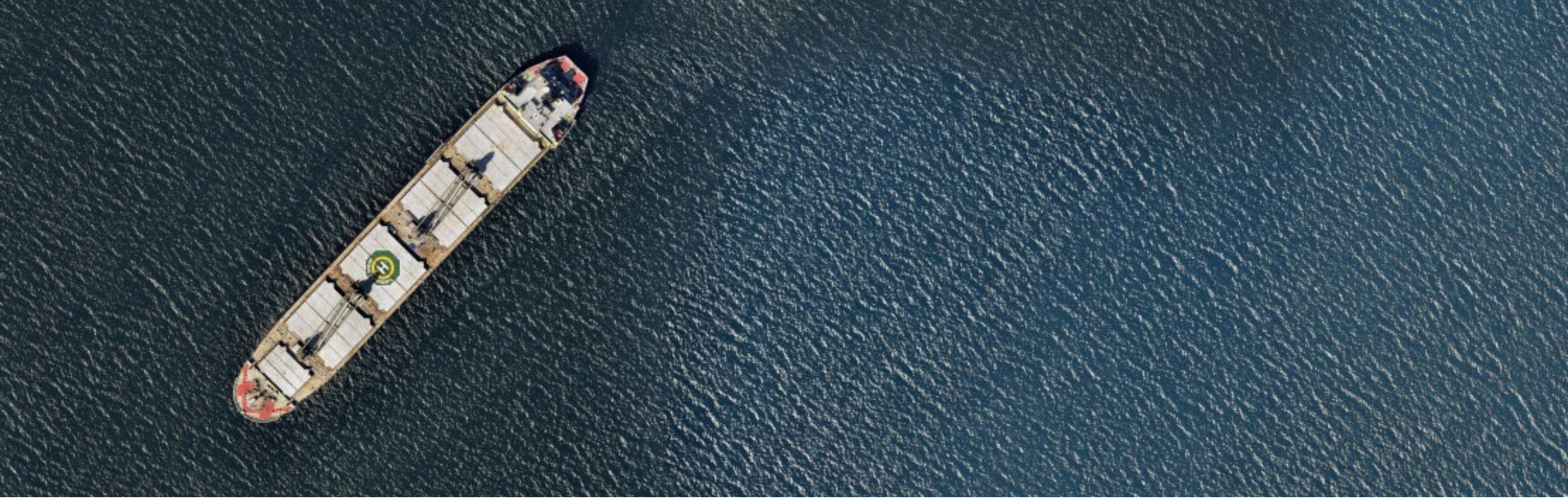

The future market for low carbon hydrogen

11 May 2022

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Agenda

- **Introduction**
- Scenario assumptions
- Model results

Our hydrogen ambition

OUR AMBITION

To be the leading advisor to the hydrogen industry providing advisory services and technical expertise across the whole value chain

Providing a ***'One-Stop-Shop'*** for our clients at whatever stage of their journey in the energy transition

Our hydrogen expertise

KEY FIGURES

1 Over 80 projects delivered globally in over 30 countries since start of 2021

2 Technical/engineering on projects with over 10GW electrolyser capacity globally

3 Expertise covers the entire value chain from production to end-use

4 Expertise in Ammonia, e-methanol and Sustainable Aviation Fuels

5 Over 50 experts located globally involved in projects

INDUSTRY

TRANSPORT

POWER

HEAT

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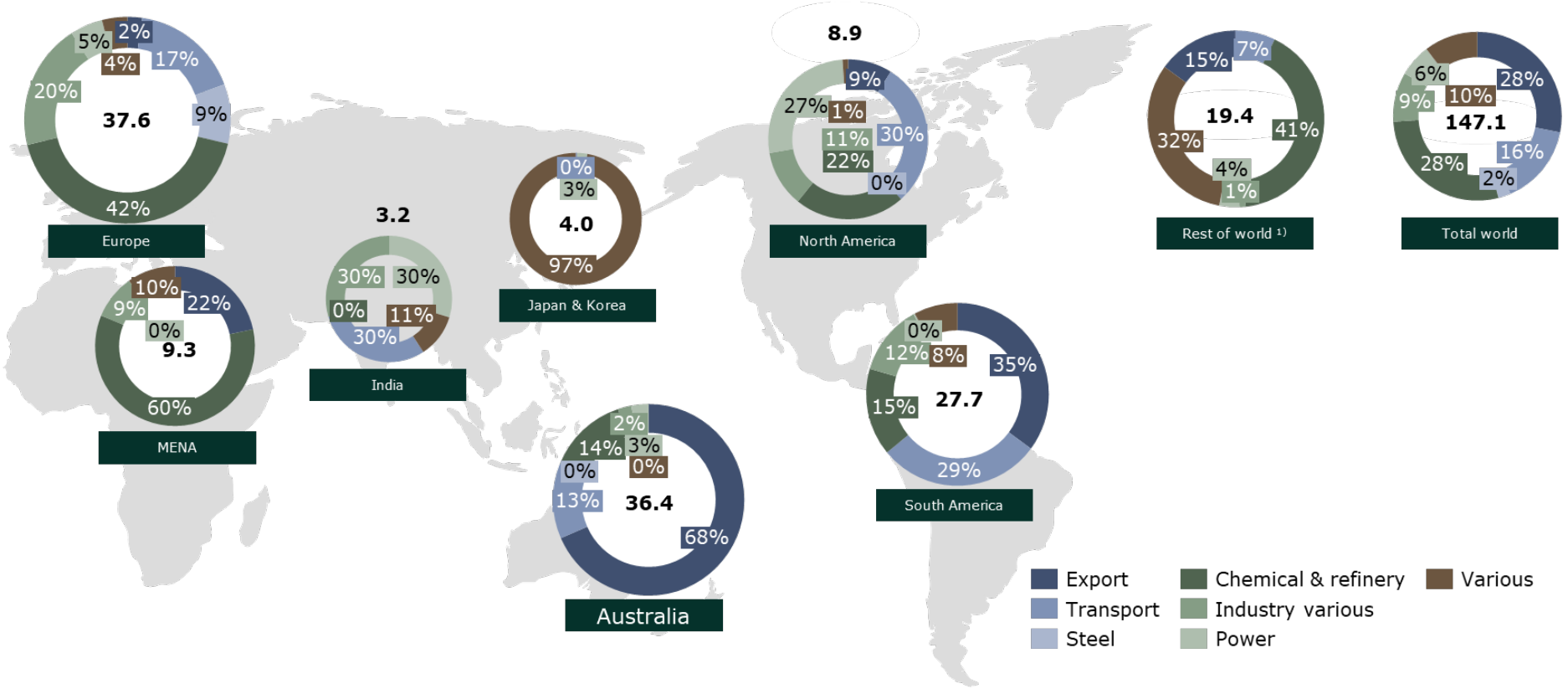
Global interest can be seen in the number and location of announced projects with a focus on industry, transport use and exports

ANNOUNCED PROJECTS BY CAPACITY AND END-USE



All totals in GW

Source: Global Data and AFRY analysis 1) For illustrative purposes, regions China, Russia and Africa are aggregated under 'Rest of world', among others

Contents of the presentation

- This document presents our Global Hydrogen Trade Model that has been developed by AFRY
- The model has been used to project the evolution of the future market for low carbon hydrogen based on assumptions on future demand and supply costs from different markets
- The results are intended to be an illustrative ‘what-if’ scenario rather than an AFRY Central scenario or most likely view of the future
- The results shown here are the initial model results and will be further developed over time

AFRY's Global Hydrogen Trade Model

MODEL INPUTS AND OUTPUTS

Inputs

Demand
Annual volume by region

Investment costs
Low carbon hydrogen production costs by region

Potential
Potential production volumes by region

Transport
Capacities, modes, distance and costs

H2 Model

Outputs

Production
Individual region and global hydrogen supply mix

Prices
Market prices in each region

Hydrogen flows
Trade flows between regions

Revenue and profit
Revenue and potential profit of a project in each region

COMMENTARY

- The model solves for the least cost method for meeting global hydrogen demand given potential supply costs in different regions and the cost of transporting hydrogen between regions.
- There are 31 modelled regions that cover the total global supply and demand for low carbon hydrogen
- The model provides a range of outputs that provide a deep understanding of the future global hydrogen market and help identify key opportunities for investors and developers
- It provides projections for the different characteristics of the hydrogen market in eight modelled years (every five years from 2025 until 2060)

Model supply function and objective function

SUPPLY FUNCTION

- The supply of low carbon hydrogen in each region is proportional to:
  - **Price compared to LCOH**: The differential between the region's hydrogen price and the region's LCOH (assuming a good quality site)
  - **Resource**: The region's potential hydrogen resource
- Supply is therefore highest in regions where the hydrogen production potential is high and the differential between the price and the cost of production are high
- The size of the region's potential hydrogen resource is sized based on:
  - **Blue**: Current gas production
  - **Green**: Available land area for deployment of wind or solar
- The price in each region is the price at the point of import / export from that region. It is a variable that the model solves for.

OBJECTIVE FUNCTION

- The model is constructed as a linear optimisation in Python
- The model minimises the cost to consumers of meeting future demand for low carbon hydrogen:
  - production in each region x price
  - trade volumes between regions x cost of transport between regions
- Constraints are defined on the objective function and apply to each region
  - Supply = consumption + exports
  - Demand = production + imports
  - Supply < technical potential for hydrogen production
  - Supply >= 0
- Hydrogen therefore flows from markets with low prices to markets with high prices until differentials between markets reduces to the cost of transport between regions (subject to transport constraints between markets)

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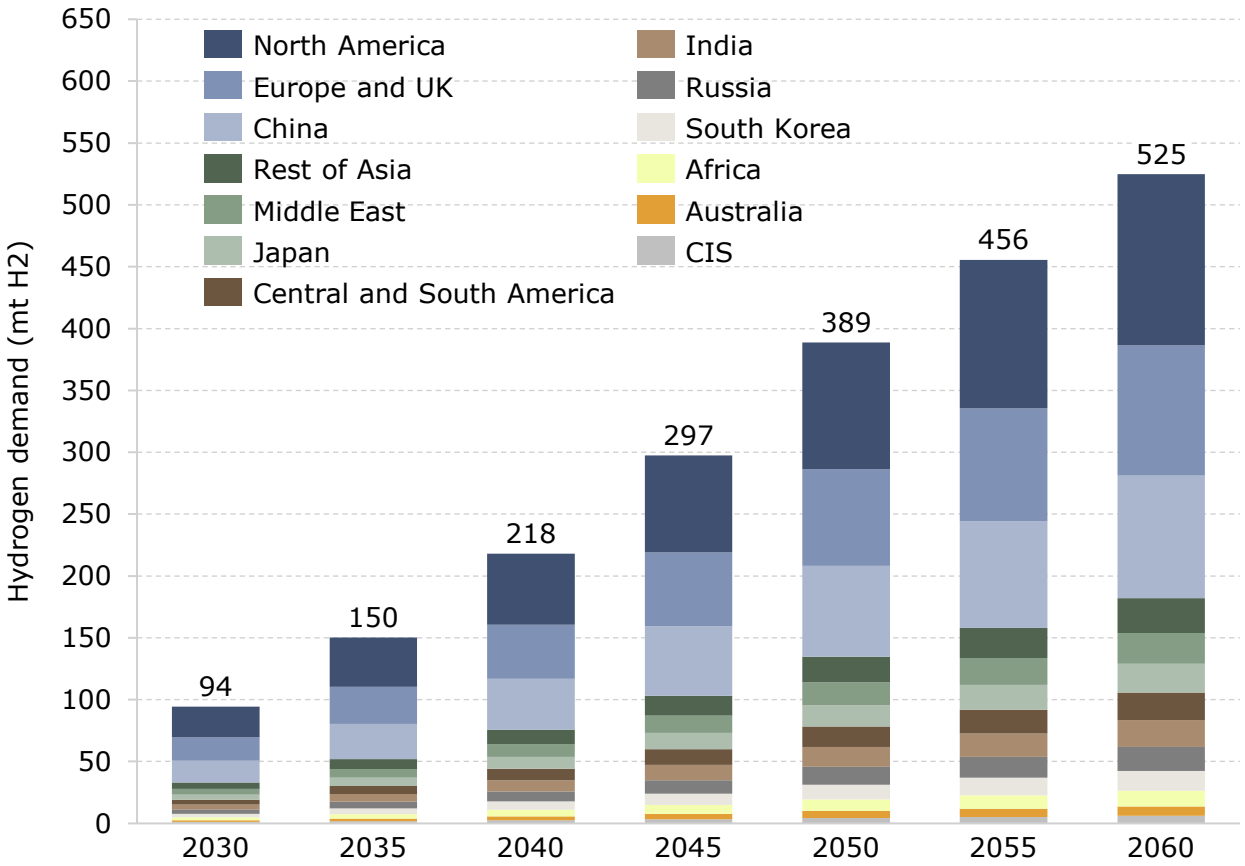
- Introduction
- **Scenario assumptions**
- Model results

Low-carbon hydrogen demand

GLOBAL LOW-CARBON HYDROGEN DEMAND



COMMENTARY

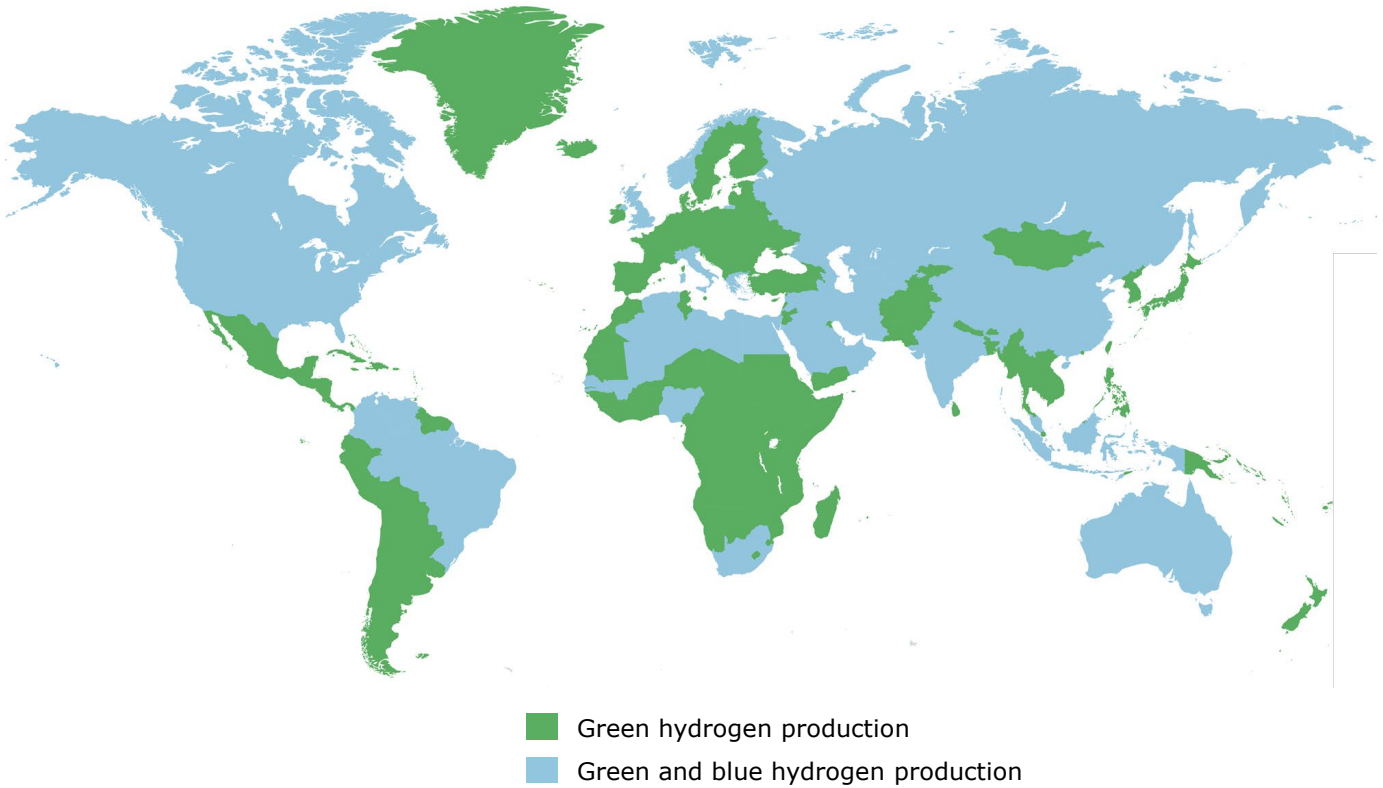
- Global hydrogen demand projections are based on IEA's 2050 net-zero roadmap with the assumption that the 2050 target is delayed by ten years
- The demand is split into regions based on that region's share of global energy consumption
- A multiplier of 2 is applied to regions that have made strong commitments to using low carbon hydrogen in their domestic energy mix. This includes Australia, Canada, Japan, South Korea, United Kingdom, United States and Europe

Hydrogen supply

PROJECTIONS FOR HYDROGEN SUPPLY

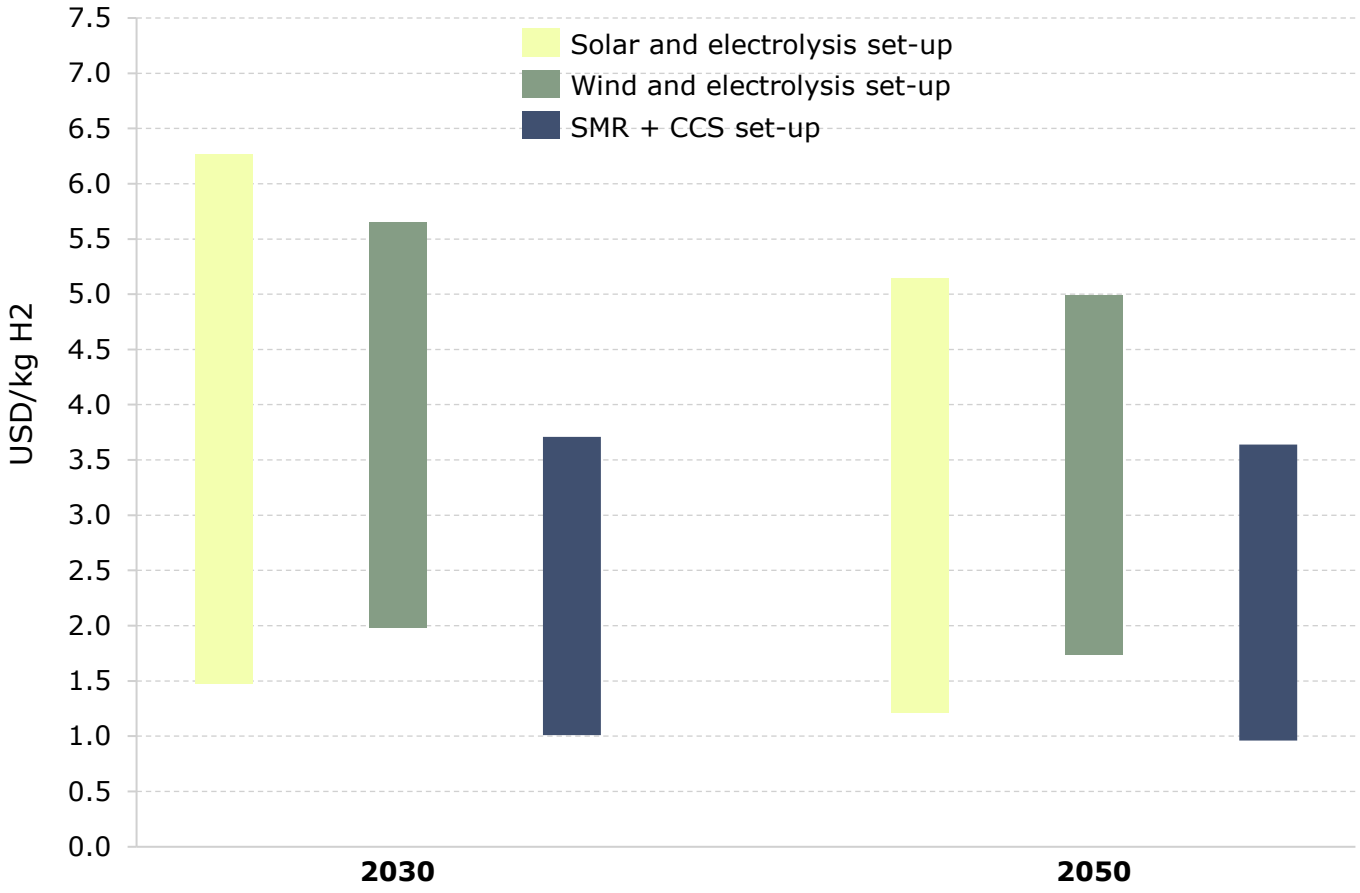
- Three possibilities for hydrogen production are considered in the analysis:
  i. Dedicated solar PV and electrolysis setup
  ii. Dedicated onshore wind and electrolysis setup
  iii. Steam methane reformer with carbon capture and storage
- Blue hydrogen production is assumed to happen only in gas producing regions as CO_2 storage sites are likely to be better in producing markets
- The model optimises production in each region based on the relative availability of wind, solar and gas resources where applicable

HYDROGEN PRODUCTION POTENTIAL AND TECHNOLOGY



Levelized cost of hydrogen

LCOH RANGE FROM DIFFERENT SET-UPS

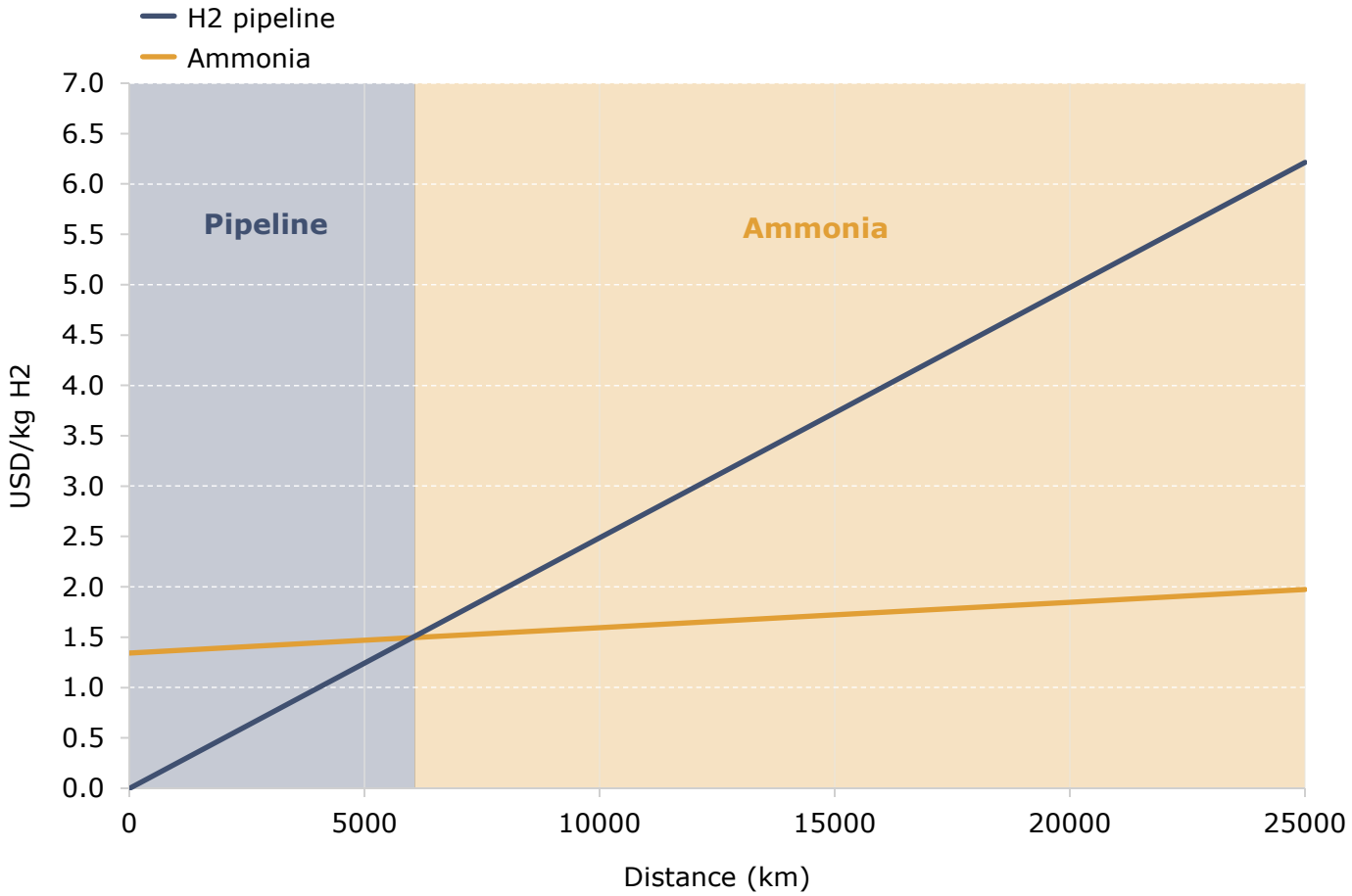


COMMENTARY

- The cost of producing green hydrogen has a downwards trend in all markets, driven by falling capital costs and technological improvements
- The cost of producing blue hydrogen sees slight improvements; gas price is the main cost parameter associated with this set-up
- Producing green hydrogen becomes increasingly more competitive with blue hydrogen

Hydrogen transport

COST CURVES FOR DIFFERENT MODES OF TRANSPORT



COMMENTARY

- Transportation distance is based on distance between the major ports in every region
- Two options are available for hydrogen transport:
  i. Pipeline
  ii. Ammonia as a carrier
- The model determines the optimal mode of hydrogen transport between each region based on the cheapest amongst the two available options for each possible trade route
- Transportation costs for each mode of transport are based on the European Commission's assessment of hydrogen delivery options
- Hydrogen transport capacity between the different regions does not take into account current and future infrastructure requirements and is therefore unrestricted in the model

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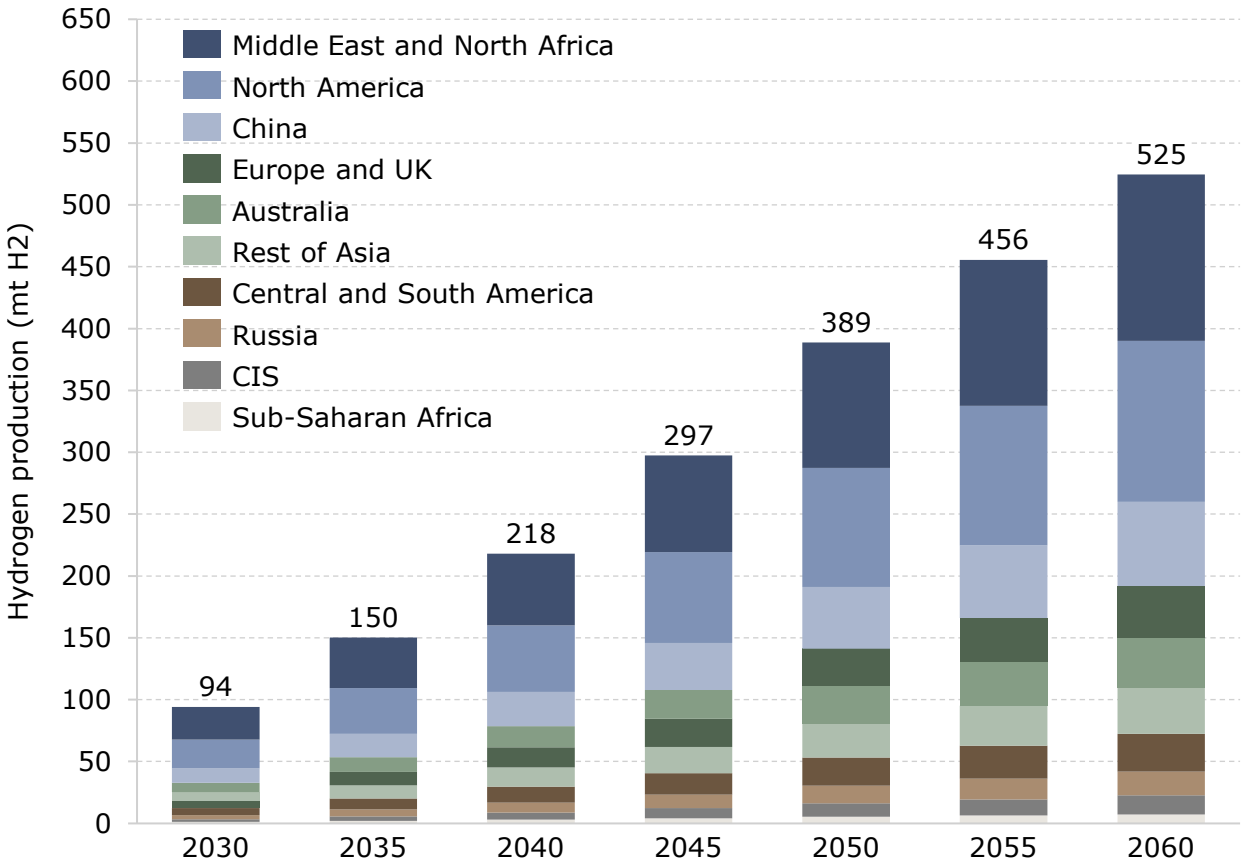
- Scenario assumptions
- **Model results**

Low-carbon hydrogen production

GLOBAL LOW-CARBON HYDROGEN PRODUCTION

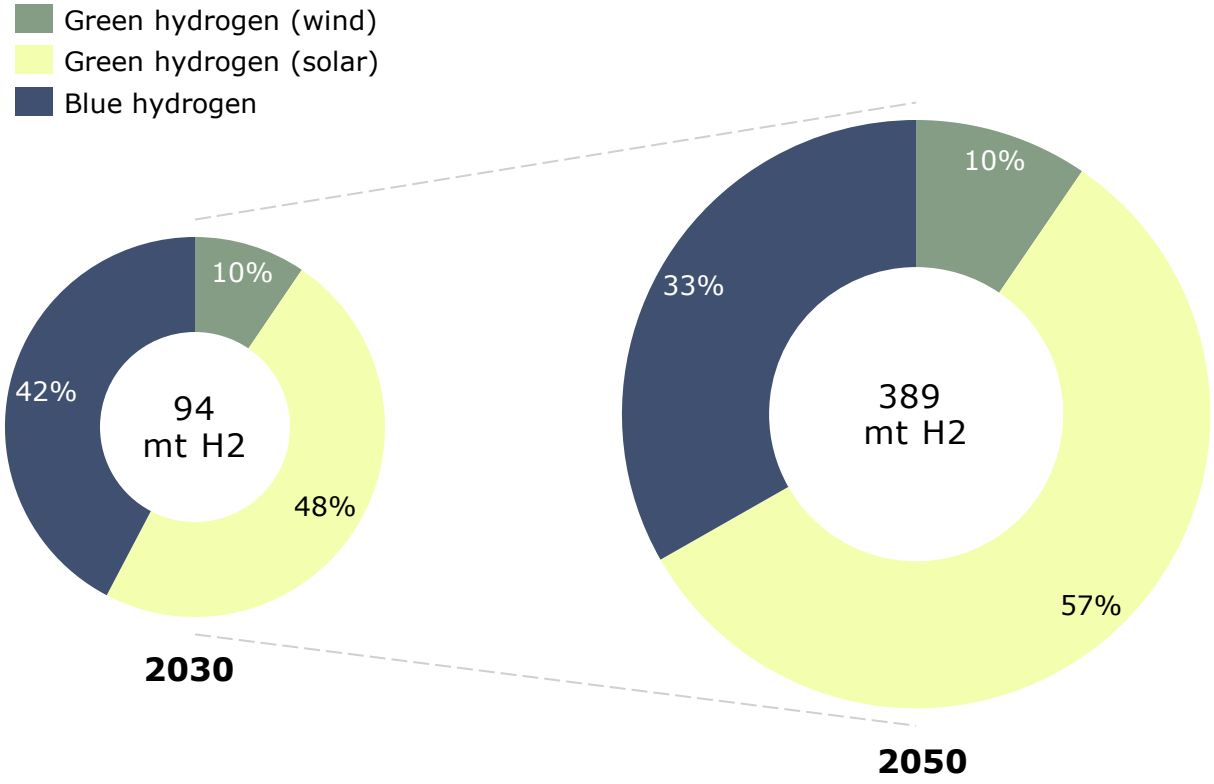


COMMENTARY

- The Middle East and North Africa are set to become the largest hydrogen producing regions due to the abundance of available resources
- Hydrogen production in North America, China and Europe is driven by high local hydrogen demand
- Australia is expected to contribute to a significant share of global hydrogen production
- Regions that are at a geographical disadvantage of being far from demand hubs are only producing hydrogen to meet domestic demand

Global low-carbon hydrogen supply mix

GLOBAL LOW-CARBON HYDROGEN SUPPLY BY TYPE (MT H2)

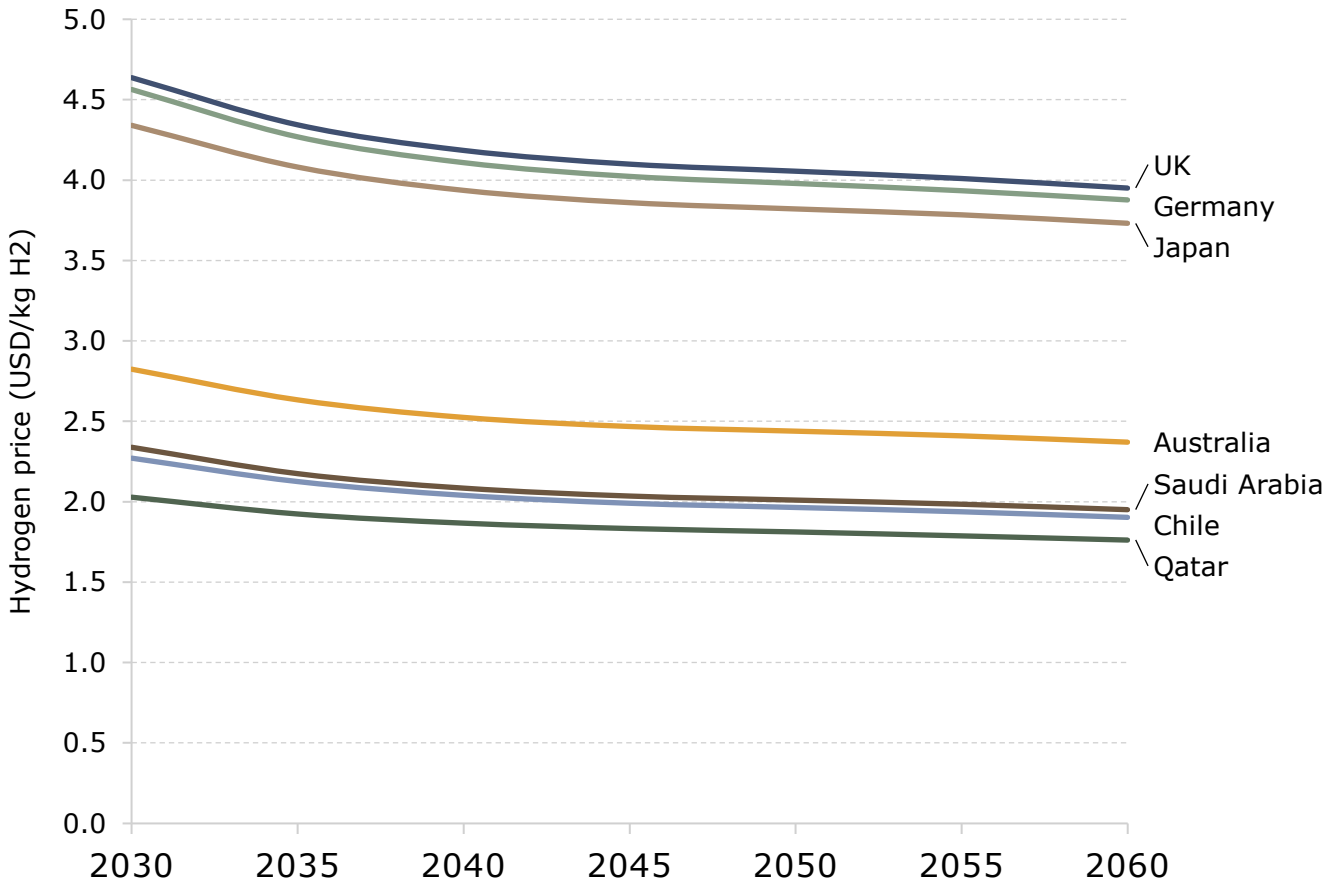


KEY INSIGHTS

- Blue hydrogen sees constant contribution towards meeting global hydrogen demand
- The share of blue hydrogen from the total hydrogen produced globally decreases over time, as the price of green hydrogen becomes more competitive due to falling capital costs of renewables (solar PV and onshore wind) and electrolysis
- In 2030, blue hydrogen makes up 42% of the overall global low-carbon hydrogen output; this number decreases down to 33% by 2050

Hydrogen prices analysis

PRICE COMPARISON BETWEEN KEY MARKETS

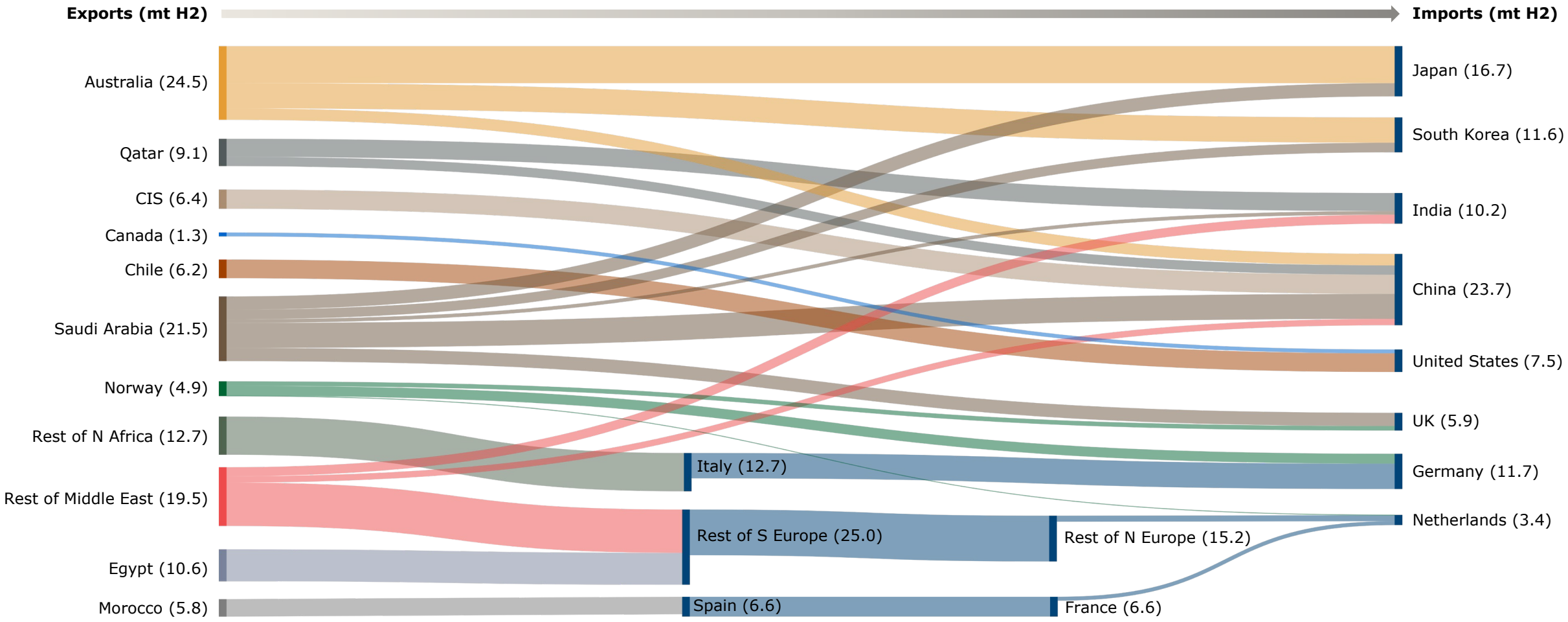


COMMENTARY

- The price shown is the price of hydrogen (converted from Ammonia if that is the mode of transportation) at the point of import/export in each market
- The end-user price will be higher once transportation, storage and retailing costs are included
- Hydrogen prices witness a downwards trend globally, driven by falling production costs of electrolysis and renewables
- This is offset against rising demand for hydrogen over time, which limits the decline by requiring a move to less attractive sites for renewable development
- Higher production costs and the additional transportation costs incurred are the main factors driving the price differences between exporting and importing regions

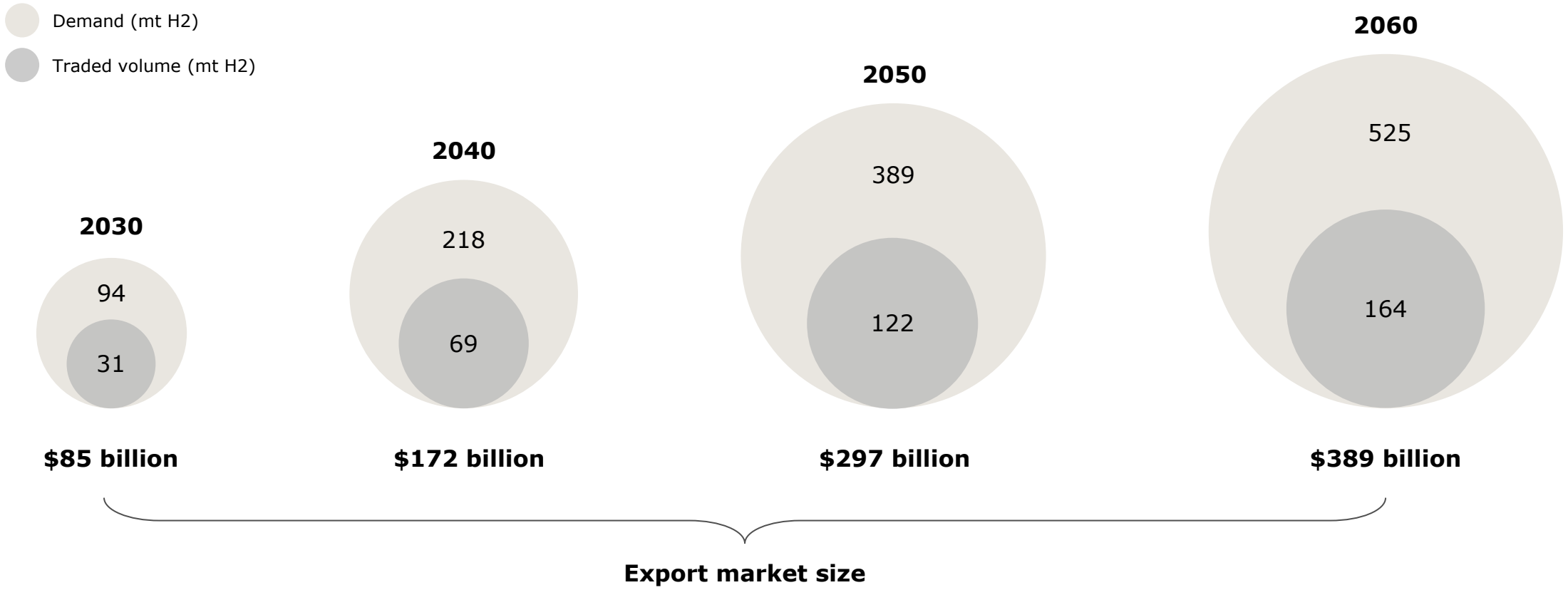
MODEL RESULTS

Global Hydrogen trade flows in 2050



Low-carbon hydrogen export market

GLOBAL LOW-CARBON HYDROGEN TRADED VOLUMES AND EXPORT MARKET SIZE



Key takeaways

Market size	The future market for low carbon hydrogen could expand to $0.5trillion per year … with over a third of the hydrogen demand traded internationally
Drivers of international trade	The difference in LCOH between regions is likely to be large and drive signficiant international trade in low-carbon hydrogen as we move to global net-zero
Future price drivers	The key driver of future low carbon hydrogen price will be speed of the decline in the cost (in particular capex) of green and blue hydrogen technology
Transportation costs	The cost of transport will also be a large component of the final price … proximity of exporters to their destination market will be a strategic advantage
Future price trajectory	It is possible for low carbon hydrogen prices to fall driven by technology gains even as demand expands rapidly
Indices and contract structures	Trade will require reliable price indicies, certification schemes and contract structures to emerge to support the global low carbon hydrogen market

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CONCLUDING REMARKS

Contact us

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- **More webinars** will follow with relevant topics, and any update on the evolving situation.

'What are the common mistakes made in evaluating renewable energy assets and how can they be avoided?'

In our next webinar, we will explore how these mistakes can be resolved in order to maximise revenue.