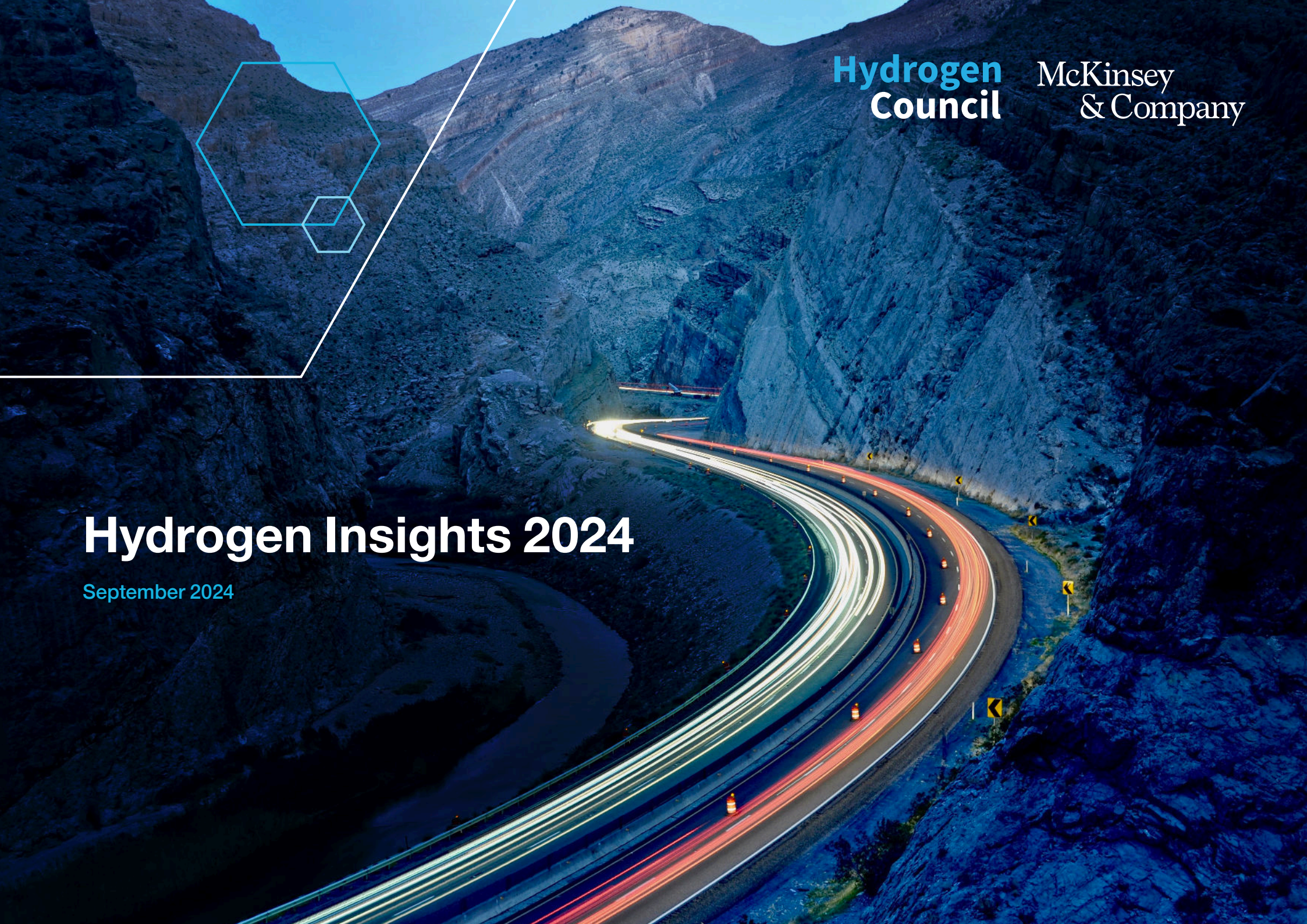

Hydrogen Council

McKinsey & Company

Hydrogen Insights 2024

September 2024

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1. There are no recommendations and / or any measures and / or trajectories within the report that could be interpreted as standards or as any other form of (suggested) coordination between the participants of the study referred to within the report that would infringe the EU competition law;

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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 is a global CEO-led initiative with a united vision and long-term ambition for hydrogen to foster the clean energy transition

Hydrogen Insights is the Hydrogen Council's regularly published perspective on the hydrogen industry's evolution. It summarizes the current state of the global hydrogen sector and actual hydrogen deployment. This report was authored by the Hydrogen Council in collaboration with McKinsey & Company. 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 explained in Hydrogen Insights 2021

Executive summary

In this latest edition of Hydrogen Insights, we take stock of the industry's progress over the past four years[2] and consider the most recent trends in the sector and major developments that have occurred since our previous publication in December 2023.

Walking the talk: Seven-fold increase in investment for hydrogen projects reaching FID globally within the past four years

The global hydrogen industry is nascent and facing challenges as it scales, however, looking at the development of the global hydrogen industry since the first publication of *Hydrogen Insights* in 2021, the progress achieved thanks to the efforts of decision-makers in industry and governments is undeniable.

Clean hydrogen[3] projects that reached final investment decision (FID) have seen a dramatic increase from 102 committed projects in 2020, representing some USD 10 billion in committed investment, to 434 in 2024, representing some USD 75 billion.

Key factors driving successful projects to FID include clear and effective incentives (e.g., 45Q tax credit in the United States), demand-side visibility that drives offtake (e.g., contract-for-difference instruments driving hydrogen demand for power production in Japan), and strong industrial policy driving cost down thanks to deployment at scale (e.g., in China).

Growing project maturity: progress towards FEED coupled with natural attrition

While the global project pipeline has grown by a factor of seven since 2020 from 228 projects in 2021 to 1,572 projects in 2024 across the value chain, it has also matured. Over the years, a larger portion of projects have shifted from announcements to more advanced stages. Between 2020 and 2024, investments made in front end engineering design (FEED) stage projects increased by factor 20.

Natural attrition drives industry maturation by phasing out less viable projects and prioritizing those with the highest potential. Similar trends have been observed in the early years of the wind and solar industries prior to reaching maturity with typical success rates of project funnels at about 10% to 20% from initial development to commissioning[4], and remain common in other fast-growing climate technologies, such as the battery industry.

Navigating turbulence: Regulatory uncertainty and macroeconomic headwinds fueling delays

Alongside other clean energy industries, hydrogen has been facing a set of macroeconomic headwinds, varying from increased inflation and interest rates to turbulence in global energy markets following the geopolitical crises, supply chain constraints, and higher than anticipated renewable electricity prices.

A key sector-specific challenge for the hydrogen industry is uncertainty associated with a number of regulatory frameworks (e.g., outstanding implementation of RED III at Member State level, rulebook for IRA 45V) which impedes project bankability. Coupled with cost increases for renewable power and electrolysers, this has led to delays and cancellations of projects – in particular, renewable hydrogen projects. Considering these delays and expected project attrition, 12-18 Mt p.a.[5] of the 48 Mt p.a. announced hydrogen supply could be deployed by 2030. At the same time, over the past year, regions such as North America become home to over 90% of global low-carbon hydrogen capacity that has passed FID[6] largely thanks to robust policy incentives (e.g., 45Q tax credit for CCS projects under the IRA).

Beyond the breakthrough: Achieving climate goals requires significant investment jump

While the industry has seen an extraordinary seven-fold increase in hydrogen capacity reaching FID globally over the past four years, the pace and scale of deployment has not been sufficient to remain on track with climate commitments. To accelerate the global energy system decarbonisation, an 8-fold increase of investments in hydrogen is required until 2030, compared to the current investment of USD 75bn past FID.

Addressing this challenge calls for a joint effort by decision-makers in government and industry. Government incentives and enabling legislative frameworks play a critical role in mobilizing private capital and advancing mature projects within this decade. In the next two years, ensuring greater regulatory clarity and certainty and support for demand drivers will be critical for tackling project delays observed today alongside the development of the enabling midstream infrastructure.

Together, governments and industry have a unique opportunity to build on the undeniable progress made over the past four years in the hydrogen sector, unlocking environmental and socio-economic gains for the global economies alongside cost-efficiency benefits for the energy systems.

In this report, renewable hydrogen refers to hydrogen produced from renewable energy sources via water electrolysis. Low-carbon hydrogen refers to hydrogen produced with low-emissions technologies with significantly lower greenhouse gas emissions impact than conventional production pathways, and therefore does not include hydrogen from unabated fossil fuels. Renewable and low-carbon hydrogen are collectively referred to as "clean hydrogen". Grey hydrogen refers to hydrogen produced from unabated fossil fuels.

We recognise different policy choices and approaches to establishing GHG emissions intensity thresholds and bands adopted across jurisdictions, using GHG emissions footprint in kg CO2-equivalent and other criteria for qualifying hydrogen as 'clean'/ 'low-carbon'/ 'renewable'/ 'sustainable'/ 'low-emission'.

2 Hydrogen Council, Hydrogen Insights 2021, 2022, 2023
3 Clean hydrogen includes both renewable hydrogen and low-carbon hydrogen
4 Covered in Hydrogen Insights December 2023
5 10 GW electrolysis per 1 Mt p.a. renewable hydrogen assuming average load factor of 55% (4,820 hours p.a.) and conversion efficiency of 50 kWh/kg
6 Including projects in FID, under construction, commissioned and operational

Exhibit 1

Announced investments through 2030 have grown strongly since 2020, including investments in projects that have passed FID reaching USD 75 billion

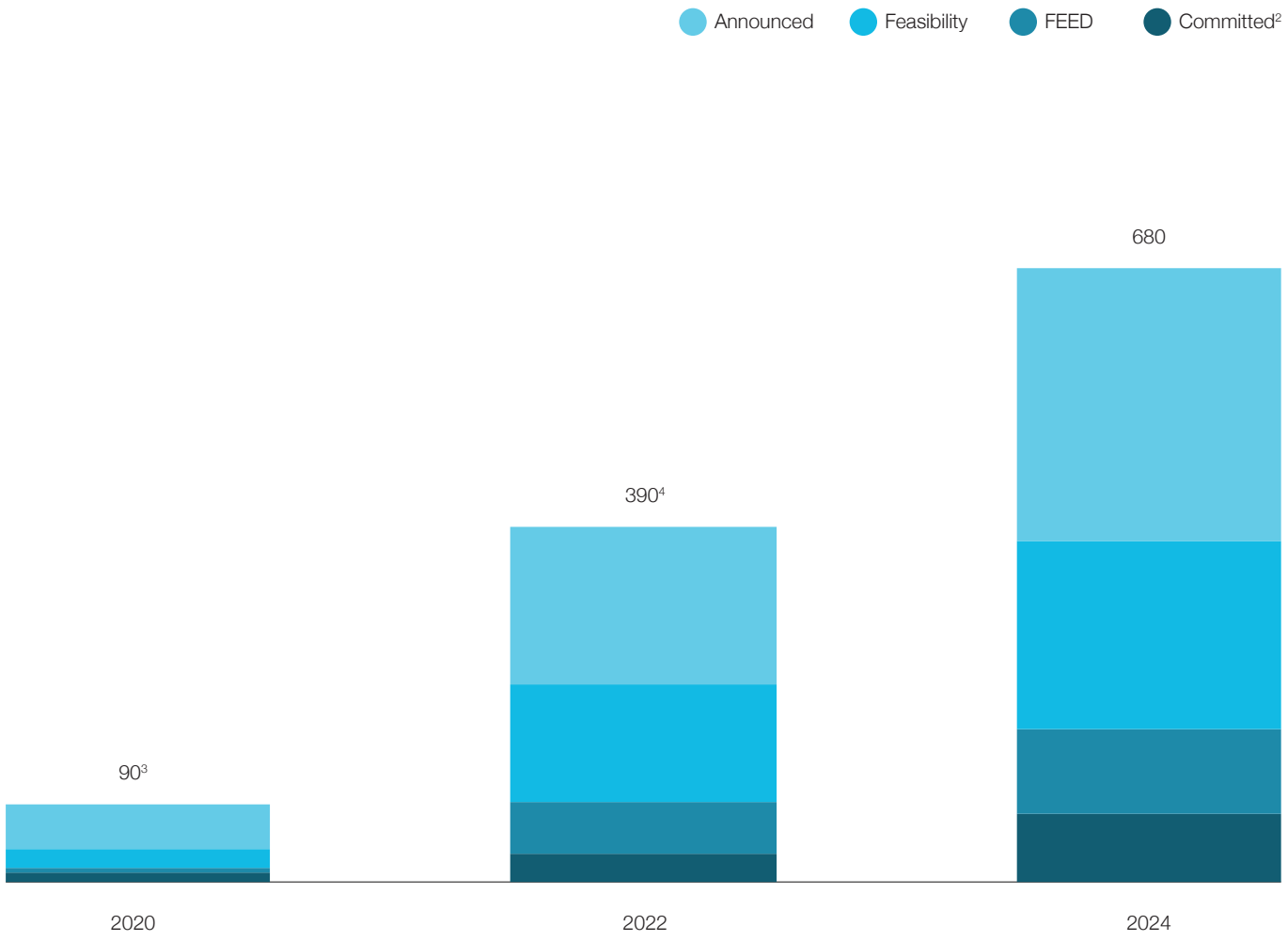
Since the inaugural Hydrogen Insights publication in 2021[7], investments in hydrogen have grown by a factor of 8 and a larger proportion of investments required are linked to more mature stages. The total investments across projects phases have increased from USD 90 billion in 2020 to USD 390 billion in 2022 and USD 680 billion in 2024 (2020 and 2022 investments normalized based on updated capital expenditure assumptions applied from December 2023 report onwards). This growth demonstrates the continued commitment from the private sector to develop hydrogen projects, despite current industry headwinds such as increased inflation and interest rates, turbulence in global energy markets following the Ukraine crisis, constrained supply chains, and higher than anticipated renewables prices. Committed investments have also grown significantly, from USD 10 billion in 2020 to USD 75 billion in 2024.

Over the years, a larger proportion of announced investments have matured to more advanced stages. In 2020, projects in the announced stage made up 55% of potential total capital allocations, while this was only 45% in 2024, indicating a maturation of existing projects. Especially investments in the committed stage have grown in recent years, more than doubling from USD 30 billion (8% of total investments) in 2022 to USD 75 billion (11%) in 2024. Furthermore, the median investment size for projects in the committed stage has increased from USD 5 million in 2020 to USD 25 million in 2024, clearly demonstrating that projects have gotten larger.

As the pipeline has gotten larger and increasingly mature, the proportion of investments directed at the various value chain steps has shifted towards more focus on hydrogen supply. Projects focused on supplying clean hydrogen accounted for more than 60% of total investments in 2020, increasing to 75% in 2024. Within infrastructure, the share of investments has remained 10% over time, while planned investments into end-use have decreased from 30% in 2020 to 15% today.

7 Data from December 2020 used for Hydrogen Insights 2021 report

Total investment throughout publications[1], USD billion



1. December 2020 data used for 2021 Hydrogen Insights report, May 2022 data used for 2022 Hydrogen Insights report, May 2024 data used for 2024 Hydrogen Insights report
2. FID, Under construction, Commissioned, Operational
3. Data from report normalized based on updated capex numbers used from the December 2023 Hydrogen Insights report onwards as well as investments in deployments removed
4. Data from report normalized based on updated capex numbers used from the December 2023 Hydrogen Insights report onwards
5. Hydrogen Council & McK project investment tracker includes inputs from the HC members & publicly available data on hydrogen and derivatives worldwide

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of December 2020, May 2022 and May 2024[5]

Exhibit 2

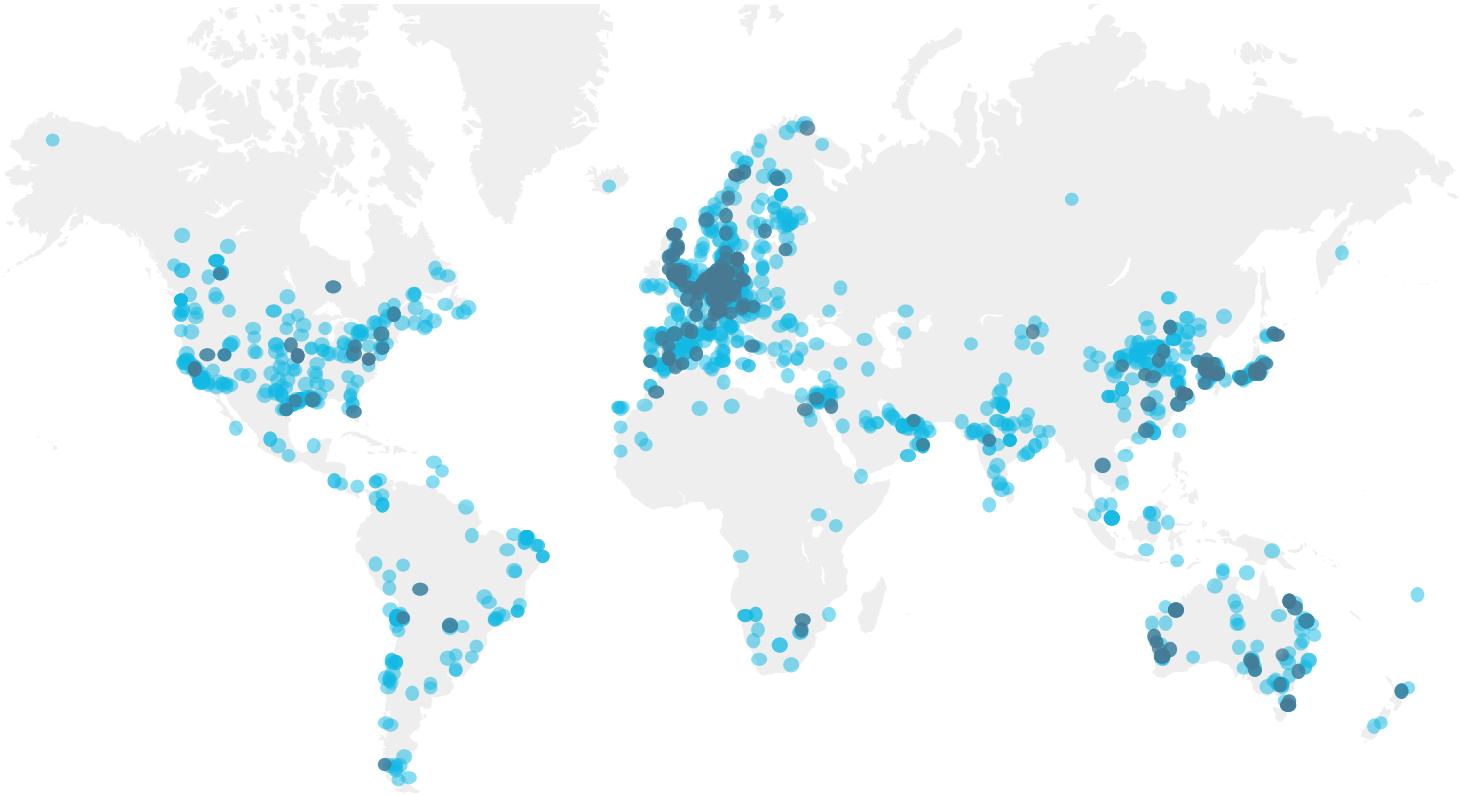
The global hydrogen project pipeline has grown 7-fold since 2020

The growth of investments has been coupled with a growth in the number of announced projects, with the industry becoming increasingly global. The number of projects in the pipeline has risen from 228 in December 2020 to 1,572 projects as of May 2024, including an increase in the number of projects in the committed stage from 102 to 434. Since 2020, clean hydrogen supply capacity past FID has grown from 716 kt p.a. by 2030, mainly consisting of low-carbon hydrogen, to 4.6 Mt p.a. by 2030 with the capacity evenly split between low-carbon and renewable hydrogen.

Between 2020 and 2024, clean hydrogen supply capacity planned through 2030 has grown from about 7 Mt p.a. in 2020 to 48 Mt p.a. today, in line with growth in number of projects, indicating the average size of announced projects has remained steady. This is likely driven by the prevalence of large-scale low-carbon projects deployed in the context of carbon capture and storage (CCS) prior to 2020, and the pipeline today including nearly 200 giga-scale[8] projects which account for nearly two thirds of all announced supply capacity through 2030. Meanwhile, the composition of the hydrogen supply has evolved from approximately 60% renewable hydrogen in 2020, to about 75% renewable today as projects have been announced in renewables-rich regions such as Latin America, Australia, Africa, and the Middle East.

In 2020, the majority of projects were being developed in Europe, accounting for 55% of the total project pipeline, respectively, in terms of the number of projects. However, in recent years the balance has shifted, and the 'global south' has taken a more prominent role. Europe's share of projects within the global project pipeline has reduced to 40% (although number of projects has grown from 125 to more than 600), and the second-largest region is now North America (20%) followed by China and Latin America (10% each). Notably, North America has the largest relative increase in projects in a committed stage, with close to 100 projects past FID today (up from less than 10 in 2020). This entails an increased proportion of projects past FID is in North America, at more than 20% of total projects in FID, up from less than 10% in 2020.

Project overview December 2020 vs May 2024



228
Projects pipeline in December 2020, 102 have passed FID

1,572[1]
Projects pipeline as of May 2024, 434 have passed FID

7x
increase in the number of projects in the pipeline

4 Mt p.a.
increase in 2030 hydrogen capacity that has passed FID

8 Giga-scale projects include over 1 GW of electrolysis for renewable hydrogen or more than 200,000 kilotons per annum (kt p.a.) of low-carbon hydrogen

1. Project announcements below 1 MW are excluded

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of December 2020, May 2022 and May 2024

01

Project pipeline maturing with a shift in focus to advancing projects towards FID

1,572

hydrogen projects have been announced globally, 1,125 of which have a commercial operations date (COD) date through 2030

USD 680 billion

in direct investments in hydrogen projects have been announced through 2030 (+20% versus previous publication)

USD 75 billion

invested in projects that have passed FID stage, a 90% increase versus the previous publication

48 Mt p.a.

of clean hydrogen supply through 2030 have been announced, of which 75% is renewable and 25% is low-carbon

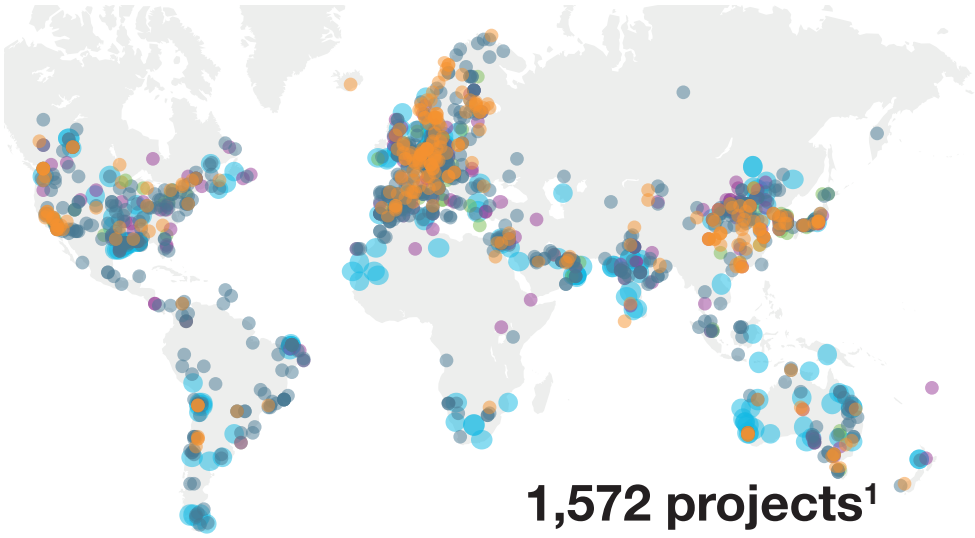
Exhibit 3

Hydrogen momentum continues: 1,572 projects have been announced globally – USD 680 billion investments announced through 2030

Globally, the industry has announced 1,572 clean hydrogen projects as of May 2024. Since the previous publication[9], the pipeline had a net growth of 154 projects. 1,125 of the total 1,572 projects have a planned COD through 2030, representing investments of about USD 680 billion in hydrogen value chains (up from USD 570 billion). Giga-scale projects account for more than half at over USD 380 billion.

Growth is apparent across most regions in terms of both investments and the number of projects, although growth is slower than in previous years. Europe continues to have the largest number of projects (617), followed by North America (280). Europe also has the highest total investments announced (USD 199 billion). Latin America has the second largest volume of announced investments (USD 107 billion), while North America has the third highest investments (USD 96 billion) and the highest absolute growth in announced investments (USD 28 billion). Japan and South Korea show the highest relative growth in investments of about 130%, while India demonstrates growth of 110%, followed by Rest of Asia with 75% growth. Africa experiences a decrease in capital invested through 2030 (USD 11 billion), due to large projects being shifted over multiple phases, where later phases occur after 2030. This includes USD 7 billion related to a single giga-scale project where phases have been introduced, with phase 2 being post-2030.

Global project overview



1,572 projects[1]

1,418 in Oct 2023

186 Giga-scale production

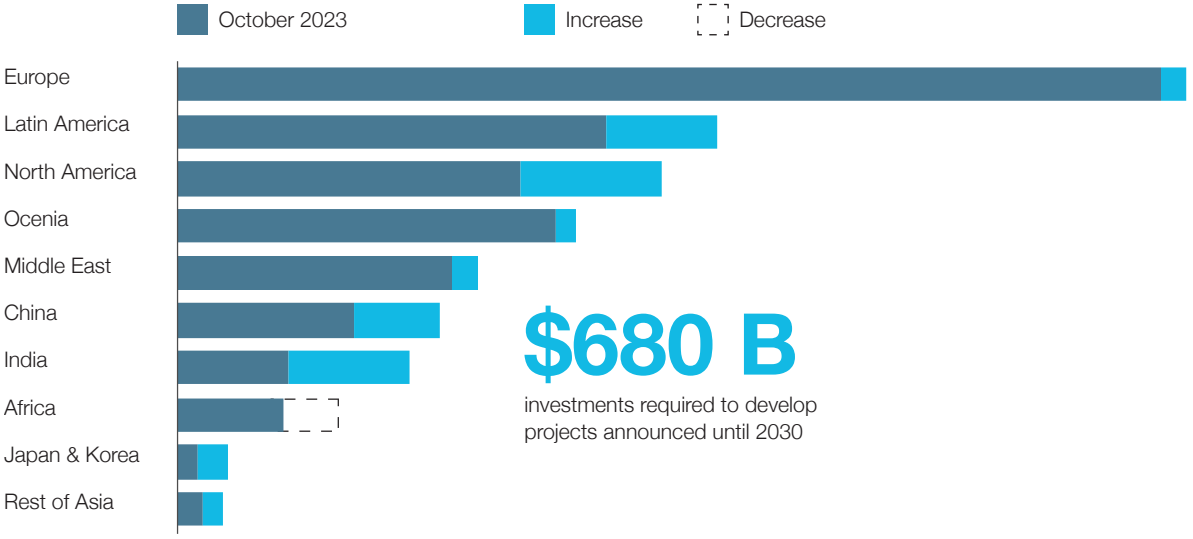
783 Large-scale industrial use

268 Mobility

190 Integrated H_2 economy

138 Infrastructure projects

2024 May vs 2023 Oct



$680 B

investments required to develop projects announced until 2030

1. Project announcements below 1 MW are excluded. 7 projects have not announced project type

Source: Project & Investment tracker, as of May 2024

9 Hydrogen Insights 2023; published in December 2023; comparisons in this report are relative to this publication unless stated otherwise.

Exhibit 4

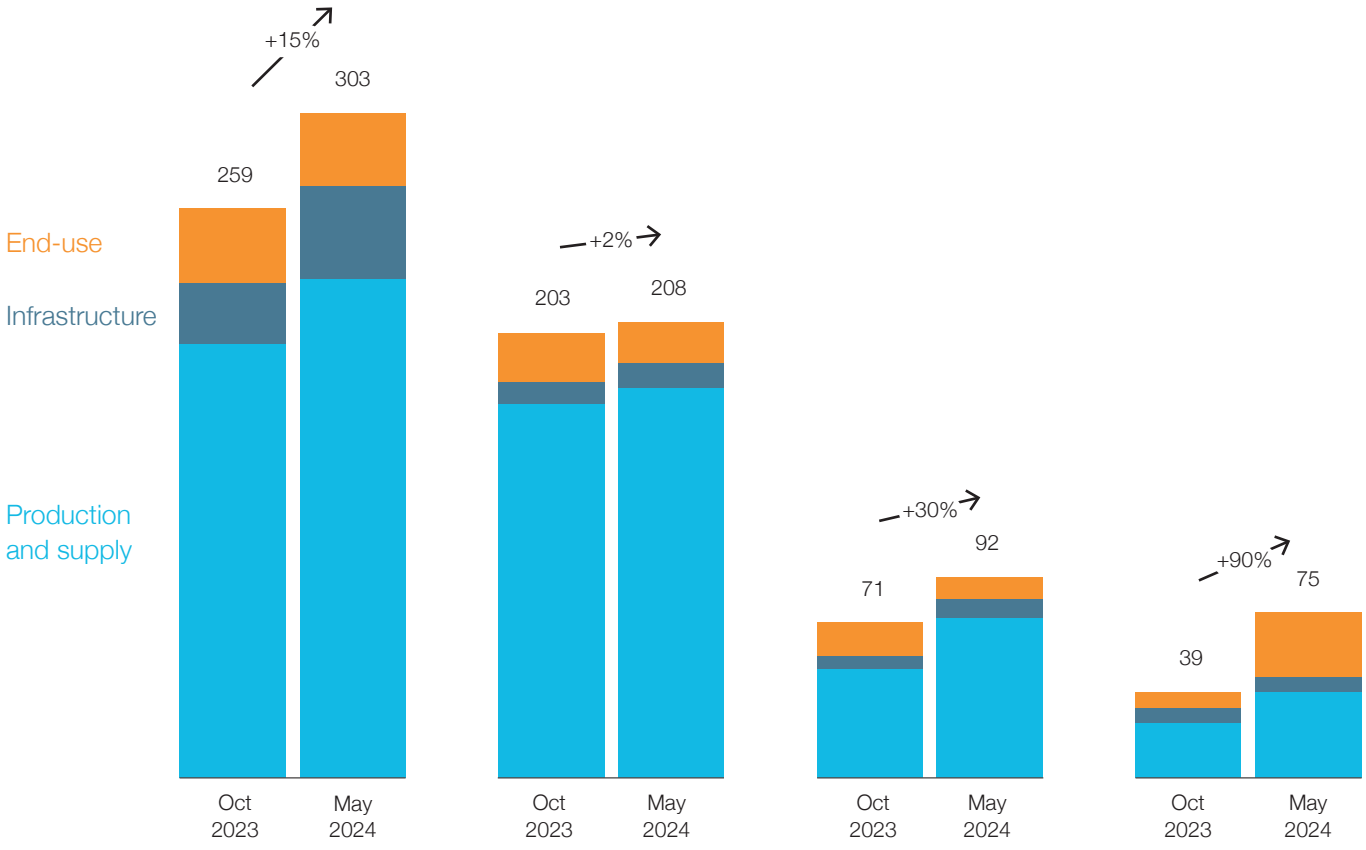
The project funnel is growing across project stages, with the fastest growth occurring in more advanced stages

Total announced investments through 2030 have increased by approximately 20% in the past six months – from USD 570 billion to USD 680 billion. The increase is unevenly distributed across project stages with the strongest growth in committed capital of 90%. This is followed by approximately 30% growth in FEED, 15% in announced, and 2% in projects in feasibility stage. The growth in committed and FEED stages is a sign that projects are maturing. Overall, 11% of investments in clean hydrogen are now committed (up from 7% versus previous publication), while FEED makes up 14% of all investments (up from 12%).

Of the 90% growth in the committed stage, 60% is driven by end-use investments (USD 21 billion). Infrastructure investments grow at approximately 40% (USD 20 billion), while production and supply investments grow with 15% (USD 70 billion) compared to previous publication. Growth in production and supply investments is high in both announced (USD 25 billion) and FEED (USD 22 billion). Overall, investments in production and supply make up 75% of total investments, followed by 15% in end-use investments and 10% of investments in infrastructure.

USD 370 billion is invested in projects that have passed the announced stage (including feasibility, FEED and committed), up from USD 310 billion in previous publication. Mature investments are unevenly distributed across regions. In the committed stage, China (USD 31 billion) and North America (USD 17 billion) contribute over 60% of investments, with majority of their investments in production and supply. Other regions with large committed investments (Europe, Japan & Korea and the Middle East) are end-use focused. Meanwhile, India (USD 28 billion) and Oceania (USD 12 billion) see an increase in investments in FEED stage projects and Latin America (USD 70 billion) and Oceania (USD 37 billion) have a large share of the investments in feasibility stage projects.

Direct hydrogen investments until 2030, USD billion



$370 B
in planning stage and beyond
(versus $310 B in previous publication)

75%
of investments focus on supply
(in line with previous trend)

Source: Project & Investment tracker, as of May 2024

Exhibit 5

Europe, North America and China have the largest number of projects in committed stage

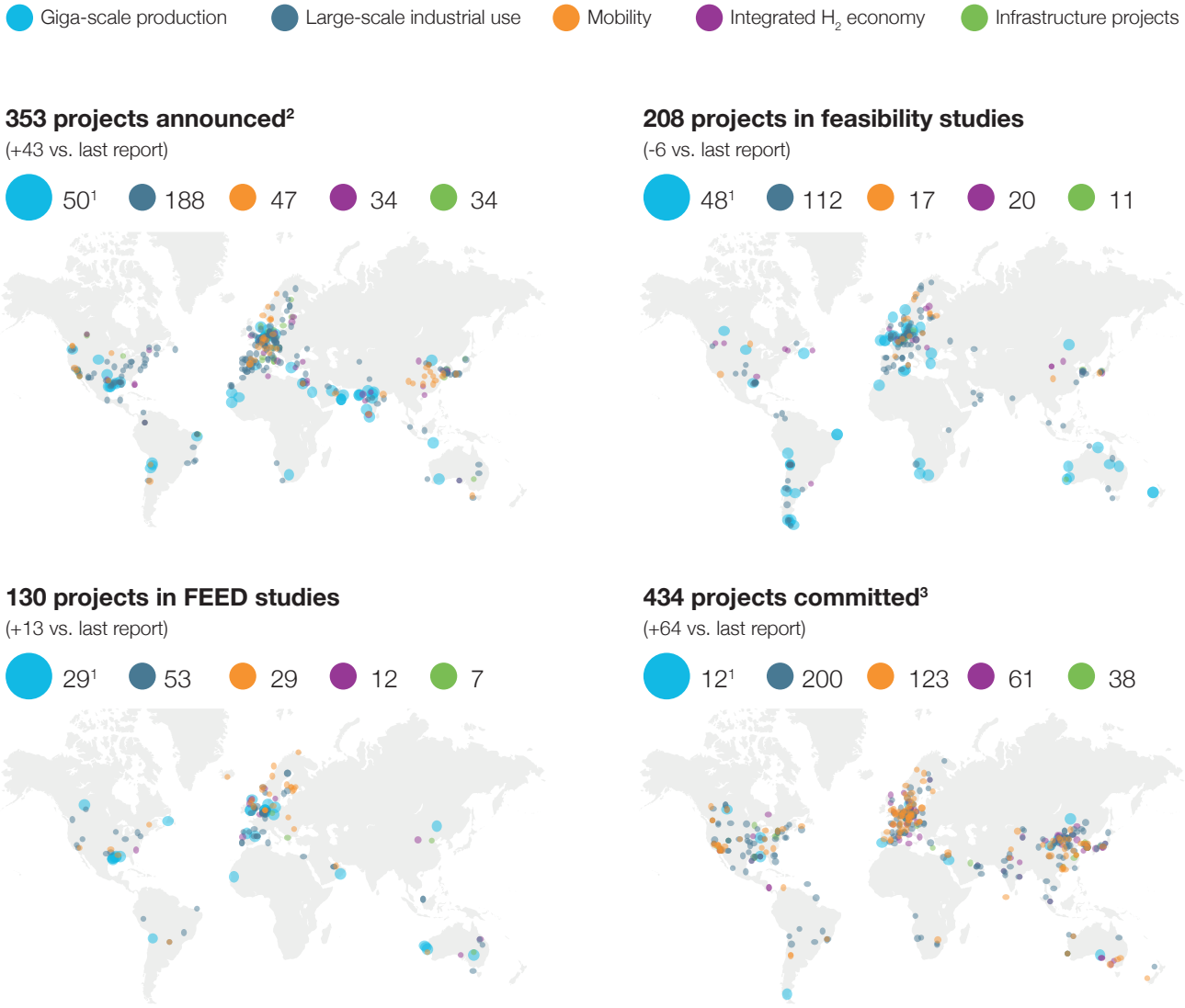
Considering projects with a COD through 2030 (1,125 projects), 40% are in committed stage, 10% in FEED, 20% in feasibility and 30% in 'announced only'. All stages demonstrate a net growth in project numbers compared to the previous publication, except for the feasibility stage.

Highest growth is observed in committed projects (64), consisting of known projects advancing through the pipeline and new projects added to pipeline (44 projects). Committed projects at times do not announce progress throughout the development funnel. This is particularly prevalent in China, where many companies only announce when FID is taken and capital is committed. The number of projects in FEED grows moderately (13) as both new projects get announced and other projects mature. Meanwhile, the number of projects in feasibility decreases (-6) as projects progressing to more mature stages outpaces the number of incoming projects.

Generally, 50% of projects with a COD through 2030 are dedicated to large-scale industrial use (553), followed by mobility projects as the second largest group at 20% (216). However, while large-scale industrial projects are the largest category of projects across every stage, the relative number of mobility projects per stage varies. For example, in the committed stage mobility projects make up 30% of projects. Projects in the committed stage are mainly found in Europe, North America and China, with high proportion of mobility projects being in Europe and Asia.

Other stages are more geographically dispersed, with a high number of announced projects in Europe, North America, the Middle East and India. High proportion of projects in feasibility are observed in Europe, Latin America and Oceania, while projects in FEED stage mainly occur in Europe.

Global project overview by stage through 2030



1. For multi-phase projects, phase 1 decides the project maturity
2. Preliminary studies or press announcement stage
3. FID taken, under construction or operational

Source: Project & Investment tracker, as of May 2024

Exhibit 6

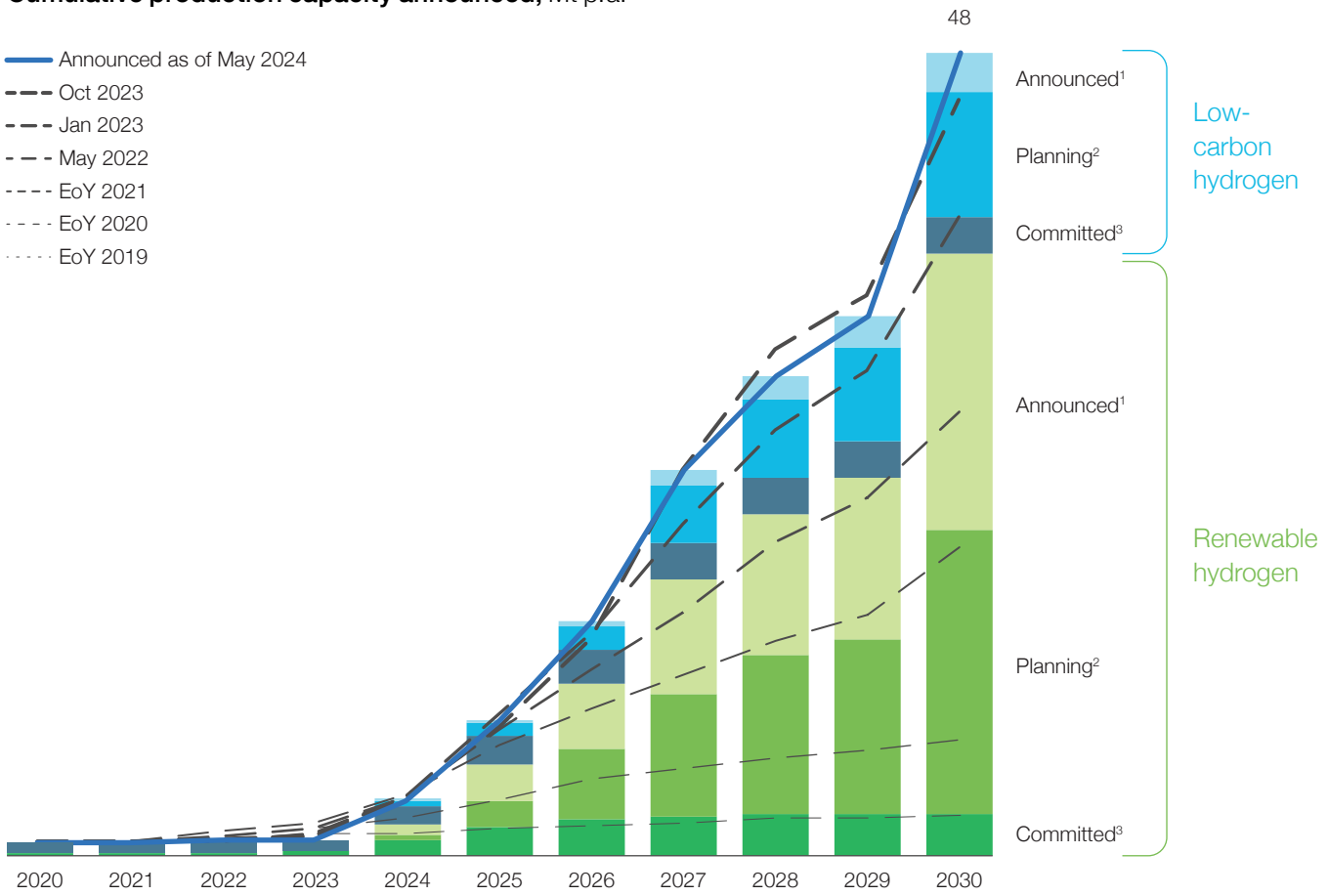
Announced production volumes increased to 48 Mt p.a., with majority of growth driven by renewable hydrogen announcements

Companies have announced 48 Mt p.a. of clean hydrogen production capacity globally through 2030 (previously 45 Mt p.a.), of which about 9% of volume is in committed and 50% is in the planning stage. While the split between total announced investments in renewable and low-carbon hydrogen is relatively even in 2024 (60% renewable, 40% low-carbon), the balance is shifting gradually towards renewable hydrogen. Based on announcements 75% of capacity through 2030 is renewable hydrogen (36 Mt p.a.), with the remainder being low-carbon (12 Mt p.a.). Across committed capacity, renewable hydrogen will outgrow low-carbon hydrogen by 2026 if announced volumes are deployed according to their timeline. Of the 3 Mt p.a. growth compared to the previous publication, India contributes 1.5 Mt p.a. and Latin America contributes 1 Mt p.a., following large renewable project announcements. Announced renewable capacity increased with more than 4 Mt p.a. Meanwhile, the number of low-carbon projects increased as well (19), however, a refinement in the assumptions of giga-scale project ramp-ups shifts capacity to post-2030, leading to a 1 Mt p.a. decrease in volumes in 2030 compared to previous publication.

Of the announced investments through 2030, 65% is announced in Europe (13 Mt p.a.), North America (10 Mt p.a.) and Latin America (8 Mt p.a.). While Europe and Latin America lean towards renewable hydrogen (11 Mt p.a. and 7 Mt p.a. respectively), North America has a substantial base of low-carbon hydrogen (7 Mt p.a.). Of the 7 Mt p.a. low-carbon hydrogen announced in North America, 2 Mt p.a. has a COD in 2025, making up over 70% of low-carbon capacity globally in 2025.

While announced capacity continues to grow, project delays are increasing. This can be observed from announced production capacity in 2028 and 2029 being more than 1 Mt p.a. lower than the previous publication. Nevertheless, growth picks up towards 2030, as total announced production capacity shows overall growth compared to previous publications.

Cumulative production capacity announced, Mt p.a.



>50%
increase in 2030 committed capacity (4.6 Mt p.a., versus 3 Mt p.a. in October 2023)

65%
share of capacity of top 3 markets (Europe, North America, Latin America)

+21Mt
additional capacity (low-carbon and renewable) with commissioning after 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 May 2024

Exhibit 7

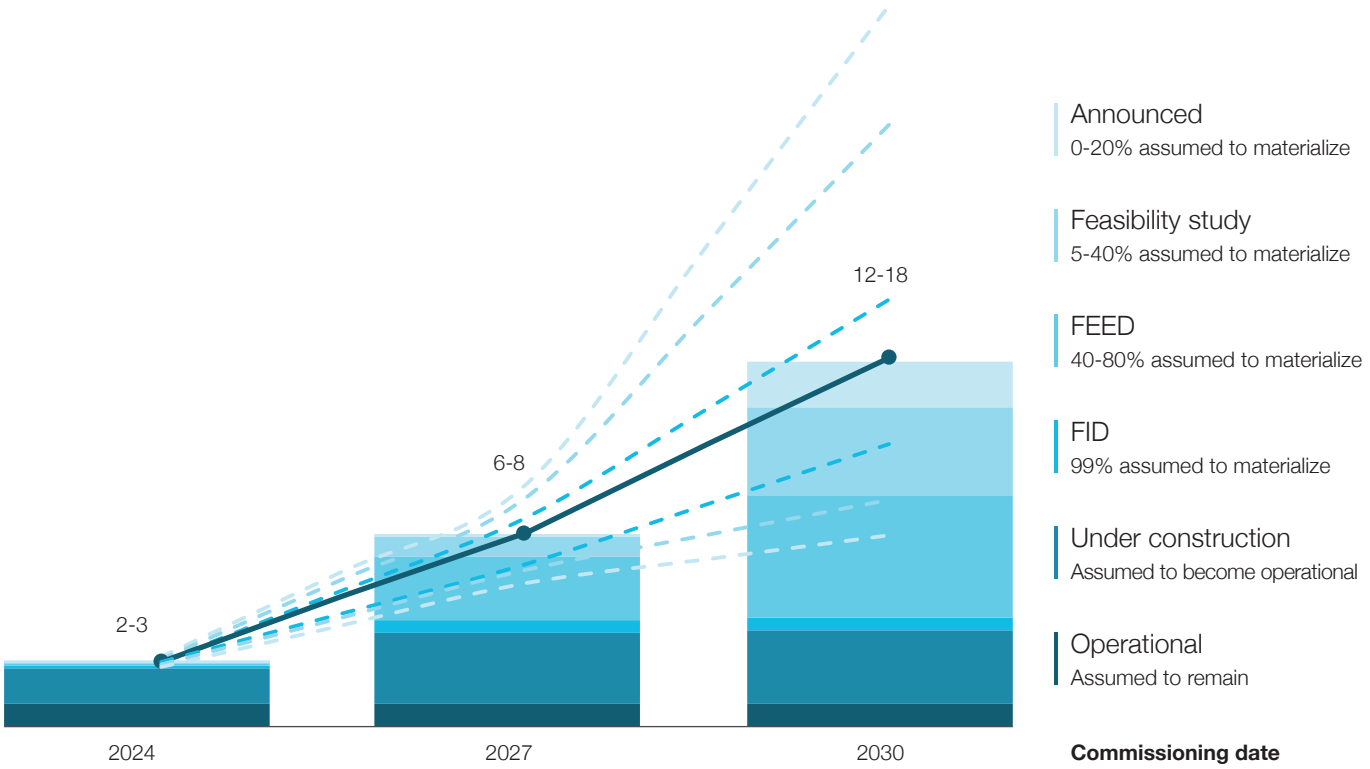
A probability adjustment of the clean hydrogen pipeline suggests that 12-18 Mt p.a. is likely to come online globally through 2030

To provide an adjusted outlook on the expected supply of clean hydrogen through 2030, a probability adjustment (based on renewables project completion rate) can be applied to the project pipeline. Historically, project completion rates in the renewables sector have been relatively low vs. announcements. While this may be too pessimistic for clean hydrogen, similar completion rates are applied to calculate a probability adjusted pipeline[10]. This reflects the early-stage nature of the hydrogen industry.

By applying this methodology, the global supply of clean hydrogen reaches 12-18 Mt p.a. (around 30% of the total announced 2030 capacity of 48 Mt p.a.). Notably, this number does not account for further project announcements beyond those currently on the record. Based on the current pipeline, two thirds of the supply consists of renewable, with low-carbon hydrogen accounting for the remaining third (7-11 Mt p.a. and 5-7 Mt p.a., respectively).

When applying the probability adjustment, 30% of the supply in 2030 will come from North America (4-6 Mt p.a., 75% low-carbon, 25% renewable), followed by 3-5 Mt p.a. in Europe, mostly renewable.

Probability adjusted supply of clean hydrogen by 2030, Mt p.a.



12-18 Mt p.a. = **7-11 Mt p.a.** **5-7 Mt p.a.**

Clean hydrogen production likely to come online by 2030 – based on current pipeline of publicly announced projects

Renewable likely to come online by 2030

Low-carbon likely to come online by 2030

Source: Project & Investment tracker, as of May 2024

10 In the probability adjustments, the following success rates are considered versus announced kt p.a. capacity: 99% for projects post-FID, 40-80% for FEED, 5-40% for feasibility and 0-20% for announced projects based on project maturity versus COD

Exhibit 8

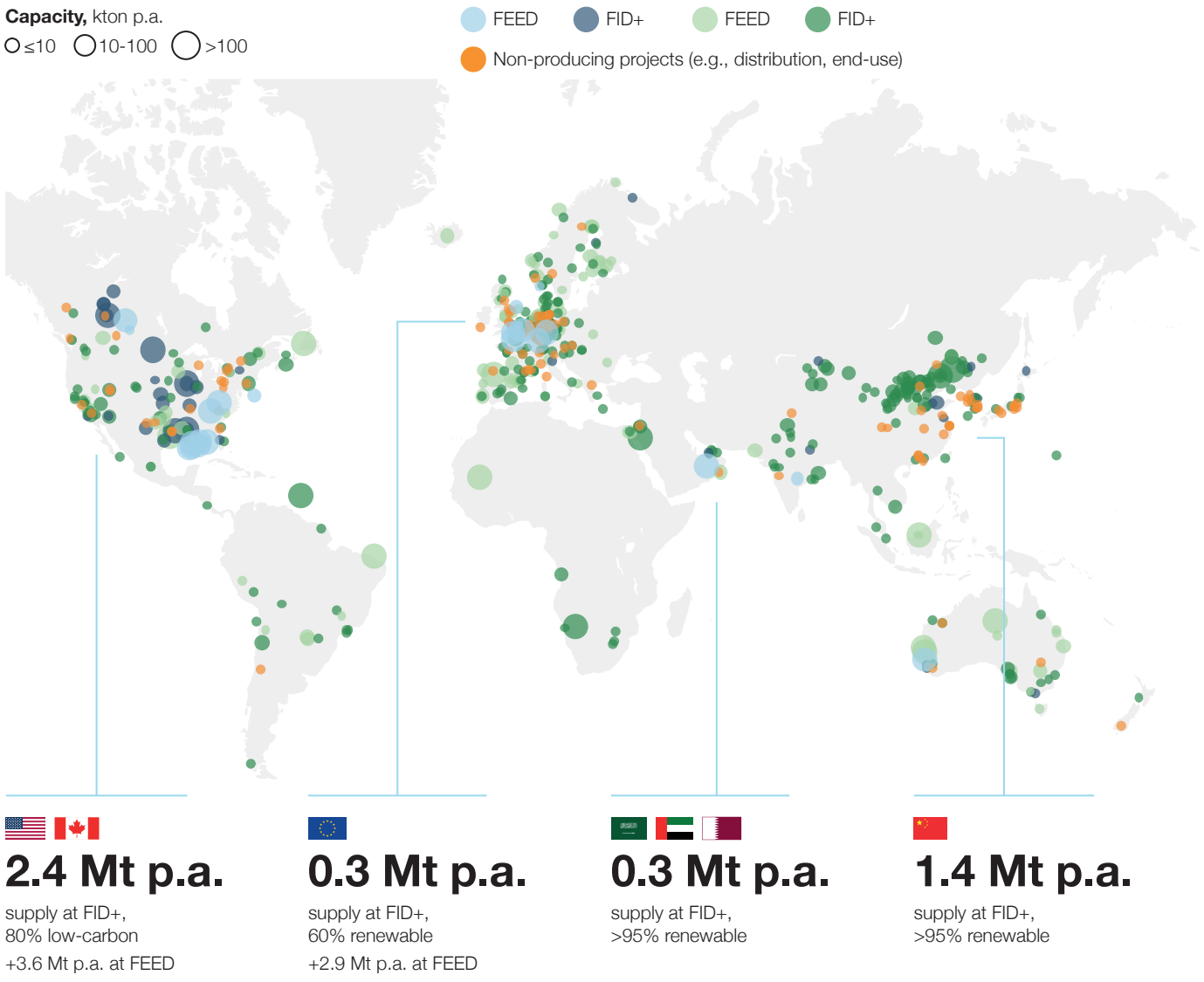
North America has the most mature clean hydrogen pipeline with 2.4 Mt p.a. supply committed

North America has the largest committed clean hydrogen supply of 2.4 Mt p.a. post FID and an additional 3.6 Mt p.a. in FEED. The committed projects in North America are predominantly low-carbon, with growth in both low-carbon and renewable (respectively 370 kt p.a. and 270 kt p.a.) since previous publication.

China has reached 1.4 Mt p.a. post FID. Several projects have recently been announced (+720 kt p.a. since previous publication), with multiple projects already in construction. Europe has 0.3 Mt p.a. post FID and 2.9 Mt p.a. in FEED, with projects generally being smaller in scale. The Middle East has 0.3 Mt p.a. supply post FID with COD pre-2030, largely driven by a single giga-scale project.

North America accounts for +90% of the committed low-carbon volumes. For renewable hydrogen, China accounts for about 55% of the committed supply globally.

Clean hydrogen FEED+ projects globally, (size of bubble indicate production capacity in 2030)



Source: Project & Investment tracker, as of May 2024

Exhibit 9

375 GW of electrolysis capacity has been announced through 2030, up from 305 GW previously

375 GW of electrolysis deployment has been announced through 2030[11], 70 GW more than previously announced. Half this capacity (185 GW) is past the 'announced only' stage. Of this, nearly 160 GW are undergoing feasibility studies or FEED while 26 GW have passed FID. The volumes of electrolysis capacity past FID increased from 12 GW to 26 GW, with most of the capacity in China followed by North America (about 10%), the Middle East (about 10%), and Europe (about 5%). Deployments in China continue to outpace the rest of the world, as committed electrolyzer volumes previously grew from 40% to about 55% of global capacity, and now reached 65%.

Europe is the region with the most announced electrolyzer capacity at 105 GW (30% of total), with 45 GW having entered at least the feasibility stage. Latin America is home to 20% of all announced volumes through 2030 at 70 GW capacity, followed by Oceania at 50 GW capacity and the Middle East and India at 40 GW capacity each. Of the respective regions, India demonstrated the highest growth of 160% compared to the previous publication (15 GW). Meanwhile, growth in North America is 60%, reaching more than 30 GW.

Electrolysis capacity follows the trend of investments maturing, with 7% of capacity beyond the FID stage (compared to 4% in previous publication). However, to realize the full pipeline of 375 GW through 2030, acceleration in the coming six years is needed. With current operational capacity of merely 2 GW, deployment needs to grow by about 200 times. This implies not only that project developers across regions and sectors need to mature projects, but also that OEMs need to scale up supply chain and manufacturing capacity.

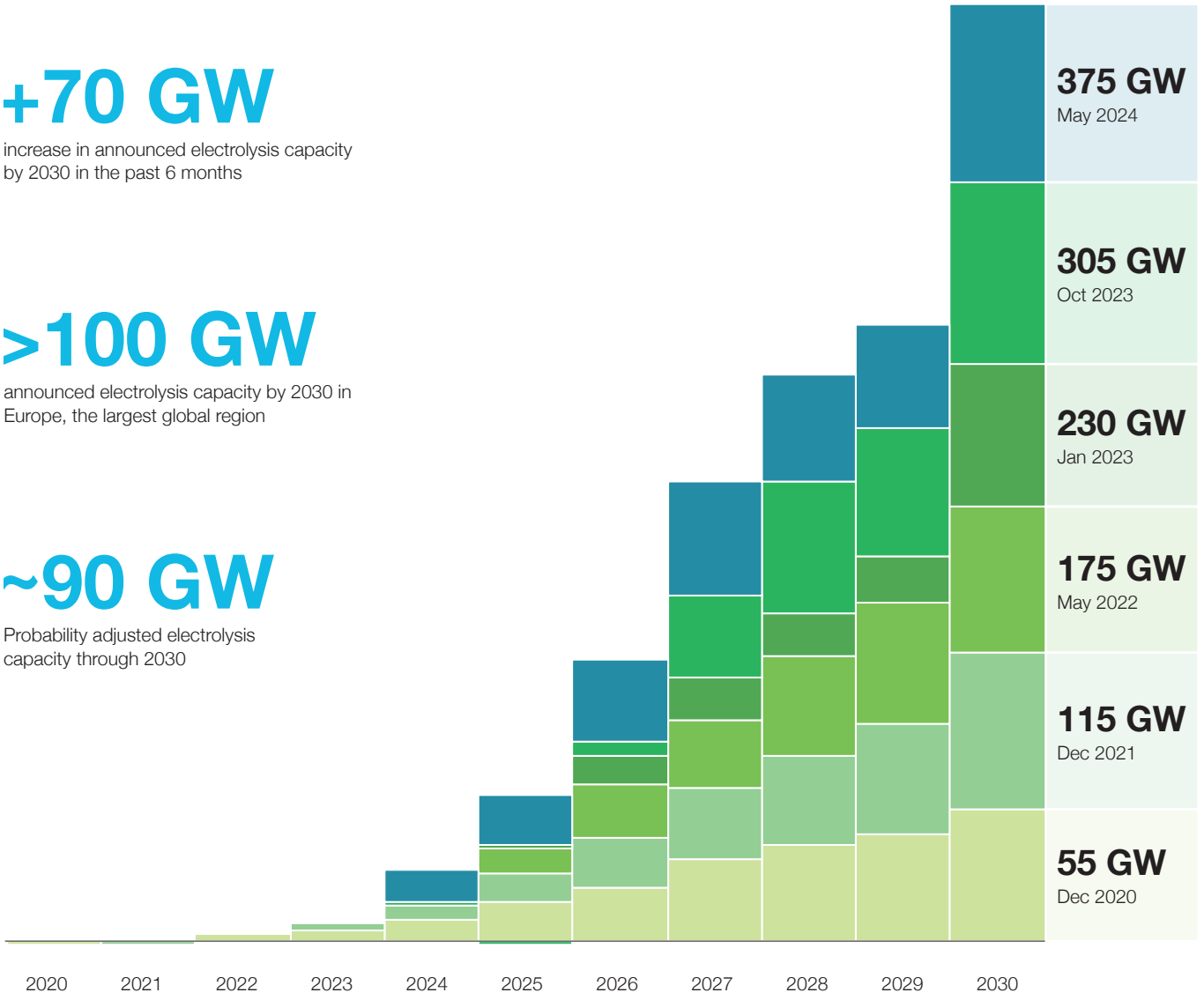
11 Announced electrolyzer capacity cannot directly be translated to volumes of renewable hydrogen as the hydrogen output depends on the capacity factor of the electrolyzer. Capacity factors are determined by individual technical set-ups.

Cumulative electrolysis capacity (announced)[1], GW

+70 GW
increase in announced electrolysis capacity by 2030 in the past 6 months

>100 GW
announced electrolysis capacity by 2030 in Europe, the largest global region

~90 GW
Probability adjusted electrolysis capacity through 2030



1. Announcements are based on publicly available data only; include projects that were announced in hydrogen production capacity and converted into electrolyzer capacity. For projects without known deployment timeline capacity additions were interpolated between known milestones; includes projects in all maturity stages.

Source: Project & Investment tracker, as of May 2024

Exhibit 10

An investment gap of USD 335 billion remains to the 2030 ambition

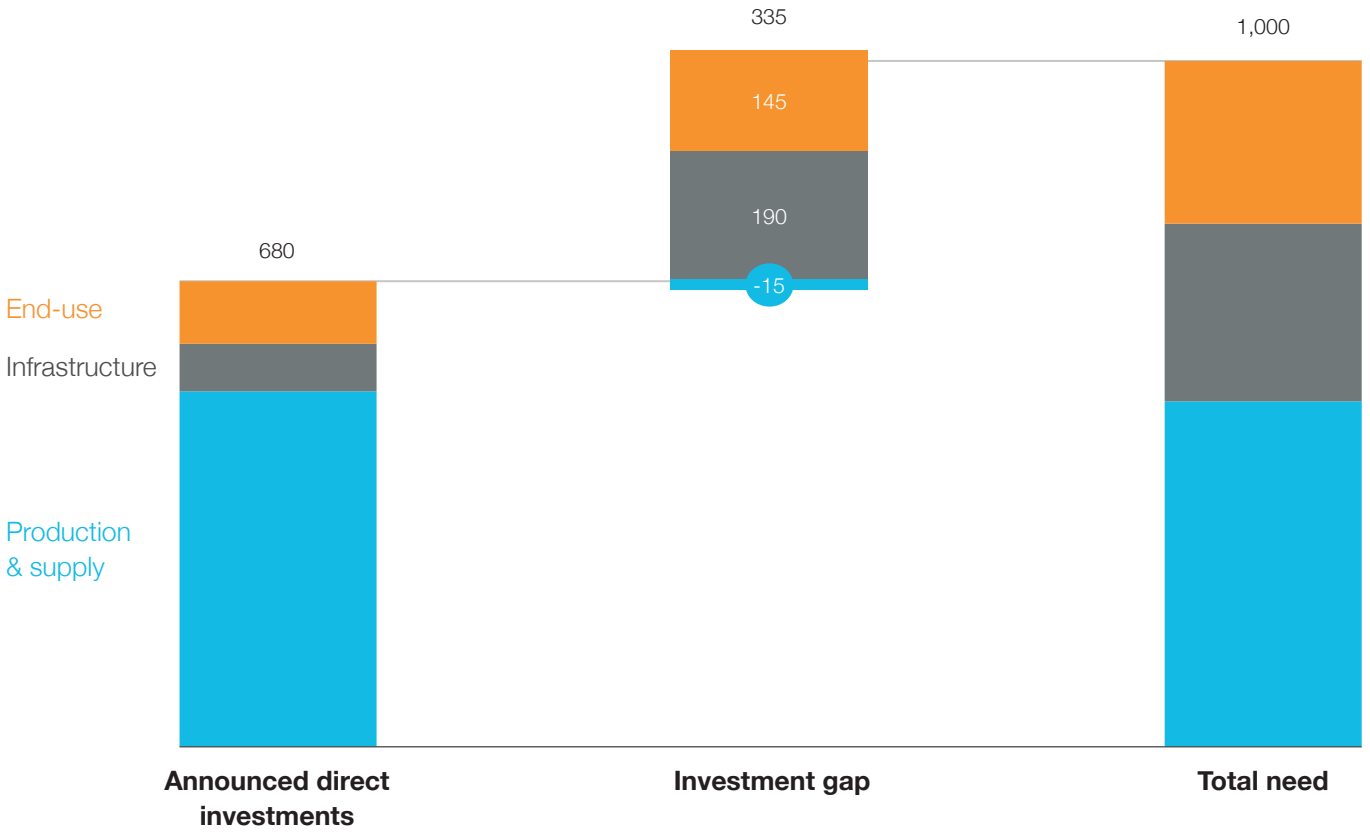
Announced investments through 2030 surpassed USD 680 billion (previously about USD 570 billion). However, additional projects are required across the clean hydrogen value chain to be in line with a net-zero scenario[12]. The total investment gap of USD 335 billion has been brought down by 10% compared to the previous publication.

Growth in announced hydrogen supply projects continues to outpace end-use and infrastructure investments, accounting for more than 75% of total announced investments (growth of about USD 70 billion since previous publication). This means that for the first time announced investments in a category surpass their 2030 target. Production & supply investments are USD 15 billion above estimated net-zero requirements, assuming that all announced projects become operational. With the potential for delays and cancellations, more announcements are needed to increase the likelihood of clean hydrogen investments meeting net-zero needs.

The remaining investment categories continue to see investments gaps, with a 60% investment gap in end-use (about USD 145 billion) and a 75% investment gap in hydrogen infrastructure (about USD 190 billion). Announced investments in hydrogen infrastructure grew by USD 20 billion, a major uptake from the USD 3 billion increase in the previous publication, while end-use investments grew by about USD 10 billion.

It is unclear when the investment gap can be expected to be closed. With the current announced investments and the growth observed since last publication investments are behind the required net-zero pathways with net-zero targets unlikely to be met.

Announced and required direct investments into hydrogen through 2030, USD billion



$680 B
total investments, with $15 B above the production & supply investment need

$145 B
investment gap in end-use applications

$190 B
investment gap in infrastructure

Source: Project & Investment tracker, as of May 2024

12 For a detailed explanation of the applied net-zero scenario see 'Hydrogen for Net-Zero'

02

Clean hydrogen deployment is primarily driven by commitments in production

1.75 GW

of electrolysis capacity deployed by May 2024 (additional 650 MW versus previous publication), with about 26 GW having passed FID globally (additional 14 GW)

895 kt p.a.

operational clean hydrogen supply capacity deployed today – about 1% of the grey hydrogen market today

>200

methanol fueled ships ordered – 9 ships already being deployed and more than 40 additional orders since the previous publication

Exhibit 11

Deployment is steadily growing across the value chain

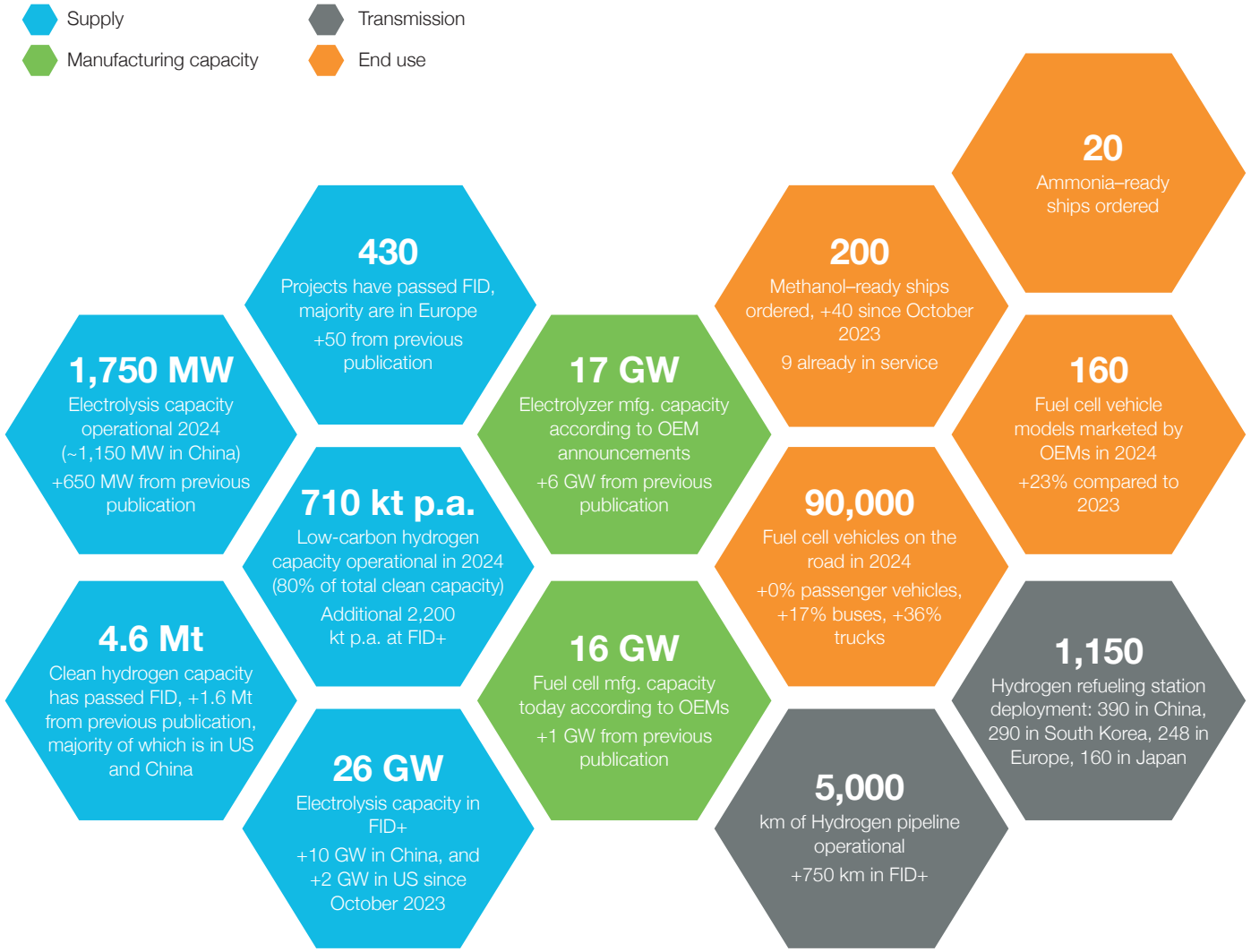
Supply: About 895 kt p.a. of clean hydrogen supply is operational globally, up from 860 kt p.a. previously. About 710 kt p.a. is low-carbon hydrogen (primarily in North America), and the remainder is renewable hydrogen. About 4.6 Mt p.a. have passed FID, of which about half is renewable hydrogen.

Infrastructure: The deployment of hydrogen infrastructure is gradually progressing. Committed investments in hydrogen infrastructure are about USD 6.5 billion, of which 45% are in the Middle East. Today, there are about 5,000 km[13] of hydrogen pipelines (primarily in existing grey hydrogen hubs and industrial areas). The deployment of infrastructure for hydrogen-fueled mobility has been flattening in the previous year, especially in Europe and North America. There are currently +1,150 hydrogen refueling stations deployed globally, mostly concentrated in China, South Korea, and Japan.

Manufacturing capacity: Electrolyzer and fuel cell manufacturers are preparing to scale up. Electrolyzer manufacturing capacity has reached nearly 17 GW (up from 11 GW previously) according to OEM statements. For fuel cell manufacturing, the total global capacity stands at 16 GW, with South Korea, China, and Japan being the largest supply markets (up from 15 GW previously).

Hydrogen end use: Committed investments in hydrogen end-use have reached more than USD 29 billion, with the largest share of investments in China and North America (both with total committed investments of about USD 7 billion). By sector, steelmaking has the highest committed investments (about USD 9 billion), followed by chemicals, maritime, and road transport (at about USD 4 billion each). Within mobility, cumulative fuel cell electric vehicle (FCEV) sales as of May 2024 stood at about 90,000 vehicles, up 14% from October 2023. Vehicle OEMs have announced over 160 FCEV models expected to be available on the market in 2024, of which the majority consist of commercial vehicles (trucks and buses) in China.

Key figures on deployment across the value chain



Source: Project & Investment tracker, as of May 2024

13 IEA, Global Hydrogen Review, 2023

Exhibit 12

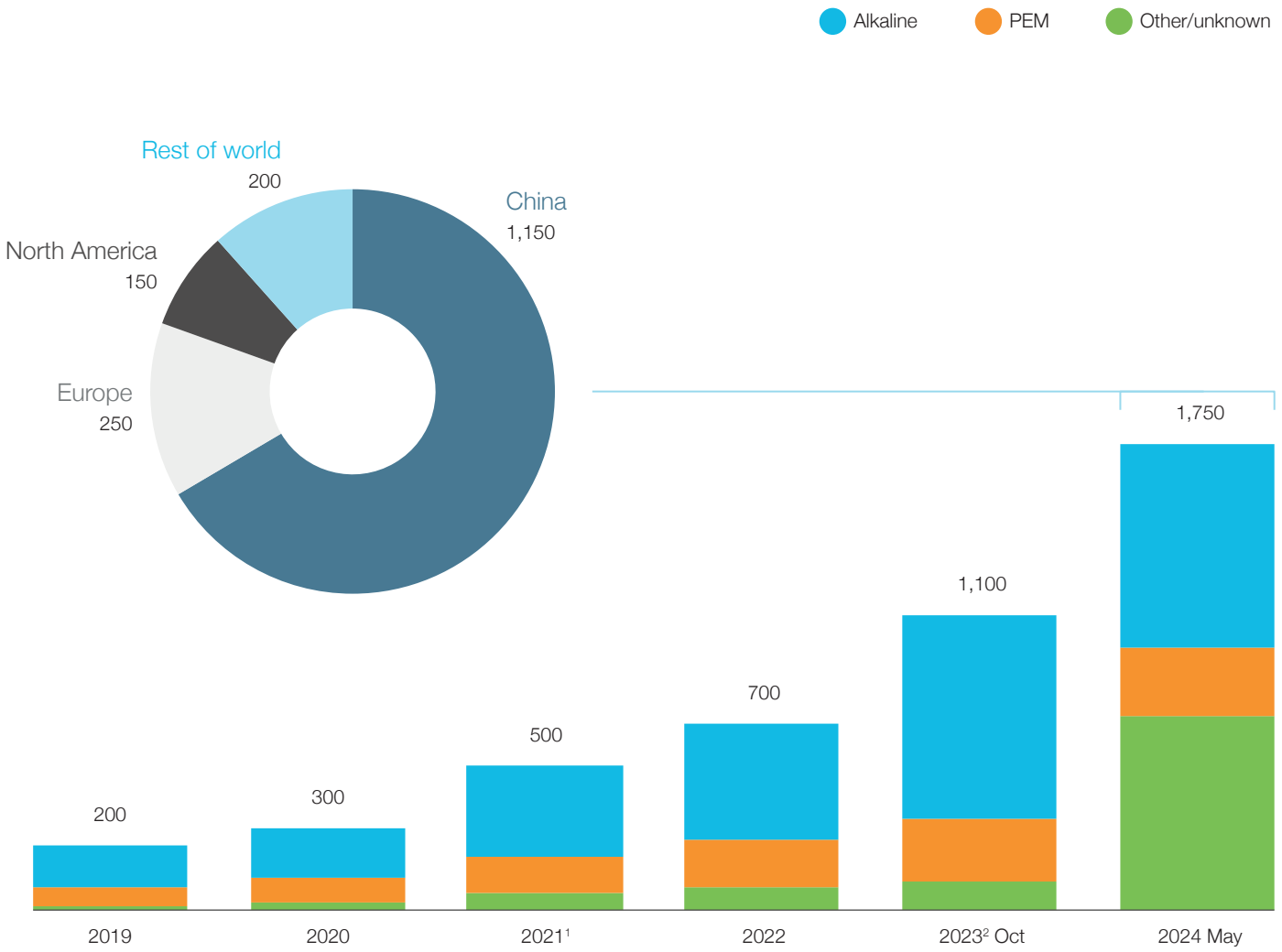
650 MW electrolysis has been deployed since previous publication, bringing the total to 1.75 GW, with most capacity added in China

The deployment of electrolysis capacity grew by around 60% since previous publication, reaching 1.75 GW, up from 1.1 GW. The installed capacity equals about 185 kt p.a. of renewable hydrogen supply, meaning renewable hydrogen accounts for about 20% of installed clean hydrogen production capacity globally.

Today, the largest deployed electrolyzer capacity is in China (1,150 MW), where the world's two largest operational projects with capacities of 260 MW and 150 MW are located. China is followed by United States (110 MW), Germany (80 MW), as well as India, Spain, Taiwan, Sweden, Canada, and Japan (each with about 25 MW).

Of the 1.75 GW of deployed electrolyzer capacity, about 60% have a stated technology – of this around 75% is alkaline and 25% proton-exchange membrane (PEM); implying that the share of PEM remains stable. Majority of the capacity increase versus previous publication is in China. Within China, 95% of the deployed electrolysis capacity is based on alkaline technology, whereas PEM technology is more prevalent in Europe and North America, accounting for 60% of the total installed capacity.

Global cumulative installed electrolysis capacity, MW



1. Growth from 2020 to 2021 driven by 150 MW Ningxia Project
2. Growth from 2022 to 2023 driven by 260 MW Kuqa Green Hydrogen Project, currently the largest operational electrolyzer

Source: IEA Global Hydrogen Review 2021 & 2022; Project & Investment tracker, as of May 2024

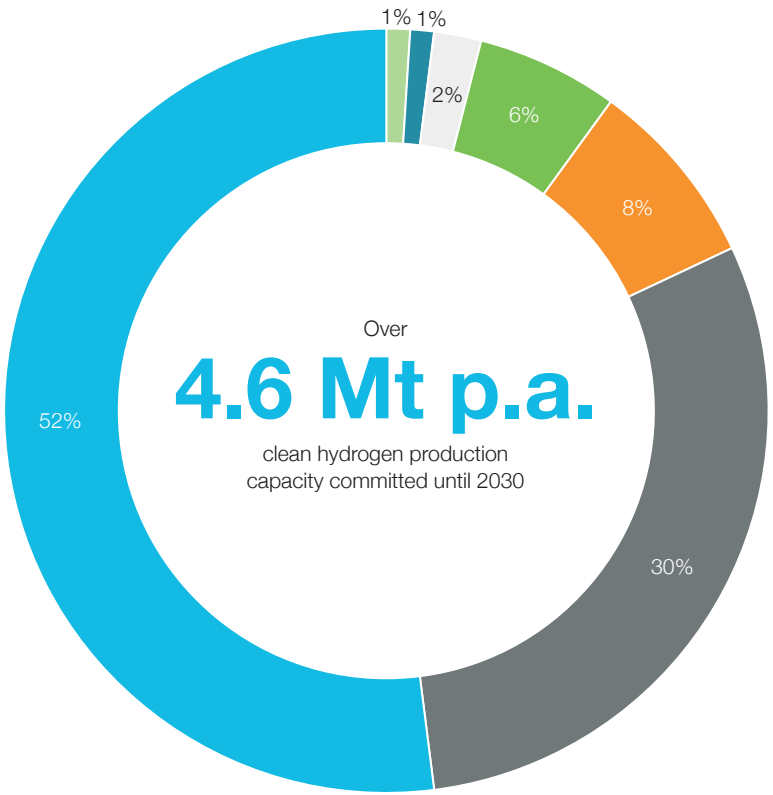
Exhibit 13

Currently, over 4.6 Mt p.a. of clean hydrogen capacity has passed FID, with North America and China leading

In addition to the 895 kt p.a. of operational capacity, about 3.7 Mt p.a. of clean hydrogen has passed FID. Renewable hydrogen accounts for about 2.4 Mt p.a. of capacity past FID, whereas low-carbon accounts for about 2.2 Mt p.a. Capacity past FID has grown by about 1.6 Mt p.a. since the previous publication. The increase is mostly driven by commitments in renewable hydrogen, majority of which is in China and North America (1,300 kt p.a. and 400 kt p.a. renewable hydrogen post FID, respectively).

North America is the largest region in terms of committed clean hydrogen capacity with volumes of about 2.4 Mt p.a., of which about two-thirds is in the United States and one-third in Canada. Around 85% of these volumes are low-carbon hydrogen, potentially due to higher maturity and driven by the early deployment of CCS technology in grey hydrogen production. Of the North American low-carbon hydrogen volumes past FID, about 60% have stated technology. About 50% of this is autothermal reforming (ATR), and the remaining 50% a mix of other technologies with CCS.

Committed[1] production capacity until 2030, %



North America
Low-carbon hydrogen accounts for around 85% of committed production capacity in North America (of which ~670 kton is already operational), with demand driven by hydrogen for ammonia production and refining

China
Several large-scale renewable hydrogen projects (>100 MW) already operational

Europe
Renewable hydrogen accounts for half of committed production capacity (~60%) in Europe, with industry feedstock sectors (e.g., refining) driving demand

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

Japan, South Korea, Oceania and Latin America

India

Africa

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

Source: Project & Investment tracker, as of May 2024

Exhibit 14

Hydrogen refueling infrastructure deployment continues to accelerate in China and South Korea, but appears to be stagnating in Europe and North America

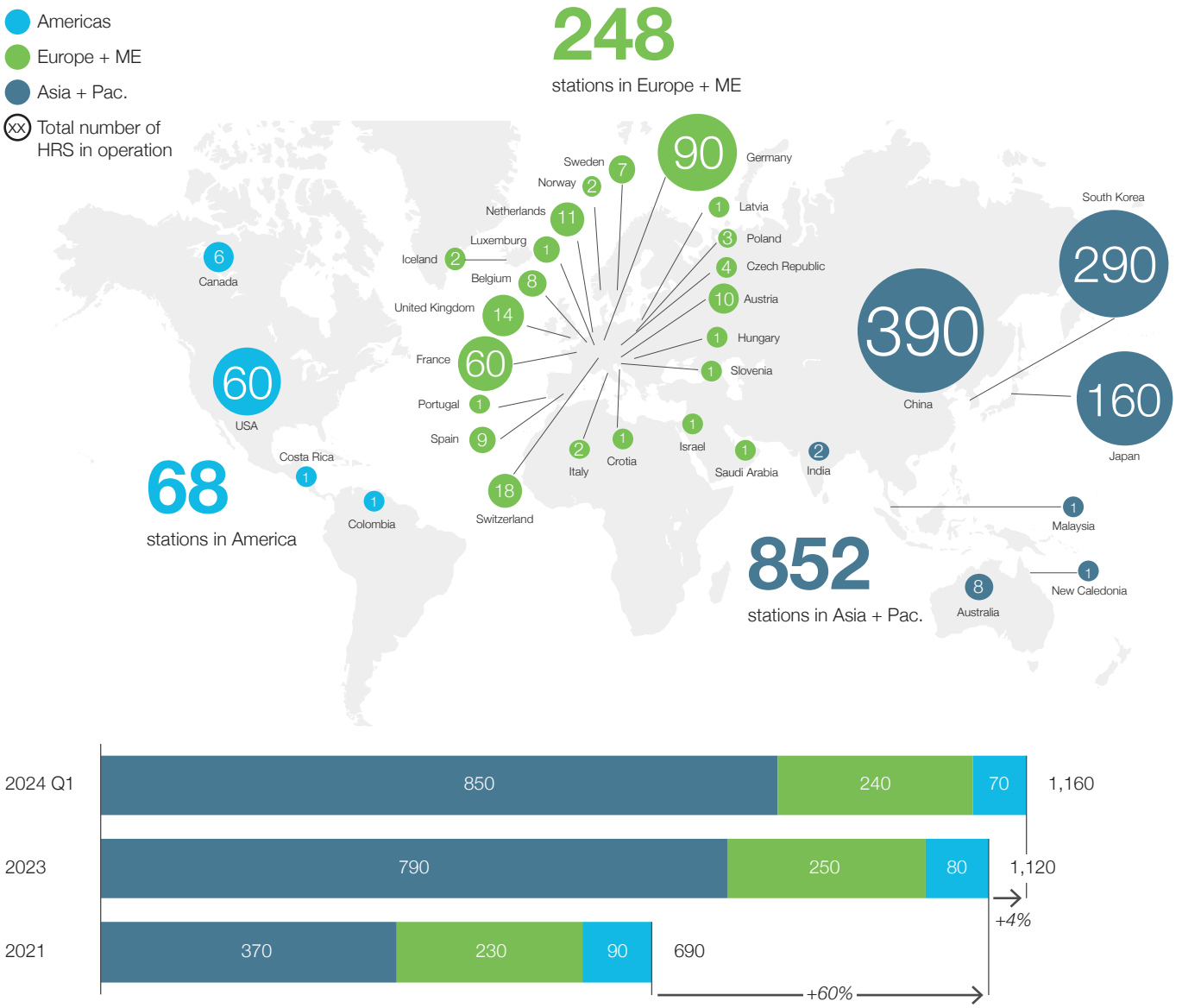
More than 1,150 hydrogen refueling stations are now operational globally, with deployment growing by 65% from 2021. China, Japan, and South Korea are the largest markets exceeding 850 stations in total, followed by Europe with around 250 stations. In Europe and North America, there has been a downward trend for hydrogen refueling stations the previous year, with a decline in number of operational hydrogen refueling stations of about 10% and 40% respectively.

The number of hydrogen refueling stations could grow if ambitious government targets are realized. South Korea and Japan plan to expand their networks to more than 600 stations each through 2030, which could double the number of stations in Asia. In the EU, the recently adopted Alternative Fuels Infrastructure Regulation (AFIR) will require the deployment of a hydrogen refueling station every 200 km along the Trans-European Transport Network (TEN-T), corresponding to more than 400 stations through 2030.

Sales of hydrogen-powered vehicles correlate geographically with the roll-out of hydrogen refueling infrastructure. South Korea and Japan continue to lead in light hydrogen-fueled vehicles (about 65% of current light vehicle fleet), and China in the global hydrogen truck and bus market (about 95% and 85% of each respective market). Heavy hydrogen-fueled vehicles, especially trucks, are gaining momentum. This is reflected in the number of hydrogen-fueled bus and truck models exceeding 130. As the hydrogen-fueled vehicle park could potentially transition toward heavier vehicles, requiring higher refueling station capacities, existing stations might require expansion and adaptation. Additional hydrogen refueling infrastructure might be needed for off-road mobility such as rail and inland shipping.

While most hydrogen-fueled vehicles continue to be fuel cell electric vehicles (FCEVs), there is ongoing development in hydrogen combustion powertrains.

Hydrogen refueling stations



Source: h2stations.org; iphe.net, Press research