Global Hydrogen Developments

The Gulf Coast Hydrogen Ecosystem: Opportunities & Solutions

17 April 2024 | Houston, Texas

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The Hydrogen Council

A global, cross-sector CEO-led initiative

Founded at

WORLD ECONOMIC FORUM

in 2017

Grown From 13 to

ca **140**

companies

6.8

MILLION

jobs

$6.4

TRILLION

in revenues

ONE SHARED VISION

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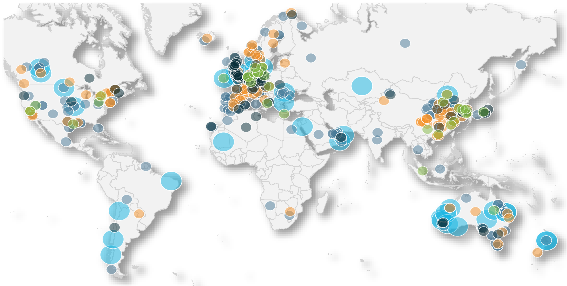
Who we are

Thought Leader

Unique Source of Global Industry Data



Insights into the evolution of the global industry based on data from >145 industrial leaders

Trusted Partner to Global Organisations

IRENA
International Renewable Energy Agency

iea
International Energy Agency

CLEAN ENERGY MINISTERIAL
Advancing Clean Energy Together

ISO
International Organization for Standardization

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Data and insights to inform decision makers

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Global hydrogen developments

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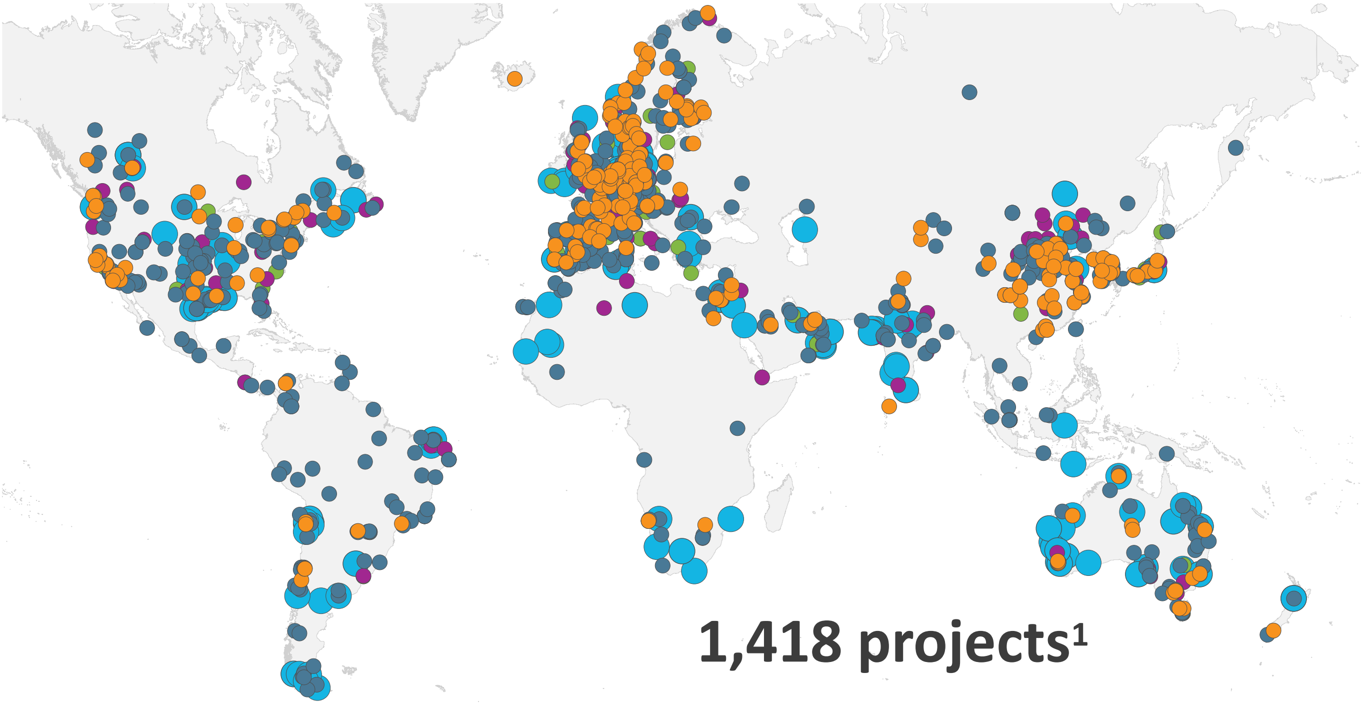
Status	Some positives	Some less positives
Prospects	Opportunities at the global scene	Where our focus is needed

Exhibit 1

Positive: Strong momentum

More than 1,400 projects announced globally (+40%)

AS OF OCT 18 2023



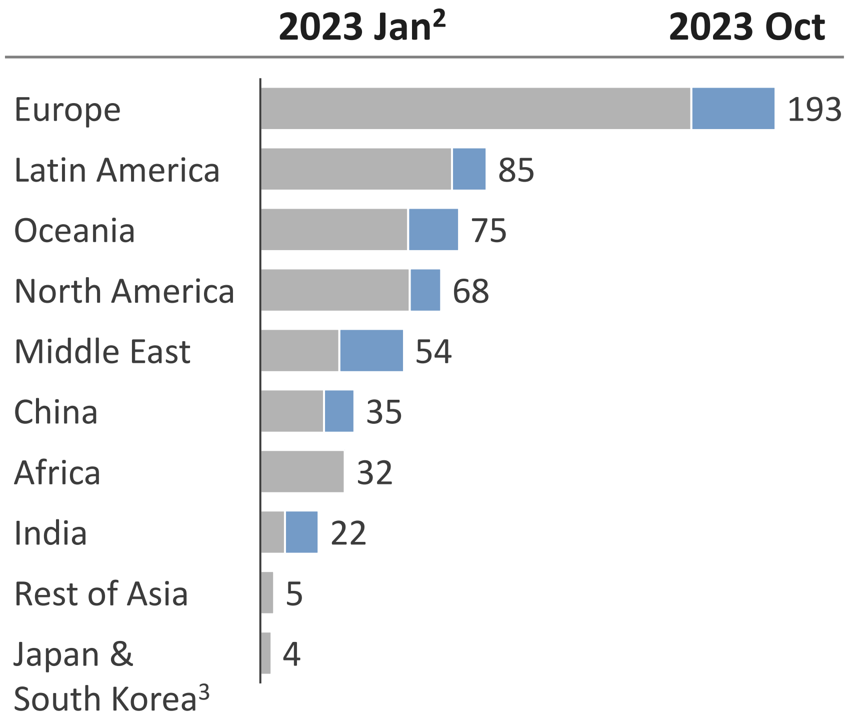
1,418 projects[1]

1,046 in Jan 2023, 684 in May 2022

166	**719**	**256**	**144**	**126**
Giga-scale production	Large-scale industrial use	Transport	Integrated H_2 economy	Infrastructure projects

$570 B

investments required to develop projects announced until 2030



1. Project announcements below 1 MW are excluded. 7 projects have not announced project type
2. Jan 2023 values have been updated to most recent Capex estimations to keep values comparable
3. Restatement of 2023 Jan data for Japan & South Korea prevents comparison to Oct 2023 data

Source: Project & Investment tracker, as of Oct 2023, McKinsey

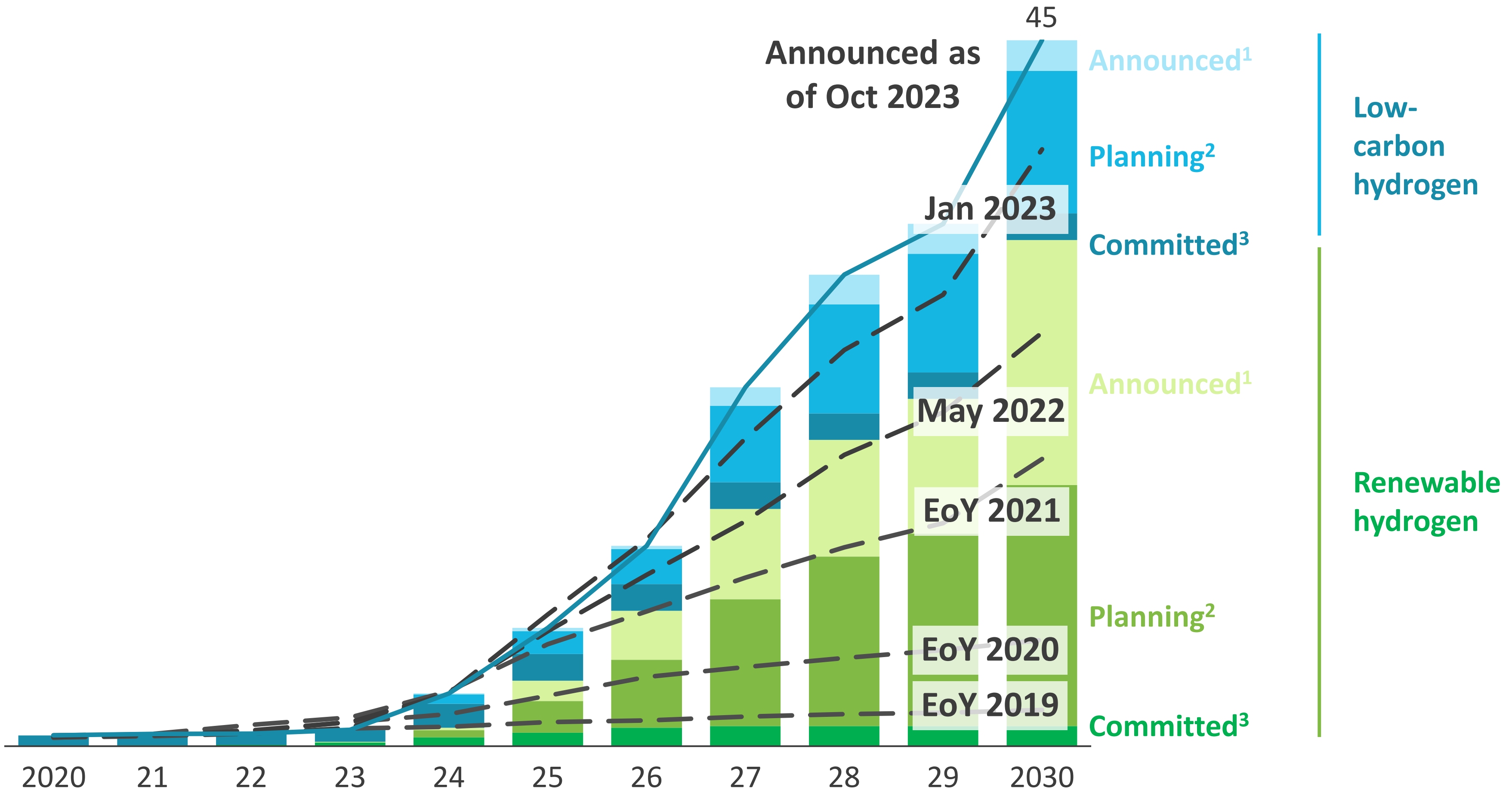
Exhibit 4

Positive: Clean hydrogen production capacity up

Announced capacity increased to 45 Mt p.a. (+17%) over the last 9 months

Cumulative production capacity announced, Mt p.a.

AS OF OCT 18 2023



70%

share of capacity of top 3 markets (Europe, North America, Latin America)

+15 Mt

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

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

Source: Project & Investment tracker, as of Oct 2023, McKinsey

Positive: Strong growth in deployment *across the hydrogen ecosystem*

1,100 MW
Electrolysis capacity operational 2023; >600 MW in China
+400 MW from previous publication

370
Projects have passed FID, majority are in Europe
+ 81 from previous publication

710 ktpa
Low-carbon hydrogen capacity operational in 2023, in addition to 25 kt p.a. under construction

3 Mt
Clean hydrogen capacity has passed FID, majority of which is in North America

12 GW
Electrolysis capacity in FID+
~7 GW in China, ~2 GW in the Middle East, ~2 GW in Europe

11 GW
Electrolyzer mfg. capacity according to OEM announcements
+2 GW

15 GW
Fuel cell mfg. capacity today according to OEMs
+3 GW

6
Methanol–ready ships in service, +163 ordered

79,000
Fuel cell vehicles on the road in 2023
+ 20% from 2022[2]

5,000
km of Hydrogen pipeline operational
+ 600km in FID+

>160
Fuel cell vehicle models to be assembled by OEMs in 2023
+20% from 2022

1,100
Hydrogen refueling station deployment: 350+ in China, >250 in South Korea, >200 in Europe, >160 in Japan

Supply
Transmission
Manufacturing capacity
End-use

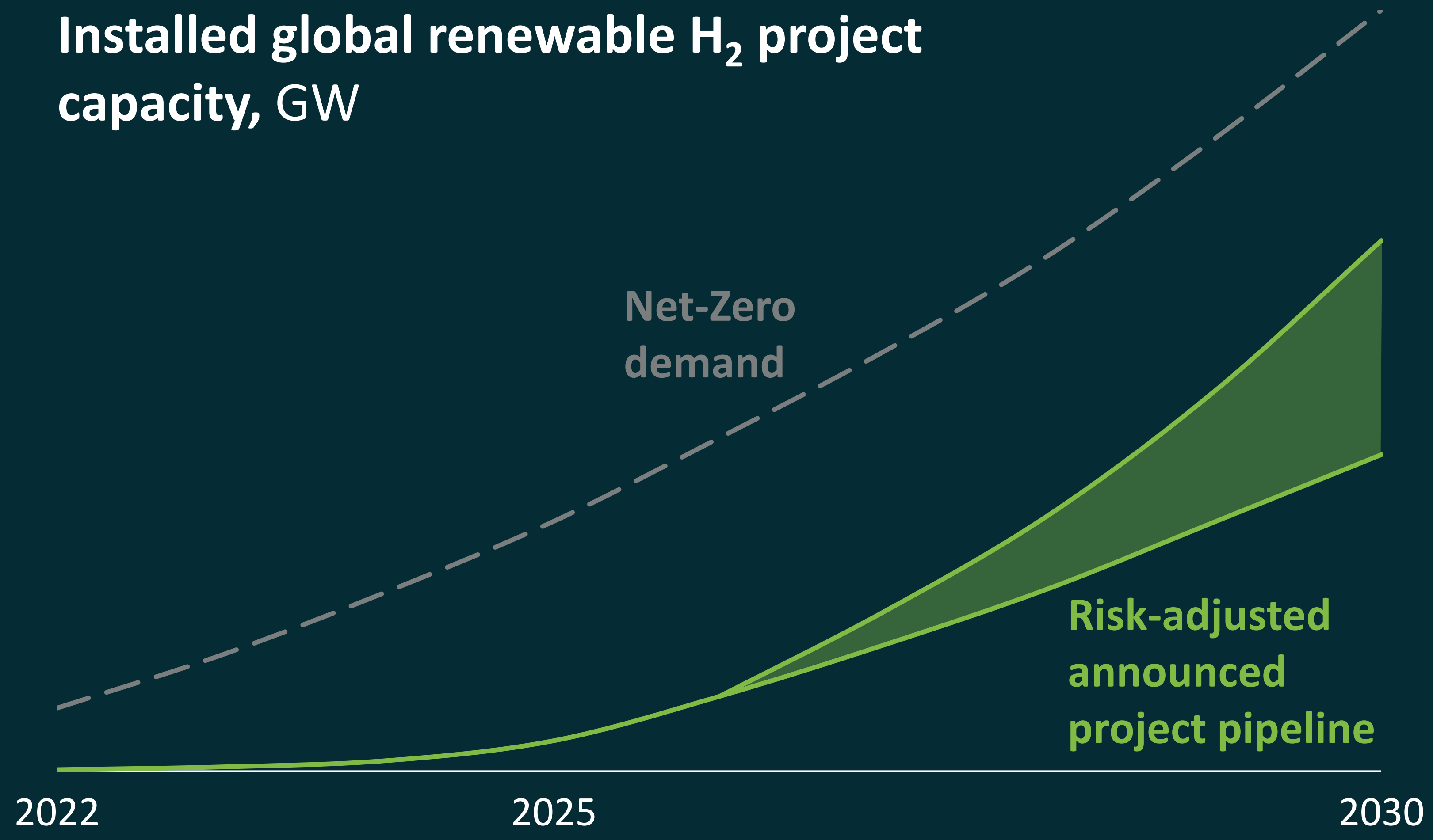
1. Low-carbon hydrogen capacity was adjusted downwards compared to the May 2023 report due to a restatement of the underling data
2. FC electric bus sales in China were adjusted downwards compared to the May 2023 report due to an error in the underlying data

Source: Hydrogen Council; McKinsey

Less positive: the growth is not fast enough

Renewable H2 projects accelerating but still short of Net Zero

Installed global renewable H_2 project capacity, GW



225 GW

of H_2 capacity required by 2030 to meet net-zero H_2 demand

~120 GW

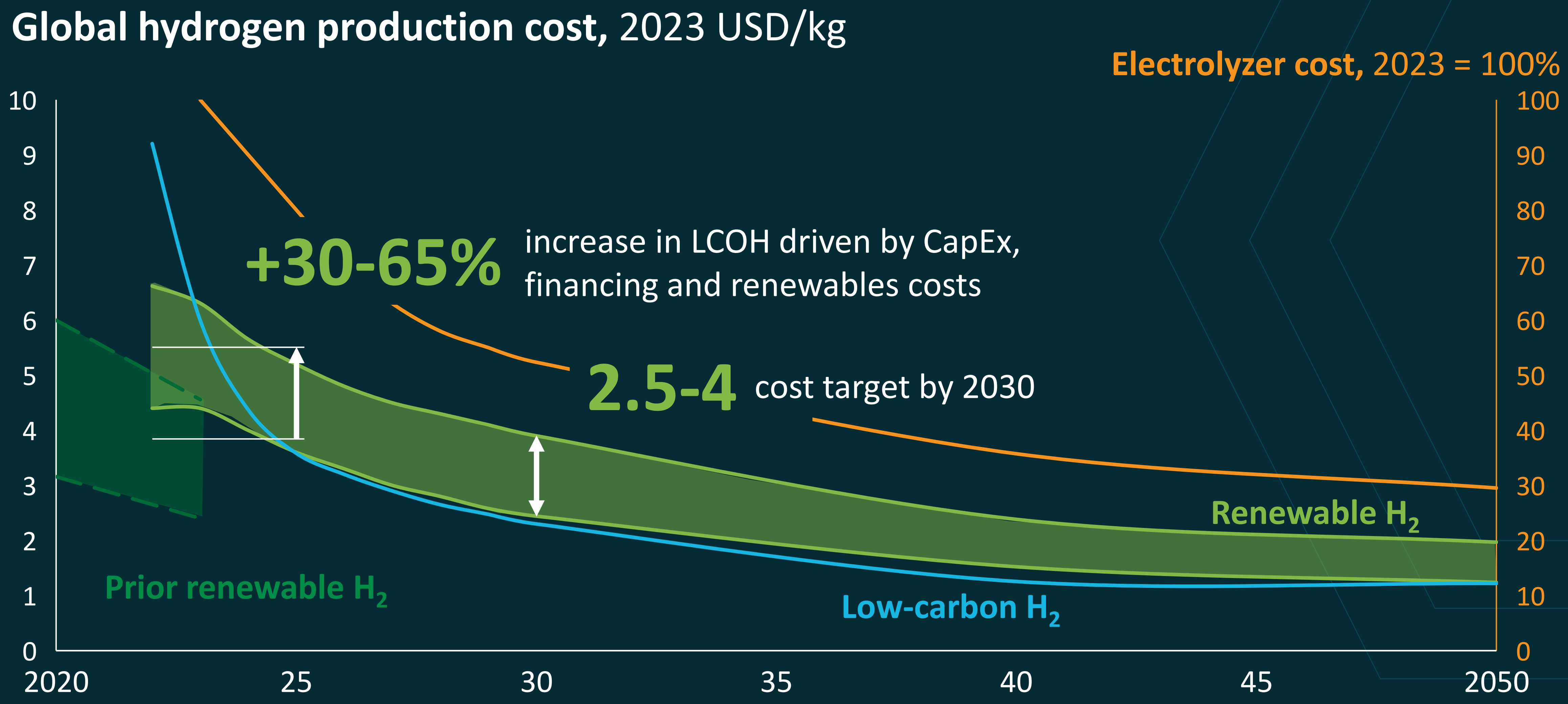
expected capacity online by 2030 when considering delays and cancellations

Net Zero Scenario - 2050

- 22% of global final energy demand
- 660 MT hydrogen
- 80 Gt cumulative CO2 abatement

Less positive: Costs have increased

Near-term renewable hydrogen costs have increased



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Global hydrogen developments

Status	Some positives	Some less positives
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Opportunities: Future global hydrogen trade flows

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There is a mismatch between the best locations for H2 production and demand centers

65%
of global hydrogen demand concentrated in North America, Europe, and East Asia

>20X
difference between lowest- and highest-cost production locations

Hydrogen will need to be transported from supply to demand centers

↓

Trade based on cost competitiveness

↓

We can simulate and compare potential trade routes, and look at the resulting picture

Opportunities: Future global hydrogen trade flows

November 2023

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Hydrogen will need to be transported from supply to demand centers

↓

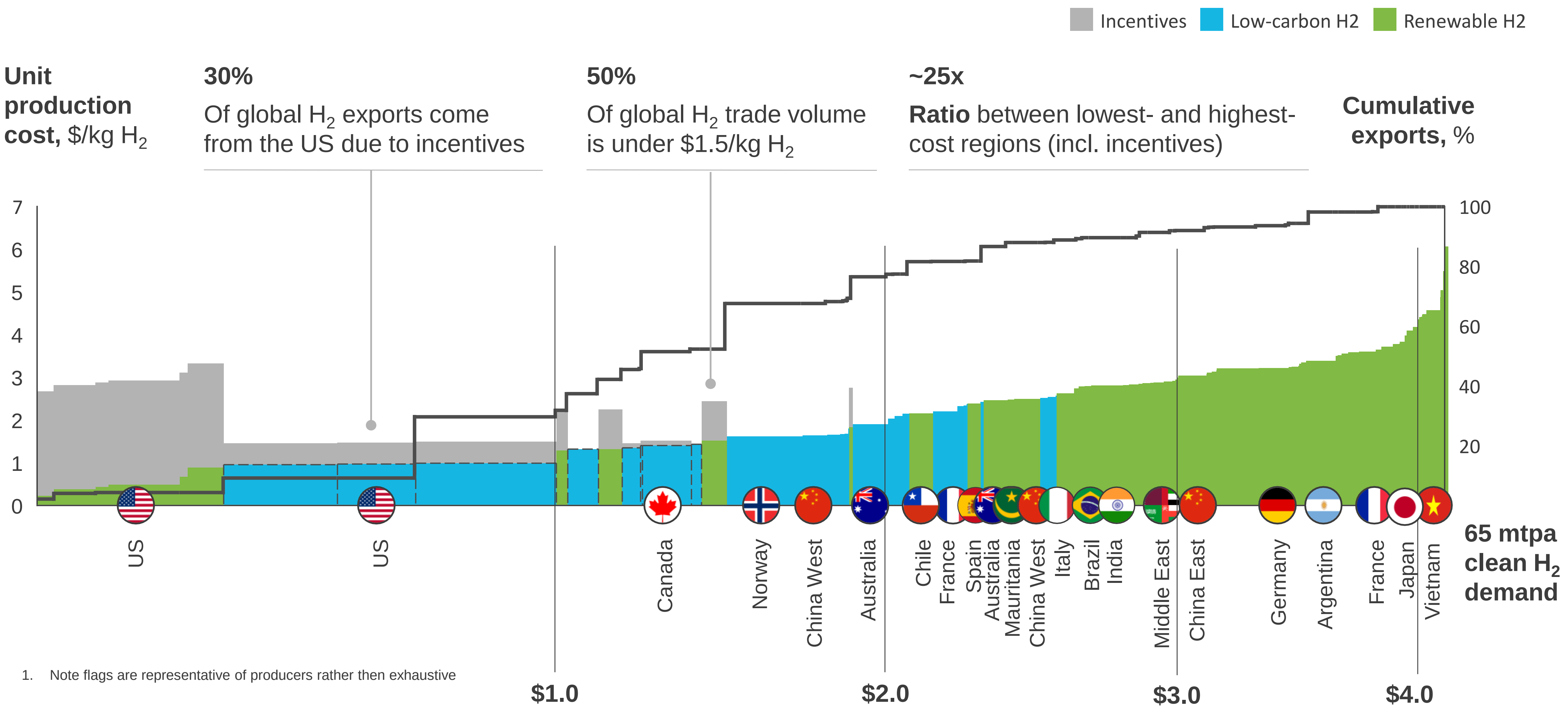
Trade based on cost competitiveness

↓

We can simulate and compare potential trade routes, and look at the resulting picture

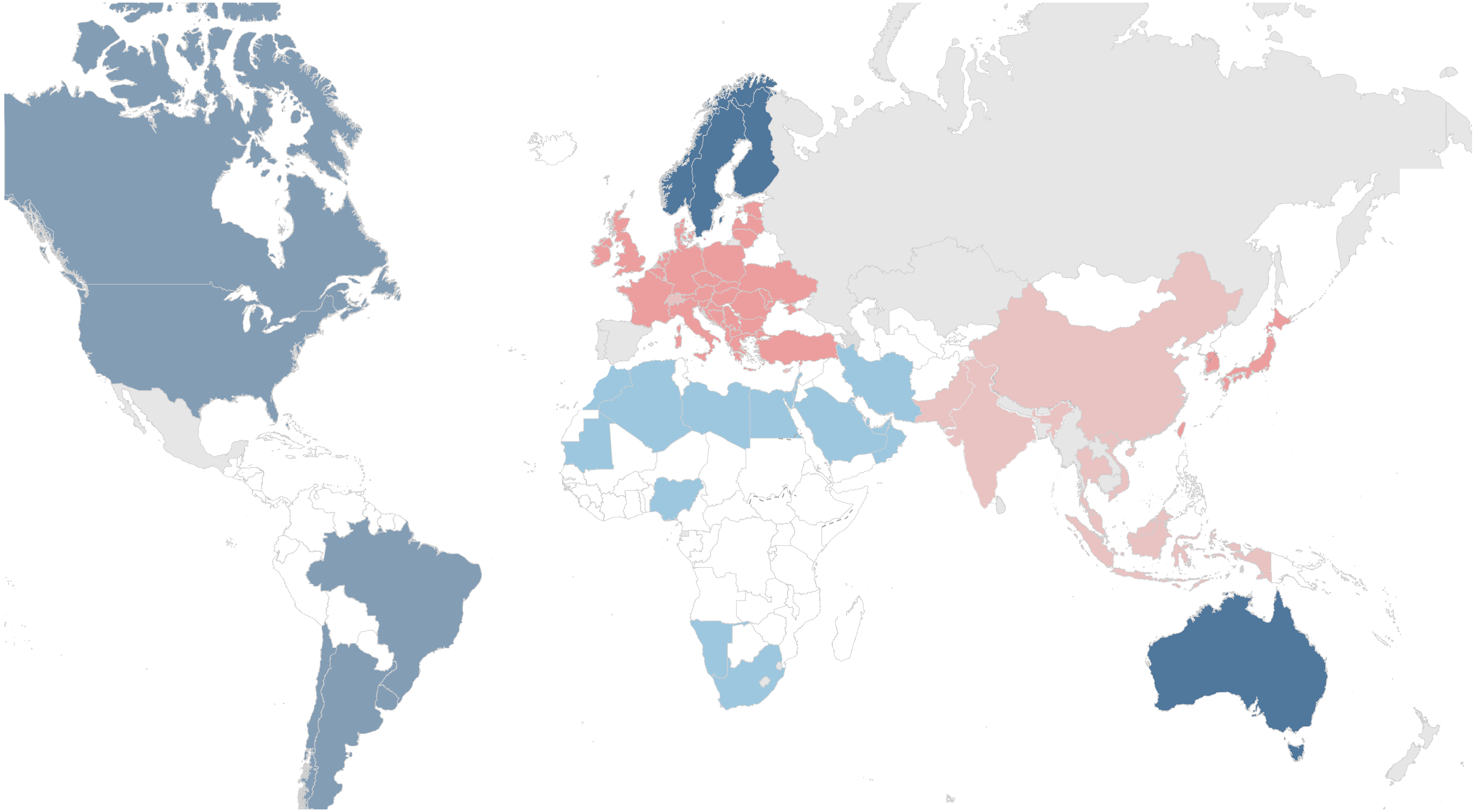
The Net Zero 2030 cost curve sees an additional 25 mtpa of clean H_2 demand with more countries entering the mix

Global clean H_2 production cost curve[1] – Net Zero, 2030



1. Note flags are representative of producers rather then exhaustive

Where are the “natural” importing, exporting countries?



Region consumes more than it produces

Neutral

Region produces more than it consumes

Net trade flows, mtpa H_2

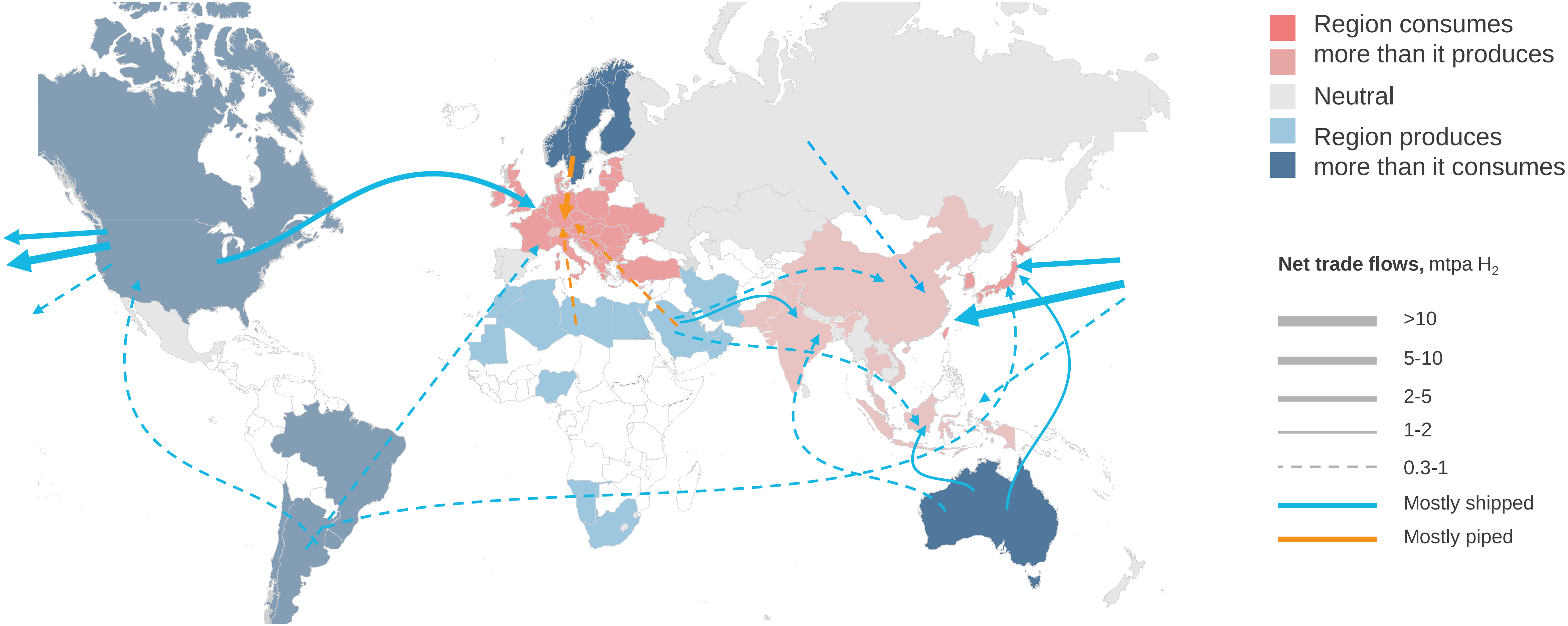
- >10
- 5-10
- 2-5
- 1-2
- 0.3-1
- Mostly shipped
- Mostly piped

Note: Arrows show trade flows between 13 regions (i.e., Latin America, North America, core Europe, peripheral Europe, North Africa, Sub-Saharan Africa, Middle East, CIS, India + Pakistan, China, Northeast Asia, Southeast Asia and Australia)

Source: McKinsey Global Hydrogen Flow Model

By 2030, major early trade routes from North America will already be established

Major flows of hydrogen and derivatives 2030 – Net Zero scenario, mtpa H_2 equivalent



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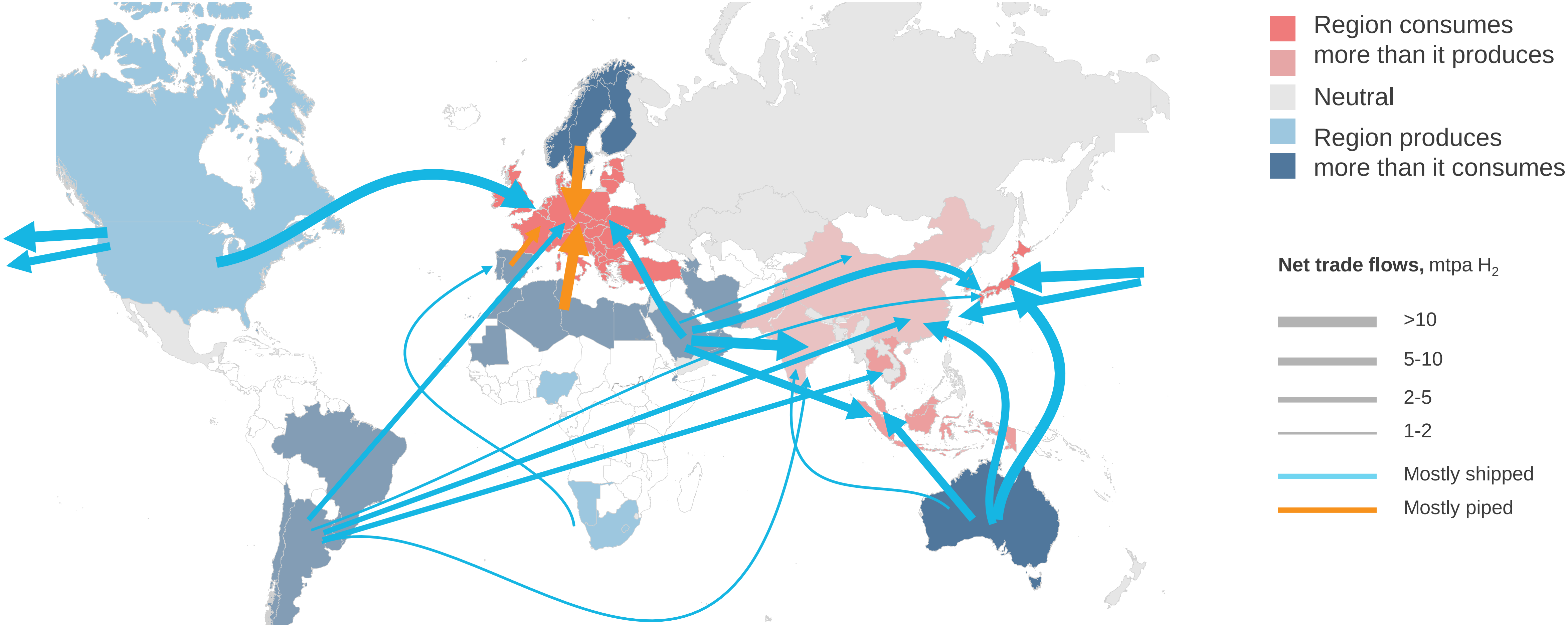
Source: McKinsey Global Hydrogen Flow Model

By 2050, there are several trade routes >10 million tons per year

Major flows of hydrogen and derivatives 2050 – Net Zero scenario, mtpa H_2 equivalent



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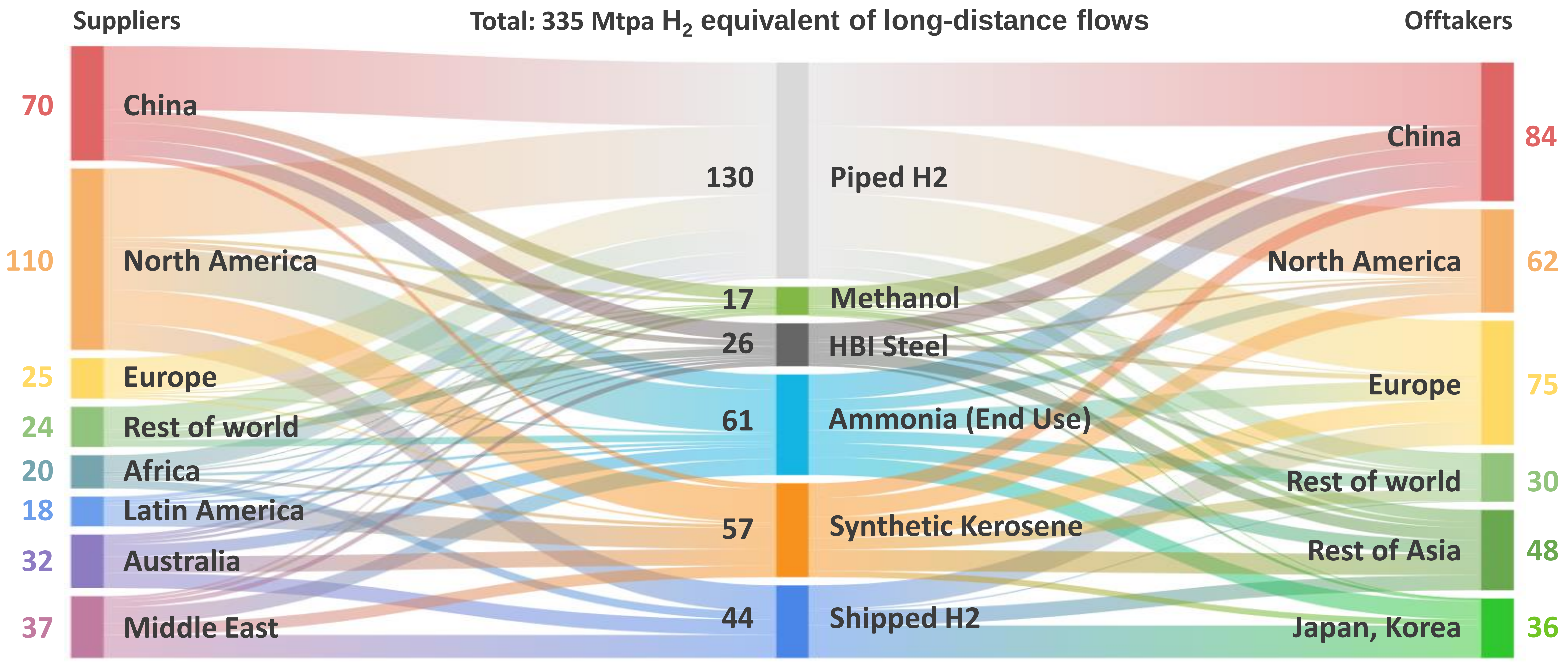
Source: McKinsey Global Hydrogen Flow Model

Under Net Zero, over 50% of clean hydrogen is transported over long distances

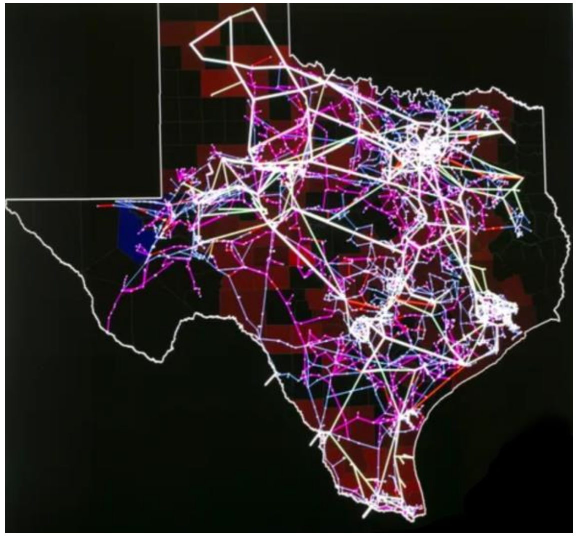
Global H_2 and derivative long-distance trade flows, 2050 mtpa H_2 equivalent

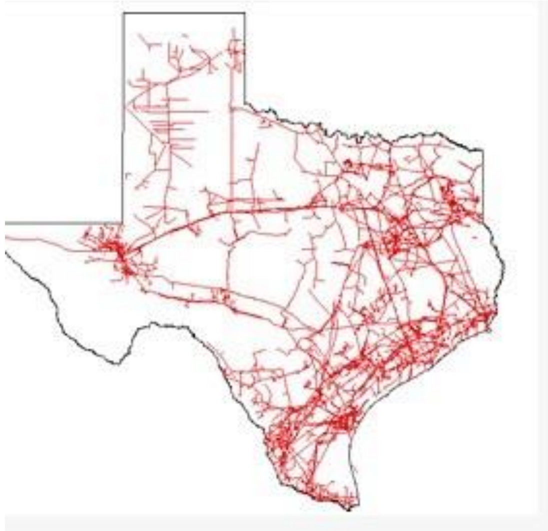


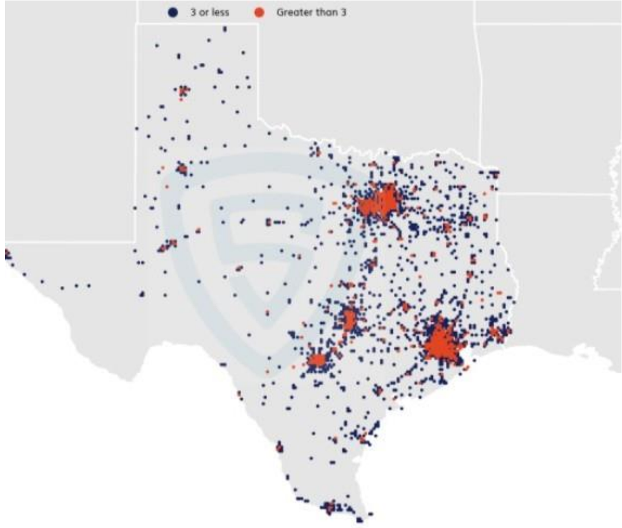
Challenge: our energy system is not integrated

The energy system is composed of different grids, managed separately

Electricity	Gas	Liquid







- Hydrogen will play a role in all three and act as an integrator
- However: our reflections and decisions on energy need to become more holistic and integrative instead of single grid based

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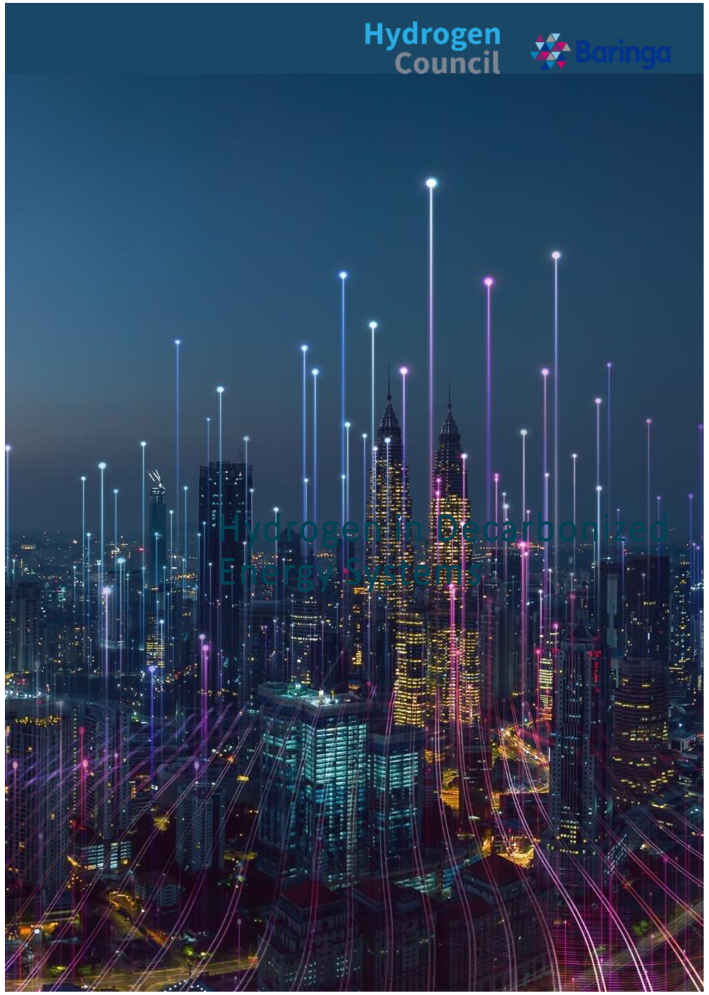
Opportunity: benefits and added value of hydrogen when integrated in the energy system



- We have modeled the role and value of hydrogen integrated in the energy system (C/W Europe, Japan, Texas)

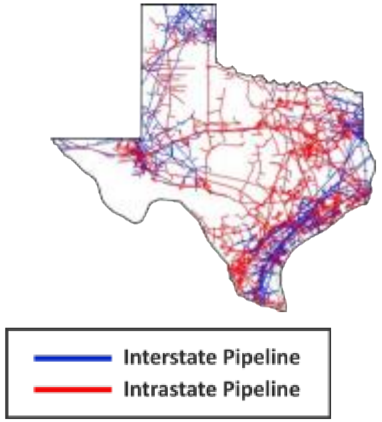
- Message: Electrolyzers responding to market signals could **reduce the renewable capacity** needed by **9%** while lowering system costs by $2.1 billion per year. (for C/W Europe)

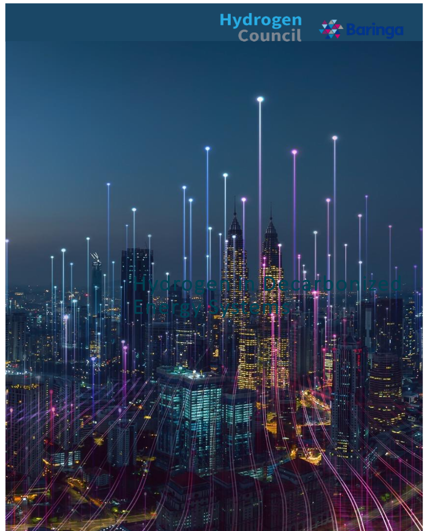
- Conclusion: H2 is about decarbonization.
  But it is also about making REN investments more efficient

(Source: Hydrogen in Decarbonized Energy Systems - Hydrogen Council, October 2023)

Texas as a case study region: resource rich, grid-islanded with demand clusters located far away from resource zones

Texas gas pipelines today





- Produces 25% of US gas, over 40% of U.S. oil, and has built 28% of US wind capacity
- Solar, wind, and gas needs to move from rural areas to ‘Texas triangle’ of demand in the East and South where > 70% of GDP occurs
- Energy exports from Texas and Louisiana represented $315 billion in 2022, and 83 percent of U.S. energy exports
- Currently Potential to export 9 Mt of hydrogen and derived fuels by land and sea

(Source: Hydrogen in Decarbonized Energy Systems - Hydrogen Council, October 2023)

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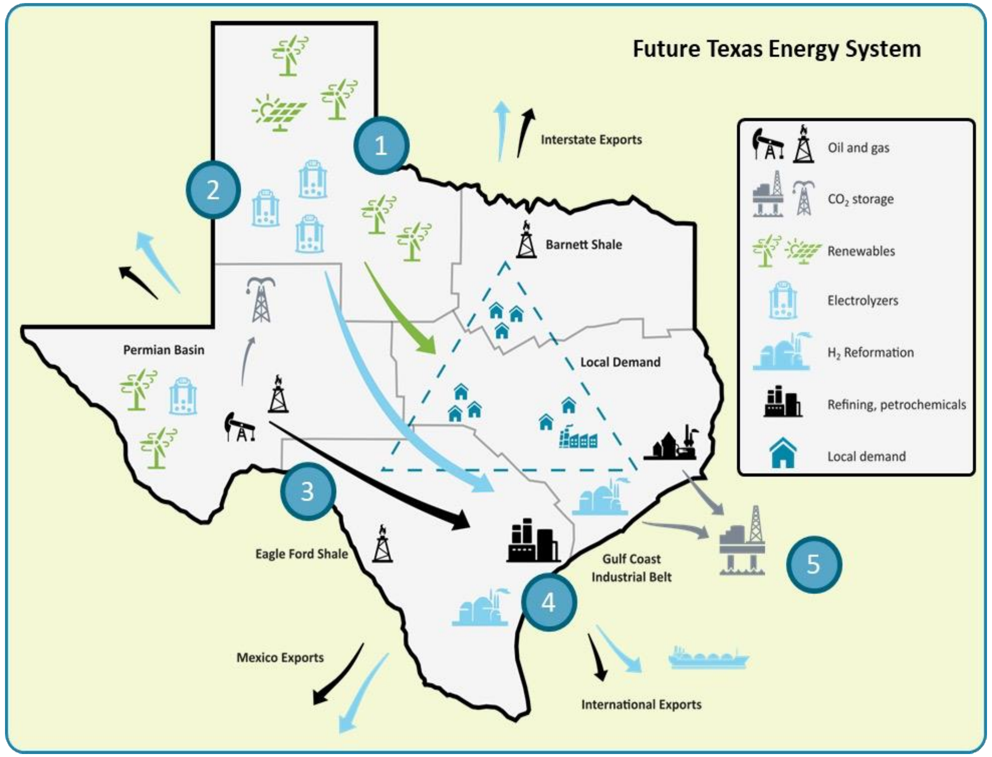
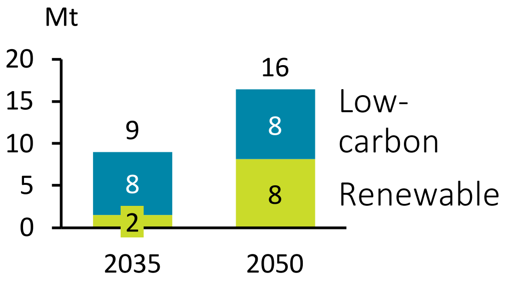
Texas will continue to be an energy exporter but with much more coming from solar and wind via hydrogen

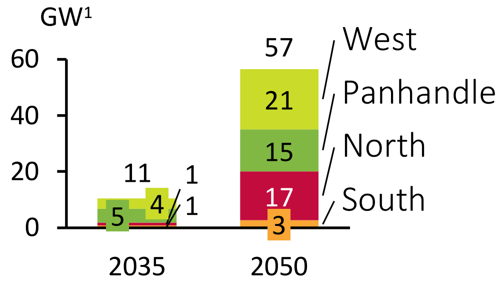


1. Expansion of renewable generation and transmission capacity
2. Co-location of electrolyzers with renewable power supply
3. Repurposing of gas pipeline infrastructure for hydrogen pipelines
4. Production facilities for hydrogen derived liquid fuels
5. CO_2 transport and storage network

Hydrogen production by technology



Electrolyzer capacity by region



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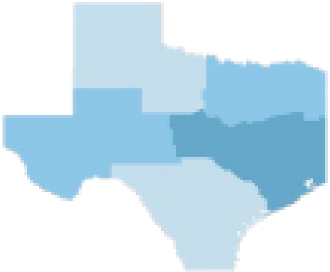
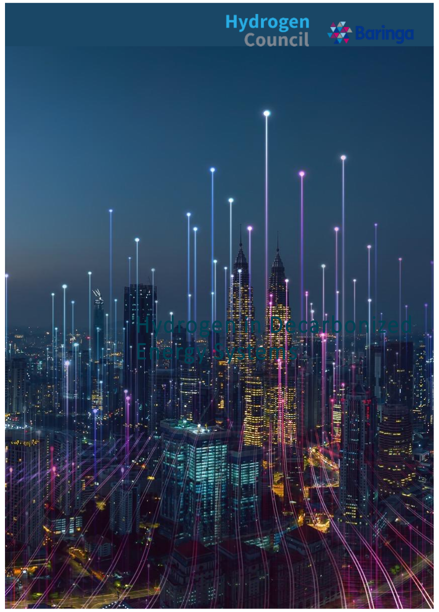
Energy System Modeling: Conclusions for Texas



Texas



Hydrogen can allow Texas to continue to be an energy exporter

- adopting both renewable and low-carbon hydrogen production
- taking advantage of relatively low-cost solar, wind, and natural gas resource, and carbon sequestration potential.

Growth in renewable hydrogen production means electrolyzers and hydrogen-to-power peakers can help stabilize the power system,

- requiring proportionally less batteries and natural gas firing to offer flexibility for every unit of intermittent wind and solar.
- this should not require temporal correlation rules, as prices alone should promote electrolyzers to run when it is best for the system to do so.

Low-carbon hydrogen offers some insurance against any decline in natural gas production that could arise from decarbonization.

- Repurposing of pipelines and storage infrastructure will bring benefits through extended asset life, avoiding stranded network infrastructure.

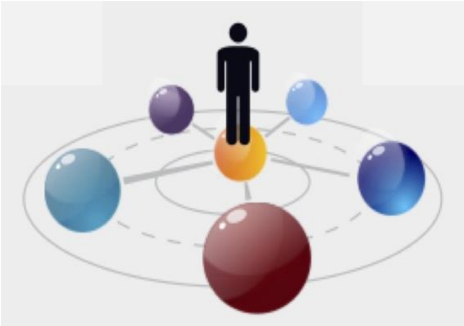
(Source: Hydrogen in Decarbonized Energy Systems - Hydrogen Council, October 2023)

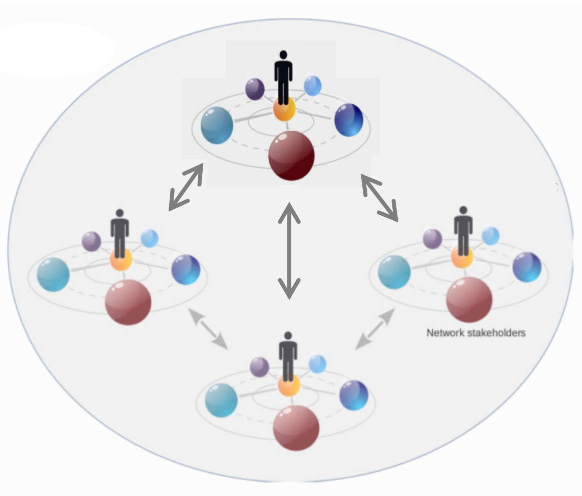
Focus item: hydrogen ecosystems don’t grow magically

Ecosystem growth is a staged process

From

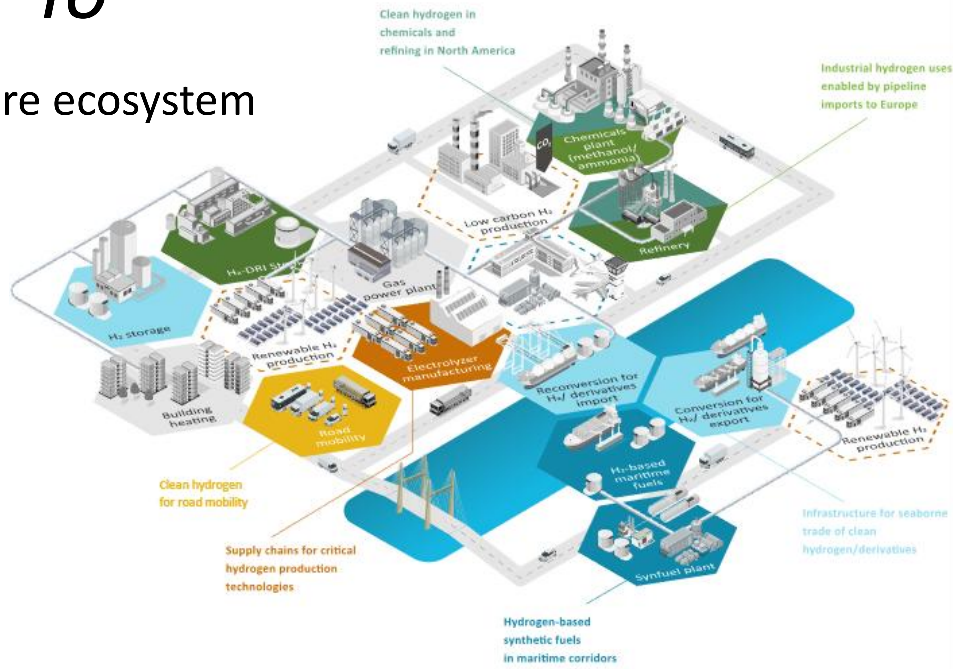
Minimum viable ecosystem





To

Mature ecosystem



Example

- 200 FCEV taxis in a city, with 5 HRS with guaranteed H2 supply and OEM service point

Individuals that make a difference

Many more actors brought in the game

MVE: the smallest ecosystem configuration of elements that need and can be brought together in order to operate as an ecosystem creating unique commercial value

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Some conclusions & challenges

The need for Planning, Adoption, Collaboration between many actors

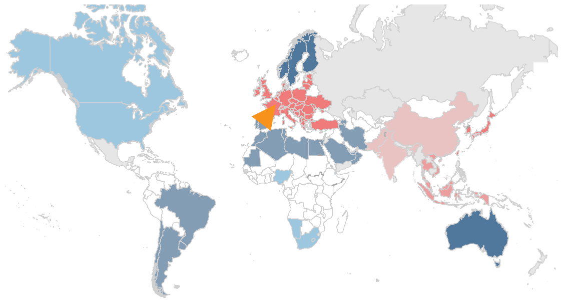
1. The growth of the hydrogen based economy is happening.
There is sustained momentum, but we also face some headwinds

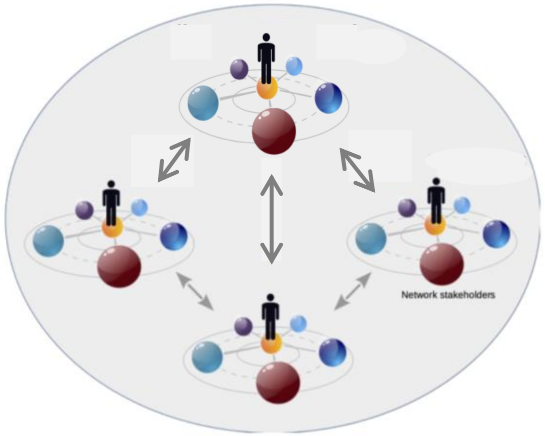
2. Governments & industry need to work together
to maximize the opportunities offered by global hydrogen trade and the integrated role of hydrogen *(building infrastructure)*

3. We need to reason in terms of staged ecosystem growth
(first focus: minimal viable ecosystems)

4. More than supply & demand: we need to reason in terms of the entire supply chain *(synchronized rise)*

5. Success = Infrastructure **X** Products **X** Economics





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Thank you

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