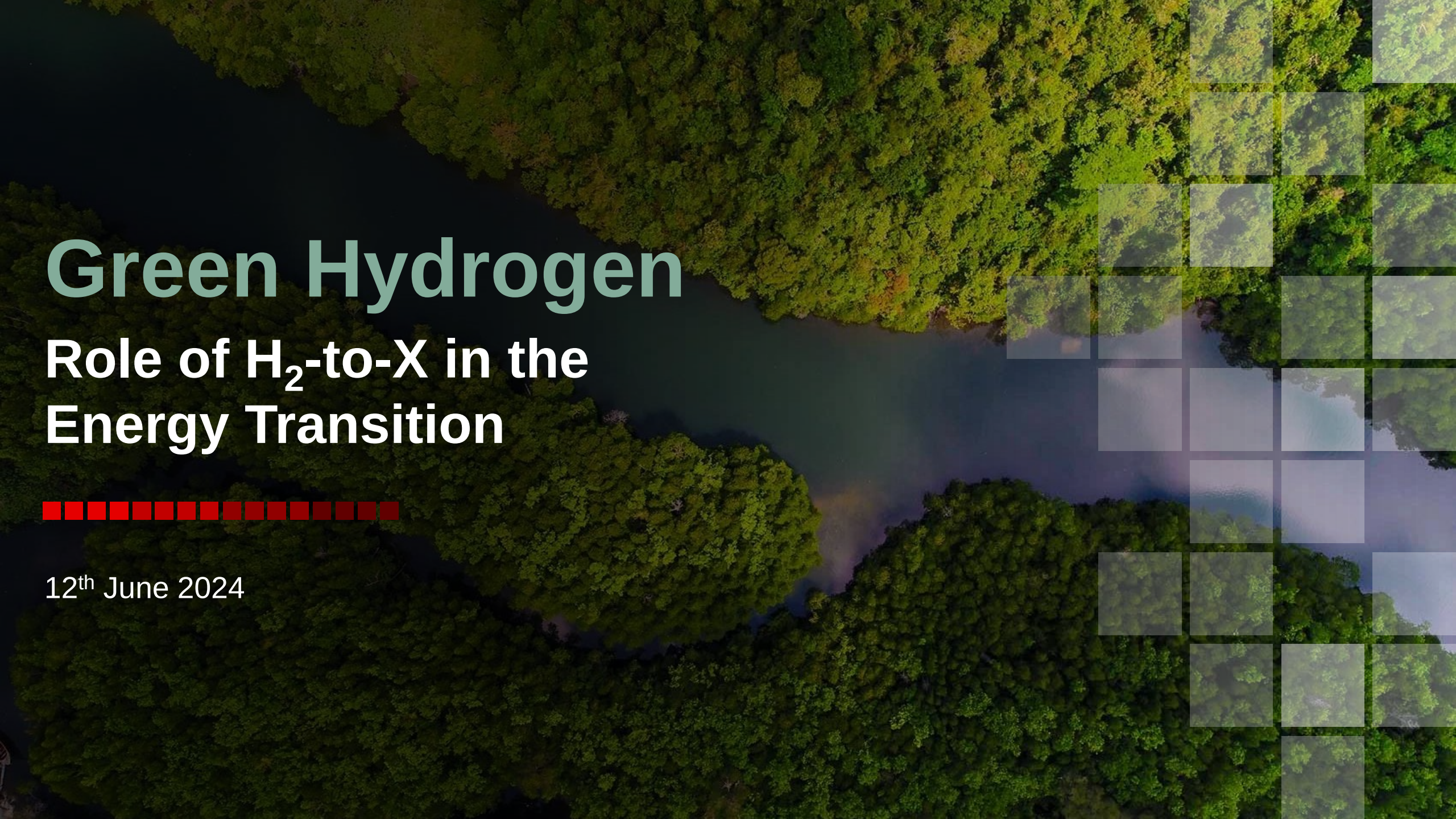


Green Hydrogen

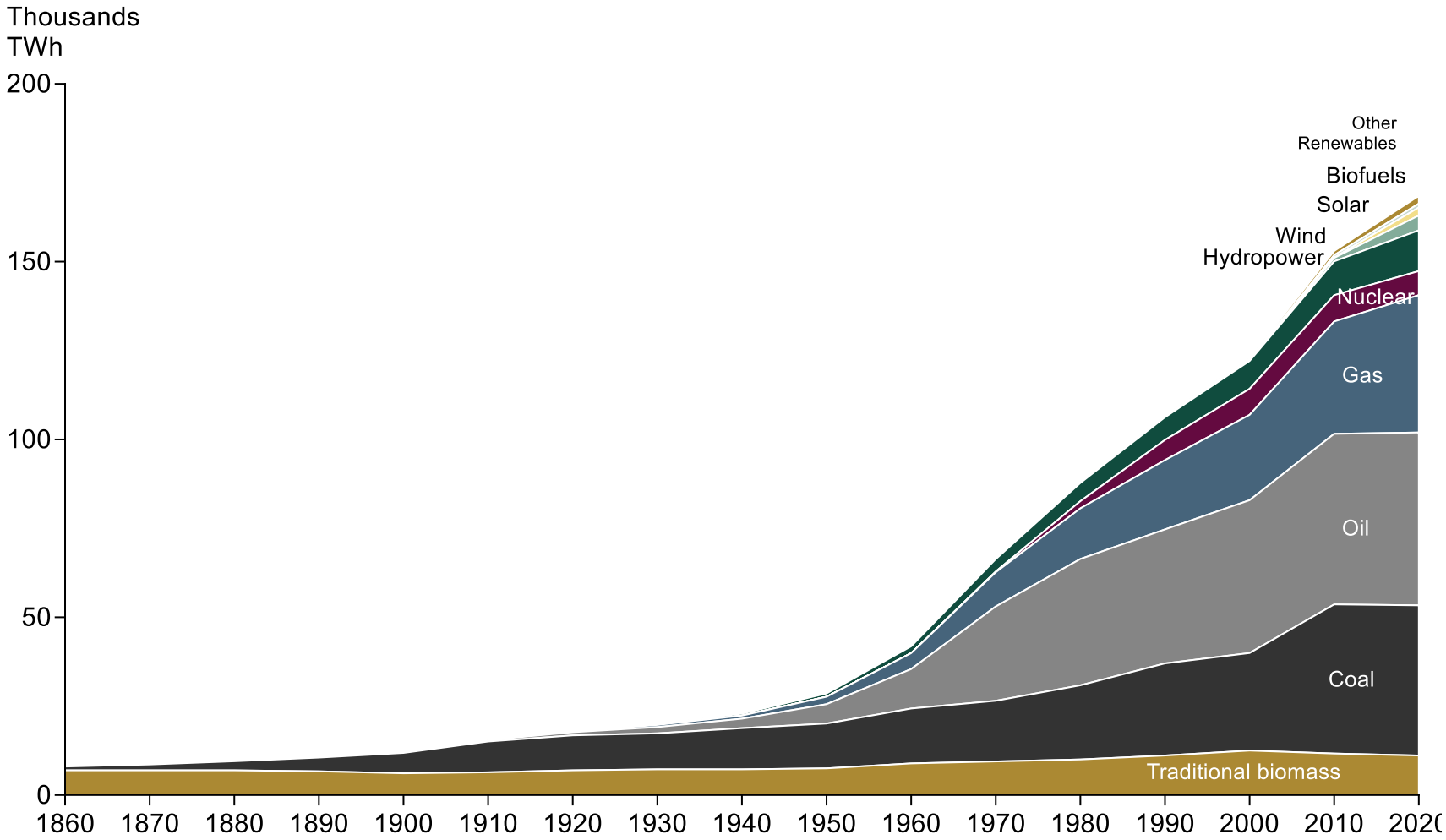
Role of H_2-to-X in the Energy Transition

12th June 2024

Secure, low cost energy from biomass/fossil fuels has driven economic growth for 200 years

…supplemented by Hydro, Wind, Solar, Biofuels and other renewables

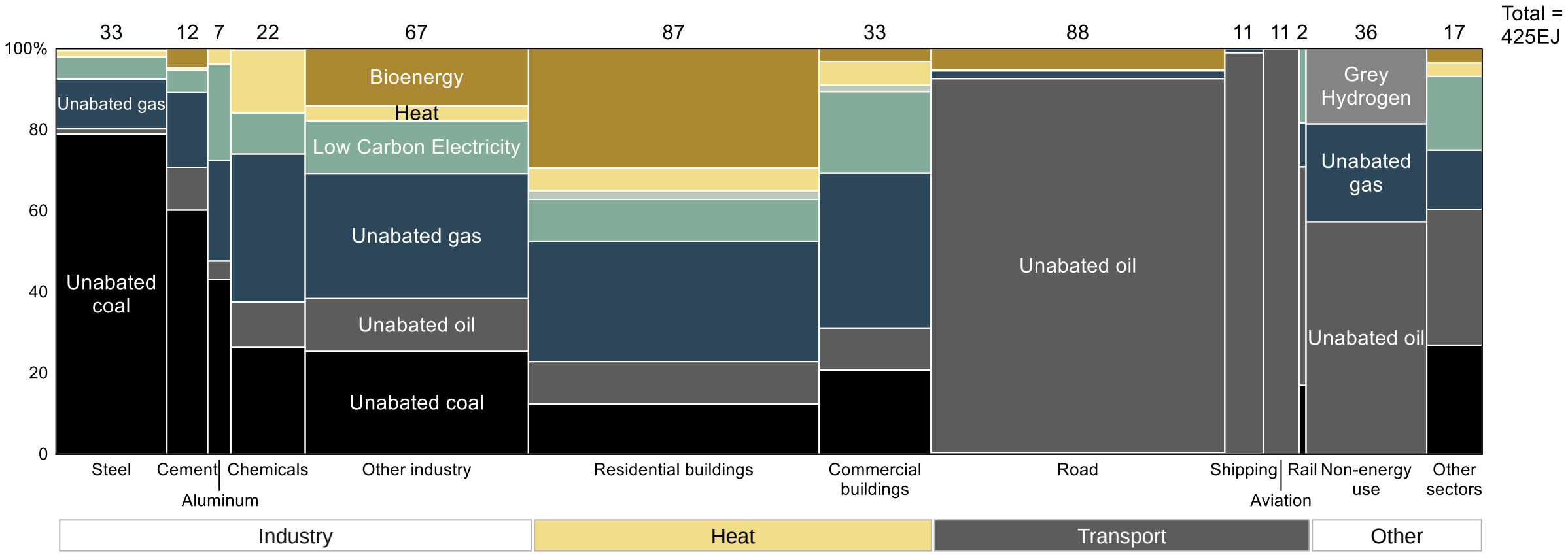
Growth in energy sources since industrial revolution



Source: Energy Institute – Statistical Review of World Energy (2023); Smil (2017)

This energy is integrated in every sector of the economy

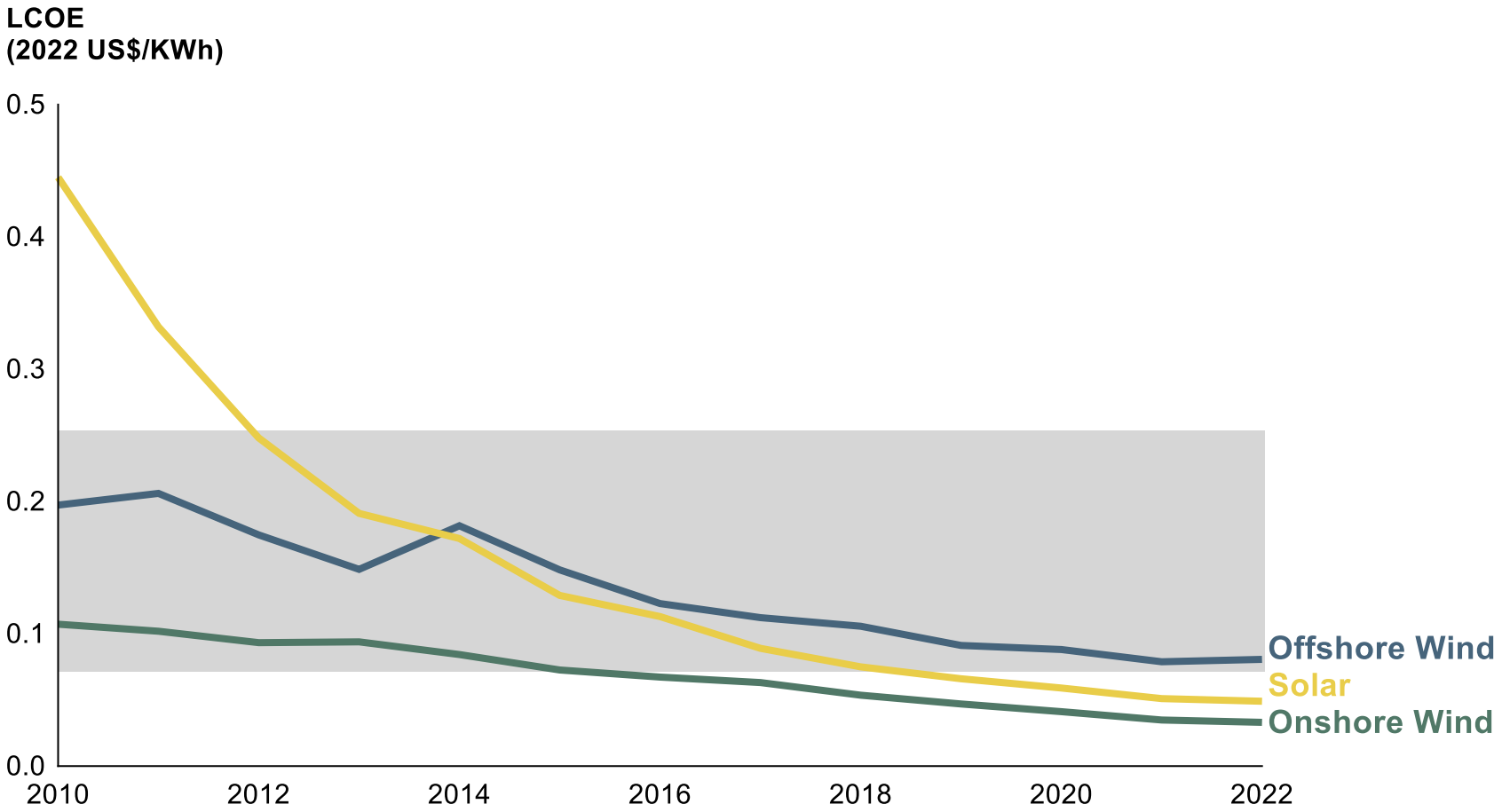
2022



Source: BNEF New Energy Outlook 2024; Adjusted for Global Electricity Mix

Low Carbon electricity costs have fallen by 60-90% since 2010

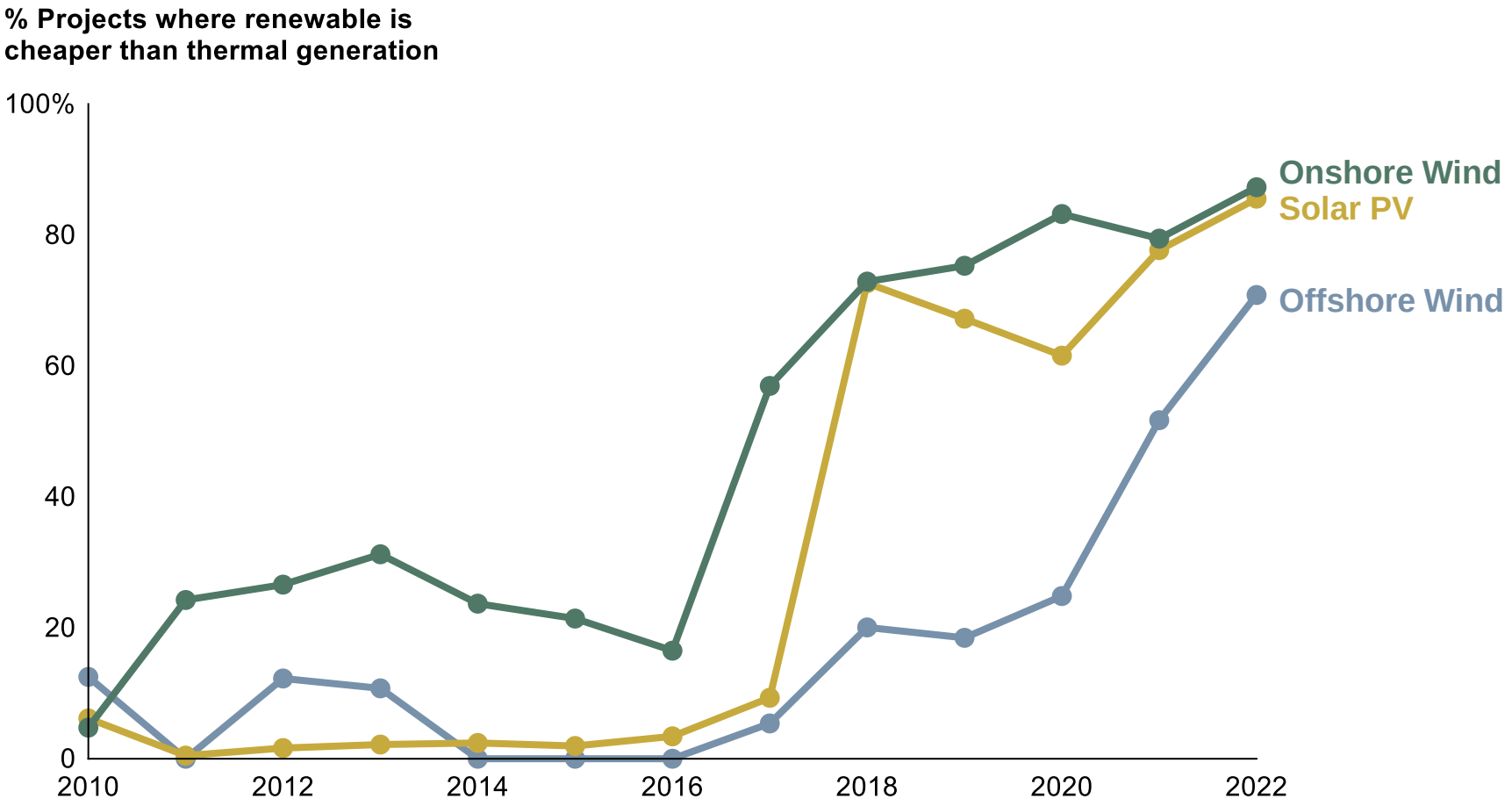
Levelized cost of renewable electricity (2022 US$/KWh)



Source: IRENA (2023) Renewable Costs in 2022

Low Carbon electricity is now cheaper than most new thermal generation

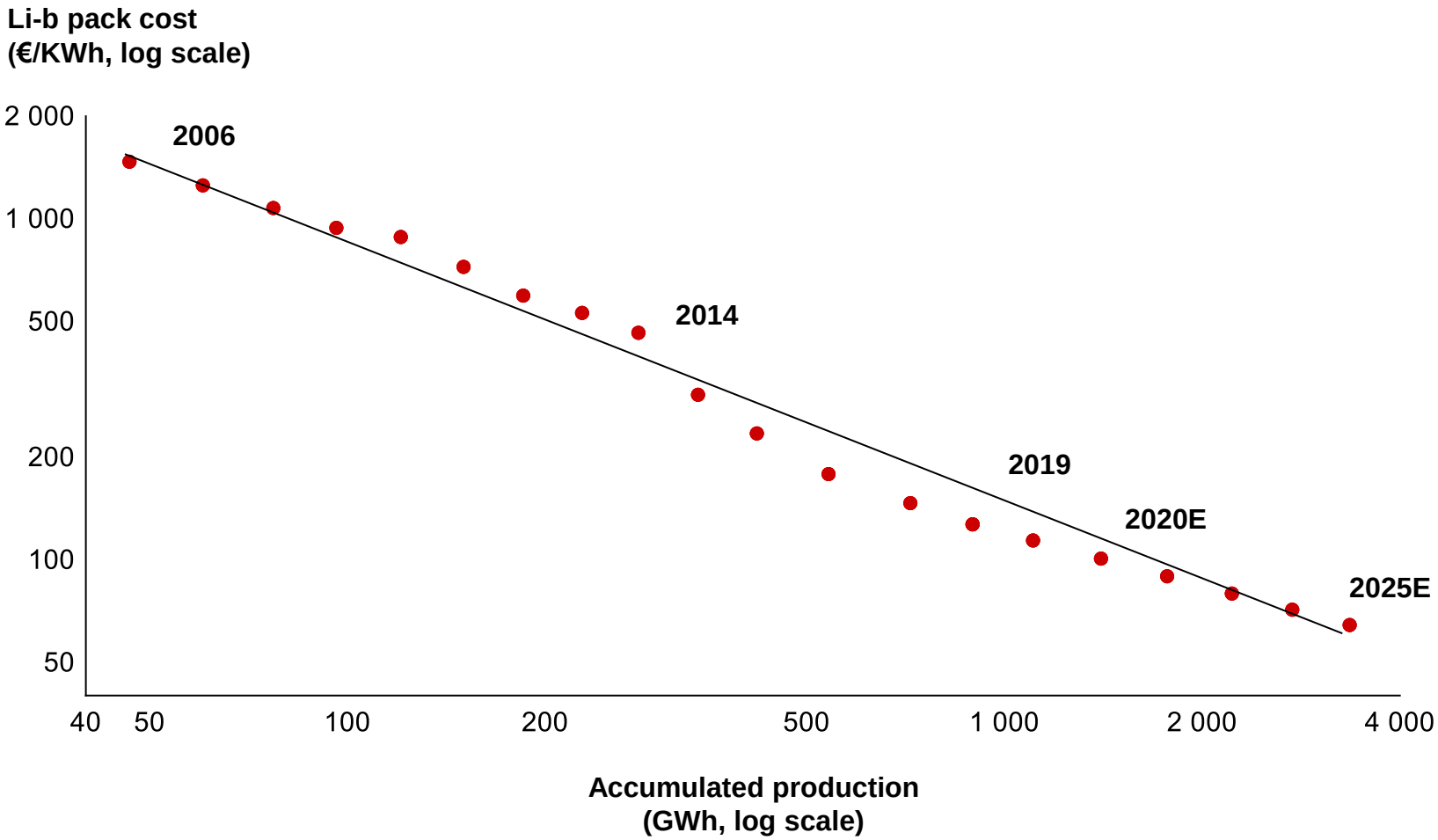
Projects where new renewable is cheaper than thermal generation



Source: IRENA (2023) Renewable Costs in 2022

…and can help decarbonize many sectors

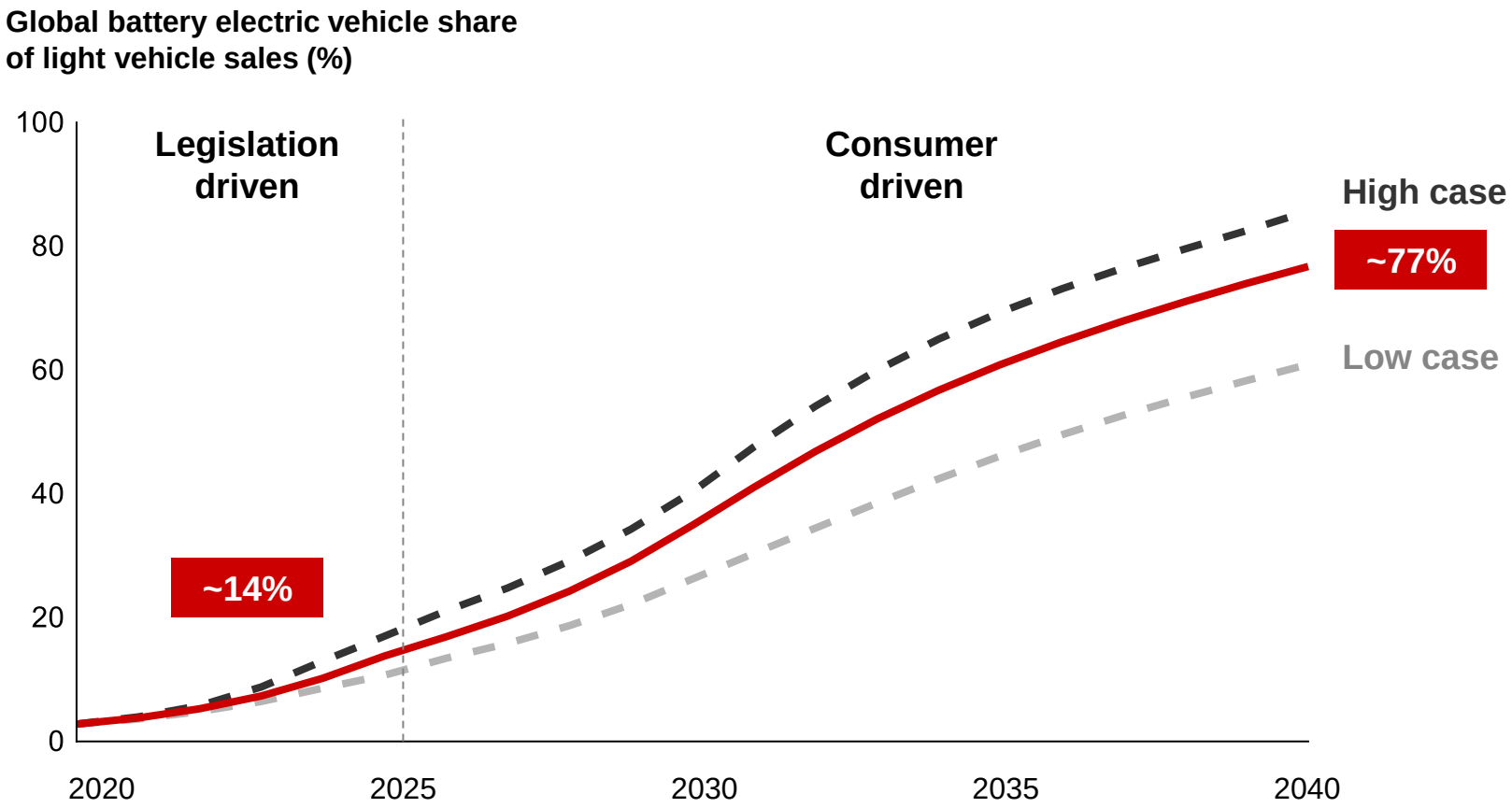
Battery experience curve (€/KWh)



Source: Bain EV Market Model

…and can help decarbonize many sectors

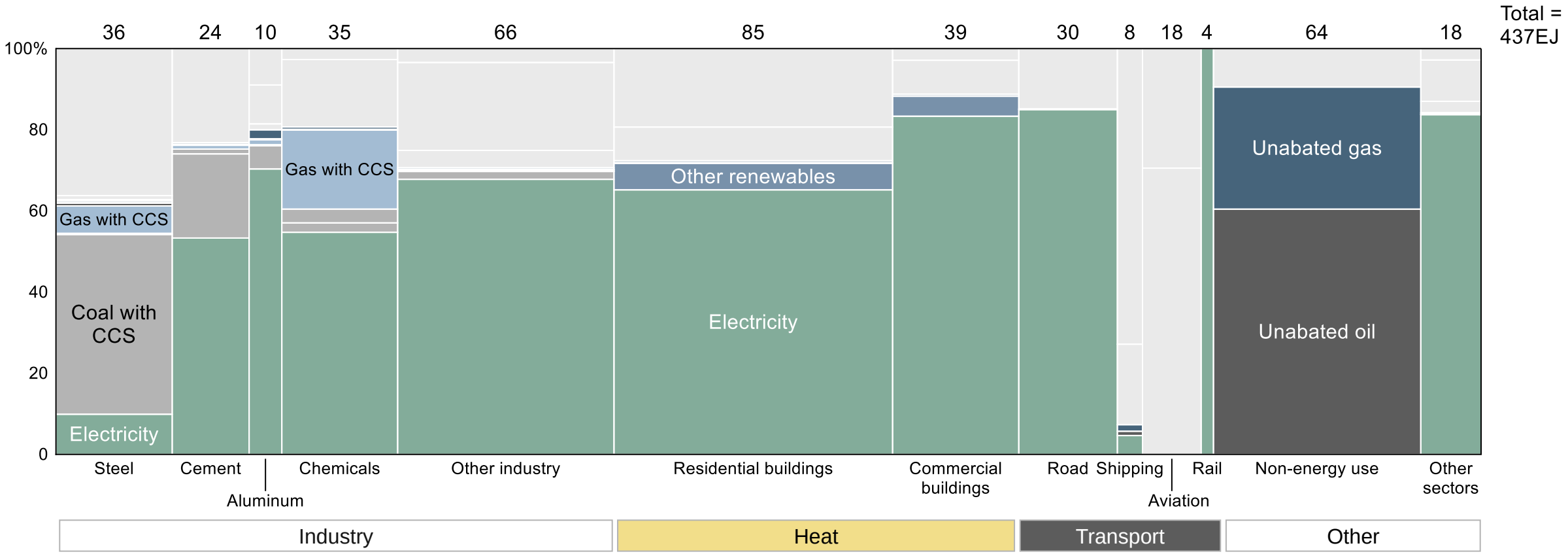
EV tipping point to be reached by 2025



Source: Bain EV Market Model

Low carbon electricity will help decarbonise many sectors along with CCS

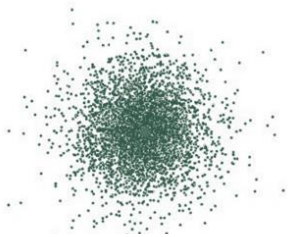
2050



Source: BNEF New Energy Outlook 2024

However, electrons and gaseous molecules have complementary contributions to make to the energy transition

NET ZERO



End-to-End Efficiency	(e.g. renewables to electric motors)	(e.g. conversion losses across value chain)
Transport & Distribution	(e.g. low losses over short-medium distances)	(e.g. viable over longer distances)
Storage Duration & Energy Density	(e.g. batteries for short-medium term; low-medium energy density)	(e.g. stores and ships/pipes; medium-high energy density)
Heat Grade	(e.g. low grade for residential to medium grade industrial)	(e.g. medium to high grade for industrial)
Products	(e.g. via Power-to-H2)	(e.g. H2-to-X)

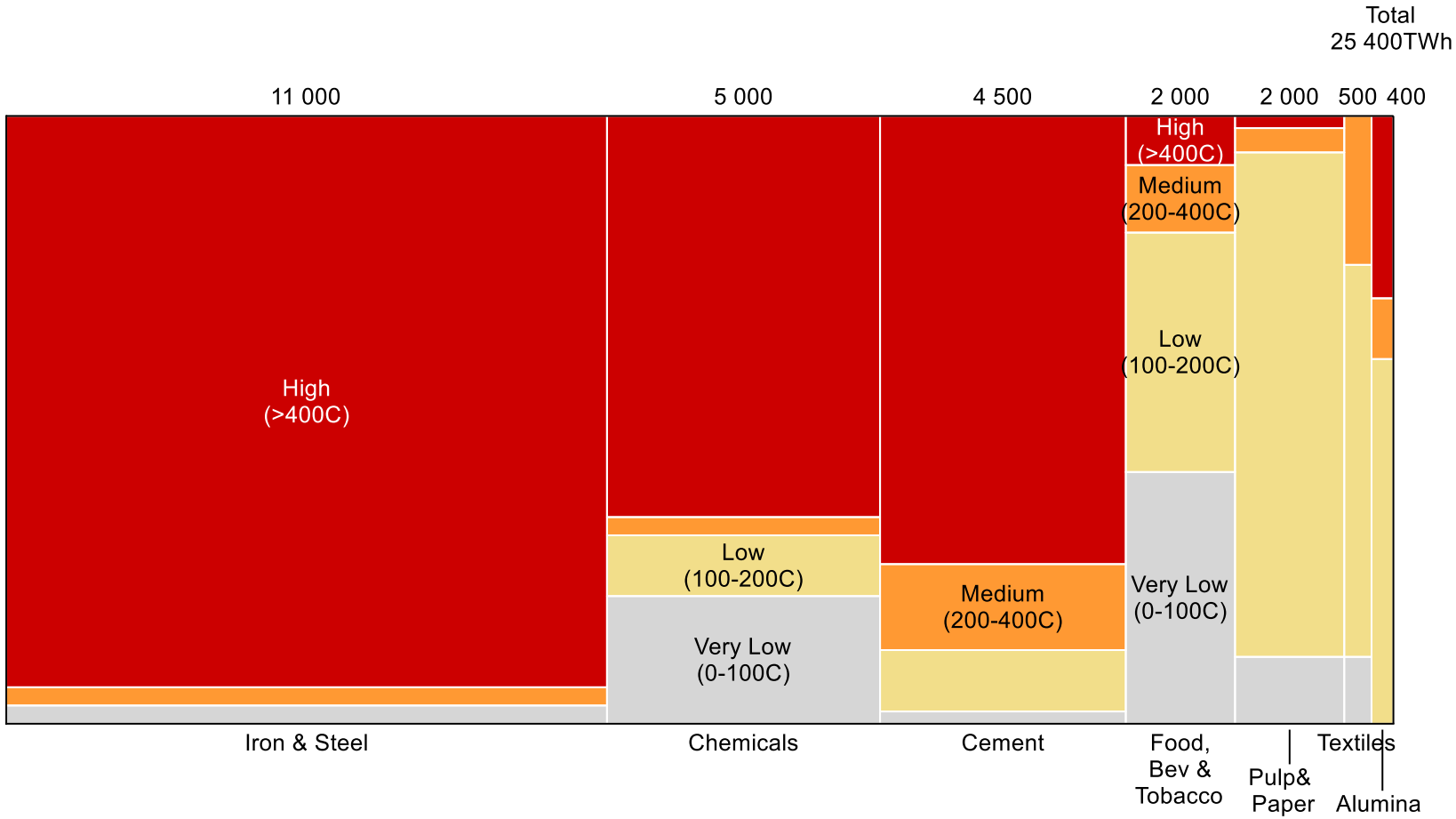
Hydrogen-to-X

	Freight trucks	Maritime	Aviation	Iron & steel	Chemicals
Activity	30 trillion tkm	110 trillion tkm	6 trillion pkm 220 billion tkm	1.8 billion tonnes	719 million tonnes
Energy consumption (EJ/year)	26.8	11.2	11.0	35.0	16.0
Demand reduction/ Energy efficiency	◔	●	●	●	●
Electrification	●	◑	◔	◑	◑
Biomass/ renewable heat	◔	●	●	◔	●
CCS	○	◔	○	◑	◑
H2-to-X	◔	●	●	●	●

Source: IRENA Decarbonising Hard to Abate Sectors (2024) using ICAO 2023, IEA 2023, UNCTAD 2022

Hydrogen-to-Steel

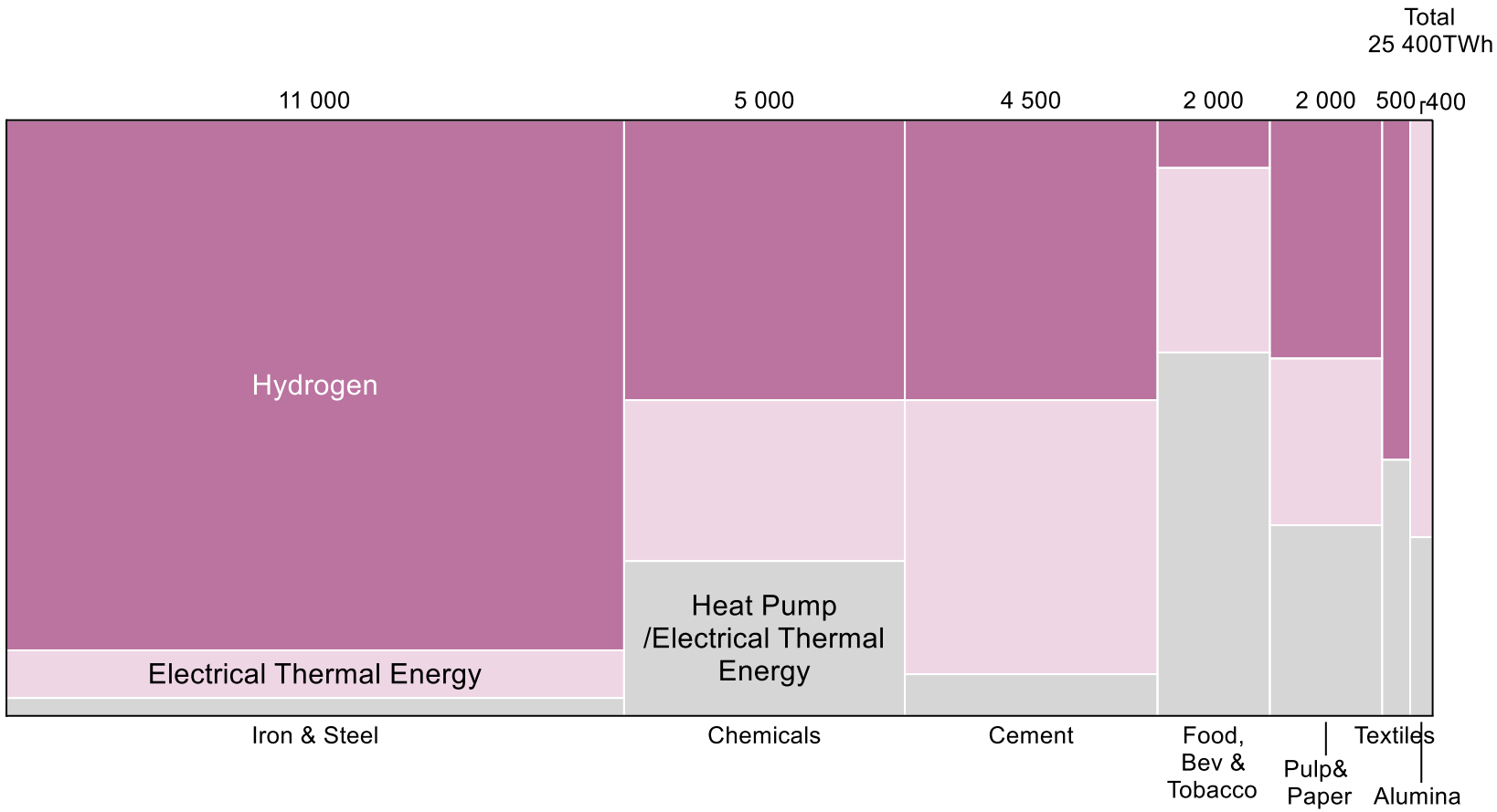
Global Combustion Energy Usage in Selected Industries



Source: SystemIQ (2024) using UNFCCC data set (2021), except for Australia (2019); International Aluminum Institute; World Steel Association; Eurostat; EuraTEX; USGS; Petrochemical Europe; EU heat profile is derived from EU Joint Research Center; US heat profile is derived from Decarbonizing Low-Temperature Industrial Heat in the U.S., Energy Innovations, 2023

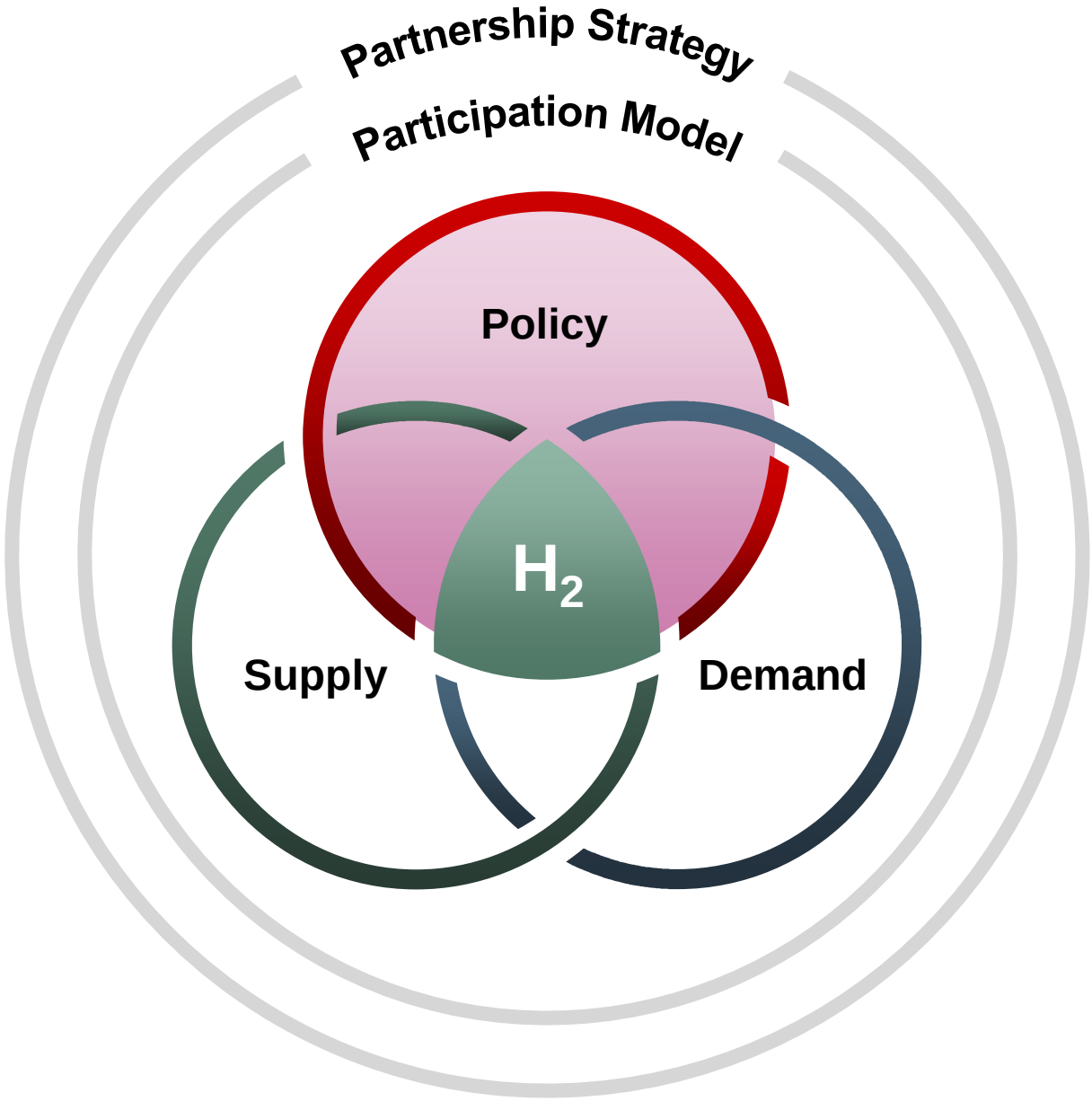
Hydrogen-to-Steel

Potential Future Energy Source in Selected Industries



Source: SystemIQ (2024) using UNFCCC data set (2021), except for Australia (2019); International Aluminum Institute; World Steel Association; Eurostat; EuraTEX; USGS; Petrochemical Europe; EU heat profile is derived from EU Joint Research Center; US heat profile is derived from Decarbonizing Low-Temperature Industrial Heat in the U.S., Energy Innovations, 2023

Green Hydrogen depends on the interlock between Policy, Supply & Demand across sectors



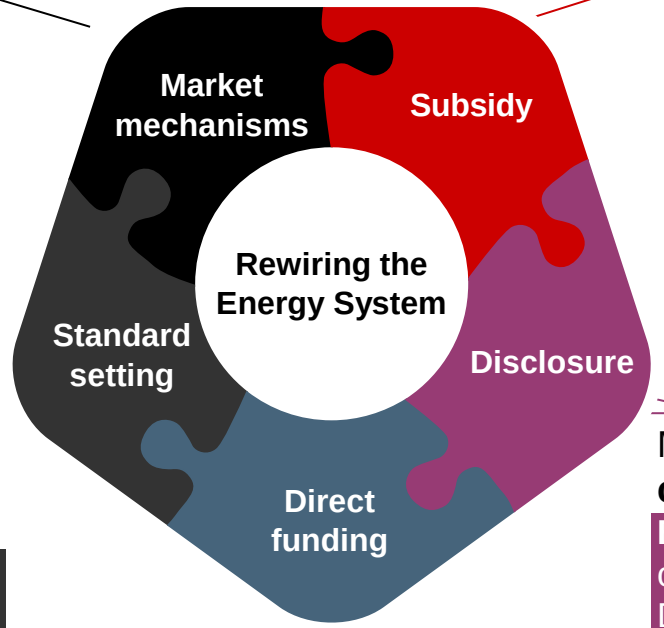
Governments have five main tools to shape demand and supply for Green Hydrogen

Measures which **increase the costs of higher carbon** technologies

Example: SPOC for investments

Measures which **decrease the costs of lower carbon** technologies

Example: Low interest loans



Measures to **require lower carbon technologies be deployed**

Example: Local Content Requirements

Measures to **increase corporate accountability**

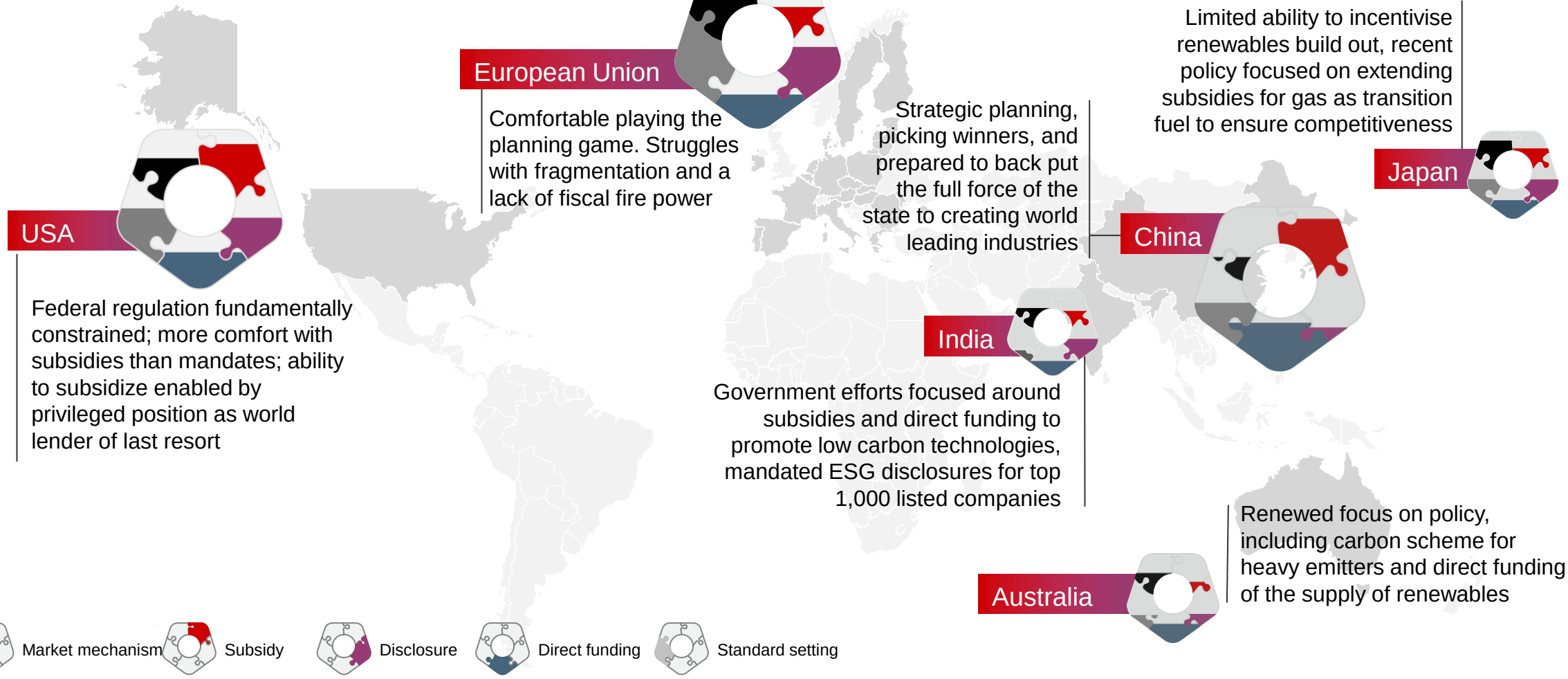
Example: TCFD - Task Force on Climate-Related Financial Disclosures

Direct government financing of low carbon technology development, infrastructure, or skills

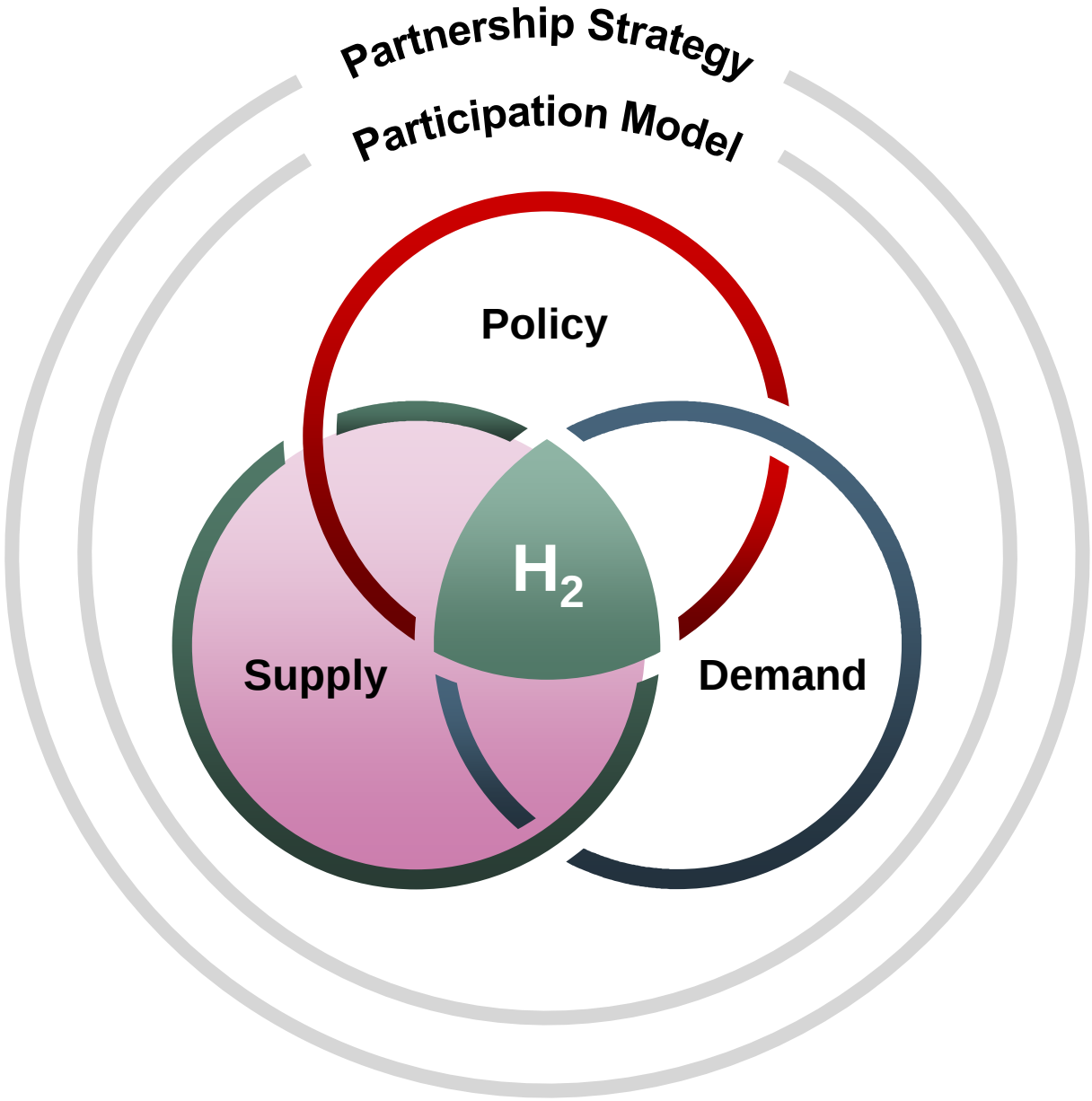
Example: Direct investments in renewables build out

Across the globe, the policy tools are applied very differently

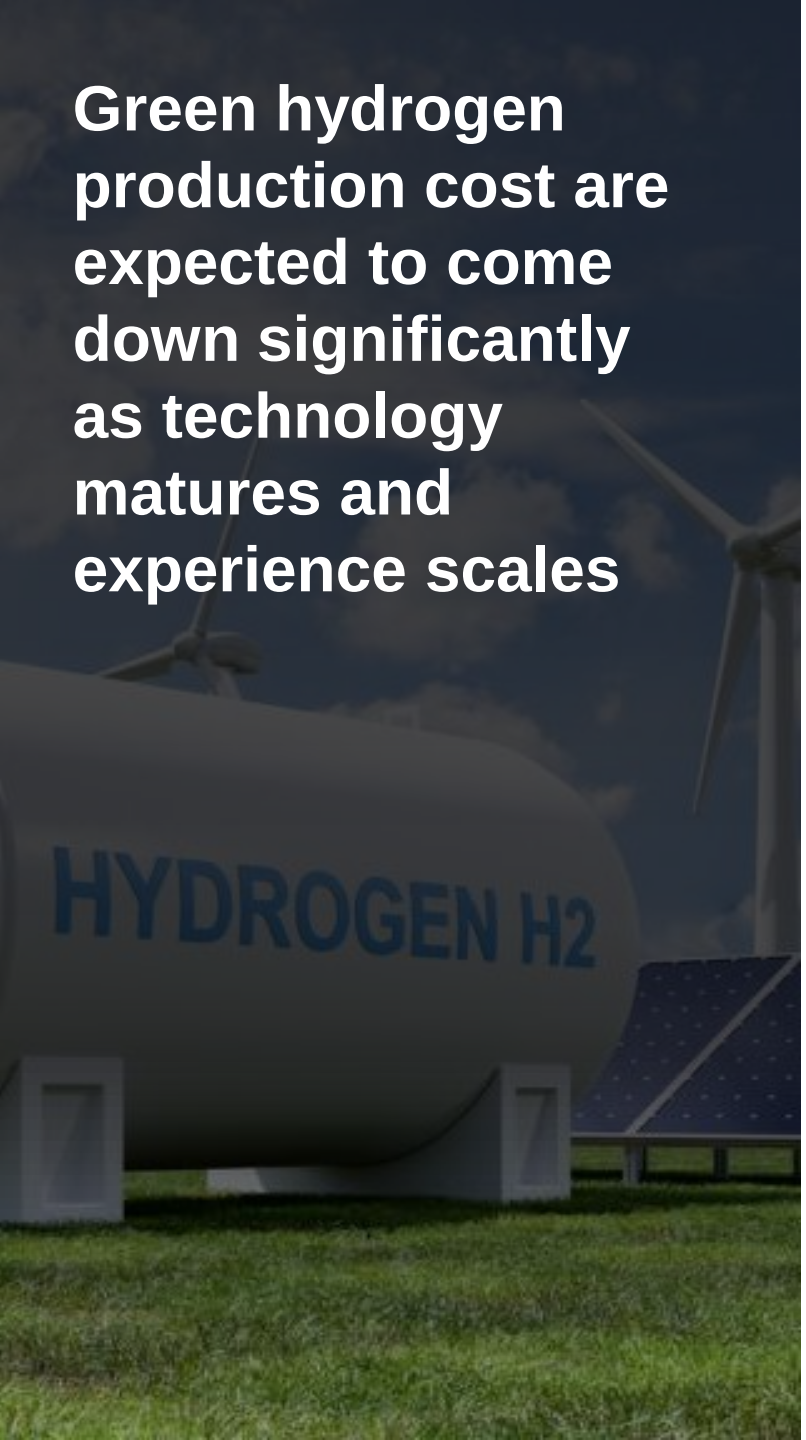
Application of policy levers in different regions



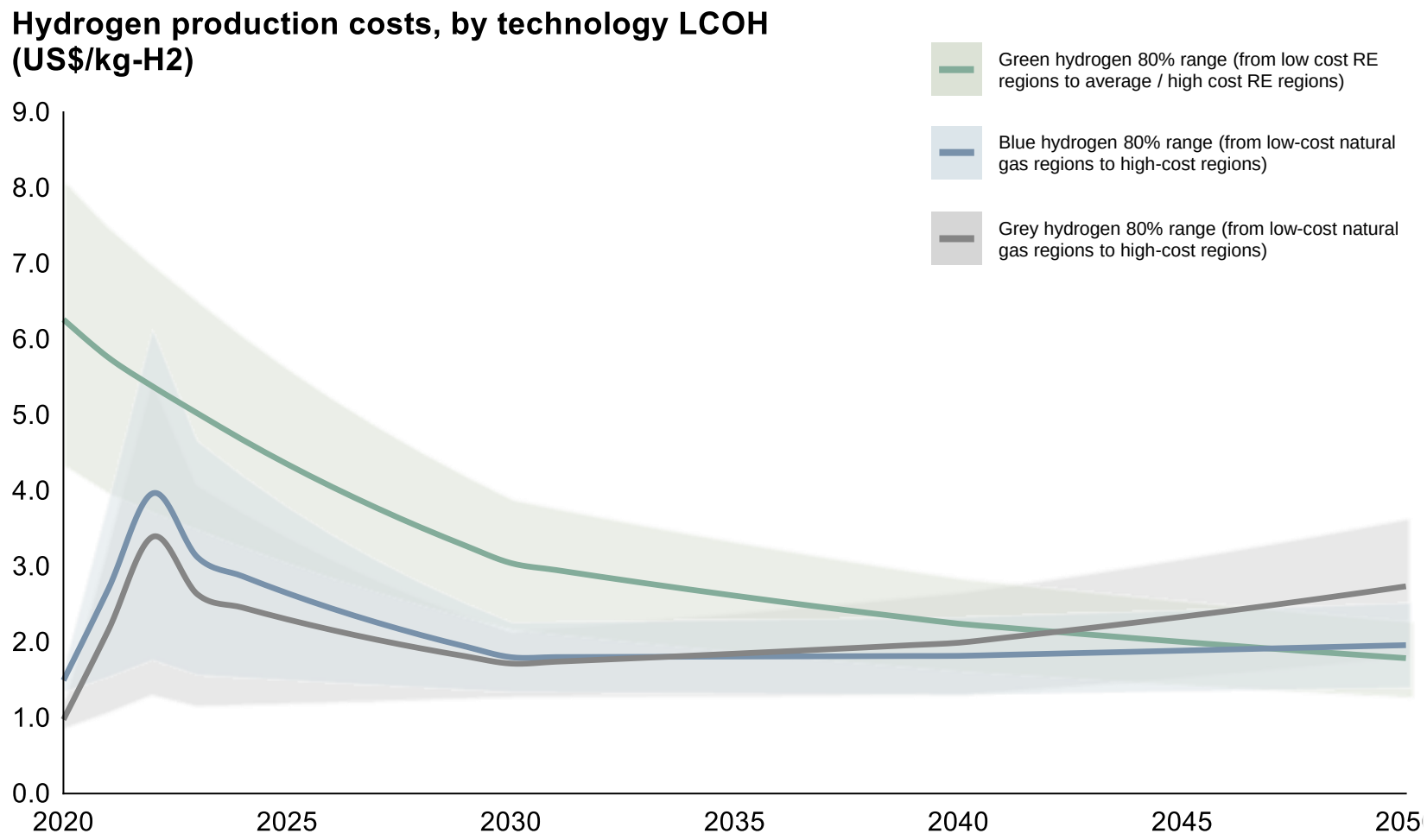
Green Hydrogen depends on the interlock between Policy, Supply & Demand across sectors



Green hydrogen production cost are expected to come down significantly as technology matures and experience scales

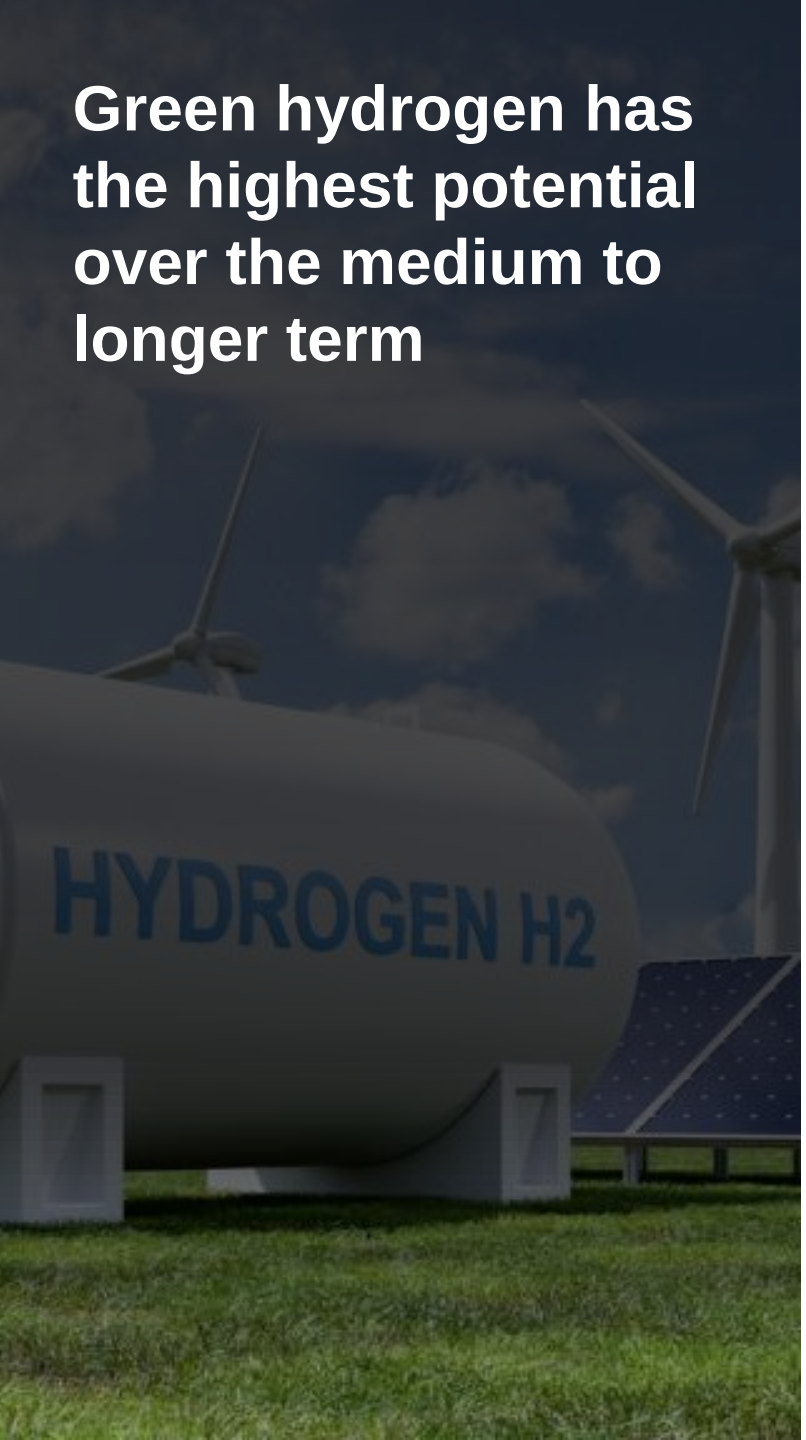


Levelized cost of hydrogen production by source ($/kg)



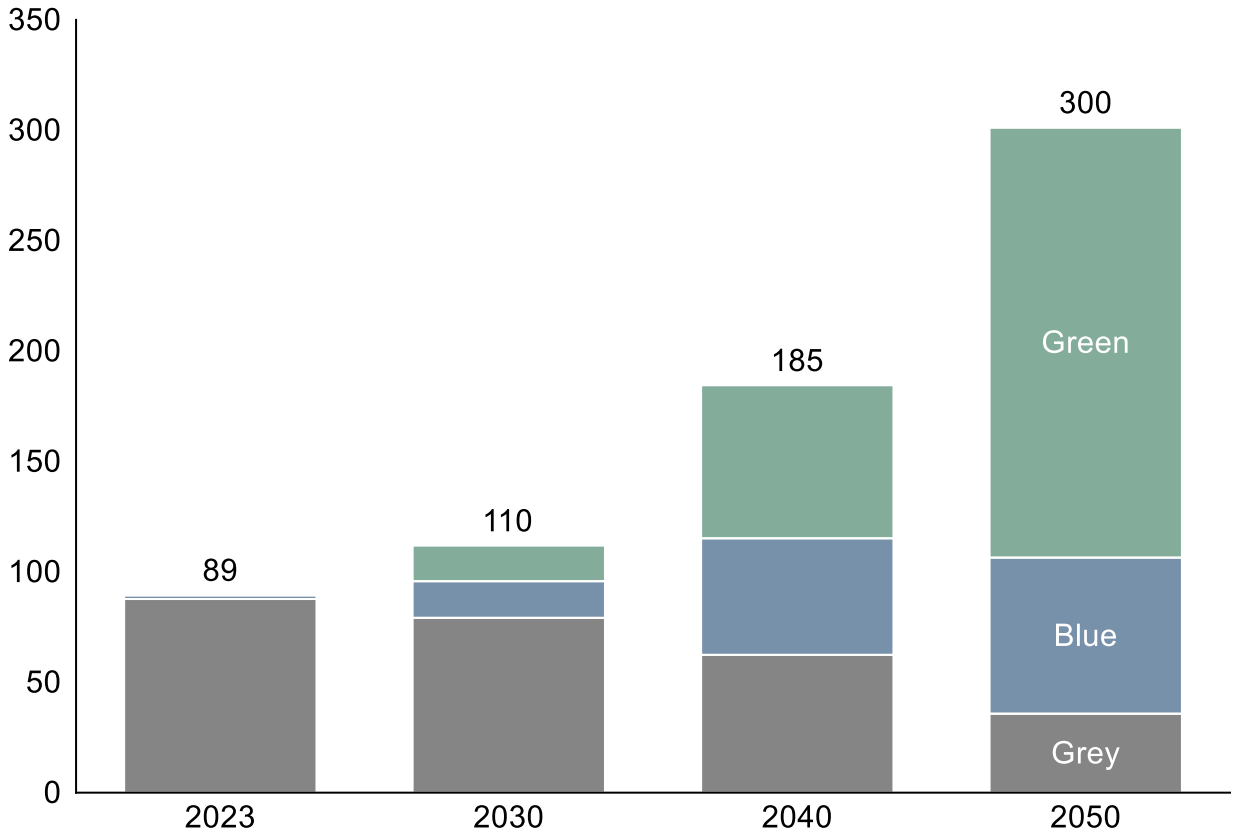
Source: IRENA, IEA, EIA, WEO, WoodMac, Bain analysis

Green hydrogen has the highest potential over the medium to longer term



Global hydrogen demand by type (MMT)

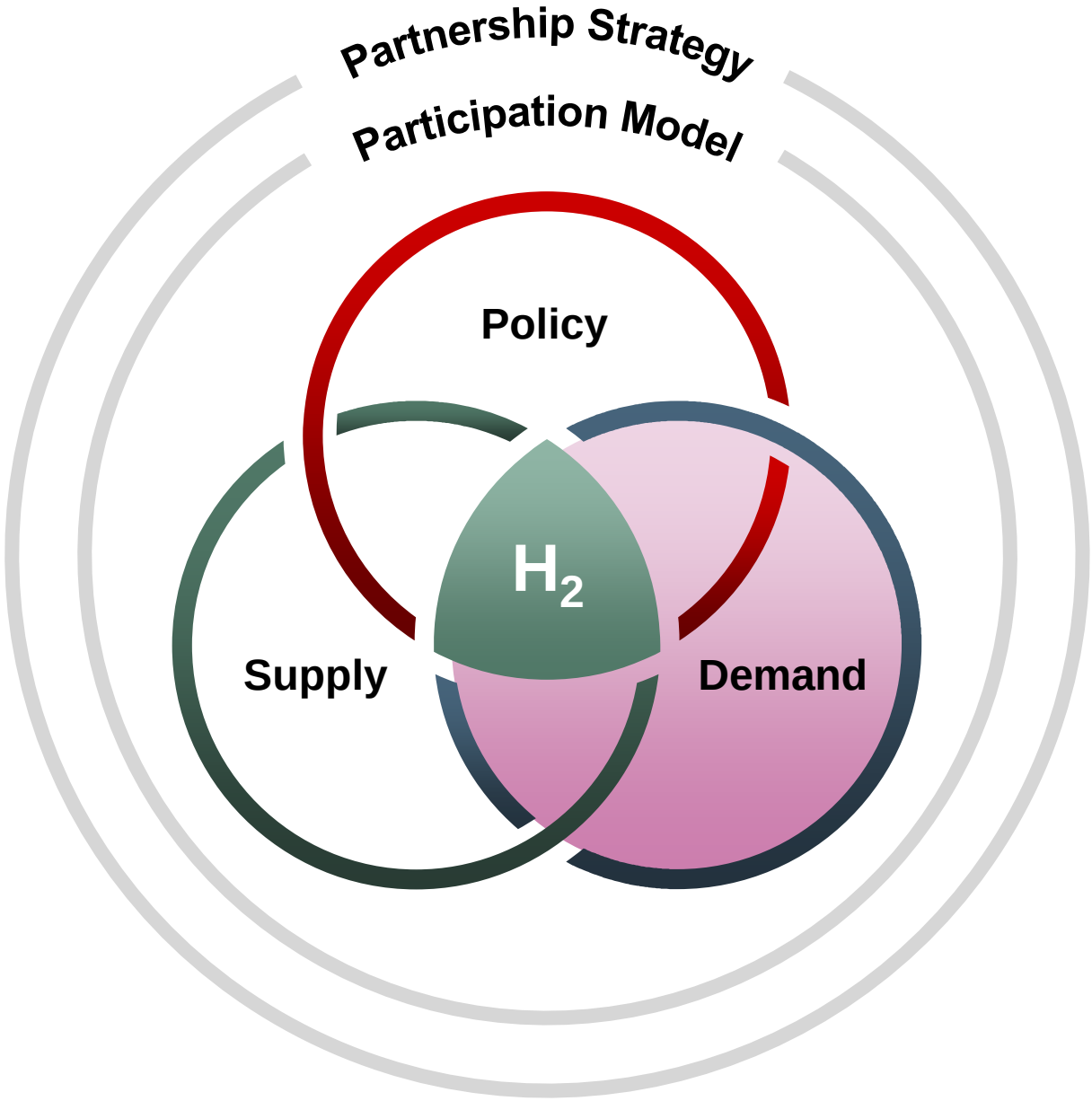
Global hydrogen demand (MMT)
Base case, by supply colour



	CAGR '22-'50	Share 2050
	5%	
Green	31%	60-70%
Blue	15%	20-30%
Grey	-3%	~10%

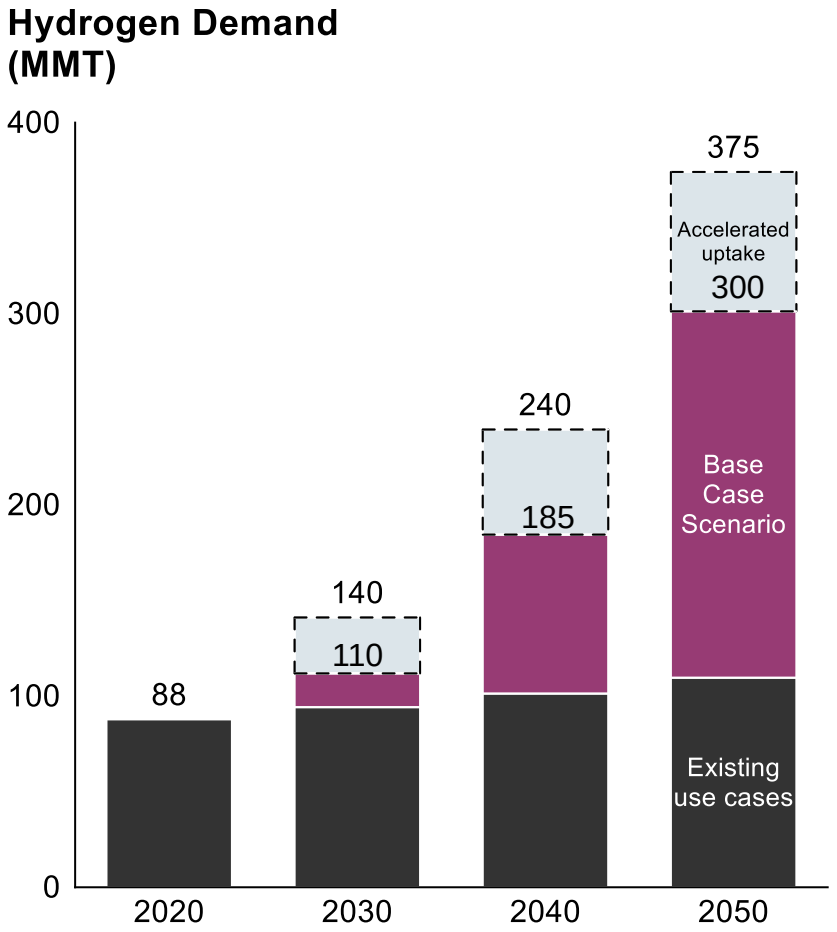
Source: Bain Hydrogen Demand Model; GlobalData Hydrogen Plant database

Green Hydrogen depends on the interlock between Policy, Supply & Demand across sectors

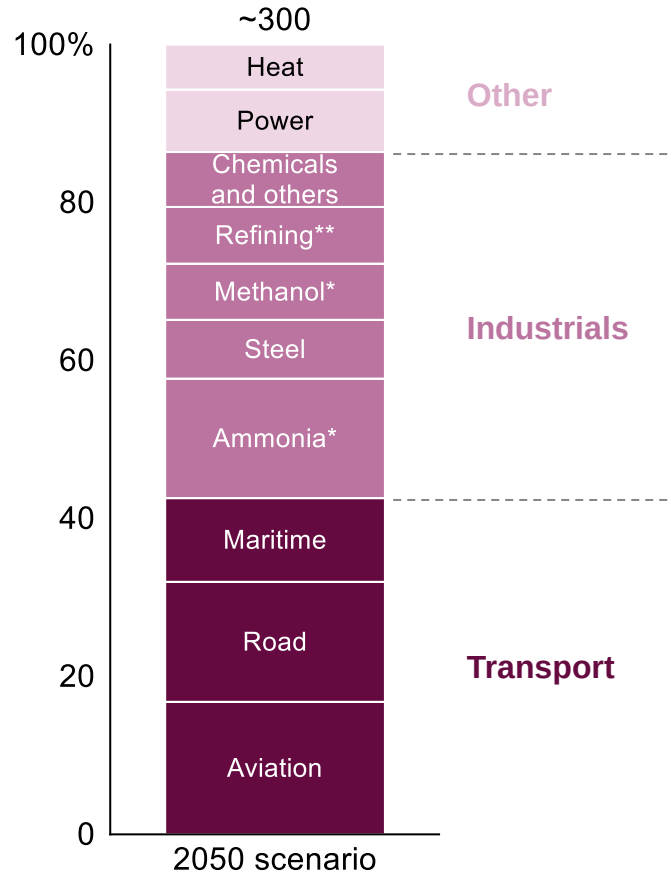


Long-term demand potential is expected to be ~300 MMT across applications

Hydrogen demand scenarios (MMT)



Growth drivers to 2050

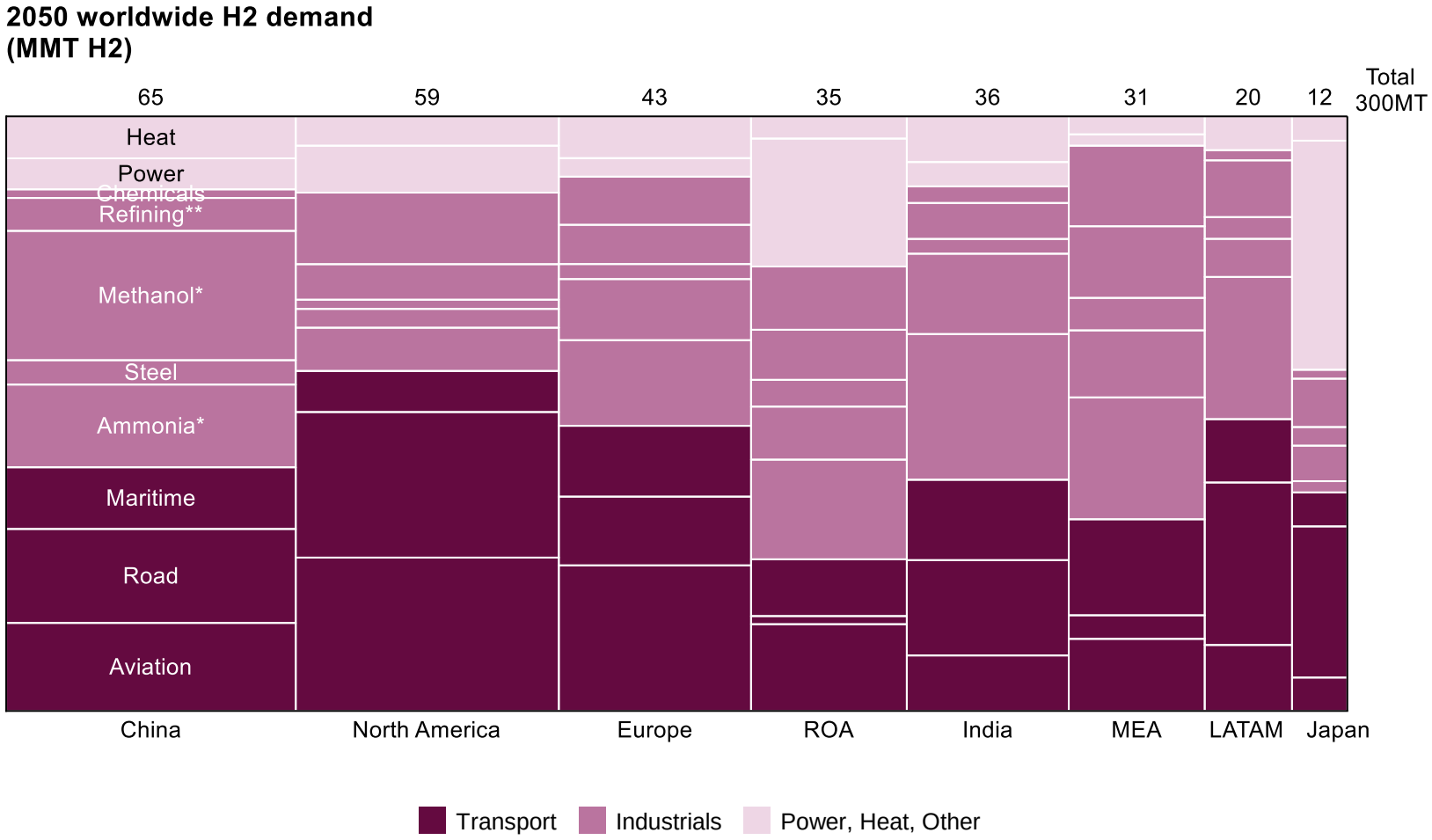


Note: *Excludes ammonia and methanol for use in transportation; **Includes bio-refining
Source: Bain Hydrogen Demand Model

Hydrogen adoption across use cases and regions will accelerate after 2030

2050

Hydrogen growth by type in regions (MMT)

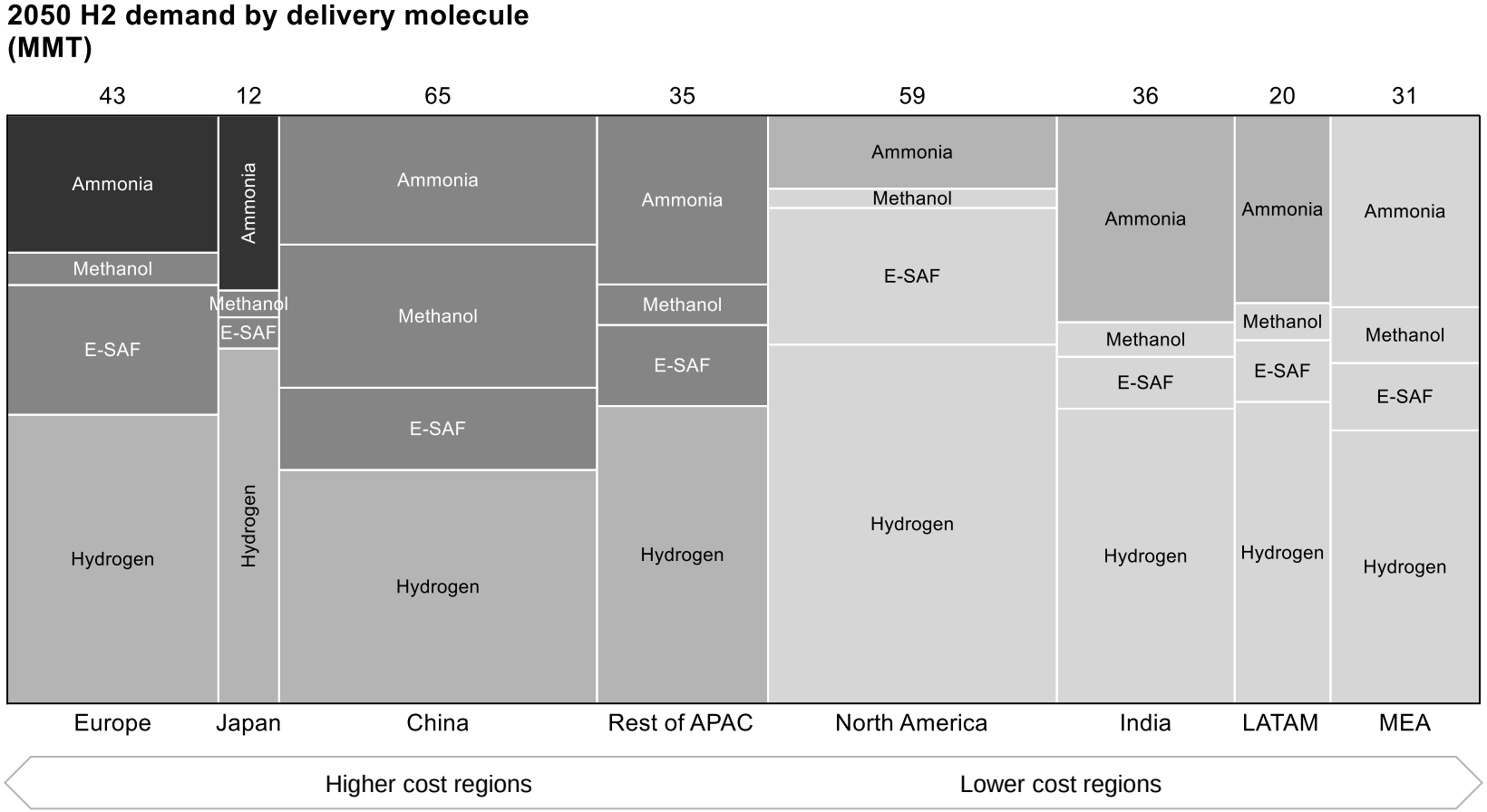


Note: *Excludes ammonia and methanol for use in transportation; **Includes bio-refining
Source: Bain Hydrogen Demand Model

Hydrogen delivery will vary by region

2050

Hydrogen demand by molecule (MMT)

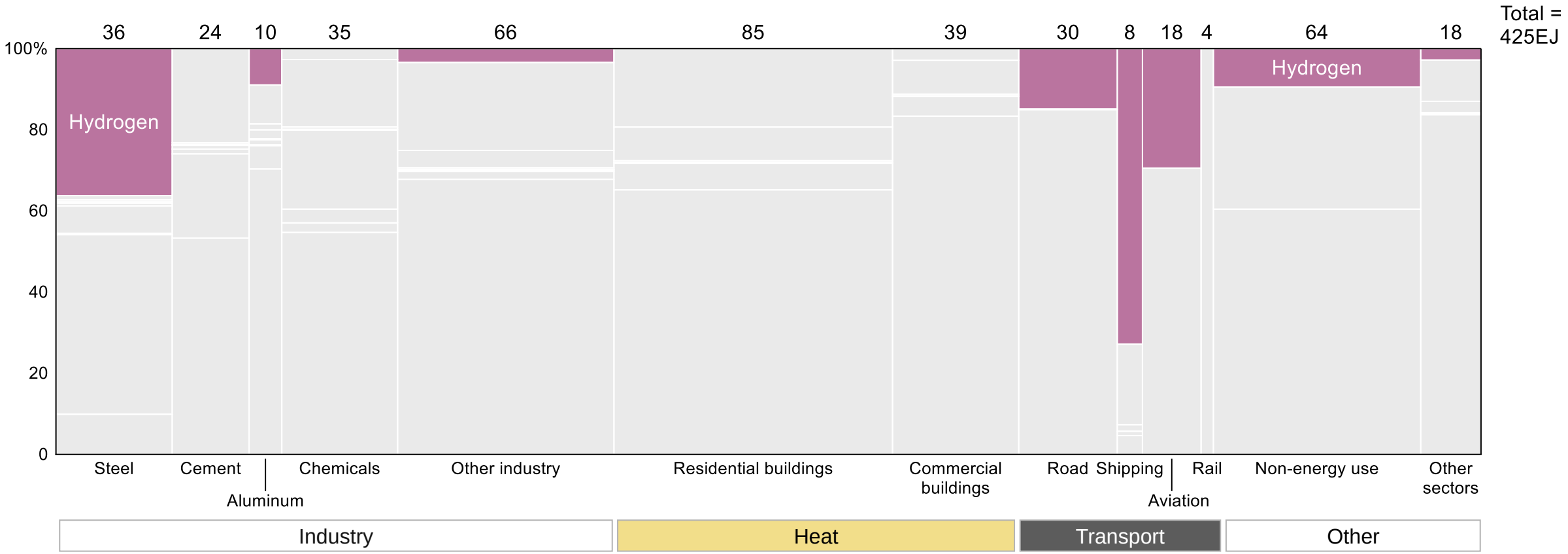


Source: Bain Hydrogen Demand Model

Mostly interregional supply driven by lower (landed) cost potential	Mixture of intra- and interregional supply options	Considerable intra-regional supply (plus local in clusters	Mostly local or intra-regional supply (e.g., high volume pipelines)

Green Hydrogen will play a big role in driving the energy transition

2050



Source: BNEF New Energy Outlook 2024 NZE Scenario

BAIN & COMPANY