WHEN TRUST MATTERS

ENERGY TRANSITION OUTLOOK

Hydrogen forecast to 2050

ETN Berlin 2022

12th October 2022

Chris Dagnall – Senior Principle Consultant
General Manager Rotating Machinery Solutions

An introduction to DNV

An independent assurance and risk management company

158	~12,000	100,000	100+	5% R&D
years	employees	customers	countries	of annual revenue

Ship and offshore classification and advisory

Energy advisory, certification, verification, inspection and monitoring

Management system certification, supply chain and product assurance

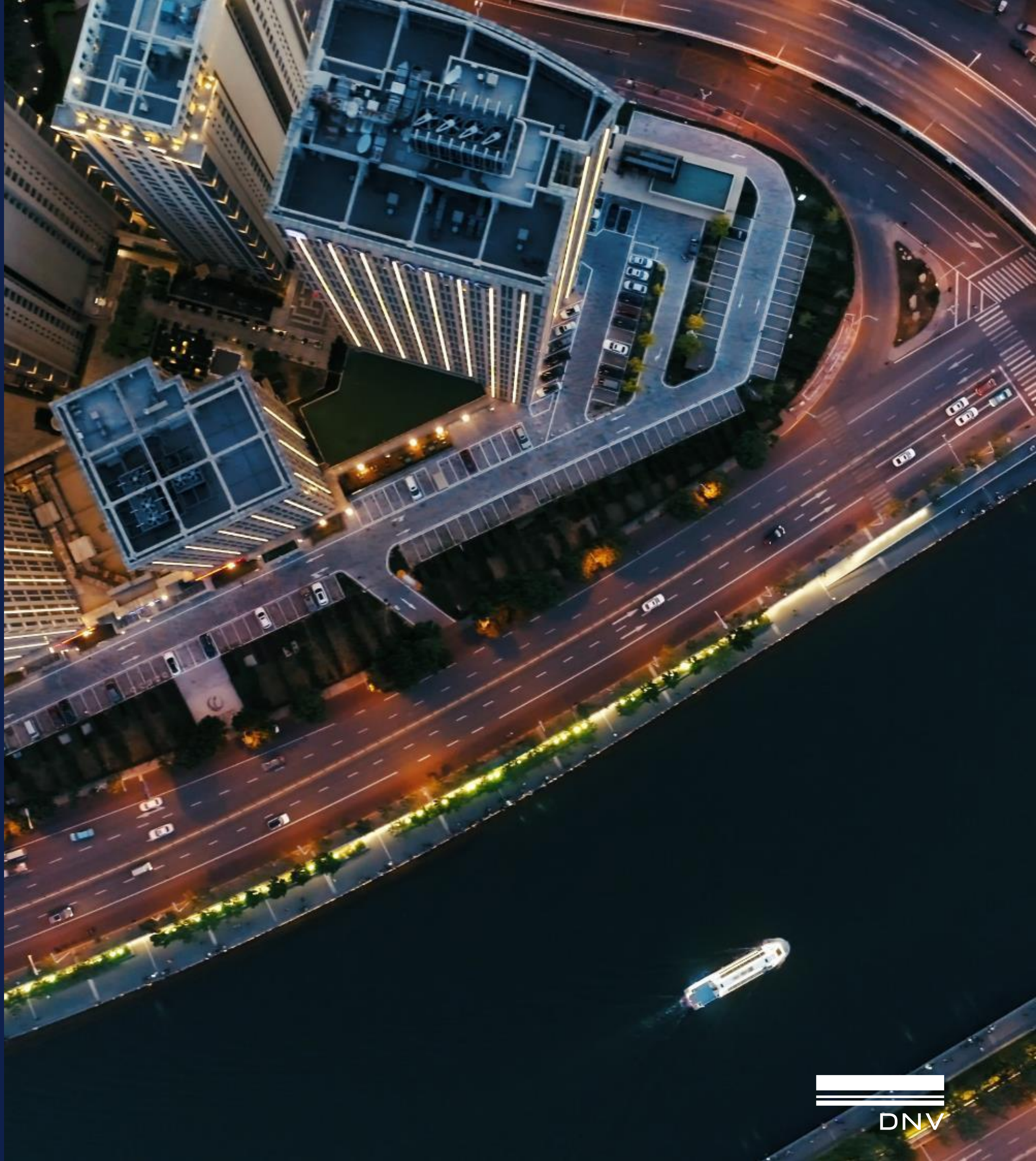
Software, platforms and digital solutions

DNV

In the energy industry

Our core global services

- Energy markets and strategy
- Risk management
- Renewables advisory and monitoring
- Renewables certification
- Technology advisory and testing
- Verification and marine warranty services
- Inspection
- Grid advisory
- Cyber security
- Energy management



The world's leading resource of independent energy experts and technical advisors

4000 experts

provide local access to global best practice delivering safe and effective energy systems

90+ years

serving the energy industry, including the oil and gas, wind and solar sectors

24

laboratories and test centres including facilities for full-scale testing

170

industry standards, guidelines and recommended practises, and approx. 30 joint industry projects per year

65%

of offshore pipelines designed and installed to DNV standards

42 GW

of real-time operational data from solar PV, wind and storage assets under management

>100

large power utility companies trust us as their technical advisor

World 1st

hydrogen full-scale testing facility supporting safety, infrastructure and policy

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Energy Transition Outlook 2021

A global and regional forecast to 2050

1 September 2021

Main presentation

Highlights

COVID-19 recovery spending is a lost opportunity.
We are far from achieving Paris Agreement ambitions

Electrification is surging ahead.
Variability and low prices are not roadblocks to solar and wind dominance

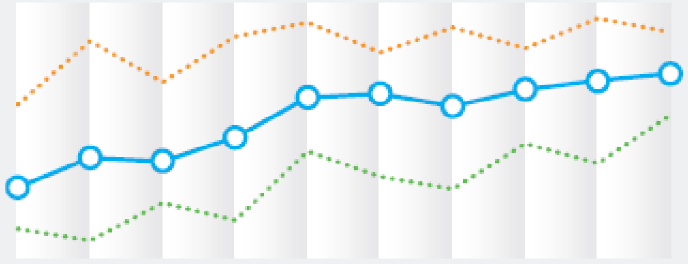
Fossil fuels slowly losing position.

Decarbonization of gas and deployment of CCS are slow

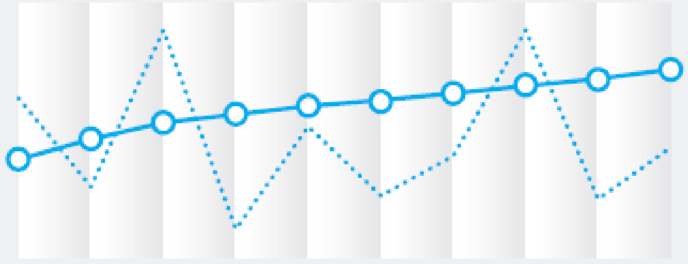
Much more H_2 and e-fuels needed in hard-to-abate sectors.
Most H_2 to come from dedicated renewables

Our approach

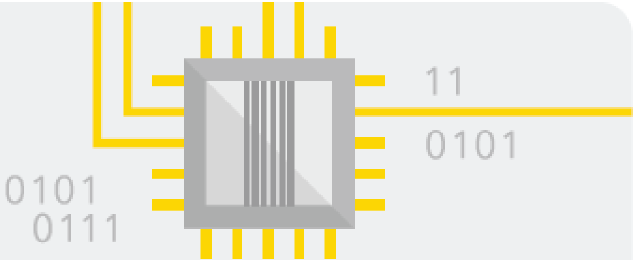
Our **best estimate**,
not the future we want



A single forecast, not scenarios



Long term dynamics,
not short-term imbalances



Continued development
of proven **technology**, not
uncertain breakthroughs

Main **policy** trends included;
caution on untested
commitments, e.g. NDCs, etc.

Behavioural changes: some
assumptions made, e.g. linked
to a changing environment

Policy factors influencing our Outlook

1. Renewable power support
2. Energy storage support
3. Zero emission vehicle support
4. Hydrogen support
5. CCS support
6. Energy efficiency standards
7. Bans and phase-out plans
8. Carbon-pricing schemes

TAX

9. Fuel-, energy- and carbon taxation
10. Air-pollution interventions
11. Plastic pollution interventions
12. Sustainable aviation fuels support

Dedicated research unit focusing on researching and forecasting the energy transition

100+ internal experts across supply and demand and transport infrastructure sectors

~25 external collaboration partners in business and academia

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Hydrogen Forecast to 2050

14 June 2022

Hydrogen highlights

1 Meeting the Paris Agreement

Hydrogen is essential to reach the Paris Agreement,

…but global hydrogen uptake is low and late, at 5% in 2050, it is only a third of what it should be

2 Leading sectors

Direct use of hydrogen will initially be dominated by the manufacturing sector,

…while hydrogen derivatives will be important in heavy transport

3 More green than blue

Green hydrogen from dedicated renewables and grid will dominate production for high emission reductions,

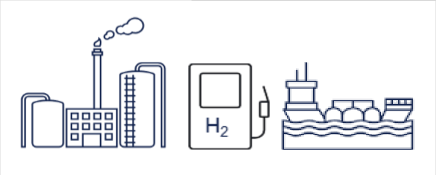
…but blue hydrogen will contribute to low carbon hydrogen

4 Mainly regional transport

Hydrogen will be transported between countries and not between continents,

…while ammonia will be transported globally

Policy categories shaping the hydrogen transition

			
National H_2 strategies ▪ Plans / roadmaps ▪ Targets ▪ Timelines	**Technology-push** ▪ Government funding to CAPEX investments ▪ Supporting H_2 technologies from R&D, pilot, to scale-up ▪ RE power buildout ▪ CCS for blue hydrogen	**Demand-pull** ▪ Measures stimulating end use / offtake ▪ CAPEX support for conversions (e.g., industrial process tech, equipment upgrades, new H_2 uses in transport)	**Fiscal policies** ▪ Carbon pricing (to make renewable and low-carbon hydrogen competitive) ▪ Energy taxation (to encourage ‘switching’)

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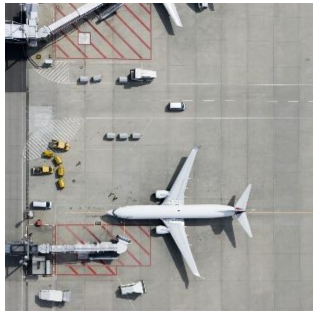
The world's total future hydrogen demand is broadly divided into three categories

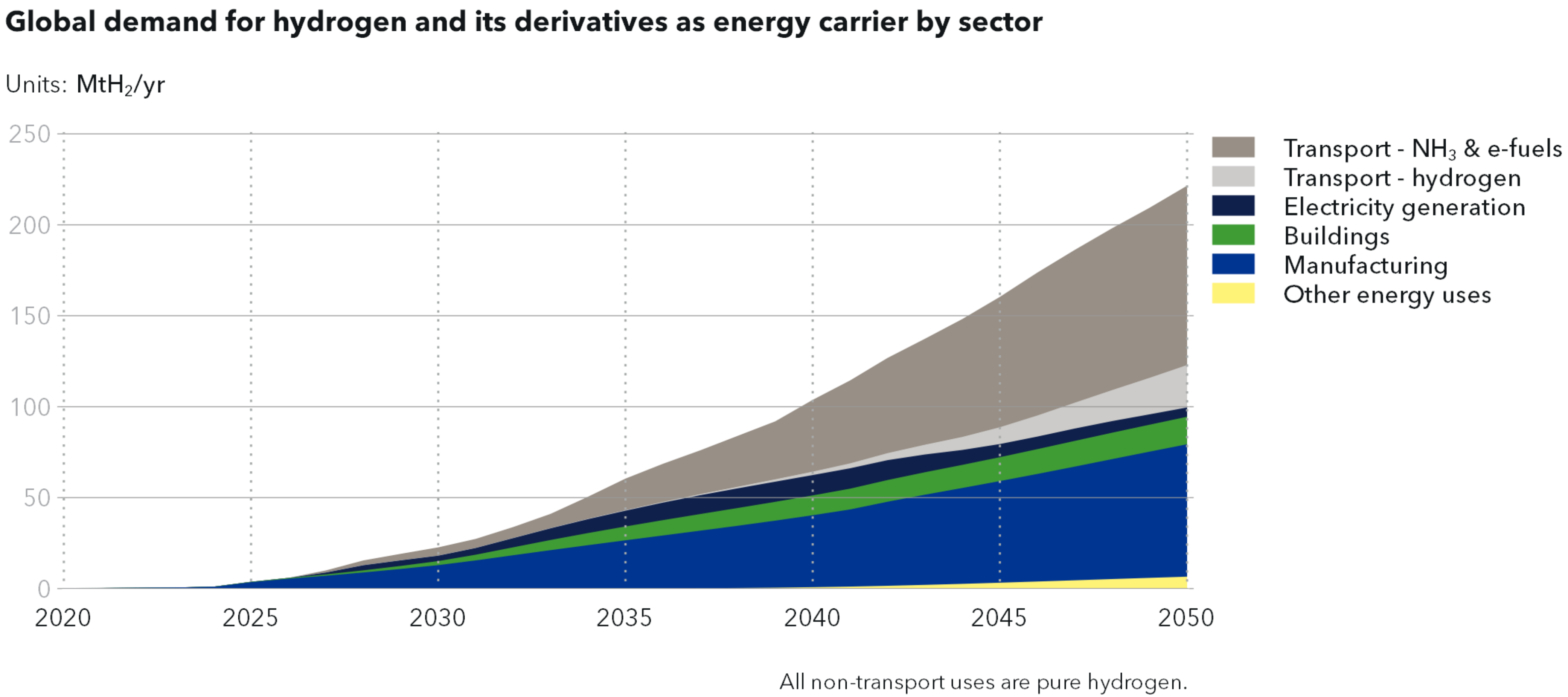
Decarbonizing existing use of hydrogen
replacing unabated fossil fuels with lower-emission alternatives

Fuel switching to hydrogen and its derivatives
retrofitting and modification of infrastructure

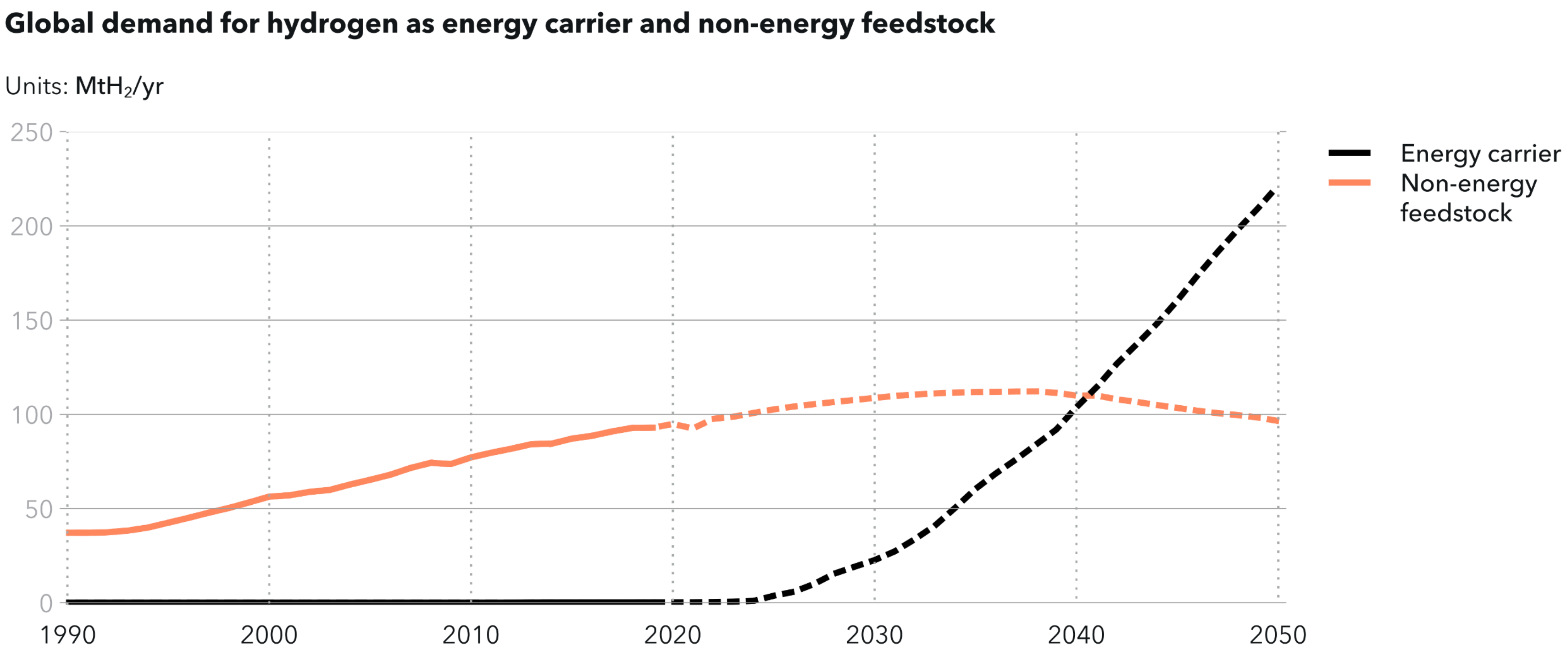


New use of hydrogen
where new infrastructure has to be established

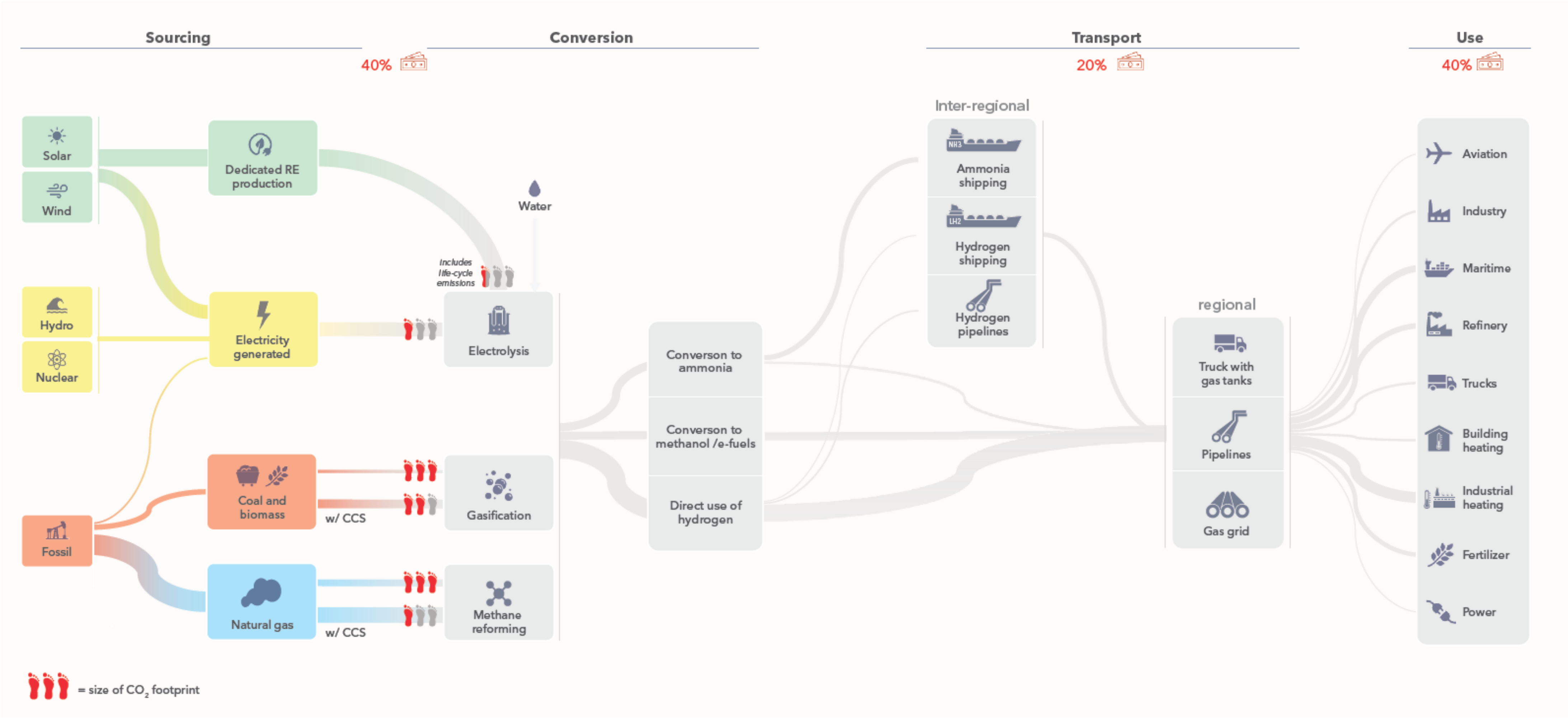
Direct use of hydrogen will be mainly in manufacturing, derivatives will be key in decarbonizing transport



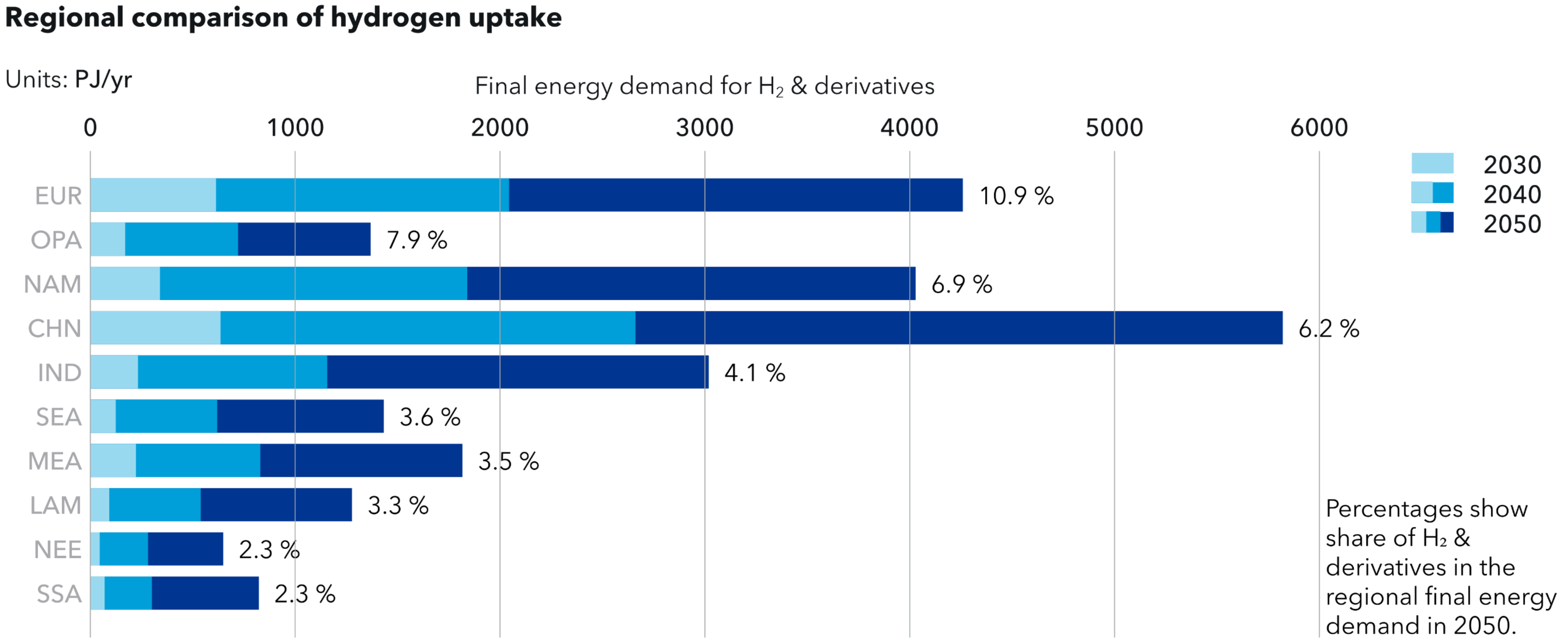
Energy use of hydrogen will overtake non-energy use in 2040



Hydrogen production and use by 2050



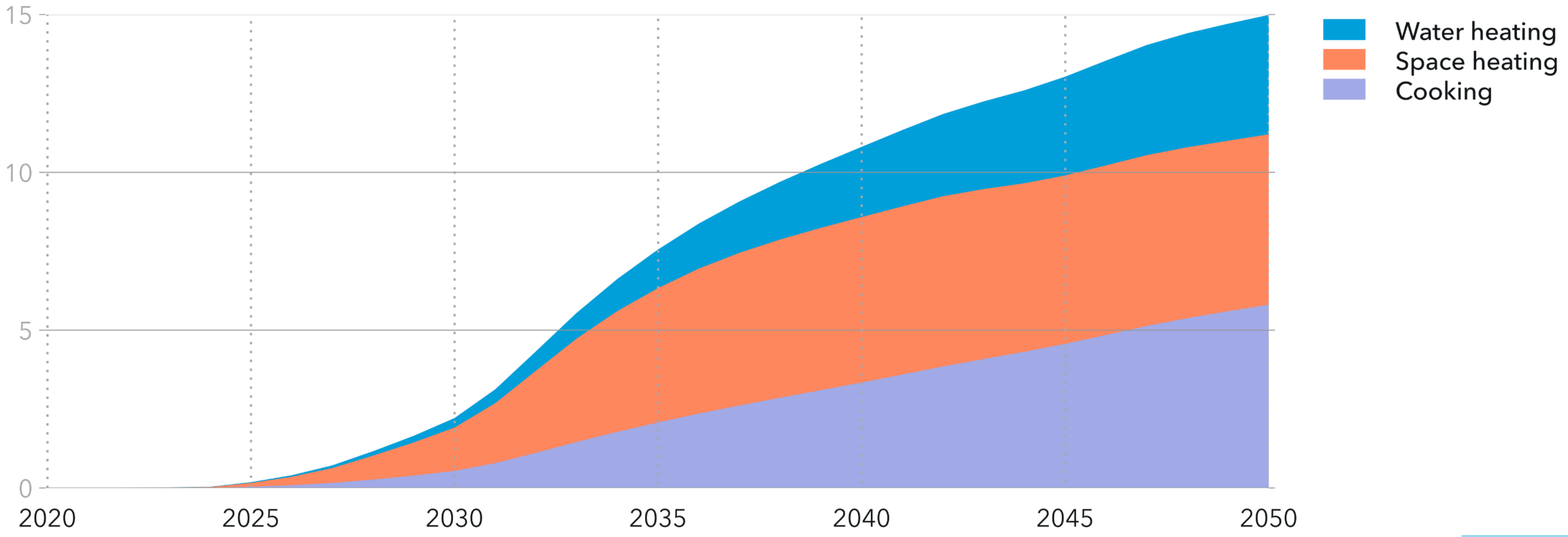
Four leading regions will together consume two-thirds of the global hydrogen demand for energy purposes



Hydrogen for buildings, typically blended with natural gas, will be 1.3% of sector's energy demand in 2050

Global buildings hydrogen demand by end use

Units: MtH_2/yr



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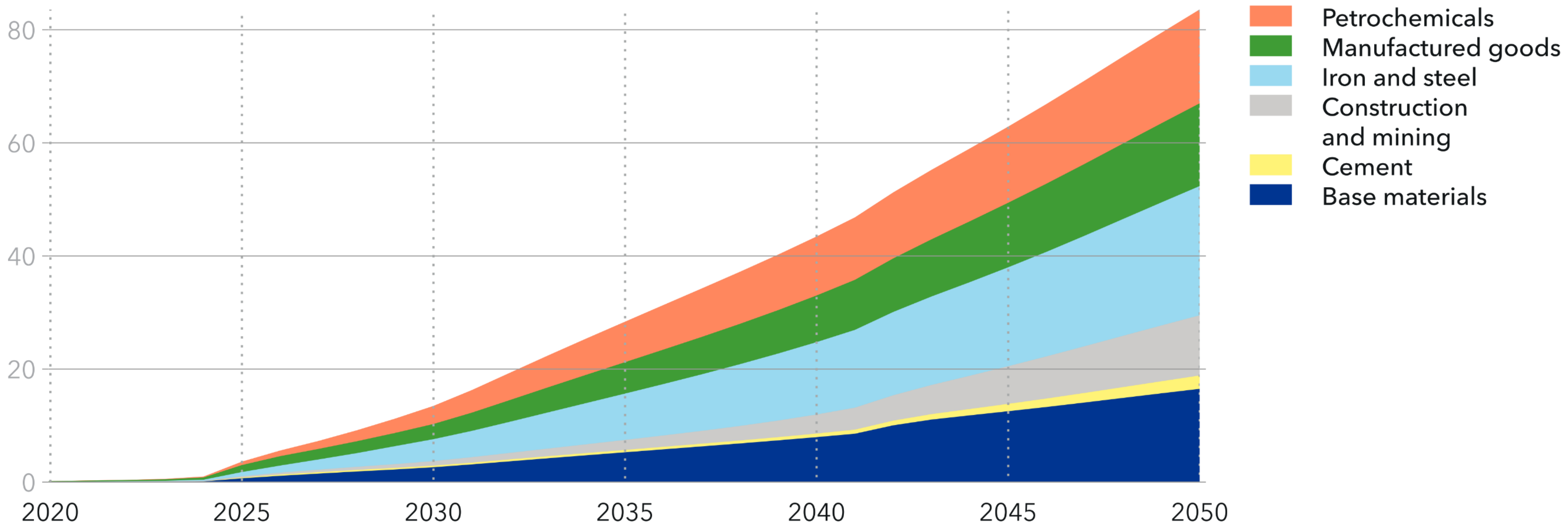
Hydrogen in manufacturing will be mostly used in high-heat processes: 7% of sector's energy demand in 2050

Global hydrogen demand in manufacturing by subsector

Units: MtH_2/yr



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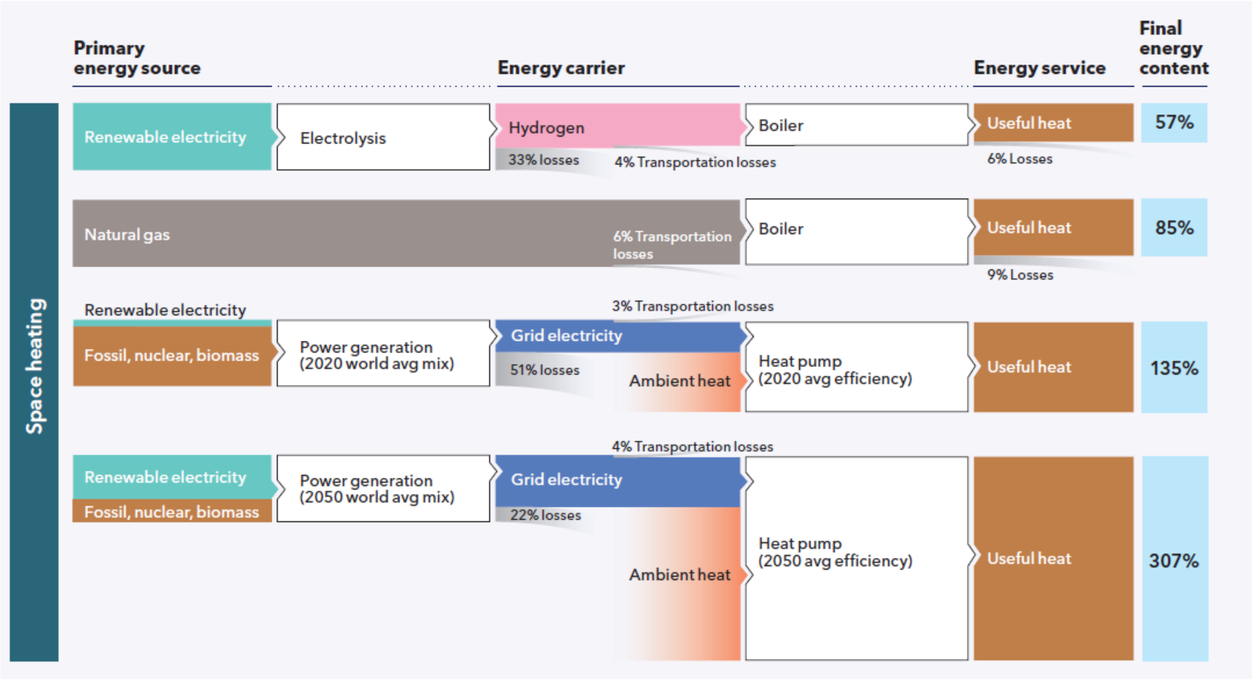
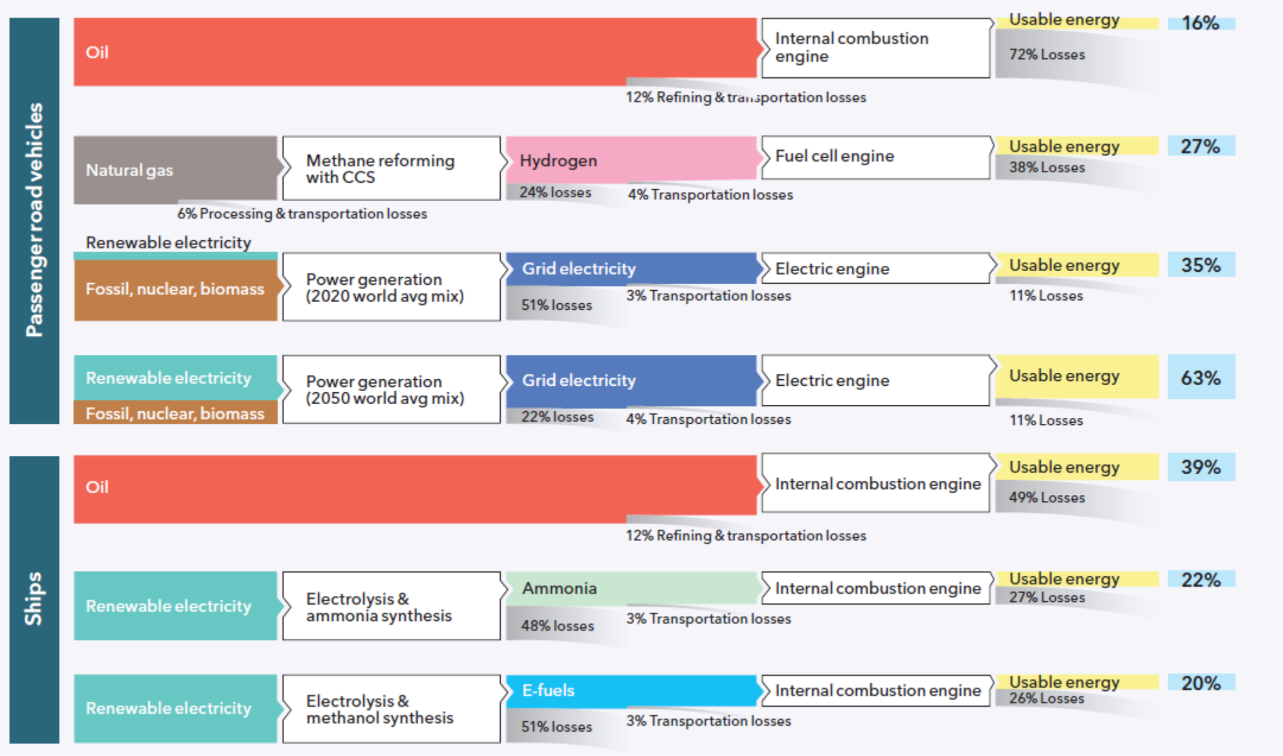
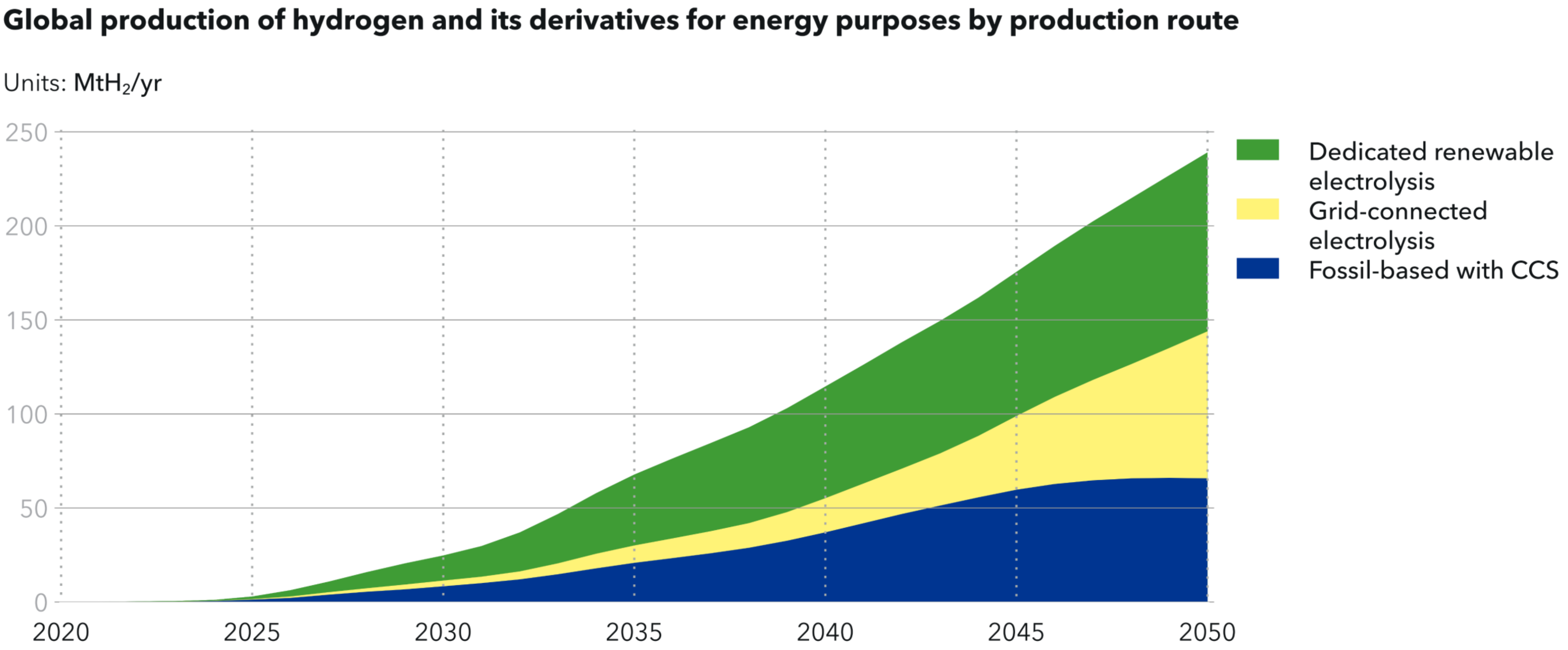
H_2 should be prioritized for hard-to-abate sectors: Elsewhere, it is inefficient and expensive compared with direct use of electricity



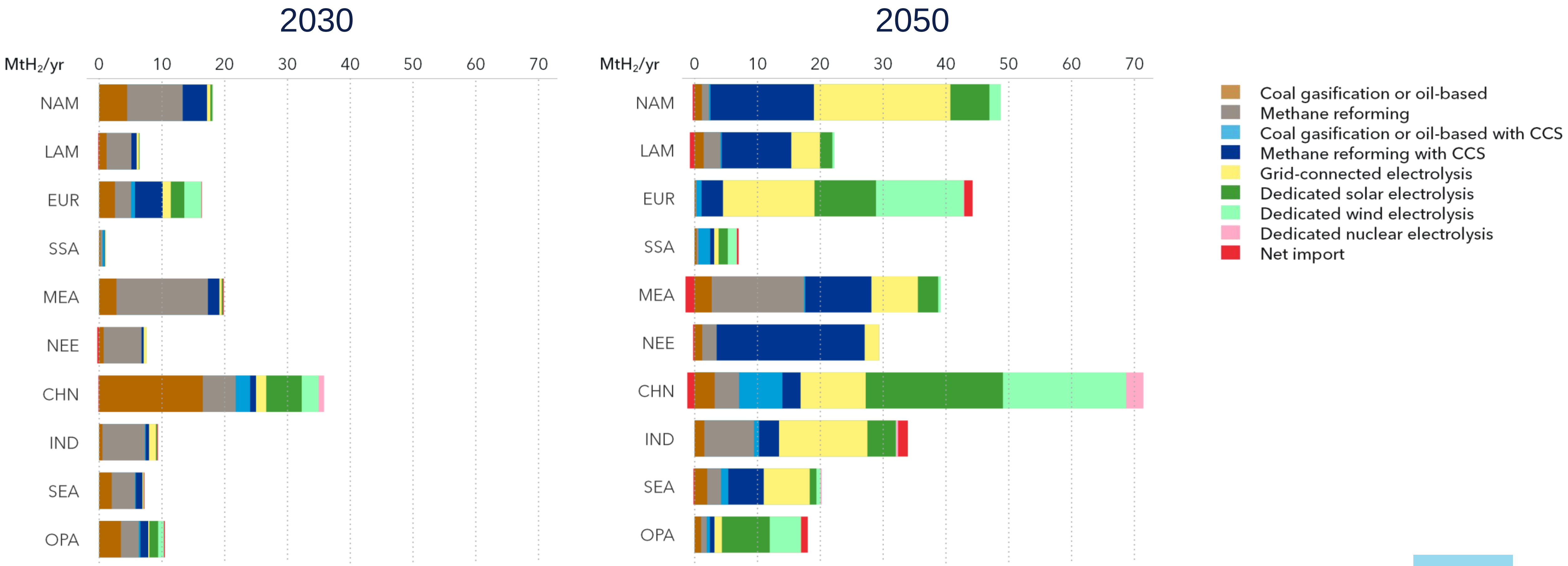


By 2050, 72% of hydrogen and its derivatives used as energy carrier will be from electrolysis

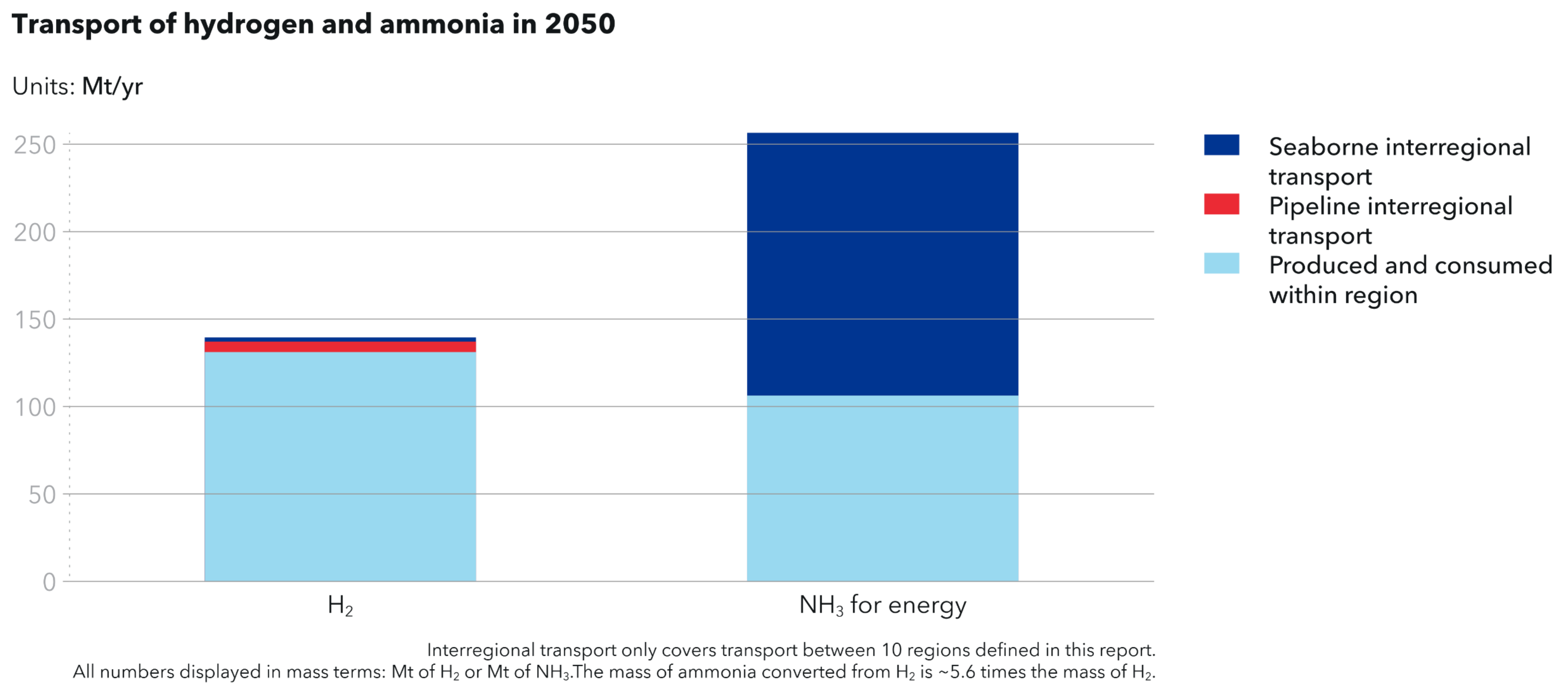


Hydrogen mix will vary due to differences in fuel prices, local conditions, availability of support, cost of capital

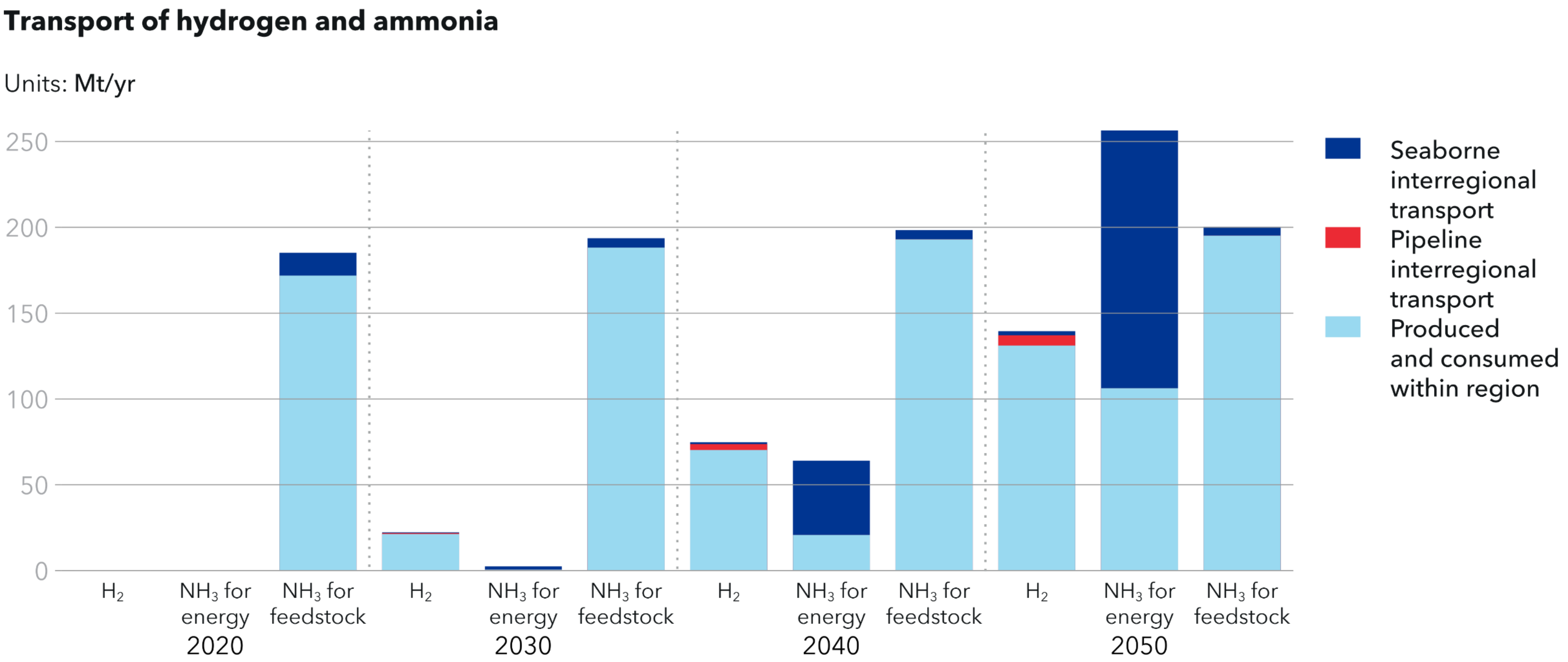
Production of hydrogen by production route and region



Hydrogen transport will be mostly limited to medium distances, not between continents

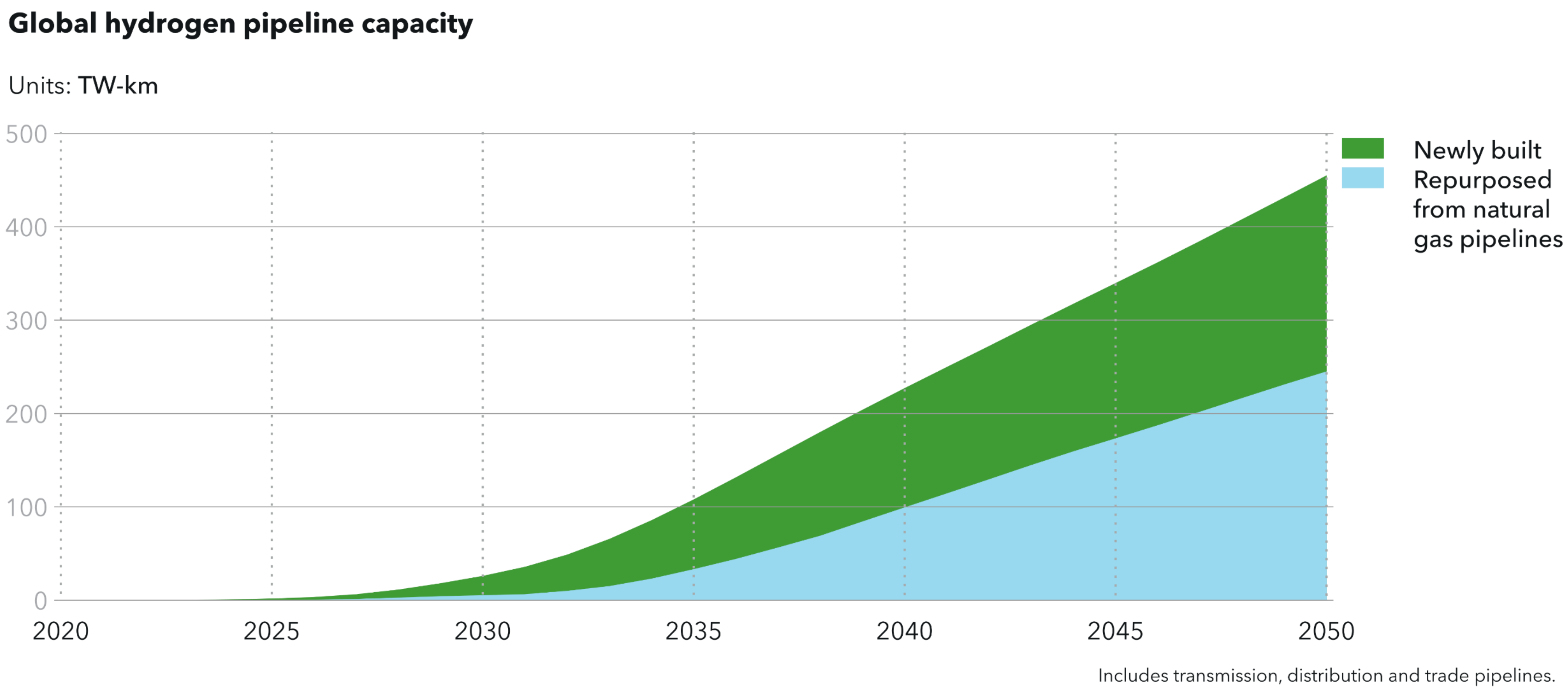


Ammonia is cheap to transport by ship: 59% of NH_3 used for energy will be traded inter-regionally by 2050



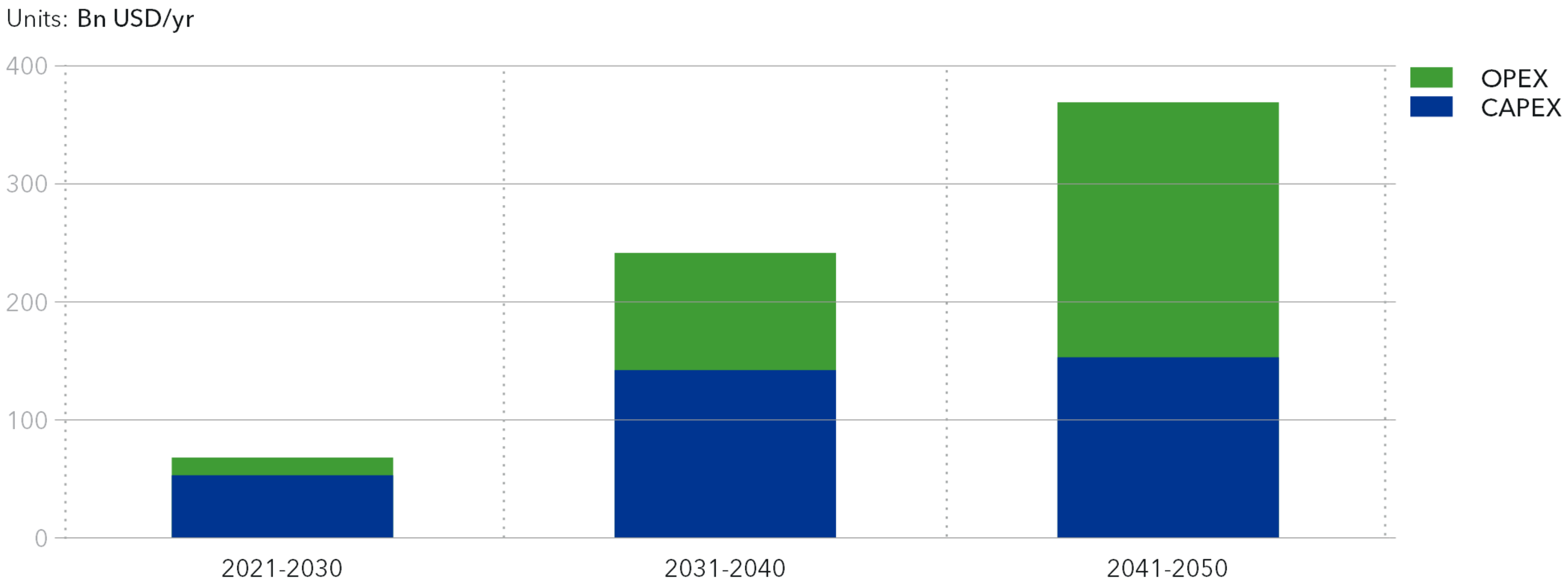
All numbers displayed in mass terms: Mt of H_2 or Mt of NH_3. The mass of ammonia converted from H_2 is ~5.6 times the mass of H_2.

More than 50% of global hydrogen pipelines will be repurposed from natural gas pipelines



Global spend on producing hydrogen & derivatives for energy purposes by 2050 will be USD 6.8trn

Global annual average expenditure for production of hydrogen and its derivatives for energy purposes

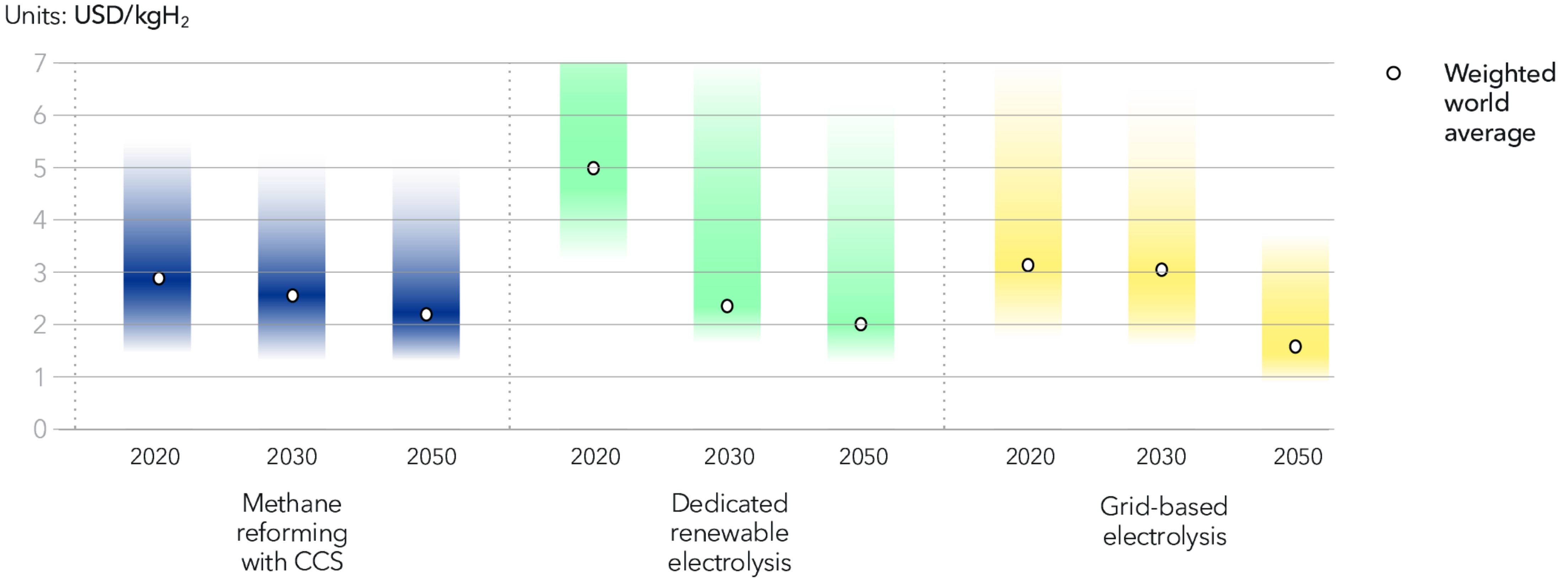


Does not include expenditures related to non-energy feedstock use.

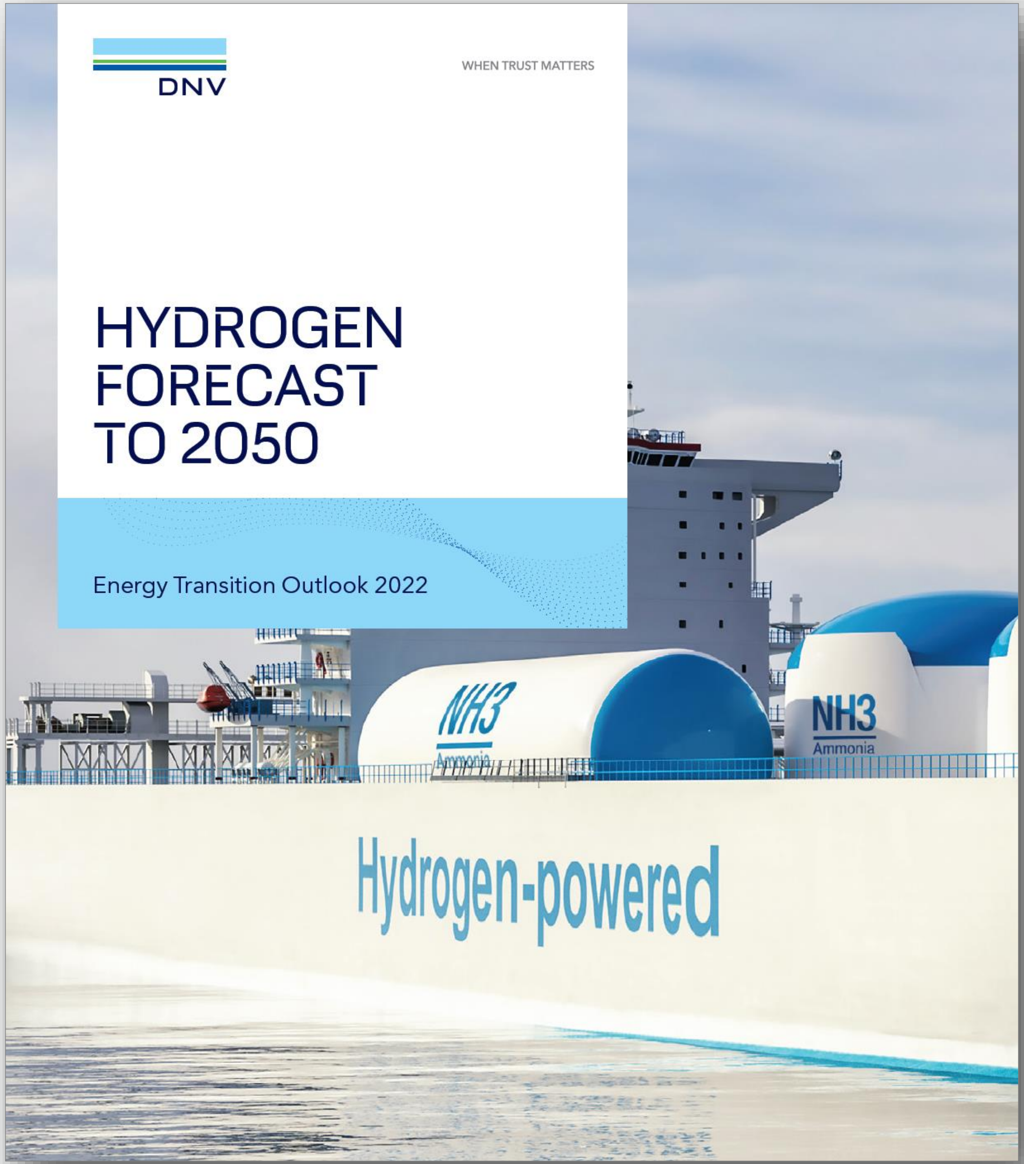
Electrolysis costs will decrease significantly towards 2050 and reach an average price of 1.5-2 USD/kg

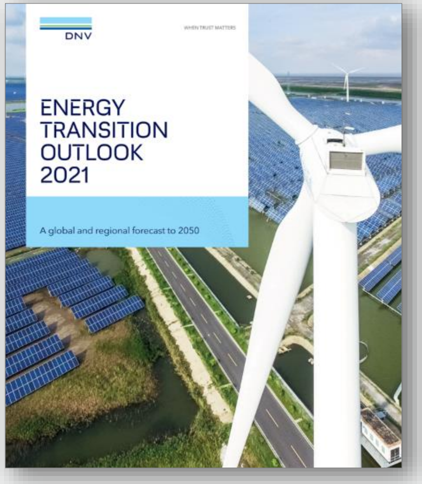
Average cost for blue H_2 will fall to USD 2.2/kg in 2050, in regions with cheap gas, costs are already USD 2/kg

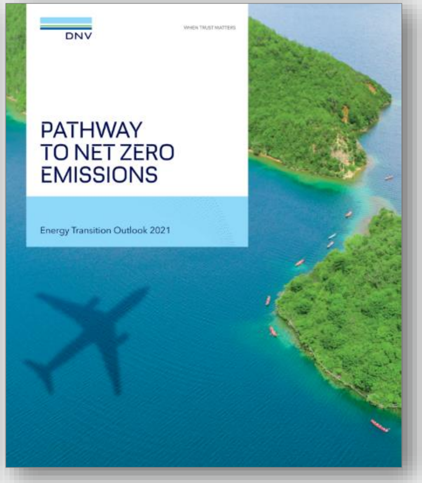
Levelized cost of hydrogen

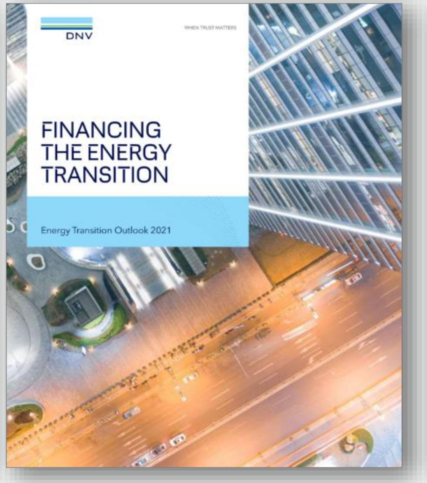


Levelized cost of production after support.









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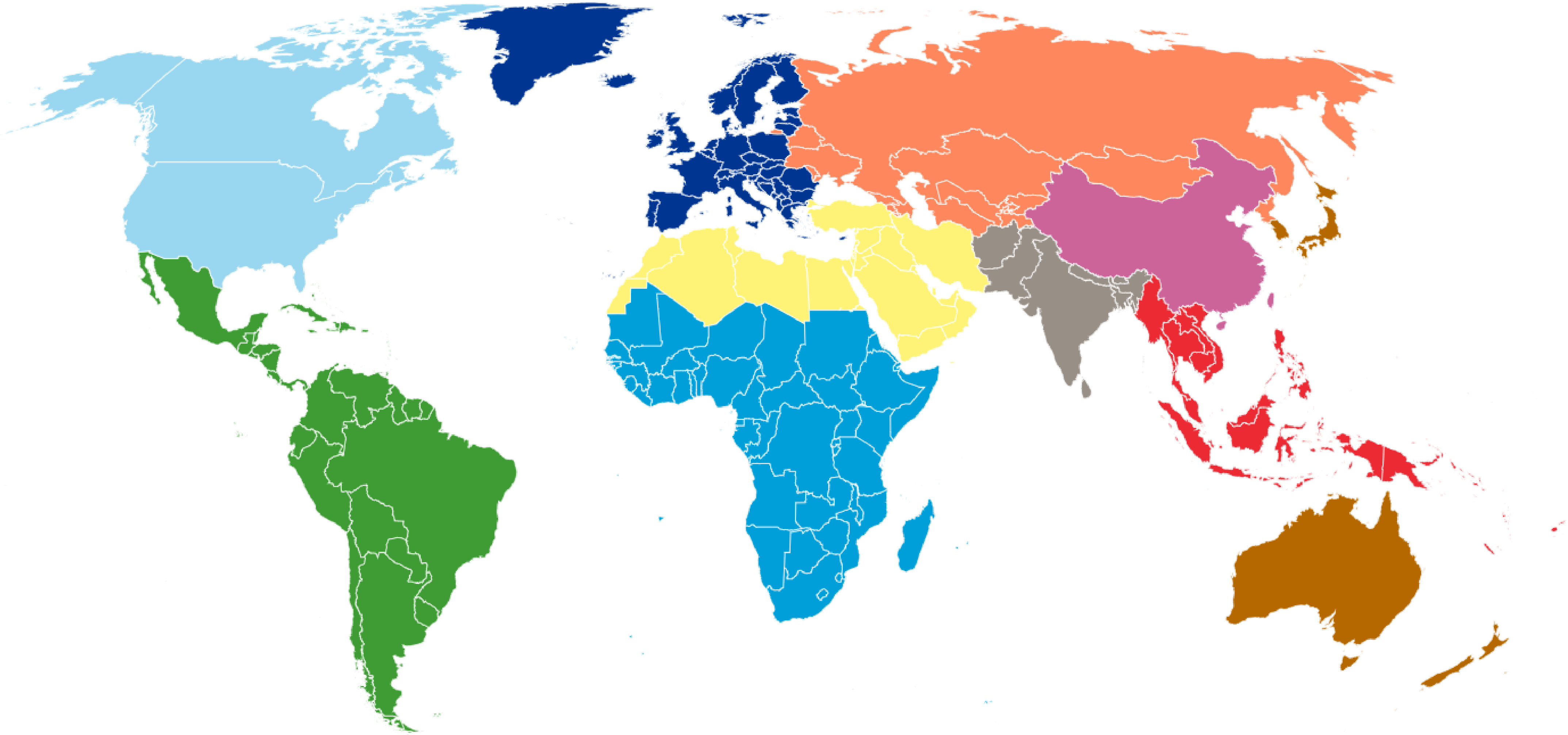
A global and regional forecast



Breakdown of barriers for policies to overcome

Hydrogen barriers which policies must overcome

1. Costs and financial support

No carbon cost internalization and limited support to first phase scaling and commercialization

2. Demand and competition

Competition between 1) low-carbon blue and renewable green hydrogen 2) electrification, and 3) fossil alternatives

3. Technology and manufacturing

Limited manufacturing for green and blue H_2 technologies, and offshore PtX needs maturing

4. Safety and hazards

Acceptance criteria and documentation varying from country to country

5. Infrastructure and indirect enablers

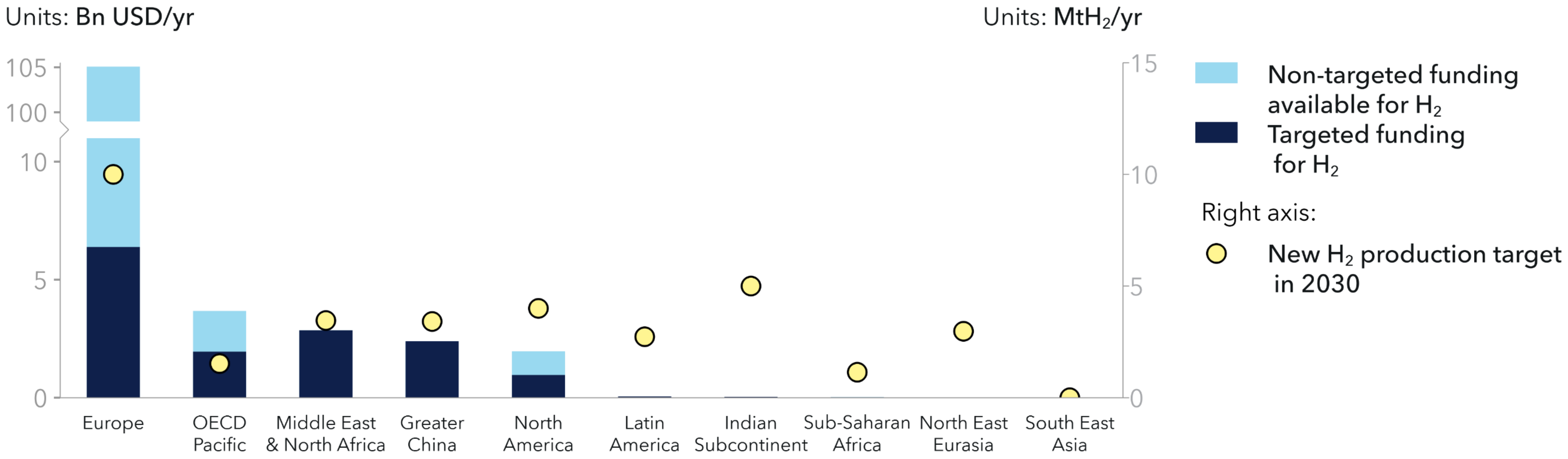
Renewable power production with robust grids onshore and offshore, and CCS value chains

6. Standards & certification

No GoO certification with traceability and LCA frameworks, standards for large-scale safe design needs updating

Available funding not always matching regional targets

Available public funding and production target for hydrogen by region

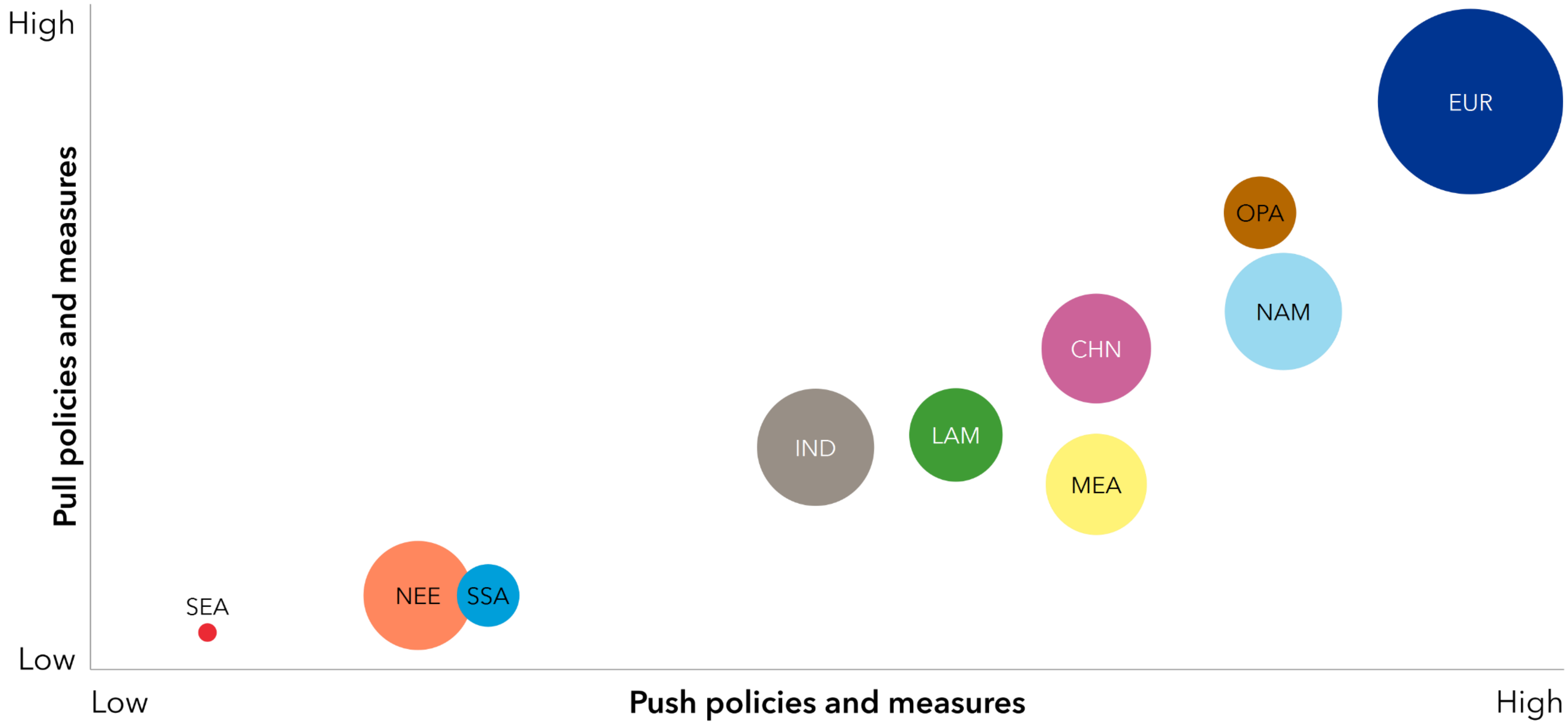


Sources: DNV analysis; IRENA (2022)

Note on funding: The figure provides an overview of the funding support potentially available for hydrogen projects in the 10 regions as of April 2022. More funds might be available.
Note on production targets: The production targets represent outspoken targets on new (renewable or low-carbon) hydrogen production per year in 2030. Where targets are based on installed electrolyser capacity from dedicated renewables, such as for some countries in LAM, NEE, CHN and SSA, yearly production is calculated using an efficiency of 65% and 5000 full load hours per year.

Great variation among regions in policy ‘completeness’

Regional production targets and policy comprehensiveness



From left to right:

SEA: South East Asia
NEE: North East Eurasia
SSA: Sub-Saharan Africa
IND: Indian Subcontinent
LAM: Latin America
MEA: Middle East & North Africa
CHN: Greater China
OPA: OECD Pacific
NAM: North America
EUR: Europe

Bubble area is proportional to new H_2 production target in 2030.

Policies exert influence on our forecast — in three main areas

- **Supporting technology development** and stimulating market uptake of clean technologies
- **Restricting the use of inefficient or polluting products/technologies** by means of technology requirement or standards
- **Providing economic signals (e.g. a price incentive)** to reduce carbon-intensive behaviours

Carbon-pricing schemes

Taxation of fuel, energy, carbon and grid connections

Hydrogen support

Renewable power support

The journey begins today, and may close the gap to 1.5ºC

Early start

Decarbonize existing hydrogen production and use
Accelerate production *and* offtake

Regulation is complex, but can be tailored

Retrofit and modification for fuel switching, and new infrastructure for new use and storage are needed

Policies must target multiple sectors

Hydrogen can assist decarbonization where electrification is difficult, making sustainable end products, materials and chemicals

Safety guidelines

Require new or updated regulatory frameworks, standards, and guidelines – especially for large scale production and storage

Barriers for scaling can be overcome

1) Frameworks for guaranteeing the origin or traceability of hydrogen;
2) Renewable power and CCS capacity must scale while reducing costs
3) Support mechanisms such as CfDs *and* higher carbon pricing on fossil hydrogen will make renewable and low-carbon hydrogen competitive