King Abdullah University of Science and Technology (KAUST)

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Opportunities for collaboration between governments and their role in hydrogen developments

Dec 6th, 2022

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Executive Director
Hydrogen Council

Hydrogen Council

Hydrogen Council Members as of June 2022

Steering members

Supporting members

Investors

Same Hydrogen Different Place – Currently 90 MMT

Industrial Gas

- Captive markets
- Behind the fence
- Private ownership
- Industrial Customer
- Traditional Markets
- High user competence
- Long history of practice
- Mostly fossil origin
- Traditional built environment fire & building codes; installation codes, pressure vessel codes

Hydrogen Energy

- Public domain
- Outside the fence
- Public project proponent
- Public Customer
- Residential sector
- Public risk profile
- New users / markets
- Energy markets / utility integration
- Environmental / Sustainability attributes

Implications:

- Mega growth
- Maturing International Standards
- Global Tech Regulations
- Extension
- Regulation of new applications space
- Sustainability agenda

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There is no climate solution without Hydrogen

The contribution at 22% of final energy use by 2050 is too substantial to miss

22%

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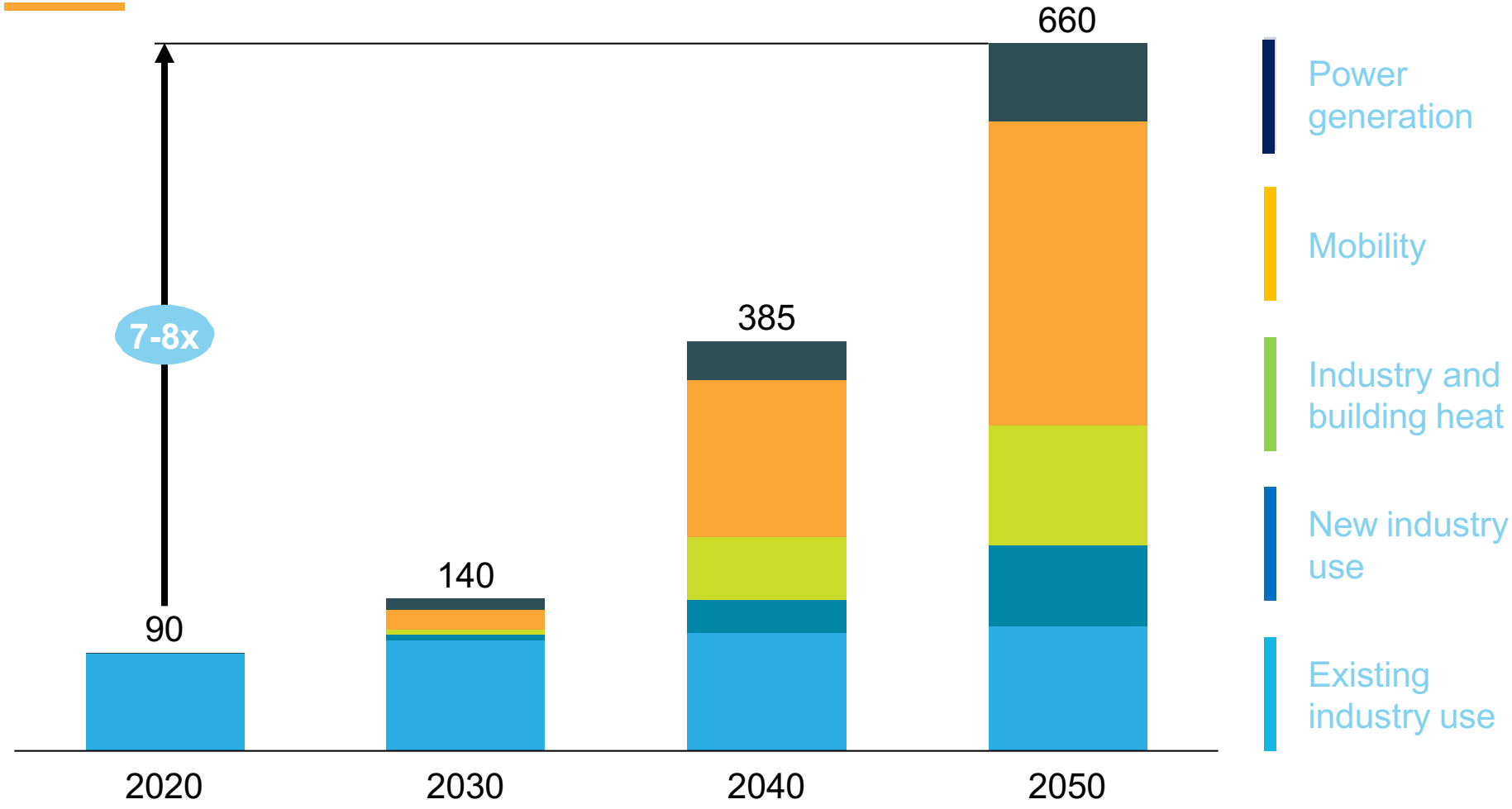
Hydrogen is essential to achieve net-zero long-term

- Hydrogen end-use demand by segment, MT H_2 p.a.



22%

of global final energy demand[1]

660 MT

hydrogen required p.a. in 2050 for net-zero

1. IEA net-zero scenario with 340 EJ final energy demand in 2050. HHV assumed. Excluding power.

Source: IEA Net Zero by 2050

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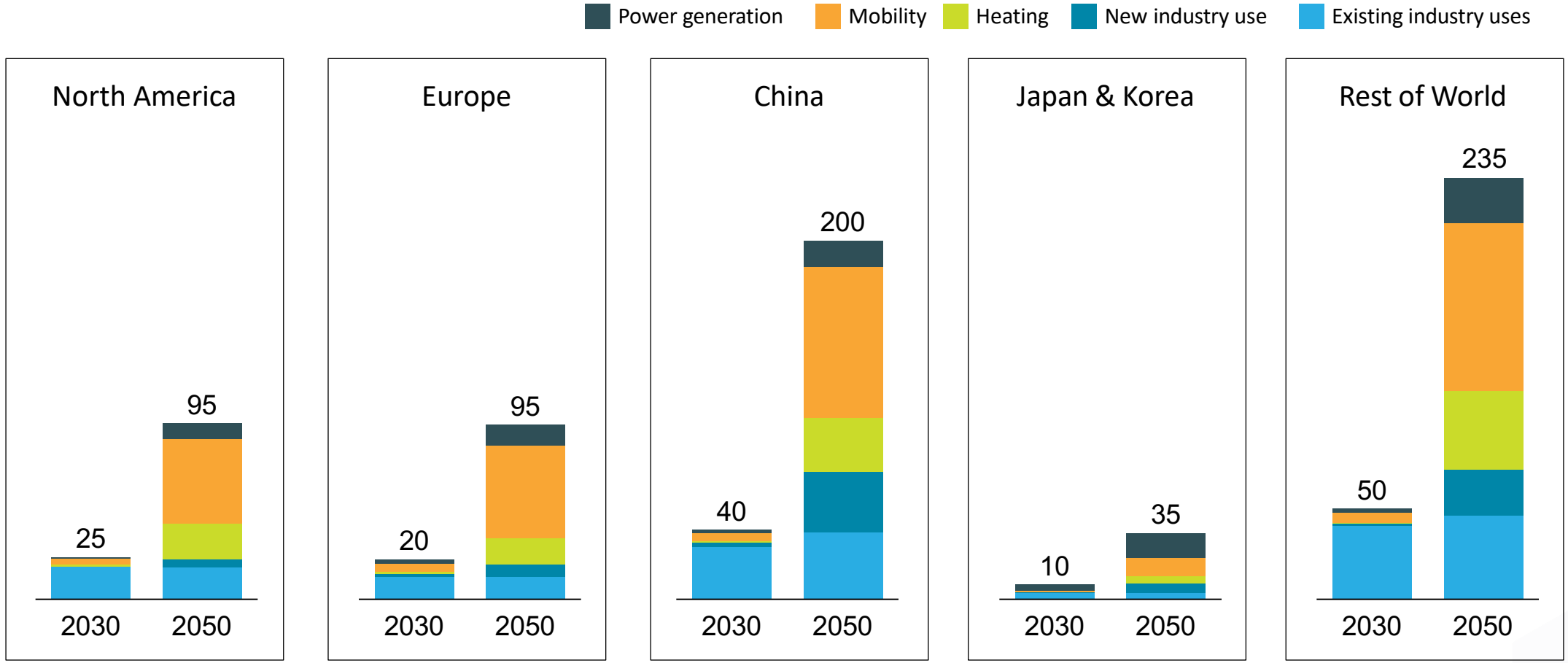
China, Europe, and North America will be the largest hydrogen markets in 2050

- Hydrogen end-use demand by region, MT H_2 p.a. in 2030 and 2050



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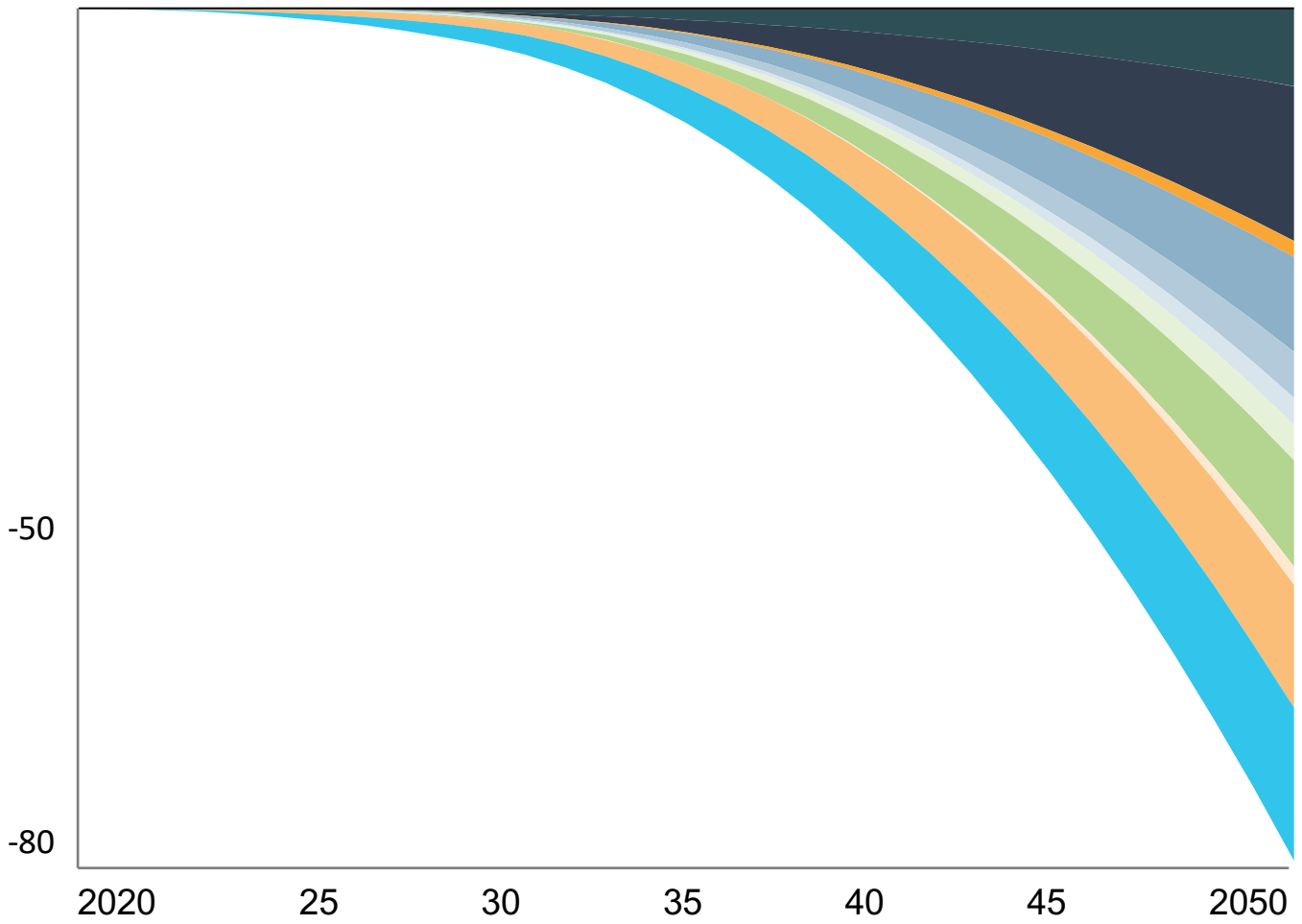
Clean hydrogen can abate 80 GT CO_2 until 2050

CO_2 abated from hydrogen end-use, gigaton CO_2 cumulative until 2050



Power generation

Mobility

Heating

New industry feedstock

Existing industry use

80 Gt

cumulative abatement by 2050 - or ~11% of total abatement required to remain within the carbon budget[1]

20%

of annual emissions avoided due to H2 in 2050 (current trajectory ~35 Gt CO_2 emitted p.a. in 2050)

1. Assumes annual emissions gradually decline to 35 GT in the year 2050 in current trajectory and a CO_2 budget 420 GT

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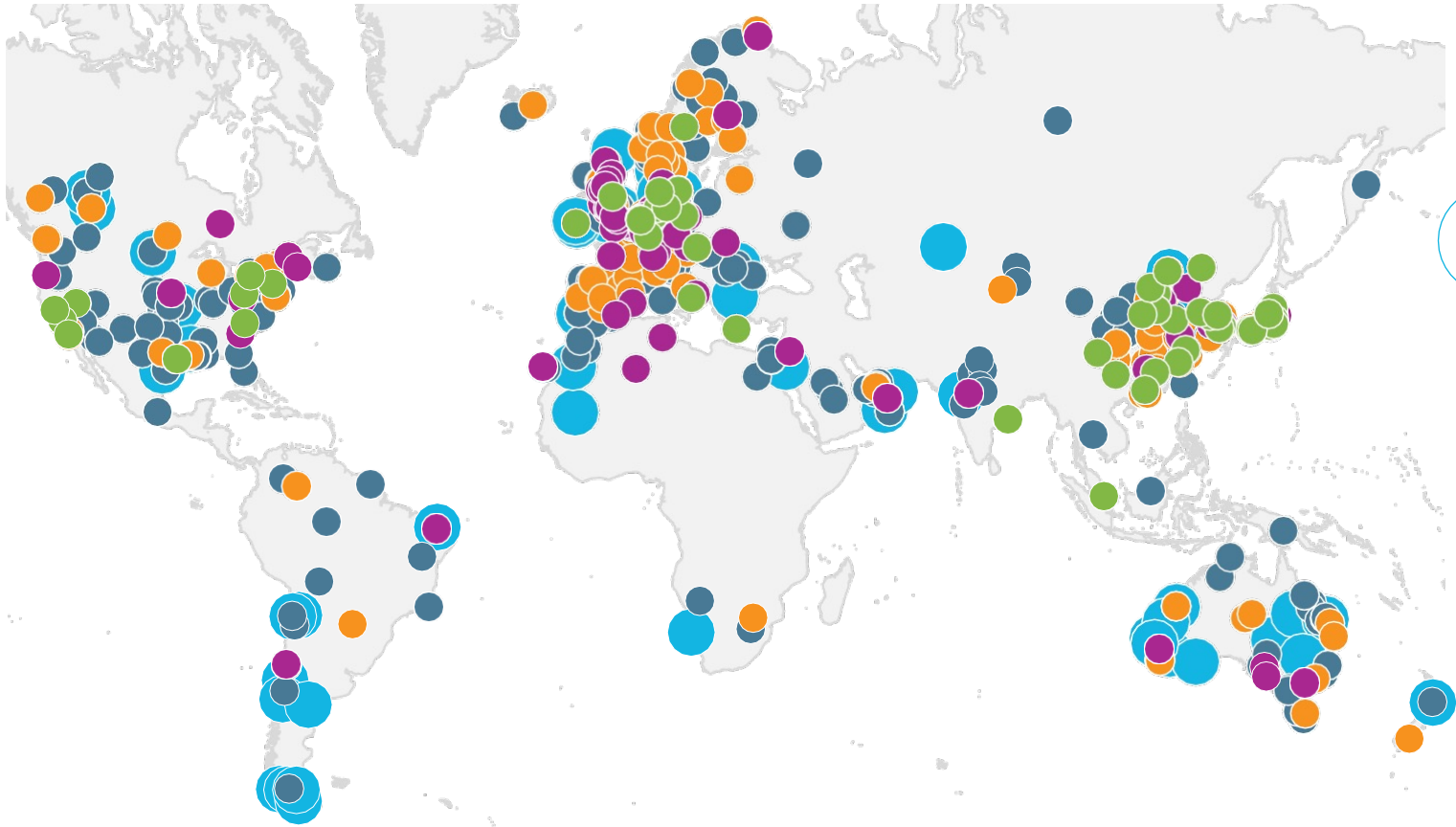
Global hydrogen project announcements (including past 2030)



20-50% increase since November 2021 report

50+% increase since November 2021 report

684 **Announced MW-scale projects[1]**

- **314** Europe
- **154** Asia and China
- **103** North America
- **54** Oceania
- **25** Latin America
- **34** Middle East and Africa

61
Giga-scale production
Renewable H_2 projects >1 GW, low-carbon H_2 projects >200 ktpa

332
Large-scale industrial usage
Refinery, ammonia, methanol, steel, and industry feedstock

150
Transport
Trains, ships, trucks, cars and other hydrogen mobility applications

78
Integrated H_2 economy
cross-industry, and projects with different types of end-uses

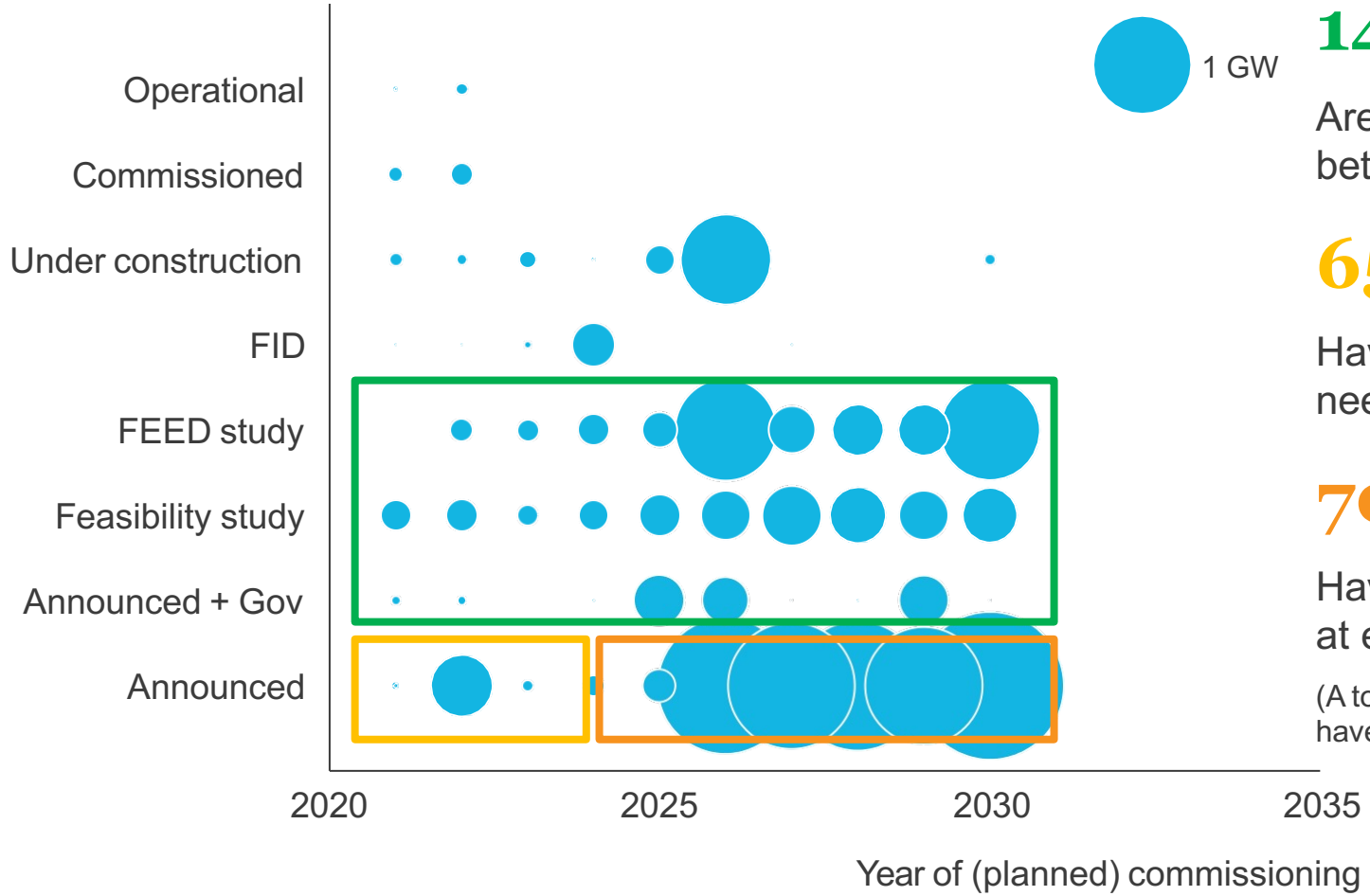
63
Infrastructure projects[2]
H_2 distribution, transportation, conversion, and storage

1.Focus on projects of >1 MW, including commissioning after 2030, >1000 small scale projects and project proposals not included
2.Includes 9 hydrogen production projects in China (8) and India (1) without announced end-use

Source: Project & Investment tracker, as of May 2022, McKinsey

Project sizes are increasing and there are ~118 bn USD of projects under development, likely to seek funding in the next years

Average estimated investment of announced projects[1]



147 projects, 118 bn USD

Are being developed and will seek funding between 2021 and 2030

65 projects[2], 25 bn USD

Have been announced for 2021 to 2024, but need to be developed

70 projects[2], 73 bn USD

Have been announced for 2025 to 2030 and are at early stage

(A total of 79 projects within these three categories do not have a specified investment and hence not included above)

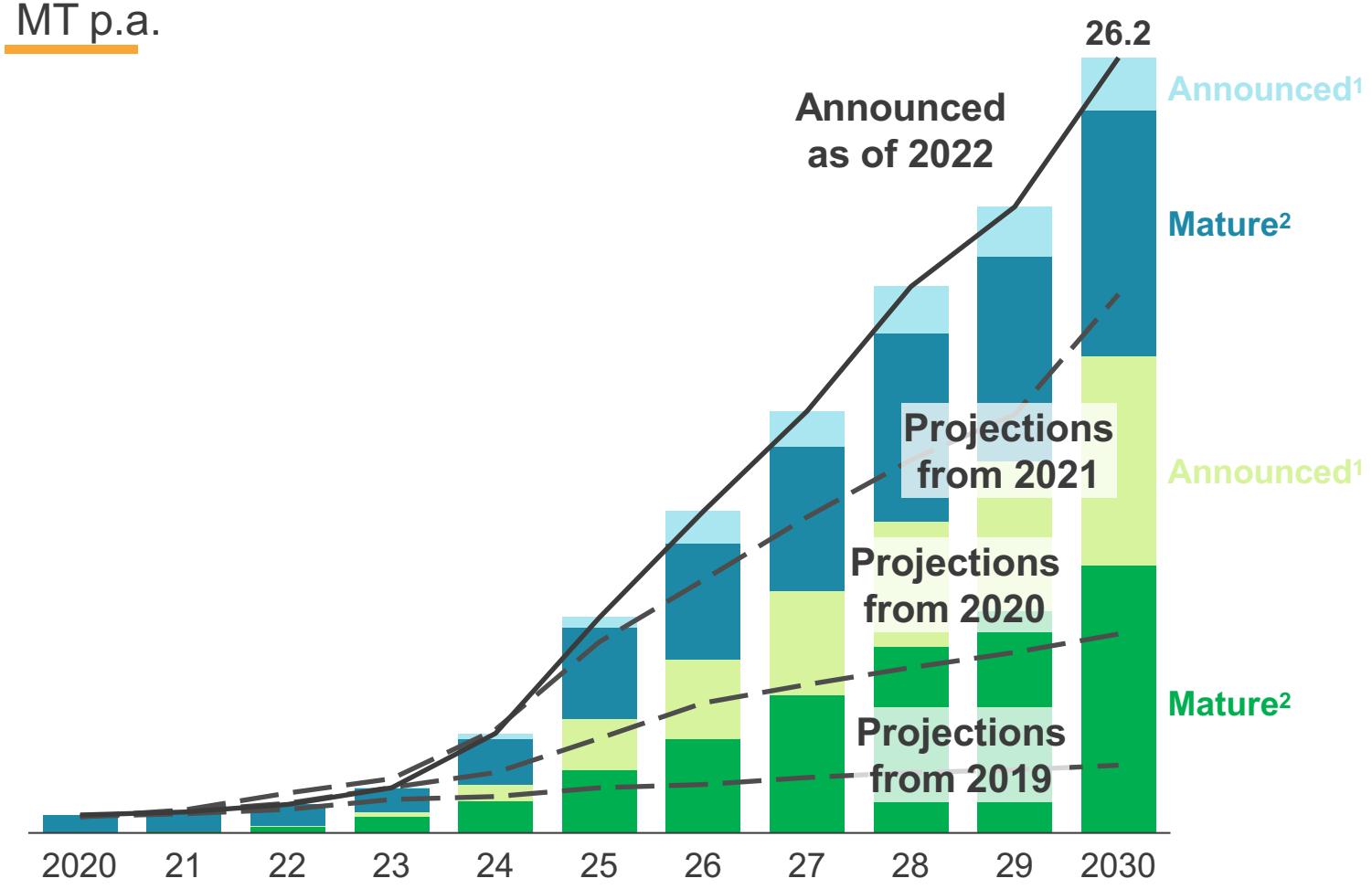
1. Estimated deployed investment from 2021-2030.
2. 16 projects falls within both the category "announced for 2021 to 2024" and "announced for 2025 to 2030", due to several phases of the project.

Source: Project & Investment tracker, as of May 2022, McKinsey

Announced clean hydrogen production capacity almost quadrupled since YE 2020

Cumulative production capacity

MT p.a.



Low-carbon hydrogen

Renewable hydrogen

4x capacity

increase in capacity announced in the past 16 months

175 GW

electrolysis capacity by 2030 announced

+15 MT

additional capacity (low-carbon and renewable) announced for post-2030

1. Preliminary studies or at press announcement stage
2. Feasibility study, front-end engineering and design stage, final investment decision has been taken, under construction, commissioned or operational

Source: Project & Investment tracker, as of May 2022, McKinsey

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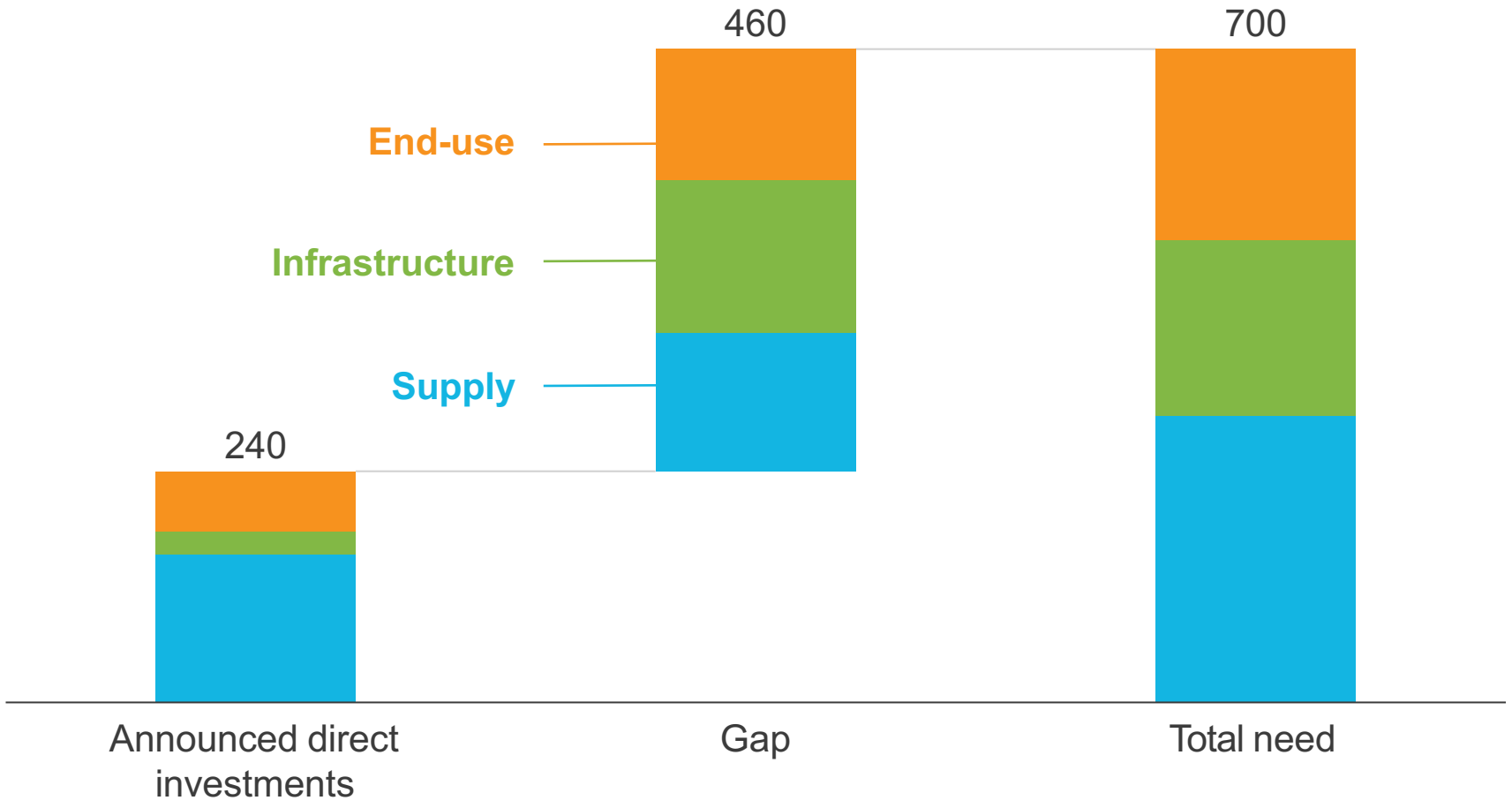
McKinsey & Company

Investment gap of USD 460 billion remains across the hydrogen value chain

Announced and required direct investments into hydrogen

USD bn until 2030



USD 150 bn

investment gap in supply

USD 165 bn

investment gap in infrastructure

USD 145 bn

investment gap in end-use applications

Source: Project & Investment tracker, as of May 2022, McKinsey

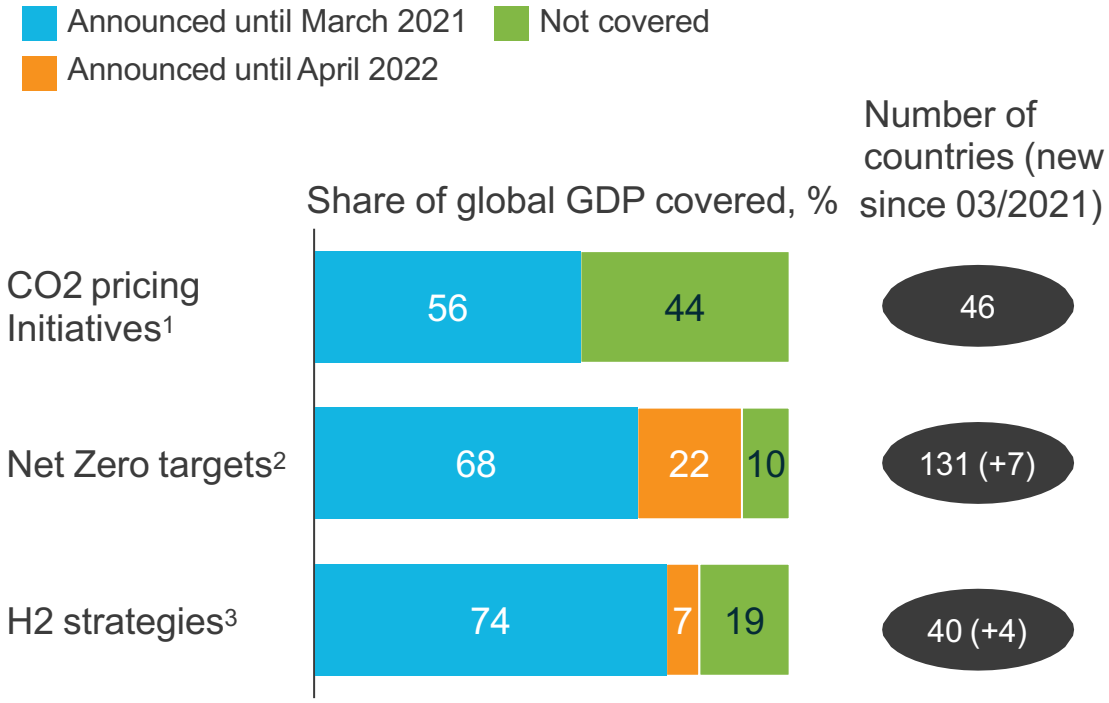
Hydrogen Insights 2022

- Europe leads in *proposed* electrolyser projects (~30% globally)
- China is ahead on *actual deployment* of electrolyzers (200 MW)
- Japan and South Korea are *in the lead on fuel cells* with more than half of the world's 11 GW manufacturing capacity

Decarbonization ambitions have been accelerated across the world in the last year

NON-EXHAUSTIVE

Share of global GDP covered by respective regulatory support mechanism, %



1 Implemented or scheduled; share of global GDP covered assumes that CO2 pricing initiatives encompass 100% of national GDP
2 Includes 14 EU member states that have not announced targets but fall under the EU's overarching net-zero target by 2050.
3 Covers EU27 and Australia, Canada, Chile, China, Colombia, India, Japan, Norway, South Africa, South Korea, United Kingdom, USA, Uzbekistan

Source: World Bank, Net Zero Tracker, McKinsey Hydrogen Insights Project & Investments Tracker, Press search

Highlights across decarbonization initiatives/instruments

REPowerEU proposed, acceleration of the transition to renewable energy and deployment of clean H2
FitFor55, 55% emissions reduction by 2030

EUR 80/tCO2 carbon price in the EU ETS during April 2022 (up from EUR 45/tCO2 in April 2021)

Announced net zero target at COP26 and plans to increase its 2030 goals

Carbon neutral by 2060 and formally committed to peaking emissions before 2030

Up to **50% emissions reduction by 2030** against 2005 levels after revising its climate target upwards

Hydrogen production targets are being ramped up by governments…

NON-EXHAUSTIVE

Production targets released in last 12 months

Additional 10 Mt of renewable hydrogen imports by 2030 and **5 Mt of domestic renewable hydrogen production**

5 Mt of renewable hydrogen by 2030 production target.

2.9 Mt annual clean hydrogen production by 2030 ramping up to 4 Mt by 2035

10 GW low-carbon hydrogen production target by 2030 as both countries will double their respective target of 5GW

Announced hydrogen production capacity targets[1]

In Mt per year, in 2030

1 Does not include EU import target to avoid double-counting; Does not include grey hydrogen
2 Important Projects of Common European Interest
3 Deviates from number in previous report due to corrections

Source: McKinsey Hydrogen Insights Project & Investments Tracker, Press Search

… who are also increasing their public funding commitments

Public funding announced in last 12 months

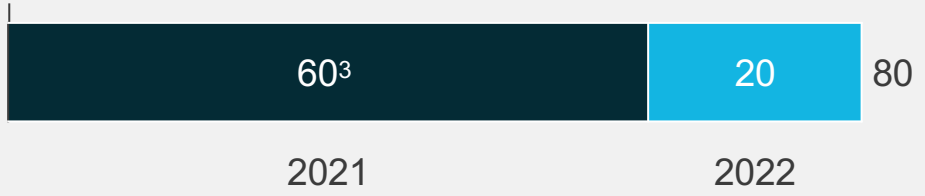
USD 8bn allocated to four clean hydrogen hubs, USD 1bn into lowering the cost of electrolysis and USD 500mn into clean hydrogen research

USD 9.3bn pledged to support hydrogen projects across the value chain as part of the IPCEI[2] Hydrogen

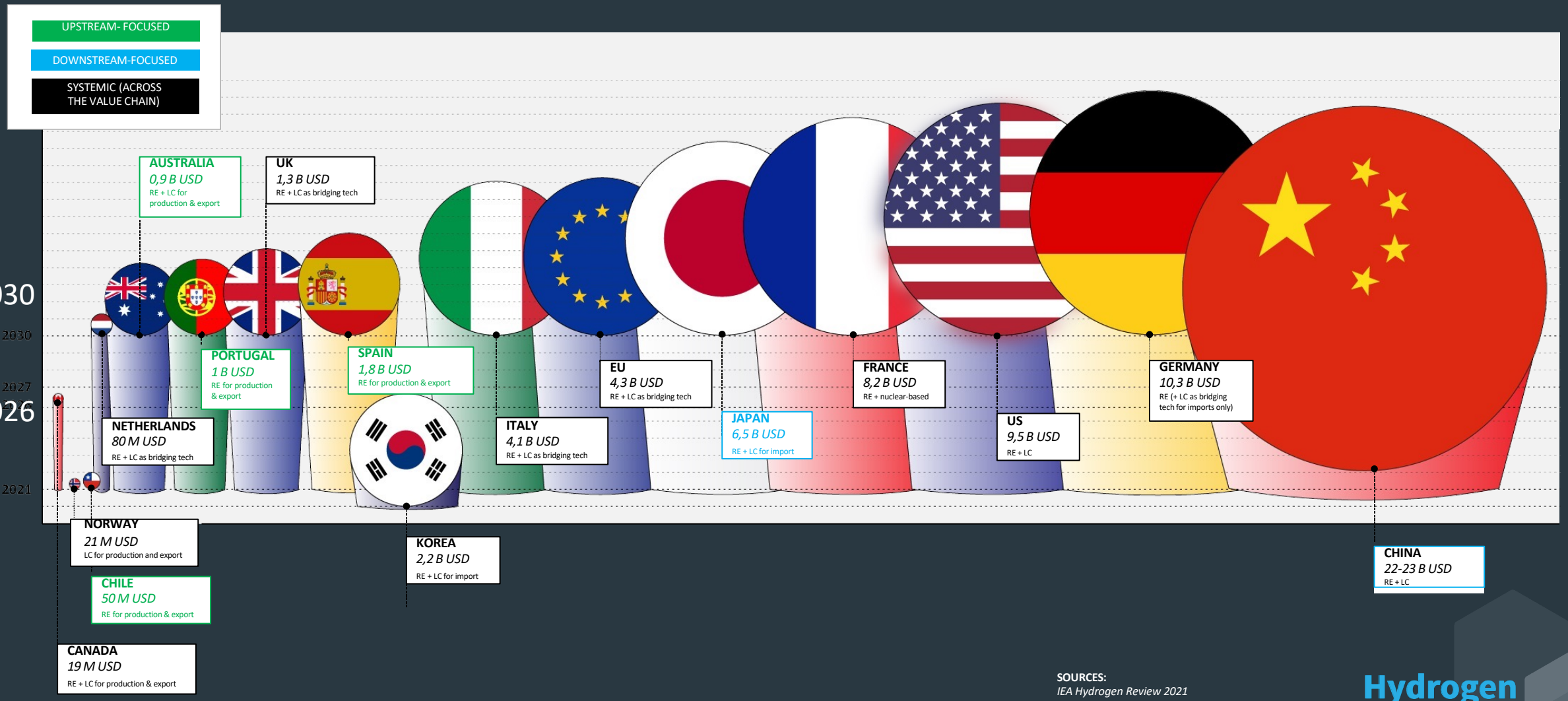
USD 2.2bn announced investment in domestic hydrogen production

Global public funding for Hydrogen

In USD billion



Status of Hydrogen Funding



SOURCES:
IEA Hydrogen Review 2021
Hydrogen Europe Clean Hydrogen Monitor 2021
National hydrogen strategies

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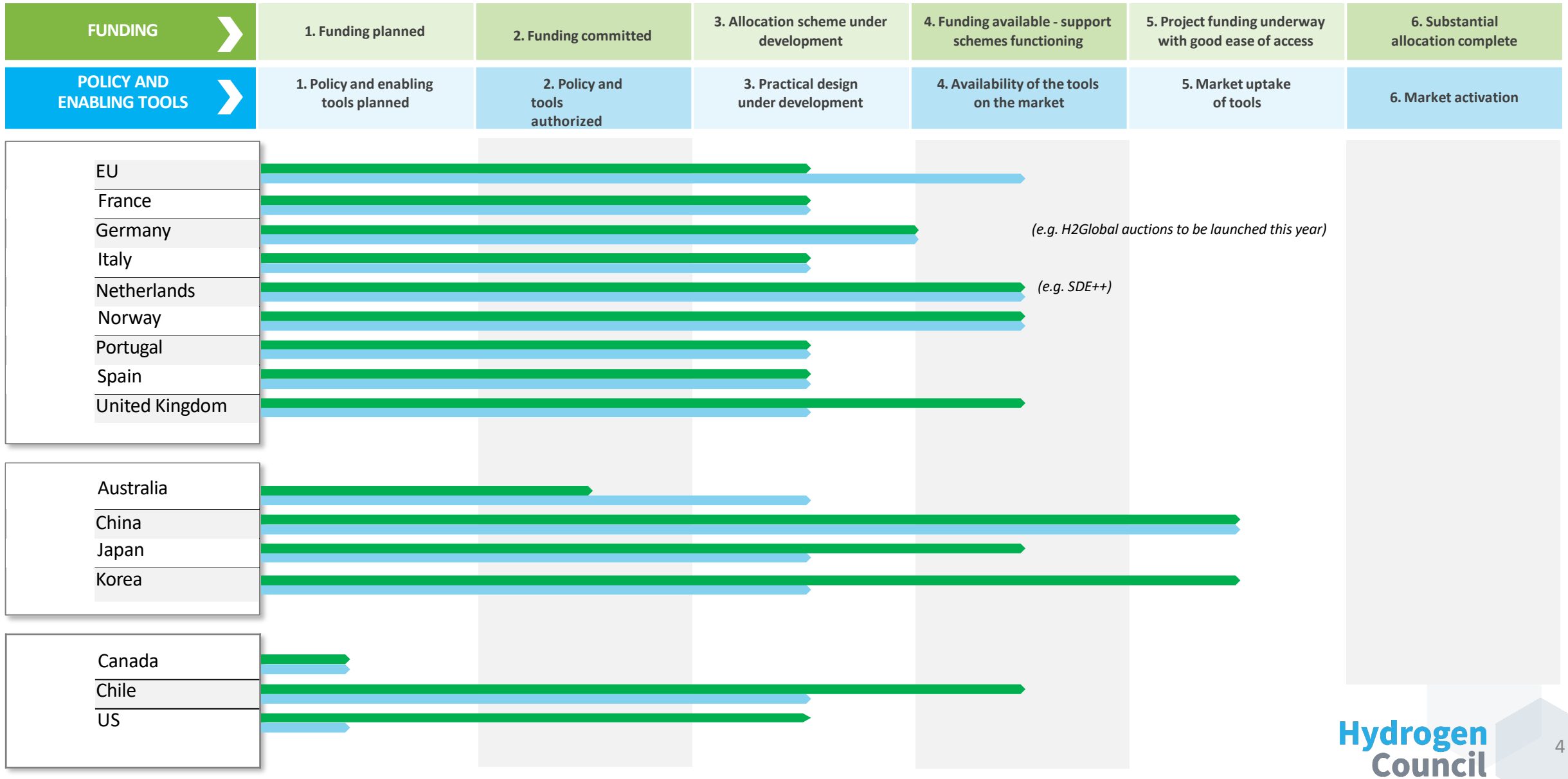
Funding & Policy Implementation Progress



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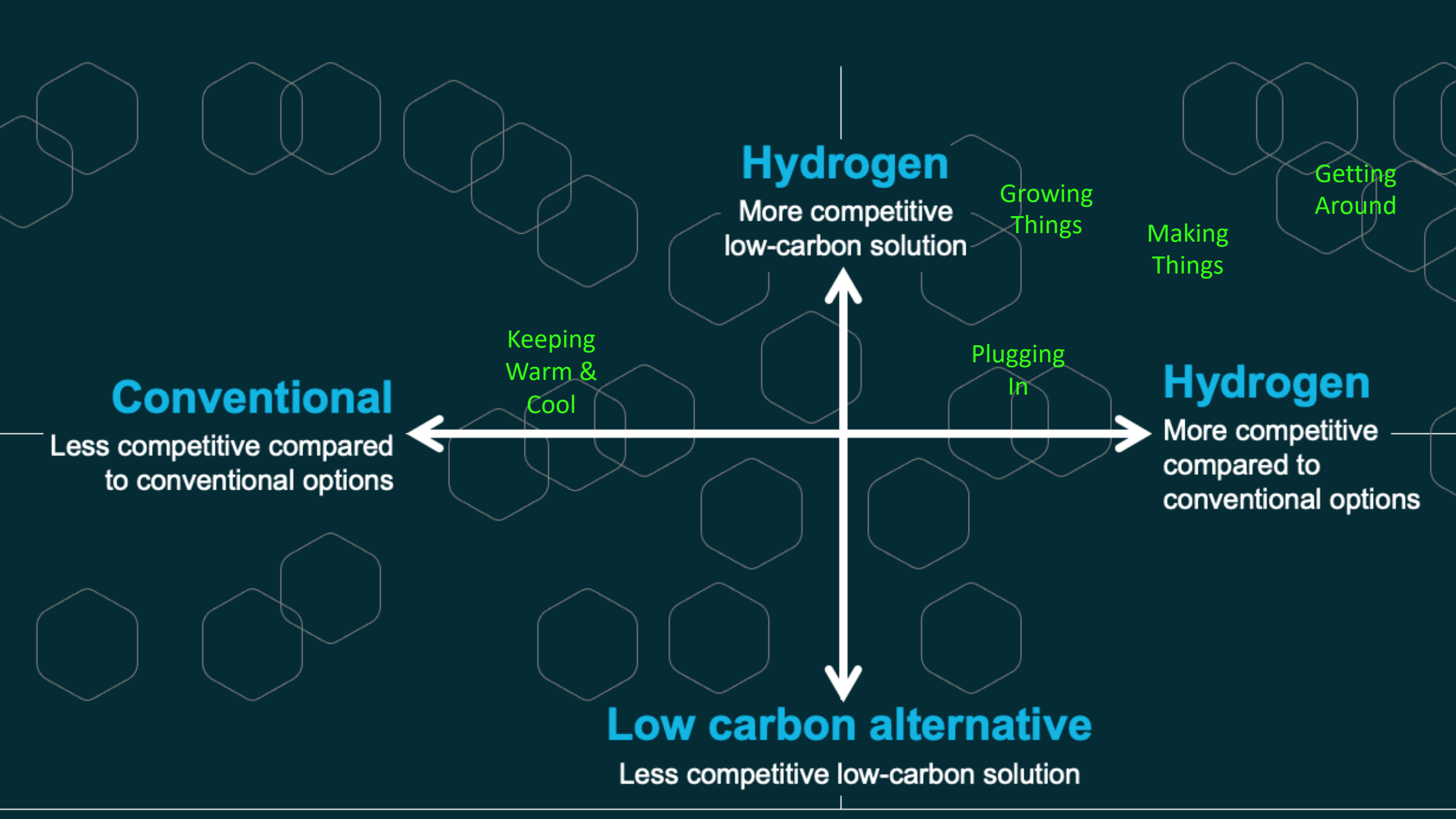
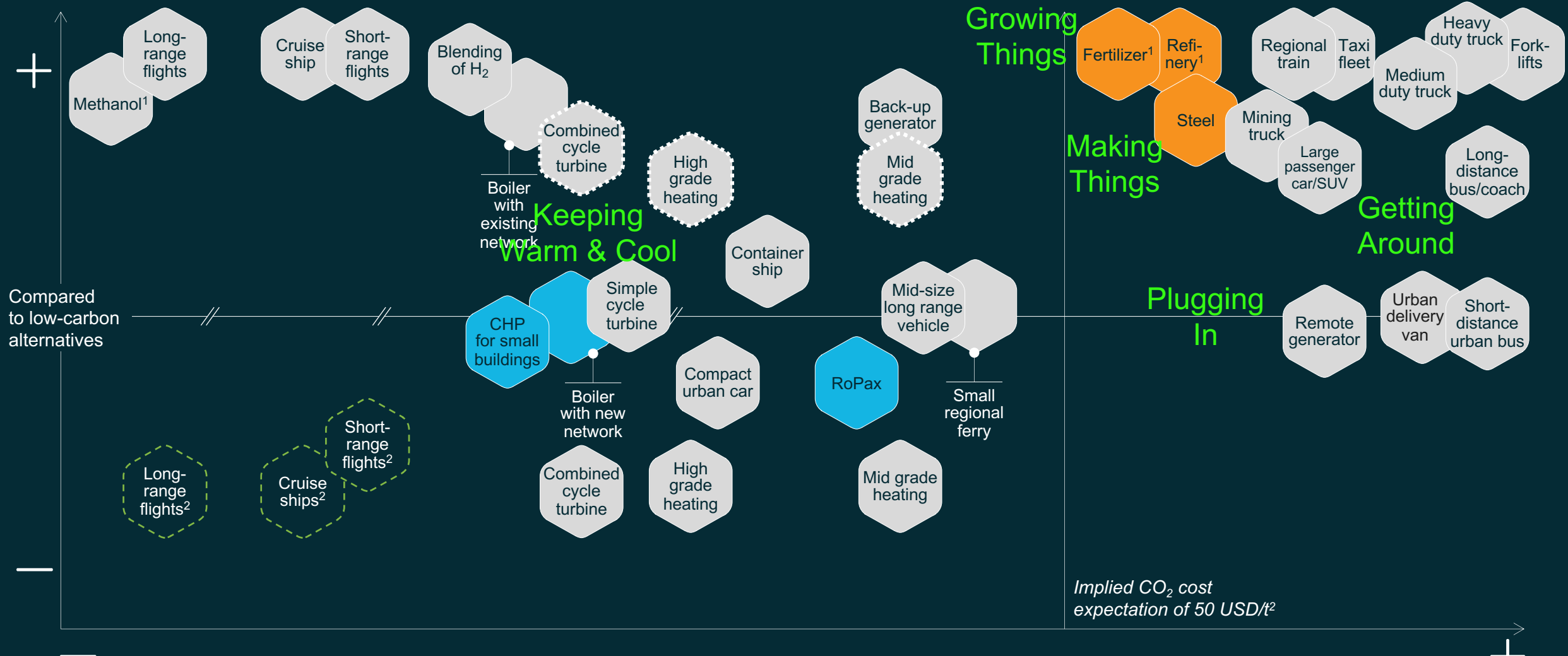

Hydrogen
More competitive low-carbon solution
Growing Things
Getting Around
Making Things
Keeping Warm & Cool
Plugging In
Conventional
Less competitive compared to conventional options
Hydrogen
More competitive compared to conventional options
Low carbon alternative
Less competitive low-carbon solution

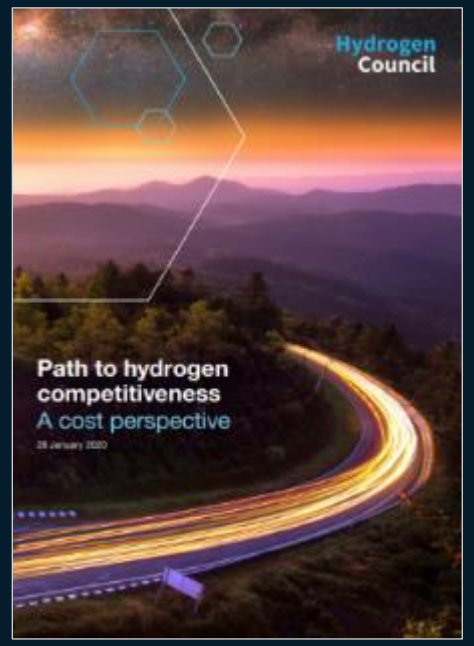
With falling costs of hydrogen and various technologies, over 20 hydrogen applications are considered the most competitive low-carbon solution by 2030



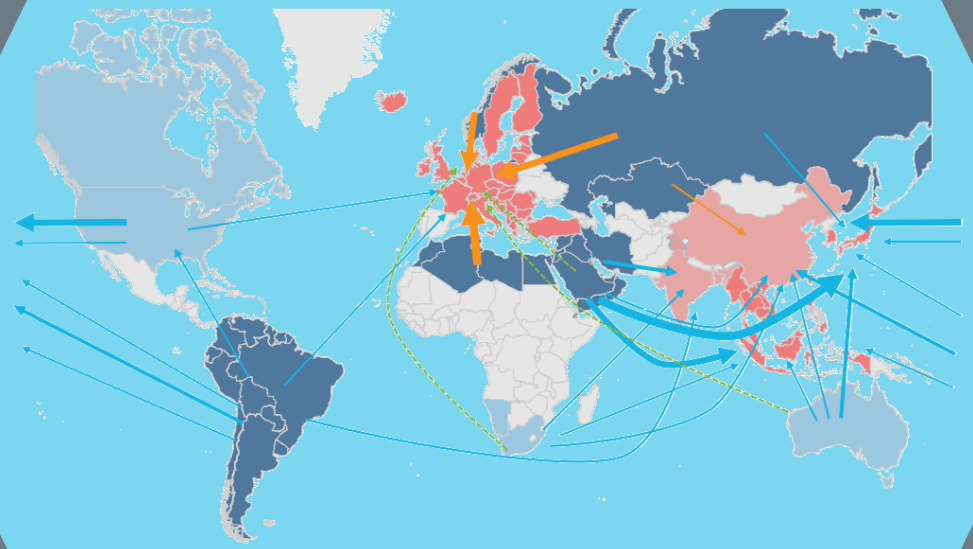
1. Clean hydrogen is the only alternative
2. Carbon breakeven cost represents average cost over lifetime of asset

The Global Hydrogen Flows Perspective will fill the gap between the supply and demand views from our previous reports on costs and demand

Distinctive technology outlook

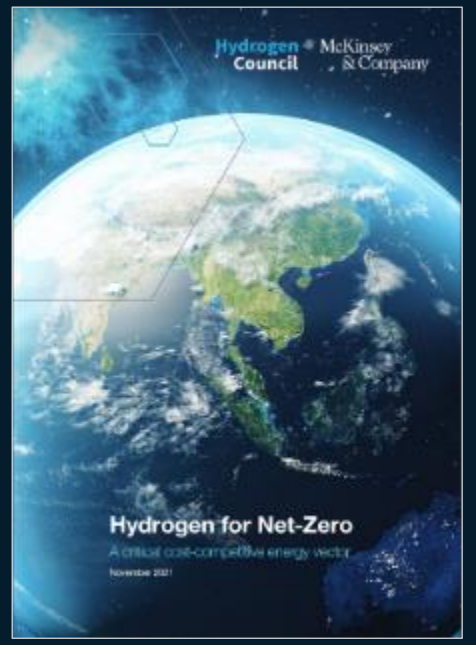


Transparency on global H_2 trade balances



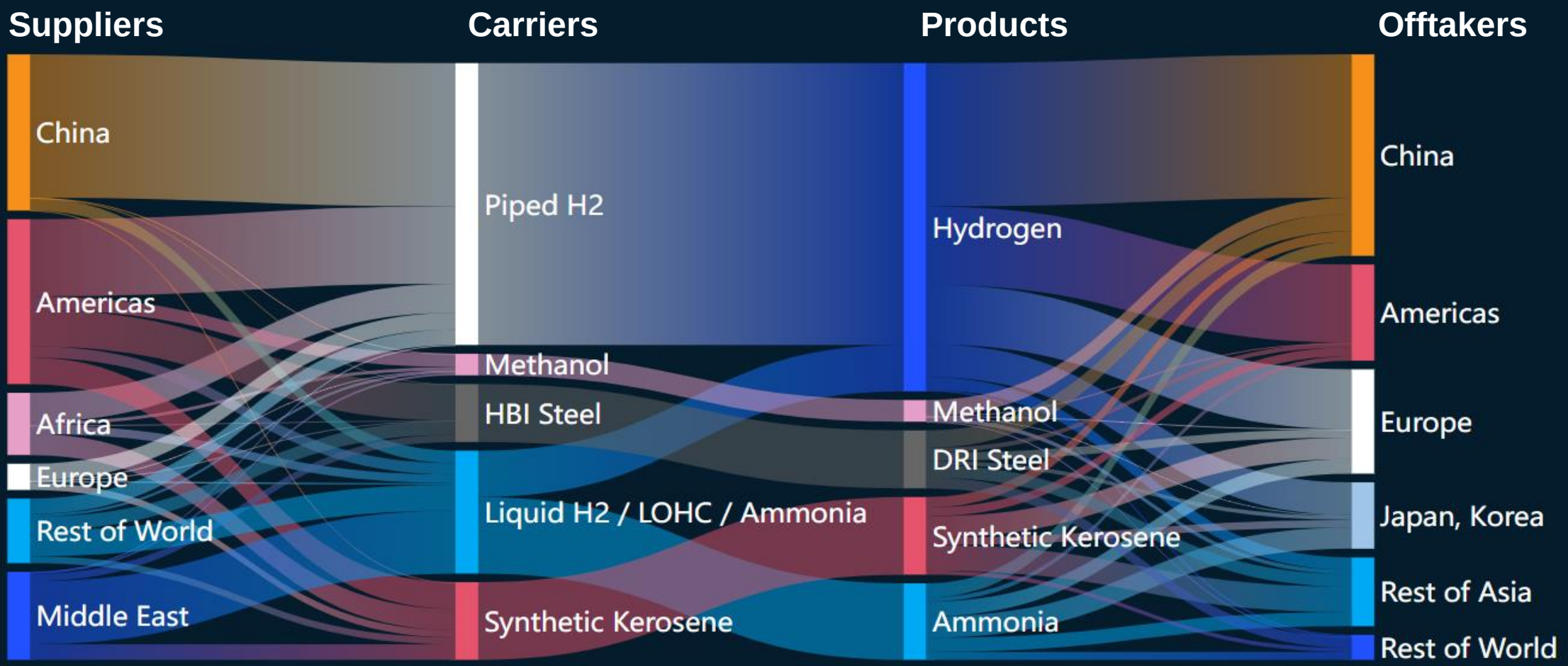
- Future hydrogen and derivative trade flows
- Multiple scenarios addressing key uncertainties
- Key unlocks to global hydrogen trade and consumption

Detailed outlook on demand

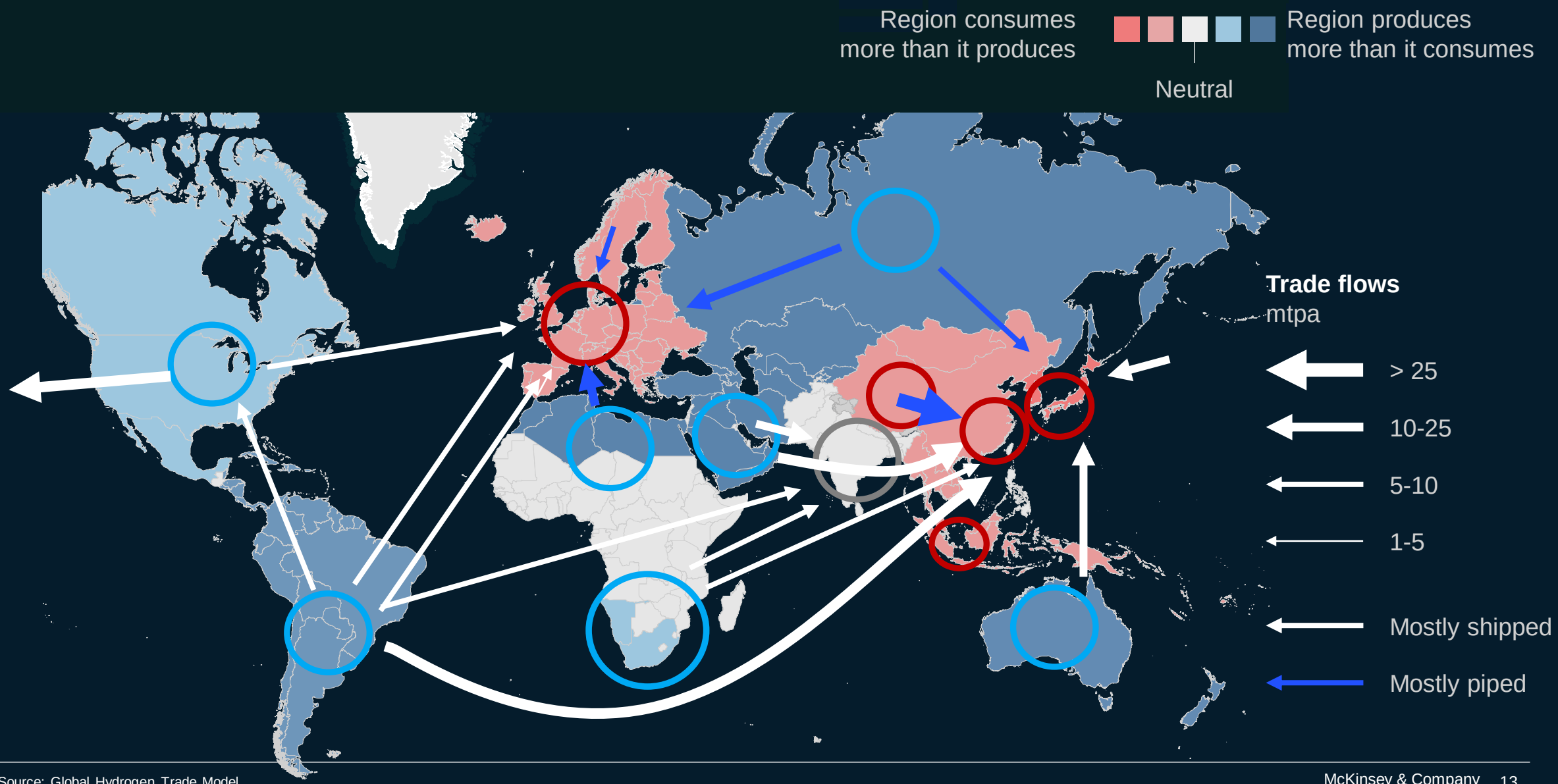


A global market is expected to emerge with production region specialization and trade driven by relative competitiveness

2050 Trade flows



By 2050, >300mt of H2 would be traded, with east Asia and Europe relying on imports from around the world



Source: Global Hydrogen Trade Model

1. Systems Thinking – Whole Energy System
2. Infrastructure Vision
3. Policy which respects market evolution
4. Beyond announcements to continuous collaboration

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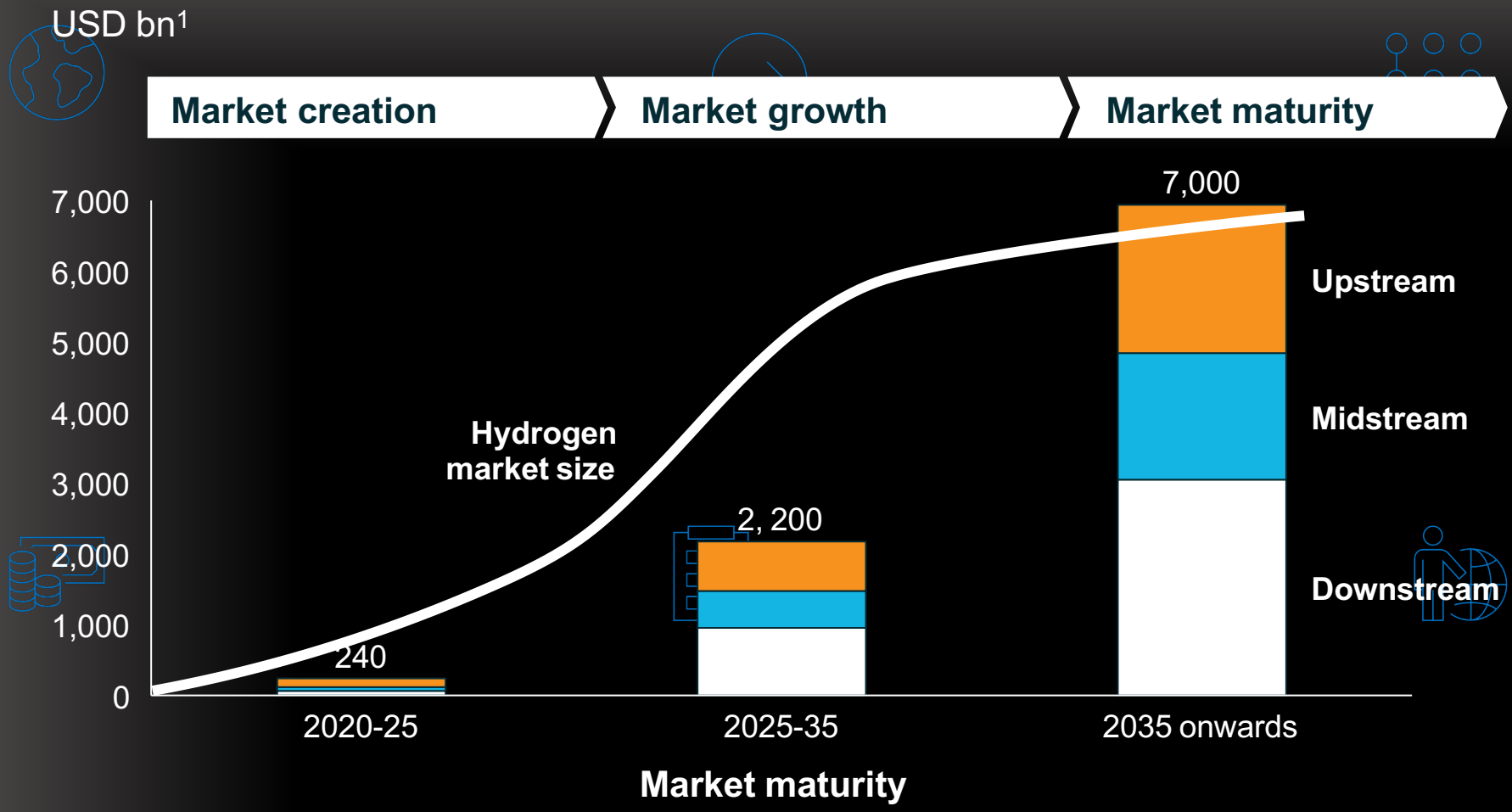
Policy which respects evolution



1. Investment in line with the "Hydrogen for Net Zero" scenario; upstream includes hydrogen production (electrolyzers, CCS retrofits for blue H2, new SMR/ATR plants), excludes renewables/gas upstream; midstream includes distribution, transmission (shipping, pipelines, conversion etc.) and storage; downstream investments for end-applications (ammonia plants, fuel cells etc.)

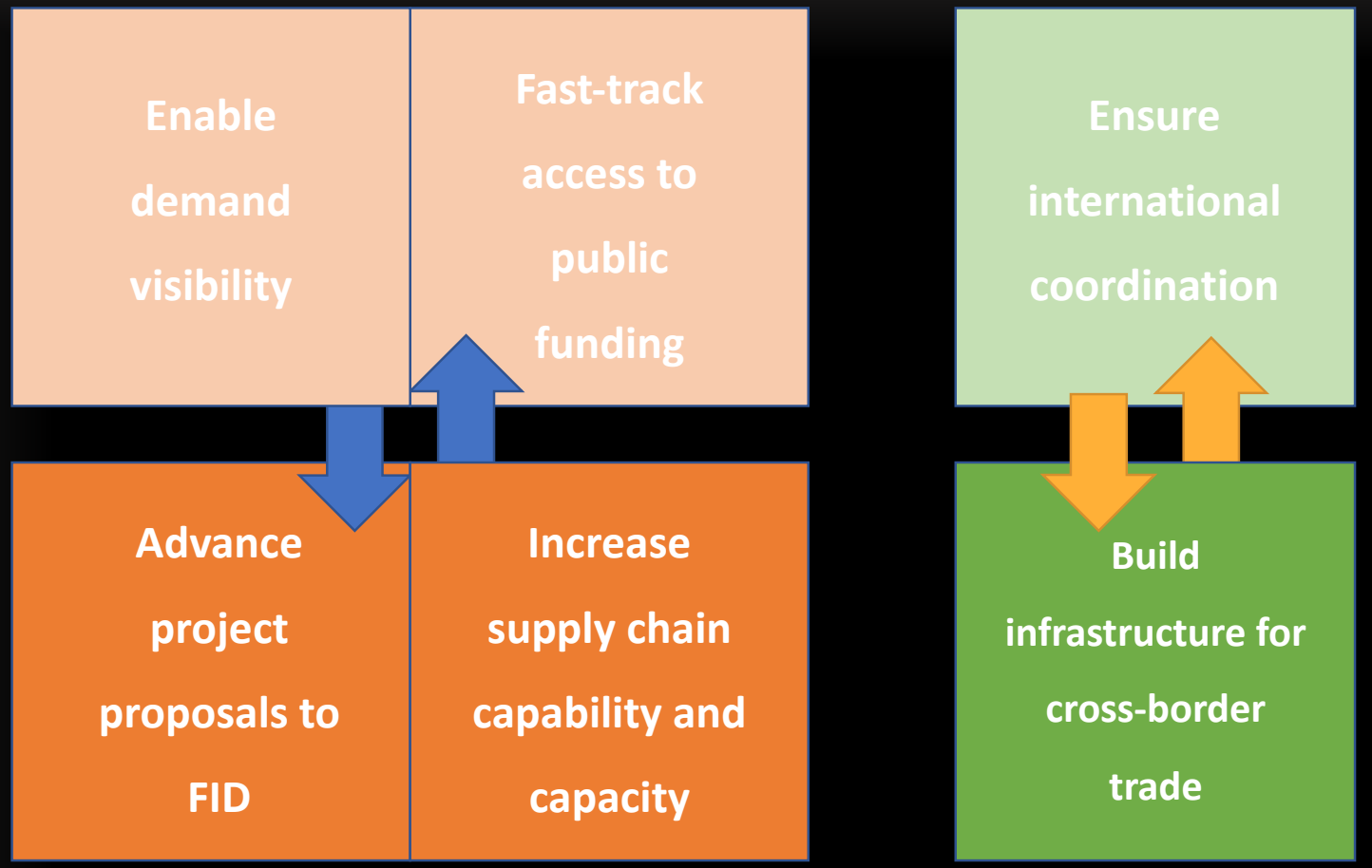
Beyond announcements to continuous collaboration

Progress projects and **scale up** deployment in regions

Enable global hydrogen trade

Priority actions for **policymakers**

Priority actions for **industry**



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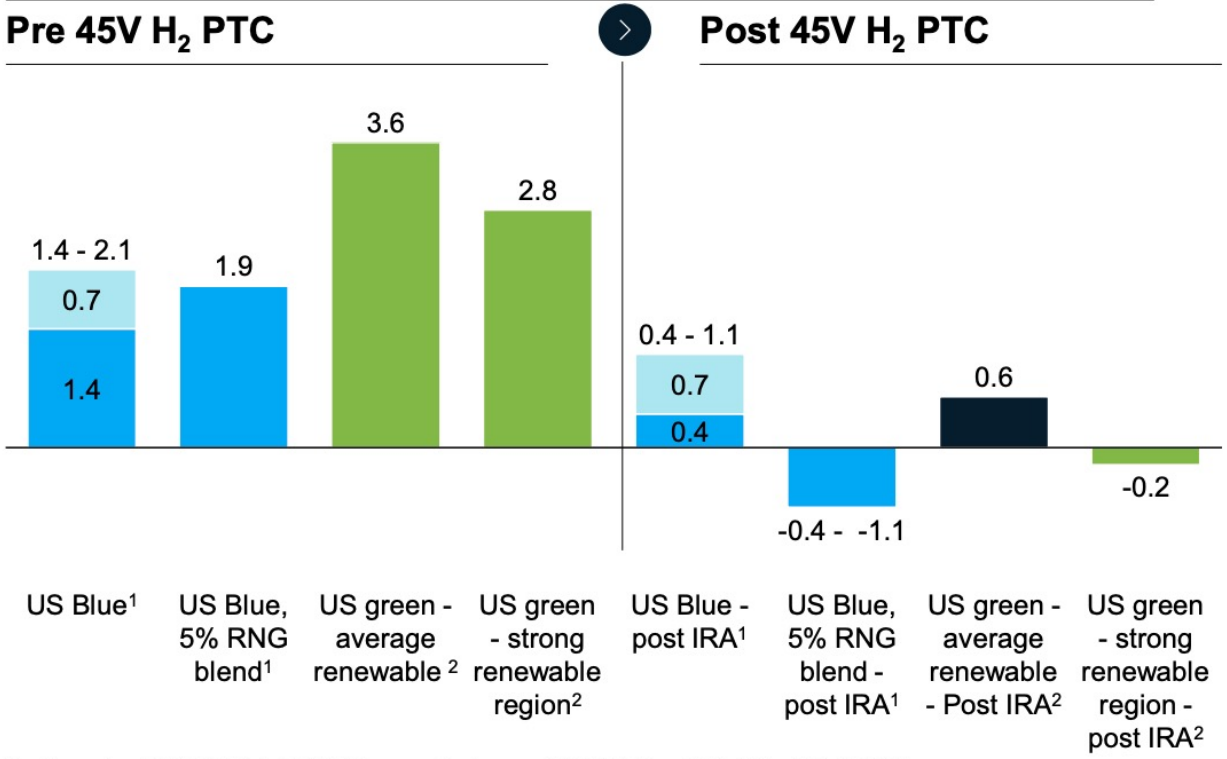
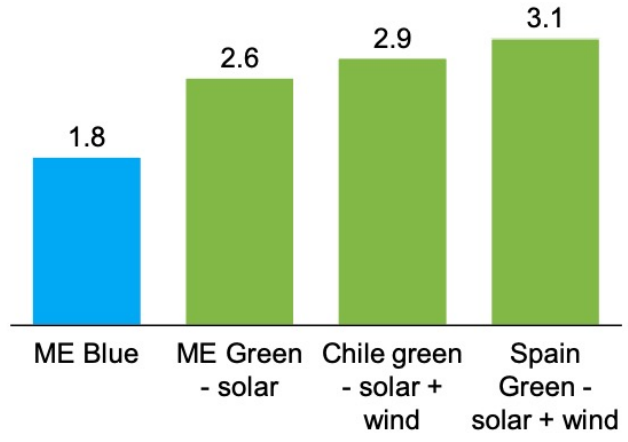
US Inflation Reduction Act – a game changer

Hydrogen PTC makes US renewable and low carbon H2 the lowest effective cost in the world today

Levelized cost of H_2 production in the US after applying H_2 PTC, 2022 ($/kg)[3]

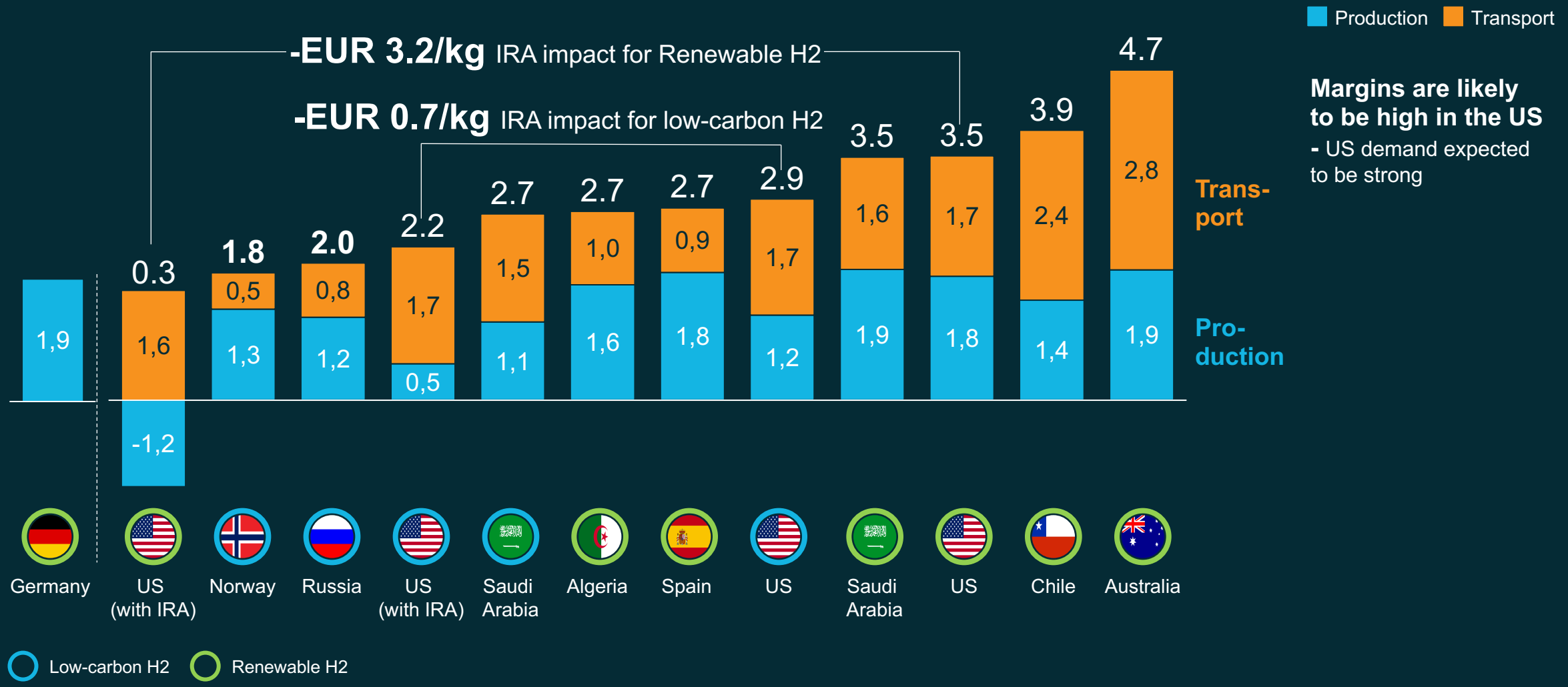


Levelized cost of H_2 production globally, 2022 ($/kg)



1. Range from $3.5/MMBTU to $9/MMBTU gas costs; Assumes $80/MMBTU ag RNG at CI = -300 gCO2/MJ
2. Electricity prices assumed to be: Best region: $22/MWh in 2022; Average region: $40/MWh in 2022; 50% capacity factor assumed
3. Assumes green H2 and 5% RNG blend blue H2 gets $3/kg credit and blue gets $1/kg credit

Landed costs of to Germany for hydrogen as an end-product 2030, EUR/kg



Towards global, cross-border trade in hydrogen: common industry standards and robust certification systems are key

Common international standards

Standard ISO methodology for life cycle analysis assessment of GHG emissions associated with hydrogen production, alongside other sustainability attributes **are crucial to inform**

- Thresholds for qualifying hydrogen as low carbon/ renewable
- Aligned taxonomies
- Common rules and standards to underpin international certification systems for hydrogen

Hydrogen certification systems

Robust hydrogen certification systems are key to

- Build consumer trust
- Enable a market-based approach to hydrogen sourcing
- Stimulate demand
- Foster cross-border trade

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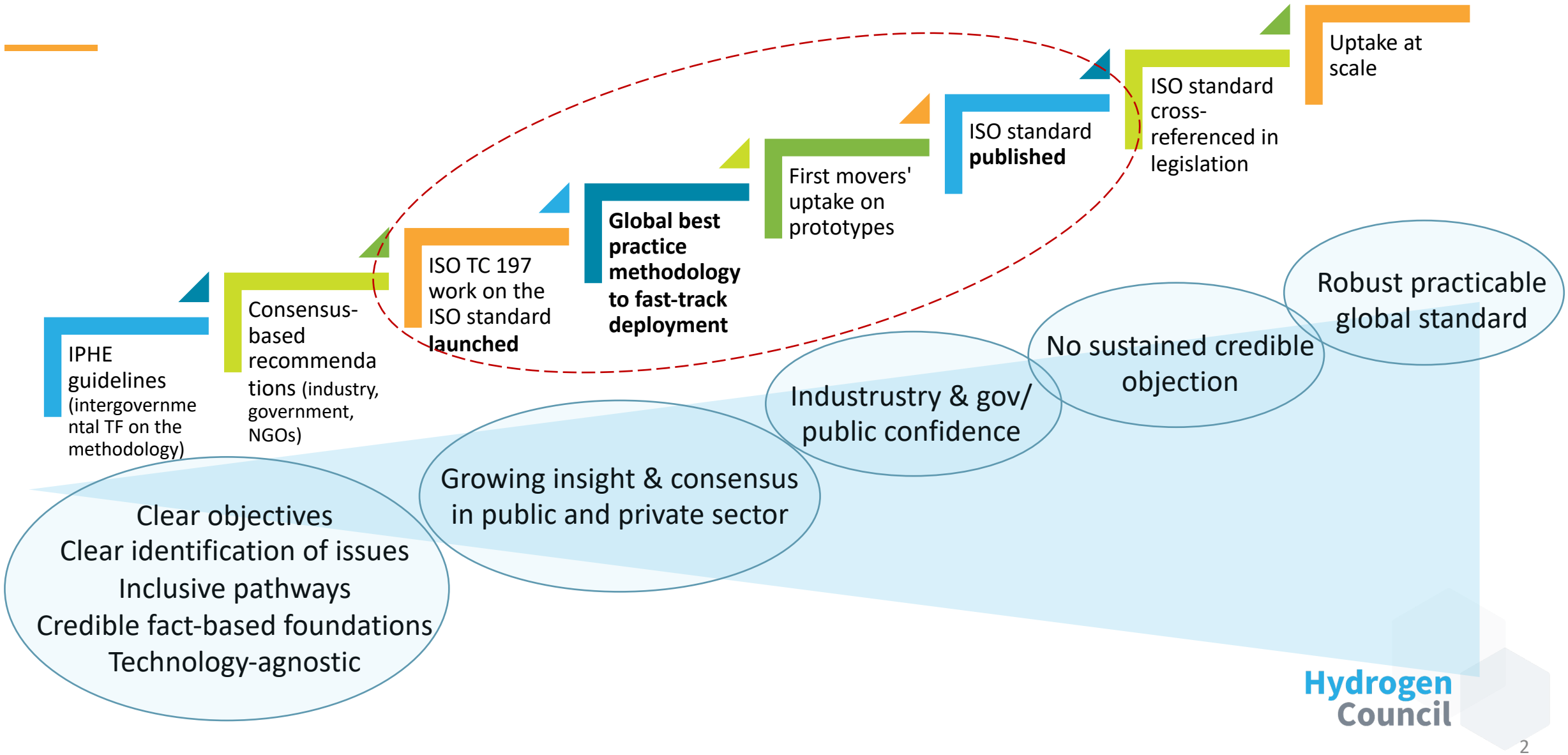
Towards a common global ISO standard methodology for GHG assessment of H2 production and transport pathways



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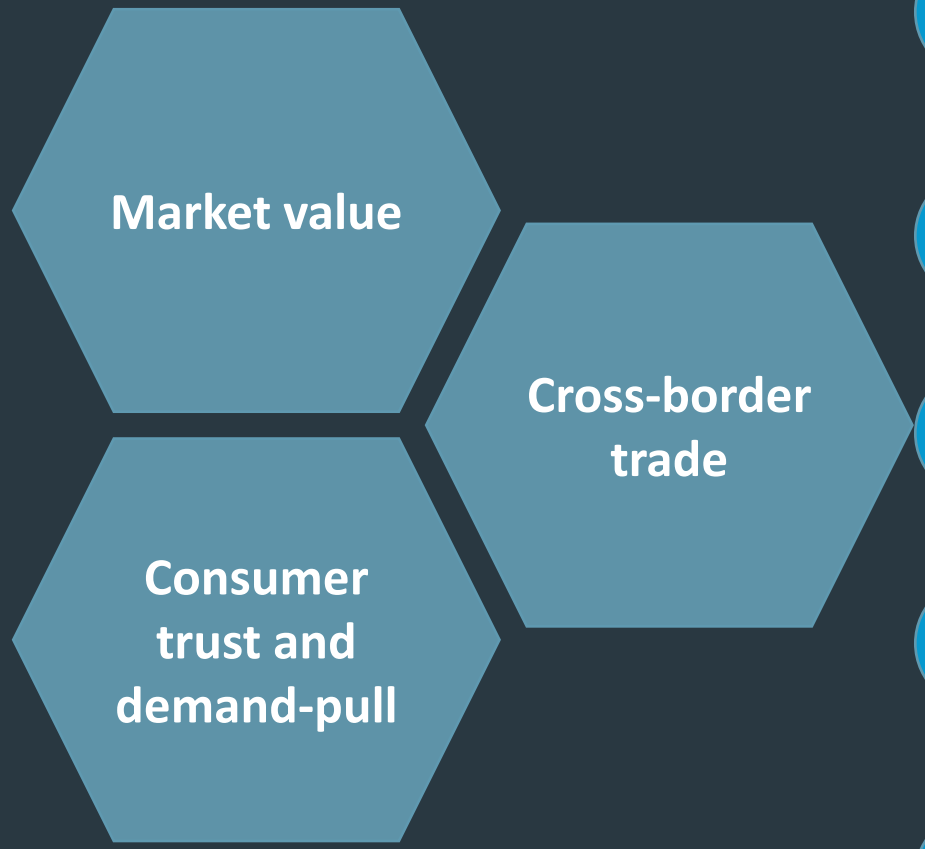
Certification - a crucial instrument for the hydrogen economy

Unloking market value, building consumer trust, faccilitating demand creation, enabling trade



1. Evidence the **sustainability attributes** of hydrogen (carbon footprint in particular) in a **credible and consistent manner** internationally
2. Support project bankability by **enabling access to compliance markets**
3. Create **transparency for consumers** and enable **consumer choice**
4. Allow consumers to **signal demand** for hydrogen based on its sustainability credentials
5. Create trust between prospective importers and exporters, fostering global, **cross-border trade in hydrogen** based on its sustainability credentials

Environmental attributes – key value driver for hydrogen across the emerging compliance and voluntary markets

EU has multiple regulations covering different end sectors

Market	Transport Fuels	Maritime fuel	Aviation fuel	Renewable transport fuel: RFNBO	Renewable feedstock for industry: RFNBO	Imports	ETS: carbon intensive industry, built environment, heavy transport	JERA /JOGMEC	Imports
Physical product	H2	NH3, MeOH, e-diesel	e-kerosene	H2, NH3, MeOH, e-diesel	H2	Fertilizers (incl NH3)	Any molecule under ETS	NH3	NH3
Customer	Transport Fuel Suppliers	Ship operators	Fuel suppliers	Transport fuel suppliers	Traditional Industrial H2 users:	Any conventional product off-taker	Any conventional product off-taker	Power Plant	Road Transport, Power Plant, Steel Making
Applicable regulation	Low Carbon Fuel Standard (LCFS)	EUFuel Maritime, ETS	ReFuelEU aviation	(RED II Art. 25-30)	(RED III Art. 22a)	ETS and CBAM interplay	ETS	TBD	TBD

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