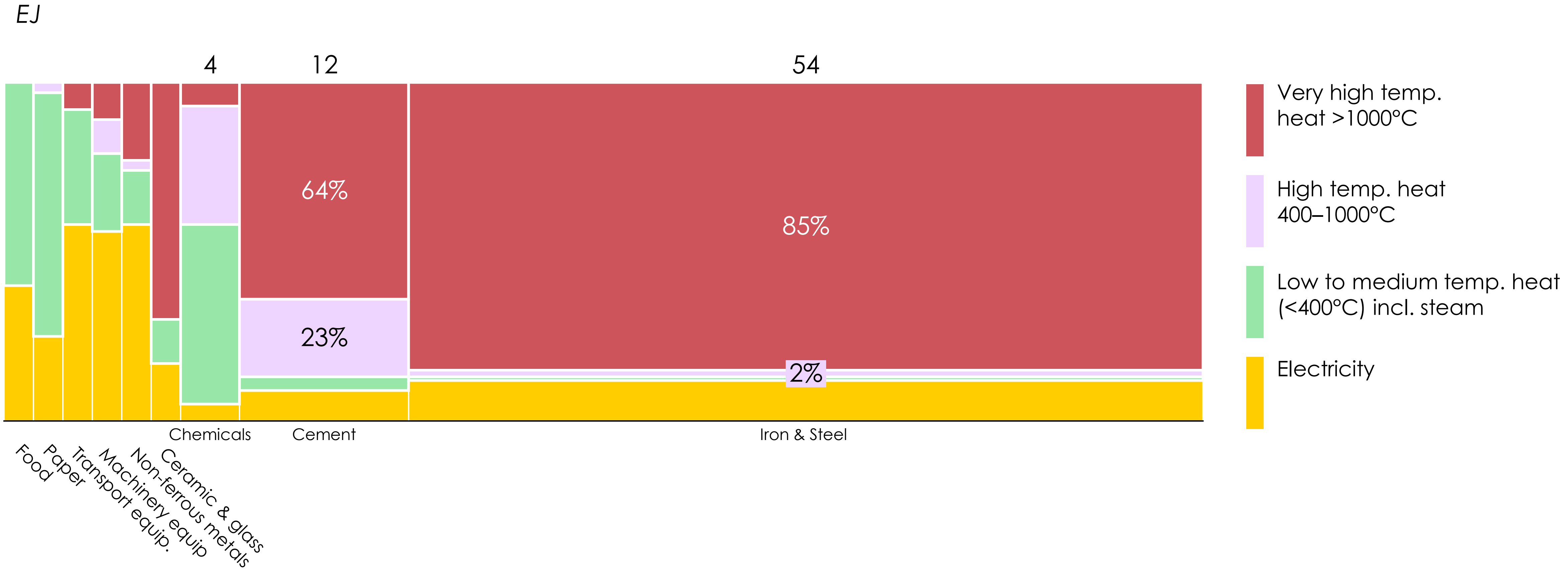
Source: BNEF (2025) *New Energy Outlook*

Installed global manufacturing capacity by country/region 2023



Source: IEA (2024) *Clean Technology Perspectives*

Energy use by temperature and industry sector[1] in 2050 (EJ)



Notes: 1. Data representing energy split by temperature in EU across the sectors applied to a global level based on a study from Madeddu (20220) with adaptions for the chemical sector to include plastics from Coolbrook (2024).
Sources: Final energy demand in 2050 based on Systemiq analysis (2024) from ETC (2023), Fossil Fuels in Transition Report; Silvia Madeddu (2020), The CO_2 reduction potential for the European industry via direct electrification of heat supply. Coolbrook (2024), Electric cracking: RotoDynamic Reactor cuts 100% of CO_2 in steam cracking

New technologies currently under development could electrify industrial energy demand at high temperatures (over 400°C)

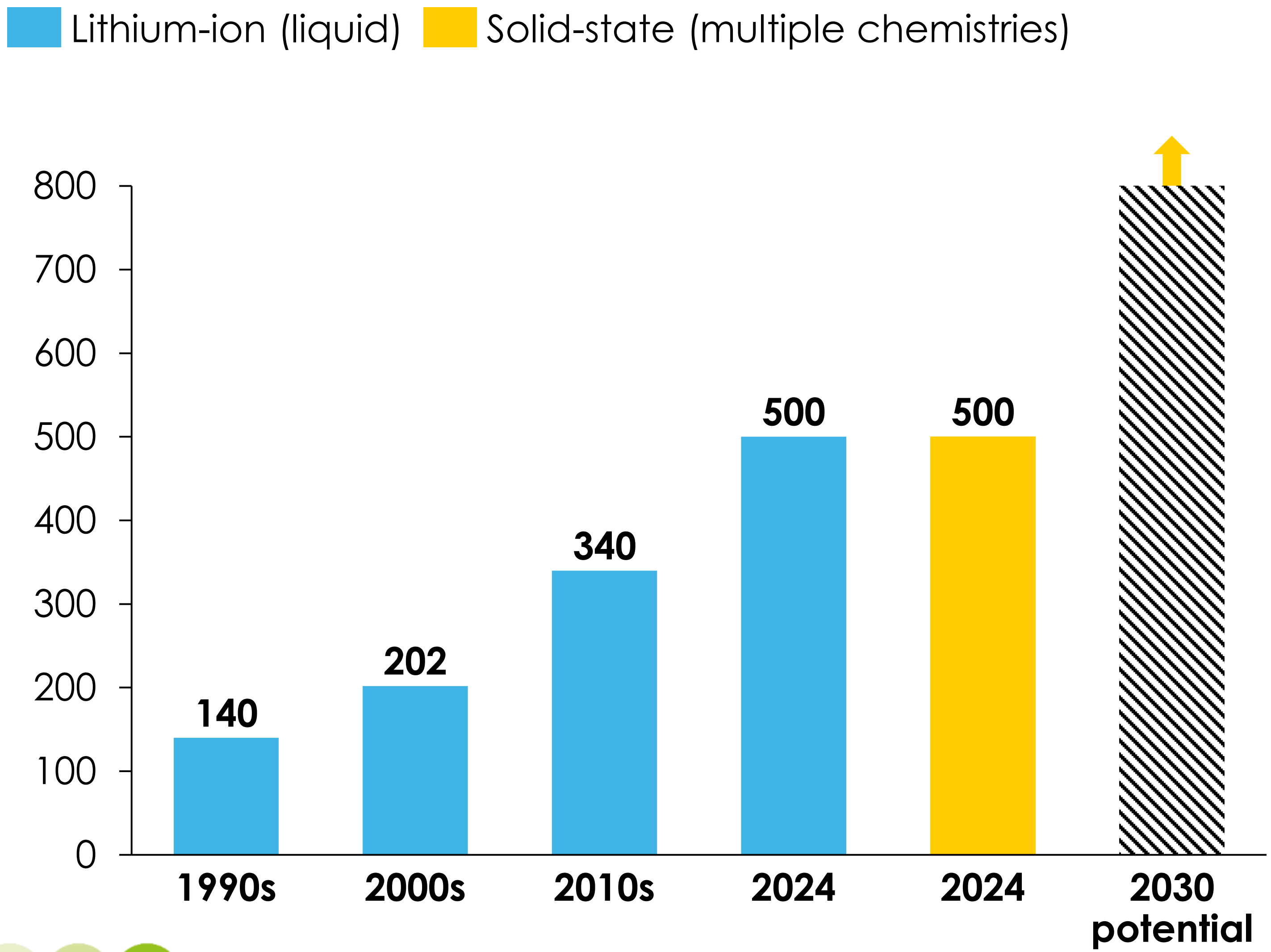
Technology[1]	Process	Sectors[2]	TRL	Energy Efficiency	Company *Non-exhaustive examples*
Shock-wave heating	**Rotation turbines** employ an **electric motor** to spin **blades** and **gas**, where **supersonic speed** and **rapid deceleration** creates a shock-wave and turbulent gas, which generates high temperature heat	Cement, chemicals, steel, aluminum, other industry (glass)	6-7	50-95%	Siemens, Coolbrook, T.EN Technip Energies
Arc and plasma heating	Two electrodes connected to a high-voltage power supply create an **electric field that ionises the air, forming a plasma with electrons and positively charged particles**. The applied electric field causes the ionized gas molecules to oscillate to generate heat	Cement, Steel, other industry (Machinery, transport equipment)	3-9	50-90%	Algoma Steel Inc., SaltX Technology, Cementa (HeidelbergCement Group), PyroGenesis
Resistance	An electric current passes through **resistive elements**, causing electrons to **collide with the atoms** of the material, converting electrical energy into heat, the heat is then transferred by gas through convection or through radiation	Steel, aluminum, chemicals, other industry (glass, machinery, transport equipment)	6-9	50-95%	Linde, BASF, T.EN Technip Energies, Chevron, سابك SABIC
Microwave	Electricity powers a **microwave generator**, producing **microwaves** that cause molecules (especially water or other polar materials) to **oscillate**, generating collisions and with that heat	Steel (sintering), other industry (e.g., ceramics)	Unsure	50-85%	Ferrite Microwave Technologies
Induction	**High-frequency current passes** through an induction coil (e.g., copper), creating a **magnetic field**. This process generates induced force and produces heat because of the electrical collisions in the material.	Steel, aluminum, other industry (machinery, glass, minerals, transport)	7-9	50-90%	GH Induction, Inductotherm

Note: 1. Only includes the sectors where a technology can electrify a high temperature processes; 2. Other technologies can be implemented for industry electrification, e.g. ultraviolet (UV), infrared, thermoelectric cooling, electron beam, and laser heating but have a narrow field of application

Source: Silvia Madeddu (2020), The CO2 reduction potential for the European industry via direct electrification of heat supply. Fraunhofer ISI (2024): Direct electrification of industrial process heat. An assessment of technologies, potentials and future prospects for the EU. Study on behalf of Agora Industry.

Top-tier battery cell energy density over time

Gravimetric densities, Watt-hours/kg



Feasible sector application

Short-haul passenger aircrafts[1]
Medium-haul shipping

Shorter-haul aviation[2]

Shorter-haul shipping[2], Heavy trucks

Light trucks

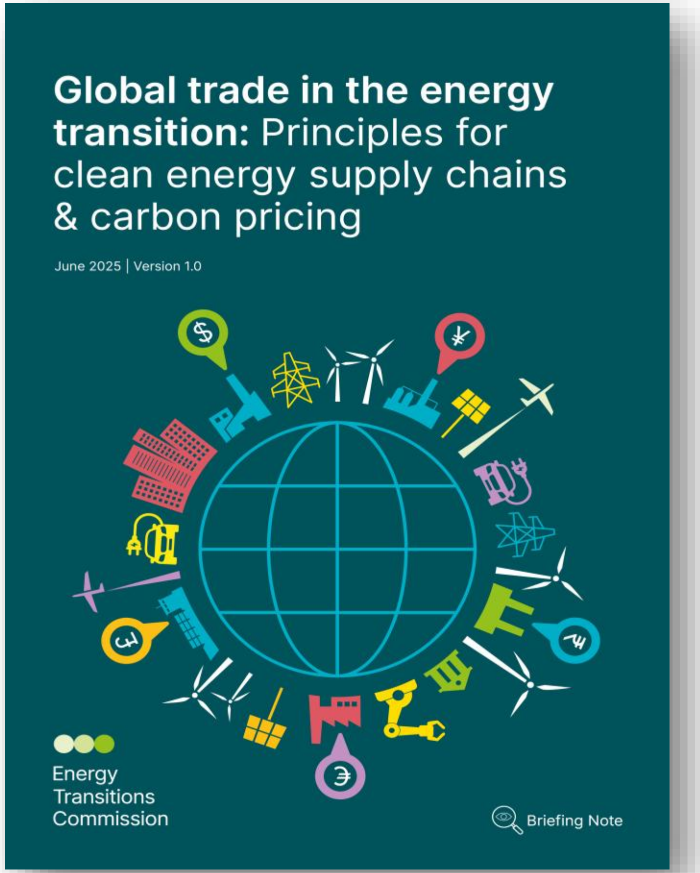
Passenger cars

Consumer electronics

Sources: ETC (2025) Carbon in an electrified future: Technologies, trade-offs and pathways

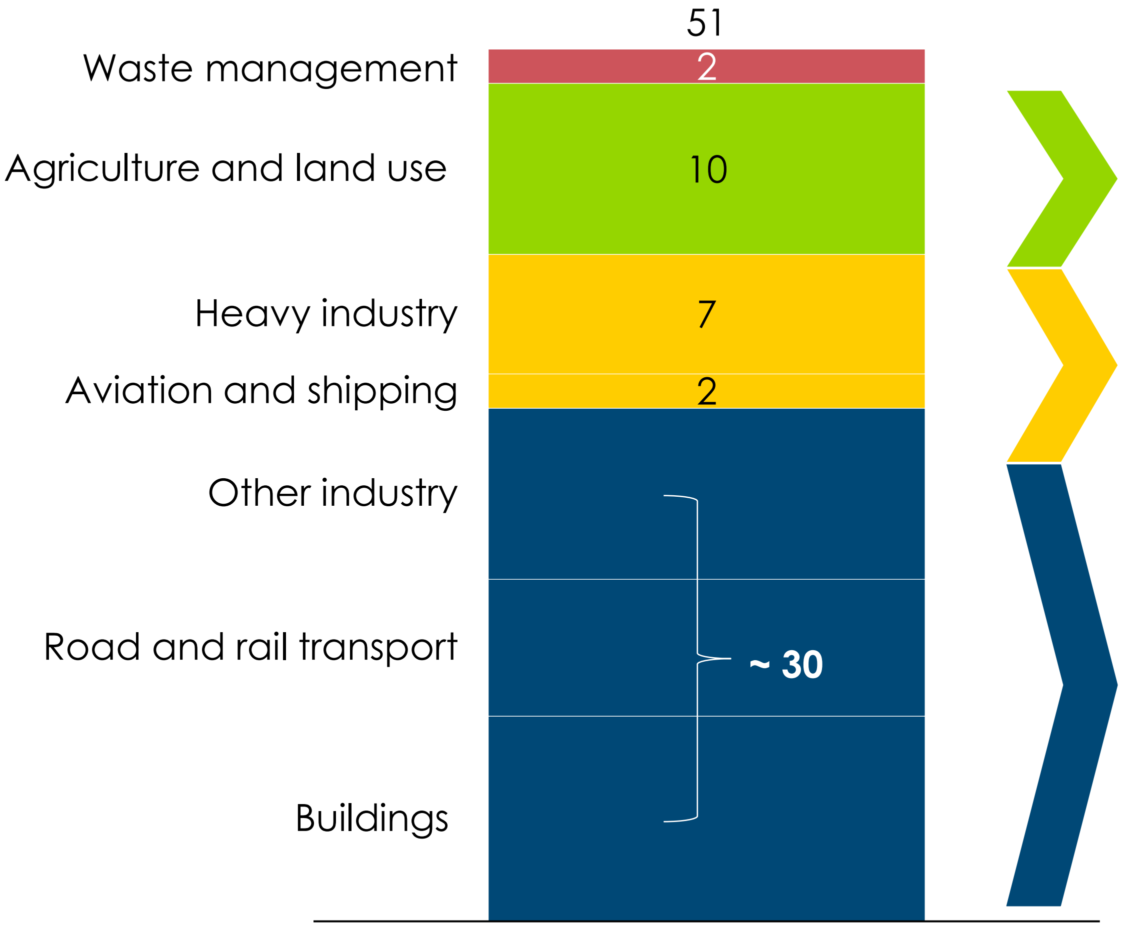
Developing domestic supply chains: five principles

1. Aim for diversified supply chains but **not complete autarky**
2. Think straight about **different dimensions of "security"**
3. **Vary policy by sector** to reflect different starting points and inherent characteristics
4. Use **tariffs in a fact-based and WTO compliant** fashion
5. Focus primarily on the **location of employment and value added**, rather than ownership.



GHG emission by broad sector

Gt CO_{2eq}



No clear technology answer – and feasible actions will add cost

Known technologies but with significant green cost premia

Known technology solutions reduce both emissions and costs