UNIVERSITY OF CAMBRIDGE | Energy Policy Research Group

Future of Hydrogen

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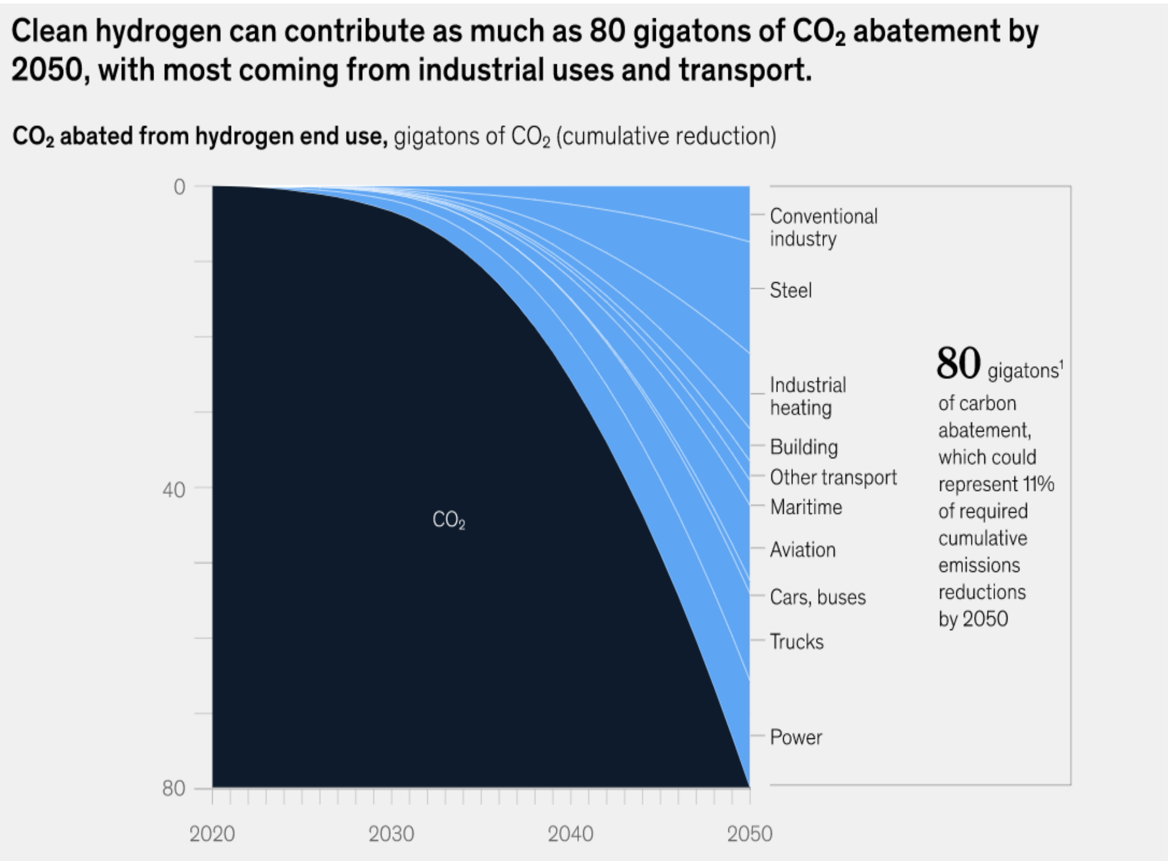
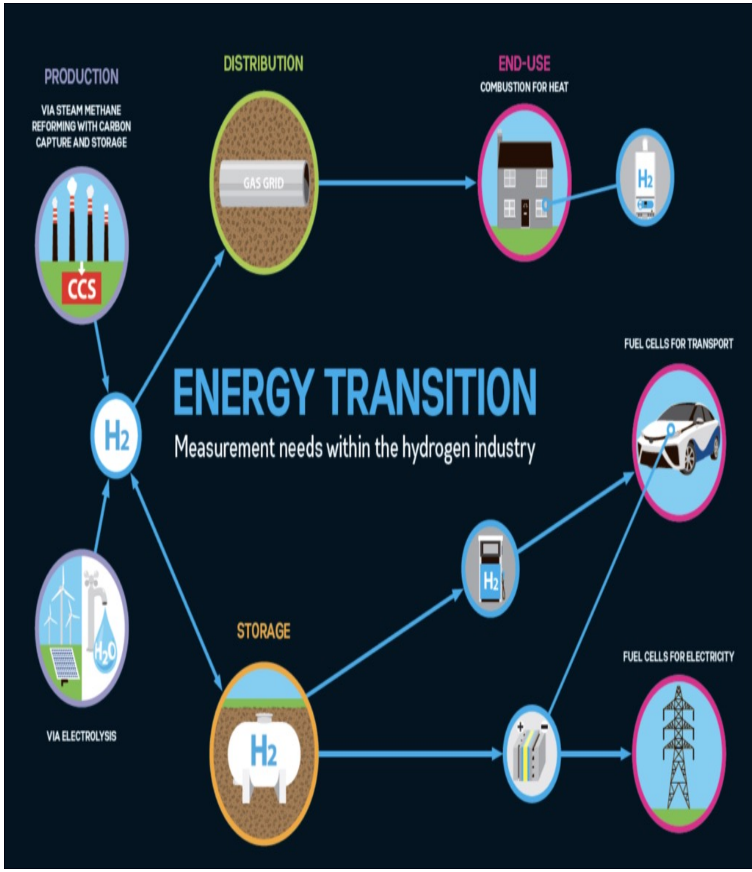
Content

McKinsey: Hydrogen responsible for 11% of cumulative emissions reductions by 2050

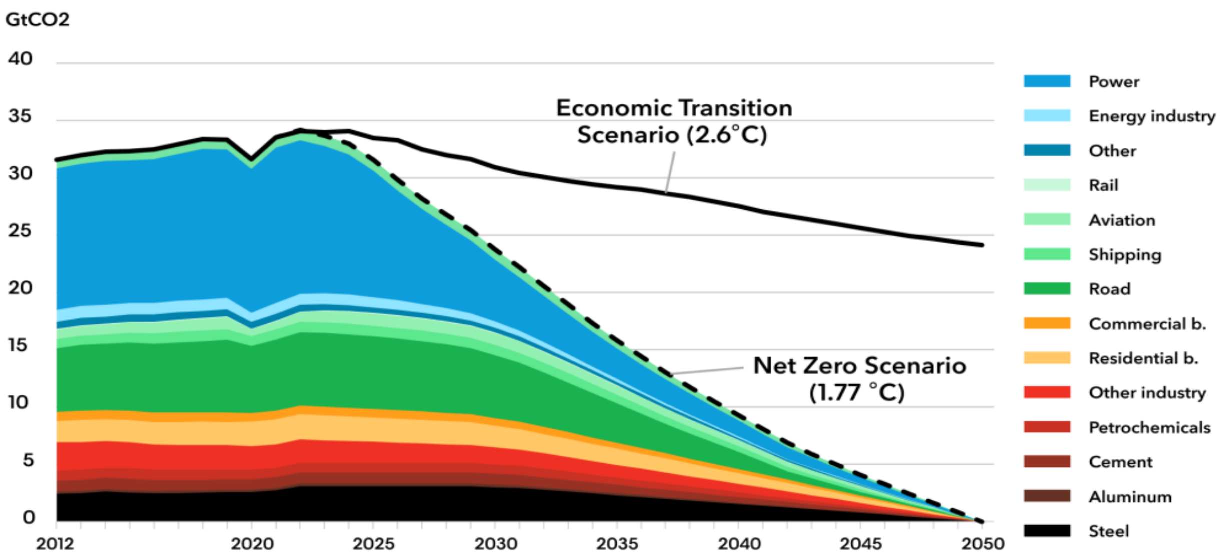


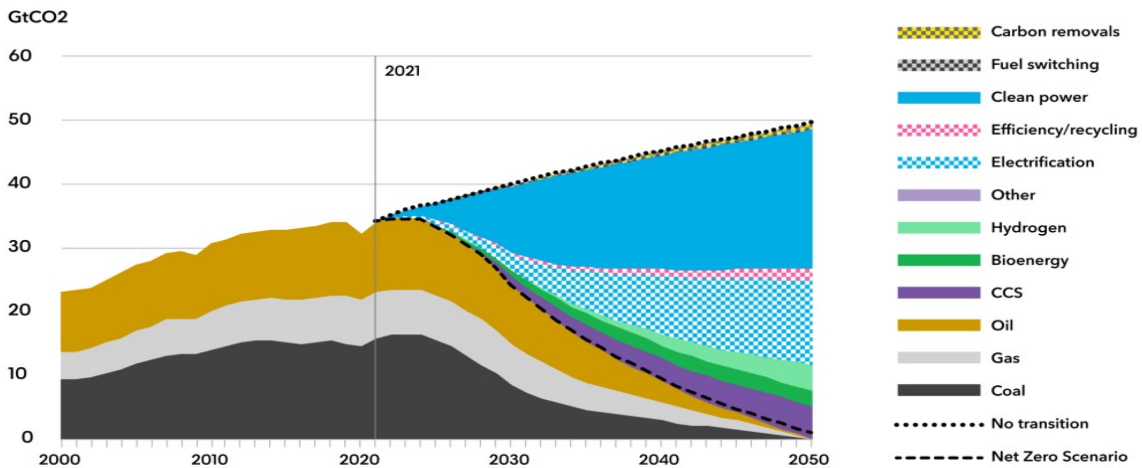


Source: McKinsey Hydrogen Insights 2022

- Currently, climate change ambition is the key driver for hydrogen in addition to historical stimuli such as 1970s oil price shocks and 2010 oil peak
- Hydrogen has potential sharp relief to the challenge of tackling hard-to-debate emission sources
- It can support energy security through its diverse feedstocks and applications

IEA: Hydrogen responsible for <5% of cumulative emissions reductions by 2050





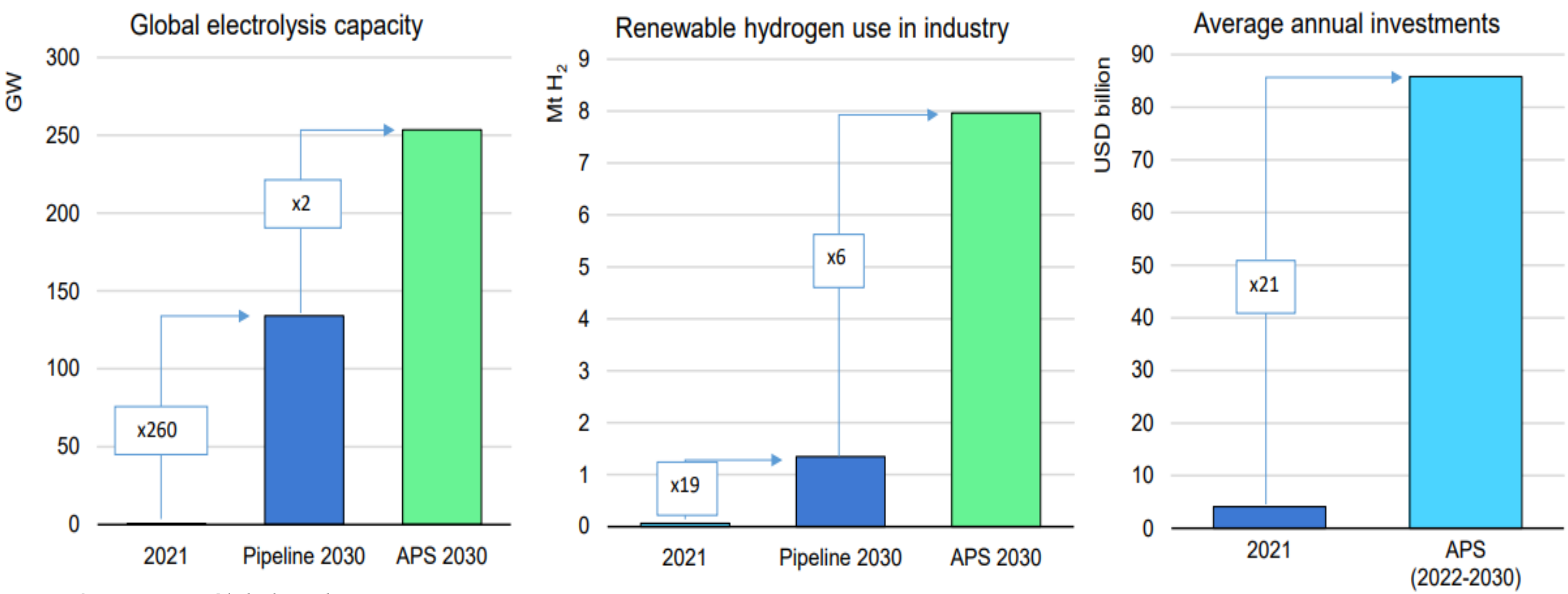
Source: IEA World Energy Outlook 2022

- Choices of transition would influence the decarbonisation of different sectors
- Possible ranges of low-carbon technologies to achieve the

Scaling up for net zero

Policy action is needed to scale up hydrogen production and use

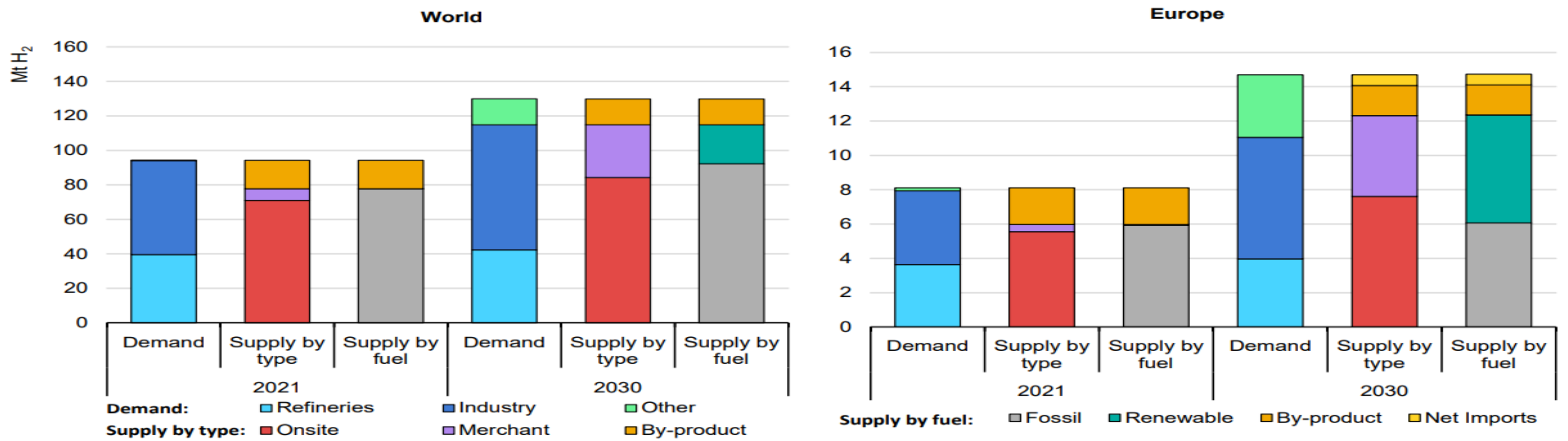
Electrolysis capacity, renewable hydrogen use in industry and average annual investment in low-emission hydrogen in the Announced Pledges Scenario, 2021 and 2030



Source: IEA Global Hydrogen Review 2022

Background: Hydrogen demand and supply

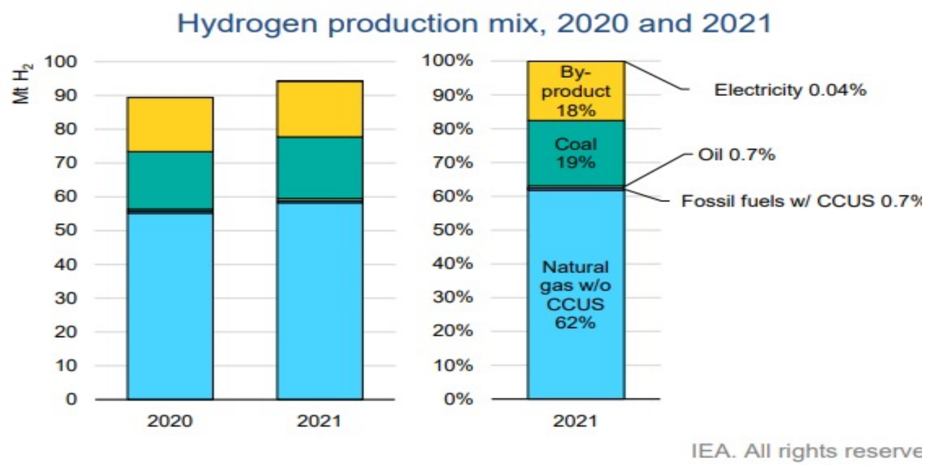
Global and European hydrogen demand by sector, and hydrogen supply by type and fuel in the Announced Pledges Scenario, 2021-2030

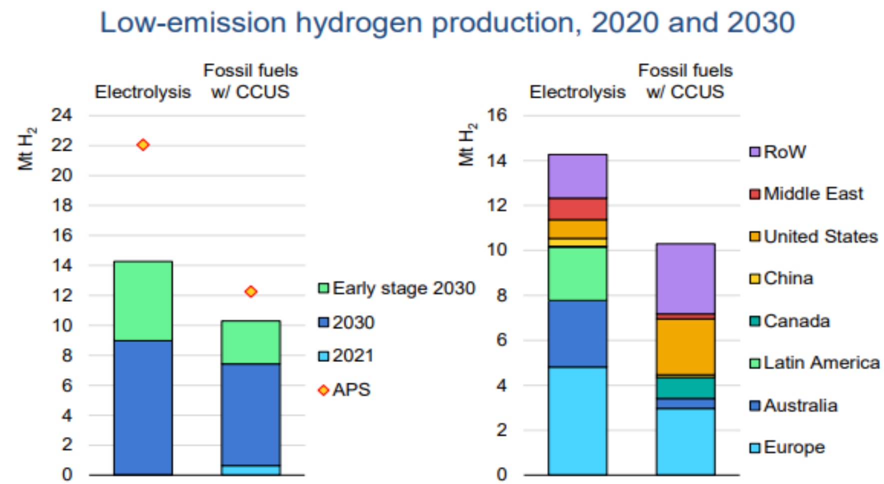


Source: IEA Global Hydrogen Review 2022

- The overwhelming majority of hydrogen produced today is from fossil fuels, responsible for 830MtCO_2/year [IEA, 2022]

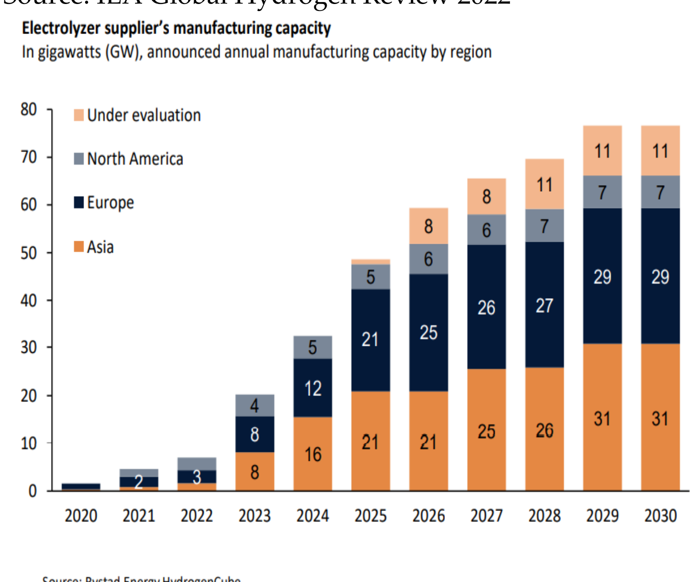
Hydrogen Production and Capacity

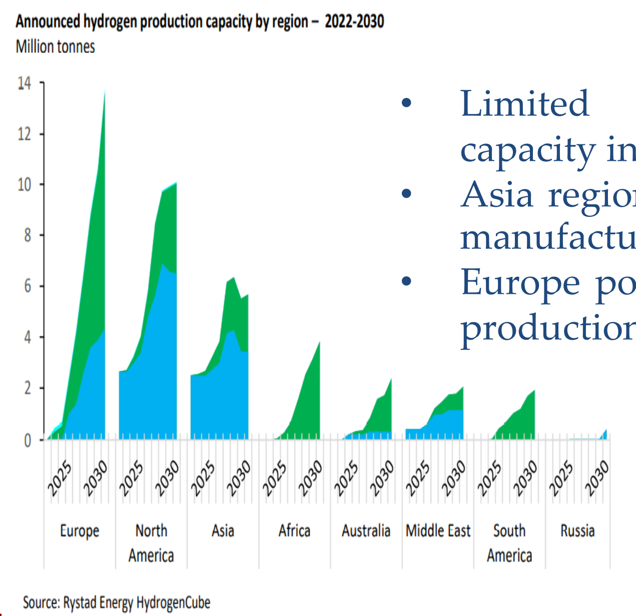




Note: CCUS = carbon capture, utilisation and storage.

Source: IEA Global Hydrogen Review 2022

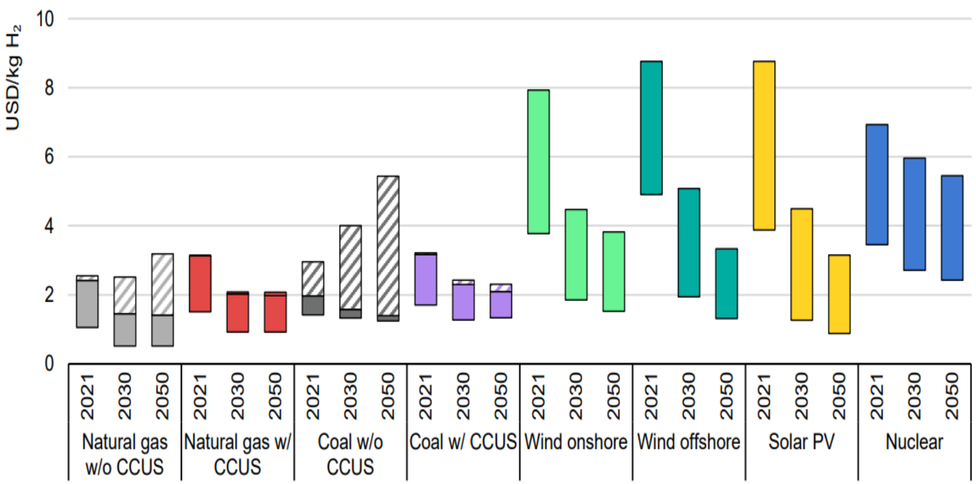




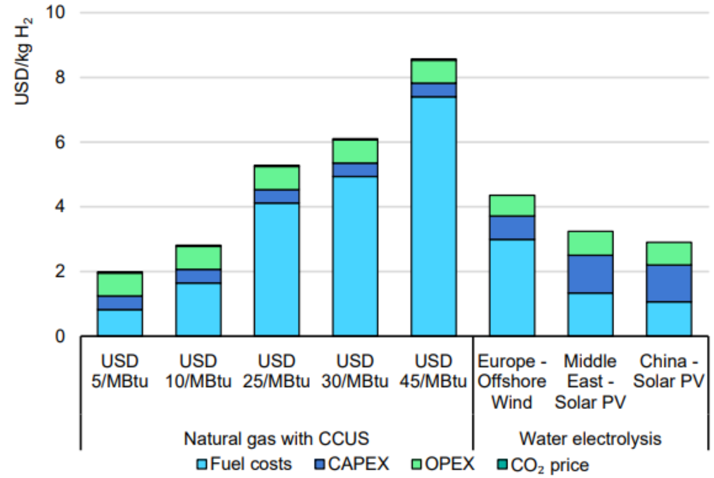
- Limited electrolysis manufacturing capacity in near term
- Asia region has the largest electrolyser manufacturing capacity
- Europe possesses the largest hydrogen production capacity

Hydrogen Production Cost

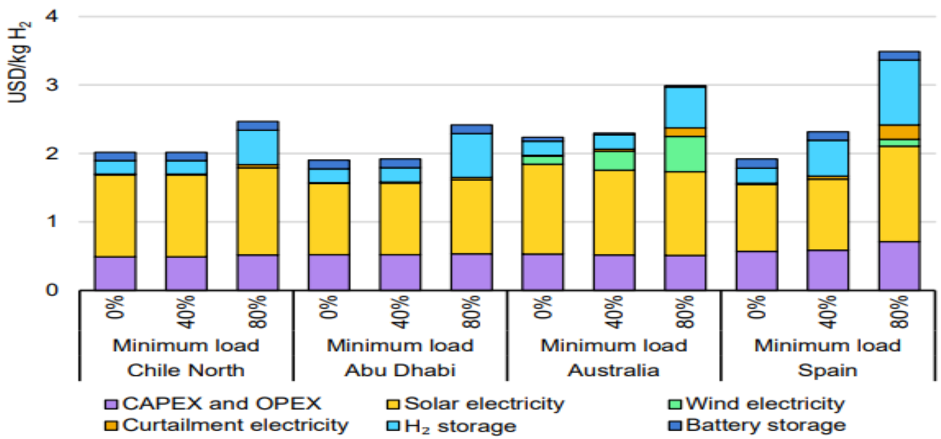
Levelised cost of hydrogen production by technology in 2021 and in the Net Zero Emissions by 2050 Scenario, 2030 and 2050



Levelised hydrogen production costs from natural gas at various gas prices and from renewable electricity, 2022



Levelised hydrogen production costs from solar PV and wind at different locations and minimum load factors, 2030



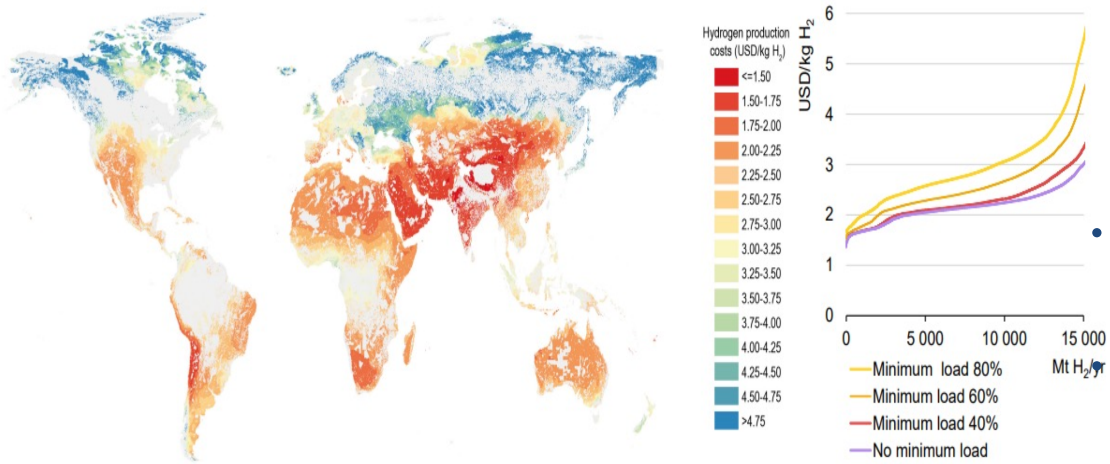
- Lack of cost competitiveness of green hydrogen in short term
- Electrolysis technology is not commercially viable before the mid 2020s [Lazard, 2021]
- Uncertainty about governments' speed in pushing transition to low-carbon sources

Source: IEA Global Hydrogen Review 2022

Green Hydrogen Production Costs

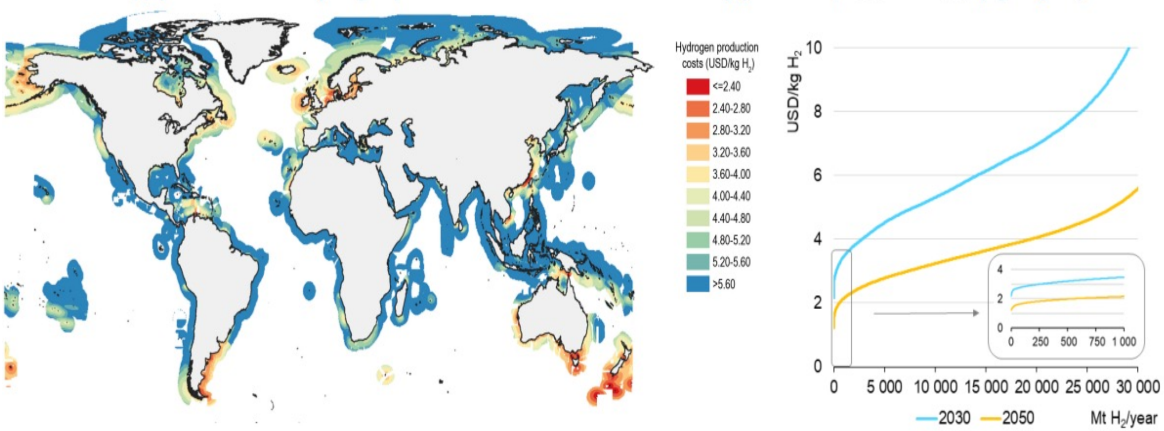
Hydrogen production costs from hybrid solar PV and wind systems for a minimum load of 40%, 2030 (left map)

Global supply cost curves for different minimum load factors (right figure)



Hydrogen production costs from offshore wind in the Net Zero Emissions Scenario, 2030 (left figure)

Supply cost curves for hydrogen production with offshore wind electricity generation, 2030 and 2050 (right figure)

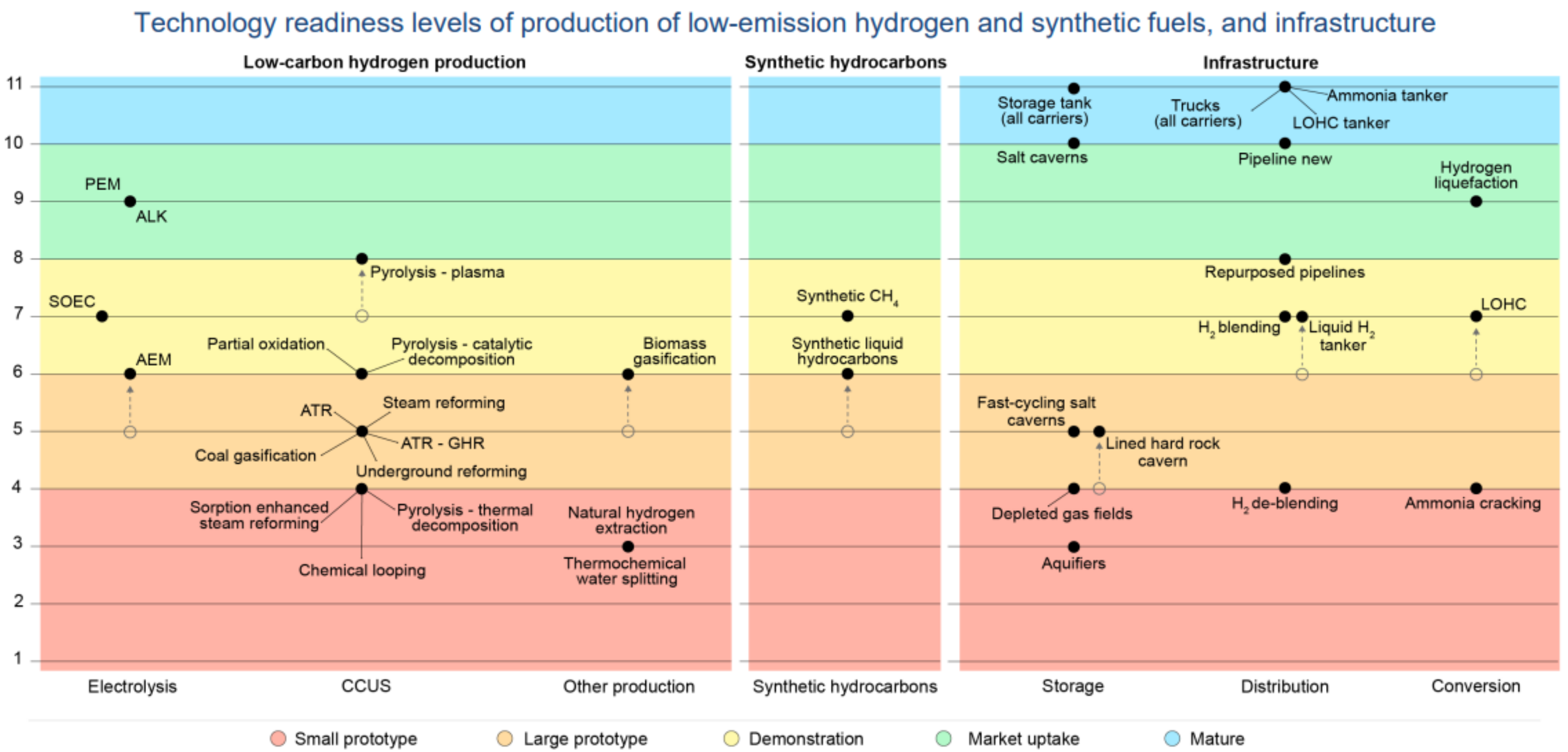


- Significant variations in green hydrogen production costs across the globe

The cost trajectory of renewable energy and availability of excess/low-cost renewables generation will be the key drivers of cost competitiveness of green hydrogen

Source: IEA Global Hydrogen Review 2022

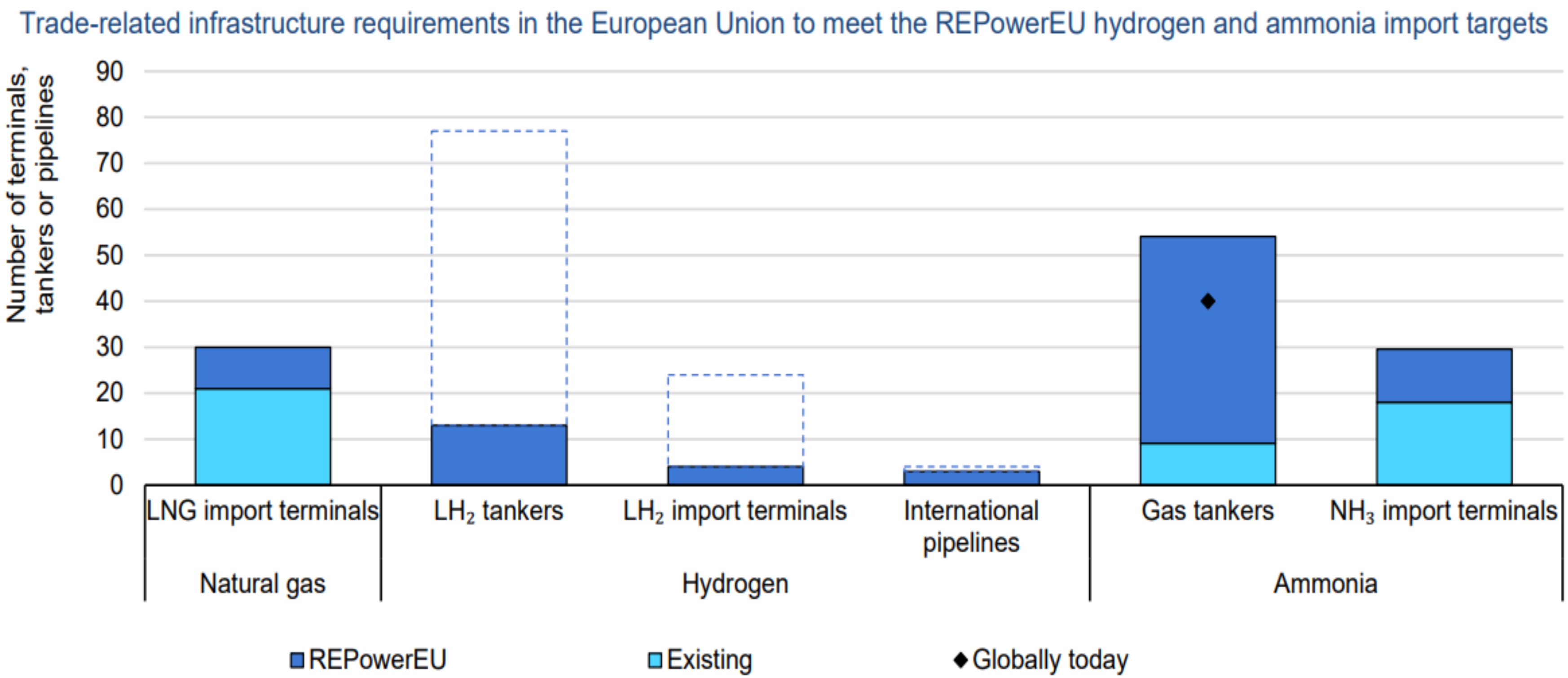
Hydrogen Infrastructure Barriers



Source: IEA Global Hydrogen Review 2022

- Low market uptake of hydrogen technology and infrastructure
- Current pace of infrastructure development is a brake on hydrogen adoption
- Limited ability of governments to commit to large and necessary infrastructure investments
- Refuelling stations need sophisticated storage facilities
- Difficulty of existing gas distribution infrastructure to accommodate pure or blended hydrogen

Hydrogen Infrastructure Gaps



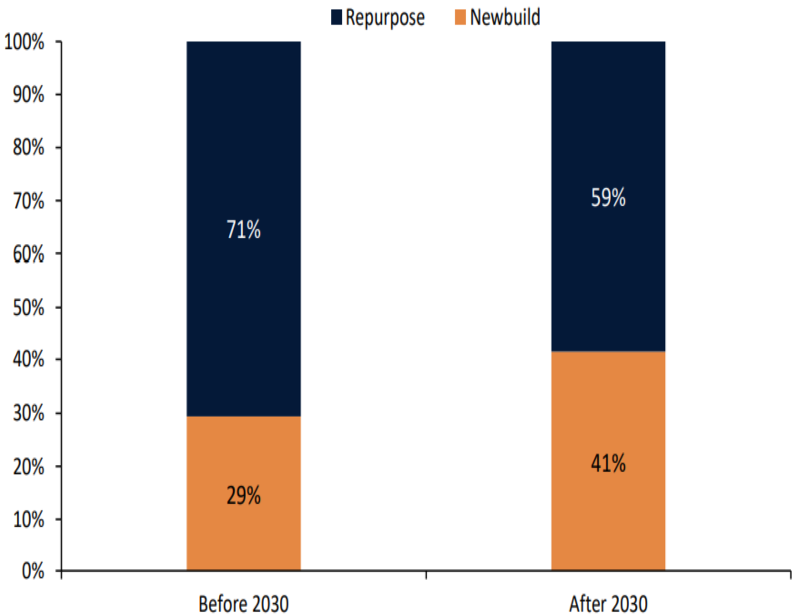
Source: IEA Global Hydrogen Review 2022

- Inadequate infrastructure for hydrogen trade
- International collaboration for these investments is not yet seen for hydrogen
- Non-pipeline transportation (shipping and trucking) is substantially more expensive, but facilitates longer-range and more flexible transportation

Hydrogen Infrastructure Enablers

Announced newbuilt vs repurposed hydrogen pipelines before and after 2030

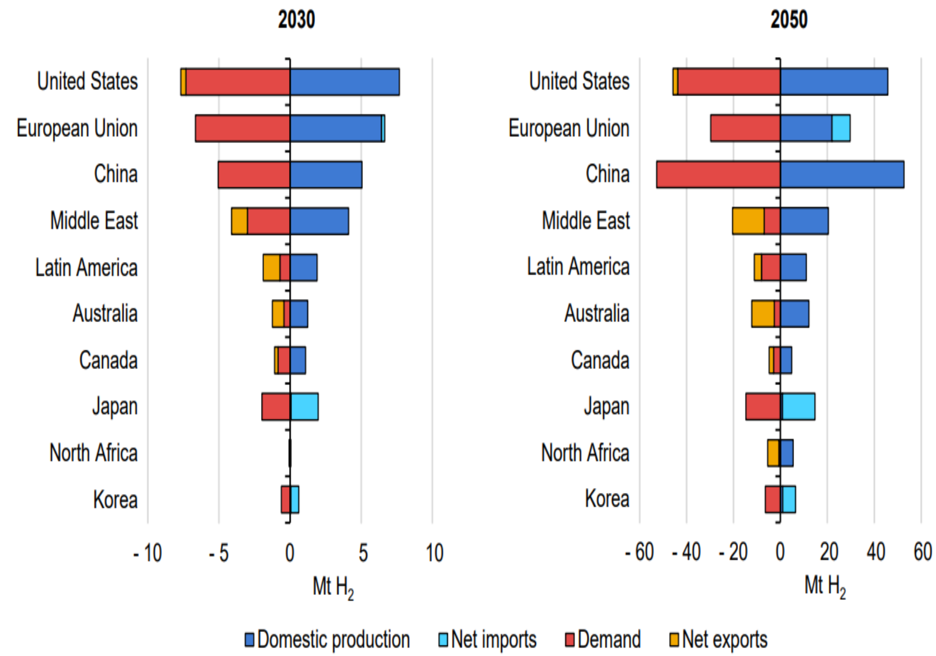
In percentage (%)



Source: Rystad Energy research and analysis

Opportunities to repurpose natural gas infrastructure to facilitate hydrogen trade

Domestic production, imports and exports for low-emission hydrogen in selected regions in the Announced Pledges Scenario, 2030 and 2050

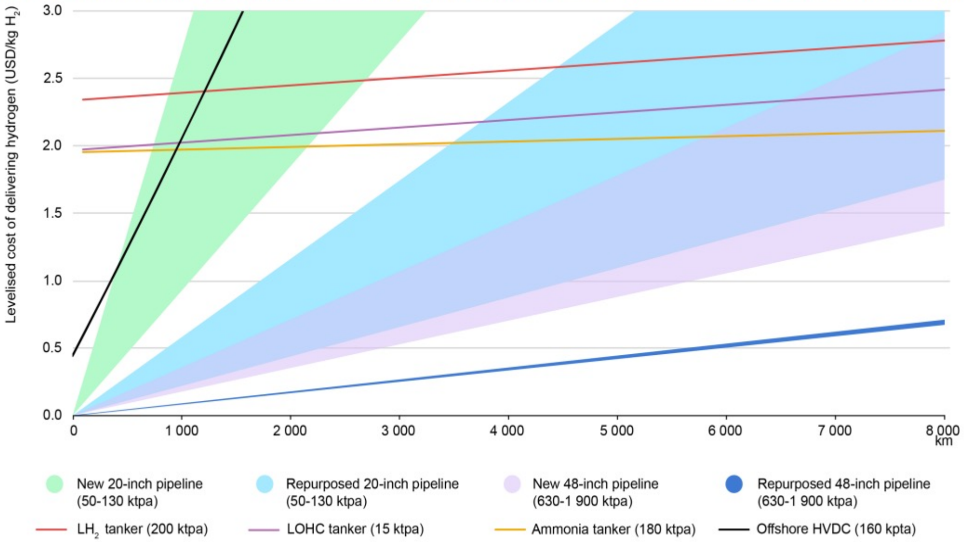


Source: IEA Global Hydrogen Review 2022

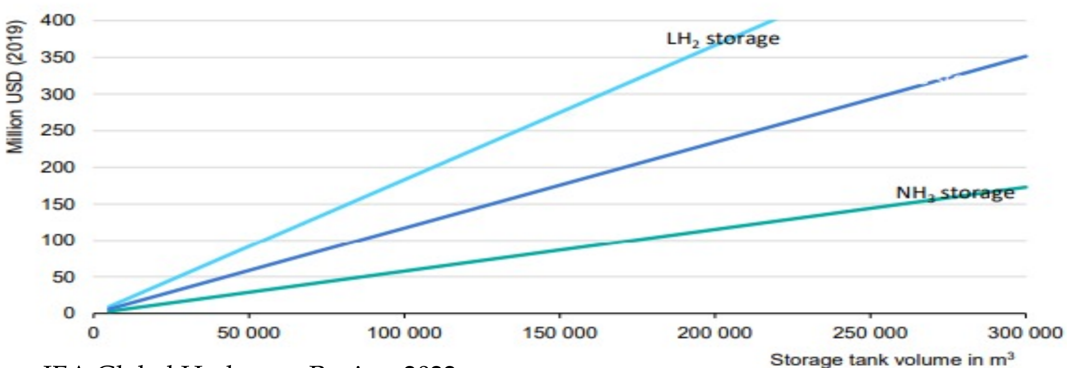
- Opportunities to repurposing existing natural gas infrastructure
- Middle East, Latin America and Australia have the potential of becoming net exporters for low-emission hydrogen in both near and long-terms

Hydrogen Delivery and Storage Issues

Levelised costs of delivering hydrogen by pipeline and by ship as LH_2, LOHC and ammonia carriers, and electricity transmission, 2030



Capital cost of selected storage tanks for LNG, liquefied hydrogen and ammonia



Source: IEA Global Hydrogen Review 2022

- Huge delivery and storage cost of hydrogen
- Cost of transportation, conversion, infrastructure and end-use upgrade will influence the cost structure of green hydrogen against alternative fuels

Enablers of Hydrogen Development

- Synchronise investments and policies in scale and time
- Design public-private investment models to address hydrogen infrastructure gaps
- Leverage existing gas infrastructure to boost low carbon hydrogen supply
- Establish long-term signals to foster investor confidence
- Support revenue from low-carbon hydrogen projects in near term
- Establish new contractual relationship to build trust for well-coordinated value-chain investments
- Create industrial hubs to bring down the cost of low-carbon hydrogen pathways
- Start soon on international hydrogen trade to make an impact on global energy system

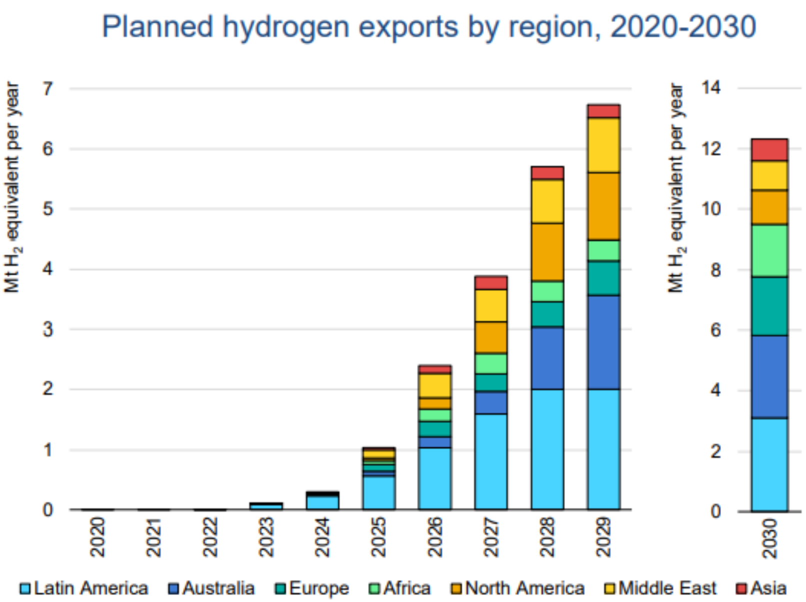
Enablers at Global, Regional and National Levels

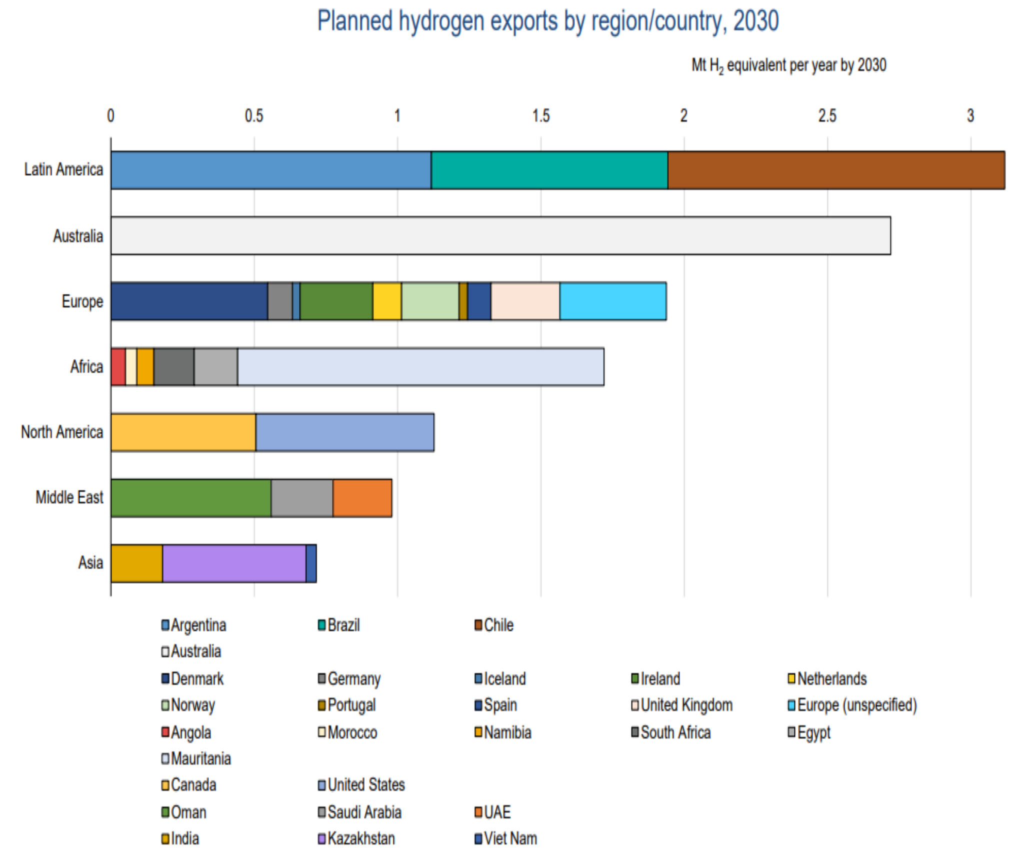
- **At the global level:**
  - strong and coordinated climate action;
  - help market develop and better match supply and demand in immediate term;
  - mobilise public and private financing to de-risk investment, increase the number and volume of projects; and support infrastructure development;
  - develop cross-border infrastructure;
  - share good practices in installations, policies, finance mechanisms etc

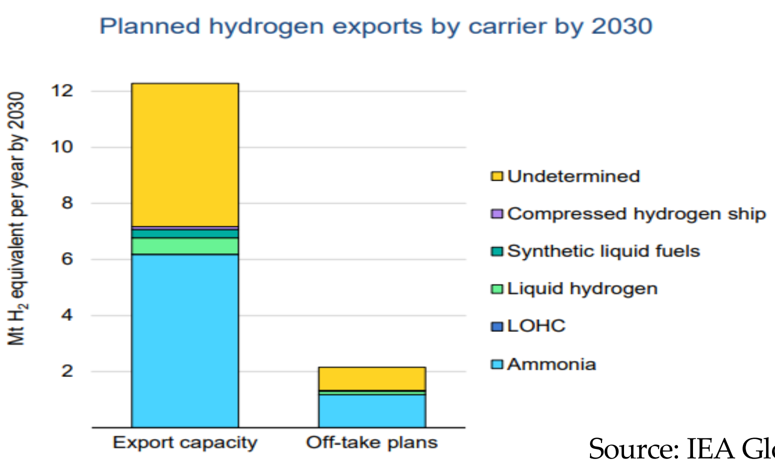
- **At the regional level:**
  - In EU: eliminate regulatory obstacles
  - In other regions, better identify and build on individual national strengths to work towards an integrated low-carbon hydrogen energy system

- **At the national level:**
  - have a well defined national strategy which includes plans for market development, targets to provide long-term visibility, regulatory priorities to unlock low-carbon hydrogen potential;
  - economic and financial incentives in form of carbon pricing, blending quotas, and low-carbon fuel credits;
  - implementation of published strategies; national support schemes for the development of hydrogen hubs to facilitate the creation of local demand and supply in concert

Potential Hydrogen Export by Regions/Countries





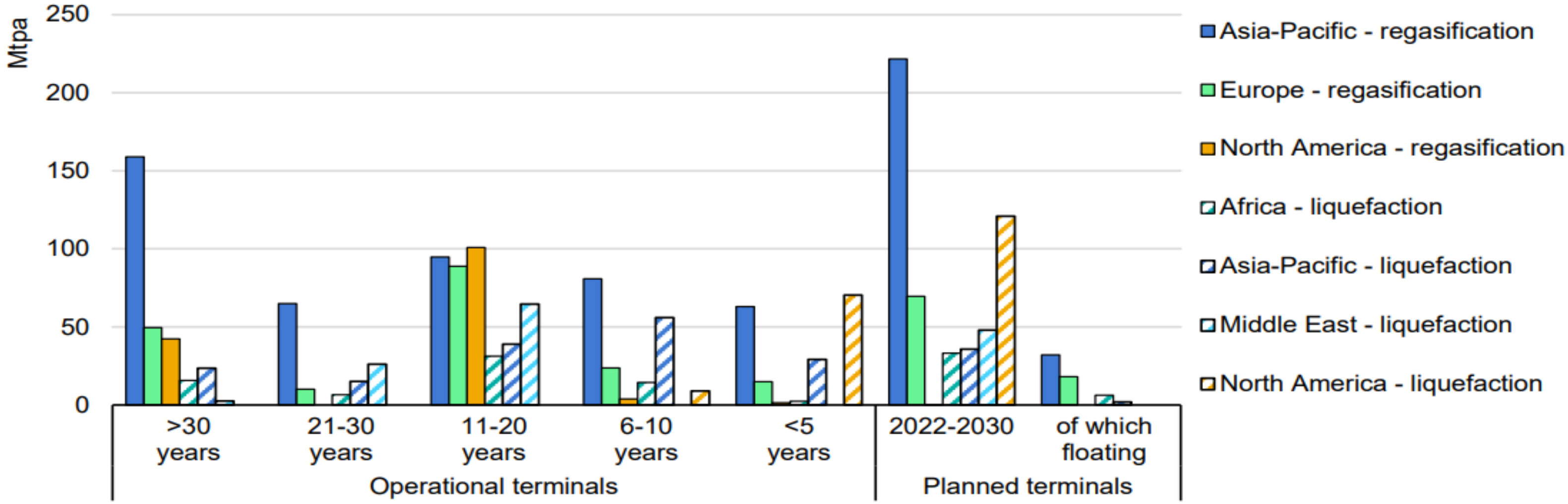


Source: IEA Global Hydrogen Review 2022

Infrastructure Enablers

Design and construction of new LNG facilities should aim to be hydrogen-ready to reduce risks of stranded assets and to boost energy security

Operational and planned LNG terminal capacity by type, region and age

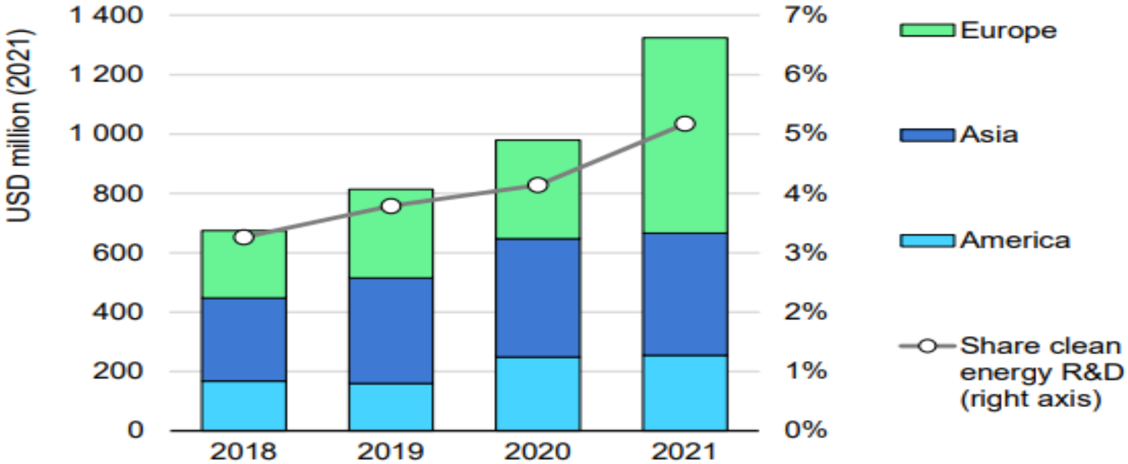


Notes: Mtpa = million tonnes per year. The age of operational terminals is as of 2022. Planned terminals include facilities under construction and announced with a disclosed start year for operation.
Source: IEA analysis based on Global Gas Infrastructure Tracker.
Source: IEA Global Hydrogen Review 2022

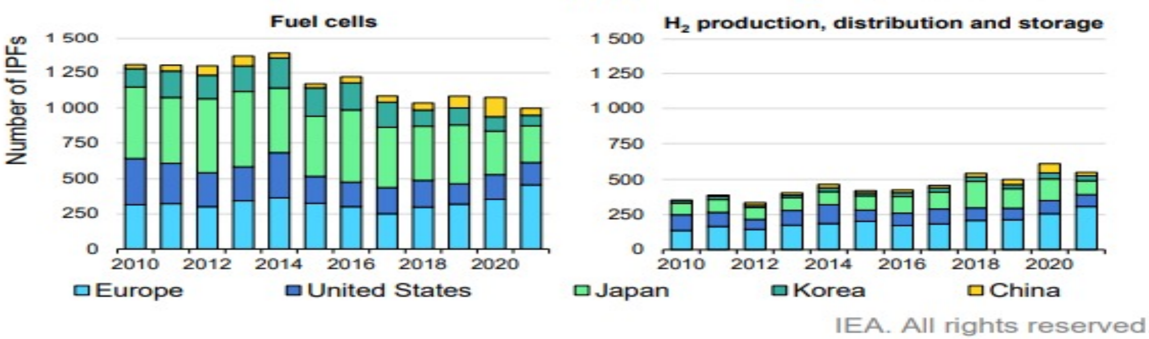
- Leverage on new LNG facilities to support hydrogen deployment
- Potential regasification in the Asia-Pacific region is relatively high compared to Europe and Latin America

Global Hydrogen Policy and Co-operative Ecosystem

Government RD&D spending for hydrogen technologies by region, 2018-2021



International patent families by type and region, 2010-2021



Note: IPFs = international patent families.
Source: Based on European Patent Office data. Fuel cells match patent category Y02E60/50-56H, H_2 production matches Y02E60/36 (B-F2), H2 distribution Y02E60/34 and H_2 storage Y02E60/32 (B-F6).

Source: IEA Global Hydrogen Review 2022

- Europe led the world in providing R&D support for hydrogen technologies in 2021
- Japan historically dominates the fuel cell innovation
- While Europe leads innovation in hydrogen production, distribution and storage

Policy Measures to de-risk hydrogen projects

Country	Description of Policy measures
Australia	Grant: US$ 349 million to roll-out Hydrogen Industrial Hubs
Canada	Grants: Clean Fuels Fund of US$112 million to new clean fuels production capacity; Zero Emissions Vehicles programmes (US$ 1.3 billion) to provide purchase incentives for zero emission medium-and heavy-duty vehicles; Net Zero Accelerator of US$6.3 billion to support low-emission hydrogen in heavy industry. Tax incentives: Accelerated capital cost allowance for renewable hydrogen production equipment; Investment tax credit for green hydrogen ; 50% tax cut for hydrogen production
France	**Public calls for tenders of Euro 100 million investment**: to decarbonise the industry and develop hydrogen mobility; Euro 7.2 billion Investments for the next decade (in Hydrogen Strategy): for hydrogen mobility ecosystems (that support the development of range of heavy vehicles) and decarbonated hydrogen production for industry (to reduce carbon hydrogen and support a competitive approach for the industrial sector)
Germany	Grants: US$414 million grant programme to support international hydrogen production. Tax incentives: Exempting electrolysis hydrogen production from the green power levy
United Kingdom	Grants: Net Zero Hydrogen Fund of US$ 300 million to support projects' capital expenditure; Industrial Energy Transformation Fund of US$75 million for feasibility studies and deployment of clean technology projects including hydrogen in industry
United States	Grants: Clean Hydrogen Electrolysis Program (US$1 billion) to reduce production costs; US$0.5billion grant for manufacturing and recycling of clean hydrogen technologies ; INFRA and RAISE grants to support hydrogen vehicle infrastructure. Tax incentives: Hydrogen Production Tax Credit: incentivise the domestic production of clean hydrogen to meet the ambitious goals of the Hydrogen Shot

Source: Excerpted from IEA Global Hydrogen Review 2022 & McKinsey 2022

Government Support Programmes for Hydrogen

Country	Programme Description
Germany	**Hydrogen Flagship Projects** (US$828 million): For electrolyser manufacturing, offshore hydrogen production and hydrogen transport; **National Innovation Programme & Hydrogen and Fuel Cell Technology** (US$422 million): to support market activation; **Regulatory Sandboxes for the Energy Transition** (US$198 million): for large-scale demonstration projects of hydrogen and sector decoupling
France	Hydrogen Research and Development (Euro 65 million); Hydrogen Education (Euro 30 million); the establishment of a Guarantee of Origin System for Hydrogen; Technological Bricks and Demonstrators (Euro 350 million): to develop innovation work in the hydrogen value chains; Territorial Hydrogen Hubs (Euro 275 million): to develop an economic model of hydrogen at the scale of a local territory and demonstrate the environmental benefits of hydrogen
United Kingdom	**Low Carbon Hydrogen Supply 2** (US$75 million): to develop a wide range of innovative low-carbon hydrogen supply solutions; **Industrial Hydrogen Accelerator** (US$ 33 million): to accelerate the commercialisation of innovative hydrogen technologies; **Industrial Fuel Switching** (US$75 million): to support fuel switching technologies in industry including hydrogen; **Clean Maritime Demonstration Competition** (US$48 million): to support the design and development of zero emission vessel technologies and greener ports (with use of hydrogen); **Long-Duration Energy Storage Demonstration Competition** (around £66 million): to store hydrogen produced from excess electricity; **Red Diesel Replacement Competition** (£40 million): to fund the development and demonstration of innovative technologies to switch from red diesel to hydrogen or other low carbon fuels
United States	**Bipartisan Infrastructure Law -R&D Funding Provisions** (US$1.5billion): For electrolysis and manufacturing clean hydrogen technologies; **Inflation Reduction Act** (about US$13 billion): to support hydrogen industry

Source: Excerpted from IEA Global Hydrogen Review 2022; BEIS UK Hydrogen Strategy 2021; McKinsey 2022; US Whitehouse Inflation Reduction Act Guidebook 2022

Local Opposition

HyNot

Reflections on Possible Futures for Hydrogen

- There is large uncertainty, however, in several key sectors, decarbonisation and hence net zero is very difficult without a role for hydrogen
- In the short to medium term, rollout of blue hydrogen can help enable the development of green hydrogen in the longer term by earlier development of infrastructure and business models. Decisions to exclude blue hydrogen may impact medium term deployment of green hydrogen (Mac Dowell et al, 2022)
- Creation of suitable framework needed to address conflicting views that create complexity for hydrogen projects and discourages investment
- Distribution costs (storage and infrastructure) for hydrogen are likely to be substantial and could limit growth
- Carbon prices or incentives will be needed to make cost of green hydrogen competitive with fossil fuel alternatives
- Green hydrogen production price is expected to decline due to falling renewable electricity costs, technological developments and economies of scale
- The infrastructure for large scale hydrogen use is expected to take many years (12+ years based on gas infrastructure) to develop so focus on industrial clusters
- Growing hydrogen demand in parallel with infrastructure is expected by 2030 with stronger demand after 2030 in line with the time required to develop infrastructure
- It is not clear if the 'optimistic' view for an expansive role for hydrogen might ultimately undermine the development of hydrogen in its core areas (e.g., HyNot and hydrogen villages)

Thanks!

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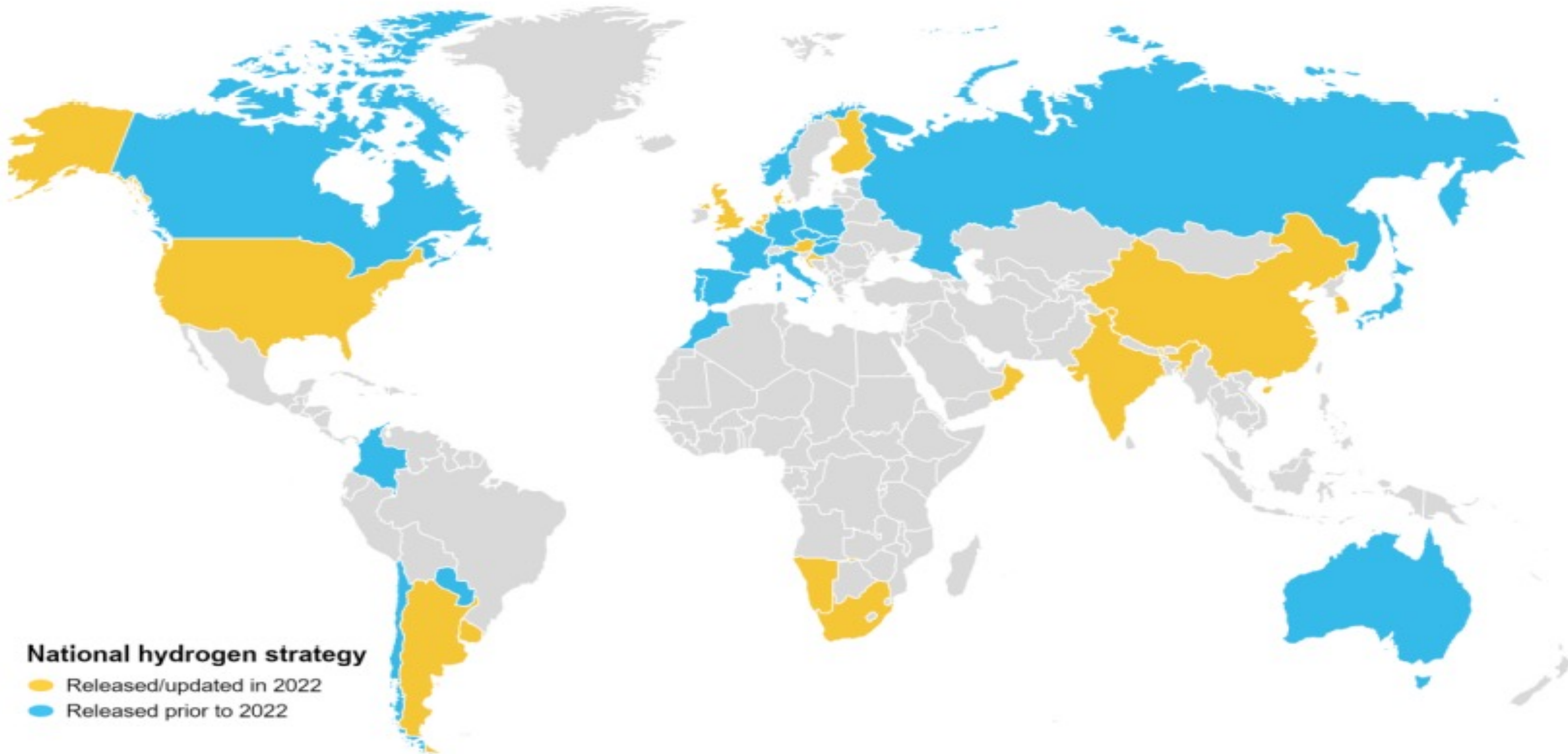
Thanks!

Hydrogen Strategy Adoption

17 countries released a new hydrogen strategy in 2022



Note: Belgium, China, Netherlands, South Korea and UK updated strategy in 2022
Source: Rystad Energy research and analysis

UK Hydrogen Strategy: Commitment Plans

- Create appropriate regulatory changes across the hydrogen value chain
- Incorporate the potential role of hydrogen into wider future energy regulatory and policy changes
- Establish a Hydrogen Regulators Form with representation across environmental, safety, markets, competition and planning areas
- Ensure appropriate synergy between hydrogen and broader governance and regulatory changes
- Improve visibility of low-carbon hydrogen project pipeline across the supply chain
- £1bn Net Zero Innovation Portfolio to support hydrogen innovation
- Public-Private Sector engagement to provide further incentives for investment into hydrogen R&I in the UK
- Develop a hydrogen technology R&I roadmap to inform stakeholders R&1 investment and prioritisation
- Active international engagement and research sharing (through IEA Hydogen Technology Collaboration Programme (Hydrogen TCP) to accelerate Hydrogen R&I progress and maximise its benefits
- Facilitate greater coordination and progress across international hydrogen innovation, deployment and policy activity
- Develop metrics to monitor progress

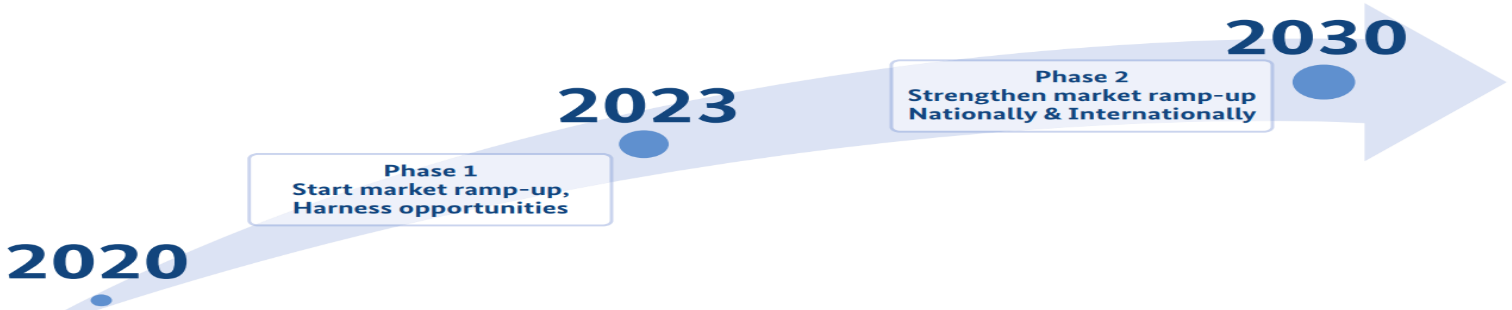
Source: BEIS UK Hydrogen Strategy 2021

US Inflation Reduction Act

	Description of Policy measures
Zero-emission Nuclear Power Production Credit	• For electricity produced at a qualified nuclear power facility and applicable to electricity sold after the end of 2023 (0.3 cents/kWh inflation adjusted) • Rural Energy for America Program (REAP) grant of US$1.7billon: include hydrogen production; Alternative Fuel Vehicle Refueling Property Credit: include tax credit for hydrogen fuel in low-income and rural areas; Domestic Manufacturing Conversion Grants: to provide cost-shared grants for domestic production of efficient hybrid, plug-in hybrid, plug-in electric drive and hydrogen fuel cell vehicles
Clean Electricity Production Tax Credit	• Provides a technology-neutral tax credit for production of clean electricity • This replaces the production tax credit for electricity from renewables • Energy Loan Program of US$ billion: to support the cost of loans for innovative clean energy technologies • Hydrogen Production Tax Credit: to incentivise the domestic production of clean hydrogen to meet the ambitious goals of the Hydrogen Shot which is launched by the DOE to accelerate breakthroughs in hydrogen technology and cut the cost of clean hydrogen by 80% to U$1 per kilogram in one decade
Clean Electricity Investment Tax Credit	• Technology-neutral tax credit for investment in facilities that generate clean electricity(include qualified energy storage technologies): 6% investment basis • Grants: Greenhouse Gas Reduction Fund (up to US$27billion): For clean energy and climate projects that reduce greenhouse gas emissions to benefit low-income and disadvantaged communities

Source: Excerpted from US Whitehouse Inflation Reduction Act Guidebook 2022

Germany Hydrogen Strategy: Action Plans to success



Measure 1

- Better framework for the efficient use of electricity from renewables;
- A fair design of the energy price components in line with the climate targets and the energy transition targets to create greater scope for the production of green hydrogen
- Introduction of carbon pricing for fossil fuels used in transport and heating sectors
- Exempting electricity used for the production of green hydrogen from taxes, levies, and EEG surcharges

Measure 2

- Exploring possibilities for new business and cooperation models for operators of electrolysers, and grid network operators in line with the principle of regulatory unbundling

Measure 3

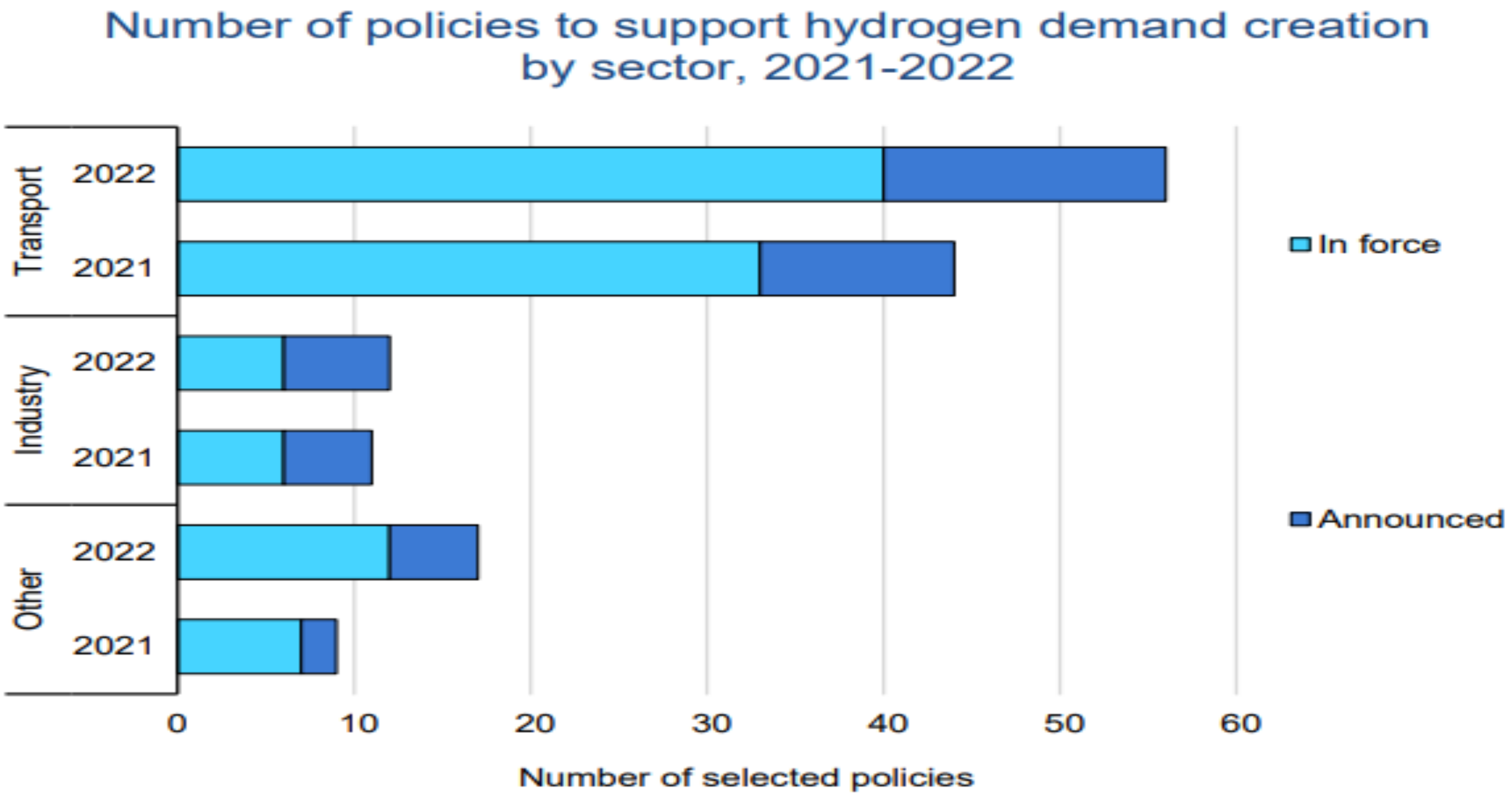
- Supporting switchover to hydrogen in the industrial sector by providing funding for investment in electrolysers
- Exploring potential tendering schemes for the production of green hydrogen

Measure 4

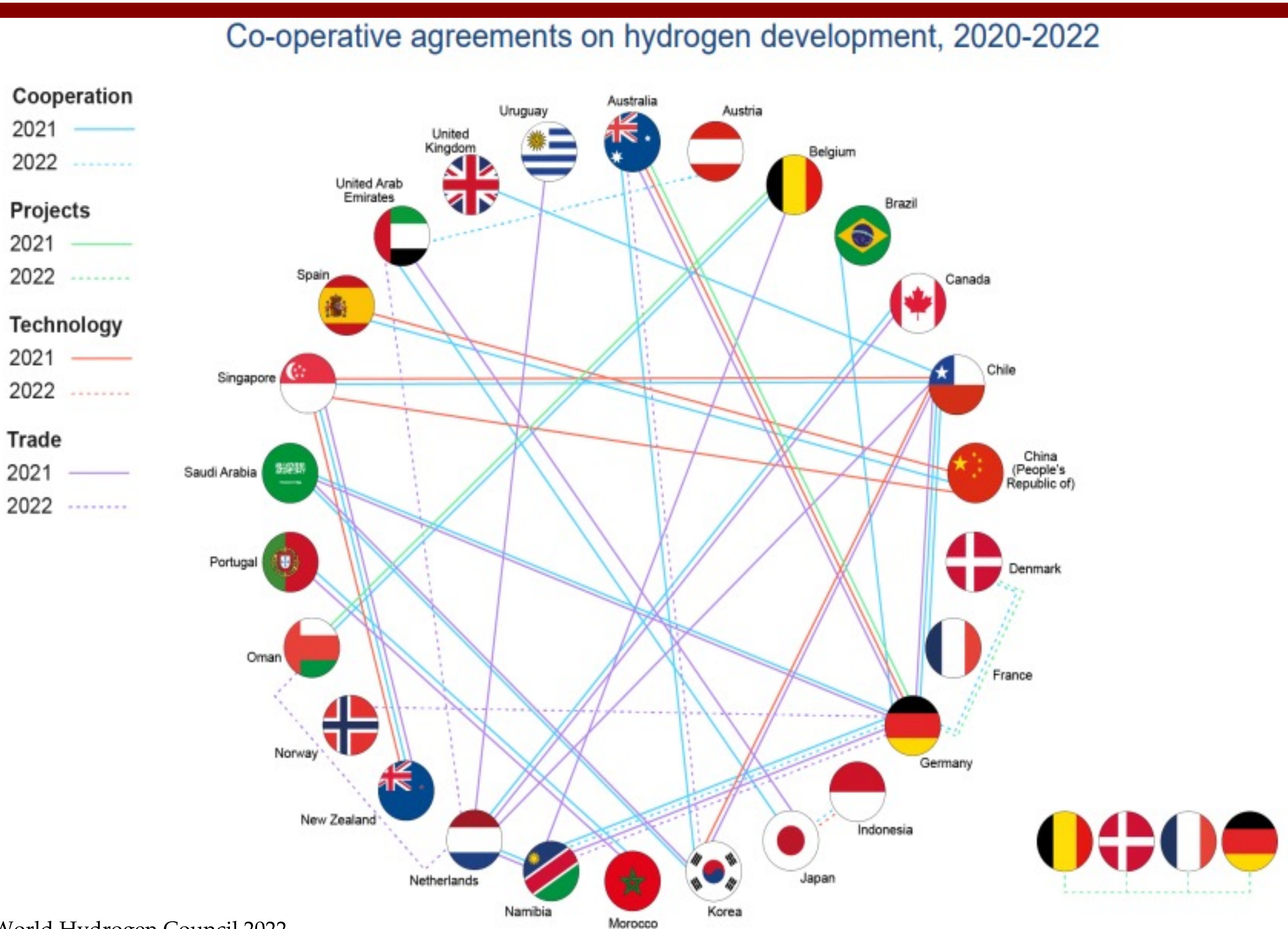
- Developing further the framework that adjusts offshore production of hydrogen/PtX and necessary infrastructure to ensure that investments in offshore wind pay off

Source: Excerpted from the German Federal Government Hydrogen Strategy 2020

Measures to stimulate hydrogen demand

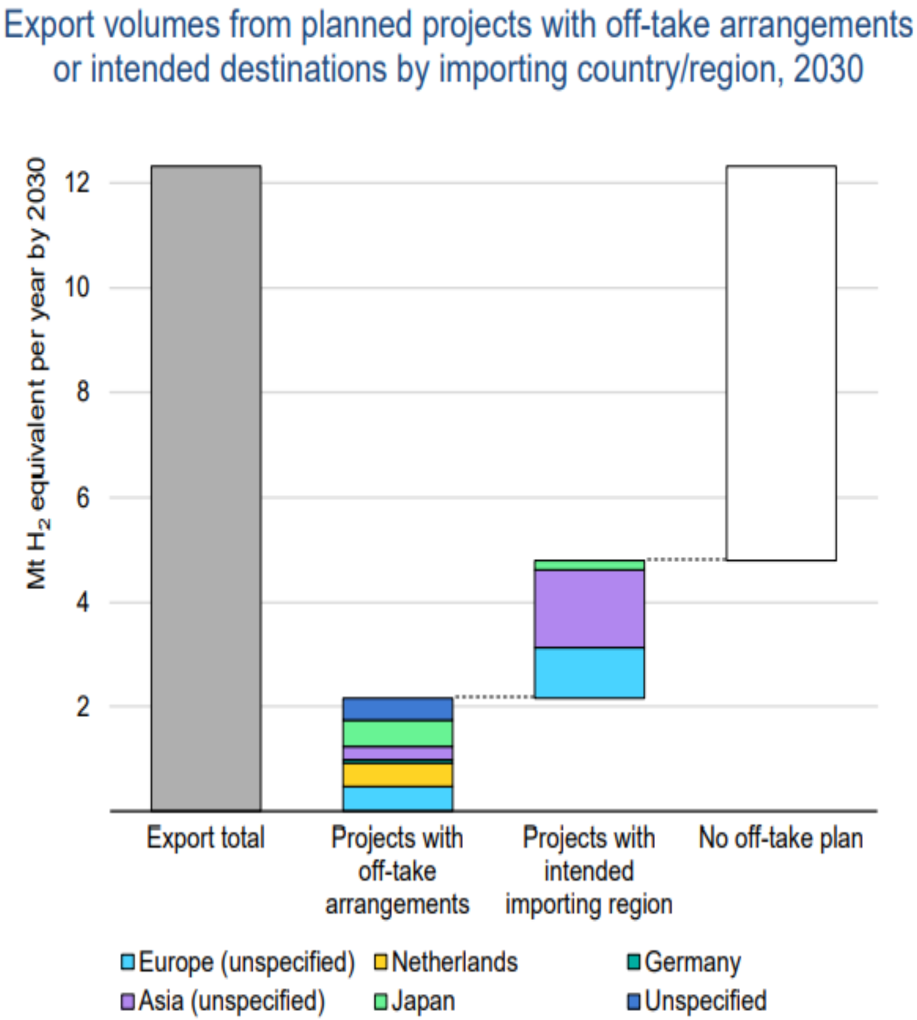


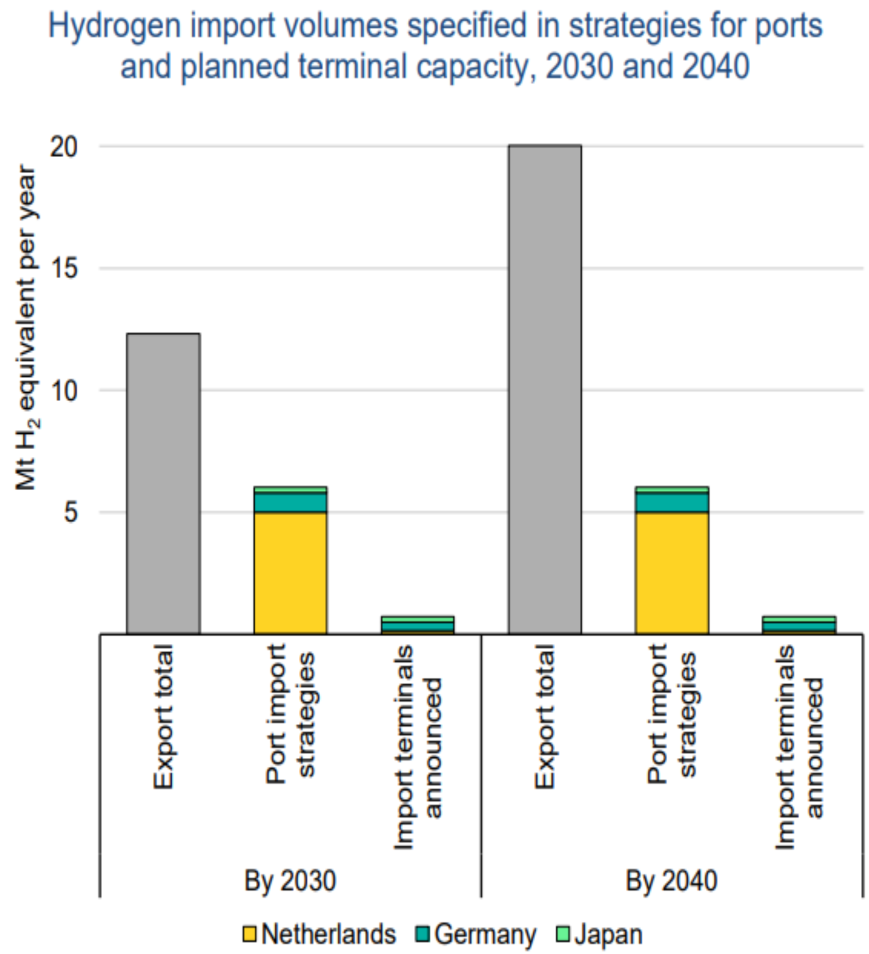
International Collaboration on Hydrogen Development



Source: World Hydrogen Council 2022

Potential Hydrogen Trade Volume



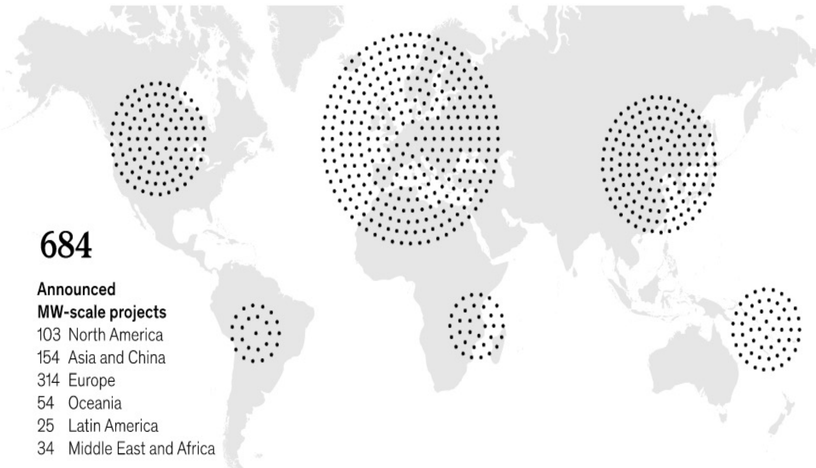


Source: IEA Global Hydrogen Review 2022

Regional Hydrogen Projects

More than 680 large-scale hydrogen projects have been announced globally, with a focus on production, industrial usage, transport, and infrastructure.

684 announced megawatt-scale projects[1]



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Gigascale production Renewable H_2 projects >1 gigawatt, low-carbon H_2 projects >200 kilotons per annum

332

Large-scale industrial usage Refinery, ammonia, methanol, steel, and industry feedstock

78

Integrated H_2 economy Cross-industry and projects with different types of end uses

150

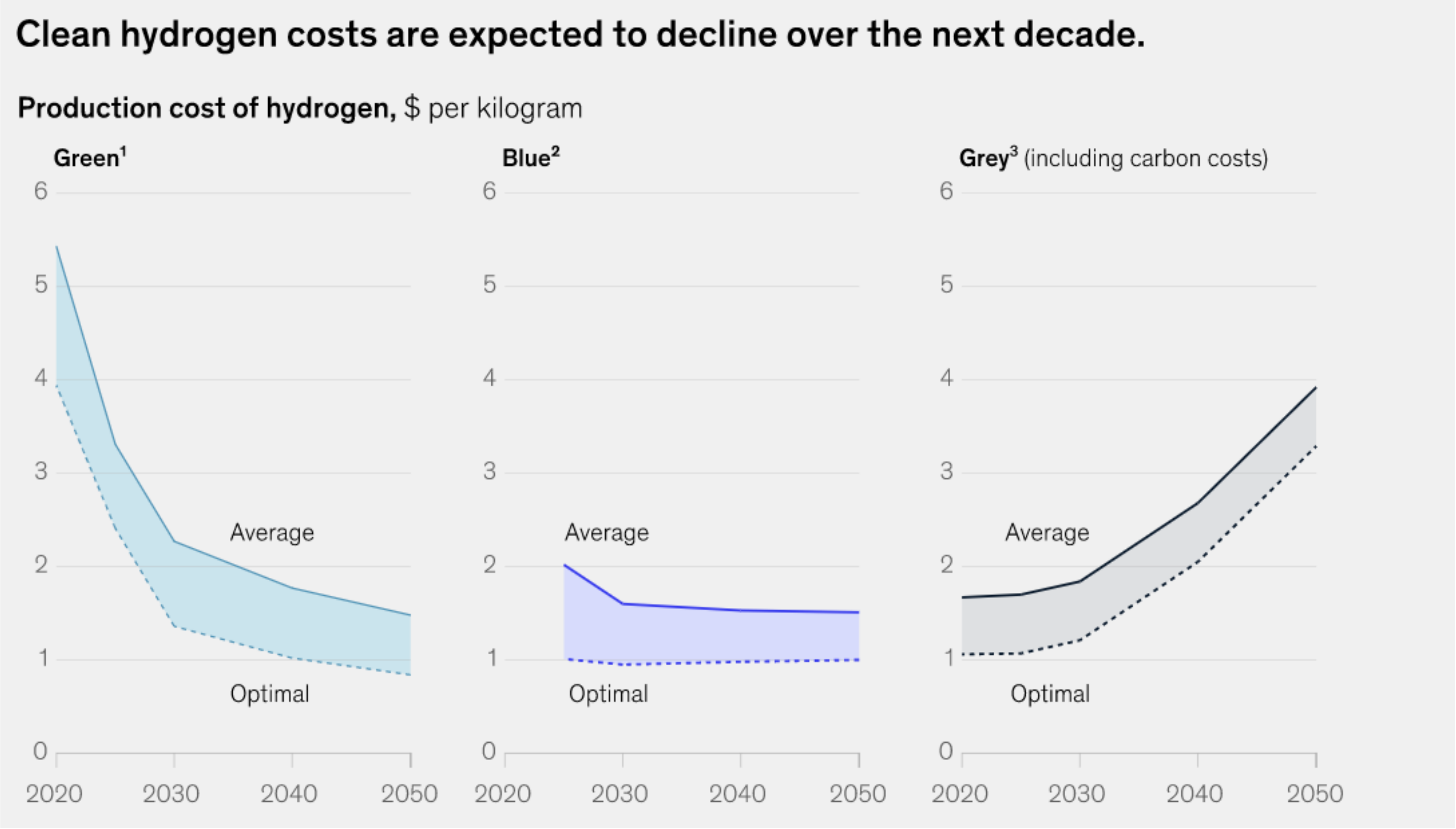
Transport Trains, ships, trucks, cars, and other hydrogen mobility applications

63

Infrastructure projects[2] H_2 distribution, transportation, conversion, and storage

Source: McKinsey Hydrogen Insights 2022

Anticipated Hydrogen Costs

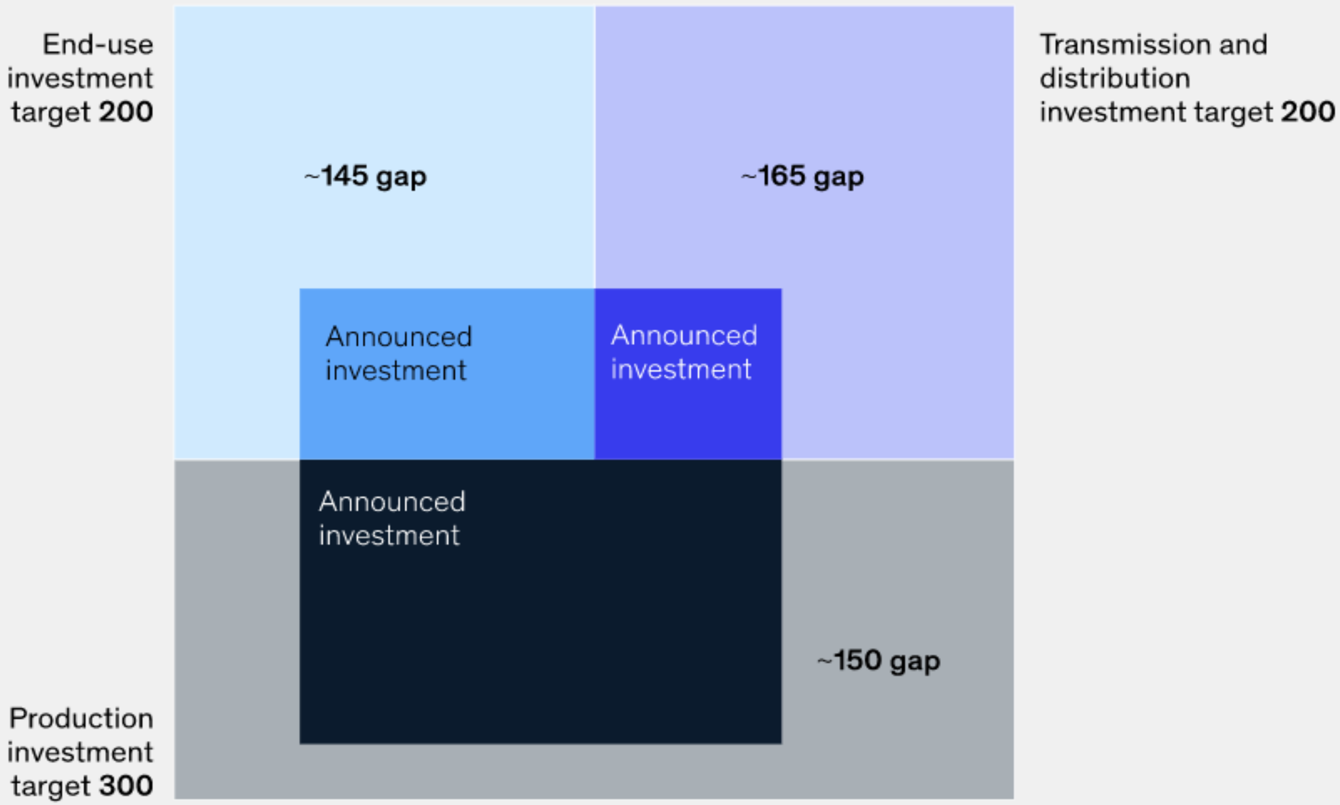


Source: McKinsey Hydrogen Insights 2022

Hydrogen Investment Gaps

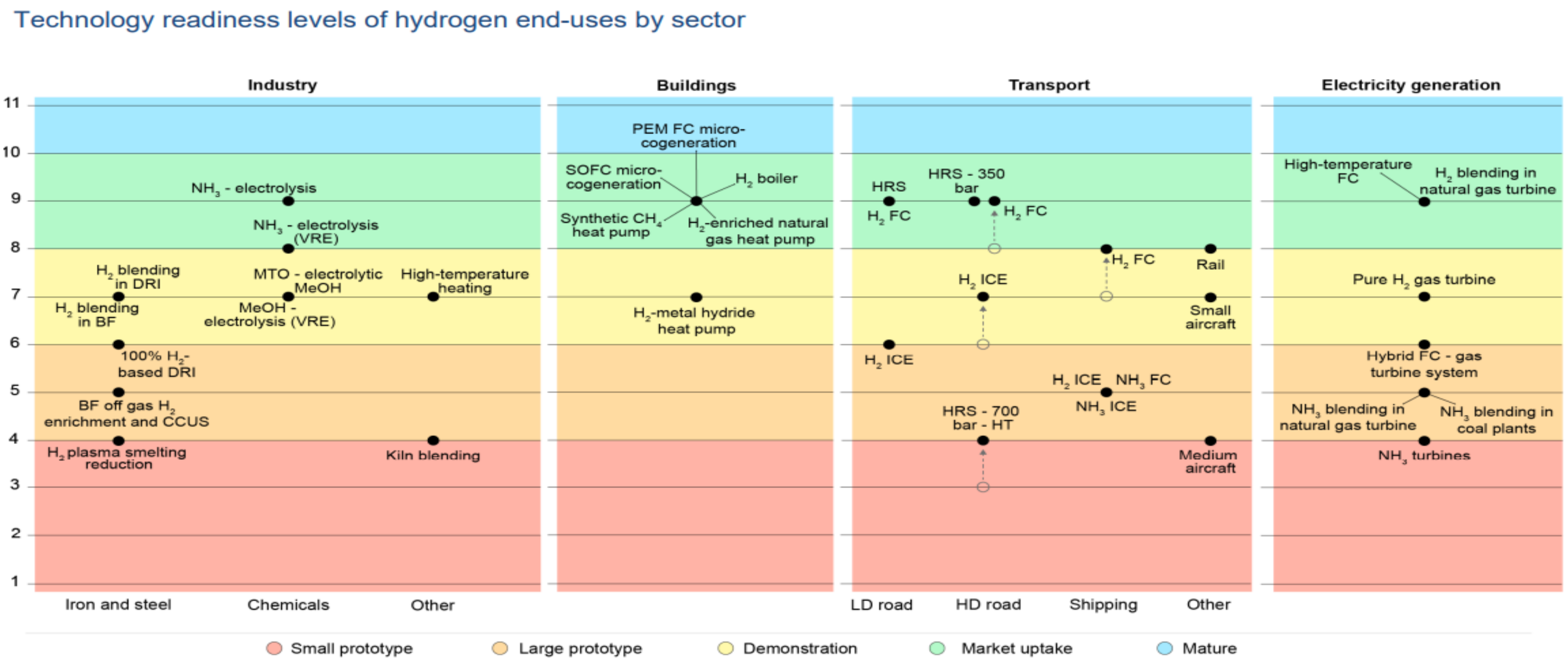
An investment gap of roughly $460 billion remains across the hydrogen value chain.

Announced and required direct investments into hydrogen until 2030, $ billion



Source: McKinsey Hydrogen Insights 2022

Hydrogen Application by Sector



Source: IEA Global Hydrogen Review 2022

- Most low-carbon hydrogen applications are not cost-competitive without direct government support
- Scaling up end-use hydrogen technologies is needed
- Hydrogen-related technologies (fuel cells, water electrolysers, hydrogen refuelling and hydrogen turbines) wait for large-scale demand and standardisation
- Current prices of green hydrogen and related-uses are not competitive