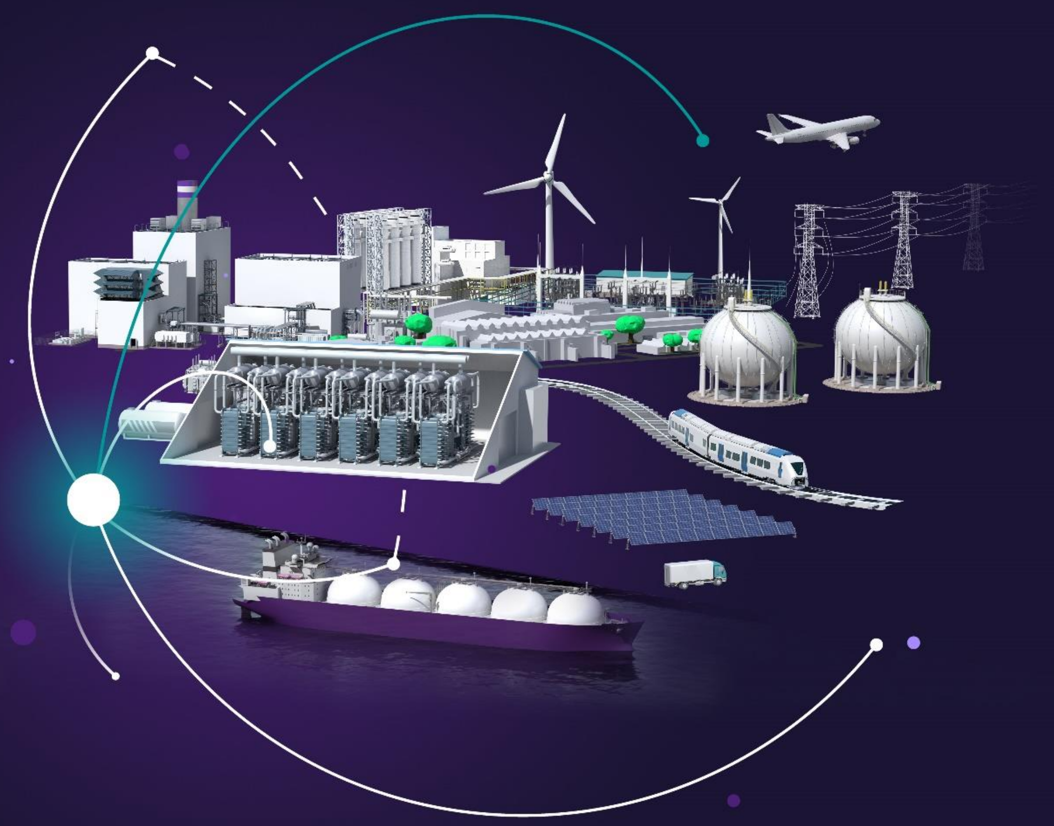
Siemens Energy

Comissão de Transição Energética e Produção de Hidrogênio Verde



Sustainable Energy Systems
Andreas Eisfelder

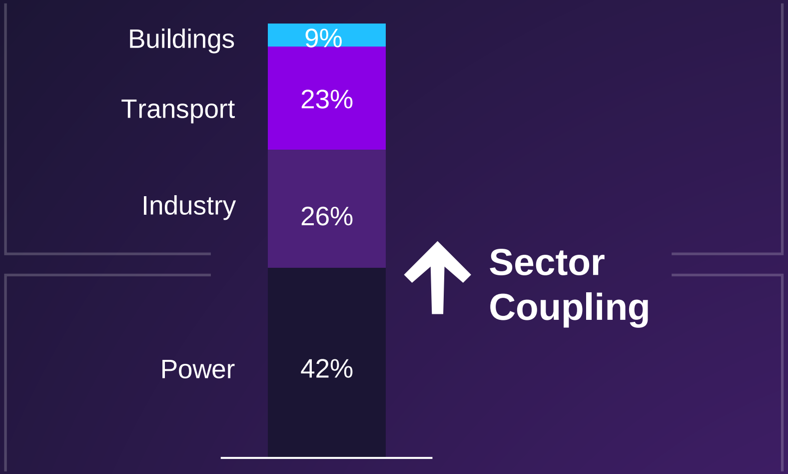
August 8, 2023

"Sector Coupling"
Key lever for decarbonization of all end-user sectors

SIEMENS energy

Shares in global CO_2 emissions by sectors

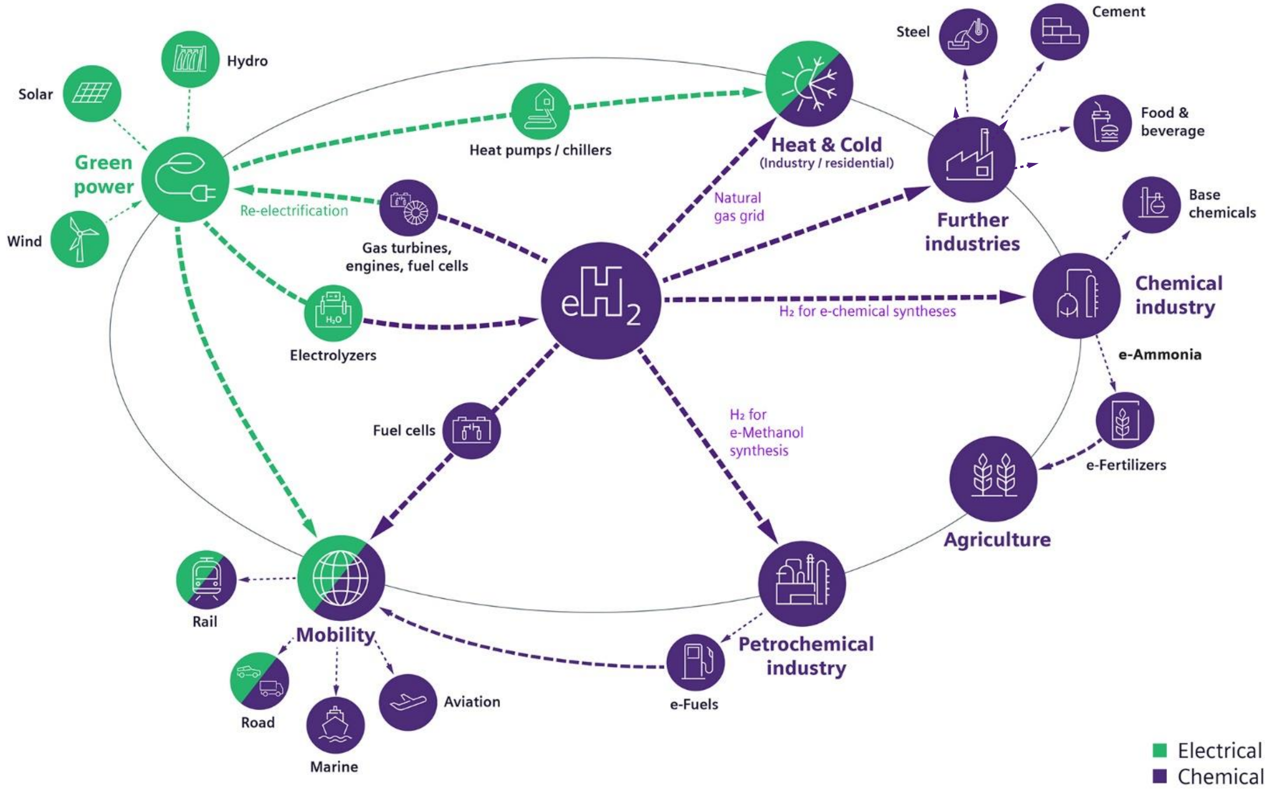
Leverage green electricity in other sectors
Share on CO_2 emissions: 58%
Share of Renewables: 11%



Successful integration of renewables in Power
Share on CO_2 emissions: 42%
Share of Renewables: 27%

Source: 2022 data from IEA and own estimates

The role of hydrogen – A versatile molecule

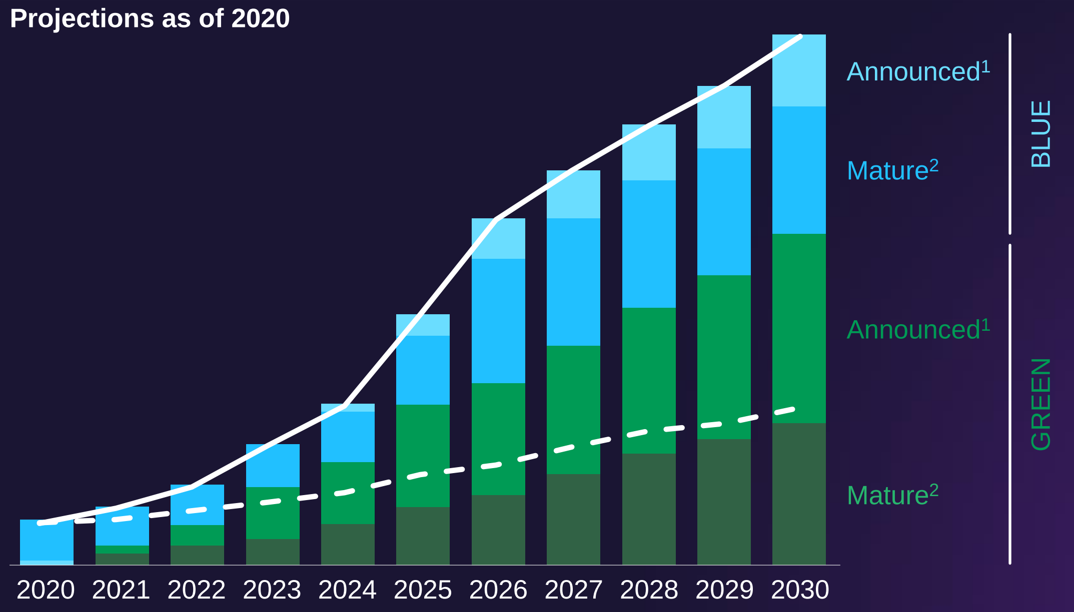


Strong growth in green hydrogen production drives cost competitiveness

SIEMENS energy

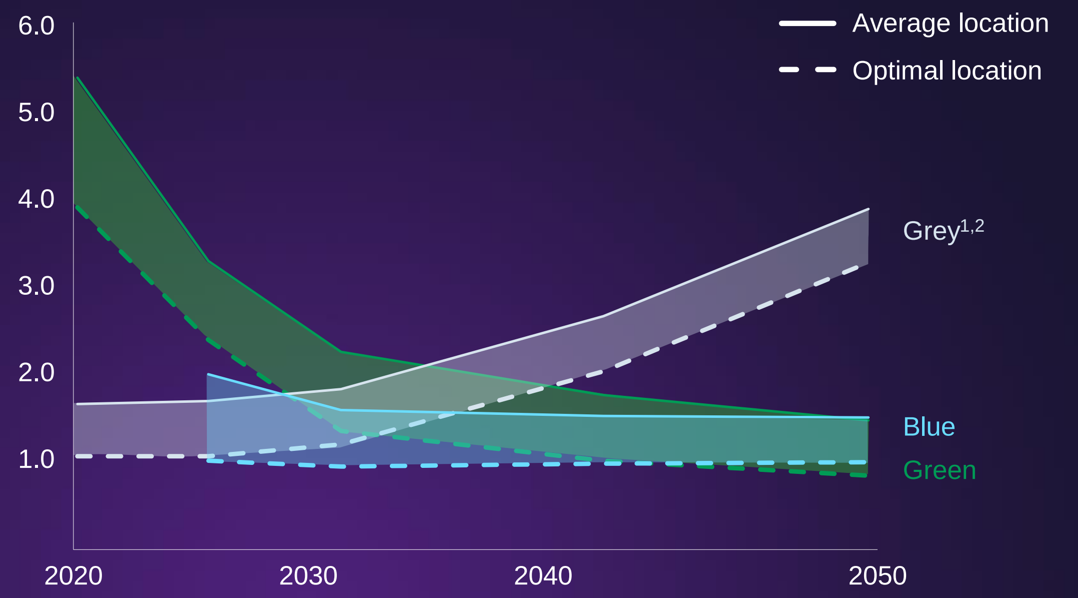
Announced clean hydrogen capacity through 2030

Production capacity
Mt p.a.



Hydrogen production pathways, including carbon costs

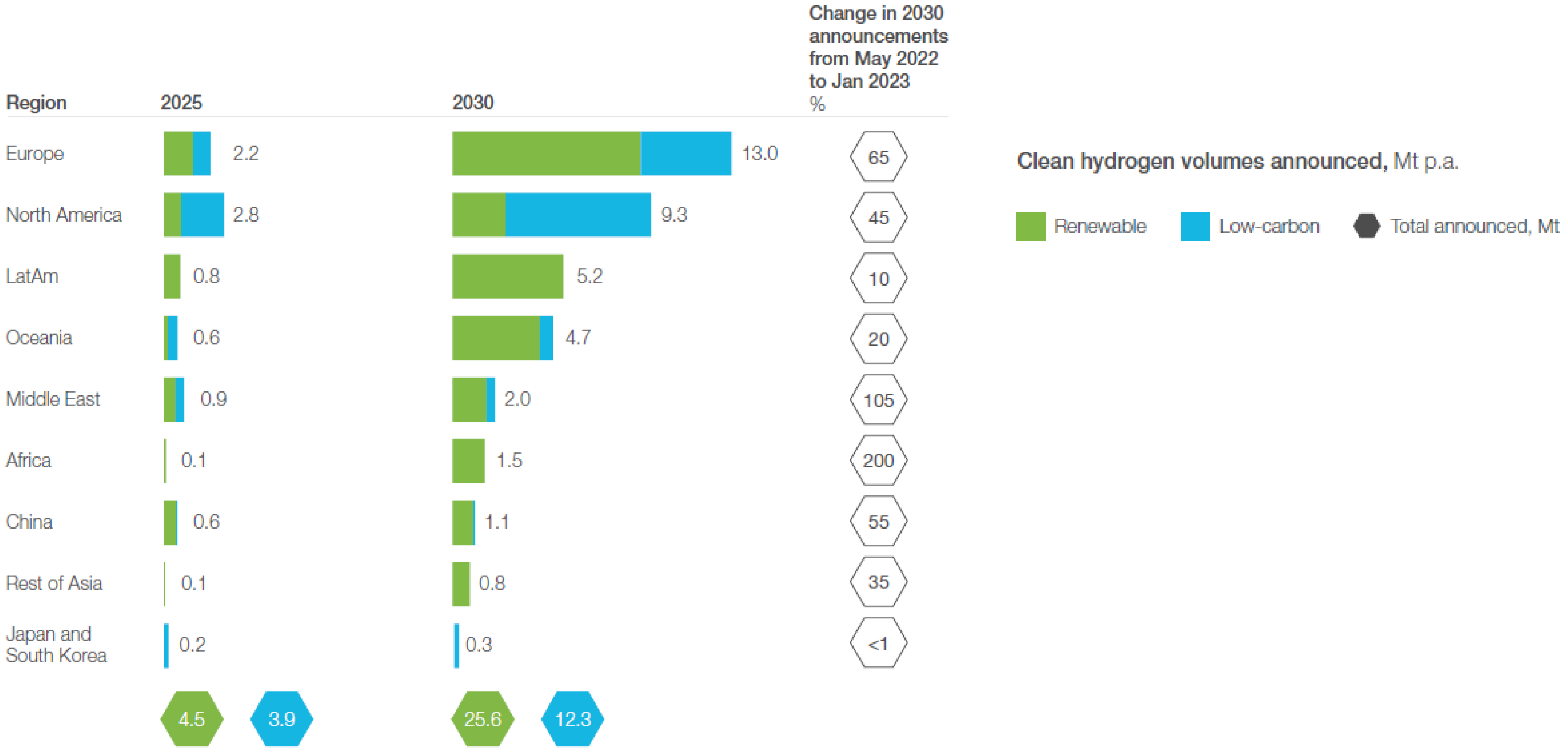
Production cost of hydrogen
US$/kg



Key assumptions: Gas price 2.6 – 6.8 US$/Mmbtu
Cost US$/Ton CO_2 30 (2020), 50 (2030), 150 (2040) and 300 (2050)
LCOE US$/MWh 25 – 73 (2020), 13 – 37 (2030) and 7 – 25 (2050)

Source: Hydrogen Council, McKinsey "Hydrogen insights report 2021" | 1 Includes projects at preliminary studies or at press announcement stage | **2** Includes projects that are at the feasibility study or front-end engineering and design stage or where a final investment decision (FID) has been taken, under construction, commissioned or operational

Hydrogen Insights 2023
Source: Hydrogen Council, McKinsey & Company



Explore the potential of green hydrogen

Green Hydrogen Production Website
www.siemens-energy.com/electrolyzer

Haru Oni App
www.haruoni.com

Haru Oni Project Website
Haru Oni hydrogen plant | 2021 | Siemens Energy Global (siemens-energy.com)

ESD Website
Energy System Design | Power plant solutions | Siemens Energy Global

Hybrid Power Solutions Website
Hybrid power solutions | Power plant solutions | Siemens Energy Global

Hydrogen Website
Hydrogen | Future Technologies | Siemens Energy Global

Hydrogen Council

McKinsey & Company

Hydrogen Insights 2023

An update on the state of the global hydrogen economy, with a deep dive into North America

May 2023

Published in May 2023 by the Hydrogen Council. Copies of this document are available upon request or can be downloaded from our website:

www.hydrogencouncil.com

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2. It is not their intention that any such form of coordination will be adopted.

Whilst the contents of the report and its abstract implications for the industry generally can be discussed once they have been prepared, individual strategies remain proprietary, confidential, and the responsibility of each participant. Participants are reminded that, as part of the invariable practice of the Hydrogen Council and the EU competition law obligations to which membership activities are subject, such strategic and confidential information must not be shared or coordinated – including as part of this report.

The Hydrogen Council has **145 members** and is a **global CEO-led initiative** with a **united vision** and **long-term ambition** for hydrogen to foster the clean energy transition

Hydrogen Council

Steering members

Supporting members

Investors

Hydrogen Insights is the Hydrogen Council's perspective on the hydrogen industry's evolution. It summarizes the current state of the global hydrogen sector and actual hydrogen deployment. The Hydrogen Council and McKinsey & Company co-author this publication. It represents a collaborative effort to share an objective, holistic, and quantitative perspective on the status of the global hydrogen ecosystem.[1]

[1] Detailed methodology described in Hydrogen Insights 2021

01

Hydrogen momentum continues to accelerate, but investment decisions are lagging

>1,000
hydrogen project proposals announced globally, 795 of which plan full or partial deployment by 2030

USD 320 billion
direct investments into hydrogen projects announced through 2030, of which USD 29 billion have passed the final investment decision (FID)

38 Mt p.a.
clean hydrogen supply announced globally 2030, less than 1 Mt p.a. deployed today

Exhibit 1

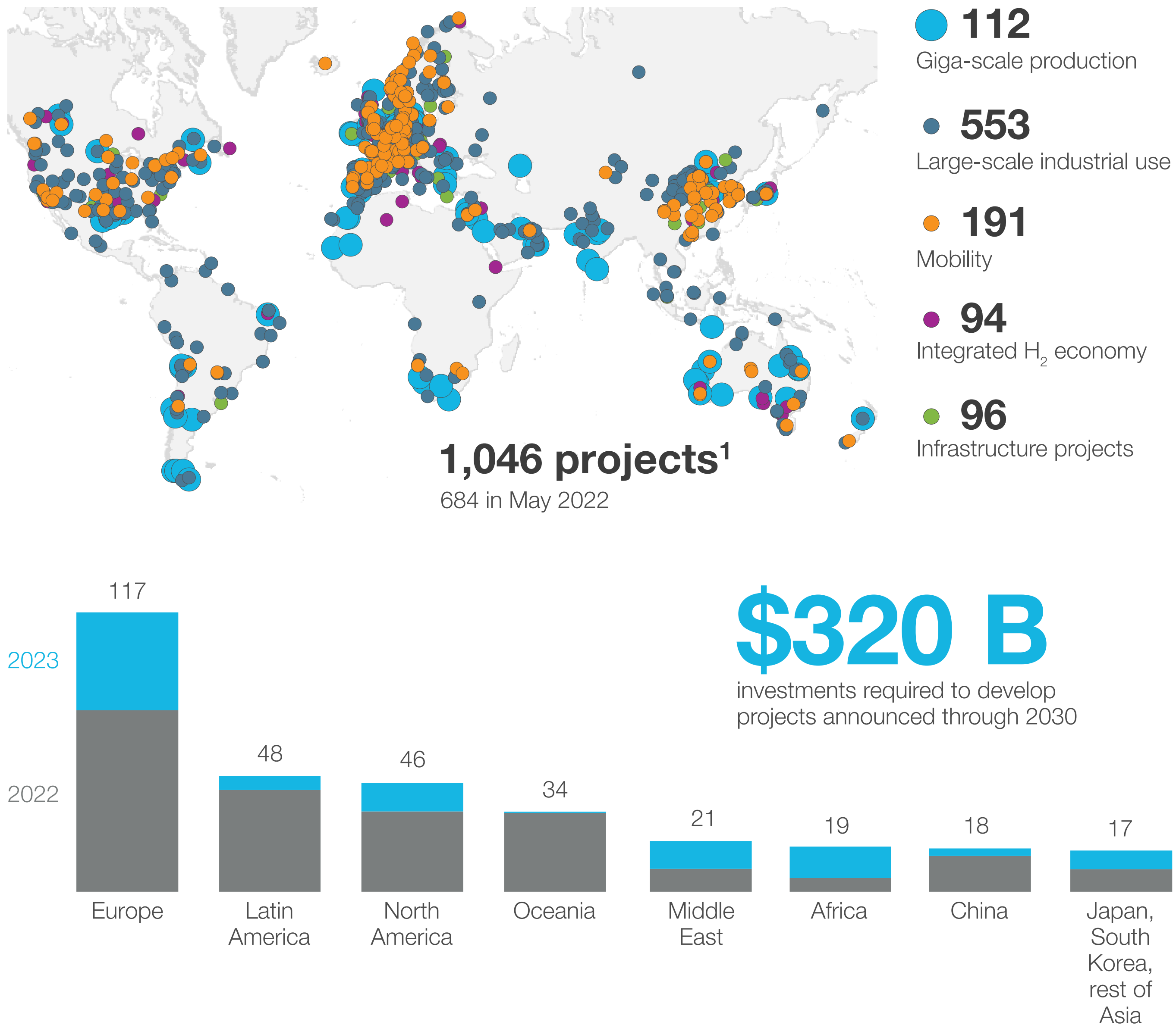
Hydrogen momentum is strong: more than 1,000 project proposals have been announced globally

Globally, the industry has announced more than 1,000 large-scale project proposals as of the end of January 2023. Since the previous publication,[2] more than 350 new proposals have been announced. Of the total, 795 aim to be fully or partially commissioned through 2030 and represent total investments of USD 320 billion of direct investments into hydrogen value chains through 2030 (up from USD 240 billion).

Europe remains the global leader in hydrogen project proposals, with the highest total investments (USD 117 billion, 35% of global investments) and highest absolute growth (USD 40 billion). Latin America and North America follow Europe, each representing about 15% of announced investments. Growth in North America increased following the announcement of the IRA (see Section 03 of this publication).

Giga-scale project proposals (over 1 GW of electrolysis for renewable hydrogen supply or more than 200,000 kt p.a. of low-carbon hydrogen) account for 112 project proposals (requiring about USD 150 billion investment until 2030), nearly doubling from 61 eight months ago. Of these 112 proposals, 91 are renewable and 21 are low-carbon hydrogen.

Momentum is strong, and the industry is planning investments into clean hydrogen, yet much more needs to be done. To be on track to net zero in 2050, more than a doubling of announced investments is needed by 2030 – and these need to be matured and deployed.



1. Focus on projects of >1 MW

Source: Project & Investment tracker, as of Jan 31, 2023

[2] Hydrogen Insights 2022 with data from May 2022; comparisons in this report are relative to this publication unless stated otherwise

Exhibit 2

The project funnel is growing across project stages, yet remains skewed toward announcements

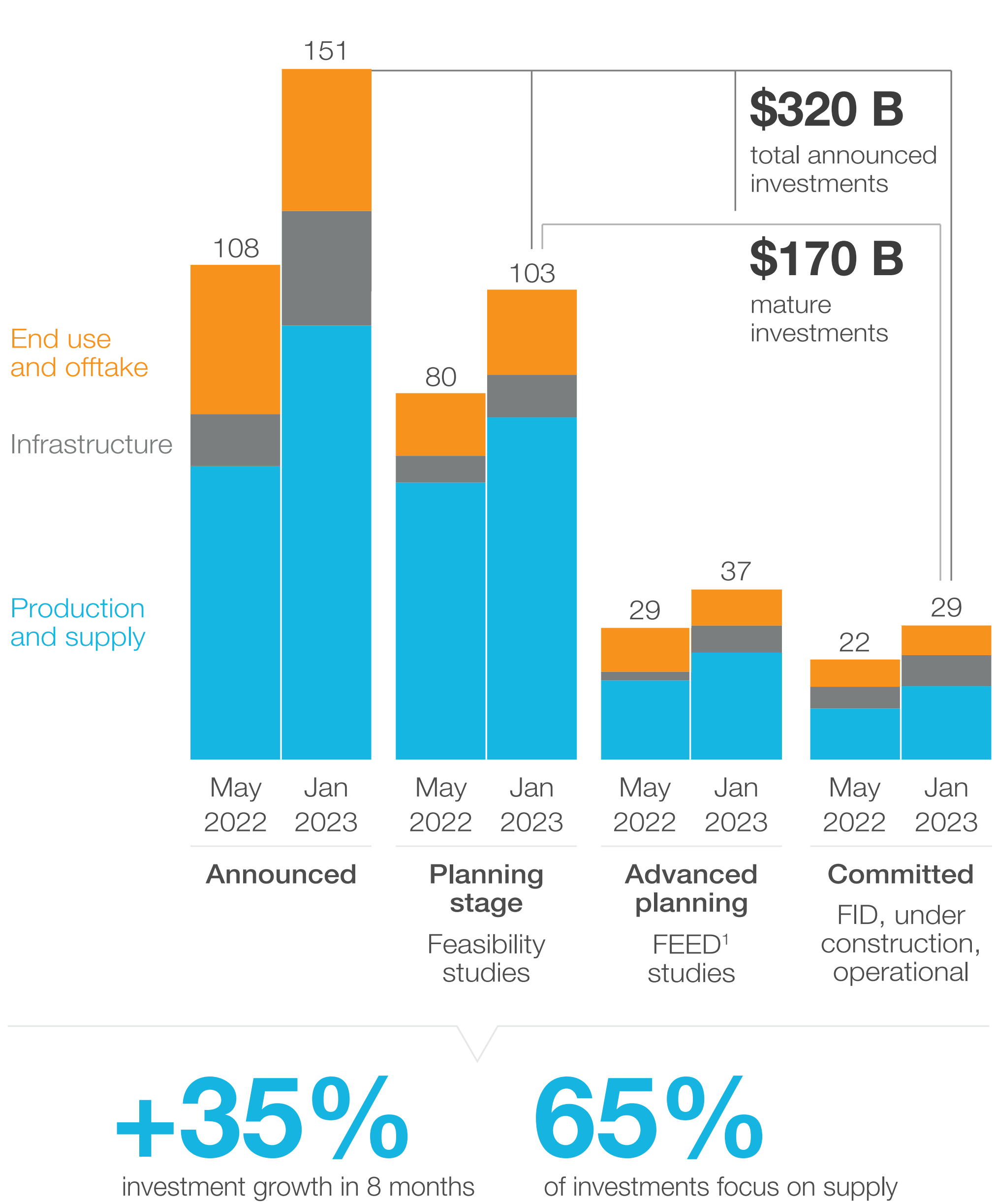
Total announced investments until 2030 have increased by 35% in the past eight months – from USD 240 billion to USD 320 billion. All project maturity stages have grown by 30% to 40% yet remain heavily skewed toward early-stage projects: almost half of the projects are announced but have not yet entered the planning stage, received government funding, are in advanced planning, or have taken FID.

Overall, investments in the committed category have accelerated. They grew only 10% from September 2021 to May 2022 and 30% from May 2022 until January 2023, and the first large-scale projects have achieved FID in the last months. While Europe leads on announcements, North America leads with committed investments (USD 10 billion). Europe (USD 7 billion), the Middle East (USD 5 billion), and China (USD 5 billion) follow, with growth in China being the highest at more than 200%.

For developers to take FID, securing offtake and potentially government funding is key. Most projects at or past FID have either captive offtake, i.e., developed by companies with internal demand for hydrogen, or long-term offtake contracts. In terms of government funding, the largest schemes are IPCEI[3] in Europe (EUR 10.6 billion granted in the first two rounds), the production tax credits (45V), and credits for carbon capture and storage (45Q) in the US. In Japan and South Korea, funding has supported infrastructure buildout (e.g., refueling stations, liquid hydrogen value chain in Japan), whereas hydrogen clusters have received government funding in China.

Despite a positive trend, less than 10% of the USD 320 billion announced investments through 2030 are real committed capital. The industry is maturing in strained supply chains, labor shortage (e.g., EPC), increasing inflation and interest rates, and lack of public support in many markets, all of which may slow deployment. By 2030, committed capital must increase more than twentyfold to track a net-zero scenario. For this to result in clean hydrogen deployment, the resources and equipment must be available to ensure deployment of clean hydrogen supply projects, prevent infrastructure bottlenecks, and enable hydrogen-ready end-user plants.

Direct hydrogen investments until 2030, $B



1. Front-end engineering design

Source: Project & Investment tracker, as of Jan 31, 2023

[3] Important projects of common European interest

Exhibit 3

Europe, North America, and the Far East have the largest number of projects with committed capital

The geographic perspective on the project funnel indicates that regions with high energy demand and early focus on hydrogen as a decarbonization vector (e.g., Europe, China, and North America) have advanced more projects to FID.

In regions expected to export clean hydrogen and its derivatives (e.g., Latin America, Australia, Middle East, Africa) with limited local demand, projects tend to be larger and in earlier stages of development (feasibility or FEED studies). Few of these projects have passed FID, and many are developed in phases, potentially due to the lower risk of deploying a smaller project or limited current market size for clean hydrogen and hydrogen derivatives (e.g., ammonia, methanol).

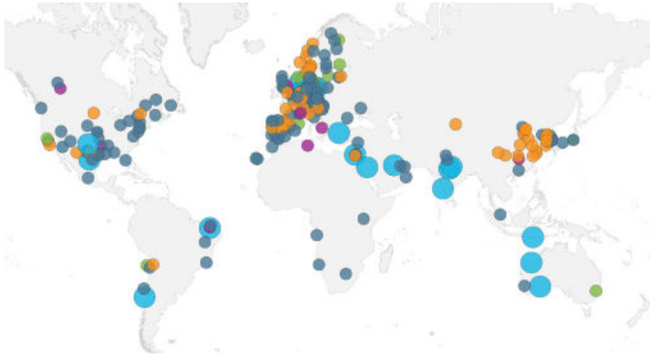
The average investment size of a project that has passed FID is about USD 100 million on average, whereas projects in the early stage (i.e., announced) require about USD 600 million investment on average,[4] showcasing the growing scale of hydrogen projects.

Giga-scale production · Large-scale industrial use · Mobility · Integrated H_2 economy · Infrastructure projects

260 projects announced

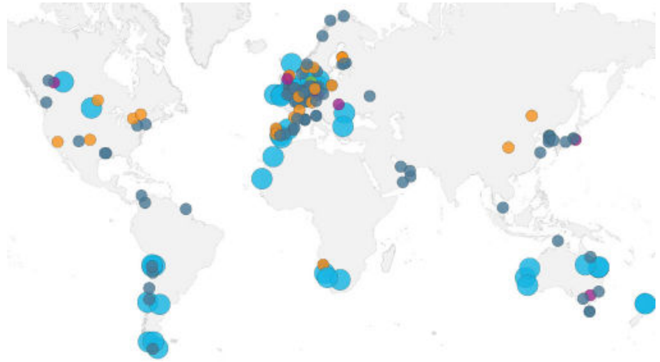
Preliminary studies or press announcement stage

28[1] · 151 · 47 · 13 · 21



172 projects in feasibility studies

42[1] · 90 · 22 · 10 · 8



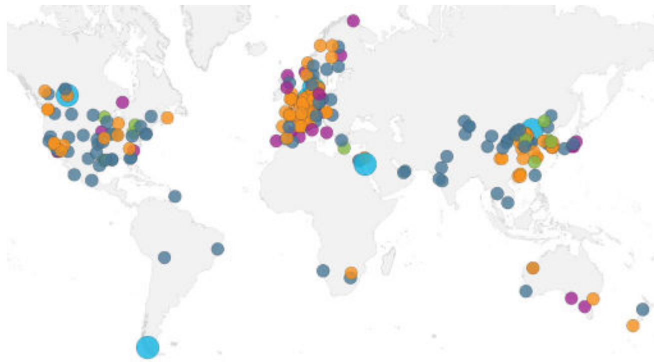
83 projects in FEED studies

16[1] · 40 · 14 · 6 · 7

280 projects committed

FID taken, under construction or operational

6[1] · 132 · 78 · 36 · 28



795 projects with full or partial commissioning (COD) by 2030

+251 projects without specified COD or COD post-2030 (not shown)

1. For multiphase projects, phase 1 decides the project maturity

Source: Project & Investment tracker, as of Jan 31, 2023

4 Total announced investment volumes divided by number of projects in each investment stage (project counted by earliest maturity stage, e.g., a project with phase 1 in FEED and phase 2 in Announced will be counted as FEED)

Exhibit 4

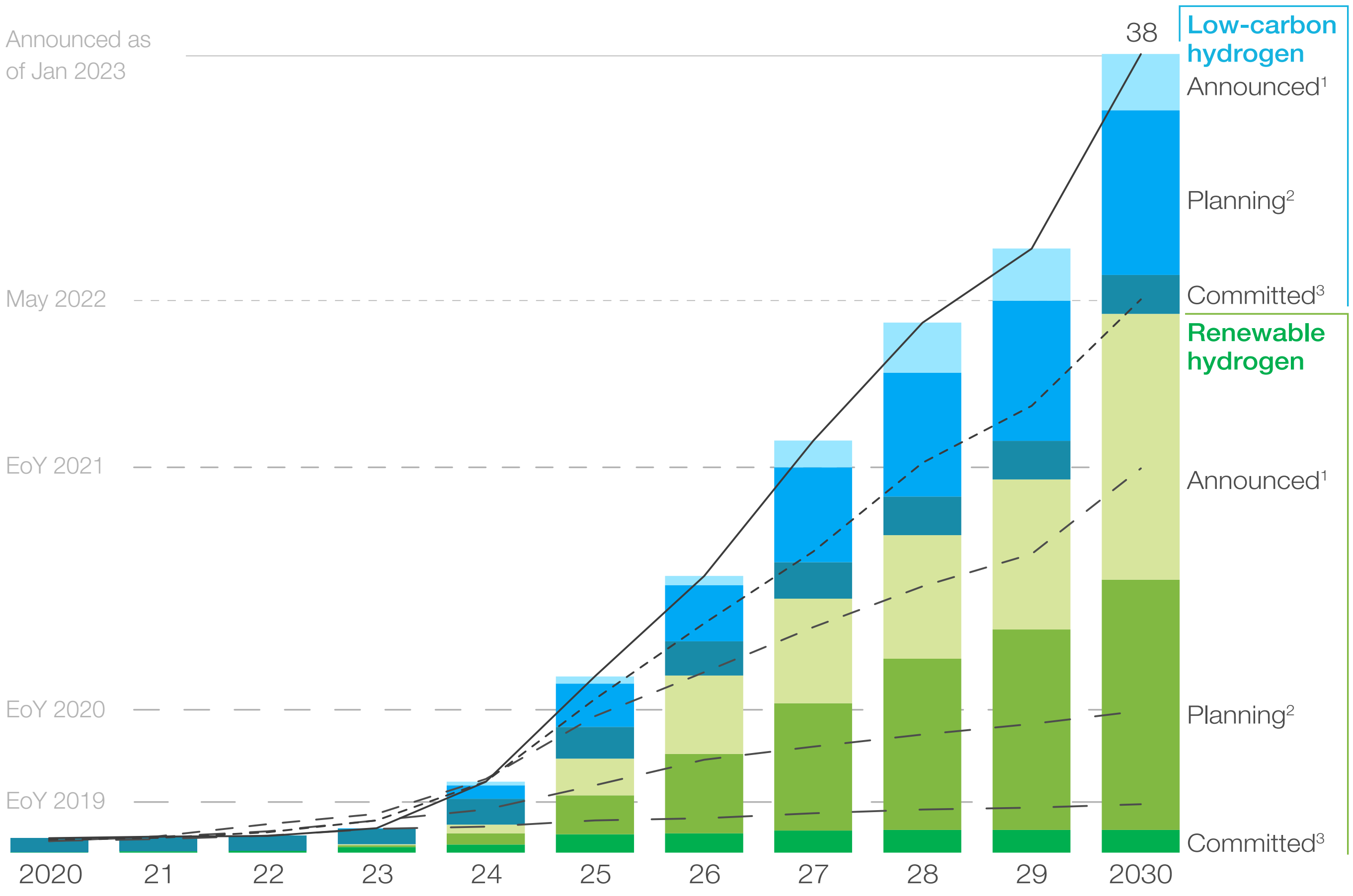
Announced production volumes increased by more than 40% to 38 Mt p.a., reaching half the volume needed in 2030 to be on track to net zero

Companies have announced 38 Mt p.a. clean hydrogen production plans globally for 2030 across low-carbon and renewable hydrogen (up from 26 Mt p.a.), of which about half is in the planning stage or has committed capital. More than two-thirds of the 38 Mt p.a. are renewable hydrogen (about 25 Mt p.a.), and the remainder is low-carbon (about 13 Mt p.a.). Of the 12 Mt p.a. supply projects added in the past eight months, about 10 Mt p.a. are renewable hydrogen driven by the high growth in announcements in renewables-rich regions (e.g., Africa, Middle East).

The data also reveals that developing and deploying projects can take longer than initially estimated by developers. For instance, as of October 2021, the industry had announced a cumulative deployment of nearly 6 GW electrolysis by the end of 2022 (equivalent to about 0.7 Mt p.a.[5] renewable hydrogen supply), while actual deployment as of January 2023 stands at only 700 MW. The next three to five years represent a significant scale-up challenge: nearly 3 Mt p.a. of capacity has passed FID (of which only 0.8 Mt p.a. is operational) and should be deployed in the coming years, predominantly in North America (about 70% of volumes), followed by Asia-Pacific (about 15%, most of which is in China) and the Middle East (8%).

In 2030, 38 Mt p.a. is roughly half what is needed to be on track to a net-zero scenario[6] (75 Mt p.a. in 2030). Closing this gap is challenging, as renewable hydrogen projects are struggling with slow permitting, supply of electrolyzers, solar panels, wind turbines, and EPC capacity constraints. Low-carbon hydrogen projects also face challenges; large-scale infrastructure for carbon capture, transportation, and storage must be built, which requires permitting (often complex and lengthy) as well as significant capital and labor.

Cumulative production capacity announced, Mt p.a.



>70%
share of capacity in top 3 markets (Europe, North America, Latin America)

+16 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 made, under construction, commissioned or operational

Source: Project & Investment tracker, as of Jan 31, 2023

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[5] Assuming 70% load factor and 67% efficiency (lower heating value)
[6] Detailed in the Hydrogen for Net Zero publication (November 2021)

Exhibit 5

Europe is the largest in terms of announced supply, followed by the Americas and Oceania

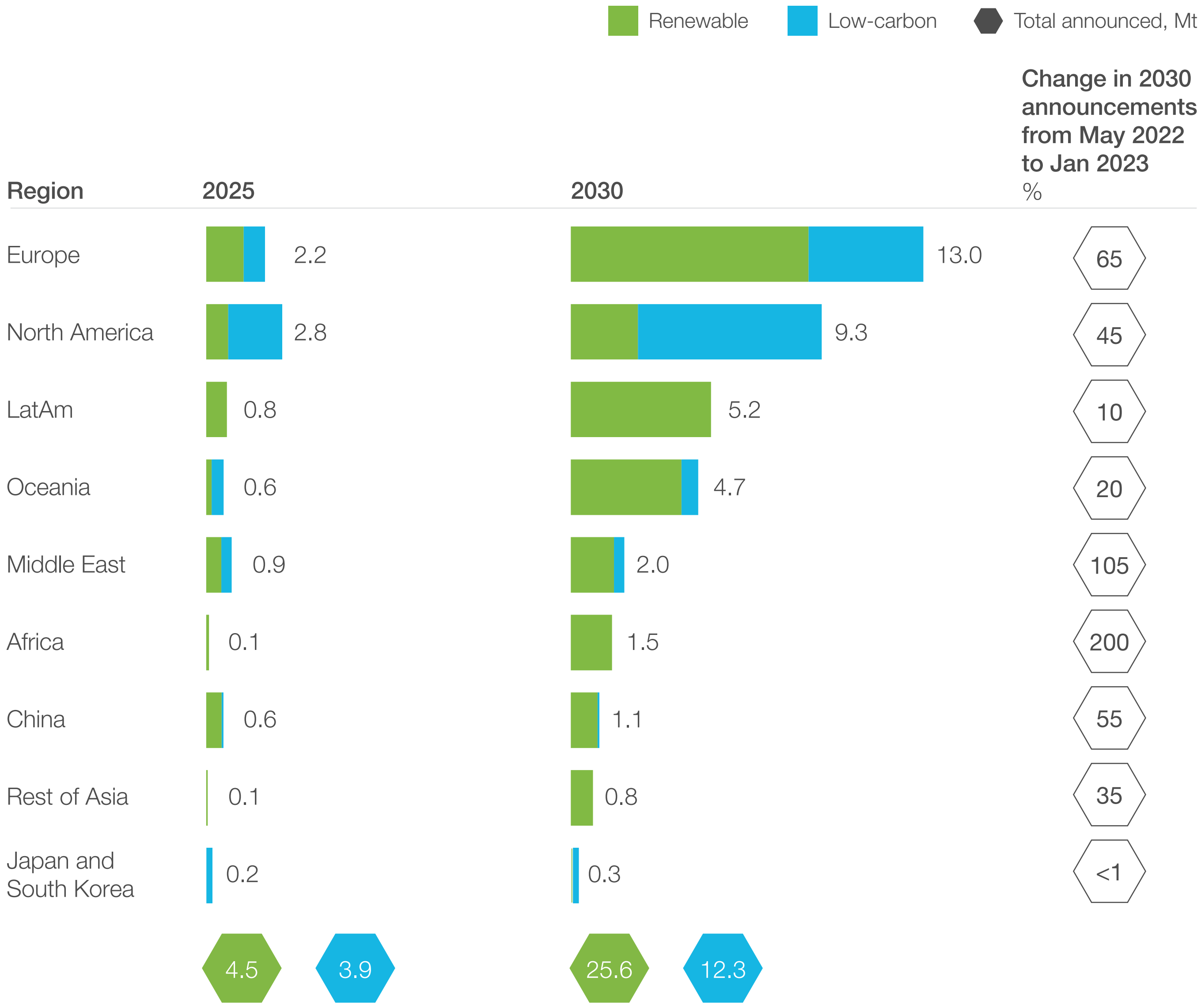
Announced supply of clean hydrogen is a global phenomenon, and each region shows growth in announced supply. Particularly the African continent has announced significant new capacity (more than 200%), as has the Middle East, where announced volumes more than doubled. Yet, Europe and North America remain the largest markets for announced hydrogen supply, with 13 Mt p.a. and 9 Mt p.a., respectively. Notably, North America has the largest volumes in 2025, with 2.8 Mt p.a. announced, of which 70% is low-carbon hydrogen.

Despite Europe's clear position as leading on announced volumes, this is not reflected in the maturity of the project funnel, of which only 5% are committed volumes. Other regions have a significantly higher share of mature volumes. Of the total announced supply in China, about 40% is committed, while in North America, the share is 20%. The low announced volumes in China particularly could be due to fewer companies announcing their plans or different public support schemes.

In North America, more than 70% of the capacity announced is low-carbon hydrogen, which, in many cases, is lower cost for the end user. Developers in the US have received tax credits to capture and store CO_2 (45Q credit in place before the IRA). Further, low-carbon hydrogen is less capital intense at about USD 2.5 to USD 3.5 billion per Mt capacity versus USD 4.5 to USD 7 billion per Mt capacity for renewable hydrogen. This could explain the higher maturity of the project pipeline in North America.

Source: US 45Q federal tax credit

Clean hydrogen volumes announced, Mt p.a.



Source: Project & Investment tracker, as of Jan 31, 2023

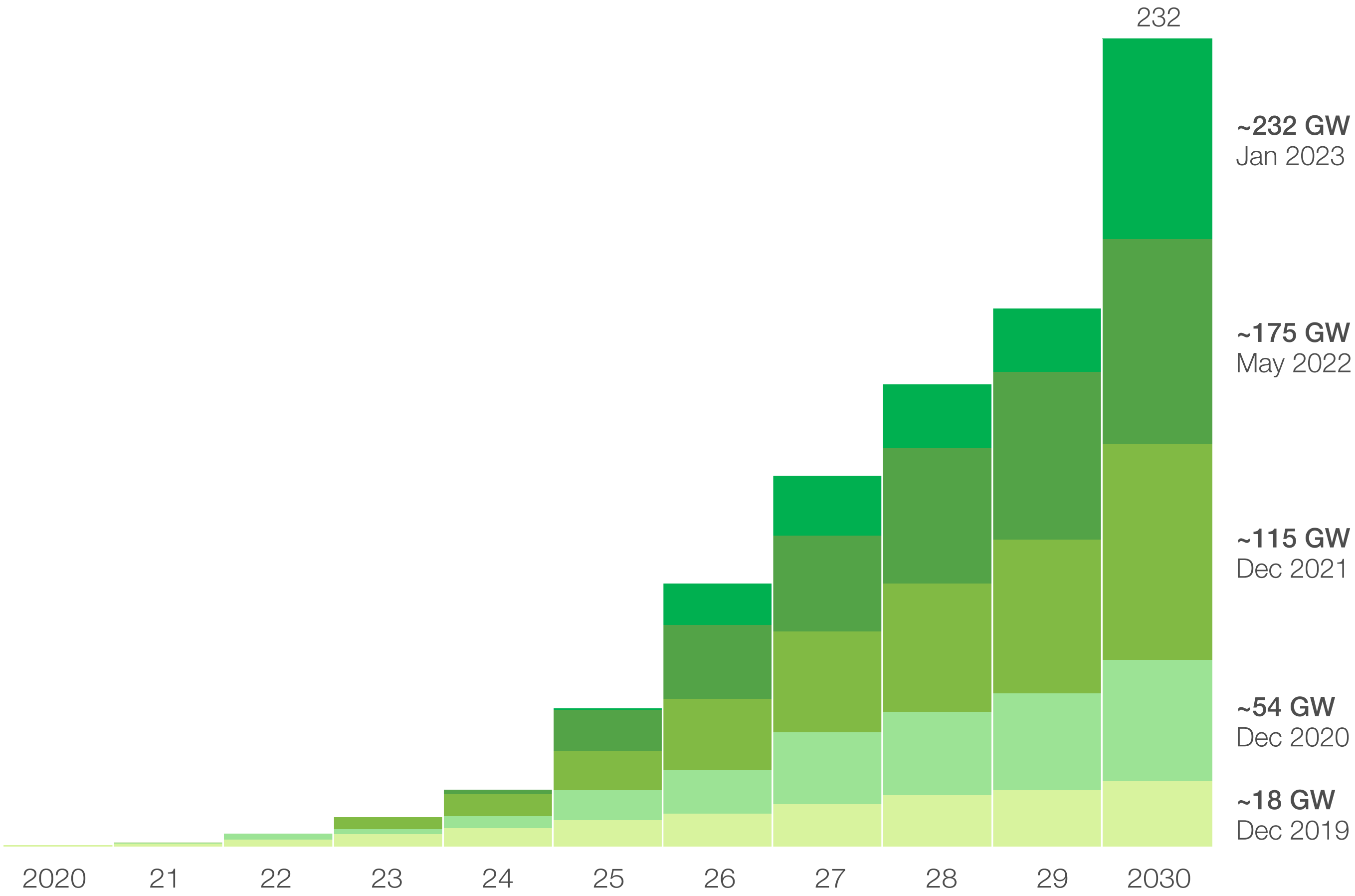
Exhibit 6

More than 230 GW electrolysis capacity announced to be operational by 2030, implying a more than 300 times growth in deployment is needed over the next seven years to realize this

More than 230 GW of electrolysis deployment has been announced through 2030, nearly 60 GW more than previously. More than half of this capacity (about 120 GW) is considered mature, i.e., undergoing feasibility or FEED studies (nearly 111 GW) or has passed FID (about 9 GW). The volumes of electrolysis capacity at or past FID nearly doubled from 5 GW to more than 9 GW, with the majority in China (about 40% of the 9 GW) followed by North America and Europe (about 15% each). The high share of mature renewable hydrogen projects in China may be due to fewer companies announcing companies or stronger or more focused government support.

Geographically, Europe is the largest market, with over a third of the global announced capacity (about 80 GW), with 40% of volumes at the planning stage or beyond. However, less than 1.5 GW has passed FID. Latin America and Oceania follow Europe as the largest markets for announced volumes, with 20% and 15% of announced volumes, respectively. Despite the volume of announcements in these three markets, the maturity of the renewable hydrogen project pipeline is low, with less than 2% of announced volumes committed.

Cumulative electrolysis capacity,[1] GW announced (incl. all project maturity stages)



+57 GW increase in announced electrolysis capacity by 2030 in the past 8 months

>70% capacity announcements found in 3 regions, i.e., Europe, Latin America, and Oceania

>80 GW announced electrolysis capacity by 2030 in Europe, the largest global region

1. For projects without known deployment timeline, capacity additions were interpolated between known milestones

Source: Project & Investment tracker, as of Jan 31, 2023

Exhibit 7

More investments are needed along the hydrogen value chain to close an investment gap of USD 380 billion by 2030

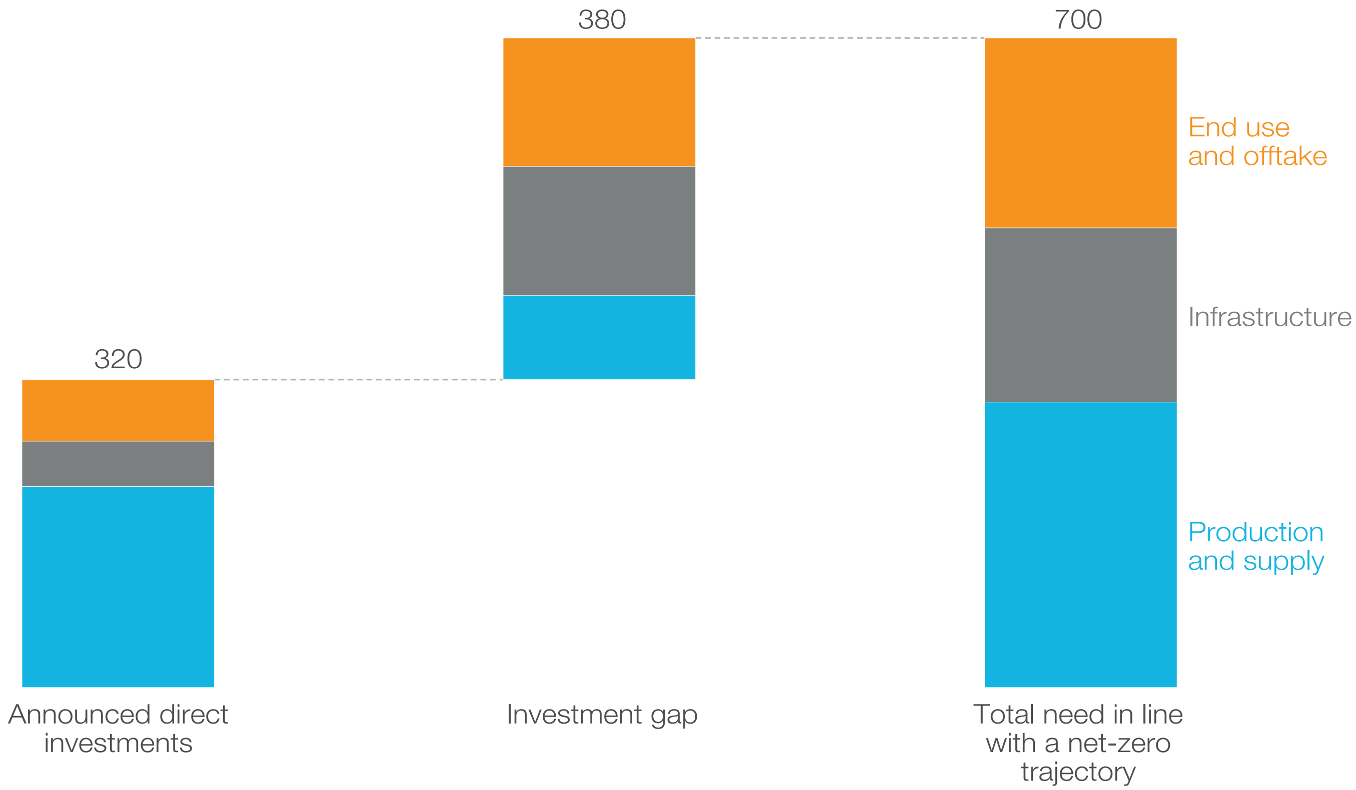
Growth in total announced investments (from USD 240 billion to USD 320 billion) and projects passing FID (from USD 22 billion to USD 29 billion) is positive. However, more is needed regarding new project proposals and in ensuring existing proposals are matured towards FID.

The total investment gap stands at USD 380 billion until 2030 to be on a net-zero trajectory by then, assuming all announced project proposals of USD 320 billion are deployed until then. The largest gap is within hydrogen infrastructure and end use at about USD 135 billion each, about two-thirds of needed investments, followed by supply (USD 110 billion). The investment gap (about 30%) in clean hydrogen supply is lower than the gap in announced hydrogen volumes (about 50% of the needed 75 Mt p.a. in 2030), likely driven by relatively less announced investments in low-carbon hydrogen that require less capital per Mt p.a. capacity.

The investment gap is notably higher when considering investments at FID or beyond at more than 95% across the value chain, as only USD 29 billion of the needed USD 700 billion is committed capital.

Not all projects, even in advanced planning stages, will reach FID and be built. For instance, in early renewable energy project development, the typical success rate of a project funnel was about 10% to 20% from initial development to commissioning.[7] The implication is that the industry needs to develop significantly more project proposals to enable the needed deployment. If investments of USD 700 billion are to be deployed until 2030, they likely need to pass FID before 2027 or 2028, given the time needed to build the projects.

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



$110 B
investment gap in supply

$135 B
investment gap in infrastructure

$135 B
investment gap in end use applications

[7] The funnel success rate will have varied by developer, and the estimated figures are a result of interviews with industry experts

Source: Project & Investment tracker, as of Jan 31, 2023, McKinsey

02

Clean hydrogen deployment steadily continues

800 kt p.a.
operational clean hydrogen supply capacity today, less than 1% of the gray hydrogen market today

700 MW
electrolysis capacity deployed by the end of 2022, with about 9 GW having passed FID globally

>1,070
hydrogen refueling stations deployed globally, with more than 50% growth year-on-year

Exhibit 8

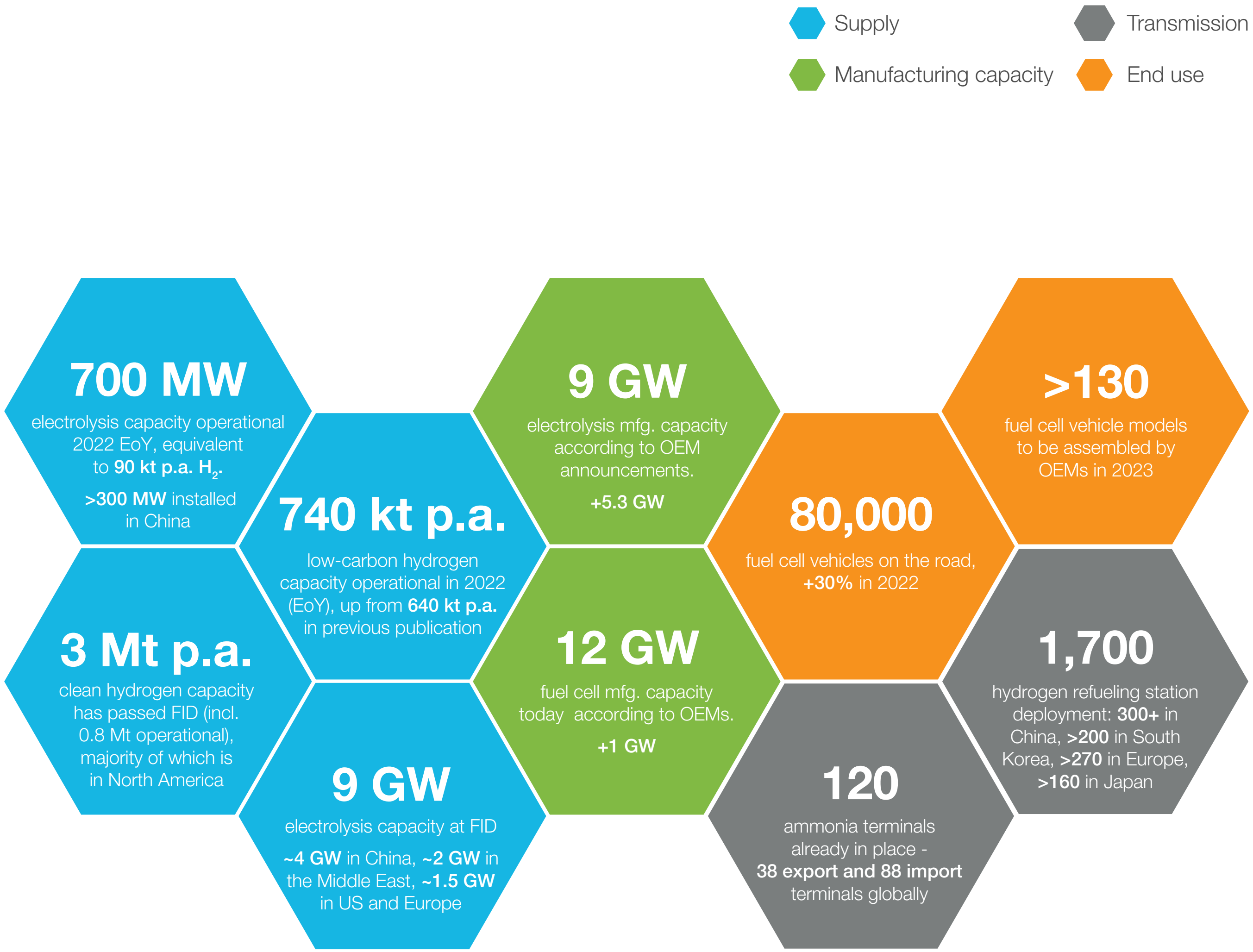
Deployment is steadily growing across the value chain; however, acceleration is needed to be on track to net zero

Supply: About 800 kt p.a. clean hydrogen supply is operational globally, up from about 700 kt p.a. About 740 kt p.a. are low-carbon hydrogen (primarily in North America), and the remainder is renewable. In addition to this volume, about 2 Mt p.a. has passed FID, of which more than half is low-carbon hydrogen.

Infrastructure: Infrastructure deployment is progressing and is critical to ensuring (low-cost) clean hydrogen supply matches the demand. Committed investments in hydrogen infrastructure have grown from about USD 5 billion to about USD 7 billion, of which more than three-quarters are in Asia.

Hydrogen end use: Committed investments into hydrogen end uses increased by about USD 0.5 billion, with the most growth in North America. Within mobility, cumulative FCEV sales now stand at about 80,000 vehicles, up 30%, representing annual sales of about 17,000 vehicles in 2022 – less than 1% of global vehicle sales. Vehicle OEMs have announced more than 130 FCEV models expected to be assembled in 2023, of which the majority consists of commercial vehicles (trucks, buses) in China.

Manufacturing capacity: Electrolyzers and fuel cell manufacturers are readying for scaling up. According to OEM statements, growth in electrolyzer manufacturing capacity has reached nearly 9 GW, a growth of 150%. For fuel cell manufacturing, the total global capacity stated by OEMs stands at 12 GW, with Japan and South Korea as the largest supply markets.



Source: Hydrogen Council; McKinsey

Exhibit 9

170 MW electrolysis was deployed in 2022, bringing the total to 700 MW, with majority of the capacity added in China

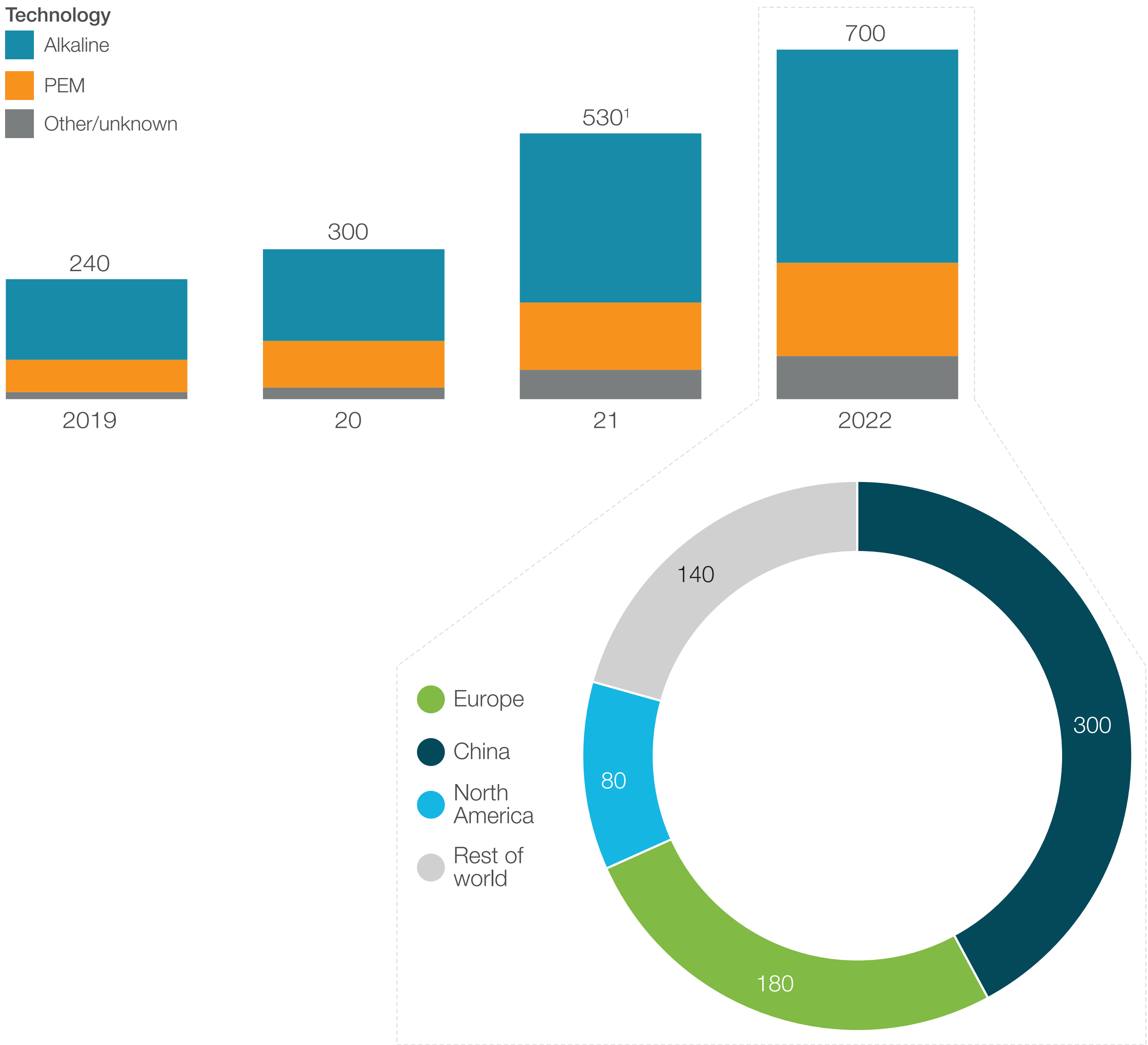
Deployment of electrolysis capacity grew 30% by the end of the year in 2022 versus 2021, reaching 700 MW (up from 530 MW). The installed capacity equals about 90 kt p.a. of renewable hydrogen supply[8] or about 10% of installed clean hydrogen production capacity globally.

Deployment is lagging: more than 200 GW electrolysis capacity is needed by 2030 to track net zero in 2050 – more than 200 times the capacity installed today. The slow deployment may be due to lacking government support and offtake commitments (i.e., willingness to pay a green premium), constraints in supply chains, increased cost of deploying projects, EPC capacity, or potentially lengthy permitting processes for projects.

Today, the largest deployed capacity is in China (about 300 MW), followed by Europe (about 180 MW). Notably, the growth appears to be slower from 2021 to 2022. Growth in 2021 was largely driven by one large project in China, accounting for 150 MW out of the 230 MW growth from 2020 to 2021.

The share of alkaline, PEM, and other electrolyzer technologies has been relatively stable in the past two years, with alkaline electrolysis technology accounting for about 60%, followed by PEM (about 30%). Within China, the largest market, most of the deployed electrolysis capacity is alkaline technology, whereas the share of PEM technology is higher in Europe and North America.

Global cumulative installed electrolysis capacity, MW (EoY)



1. Growth from 2020 to 2021 driven by 150 MW Ningxia Project; the currently largest operational electrolyzer

Source: IEA Global Hydrogen Review 2021 and 2022; Project & Investment tracker, as of Jan 31, 2023

8 Assuming renewable energy supply, 70% load factor, and 67% efficiency (lower heating value)

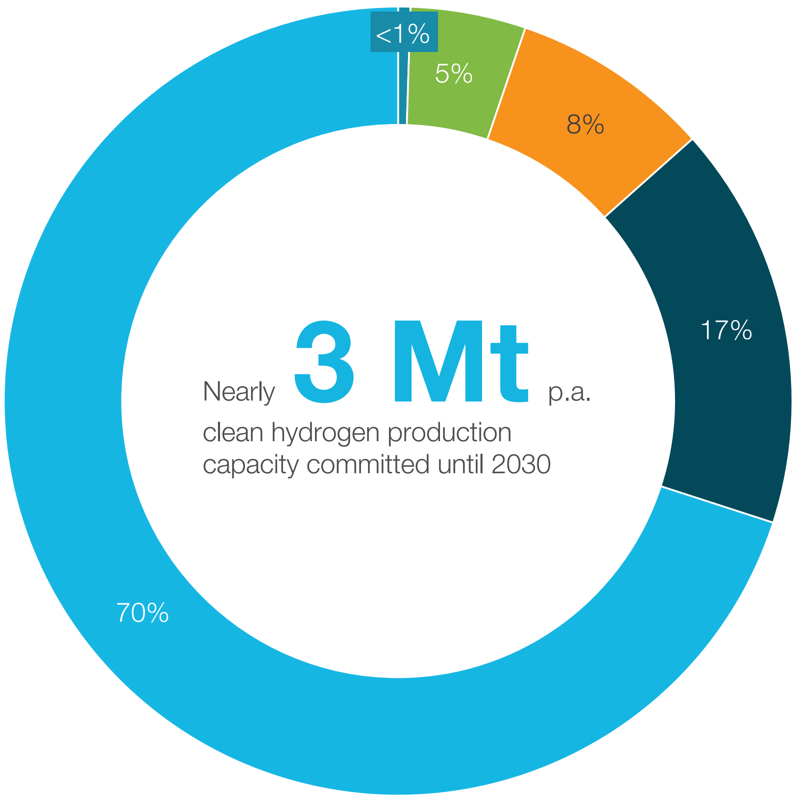
Exhibit 10

3 Mt p.a. clean hydrogen capacity has passed FID, with North America and China leading

About 2.1 Mt p.a. clean hydrogen has passed FID in addition to the 800 kt p.a. operational capacity, of which about 1.1 Mt p.a. is low-carbon hydrogen, and the remaining 1 Mt p.a. is renewable. Since the previous publication, the volumes of low-carbon and renewable hydrogen have grown notably, with about 0.4 Mt p.a. of each technology having passed FID.

All low-carbon hydrogen volumes at or past FID are in North America, whereas renewable hydrogen is more geographically dispersed; China is the largest market at 35% share of volumes, followed by the Middle East and North America with about 20% of volumes each. Although being the largest in announced supply, with 13 Mt p.a. announced until 2030, Europe accounts for less than 5% of committed supply capacity. This may be driven by a lack of transparency on regulatory framework and subsidies, as well as high energy prices following the war in Ukraine.

Committed[1] production capacity until 2030, %



North America
Low-carbon hydrogen accounts for ~90% of committed production capacity in North America (of which ~740 kt p.a. is already operational), with demand driven by hydrogen for ammonia production and refining

Asia-Pacific
China accounts for almost 90% of committed production capacity in Asia-Pacific, with several large-scale renewable hydrogen projects (>100 MW) already committed

Middle East and Africa
Committed production capacity driven by giga-scale renewable hydrogen project in Saudi Arabia

Europe
Renewable hydrogen accounts for close to all committed production capacity (>95%) in Europe, with industry feedstock sectors (e.g., refining) driving demand

Latin America
Significant project pipeline, but yet to commit to large-scale projects

1. Final investment decision has been made, under construction, or operational

Source: Project & Investment tracker, as of Jan 31, 2023

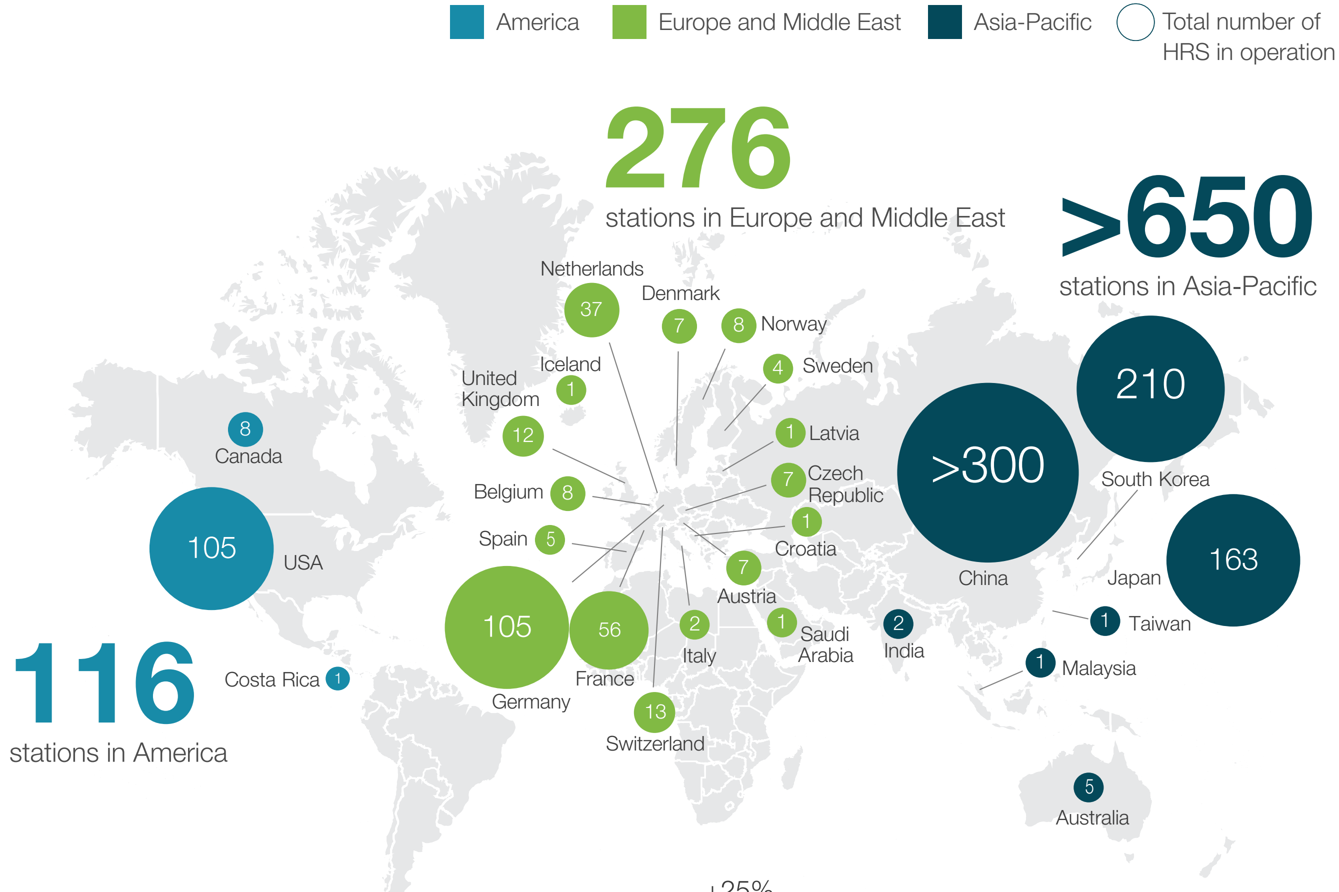
Exhibit 11

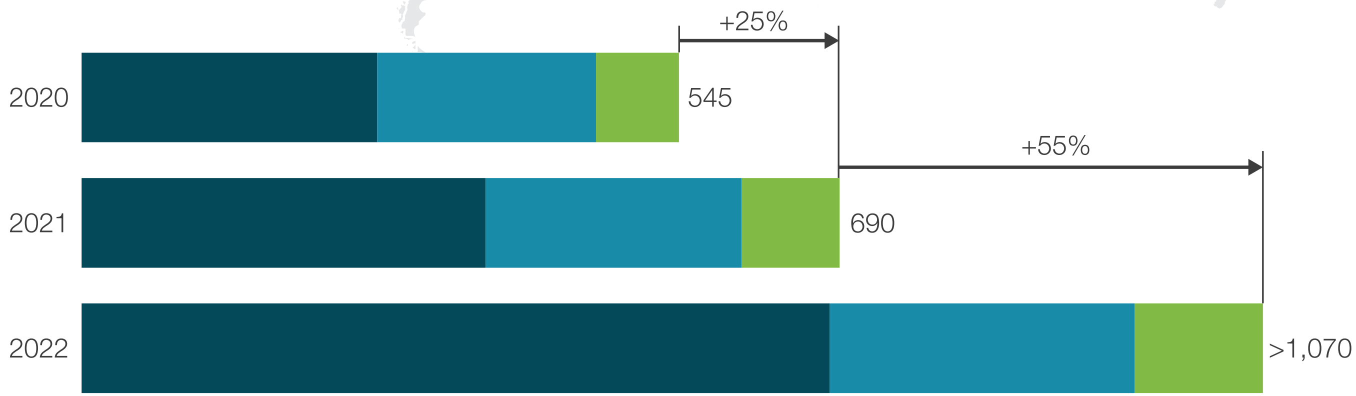
Hydrogen refueling infrastructure deployment is accelerating, particularly in Asian markets

More than 1,070 hydrogen refueling stations are now operational globally, with deployment growing more than 50% from the end of 2021 to 2022. Most of these stations are located in Asia, i.e., China, Japan, and South Korea as the largest markets (more than 650 in total), followed by Europe (about 280) and North America (about 120).

The majority of new stations in the past year have been deployed in China and South Korea, with more than 200 stations added in China and nearly 100 in South Korea. In contrast, deployment in Europe and Japan appears to be slowing, with less than 50 new stations deployed in Europe and less than 10 in Japan. Japan has had a relatively good station coverage, with about 160 stations deployed. In Europe, the coverage varies significantly by country (e.g., Germany has the highest number of stations).

Currently, most stations deployed are relatively small, with less than 500 kg per day dispensing capacity sufficient to refuel up to 100 passenger vehicles with a 5 kg capacity tank. In the future, deployment needs to accelerate overall, and stations need to be larger to enable growth in the deployment of large commercial vehicles, such as heavy-duty trucks that could need more than 50 kg of hydrogen per refueling or ten times more than a car.





Source: h2stations.org, as of

03

Hydrogen in North America: Industry tailwinds and what it could take to realize the opportunity

USD 46 billion
investment announced in hydrogen projects by 2030

Up to **USD 3/kg H_2**
incentives for clean hydrogen production

Exhibit 12

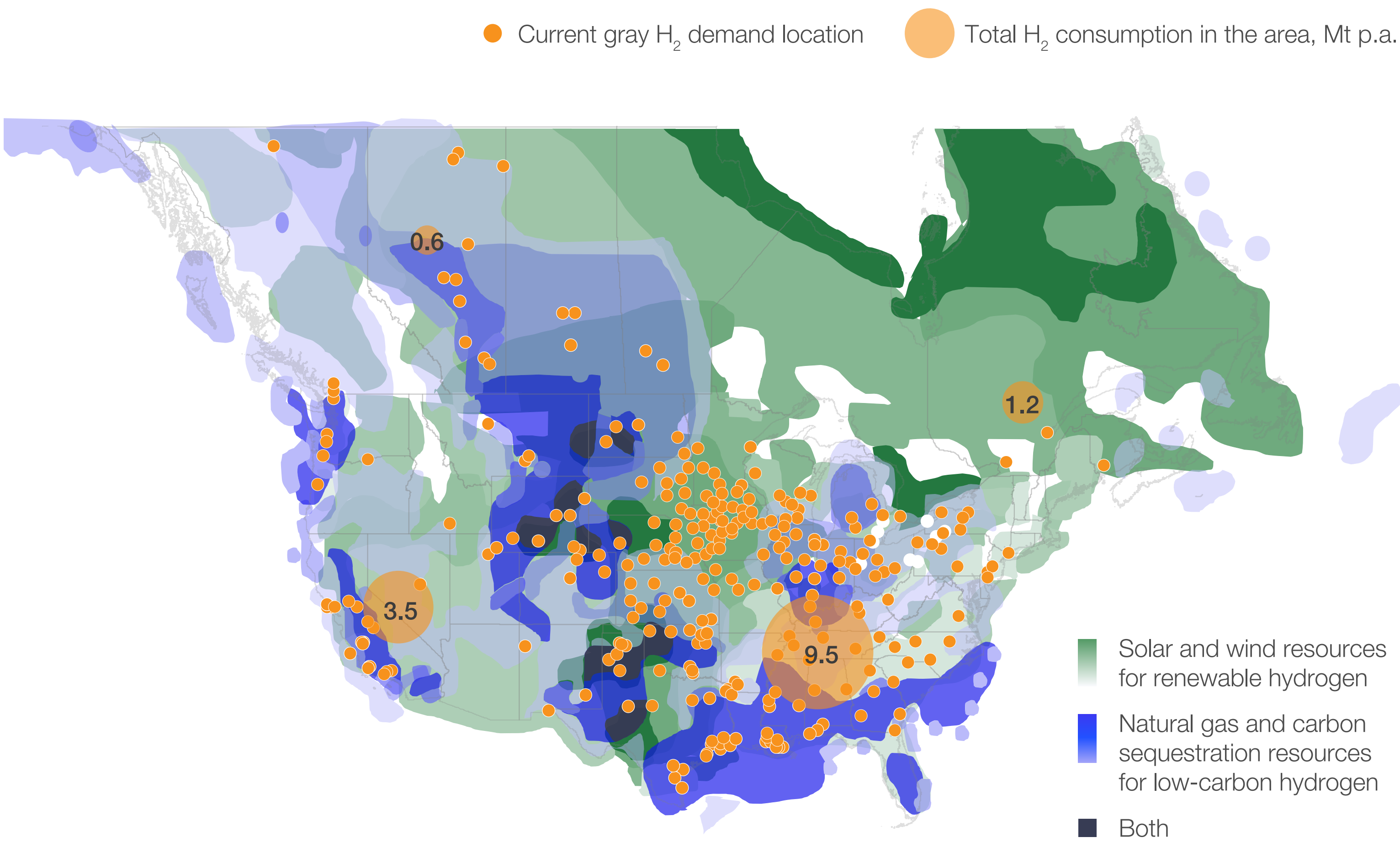
North America has high-quality energy resources for clean hydrogen production

The US and Canada combined are the second-largest consumers of hydrogen in the world, with 15 Mt p.a. demand today, accounting for approximately 17% of total global hydrogen demand. Today's hydrogen demand in North America is driven almost entirely by the chemical and refining industries, all of which are met by gray hydrogen.

However, abundant wind and solar, along with low-cost natural gas and sequestration resources, position North America as a region with high potential to produce both renewable and low-carbon hydrogen at low cost.

With these resources, North America could be a major region for clean hydrogen, with sizeable domestic demand and the potential to export hydrogen. Potential implications for 2050[9] are as follows:

- North America is expected to be among the top regions globally for hydrogen production, achieving average renewable hydrogen production costs of USD 1.1 per kg.
- 20% of energy demand in North America could be provided by hydrogen, more than half of which could be used in sectors such as road transportation, synthetic fuel production, and chemicals.
- 20% of global hydrogen could be produced in North America – almost all pure hydrogen produced in the US could be consumed locally; however, hydrogen derivatives such as ammonia and methanol could be exported globally.
- With both sequestration resources and abundant renewables, the North American hydrogen supply mix is expected to be roughly a 50:50 split between renewable and low-carbon hydrogen production.



15 Mt p.a. total consumption of gray H_2

>60% of H_2 is consumed by refineries

~17% of total global H_2 demand

Source: McKinsey Hydrogen Insights and Power Solutions; Energy Insights Global Emission and Subsurface Database; McKinsey CCS Hub Explorer Tool; EPA FLIGHT

[9] Based on Global Hydrogen Flows perspective from October 2022, updated to incorporate the impact of the IRA

Exhibit 13

Clean hydrogen momentum in North America continues, with 170 clean hydrogen projects announced across the continent

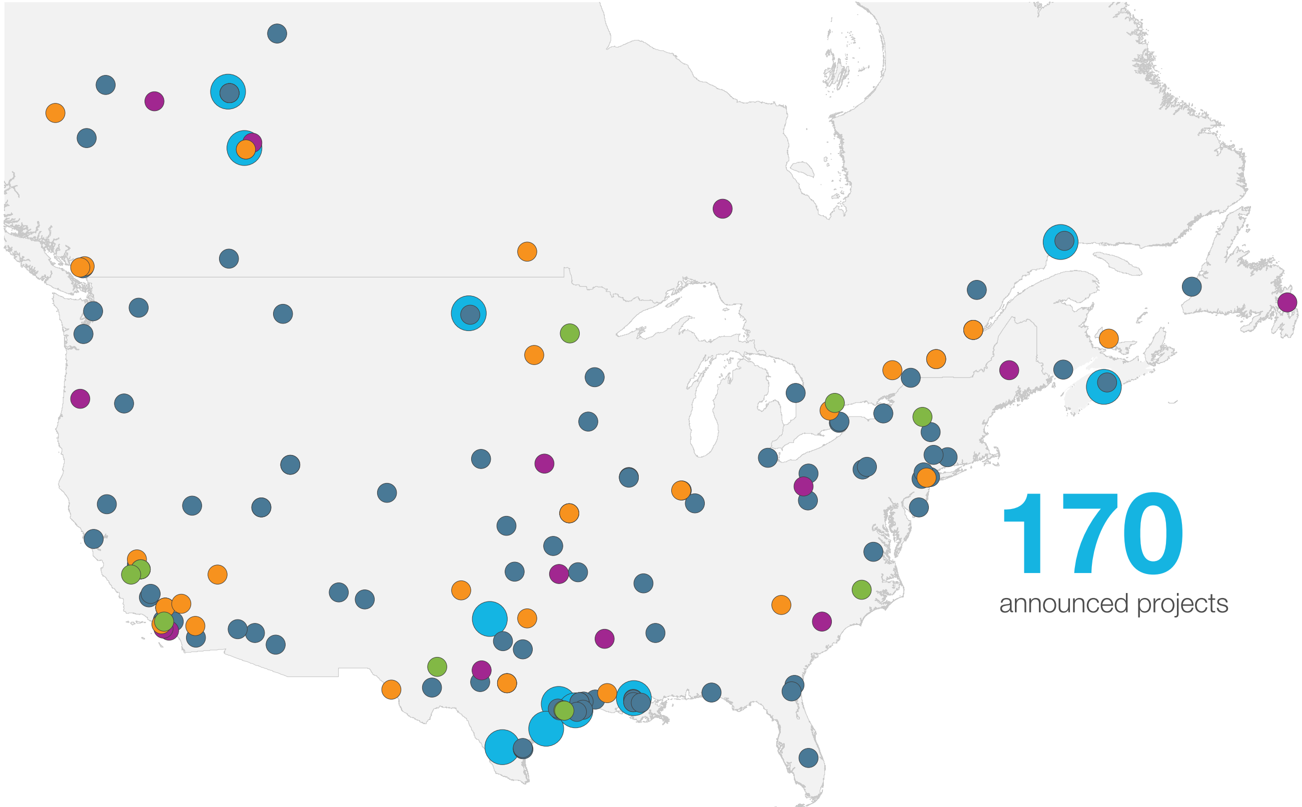
The industry has announced a total of 170 hydrogen projects in North America as of the end of January 2023, accounting for approximately 15% of total announced projects globally. In the past eight months, about 70 new projects were announced. Of the 170 total projects, 135 aim to be fully or partially commissioned by 2030, representing USD 46 billion of announced direct investment in hydrogen value chains.

Of the 135 projects proposed by 2030, more than 40% have reached a final investment decision (FID), are under construction, or are operational, and 25% are undergoing feasibility and FEED studies. The number of announced projects through 2030 has grown by 60% in the past eight months, while the share of projects at each level of project maturity has stayed consistent, indicating an even distribution of growth across the project funnel.

Large-scale projects for industrial offtakers account for more than half of the announced projects. Out of 106 large-scale industrial projects announced, 86 are planning full or partial commissioning by 2030 – 19 projects are undergoing feasibility or FEED studies, and 35 projects have passed FID. There are eight giga-scale projects announced. Of these eight, five are undergoing feasibility and FEED studies and one is at the FID stage. Three out of eight giga-scale projects are on renewable hydrogen supply with intended use in sustainable aviation fuel (SAF) or for the transportation sector.

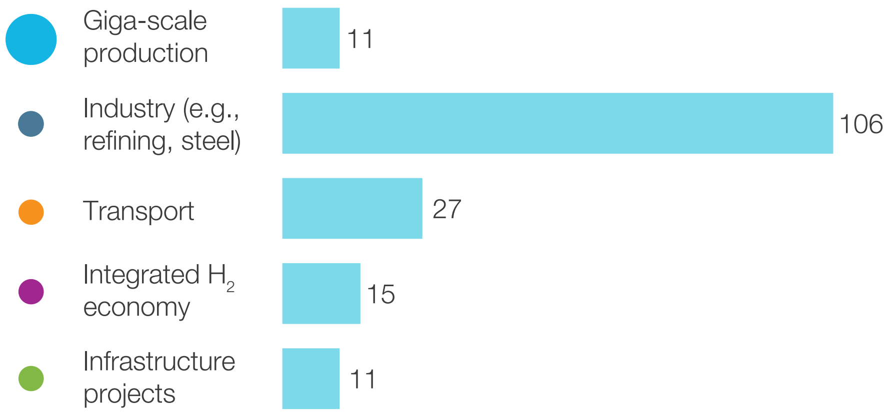
Out of a total of 175 announced projects, 134 projects have disclosed their intended offtake sector. Road transport is the offtaker for 40 projects, followed by ammonia (34 projects), and power/blending into gas grid (25 projects).

Announced H_2 projects in North America



170
announced projects

Number of projects announced



16%
of total announced projects globally

$46 B
investment required to develop projects announced until 2030

Source: Project & Investment tracker, as of Jan 31, 2023

Exhibit 14

More than half of announced investments in North America are still in early stages

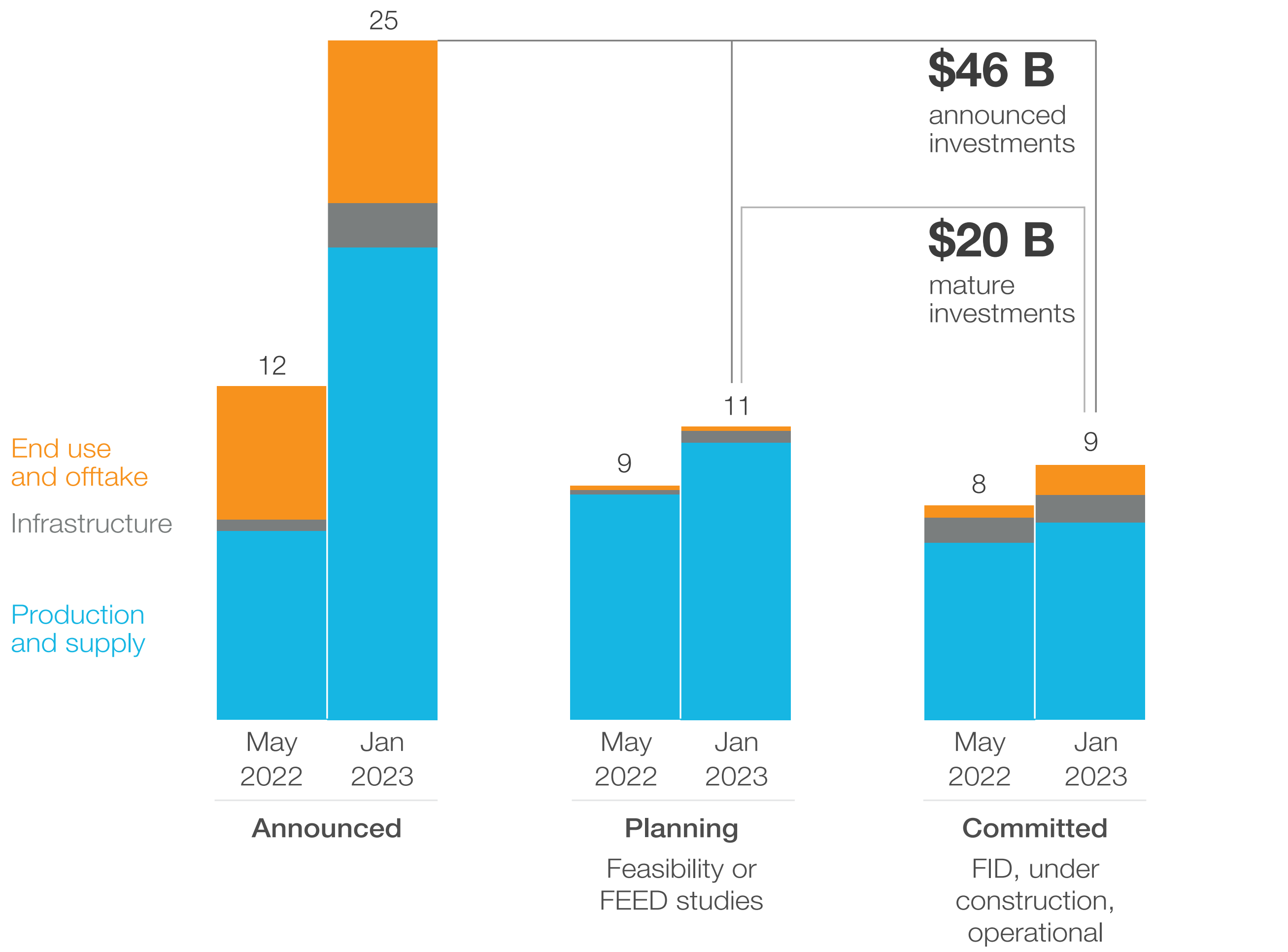
Announced hydrogen projects in North America through 2030 amount to total direct investments of USD 46 billion, up from USD 29 billion in the previous publication. Along the value chain, most investments are focused on clean hydrogen supply, accounting for more than three-quarters of investments, followed by end use (about 15%) and infrastructure (about 5%). The investment gap in midstream and end use has increased after the Inflation Reduction Act (IRA) as the incentives focus on hydrogen production.

Committed investments (projects already at FID or beyond) account for 20% of investments in North America compared to only 7% for the rest of the world. This could be due to the fact that almost three-quarters of North American projects are low-carbon projects, compared to 20% across the rest of the world. The value chain for low-carbon hydrogen production is more mature than for renewables, and the projects tend to be larger. Additionally, the deployment process is faster when retrofitting existing steam methane reforming (SMR) facilities.

The past eight months have seen an increase of more than 50% in total announced investments. Almost half of the investments in North America are considered mature (either in the planning stage or already committed), having grown by about 20% in the past eight months to USD 20 billion. Estimated investments in projects in an early announcement stage (i.e., before the detailed planning and engineering stage) have more than doubled, from USD 12 billion to USD 25 billion. This is likely driven by the passage of the IRA in August 2022, spurring new announcements that are still in relatively early stages.

As momentum around project announcements accelerates, challenges to deploying at scale remain for – and in some cases are exacerbated by – the rapidly growing hydrogen industry. Key potential challenges will be explored in the coming pages.

North America direct hydrogen investments through 2030, $B



+55% investment growth in the past 8 months

+20% growth in "mature" investments in the past 8 months

80% of investments focus on supply

Source: Project & Investment tracker, as of Jan 31, 2023

Exhibit 15

Announced renewable hydrogen momentum has accelerated since the passage of the IRA

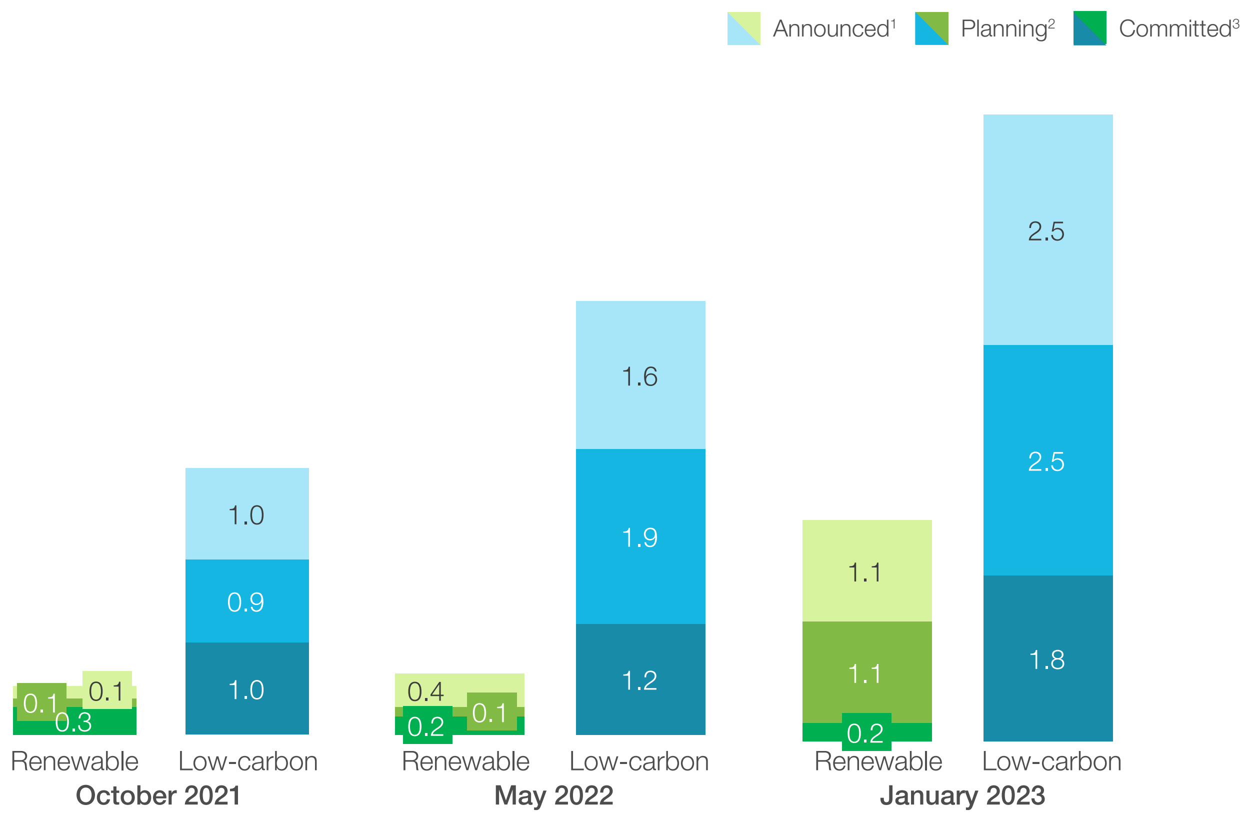
Companies have announced projects that would produce up to 9.3 Mt p.a. of clean hydrogen capacity by 2030 in North America, an increase of about 3.8 Mt over the last eight months. Though more than 70% of the announced capacity is from low-carbon hydrogen, renewable hydrogen capacity has grown by 2.5 times since May 2022. This could, in part, be due to the IRA production tax credit (PTC), which scales based on the carbon intensity of the hydrogen produced, favoring renewable hydrogen production.

Since 2021, the total announced production capacity has grown 1.5 times faster in North America compared to the rest of the world. Further acceleration is expected in the coming years as many developers await the announcement of the IRA implementation regulations before finalizing investment decisions.

3.7 Mt p.a. of announced clean hydrogen production capacity has not yet reached detailed planning stages, whereas 3.6 Mt p.a. is in planning stages undergoing feasibility or FEED studies, and 2 Mt p.a. (about 20% of total announced capacity) has passed FID, is under construction, or operational.

North America accounts for 25% of the total announced clean hydrogen supply volumes globally, with the highest volume of announced production capacity in Europe (about 13 Mt p.a.). North America accounts for the largest volume of announced low-carbon hydrogen production capacity in the world (about 55% of total low-carbon hydrogen capacity), while Europe has the largest volume of announced renewable hydrogen production capacity (8.7 Mt p.a., accounting for 35%).

North America clean hydrogen production capacity announced by 2030, Mt p.a.



>70%

share of announced low-carbon H_2 capacity in North America compared to 20% in the rest of the world

3.5x

announced renewable H_2 capacity growth in the past 8 months

1. Preliminary studies or at press announcement stage
2. Feasibility studies or at FEED stage
3. Final investment decision has been made , under construction, commissioned, or operational

Source: Project & Investment tracker, as of Jan 31, 2023

Exhibit 16

The IRA could help significantly accelerate clean hydrogen in the US

The IRA was signed into law in August 2022, with the goal of lowering US carbon emissions by the end of this decade. Over USD 400 billion of funding in climate spending has been budgeted toward the energy industry, environmental justice, cleantech manufacturing, land and agriculture, and transportation, with the energy industry receiving the biggest share.

The IRA is expected to have broad and significant impacts on existing energy transition sectors such as renewables, batteries, and existing nuclear power, as well as on earlier-stage sectors such as carbon capture, clean hydrogen, and other low-carbon fuels (e.g., SAF).

Hydrogen and hydrogen derivatives could benefit from the IRA through a mix of incentives such as the extension and expansion of solar and wind power incentives, the introduction of a tax credit for hydrogen production, the expansion of tax credits for carbon capture, utilization, and storage (CCUS), and incentives for SAF and other clean fuels. As of the time of publication, many key details on how the legislation will be implemented have not yet been released from the IRS.

The IRA hydrogen production tax credit is calculated based on the carbon intensity of the hydrogen. To capture the full USD 3 per kg credit, the carbon intensity of produced hydrogen must be lower than 0.45 tons of CO_2 per ton of hydrogen. Renewable hydrogen powered by renewable power can get the full USD 3.0 per kg; low-carbon hydrogen would require carbon sequestration to below 4 tons of CO_2 per ton of hydrogen to receive the minimum credit of USD 0.6 per kg with variation based on upstream emissions.

Renewable hydrogen could benefit from the IRA's renewable PTC in addition to the hydrogen PTC. Low-carbon hydrogen could instead benefit from expanded 45Q incentives for CCUS; however, the 45V hydrogen PTC and 45Q are not stackable, i.e., a low-carbon hydrogen project cannot receive both.

Key IRA provisions for hydrogen and hydrogen derivatives

Clean fuels: up to $1/gal base; up to $1.75/gal for SAF

CCUS 45Q credit[4]: utilized - sequestered
- **DAC:** $130 - 180/$tCO_2$
- **Point source:** $60 - 85/$tCO_2$

Hydrogen PTC/45V: up to $3/kg H_2

Low-carbon hydrogen cannot be eligible for both carbon capture 45Q credit and hydrogen 45V

Renewable PTC[2]: $26/MWh

Details of the hydrogen PTC[1,2]

Who will qualify?

- Projects that emit $<4\ tCO_2/tH_2$ (with max $3/kg credit available to facilities $<0.45\ tCO_2/tH_2$)
- Projects that are based in the US
- Greenfield projects put into service before 2033
- Facilities that do not claim 45Q or clean fuel tax credits

How will credits work?

- Based on the full lifecycle, GHG emissions calculated with GREET model[3]
- Eligible for 10 years from the COD date, with 5 years of direct pay, 5 years of tax credits
- Can be stacked with renewable PTC
- No cap on the credit program

What questions remain?

- Can producers power with grid electricity with RECs to reduce CI?
- What is CI calculation methodology and validation process?
- Are there further details on rules related to prevailing wage rate and apprenticeship requirements?
- Can CCUS and clean fuels credits at separate facilities be stacked (e.g., can H_2 Co. sell to SAF Co. and each claim H_2 and SAF credits, respectively)?

Disclaimer:
Intended to provide insight based on currently available information for consideration and not specific advice

1. DoE has up to 1 year to establish final rule making
2. Projects that do not pay prevailing wage and apprenticeship lose 80% of credit value
3. $<0.45\ tCO_2/tH_2$ = $3/kg; 0.45 – 1.5 = $1/kg; 1.5 – 2.5 = $0.75/kg; 2.5 – 4 = $0.6/kg
4. Low-carbon hydrogen can receive the 45Q credit regardless of carbon intensity of the hydrogen

Source: US Inflation Reduction Act of 2022

Exhibit 17

With the IRA, renewable hydrogen could become cost competitive sooner

The IRA will improve renewable and low-carbon hydrogen economics in the coming years. The IRA's hydrogen production tax credit of up to USD 3 per kg hydrogen for the first ten years of a project's operations reduces the levelized cost of hydrogen for clean hydrogen by USD 0.5 to 1.8 per kg in the US over the lifetime of the project.

The renewable PTC could potentially decrease the cost further by up to USD 0.80 per kg of hydrogen.

As the market is rapidly evolving, these numbers are likely to shift quickly in the coming years. Many factors that vary by project will impact LCOH. For example, exact value capture is likely situationally dependent based on value chain control points. For example, if electrolyzer demand from announced projects outstrips manufacturing capacity, there would be a shortage of electrolyzers allowing OEMs to extract higher margins, which would drive up the cost of hydrogen as produced.

Retrofitting existing SMR plants with carbon capture and sequestration could make low-carbon hydrogen cost competitive with gray hydrogen today. Many low-carbon hydrogen producers are pursuing the 45Q, as opposed to 45V, to capture value from IRA incentives as they await clarity on how carbon emissions will be calculated for the 45V PTC.

IRA incentives could make clean hydrogen economic for many offtakers five to ten years earlier:

- Heavy-duty hydrogen fuel cell trucks could reach breakeven with new diesel vehicles in the next several years.
- Conventional hydrogen uses today (e.g., ammonia production, refineries) could become competitive within coming years in most parts of the country.
- If IRA credits can be combined (hydrogen PTC, carbon credits, and clean fuels credits), the IRA could help the US government on its path towards achieving a target of 3 billion gallons of SAF – equivalent to 10% of the US's jet fuel consumption.

However, beyond the pure economics, many end users continue to face challenges that prevent them from transitioning to clean hydrogen – such as a lack of midstream infrastructure for cost-effective hydrogen delivery and the need to shift their operations – for example, for hydrogen trucking.

Depending on how the provisions are implemented, the IRA's 45V, 45D (renewable), and 45Q incentives could make the US among the most competitive production region for clean hydrogen. Global hydrogen trade dynamics could be significantly altered, though this will depend on evolving policy. Other countries are likely to pass policies in response to the IRA.

Canada has instituted policies that could accelerate Canada's competitiveness as a hydrogen-producing region, including an investment tax credit (ITC) of 15% to 40% for hydrogen production – varying based on the hydrogen's carbon intensity, a CCUS ITC of 50% applicable to CCS equipment – and cleantech ITC of 30% for clean electricity generation systems (e.g., solar, hydro, nuclear, and wind). The majority of these credits begin to be phased out by 2035. These incentives would complement Canada's existing carbon pricing and credit systems.

Source: US Inflation Reduction Act of 2022; Canada, Budget 2023

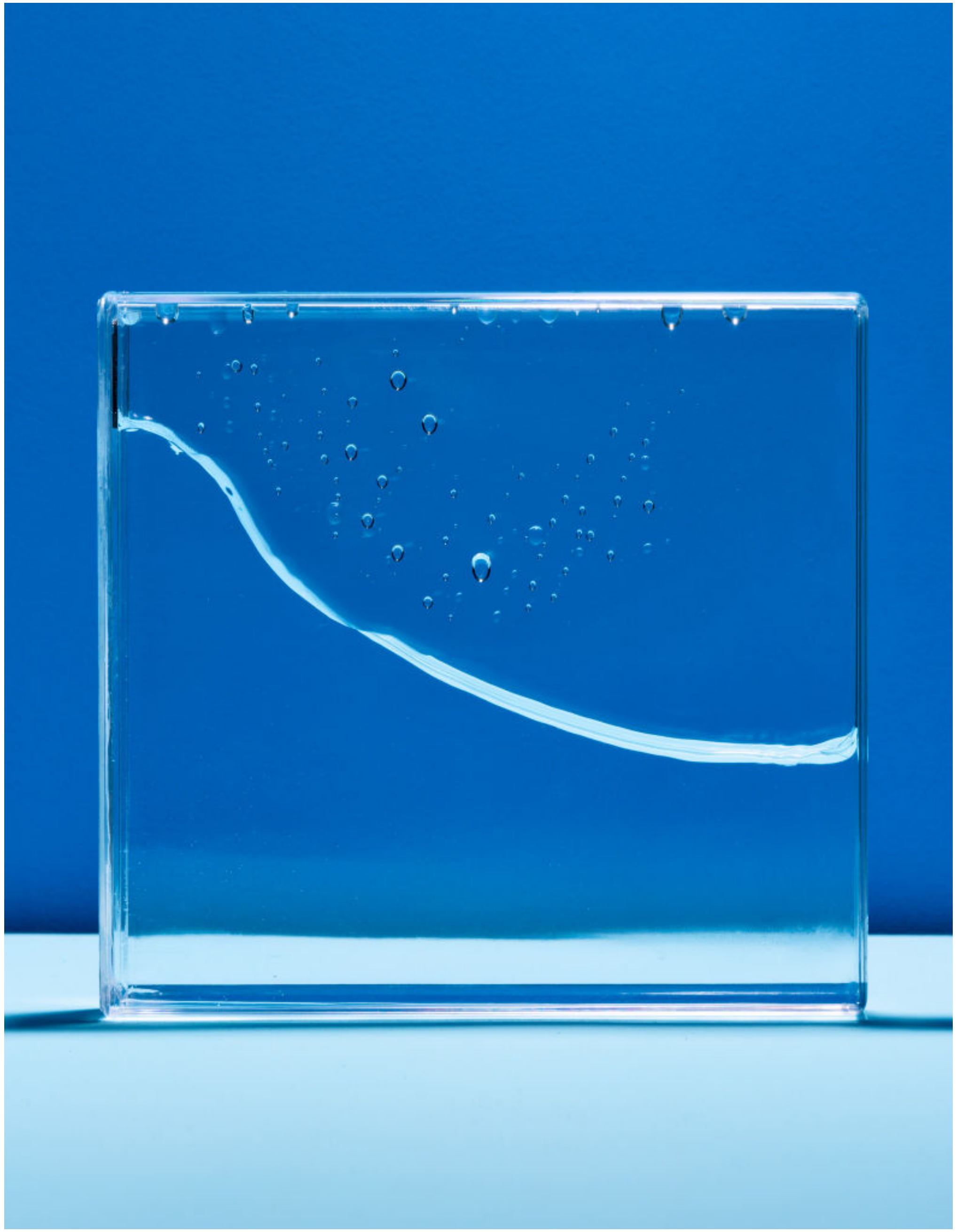


Exhibit 18

Significant production scale-up is required to bring the cost down and enable the shift to clean hydrogen production

Despite regulatory momentum, producing clean hydrogen is more expensive today than it was two years ago in the US, which is potentially driven by an increase in national average PPA (power purchase agreements) prices from USD 27 per MWh in 2020 to USD 45 per MWh in 2022, EPC capacity shortages and increasing labor costs by up to 20%, as well as a two- to fourfold increase in gas price. For costs to decrease in the coming years and a sustainable, competitive clean hydrogen ecosystem to develop, further value chain scale-up is required.

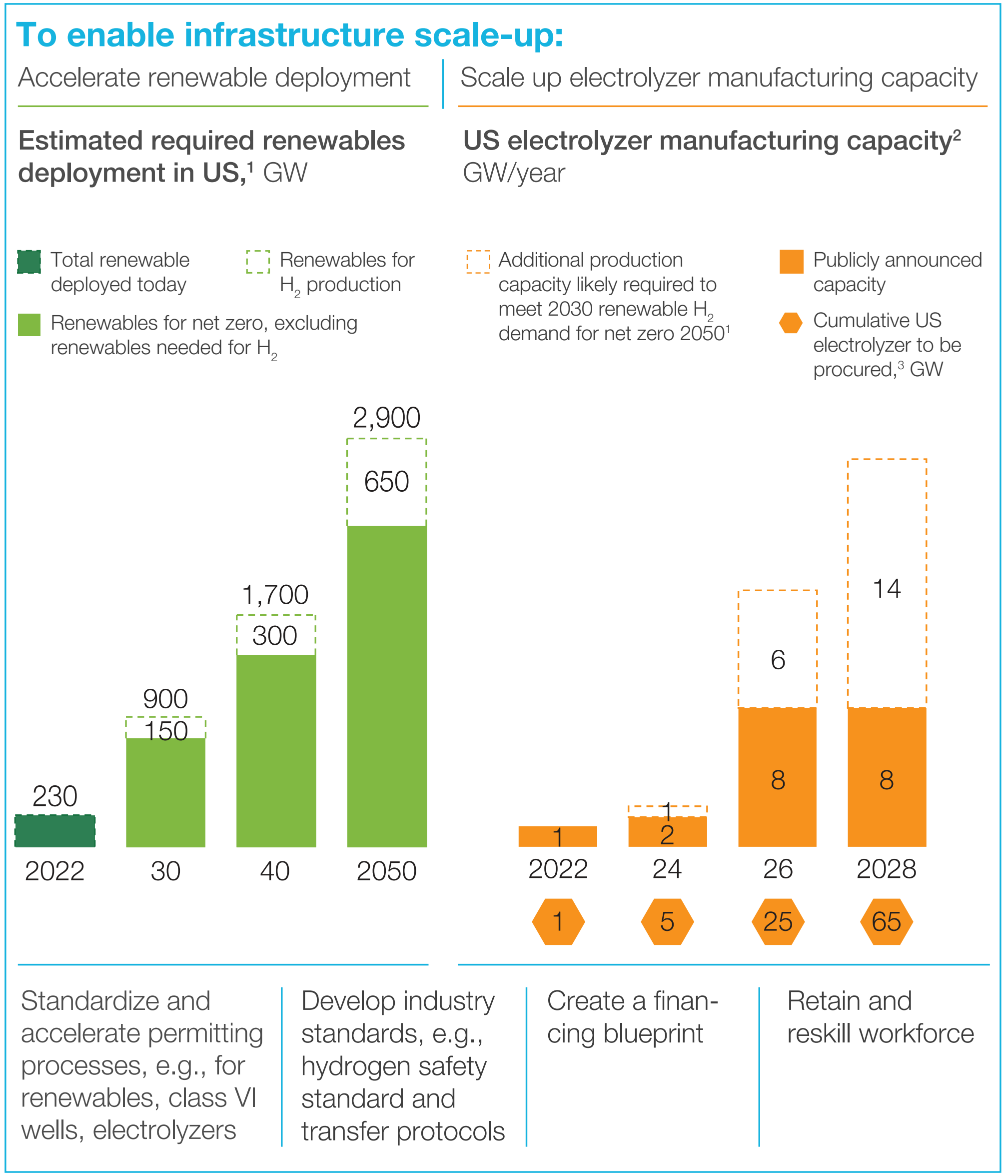
Renewable hydrogen is projected to account for about one-third of the total hydrogen production in the US by 2030 and increase to half of the production by 2050.10 Enabling this would require a significant liftoff on both renewable deployment and electrolyzer manufacturing capacity, among others:

— Meeting the US goal of a net-zero grid by 2035 and a net-zero economy by 2050 is estimated to require reaching 900 GW of renewables in 2030 which is only achievable at four times the current renewable installation rate. Potential challenges for scaling the renewable industry would prevail, with or without hydrogen, since the renewable capacity required for hydrogen production accounts for 15% to 20% of total renewables needed in 2030 and 2050, respectively. Nevertheless, hydrogen producers can strategically plan for their renewable power. For example, they could benefit from co-locating with renewable projects struggling to connect to the electricity grid – making use of otherwise stranded renewables. Also, large hydrogen producers can unlock scale benefits, potentially via partnerships with renewable producers, to secure volumes.

— Total electrolyzer manufacturing capacity announced in the US in 2028 is 8 GW across 5 OEMs. To meet the required renewable hydrogen demand for net zero in 2030, 14 GW of additional electrolyzer production capacity is estimated to be required by 2028. The gap between the demand and announced capacity has led to a short-term supply shortage while the manufacturing capacity scales up. Since the IRA currently does not require domestically manufactured electrolyzers, part of electrolyzer demand will likely be imported. However, a global electrolyzer shortage is not unlikely if renewable hydrogen projects accelerate. Increasing electrolysis capacity necessitates scale-up of electrolyzer manufacturing, maturity of supply chains, and development and enforcement of industry standards for hydrogen safety and transportation.

In addition, enabling production scale-up likely requires:

1. A skilled workforce for manufacturing and EPCs that can install electrolyzers, renewables, and low-carbon hydrogen production equipment (e.g., CCUS). Workforce development could be accelerated by targeted training programs and facilitating job transitions from adjacent industries (e.g., from fossil-fuel-based sectors).
2. Standardization and acceleration of permitting processes, e.g., for renewables, electrolyzers, class VI wells for CO_2 injections, facility retrofits/modifications, and pipelines. Today, permitting process can take multiple years. Adequate dedicated staff for handling permit requests and guiding the permit processes, as well as standardization of processes across agencies and jurisdictions could help decrease the process time.
3. A financial blueprint for investors could decrease risk and accelerate deployment. This could include education for investors and lenders on hydrogen project economics, risks, regulations, and offtake dynamics, as well as financial models for hydrogen projects – ideally supported by assumptions and proof points from deployed hydrogen projects.



1. Global hydrogen flow model adjusted based on IRA impact
2. Assuming each new factory requires 3 years to reach peak performance for missing production; assuming electrolyzer purchasing happens 2 years ahead of COD
3. This electrolyzer capacity is to meet the demand for operational electrolysis 2 years later

[10] From Global Hydrogen Flows perspective from October 2022, updated to incorporate the impact of the IRA

Midstream infrastructure to transport hydrogen does not exist at scale today

Large-scale, cost-effective transport of hydrogen could require a hydrogen pipeline network complemented by trucking-based transport for distributed end uses (e.g., hydrogen refueling stations). With only 1,600 miles of hydrogen pipelines in place today, the US hydrogen industry would rely on truck-based delivery despite higher unit costs for new uses outside of industrial clusters where hydrogen pipelines currently exist. Trucking could add more than USD 1 per kg to the cost of delivered hydrogen compared to pipeline delivery (cost range will vary based on distance, capacity, equipment utilization, and hydrogen form, e.g., gaseous versus liquid).

Projections show 60% of US hydrogen production will flow through pipelines in 2050.[11] However, there are only 1,600 miles of hydrogen pipelines in the US today (primarily concentrated in major industrial clusters in the Gulf Coast and California) – in contrast to 500,000 miles of natural gas transmission pipelines to move natural gas from producing regions to demand centers across the country.

Building the long-term network to connect potential hydrogen clusters with approximately ten north-south pipelines and five east-west pipelines could require an estimated USD 100 billion. Investments of only USD 3 billion in hydrogen infrastructure projects until 2030 have been announced in North America so far. A rapid ramp-up is needed to enable a pipeline network.

Pipelines to distribute hydrogen could be developed from:

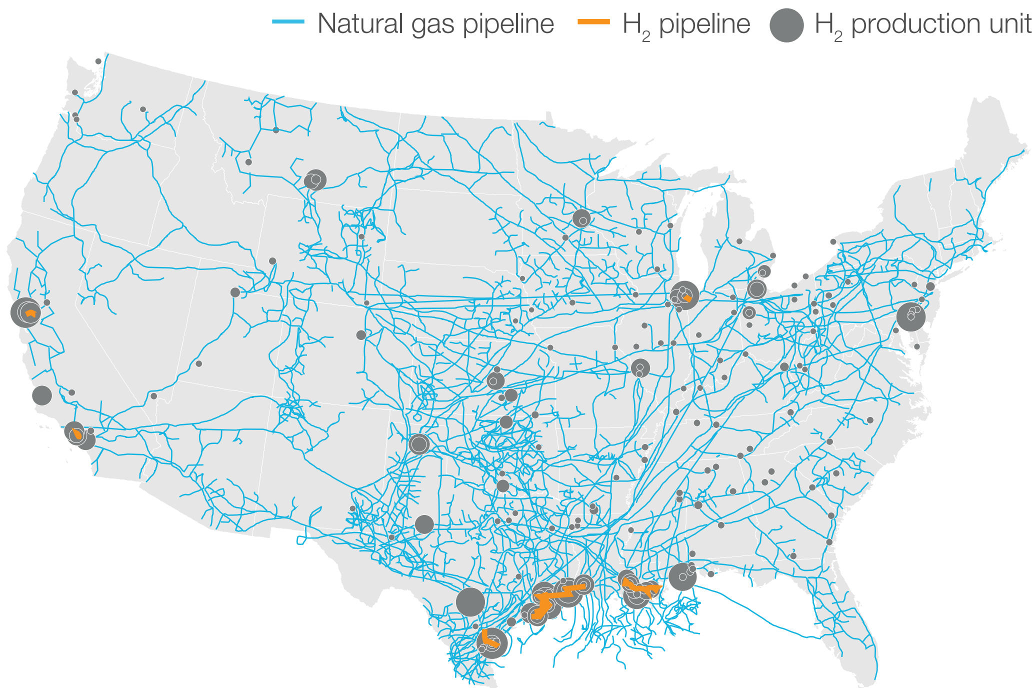
1. Retrofitting the existing natural gas pipeline, which could require both infrastructure upgrades to enable the existing natural gas pipeline to accommodate hydrogen molecules, and the phasing out of existing natural gas transport in order to use the pipelines for hydrogen. The US – unlike Europe – does not have many places with parallel natural gas pipelines running the same routes, making pipeline retrofits a less viable option for most of the US as compared to Europe.
2. Building new pipelines may be more feasible than retrofits in the US. However, new pipelines face their own potential challenges – primarily permitting. Interstate pipelines complicate the process of obtaining rights of way, making permitting a multi-year process.

In the meantime, producers are developing alternatives such as co-location of end uses and production facilities and trucking for hydrogen distribution, particularly to smaller end uses like refueling stations and small industrials:

— Producers, offtakers, and transporters can coordinate to aggregate and connect regional supply and demand. The US Department of Energy's hydrogen hub funding is mobilizing these efforts across the country.

— Adding twin pipelines to existing natural gas pipelines could accelerate the process in some cases by utilizing existing pipelines' right of way.

— Interagency and interjurisdiction coordination to streamline the permitting process and create consistency across regions could help to reduce timelines.



500,000
miles of existing transmission natural gas pipelines

1,600
miles of existing H_2 pipelines

To help enable infrastructure scale-up:

Aggregate regional demand	Retrofit natural gas pipelines	Add twin lines to existing natural gas pipelines	Streamline permitting

Source: National Renewable Energy Laboratory; Energy Information Administration

[11] From Global Hydrogen Flows report

The IRA helps kickstart the US hydrogen ecosystem, however, demand uptake is likely needed for a sustainable ecosystem beyond IRA

Securing committed offtake at scale is essential for a sustainable hydrogen ecosystem. Today, investments in production outpace offtake, and many offtakers are hesitant to sign long-term contracts.

In part, this is because costs could still be a potential challenge once the IRA sunsets after 2032. Despite continued technology innovation, scale-up, and maturity of manufacturing and supply chains, without the IRA incentives, renewable hydrogen is still expected to be more expensive than gray hydrogen.

In addition, offtakers hesitate to commit to clean hydrogen contracts without certainty of reliable, long-term supply. To accelerate demand uptake, the industry likely needs mechanisms that give offtakers certainty about the availability and affordability of clean hydrogen over time. For example, contracts could mitigate risks for offtakers, and policies could support a liquid market to help create certainty for both suppliers and offtakers. An example of this is H_2Global in Germany – a support scheme created by the government to support producers and offtakers by bridging the difference between the cost of clean production and the market price with public funding.

Though the cost for clean hydrogen would not be competitive with gray, to stay on track for the US's decarbonization goals, a shift toward clean hydrogen and its derivatives is likely needed. Codes, standards, and regulations that require emissions reductions and incentives that reward lower carbon intensity products and services could create long-term demand for clean hydrogen. With lower cost achieved for renewable hydrogen in the next ten years, stemming from the scale-up and maturity of manufacturing and supply chains, clean hydrogen could become a viable decarbonization option for many sectors.

To help accelerate demand:

Motivate decarbonization potentially with regulations, standards, or incentives	Facilitate certainty of available and affordable supply

Source: Bundesministerium für Wirtschaft und Klimaschutz